CalVal altimetry/tide gauges

Validation of altimetric data by comparison with tide gauge measurements

for TOPEX/Poseidon, Jason-1, Jason-2 and Envisat

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CLS - 8-10 Rue Hermès - Parc Technologique du Canal - 31520 Ramonville St-Agne - FRANCE
Telephone 33 5 61 39 47 00 / Fax 33 5 61 75 10 14

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People involved in this issue:		
Written by:	G. Valladeau M. Ablain	CLS CLS
Checked by:	S. d'Alessio	CLS
Approved by:	J.P. Dumont M. Ablain	CLS
Application authorized by:		

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1. Introduction - Document overview

This document is the altimeter/in-situ validation activities synthesis report for 2010, which aims at comparing altimetric data with measurements provided by tide gauges. This activity is supported by the CNES in the frame of the SALP contract (package 2-C) for the whole altimeter missions but also by the ESA as a support for the ESA EOM-ADQ RA-2 and MWR activities in the frame of the ENVISAT Phase E.

Note that a synthesis report on the cross-comparison between alitmeter data and Argo T/S profiles is also available. Indeed, tide gauge measurements and Argo T/S profiles constitute two complementary datasets for this activity. Although the spatial coverage is worse with tide gauges (only a few part of coastal areas are covered while the Argo network can sample the global open ocean), the temporal sampling of tide gauge measurements is really better (one measure each hour whereas one profile every ten days for Argo T/S profiles). That be, the combination of the several results obtained through this activity can be considered as reliable thanks to the use of multiple in-situ datasets. Moreover, these cross-comparisons with external independent in-situ measurements increase the quality of calibration and validation of altimeter measurements.

Whatever in-situ dataset used in the frame of this activity, tide gauge measurements as well as ARGO T/S profiles, these studies are focusing on the comparison with the Sea Surface Height (SSH) derived from altimetry in order to:

1. Monitor the SSH between altimeter and external independent in-situ measurements in order to detect potential drifts or jumps in the altimeter Mean Sea Level (MSL)

2. Estimate the improvements performed on the new altimeter standards in the SSH calculation

3. Detect the potential anomalies of the computed in-situ datasets

The main interest of tide gauge measurements lies in the detection of possible jumps or drifts in the MSL evolution as one of the main indicators for climate warming studies. But it has been demonstrated that the comparison of altimeter data with external and independent measurements is also useful to measure improvements of new altimeter standards such as the orbit. Finally, this cross-comparison underlines the need of computing relevant in-situ data time series, which supports the idea of performing a quality control on the in-situ measurements. This work, which has taken place since 2009, is possible thanks to the whole altimetric time series available.

In the first place, the document describes the tide gauges database used and its computation in order to make them comparable to altimetric SSH. The tide gauge networks used and the data availability are precisely described, especially for the new networks added in the database in 2010. New corrections used in the in-situ SSH calculation are also specified.

During 2010, the main goal was to state on a new processing sequence to compare altimeter data and in-situ measurements. The document thus details the new method developed to compare altimeter data and tide gauge measurements and the improvements resulting from this new cross-comparison of both datasets.

It then points out the main results concerning the detection of altimeter MSL drift. It gets onto multi-mission analysis for the four main altimetric missions TOPEX/Poseidon, Jason-1, Jason-2 and Envisat.
Results concerning the comparison procedure of new altimetric standards are discussed from temporal and spatial diagnostics, especially through variance differences histograms.
The report will also present the way of using the quality control performed on in-situ measurements to remove spurious tide gauges. Basically, this method is based on a multi-cross-calibration between tide gauge measurements and all altimeter time series available in order to detect potential jumps or abnormal drifts in tide gauge SSH evolutions.
Finally some particular studies realised during 2010 are presented to demonstrate the interest of comparing altimetry with in-situ tide gauge measurements to detect the 58.74 day signal observed on the MSL derived from Jason-1&2 and TOPEX or anomalies on the Envisat altimeter data.

2. Presentation of the tidal database

2.1. Overview

The tidal database consists in records of tide gauge Sea Surface Height (SSH) from independent networks. Several types of geophysical corrections such as tide, pressure and wind effects are then applied on these raw data so as to deduce filtered Sea Level Anomalies (SLA) from high frequency phenomena in order to be consistent with altimetric data. The comparison between altimetric data and tide gauge measurements is thus made possible thanks to this tidal database and softwares dedicated to its computation. This section details the way of manipulating tide gauge measurements.

2.2. Origin

The tidal database, which to date consists in 5 different tide gauge networks (GLOSS/CLIVAR, SONEL, OPPE, BODC and IMEDEA), results from different collaborations. During 2010, in the frame of different projects, the CLS in-situ database has been enhanced with tide gauges from GLOSS/CLIVAR, SONEL and IMEDEA networks. The goal of such increase of tide gauges is not only to improve the in-situ spatial sampling to detect altimetric drifts or jumps but the interest of a dense network to study impacts of new altimeter standards locally, such as in the Mediterranean or in the Arctic Sea. Concerning the latter the processing sequence (see section 3.3.) is used in the framework of a study on sea level variability in the Arctic Ocean. Indeed, a subset of monthly mean sea level data has been extracted from the PSMSL [1] database (www.psmsl.org) and is compared to Envisat altimetry at high latitudes. Results show that the method described in this document is reliable even with low frequency tide gauge data, leading to potential integration of the PSMSL database to CLS's tide gauge database.

Here are the details of the networks computed in the CLS database (figure 1):

- GLOSS/CLIVAR (Global Sea Level Observing System/Climate Variability and Predictability) "fast" sea level data: this network provides 271 tide gauges gathered by the University of Hawaii Sea Level Center (USHLC) and updated within a few weeks or a few months (*ilikai.soest.hawaii.edu/uhslc*), which is 14 more tide gauges comparing to 2009.

- SONEL (Système d'Observation du Niveau des Eaux Littorales): this network consists in 33 tide gauges which major part is set on the french shoreline (3 more tide gauges comparing to 2009, *www.sonel.org*).

- BODC (British Oceanographic Data Centre): 46 UK tide gauges of this network, which are held by the Permanent Service for Mean Sea Level (PSMSL), are computed in the tidal database (*www.bodc.ac.uk*)

[1] The Permanent Service for Mean Sea Level (PSMSL) is the global data bank for long term sea level change information from tide gauges and bottom pressure recorders.

- OPPE (Organismo Público de Puertos del Estado): 19 of these tide gauges are built in the CLS database, which uniformly samples spanish coasts (*www.puertos.es*)

- IMEDEA (Mediterranean Institute for Advanced Studies): 48 tide gauges widespread in the Mediterranean Sea are routinely computed in the CLS in-situ tide gauge database (*www.imedea.uib.es*)

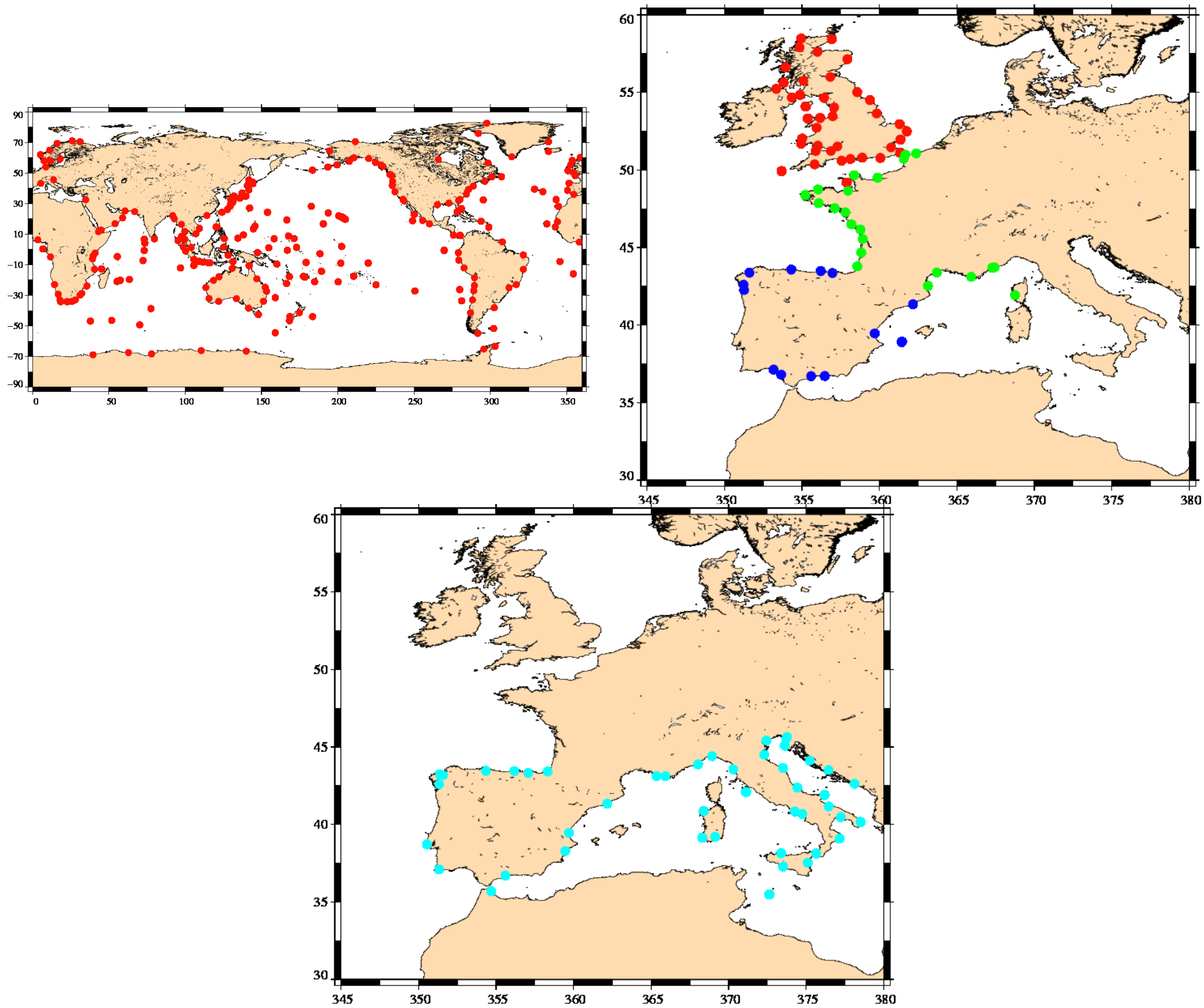


Figure 1: *Location of the tide gauges. Top left: GLOSS/CLIVAR. Top right: SONEL (green) , OPPE (blue) and BODC (red). Bottom: IMEDEA*

Note that to date one of the Senetosa tide gauges has been collected. It will be officially added to the global network in the early 2011. Moreover, 2 new tide gauges are also provided by the IMEDEA network (Pollensa and Andratx, respectively based North and South of Mallorca) and are currently under quality controlled. In 2011, new tide gauges from IMEDEA are about to be computed in the CLS tidal database.

2.3. Data availability

For the whole tidal networks, hourly data are computed and archived according to a linear procedure:

- 1. Weekly download of the updated data
- 2. Conversion from the original-sized data to the CLS-sized data (in-situ measurements tables) with several steps of validations
- 3. High frequency tidal waves filtering (diurnal and semi-diurnal tides) by a specific algorithm based on the Demerliac low-pass filter [Bessero, 1985]
- 4. Long-time tidal waves filtering by a specific algorithm based on well-balanced tide tables [Cartwright and Eden, 1973]
- 5. Withdrawal of the high frequency Dynamical Atmospheric Correction (DAC) [Dorandeu and Le Traon, 1999, Carrere and Lyard, 2003]

By the means of "in-situ measurements tables" specific format, SSH measured by tide gauges can be filtered from high frequency phenomena quoted above.

Here are the main fields recorded into in-situ measurements tables:

- 1. raw data
- 2. tide filtered data (semi-diurnal, diurnal and long period constituent)
- 3. tide filtered and improved inverse barometer corrected data
- 4. tide filtered and high frequency MOG2D corrected data

The tidal database is updated every week according to the availability of new tide gauge measurements.

3. Description of the altimeter/tide gauges comparison procedure

3.1. Overview

The main goal of this activity is to compare altimetric and in-situ tide gauge sea level anomalies. To make this comparison possible, sea surface height measurements have first to be processed. The physical content of tide gauge measurements and altimetric data are not completely equivalent. Both datasets have thus to be pre-processed before comparing each other. The physical principle of altimeter/tide gauge comparison is displayed in figure 2. It highlights 3 sources of discrepancies between both datasets:

- The SSH reference is not the same since tide gauge measurements have been already referenced to a mean sea surface (MSS). Thus the MSS has to be removed from altimeter SSH.
- Oceanic tidal effects have to be corrected on altimeter and tide gauge data since measurements are not located exactly in the same place. Concerning altimeter measurements, an ocean tide model is applied (GOT00 for instance), whereas dedicated filters are applied for tide gauge data in order to remove the short and long tide wavelengths (diurnal, semi-diurnal and long period tides) as explained above.
- Atmospheric effects have also to be corrected for the same reason applying on the first hand a dynamical atmospheric correction (MOG2D model) for altimeter measurements and on the second hand a dedicated filter for tide gauge data in order to remove high frequency signals.
- Finally, sea level anomalies are compared between altimeter and in-situ data.

3.2. Pre-processing of the altimeter and in-situ tide gauge sea surface heights

A pre-processing is thus performed on altimetric and in-situ tide gauge sea surface heights so as to compare each other.

3.2.1. Calculation of the altimetric sea surface height

The Sea Surface Height (SSH) calculation is defined below :

$$SSH = Orbit - Altimeter\ Range - \sum_{i=1}^{n} Correction_i - Mean\ Sea\ Surface$$

The Mean Sea Surface (MSS) used is the CLS2001 Mean Sea Surface model [Hernandez and Schaeffer, 2001] and the usual corrections are the following:

$$\begin{aligned}
\sum_{i=1}^{n} Correction_i &= Dry\, troposphere\, correction : new\, S1\, and\, S2\, atmospheric\, tides\, applied \\
&+ Combined\, atmospheric\, correction : highresolution MOG2D\, and\, inverse\, barometer \\
&+ wet\, troposphere\, correction\, coming\, from\, ECMWF\, model \\
&+ Filtered\, dual\, frequency\, ionospheric\, correction \\
&+ Non\, parametric\, sea\, state\, bias\, correction \\
&+ Geocentric\, ocean\, tide\, height,\ GOT\, 2000 :\ S1\, atmospheric\, tide\, is\, applied [Ray, 1999] \\
&+ Solid\, earth\, tide\, height \\
&+ Geocentric\, pole\, tide\, height
\end{aligned}$$

Generally, the same corrections are applied for each mission but there are some exceptions due to instrumental anomalies on satellites or the unavailability of geophysical models. The different SSH formula used for each altimetric mission are presented in annex 10.2. for TOPEX/Poseidon, Jason-1, Jason-2 and Envisat.

3.2.2. Calculation of the in-situ sea surface height

The assessment of in-situ sea surface height is almost the same one as previously. However, since potential bias are searched out, there's no need to have an absolute reference frame for tide gauges. It is simply necessary to remove geophysical and atmospheric effects from in-situ measurements in order to stay consistent with altimetric data. This is almost immediate starting from in-situ time series:

- By developing specific tide filters so as to remove short wavelengths phenomena (diurnal, semi diurnal tides and short-time atmospheric effects)

- By carrying out an algorithm of long period time series or low frequency tide withdrawal (from one week to one year in term of wavelength)

3.3. Computation of the potential relative bias

From all these corrections, the altimetric drift can be calculated as presented below:

Bias = ΔAltimeter - ΔTide Gauge (+/- errors on models, corrections and measurements)

Figure 2 presents the general diagram used for the Envisat RA-2 altimeter.

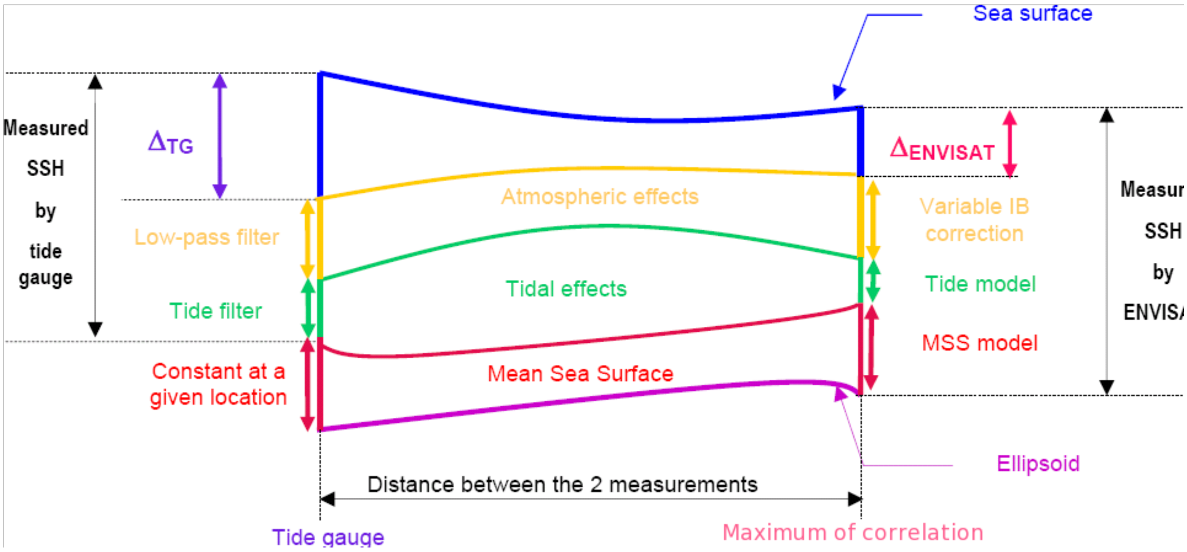


Figure 2: *Bias estimation between RA-2 and in-situ measurement*

Note that since relative bias between altimetric and tide gauges data are searched out, there is no use mastering the Mean Sea Surface (MSS) at the location of the tide gauge.

3.4. New sequences of the altimeter/tide gauges processing

In 2010, results are computed using a new method based on the maximum of correlation between altimeter and in-situ time series. This method selects the best correlated altimeter point (and thus SSH) on theoretical tracks with in-situ time series, which tends to minimize the error in the altimeter/tide gauges comparison. Indeed, there is no more residual error on the assessment of the Mean Sea Surface (as the same altimeter point is considered at each cycle) and the effect of oceanic variability is reduced. The colocation method between altimeter data and tide gauge measurements has thus been improved.

The next subsections of this part will describe the several steps of the new processing sequence.

3.4.1. Improvement of the altimeter/tide gauge colocation method

As said earlier, the processing which aims at colocating altimeter data and tide gauge measurements has been enhanced:

- Although the historical processing used to estimate sea level on altimetric tracks at the closest location of a given tide gauge, the new method first consists in selecting the altimeter point which SSH time serie is the most correlated with the in-situ one. Thus the new colocation method is based on the maximal correlation criteria instead of minimal distance (figure 3). The main advantage of the method is to reduce the effect of the oceanic variability and the error on the Mean Sea Surface considering the same altimeter point on the theoretical track (whereas the older process considered the four closest points on altimeter tracks at each cycle).

- In this new release the spatial weighting of tide gauge networks has been computed (4x4 degree boxes weighting to reduce the effect of the heterogeneous spatial coverage of tide gauge networks). This improvement will allow us to add new dense tide gauge networks, even if they are not globally widespread.

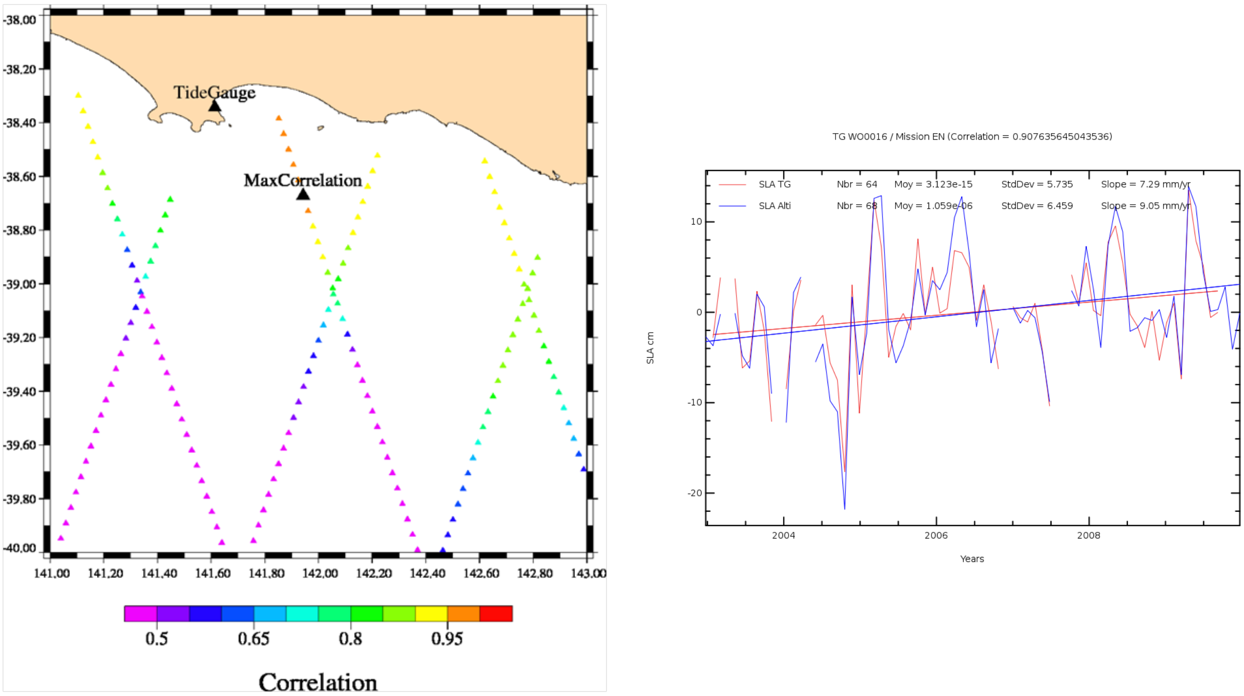


Figure 3: *Left: Example of colocation between altimeter and in-situ time series by computing the maximum of correlation. Right: Time series of the Rikitea tide gauge and altimeter relative to the maximum of correlation.*

While the drawback of this method can be found in the need of having a "classical" space mission (classical implies a repetitive mission), the main advantages of this new processing sequence are:

- the easier way of improving some functionalities such as the editing performed on both altimeter data and tide gauge measurements
- the computation of all space missions available
- the optimization of the time computation
- the relevance and reliability of results provided

3.4.2. Editing of altimetric and in-situ data

Thanks to the new colocation method, the editing procedure is part of the calculation of altimeter and tide gauge SSH differences. Indeed the purpose of this editing procedure is to perform some additional "quality" controls on each altimetric and in-situ dataset and thus perform the computation on the most reliable time series.

As previously performed on the processing sequence, the selection of the most consistent and relevant data time series are directed around several criterium. Concerning the consistency, the minimum of correlation between tide gauges and altimetric track time series is used. While Mitchum specified it to 0.3 (see [14]), this criteria is fixed to a minimum of 0.7 in the new processing sequence, which is pretty high but so far allows to consider a large number of tide gauges.

Two additionnal thresholds are part of the consistency:

- one concerning altimeter/tide gauges SSH differences. In the new processing sequence, it is fixed to 12 cm, which allows to get rid of strong ocean variability or potential aberrant values in altimeter data time series.

- the other on the standard deviation of altimeter/tide gauge SSH differences, with a threshold of 30 cm.

Note that while the standard deviation threshold is performed on the whole SSH differences time serie, the potential aberrant values are edited with the SSH difference threshold without edited the whole time serie so far. An example of consistent altimeter and in-situ time series is given on figure 3.

As regards to the relevance of the statistics, one criteria is also defined: the minimum number of points of an altimeter data time serie to take it in account (in percentage of the number of cycles to be computed). Indeed, when the altimeter residual time serie contains less than 70% of valid points, the serie is edited and the process considers the next altimeter time serie the best correlated to the in-situ tide gauge one.

Statistics on these "valid" results are then performed so as to determine potential drifts between altimetric data and in-situ tide gauge measurements.

3.4.3. Computation of the global reference bias

As explained in previous annual reports, tide gauges are not referenced to the same mean sea surface. Investigations on altimeter/tide gauges SSH comparisons have leaded this year to consider the global reference bias for each tide gauge with regard to the colocated altimeter data. Indeed, in the frame of altimetric/in-situ difference monitoring, tide gauge measurements can be offset on the Mean Sea Surface (MSS) used in the altimeter SSH computation. The main effect of the computation of this reference bias is to improve the consistency between both SSH and thus to better estimate potential drifts or jumps in the altimetric measurements.

In the new processing, the altimeter/tide gauges differences are currently reduced from their averaged time series. Thus each time serie is centered on zero, which allow to homogeneize the whole

altimeter/tide gauges differences time series.
As this way of computing the global reference bias is not currently accurate enough, a future work (planned in 2011 in the frame of the the SALP contract) will consist in using the least square residual method to correct the whole differences time series and thus compute a global and more precise reference bias.

3.4.4. Correction of vertical movements on tide gauges

In order to assess the rate of global sea level rise, two problems have to be taken into account when using tide gauges. The first is the fact that tide gauges measure sea level relative to a point attached to the land which can move vertically at rates comparable to the long term sea level signal. The second problem is the spatial distribution of tide gauges, in particular those with long records, which are restricted to the coastlines (Wöppelmann et al., 2007). This part of the document focuses on the first point.

The problem of correcting tide gauges records from vertical land motion upon which they are settled has only been partially solved. At best, the analyses so far have included corrections for one of the many processes that can affect the land stability, namely the Glacial Isostatic Adjustment (GIA). However, GIA models don't account for the other sources of vertical land motion that can affect tide gauges.

Thanks to GPS beacons, a very accurate estimate of vertical movements could be calculated at tide gauge locations. But the spatial sampling of such instruments is so poor that results are not really reliable concerning the assessment of vertical movements at tide gauges. In the frame of the ESA Climate Change Initiative, studies will be leaded in 2011 so as to perform a new method to compute an accurate vertical movement correction at each tide gauge.

3.4.5. Monitorings of SSH bias between altimetric and in-situ-data

Like the former one, the new data processing underlines the reliability of the altimeter/tide gauges comparison procedure. Both methods are still routinely performed to validate several results obtained or because some studies (like the Envisat mini commissioning phase) requires only one of the two existing data process. A monitoring report, composed of statistics results on several quantities, is still generated for each space altimetric mission with the original altimeter/tide gauge method and will be performed during 2011 for the new one.
Thanks to such statistics can be pointed out the influence and the impact of altimeter corrections brought to sea surface heights. Thus potential altimetric drifts can be estimated from the comparison to in-situ measurements.

In 2010 as well as in 2009, one part of the work has consisted in routinely presenting the most important results for each mission. A global powerpoint document, gathering the main results concerning altimeter and in-situ comparisons (tide gauges as well as T/S profiles) has been initialized in order to display a global view of the whole studies concerning each in-situ activity (see annex 10.3.).

4. Analysis of potential drifts or jumps in altimeter MSL

4.1. Overview

With the new processing sequence, as well as with the original one, the cycle by cycle monitoring of average SLA differences between altimeter and tide gauge data provide relevant information to detect potential drifts or jumps on mean sea level trend derived from altimetric data. New assessments of these long-term comparisons until the end of 2010 are presented in this part in agreement with the MSL calculation and using an extended in-situ network.

During 2010, the Jason-2 space mission has been routinely added to the global altimeter/in-situ tide gauge comparison. However, as it will be shown on Jason-2 monitorings, results can't lead to an accurate assessment of the Jason-2/tide gauge long term difference trend yet. The main three altimeter missions TOPEX/Poseidon, Jason-1 and Envisat are still being studied.

Moreover, trends for the SLA differences statistic monitoring are calculated from quality controlled tide gauge measurements, 60-day filtered with annual and semi-annual signals removed. As only a few tide gauges can be corrected from vertical movements (their colocation with GPS stations is effective for only 60 tide gauges), a global vertical movement correction of 0.2 mm/year was applied, in agreement with Peltier GIA global correction. However, results presented in this part of the document don't take this global correction into account as new computations of vertical movements at tide gauge locations are expected in 2011, thanks to studies which will be performed in the frame of the ESA Climate Change Initiative.

4.2. Analyses for each altimetric mission

4.2.1. TOPEX/Poseidon

Results presented here have been performed from 1993 onwards from M-GDRs after updating best altimeter standards for TOPEX SSH (GSFC orbit, SSB, GOT4.7 tidal model, corrected TMR… see annex 10.2.). To date, this is the best SSH computed for TOPEX/Poseidon, which is moreover homogeneous with other space missions studied in the present document (Jason-1, Jason-2 and Envisat).

The monitoring of SLA differences between TOPEX/Poseidon and tide gauges is plotted in figure 4. Note that a 2-month Lanczos filter is applied and results obtained on both sides of T/P new orbit are merged using a least square residual method. Moreover, periodic signals such as annual and semi-annual are removed from the monitoring af altimeter/in-situ differences.
Considering the first monitoring on the left, the new global trend is then close to 0.7 mm/year over the 1993-2005 while it was -0.3 mm/year in 2009. A strong negative drift appears on the TOPEX-A time period between 1994 and 1996 since the computation of the new SSB correction (with Gourrion's wind). After filtering out signals lower than 2 months, a jump close to 7 mm is highlighted in 1996. Indeed the drift is strongly negative before 1996 (-1.9 mm/yr) and slightly positive after (+0.4 mm/yr). This jump corresponds to the beginning of the TOPEX-A anomaly (cycles 130 to 236).

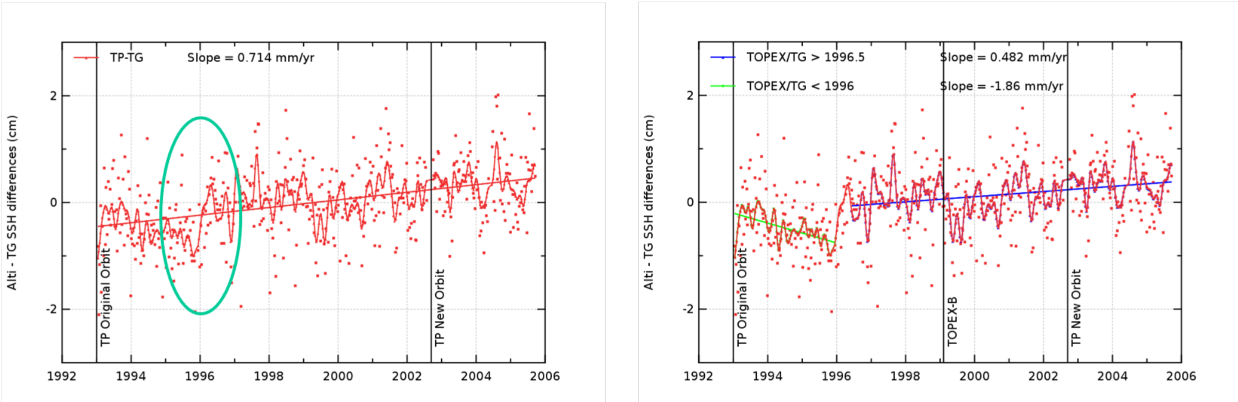


Figure 4: *Cycle by cycle monitoring of mean SLA differences between TOPEX/Poseidon and tide gauge measurements.*

The cycle by cycle monitoring of standard deviation SLA differences is plotted in figure 5. Whereas results provided in 2009 were displaying a standard deviation close to 7 cm in average on the TOPEX-A and TOPEX-B time period and 9 cm with TOPEX-N (corresponding to the TOPEX orbit change in September 2002 when the satellite moved over the Jason-1 interleaved track), the standard deviation computed with the new processing sequence shows a mean value of about 4.2 cm on the whole T/P time period. When not filtered out, the standard deviation is not really homogeneous overall the T/P period, with stronger values for Poseidon measurements than TOPEX's one for instance. Moreover, some studies (Vincent et al, 2004 [20]) already shown the slight increase of TOPEX SLA variance after 2002, especially due to the MSS performances lower over the new ground track. Thus it's interesting to notice the ability of the method to measure with independent data the altimeter SLA performances.

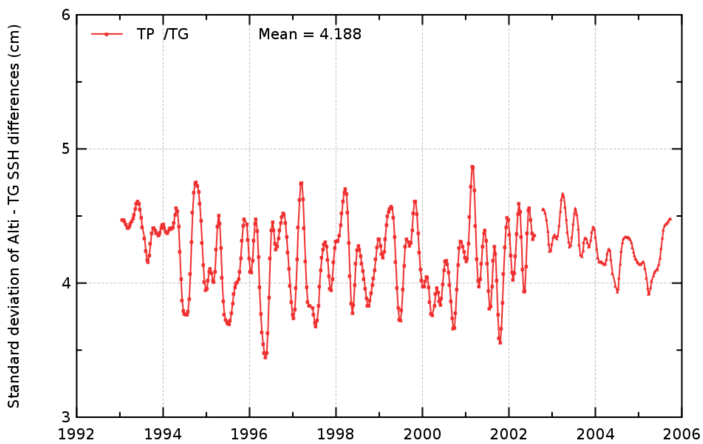


Figure 5: *Cycle by cycle monitoring of standard deviation SLA differences between TOPEX and tide gauge measurements*

4.2.2. Jason-1 and Jason-2

Concerning Jason-1 space mission, there were two major events in 2010: the swap from gyro 1 and 2 to gyro 2 and 3 the 14 of April and the 12 maneuvers of fuel depletion performed from the 20 of July to the 5 of August.
Concerning the ground processing, no major change or improvement have been realized on the Jason-1 mission during 2010 as the latter data are homogeneous overall the time period. Jason-1 and tide gauges SSH differences have thus been performed from homogeneous GDR-C release.

The cycle by cycle monitoring of Jason-1 and tide gauges SLA differences is plotted on figure 6 left. The global trend is 0.3 mm/year, within the error of the method (± 0.5 mm/year). A said earlier, there are two main sources of the error on the method itself:

- Only a few tide gauges are corrected from vertical movements, which prevents us from using it on the whole in-situ dataset.

- There is obviously a pretty strong location error and thus SSH assessment due to the position of both altimeter point and tide gauge.

Figure 6 right displays the monitoring of Jason-2 and tide gauges SSH differences. A negative trend of -1.74 mm/year is calculated on the whole period on the altimeter. Although this result is not significant due to the short period considered (and thus an important error of the method), it is to be noticed that this is the first time the processing sequence is really able to compare Jason-2 altimeter data with tide gauges measurements. Moreover, looking at the Jason-2/tide gauge residual signals superimposed with Jason-1's ones, the main result is that SSH raw differences are consistent with each other. Thanks to next Jason-2 cycles computed, this trend will be refined during 2011.

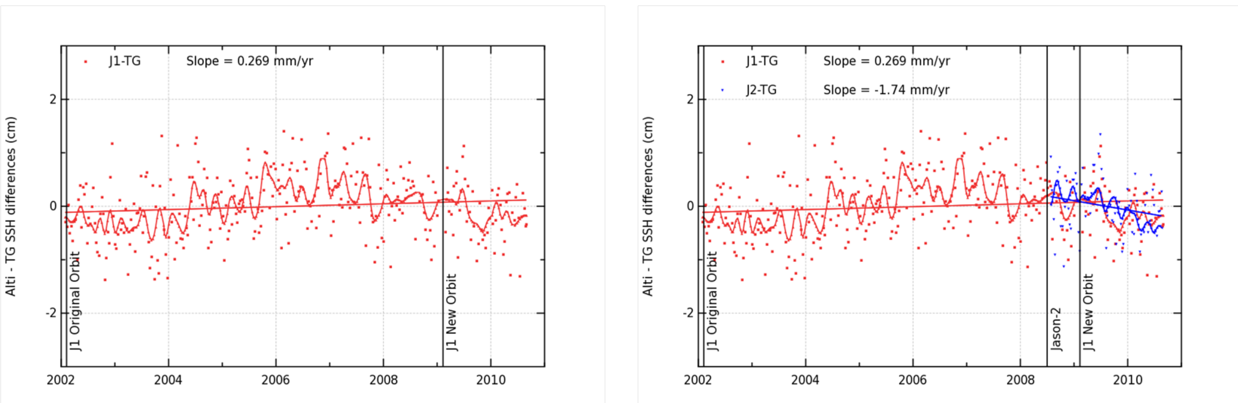


Figure 6: *Cycle by cycle monitoring of mean SLA differences between Jason-1 and Jason-2 and tide gauge measurements. left: Jason-1. Right: Jason-1 and Jason-2 superimposed*

Although previous monitorings have been adjusted from periodic signals, it is important to determine the origin of such signals remaining on altimeter/in-situ SSH differences, especially because of their relatively strong amplitude (about 2 mm, see figure 7 left). For instance, it is to be understood if such signals could result from one or several altimeter corrections. To date, possible explanations for this signal have to be investigated through rainfall, land waters, tide models or atmospheric loading on tide gauges. Indeed such natural phenomena could affect the terrestrial crustal vertical movements at large scales and these movements may not be measured the same way by the altimeter and by tide gauges. Note that such periodic signals are visible on all altimeter/in-situ tide gauges comparisons.

After filtering out signal lower than 2 months and removing periodic signals, a parabolic curve close to 5 mm amplitude is highlighted (figure 7 right). Regarding such results, the estimate of a simple trend (level 1 degree) in the Jason-1 altimeter/in-situ SSH differences doen't seem to be realistic. To date, no further investigation has been realized concerning the behaviour of Jason-1 by comparison to tide gauge measurements. This particular investigation will be thus studied in 2011.

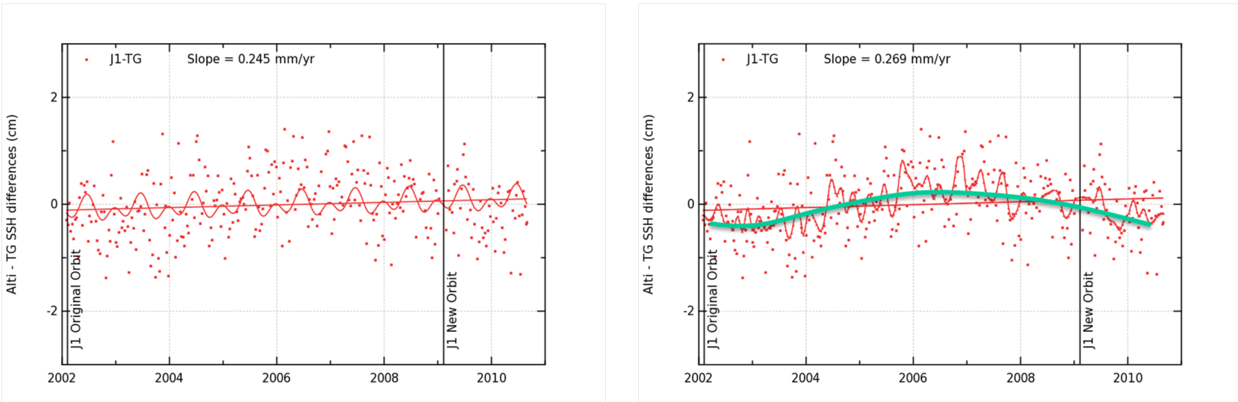


Figure 7: *Left: Annual and semi-annual signals deduced from cycle by cycle monitoring of mean SLA differences between Jason-1 and tide gauge measurements. Right: Parabolic approximation of the altimeter/in-situ SSH differences for Jason-1 space mission*

Using the new processing sequence, the mean value of standard deviation of SSH differences between altimeter data and tide gauge measurements is in the order of these of TOPEX/Poseidon, close to 4.2 cm. As new standards are more homogeneous between all the missions, this level of RMS differences is a good result and show a good SSH consistency between altimeter data and tide gauge measurements.

However, results presented in 2009 displayed a strong increase of the standard deviation of SSH differences since Jason-1 moved to the Tandem Mission orbit on the new ground track. This raise was explained by the MSS which adds errors when using outside the nominal track. One of the advantages of the new processing sequence is that using altimeter data on a theoretical track homogeneizes altimeter/SSH differences on the whole period. Moreover, the amplitude of the standard deviation since the orbit change seems to be weaker, lower than 0.5 cm from peak to peak while it was close to 1 cm before. The new 2010 method is thus more relevant considering altimeter/in-situ SSH differences with regard to the Jason-1 orbit change.

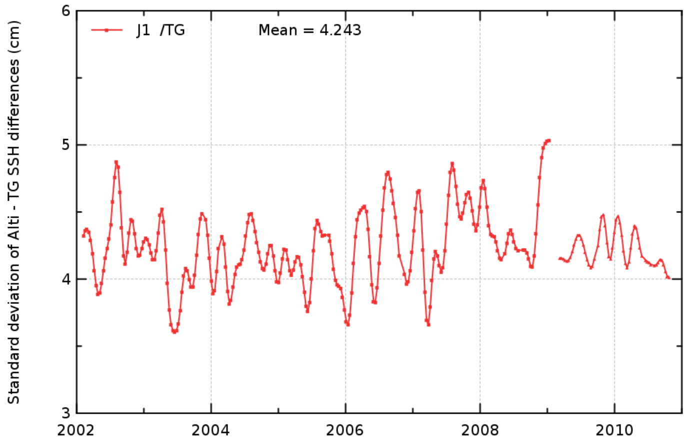


Figure 8: *Cycle by cycle monitoring of standard deviation SLA differences between Jason-1 and tide gauge measurements*

4.2.3. Envisat

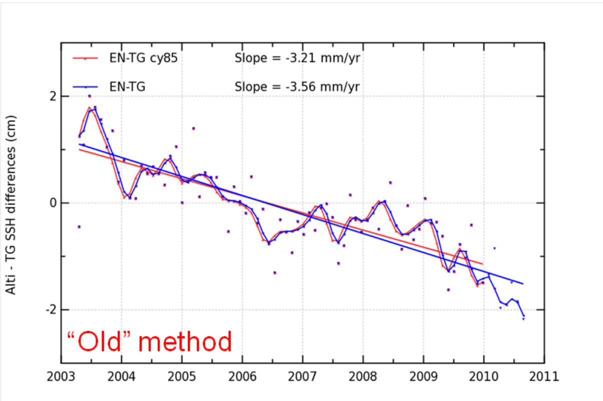
As for Jason-1 and Jason-2, Envisat measurements are computed in order to provide an accurate SSH and can thus be qualified through in-situ comparisons. However global MSL studies have shown until now a particular behavior of the Envisat MSL, especially at the beginning of the period where the MSL slope is not in agreement with Jason-1 and TOPEX/Poseidon ones. Indeed, differences between Envisat SSH data and tide gauges measurements are performed from not homogeneous GDR datasets (A, B and C).
Despite of the remaining level-1 processing inhomogeneities for instance, some of the most relevant corrections like the orbit have been updated with GDR-C standards. This makes Envisat SSH homogeneous enough to be compared with Jason-1 while the whole reprocessing is performed. The latter is currently under validation for the first cycles reprocessed and will be available some time in 2011.

Considering the cycle by cycle monitoring of the mean SSH differences between altimeter data and tide gauges measurements on figure 9, the new processing sequence seems to have homogeneize results considering the Envisat space mission. Indeed, the assessment of the drift until cycle 85 change from -3.2 mm/year to -1.7 mm/year. Comparing to results estimated on other missions (Jason-1, TOPEX/Poseidon), a significant neagtive drift is still detected on Envisat between 2003 and 2010.

Explanations on such a change in the Envisat/TG drift can be linked to the way altimeter points on tracks were selected compared with tide gauges. Since Envisat displays a better spatial sampling as Jason-1, the closest altimeter point selected with the older method was likely to be less representative (considering the SSH) than the one outcoming from the new processing sequence, based on the maximum of correlation. This could explain why results seems to be more reliable, especially for the Envisat space mission.
Moreover, the Envisat negative trend could be also related to the strong regional drift dependant

on the longitudes (East/West) likely in relationship with the orbit calculation. This result will have to be further studied in 2011 as GDR-C reprocessing should improve the Envisat long-term stability.

Finally, considering the whole time period, the drift is more negative, around -2.3 mm/year. The potential jump which is displayed on cycle 86, not linked to the change of the IPF version, will have to be further studied. One of the possible explanation could stem the pre-processing with the editing performed on tide gauges. Once again, such a result demonstrates the need to have the best in-situ data time series to estimate altimeter potential drift and thus the need to perform an accurate tide gauge quality control (see section 6.1.).



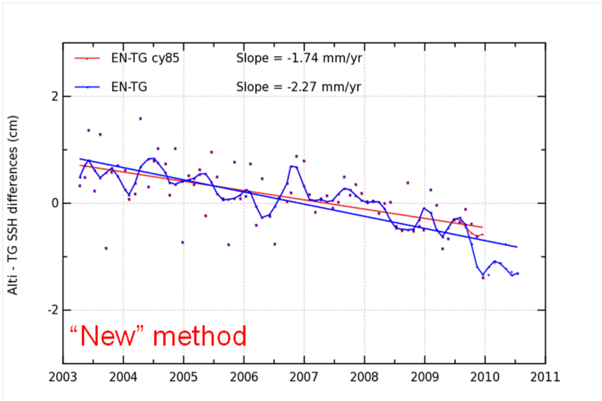


Figure 9: *Cycle by cycle monitoring of mean SSH differences between Envisat and tide gauge measurements. Left: using the original method. Right: using the new processing sequence*

In order to underline the reliability of the new processing sequence, a comparison with Jason-1 and Envisat global MSL results have been performed. As shown on figure 10, the Jason-1 / Envisat trend differences at tide gauges location is coherent with the global MSL trends difference. Indeed, on the 2004-2010 time period, a difference of about -1.6 mm/year is detected between both trends of the mean altimeter SSH colocated to tide gauges. This difference is of the order of the one between Jason-1 and Envisat global MSL, with a trend of -1.3 mm/year.
Thus the good consistency between global MSL differences and altimeter/tide gauges cross-comparisons for Envisat and Jason-1 demonstrates the robustness of this in-situ method comparison.
Note that additionnal noise on Jason-1 monitoring comes from the cycle time period (about 10 days for Jason-1, 35 days for Envisat).

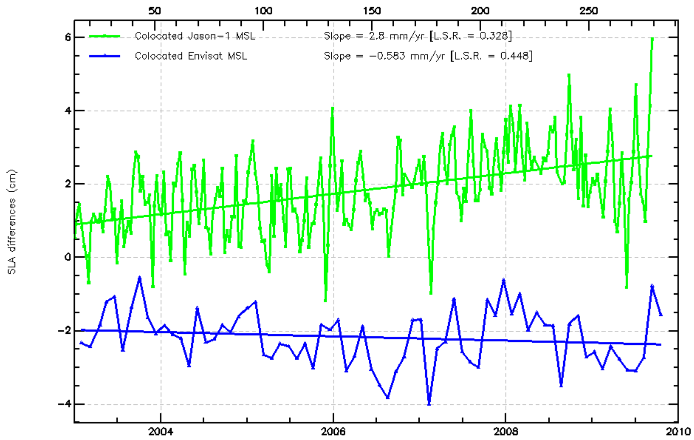


Figure 10: *Comparison of the global MSL at tide gauge locations for Envisat and Jason-1.*

Concerning the monitoring of the SLA differences standard deviation (figure 11), the average value (about 4 cm RMS) is lower than both TOPEX/Poseidon and Jason-1. In fact, the low Envisat figure is not really comparable as the standard deviation is calculated cycle by cycle but the 35-day repetitivity for Envisat (instead of the 10-day repetitivity for Jason-1 and TOPEX/Poseidon) reduces the SLA RMS differences. Indeed even with the new processing sequence based on the maximum of correlation, there might be more homogeneous measurements for each tide gauge considering the Envisat mission. It is thus planned to reprocess Envisat in 2011 with a 10-day sub-cycle in order to be better compared with Jason-1 and TOPEX/Poseidon.

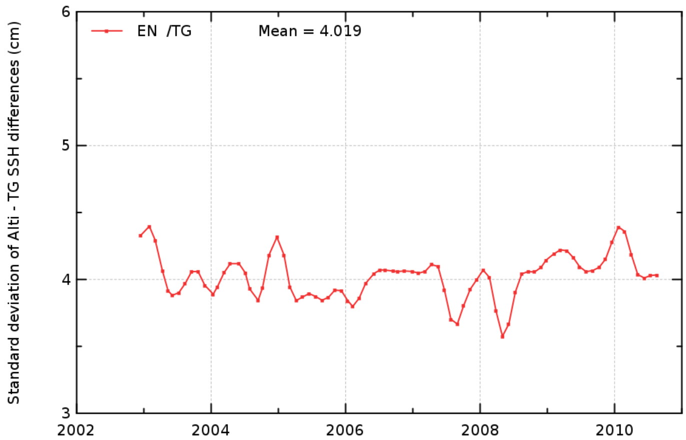


Figure 11: *Cycle by cycle monitoring of standard deviation SLA differences between Envisat and tide gauge measurements*

4.2.4. Conclusion

Although the new processing sequence is reliable to estimate the SSH altimeter drift, the error of the method has to be taken into account. To date it is assessed to 0.5 mm/year, based on long-term time series. Moreover, the question of residual periodic signals has still to be further studied. Some explanations for this signal have to be investigated through natural phenomena which could affect the terrestrial crustal vertical movements at large scales, movements which may not be measured the same way by the altimeter and by tide gauges This question has to be thoroughly considered in the future.

5. Estimation of altimetric SSH improvements

5.1. Overview

As already mentioned, the second main goal of the Calval in-situ activity is to estimate improvements of altimetric data analyzing the SSH consistency between altimeter and in-situ measurements. This part aims at presenting the capability of the altimeter/tide gauges comparison procedure to measure the impact of new altimetric standards on the SSH consistency. These new altimeter standards can be new geophysical corrections (tide model correction, dynamical atmospheric correction,...), new orbits or new algorithms in ground processing. These evolutions can be included in a new release of altimetric products, or evaluated prior to a reprocessing campaign.

The basic principle of the method is to compare the SLA consistency between altimeter and tide gauges data using successively the old and new standards in the altimeter SSH calculation. The main criteria used is the analyse of SLA variance differences :

$$\Delta VAR(SLA)_{Alti} = VAR(SLA_{Alti(NewStandards)} - SLA_{TG}) - VAR(SLA_{Alti(OldStandards)} - SLA_{TG})$$

If $\Delta VAR(SLA)_{Alti}$ is negative, this argues for an improvement of new standards in the SSH calculation. The cycle by cycle monitoring of these statistics is systematically performed in order to detect changes in the new standards in comparison with the former ones. Another diagnostic also developed is the histogram of the variance SLA differences as function of the tide gauge number as plotted in figure 12.

In the same idea, the correlation of altimeter and tide gauge SSHs is locally analyzed for a given tide gauge (see information cards of tide gauges in annex 10.4.). The difference of correlation using old and new altimeter standards is mapped in order to detect accurately areas where the altimetric SSH is improved.

The following analyses presented here are not exhaustive. Their main objective is to illustrate and demonstrate the interest of the method.

5.2. Impact of new GOT4.7 tidal model correction

The first study is about the enhancement of the new GOT4.7 tidal model correction in the altimetric SLA computation. This study has been performed in 2008 in relationship with the PISTACH project. As this new standard was updated in CLS altimeter tables in 2009, the comparison with in-situ tide gauge measurements has been performed with these new standard. Thus figure 12 displays histograms of SLA variance differences between altimeter and in-situ data using successively GOT4.7 and GOT00V2 tide models for the three main missions TOPEX/Poseidon, Jason-1 and Envisat. This diagnostic is a way of demonstrating the improvement of new standard at tide gauge locations.

For availability reasons of datasets, the global period is different between all these missions as the performance of the GOT4.7 tide correction is studied on their own global time period. Positive values mean that altimetric SLA using GOT00V2 tide correction is more coherent with tide gauge SLA than altimetric SLA using GOT4.7. Conversely, negative values mean that the use of the GOT4.7 tide correction makes altimetric SLA more coherent with tide gauge SLA than with GOT00V2. Negative values mean therefore that the use of GOT4.7 for altimetric SLA reduces the variance.
Results with regard to the three space missions display a mean gain value of about -1.5 cm^2 for TOPEX/Poseidon, -1.7 cm^2 for Jason-1 and -0.6 cm^2 for Envisat. As it was demonstrated in CalVal studies, the new tide correction is more efficient in coastal areas except in the Hudson Bay and in the north of the Bering strait. Comparisons with tide gauge measurements logically lead to good results for the space missions considered through these histograms of variance differences and confirm the improvement of the computation of altimeter SSHs with the new GOT4.7 tide correction.

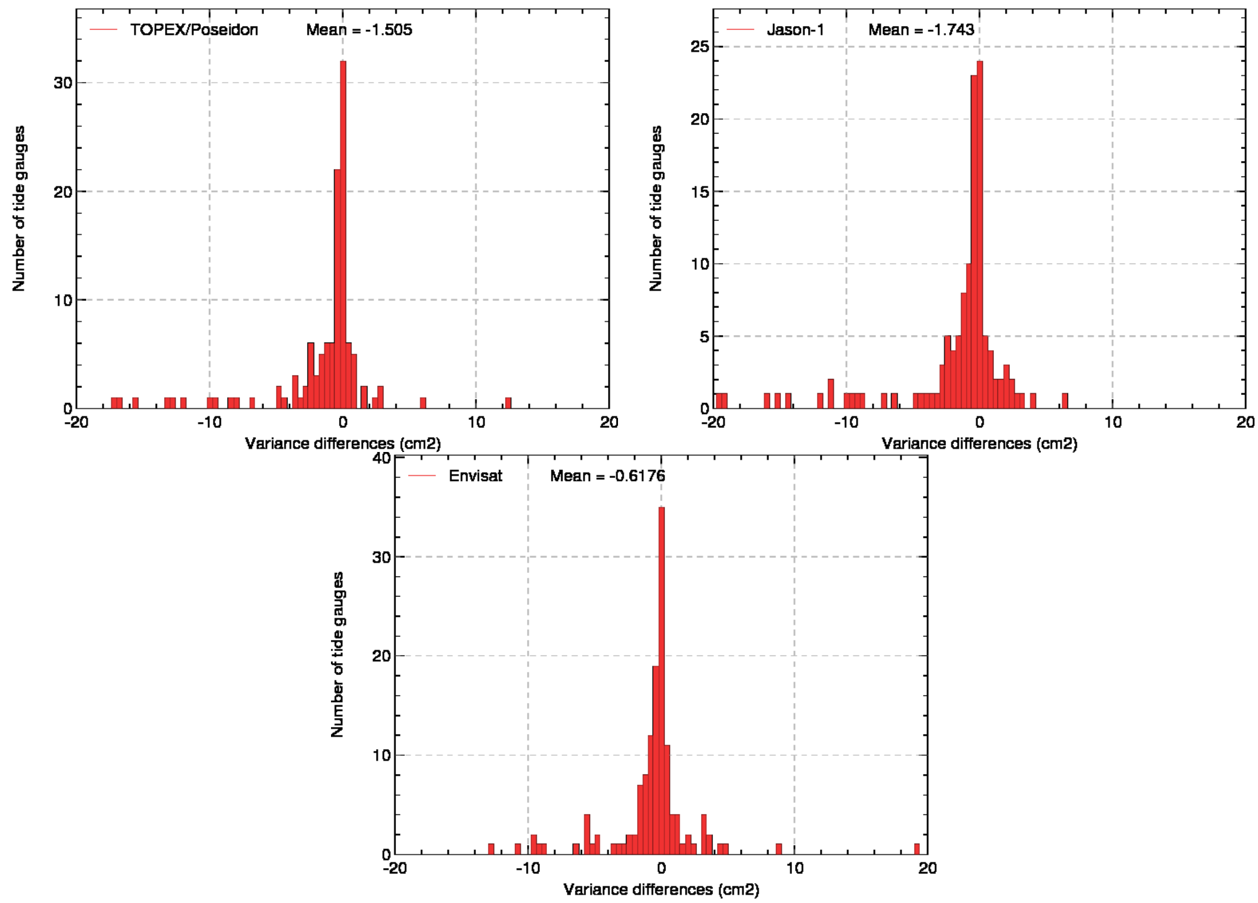


Figure 12: *Histograms of SLA variance differences between altimeter and in-situ data using successively GOT4.7 and GOT00V2 tide models. Top left: TOPEX/Poseidon, top right: Jason-1, bottom: Envisat*

5.3. Impact of the coastal editing flag on altimeter/in-situ SLA consistency

With the same method as previously, we also studied the performances of the new coastal editing flag. In figure 13 is plotted the histogram of the variance SLA differences as function of the tide gauge number in order to estimate the impact of new editing criteria allowing to compute the SSH closer to the coasts. Negative values indicate that the coastal editing flag is better. Results provided explain how can be improved the consistency between altimeter data and in-situ measurements at the different tide gauge locations. Here the impact of the coastal editing flag is relevant, with a mean variance of -2.9 cm^2 for Jason-1 and -2 cm^2 for Envisat, which demonstrates the improvement of altimeter/in-situ SLAs consistency using this criterion.

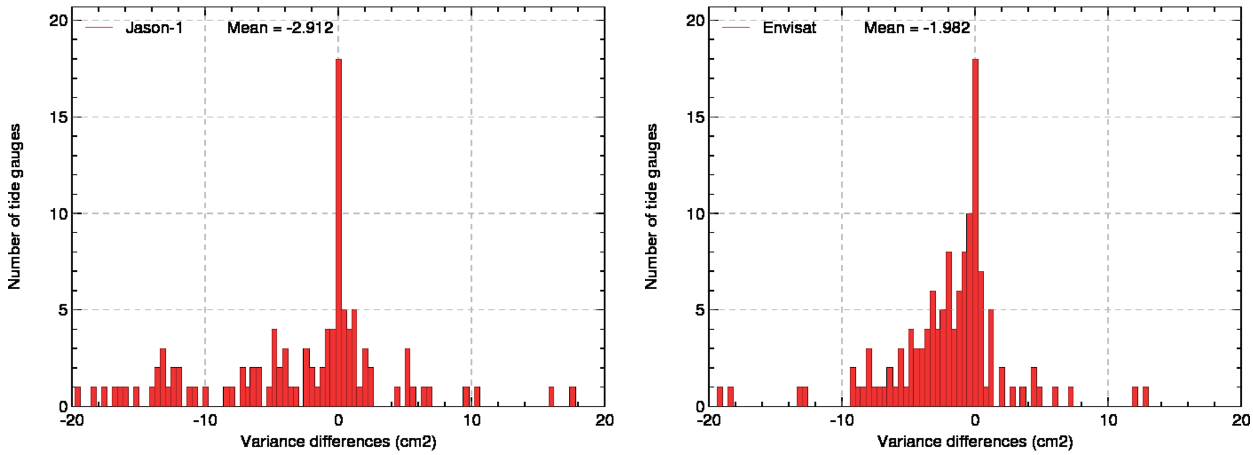


Figure 13: *Differences of SLA variance differences between altimeter and in-situ data using successively basic and coastal editing flag. Left: Jason-1, right: Envisat*

5.4. Impact of the GDR-C reprocessing on altimeter/in-situ SLA consistency

As for the two previous kind of corrections and described in the overview section, the impact of the new GDR-C reprocessing on Jason-1 can be estimated at tide gauge locations by comparison with GDR-B products. Here are the main improvements released in this reprocessing (see [8] and [9]):

- the main change of the new version is the POE orbit solution, which includes a new gravity model (EIGENGL04C instead of EIGEN-CG03C), and a time-varying part (without drifts).
- the JMR (radiometer) has been recalibrated with parameters derived from cycles 1 to 227 (GDR-B) so as to provide more accurate brightness temperature and therefore wet tropospheric correction.
- altimeter instrument corrections were updated. This has an impact on several altimeter parameters: backscattering coefficient (sigma0), sea wave height, range. Through the range, the bifrequency ionospheric correction is also slightly modified.
- a new sea state bias (SSB) solution, computed on a 3-year basis of GDR version B (cycles 1 to 111), improves significantly the sea surface height (SSH) calculation.
- the dry troposphere correction still uses the ECMWF model, which has evolved to correct for spurious oscillation effects.
- the dynamical atmospheric correction (DAC), which includes inverse barometer and MOG2D model, now uses high resolution MOG2D grids.
- for FES2004 ocean tide model, S1, K2 and loading tides have been updated.
- an empirically-computed pseudo time-tag bias correction has been added in the product and taken into account in SSH calculation, and a mean dynamic topography (MDT Rio, 2005) has been added too.
- a new algorithm, based on AGC instead of sigma0, is used for rain flag estimation.

- the computation of the ice flag is also slightly changed. It no longer shows a discontinuity in the Hudson bay.

While the main benefit is to estimate the performance of the GDR-C reprocessing through in-situ independent datasets comparison, the drawback of this method is that each correction can't be individually assessed in the global reprocessing. Results displayed on figure 14 show the better temporal consistency between altimeter data and tide gauge measurements with a mean value of -0.73 cm^2. However, a residual annual signal is remaining, which periodically inverts the consistency to either GDR-C or GDR-B orbit. In agreement with Calval studies, this annual signal may be due to the new gravity model and the time-varying part used in the POE orbit solution.
Moreover, at tide gauge locations, the SSH consistency is also slightly improved, maybe influenced by the sign inversion of variance differences. Thus the mean is -0.13 cm^2 and confirm the enhancement of the consistency between altimeter and in-situ data thanks to GDR-C reprocessing.

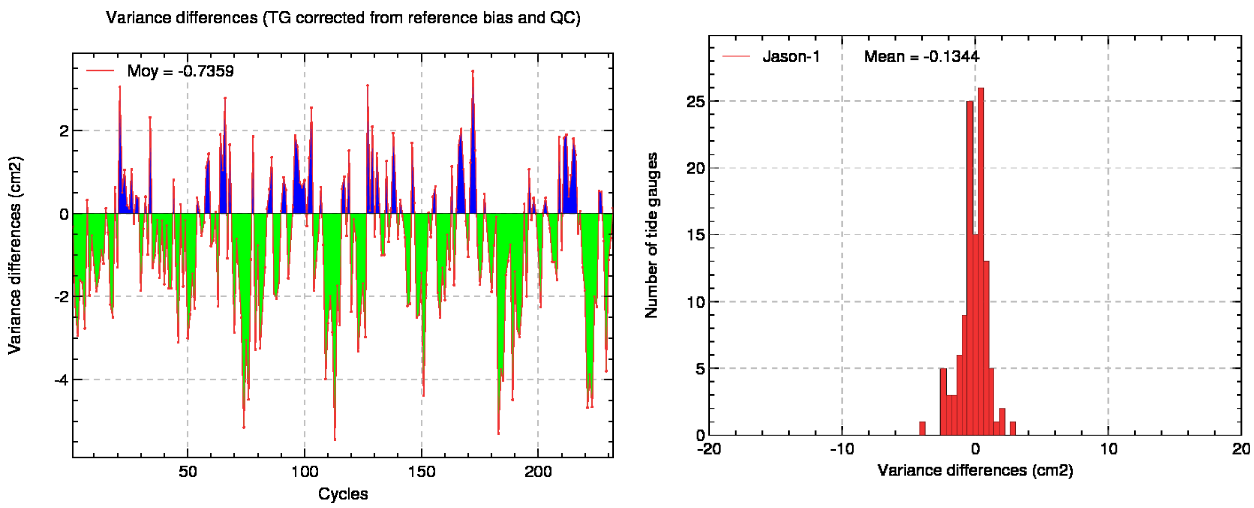


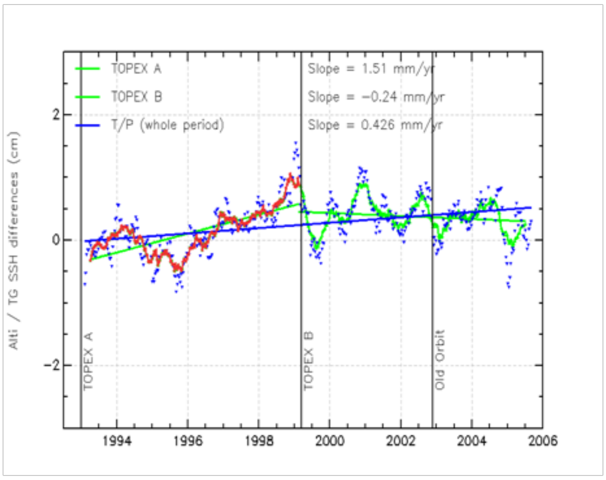
Figure 14: *Monitoring of SSH variance differences computed with GDR-C and GDR-B for Jason-1 (cm^2)*

5.5. Impact of new Sea State Bias (SSB) correction on TOPEX/Poseidon

Reprocessings of SALP/DUACS multimission products aim at computing the latest and most accurate altimetric corrections in the SSH calculation (GSFC orbit, GOT4.7 tide correction ...). The use of the Gourrion wind, more relevant than Chelton's one, have led to a new computation of the TOPEX/Poseidon SSH (see technical note [17]). Next to the study between the old and the new SSB corrections, the altimeter and in-situ long term differences provide results as seen on figure 15. On the left, a drift is observed on the TOPEX-A time period, corresponding to instrumental problems (OSTST, Seattle 2009). When comparing new results to in-situ tide gauge measurements, this drift is strongly decreased, which indicates the new TOPEX MSL is more reliable. The new trend on TOPEX-A is 0.8 mm/year with the new 2-parameters SSB computed with Gourrion's wind whereas it was 1.5 mm/year with Chelton's wind.

Moreover, as presented on figure 16, the histogram of variance differences between both solutions of Sea State Bias show that altimeter and in-situ measurements are more consistent using the 2-

parameters Sea State Bias calculated with Gourrion's wind. Thus, the mean of variance differences is -0.6 cm^2, which is a good improvement in the altimeter SSH computation.



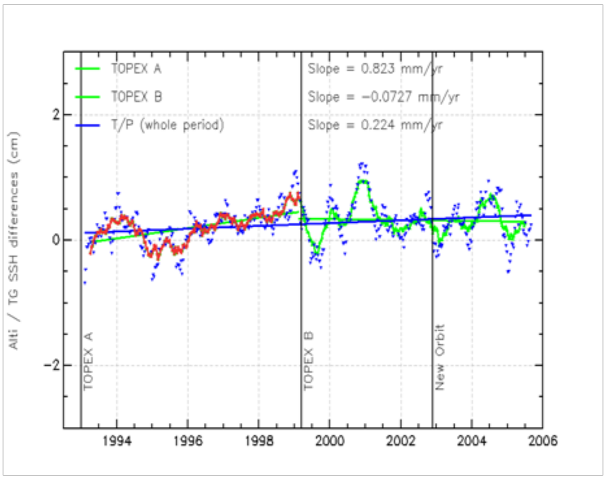


Figure 15: *Impact of the new 2-parameters Sea State Bias computed with Gourrion's wind on the monitoring of the mean altimeter/in-situ tide gauge differences. Left: Old SSB (Chelton's wind). Right: New SSB (Gourrion's wind)*

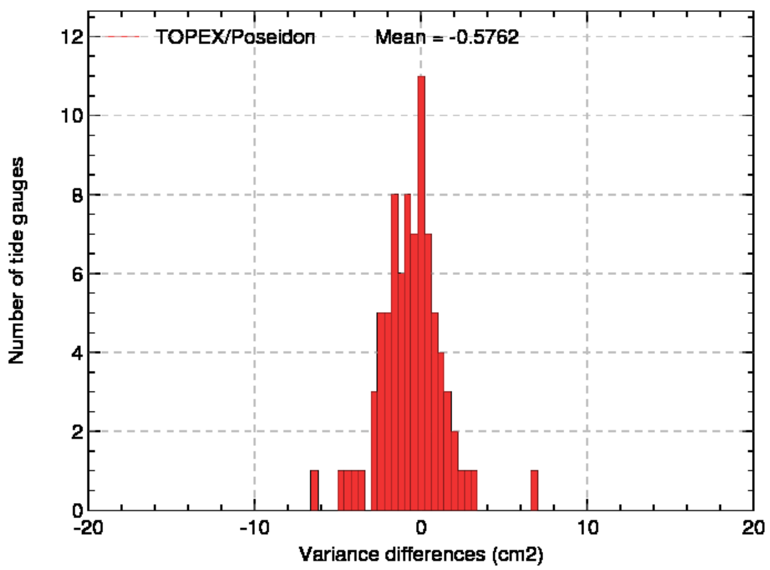


Figure 16: *Histogram of SSH variance differences computed with GDR-C and GDR-B for TOPEX/Poseidon (cm^2)*

6. Quality assessment of in-situ tide gauge time series

To complete the global assessment of altimeter data where in-situ measurements are used as independent sources of comparison, tide gauge networks are compared to altimeter SLA time series. This part aims at detecting anomalies on in-situ time series from comparisons with all available altimeter data. This is mainly possible comparing SLA differences and allows us to detect jumps on in-situ time series which are not detected on altimeter ones. Moreover, maps of temporal correlation between altimeter and in-situ SLA time series are systematically produced for each tide gauge.

6.1. Presentation of the tide gauge information cards

The basic principle of the information cards is based on a summary of in-situ informations compared to altimeter data, which are then used to perform a quality control on each tide gauge.
Here are the main purposes of such information cards (figure 17):

- Tide Gauge identification: this part contains general informations about the tide gauge (network, coordinates, time period coverage and potential colocated GPS close to the tide gauge). The latter is important to correct the tide gauge from vertical movements. But to date, only a few tide gauge are colocated to a GPS beacon, that's why tide gauges are corrected from a global bias of -0.2 mm/year (Peltier, 2004).

- Temporal SLA comparisons with TOPEX/Poseidon, Envisat, Jason-1: in this part results from the tide gauge processing data are used to compare the in-situ and altimeter SLAs and their differences on the tide gauge time period. Thanks to the multi-cross-calibration, drifts or jumps on tide gauge time series can be detected and then be used to perform the quality control.

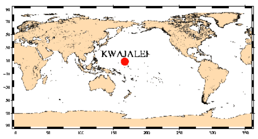
- Maps of SLA correlation with Jason-1, TOPEX/Poseidon and Envisat: to make the multi-cross-calibration reliable, another useful diagnostic concerns the correlation between altimeter and in-situ SLAs. Such maps have a double interest, first to estimate the distance between altimeter tracks and the tide gauge and second to see if both SLA are well correlated. The proximity of altimeter tracks depends on the mission itself, thus the distance between Envisat tracks and tide gauges is logically smaller than for Jason-1 (which does not mean correlations are better). Concerning TOPEX/Poseidon, the tandem mission has a positive effect on this proximity with regard to Jason-1. Generally the correlation is good close to the coasts up to 0.9. But for some tide gauges, the value is low, maybe due to geophysical processes but also to jump or drift in in-situ data. The comparison of altimeter and in-situ SLA allows us to assess the tide gauge SLA as well as the altimeter SLA.

- Tide Gauge reliability: finally the information card gives a summary of different relevant diagnostics such as the slope of the potential tide gauge crustal drift, the SLA maximal correlation, the filtered and non-filtered SLA differences RMS, the SLA differences slope and finally the quality control applied on each tide gauge deduced from all these informations.

TIDE GAUGE : WO0055

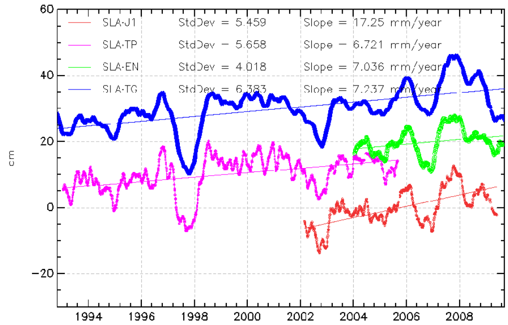
Tide Gauge identification

Tide Gauge Network	WOCE
Location (Lat/Lon)	8.73 deg / 167.73 deg
Time series coverage	From 01/01/1950 to 24/11/2009
Vertical movements drift	YES

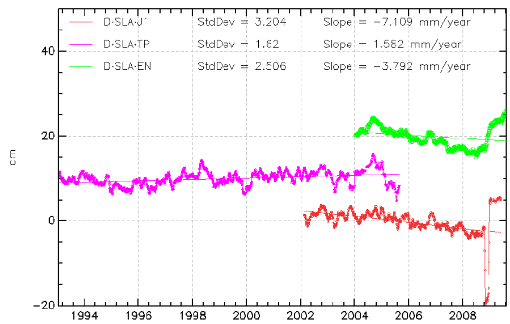


Temporal SSH comparisons with T/P, Envisat, Jason-1 and Jason-2

Monitoring of SSH

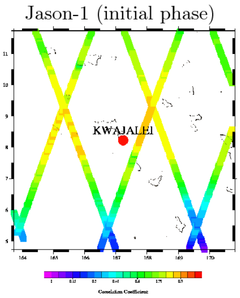


Monitoring of SSH differences

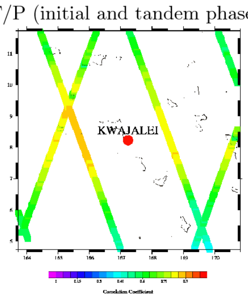


Maps of SSH correlation with Jason-1, T/P and Envisat

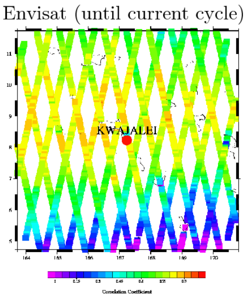
Jason-1 (initial phase)



T/P (initial and tandem phase)



Envisat (until current cycle)



Tide Gauge reliability

	T/P	T/P (tandem)	Jason-1	Jason-2	Envisat
Minimal distance from TG	xx kms	xx kms	xx kms	xx kms	xx kms
TG crustal drift	0.9 mm/yr	0.9 mm/yr	0.9 mm/yr	- mm/yr	0.9 mm/yr
Maximal SSH correlation	0.90	-	0.88	-	0.91
Non-filtered SSH diff RMS	3.8 cm	- cm	4.3 cm	- cm	4.3 cm
Filtered SSH diff RMS	1.8 cm	- cm	2.6 cm	- cm	2.7 cm
SSH differences slope	1.9 mm/yr	- mm/yr	-7.1 mm/yr	- mm/yr	-3.8 mm/yr
Quality control	OK	OK	KO	-	KO

Figure 17: *Example of an information card for the Kwajalei tide gauge*

From these information cards, 4 quality control flags can be applied:

- 1: in-situ and altimeter SLA time series are consistent
- 2: a problem is detected on one of the in-situ or altimeter time series
- 3: a problem is detected on the in-situ time series
- 4: a problem is detected on the method or on the altimeter SLA time series

To date, only tide gauges which quality control is 1 are considered reliable and used to detect potential drifts or jumps on altimeter time series, or in the estimate of the quality of new altimeter standards. Moreover, this quality control has only be performed on the GLOSS/CLIVAR and REFMAR networks for now, which means that about 100 tide gauges are not used in the altimeter/in-situ SLA comparisons. The quality control for the whole networks will be performed in 2011.

6.2. Availability of tide gauge information cards

Since September 2009, information cards for both GLOSS/CLIVAR and REFMAR networks are routinely performed each week and distributed on the AVISO website (*www.aviso.oceanobs.com/fr/calval/in-situ-global-statistics*). A googlemap mapplet has been developed and information cards can be visualized online (figure 18). As the tide gauge coordinates accuracy is on the order of the minute, the geodetic reference system of our database may slightly differ from the googlemap one, which can induce some slight differences in tide gauge locations. Future actions in 2011 will improve this googlemap on the AVISO website, especially with arrows concerning the Mean Sea Level trend at the tide gauge location.

Figure 18: *Availability on tide gauge information cards on the AVISO website*

7. Particular investigations using in-situ tide gauge measurements

7.1. Overview

The new processing sequence developped during the past year reinforced the idea that using independent datasets like in-situ measurements is a reliable external way of validating altimeter data of multiple space missions. In addition to these basic diagnostics, several studies were performed in the frame of the different activities involving tide gauge measurements. This part will thus demonstrate the interest of comparing altimetry with in-situ tide gauge measurements to detect the 58.74 day signal observed on the MSL derived from Jason-1/2 and TOPEX or anomalies on the Envisat altimeter data.

7.2. Analysis of the 58.74 day signal observed on the MSL derived from Jason-1&2 and TOPEX data

As shown on figure 19 left, global MSL time series computed with GOT4.7 tide model display a strong 58.74 day signal on Jason-1 and 2 (with amplitudes around 3-4 mm)) while it is smaller on TOPEX data (1 mm). In the same way, the map of the 58.74 day amplitude signal (figure 19 right) displays stronger amplitude patterns for Jason-1 (greater than 5 mm) in the −40/40 latitude area.

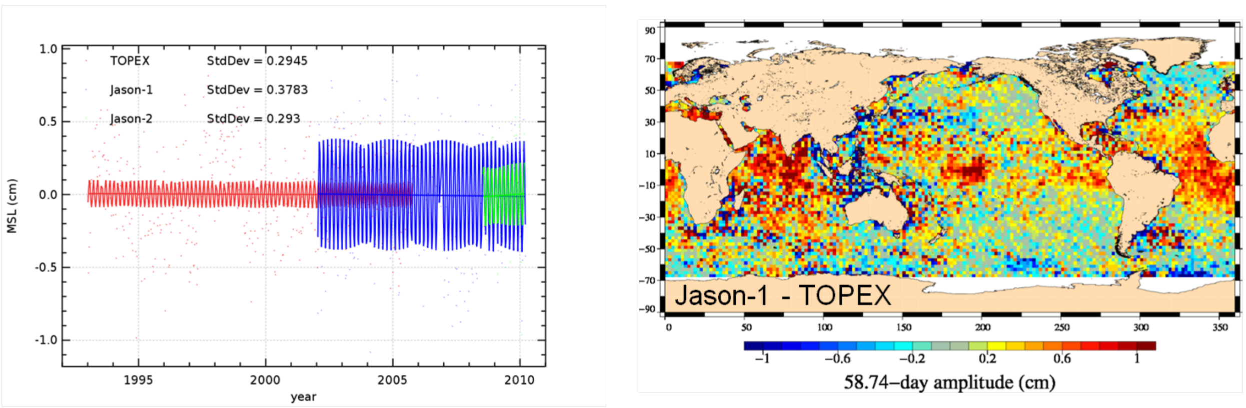


Figure 19: *Left: 58.74 signal day on global MSL after removing the global trend. Right: Map of the 58.74 day signal observed between Jason-1 and TOPEX.*

To check such results obtained between Jason-1 and TOPEX, in-situ measurements were used and computed in the new processing sequence developped in 2010. It appears that SSH differences between altimetry and tide gauges highlight a 58.74 signal of about 3-4 mm for Jason-1 and 1 mm for TOPEX too (see figure 20).
Thanks to the comparison with independent in-situ tide gauge datasets, it has been demonstrated that the 58.74 day signal was not a physical signal but an error in altimeter data.

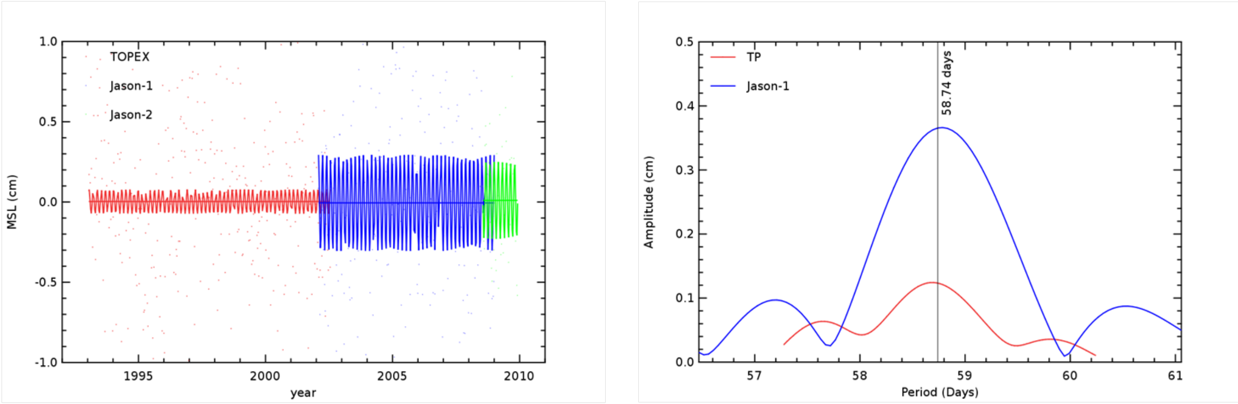


Figure 20: *Left: 58.74 signal day on altimeter/tide gauges SSH differences after removing the global trend. Right: Periodogram on altimeter/tide gauge SSH differences focused on 58.74 day signal*

Although the comparison of altimeter data with tide gauge measurements don't bring the solution of this processing anomaly, this study demonstrates how useful are such independent in-situ measurements to check such potential problems and thus further studied the correction to bring in order to correct the anomaly. In this case, it has been concluded that the main part of the 58.74 day signal observed on the Jason-1 MSL is due to the use of the GOT model in the SSH calculation. Indeed, using the altimeter/tide gauges SSH differences data to estimate the spatial amplitude of the 58.74 day signal on Jason-1 (see figure 21), we can observe that residual signals are higher in terms of amplitude considering the GOT4.7 tide model in SSH differences with tide gauges, at a rate of about twice FES04 one (8 mm with GOT4.7 whereas it is 4 mm with FES04).

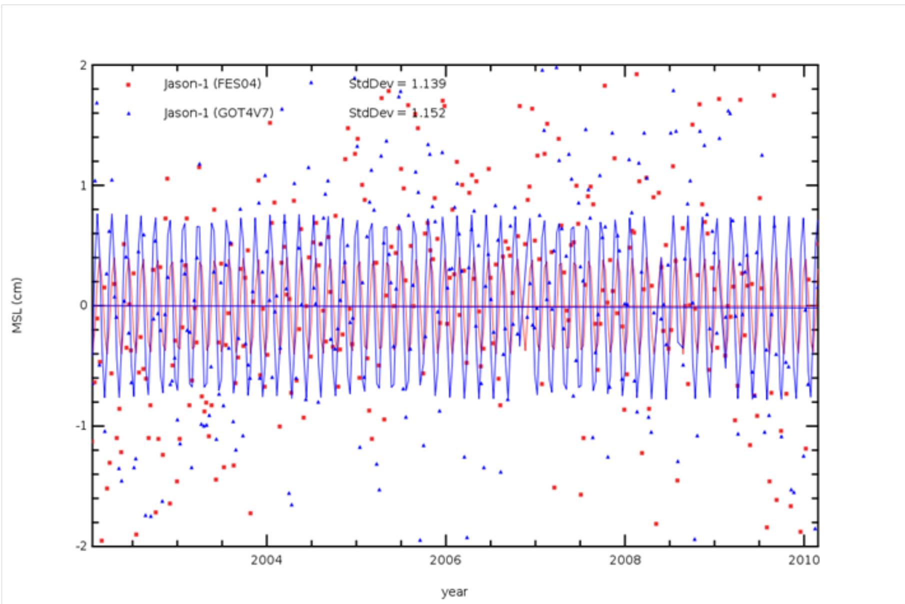


Figure 21: *Spatial amplitude of the 58.74 day signal on Jason-1/tide gauges SSH differences using GOT4.7 and FES04 tide models*

7.3. The Envisat PTR anomaly

First, as the PTR correction is itself a correction of some kind of behaviour of the Envisat satellite, the problem which has been detected and which is described in this part is not really an anomaly. However, it will be considered as such in this particular investigation.

Between September 2008 and May 2009 an abnormal jump has been detected in the MSL differences between Envisat and Jason-1 missions, as shown in figure 22. In order to determine whether this anomaly comes from Jason-1 or Envisat mission, we compare altimeter SLA with in-situ tide gauge measurements. Thus we can observe and quantify the impact of this anomaly on the Envisat MSL (red curve of figure 22) which is about 5 mm. The monitoring of instrumental corrections of Envisat (green curve) underlines the anomaly too. It has been observed similarly while comparing altimetry with tide gauges measurements. It is to be noticed that this anomaly has also been detected using ARGO T/S profiles. Thanks to comparisons with in-situ data, small jumps can thus be detected on the altimeter MSL, whatever the mission considered.

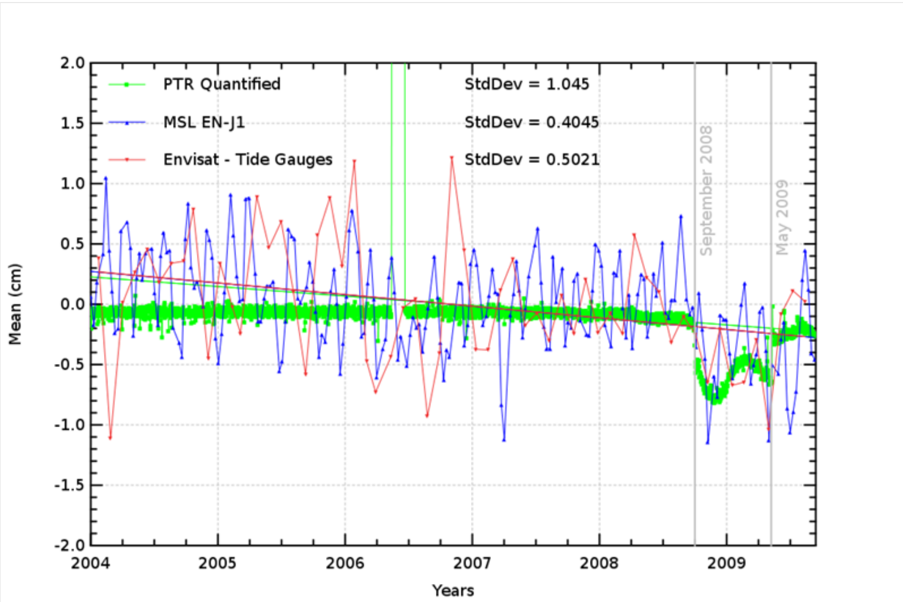


Figure 22: *Detection of the PTR anomaly on Envisat using tide gauge measurements*

8. Conclusion

This report demonstrates the interest of this comparison method in order to assess potential drifts or jumps in the altimetric measurements. Reliable results are obtained thanks to a data processing procedure performed in an operational frame (development and operational account, automatic processing, ...). This operational aspect of the data processing procedure is fundamental to quickly reprocess the whole altimetric period and take into account new altimetric standards as it was performed in 2009 for Jason-1 and will be perform in 2011 for Envisat GDR-C releases.

Thanks to the new method developed in 2010 and based on the maximum of correlation between altimeter and in-situ tide gauge SSHs, the comparisons of altimeter data with in-situ measurements and thus the MSL drift can be more precisely estimate, especially for the Envisat mission which spatial sampling is greater than those of Jason-1 and 2 and TOPEX/Poseidon.
In this way, drifts for Jason-1 and TOPEX/Poseidon on their whole time period have been respectively estimated to 0.3 mm/year and 0.7 mm/year, within the error of the method (± 0.5 mm/yr). In the meantime an Envisat MSL drift close to -1.7 mm/yr is detected, which can be related to the strong regional drift dependant on the longitudes (East/West) likely in relationship with the orbit calculation. Indeed, GDR-C reprocessing should improve the Envisat long-term stability.
These results are in agreement with global Cal/Val studies, which reinforced the idea of using independent in-situ tide gauge measurements is a way of getting an assessment of the error on the global MSL trend.
Finally, a negative trend of -1.74 mm/year has been calculated on the Jason-2 time period. Although this result is not a significant due to the short period considered (and thus an important error of the method), it is to be noticed that this is the first time the processing sequence is really able to compare Jason-2 altimeter data with tide gauges measurements. Thanks to next Jason-2 cycles computed, this trend will be refined during 2011.

We also demonstrate the interest of the method to estimate the impact of new altimeter standards in the SSH calculation. Though the tide gauge coverage is poor (only close to the coast), the SSH consistency analysis between altimeter and tide gauge gives independent information to measure the quality of new altimetric standards. Diagnostics which have been developed, like the spatial distribution of variance differences at tide gauge locations, explain how can be improved the consistency between altimeter data and in-situ measurements at the tide gauge locations. Indeed, the performance of Jason-1 GDR-C reprocessing was assessed thanks to in-situ data. As soon as Envisat GDR-C reprocessing will be performed, this method will be used to quantify its consistency with the latest altimetric, radiometric and geophysical corrections.

Moreover, the method presented here can provide a quality assessment on both altimeter and in-situ datasets through SSH comparisons. Thus, information cards for both GLOSS/CLIVAR and SONEL networks are now routinely performed each week and distributed on the AVISO website (*www.aviso.oceanobs.com/fr/calval/in-situ-global-statistics*). Thanks to such comparisons, a relevant selection of reliable tide gauges is performed so as to detect potential drifts or jumps on altimeter time series, or to estimate the quality of new altimeter standards. To date, about 300 tide gauges are used in the altimeter/in-situ SLA comparisons although the tidal database consists in about 400 tide gauges. Future projects and collaborations will aim at enhancing the number of relevant tide gauges used in the altimeter/in-situ cross-comparison.

It's important to underline the synergy of both methods to estimate the altimetry MSL drift. Indeed, while tide gauge measurements provide long time series but a limited spatial sampling, Argo T/S profiles provide a global coverage but are available on a shorter time period.
Thanks to the cross-comparisons between results provided by the different approaches (global comparison between altimetric missions, altimeter/tide gauge and altimeter/T/S comparisons), the assessment of the MSL drift is more and more reliable and accurate, globally as well as regionally.

Although the new processing sequence is fully operational and routinely used in the different studies involving in-situ data, several improvements are planned for the next years in order to better benefit from tide gauge measurements and thus improve the relevance of analyses. To date, at least 3 points have to be investigated to give better results:

- the way of computing vertical movements, by using more GPS at tide gauge locations
- the correction of jumps in tide gauge time data series
- Investigations on periodic signals linked to altimeter/in-situ cross-comparisons

To reach such goals, future actions will be performed in 2011, and some new ideas to get better results will be investigated:

- A feedback to the suppliers of tide gauge measurements to perform a routinely operationnal quality control of the in-situ data distributed.
- The tide gauge quality control has to be performed on the whole tide gauge networks.
- The tide gauge googlemap will be improved, especially with Key Performance Indicators computed from altimeter/in-situ SSH comparisons at tide gauge locations. For that matter, a training period has been proposed on this purpose in 2011.
- Concerning vertical movements, several tests on regional areas or specific basins are expected to be done in order to quantify the impact of this correction with a better GPS space sampling at tide gauge locations. This work is planned in 2011 in the frame of the Climate Change Initiative.

Finally, this work has been presented this year at the ESA Living Planet Symposium in Bergen [3] and at the OSTST in Lisbon [1].

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10. Annexes

10.1. Annex: General operating diagram

The following diagram sums up the main steps of the altimeter/tide gauges comparison procedure:

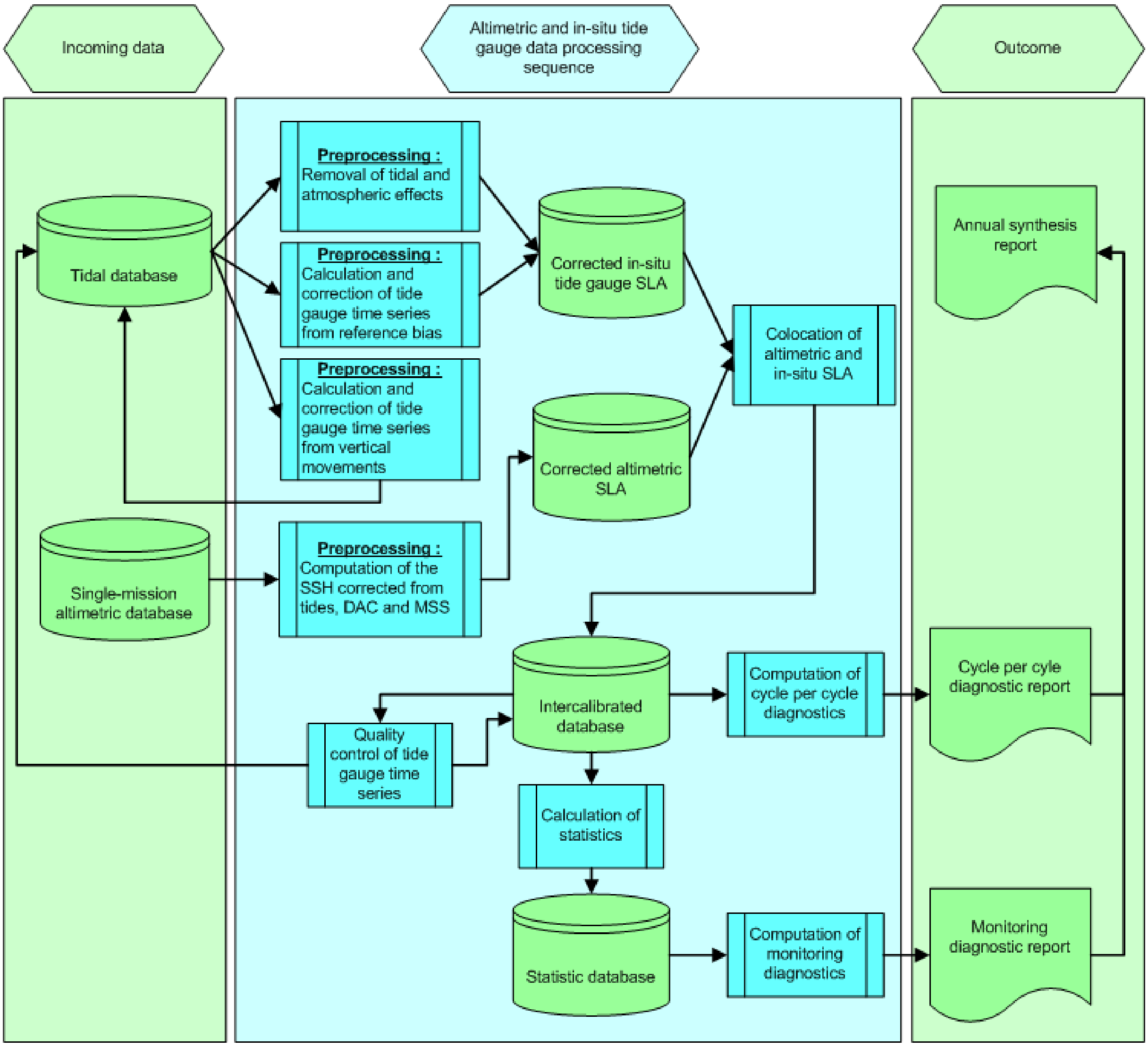


Figure 23: *General operating diagram of the tide gauge data processing sequence*

The main point is to underline the matter of the whole components of the Calval activity and their flexibility in performing this data processing sequence. In addition, the method presented here is scalable and thus reliable, which makes the altimeter/tide gauges comparison procedure a perennial validation activity for space missions in the Space Oceanography Division at CLS.

10.2. Annex: Corrections applied for altimetric SSH calculation

All the corrections applied on SSH for TOPEX/Poseidon, Jason-1, Jason-2 and Envisat space altimetric 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-B
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 1: *Corrections applied for altimetric SSH calculation*

10.3. Annex: Cross-comparisons of Sea Surface Height derived from In-Situ and Altimeter measurements

Service Altimetrie & Localisation Precise

Cross-comparisons of Sea Surface Height derived from In-Situ and Altimeter measurements

M. Ablain, G. Valladeau, J.F. Legeais

CLS
COLLECTE LOCALISATION SATELLITES

Overview

- This study is supported by ESA for Envisat and CNES for TOPEX/Poseidon, Jason-1&2 altimeter in the frame of the SALP project.

- The objective of this study is to compare the Sea Surface Height (SSH) derived from altimetry and In-Situ measurements in order to :
  - Monitor the SSH bias between altimeter and external independent in-situ measurements in order to detect potential drift or jumps in altimeter MSL
  - Estimate improvements of new altimeter standards in the SSH calculation
  - Detect potential anomalies in in-situ datasets

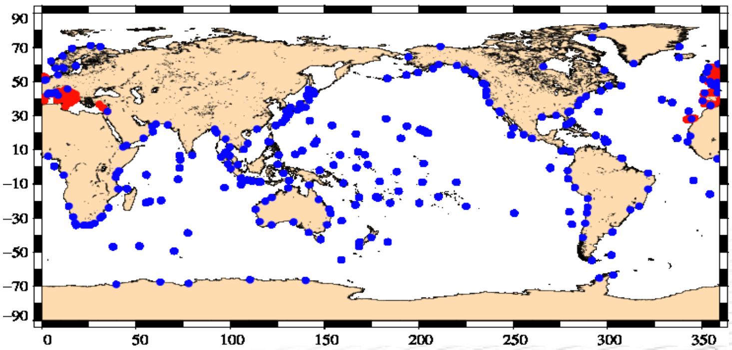
- In-situ data used are:
  - Tide gauges from global network (GLOSS/CLIVAR) and regional network (SONEL)
  - Temperature and Salinity profiles from ARGO data

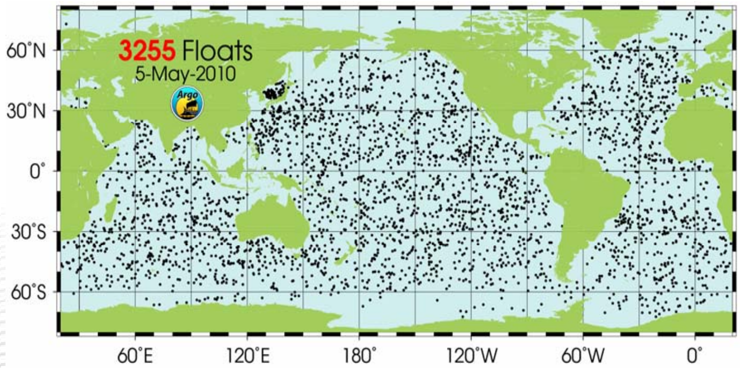
- Here, we are focusing on main results concerning the altimetric and in-situ SSH comparisons.

In-situ datasets and methodology

Description of in-situ datasets

- The main tide gauge network used is GLOSS/CLIVAR with a global coverage over all the altimeter period from 1992 onwards and with more than 300 tide-gauges. Regional networks as SONEL is also used
- Concerning T/S profiles, ARGO data are available from 2002 onwards with more than 3000 profiles available since November 2007.
- Both data are complementary since tide gauges provide a very good temporal sampling (hourly) but a poor spatial sampling with data only close to the coasts, whereas ARGO data are very well spread out over the open ocean but with only a 10-day sampling.





- GLOSS/CLIVAR (blue dots) and SONEL networks (red dots): about 400 tide gauges
- Global comparison from mid 2004 with more than 3000 profiles and 80% of ocean surface covered

Methodology to compare tide gauge and altimetry SSH

- The comparison method is composed of the following steps :

⇒ Calculation of the altimeter and tide gauge SSH applying DAC and tidal corrections, MSS

⇒ Colocation of altimeter and in-situ data selecting the altimeter the best correlated time data series with tide gauge one (within a maximal distance)

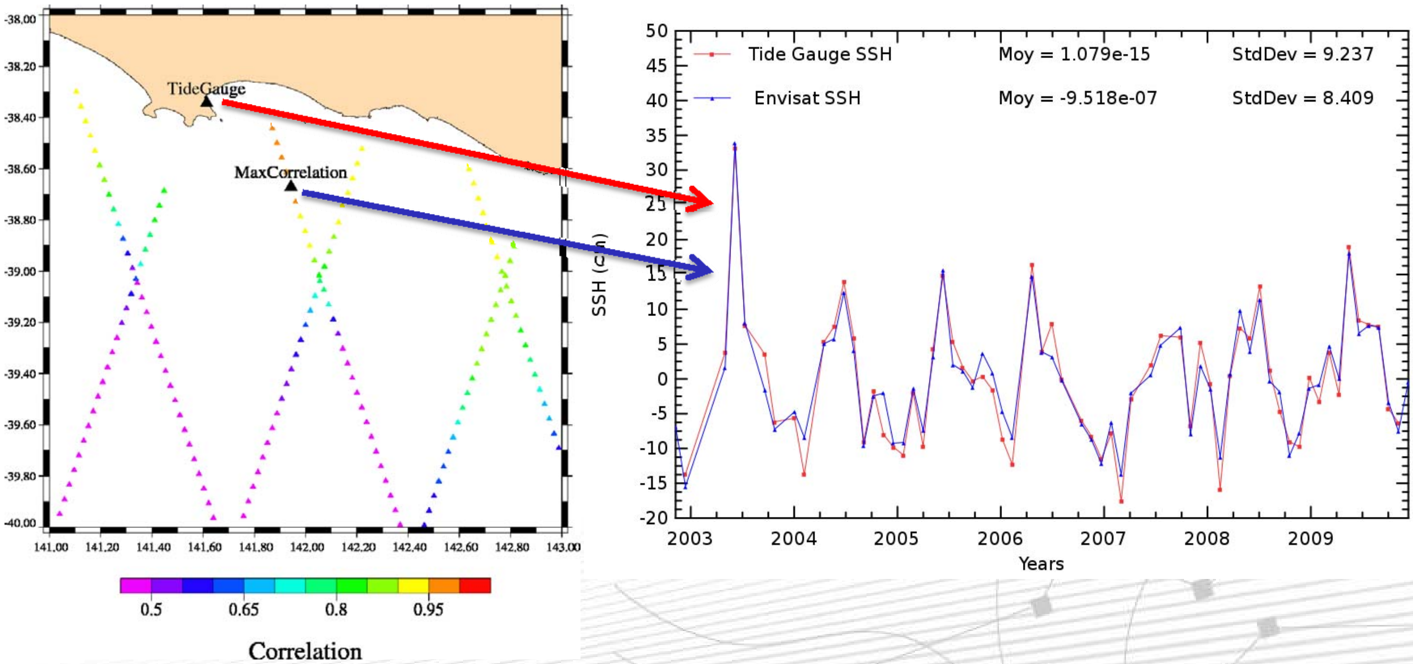
⇒ Calculation of SSH differences at each tide gauges after removing colocated time data series which are not well correlated enough (due geophysical processes, jump in tide gauges) and too short tide gauge time data series

⇒ Computation of the altimeter SSH drift from all the remaining time data series (after editing)

- More information are available on AVISO website :

http://www.aviso.oceanobs.com/fileadmin/documents/calval/validation_report/insitu/annual_report_insitu_2009.pdf

Methodology to compare tide gauge and altimetry SSH



CLS

Methodology to compare T/S profiles and altimetry SSH

- Altimeters measure the total height of the water column (mass and steric parts) whereas T/S in-situ profiles only measure the steric part

  ⇒ need to use of regression coefficients to extrapolate the steric content of T/S profiles to the total water column

  ⇒ Spatial / temporal interpolation between in-situ profiles and 10-days mean gridded altimeter data (to provide sufficient spatial density of data)

  ⇒ Global statistics and coherence analyses between two types of data

- More information are available on AVISO website :

http://www.aviso.oceanobs.com/fileadmin/documents/calval/validation_report/insitu/annual_report_insitu_TS_2009.pdf

Estimation of the global MSL drift

Jason-1 SSH calculation : altimetry standards applied

- Jason-1 GDR products have been used and last and homogenous altimetry standards have been applied in order to improve the Jason-1 SSH calculation.

SSH Field Name	Altimetry Standards
Orbit	CNES POE (GDR-C standards)
Mean Sea Surface (MSS)	MSS CLS01 (v1)
Dry troposphere	ECMWF model computed
Wet troposphere	Jason-1 radiometer (JMR)
Ionosphere	Filtered dual-frequency altimeter range measurements
Sea State Bias	Non parametric SSB (GDR product)
Ocean tide and loading tide	GOT4.7 (S1 parameter is included)
Solid Earth tide	Elastic response to tidal potential [Cartwright and Tayler, 1971], [Cartwright and Edden, 1973]
Pole tide	[Wahr, 1985]
Combined atmospheric correction	High Resolution Mog2D Model [Carrère and Lyard, 2003] + inverse barometer computed from ECMWF model (rectangular grids)
Specific corrections	Jason-1 / T/P global MSL bias

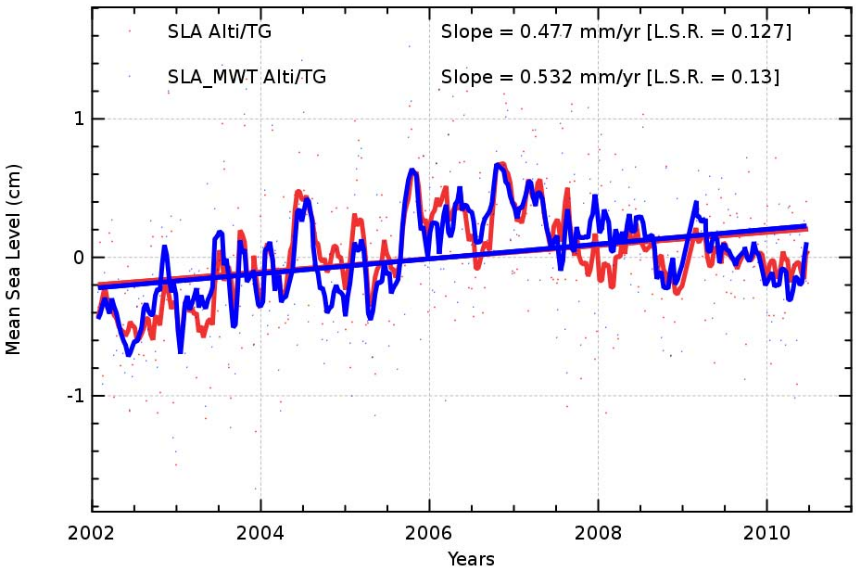
Global SSH drift between Jason-1 and tide gauges

- The global SSH drift between Jason-1 and tide gauges is 0.48 mm/yr from 2002 using the JMR wet tropospheric correction, with a formal adjustment error of 0.13 mm
- Using the ECMWF model wet tropospheric correction the global SSH drift is similar: 0.53 mm/year

- Although this method is reliable to estimate the SSH altimeter drift, the error of the method has to be taken into account: it is close to 0.5 mm/yr :

⇒ Crustal corrections not applied on TG

⇒ Colocation error between altimeter and TG data



Jason-2 SSH calculation : altimetry standards applied

- Jason-2 GDR products have been used and last and homogenous altimetry standards have been applied in order to improve the Jason-2 SSH calculation.

SSH Field Name	Altimetry Standards
Orbit	CNES POE (GDR-C standards)
Mean Sea Surface (MSS)	MSS CLS01 (v1)
Dry troposphere	ECMWF model computed
Wet troposphere	Jason-2 radiometer (AMR)
Ionosphere	Filtered dual-frequency altimeter range measurements
Sea State Bias	Non parametric SSB (GDR product)
Ocean tide and loading tide	GOT4.7 (S1 parameter is included)
Solid Earth tide	Elastic response to tidal potential [Cartwright and Tayler, 1971], [Cartwright and Edden, 1973]
Pole tide	[Wahr, 1985]
Combined atmospheric correction	High Resolution Mog2D Model [Carrère and Lyard, 2003] + inverse barometer computed from ECMWF model (rectangular grids)
Specific corrections	Jason-2 / T/P global MSL bias

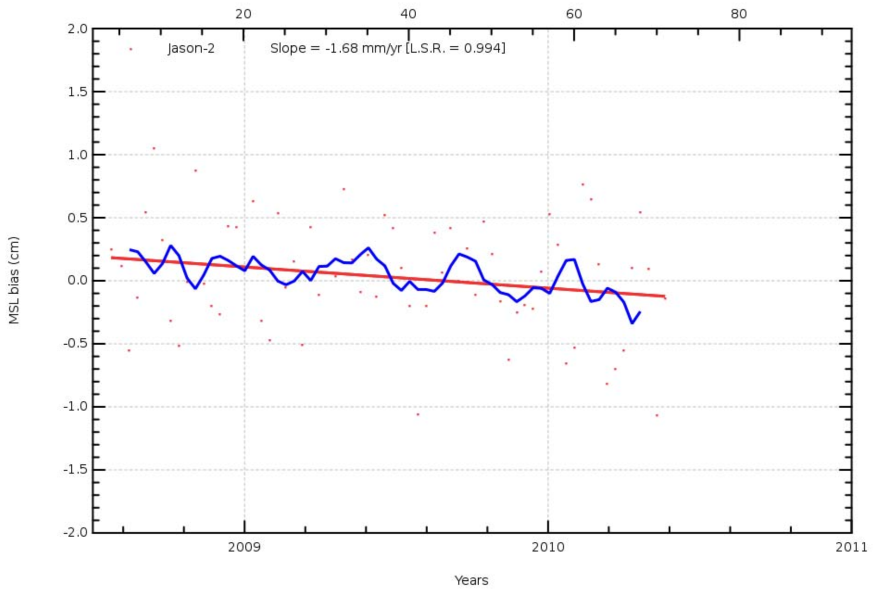
Global SSH drift between Jason-2 and tide gauges

- The global SSH drift between Jason-2 and tide gauges is -1.68 mm/yr from mid-2008, with a formal adjustment error of 1 mm
- The short time period considered implies a strong error on the global slope. However, these result has to be further studied to better understand the negative slope deduced from such analyses

- Although this method is reliable to estimate the SSH altimeter drift, the error of the method has to be taken into account: it is close to 0.5 mm/yr :

⇒ Crustal corrections not applied on TG

⇒ Colocation error between altimeter and TG data



Envisat SSH calculation : altimetry standards applied

- Envisat GDR products have been used and last and homogenous altimetry standards have been applied in order to improve the Envisat SSH calculation.

SSH Field Name	Altimetry Standards
Orbit	Cycle 15 onwards: CNES POE (GDR-C standards)
Mean Sea Surface (MSS)	MSS CLS01 (v1)
Dry troposphere	ECMWF model computed
Wet troposphere	MWR (corrected from side lobes from cycle 41)
Ionosphere	Dual-Frequency Updated with S-Band SSB (< cycle 65) GIM model + global bias of 8 mm (>= cycle 65)
Sea State Bias	Updated homogeneous to GDR-B
Ocean tide and loading tide	GOT4.7 (S1 parameter is included)
Solid Earth tide	Elastic response to tidal potential [Cartwright and Tayler, 1971], [Cartwright and Edden, 1973]
Pole tide	[Wahr, 1985]
Combined atmospheric correction	High Resolution Mog2D Model [Carrère and Lyard, 2003] + inverse barometer computed from ECMWF model (rectangular grids)
Specific corrections	USO correction from auxiliary files + bias for side-B

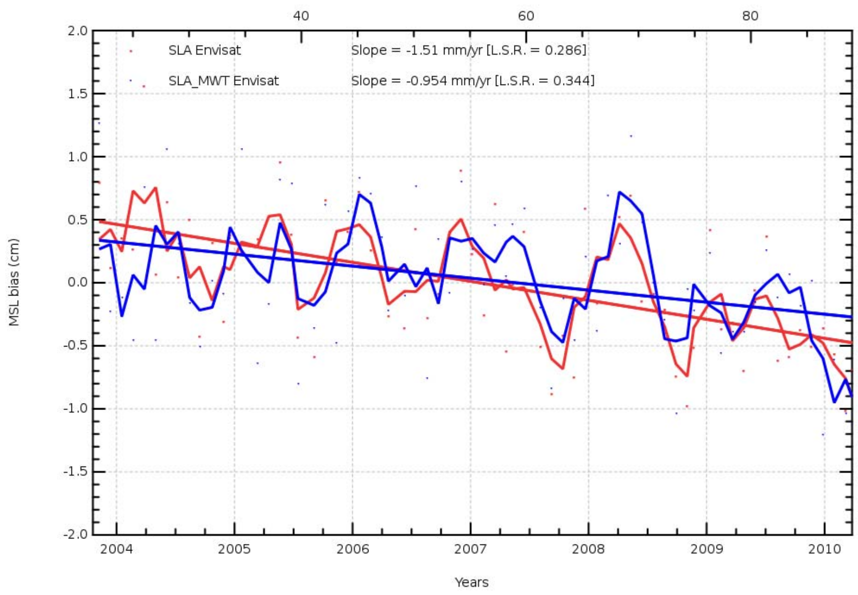
Global SSH drift between Envisat and tide gauges

- The global SSH drift between Envisat and tide gauges is -1.5 mm/yr from 2004, using the radiometer wet troposphere correction.
- Using the ECMWF one, the drift becomes -1 mm/year, with a slightly greater formal adjustment error (0.34 mm vs 0.29 previously).

- Although this method is reliable to estimate the SSH altimeter drift, the error of the method has to be taken into account: it is close to 0.5 mm/yr :

⇒ Crustal corrections not applied on TG

⇒ Colocation error between altimetry and TG data



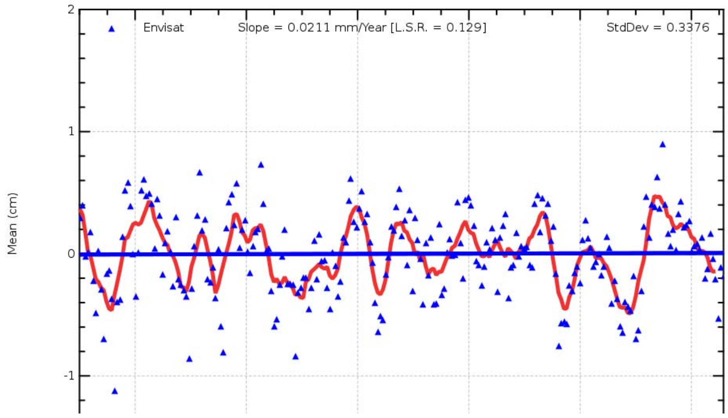
Global SSH drift between Altimetry and T/S profiles

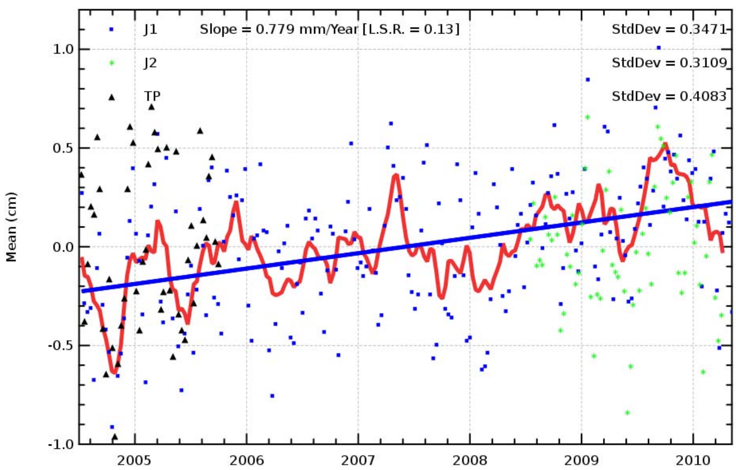
- The global SSH drift between altimeter data and T/S profiles has been estimate from mid-2004 with common temporal reference:
  - ⇒ For Envisat/TS : 0.0 mm/yr
  - ⇒ For Jason-1/TS: +0.8 mm/yr

- To date, the error of the method is likely higher than using TG: 0.7 mm/yr

⇒ Due to different physical content

- However, the drift obtained are in agreement with Altimeter/TG comparisons, with the same drift differences between Jason-1 and Envisat.





TOPEX/Poseidon SSH calculation : altimetry standards applied

- T/P homogeneous products have been used for the SSH calculation, especially with the new SSB correction from the 2-parameter Gourrion's method (SWH and Sigma-0)

SSH Field Name	Altimetry Standards
Orbit	GSFC POE (09/2008), ITRF2005+Grace
Mean Sea Surface (MSS)	MSS CLS01 (v1)
Dry troposphere	ECMWF model computed
Wet troposphere	TMR with drift correction [Scharoo et al. 2004] and empirical correction of yaw maneuvers [2005 annual validation report]
Ionosphere	Filtered dual-frequency altimeter range measurements (for TOPEX) and Doris (for Poseidon)
Sea State Bias	Non parametric SSB (for TOPEX), BM4 formula (for Poseidon)
Ocean tide and loading tide	GOT4.7 (S1 parameter is included)
Solid Earth tide	Elastic response to tidal potential [Cartwright and Tayler, 1971], [Cartwright and Edden, 1973]
Pole tide	[Wahr, 1985]
Combined atmospheric correction	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

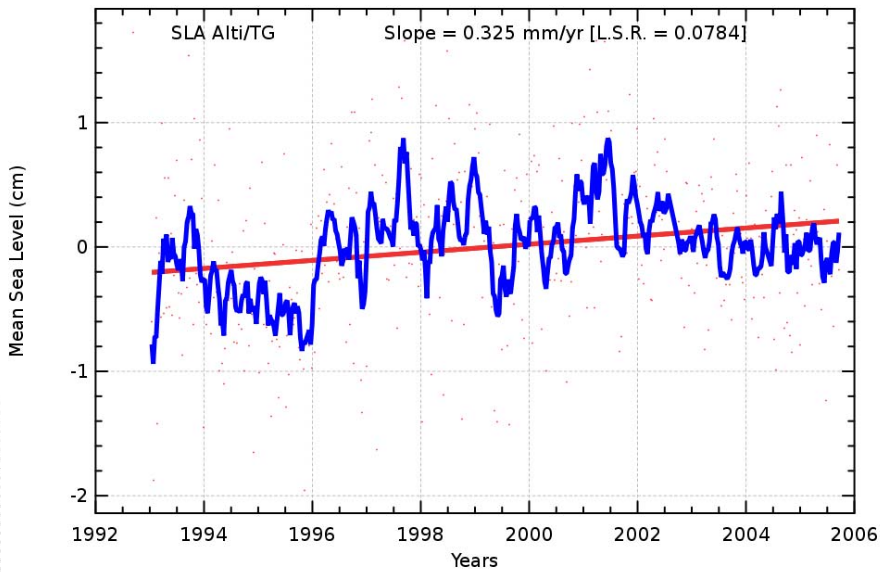
Global SSH drift between TOPEX/Poseidon and tide gauges

- The global SSH drift between T/P and tide gauges is 0.32 mm/yr with a formal adjustment error of 0.08 mm
- A strong negative drift appears on the TOPEX-A time period between 1994 and 1996 since the new SSB correction. This result will have to be investigated.

- Although this method is reliable to estimate the SSH altimeter drift, the error of the method has to be taken into account: it is close to 0.5 mm/yr :

⇒ Crustal corrections not applied on TG

⇒ Colocation error between altimeter and TG data



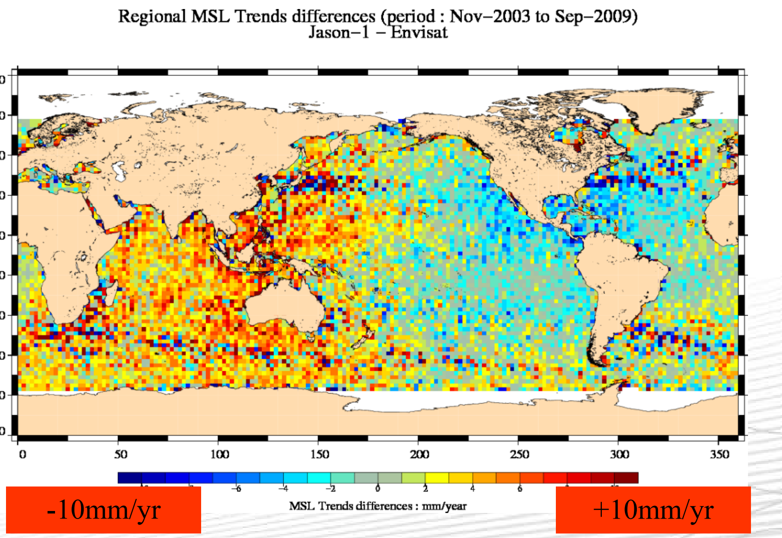
2010 investigations

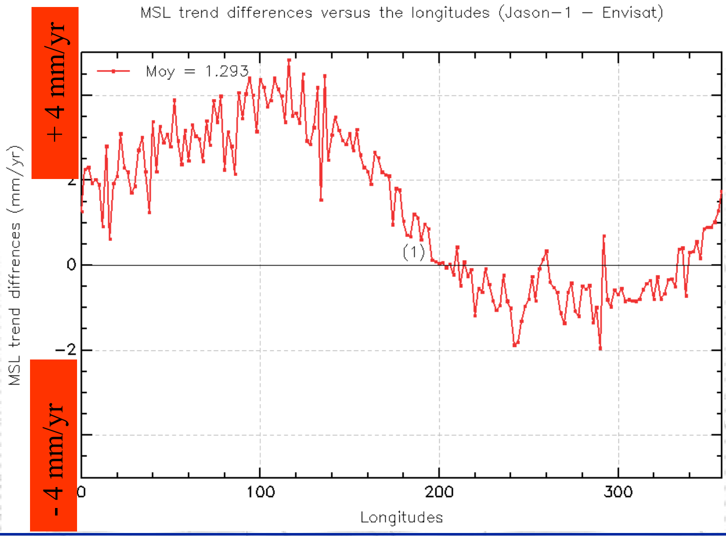
Envisat/Jason-1 regional MSL discrepancies

- Regional MSL trend differences between Jason-1 and Envisat underline East/West discrepancies :

⇒ +/- 3 mm/yr

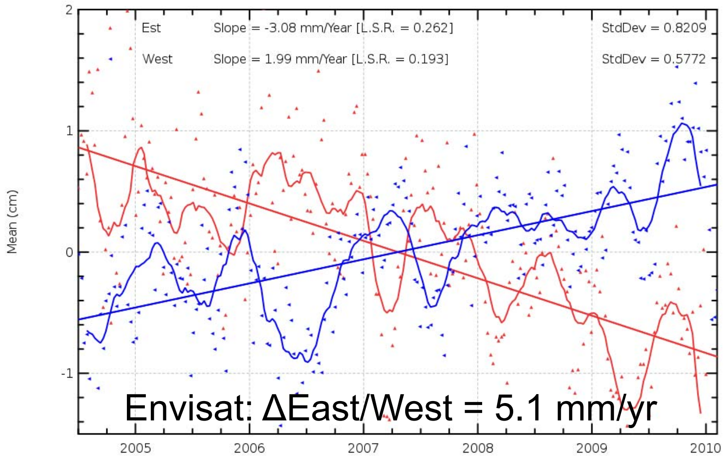
⇒ with a strong dependence versus the longitudes : sinusoidal shape

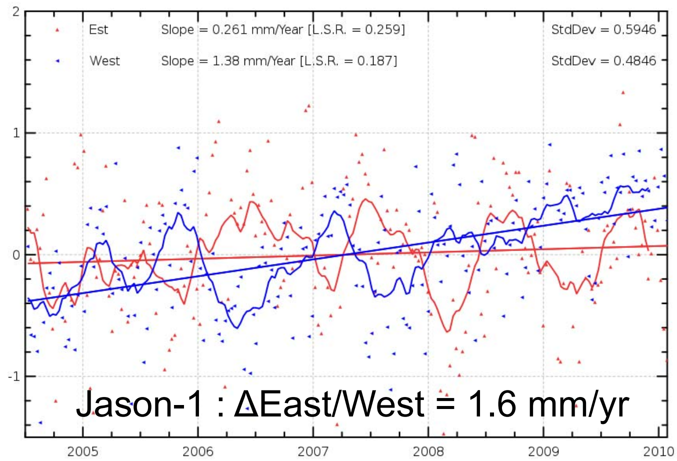




Envisat/Jason-1 regional MSL discrepancies

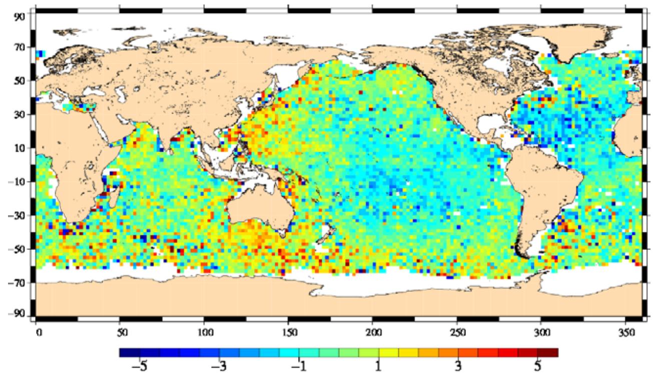
- We compute Envisat and Jason-1 SSH drift with in-situ data separating East (0°/180°) and West (180°/360°) part
- We observe that the East/West drift is more homogenous comparing Jason-1 and T/S profile than comparing Envisat and T/S profiles
- This probably demonstrates that the East/West regional differences observed between Jason-1 and Envisat is mainly due the Envisat MSL.
- It could be in relationship with the orbit calculation (under investigations).





Envisat/Jason-1 MSL discrepancies vs T/S profiles

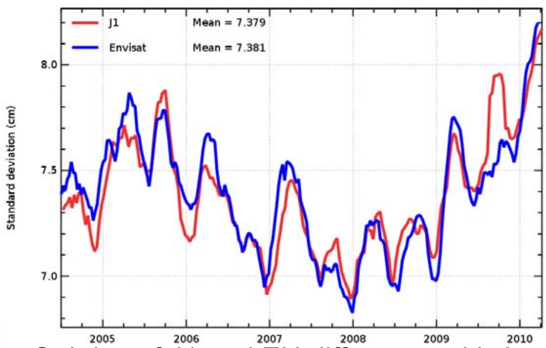
=> Which mission is more coherent with Argo data?



J1 – EN mean differences of SLA differences (cm)

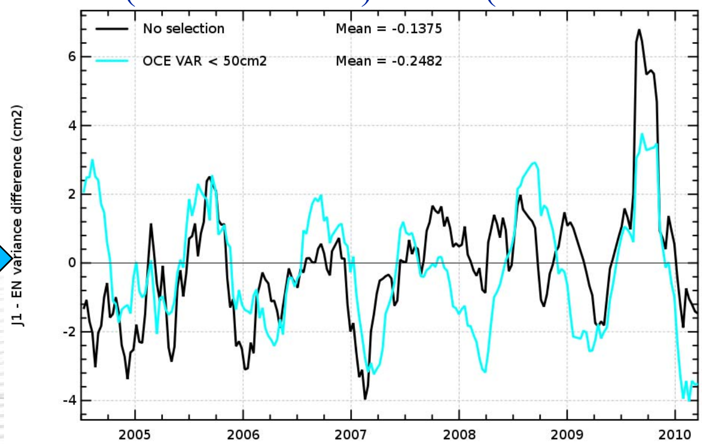
Difference J1 – EN of mean differences between altimetry and T/S profiles

=> Reduction of geographical bias due to the use of same temporal reference



Std dev of J1 and EN difference with Argo

$$VAR(SLA_{J1} - DHA_{TS}) - VAR(SLA_{EN} - DHA_{TS})$$

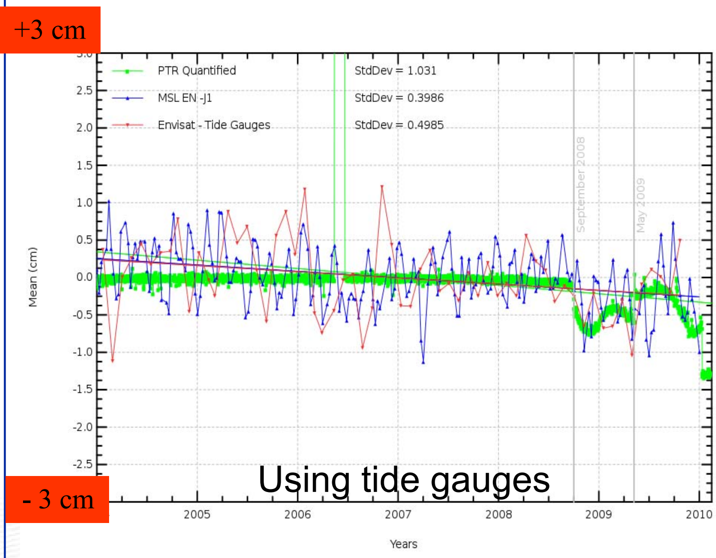


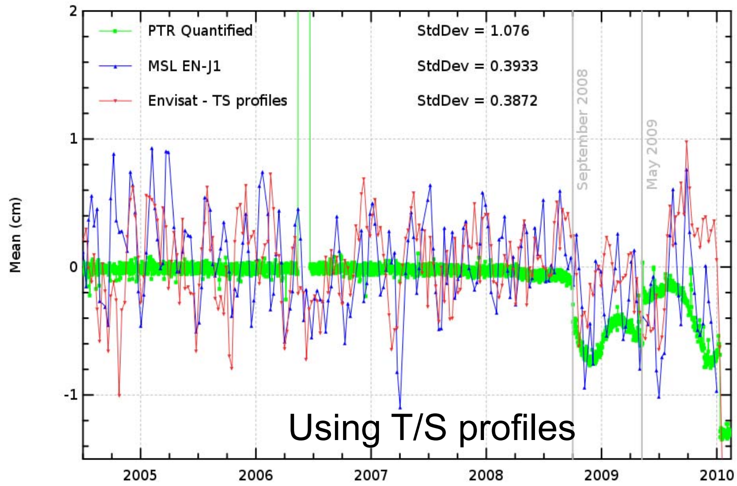
=> Why such annual signal in variance differences?

Detection of instrumental anomalies

- A PTR anomaly occurred between September 2008 and May 2009 (Faugere's talk)
- Thanks to comparisons in-situ data, we have observed and quantified the impact of this anomaly on the Envisat MSL
- This anomaly has been observed similarly using tide gauge or T/S profiles

⇒ This demonstrates the accuracy of these comparison methods to detect jumps on the altimeter MSL





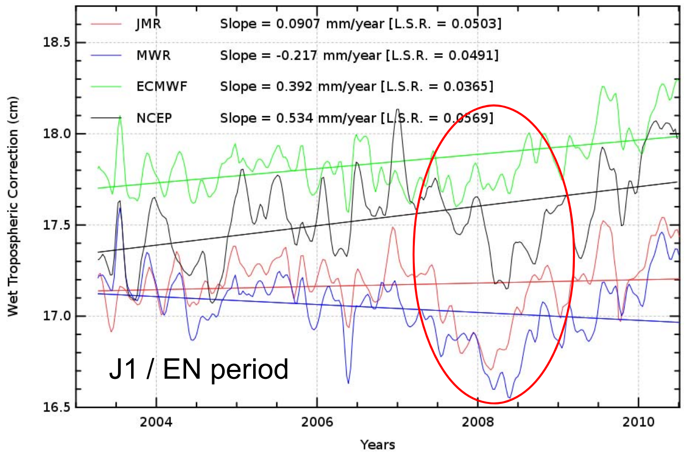
MSL computation: on the stability of the wet tropospheric correction

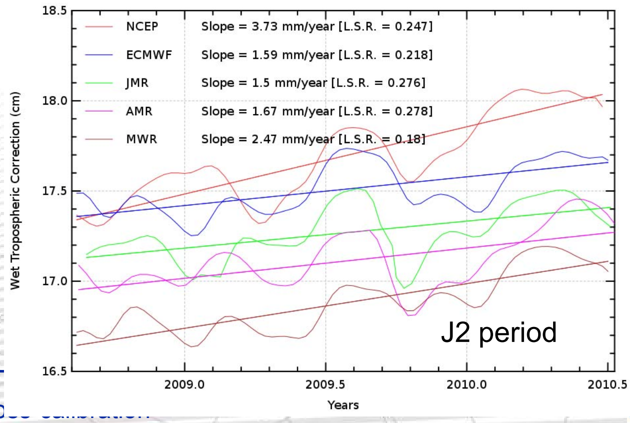
- Monitoring of radiometric and modeled wet tropospheric correction show differences of trends

⇒ +0.5 mm/yr (NCEP)

⇒ -0.2 mm/y (MWR)

- A dryness event appears in 2008: why ECMWF model wouldn't have taken it into account?





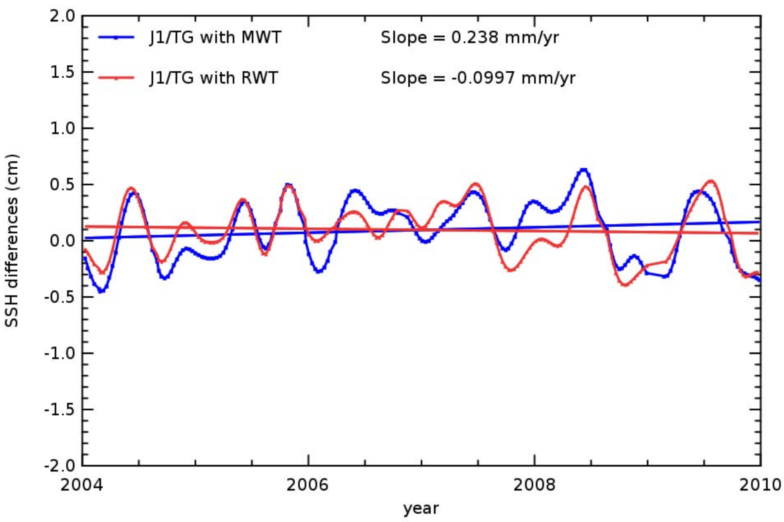
CLS

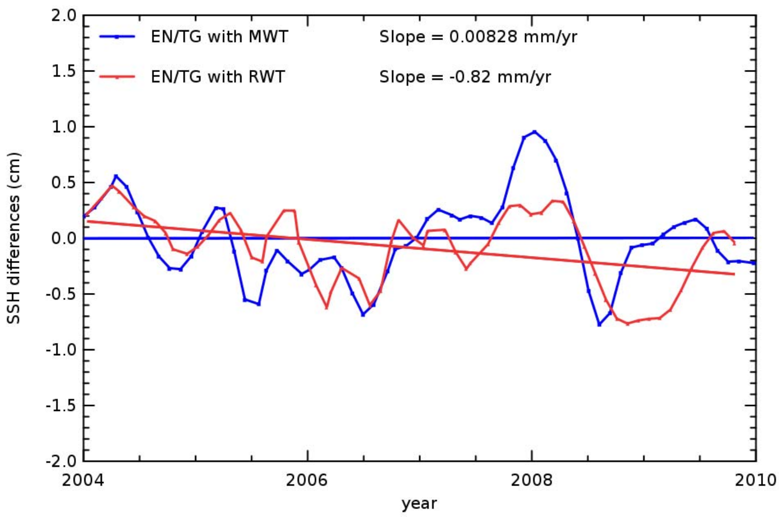
MSL computation: on the stability of the wet tropospheric correction

- Comparing altimetry with TG, with radiometric and modeled correction:
- J1 vs TG suggests good confidence with model at TG locations

⇒ Hence, EN vs TG indicates that we have less confidence in MWR measurements at TG locations

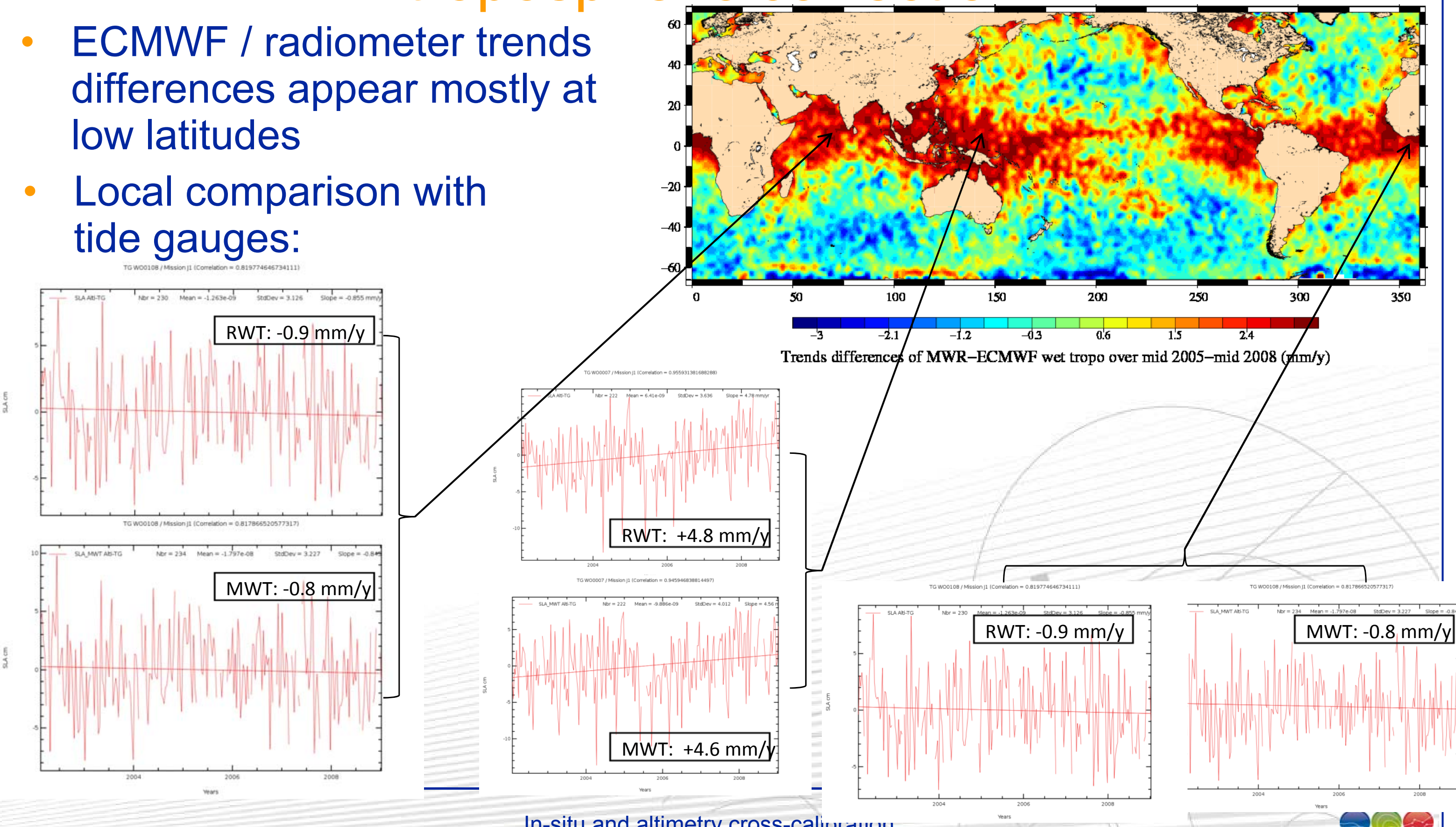
⇒ We can't say whether the radiometer or the model leads to more coherence with in-situ data





MSL computation: on the stability of the wet tropospheric correction

- ECMWF / radiometer trends differences appear mostly at low latitudes
- Local comparison with tide gauges:

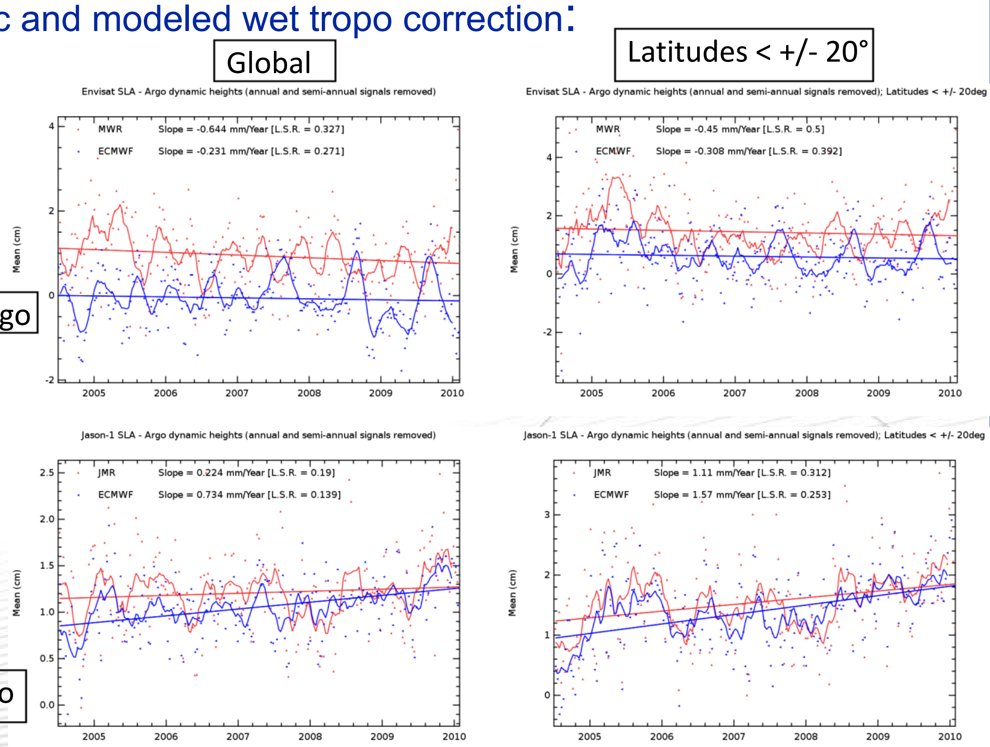


MSL computation: on the stability of the wet tropospheric correction

- Comparison with Argo T/S profiles:
- Altimetric SLA with radiometric and modeled wet tropo correction:
- Restriction at low latitudes doesn't show any signature of the dry event of 2008:

⇒ Because the amplitude of the signal we're looking for is smaller (0.4mm) than the one observed here.

⇒ We can't say whether the radiometer or the model leads to more coherence with in-situ data



Conclusions and Prospects (Tide Gauges)

- Developments and investigations performed recently allow us to refine the Envisat MSL drift estimation :
  - ⇒ The MSL drift detected on Envisat with TG is about -1 mm/yr from 2004 to 2010
  - ⇒ The accuracy of this drift estimation has been improved and is close to 0.5 mm/yr
  - ⇒ The East/West MSL trend differences observed between Jason-1 and Envisat are likely due to the Envisat SSH (same conclusion with T/S profiles => see next slides)
  - ⇒ This Envisat East/West MSL drift limits the accuracy of the global MSL drift estimate with TG due to the poor TG spatial coverage

- In the following months is planned:
  - ⇒ To extend the global tide gauge network with GLOUP (bottom pressure tide gauges)
  - ⇒ To improve the vertical movement correction thanks to new GPS-colocated beacons
  - ⇒ To go on refining the method to even better colocate TG and altimetry
  - ⇒ To try to correct the spurious TG time series when it's possible (jumps for instance)
  - ⇒ …

Conclusions and Prospects (Argo T/S profiles)

- Investigations performed recently allow us to better estimate MSL drift from altimetry:
  - ⇒ The MSL drift *vs* T/S on 2004-2010 is 0.0 mm/y with Envisat and +0.8mm/y with J1
  - ⇒ The associated uncertainty remains high due to the short period, however these results are in agreement with the MSL drift detected with TG
  - ⇒ The East/West MSL trend differences observed between Jason-1 and Envisat are likely due to the Envisat SSH (same conclusion as TG)
  - ⇒ This method is also able to detect the recent jump in the Envisat MSL due to the PTR correction

- In the future:
  - ⇒ The method will be adapted to quantify the improvement brought by reprocessed Envisat GDR published soon
  - ⇒ Extension of the in-situ time series will allow to reduce uncertainties on slopes
  - ⇒ Implementation of recent diagnostics in the automatic data processing will provide better results

Summarize on both in-situ comparison methods

- It's important to underline the synergy of these both methods to estimate the altimetry MSL drift:
  - ⇒ While tide gauge measurements provide long time series but limited spatial sampling, T/S profiles provide global coverage but are available on a shorter time period

- The East/West Envisat MSL drift and the PTR correction anomaly are detected by both methods:
  - ⇒ This homogeneous result provide a good confidence in the MSL drift estimation
  - ⇒ Both methods are necessary to compensate the not negligible uncertainty associated on each of them

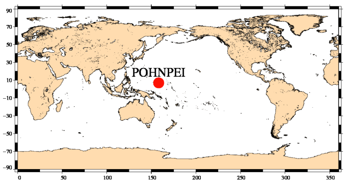
- Finally, thanks to the cross-comparisons between results provided by different approaches (global comparison between altimetry missions, Alti/TG and Alti/TS comparisons), the estimate of the MSL drift from altimetry is more and more reliable and accurate (globally and regionally)

10.4. Annex: Information cards for the Rodrigue and Cocos Island tide gauges

TIDE GAUGE : WO0001

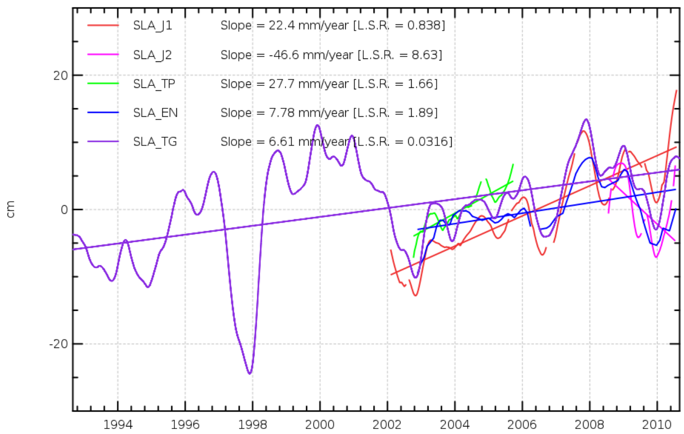
Tide Gauge identification

Tide Gauge Network	WOCE
Location (Lat/Lon)	6.99 deg / 158.24 deg
Time series coverage	From 01/01/1975 to 31/08/2010
Vertical movements drift	NO

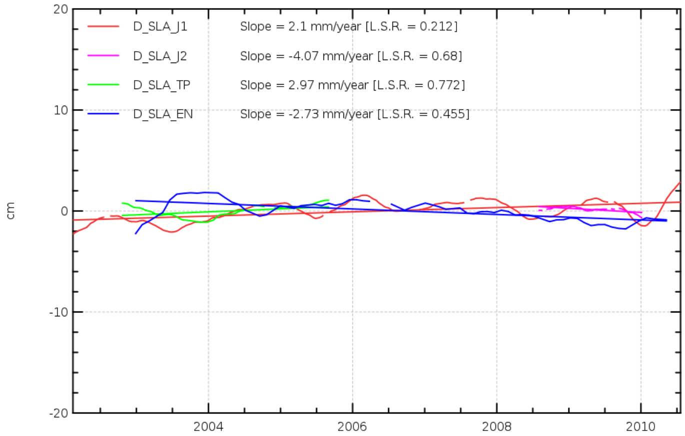


Temporal SSH comparisons with T/P, Envisat, Jason-1 and Jason-2

Monitoring of SSH

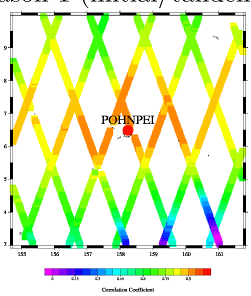


Monitoring of SSH differences

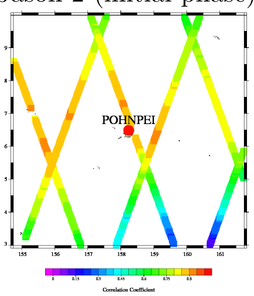


Maps of SSH correlation with Jason-1 and Jason-2, T/P and Envisat

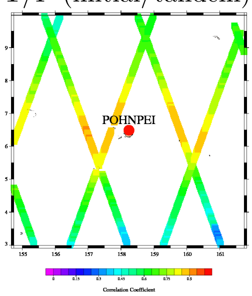
Jason-1 (initial/tandem)



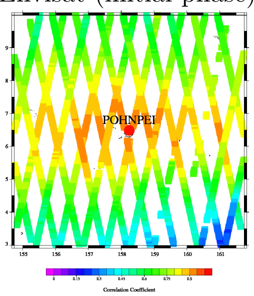
Jason-2 (initial phase)



T/P (initial/tandem)



Envisat (initial phase)



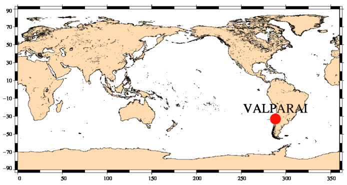
Tide Gauge reliability

	T/P	T/P (tandem)	Jason-1	Jason-1 (tandem)	Jason-2	Envisat
Minimal distance from TG	xx kms	xx kms	xx kms	xx kms	xx kms	xx kms
TG crustal drift	- mm/yr	- mm/yr	- mm/yr	- mm/yr	- mm/yr	- mm/yr
Maximal SSH correlation	-	0.90	0.93	0.94	0.91	0.93
Non-filtered SSH diff RMS	- cm	3.2 cm	3.1 cm	3.5 cm	3.2 cm	2.7 cm
Filtered SSH diff RMS	- cm	0.0066 cm	0.0096 cm	0.014 cm	0.56 cm	1 cm
SSH differences slope	- mm/yr	0.0 mm/yr	0.0 mm/yr	-0.1 mm/yr	-4.1 mm/yr	-2.7 mm/yr
Quality control	-	-	OK	OK	OK	OK

TIDE GAUGE : WO0081

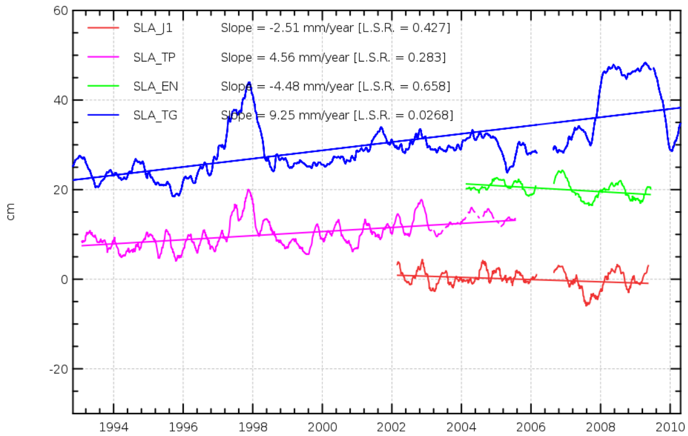
Tide Gauge identification

Tide Gauge Network	WOCE
Location (Lat/Lon)	-33.03 deg / 288.37 deg
Time series coverage	From 01/01/1950 to 19/06/2010
Vertical movements drift	NO

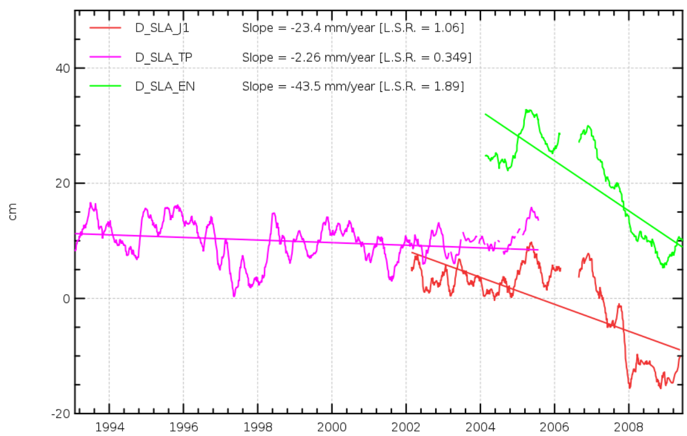


Temporal SSH comparisons with T/P, Envisat, Jason-1 and Jason-2

Monitoring of SSH



Monitoring of SSH differences



Maps of SSH correlation with Jason-1, T/P and Envisat

Jason-1 : No data over the TG period

T/P : No data over the TG period

Envisat : No data over the TG period

Tide Gauge reliability

	T/P	T/P (tandem)	Jason-1	Jason-2	Envisat
Minimal distance from TG	xx kms	xx kms	xx kms	xx kms	xx kms
TG crustal drift	- mm/yr	- mm/yr	- mm/yr	- mm/yr	- mm/yr
Maximal SSH correlation	-	-	-	-	-
Non-filtered SSH diff RMS	- cm	- cm	- cm	- cm	- cm
Filtered SSH diff RMS	- cm	- cm	- cm	- cm	- cm
SSH differences slope	- mm/yr	- mm/yr	- mm/yr	- mm/yr	- mm/yr
Quality control	-	-	-	-	-