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ESA Sea Level CCI

Validation Report: WP2400 Sea State Bias correction

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| People involved in this issue: | | |
| Written by (\*): | J.-F. Legeais, N. Tran (CLS) | Date + Initials:( visa or ref) |
| Checked by (\*): | G Timms (Logica) | Date + Initial:( visa ou ref) |
| Approved by (\*): | G Larnicol (CLS) | Date + Initial:( visa ou ref) |
| Application authorized by (\*): | ESA | Date + Initial:( visa ou ref) |

*\*In the opposite box: Last and First name of the person + company if different from CLS*

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| Applicable documents |

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

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| Reference documents |

RD 1 Manuel du processus Documentation  
CLS-DOC

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# Introduction

The main objective of this document is to provide the analysis of the RRDP reports dedicated to the sea state bias correction (WP2400) in order to estimate the best algorithm to compute this correction and improve the sea-level calculation for climate applications.

The following Round Robin Data Packages (RRDP) have been performed for Envisat mission:

* Comparison of the 3D non-parametric SSB model with the reference 2D non-parametric SSB (2005 version) currently used in Aviso products for Envisat mission: [RRDP\_WP2400\_SSB\_3D\_vs\_2D2005\_11-09-05.pdf](ftp://slcci_team:%2fextcci2011-@ftp.esa-sealevel-cci.org/Data/RRDP/RRDP_WP2400_SSB_3D_vs_2D2005_11-09-05.pdf)
* Comparison of the 3D non-parametric SSB model with the reference 2D non-parametric SSB (2007 version) for Envisat mission, which will be available in the reprocessed Envisat data:  [RRDP\_WP2400\_SSB\_3D\_vs\_2D2007\_11-09-05.pdf](ftp://slcci_team:%2fextcci2011-@ftp.esa-sealevel-cci.org/Data/RRDP/RRDP_WP2400_SSB_3D_vs_2D2007_11-09-05.pdf)

The 3D non-parametric Sea State Bias model takes into account a third parameter, the mean wave period (Tm), from a numerical wave model (WaveWatch3, version 3.14b released in 2009) forced by ECMWF wind fields. Such 3D models have been initially developed for the Jason missions and have shown some improvements in term of SSH variance reduction when compared with that from the application of the standard 2D SSB model. Within the Envisat Phase-E ESL activities, the 3D version of the SSB model has been computed (See Tran 2010, CLS-DOS-NT-10-287, RA2 Ocean and MWR measurement long-term monitoring - Annual report for WP3, Task 2:”SSB estimation for RA2 altimeter”). Its evaluation is performed hereafter.

We successively compare this new SSB with the reference 2D non parametric SSB currently used in Aviso products (2005 version) and with the 2007 version of this 2D SSB, which will be used in reprocessed Envisat GDR products (Labroue S., 2007:”RA2 ocean and MWR measurement long term monitoring”, Technical Report CLS- DOS-NT-07-198, ESA Contract n 17293/03/I-OL). All the SSB estimates have been computed with homogeneous wind speed time-series. The wind speed (Abdallah, 2006) has been updated in the database to be homogeneous over the period since it is not the case in the GDR products.

This document discuss the impact of all new algorithms separating the different climate applications defined in the sea level CCI URD (User Requirement Document) and separating the several temporal scales related with climate applications. A clearly and easily understandable impact indicator has been defined and is described in annex of this document (see **Erreur ! Source du renvoi introuvable.**).

# Global Mean Sea Level

## Long-term evolution

### Validation diagnoses used

The validation diagnostic of the long-term sea-level evolution (A201-a) allows us to evaluate the impact on the global MSL trend using successively the different SSB corrections. Their impact is also analyzed separating descending and ascending passes (A201-b) but the SSB correction is not expected to have an impact on this result. Cross-comparison of MSL trends between altimetric missions collocated on the same period (B001) is not yet possible since only Envisat data are analyzed. At last, the comparison with in-situ measurements (tide gauge, C001) could also contribute to know whether the potential drift of altimeter MSL is reduced or not with new correction. Nevertheless the comparison of Envisat SSH with tide gauges is not relevant since some corrections currently used (as the Point Target Response - PTR) is known to significantly deteriorate the global Envisat MSL trend and the level of accuracy of our tide gauges comparison method is below the MSL trend estimated error.

### Envisat mission (3D model)

For Envisat, the impact of the 3D non-parametric SSB correction is significant concerning the estimation of the Envisat global MSL trend compared with the 2D non-parametric SSB correction currently used in the sea-level AVISO products (A201). The global MSL trend is decreased by 0.2 mm/yr for Envisat (see the following table).

|  |  |  |  |
| --- | --- | --- | --- |
| **Altimetric mission** | **2005 2D SSB** | **2007 2D SSB** | **3D SSB** |
| **Envisat** | 0.69 mm/yr | 0.69 mm/yr | 0.49 mm/yr |

Table : [Diagnosis A201-a] Impact of the 3D non-parametric SSB correction on global MSL trend

As previously mentioned, we don’t expect to detect any impact of the SSB correction on the consistency of the global MSL trend when separating ascending or descending tracks, which is effectively shown with our results (diagnosis A201-b). Therefore, in this case, this diagnosis is not relevant to determine the best correction for the long-term evolution of the global MSL.

## Inter-annual signals

### Validation diagnoses used

The monitoring of the differences between both corrections (A001) but also of the variance differences of SLA (A202) may provide information concerning the impact of the studied correction on the global MSL at inter-annual time scales.

### Envisat mission (3D model)

The period of study of Envisat mission may be long enough but none of the diagnoses performed allows us to detect any variation at temporal scales higher than 1 year.

## Annual and semi-annual signals

### Validation diagnoses used

The periodograms of differences between two different SSB corrections allow us to determine the impact of the studied correction at annual and semi-annual scales (A003). Analyzing the difference of sea-level periodograms (A206), we can describe which correction allows us to reduce the periodic signals. Generally, a reduced annual or semi-annual signal is a good indication of a better correction. As discussed above for the global MSL trend, the comparison with in-situ measurements (tide gauge) is not relevant concerning the Envisat mission to assess whether the periodic signals are reduced or not with the new correction (C003).

### Envisat mission (3D model)

For Envisat mission, the use of the 3D SSB correction has a low impact on the annual signal amplitude compared with the 2D non parametric correction (A003) (<0.5 mm). Concerning the semi-annual signal amplitude, the impact is low (0.3mm) compared with the 2005 non parametric SSB and no impact is detected when compared with the 2007 SSB.

Moreover, the very weak difference detected on the SLA annual signal amplitude (A206) doesn’t allow us to assess which SSB reduces this amplitude and thus which one is the best.

# Regional Mean Sea Level

## Long-term evolution

### Validation diagnoses used

The validation diagnosis of the regional trend of sea-level differences using successively two SSB corrections (A204a) allows us to evaluate the impact of the different corrections on the local MSL trends. Their impact is also analyzed separating descending and ascending passes (A204-b) but this diagnosis is not the most relevant concerning the SSB correction.

### Envisat mission (3D model)

Concerning Envisat, the impact of using the 3D SSB correction instead of the reference 2D SSB correction (both 2005 and 2007 versions) on the long term evolution of the regional MSL is significant (A204). The MSL trend obtained with 3D SSB is globally lower than with the reference by more than 1.0 mm/yr (Figure 1, A204-a), particularly in western boundary currents and in the Antarctic circumpolar current. The same impact is detected when separating ascending and descending passes (A204-b). Nevertheless, no diagnosis allows us to assess if this change is an improvement.

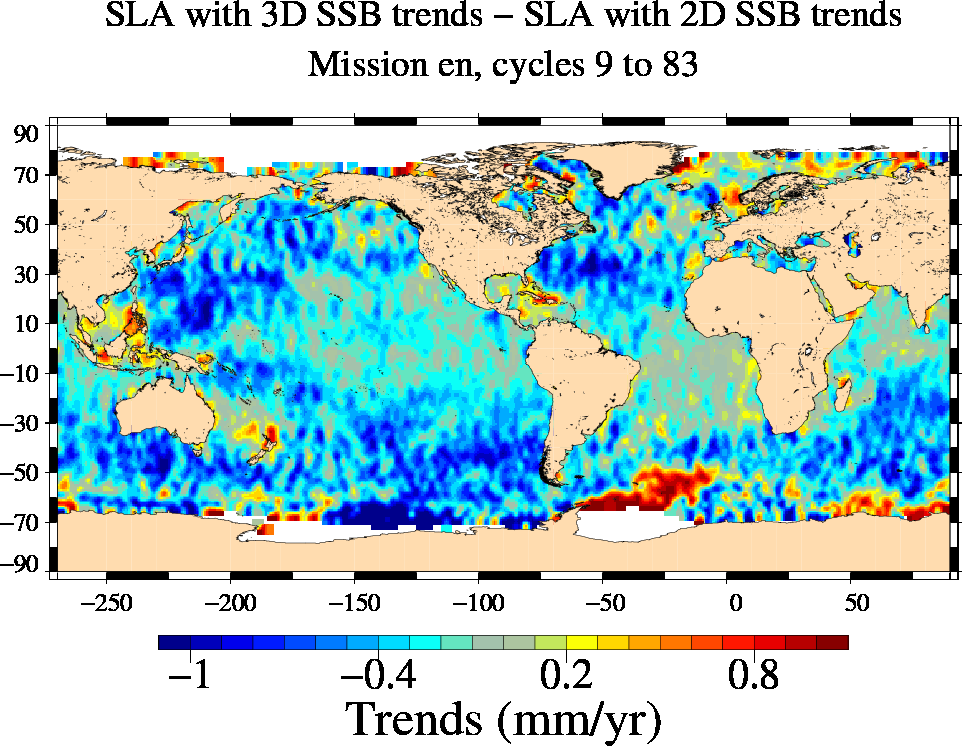


Figure : [Diagnosis A204-a] Map of the MSL trend differences using the 3D SSB correction compared with the 2005 version of the 2D non parametric SSB.

## Annual and semi-annual signals

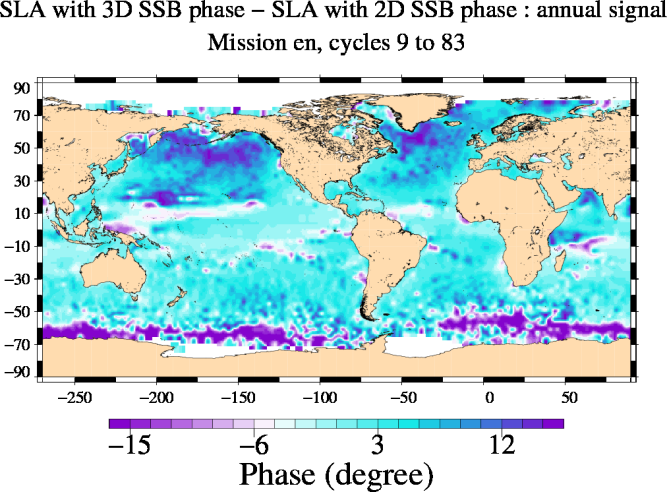
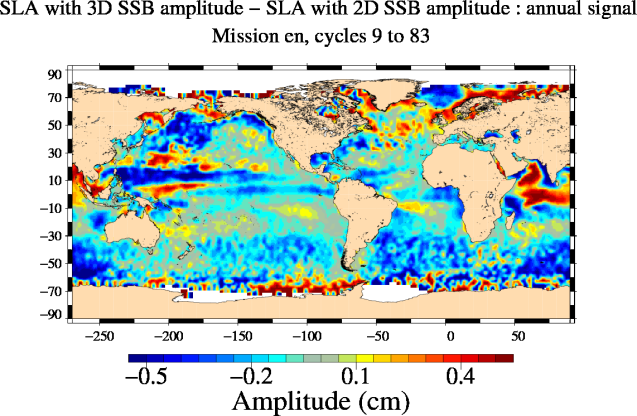
### Validation diagnoses used

The analyses of periodic signals of regional mean sea level are performed thanks to diagnosis A205 where the difference of amplitudes and phases between SLA using successively two SSB corrections are mapped for annual and semi-annual signals. These diagnoses allow us to characterize the local or regional impact of new corrections.

The comparison with in-situ measurements (temperature and salinity profiles for instance) also give a relevant indication of whether the periodic signals are better estimated or not with the studied correction. Nevertheless, this diagnosis has not been yet processed.

### Envisat mission (3D model)

The amplitude and phase differences of annual (Figure 2) and semi-annual (Figure 3) signals have been mapped using the 3D SSB correction versus the 2005 and 2007 versions of the 2D SSB corrections (top and bottom parts of the figures respectively) in Envisat MSL computation. For annual signals, a significant impact (>5mm) is detected in the open ocean, in coastal regions and in areas of strong ocean variability both with increased or reduced amplitude, when compared with the 2005 2D SSB. An impact is detected on the phase differences compared with the 2005 version, especially in the subpolar gyres and in the circumpolar current (phase change of more than 15°). This impact is not detected compared with the 2007 version.



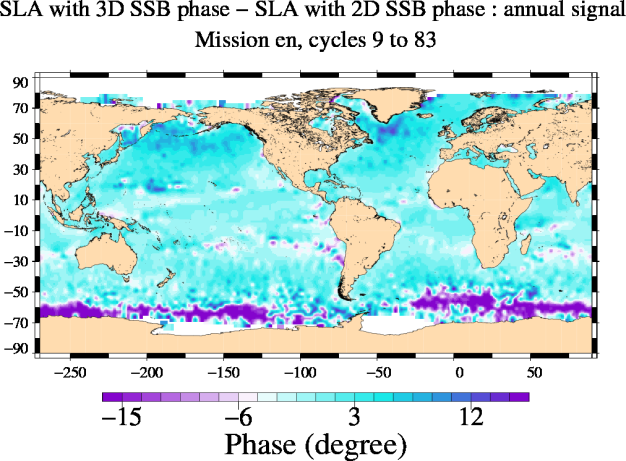
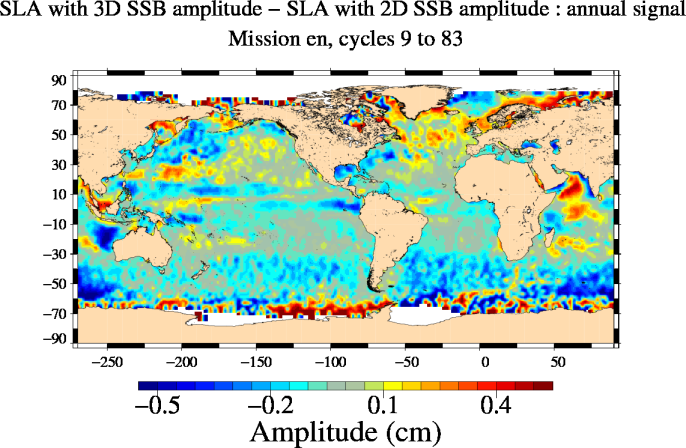
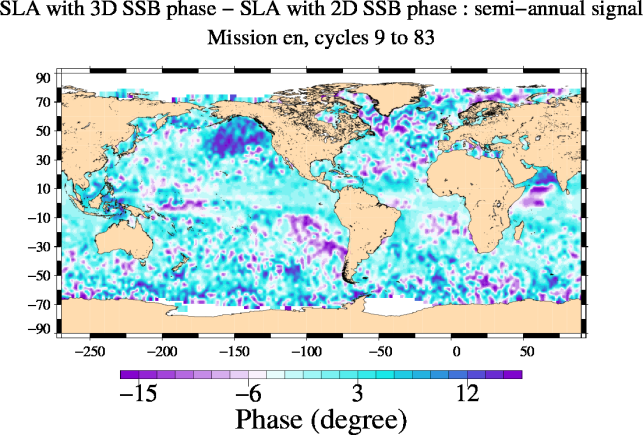
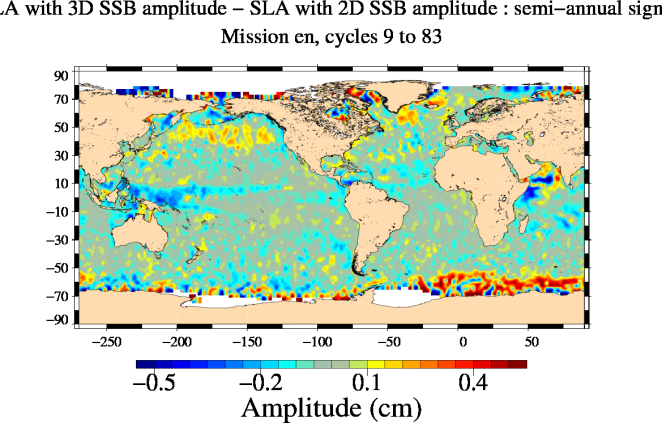


Figure : [Diagnosis A205] Amplitude (left) and phase (right) differences of regional MSL annual signals using the 3D SSB correction versus the 2005 2D SSB (top) and the 2007 2D SSB (bottom) for Envisat mission.

Concerning the semi-annual signal (Figure 3, A205), a low impact of the 3D SSB correction is detected on its amplitude. The phase of the semi-annual signal is also impacted but is not restricted to specific regions as well as with the annual signal (Figure 2).



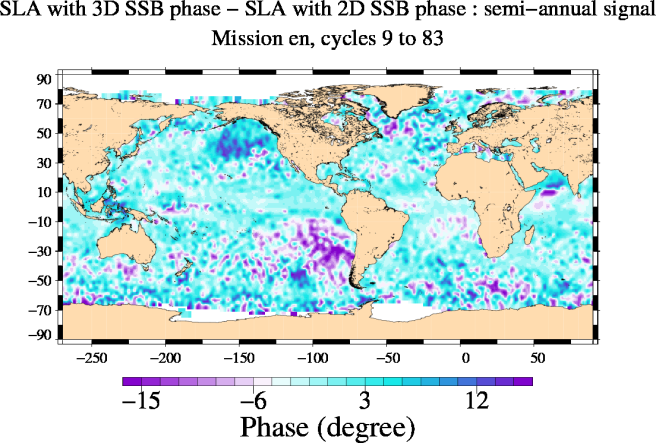
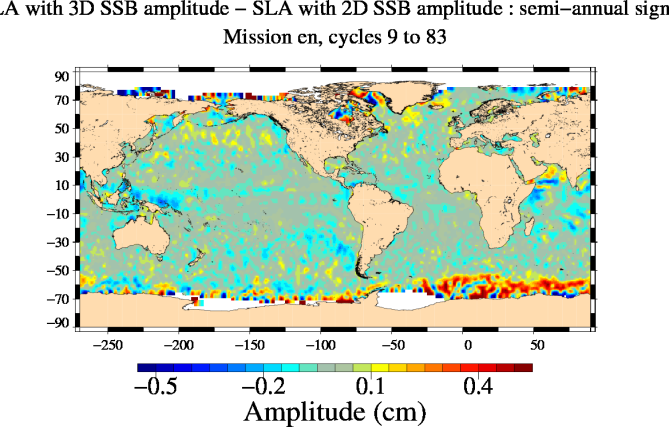


Figure : [Diagnosis A205] Amplitude (left) and phase (right) differences of regional MSL semi-annual signals using the 3D SSB correction versus the 2005 2D SSB (top) and the 2007 2D SSB (bottom) for Envisat mission.

## Coastal areas

Figure 4 shows the difference between the 3D and the 2005 2D SSB corrections versus the coastal distance. The difference between both corrections increases by more than 6 mm between the coast and 100km offshore.

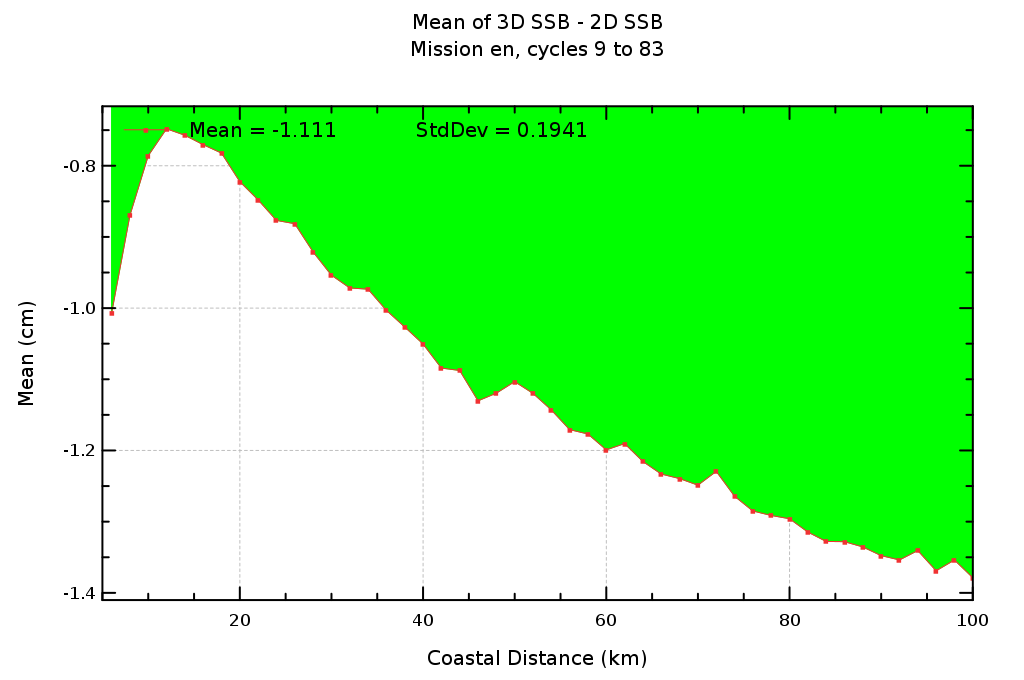


Figure : [Diagnosis A004] Mean difference versus coastal distance of the 3D SSB versus the 2005 2D non parametric SSB difference.

Figure 5 displays the evolution versus the coastal distance of the mean sea level anomalies (referenced to a MSS) computed with the different version of the SSB correction. Both 2D versions of the non parametric SSB correction show increased values close to the coast compared with 100km offshore. This increase is higher with the 2005 version (7 mm) rather than the 2007 version (5 mm). The use of the 3D SSB shows almost no increase versus coastal distance (<1 mm). No physical reason is expected to explain the observed increase of the MSL in this very short range of coastal distances. As the distribution of water masses is expected to be homogeneous over a few tens of kms, we could think that the 3D SSB correction is the best in coastal areas concerning the MSL trend estimation in coastal regions.

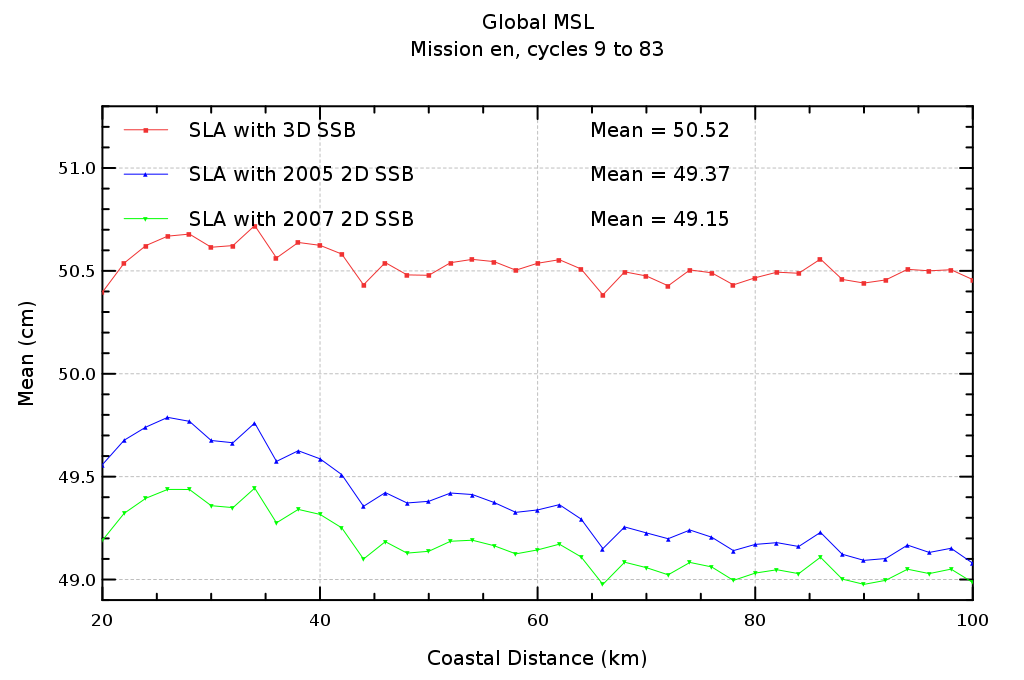


Figure : [Diagnosis A207] Mean of the sea level anomalies versus coastal distance computed with different SSB corrections

## High latitudes

Figure 1 (A204-a) indicates that the use of the 3D SSB correction has a significant impact at high latitudes (>0.5 mm/yr) but no specific behavior is detected compared with other parts of the global ocean. As suggested by Figure 5, it may be associated with an improvement. However, a lot of data are missing in these regions because of the ice coverage and the MSL trend estimation at high latitudes is thus affected by a strong formal error.

# Mesoscale

## Validation diagnoses used

Along-track sea-level analyses and differences at crossover points allow us to detect improvements at short temporal scales (< 2months) for mesoscale applications. The most relevant diagnoses performed in RRDP are the monitoring and the map of the variance SSH differences using successively 2 different SSB corrections.

Diagnoses A102 and A104 display the monitoring and the map of SSH variance differences at crossover points. In many cases, if one observes a reduction of the SSH variance difference at these crossovers with a studied SSB correction, this should indicate that it outperforms the reference SSB. However, some cases when this may not be true are when a) the region under assessment contains substantial mesoscale or HF barotropic variability modifying SSHA, b) the region under study carries a spurious correlation between some other orbit or geophysical correction and either one of the sea state parameters used in SSB estimation (the wind, SWH, or wave period), c) regions of persistent wind and wave conditions such at the trade winds band where little temporal variability in any SSB correction model will occur over the period when variance is being assessed.

Diagnoses A203 and A209 display the monitoring and the map of SSH variance differences relative to a mean sea surface (MSS): a reduction of variance indicates a better homogeneity with the MSS. Most of the time, it indicates an improvement of the sea-level computation. But note that in few cases, the variance increase can also indicate a systematic error in the MSS due to geographical bias for instance.

## Envisat mission (3D model)

### Global analyses

The use of the 3D SSB correction compared with the currently used 2005 version of the 2D SSB has no significant impact on the sea level estimation at short time scales (coherence between ascending and descending passes) (A102). A low difference (0.5 cm2) is detected on average over the Envisat period when compared with the 2007 version of the 2D SSB (A102). This difference is mainly located at mean and high latitudes where it reaches significant values (>1 cm2) (Figure 6, A104) whereas no impact is observed at low latitudes. As discussed above, this diagnosis is not relevant for the SSB correction and the observed increase of variance may not necessarily be associated with deterioration. Note a significant reduction of variance obtained with the 3D SSB in regions of high ocean variability (>3 cm2) (Agulhas current and Confluence zone particularly).

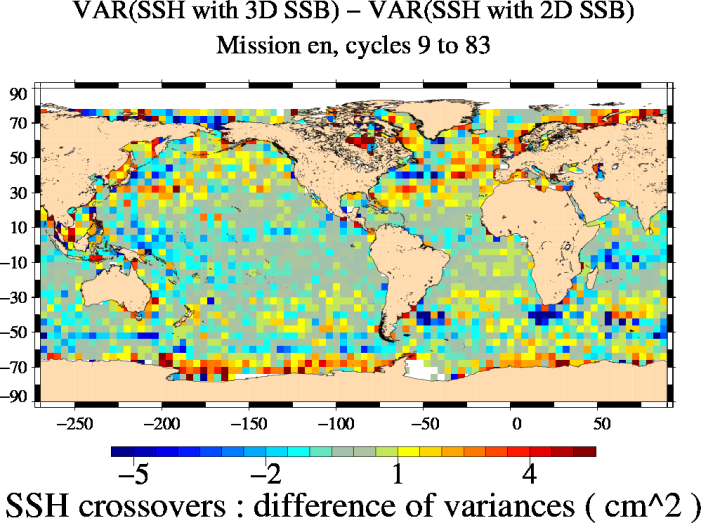


Figure : [Diagnosis A104] Maps of the SSH variance differences at crossover points comparing the 3D SSB correction with the 2005 2D SSB correction.

The analyses of the SLA variance differences confirm that the 2007 version of the non parametric SSB provides a better SLA (compared with the MSS) rather than the 2005 version since an increased gain of variance is observed (-1.7 cm2 versus -1.0 cm2, cf Figure 7).

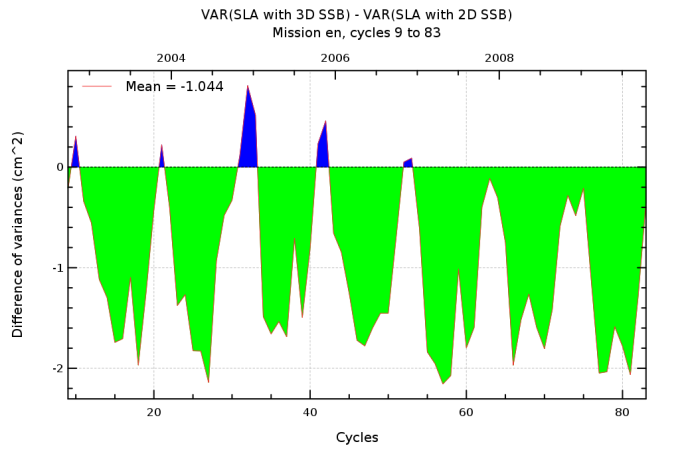
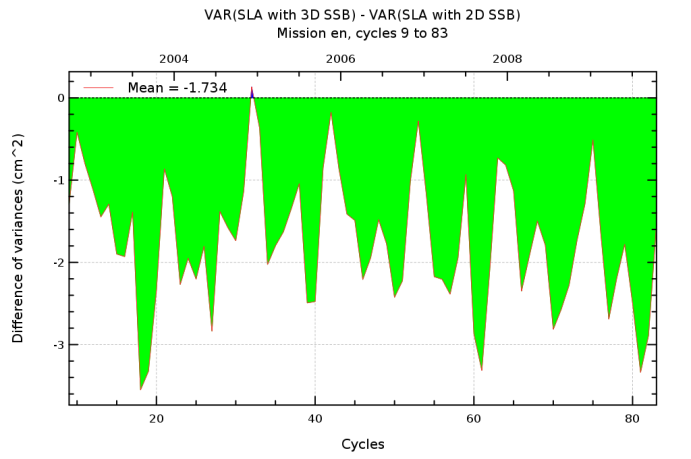


Figure : [Diagnosis A202] Monitoring of the SLA variance differences comparing the 3D SSB correction versus the 2005 2D SSB (left) and the 2007 2D SSB correction (right).

The spatial distribution of the SLA variance differences between the 3D SSB and the currently used 2005 2D SSB correction (Figure 8) reveals a strong variance reduction (>5 cm2) located in regions of high ocean variability. More locally, we also observe a variance increase along the North European coasts and in the northwestern Indian Ocean.

Most of the time, a variance reduction means that the new correction improves the SLA calculation. However in this case, the result is quite disturbing since the signature of the variance reduction is on the one hand very strong (which is not usual when assessing a SSB correction) and on the other hand very well correlated with the ocean circulation variability. Furthermore, we do not observe such similar results on SSH variance differences at crossovers (as just previously observed in Figure 6). This means that only temporal scales higher than 10 days are concerned.

The observed strong variance reduction (except along some coastal areas) may not be an improvement, but an effect of the covariance terms between the SLA and both SSB corrections which could be significant. Currently, this hypothesis has not been demonstrated. But it is true, the diagnosis of variance reduction to estimate the SLA quality is likely not applicable.

Therefore, more investigations are needed in order to be able to conclude on the impact of the new SSB-3D correction.

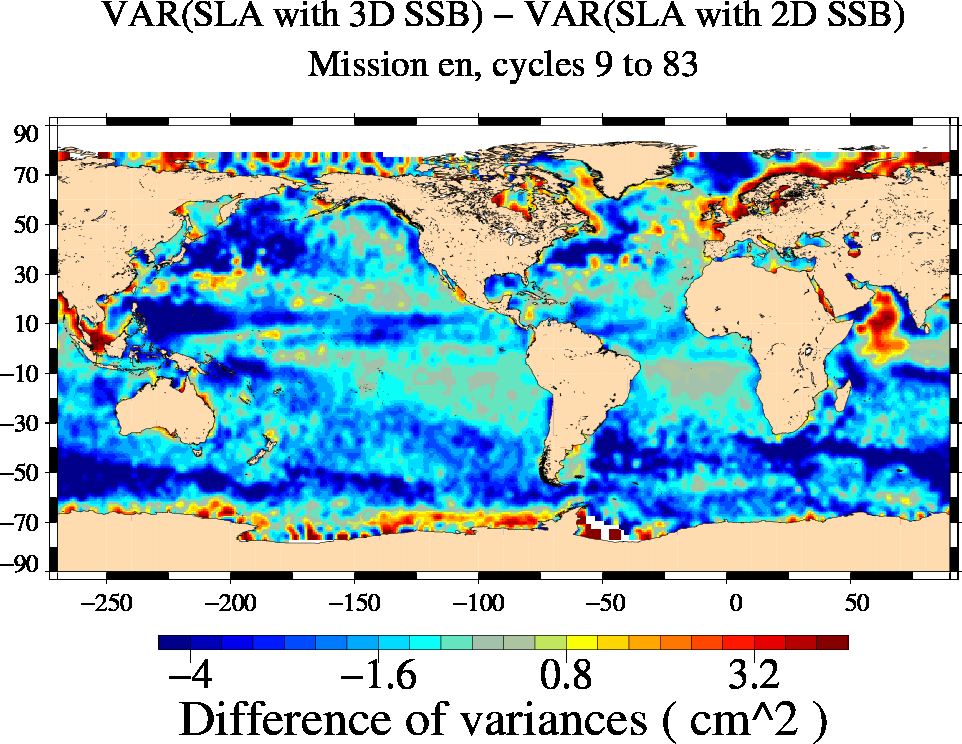


Figure : [Diagnosis A209] Maps of the SLA variance differences comparing the 3D SSB versus the currently used 2005 2D SSB correction.

### Coastal areas

As shown on Figure 6 (A104), no particular impact of the 3D SSB correction is detected in coastal regions concerning the estimation of the short temporal scales of the sea level.

### High latitudes

No particular impact of the 3D SSB correction is detected at high latitudes concerning the estimation of the short temporal scales of the sea level. Note however a region of deterioration located along the north European coast and part of the northern russian coast (Figure 8, A209). This is probably associated with the characteristics of the model used to provide the 3rd dimension of the SSB correction, which might be not adapted in this region.

# Conclusions and recommendations

As expected, these analyses have confirmed that the 2007 version of the non parametric SSB correction is better than the currently used 2005 version particularly in terms of mesoscale applications (SLA performances).

Concerning the new 3D SSB correction, the impact is stronger for all the climate application with an impact close to 0.2 mm/yr on the global MSL for instance and higher than 1 mm/yr regionally. The spatial distribution of the SLA variance differences between the 3D SSB and the currently used 2005 2D SSB correction reveals a strong variance reduction (>5 cm2) located in regions of high ocean variability. Currently we are not able to determine if this SLA variance reduction shows an improvement or if it is an artifact for instance due to the covariance terms between the SLA and both SSB corrections which could be significant.

* Although the use of the 3D SSB correction in the MSL computation provides interesting improvement concerning some climate applications, we suggest to analyze the impact of this algorithm in more details before recommending its use for climate studies. Therefore, we recommend to use the 2007 version of the non parametric SSB correction.

1. Synthesis

This section synthesizes the impact of the new algorithms dedicated to the SSB correction for the Envisat altimetric mission and separating the different climate applications defined in the sea level CCI URD (User Requirement Document). The impact is also estimated for several temporal scales impacting climate studies for each application.

In order to have a clear view of these potential impacts, the information is summarized in a table (1 table per altimetric missions). An impact indicator clearly and easily comprehensible has been defined with 3 levels: significant impact, low impact, no impact detected. Each level is represented by a different color box.

The choice of a value indicator (significant, low or null) is quite subjective. As it depends on the application (Global MSL, regional MSL, mesoscale…), the rule to classify this impact has been defined in annex of this document (see Appendix B -).

## Envisat

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Envisat [October 2002- December 2009] | | | | | |
| Climate  Applications | Temporal Scales | Round Robin Data Package (RRDP) | | | |
| 3D vs 2D\_2005 | | 3D vs 2D\_2007 | |
| Global Mean Sea Level | Long-term evolution (trend) |  | |  | |
| Inter annual signals (> 1 year) |  | |  | |
| Annual and semi-annual Signals | + | |  | |
| Regional Mean Sea Level | Long-term evolution (trend) |  | |  | |
| Annual and semi-annual Signals |  | |  | |
| Mesoscale | Signals < 2 months | + | | + | |
| Specific regional areas of main interest for climate studies: | | | | | |
| Coastal areas | Long-term evolution (trend) | + | | + | |
| Signals < 2 months |  | |  | |
| High latitudes | Long-term evolution (trend) |  | |  | |
| Signals < 2 months |  | |  | |
|  | | | | | |
|  | Significant impact | Low impact | No impact detected | | Not yet evaluated |
|  | + | Positive impact (low) | | | |
|  | - | Negative impact (significant) | | | |

1. Definition of the indicator value

In this table, the choice of the indicator value is defined for each climate applications and temporal scales. The thresholds defined here are valid for time series long enough (> 7 years). If time series is too short, the thresholds have to be majored.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Climate  Applications | Temporal Scales | Definition of the indicator value | | |
| Significant impact | Low impact | No impact detected |
| Global Mean Sea Level | Long-term evolution (trend) | Trend >0.15 mm/yr | Trend> 0.05 mm/yr | Trend< 0.05 mm/yr |
| Inter annual signals (> 1 year) | Amplitude> 0.5 mm | Amplitude> 0.2 mm | Amplitude< 0.2 mm |
| Annual and semi-annual Signals | Amplitude> 1 mm | Amplitude> 0.2 mm | Amplitude< 0.2 mm |
| Regional Mean Sea Level | Long-term evolution (trend) | Trend > 0.5 mm/yr | Trend> 0.1 mm/yr | Trend< 0.1 mm/yr |
| Annual and semi-annual Signals | Amplitude> 5 mm | Amplitude> 0.5 mm | Amplitude< 0.5 mm |
| Mesoscale | Signals < 2 months | Crossovers Variance differences > 1 cm² | Crossovers Variance differences > 0.2 cm² | Crossovers Variance differences < 0.2 cm² |
| Specific regional areas of main interest for climate studies: | | | | |
| Coastal areas | Long-term evolution (trend) | Trend > 0.5 mm/yr | Trend> 0.1 mm/yr | Trend< 0.1 mm/yr |
| Signals < 2 months | Crossovers Variance differences > 1 cm² | Crossovers Variance differences > 0.2 cm² | Crossovers Variance differences < 0.2 cm² |
| High latitudes | Long-term evolution (trend) | Trend > 0.5 mm/yr | Trend> 0.1 mm/yr | Trend< 0.1 mm/yr |
| Signals < 2 months | Crossovers Variance differences > 1 cm² | Crossovers Variance differences > 0.2 cm² | Crossovers Variance differences < 0.2 cm² |

1. List of acronyms

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| TBC | To be confirmed |
| TBD | To be defined |
| AD | Applicable Document |
| RD | Reference Document |