CalVal In-Situ altimetry / Argo TS profiles

Validation of altimeter data by comparison with in-situ T/S Argo profiles

for Jason-1, Envisat and Jason-2

2011-2015 SALP contract No 104685

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1. Introduction

The calibration and validation of the altimeter sea level is usually performed by internal assessment of the mission and via inter comparison with other altimeter missions. The comparison with in-situ measurements is fondamental since it provides an external and independant reference. This document is the synthesis report for 2012 concerning altimeter and in-situ validation activities which aims at comparing altimeter data with temperature and salinity (T/S) profiles provided by lagrangian floats of the ARGO network. This activity is supported by CNES in the frame of the SALP contract for all altimeter missions and by ESA for Envisat mission. The method uses results of a study made at CLS in the frame of an IFREMER / Coriolis contract.

Three objectives are achieved with the comparison of altimetry with the in-situ T/S profiles:

- To detect potential anomalies (jumps or drifts) in altimeter sea level measurements which can not be detected by comparison with other altimetric missions.
- To evaluate the quality of altimetric measurements and the improvement provided by new altimeter standards in the computation of sea level anomalies (geophysical corrections, new orbit, retracking,...).
- To detect potential anomalies in in-situ data and estimate their quality.

Argo T/S profiles constitutes a complementary dataset to tide gauges measurements. Indeed, although the temporal sampling is reduced (10-day profiles for a single float and hourly measurements for tide gauges), the spatial coverage of the Argo network is much larger since the global open ocean is almost completely sampled. Several results obtained through this activity are made robust thanks to the cross comparisons with several types of in-situ datasets (T/S profiles and tide gauges), which increases the quality assessment of altimeter measurements. In addition, the comparison with external and independant data enables us to contribute to the improvement of the error characterization of altimetry measurements, and especially at climate scales (Ablain et al., OSTST 2012, [1]).

Argo T/S profiles only provide the steric Dynamic Height Anomaly (DHA) above a reference level (chosen as 900 meters) and the associated physical content is thus different than the altimeter observations of the total height of the water column. In 2012, a major improvement of the method has been achieved by including the mass contribution to the sea level derived from the Gravity Recovery And Climate Experiment (GRACE) in order to compare homogeneous physical content. Some evolutions of the method have been made in order to better close the sea level budget and thus better estimate the absolute altimeter MSL drift. They are first described and the altimeter residuals from various missions are then analyzed. The altimeter MSL drift differences between Jason-1 and Envisat are discussed with the new approach globally as well as regionally. The impact estimation of new altimeter standards is analyzed by comparison with the external in-situ reference. The studies concern the MSS CNES/CLS11 and several orbit solutions but also the updated version of Envisat reprocessed data and the Jason-2 GDR-D reprocessed measurements.

2. Presentation of the databases

2.1. Altimeter measurements

In this study, along-track (level 2) altimeter SSH are used from several satellite altimeters, where standards are updated compared with the raw Geophysical Data Record (GDR) altimeter products. Details of the SSH computation and time period for each altimeter are presented in annex 8.1. and available in the MSL part of the Archiving, Validation and Interpretation of Satellite Oceanographic website (AVISO, http://www.aviso.oceanobs.com/en/news/ocean-indicators/mean-sea-level/processing-corrections/index.html). As the comparison with in-situ data is performed since 2004, we focus the analyses on the Envisat, Jason-1 and Jason-2 space missions. SLA for the whole altimeter missions are computed with a reference to the Mean Sea Surface (MSS) CLS2001 model (Hernandez and Schaeffer, 2001, [6]). Concerning Envisat mission, the reprocessed (V2.1) altimeter data are used (which includes the GDR-C orbit solution) and the new PTR correction developed for the V2.1+ version of Envisat products is also included. Envisat data are subsampled over 10 days (usual cycles are longer) in order to be consistent with results from Jason missions. Grids of DUACS delayed time merged altimeter products (L4) can also be compared with in-situ data.

2.2. Argo in-situ measurements

The lagrangian profiling floats of the Argo program are used as a reference in this study. They provide a global monitoring of ocean temperature and salinity (T/S) data between the surface and around 2 000 dbar for most of them with a 10-day sampling. The objective of a global network of 3 000 operating floats has been achieved in 2007 and figure 1 displays the spatial distribution of the floats that have delivered data within the last 30 days before the mentionned date. The associated steric Dynamic Height Anomalies (DHA) are computed using a reference level at 900 dbar (∼ 900 m, chosen for sampling reasons) and a contemporaneous mean dynamic height (also called synthetic climatology).

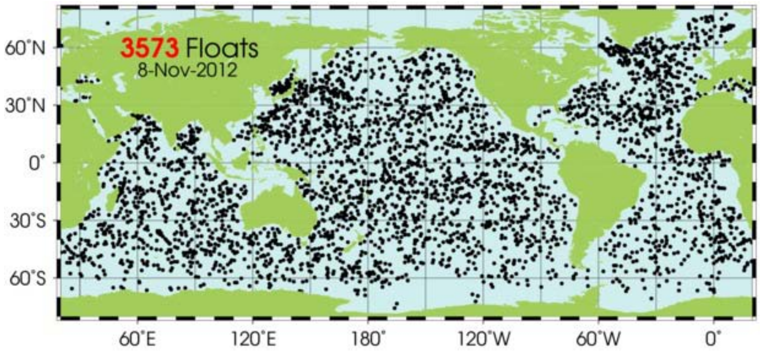

Figure 1: *Spatial distribution of the floats that have delivered data within the last 30 days before the mentionned date (Argo Information Center).*

In this study, we use delayed mode and real time quality controlled (Guinehut et al., 2009: [5]) T/S profiles from the Coriolis Global Data Assembly Center (www.coriolis.eu.org). Note that the delayed mode data concerns only two thirds of the dataset. Figure 2 shows spatial and temporal distribution of Argo measurements over the period 2002 - September 2012 (last update of the in-situ database).

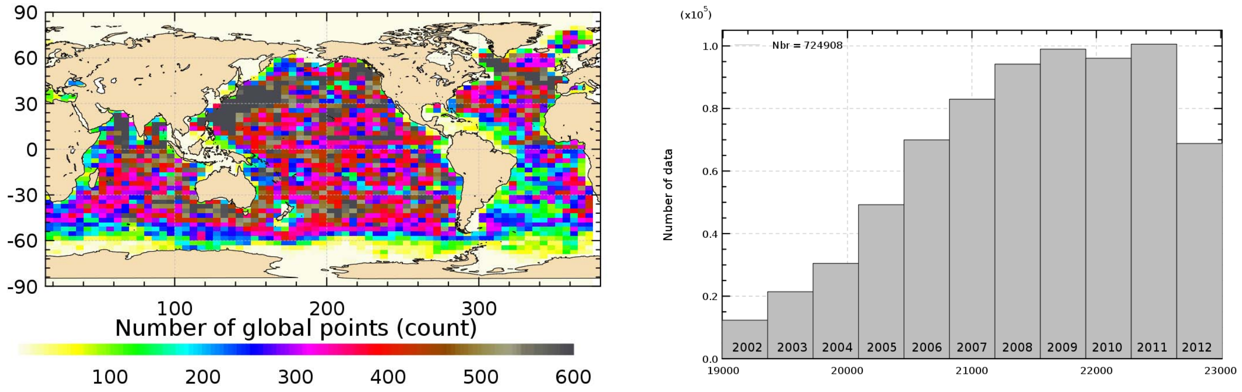

Figure 2: *Spatial (left) and temporal (right) distribution of temperature and salinity Argo profiles from 2002 to 2012.*

The vast amount of T/S profiles are available over almost the global open ocean (figure 2, left). Best sampled areas (Kurushio current, north Indian Ocean) have more than 600 profiles per box of 3°x5°. But no more than about 120 profiles per boxes are available in the southern ocean. The number of available profiles has regularly increased since 2002 (figure 2, right) and reaches 100 000 per year since 2009 (in 2012, data are used until September). Nevertheless, spatial distribution has not always been high enough in some areas to produce statistically valid analyses. As discussed by Roemmich and Gilson, 2009 ([13]), figure 3 indicates that considering a threshold of two thirds of the open ocean surface covered by Argo floats (±60°), analyses should be performed with in-situ data from mid 2004 onwards, which is done in this report. This constitues a great asset for latest altimeter missions (Jason-1, Envisat et Jason-2). It leads to a global in-situ dataset of more than 700 000 T/S profiles distributed over almost the global open ocean.

The large number of available T/S profiles constitutes an independent dataset well adapted for comparison with altimeter data over the open ocean where tide gauges distribution is insufficient. To perform these studies, a processing sequence has been developped (in the frame of the SALP project) which aims at being regularly operated in order to have an efficient tool to validate all altimeter missions.

2.3. GRACE measurements of the mass contribution

The mass contribution to the sea level that is missing in the Argo observations is derived from GRACE data. The ocean data are based on spherical harmonics from either the University of Texas Center for Space Research CSR, Jet Propulsion Laboratory or the Geoforschungzentrum Potsdam (GFZ) and after several discussions with scientists already using the data (LEGOS), we have chosen to use the first dataset from CSR. The RL04 version used provides monthly grids (1° x 1°) of equivalent sea level from Februray 2003 to January 2012. A post glacial rebound correction derived from Paulson et al., 2007 is applied. A destriping filter has been applied to the data to minimize the effect of an error associated with N-S stripes in GRACE monthly maps and a gaussian

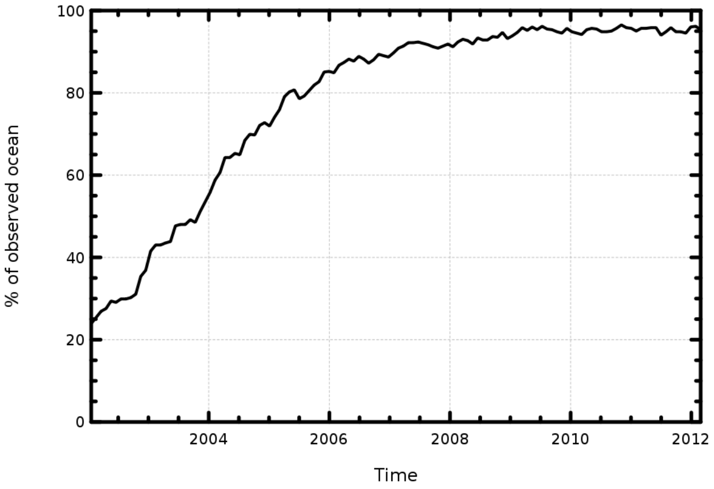

Figure 3: *Monitoring of the percentage of the ocean covered by Argo profiling floats (±60° and without inland seas).*

filter leads to a smoothed dataset without any information at less than 300km from the coast. A spherical harmonic filter cutoff at degree 40 acts as a third filter on the data. Because of this filter, the ocean data contain no wavelength shorter than about 1000km. Then, the obtained grids are projected onto the Empirical Orthogonal Functions (EOFs) of the Ocean Model for Circulation and Tides (OMCT), and the signal is reconstructed using the first 10 modes. As a result, the reconstructed data filter out signals in the GRACE data which are inconsistent with the physics embodied in the ocean model. Chambers and Willis found that this reconstructed data set better fit radar altimetric sea surface height corrected for steric effects using Argo float data (Chambers, 2006, [3] and Chambers and Willis 2010, [4]; http://grace.jpl.nasa.gov). Concerning our activity, the remaining uncertainty associated with these data is estimated to reach at least 0,5 mm/yr for the global MSL trend. In 2012, the RL04 dataset has been available over a longer temporal period (May 2011 increased to January 2012). The impact of using this longer timeseries is discussed in the section 3.2.3 and this estimation provides a better characterization of the associated uncertainty.

3. Description and evolution of the CalVal processing chain Altimetry / in-situ Argo

We first present the method of comparison of altimeter SLA with Argo+GRACE data. Then evolutions of the datasets and of the method of comparison is discussed.

3.1. Description of the processing sequence

3.1.1. Overview

Altimeter measurements are compared with in-situ dynamic height anomalies (DHA) derived from the Argo temperature and salinity profiles and with the mass contribution to the sea level derived from GRACE measurements. These are described hereafter:

1. Colocation of altimeter and GRACE data with Argo in-situ profiles
2. Validation of colocated measurements in order to exclude bad data
3. Estimate of statistics

3.1.2. Comparison of similar physical contents

Altimeter measurements are representative of the total elevation of the sea surface (surface to bottom), that includes barotropic and baroclinic components, whereas, DHA from profiling floats are representative of the steric elevation associated with the thermohaline expansion of the water column from the surface to 900 dbar (i.e. baroclinic component). We combine these data with grids of the mass contribution to the sea level from GRACE to provide an estimation of the total height of the water column so that the same physical content is compared with altimetry. The deep steric contributions are not taken into account in our study.

As discussed in previous annual report of the activity ([7]), in-situ DHA are referenced to a mean of the Argo dynamic heights over a time period different from the reference period of altimeter SLA. In order to compare both types of data with a common temporal reference, altimeter data are computed with the in-situ reference period by removing the mean of altimeter SLA over 2003-2009. The RL04 monthly grids of the mass contribution from GRACE are anomalies referenced to a mean of the mass contribution over the period March 2003 to February 2010. The use of a common temporal reference provides more homogeneity between the two types of data and increase their correlation, which thus improves our confidence in the results (see 2011 annual report of the activity, [8]). Note that the reference period will be updated with recent measurements.

3.1.3. Colocation of in-situ and altimeter data

The quality assessment of the altimeter SLA from a single mission is based on the along-track (L2) SLA. As the altimeter sampling is better than the in-situ coverage (a global altimeter coverage of the ocean, for Jason missions, versus a single T/S profile every ten days), grids of 10-day averaged along-track SLA are computed in order to have a sufficient spatial coverage. The quality of level 4 products can also be estimated based on the available grids of SSALTO/DUACS merged altimeter SLA. Then the colocation of both types of data is made via the interpolation of these grids for each altimeter mission (bi-linearly in space and linearly in time) at the location and time of each in-situ profile. The impact of averaging the altimeter L2 data over 10 days is estimated to be weak considering that the ocean state has not changed significantly within less than 10 days. However, maps of L2 SLA could be derived by optimal interpolation (objective analysis) and the impact of using this updated method has been analyzed (see the following section, 3.2.4) Similarly, the monthly grids of GRACE data are also colocated with each Argo profile.

3.1.4. Validation of compared altimeter and in-situ measurements

In order to exclude potential remaining spurious values and improve the correlation between both types of data (and thus increase our confidence in the results), a two steps selection is made in the processing chain over altimeter SLA and in-situ DHA (the mass contribution is not taken into account):

- Selection differences between altimeter SLA and in-situ DHA lower than 0.20 m. The choice of this threshold is based on the histogramm of SLA differences (figure 4, left). The selection is written as: $|SLA_{alti} - DHA| \leq 0.20m$.
- Selection over a maximal DHA from in-situ data. According to results from global Cal/Val analyses and from analyses of the in-situ dataset, values greater than 1.5 m are not taken into account: $|SLA_{InSitu}| \leq 1.5m$

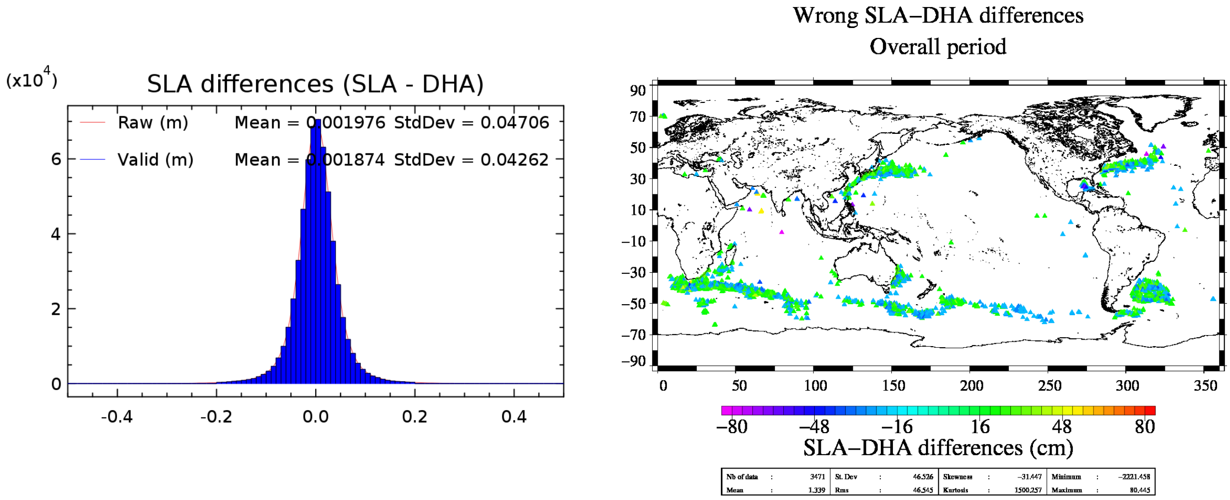

Figure 4: *Histogram of raw and validated SLA - DHA differences (number of profiles according to the observed sea level differences in meters, left) and map of the invalid SLA - DHA differences (right) for Duacs multi missions altimeter products*

It has already been shown that this selection excludes 1.6% of the total colocated measurements of Jason-1 data and figure 4 (right) indicates that the excluded measurements are mainly located in regions of high ocean variability. They are not associated with erroneous data but their rejection is due to the colocation method itself. Thus, if this validation would not be performed, the uncertainty in these regions would be too much increased to produce any valid results. The exluded data are totally attributed to the first validation step (threshold on the differences) but the second validation step is kept in case of potential remaining erroneous Argo data. The correlation and rms differences between altimeter SLA and in-situ steric DHA become 0.72 and 6.3 cm respectively whereas they are 0.65 and 7.2 cm when the validation phase is not considered. Thus the results will not be significantly affected by this selection but it strongly increases our confidence in the method.

3.1.5. Computation of global statistics

The processing sequence uses the database of colocated altimetry, GRACE data and Argo profiles to generate statistics of the altimeter sea level differences compared with Argo and GRACE measurements for each altimeter mission. Then, various diagnoses are produced from these statistics in order to detect potential anomalies in altimeter data. The global dispersion of the datasets (figure 5) provides information on the correlation and coherence between both types of data and then, deeper analyses can be performed. The evolution of the method of comparison and the integration of new diagnoses are discussed in the following section (3.2.4).

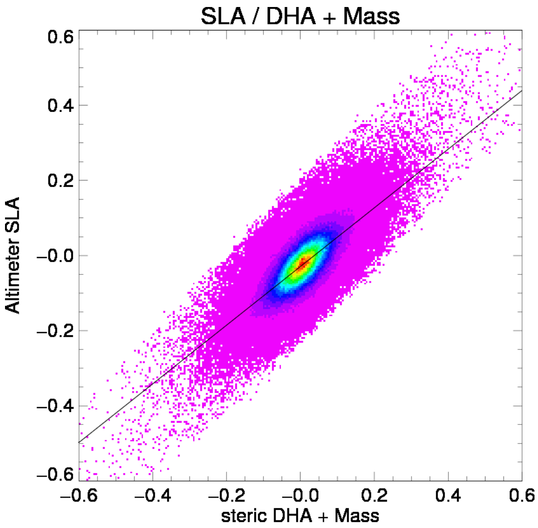

Figure 5: *Dispersion between Jason-1 altimeter SLA and the steric DHA from Argo plus the mass contribution from GRACE.*

3.2. Evolution of the processing sequence in 2012

According to the objectives described in previous annual report (see [8]) some improvements have been performed in 2012 concerning the different types of data but also within the method itself.

3.2.1. In-situ T/S database

In our study, the operational database of Argo profiles is quarterly mirrored in order to avoid being impacted by potential evolutions. Most of the results presented in this report have been computed until September 2012, except some analyses which were computed with an updated version of March 2012.

3.2.2. Altimeter database

Several evolutions of altimeter standards have been available in 2012 for Jason-1 & 2 and Envisat missions and their impact have been estimated by comparison with the independant reference dataset from Argo and GRACE. This is described in a dedicated following part of this report (section 5.6).

The DUACS merged altimeter SLA is also compared with Argo and GRACE data. This altimeter SLA timeseries is also quarterly updated together with the update of the Argo T/S database and both delayed time (DT) and near real time (NRT) DUACS SLA are used. An anomaly (jump) has been detected at the transition between these types of data in July 2011 (figure 6, left). This has not been observed in the altimeter data only, since the bias between DT and NRT data is small compared with the signal amplitude. But this can be detected when the Argo+GRACE signals have been removed. With the following update of the DUACS altimeter SLA together with the update of the Argo database of September 2012, this jump has disappeared (figure 6, right) since the transition DT/NRT between occurs later. Note that the date of the transition varies with the update of the database and it has been the first time such anomaly has been observed.

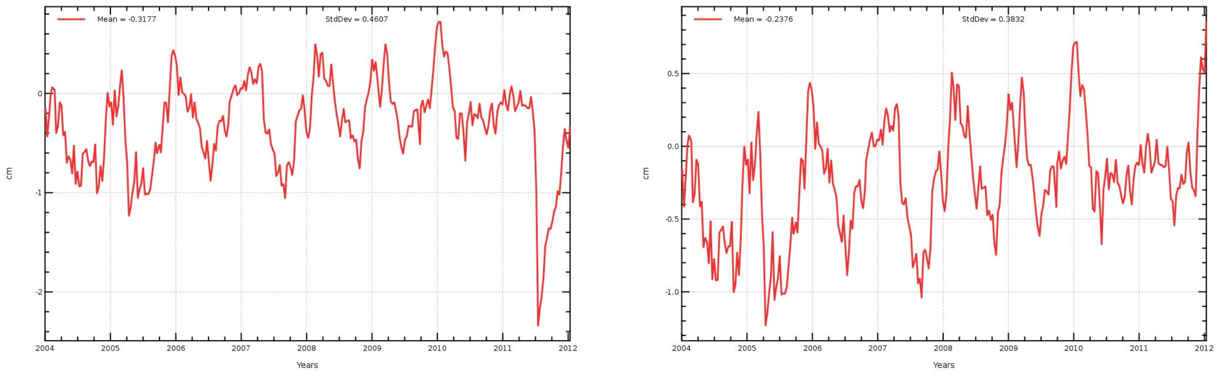

Figure 6: *Monitoring of the DUACS merged products sea level differences with the Argo database version of March 2012 (left) and September 2012 (right). Annual signals are included.*

3.2.3. The mass contribution from GRACE

The release 4 version of the Gravity Recovery and Climate Experiment (GRACE) dataset has been available from February 2003 to March 2011. An updated version of this database with measurements until January 2012 has been delivered and the impact of this update is described in this section. Note that the temporal reference period of these anomalies of the sea level associated with the mass contribution is unchanged between the reference dataset and the updated version (Mar. 2003 - Feb. 2010).

Figure 7 (left) indicates that increasing the length of the mass dataset leads to an increase of the trend of the mass contribution to the sea level of 0.4 mm/yr. The spatial distribution of the trend of the updated dataset (on the right) shows values between ±5 mm/yr and the distribution is not significantly different from the one of the previous version (see 2011 annual report, [8]).

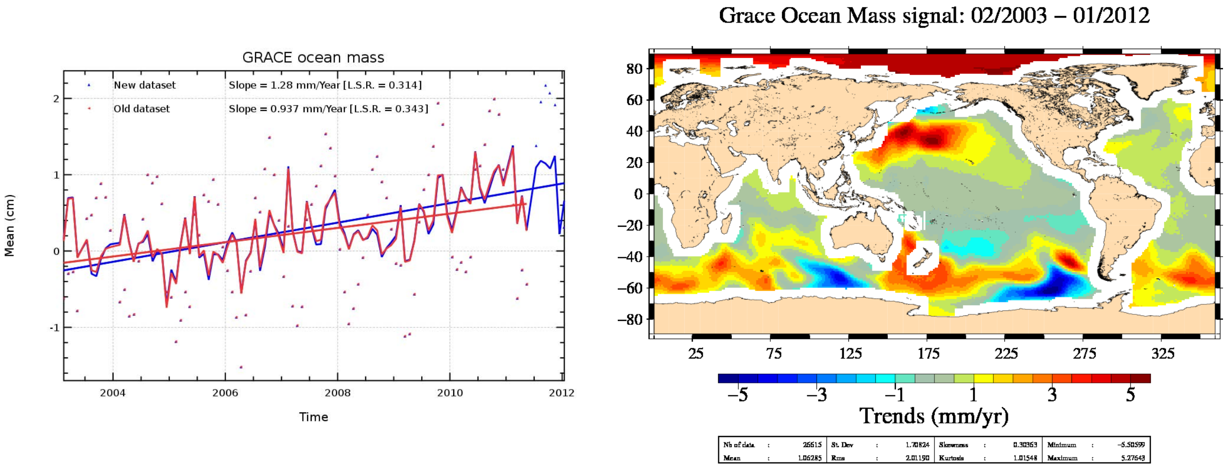

Figure 7: *Monitoring of the former and updated RL04 GRACE dataset (left) and spatial distribution of the trend of the updated dataset (right).*

The evolution of the correlation and the standard deviation of the differences between altimeter SLA and Argo+GRACE data is shown in table 1 with both versions of the mass contribution for various altimeter SLA. These statistics include all spatial and temporal scales of the signal. Whatever the altimeter mission, the variability of the differences is unchanged and a very low decrease (0.4%) of the correlation is systematically observed. The histogram of the variance differences between sea level differences obtained with DUACS DT and the updated versus the previous mass dataset (figure 8, left) confirms that the coherence between altimetry and the Argo+GRACE reference is unchanged on average. The spatial distribution of these differences (on the right) provides statistics on all in-situ profiles available in each box of the map over the studied period. It indicates that the temporal coherence in each box is slightly improved (negative values in blue) in some regions of strong ocean variability (Gulf stream, Kuroshio and confluence zone).

The monitoring of Jason-1 altimeter SLA and of the summed steric DHA and mass contributions (figure 9, top left) reveal that both timeseries are in a good agreement: the amplitude and phase of the annual signal are similar and the altimeter SLA presents more physical content at high frequencies.

Other panels of figure 9 show the impact of using the updated mass contribution on the trend of

Mission	**SLA/DHA+Mass**	**GRACE RL04: 2003/2011**	**GRACE RL04: 2003/2012**
Jason-1	Correlation	74.4%	74.1%
	Std Dev of differences	5.2 cm	5.2 cm
Jason-2	Correlation	74.6%	74.2%
	Std Dev of differences	5.2 cm	5.2 cm
Envisat	Correlation	73.2%	72.8%
	Std Dev of differences	5.3 cm	5.3 cm
Duacs DT	Correlation	87.5%	87.1%
	std of differences	4.0 cm	4.1 cm

Table 1: *Correlation and standard deviation of differences between altimeter SLA and DHA + Mass*

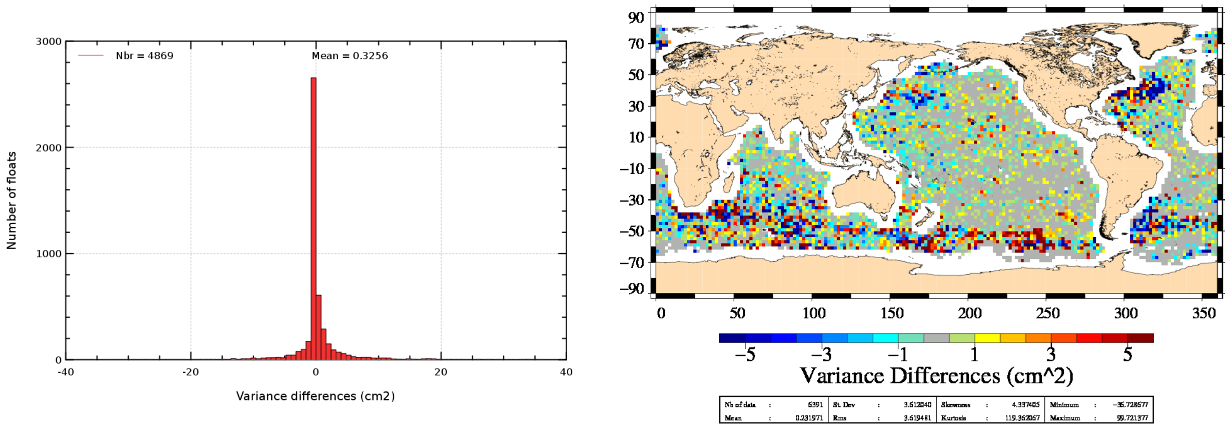

Figure 8: *Histogramm and spatial distribution of the variance differences between the sea level differences obtained with Duacs DT merged products and with the former mass contribution versus the updated version.*

the sea level differences for various altimeter datasets. For altimeter timeseries long enough, the altimeter SLA trend is not significantly modified with the use of the updated mass contribution dataset ($< 0.1mm/yr$). The higher sensitivity of Jason-2 altimeter SLA trend to this change (+0.5 mm/yr) suggests that less confidence should be attributed to diagnoses associated with sea level trend over such a short period. Indeed, the formal error adjustment associated with the Jason-2 slope estimation is three times greater than the one of Jason-1 or Envisat with the updated GRACE dataset and even four times greater with the shorter RL04 version (0,4 mm/yr vs 0,1 mm/yr). But whatever the altimeter data considered, this formal error is systematically reduced with the use of the longer dataset. This indicates that the uncertainty on the results of our method has been reduced.

Thus, the use of a longer timeseries of the mass contribution from GRACE RL04 dataset has not changed the results concerning the quality assessment of altimeter SLA but the associated uncertainty has been reduced, which is an improvement. Although Jason-1 mission has been a reference mission in DUACS merged products over 2004-2008, the trends associated with these datasets are

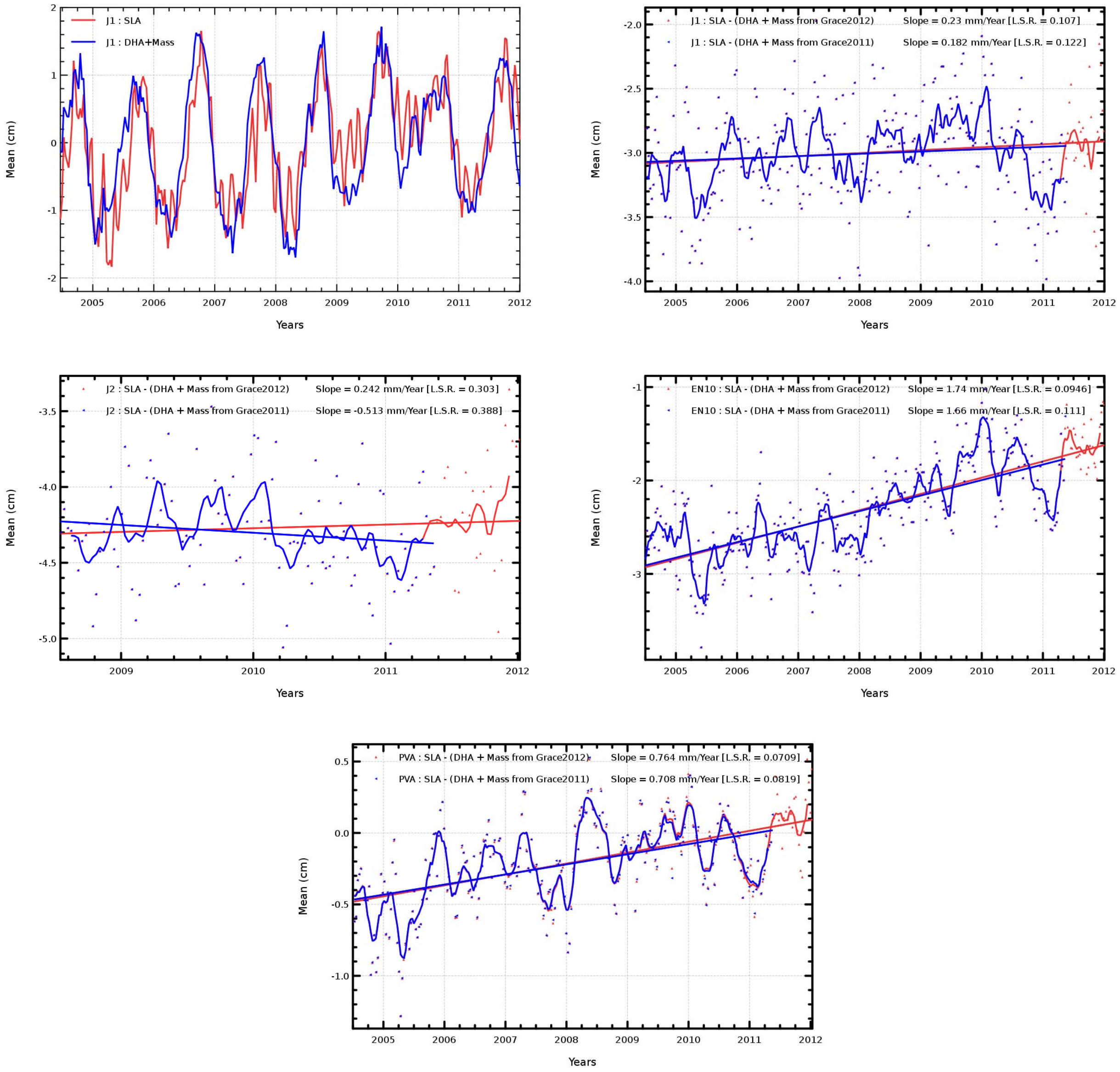

Figure 9: *Monitoring of Jason-1 SLA and summed DHA and updated RL04 mass contribution (top left). Monitoring of the altimeter sea level differences referenced to the previous (blue) and updated (red) mass dataset for Jason-1 (top right), Jason-2 (bottom left), Envisat (bottom right) and DUACS DT (bottom). Timeseries without annual and semi-annual signals and with a 2-months low-pass filtering are also shown.*

different (0.2 and 0.7 mm/yr). This is partly associated with differences in the altimeter standards used (e.g. orbit) and with the contribution of Jason-2 in Duacs over this period.

A release 5 version of the GRACE dataset should be soon available over the Argo period and it is expected to be much more accurate than the previous RL04 version. In the framework of the estimation of the quality assessment of altimeter SLA, the impact of using this updated version is planned to be analyzed in 2013.

3.2.4. Improving altimeter and Argo profiles comparison

- **Improving the efficiency of the data processing**

For each run of the comparison of altimeter SLA with the Argo+GRACE reference, one of the main step consists in creating the inter calibrated database which contains all necessary information from the different types of data to further generate statistics and diagnoses. This is currently time consuming, especially if the impact of a new altimeter standard is estimated since the processing chain has to be run twice with each altimeter version. In order to make the calculation more efficient, some steps of the processing sequence have been parallelized when it was possible. For instance, the duration of the processing of the 8 years of Jason-1 data has been approximately reduced from 36 hours to 15 hours.

- **Towards a better understanding of the comparison: new diagnoses**

Altimetry is compared with independant data in order to detect drift and anomalies but the physical content of the sea level differences still remains to be better understood. Specific diagnoses have been added in the processing chain.
Monitoring or maps of altimeter sea level differences compared with Argo + GRACE constitute specific analyses of the data but before looking at such elements, there has been a clear need of having macro information describing the datasets we want to compare. Indeed, we first want to know in which extent the altimeter SLA is homogeneous enough with Argo + GRACE for them to be compared. Thus, dispersion diagramm is now systematically first computed in order to assess the global correlation and rms of the differences between altimeter SLA and steric + mass signals (see example in figure 5). All temporal and spatial scales are included in such diagnosis but the global correlation is mainly associated with the annual signal of the differences which strongly dominates in the spectrum of the differences. In order to better characterize the influence of this signal, the periodogram of the differences is now computed (ex in figure 10). This provides the frequencies where the magnitude of the differences are significant.

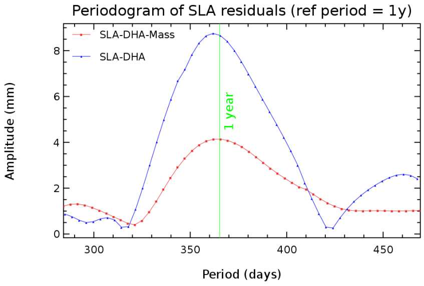

Figure 10: *Periodogram of the DUACS multimissions SLA differences with Argo and GRACE data.*

- **Averaging the altimeter data before the colocation with Argo profiles**

As previously mentionned, along-track altimeter level 2 measurements are box-averaged in 10-days grids in order to provide a sufficient spatial coverage before the colocation with every Argo profiles.

This box-averaging is a basic approach and the impact of computing 7-day altimeter grids of SLA by objective analysis via optimal interpolation is estimated. As SSALTO/Duacs system provides 7-days grids of mono-mission altimeter SLA (T/P - Jason), we use this available dataset to make the analysis.
The impact of this new SLA estimation is first assessed in terms of global correlation and variability of the differences between Jason-1 altimeter SLA and Argo + GRACE reference over 2004-2011. These statistics include all temporal and spatial scales. The correlation between altimetry and the reference is strongly increased (+11%) and the standard deviation is reduced (−3.2 cm rms) when SLA grids are computed by objective analysis (first two lines of table 2). The spatial distribution of the variance differences (figure 11, left) provides statistics on all in-situ profiles available in each box of the map over the studied period. It indicates that the temporal coherence with in-situ data in each box is improved by 9 cm^2, varying from 3 cm^2 at low latitudes and more than 10 cm^2 elsewhere. This significant improvement is directly associated with the SLA averaging technique: for each grid, temporal correlation scales are used to weight the data in the objective analysis which is an optimal technique whereas all the data have the same weight when averaging over a 10-day window.

	Correlation	**Std Dev of differences**
$SLA_{J1_{BoxAveraged}}$ / DHA + Mass	74.4%	5.2 cm
$SLA_{J1_{ObjAnalysis}}$ / DHA + Mass	85.1%	4.1 cm
$SLA_{DuacsDT_{ObjAnalysis}}$ / DHA + Mass	87.5%	4.1 cm

Table 2: *Correlation and standard deviation of differences between altimetry and in-situ DHA + Mass with Jason-1 altimeter data derived from along-track box-averaged data, from objective analysis and with Duacs DT merged products also computed by objective analysis.*

Similar statistics are computed with altimeter SLA derived from SSALTO/DUACS merging several missions (7-days grids) also obtained by objective analysis (last line of table 2). Compared with the altimeter SLA derived from a single mission, the correlation is increased by 2.4% and the variability of the differences is globally unchanged. This is a global estimation over the period including all temporal and spatial scales and to provide more details, the spatial distribution of the variance differences between these situations is shown on figure 11 (right). It indicates that in almost the whole global ocean (positive values), the temporal coherence between altimetry and in-situ data is increased with the use of DUACS merged products rather than with single satellite altimeter data (Jason-1 derived from objective analysis). However, this is not the case in regions of high ocean variability as in the Antarctic Circumpolar Current (negative values). This could be associated with a potential remaining error in part of the Argo profiles, in the GRACE processing or with a potential additionnal error introduced in DUACS merged products by a different mission than Jason-1. But no explanation has been found and depper analysis is required: the sensitivity of the results could be addressed with the use of the updated RL05 version of GRACE data and also by performing a similar analysis with Envisat SLA also computed by objective analysis in order to only assess the impact of changing the mission.

These comparisons indicate that the altimeter data processing (objective analysis versus box-averaged) has a significant impact on the correlation and coherence of altimetry with Argo and GRACE data and the added value related with the use of multi-satellite merged products compared with the use of a single satellite is not as important since merged products mainly provide new information concerning the resolution of mesoscale signals which are less resolved with Argo data.

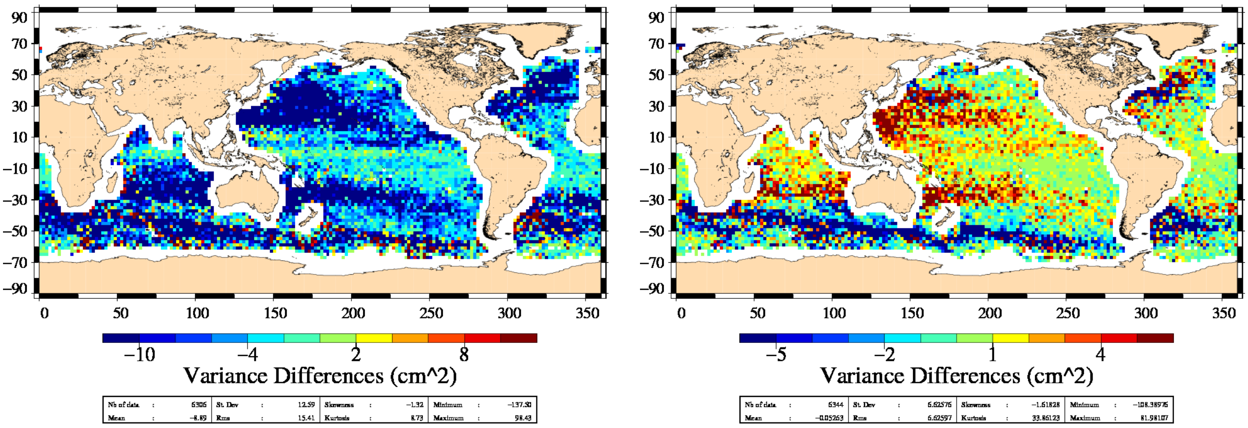

Figure 11: *Spatial distribution of the variance differences between the sea level differences with J1 SLA derived from objective analysis and from along-track box-averaged data (left), and between J1 and Duacs DT merged altimeter sea level differences, both with SLA derived from objective analysis (right).*

Secondly, concerning the impact on the drift of the sea level differences, figure 12 shows that for altimeter data of a single mission, the use of SLA derived from optimal interpolation leads to an increase of the drift of the sea level differences by 0.4 mm/yr (red and blue). Note that it has been checked that the slope of the global Jason-1 SLA derived from both averaging methods is the same.

The slope of the sea level differences with Jason-1 derived from objective analysis is very close to the one obtained from merged products (0.6 mm/yr versus 0.7 mm/yr). As our confidence in the latter is stronger, this suggests that using altimeter data from a single mission derived by objective analysis provides a major improvement compared with the reference processing of the data (along-track box-averaged).

Thus, in the context of the comparison of altimetry with Argo and GRACE data, it would be better to generate altimetric grids by objective analysis rather than using box-averaged along-track data. This analysis has been performed since the Jason-1 timeseries of SLA grids derived by optimal interpolation are available, but this is not the case for other missions as Envisat. And generating these altimeter grids would require significant efforts. In particular, this becomes complicated if it has to be performed everytime the impact of a new altimeter standard has to be quantified in the SLA computation since the time required could be dissuasive. Therefore, before using the new approach of SLA computing, the operationnal feasability and the associated constraints should be quantified (objective analysis parameters to be validated, time required for each calculation to be characterized) and the reference will remain the usual calculation of averaging per box for the following studies.

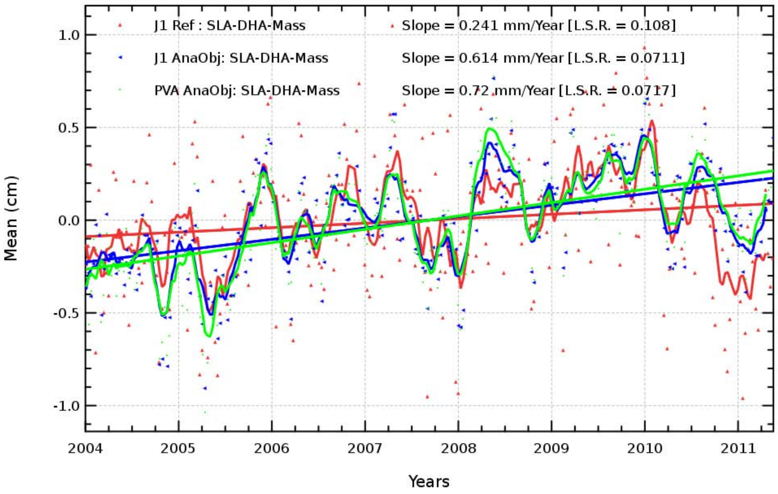

Figure 12: *Monitoring of the sea level differences with Jason-1 SLA derived from along-track box-averaged data (red), from objective analysis (blue) and from Duacs DT products (green). Annual and semi-annual signals are removed and data are 2-month filtered.*

4. Analyses of the altimeter sea level differences with the external reference

We describe here the analyses of the differences between the altimeter SLA and the reference Argo steric DHA and the mass contribution from GRACE as detailed in previous section. The mean and the variance of the sea level differences from various altimeter missions are first analyzed spatially and temporally. The detection of regional altimeter MSL drift difference between Jason-1 and Envisat is then discussed with the use of the new method of comparison.

4.1. Mean sea level differences

4.1.1. Temporal analysis of the mean differences

The monitoring of the sea level differences is shown in figure 9 for Jason-1 and 2, Envisat and DUACS DT products from July 2004 to January 2012. The drift from Jason-1 and Jason-2 are identical (0.2 mm/yr) despite their different respective period and the Envisat drift reaches 1.7 mm/yr while the drift of the multi satellites merged products is of 0.8 mm/yr.

- **Altimeter MSL drift differences between Jason-1 and Envisat**

The reprocessing of the Envisat altimeter data has provided significant improvements of the mission and the data are now much more coherent with Jason-like missions (Ollivier et al. 2012, [11]). However, some differences remain between Envisat and Jason-1 altimeter MSL trends if focused over 2004-2012 period: +1.0 mm/yr is observed between Envisat and Jason-1 (figure 13 top and 2nd column of table 3). It suggests that the drift of one of these missions is greater than the other.

In-situ data are used to estimate which mission is closer to the reality. We have shown that our method is very useful to detect relative differences, but can we have confidence in the estimation of the absolute altimeter MSL drift? In other words, can we detect a bias on the drift?

MSL trends (mm/yr, GIA included)	**Altimeter MSL**	**MSL drift vs Argo+GRACE**	**MSL drift vs tide gauges**
Jason-1	2.4	0.6	-0.1
Envisat	3.4	2.0	0.8
Trend differences	1.0	1.4	0.9

Table 3: *Altimeter MSL trends of Jason-1 and Envisat and MSL drifts compared with in-situ measurements over the period 2004 / January 2012. Note that the 0.3 mm/yr GIA correction is taken into account in these figures which is not systematically the case in all the graphs of the report.*

The altimeter MSL is compared with Argo and GRACE data from January 2004 onwards (figure 13 left and 3rd column of table 3). First, the altimeter MSL drift is greater for one of these missions than the other (1.4 mm/yr difference close to 1.0 mm/yr global difference). Note that the error

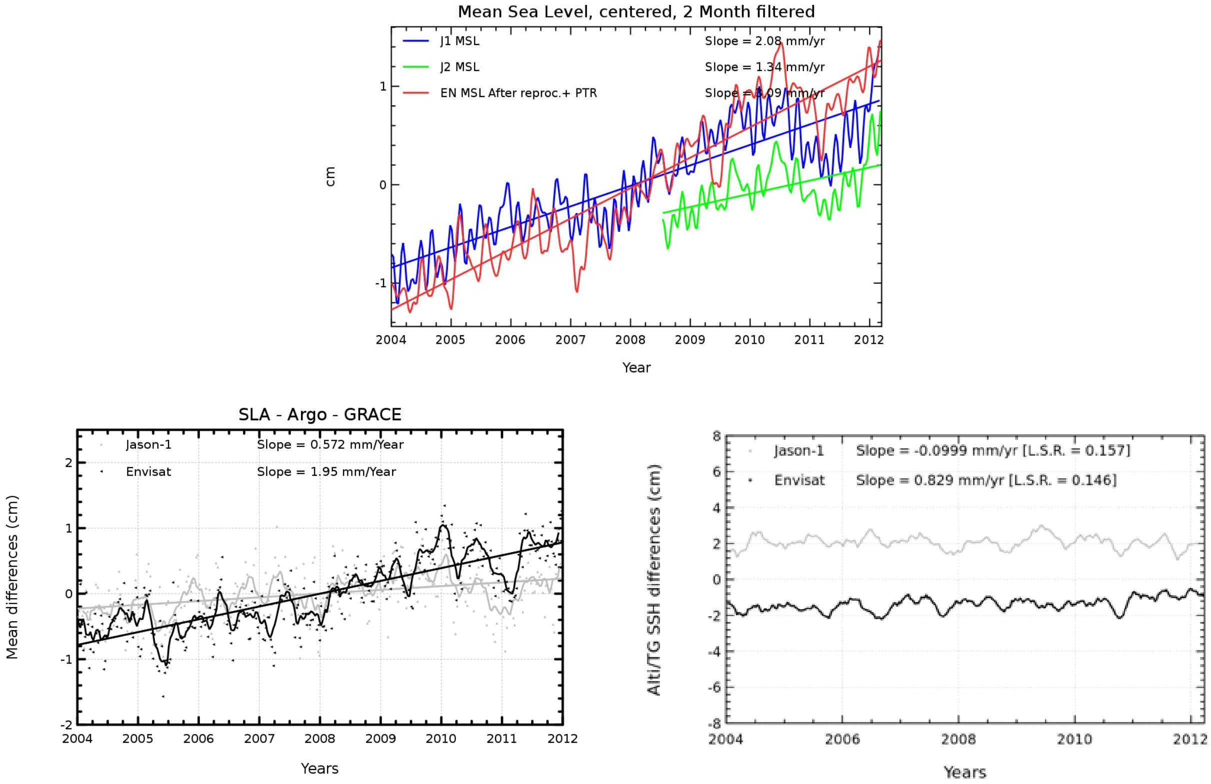

Figure 13: *Altimeter MSL trends of Jason-1 and 2 and Envisat over 2004-2012 without the GIA contribution (+0.3mm/yr) (top). MSL drift of Jason-1 and Envisat compared with Argo+GRACE (left) and tide gauges (right) over the same period (GIA included) and without annual and semi-annual signals and after 2-month filtering.*

over this period is estimated to be around ±0.8 mm/yr, taking into account the errors associated with both types of data, their processing and the colocation process. Secondly, absolute MSL drifts referenced to Argo and GRACE data suggest that the Envisat MSL drift is greater than the one of Jason-1 (2.0 vs 0.6 mm/yr).

These results are confirmed when compared with tide gauges over the same period (figure 13 right and last column of table 3). First, the altimeter MSL drift is greater for one of these missions than the other (0.9 mm/yr difference close to 1.0 mm/yr). The associated error over this period is estimated to be ± 0.7 mm/yr, taking into account the spatial sampling restricted to coastal areas and the terrestrial crustal movements (See 2012 annual report, [15]). Secondly, absolute drift compared with tide gauges suggest that the drift is greater for Envisat mission (0.8 vs -0.1 mm/yr).

Thus, the combination of different types of in-situ data allow to detect and indicate the greater MSL drift of Envisat than the one of Jason-1 over the period 2004-2012.

- **Inter annual evolution of the sea level differences**

Figure 14 show the sea level differences for 3 different missions over the Jason-2 period. Without annual and semi-annual signals, the amplitude of the remaining inter-annual signals ranges within

±5 mm and a good coherence is observed between the three missions. The sea level differences obtained with Envisat are more different than both Jason differences which are more similar to each other. This is associated with the differences of altimeter standards and corrections (USO, PTR). Note that the 3.5 years period analyzed here remains short to allow the analysis of inter annual signals whose signature is detected at 3 to 5 years minimum.

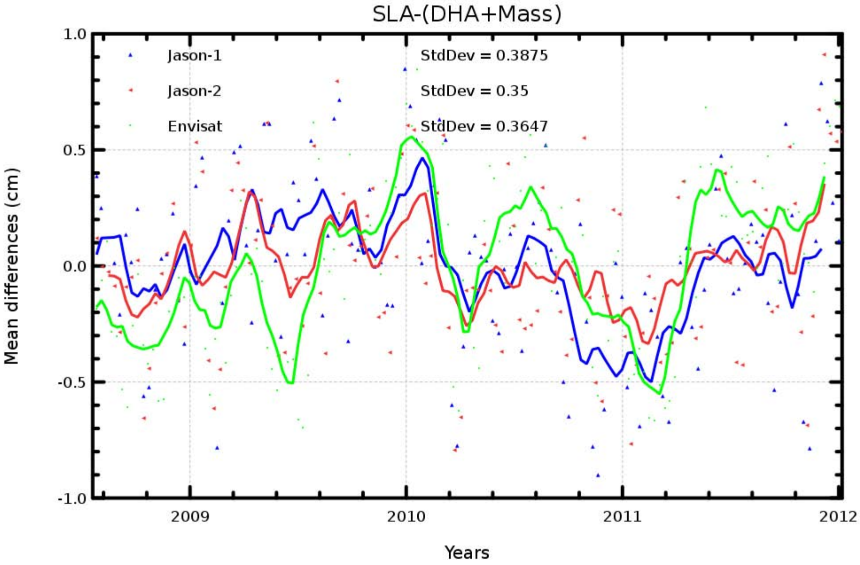

Figure 14: *Monitoring of the altimeter sea level differences compared with Argo and GRACE data for Jason-1, Jason-2 and Envisat over the Jason-2 altimeter period. Annual and semi-annual signals are removed and data are 2-month filtered.*

4.1.2. Spatial analyses of the mean differences

Regional sea level biases have already been detected in altimetry thanks to the cross comparison beween various missions, but the detection of potential systematic altimeter errors is made possible thanks to the comparison with independent measurements. Map of the mean differences with the Jason-1 SLA is shown on figure 15. Remaining biases are observed in particular in the Pacific ocean. The observed negative differences in the north-west and south-west Pacific ocean appears to be strongly correlated with the GRACE data since similar patterns are observed on the trend of the ocean mass signal (see figure 7). Note that similar signals are observed when using Envisat measurements. A deeper analysis of these elements could be made by using another dataset of the GRACE mass contribution to assess the impact of this field.

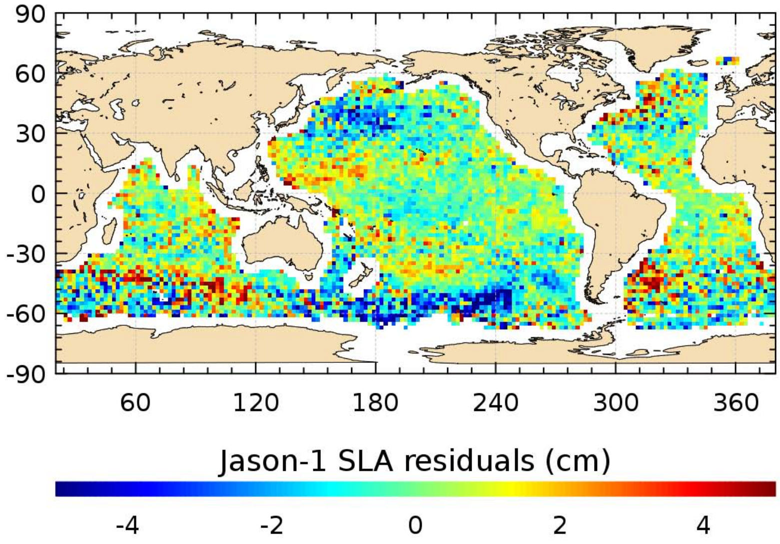

Figure 15: *Map of the Jason-1 SLA differences compared with Argo and GRACE data.*

4.2. Variance of the sea level differences

The evolution of the coherence of altimeter data with combined Argo and GRACE external data is provided by the variance of the sea level differences over the studied period (figure 16, left). This is the monitoring of the spatial variability of the sea level differences. The mean variability obtained with all missions are very close to each other (5.1 cm).

Compared with the total studied period, the spatial variability increases from 2009 for the three available missions by more than 5 mm. The impact of the relative increase of the Argo sampling in regions of high ocean variability over the recent years has already been analyzed but (see 2011 annual report, [8]) it is considered to be rather weak. Then we compare on figure 16 (right) the standard deviation of the sea level as seen by the Jason-1 SLA (both globally and colocated with

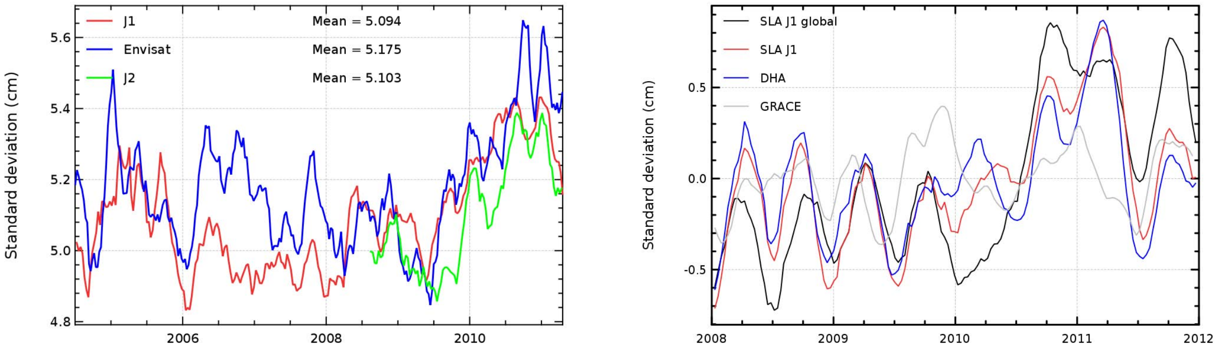

Figure 16: *Monitoring of the standard deviation of the sea level differences from various altimeter data (SLA-Argo-GRACE) (left) and standard deviation of the Jason-1 SLA and Argo steric DHA with removed average (right).*

Argo profiles) and by the steric DHA from Argo and the contribution from GRACE. The variability increase on 2009-2011 is observed with altimetry as well as Argo data. This is likely associated with the La Nina 2010 event and at this period, the altimeter SLA are thus more different from the MSS and the steric dynamic heights anomalies (DHA) are more different from the reference mean DHA. The mass contribution is not affected by a similar evolution. The fact that this increase is also observed in the difference (figure 16, left) suggests that it is not seen similarly by altimetry and Argo+GRACE.

4.3. Detection of regional altimeter MSL drift

A regional MSL trend difference observed between Jason-1 and Envisat with the use of GDR-C orbit solution has already been discussed (Valladeau and Legeais, 2012; [16]). Thanks to the comparison of altimeter data with Argo in-situ profiles, it has been demonstrated that the observed regional discrepancies are removed with the use of the preliminary CNES GDR-D orbit solution (Cerri et al., 2011: [2]). Thus the comparison of altimeter measurements with Argo profiles makes possible the estimation of the impact of a new altimeter standard in the SSH calculation. But this analysis had been performed by comparing altimeter data with the steric signal only from Argo profiles. Our method of comparison has evolved since the mass contribution to the sea level from GRACE is now included and we thus want to estimate if it affects the results.

Similar analysis as in the initial study is performed by comparing the MSL trend differences between the western (≥180°) and eastern (≤180°) hemispheres for Jason-1 and Envisat (not reprocessed) with GDR-C orbit solution (figure 17). When the mass contribution is taken into account, the conclusion is not changed since the hemispheric MSL trend difference for Envisat is much greater than the one obtained with Jason-1 and the difference between both missions is much greater than the estimated uncertainty on the regional MSL trend estimation (about 1.0 mm/yr). However, such analysis is expected to be very sensitive to the solution of the mass contribution from GRACE since it derives from an orbit calculation and hemispheric bias may also be included in the GRACE solution. Thus, the results may be affected by the use of the updated RL05 GRACE version.

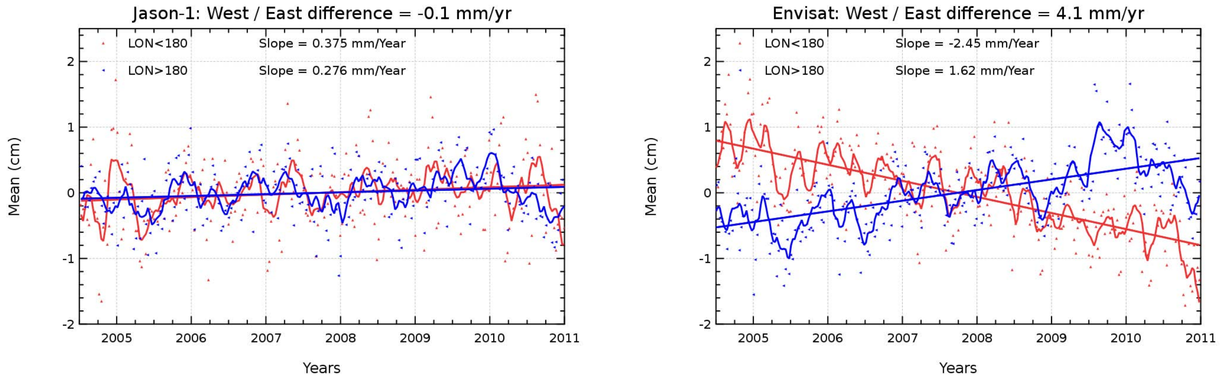

Figure 17: *SSH difference (cm) between altimeter data and Argo + GRACE measurements for Jason-1 (left) and Envisat (right) computed with GDR-C orbit, separating east (≤180°) and west (≥180°) longitudes. Corresponding annual and semi-annual signals are removed. Trends of raw data are indicated and the 2-month filtered signal is added.*

5. Evaluation of new altimeter standards

5.1. Overview

The impact of a new altimeter standard (orbit solution, geophysical or instrumental correction, retracking algorithm) on the sea level computed from altimetry may be estimated by comparison with in-situ measurements using successively the old and new version of the altimeter standard. This approach also helps us to better characterize the uncertainty associated with our method. Indeed, the more analyses of impacts are performed, the more it will be possible to a priori determine in which situation the impact of a new standard can be detected or not.

Various analyses of impact have been performed over the previous years concerning Jason-1 GDR-B and GDR-C, the updated Duacs delayed time merged products, the modelled or radiometric wet troposphere correction and so on (see previous annual reports of the activity). The criterion of improvement used for these analyses is mainly based on the consistency (variance difference) between the updated altimeter data and the in-situ reference. The previous method of comparison has been used, only based on Argo DHA extrapolated over the total water column to be homogeneous with altimetry and the searched impact was usually smaller than the uncertainty of the method (of the order of 1 cm^2).

The new method of comparison including the mass contribution to the sea level from GRACE should improve the detection of weak evolutions since it makes the compared datasets more homogeneous. Moreover, besides of the rms of the differences, other diagnoses should be used such as the evolution of the correlation between altimeter data derived with the old and new standards and the in-situ reference. An improved correlation between datasets will provide a reduced formal error adjustment of the altimeter MSL drift and thus an improved confidence in this drift. But the global estimate of the correlation include all spatial and temporal scales of the signal and it is thus mainly associated with the annual signal of the differences which strongly dominates in the spectrum of the differences (see example of figure 10). Therefore, an evolution of the global correlation will be mainly related with a change of amplitude and/or phase of the annual signal of the MSL. An estimation of the coherence diagramm providing the frequency distribution of the correlation could help to better characterize the impact of the new standard at various temporal and spatial scales. Similarly, as the searched evolution is of much less magnitude (1 to 5 cm^2) than the global variance of the sea level differences (about 30 cm^2), data should be first filtered out in the frequency band where the impact of the new standard is expected to be maximal. At last, the impact of an updated altimeter standard can also be estimated in term of the evolution of the trend (after removing the annual signal) but only if the observed evolution is greater than the uncertainty associated with the estimation of this trend. All the aformentioned diagnoses have not been used yet in the studies performed in 2012, which are synthetized below. They concern the impact estimation of the MSS CNES/CLS11, several orbit solutions and updated or reprocessed data for Jason-1, Envisat and Jason-2.

5.2. Impact of a new Mean Sea Surface solution

Altimeter SLA from Jason-1 & 2 and Envisat have been computed so far with a reference to the MSS CLS01V1 (Hernandez and Schaeffer, 2001; [6]). We estimate here the impact of using the new MSS CNES-CLS11 (Schaeffer et al., 2012; [14]) on the quality of altimeter SLA from Jason-1 and Envisat by comparison with independent reference over the period mid 2004 - May 2011. Figure 18 shows the difference between the MSS CNES-CLS11 and CLS01. The differences are of the order of the millimeter and are homogeneously distributed (except at high latitudes, but no Argo float are available there).

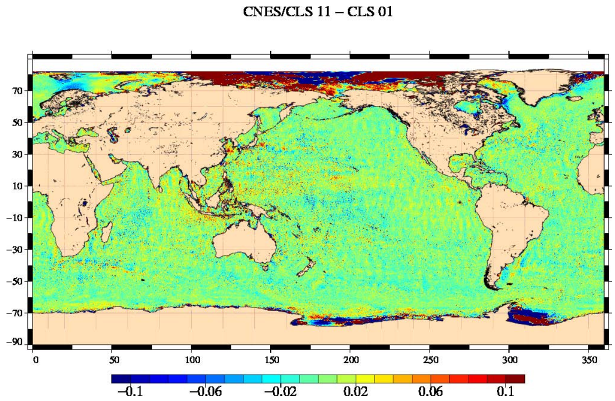

Figure 18: *Map of mean differences between MSS CNES-CLS11 and CLS01.*

Table 4 indicates that the global correlation between altimeter and Argo+GRACE data and standard deviation of their differences are weakly improved for Jason-1 but almost unchanged for Envisat. The monitoring of the Jason-1 and Envisat altimeter sea level differences with both MSS (figure 19) indicate that the drift of altimeter SLA is globally unchanged over the studied period whatever the MSS used.

	Jason-1		**Envisat**	
	Correlation	std of differences	Correlation	Std Dev of differences
$SLA_{MSS_{2001}}$ / DHA + Mass	74.4%	5.2 cm	73.3%	5.3 cm
$SLA_{MSS_{2011}}$ / DHA + Mass	74.8%	5.1 cm	73.4%	5.3 cm

Table 4: *Correlation and standard deviation of differences between altimeter SLA derived from Jason-1 and Envisat referenced to the* MSS_{2001} *and* MSS_{2011} *and Argo DHA + GRACE over July 2004 - May 2011*

Concerning the inter annual evolution, a 1 mm jump is observed between both Envisat sea level differences at the end of 2010 (figure 19, left). This is related with the orbit drift of the mission since November 2010 and it shows that the quality of both MSSs are different in the regions where no repetitive track is available. Concerning Jason-1 (figure 19, right), no particular distinction can be made between both curves after the orbit change of the mission in February 2009. Note that the Envisat orbit had changed for a drifting orbit whereas the new orbit of Jason-1 remained a cyclic orbit, but this may not explain the observed difference of impact between both missions.

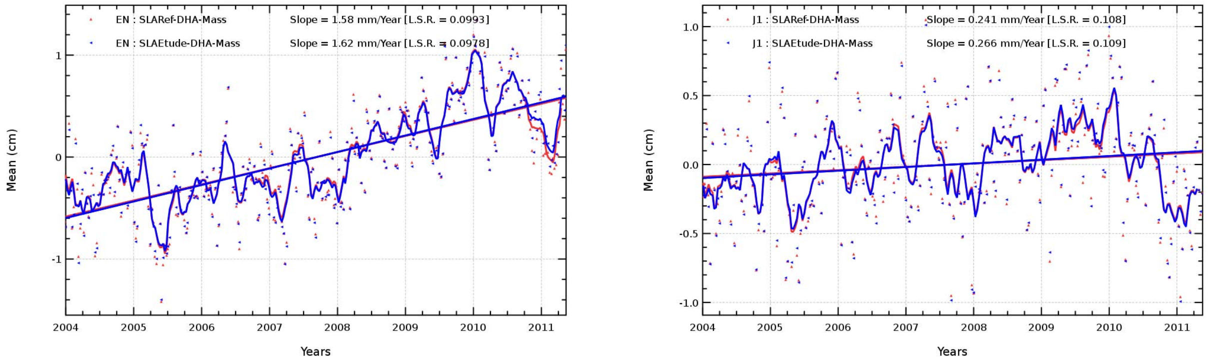

Figure 19: *Sea level differences with Argo+GRACE from Envisat (left) and Jason-1 (right) corrected from* MSS_{2001} *(red) and corrected from* MSS_{2011} *(blue).*

As mentionned above, the variance of the sea level differences are almost unchanged with the new MSS. However, the monitoring of the variance difference of altimeter SLA computed with both MSSs reveal a jump of almost 1 cm^2 for Envisat at the end of 2010 (figure 20, left) as well as for Jason-1 in February 2009 (right). They both correspond to a reduction of the variance of the sea level differences with the new MSS, which means an improvement obtained with the MSS_{2011}.

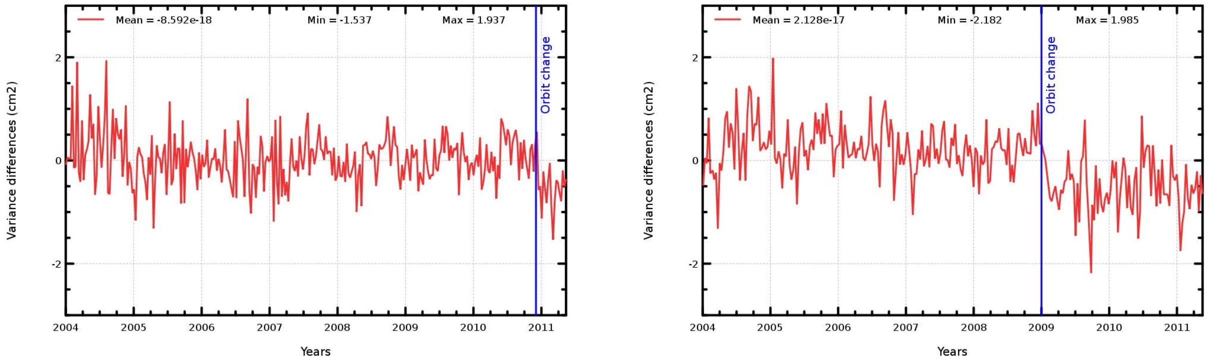

Figure 20: *The temporal tracking of the variance differences between the sea level differences with altimetry corrected from* MSS_{2011} *and from* MSS_{2001}*, for Envisat (left) and Jason-1 (right).*

This analysis provides us with three conclusions: (i) The use of the new MSS to compute altimeter SLA instead of the previous version does not affect the results of the altimetry comparison with in-situ measurements (global correlation, rms of differences and the drift of the sea level differences), which was expected. (ii) **the improved quality of the new MSS in the regions of interleaved tracks can be quantified with our method of in-situ comparison (almost 1 cm^2)** . (iii) These results help us to better quantify the order of magnitude of the signals which can be detected with our method of comparison with in-situ data (about 1 mm on the mean) and thus reduce the method uncertainty. This can be used for further analyses.

5.3. Comparison of orbit solutions: GPS and DORIS+SLR vs tritechnique

A study has been performed concerning the determination of the origin of observed differences between two orbit solutions for Jason-2. Results are synthesized here and the complete study is available in a technical note (Legeais 2012, [9]).

5.3.1. Comparison of orbits GPS and DORIS+SLR

The difference between the orbit solutions for Jason-2 based on GPS and DORIS+SLR techniques reveals an annual signal directly associated with the position difference between the GPS system reference linked with the Earth center of mass and the DORIS+SLR system reference linked with the ITRF frame (Cerri et al., 2011 [2]). Figure 21 (left) reveals an annual signal associated with ocean measurements which is increased when restricted at high latitudes. This is confirmed by the map of the differences of the annual signal magnitudes (fig. 21, right) which shows values of 3 mm at high latitudes (red values).

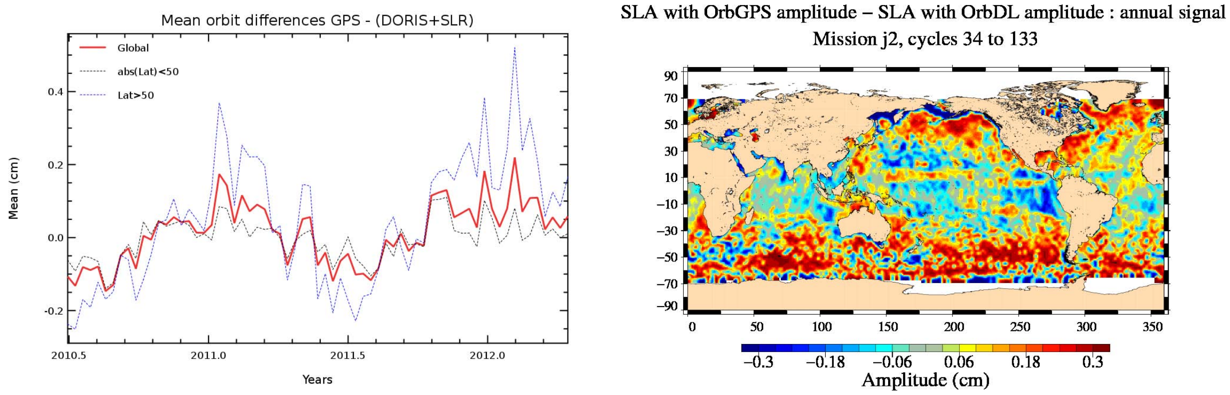

Figure 21: *Mean orbit solution differences between the GPS solution and DORIS+SLR solution for ocean measurements in different latitudinal regions (left). Map of the differences of the annual signal magnitudes associated with Jason-2 SLA computed with the GPS versus DORIS+SLR orbit solution.*

It has been shown (see details of the study, [9]) that the use of the GPS or DORIS+SLR orbit solutions instead of the tri-technique GDR-D reference has no significant impact on the coherence of ascending and descending tracks (crossover analysis) neither on the along-track Jason-2 SLA performance. Similarly, the use of the GPS orbit instead of the DORIS+SLR orbit solution does not affect significantly the SSH performances. However, the Jason-2 SLA computed with these orbits are compared with the external Argo+GRACE data in order to determine in which extent the origin of the observed annual signal can be detected with our method of comparison.

5.3.2. Comparison with in-situ measurements

Jason-2 SLA derived with both studied orbit solutions and the tri-technique reference orbit are compared with Argo steric DHA and GRACE measurements and their monitoring is shown on figure 22 (left). All signals display an annual signal (of about ±4 mm amplitude) whose amplitude is maximal with the use of the GPS orbit solution (in red) and reduced with the DORIS+SLR solution (in blue). The difference between these both timeseries is shown on figure 22 (right) and is of about ±1 mm, which remains very small. Thus, using the Argo+GRACE system as a reference, this suggests that the periodic signal observed between both studied orbit solutions would be more associated with the GPS orbit rather than the DORIS+SLR orbit solution. Note that no impact of the orbit solutions has been detected on the agreement between the altimeter SLA and the external data (correlation and variance of the sea level differences). However, taking into account the magnitude of the annual signal observed between altimetry and Argo+GRACE data (about ±4 mm), the observed reduction of amplitude obtained with both studied orbits appears to be statistically not significant and the confidence in the conclusion is thus reduced.

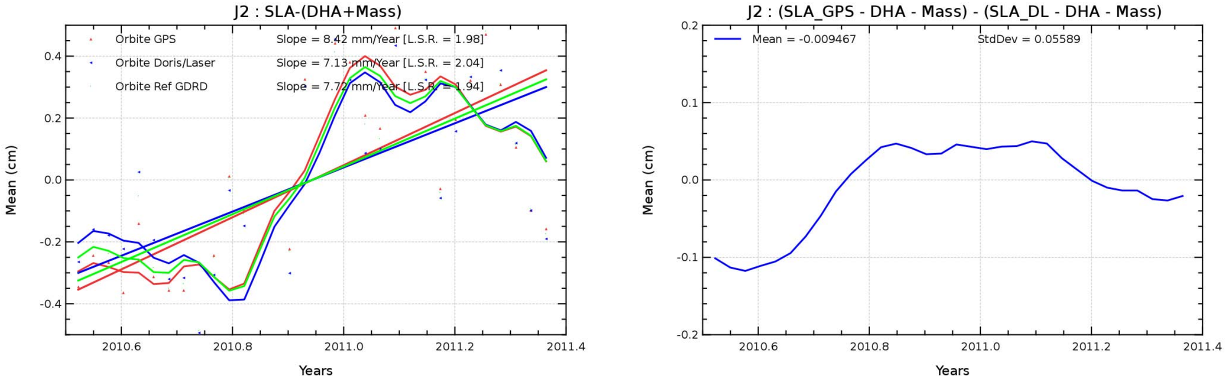

Figure 22: *Monitoring of the Jason-2 sea level differences with Argo+GRACE with the use of the GPS orbit (red), the DORIS/Laser orbit (blue) and the reference orbit (green) (left) and differences using successively the GPS orbit and the DORIS/Laser orbit solution (2-month filtered) (right).*

5.4. Impact of the CNES GDR-D orbit solution on the regional E/W bias

The East/West MSL trend discrepancies obtained with the GDR-C orbit solution concerning Jason-1 and Envisat has been detected thanks to the comparison with in-situ measurements and has already been analyzed (see figure 17). The anomaly is mainly associated with the Envisat mission (more affected by the gravity field solution) and the impact of using the new GDR-D orbit solution in the SSH calculation has already been assessed by comparaison with steric DHA only (Valladeau and Legeais, 2012 [16]). We want to assess if the results are affected when the mass contribution is included. Envisat data are the timeseries not reprocessed and the GDR-D orbit is the preliminary solution. The same approach is used and figure 23 indicates that the impact of the new standard is as well detected with our updated method of comparison as when compared with the steric DHA only. In addition, the new orbit solution makes both missions more homogeneous since the East/West difference observed with Jason-1 (1.3 mm/yr on figure 23, left) is very close to the difference observed with Envisat (1.5 mm/yr on figure 23, right) and these both values are closer when the mass contribution is included.

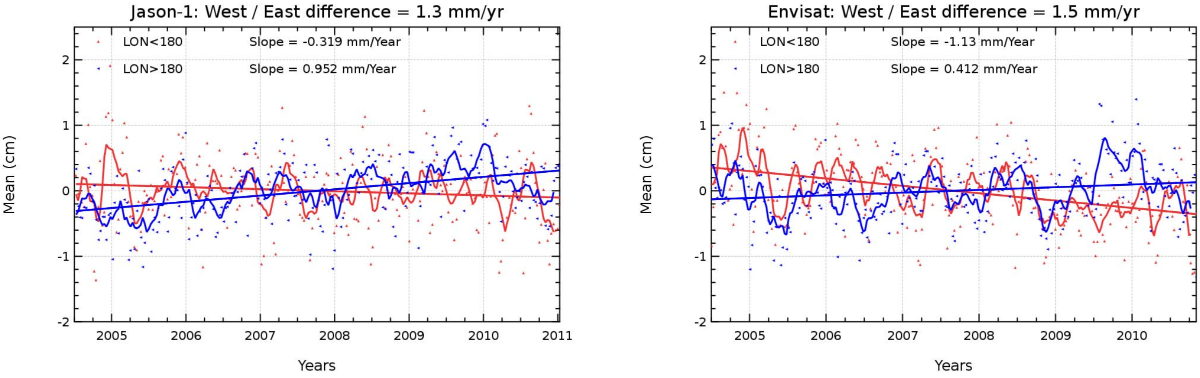

Figure 23: *SSH difference (cm) between altimeter data and Argo + GRACE measurements for Jason-1 (left) and Envisat (right) computed with CNES preliminary GDR-D orbit, separating east (≤180°) and west (≥180°) longitudes. Corresponding annual and semi-annual signals are removed. Trends of raw data are indicated and the 2-month filtered signal is added.*

However, even if both missions are now more homogeneous, a residual hemispheric bias is detected for Jason-1 (1.3 mm/yr whereas it was only -0.1 mm/yr with GDR-C orbit). This could be related with a residual error of the method concerning the regional estimation of the MSL trends (potentially related with the GRACE field) but also with a residual error in the orbit determination. In order to better understand these potential errors, similar diagnoses should be performed with the RL05 GRACE dataset when it will be available and also with new orbit solutions, such as GSFC solutions. This latter suggestion is discussed in the following part.

5.5. Comparison of GSFCstd1209 and CNES GDR-D orbit solutions

The difference of performance between two orbit solutions can be assessed thanks to the comparison with Argo in-situ data. This has proved the improved quality of GDR-D orbit solution compared with the GDR-C standard but remaining errors are observed (see previous section). They can either be associated with the method of comparison or with the orbit solution. Similar analysis is performed by computing the Jason-2 MSL with GSFCstd1209 and CNES GDR-D orbit solutions and comparing them with Argo + GRACE data. The trends of the mean differences are computing separating East (≤180°) and west (≥180°) hemispheres in order to determine which solution is closer to the external reference (figure 24). A 0.5 mm/yr hemispheric MSL trend difference is observed with the GSFC solution and a greater difference of 1.6 mm/yr is obtained with the GDR-D solution. Statistically, this would suggest an improved quality of the GSFC orbit. However, taking into account the error on the regional MSL trend estimation per ocean basin of about 1.0 mm/yr due to the short period considered of 3.5 years (leading to relatively high formal error adjustment of the trends), the error related with the colocation method and the uncertainty related with the GRACE dataset, the observed hemispheric differences (0.5 and 1.6 mm/yr) can thus not be distinguished within the error of the method and the best orbit solution can not be precisely determined. Similar analyses could be performed without taking into account the mass contribution to assess the sensitivity of the results to GRACE measurements.

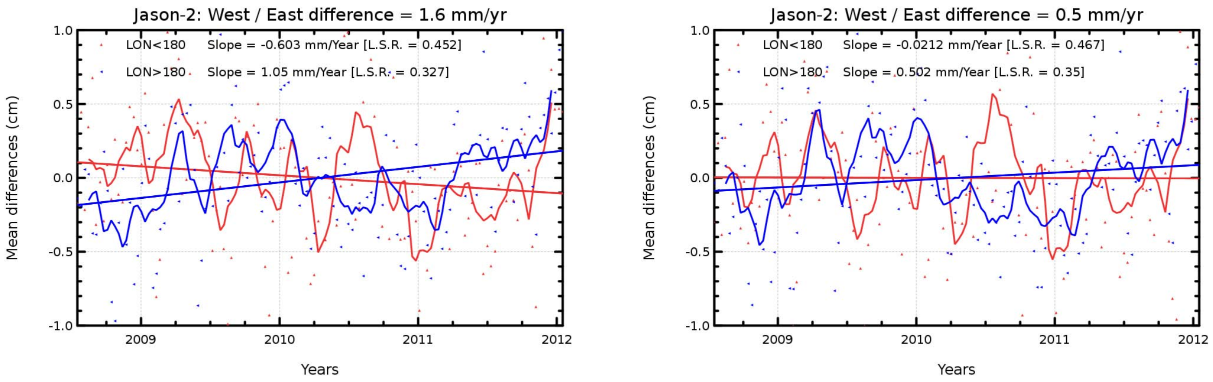

Figure 24: *SSH difference (cm) between altimeter data and Argo + GRACE measurements for Jason-2 computed with CNES GDR-D orbit (left) and with GSFCstd1209 orbit (right), separating east (≤180°) and west (≥180°) longitudes. Corresponding annual and semi-annual signals are removed. Trends of raw data are indicated and the 2-month filtered signal is added.*

5.6. Impact of new altimeter standards on Envisat, Jason-1 and Jason-2 SLA

5.6.1. ENVISAT: impact of updated altimeter standards

Envisat altimeter data have been recently reprocessed to produce the V2.1 products which are now more consistent with Jason's missions (Ollivier et al., 2012, [11]). We propose here to use the external Argo+GRACE data to estimate the impact on the SLA of using the V2.1+ Envisat products (reprocessed data with the GDR-D orbit solution, the corrected PTR instrumental correction and the corrected radiometer wet troposphere correction, MWR) compared with the V2.1 products (reprocessed data with GDR-C orbit and reference MWR correction) with additionnal use of the PTR correction.

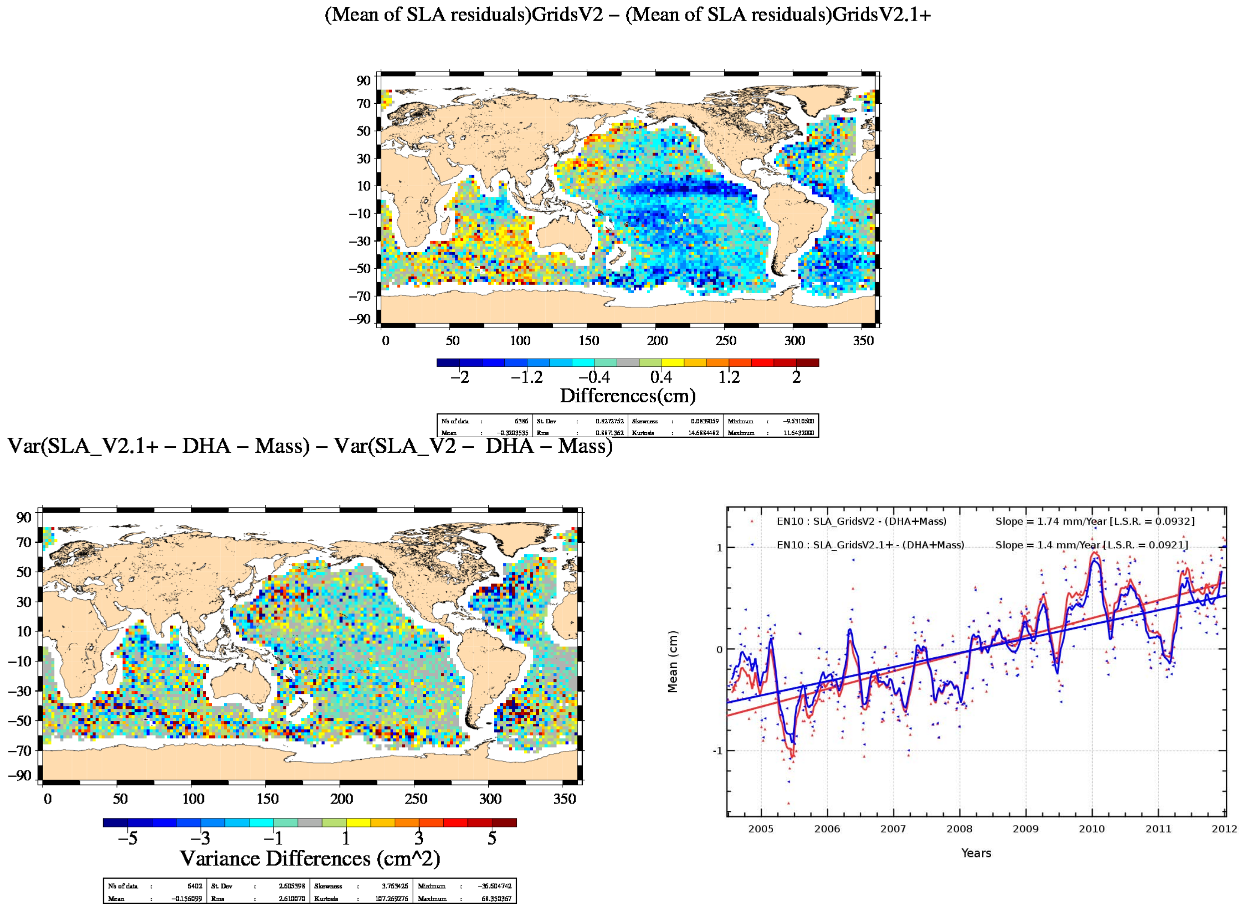

Figure 25: *Mean of the sea level differences obtained with Envisat with V2.1+ and V2.1 version (top). Spatial distribution of the variance differences between the sea level differences obtained with Envisat V2.1+ and V2.1 (left). Monitoring of the sea level differences with both altimeter standards (right), where annual and semi-annual signals are removed and the curves are the 2-months filtered signal.*

The spatial distribution of the mean sea level differences obtained with both versions (figure 25, top) displays hemispheric differences (East/West) of ±1.5 cm directly associated with the difference between the GDR-D and GDR-C orbit solutions. Difference of more than 2 cm is locally detected at low latitudes in the Pacific ocean which are related with the difference of wet troposphere correction.

The global correlation between altimetry and Argo+GRACE data is weakly increased (73.4% vs 72.8%) with the new version and the standard deviation of the differences is reduced by 1.0 cm RMS (5.2 cm vs 5.3 cm). The map of the variance difference between both versions of sea level differences (figure 25, left) displays no significant signal and in particular at low latitudes in wet areas, the impact of the updated MWR correction is not detected.

Concerning the impact on the altimeter MSL drift referenced to the independent in-situ measurements, figure 25 (right) indicates that it is reduced by 0.3 mm/yr with the use of the updated standards (1.7 vs 1.4 mm/yr). This decrease is mainly associated with the updated GDR-D orbit solution compared with the GDR-C standard (Ollivier et al., 2012, [11]).

5.6.2. Jason-1 : Impact of the GDR-D orbit solution

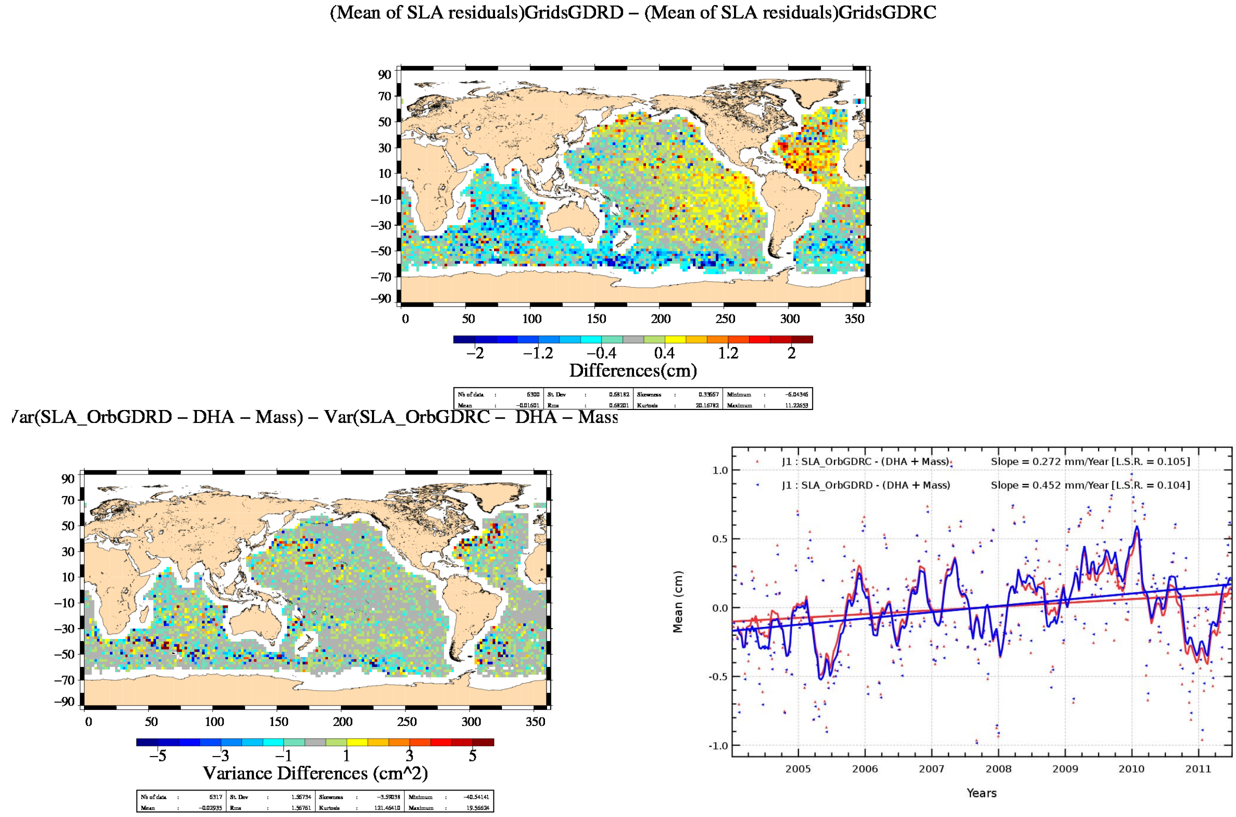

Figure 26: *Mean of the sea level differences obtained with Jason-1 SLA derived from GDR-C and GDR-D orbit solution (top). Spatial distribution of the variance differences between the Jason-1 GDR-C and GDR-D altimeter residuals (left). Monitoring of the sea level differences with both altimeter standards (right), where annual and semi-annual signals are removed and the curves are the 2-months filtered signal.*

All the results concerning Jason-1 mission have been computed so far with the GDR-C standards. We propose here to use the external Argo+GRACE data to estimate the impact on the SLA of using the GDR-D orbit solution compared with the GDR-D reference. The spatial distribution of the mean sea level differences obtained with both versions (figure 26, top) displays hemispheric differences (East/West) of ±1.5 cm directly associated with the difference of orbit solutions, which has already been observed when comparing the global altimeter SLA.

The global correlation between altimetry and Argo+GRACE data (including all spatial and temporal signals) is modified from 74.1% to 73.9% with the GDR-D orbit. Note that it is mainly associated with the annual signal which strongly dominates the spectrum of the differences. Thus, the observed small evolution of this global correlation is mainly related with a change of amplitude and/or phase of the annual signal. The global variance of the differences are not modified with the updated orbit solution and the map of the variance differences (figure 26, left) shows that the coherence with in-situ data is homogeneously distributed. Concerning the impact on the altimeter MSL drift referenced to the independent in-situ measurements, figure 26 (right) indicates that it is increased by 0.2 mm/yr with the use of the GDR-D orbit solution.

5.6.3. Jason-2 : Impact of the GDR-D reprocessing

Since the beginning of the Jason-2 altimeter mission in July 2008, the available GDR (Geophysical Data Record) product version was GDR-T (for Test). In 2012, Jason-2 data have been reprocessed in version GDR-D, which contains numerous evolutions as the GDR-D orbit standard, updated altimeter and radiometer derived corrections, ocean tide and mean sea surface version CNES-CLS 2011 ([12]). The Argo+GRACE data have been used to estimate the impact of the reprocessed data on the quality of the altimeter SLA.

The spatial distribution of the mean differences obtained with both versions (figure 27, top) displays hemispheric (East/West) differences of ±1 cm directly associated with the GDR-D orbit solution. The impact of other GDR-D standards are masked by the dominant effect of the orbit.

The global correlation between altimetry and the external reference is unchanged with the GDR-D version (74.1% vs 74.2%). The global standard deviation of the differences is unchanged (5.2 cm) and the map of the variances difference (figure 27, left) shows the spatial distribution of this statistic, and thus, only the temporal evolution of the variability is taken into account (contrary to the previous global estimate where both spatial and temporal scales are included). Higher values observed in regions of high ocean variability are associated with the higher uncertainty of the method due to the colocation of the data in these regions. Except these regions, a relatively homogeneous distribution of the variance difference is observed.

Concerning the impact on the altimeter MSL drift referenced to the independent in-situ measurements, figure 27 (right) indicates that it is increased by 0.1 mm/yr with the use of the GDR-D standards over the studied period. This evolution is mainly associated with the updated wet troposphere correction and the GDR-D orbit solution.

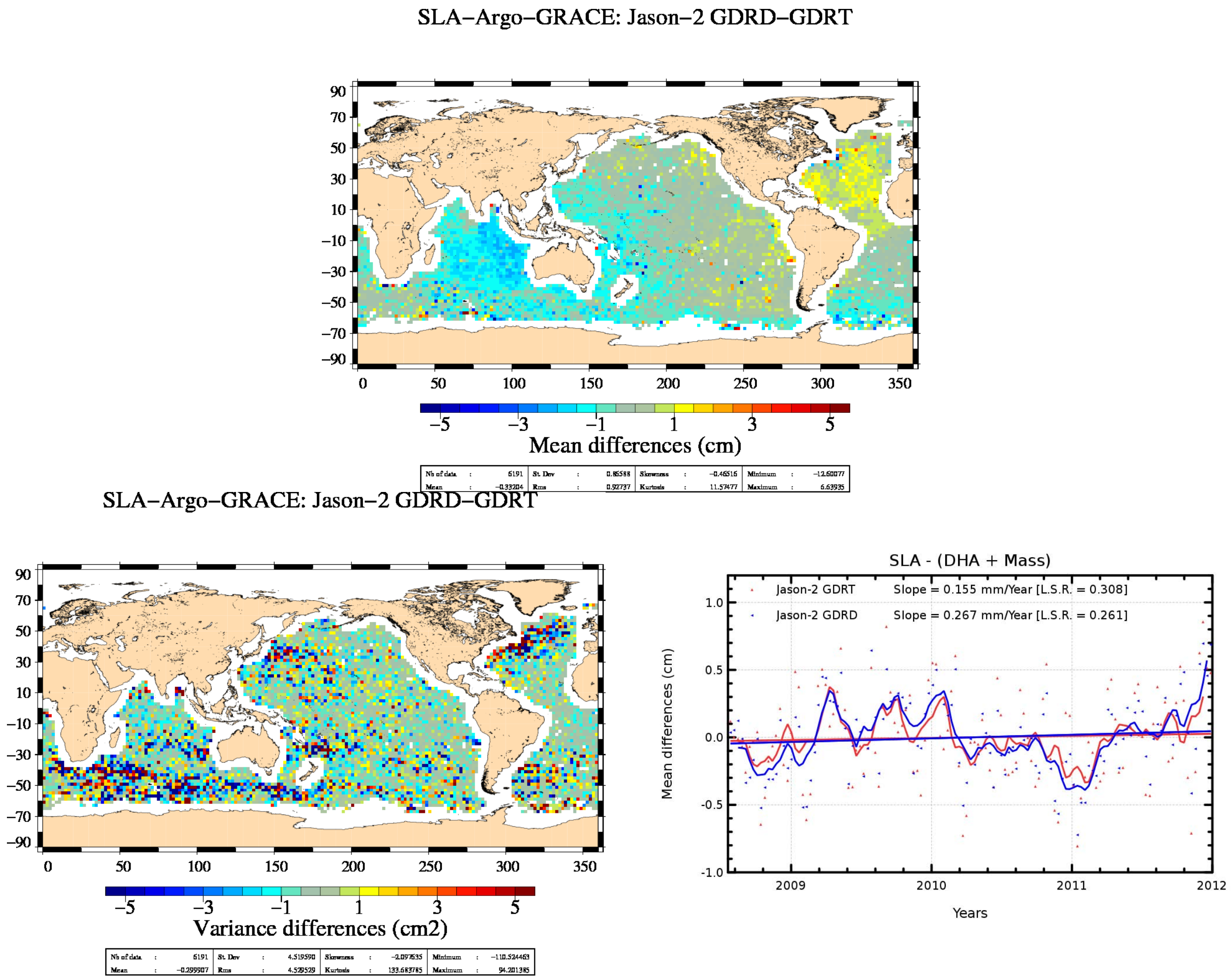

Figure 27: *Mean of the sea level differences with Jason-2 derived from GDR-T and GDR-D standards (top). Spatial distribution of the variance differences between Jason-2 GDR-D and GDR-T sea level differences (left). Monitoring of the sea level differences with both altimeter standards (right), where annual and semi-annual signals are removed and the curves are the 2-months filtered signal.*

6. Conclusions and futures

Major improvements have been achieved in 2012 with the use of the mass contribution to the sea level from GRACE. Together with the steric in-situ DHA from Argo, it provides sea level estimations with the same physical content as the altimeter measurements (the deep steric contributions are considered to be unsignificant in this study). All the objectives of the activity have benefited from this improvement: first, the uncertainty associated with the altimeter MSL drift has been reduced and thus, the detection of relative differences is improved and more confidence is attributed in the absolute altimeter MSL drift estimation. In 2012, the mean and the variance of the sea level differences derived from various missions have been analyzed spatially and temporally with the updated method of comparison using the mass contribution. In particular, the comparison of altimeter measurements with Argo+GRACE has allowed to detect a greater MSL drift of the Envisat mission compared with Jason-1 over the period 2004-2012. Moreover, the improvement provided with the updated method using GRACE has been illustrated with a better detection of the regional MSL drift discrepancies already observed between these both missions with the use of the steric Argo DHA only.

Secondly, new altimeter standards are used to improve altimeter products for end-users and the new method of comparison provides a better detection of their impact since it makes the compared datasets more homogeneous. The analyses performed this year concern several aspects: the impact of changing the altimeter SLA reference (MSS) has been quantified and we have shown that the improved quality of the new MSS CNES/CLS11 in the regions of interleaved tracks can be quantified with our method of in-situ comparison (almost 1 cm^2). Other analyses have illustrated the improved quality of the updated method of comparison: differences of the order of the millimeter are detected between the annual signal of two SLA differences using different orbit solutions; altimeter MSL trend disprepancies are now detected even over the relatively short period of Jason-2 and the impact of altimeter reprocessed data (Envisat V2.1+, Jason-2 GDR-D) is quantified. All these results demonstrate the ability of Argo in-situ T/S profiles to detect altimeter regional MSL drift and to estimate the impact of new altimeter standard on the sea level computation with an increased accuracy. These analyses also help us to better quantify the order of magnitude of the error which can be detected with our method of comparison and thus reduce the associated uncertainty.

The third goal is to detect anomalies in in-situ measurements and thus qualify these data, which is supported by a Coriolis project and not performed in the context of this study (Guinehut et al., 2009 [5]). Our results are strongly dependent of this validation phase since it provides reliable datasets of in-situ measurements.

This work has been presented this year at the OSTST meeting in Venice ([10]), the American Geophysical Union (AGU, [17]), at the Envisat Quality Working Group (QWG) meetings (May and November 2012) and at informal discussion with CNES (June 2012). In addition, results concerning the regional MSL trend discrepancies between Jason-1 and Envisat missions have been published in Marine Geodesy [16].

All the discussed results would not have been obtained with the same confidence with the former method of comparison using extrapolated estimation of the steric content over the total water column. The increased confidence in the updated method is confirmed by comparison with the results derived from global altimeter internal analyses and from the comparison with tide gauges. The synergy between these approaches is a key element to provide more and more reliable and accurate results, globally as well as regionally. However, the method could benefit from some improvements which could reduce the remaining uncertainty and whose integration is planned in 2013. Among them, the use of the new GRACE RL05 dataset of the mass contribution is expected to increase the coherence with altimeter SLA and also reduce the formal error adjustment of the MSL trends. Concerning the computation of these trends, the sea level is affected by the post glacial rebound effect due to the reduction of the ice sheets and glaciers and the Glacial Isostatic Adjusment (GIA) correction would have to be taken into account and homogeneized between altimeter data, Argo profiles and GRACE data. Moreover, new diagnoses of comparisons are planned in order to better understand the observed residual signals and thus reduce the uncertainty, concerning the interannual and annual signal at global scales but also the regional evolution of the long term signals. The impact estimation of a new altimeter standard can also be improved by quantifying (i) the evolution of the frequencies distribution of the correlation between altimeter and in-situ data, (ii) the impact on the magnitude and phase of the annual signals of the sea level differences and (iii) by filtering the signal to keep the wavelengths where the impact is expected to be the greatest. In this way, in-situ data will be adapted to assess the impact of the new FES12 tide model and also the reprocessed DUACS delayed-time altimeter merged products. This work is performed in an operationnal framework which is essential to make this activity durable and the efficiency of the processing is planned to be improved.

7. References

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8. Annexes

8.1. Annex: Corrections applied for altimeter SSH computation

All the corrections applied on SSH for TOPEX/Poseidon, Jason-1, Jason-2 and Envisat altimeter missions are summarized in the following table:

Orbits and corrections	TOPEX/Poseidon	Jason-1	Jason-2	Envisat
Orbit	GSFC POE (09/2008), ITRF2005+Grace	CNES POE (GDR-C standards)	CNES POE (GDR-C standards)	Cycle 15 onwards: CNES POE (GDR-C standards)
Mean Sea Surface (MSS)	MSS CLS01 (v1)	MSS CLS01 (v1)	MSS CLS01 (v1)	MSS CLS01 (v1)
Dry troposphere	ECMWF model computed	ECMWF model computed	ECMWF model computed	ECMWF model computed
Wet troposphere	TMR with drift correction [Scharoo et al. 2004] and empirical correction of yaw maneuvers [2005 annual validation report]	Jason-1 radiometer (JMR)	Jason-2 radiometer (AMR)	MWR (corrected from side lobes from cycle 41)
Ionosphere	Filtered dual-frequency altimeter range measurements (for TOPEX) and Doris (for Poseidon)	Filtered dual-frequency altimeter range measurements	Filtered dual-frequency altimeter range measurements	Dual-Frequency updated with S-Band SSB (< cycle 65) GIM model + global bias of 8 mm (>= cycle 65)
Sea State Bias	Non parametric SSB (for TOPEX), BM4 formula (for Poseidon)	Non parametric SSB (GDR product)	Non parametric SSB (GDR product)	Updated homogeneous to GDR-C
Ocean and loading tides	GOT4.7 (S1 parameter is included)	GOT4.7 (S1 parameter is included)	GOT4.7 (S1 parameter is included)	GOT4.7 (S1 parameter is included)
Solid Earth tide	Elastic response to tidal potential [Cartwright and Tayler, 1971] [Cartwright and Edden, 1973]	Elastic response to tidal potential [Cartwright and Tayler, 1971] [Cartwright and Edden, 1973]	Elastic response to tidal potential [Cartwright and Tayler, 1971] [Cartwright and Edden, 1973]	Elastic response to tidal potential [Cartwright and Tayler, 1971] [Cartwright and Edden, 1973]
Pole tide	[Wahr,1985]	[Wahr,1985]	[Wahr,1985]	[Wahr,1985]
				.../...

Orbits and corrections	TOPEX/Poseidon	Jason-1	Jason-2	Envisat
Combined atmospheric correction	High Resolution Mog2D Model [Carrère and Lyard, 2003] + inverse barometer computed from ECMWF model (rectangular grids)	High Resolution Mog2D Model [Carrère and Lyard, 2003] + inverse barometer computed from ECMWF model (rectangular grids)	High Resolution Mog2D Model [Carrère and Lyard, 2003] + inverse barometer computed from ECMWF model (rectangular grids)	High Resolution Mog2D Model [Carrère and Lyard, 2003] + inverse barometer computed from ECMWF model (rectangular grids)
Specific corrections	Doris/Altimeter ionospheric bias, TOPEX-A/TOPEX-B bias and TOPEX/Poseidon bias	Jason-1 / T/P global MSL bias	Jason-2 / T/P global MSL bias	USO correction from auxiliary files + bias for side-B

Table 5: *Corrections applied for altimetric SSH calculation*