Validation of altimeter data by comparison with tide gauge measurements

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

Contract No 104685/00 - lot1.2A

Reference : CLS.DOS/NT/12-259
Nomenclature : SALP-RP-MA-EA-22157-CLS
Issue : 1rev 1
Date : March 14, 2013

Service Altimetrie & Localisation Precise

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

List of tables and figures

List of Tables

List of Figures

List of items to be defined or to be confirmed

Applicable documents / reference documents

Contents

1. Introduction - Document overview

This document is the altimeter/tide gauges comparison activities synthesis report for 2012, performed in the frame of the 2011-2015 SALP project (CNES) and supported by ESA concerning Envisat.

Calibration and validation of altimeter data is widely processed by comparison with in-situ time series since they provide external and independent information to be used as a reference (note that a synthesis report on the cross-comparison between altimeter 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. Detect drifts and jumps in the altimeter sea level time series and give an assessment of the global and regional MSL trend

2. Estimate the potential improvement provided by new altimeter standards (orbit solution, geophysical corrections...) on the SSH consistency

3. Perform a quality control of the in-situ time series, where drifts and jumps can remain, with no physical signification (drift of sensors, anthropogenic sources ...)

This complementary approach tends to improve our knowledge of the measured physical content, where tide gauges provide high temporal resolution of SSH in coastal regions whereas T/S profiles of the Argo network provide sea level dynamic heights in the almost whole global open ocean with a 10-day sampling.

In the first place, the document describes the tide gauge 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, and new corrections used in the in-situ SSH calculation are also specified.

Concerning this activity, some major improvements were performed in 2012, about the tide gauge database but also on the accuracy of the results computed from the processing sequence. For instance, a new acquisition process of tide gauge measurements is ready to be routinely performed with new kind of tidal networks for regional studies and climate applications. Moreover, the Altimetry/Tide Gauge comparison procedure was used to assess the impact of Envisat V2.1 or

Jason-2 GDR-D reprocessings and for new scientific topics such as the improvement linked to the use of geodetic data instead of the GIA model trends at tide gauge locations.

In addition to the particular investigations performed in 2012 and partially discussed above, the document describes the main results concerning the detection of the altimeter MSL drift for TOPEX/Poseidon (T/P), Jason-1, Jason-2 and Envisat.
The comparison procedure of new altimeter standards is also presented and discussed from temporal and spatial diagnoses, especially through the variance differences of both reference and studied parameters.
Finally, the report tackles the cross-comparison indicator performed on tide gauges to highlight spurious measurements and the futures of this activity, especially on the 2013 scientific investigations to be performed.

2. Presentation of the tide gauge database

2.1. Overview

The tidal database consists in records of tide gauges 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 altimeter data. The comparison of the latter with 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.

A new way to acquire tide gauge data was developed this year and consists of two parts. The first one is the download and the storage of the raw data in CLS format. Then the latter data are subsampled and some complementary information are added. Unlike the first step which is the same for all networks, this part of the processing is specific for each one. Nevertheless the method allows to easily download data from ftp, http adresses or even process local data.

2.2. Origin

The historical tidal database consists in 5 different tide gauges networks (GLOSS/CLIVAR, REFMAR, OPPE, BODC and IMEDEA) and results from different collaborations. Data from these networks cover several time periods and can be used for many kind of scientific studies. To date and concerning these 5 tidal networks, only the GLOSS/CLIVAR (Global Sea Level Observing System/Climate Variability and Predictability) one is weekly updated for almost 300 tide gauges.

In 2012, the new database has been supplied with two other networks:

- MyOcean: tide gauges from different providers and delivered by IFREMER (Institut Français de Recherche pour l'Exploitation de la MER), with a temporal resolution varying from 1 to 60 minutes. These data are expected to be routinely acquired and to complete the CLS tide gauge database in 2013.

- PSMSL (Permanent Service for Mean Sea Level): 1253 monthly tide gauges of this network are computed in the tidal database (*www.psmsl.org/*), with a temporal resolution of 30 days. Data of these tide gauges are homogeneously computed and are relevant for climate studies.

These new data will improve the tide gauge global sampling (figure 1) and provide more reliable studies about long-term sea level variability, globally and regionally. For instance, studies performed in the Artic Sea relies upon the processing sequence developed in the frame of this activity (see part 3.3.), where a subset of monthly mean sea level data has been extracted from the PSMSL database (*www.psmsl.org*) and compared to DUACS DT multi-mission products at high latitudes. Results are discussed in part 11.6.3., showing that the method described in this document is reliable, even with low frequency tide gauge data.

Finally, concerning the Senetosa tide gauge, time series of the M3, M4, M5 and M7 sensors are available on the AVISO website (*www.aviso.oceanobs.com*), where the in-situ section is divided into 2 parts, one concerning the absolute calibration and the other dedicated to the global comparison with altimetry.

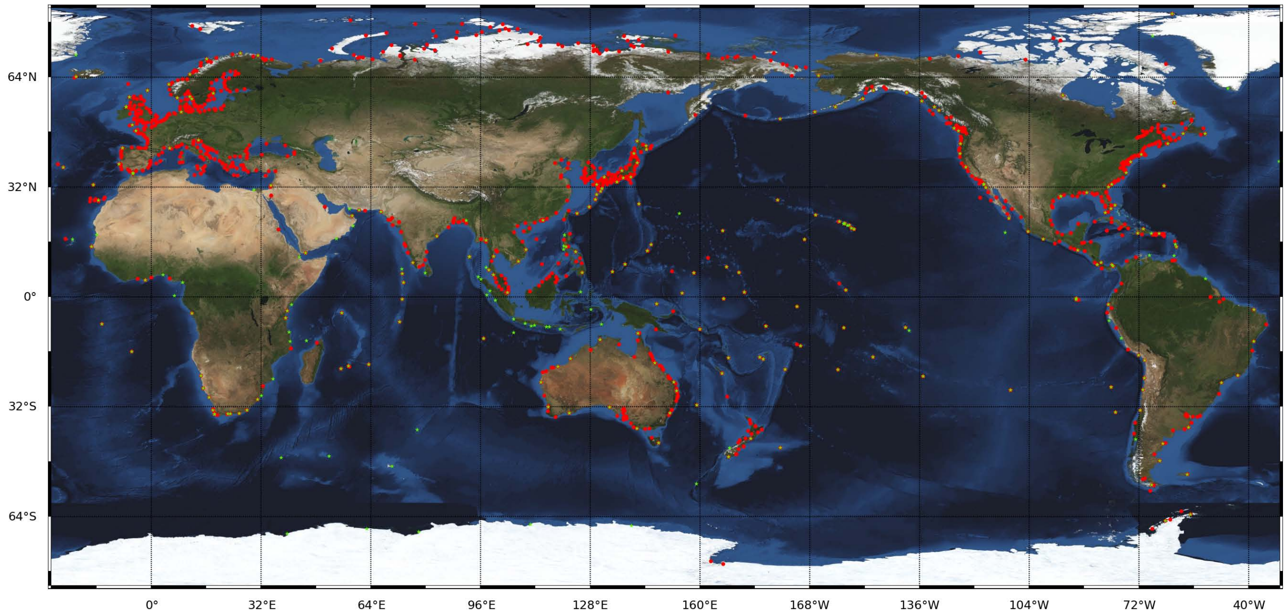


Figure 1: *Location of the GLOSS/CLIVAR (green stars) and PSMSL (red dots) tide gauges.*

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 validation
- 3. Implementation of dedicated filters for tide gauge data in order to remove the short and long tide wavelengths (diurnal, semi-diurnal and long period tides)
- 4. Record of the high resolution dynamical atmospheric correction (MOG2D model) to remove high frequency signals

By the means of "in-situ measurements tables" specific format, SSH measured by tide gauges can be filtered from high frequency phenomena quoted above.
To date, the tidal database is updated every week according to the availability of new tide gauge

measurements. To date, the acquisition processing is considered as an operational system. In 2013, with the MyOcean network, the tidal database will be updated every day, in line with the availability of the MyOcean tide gauge measurements.

3. Description of the altimeter/tide gauges comparison procedure

3.1. Overview

The main goal of this activity is to compare altimeter 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 altimeter data are not completely equivalent. Both datasets have thus to be pre-processed before comparing each other. The general operating diagram derived from the altimeter/tide gauges comparison is displayed in annex 11.1..

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

3.2.1. Calculation of the altimeter sea surface height

Radar altimeters provide Sea Surface Heights (SSH), which need to be referenced and corrected from geophysical signals to provide Sea Level Anomalies (SLA) comparable with in-situ measurements. In this study, we use along-track (level 2) SSH from several satellite altimeters, where standards are updated compared with the raw Geophysical Data Record (GDR) altimeter products. Details of the SSH computation and time period for each altimeter are presented in annex 11.2..

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

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

where the usual corrections are:

$$\begin{aligned}
\sum_{i=1}^{n} Correction_i \quad = & \quad Dry\ troposphere\ correction : S1\ and\ S2\ atmospheric\ tides\ applied \\
+ & \quad Combined\ atmospheric\ correction : high\ resolution\ MOG2D\ and\ inverse\ barometer \\
+ & \quad wet\ troposphere\ correction\ coming\ from\ ECMWF\ model \\
+ & \quad Filtered\ dual\ frequency\ ionospheric\ correction \\
+ & \quad Non\ parametric\ sea\ state\ bias\ correction \\
+ & \quad Geocentric\ ocean\ tide\ height,\ GOT\ 4.7 \\
+ & \quad Solid\ earth\ tide\ height \\
+ & \quad Geocentric\ pole\ tide\ height
\end{aligned}$$

Note that SLA for the whole altimeter missions are computed with a reference to the Mean Sea Surface (MSS) CLS2001 model (Hernandez and Schaeffer, 2001 [17]). We focus our analyses on T/P, Envisat, Jason-1 and Jason-2. The comparison with in-situ data is performed by computing

10-days global altimeter SLA grids with a spatial resolution of 1 degree latitude and 3 degrees longitude. Concerning the space resolution, the impact on altimeter SLA grids was assessed in 2012 (see part 7.2., page 31).

3.2.2. Calculation of the in-situ sea surface height

The assessment of in-situ sea surface height is comparable to the altimeter one. However, since relative bias between altimeter and in-situ data are searched out, tide gauge time series are offset on the Mean Sea Surface (MSS) used in the altimeter SSH computation, which provides a common reference to the whole tide gauge dataset considered. Oceanic tidal effects are corrected by filtering high frequency diurnal and semi-diurnal tides using the Demerliac low-pass filter (Bessero, 1985 [7]). Long-time tidal waves are also corrected using a specific algorithm based on well-balanced tide tables (Cartwright and Eden, 1973 [12]). Furthermore, atmospheric effects are corrected by withdrawing the high frequency Dynamical Atmospheric Correction (DAC) (Dorandeu and Le Traon, 1999 [14]; Carrere and Lyard, 2003 [11]).
Note that concerning PSMSL monthly data, the computation is slightly different since high frequency signals are not considered. Thus, the calculation of the SSH is performed by applying ERA-Interim inverse barometer.

Next to the 2011 improvement concerning the correction of tide gauge time series from Glacial Isostatic Adjustment (GIA) using the ICE-5G model (Peltier, 2004 [23]), a study took place in 2012 on the way to combine multiple techniques to provide reliable in-situ time series for climate applications (Valladeau et al., 2012 [15], see annex 11.4.). Since King et al. (2012, [18]) demonstrate that the relative sea level at tide gauges is underestimated with the ICE5G GIA model from ± 0.5-2 mm/year, the goal of this study is to consider DORIS and GNSS as complementary techniques to accurately determine the crustal motion at a cm level (or better) at tide gauge locations. However, even if such projects as the International Global Navigation Satellite System Service (IGS) Tide Gauge Benchmark Monitoring Pilot Project (TIGA) (Schöne et al., 2009 [25]) are willing to position GPS at each tide gauge site (Bouin et al., 2010 [10]), only a few of the latter, belonging to the GLOSS/CLIVAR database considered, can be corrected from crustal drift movements. Thus, the aim of such study is to improve the in-situ SSH by considering accurate measurements of geodetic time series.

Considering the homogeneous SSH derived from both altimeter and tide gauges, reliable long-term trend evolutions are studied. Thus, the selection of the most relevant tide gauge measurements is performed by considering time series lasting for at least 2 years. Moreover, the potential spurious values detected through the mean of SSH differences threshold (specified at 12 cm in order to get rid of strong ocean variability or potential aberrant values in the tide gauges measurements) are filtered out without impacting the whole time series so far.

3.2.2.1. Comparison of tide gauge measurements with gridded altimeter time series

In order to compare both in-situ and altimeter datasets, time series need to be first processed. This processing consists in resampling both altimeter and tide gauge time series using a bilinear interpolation. Although no filtering is applied before, this interpolation can be considered as a resampling and the interpolated values represent the tide gauge trends over the time period considered. The new dataset will therefore contain an aliasing of the frequency from an hour to twice the time period considered.

Up to now, altimeter gridded data time series were compared to in-situ discrete values on the 10 days time period, which implied potentially noise (see figure 2). In order to reduce this noise, the interpolation method was replaced during 2012 by a mean value method (see the "Tested solution" from figure 2), which is equivalent to applying a low pass filter (figure 3).

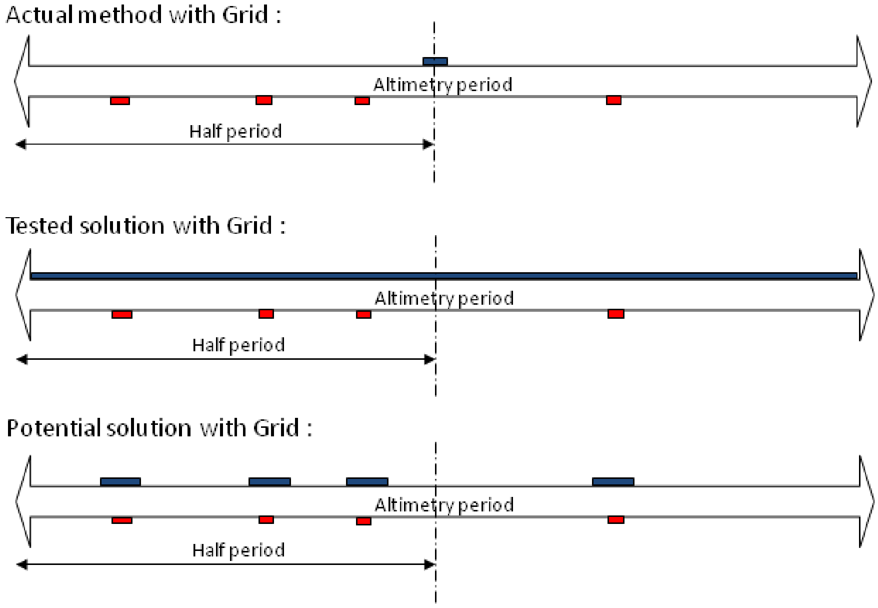


Figure 2: *Resampling computation of both altimeter(Grid, example for one box) and in-situ time series. Red rectangles: altimeter data. Blue rectangles: tide gauge measurements. Considering altimeter data, each rectangle represents a few seconds of data and each little blue rectangle represents the in-situ interpolation between two hourly data.*

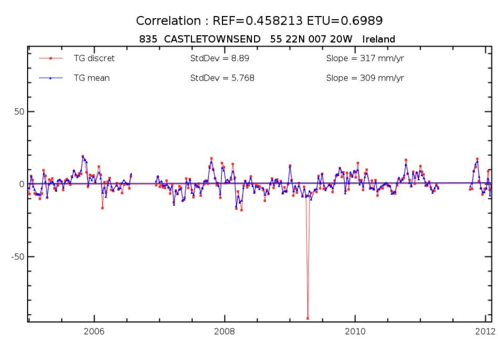


Figure 3: *Computation of the in-situ SSH with both "interpolation" (red) and "mean value" (blue) methods for the Castle Townsend tide gauge.*

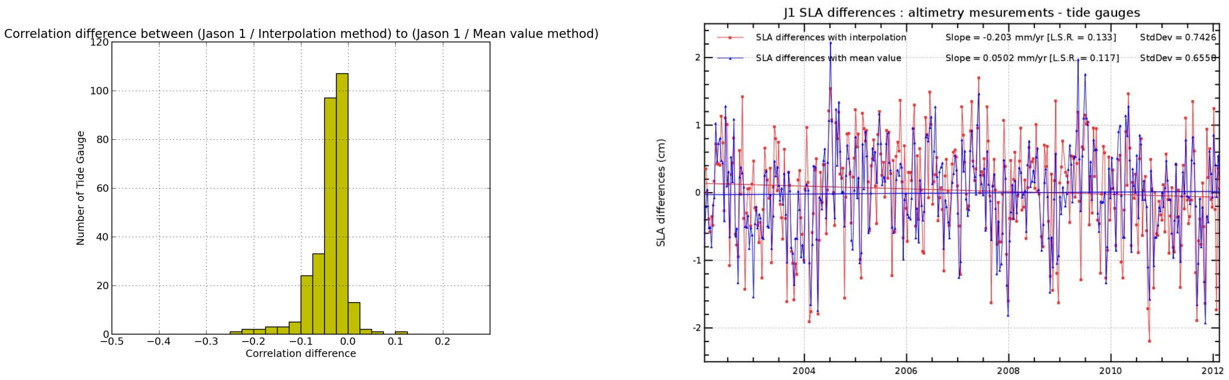


Figure 4: *Left: Correlation differences between (Jason 1 / In situ interpolation method) and (Jason 1 / In situ mean value method). Right: Computation of SLA differences with both "interpolation" (red) and "mean value" (blue) methods.*

Figure 4 left shows the evolution of the correlation between altimetry and tide gauge for both methods. For each mission, we observe a global increase of this correlation value. Moreover the largest differences of the correlation value can be explained by removing high frequency events with a mean computation(see figure 3 where the Castle Town tide gauge correlation value increases by 0.25). For all missions, there is an increase of the number of tide gauges on the correlation value is above 0.7. Every tide gauge above 0.7 is selected by the algorithm to go further (see Table 1). Increasing the number of the selected tide gauges is likely to enhance the reliability of the long-term trend differences.

Mission	J1	EN	TP
Selected TG with the "interpolation" method	148	133	114
Selected TG with the "mean value" method	170	157	132

Table 1: Number of selected tide gauges for each mission with both "interpolation" and "mean value" methods. For each mission, an increase of around 15 % is to be noticed on the selected tide gauges.

The trend of the differences (figure 4 right) shows some discrepancies between altimetry and tide gauges. Nevertheless the evaluation of the trend is not the only way to measure the performance of the new method. The trend value, which is calculated thanks to a least square root method, is sensitive to the observed period. For each altimeter mission, a decrease of the standard deviation of the differences and the LSR error is observed, which means altimeter and in-situ data are more coherent, in agreement with the increase of the correlation value.

Furthermore, local differences allow detecting in-situ data distortion. Figure 5 represents the variance of altimetry minus TG (considering the interpolation method) minus the variance of altimetry minus TG (considering the mean value method). If this value is positive, then the variance decreases with the new mean value method. For each mission, a large part of tide gauges show a decreasing variance whereas only a few tide gauges do not verify this trend. This problem can be explained considering that for some tide gauges the colocation of altimeter is modified by the selection process(correlation value between altimeter and tide gauge). Therefore, the mean value method is a way of providing more consistent in-situ measurements to be collocated to gridded altimeter data.

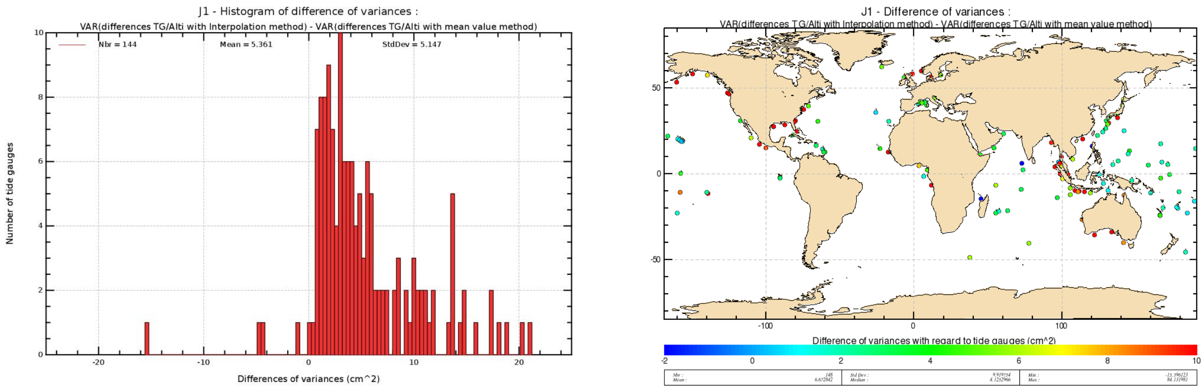


Figure 5: *Histogram (left) and Map (right) of the variance differences between both "interpolation" and "mean value" methods on Jason 1.*

3.3. Computation of the potential relative drift

After homogenizing in-situ measurements and altimeter SLA, the method of comparison consists in colocating both types of data. Thus, the method is based on a criterion of maximal correlation between tide gauges time series and altimeter gridded products, where the most consistent state of the ocean between both data time series is considered within a 100 km distance circle around the tide gauge (figure 6). 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. A spatial weighting of the in-situ network has to be performed in order to take into account the non-homogeneous sampling of tide gauges in the whole ocean.

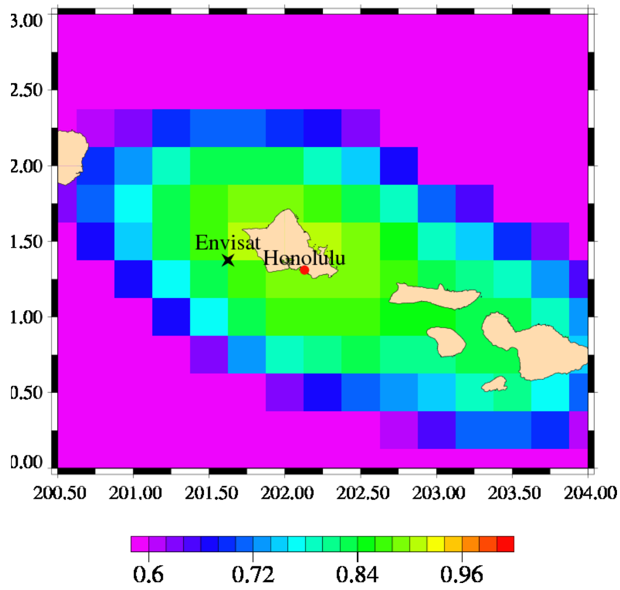


Figure 6: *Example of colocation between altimeter and tide gauge time series by computing the maximum of correlation on Envisat from gridded altimeter products*

After extracting couples of altimeter and tide gauges data, some additional quality controls are performed on each altimeter and in-situ dataset in order to perform the computation of SSH differences on the most reliable time series. Colocated altimeter and tide gauges time series are kept if their correlation is higher than 0.7. This value is high compared to other studies (0.3 in Mitchum, 1998 [20]) but allows so far keeping a large number of tide gauges. Colocated altimeter and tide gauges time series are then kept if the standard deviation of the differences is lower than 10 cm. Finally, the altimeter time series should contain at least 70% of valid points (in percentage of the number of data to be computed). Indeed, when the altimeter residual time series contains less than 70% of valid points, the time series is rejected and the process considers the next altimeter time series the most correlated to the in-situ tide gauge one.

Then, from all corrections previously detailed, the global altimeter drift can be calculated and statistics of sea level differences are computed on the whole CLS tide gauge database.

4. Analyses of potential drifts or jumps in altimeter MSL

4.1. Overview

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 are presented in this part in agreement with the MSL calculation and using an extended in-situ network, and trends for the SLA differences statistic monitoring are 60-day filtered.
Note that all results presented here are corrected from the post glacial rebound effect estimated to 0.3 mm/year over the whole ocean using the ICE5G_VM4 GIA model (Peltier et al., 2004).

4.2. Analyses on T/P, Jason-1, Jason-2 and Envisat altimeter missions

Collocated altimeter and tide gauges SLA differences are first averaged globally to assess the long term MSL drift from the different altimeter time series. The number of tide gauges considered may vary from one altimeter mission to another regarding both altitude and orbit of the satellite. While the global number of in-situ time series available in the GLOSS/CLIVAR network is to date close to 300, the mean number of selected tide gauges ranges from 80 to 170, linearly evolving with the availability of new tide gauges in the whole ocean. From this subset of tide gauges, results displayed in this study are in agreement with Nerem et al. (2010 [21]) considering T/P and Jason-1&2.

4.2.1. TOPEX/Poseidon

Since T/P space mission delivered the longest available altimeter time series, the comparison with tide gauges has become of reference regarding studies about MSL drift. Results on the differences between T/P data and tide gauge measurements (figure 7) display a global trend of about 0.9 mm/yr over the 1993-2005 time period. The low rms differences (< 3.6 cm) and the low formal adjustment error (< 0.1 mm/yr) is in favor of a reliable assessment of T/P global MSL on the whole altimeter time period. However, focusing on both TOPEX-A (cycles 11 to 236) and TOPEX-B (cycles 237 to 364) time periods, the behavior of the altimeter is quite different. Next to the improvements on the method, the trend slightly increased, allowing a better reliability on the consistency between altimeter data and tide gauge measurements. However, some remaining drifts and high amplitude residual signals are still to be understood, especially over the TOPEX-A time period where a negative slope was highlighted between 1993 and 1996 and a positive one from 1996 to 1999. Although both TOPEX-A periods are likely too short (3 years) to determine an accurate drift by comparison with tide gauges, the TOPEX-B MSL appears more stable with no drift from February 1999 onwards. The significant positive drift detected on TOPEX-A from 1996 onwards corresponds to the beginning of the TOPEX-A anomaly (cycles 130 to 236) where strong instrumental instabilities have been highlighted on significant wave height and backscatter coefficient parameters (Ablain et al., 2012 [1]). Comparisons with tide gauges tend to demonstrate that these anomalies have also an impact on the sea-level stability during this period. On the beginning of TOPEX-A from 1993 to 1996, thorough investigations have to be performed to explain the negative drift observed. Although T/P measurements provide accurate measurements for climate studies, the long-term stability of TOPEX-A data could be improved.

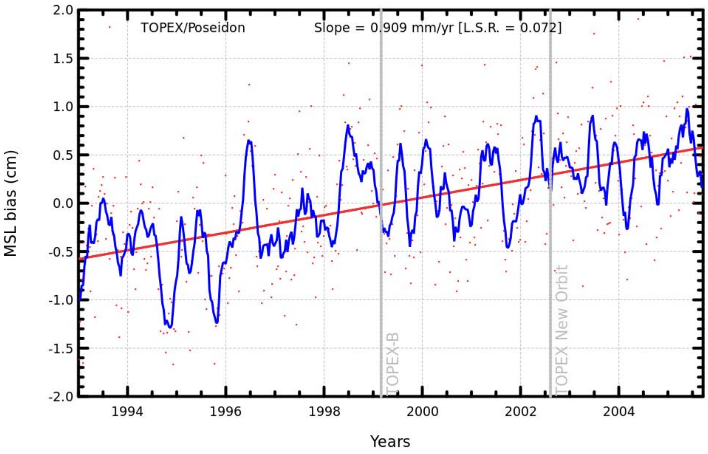


Figure 7: *Cycle by cycle monitoring of mean SLA differences between T/P and tide gauge measurements.*

4.2.2. Jason-1

Considering Jason-1, the comparison with tide gauges measurements provides consistent long-term trend differences of 0.3 mm/yr (figure 8 left), with a formal adjustment error of 0.1 mm/yr. On almost 10 years of consistent altimeter data delivery, the coherence with in-situ measurements along coastal areas is pretty good, and rms differences are lower than 3.7 cm. In addition to the long-term trend differences observed here, further investigations would provide potential explanation on the amplitude of residual signals. That be, the accuracy of the method of comparison between altimetry and tide gauge is not able to determine if these signals are due to errors on Jason-1 data or intrinsic uncertainties of the method.

4.2.3. Jason-2

Comparison with results on Jason-2 (figure 8 right) would be a way of providing relevant metrics on both error on the datsets as well as on the method. In 2012, long-term differences using tide gauges and concerning Jason-2 GDR-T products were not in agreement with those of Jason-1 (respectively -0.9 and 0.1 mm/year). The reprocessing of Jason-2 GDR-D data, which took place in 2012, significantly improved the coherence with tide gauge measurements, leading to a global drift of 0.4 mm/yr and a formal adjustment error of the same order. Although tide gauge measurements will have to wait for longer time series to be compared with the other on-flight altimeter missions like Jason-1 or Envisat for instance, results concerning Jason-2 GDR-D data are in very good agreement with the global trend differences observed using tide gauge time series.

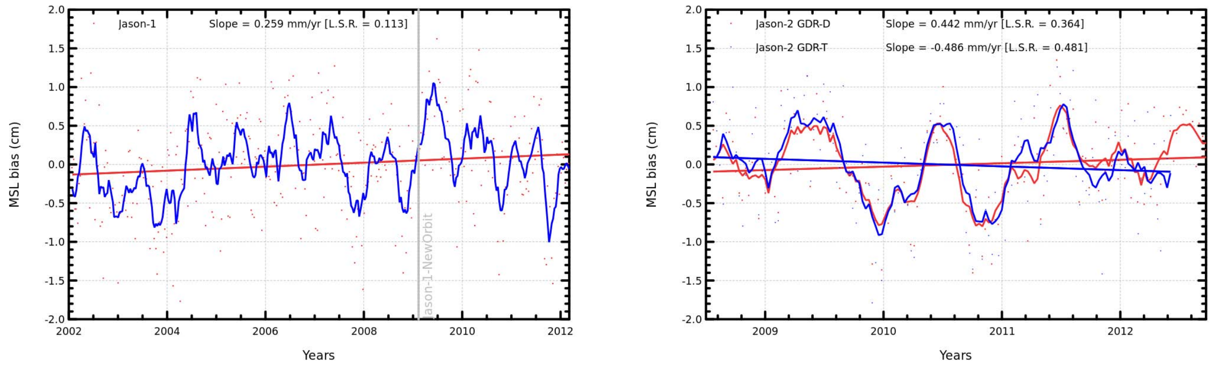


Figure 8: *Cycle by cycle monitoring of mean SLA differences between altimetry and tide gauge measurements. Left: Jason-1. Right: Jason-2.*

4.2.4. Envisat

As for Jason-1 and Jason-2, Envisat measurements are computed in order to provide an accurate assessment of the SSH. Global MSL studies showed a particular behavior of the Envisat MSL on the whole altimeter time period, especially at the beginning of the period (AVISO, 2012, Envisat annual validation report [4]). Next to the reprocessing which occured in 2011 and some additional processings like improvements of the Point Target Response (see part 11.5.2.), the comparison of V2.1+ Envisat GDR products with tide gauge measurements is routinely performed and compared with other missions. From now on, differences between Envisat data and tide gauge measurements display a drift of 0.8 mm/yr (figure 9) over the 2004-2012 time period, in agreement from results obtained on T/P, Jason-1 and Jason-2. The formal adjustment error is close to 0.1 mm/yr and amplitudes of residual signals are lower than 2 cm. Although these results are pretty encouraging concerning the ability of Envisat to assess the GMSL, some investigations were performed concerning Envisat MSL drift differences with Jason-1 and the impact of coastal selection on the altimeter dataset (see part 8.2.).

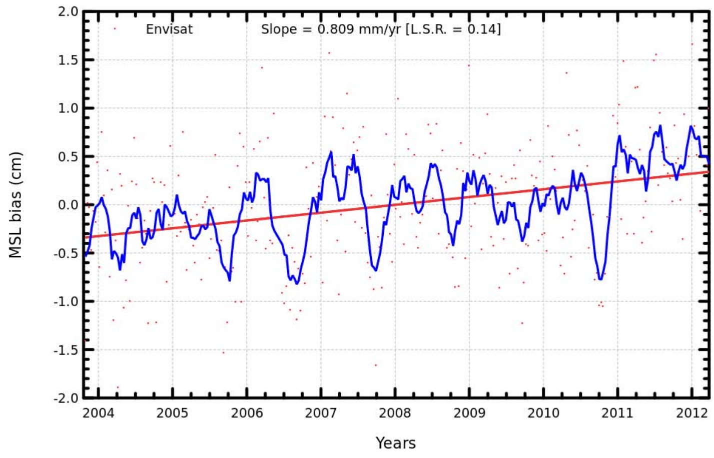


Figure 9: *Cycle by cycle monitoring of mean SLA differences between Envisat and tide gauge measurements.*

Results using tide gauge measurements for the main altimeter missions demonstrate both reliability and accuracy of the method in order to detect potential drifts over the global ocean. Moreover, multi-mission cross-calibration are useful to understand and then enhance the relevance of the altimeter GMSL.

4.3. Assessment of SSH differences on the whole altimeter time period

The DUACS Delayed Time grideed products have been compared with tide gauges on the entire altimeter time period. Both multi-mission and mono-mission products are studied in order to assess the reliability of the comparison with tide gauge measurements with or without combining the multiple altimeter data. On the 1993-2012 time period, the MSL drift is almost null whatever DUACS Delayed Time product is considered (figure 10), within the error of the method of $\pm$ 0.7 mm/yr (Ablain et al., 2009 [2]). Amplitudes of SSH differences are of the same order except between the 16 of September 2002 and the 8 of October 2005 where the amplitude seems to be reduced with the combination of the four missions T/P, Geosat Follow-On, Jason-1 and Envisat. Furthermore, the standard deviation is quite low, with a mean value close to 3 cm for both multi-mission and mono-mission products. Therefore, the use of tide gauges measurements can also be considered as a way of assessing long-term drifts considering DUACS DT gridded products.

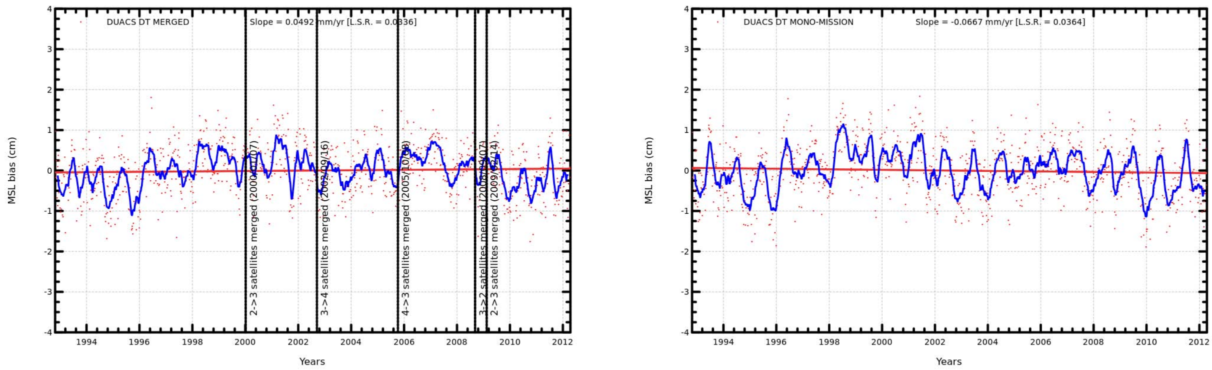


Figure 10: *Cycle by cycle monitoring of mean SLA differences between DUACS DT products and tide gauge measurements (60-day filtered). Left: multi-mission. Right: mono-mission.*

4.4. Standard deviation and number of tide gauges of the SSH differences

Concerning the standard deviation of the SSH differences computed from level-2 altimeter gridded products (figure 11 left), results obtained are in agreement between the whole missions, with a mean value between 3 and 3.5 cm. Whatever mission and time period considered, the standard deviation of SSH differences is stable and in agreement with DUACS Delayed Time multi-mission products, which reinforces the reliability of the comparison method between altimetry and tide gauges. However, the use of level-2 gridded products provides some interesting information in SSH differences. For instance, the jump in 2002 when T/P moved on its new ground track (corresponding to the TOPEX new orbit phase) may be related to the higher SLA variability explained by the less precise MSS outside T/P's nominal track (AVISO, 2006, TOPEX/Poseidon annual validation report [5]).
The number of tide gauges considered in the processing sequence is varying between 100 and 150 and is the highest for Jason-2 and DUACS DT products with more than 150 tide gauges considered. Concerning level 2 mono-mission data, improvements in the collocation process are part of the sources of this increase of the mean value of tide gauges taken into account (with regard to 2011 results). Regarding Jason-2 results especially, this is a pretty good result since altimeter data are physically consistent with tide gauge measurements along coastal areas, especially thanks to the use of the median tracker on Jason-2 (AVISO, 2012, Jason-2 annual validation report). Moreover, the high rate of tide gauges accounting to assess the global MSL drift using DUACS DT multi-mission products can be explained as the smoothing enables more tide gauges to be correlated to altimeter time series within a 500 km distance circle.

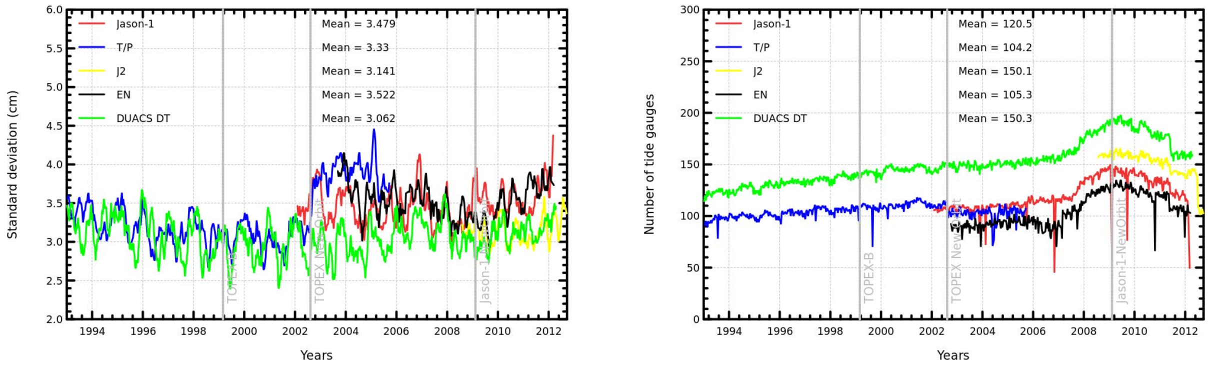


Figure 11: *Left: Cycle by cycle monitoring of the standard deviation of SLA differences between altimeter data and tide gauge measurements. Right: Cycle by cycle monitoring of the number of tide gauges considered in the processing sequence.*

5. Estimation of altimeter SSH improvements

5.1. Overview

As already mentioned, the second main goal of the Altimetry/Tide Gauge comparison activity is to evaluate improvements of altimetric data by analyzing the SSH consistency with in-situ measurements. This part aims at presenting the capability of the comparison procedure performed in the frame of this activity to measure such impact of new altimeter standards. Thus, new geophysical corrections (tide model correction, dynamical atmospheric correction,...), new orbits or new algorithms in ground processing are estimated by comparison with tide gauge measurements using successively the old and new version of the altimeter standard in the SSH calculation. The potential improvement is assessed through the trend and correlation values of the sea level differences, with the aim of computing a new release of altimeter products.

The following analyses presented in this part of the document are not exhaustive. Their main objective is to illustrate and demonstrate the interest of the method. Note that this part will present the evaluation of new standards performed in 2012. Previous studies on other altimeter standards are presented in annex 11.5..

5.2. Impact of Jason-2 GDR-D reprocessing with regard to tide gauges

The first study concerns the impact of the new GDR-D reprocessing on Jason-2, which can be estimated at tide gauge locations by comparison with GDR-C products. Here are the main improvements implemented in this reprocessing (AVISO, 2012, Jason-2 reprocessing report [6]):

- EIGEN-GRGS_RL02bis_MEAN_FIELD with time-varying gravity (annual, semi-annual, and drifts up to deg/ord 50) + ITRF 2008 & DORIS+SLR+GPS & DORIS+SLR+GPS (increased weight for GPS).
- Altimeter Retracking: close to GDR-T, in addition altimeter parameters are also available using MLE3 retracking.
- Altimeter Instrument Corrections: one consistent with MLE4 retracking + one consistent with MLE3 retracking.
- Jason-2 Microwave Radiometer Parameters: enhancement in coastal regions + correction of anomaly in 34 GHz channel + addition of radiometer rain and ice flag + addition of radiometer 18.7 GHz/23.8 GHz/ 34 GHz antenna gain weighted land fraction in main beam.
- SSB: empirical models derived from Jason-2 data (one consistent with MLE4 retracking + one consistent with MLE3 retracking).
- Mean Sea Surface Model: CNES CLS 2011.
- Mean Dynamic Topography: CNES CLS2009 solution.
- Tide Solution 1: GOT4.8 (S1 ocean tide and S1 load tide are included).

- Non-equilibrium long period ocean tide model: Mm, Mf, Mtm, and Msqm from FES2004 + correction for a bug.
- Pole Tide Model: equilibrium model + correction of error which was present over lakes and enclosed seas.
- Altimeter Wind Speed: table is identical to GDR-T, but the inputs differ.
- Altimeter Rain Flag: derived from Jason-2 sigma naught MLE3 values.
- Update of the altimeter characterization file
- Other: LTM calculated over 7 days (sliding window) and applied for one day. The origin of the constant part of the time tag bias was found and is directly corrected in the GDR-D datation.

While the main benefit is to estimate the performance of the GDR-D 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. Concerning the long-term trend differences (figure 12 left), results displayed show a change in the behavior of the drift observed on Jason-2 time series, with a mean value of 0.1 mm/yr using GDR-D while it is -0.3 mm/yr considering GDR-T products. Although this result seems to be in better agreement with the trend observed on the other on-flight missions, the formal adjustment error is still very high (close to 0.5 mm/yr) due to the short period considered. This result would have to be confirmed with the computation of the 2013 Jason-2 data.
Concerning the histogram of the difference of variances (figure 12 right), the mean value is close to zero, which demonstrates that the improvement of the reprocessing concerning Jason-2 data don't affect the behavior of the temporal variability of the signal. Therefore, residual signal of the difference between altimetry and tide gauges are neither increased nor reduced, which means that the temporal consistency between both datasets is the same when comparing to tide gauge measurements.

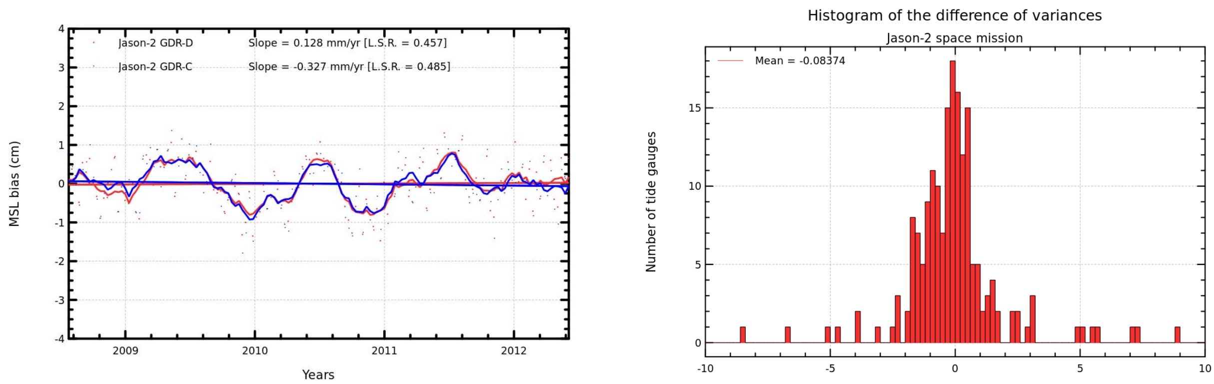


Figure 12: *Left: Monitoring of SSH trend differences computed with GDR-D and GDR-C for Jason-2 and using tide gauge measurements. Histogram of the variance differences between altimetry and tide gauges considering both GDR-D and GDR-C Jason-2 altimeter products.*

5.3. Impact of the new GDR-D orbit on Jason-1 altimeter data

In addition to the study on Jason-2 reprocessing in comparison with tide gauge measurements and in order to test the impact of the new CNES preliminary GDR-D POE orbit (see [13]) using Doris, GPS and laser released on the whole Jason-1 time series, the comparison with tide gauge measurements was perfomed and the impact on long-term trends differences was assessed (figure 13). Regarding the trend differences, results are coherent between both standards, within the error of the method of ± 0.7 mm/yr. The consistency of Jason-1 GDR-D orbit is thus slightly improved with regard to the previous GDR-C one (0.26 mm/yr versus 0.3 mm/yr, with the same formal adjustment error close to 0.1 mm/yr).

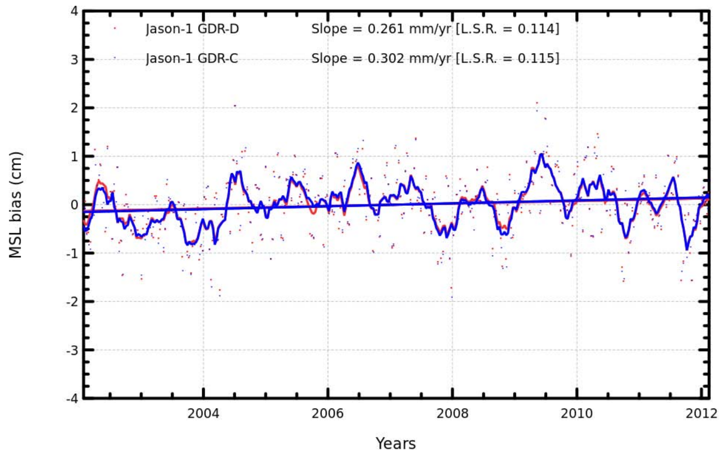


Figure 13: *Monitoring of SSH trend differences computed with CNES-POE GDR-C and GDR-D orbits for Jason-1.*

5.4. Impact of the Envisat V2.1+ GDR products using tide gauge data

Envisat altimeter data have been recently reprocessed to produce the V2.1 products which are now more consistent with Jason's missions (Ollivier et al., 2012, [22]). This study aims at evaluating the impact of the new GDR-D orbit solution and the corrected radiometer wet troposphere correction applied on Envisat V2.1+ GDR products from the comparison with tide gauge measurements. Note that this investigation was also performed in 2012 considering the external Argo+GRACE data (AVISO, 2012, Validation of altimetric data by comparison with in-situ T/S Argo profiles [8]). This comparison is performed with regard to the former Envisat V2.1 GDR products (reprocessed data with GDR-C orbit and reference MWR correction) and the use of the PTR correction is coherent between both altimeter datasets.

Concerning the monitoring of the differences between Envisat and tide gauge time series (figure 14 left), the trend is lower from 0.1 mm/year with a slightly reduced formal adjustment error. This result is in agreement with Argo+GRACE results where a reduction by 0.3 mm/yr is observed with the use of the updated standards.
Moreover, the histogram of the variance differences between both V2.1 and V2.1+ products using

tide gauge measurements (figure 14 right) displays an improvement of -0.7 cm^2 with the new standards, in line with the improvement of the updated GDR-D orbit solution compared with the GDR-C standard (Ollivier et al., 2012, [22]).

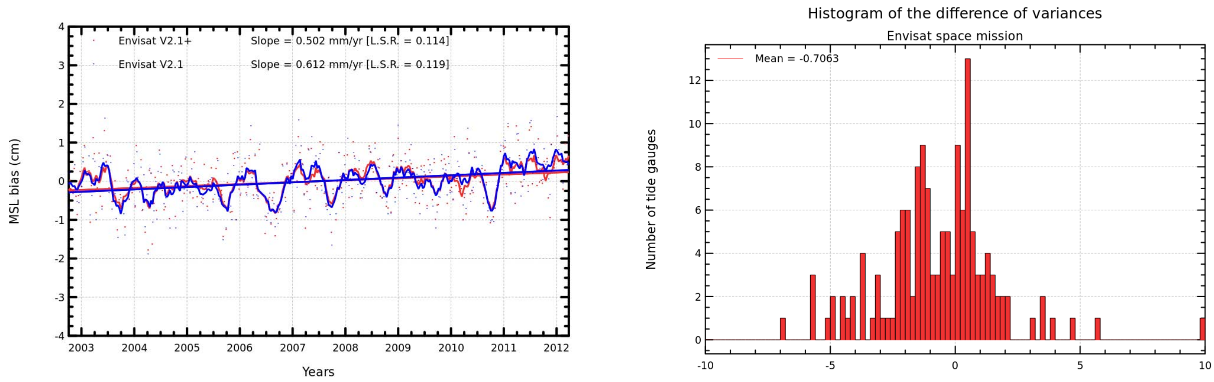


Figure 14: *Left: Monitoring of SSH trend differences computed with V2.1+ and V2.1 for Envisat and using tide gauge measurements. Right: Histogram of the variance differences between altimetry and tide gauges considering both V2.1+ and V2.1 Envisat altimeter products.*

In order to complete the histogram of the difference of variances and visualize improvements of the new release, figure 15 displays the map of the difference of variances between altimeter and in-situ data at tide gauge locations. Looking at their location, improvements seem to be homogeneously widespread, depending not only on the quality of altimeter standards but also on the in-situ time series.
Therefore, the comparison of the new release of Envisat V2.1+ with tide gauge measurements displays a slight improvement in terms of consistency between both datasets regarding the previous V2.1 release, and this enhancement goes with a global decrease of the difference of variances considering these new altimeter data.

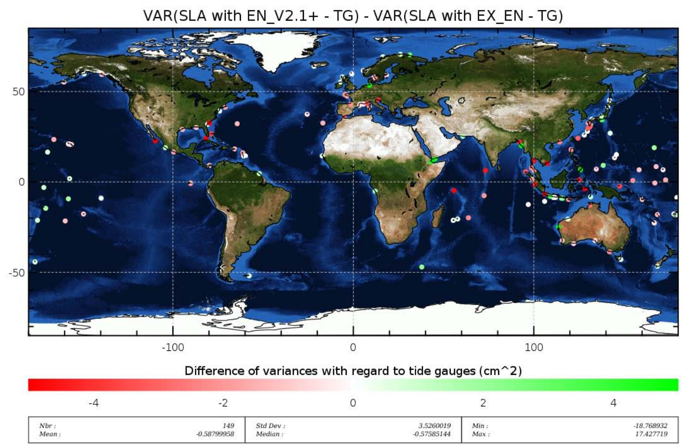


Figure 15: *Map of the difference of variances between both releases of Envisat reprocessed data with regard to tide gauge measurements*

6. Quality assessment of tide gauges 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 quality control performed on tide gauges measurements

The basic principle of the information cards is based on a summary of in-situ information 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 16):

- Tide Gauge identification: this part contains general information about the tide gauge such as 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 -0.3 mm/year (Peltier, 2004 [23]). A study has began in 2012 on the use of geodetic time series to correct tide gauges from vertical movements (see part 6.3.).

- Temporal SLA comparisons with TOPEX/Poseidon, Envisat, Jason-1 and Jason-2: 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 in-situ 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.

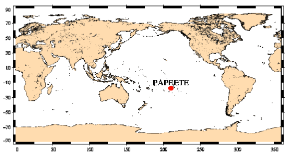
- Maps of SLA correlation with Jason-1, Jason-2, TOPEX/Poseidon and Envisat: to make the multi-cross-calibration reliable, another useful diagnostic concerns the correlation between altimeter and in-situ SLAs. Such maps have a double interest, first to estimate the distance between altimeter tracks and the tide gauge and second to see if both SLA are well correlated. Generally the correlation is good, up to 0.9 close to the coasts. But for some tide gauges, the value is low, maybe due to geophysical processes but also to jump or drift in in-situ data. Therefore, 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.

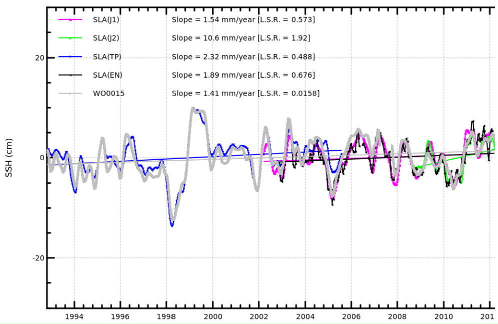
PAPEETE(WO0015)

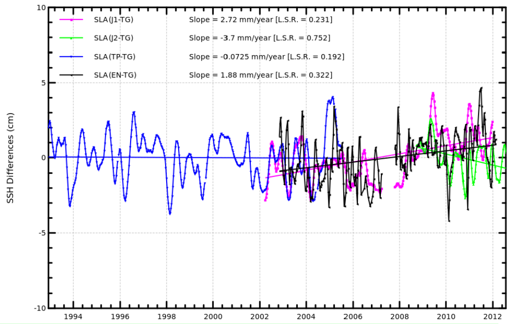
Tide Gauge identification

Tide Gauge Network	WOCE
Location (Lat/Lon)	-17.52 deg / 210.43 deg
Time series coverage	From 08/06/1975 to 30/09/2012
Vertical movements drift	YES (-2.9 mm/yr)
Key Performance Indicator [1]	

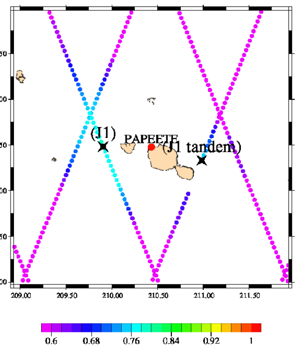


Temporal SSH comparisons with Jason-1 and Jason-2, TOPEX/Poseidon and Envisat



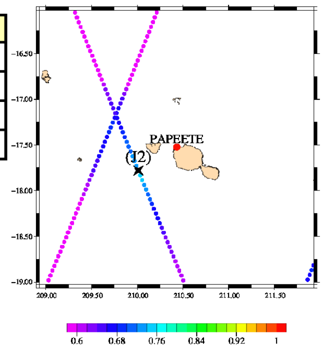


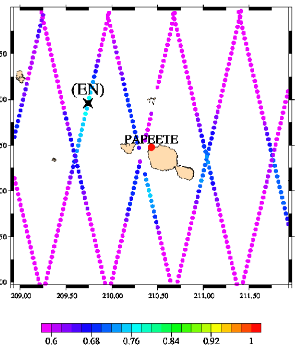
Maps of SSH correlation with Jason-1 and Jason-2, TOPEX/Poseidon and Envisat



Jason-1	Jason-2
55.9 km [2]	52.9 km [2]
0.78 [3]	0.74 [3]
1.1 cm [4]	0.99 cm [4]
0.6 mm/yr [5]	-2.2 mm/yr [5]

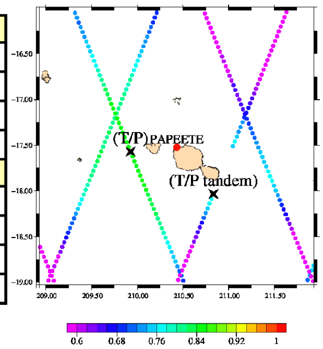
Jason-1 (tandem)
60.5 km [2]
0.76 [3]
1 cm [4]
-10.0 mm/yr [5]





Envisat	T/P
91.2 km [2]	53.9 km [2]
0.77 [3]	0.86 [3]
1.5 cm [4]	0.82 cm [4]
3.4 mm/yr [5]	0.0 mm/yr [5]

T/P (tandem)
70.8 km [2]
0.79 [3]
1.4 cm [4]
10.8 mm/yr [5]



[1] Performance of the TG with regard to altimetric missions (Correlation > 0.7 and Rms differences < 10 cm)
[2] Distance between the tide gauge and the maximum of altimeter SSH correlation
[3] Maximum of SSH correlation
[4] Standard deviation of filtered SSH differences
[5] Slope of filtered SSH differences

Figure 16: *Example of an information card for the Papeete tide gauge*

From now on, this quality control of each tide gauge is displayed as a cross-comparison indicator on the AVISO website (*www.aviso.oceanobs.com/fr/calval/in-situ-global-statistics*). It is performed to select relevant tide gauges for the altimeter/in-situ comparisons. The map of cross-comparison indicators (figure 17) displays the way comparison between altimetry and tide gauges is reliable.

This reliability of an altimeter mission in the assessment of the quality of the in-situ time series is defined through the two main criteria (correlation and rms) described in the method itself (see part 3.3.). If both altimetry and in-situ meet the conditions for the main missions T/P, Jason-1&2 and Envisat, the tide gauge is considered reliable enough to be compared with altimetry.

Figure 17: *Map of the Cross Comparison Indicator applied on tide gauges as displayed on the AVISO website. Credits: GoogleMap (Imagerie 2011 NASA)*

Thus, 5 colors have been chosen to represent the number of altimeter consistent with the tide gauges ones:

- Black: No satellite checking the criteria
- Red: 1 satellite checking the criteria
- Orange: 2 satellites checking the criteria
- Yellow: 3 satellites checking the criteria
- Green: at least 4 satellites checking the criteria

Consequently, while a green indicator will attest of the relevance of a tide gauge time series to perform SSH differences with altimetry, a black indicator does not necessarily indicate a bad quality of an in-situ time series: for instance no altimeter data may cover the time period of the tide gauge, which makes the tide gauge not considered in the assessment/validation of altimeter data. To date, the cross comparison indicator can attest of the reliability of tide gauges time series in the detection of altimeter MSL drifts or the assessment of new altimeter standards. Further out, it could be used to improve and even correct some anomalies detected in tide gauge time series, which is of particular interest to the altimeter/tide gauge comparisons.

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-calibration-and-validation/in-situ-global-statistics.html*).
A googlemap mapplet has been developed and information cards can be visualized online (figure 17). 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.

In 2013, the computation of information cards is expected to become more compliant with the need of end-users, especially thanks to a dynamical access to the multiple information and the way altimeter, tide gauge and geodetic time series can be superimposed. This will be performed for the new tide gauges networks such as MyOcean and PSMSL and thus displayed on the AVISO website.

6.3. Combination of multiple techniques for climate applications

The cross-comparisons described earlier in this document are performed by analyzing the correlation between altimeter and tide gauge SSH time series. Spurious measurements detected on tide gauge time series can then be corrected or removed to further improve the SSH comparison with altimeters. An example of potential anomaly on the in-situ time series is given for the Balboa tide gauge located at the beginning of the Panama Canal in the Pacific Ocean (figure 18).
Looking at the SSH differences with altimeter data, a weird behavior of the sensor is highlighted thanks to the 3 main missions Jason-1, TOPEX/Poseidon and Envisat between 2002 and 2006, which trends differences are on the order of -3 mm/yr for Jason-1 and Envisat and -6 mm/yr for TOPEX/Poseidon. However, since trend differences from the different altimeter regarding tide gauges measurements are very well correlated with each other, a potential anomaly seems to be detected on the tide gauge itself. Comparing multiple altimeter data with each tide gauge measurements is a way of detecting potential drifts or jumps on in-situ time series. Thus, the combination of several altimeter data can provide a quality control for the whole tide gauge dataset.

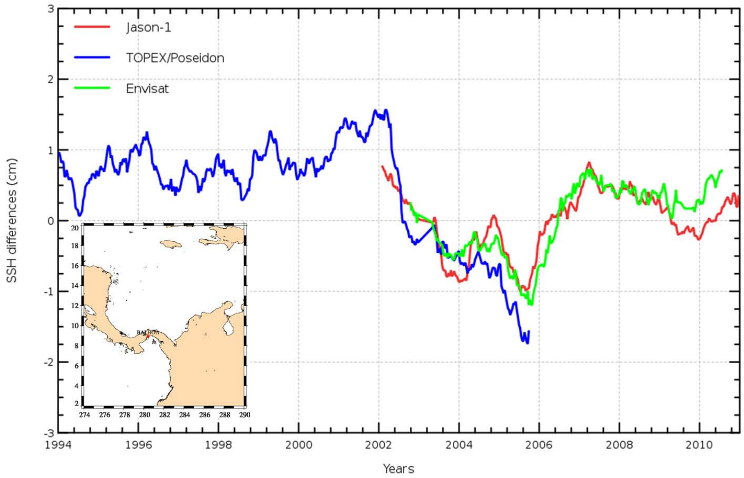


Figure 18: *SSH differences between the main altimeter data and Balboa tide gauge measurements using a 8 months Lanczos filter (and location of the Balboa tide gauge in the Panama Canal).*

Furthermore, drifts detected on the tide gauge time series require to be better analyzed. One majour source of the potential drifts or jumps on these time series correspond to vertical movements which can affect tide gauges. It is of major interest for climate applications using tide gauge measurements to get an accurate SSH to be compared to altimetry. Therefore, in addition to the quality control performed routinely on the the gauge network available, a study has been performed in 2012 on the complementarity of two of the three following techniques Altimetry, Tide Gauges and Geodesy to provide a quality assessment of the third one (see annex 11.4.). Indeed, tide gauge measurements, as observations dedicated to climate applications, require a rigorous quality control since measurements are highly sensitive to biases or drifts in datasets. One major part of the error related to the assessment of Sea Surface Height at tide gauge location originates in vertical movements. Many studies have for instance demonstrated the need for tide gauges to be corrected for land motion when compared with altimeter data. The combination of multiple techniques (altimeter, in-situ and geodetic data) is a way of providing relevant tide gauge time series for end-users and climate applications such as the contribution of ice-sheet mass balance to the global sea-level. In this way, DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite) as well as GNSS (Global Navigation Satellite System) are considered as complementary techniques. They determine the crustal motion at a cm (or better) and mm/yr accuracy for the positions and velocities respectively. As the DORIS network was deployed by a geodetic institution, great care was taken when selecting the geographical location of the tracking stations to co-locate them with other space geodetic techniques (VLBI, SLR and GNSS), but also with tide gauges. Hence, as on May 2012, 22 DORIS stations are within 10 km from a tide gauge, including 8 within 500m. Ties between the DORIS antennas and the nearby tide gauge are also available when the measurement is possible.

This study thus focuses on the example of the Thule tide gauge for which measurements are compared to the different techniques previously described. First, the comparison to both DORIS and GNSS data provides relevant information about the strong crustal movement North of Greenland. Then the use of altimeter data confirms results deduced from geodetic stations and give a larger view on the behaviour of land motion around the Thule tide gauge. Therefore, the combination of multiple techniques is used to provide reliable tide gauge time series and improve

our knowledge of the measured physical content.
This study will go on in 2013, especially with further investigations on the Thule tide gauge and the assessment of the accurate equivalent water height and then ice loss near Thule thanks to GRACE data.

6.4. Quality and pertinence of PSMSL validation flag

In order to assimilate PSMSL network in our tide gauge database, we studied the dispersion of the Altimetry versus tide gauges slope differences with regards to the percentage of available valid data over all the period studied (see figure 19). This dispersion highlights for some tide gauges an abnormal slope with complete time series (red circle).

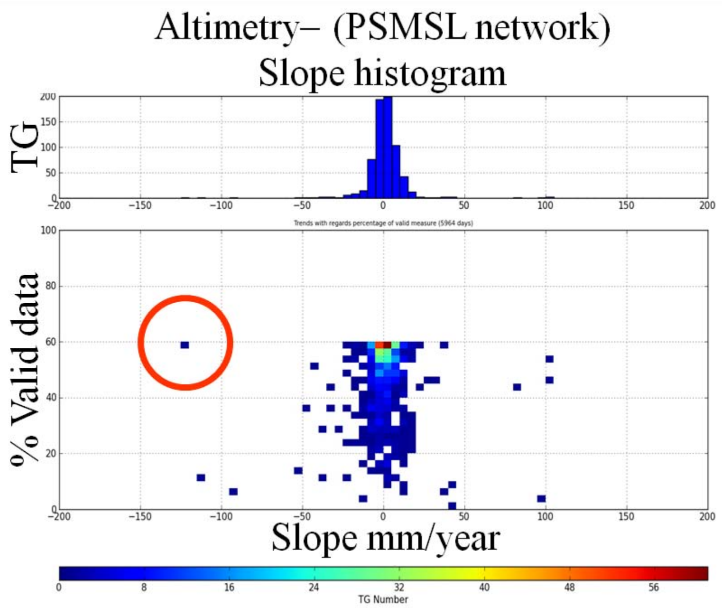


Figure 19: *Top : Altimeter - PSMSL slope (mm/year) histogram. Bottom : Scatter plot the percentage of valid data with regards of slope (trends of differences between altimetry and tide gauges). Red circle is the Kozu Sima (PS1061) tide gauge.*

This first figure allows to select some suspect TG like Kozu Sima (PS1061). Observation of figure 20 which represents two time series (altimeter an TG) allows to know quickly the origin of the high slope. A jump in the TG time serie explains the high slope. After investigating with PSMSL data, the validation flag available with PSMSL data is not used.

PSMSL data are provided with a validity flag and after investigation this latter is relevant when considering the whole altimeter (see figure 21). Nevertheless if our study begun in 2007 this information will have to be considered cautiously. It will be necessary in 2013 to perform some more investigations on this validity flag regarding the kind of studies to be performed.

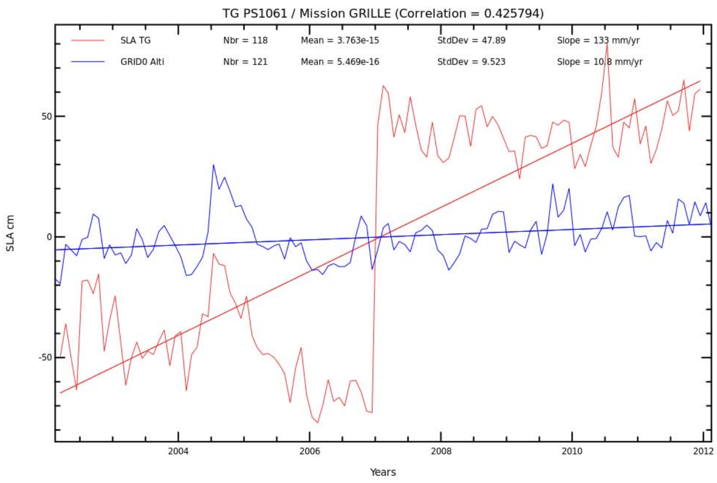


Figure 20: *Kozu Sima (PS1061): Tide Gauge (red curve) and Jason-1 altimeter(blue curve) time series comparison. PS1061 have a jump around 2007, which explains the high slope of the altimetry-tide gauges difference.*

The PSMSL validity flag is most probably calculate over all observations period[1]. Nevertheless in most of the case we have a period of interest around 10/15 years. This two point of view can be different. Whithout more investigations and innovation this flag can not be used for comparison with altimeter data. The period to calculate validation flag is not consistent with altimeter observation period.

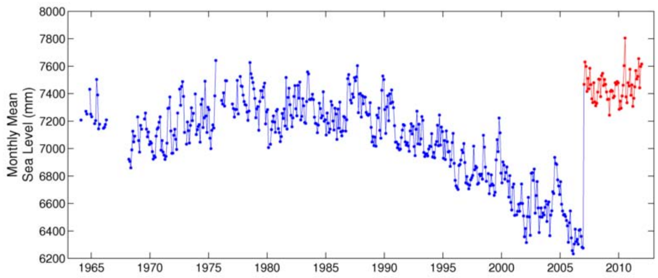


Figure 21: *Kozu Sima (PS1061) tide gauge time series over all period from PSMSL supplier. Observations spanned more than 50 years. Red dots highlight suspect data.*

Actually this flag is not used in the comparison method. Further investigations will be performed in 2013 to understand other abnormal cases.

[1] In our case around fifty years

7. Particular investigations on altimeter data computation

7.1. Improvement of the altimetry spatial sampling in the comparison method

Gridded altimeter products may provide incoherences while the spatial resolution of the grids increases. This artefact underlined in the comparaison method is due to the orbit change and some ground across boxes (figure 22) and can be solved by reducing the size of the gridded products. However, this evolution involves an increase of the altimeter noise in each box and some boxes with uncomplete altimeter time series. That be, this box size reduction improves the relevant collocation of both altimeter and tide gauge time series, because of the raise of the number of altimeter time series taken into account.

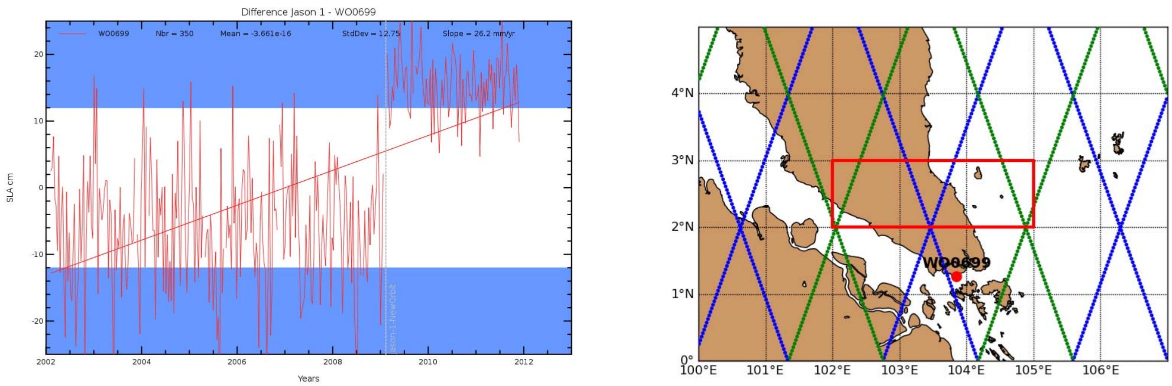


Figure 22: *Left: Monitoring of the differences between Jason-1 3*1 space resolution gridded altimeter product and Tanjong tide gauge time series. Blue strips correspond to the 12 cm threshold of maximum deviation applied on the residual time series. Right: Map of the Jason-1 nominal (blue lines) and tandem phase (green lines) altimeter tracks close to the Tanjong tide gauge. The red box is the selected area (by correlation value of time series) of altimeter observations for the Tanjong tide gauge.*

Next to this improvement and to be coherent with altimeter data geographic distribution (figure 23), the criteria of maximum distance has been increased from 100 km to 150 km. Moreover the percentage of defined altimeter measurements for each time series has been raised so as to give advantage to altimeter long time series and compute a relevant global trend of the differences with tide gauge measurements.

This evolution reduced potential jumps in altimetry selection (figure 22) and the altimeter physical content is preserved thanks to the lower space resolution of gridded products.

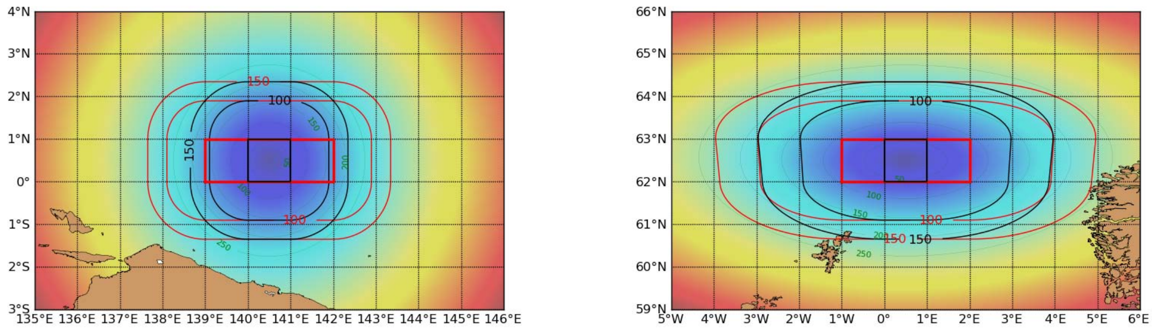


Figure 23: *Different ways to compute the distance between a box and a tide gauge.Left: Pacific ocean (at the equator 0.5 degree of latitude) - North Indonesia. Right: Norway sea (at 62.5 degree of latitude). Labels are in kilometers. Black or red curves represent the bound of the area which contains the tide gauge available to be matched with the altimeter data black box (1 degree by 1 degree) or data red box (3 degree of latitude by 1 degree of longitude). The center of the boxes center corresponds to the center of gray circle with the green label. To compute the distance in the red and black case, the dot nearest the bound of the box is used to calculate the distance between the dot and the box.*

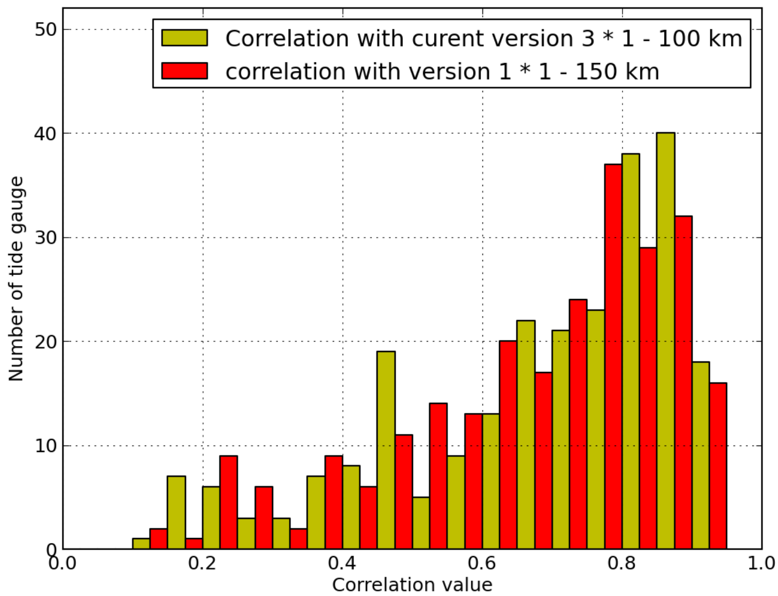


Figure 24: *Histogram of the correlations between Jason 1 time series and tide gauge considering both 1x3° and 1x1° longitude/latitude space resolutions and respectively 100/150 km distances.*

As displayed on figure 24, these enhancements on the processing sequence assure an equivalent number of altimeter/tide gauges difference time series, in spite of the correlation cut off value. Moreover, this new solution allows to produce coherent altimeter time series without modifying the global result in the selection. Altimeter grid with box of 1 by 1 degree are recommended to delete jump problems.

To go further, we must find another solution to replace deviation criteria to delete isolated and incoherent data (see technical note "Improvement_spatial_sampling_altimetry_tide_gauge.pdf").

7.2. Jason-1 - TG global trends around 2004

Further studies performed in 2012 on the comparison between Jason-1 data and tide gauge measurements highlighted a jump on the residual signal of the differences in 2004 (figure 25). In order to explain this jump and correct this abnormal behaviour of the monitoring of the differences, the spatial sampling of altimeter gridded products was studied (see previous study 7.1.).

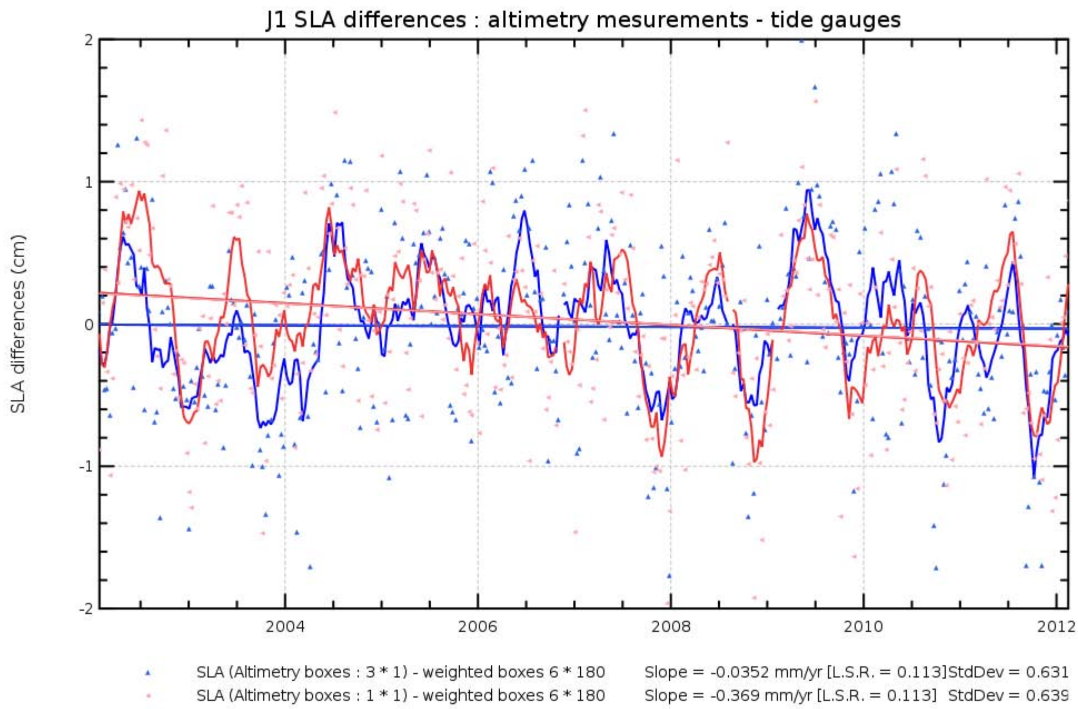


Figure 25: *Monitoring of the differences between Jason-1 altimeter and tide gauge time series for both current (blue cruve) and new version of the spatial resolution (red curve) of altimeter gridded products.*

The blue curve seems to highlight a jump in 2004, nevertheless red curve shows than previous peak (2003) was reduce with the current version of the algorithm. The red curve is calculated with altimeter grid resampled (see part 7.1.). This comparison shows that level of details can't be analysed with the actual method. Figure like figure 25 have two relevant informations : slope and standard deviation around the slope.

Nevertheless this investigation allows to highlight spatial distribution of tide gauges in the global ocean (see figure 26), an unequal distribution of the time series is highlighted. This distribution shows that some area like south hemisphere have a low weight in the global trends calculation with regards of the south ocean area.

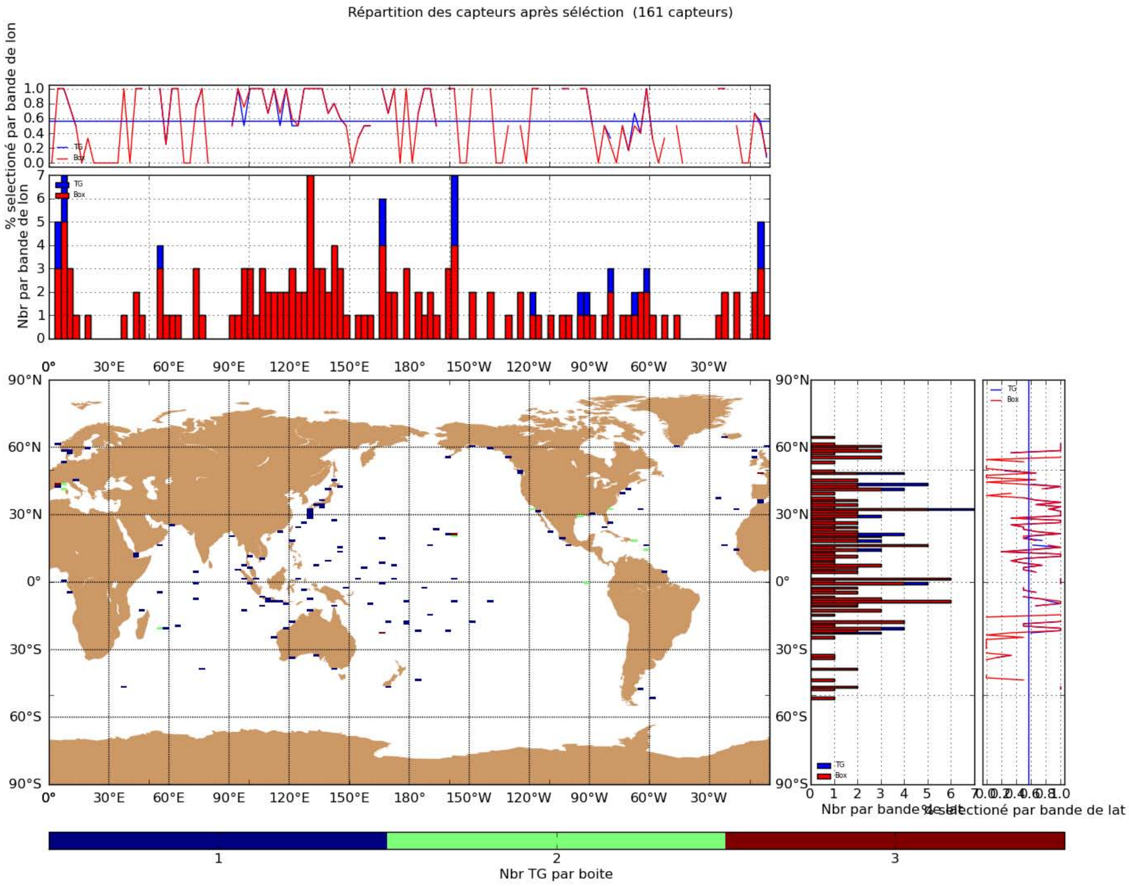


Figure 26: *Tide gauge distribution before selection. Distribution is discrete around the coast, nevertheless each strip of longitude and latitude don't have the same number of in-situ tide gauge. Histograms show the number of tide gauges (blue) and boxes (red) by strip. The number of TG is the same than the number of boxes when the red band hides the blue one.*

The unequal distribution of selected time series must be analysed (figure 26) in order to have a better comprehension of the global signal and to be able to compute regional trends or different ways to compute global trends. To see the whole study, please refer to the technical note untitled "Improvement_spatial_sampling_altimetry_tide_gauge.pdf".

8. Particular investigations using tide gauge measurements

8.1. Overview

The processing sequence which aims at comparing both altimeter and tide gauge time series reinforces 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 present the main results derived from these investigations. Note that previous studies performed using tide gauge measurements are presented in annex 11.6..

8.2. Altimeter MSL drift differences between Jason-1 and Envisat

The reprocessing of the Envisat altimeter data has provided significant improvements of the mission and the data are now much more coherent with Jason-1&2 missions (Ollivier et al. 2012, [22]). However, some differences remain between Envisat and Jason-1 altimeter MSL trends if focused over 2004-2012 period: +1.0 mm/yr is observed between Envisat and Jason-1 (figure 27 top and 2nd column of table 2). It suggests that the drift of one of these missions is greater than the other.

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

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

Table 2: *Altimeter MSL trends of Jason-1 and Envisat and MSL drifts compared with in-situ measurements over the period 2004 / January 2012.*

When comparing with tide gauges from January 2004 onwards (figure 27 right and last column of table 2), the altimeter MSL drift is greater for one of these missions than the other (0.9 mm/yr difference close to 1.0 mm/yr). The associated error over this period is estimated to be ± 0.7 mm/yr, taking into account the spatial sampling restricted to coastal areas and the terrestrial crustal movements. Considering both Jason-1 and Envisat time series, the comparison with tide gauges suggests that the drift is greater for Envisat mission (0.8 vs -0.1 mm/yr).

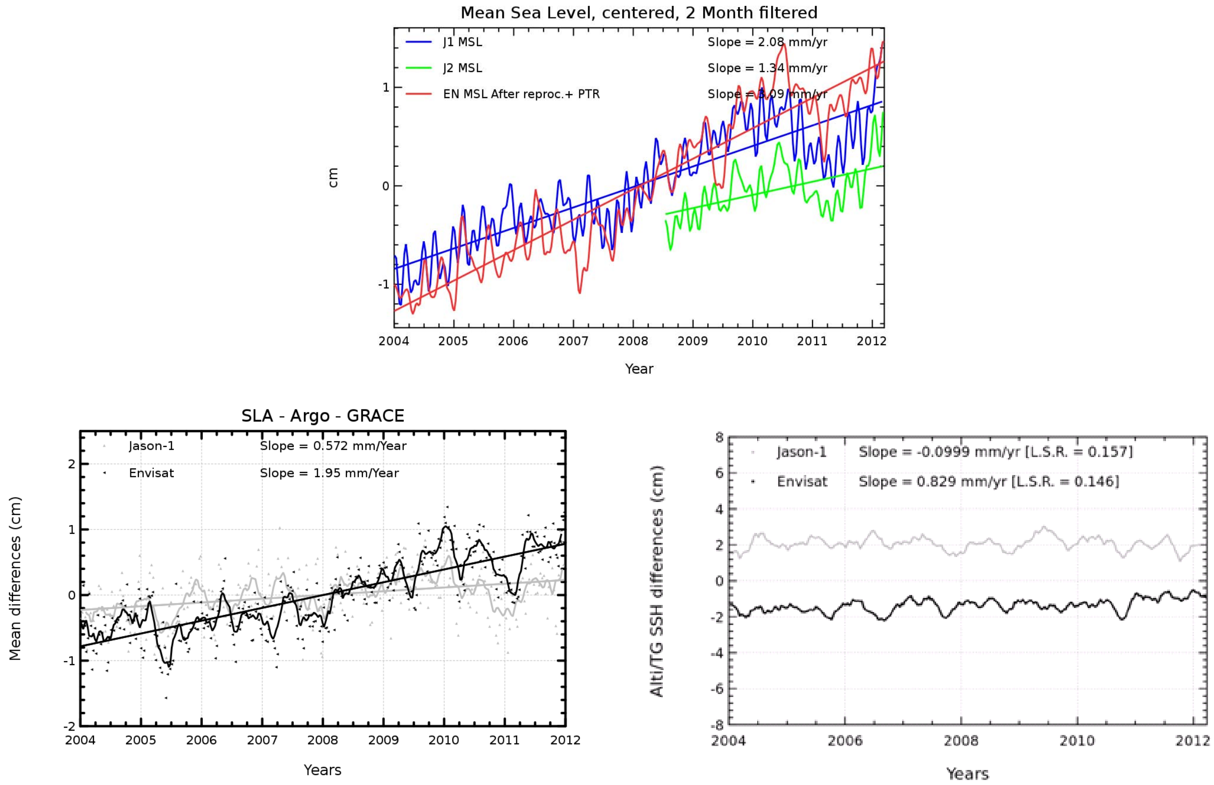


Figure 27: *Altimeter MSL trends of Jason-1 and 2 and Envisat over 2004-2012 without the GIA contribution (+0.3mm/yr) (top). MSL drift of Jason-1 and Envisat compared with Argo+GRACE (left) and tide gauges (right) over the same period (GIA included) and without annual and semi-annual signals and after 2-month filtering.*

Furthermore, to explain this difference of sensitivity, a study was performed to estimate the impact of coastal selection on the altimeter dataset. This enables to demonstrate that the proximity modifies greatly the trend on altimetry side (approximately +/- 0.3 mm/yr depending on the standard, see table 3) and, in absolute, using MWR instead of ECMWF give more consistent trends between altimetry and tide gauge MSL. Thus, these analyses show the sensitivity of the method and results should be further investigated in coastal areas.

MSL trends diff 2003-2012 time period (mm/yr)	**EN -J1** (global)	**EN -J1** (coastal)	**EN -TG**	**J1 -TG**	**EN - J1** (colloc TG)
V2.1 (MWR)	-1.9	-1.6	-1.1	0.3	-1.4
V2.1+ PTR (MWR)	0.1	-0.3	0.6	0.3	0.3
V2.1+ PTR (ECMWF)	0.1	-0.2	0.9	Not Available	Not Available

Table 3: *Effect of the coastal selection on altimeter Envisat - Jason-1 MSL and compared with in-situ measurements over the period 2003 / January 2012.*

Finally, to complete this study in open ocean and make the results reliable, the altimeter MSL is then compared with Argo and GRACE data over the same period (figure 27 left and 3rd column of table 2, see Altimetry/Argo T/S profiles 2012 annual report [8]). Again, the altimeter MSL drift is greater for one of these missions than the other (1.4 mm/yr difference close to 1.0 mm/yr global difference). Note that the error over this period is estimated to be around ±0.8 mm/yr, taking into account the errors associated with both types of data, their processing and the colocation process. Moreover, absolute MSL drifts referenced to Argo and GRACE data also suggest that the Envisat MSL drift is greater than the one of Jason-1 (2.0 vs 0.6 mm/yr).

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

8.3. Long period non-equilibrium tides in the in-situ SSH computation

The nominal method is to compare altimeter data with tide gauge measurements. Derived from this processing sequence, the comparison of two altimeter definition with tide gauges and the comparison of two tide gauge definitions with altimeter data are made possible. This study focuses on the latter considering the long period non-equilibrium tides taken into account in the SSH computation.

Further investigations on this tide signal show that the amplitude such signal is so low that it can't really be assessed with the current method. The global processing sequence derived from matching and computing both altimeter and tide gauge datsets must be improved to observe the impact of this signal. Nevertheless this study allowed developing a method to compare two tide gauge SSH with regard of altimetry. For further information on this particular investigation, please refer to the dedicated technical note [27].

8.4. Monitoring of the regional long-term trend differences

Thanks to the improvements performed on the comparison between altimetry and tide gauges, it has been possible to perform some more analyses on long-term trend differences regionally. From now on, the comparison between altimetry and tide gauges can be performed for each basin (see figure 28). To date, this global monitoring demonstrate that the Envisat global MSL drift with regard to tide gauges is largely dominated by the Pacific ocean, with a drift of 0.5 mm/yr and a formal adjustment error lower than 0.2 mm/yr. Physically this result is pretty significant since the Pacific ocean amounts to a large part of the global ocean. However, next to these results, the long-term trend differences of other basins are quite strong and opposite (1.4 mm/yr for the Atlantic ocean, -2.1 mm/yr for the Indian ocean) and denote the need to densify the tide gauge network for regional studies (only 20 tide gauges considered in the comparison method in the Indian ocean).
These results will be developped in the frame of this activity in 2013.

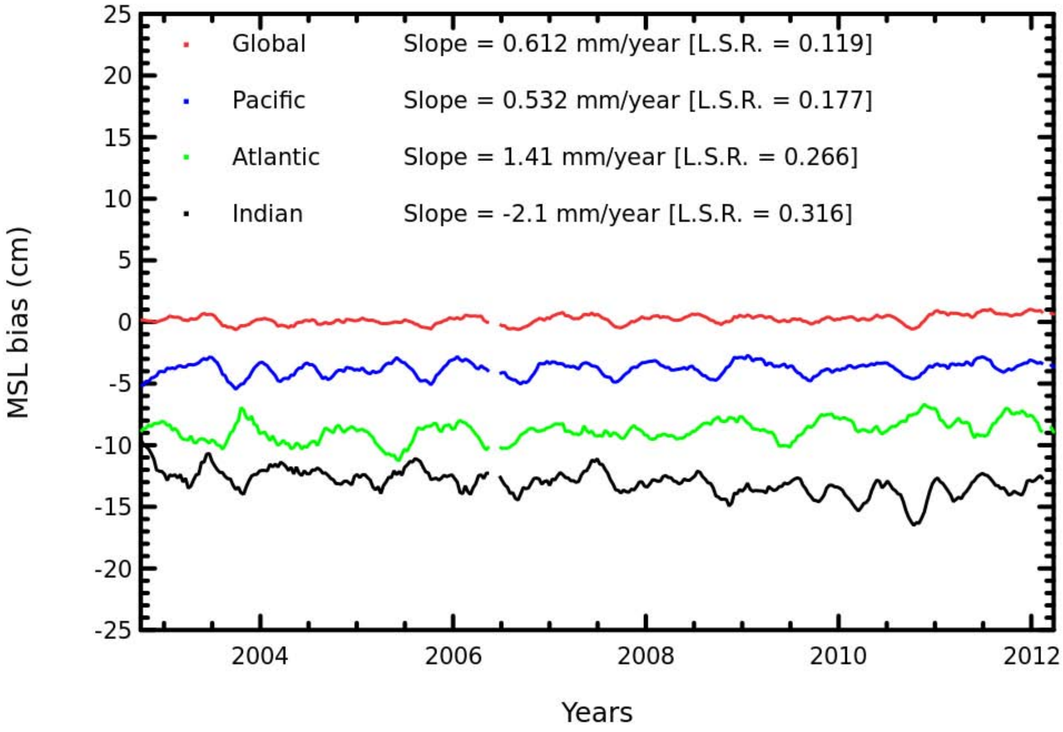


Figure 28: *Monitoring of the long-term trend differences between Envisat and tide gauges for the whole ocean and the main basins Pacific, Atlantic and Indian oceans.*

9. Conclusions and futures

This report demonstrates the relevance of tide gauge measurements in the frame of the altimeter calibration/validation activity. Reliable results are obtained thanks to a data processing procedure performed in an operational frame (development and operational account, automatic processing, ...) to assess potential drifts or jumps in the altimeter measurements. This operational aspect of the data processing sequence is fundamental to quickly reprocess the whole altimeter period and take into account new altimeter standards as it was performed this year concerning Envisat V2.1+ and Jason-2 GDR-D releases.

Concerning the accuracy of altimeter data, both improvements on the method and particular investigations have confirmed and refined results on the main altimeter missions. The reliability of Jason-1 mission has been confirmed since no MSL drift is detected when comparing to tide gauges, within the error of the method, estimated to 0.7 mm/yr over the altimeter time period. In the same way, a drift of almost 0.8 mm/yr is highlighted on Envisat, in line with Jason-1 results. This enhancement in the comparison with tide gauge measurements on Envisat is linked to the reprocessing but also to the new CNES GDR-D orbit, the new wet troposphere correction and the GOT4.8 tide model (AVISO, 2012, Envisat reprocessing report [4]). Concerning Jason-2 MSL drift, the new GDR-D altimeter product displays a better coherence with tide gauge measurements, leading to a global drift of 0.4 mm/yr and a formal adjustment error of the same order. Although tide gauge measurements will have to wait for longer time series to be compared with the other on-flight altimeter missions, results concerning Jason-2 GDR-D data are in very good agreement with the global trend differences observed using tide gauge time series.
Moreover, these results are in agreement with global Calval 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.

Global or regional drifts detected on altimeter time series are then supposed to be corrected to improve altimeter products for end-users. Therefore, new altimeter standards are produced, and their impact in the sea level computation can be assessed thanks to in-situ measurements. The comparison with tide gauges data has confirmed that the impact of the GDR-D reprocessing on both Jason-2 and Jason-1 is positive with regard to tide gauge SLA consistency. Furthermore, the new Envisat V2.1+ GDR products have been compared to in-situ time series and are also in agreement with the improvement of the updated GDR-D orbit solution compared with the GDR-C standard (Ollivier et al., 2012, [22]).

The third part of this activity concerns the way the method presented here can provide a quality assessment on both altimeter and in-situ datasets through SSH comparisons. Thus, cross-comparison indicators are displayed as information cards for both GLOSS/CLIVAR and REFMAR networks, which are routinely performed each week and distributed on the AVISO website (*www.aviso.oceanobs.com/fr/calval/in-situ-calibration-and-validation/in-situ-global-statistics.html*). The goal of such quality assessment is to detect anomalies and thus qualify in-situ measurements using multiple altimeter time series. Therefore, the comparison of tide gauge measurements with altimeter data enables to point out drifts or jumps in in-situ time series, which need to be corrected to improve the coherence between both datasets.
These quality controls then provide reliable datasets of in-situ measurements, which are relevant to detect potential altimeter drifts or jumps and to estimate the quality of new altimeter standards. Since one major source of the potential drifts or jumps on these time series correspond to vertical

movements which can affect tide gauges, it has been of major interest in 2012 to begin an interesting study on the complementarity of two of the three following techniques Altimetry, Tide Gauges and Geodesy to provide a quality assessment of the third one considering DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite) as well as GNSS (Global Navigation Satellite System) as complementary techniques for the geodetic part of this study. Next to these first results, it is expected in 2013 to further investigate these results and focus on the Thule tide gauge and the assessment of the accurate equivalent water height and then ice loss near Thule thanks to GRACE data.

Furthermore, it is important to underline the synergy of both in-situ datasets to assess the quality of altimeter data. Indeed, while tide gauge measurements provide long time series but a limited spatial sampling, Argo T/S profiles cover the global ocean on a shorter time period. Other kinds of in-situ instruments such as gliders (Bouffard et al., 2010 [9]) can be considered to perform comparison with altimeter sea level provided that physical contents are corresponding. The duality of these both types of data will constitute an asset for the calibration of future space missions as the Sentinel3 mission (*sentinelle3.com*) or the Surface Water Ocean Topography (SWOT) mission (*swot.jpl.nasa.gov*). It will also be of great interest to assess improvements of reprocessed altimeter data such as time series of ERS-1&2 (ESA REAPER project). Thanks to the cross-comparisons between results provided by the different approaches, the assessment of the MSL drift is more and more reliable and accurate, globally as well as regionally.

From now on, the processing sequence is fully operationnal and can be routinely used in the different studies involving in-situ data in order to better benefit from tide gauge measurements and thus improve the relevance of analyses.
In 2013, the tide gauge database will routinely compute PSMSL time series with the aim of making climate applications more and more reliable. Concerning vertical movements, the objective is to complete tide gauge time series with geodetic information wherever it is possible to. Thus, several tests on regional areas or specific basins will be performed to quantify the impact of this correction with a better DORIS or GPS space sampling at tide gauges locations.
Considering the AVISO website, a new dynamic interface is planned instead of the current tide gauge google map. This improvement is in line with the need for end-users to access and combine the multiple information available at CLS.

Finally, note that this activity has been presented this year at both Envisat Quality Working Group (QWG) in Corsica and Italy, at the OSTST in Venice [29], and at the AGU Fall meeting in San Francisco [3] (see annex 11.3.). Moreover, the main results concerning this activity of Altimetry/Tide Gauge comparison will be available in the 2012 Special Issue of Marine Geodesy (Valladeau et al., [28]).

10. References

References

[1] Ablain M., S. Philipps, M. Urvoy, N. Tran, and N. Picot, 2012: Detection of long-term instabilities on altimeter backscatter coefficient thanks to wind speed data comparisons from altimeters and models. Marine Geodesy 2012, DOI: 10.1080/01490419.2012.718675.

[2] Ablain M., A. Cazenave, G. Valladeau, and S. Guinehut, 2009: A new assessment of global mean sea level from altimeters highlights a reduction of global trend from 2005 to 2008. Ocean Sci. Disc., 6, 31-56.

[3] Valladeau G., J.-F. Legeais, M. Ablain, A. Delepoulle, N. Picot and P. Femenias, 2012: Comparing altimetry with in-situ measurements for quality assessment in Mean Sea Level studies. AGU Fall Meeting, San Francisco.

[4] AVISO, 2012: Envisat RA2/MWR ocean data validation and cross-calibration activities. 2012 annual validation report. SALP-RP-MA-EA-21920-CLS ed. 1.1, 129 pp.

[5] AVISO, 2006: TOPEX/Poseidon validation activities. 13 years of T/P data (GDR-Ms). SALP-RP-MA-EA-21315-CLS ed. 1.1, 106 pp.

[6] AVISO, 2011: Jason-2 reprocessing impact on ocean data (cycles 001 to 145). SALP-RP-MA-EA-22118-CLS.

[7] Bessero, G., 1985: Marées, Service Hydrographique et Océanographique de la Marine, Brest.

[8] Legeais J.F., and M. Ablain, 2012: Validation of altimeter data by comparison with in-situ Argo T/S profiles. Note technique CLS.DOS/NT/12-261, Contrat SALP-RP-MA-EA-22045-CLS.

[9] Bouffard, J., A. Pascual, S. Ruiz, Y. Faugère, and J. Tintoré, 2010: Coastal and mesoscale dynamics characterization using altimetry and gliders: A case study in the Balearic Sea. J. Geophys. Res., 115, C10029, doi:10.1029/2009JC006087.

[10] Bouin, M.-N., and G. Wöppelmann, 2010: Land motion estimates from GPS at tide gauges: a geophysical evaluation. Geophys. Journal International, vol. 180, doi:10.1111/j.1365-246X.2009.04411.x.

[11] Carrère, L. and F. Lyard, 2003: Modeling the barotropic response of the global ocean to atmospheric wind and pressure forcing - comparisons with observations. Geophys. Res. Lett., Vol. 30, 1275, 4 pp. doi:10.1029/2002GL016473.

[12] Cartwright, D.E., and A.C. Eden, 1973: Corrected Tables of Tidal Harmonic, Geophys. J. R. Astr. Soc., 17 (5), 619-622.

[13] Cerri, L., A. Couhert, S. Houry, and F. Mercier. 2011. Improving the long-term stability of the GDR orbit solutions. Oral presentation at OSTST meeting, San Diego, USA.

[14] Dorandeu, J., and P.-Y. Le Traon, 1999: Effects of global mean atmospheric pressure variations on mean sea level changes from Topex/Poseidon, J. Atmos. Oceanic Technol., 16, 1279-1283.

[15] Valladeau G., L. Soudarin, and M. Gravelle, 2012 : How to combine multiple techniques to provide reliable in-situ time series for climate applications. AGU Fall Meeting, San Francisco.

[16] Valladeau G., 2009: Influence de l'algorithme de calcul de vitesse de vent Gourrion à 2 paramètres pour l'altimètre de TOPEX/Poseidon. Technical Note CLS-DOS-NT-09-206.

[17] Hernandez, F., and P. Schaeffer, 2001: The CLS01 Mean Sea Surface: A validation with the GSFC00.1 surface. Tech. rep., CLS, Ramonville St Agne.

[18] King, M. A., M. Keshin, P. L. Whitehouse, I. D. Thomas, G. Milne, and R. E. M. Riva, 2012: Regional biases in absolute sea-level estimates from tide gauge data due to residual unmodeled vertical land movement. Geophys. Res. Lett., Vol. 39, L14604, doi:10.1029/2012GL052348.

[19] Labroue S., 2007 : RA2 ocean and MWR measurement long term monitoring, 2007 report for WP3, Task 2 - SSB estimation for RA2 altimeter. Contract 17293/03/I-OL. CLS-DOS-NT-07-198, 53pp. CLS Ramonville St. Agne

[20] Mitchum, G.T., 1998. Monitoring the stability of satellite altimeters with tide gauges. J. Atmos. Oceanic Tech., 15, 721-730.

[21] Nerem, R. S., D. Chambers, C. Choe, and G. Mitchum, 2010: Estimating Mean Sea Level Change from the TOPEX and Jason Altimeter Missions. Marine Geodesy, 33, 435-446.

[22] , Ollivier A., M. Ablain, Y. Faugere, N. Picot, and P. Femenias, 2012: Contribution of Envisat to the better knowledge of global and regional Mean Sea Level long term evolution. Marine Geodesy, in press.

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

[24] Ray, R., 1999: A Global Ocean Tide Model From TOPEX/Poseidon Altimetry: GOT99.2. NASA/TM-1999-209478. Greenbelt, MD, Goddard Space Flight Center/NASA: 58.

[25] Schöne, T., N. Schön, and D. Thaller, 2009: IGS Tide Gauge Benchmark Monitoring Pilot Project (TIGA): scientific benefits. J. Geod., 83, 249-261, doi:10.1007/s00190-008-0269-y.

[26] Ablain M., G. Valladeau, A. Lombard, E. Bronner, and P. Femenias, 2009: Quality assessment of in-situ and altimeter measurements through SSH comparison. OSTST, Seattle.

[27] Delepoulle A., 2012: Envisat and Jason-1 altimeter data comparison with tide gauge measurements (with two ways of SLA computation). Technical Note CLS.DOS/NT/12-291.

[28] Valladeau G., J.F. Legeais, M. Ablain, S. Guinehut, and N. Picot, 2012: Comparing altimetry with tide gauges and Argo profiling floats for data quality assessment and Mean Sea Level studies. Marine Geodesy 2012, DOI: 10.1080/01490419.2012.718226.

[29] Valladeau G., M. Ablain, A. Delepoulle, N. Picot, and P. Femenias, 2012: Quality assessment of altimeter and tide gauge data for Mean Sea Level and climate studies. OSTST, Venice.

[30] Wöppelmann G., B. Martin Miguez, M-N. Bouin, and Z. Altamimi, 2007: Geocentric sea-level trend estimates from GPS analyses at relevant tide gauges world-wide. Global and Planetary Change, 57 (3-4), 396-406.

11. Annexes

11.1. Annex: General operating diagram

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

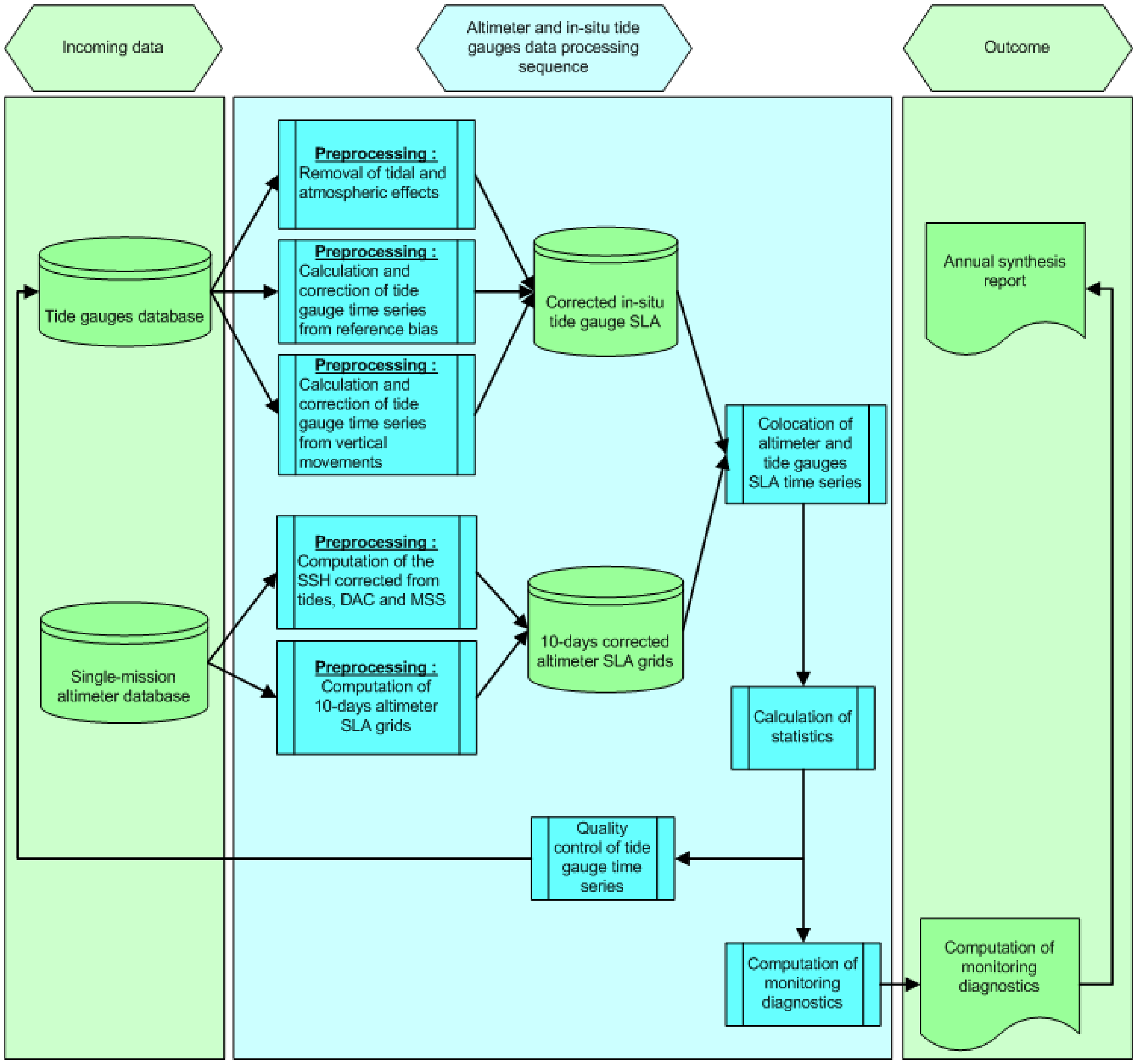


Figure 29: *General operating diagram of the tide gauge data processing sequence*

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.

11.2. Annex: Corrections applied for altimeter 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 (MGDR)	Jason-1 (GDR-C)	Jason-2 (GDR-T)	Envisat (GDR-V2.1+)
Orbit	GSFC POE (09/2008), ITRF2005+Grace	CNES POE (GDR-C standards)	CNES POE (GDR-C standards)	CNES POE (GDR-D standards[2])
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) + new corrected files
Ionosphere	Filtered dual-frequency altimeter range measurements (for TOPEX) and Doris (for Poseidon)	Filtered dual-frequency altimeter range measurements	Filtered dual-frequency altimeter range measurements	Dual-Frequency updated with S-Band SSB (< cycle 65) GIM model + global bias of 8 mm (>= cycle 65)
Sea State Bias	Non parametric SSB (for TOPEX), BM4 formula (for Poseidon)	Non parametric SSB (GDR product)	Non parametric SSB (GDR product)	Updated homogeneous to GDR-C (Labroue, 2007 [19])
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]
				.../...

[2]External corrections available on ESA website near V2.1 GDR products

Orbits and corrections	TOPEX/Poseidon (MGDR)	Jason-1 (GDR-C)	Jason-2 (GDR-T)	Envisat (GDR-V2.1+)
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 included in the range after V2.1 reprocessing + PTR[2]

Table 4: *Corrections applied for altimetric SSH calculation*

[2]External corrections available on ESA website near V2.1 GDR products

11.3. Comparing altimetry with in-situ data for MSL studies

G31A-0904

SALP — Service Altimétrie & Localisation Précise

Comparing altimetry with in-situ measurements for quality assessment in Mean Sea Level studies

Guillaume Valladeau (1), Jean-François Legeais (1), Michaël Ablain (1), A. Delepoulle (1), Nicolas Picot (2), Pierre Femenias (3)
(1) Collecte Localisation Satellite (CLS), Toulouse, France.
(2) Centre National d'Etudes Spatiales (CNES), Toulouse, France.
(3) ESA-ESRIN, Via Galileo Galilei CP64 I-00044, Frascati, Italy
E-mail: guillaume.valladeau@cls.fr

Overview (1)

Assessment of MSL drifts

Evaluation of altimeter standards

Focus on Jason-1/Envisat drift detection

Quality assessment of tide gauges time series

Data

➢ Altimetry: Along-track (level 2) SSH from satellite altimeters, where standards are updated compared with the official Geophysical Data Record (GDR) altimeter products (see AVISO website (2))

➢ Tide gauges: In-situ measurements from the GLOSS/CLIVAR "fast" sea level data network (http://ilikai.soest.hawaii.edu/uhslc)

➢ Argo T/S profiles: Steric DHA derived from Argo T/S profiles (Coriolis-GDAC dataset)

➢ Mass contribution: monthly grids derived from GRACE (http://grace.jpl.nasa.gov)

Tide gauges comparison

➢ Collocation Method: maximal correlation criteria derived from theoretical altimeter along track products within a 100 km distance circle (Fig. 1)

➢ Spatial weighting to take into account the non-homogeneous sampling of tide gauges in the whole ocean

➢ Additional quality controls to compute SSH differences for the most reliable time series

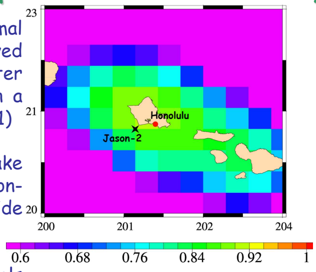


Fig. 1: Computation of the maximum of correlation on Jason-2 from 1/4°x1/4° gridded altimeter products.

Argo and GRACE comparison

Altimetry is compared with the steric and mass contributions from Argo and GRACE (Chambers, 2006 (3)) data (Fig. 2):

➢ Averaging of along-track altimeter data in 10-days grids

➢ Spatial and temporal interpolation of both altimeter and GRACE data at the position and time of each in-situ Argo profile

➢ Global statistics and coherence analyses are performed between altimetry and the two independent datasets

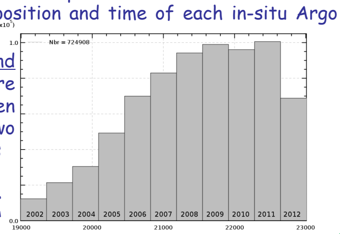


Fig. 2: Histogram of the number of Argo profiles per year from 2002 to September 2012

1 Assessment of altimeter MSL drifts

➢ Good reliability of both Jason-1 and Envisat global MSL trend estimate with regard to tide gauges on 2002-2012 (respectively **0.3 mm/yr** and **0.6 mm/yr**), within the error of the method of +/- 0.7 mm/yr (Fig. 3)

➢ Differences between Jason-2 and tide gauges provide a negative drift of **-0.7 mm/yr**, with a strong formal adjustment error of 0.5 mm/yr, linked to its short time period

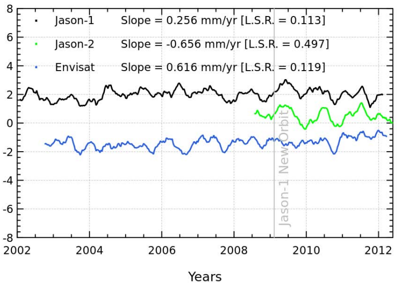


Fig. 3: Monitoring of the SSH differences between Altimetry and Tide Gauges. Left: Jason-1 (black), Jason-2 (green) and Envisat (blue) along-track data. Right: DUACS DT gridded products

In-situ measurements are reliable enough to monitor the accuracy of altimeter data, within the error margin of the method, estimated to 0.7 mm/yr for the altimeter time period

Impact of Jason-2 GDR-D reprocessing

➢ Jason-2 altimeter data have been partly reprocessed with GDR-D standards (cycles 1 to 36 and 86 onwards)

➢ Argo and GRACE independent measurements are used to estimate the impact of this reprocessing

➢ **Increase of the coherence between altimeter and Argo + GRACE data by 2 cm2** with GDR-D standards (Fig. 4)

➢ The 2.5 yrs of available reprocessed Jason-2 GDR-D data show promising results

➢ The comparison with in-situ measurements will be adapted to estimate the impact of the reprocessing when all data will be available

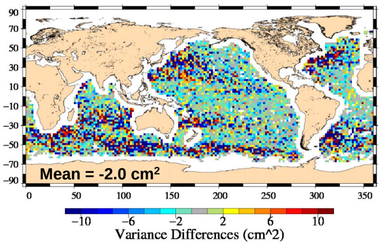


Fig. 4: Map of the differences of variances betwen (Jason-2 GDR-D and GDR-T data using (Argo+GRACE) in-situ measurements

2 Focus on Jason-1/Envisat altimeter drift detection

➢ Reprocessing of Envisat mission has strongly improved the ability of assessing the Mean Sea Level

➢ However, Jason-1 and Envisat MSL trends over 2004-2012 still differ by **+1.0 mm/yr**. Is the confidence in the altimeter MSL drift greater for one of these missions ?

⇒ **Can in-situ data assess which mission is closer to the reality?**

➢ Using both **tide gauges** and **Argo T/S profiles** (Fig. 5), differences between Envisat and Jason-1 are close to the 1.0 mm/yr difference obtained with the global altimeter MSL differences (respectively **0.9 mm/yr** and **1.4 mm/yr** since 2004, see Table 1)

➢This confirms that the drift of one of these missions is greater than the other

Absolute values of MSL trends referenced to in-situ datasets suggest that Envisat MSL drift is greater than Jason-1 from 2004 onwards (Table 1)

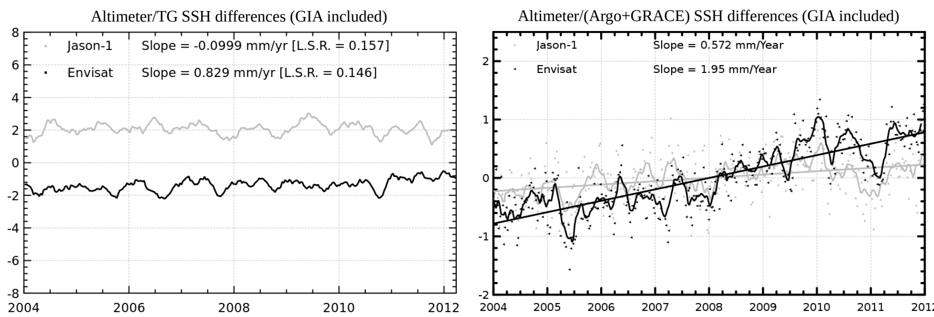


Fig. 5: Monitoring of the SSH differences between altimeter data and in-situ measurements considering Jason-1 and Envisat missions from 2004 onwards. Left: using Tide Gauges. Riight: using Argo and GRACE

MSL trend differences (mm/yr) Time Period: 2004-2012	Altimeter MSL	MSL differences with tide gauges	MSL differences with Argo+GRACE
Jason-1	2.4	-0.1	0.6
Envisat	3.4	0.8	2.0
Jason-1/Envisat differences	**1.0**	**0.9**	**1.4**

Table 1: Comparison of the MSL trend differences between Jason-1 and Envisat using altimeter MSL only, Tide Gauges and Argo T/S profiles

3 Quality assessment of tide gauge time series

➢ Cross-comparison of altimeter and in-situ SSH differences from all altimeter missions (Jason1&2, Envisat and TOPEX/Poseidon)

➢ Tide gauge quality control performed and displayed as a cross-comparison indicator on the AVISO website (Fig. 6) and used to select relevant tide gauges for altimeter/in-situ comparisons

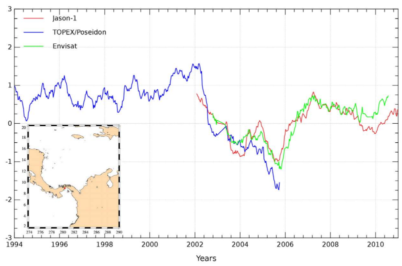


Fig. 6: SSH differences between the main altimeter data and Balboa tide gauge measurements using an 8 month Lanczos filter (and location of the Balboa tide gauge in the Panama Canal)

The comparison of tide gauge measurements with altimeter data makes it possible to detect drifts or jumps in in-situ time series

Conclusion

This study focuses on results deduced from the comparison method between altimetry and in-situ measurements (tide gauges, Argo T/S profiles) and the way these data are used as input for:

1 detecting global and regional drifts in the altimeter Sea Surface Height

2 evaluating new standards in altimeter products

3 providing a cross-comparison indicator on tide gauges using multiple altimetric systems (Jason1&2, Envisat and TOPEX/Poseidon, available on the AVISO website)

- (1) Valladeau et al., 2012: Comparing altimetry with tide gauges and Argo profiling floats for data quality assessment and Mean Sea Level studies. Marine Geodesy 2012, DOI: 10.1080/01490419.2012.718226

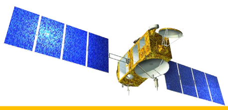
- (2) CLS Aviso website: http://www.aviso.oceanobs.com

- (3) Chambers, D.P., 2006: Evaluation of New GRACE Time-Variable Gravity Data over the Ocean. Geophys. Res. Lett., 33(17), LI7603

11.4. Combination of multiple techniques to provide reliable in-situ time series

G53B-1129

How to combine multiple techniques to provide reliable in-situ time series for climate applications



Guillaume Valladeau (1), Laurent Soudarin (1), Médéric Gravelle (2)
(1) Collecte Localisation Satellite (CLS), Toulouse, France.
(2) Université de La Rochelle (ULR), UMR 6250 LIENSS, La Rochelle, France
E-mail: guillaume.valladeau@cls.fr

Keywords
Vertical movements at tide gauge locations
Geodetic techniques (DORIS, GPS)
Altimetry
Thule tide gauge

Tide gauge measurements require a rigorous quality control since measurements are highly sensitive to biases or drifts in datasets, especially vertical movements.

The combination of multiple techniques is a way of providing relevant tide gauge time series for end-users and climate applications

In this study, DORIS and GNSS are considered as complementary techniques to accurately determine the crustal motion at a cm (or better) and mm/yr accuracy for the positions and velocities

References

(1) Valladeau et al., 2012: Comparing altimetry with tide gauges and Argo profiling floats for data quality assessment and Mean Sea Level studies. Marine Geodesy 2012, DOI: 10.1080/01490419.2012.718226

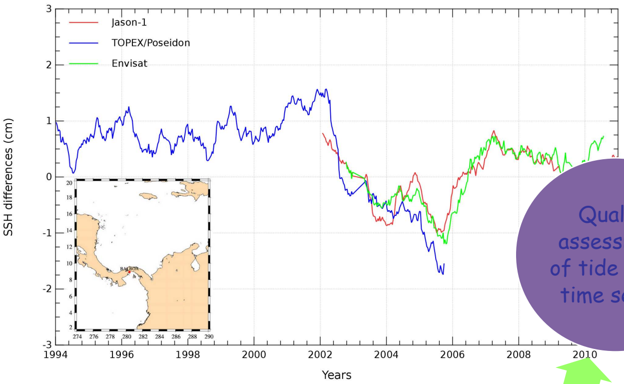
(2) Prandi et al, 2012: A new estimation of mean sea level in the Arctic Ocean from satellite altimetry. Marine Geodesy 2012, DOI:10.1080/01490419.2012.718222

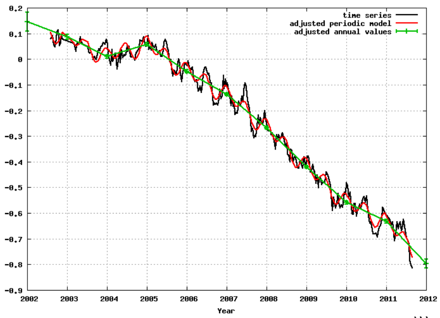
(3) Ablain et al., 2009: A new assessment of the error budget of global mean sea level rate estimated by satellite altimetry over 1993-2008, Ocean Sci., 5, 193-201

(4) Santamaría-Gómez et al., 2012: Mitigating the effects of vertical land motion in tide gauge records using a state-of-the-art GPS velocity field. Global and Planetary Change, Vol. 98-99, 6-17

➢ Cross-comparison of altimeter and in-situ SSH differences from all altimeter missions (Jason1&2, Envisat and TOPEX/Poseidon)

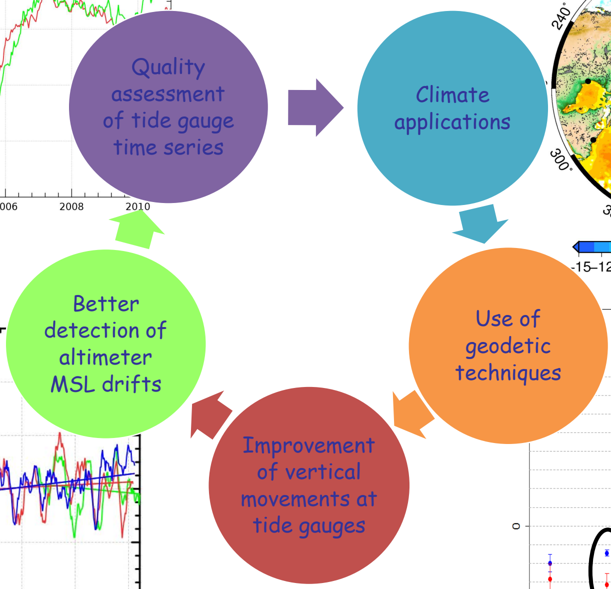
➢ Used to select relevant tide gauges for altimeter/in-situ comparisons from the 3 main missions, Jason-1, TOPEX/Poseidon and Envisat **(1)**

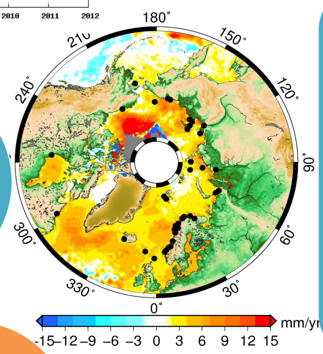




➢ Equivalent water height deduced from GRACE data at the Thule tide gauge location (courtesy of J.M. Lemoine)

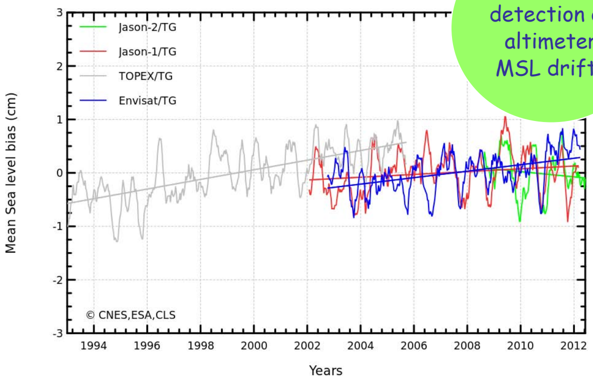
➢ Results can be further explained thanks to the complementarity of altimeter, tide gauge and geodetic time series

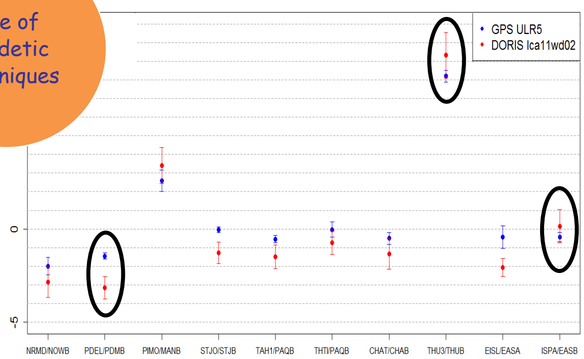




➢ Altimeter datasets can be validated thanks to tide gauges which provide independent sea level data

➢ New dataset of weekly gridded sea level anomaly fields over the Arctic region from 1993 to 2009 **(2)**





➢Tide gauge measurements = independent sources of comparison to better assess the multiple system performances and detect potential drifts in altimeter time series

➢ Good reliability of both Jason-1 and Envisat global MSL trend estimates with regard to tide gauges on the 2002-2012 time period (respectively 0.3 mm/yr and 0.6 mm/yr)

➢ Error of the method: +/- 0.7 mm/yr **(3)**

➢ Comparison of vertical movements deduced from both ULR5 GPS solutions **(4)** and lca11wd02 DORIS solutions performed by CNES-CLS

➢ Computation of linear trends on tide gauge time periods and calculation of the uncertainties with the CATS software (GPS coordinate time series analysis software)

➢ On 10 tide gauge sites colocated with GPS and DORIS stations (distance < 15 km), differences are lower than 3σ
-> GPS and DORIS velocities are coherent with each other

➢ Quality assessment of tide gauges is made possible thanks to the use of geodetic time series and the comparison with altimetry

➢ Results on the combination of multiple techniques have to be further investigated to understand the differences between these contributions

➢ Improvements on tide gauge time series lead to reliable datasets for climate applications such as new altimeter products or studies about Arctic sea ice loss considering GRACE data

Tide Gauge name (Time Period)	Tide Gauge trend (mm/yr)	Colocated Envisat trend (mm/yr)	Colocated DORIS trend (mm/yr)	Colocated GPS trend (mm/yr)
Ponta Delgada (2002-2011)	11.9 +/- 0.54	-3.86 +/- 0.92	-3.16 +/- 0.60	-1.46 +/- 0.17
Thule (2007-2011)	-20.2 +/- 3.2	-16.7 +/- 7.66	9.32 +/- 1.24	8.21 +/- 0.32
Easter Island (2004-2010)	-1.97 +/- 0.06	0.42 +/- 0.26	0.15 +/- 0.90	-0.43 +/- 0.25

Collecte Localisation Satellites
8-10 rue Hermes
31520 Ramonville Saint-Agne - France

AGU Fall Meeting
San Francisco, December 2012

11.5. Estimation of previous altimeter SSH improvements

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

Reprocessings of SSALTO/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 [16]). 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 30. On the left, a drift is observed on the TOPEX-A time period, corresponding to instrumental problems (OSTST, Seattle 2009 [26]). 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.

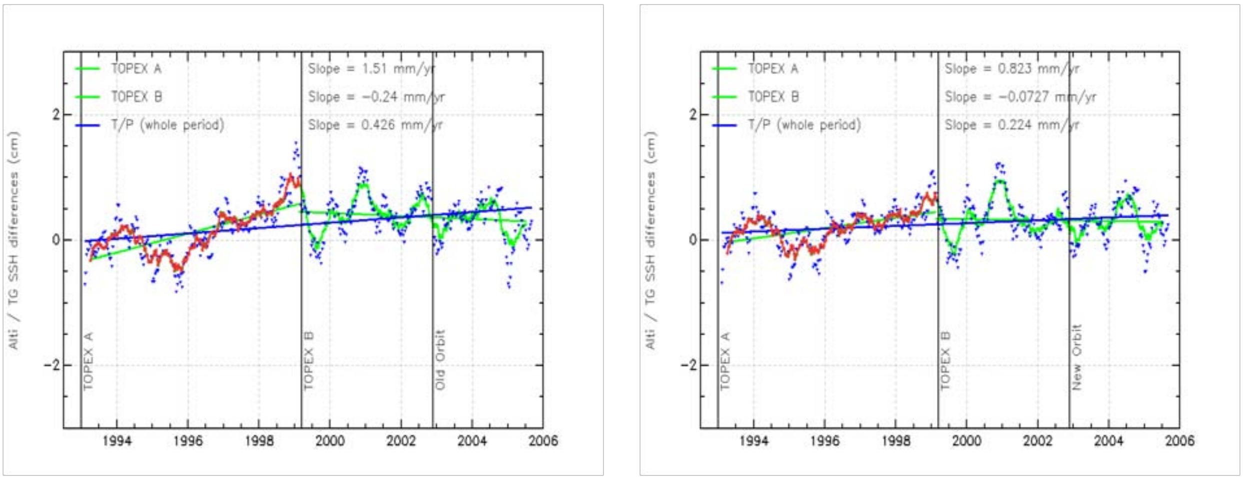


Figure 30: *Impact of the new 2-parameters Sea State Bias computed with Gourrion's wind on the monitoring of the mean altimeter/in-situ tide gauge differences. Left: Old SSB (Chelton's wind). Right: New SSB (Gourrion's wind)*

11.5.2. Impact of the new PTR data processing on Envisat V2.1 GDR products

As already discussed earlier in part 4.2. concerning Envisat, some discrepancies can come from corrections applied to the raw Sea Surface Height provided by the altimeter. Improvements of new altimeter standards can be assessed thanks to tide gauges measurements to make the SSH more accurate. An example is described here when applying a new PTR data processing (that corrects for the internal path delay and attenuation) in the SSH calculation.

Since tide gauges measurements are a way of estimating new standards in altimeter products, they have been used to demonstrate the relevance of a new PTR correction in the frame of the Sea Level Climate Change Initiative (SL-CCI) project supported by ESA (*www.esa-sealevel-cci.org*). In this frame, a study has been realized to compare the Envisat SSH time series deduced from 2 different PTR corrections with tide gauges measurements. As shown on figure 31, on the 2004-2010 time period, the monitoring of Envisat data when adjusting the new PTR displays an improvement in the consistency with tide gauges compared to the previous PTR correction. The slope differences between altimetry and tide gauges becomes on the same order of Jason-1 results, with a global trend of 0.2 mm/yr and a formal adjustment error of 0.17 mm/yr, in agreement with the theory and the multi-mission cross calibration studies. Such results demonstrate the ability of tide gauges measurements to quantify the improvement of the long-term MSL drift evolution on Envisat. Therefore, using external and independent datasets such as tide gauges is relevant in the estimate of new altimeter standards and thus the computation of new altimeter products.

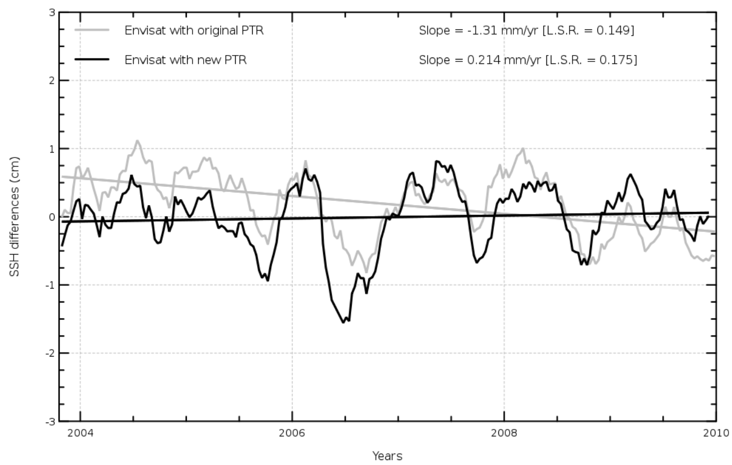
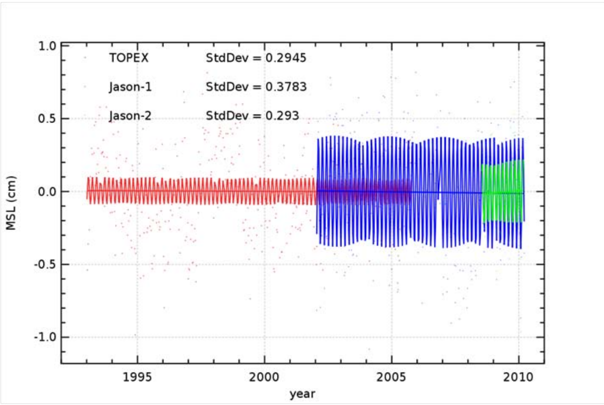


Figure 31: *Sea level differences between Envisat altimeter and tide gauges over the 2004-2010 time period (cm). Grey curve: Envisat original data. Black curve: Envisat corrected from the new PTR data processing.*

11.6. Particular investigations using tide gauge measurements

11.6.1. Analysis of the 58.74 day signal observed on Jason-1&2 and TOPEX data

As shown on figure 32 left, global MSL time series 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 32 right) displays stronger amplitude patterns for Jason-1 (greater than 5 mm) in the -40°/40° latitude area.



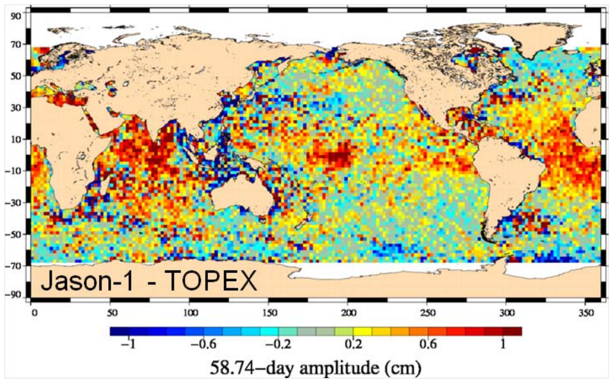


Figure 32: *Left: 58.74 signal day on global MSL after removing the global trend. Right: Map of the 58.74 day signal observed between Jason-1 and TOPEX.*

To check such results obtained between Jason-1 and TOPEX, in-situ measurements were used and computed 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 33).
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.

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 34), 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).

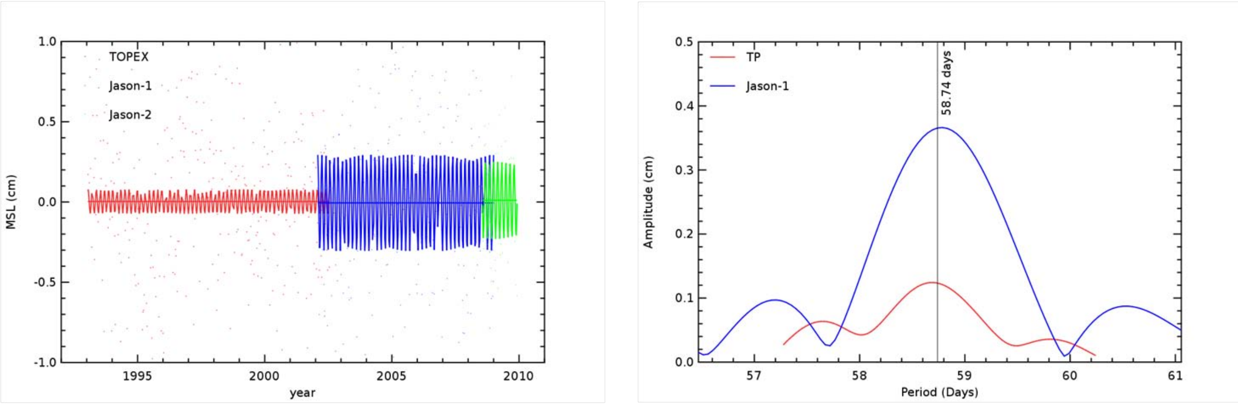


Figure 33: *Left: 58.74 signal day on altimeter/tide gauges SSH differences after removing the global trend. Right: Periodogram on altimeter/tide gauge SSH differences focused on 58.74 day signal*

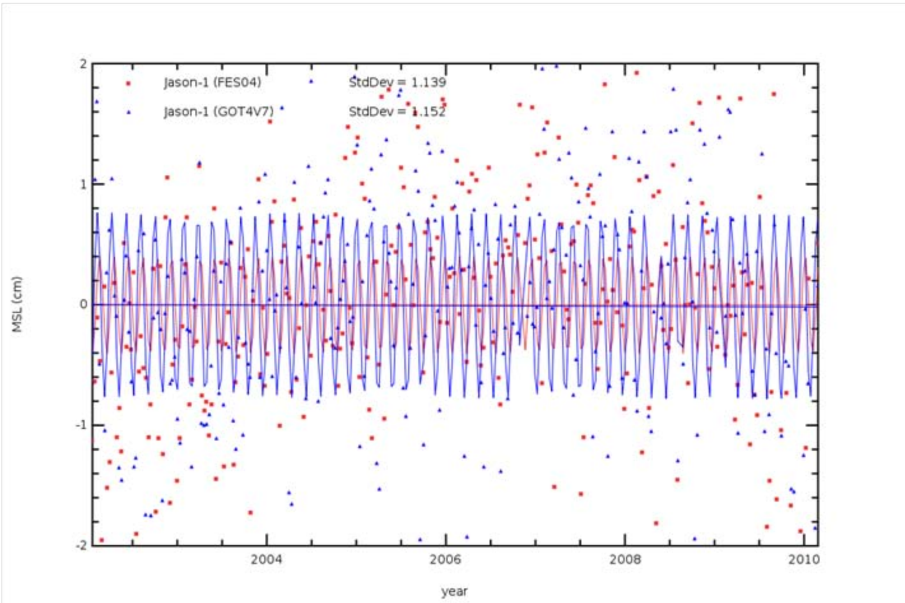


Figure 34: *Spatial amplitude of the 58.74 day signal on Jason-1/tide gauges SSH differences using GOT4.7 and FES04 tide models*

11.6.2. Assessment of the Glacial Isostatic Adjustment on tide gauges time series

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 (Woppelmann et al., 2007 [30]). This part of the document focuses on the first point, related to the Glacial Isostatic Adjustment (GIA).

Indeed, so as to make the comparison with altimeter data more relevant, the effect of GIA on tide gauges has to be taken into account. To date, 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). In this study, the two main GIA models which are ICE-5G VM2 and ICE-5G VM4 are considered (Peltier, 2004 [23]). Figure 35 displays the global trends derived from these both datasets. Since only slight differences remain between these ice models, it has been decided to correct tide gauges time series from the ICE-5G (VM4), which is the most recent and updated GIA model (it is computed with the VM4 viscosity profile in the Earth model) and thus provides the most accurate assessment of GIA trends at each tide gauge location.

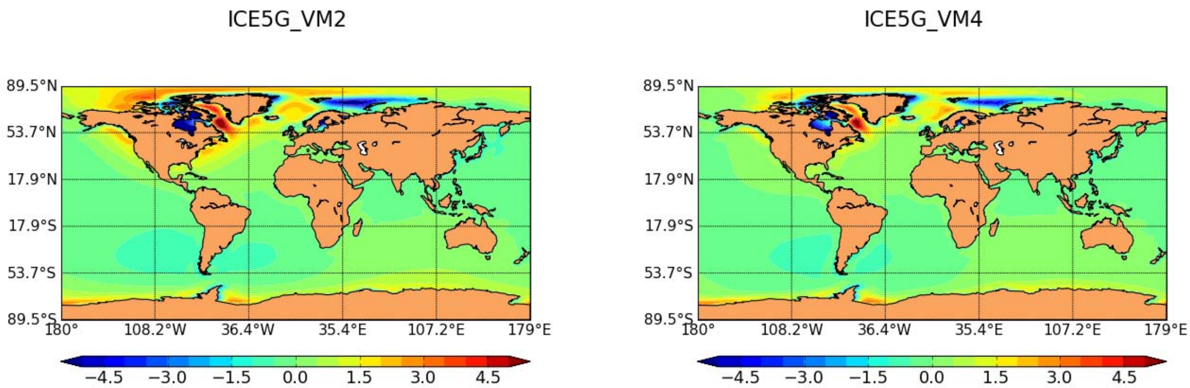


Figure 35: *Map of the trends of GIA derived from the ICE-5G model from Peltier (mm/year). Left: VM2. Right: VM4.*

Considering Jason-1 (figure 36 left), the global trend of the time series considering the ICE-5G (VM4) GIA model is reduced to 0.1 mm/year (red curve), which seems to slightly improve the consistency between both datasets. On the Envisat monitoring (figure 36 right), the slope is -2 mm/year considering the ICE-5G (VM4) GIA model (red curve). Linked to previous results (see part 11.5.2.), the consistency should be improved with the new PTR correction.

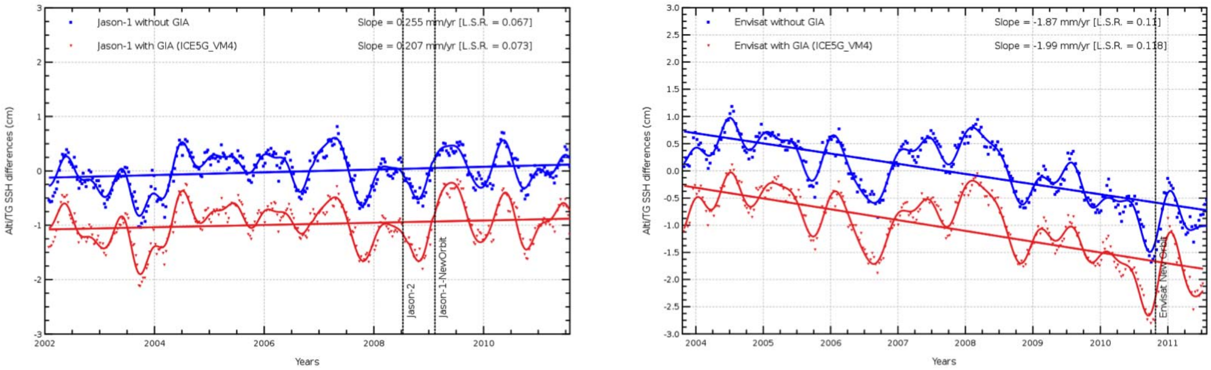


Figure 36: *Impact of the ICE-5G (VM4) ice model on the cycle by cycle monitoring of mean SLA differences between altimeter and tide gauges measurements. Left: Jason-1. Right: Envisat.*

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. Thus, studies will have to be performed in the next years to perform a new method to compute an accurate vertical movement correction at tide gauges location using GPS data.

11.6.3. Sea level variability in the Arctic Ocean

This part aims at comparing monthly tide gauges time series from the Pemanent Service for Mean Sea Level (PSMSL) at high latitudes to the reprocessed Arctic gridded products derived from DUACS DT data. Results deduced from this study has underlined several problems on both in-situ and altimeter data in this area, such as discontinuities on data time series or a strong impact of the GIA. Indeed, while the map of maximum of correlation between altimetry and tide gauges (figure 37 left) displays a pretty good consistency between both datasets along the Norvegian coasts, correlations strongly decrease when evolving inside the basin. However, the comparison between altimeter data and tide gauges measurements lead to multiple interesting conclusions:

- Map of the RMS of SLA for both altimetry (background colors) and tide gauges (colored circles surimposed) as displayed on figure 37 right confirms the idea of a strong variability area in the East Siberian Sea, which is therefore not an error in the altimeter data.
- High resolution altimeter gridded products (1/8° spatial resolution) are able to render the same coastal dynamical effetcs as recorded with tide gauges measurements (see figure 37 bottom where the correlation suddenly decreases over the continental shelf).
- However, because of errors related to the GIA on tide gauges and large uncertainties on altimetry at these latitudes, the processing sequence cannot yet provide an accurate estimate of a potential drift on altimeter data regarding tide gauges measurements.

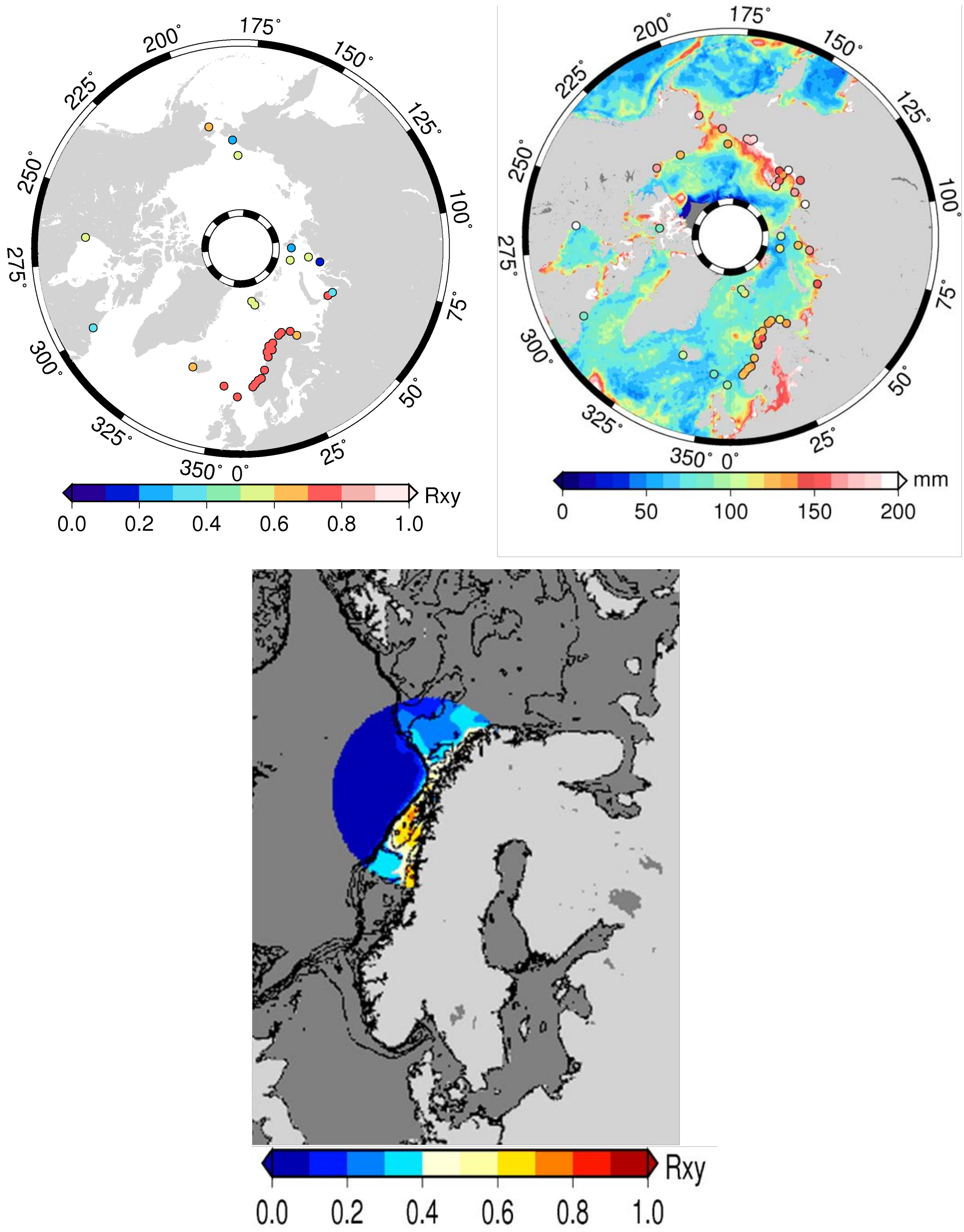


Figure 37: *Left: Maximum of correlation between reprocessed Arctic gridded products derived from DUACS DT data and tide gauges measurements in the Arctic Sea. Right: RMS of SLA for both altimetry (background colors) and tide gauges (colored circles surimposed). Bottom: Correlation coefficients between reprocessed Arctic gridded products derived from DUACS DT data and tide gauges measurements in the Arctic Sea.*

11.6.4. Evaluation of the impact of the new 2011 Mean Sea Surface on the altimeter long-term trend assessment

One of the goals of the method developed using tide gauge measurements aims at evaluating new altimeter standards to improve the MSL long-term trend assessment. This comparison is accurately performed along coastal areas when considering the whole tide gauge database available.

In this study, 10-days altimeter grids are computed for Jason-1 and Envisat on their whole altimetric time period. Results are then compared with in-situ measurements on the same subsample of tide gauges. Several diagnoses are computed to make this comparison reliable:

- The temporal evolution of SSH differences between tide gauges and altimetry data over all the altimetry period
- The difference of histograms between altimeter and tide gauges SSH differences
- The map of differences between altimeter and tide gauges SSH differences

All these diagnoses aims at providing a relevant evaluation on the capability of the new CNES/CLS MSS 2011 to improve the MSL long-term drift assessment.

11.6.4.1. Temporal evolution of SSH differences between tide gauges and altimetry data over all the altimetry period

Focusing on both Jason-1 and Envisat results, amplitudes and trends of SSH differences between Jason-1 and Envisat are in agreement whatever the MSS considered. Indeed, the slopes deduced from the comparison with the new 2011 MSS are -0.22 mm/yr for Jason-1 and -0.04 mm/yr for Envisat on their entire time period whereas it is respectively -0.08 mm/yr and -0.02 mm/yr considering the 2001 MSS (see figure 38).

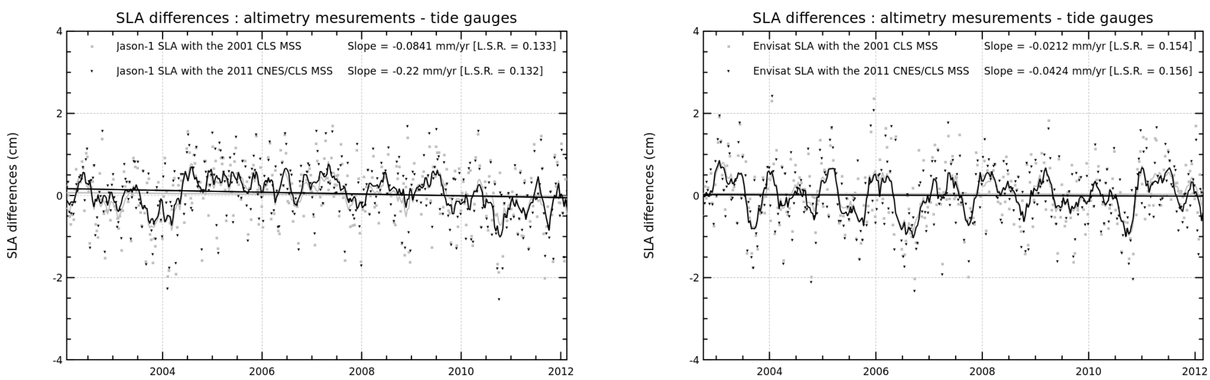


Figure 38: *SSH differences between altimetry and tide gauges using the 2001 CLS (grey) and the 2011 CNES/CLS (black) Mean Sea Surface. Left: Jason-1. Right: Envisat*

These first results tend to demonstrate that the use of the new 2011 CNES/CLS has a slight impact on the MSL long-term drift assessment, with trends on the same order, within the error of the method of *pm* 0.5 mm/yr. Results are also in favor of the reliability of the altimetry/tide gauges comparison method since both MSS provide homogeneous with regard to the comparison with tide gauges along coastal areas.

11.6.4.2. Difference of histograms between altimeter and tide gauges SSH differences

Considering histograms of the variance differences between the two MSS within the SSH computation (figure 39), results demonstrate a slight but global improvement for both Jason-1 (figure 39 left) and Envisat (figure 39 right) space missions. The better enhancement on Jason-1 than on Envisat (where the mean of variance differences are respectively 1 cm^2 and 0.5 cm^2) can originate:

- In the greater number of tide gauges considered (144 on Jason-1, 129 on Envisat)
- In the distance of correlation between altimetry and tide gauges. Thus, MSS values can be more or less accurate when considering closer or further altimeter measurements from the tide gauges.

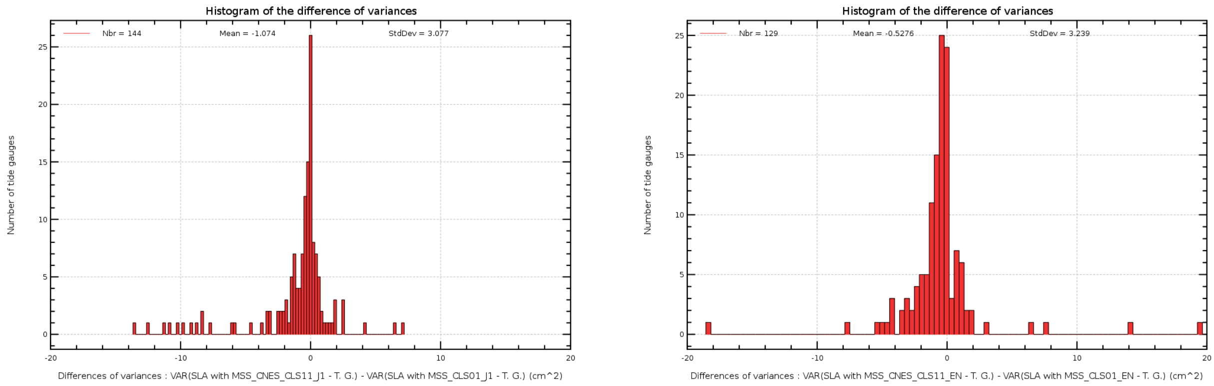


Figure 39: *Histograms of the difference of variances between altimetry and tide gauges using the 2001 CLS and the 2011 CNES/CLS Mean Sea Surface in the altimeter SSH computation. Left: Jason-1. Right: Envisat*

Thus, in spite of some local variance differences greater than 10 or 20 cm^2 which are observed on the comparison between altimetry and tide gauges, results are homogeneous for most of the tide gauge dataset, which is in favor of a slight impact on the new 2011 CNES/CLS MSS compared to the 2001 CLS one.

11.6.4.3. Map of differences between altimeter and tide gauges SSH differences

Previous results on the homogeneity of the new M2011 CNES/CLS MSS applied on the altimetry/tide gauge SSH comparisons are displayed as maps of the difference of variances (figure 40) between altimetry and tide gauges for both missions Jason-1 and Envisat. The aim of these maps is to complete this study in locating and analyzing the significant discrepancies between altimetry and tide gauges concerning Jason-1 and Envisat.

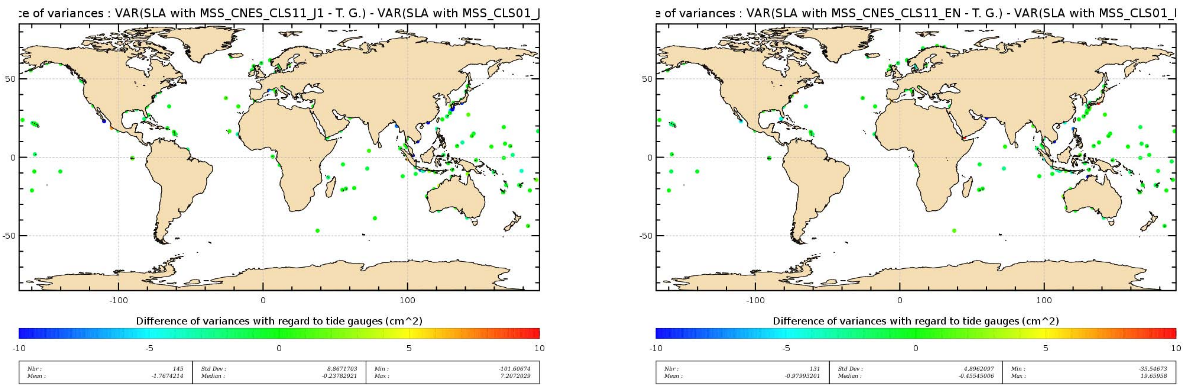


Figure 40: *Map of the difference of variances between altimetry and tide gauges using the 2001 CLS and the 2011 CNES/CLS Mean Sea Surface in the altimeter SSH computation at tide gauge locations. Left: Jason-1. Right: Envisat*

2 tide gauges have been selected in Mexico (Cabo San Lucas, WO0034) and Indonesia (Padang, WO0107) and display some discrepancies on Jason-1 and Envisat. Figure 41 left displays the Jason-1 altimeter SSH monitoring collocated to the Cabo San Lucas tide gauge when considering both 2001 CLS and 2011 CNES/CLS MSS. The comparison of the two MSS in the altimeter SSH computation thanks to tide gauge measurements seems to reveal an abnormal behavior of the 2001 CLS MSS in the consistency between both altimetric and in-situ signals from 2009 onwards. Comparing different Jason-1 along-track MSS time series collocated to the Cabo San tide gauge is of interest. Thus, figure 41 right display both 2001 CLS and 2011 CNES/CLS time series superrimposed to the 2010 DTU Mean Sea Surface one. Considering the 2011 CNES/CLS or the 2010 DTU MSS lead to better results near this tide gauge, due to the coastal computation of the Mean Sea Surface. Therefore, the use of the new CNES/CLS 2011 MSS is considered as an improvement applied to this coastal area.

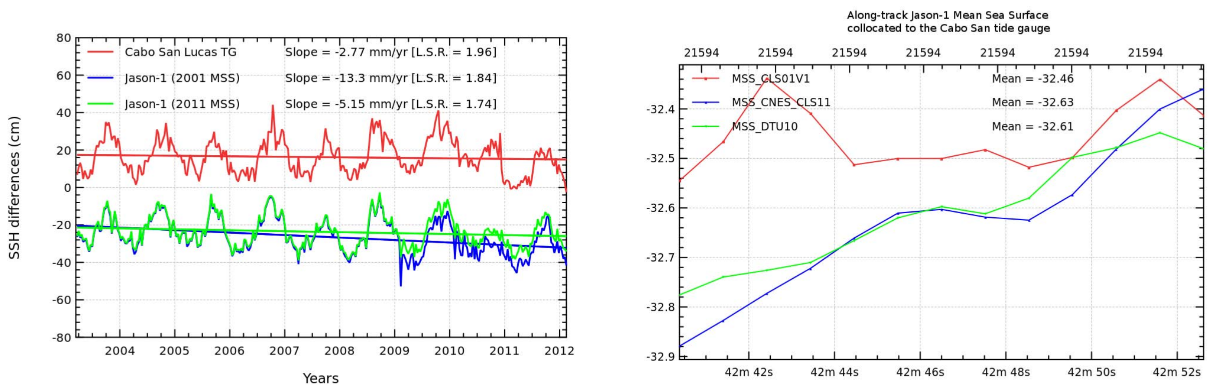


Figure 41: *Left: Monitoring of the collocated Jason-1 and tide gauge SSHs for the Cabo San Lucas tide gauge. Right: Along-track Jason-1 Mean Sea Surface collocated to the Cabo San tide gauge on 14 February 2009. Red: 2001 CLS MSS. Blue: 2011 CNES/CLS MSS. Green: 2010 DTU MSS.*

Another example of such behavior is displayed on the Padang tide gauge concerning Envisat (figure 42). Although this tide gauge obviously needs to be corrected from crustal movements, the comparison of the collocated Envisat SSH considering both MSS reveals significant differences in term of trends (13 mm/year with the 2011 CNES/CLS MSS while it is 20 mm/year with the 2001 CLS MSS) in spite of the displayed similar amplitudes of both altimeter SSH time series. Slope differences are therefore sensitive to slight variations of the MSS.

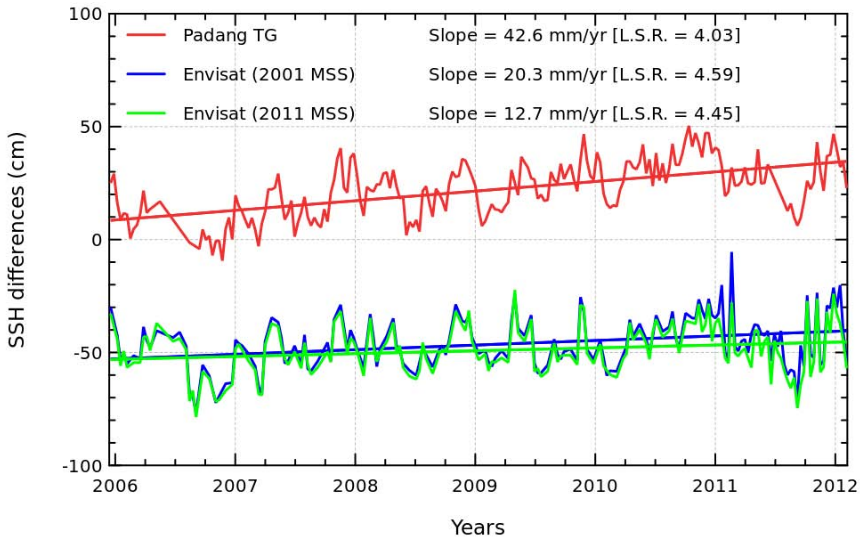


Figure 42: *Monitoring of the collocated Envisat and tide gauge SSHs for the Padang tide gauge*

Note that such differences have been highlighted on a few collocated time series, which does not significantly impact the evaluation of the new 2011 CNES/CLS MSS on the altimetry/tide gauge comparison.

11.6.4.4. Conclusion

The impact of the new 2011 CNES/CLS MSS is slight regarding altimeter/tide gauge SSH differences. Global results are consistent with the use of the 2011 CLS MSS in the altimeter SSH computation. For most of tide gauges, the homogeneity is of the same order of the 2001 CLS MSS. However the new 2011 CNES/CLS MSS reveals some significant improvements at several tide gauge locations. Thus, this new MSS has to be routinely computed in the altimetry/tide gauge processing sequence.