CalVal Envisat

Envisat RA2/MWR ocean data validation and cross-calibration activities. Yearly report 2014.

Contract No 104685. Lot 1.2A

Reference : CLS-NT-14-253

Nomenclature : SALP-RP-MA-EA-22396-CLS

Issue : 1rev 1

Date : 2014,December

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

Chronology Issues :		
Issue :	Date :	Reason for change :
1.0	01/12/2014	Created
1.1	13/01/2015	N. Picot reviews taken into account

	AUTHORS	COMPANY	DATE	INITIALS
WRITTEN BY	M. Guibbaud A. Ollivier	CLS CLS		
CHECKED BY	S. Dalessio	CLS		
APPROVED BY	JP. Dumont	CLS		

Index sheet :	
Context	
Keywords	Envisat, Jason-1, Jason-2, Calval, , MSL, orbits, reprocessing
hyperlink	

Distribution :		
Company	Means of distribution	Names
CLS/DOS	electronic copy	G. Dibarboure V. Rosmorduc
CNES	electronic copy	thierry.guinle@cnes.fr nicolas.picot@cnes.fr Jean-Damien.Desjonqueres@cnes.fr aqgp_rs@cnes.fr dominique.chermain@cnes.fr delphine.vergnoux@cnes.fr

List of tables and figures :

List of Tables

1 Editing criteria . . . 14
2 Altimetric correction updates . . . 33
3 Geophysical corrections used following the periods . . . 41

List of Figures

1 *Effect of the drifting phase near French coast. Cycles 95 to 113.* . . . 4
2 *Monitoring of the percentage of missing measurements relative to what is theoretically expected over ocean* . . . 9
3 *Envisat missing measurements for the last entire cycle (112)* . . . 10
4 *Pass segments unavailable more than 5 times between cycles 82 and cycle 92. The color indicates the occurrence of unavailability* . . . 11
5 *Cycle per cycle percentages of missing MWR measurements* . . . 12
6 *% of edited points by sea ice flag over ocean* . . . 13
7 *Cycle per cycle percentages of edited measurements by the main Envisat altimeter and radiometer parameters:* ***Top-Left****) Rms of 20 Hz range measurements > 25 cm,* ***Top-Right****) Number of 20-Hz range measurements < 10,* ***Middle-Left****) Square of off-nadir angle (from waveforms) out of the [-0.2 deg2, 0.16 deg2] range,* ***Middle-Right****) Dual frequency ionosphere correction out of [-40 , 4 cm],* ***Bot-Left****)Ku-band Significant wave height greater than 11 m, Ku band backscatter coefficient out of the [7 dB, 30 dB] range,* ***Bot-Right****) MWR wet troposphere correction out of the [-50 cm, -0.1 cm] range.* . . . 16
8 *Cross track deadband measured at equator by comparison to a theoretical track before the drifting phase.* . . . 17
9 *SSH-MSS out of the [-2, 2m] and edited using thresholds on the mean and standard deviation of SSH-MSS on each pass* . . . 18
10 ***left****) Mean per cycle of the number of 20 Hz elementary range measurements used to compute 1 Hz range.* ***right****) Mean per cycle of the standard deviation of 20 Hz measurements.* . . . 20
11 *Histogram of RMS of Ku range (cm). Cycle 112* . . . 21
12 *Mean per cycle of the square of the off-nadir angle deduced from waveforms (deg^2).* 21
13 *Histogram of off-nadir angle from waveforms (deg^2). Cycle 112* . . . 22
14 *Global statistics (m) of Envisat Ku and S SWH* ***top****) Mean and Standard deviation.* ***Middle:*** *Mean and standard deviation of Ku-S band SWH* ***bottom****) Mean Envisat-Jason-1 Ku SWH differences at 3h EN/J1 crossovers.* . . . 23
15 *Histogram of Ku SWH (m) Cycle 112* . . . 24
16 *Wind speed from different sources (EN, J1, J2 altimeters and ERA-Interim model).* 25
17 *Global statistics (dB) of* ***Top****) Envisat Ku and S Sigma0 Mean and Standard deviation.* ***Bottom****) Mean Envisat-Jason-1 Ku Sigma0 differences at 3h EN/J1 crossovers.* 26
18 *Histogram of Ku Sigma0 (dB). Cycle 112* . . . 26
19 *Comparison of global statistics of Envisat dual-frequency and JPL-GIM ionosphere corrections (cm).* ***Top****) Mean and standard deviation per cycle of Dual Frequency and GIM correction.* ***Bottom****) Mean and standard deviation of the differences for Envisat and Jason-1* . . . 28

20 *Scatter plot of MWR correction according to ECMWF model (m) (cycle 112 & 113)* 29
21 *Comparison of global statistics of Envisat MWR and ECMWF wet troposphere corrections (cm).* ***top****) Mean and standard deviation per cycle of MWR, JMR and AMR corrections* ***Bottom****) Mean and standard deviation per cycle of the differences versus ECMWF model. Vertical lines represent the major events.* 30
22 *Mean and standard deviation per cycle of the differences of MWR correction versus ERA-Interim* 30
23 *Impact of the SLA reference out of the repeat track on the wavelength between 50km and 500km.* 34
24 *Standard deviation (cm) of Envisat 10-day SSH crossover differences depending on data selection (with a maximum time lag of 10 days). Red: without any selection. Blue: shallow waters (1000 m) are excluded. Green: shallow waters excluded, latitude within [-50S, +50N], high ocean variability areas excluded.* 35
25 *Improvement of mesoscale precision, comparing* ***V2.1 with updates*** *(GDR-D orbits, F-PAC PTR, V2.1b wet tropospheric correction, iterative filtered iono, GOT 4V8 tide model) to* ***V2.1 (after reprocessing)*** 36
26 *Improvement of mesoscale precision, comparing* ***V2.1 with updates*** *(GDR-D orbits, F-PAC PTR, V2.1b wet tropospheric correction, iterative filtered iono, GOT 4V8 tide model) to* ***V1 version (before reprocessing)*** 37
27 *Anticipated updates for the next Envisat reprocessing campaign* 37
28 *MSL computed with last updates: PTR, updated tropo. correction and GDR-D orbit for the period* ***Left****: 2003-2012* ***Right****: 2004-2012* 42
29 *Envisat cycle 112,* ***Left:*** *Data under 20km are removed for drifting missions - Current DUACS solution* ***Right:*** *Data near coasts are recovered with filtering solution directly applied on Sea Level Anomaly (result of filtering is here considered under 30km)* 69

List of items to be defined or to be confirmed :

Applicable documents / reference documents :

Contents

1. Introduction **1**

2. Quality overview **3**

3. Data used and processing **6**
- 3.1. **Data used** 6
- 3.2. **Processing** 6
  - 3.2.1. GDR products and quality assessment method 6
  - 3.2.2. Particular updates added to the GDR products 7

4. Missing and edited measurements **9**
- 4.1. **Missing measurements** 9
- 4.2. **Missing MWR data** 11
- 4.3. **Edited measurements** 12
  - 4.3.1. Measurements impacted by Sea Ice 12
  - 4.3.2. Editing by thresholds 14
  - 4.3.3. Editing on SLA 16

5. Long term monitoring of altimeter and radiometer parameters **20**
- 5.1. **Number and standard deviation of 20Hz elementary Ku-Band data** 20
- 5.2. **Off-nadir angle from waveforms** 21
- 5.3. **Significant Wave Height** 22
- 5.4. **Backscatter coefficient** 25
- 5.5. **Dual frequency ionosphere correction** 27
- 5.6. **MWR wet troposphere correction** 29

6. Sea Surface Height performance assessment **32**
- 6.1. **SSH definition** 32
- 6.2. **Global improvements of SSH quality** 34
  - 6.2.1. Estimation of performance: reduction of the mesoscale error 34
  - 6.2.2. Envisat SSH quality: monomission analysis 34
    - 6.2.2.1. Effect of Envisat Orbit change 34
    - 6.2.2.2. Time varying SSH differences at crossovers 35
    - 6.2.2.3. Regional analysis of mesoscale error 36
- 6.3. **Improved performances of GDR: anticipating the next reprocessing** 37
  - 6.3.1. Envisat CorSSH products: now available in Netcdf-CF format! 38

7. ENVISAT Mean Sea Level Trend **39**
- 7.1. **Envisat MSL becoming more relevant!** 39
- 7.2. **MSL recipe** 40
  - 7.2.1. Mean Sea Level computation details 40
- 7.3. **MSL global time series** 41
- 7.4. **Remaining suspicious behaviours of Envisat global Mean Sea Level** 42

8. Particular Investigations **44**
- 8.1. **Anticipation of the next reprocessing** 44
  - 8.1.1. New ocean tide models performance assessment 44
    - 8.1.1.1. GOT 4V10 ocean tide model performance assessment 44

8.1.1.2. FES 2014 ocean tide model performance assessment 48
8.1.2. OSTST 2014: Getting ready for future reprocessing 57
8.2. **Other analysis performed in 2014** 59
8.2.1. Remaining issues observed on Envisat dataset: refined analysis of Envisat Mean Sea Level 59
8.2.2. Editing improvement for Duacs multimissions process: how to wisely use data near coasts? 68

9. Conclusion **70**

10. Bibliography **71**

LIST OF ACRONYMS

ECMWF	European Center for Medium range Weather Forecasts
GDR-A	Geophysical Data Record version A (before cycle 41 for Envisat mission)
GDR-B	Geophysical Data Record version B (after cycle 41 for Envisat mission)
GIM	Global Ionosphere Maps
IRI	Internationl Reference Ionosphere
MSL	Mean Sea Level
MWR	MicroWave Radiometer
POE	Precise Orbit Estimation
SLA	Sea Level Anomalies
SSB	Sea State Bias
USO	Ultra Stable Oscillator
PTR	Point Target Response

1. Introduction

This report is an overview of Envisat performance assessment and cross calibration studies carried out at CLS during year 2014. It is basically concerned with long-term monitoring of the Envisat altimeter system over ocean.

Before the satellite loss, Envisat GDR data was routinely ingested in the Calval 1-Hz altimeter database maintained by the CLS Spatial Oceanography Division in the frame of the CNES Altimetry Ground Segment (SALP) and funded by ESA through F-PAC activities (SALP contract N° 104685 - lot1.2.A).
In spite of the loss of the satellite on the 8th of April 2012, CLS experts teams continue to improve the mean sea level computation, taking into account analysis of new standards carried out in 2013 and 2014.
The continuation of this work allows to guarantee an optimal data quality level and to prepare the next reprocessing of the whole Envisat dataset.
This annual report concerns the reprocessed data from GDR cycles 6 through 92 and routine 93 to 113 spanning the 10 years (from 14-05-2002 to 08-04-2012) of Envisat life. The cycle 113 is uncomplete because of the loss of Envisat. All relevant altimeter parameters deduced from Ocean 1 retracking, radiometer parameters and geophysical corrections are evaluated and tested.
For further information about the original GDR data before reprocessing, please refer to [13].
A document concerning the impact of reprocessing on the data made in 2011 is also available in the frame of the reprocessing activities (see [85]).

The work performed in terms of data quality assessment also includes cross-calibration with Jason-1, Jason-2 and Cryosat-2 CNES CPP data set. This kind of comparisons between coincident altimeter missions provides a large number of estimations and consequently efficient long-term monitoring of instrument measurements. This enables the detection of instrument drifts and inter-mission biases essential to obtain a consistent multi-satellite data set.

This year, an effort has been made to refine our analysis of the Envisat Mean Sea Level, notably concerning the MSL trend at the beginning of the period (before 2003) which remains unexplained at the moment. Furthermore, we have tried to compare some behavior of MSL trend with known instrumental events. This work takes part of the next reprocessing global anticipation and the result were presented at the QWG (Quality Working Group) in April, 2014.
In the present report, part 8.2.1. presents the results of these investigations through several aspects:
- What happened on **MSL trend before 2003**? Can we establish a link with instrumental behaviour? What could be the other sources of such an observation?
- Complete list of suspicious behaviours observed on **S-Band parameters** and associated analysis.
- Side-B period: summary of the impact notably on waveform parameters.

In parallel with the analysis presented in the previous paragraph, we analysed updated versions of geophysical corrections to continue to prepare the next Envisat whole dataset reprocessing, as we made for some parameters in 2013 (see [17]).
The analysis performed this year concern:
- New **oceanic tide models**; results are gathered in part 8.1.1., concerning GOT 4.10 and FES2014 solutions.
Note that other anticipated updates are analysed, such as two new versions of radiometer wet

tropospheric corrections, taking into account a Side Lobes updated correction and different parameters as entries of neural network.

2. Quality overview

All the information concerning the historical data is available in 2012 and 2013 ([16],[17]) Yearly Reports.

Ra-2 instrumental status:

Due to the permanent RA2 S-band power drop which occurred on January 17th 2008, 23:23:40 (Cycle 65 pass 289) all the S-band parameters, including the dual ionospheric correction and rain flag remain irrelevant and MUST NOT be used from this time.

Instead, users are advised to use the ionospheric correction from GIM model, which is available in GDR data products.

Since the loss of the S-Band at the beginning of year 2008, the solar activity was in a low period, therefore the use of the JPL-GIM model correction instead of the dual-frequency correction in the SSH equation was efficient and data were weakly impacted in terms of variance. In 2011 the solar activity started to increase again and the degradation due to this correction is getting significant. In October 2011 (cyclic report 107), a warning was sent to the community to warn about the increase of the high solar activity which degrades the data.

Since V2.1 data standard the USO correction is included in the range and so it does not need to be taken into account anymore.

Drifting phase:

During the drifting phase, the 35 days cycle was reduced to a 30 day pseudo cycle with a small drift estimated to +/-1.7 km per cycle maximum (at respectively 50 deg Latitude N/S) whereas it does not drift at 38 deg N and S.

The impact on the data was already described in last year yearly report. Only a weak impact is noticed in the data quality (the visible impact concerns the SLA standard deviation) and the new Mean Sea Surface was shown to erase almost all this impact.

Note that the drift was observed to be higher than the one theoretically expected (+/-600m per cycle maximum was expected) see figure 1.

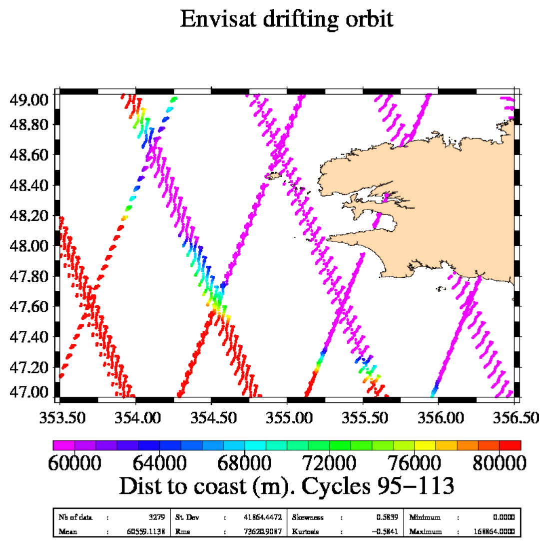


Figure 1: *Effect of the drifting phase near French coast. Cycles 95 to 113.*

Missing measurements:
The unavailability of data over ocean for the whole Envisat dataset is very low, about 3% in average.
The MWR unavailability is also rather stable and low, in average around 2% on the whole dataset.

Long term monitoring of RA-2 and MWR parameters:
The ocean-1 altimeter and radiometer parameters are consistent with expected values. They have a very good stability and high performances, comparable to Jason-1 and Jason-2. A very good availability on every surface and very low editing ratios over ocean are observed since the beginning of the mission. The high frequency content of Ku-band Ra-2 parameters is very stable.

Concerning the radiometer wet tropospheric correction, a degradation was noticed using the MWR after reprocessing in SLA computation. This degradation was systematic for all cycles. Investigations have been processed in 2013 and a preliminary MWR correction has been computed by CLS experts team to correct this degradation and to recover the quality obtained before reprocessing. The associated results are available in 2013 Yearly report ([17]).

Mean Sea Level:
Comparisons between Jason-1 and Envisat Mean Sea Level trend estimated at CLS were carried on.
These studies are possible thanks to:
- The availability of a comparison to a long Jason-1 reprocessed time series.
- The availability of a comparison to in situ datasets (Argo TS profile and Tide gauges) ingested to provide an external source of calibration. These activities are developed in [22] and [23].

With V2.1+ updates (see 2013 Yearly Report ([17]), Envisat reprocessed data enables to provide a Mean Sea Level very close to Jason-1 time series. The first year of the mission (before 2004) still presents a strange behavior, visible on some altimetric parameters. This year an effort was made to analyse Mean Sea Level trend for this period, where remarkable behaviour are noticed. The results of this analysis are presented in the Part 8.2.1..

On the rest of the period, differences between both missions can be analyzed more and more precisely. For instance, wet tropospheric correction still remains a source of error in the trend computation for all missions. Using the ECMWF operational model for the whole mission is not totally satisfactory due to the frequent jumps induced by the model upgrades, which are removed in the case of cross comparisons.
For the next reprocessing campaign, two wet tropospheric corrections are being developped and analysed, in terms of impacts on mesoscale error and on climatic scale.

3. Data used and processing

3.1. Data used

Envisat Geophysical Data Records (GDRs) from cycle 6 to cycle 113 have been used to derive the results presented in this report, for the routine part.
All cycles from 6 to 92 were reprocessed into a standard homogeneous (so called V2.1 version) to the current production since cycle 92 (September 2010). Furthermore, cycles 6 to 9 were processed for the first time, though giving access to 3 additional month of data in 2002. This corresponds to ten years spanning from May 14th 2002 to April 8th 2012.

The Envisat GDR data are generated using two softwares: the IPF, from Level0 to Level1B, and the CMA, from Level1B to Level2.
Conversely to the previous yearly reports, the standard of the whole data is the same: the so-called V2.1 version, resulting from :
- IPF 6.04.L2 Version
- and CMA 9.3 Version

For any information concerning the historical data, please refer to the previous yearly report ([15]).

For cycles 47-48, the altimeter instrument was switched to B-side during 37 days, from the 15/05/2006 14:21:50 to the 21/06/2006 11:37:32 (cycle 47 pass 794 to cycle 48 pass 847), as indicated by a dedicated flag in the input data.

3.2. Processing

3.2.1. GDR products and quality assessment method

To perform this quality assessment work, conventional validation tools are used including editing procedures, crossover analysis, collinear differences, and a large number of statistical monitoring and visualization tools. All these tools are integrated and maintained as part of the CNES SALP altimetry ground segment and F-PAC (French Processing and Archiving Center) tools operated at CLS premises. Each cycle was carefully analyzed before data release to end users. The main data quality features are reported in a cyclic quality assessment report available on http://www.aviso.altimetry.fr/en/data/calval/systematic-calval/validation-reports.html. The purpose of this document is to report the major features of the data quality from the Envisat mission.

As for all other existing altimeters, the Envisat GDR data are ingested in the Calval 1-Hz altimeter database maintained by the CLS Spatial Oceanography Division. This allows us to cross-calibrate and cross-compare Envisat data to other missions. In this study data from Jason-1 (GDRs cycles 1 to 374) and Jason-2 (GDRs cycles 1 to 138) are used. Jason-1 is the most suitable for Envisat cross calibration as it is available throughout the Envisat mission and has been extensively calibrated to T/P (Dorandeu et al., 2004b [36]). Since January 2010 a reprocessing of Jason-1 products in GDR C is available. Therefore, since January 2011 a new homogeneous Envisat/Jason-1 data set is available.

Comparisons between Jason-1 and Envisat altimeter and radiometer parameters have been carried out using 10-day dual crossovers for SSH comparison and 3-hour dual crossovers for altimeter and radiometer comparisons. The geographical distribution of the dual crossovers with short time lags strongly changes from one Envisat cycle to another. Indeed, contrary to Envisat which is sun-synchronous, Jason-1 observes the same place at the same local time every 12 cycles (around 120-day). Following the method detailled in Stum et al. (1998) [103], estimates of the differences are computed using a 120 day running window to keep a constant geographical coverage.

3.2.2. Particular updates added to the GDR products

In addition to the new homogeneous dataset provided by the V2.1 reprocessing only few updates were performed for the validation process. The corrections are directly read from GDR products except for 3 terms:

- **GOT 4.7 ocean tide** is used because its quality was already shown to be better than the FES 2004 or GOTOO available in the products (Yearly report 2009 [13]). Note that for the next reprocessing, the GOT 4.10 version will be used. Performance of this version is analysed in Part 8.1.1..

- **Sea ice flag**: An additionnal flag to the one available in the products was developped to detect data corrupted by sea ice (see 4.3.1.). This flag is more severe than the one available in the product and enables to get rid of an optimized number of spurious data for validation purposes.
- **Filtered dual-frequency ionosphere correction**: A 300-km low pass filter is applied along track on the dual frequency ionosphere correction to reduce the noise of the correction. This correction is applied up to the cycle 64 before the S-Band Power drop (17th January 2008) then the GIM ionospheric correction is used. The new method of filtering developped in 2012 and described in [16], based on an iterative filtering process, will be used for the next reprocessing. Relative SSH performance are summarized in [17].

The few updates still necessary to complete the analysis are listed in the product disclaimer document available at http://earth.esa.int/dataproducts/availability/ [88]. Note that:

- **No S-Band anomaly is present in the data anymore**: Users are yet advised that the S Band anomaly flag available in the GDR must not be accounted for.

- **No more auxiliary files needed: the USO drift is now directly/properly corrected in the range.**
  The whole data serie, including the reprocessed data have to be used without any USO auxiliary file.
  Yet, during the reprocessing, some erroneous jumps in the USO computation of some products were identified.
  To avoid those erroneous jumps, users are advised to consider an appropriated editing of the data (see part 4.3.2.).
  The number of tracks impacted are synthetized in the "Anomaly report" table in Appendix of Yearly Report 2011 (see [15]).

.

The performance of some evolutions has already been analysed in [16] and concerns:
- the F-PAC PTR correction;
- the GDR-D orbit standards;
- An updated wet tropospheric correction, used after reprocessing but degrading the mesoscale error;

In 2013, the list of analysed updates grews up, all the results are available in the 2013 Yearly Report (see [17]).

This year efforts continued and new updates have been developped notably GOT 4V10 and FES 2014 ocean tide models; associated results are gathered in Part 8.1.1..
Note that two new wet tropospheric corrections will be available for the next reprocessing campaign.

4. Missing and edited measurements

This section mainly intends to analyze the ability of the Envisat altimeter system to correctly sample ocean surfaces. This obviously includes the tracking capabilities, but also the frequency of unavailable data and the ratio of valid measurements likely to be used by applications after the editing process.

4.1. Missing measurements

From a theoretical ground track, a dedicated collocation tool allows determination of missing measurements relative to what is nominally expected. The cycle by cycle percentage of missing measurements over ocean has been plotted in Figure 2. The measurement unavailability over the whole mission is about 7% in average. Twelve cycles have more than 10% of unavailability. Several long RA-2 events occurred during cycles 6, 7, 13, 14, 16, 22, 34, 48, 51, 53, 56 which resulted in a significant number of missing passes.
Since May 2008, following an improvement of the data dissemination the average ratio of missing RA2 measurements over ocean is much smaller than the previous years.
On the plot 2, the major impact on the data availability noticed is the signature of the maneuvers to change the orbit on cycles 94-95 (see the cyclic report).
More anecdotally, a collision avoidance and a priority conflict with ATV were also noticed for cycle 101, with a weak impact on data.
Note that the last cycle of Envisat life (113) lasted 19 days and the percentage of missing data is also significant.

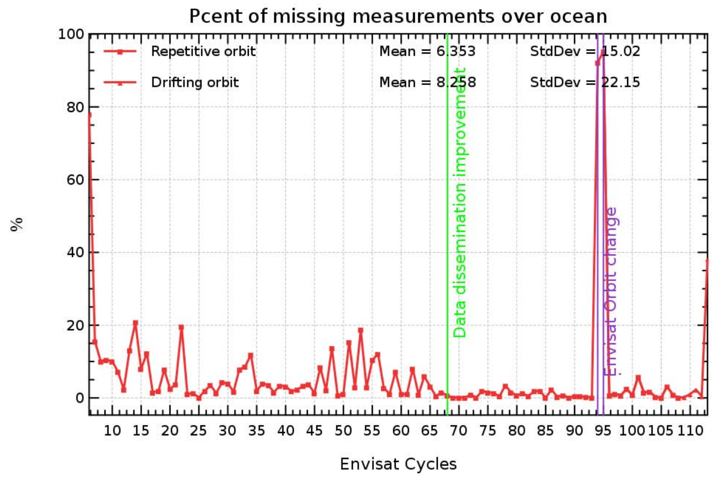


Figure 2: *Monitoring of the percentage of missing measurements relative to what is theoretically expected over ocean*

Figure 3 shows an example of missing measurements for the last complete cycle 112 . The measurements which are missing over the Himalaya are due to the IF Calibration Mode occurring on ascending passes only. This procedure was not always the same: for cycles prior to 55, it was performed over the Himalaya on both ascending and descending passes and for cycles 56 to 66 it was performed on ascending passes only but on the Rocky Mountains as well as on the Himalaya. Afterward, it is performed on ascending passes above the Himalaya only.

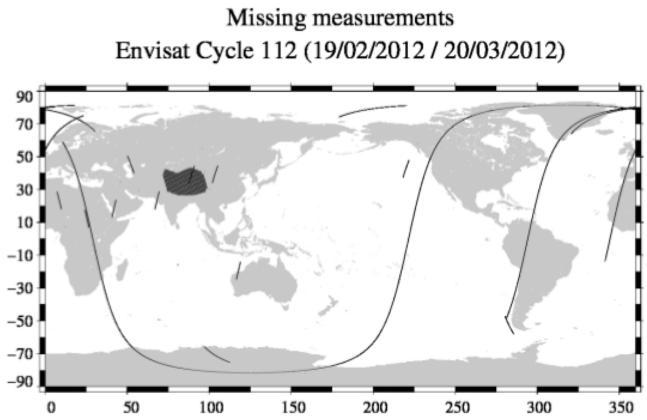


Figure 3: *Envisat missing measurements for the last entire cycle (112)*

It has been noticed that some pass segments were regularly missing. Figure 4 shows the pass segments missing more than 5 times over the 11 last cycles of the reprocessing period (cycles 82-92). Some of them are explained (PLO permanent acquisition sites (ESA/Rome, GAVDOS/ Creta), others are not. Apart from that, the data retention rate is very good on every surface observed. This might be due to the tracker used by Envisat Ra-2, the Model Free Tracker (MFT).

Note that for the drifting phase cycles, this plot cannot be updated due to the method of projection on the theoretical track.

.

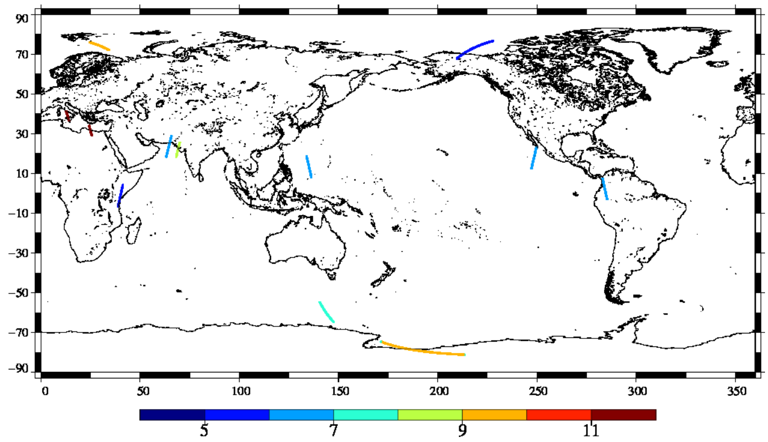


Figure 4: *Pass segments unavailable more than 5 times between cycles 82 and cycle 92. The color indicates the occurrence of unavailability*

Finally, the list of instrument and platform events is available in part 11. Apart from instrumental and platform events, up to 3% of measurements can be missing because of data generation problems at ground segment level: LRAC or PDHS level1 data generation problems or ingestion problems on F-PAC side.

4.2. Missing MWR data

The Envisat MWR exhibits nearly 100% (Dedieu et al., 2005) of availability since the beginning of the mission. However, MWR corrections can be missing in the GDRs due to data generation problems at ground segment level. When the Land/sea radiometer flag is set to land over ocean, it means that the radiometer data is missing. The percentage of missing MWR corrections over ocean has been plotted in Figure 5.

Some cycles are impacted by long period of radiometer missing data, such as cycle 33, 58, 101-102 and 110 for the most impacted. Note that the beginning of the period (before cycle 15) is more concerned by lack of MWR data.

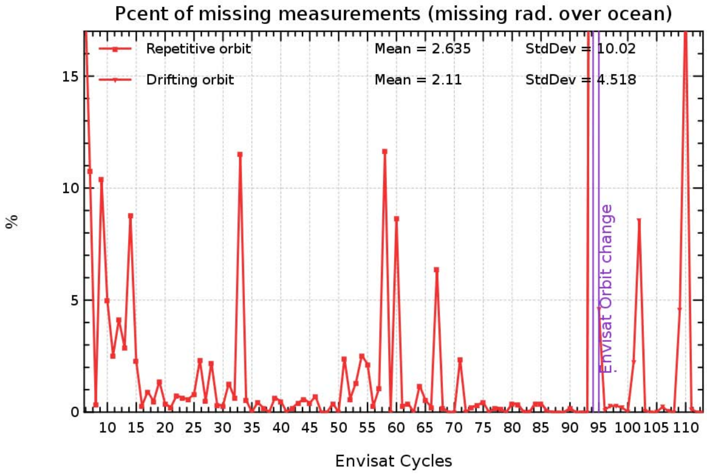


Figure 5: *Cycle per cycle percentages of missing MWR measurements*

4.3. Edited measurements

Data editing is necessary to remove altimeter measurements having lower accuracy. It consists in:
- First: removing data corrupted by sea ice.
- Then, removing measurements out of thresholds tuned for several parameters.
- The third step uses cubic splines adjustments to the ENVISAT Sea Surface Height (SSH) to detect remaining spurious measurements.
- The last step consists in removing entire pass where SSH-MSS mean and standard deviation have unexpected values.

4.3.1. Measurements impacted by Sea Ice

Since Envisat operates between 82N and 82S of latitude, sea ice detection is an important issue for oceanic applications. In the GDR, an ice flag is available but for CalVal purpose, a more severe method of flag was developped to get rid of any spurious data during validation phase. A study performed during the validation phase showed that the combination of altimetric and radiometric criteria was particularly efficient to flag most of the data over ice. The method is described in detail in (Faugere et al, 2003 [45]). We employ the peakiness parameter (Lillibridge et al, 2005 [70]) in conjunction with the MWR- ECMWF wet troposphere difference which appears to be a good means to complement the peakiness parameter in all ice conditions.

The ratio of flagged measurements over ocean is plotted on Figure 6.

In September 2007 (cycles 61-62) and 2011 (cycles 106-107) occured lower values of flagged data for the Northern Hemisphere zone (see blue curve Figure 6), due to low ice extend records.
This was observed by different Envisat instruments including its RA2 altimeter. For the first time, an altimeter satellite could observe open ocean surfaces up to 82˚N above North East Siberia during September-October 2007. Inaccurate Mean Sea Surface or tide models in this area might explain low SLA performances. See further details on http://www.aviso.altimetry.fr/en/

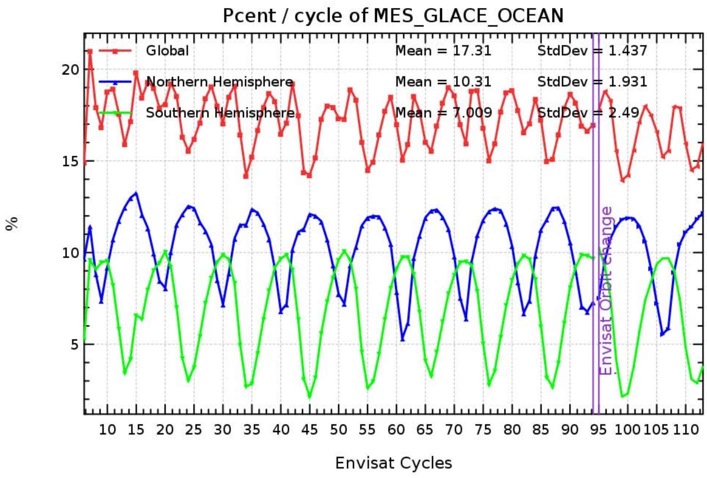


Figure 6: *% of edited points by sea ice flag over ocean*

applications/ice-and-cryosphere/sea-ice/arctic-sea-ice-extent-as-observed-by-envisat-altimeter.html.

A record-breaking maximum of flagged data also occurred for the Southern Hemisphere zone around cycles 95-96 (end of 2010), see green curve Figure 6.

4.3.2. Editing by thresholds

The second step of the editing procedure consists in using thresholds on several parameters. The minimum and maximum thresholds used in the routine quality assessment are given in table 1.

Parameter	Min thresholds	Max thresholds
Sea surface height (m)	−130	100
Variability relative to MSS (m)	−2	2
Number of 18Hz valid points	10	–
Std deviation of 18Hz range (m)	0	0.25
Off nadir angle from waveform (deg2)	−0.200	0.160
Dry troposphere correction (m)	−2.500	−1.900
Inverted barometer correction (m)	−2.000	2.000
MWR wet troposphere correction (m)	−0.500	0.001
Dual Ionosphere correction (m)	−0.200	−0.001
Significant waveheight (m)	0.0	11.0
Sea State Bias (m)	−0.5	0
Backscatter coefficient (dB)	7	30
Ocean tide height (m)	−5	5
Long period tide height (m)	−0.500	0.500
Earth tide (m)	−1.000	1.000
Pole tide (m)	−5.000	5.000
RA2 wind speed (m/s)	0.000	30.000

Table 1: *E*diting criteria

The thresholds are maintained constant throughout the ENVISAT mission, so that monitoring the number of edited measurements allows a survey of data quality. The percentage of edited measurements over ocean for the main altimeter and radiometer parameters has been plotted in Figure 7.
For almost all the plots, Cycle 6 presents high values of edited percentage. This is probably due to the instrument tests (shift of band emission, see cyclic report...) and to the small amount of available data (only 242 passes produced over 1002). Similarly, cycles 95 and 96 have few data

(orbit change maneuvers). This metric is not fully relevant for these cycles.
The RMS of elementary measurements has the strongest ratio among the altimeter parameters, more than 1% in average with a slight annual oscillation probably due to sea state seasonal variations.
The number of elementary measurements has a surprisingly low ratio compared to other missions except for cycles 14 and 20 when wrong configuration files were uploaded on-board after a RA-2 event.
The square of the off-nadir angle derived from waveforms leads to very stable editing ratio. Variations of this parameter can reveal actual platform mispointing, if any, but can also reveal waveform contamination by rain or by sea-ice. It is indeed computed from the slope of the waveform trailing edge. No seasonal signal is visible which may prove that the sea-ice detection method is efficient. Note also a small decrease of the value after the orbit shift, as already reported in the commissionning phase and stressed at ESA QWG Meetings 16 and 17.
The dual frequency ratio shows a very slight increasing trend from cycles 15 to 65 until the S-Band drop (on A-Side cycle 65 and during cycle 47-48 on B-Side configuration).
The editing on Ku-band SWH and sigma0 threshold are stable, though slightly higher than for historical data processing because the null SWH class now includes more data.
Concerning MWR ratios, it presents a significant annual signal. This signal was investigated and shown to be due to a residual annual signal in the ice coverage of Artic shelf.

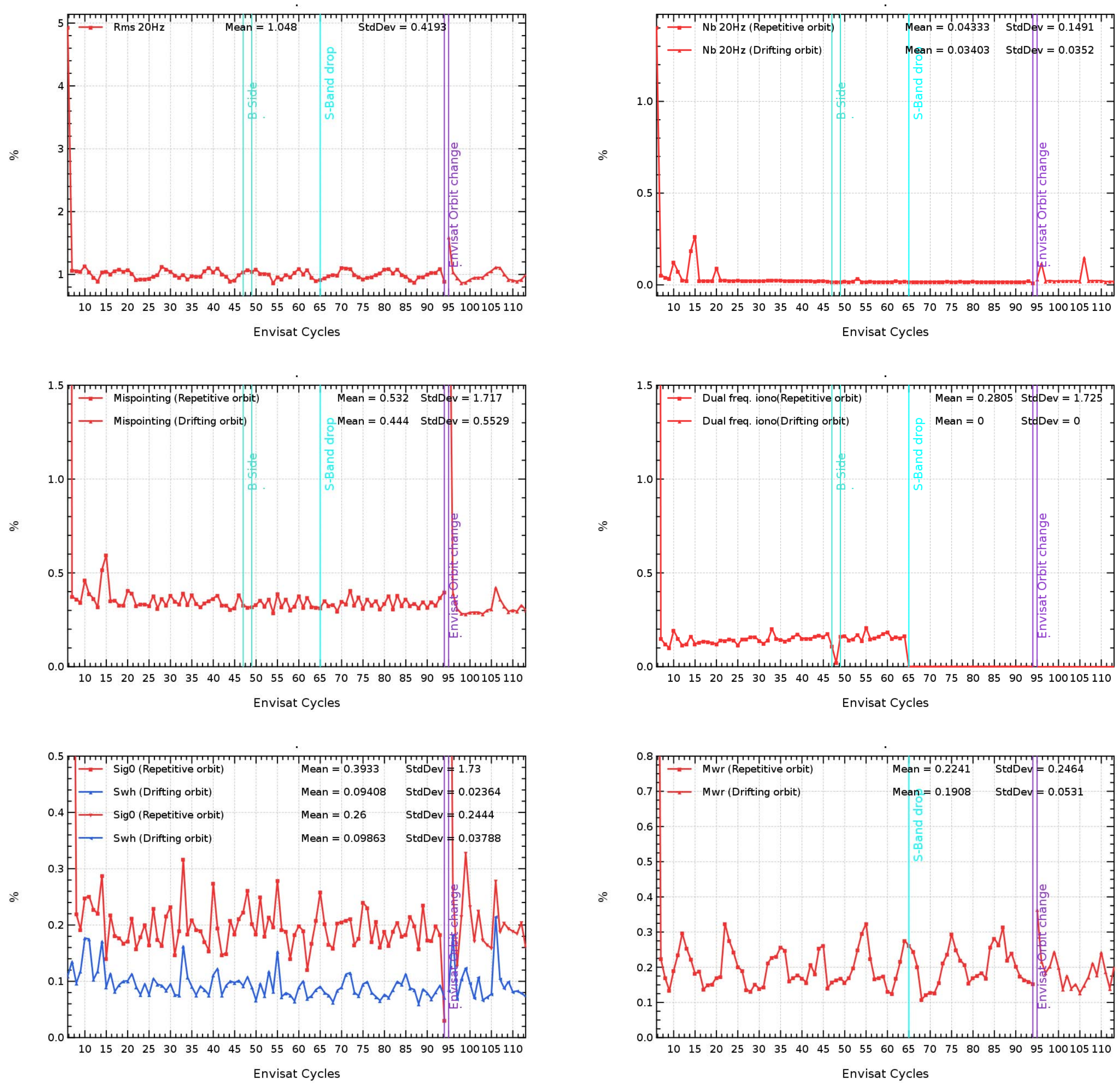


Figure 7: *Cycle per cycle percentages of edited measurements by the main Envisat altimeter and radiometer parameters:* ***Top-Left)*** *Rms of 20 Hz range measurements > 25 cm,* ***Top-Right)*** *Number of 20-Hz range measurements < 10,* ***Middle-Left)*** *Square of off-nadir angle (from waveforms) out of the [-0.2 deg2, 0.16 deg2] range,* ***Middle-Right)*** *Dual frequency ionosphere correction out of [-40 , 4 cm],* ***Bot-Left)****Ku-band Significant wave height greater than 11 m, Ku band backscatter coefficient out of the [7 dB, 30 dB] range,* ***Bot-Right)*** *MWR wet troposphere correction out of the [-50 cm, -0.1 cm] range.*

4.3.3. Editing on SLA

It is necessary to apply additional editing criteria on SSH-MSS differences in order to remove remaining spurious data. The first criterion consists in removing measurements with SSH-MSS greater than 2m. The second criterion was necessary to detect measurements impacted by

maneuvers. Maneuvers are necessary to compensate the effect of gravitational forces but can have a strong impact on the orbit quality. Two types of maneuvers are operated to maintain the satellite ground track within the +/-1km deadband (and +/-200m after cycle 54, see 8) around the reference ground track: in-plane maneuvers, every 30-50 days, which only impact the altitude of the satellite and out-of-plane maneuvers, three times a year, to control the inclination of the satellite (Rudolph et al., 2005). The out-of-plane maneuvers are the most problematic for the orbit computation. The second criterion consists in testing the mean and standard deviation of the SSH-MSS over each entire pass. If one of the two values, computed on a selected dataset, is abnormally high, then the entire pass is edited.
Note that the cross-track deadband can't be computed on drifting phase because of the lack of theoretical track (see 8).

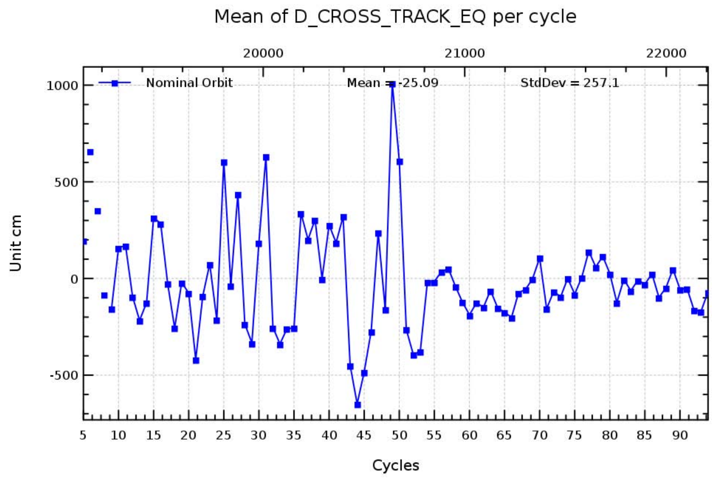


Figure 8: *Cross track deadband measured at equator by comparison to a theoretical track before the drifting phase.*

A specific study has been performed to determine how to compute the statistics, and what threshold should be applied. The statistics have to be computed on very stable area. The criteria for selecting the area and the thresholds are:

- The latitude: the range value can be degraded near the ice, despite the use of the ice flag. Moreover, the MSS is less accurate over 66 $^{\circ}$, as it has been computed without Topex, Jason-1 and Jason-2 data.
- The oceanic variability: the standard deviation of SLA can be very high because of the mesoscale variability. Areas with high oceanic variability have to be removed to detect the abnormally high standard deviation.
- The bathymetry and distance from the coast: A lot of corrections (tides for example) are less accurate in low bathymetry areas and near the coast (Japan sea).
- The sample: The statistic have to be computed on a significant number of points

All those criteria have been tested and combined as part as a specific study in a previous yearly report. The conclusion is that two criteria are needed:

1st criteria:
for small portion of pass (less than 200 points) the sample is not big enough to compute reliable statistic. The selection must not be severe: Selected areas: |latitude|<66 °, variability<30cm, bathymetry>1000m, distance to coast>100km Threshold: 30 cm on mean and standard deviation
2nd criteria:
for other passes Selected areas: |latitude|<66 °, variability<10cm, bathymetry>1000m, distance to coast>100km Threshold: 15 cm on mean and standard deviation

The percentage of edited measurements over ocean on these criteria has been plotted in Figure 9. On cycles 11, 12, 21 and 26, several full passes have been edited because of bad orbit quality related to out-of-plane maneuver or lack of Doris data (cycle 11).The special operation on RA-2 Chirp Bandwidth impacted the SSH editing ratio on cycle 47. Most of the data edited on this criteria are due to the jumps noticed on reprocessed USO correction (several hundreds of meters) and identified under the anomaly report number [IDEAS-PR-11-05520].
On cycle 56 an USO anomaly recovery, occurred at the beginning of cycle and impacted the SSH statistic editing per pass. The behavior of the Ultra Stable Oscillator (USO) clock frequency on this cycle is chaotic. The transitions between anomaly and normal mode has been very straight and the USO correction does not allow us to well correct some passes.

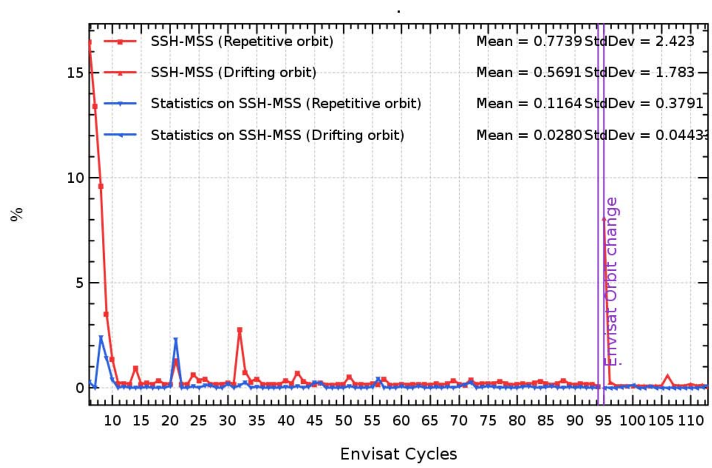


Figure 9: *SSH-MSS out of the [-2, 2m] and edited using thresholds on the mean and standard deviation of SSH-MSS on each pass*

As plotted above, some cycles are particularly impacted by a substantial editing on the two criterion previously defined.

For cycle 6 to 9, different adjustments performed during this calibration phase have impacted the homogeneity of processing.
During **cycle 6**, 26 tracks are edited on the SLA criterion, on only 242 available passes (760 tracks missing). Data was impacted by a DORIS event, orbit was extrapolated for this period with degraded performances. The **cycle 7** was impacted by some RA2 bandwidth tests, on 2002/06/18 and between 2002/06/26 and 2002/06/29 (20MHz for these two periods, 22 tracks rejected). For this cycle 95 tracks are impacted by wrong USO correction values too.

For **cycles 8 and 9**, respectively 90 and 33 tracks are rejected on these two SLA criterion, because of wrong USO correction.
For **cycle 14**, 6 passes (from 20/03/2003 11:07:17 to 20/03/2003 16:08:08) are entirely edited on SLA threshold. For these passes, USO correction was found to reach abnormal values (more than 150m) directly impacting the SLA.
Cycle 21 is impacted by a combination of events; 10 passes between 2003/10/27 and 2003/10/30 are impacted by short period of wrong USO correction applied to the range. During this cycle, high values of SLA were also observed consecutively to two altimeter restarts (pass 242 to 247, and pass 366 to 389). The SLA during instrument heating seemed to be badly corrected by the IPF USO correction, whereas the F-PAC USO expertise correction looked correct for these high values. Finally, this cycle is impacted by an exceptionally high solar activity (two strong magnetic storms on 2003/10/30 and 2003/11/21), degrading the orbit quality and then the SLA, which is rejected for 16 tracks. For cycle 21, the data rejected on SLA criterion approximates 3.5%.
During **cycle 32**, 25 tracks are entirely rejected by SLA values. These passes are impacted by jumps of several meters visible on the SLA, caused by wrong USO correction periods. This cycle is the most impacted by SLA values out of thresholds on the whole reprocessing period caused by wrong USO correction, except cycles 6 to 9.
On cycle 106, a mishandling of the USO counter clock impacts 4 tracks.
For the last cycles of the Envisat time serie (108 to 113), no particular editing has been noticed.

Note that the correction developed for expertise in F-PAC is not affected by these jumps. Yet the impact is rather weak: on the whole mission, around 300 tracks, were impacted by this anomaly (including around 200 before cycle 10).

In 2014 an analysis of editing process was realized, in order to better define what is the validity of data near coasts for a drifting mission. A new solution for validation of data near coasts has been proposed for Envisat but for other drifing missions too, such as Cryosat-2. Tests have been performed on Envisat cycle 112 to better characterize this new solution and potential improvements. Results are gathered in part 8.2.2..

5. Long term monitoring of altimeter and radiometer parameters

All GDR fields were systematically checked and carefully monitored as part of the Envisat routine calibration and validation tasks. However, Ku-band parameters are mainly presented here, as they are the most significant in terms of data quality and instrumental stability. Furthermore, all statistics are computed on valid ocean datasets after the editing procedure.

5.1. Number and standard deviation of 20Hz elementary Ku-Band data

As part of the ground segment processing, a regression is performed to derive the 1 Hz range from 20 Hz data. Through an iterative regression process, elementary ranges too far from the regression line are discarded until convergence is reached. The mean number and RMS of Ku 20Hz elementary data used to compute the 1Hz average are plotted in figure 10. These two parameters are nearly constant, which provides an indication of the RA-2 altimeter stability. The mean number of Ku 20Hz values over one cycle is about 19.97. This value is very high compared to other altimeters. It is almost not disturbed in wet areas or near the coast. The two drops on the Ku-band on cycles 14, 15 and 20 are due to wrong setting of the RA-2 just after recovery. Higher values correspond to higher waves occurring during the austral winter. The mean value is about 9.0 cm. This value represents a rough estimation of the 20 Hz altimeter noise (Zanifé et al. 2003 [118], Vincent et al. 2003a [116]). Assuming that the 20Hz measurements have uncorrelated noise, it corresponds to a noise of about 2 cm at 1Hz. It is consistent with the expected noise values.

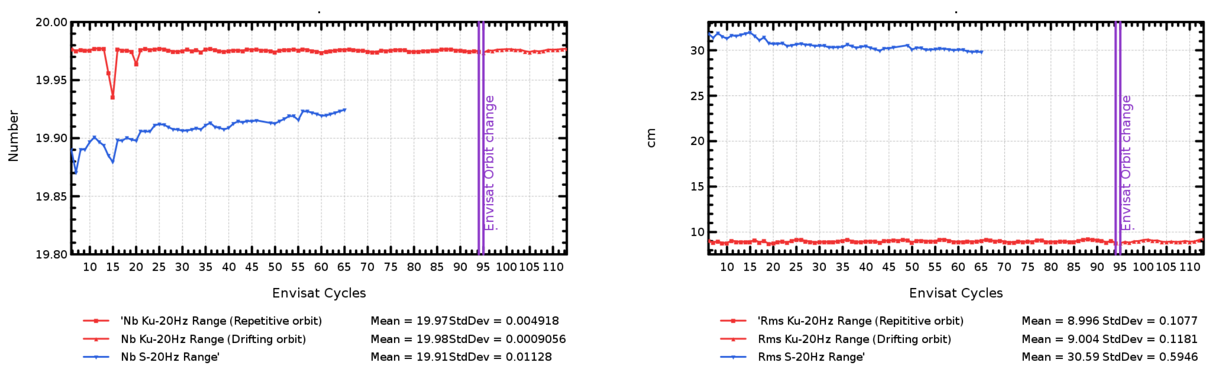


Figure 10: ***left)*** *Mean per cycle of the number of 20 Hz elementary range measurements used to compute 1 Hz range.* ***right)*** *Mean per cycle of the standard deviation of 20 Hz measurements.*

The corresponding S-Band parameters have a less stable behaviour. The S-Band mean number and RMS of 20Hz measurements have respectively an increasing and decreasing trend. This drift, as well as the jump noticed around cycle 18 appearing on reprocessed data is not understood yet but should be investigated further (impact on the MSL drift at the beginning of the period?).

The histogram of RMS of Ku Range on cycle 112 is plotted in figure 11.

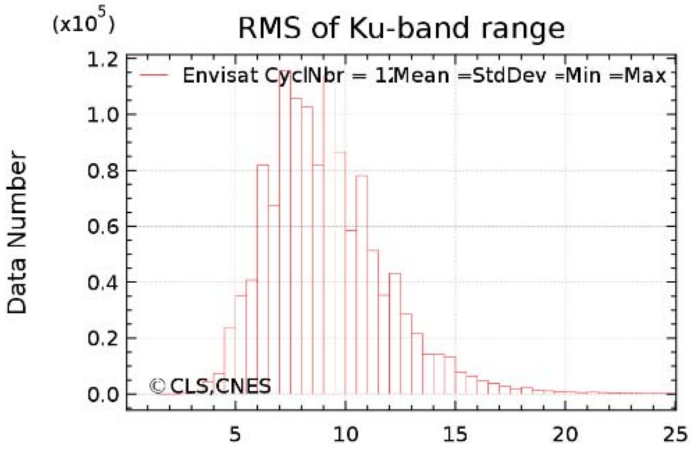


Figure 11: *Histogram of RMS of Ku range (cm). Cycle 112 .*

5.2. Off-nadir angle from waveforms

The off-nadir angle is estimated from the waveform shape during the altimeter processing. The square of the off-nadir angle is plotted in Figure 12. The mean value presents a slight decreasing trend up to cycle 65 around a value of 0.005 deg2.
Note as well that a smaller value is noticed for the cycle 48, for which altimeter was turned to its B-Side for a short period (cf. details in part 3.1).
At the end of the period, as noticed during the mini commissionning phase and QWG 17 the mispointing stabilises at a slightly lower value than before the orbit change. No reason has been found to explain this behaviour. However the value is so low that it has no impact in terms of data quality.

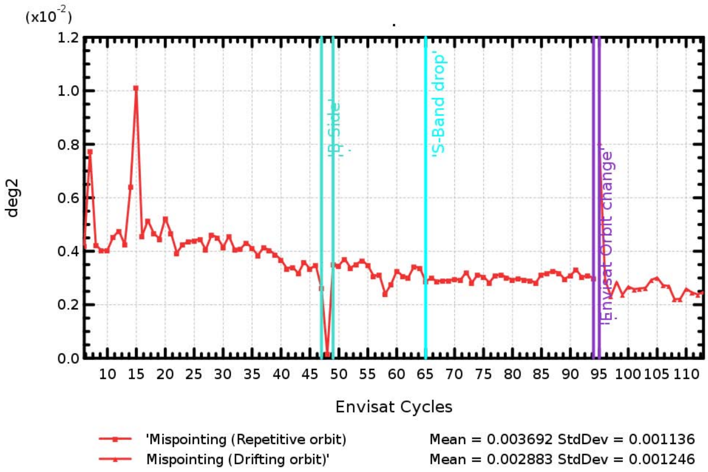


Figure 12: *Mean per cycle of the square of the off-nadir angle deduced from waveforms (deg^2).*

The histogram of the squared mispointing is plotted in figure 13.

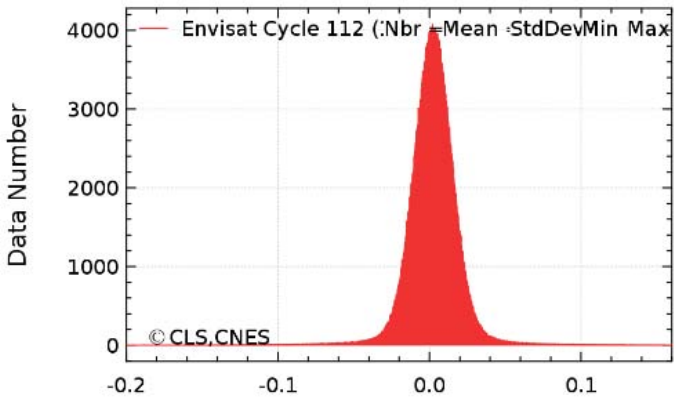


Figure 13: *Histogram of off-nadir angle from waveforms (deg²). Cycle 112 .*

5.3. Significant Wave Height

The cycle by cycle mean and standard deviation of Ku and S-Band SWH are also plotted in figure 14. Its monitoring reflects sea state variations (with a clear annual signal). The mean value of Ku SWH is 2.5 m. The S-Band mean SWH is drifting and rather lower (around 2m). The cycle by cycle mean of Envisat-Jason-1 differences is plotted in Figure 14.
These differences are quite stable (or slightly drifting before cycle 65) and centered around 0 since the V2.1 evolution on Envisat side (processing parameter modification (SigmaP)). Note that a study was performed on the SWH to understand the behavior of small waves, considered, by some users as degraded (see [15]).
As for range parameters, some strange behaviours on S-Band SWH are also noticed (see Figure 14): drifts on the standard deviation notably and odd behaviour before 2004 (cycle 22) on the mean.

The histogram of Ku SWH for the last complete cycle is plotted in figure 15.

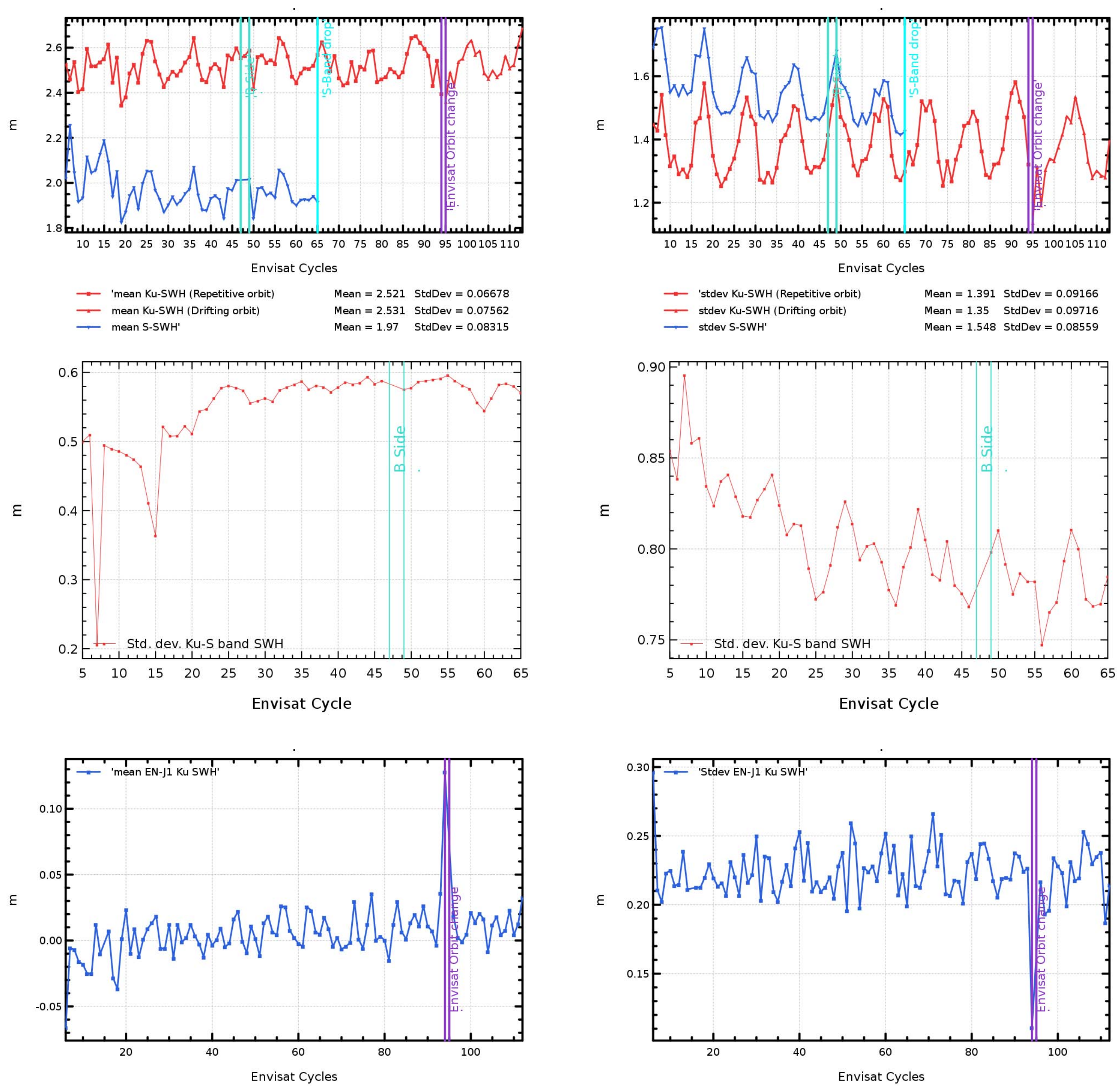


Figure 14: *Global statistics (m) of Envisat Ku and S SWH* ***top****) Mean and Standard deviation.* ***Middle:*** *Mean and standard deviation of Ku-S band SWH* ***bottom****) Mean Envisat-Jason-1 Ku SWH differences at 3h EN/J1 crossovers.*

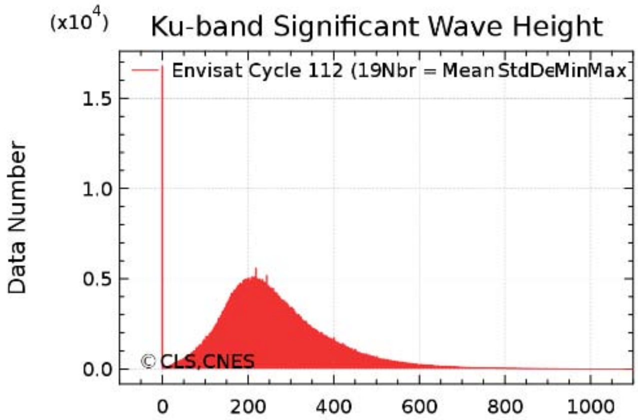


Figure 15: *Histogram of Ku SWH (m) Cycle 112 .*

5.4. Backscatter coefficient

The cycle by cycle mean and standard deviation Ku and S-Band Sigma0 are plotted in Figure 17, until 2011. Note that a -3.5 dB bias has been applied (Roca et al., 2003 [92]) on the Ku-band Sigma0 in order to be compliant with the wind speed model (Witter and Chelton, 1991 [117]). The mean values in Ku band are stable, around 11 dB. The mean difference between Envisat and Jason-1 Ku-band Sigma0 is -3 dB. This high value is explained by the fact that, Envisat Sigma0 value has been biased and not Jason-1. This mean difference has increased by 4.10-2dB/year between cycles 38 and 140 Jason-1 (corresponding to cycle 13 to 41 of Envisat) and remains constant afterwards. This drift was checked to be unchanged after correcting it from the atmospheric attenuation computed with an homogeneous reprocessed set of brightness temperature. These sigma0 differences obviously impact the wind consistency between the two satellites. Note that the wind from the ECMWF model, which does not assimilate Jason-1 data, shows a very good agreement with the Jason-1 altimeter wind with a slope close to 6 cm/s/yr whereas Envisat wind trend is much lower, 1.3cm/s/year (see [4]). This trend difference could mean that the Envisat wind slightly drifts.
Yet caution must be brought to this as Envisat is rather homogeneous to ERA-Interim reprocessed data, ECMWF solution free of most jumps and discontinuities seen in the operational model (see 16)... The global stability of this parameter was extensively studied in Ablain et al. 2012 submitted in Marine Geodesy (see [10]) and summarized in 2011 Jason-1 yearly report ([6], available on Aviso web site).
A slight decrease of Ku Sigma0 standard deviation for Envisat/Jason-1 difference is observed after orbit change.

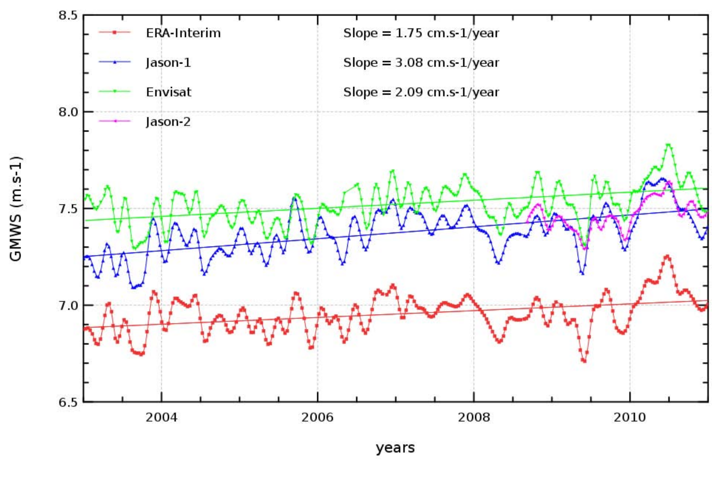


Figure 16: *Wind speed from different sources (EN, J1, J2 altimeters and ERA-Interim model).*

Histograms of Ku Sigma0 for the last complete cycle is plotted in figure 18. The Ku Sigma0 histogram has a good shape.

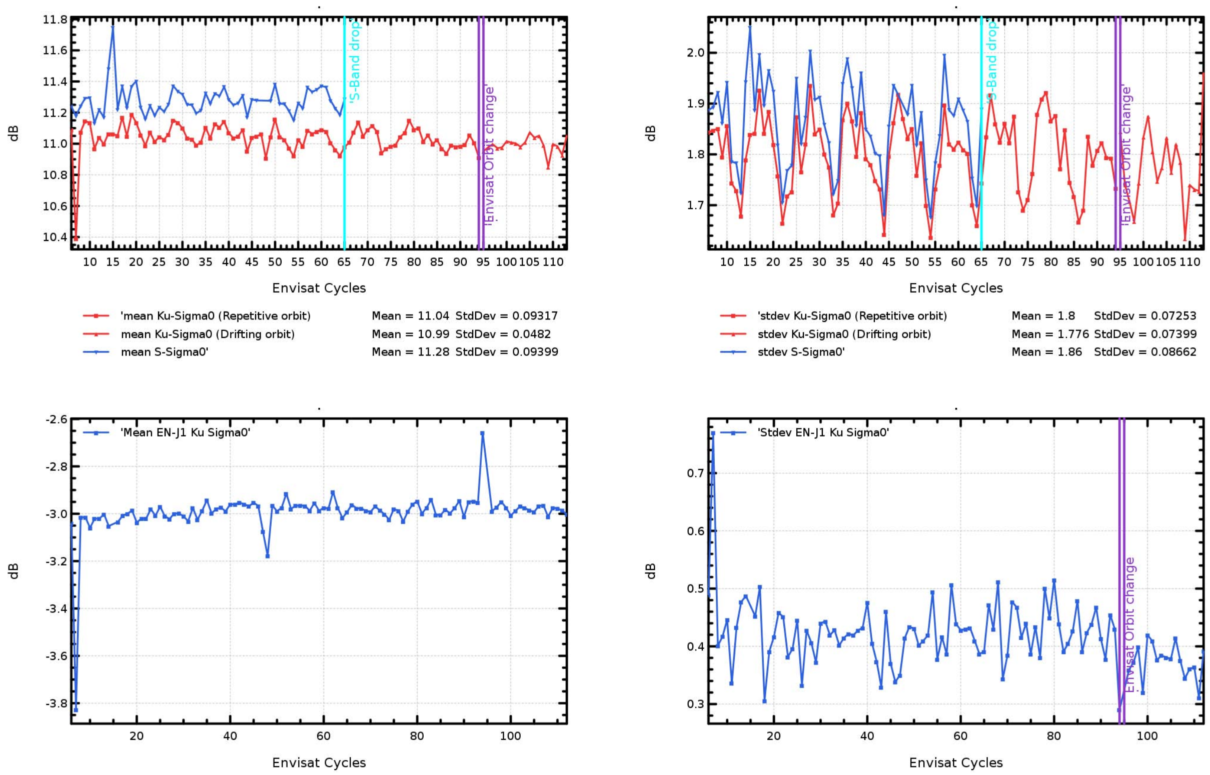


Figure 17: *Global statistics (dB) of* ***Top****) Envisat Ku and S Sigma0 Mean and Standard deviation.* ***Bottom****) Mean Envisat-Jason-1 Ku Sigma0 differences at 3h EN/J1 crossovers.*

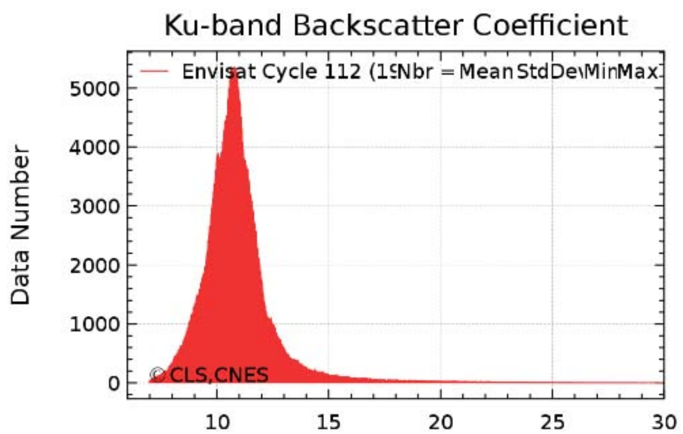


Figure 18: *Histogram of Ku Sigma0 (dB). Cycle 112 .*

5.5. Dual frequency ionosphere correction

As performed on TOPEX (Le Traon et al. 1994 [66]) and Jason-1 (Chambers et al. 2002 [33]) it is recommended to filter dual frequency ionosphere correction on each altimeter dataset to reduce noise. A 300-km low pass filter is thus applied along track on the dual frequency ionosphere correction. Note that in 2012, a new filtering method was developped in order to improve the current filtering process. This is explained in [16] and this method will enable to add the filtered field directly in the GDR as expected for the next reprocessing version, which is not feasible with the current method.
As previously mentioned, the JPL GIM ionosphere corrections are computed to assess the dual frequency altimeter based ionosphere correction. After the S-Band loss of Envisat (January 17th 2008), it was prefered to the DORIS correction also available in the products to replace the bifrequency correction for its better performances. The same GIM model is used to compute the GIM corrections on Envisat and Jason-1. The quality of Envisat's ionosphere correction can thus be assessed by monitoring the dual-frequency -GIM based ionosphere correction on Jason-1. The cycle by cycle mean of dual frequency and JPL GIM ionosphere correction are also plotted in figure 19. Different trends are observed on the two curves.

The cycle by cycle mean of dual frequency and JPL GIM ionosphere correction are plotted in figure 19. The mean value of the two corrections clearly follows the solar activity periods (11 year solar cycle): decreasing from the beginning of Envisat mission to 2008 and increases again since late 2009, after a short stable period. The mean differences is surprisingly stable around -0.8 cm whereas Jason-1 GIM-Dual presents a bigger bias for higher solar activities. This bias increasing for high values of ionospheric correction is also noticed, on Envisat, when comparing ascending (night time) and descending passes (in the daytime). This would suggest that the beginning of the mission is affected by an error which should be further investigated.
The standard deviation of the difference is plotted in figure 19. Here as well, the first year seems to have a chaotic behavior compared to Jason-1. Notice that, in this reprocessed series, a homogeneous sea state bias (SSB) has been used to correct the Ku and S-Band Ranges (Labroue 2004 [60]).

Concerning the discrepancies between both missions, note that, in terms of noise, the higher noise for Jason-1 is due to an higher noise in the C band (used for Jason-1 bifrequency ionosphere) than in S-Band (used for Envisat one). The filtering step applied on both ionospheres from the products enable to have comparable noise level for both missions. In terms of bias, differences are likely due to the difference of altitude for both missions, but the stability of Envisat ionosphere difference (Bifrequency-GIM) can also be seen as an anomaly at the beginning of Envisat mission (before cycle 22), reducing the dependency between the absolute value and the bias on this correction (observed on Jason-1). This would deserve more investigations.

In 2012, the solar activity continued to increase which has an impact on the data quality. The mean difference of SSH at cross-over is polluted by the signature of the ionospheric signal with a mid-scale impact (not presented here).

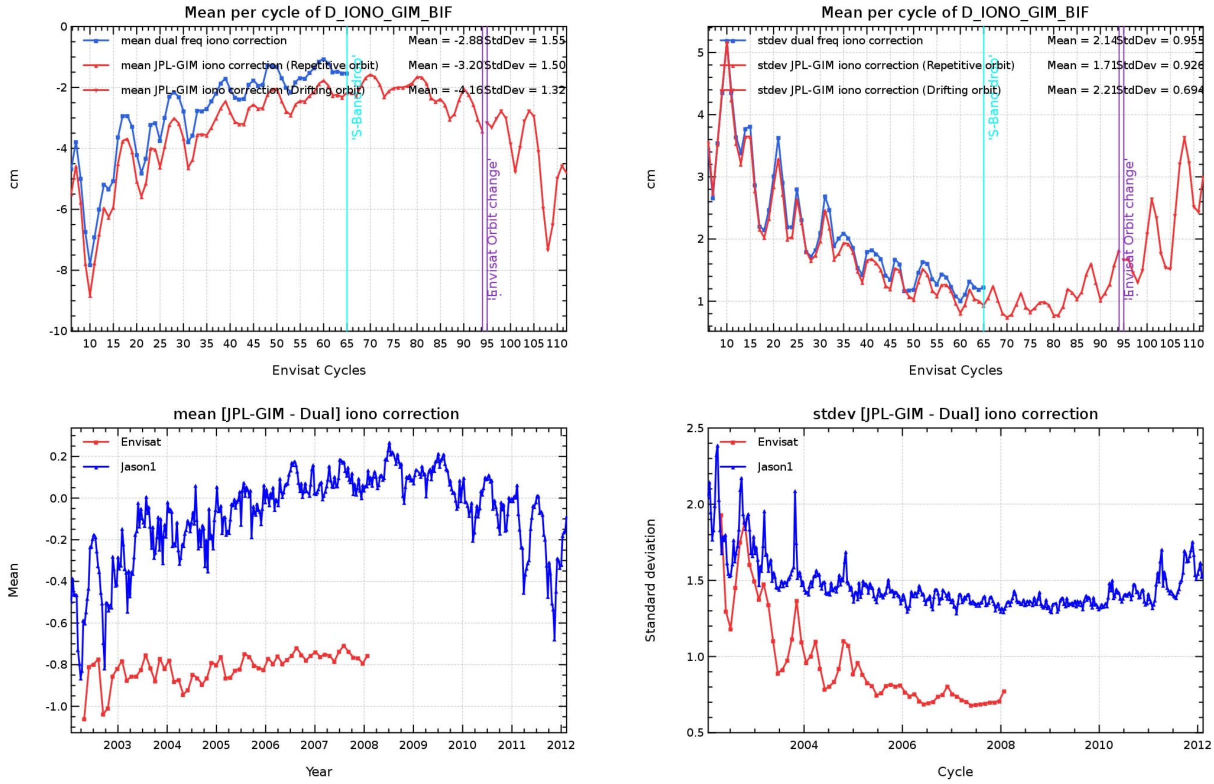


Figure 19: *Comparison of global statistics of Envisat dual-frequency and JPL-GIM ionosphere corrections (cm).* ***Top****) Mean and standard deviation per cycle of Dual Frequency and GIM correction.* ***Bottom****) Mean and standard deviation of the differences for Envisat and Jason-1*

.

5.6. MWR wet troposphere correction

A neural network formulation is used in the inversion algorithm retrieving the wet troposphere correction from the measured brightness temperatures (Obligis et al., 2005 [80]). As an example, the scatter plot of MWR correction according to ECMWF model for cycle 112 (last complete cycle) and 113 is given in figure 20.

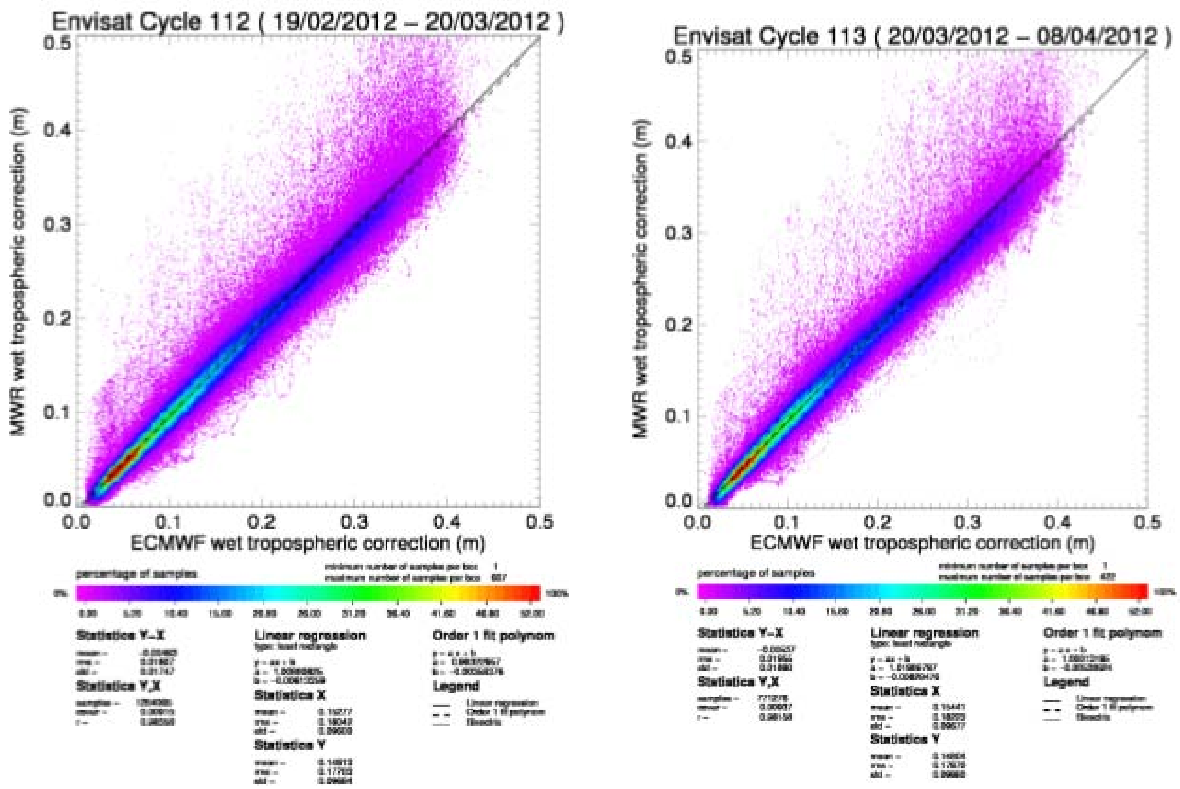


Figure 20: *Scatter plot of MWR correction according to ECMWF model (m) (cycle 112 & 113)*

Since the beginning of the mission, the stability of the instrumental parameters has been closely looked at. In particular, different behavior is observed depending on the brightness temperature values. A complete monitoring of all the radiometer parameters is available in the cyclic Envisat Microwave Radiometer Assessment available at http://earth.esa.int/pcs/envisat/mwr/reports/ ([87]). Mean and standard deviation of Radiometric correction for Jason1, Jason2 and Envisat is plotted in figure 21 (top). It is also completed by (MWR-ECMWF model) monitoring, enlighting finer jumps and discrepancies in figure 21 (bottom). This difference is not really stable, though the global mean remains small. An annual signal of about 1.5mm of amplitude can be seen. Successive jumps on the ECMWF side (marked out by vertical lines on the plots (see ECMWF web site [38])) also have an impact on the stability of the difference [radiometer wet tropospheric correction-ECMWF model]. To minimize the unhomogeneities on model side, ERA Interim is taken as a reference on figure 22. The standard deviation is very much stabilized but the annual signal on the mean remains.

Note that the 1.8cm of standard deviation is greater than the value obtained before the reprocessing

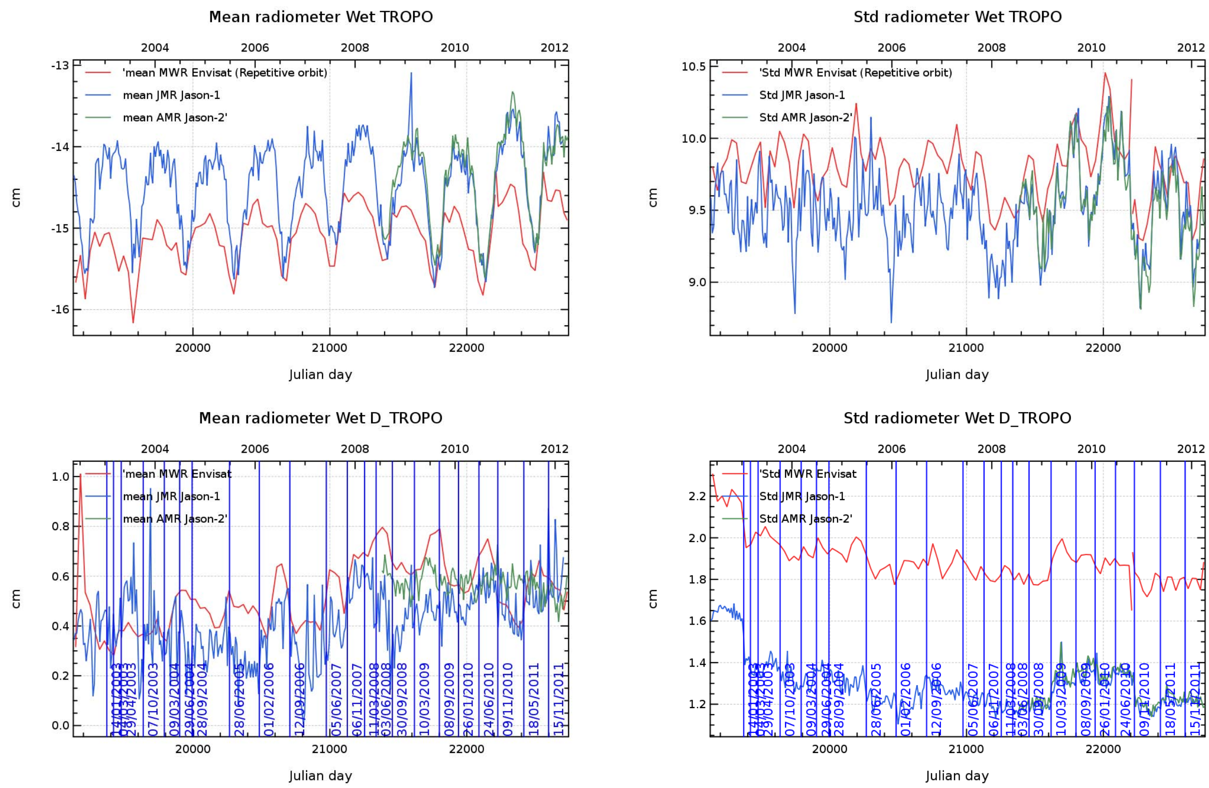


Figure 21: *Comparison of global statistics of Envisat MWR and ECMWF wet troposphere corrections (cm).* ***top****) Mean and standard deviation per cycle of MWR, JMR and AMR corrections* ***Bottom****) Mean and standard deviation per cycle of the differences versus ECMWF model. Vertical lines represent the major events.*

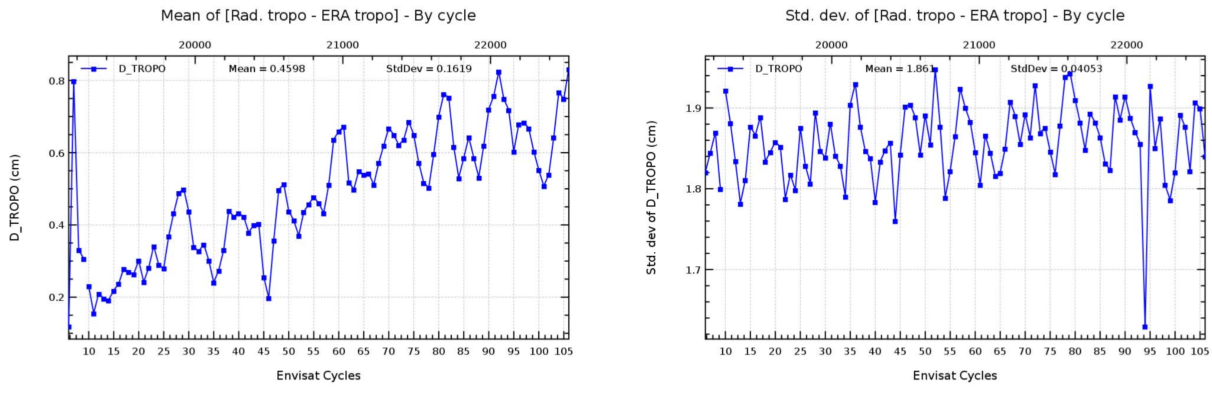


Figure 22: *Mean and standard deviation per cycle of the differences of MWR correction versus ERA-Interim*

(1.6cm). In fact, the analysis made after reprocessing enabled to evidence a degradation of this correction visible on SSH performance at crossovers (see [16]).

In 2013 a first corrected version was developped and analysed, results are available in [17].

Note that two new wet tropospheric corrections will be available for the next reprocessing campaign. These two corrections take into account an updated Side Lobe correction, which better consider the degradation of ocean data due to land, observed accross the secondary lobes. These two solutions use different type of parameters as entries of neural network too.

6. Sea Surface Height performance assessment

One of the main objectives of the Calibration and Validation activities is to assess the performance of the whole altimeter system. This means that the quality of each parameter of the product is evaluated, in particular if it is likely to be used in the Sea Surface Height (SSH) computations. Conventional tools like crossover differences and repeat-track analyses are systematically used in order to monitor the quality of the system.

6.1. SSH definition

The standard SSH calculation for Envisat is defined below.

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

$$\begin{aligned}\sum_{i=1}^{n} Correction_i \;=\; & Dry\ troposphere\ correction : S1\ and\ S2\ atmospheric\ tides\ applied \\ + \; & Combined\ atmospheric\ correction :\ Dynamic\ atmospheric\ correction \\ & and\ inverse\ barometer \\ + \; & Radiometer\ wet\ troposphere\ correction \\ + \; & ionospheric\ correction\ /GIM\ model\ after\ cycle\ 64 \\ + \; & Non\ parametric\ sea\ state\ bias\ correction \\ + \; & Geocentric\ ocean\ tide\ height \\ + \; & Solid\ earth\ tide\ height \\ + \; & Geocentric\ pole\ tide\ height\end{aligned}$$

As said in 3.2.1., the plots presented here concern the whole Envisat serie, on a basis of the V2.1 standard, improved for some terms, as explained further.

The following table 2 presents the updates computed after reprocessing to improve the SSH performance. Some of these updates have ever been analysed in previous yearly report and a part of them were studied this year, presented in this report.
To see analysis made in 2013 on anticipated updates, please refer to [17].

Altimetric correction	V2.1 product	Alternative correction	Analysed updates
Orbit standard	GDR-C	GDR-E	Impact of the new 10-days gravity field (see 8.2.1 in [17])
Range	/	PTR	/
			.../...

Altimetric correction	V2.1 product	Alternative correction	Analysed updates
MWR Wet tropo.	After reprocessing degraded version	V2.1b (see 8.1.1 in [17])	/
Ionospheric corr.	Dual frequency filtered iono.	Iteratively filtered iono. (see 8.1.2 in [17])	Impact of Envisat Altitude in GIM model computation (see 8.2.2 in [17])
Sea state bias			
Ocean tide	GOT 4V7	GOT 4V8 / GOT 4V10 / FES2014	Performance assessment of GOT 4V8 (see 8.1.3 in [17]), GOT 4V10 and FES 2014(see 8.1.1.) tide models.

Table 2: *A*ltimetric correction updates

6.2. Global improvements of SSH quality

6.2.1. Estimation of performance: reduction of the mesoscale error

To estimate the performance of a new standard, the analyse is made on SSH behaviour using this updated correction compared to a reference correction. If we consider the SSH computation at monomission crossovers, we evaluate the relevance of altimetric data on crossed tracks, so at the same localisation in two different moments. If the crossover time selection is limited to 10 days and with some relevant selections (bathymetry, oceanic variability,...), we can consider that the satellite could see the "same" ocean surface in the "same" conditions, omitting the high or low frequency content and the related impacts on SSH data. With this method, we also estimate the quality of signal in terms of **mesoscale error**. The standard deviations of SSH at crossovers using a study or a reference standard are compared and gives us a good estimation of the mesoscale error potentially made.
In terms of results presented, the quality of SSH is said as "better" if the standard deviation of SSH at 10-days crossovers considering the new standard is reduced from the one computed with the reference standard (negative difference represented in green on the plots).

6.2.2. Envisat SSH quality: monomission analysis

6.2.2.1. Effect of Envisat Orbit change

The effect of the drifting orbit on Envisat is very weak and can hardly be evidenced on previous plots. It can however be evidenced when filtering some wavelength only as shown on zoom over 14 months on figure 23.

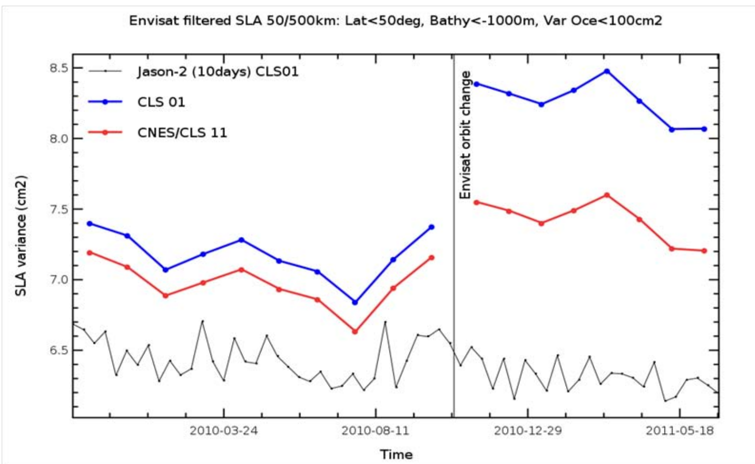


Figure 23: *Impact of the SLA reference out of the repeat track on the wavelength between 50km and 500km.*

6.2.2.2. Time varying SSH differences at crossovers

The variance of crossover differences conventionally gives an estimate of the overall altimeter system performance. Indeed, it gathers error sources coming from orbit, geophysical corrections, instrumental noise, and part of the ocean variability. The standard deviation of the Envisat SSH crossover differences has been plotted in Figure 24. Without any selection, a seasonal signal is observed because variations in sea ice coverage induce changes in ocean sampling by altimeter measurements. When only retaining deep ocean areas, excluding high latitudes (higher than 50 deg.) and high ocean variability areas, the standard deviation then gives reliable estimate of the altimeter system performances. In that case most of the cycles have a standard deviation between 5 and 6cm. But there are some exceptions that can be explained. Cycle 11 has a relative high value because of missing Doris data. Cycles 15 or before cycle 10 are higher because of the low number of crossover points. There are less than 10000 crossovers whereas other cycles lead to more than 20000. Cycle 21 has a strong value (6.8 cm) because of the combined effect of 2 maneuvers, intense solar activity between these 2 maneuvers, and lack of laser measurements between these two maneuvers.

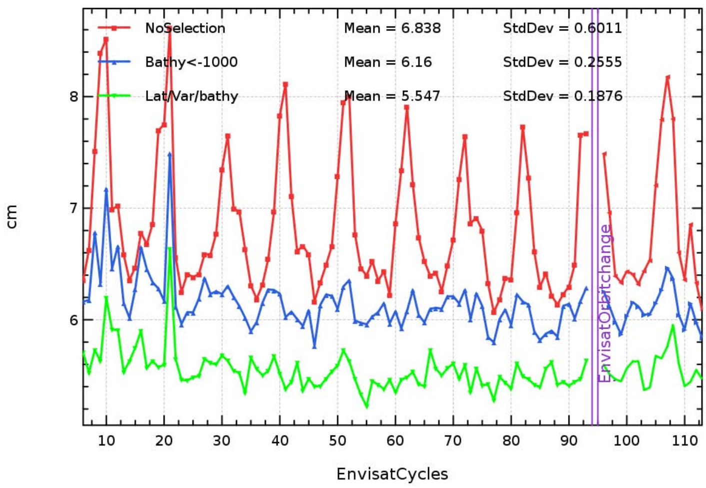


Figure 24: *Standard deviation (cm) of Envisat 10-day SSH crossover differences depending on data selection (with a maximum time lag of 10 days). Red: without any selection. Blue: shallow waters (1000 m) are excluded. Green: shallow waters excluded, latitude within [-50S, +50N], high ocean variability areas excluded.*

6.2.2.3. Regional analysis of mesoscale error

The mesoscale error estimation improvement obtained with anticipated updates names V2.1+ (see [17]) is shown on figures 25 and 26 with reference to V2.1 and V1 respectivelly.

The variance of SSH at crossovers is globally descreased on the dataset with all the developped updates; the gain reaches 1.8cm^2 compared to the V2.1 dataset after reprocessing (for a selection far form coasts, latitudes$<$ 50 deg and low oceanic variability), mainly due to radiometer wet tropospheric correction update.

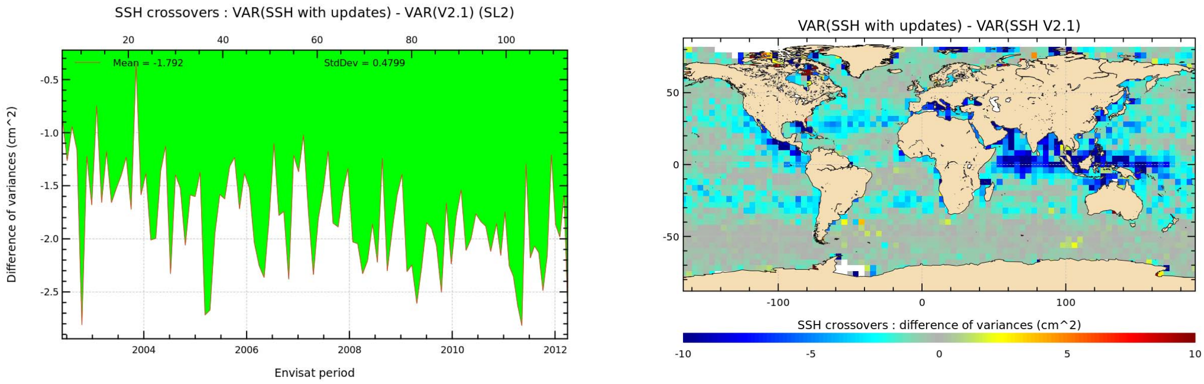


Figure 25: *Improvement of mesoscale precision, comparing **V2.1 with updates** (GDR-D orbits, F-PAC PTR, V2.1b wet tropospheric correction, iterative filtered iono, GOT 4V8 tide model) to **V2.1 (after reprocessing)***

The comparison to GDR before reprocessing (V1) is shown on Figure 26. In this case, the gain reaches 3.2cm^2 for the same selection, and globaly distributed. This global gain is important and results from all the improvements developped for the reprocessing in 2011 and after, notably the last updates which will be taken into account in the next reprocessing.

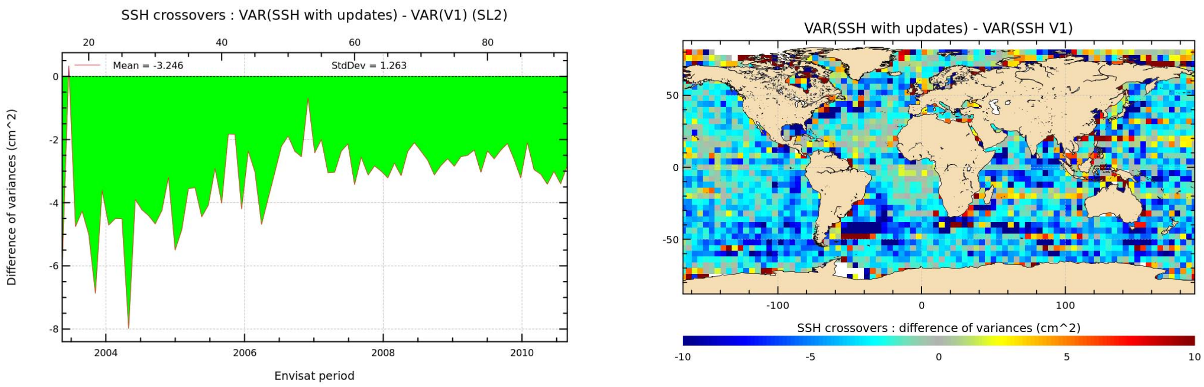


Figure 26: *Improvement of mesoscale precision, comparing* ***V2.1 with updates*** *(GDR-D orbits, F-PAC PTR, V2.1b wet tropospheric correction, iterative filtered iono, GOT 4V8 tide model) to* ***V1 version (before reprocessing)***

6.3. Improved performances of GDR: anticipating the next reprocessing

In 2012 and 2013 V2.1 reprocessed dataset was enhanced on several aspects. The V2.1+ dataset is an anticipation of future reprocessing in an expertise database maintained at CLS and for DUACS purpose. This dataset brings together the following altimetric corrections updates:
- PTR with an impact on Global Mean Sea Level (see [15] and Ollivier 2012 et al.);
- POE standard with an impact on Regional Mean Sea Level (see [15] and Ollivier 2012 et al.);
- Sea State Bias with an impact on performances at crossovers and on mean of SLA (see [16], particular investigation on SSB).

2013 yearly report ([17]) presented results concerning other anticipated updates, notably the iterative filtering ionospheric correction which will be used for the next reprocessing and a new version of wet tropospheric correction.

The table 27 presents standards and corrections updates which will be available for the next reprocessing:

Upgraded Fields	Orbit GDR-E standards	MWR wet tropospheric correction	MWR derived fields (ice flags, atmospheric attenuation...) will also be upgraded	SSB computed with all upgraded corrections	PTR Internal Path Delay drift	Look Up Tables for small waves correction	L1b reprocessing: ICU, USO, IF mask...)	Ocean Tide: MAR_GOT_4V10 FES_2014	Non eq. long period ocean tide	Updated MSS (CNES/CLS 2012)	New iono. filetring method
Expected impact	Climate scales geographical variations Short scales error reduction (crossovers)	Coastal areas Short scales error reduction (crossovers) Reduction of difference with model	Mesoscale	Mesoscale	Climate scale	Reduction of altimetry/ERA-Interim model dependency for Envisat small waves.	Climate scale + punctual effects expected?	Mesoscale	Mesoscale	Regional scale	Number of SLA valid data increase. Short scales error reduction (crossovers) Independant from editing step

Figure 27: *Anticipated updates for the next Envisat reprocessing campaign*

6.3.1. Envisat CorSSH products: now available in Netcdf-CF format!

Corrected SSH Duacs products, tradionnaly name CorSSH, are now available on AVISO in a Netcdf-CF format (http://www.aviso.altimetry.fr/en/data/products/sea-surface-height-products/global/corssh.html).
The definition and the generation of products for the whole Envisat dataset have been made this year cooperatively with ODES project. In this new version, standards are updated and products are now homogeneous on the whole Envisat dataset.
Aviso user's can now download the whole Envisat dataset, one file per track.

This exercice was made for all the operationnal missions Jason-2, Altika and HY-2A too. For the non operational missions, data are available in this new format for GFO,ERS1,ERS2,Topex/Poseidon and Jason-1 for the complete datasets.

To obtain details on products content, you can refer to the AVISO CorSSH Handbook products (http://www.aviso.altimetry.fr/fileadmin/documents/data/tools/hdbk_dt_corssh.pdf).

7. ENVISAT Mean Sea Level Trend

Observing and understanding the climate evolution is a challenge in which altimetry can play a role through, notably, ocean topography monitoring studies. For the last two decades, satellite altimetry has provided reliable time series, highlighting a rise of around 3mm/year at global scale (Cazenave et al. 2004 (see [29], Ablain et al. 2009 (see [9])) of the Mean Sea Level (MSL).
By now, most Sea Level rise studies are based on the 3 NASA/CNES missions: TOPEX/Poseidon (1993-2005), followed by Jason-1 over (2002- onwards) and Jason-2 (from 2008 onwards). The primary role of these missions is the accurate measurement at global and regional scales for climate applications (OSTM/JASON-2 science and operation requirements, 2005). Additionally to these missions, the ESA polar orbiting satellite ERS-1 (1991 - 2000), ERS-2 (1995-2011),Envisat (onwards from 2002) and Cryosat-2 (onwards from 2010) have been successively launched, providing a precious and precise complementary data set to the NASA/CNES missions. ERS1, ERS2, Geosat-Follow-On (GFO), Envisat and SARAL/Altika enable a better restitution of the mesoscale variability at all latitudes and more especially between 66 and 82 deg where no Topex, Jason-1 and Jason-2 data are available. Their strong added values in multi-mission merged products such as SSALTO/Duacs Aviso products was already extensively shown in several publications concerning mesoscale variability studies (Pascual et al. 2006 (see [86], Le Traon et al. 2003 (see [68])).
Up to now, the quality and performances of ENVISAT mission were shown to be very good (Faugere et al 2006, see [49]) and with similar level of accuracy as Jason-1 and Jason-2's for mesoscale applications (Ollivier et al 2010, see [14]). Yet, Envisat GDR have long been suffering from an inhomogeneous time series and from major events affecting data quality which prevented users from using them directly for climate oriented studies. The reprocessing performed in 2011 allowed to obtain an homogeneous data set, name V2.1. After analysis of reprocessing results, a new serie of anticipated updates have been developped and analysed notably in 2013 (see [17]).
Thanks to this homogenizing work, fine cross-calibration analysis with other missions and in situ methods are possible. They allow to highlight some remaining differences and particularities of Envisat data.

7.1. Envisat MSL becoming more relevant!

Since Envisat launch, some discrepancies between its Mean Sea Level trend and other mission's were investigated.
However after many improvements and updates over the whole time series, its similarity to Jason-1's MSL (used for climate studies) and to tide gauges after 2004 is very encouraging.
In 2012 a paper was published (Ollivier et al. 2012 [83])) to describe the data analysis process that enabled to improve considerably the pertinence of this oceanic indicator. For this, multimision and in situ comparisons analysis enable to identify errors in the datasets, to identify there origin and to solve them, thanks to fruitful exchanges with experts (Level 0 and 1 instrumental experts and orbit experts).
As already extensively developped in [15] and [16], the update of two major terms enabled to improve respectively the global and regional MSL:
- The Time Delay Calibration Factor of the Point Target Response (instrumental correction called PTR correction in this document)
- The new standard of GDR-D orbit, which better accounts for the time variable gravity field estimated from Grace data.

Since 2010, Envisat MSL is available on Aviso web page at: http://www.aviso.altimetry.fr/en/data/products/ocean-indicators-products/mean-sea-level.html. In 2012 Envisat time series was updated with the new reprocessed dataset as well as from the PTR instrumental correction, insuring a better consistency between other missions and in situ data set.
The description of the processing and the table of corrections used are available at http://www.aviso.altimetry.fr/en/data/products/ocean-indicators-products/mean-sea-level/processing-corrections.html.

Last updates in 2013 allowed to continue to analyse the fine discrepancies between Envisat and other missions mean sea level trend. The impact of new radiometer wet tropospheric correction and all other updates have been studied in 2013, see [17].

In 2014, a particular effort was made to refine the analysis of suspicious behaviours visible on Envisat global Mean Sea Level. Possible correlations were established with known instrumental issues or particular configurations used. Results were presented at the QWG 2014 and are gathered in part 8.2.1. in this report.

7.2. MSL recipe

7.2.1. Mean Sea Level computation details

In order to have comparable time resolution between Envisat and Jason-1, each point of the MSL monitoring are computed with quarter of Envisat cycle (35/4 = 8.75 days) periodicity: the closest fraction of cycle from 10 day-Jason-1 periodicity. Envisat's time series are computed by first averaging the data in 2x2 deg boxes and then by computing a global average with a weighting depending on the latitude (between 66deg N/S) following Dorandeu and Le Traon 1999 [34]. Time series are then smoothed with a 10 points (87.5 days) sliding window. This step enables to smooth the noise and to reduce the SNR (Signal to Noise Ratio) on the slope computation. The Sea Level Anomaly (SLA) formula is given below.

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

with :

$$\begin{aligned}\sum_{i=1}^{n} Correction_i &= Dry\ troposphere\ correction \\ &+ Dynamic\ atmospheric\ correction \\ &+ Wet\ troposphere\ correction \\ &+ Ionospheric\ correction \\ &+ Sea\ state\ bias\ correction \\ &+ Ocean\ tide\ height \\ &+ Solid\ earth\ tide\ height \\ &+ Geocentric\ pole\ tide\ height\end{aligned}$$

.

Now the geophysical corrections provided in the GDR products are totally homogeneous and described in part 3.2.2..
The table 3 presents the geophysical corrections for each Envisat period used in the Mean Sea Level computation.

	Cycles 6-64	Cycle 65-94	Cycle 95 onwards
Orbit	GDR-D		
Range	From GDR + PTR correction (V2.1+)		
DAC	MOG2D-HR		
Iono corr	Iteratively filtered Dual-Frequency with S-Band SSB	GIM+bias	
MWR Wet tropo	Updated composite		Updated MWR
Dry tropo	Gaussian grids S1-S2 atmospheric tides applied		
SSB	Homogeneous to V2.1+ dataset		
Solid Tides	From GDR		
Pole Tides	From GDR		

Table 3: *G*eophysical corrections used following the periods

In 2013, some analysis have been made on global and regional Mean Sea Level trend, notably based on the anticipated updates (see 2013 Yearly Report [17]).

7.3. MSL global time series

The global MSL computed with the updated dataset is presented in figure 28. The effect on global MSL is largely dominated by the PTR evolution as demonstrated in [15].
The new updates have a weak effect on global MSL, the impact is limited to 0.03mm/y on the whole Envisat period, comparing to V2.1 dataset (see [16]).

Updated Envisat MSL exhibits a 2.4mm/yr trend (not taking into account the GIA post rebound, see [17]) on the whole dataset. The difference between Envisat and Jason-1 is reduced to 0.26mm/y on the whole Envisat period, as seen on the Figure 28. The consistency with Jason-2 is also very good in terms of interannual signal (the too short period for J2 does not enable to conclude any significant absolute trend).

Yet the beginning of the period (before 2004) remains suspicious. This behaviour could be the result of a combination of suspicious effects (ionospheric correction, wet tropospheric correction, ...).
Following paragraph and 8.2.1. presents results of the analysis performed this year on this subject.
The remaining suspicious behaviours of Envisat MSL was finely analysed and correlations could

.

be established with different parameters or instrumental events.

If we consider the period 2004-2012, the difference between Envisat and Jason-1 reaches $1.2mm/y$. The difference of trends for Envisat with or without considering the first year reaches $0.8mm/y$, which is higher than on Jason-1 ($0.2mm/y$).

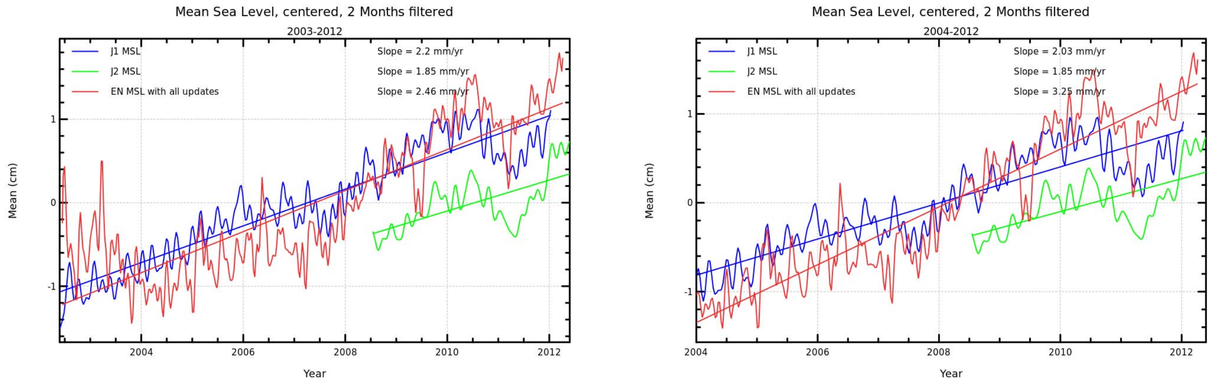


Figure 28: *MSL computed with last updates: PTR, updated tropo. correction and GDR-D orbit for the period* ***Left****: 2003-2012* ***Right****: 2004-2012*

Note that comparisons with in-situ data are available in 2013 Yearly Report ([17]).

7.4. Remaining suspicious behaviours of Envisat global Mean Sea Level

In 2014, an effort was made to refine the analysis of Envisat Mean Sea Level trend, notably based on the comparison with Jason-1. Previous yearly reports presented Envisat MSL trend, comparison with in-situ data and with other missions. Some suspicious behaviour were listed but without really investigations performed, notably for the remarkable trend before 2004. The effort made in 2014 concerns the events which could have an impact on MSL trend at the beginning of the Envisat period, but other suspicious periods too, such as Side-B configuration, and their potential impact on global Mean Sea Level.

The slides available in 8.2.1. were presented at the Envisat QWG21, Esrin, April 2014. They gathered the results of refined analysis and propose some possible correlations between observed behaviours and known effect or configuration (instrumental, ...).
For the beginning of the period, the suspicious behaviour is observed on SSH difference at crossovers with Jason-1 too. Another investigation shows that a correlation seemed to appear with some Ku-S band parameters, in particular the waves for this specific period. Some jumps seems to be really well correlated. Finally, at the beginning of the Envisat period, some jumps are observed for wrong RA2 parameters settings periods. Waveform mispointing, peakiness were impacted. Difference of parameters between Ku and S-Band are impacted too but only S-Band remains suspicious. All these phenomenon were shown to potentially have an impact on global Mean Sea Level.
Some other suspicious jumps or behaviours were noticed, such as an unexplained jump in 2009 on global Mean Sea Level.
PTR width showed suspicious behaviours too, potentially associated to observable jumps on

Envisat global Mean Sea Level and on difference with Jason-1.
Finally, another point was made on Side-B biases or particular behaviours as the one observed on peakiness, waveform mispointing and range during this period.

These analyses show that a substantial number of parameters remain a source of errors in the global Mean Sea Level computation. Some instrumental events have been detected as having an indirect impact on MSL, which had never been so much analysed and proven.
Discussions with instrument experts are therefore fruitful to anticipate the next reprocessing, knowing the potential source of these remaining suspicious behaviours. This should allow to correct some treatments to improve Envisat whole dataset quality. It should be approriate to perform these analyses with next reprocessed dataset to continue to give relevance to the global Envisat Mean Sea Level.
The complete presentation on this subject, made at the QWG21, and all the detailled results are available in 8.2.1..

8. Particular Investigations

8.1. Anticipation of the next reprocessing

8.1.1. New ocean tide models performance assessment

In this part are presented two solution for ocean tide modeling usable for the Envisat next reprocessing. GOT 4V10 ocean tide model is already available. Performance of the 4V10 version compared to the current 4V8 version is presented below in 8.1.1.1..
Finally, another ocean tide solution is presented here and will be available at the time of the reprocessing. FES 2014 version is currently under completion and will be available at the beginning of 2015. Performance assessment has been presented at the 2014 OSTST.

8.1.1.1. GOT 4V10 ocean tide model performance assessment

For the next reprocessing, ocean tide model will be updated and GOT 4V10 solution could be used. Performance assessment of this version compared to 4V8 version is presented in the following slides.
The evolutions of the 4V10 model concern the load and ocean tides for semi-diurnal wave S2. All the other files remain the same.

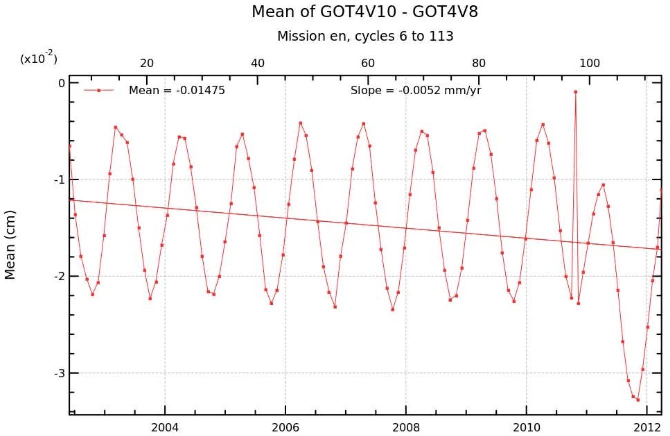
On mean difference between 4V10 and 4V8 versions, a very small annual signal is visible, around 0.15mm in amplitude. An impact of the change of Envisat orbit is observed on this amplitude.
In terms on peformances at mesoscale, the global impact is negligible; regionnaly a slight improvement is noticed at high latitudes, the variance of SSH at crossovers is reduced from 0.2cm2 in this area.
No remarkable impact is noticed on global and regional Envisat Mean Sea Level.

Comparison of the latest tide GOT4V10 with GOT4V8

GOT4V8 to GOT4V10

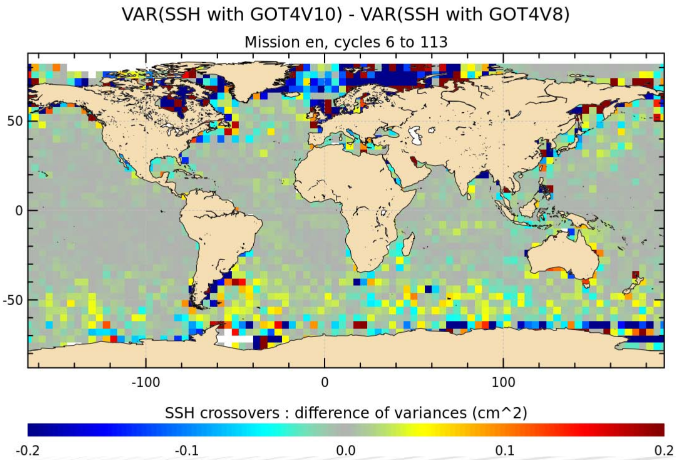
- Changes from GOT4V8 to GOT 4V10 :
  - Load tide for semi-diurnal wave S2
  - Ocean tide for semi-diurnal wave S2
  - All the other files remain the same

Mean of differences between GOT4V8 and GOT4V10 per cycle



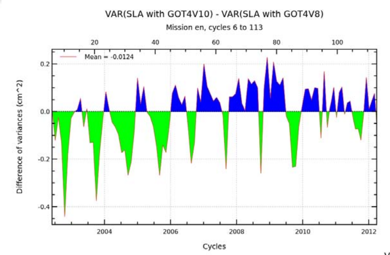
Around 0.15mm in amplitude for Envisat, and 2.8mm for Jason-1, therefore very small.
An impact of the change of Envisat orbit (drifting) can be observed .

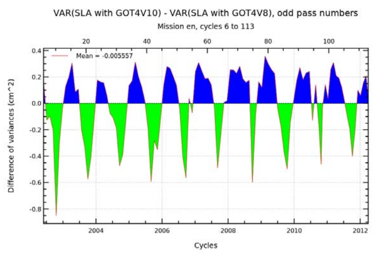
Performances at crossover

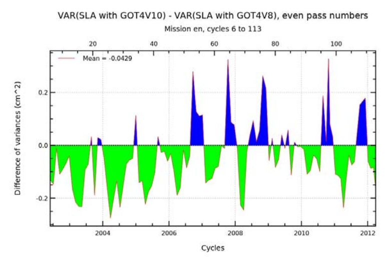


Differences at high latitudes for Envisat

Difference of variances of SLA for Envisat

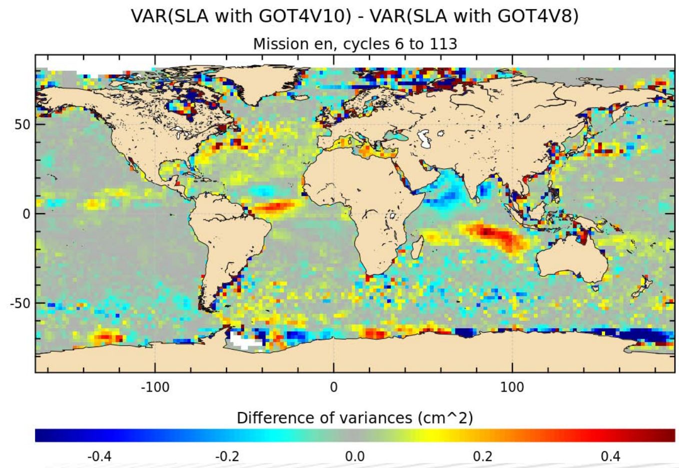






Mean of differences very small, annual signal, different behaviors between odd and even passes

Difference of variances of SLA



Some patches in the difference of variances for Envisat, at high latitudes.

8.1.1.2. FES 2014 ocean tide model performance assessment

This new version of FES model is currently in completion and will probably be available for the next reprocessing of Envisat data. The following slides present the first results of FES 2014 ocean tide model validation presented at the OSTST, Constanz 2014.

FES 2014 : a new global tidal model

L. Carrere, F. Lyard, M. Cancet, A. Guillot, S. Dupuy

10/2014

Project website : http://www.legos.obs-mip.fr/recherches/equipes/ecola/projets/fes2014

Introduction

• Accuracy of tidal models has been much improved these last 20 years, but errors remain in shallow waters & high latitudes
• Still need to improve tide correction for all altimeter missions, particularly for SWOT mission and HR altimeters planned in the coming years

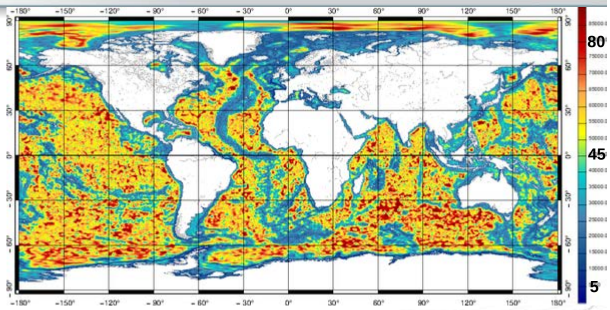
•In 2012, we have developed a new high resolution tidal model on global ocean taking advantage of:
- •19 years altimeters time series
- •Improved bathymetry & coastline, modelling/assimilation techniques

•FES2012 results are very good particularly in shallow waters and coastal regions although no TG has been assimilated (cf Stammer et al. 2014)
•But altimeter crossover variance is raised in some places when using FES2012, which was not entirely satisfying

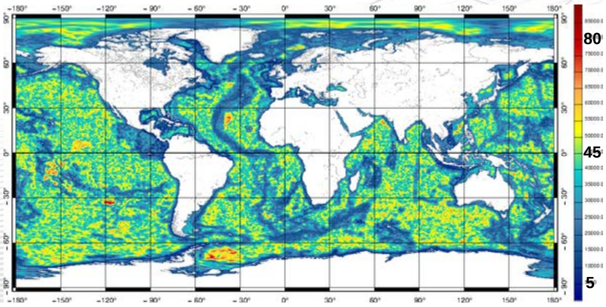
•New release FES2014 is being performed in order to improve FES2012 results in deep ocean, at high latitudes and in shallow/coastal seas.
- •=> intermediate FES2014 results are presented here

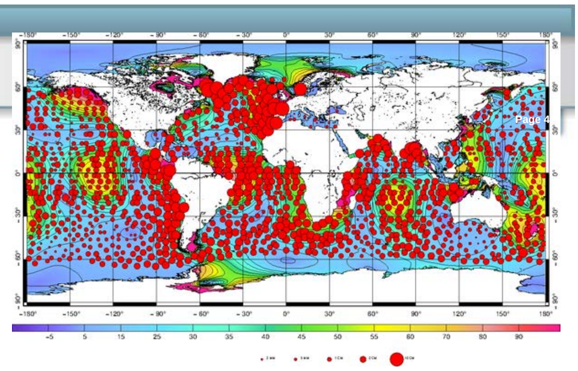
FES2014 Mesh

FES2012
- 730 000 triangles
- 1 500 000 elevation nodes
- 2 200 000 velocity nodes



FES2014
- 1 464 500 triangles
- 2 981 213 elevation nodes
- 4 393 500 velocity nodes

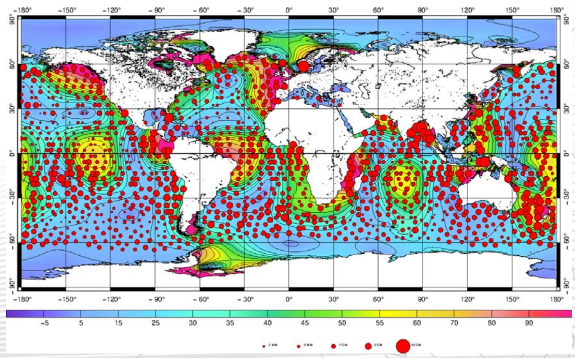




FES2012 hydro

M2 RMS (TP/J1/J2 xovers)

Deep ocean	2,5 cm
Shelf seas	9,3 cm



FES2014 hydro

M2 RMS (TP/J1/J2 xovers)

Deep ocean	1,20 cm
Shelf seas	5,37 cm

Assimilation database

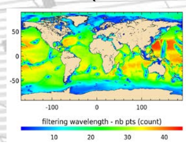
• Main issue in altimeter data harmonic analysis = aliased frequencies and subsequent separation periods (depends on the considered mission)

• 20 years time series for TP/J1/J2 nominal track => most of the alias issues have vanished

•Still aliasing issues for the T/P interleaved mission and for ERS/EN missions (6y and 17y resp.)

•CLS/CALVAL/PVA databases have been used
- •DAC_ERA_interim correction is used for TP and ERS missions
- •A multi-missions orbit-error is used for ERS-EN missions
- •GOT4.8 tidal loading effects are used (tidal loading error correction to GOT4.8 applied)

•Harmonic analysis has been improved
- •to take into account the effect of seasonal ice cover
- •Use GLORYS2-V1 to remove non tidal annual & semi-annual contaminations (TPNJ1N, ERSEN)
- •Improved along-track filtering to remove internal tide signatures



FES2014 – Assimilation

- **Spectral data assimilation code (SpEnOI)**
  - •Ensemble method within representers approach: perturbations on bathymetry, friction coefficient, wave drag coefficient, minimum bathymetry value, loading effects (=> ~900 members)

- **Assimilation process is still on-going**

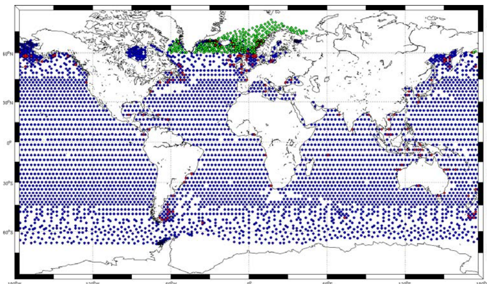
- **we present data used for the FES2014 intermediate atlas**

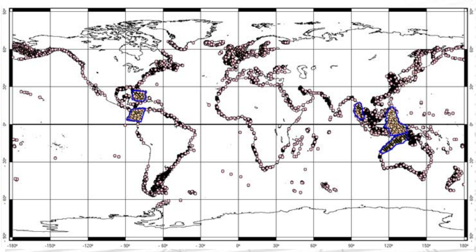
Assimilated data

– **4858 Crossover points:**
  - 4427 TPJ1J2: open ocean + shelves
  - 186 TPNJ1N: shelves
  - 245 E1E2EN: Arctic Ocean (no S2)

– **Along track data:**
  - 6258 TPJ1J2: shelves + patches

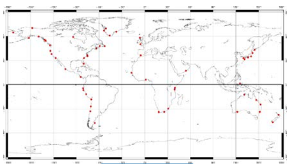
– **Only 1 TG**
  - in the Bristol Channel (UK)



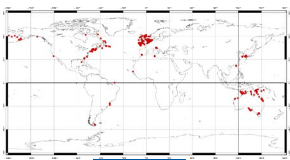


Validation in spectral domain

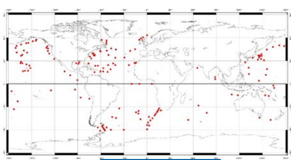
- **Performances vs tide gauge databases**
  – **Deep, Shallow, Coastal databases used in Stammer et al. paper (2014)**



Coastal



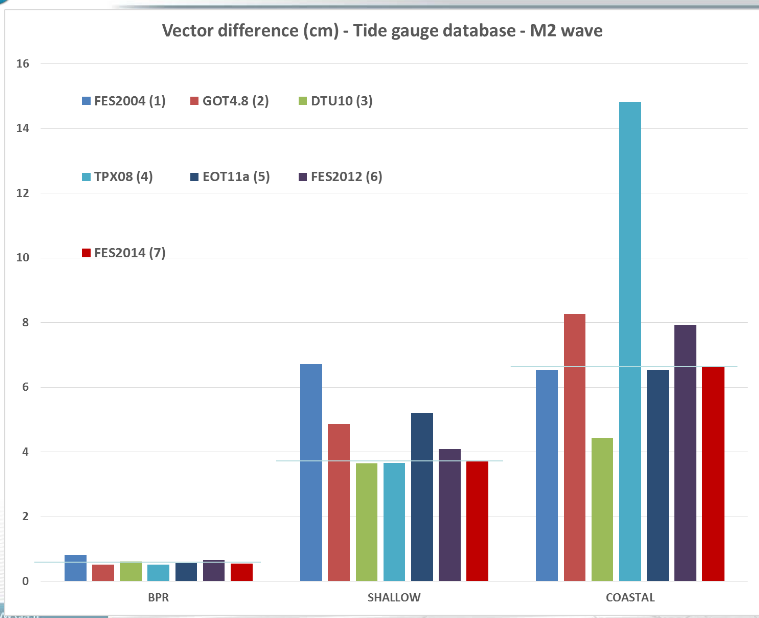
Shallow



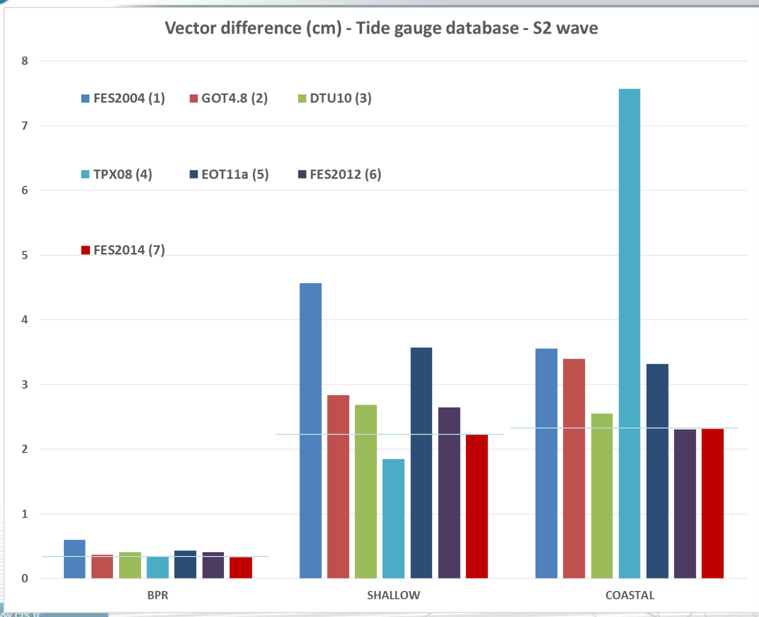
Deep BPR

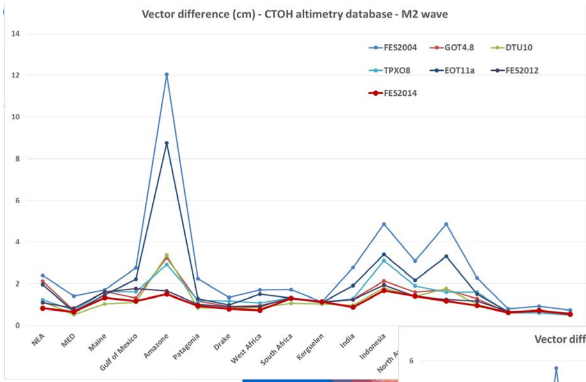
– **Models listed in Stammer et al. paper have been used for comparison**
– **Comparisons with DTU10, GOT4.8, TPXO8, EOT11a, FES2004 and FES2012 are presented**

Validation in spectral domain



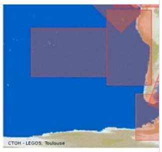
Validation in spectral domain

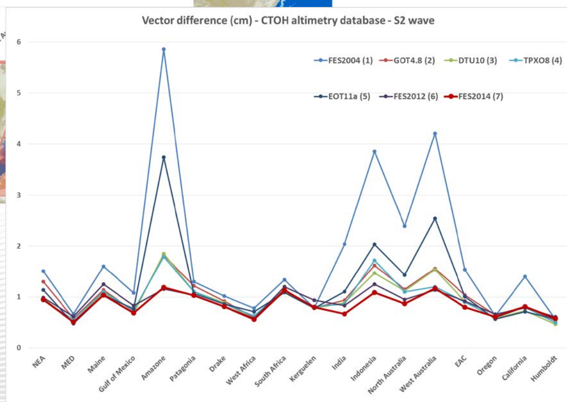




ectral domain

CTOH) : http://ctoh.legos.obs-

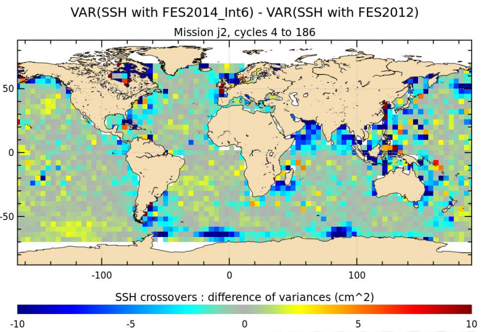


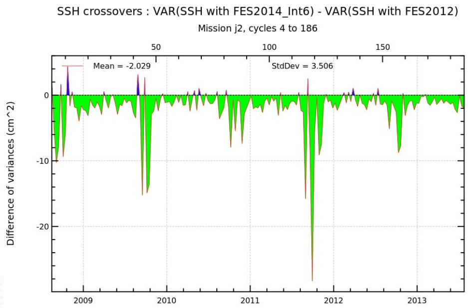


Validation in temporal domain

- **Modeling and omission errors**
- **FES2014 intermediate atlas assimilating data presented previously:**
  - 10 waves available: M2, M4, S2, 2N2, K2, N2, K1, O1, P1, Q1
  - completed **by DTU10 (S1)**
- **Performances vs global altimetry databases (CLS/CALVAL)**
  - Global ocean
  - 5 years of Jason-2 (2008-2013)
  - Variance reduction analysis at crossovers compared to DTU10 and FES2012 tide models

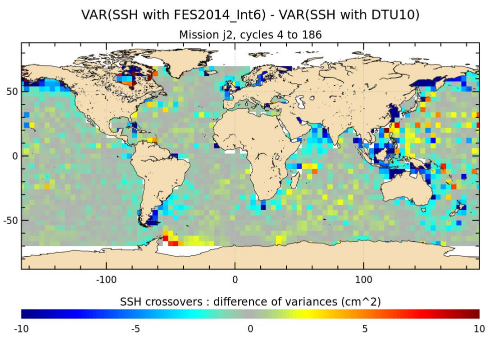
Variance reduction for J2 crossovers when using FES2014 instead of FES2012

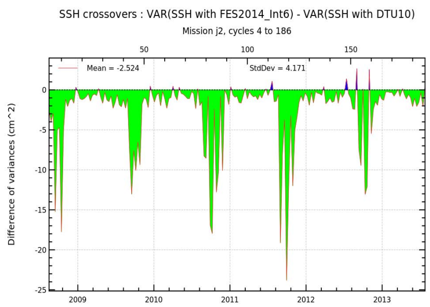




- Significant improvement in many areas: coastal regions and many deep ocean areas
- Improvement in Southern Ocean, north of Indian & south Aleutian islands

Variance reduction for J2 crossovers when using FES2014 instead of DTU10





- Significant improvement on global ocean and particularly: around Australia, in Indonesian and China seas, northern Indian Ocean, north Pacific, south Brazil/Argentine, NEA …
- narrow regions with variance raise are still noted north of Weddell sea, east of Philippines, around Seychelles=> those areas will be improved in the final FES2014

Conclusions

- •FES2014 int. atlas results show a strong improvement compared to previous version FES2012
- •FES2014 is ~/better than other models for all waves except TPXO8 in shallow waters and DTU10 in coastal region, but no TG have been assimilated yet
- •Improvement noted on most deep ocean regions for M2 + S2
- •Global temporal validation vs DTU10 & FES2012:
  - Improvement in coastal/shelf regions, in deep ocean areas and at high latitudes
  - A few regions can still be improved
- •Good results obtained in shelf/coastal regions and at high latitudes are explained by:
  - •The more accurate bathymetry + finer native resolution of the grid
  - •The better quality of the assimilation database
  - •A specific selection of assimilated data according to each region

Perspectives

- Assimilation process is on-going …
- Final FES2014 atlas will be ready by the end of November 2014
- A specific task is devoted to the analysis of the 58.77 days MSL signals:
  - •FES2014 model (hydro+assim) will be tested in this context
  - •=> cf Poster on this subjet from **Zawadzki et al.**

8.1.2. OSTST 2014: Getting ready for future reprocessing

The poster presented at the OSTST, Constanz 2014 is available below. It gathered the main anticipated standards and corrections which should be considered for the next whole dataset reprocessing.

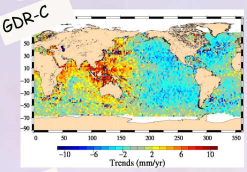
Envisat ocean altimetry performance assessment
Getting ready for future reprocessing

Marielle Guibbaud (CLS), Annabelle Ollivier (CLS), Stéphanie Urien (CLS), Nicolas Picot (CNES), Pierre Femenias (ESA)

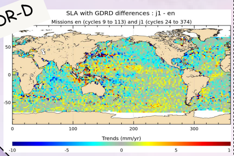
In 2012, ENVISAT mission was interrupted, after 10 years of altimetric measurements over ocean. Two years later, the mission's database is still maintained, studied and used. Used as a reference for the expected behavior of the very young or future missions such as AltiKa or Sentinel 3, historical database still evolves.
Next reprocessing is getting prepared with a tenth of algorithm improvements planned for the future products. The major evolutions are listed below with an overview on the expected effects on errors reduction at different scales.

1 Large and short scales error reduction: MSL imporovement and SSH variance at crossovers decrease

GDR-C



GDR-D

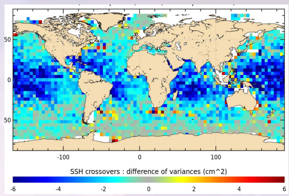


New orbit standard: GDR-E

Difference of SLA trends between Envisat and Jason-1

Future GDR-E

- •New gravity field EIGEN6S2.V3 (free harmonic 3.1)
- •Extended ITRF2013
- •New Position of geocentre
- •Reduced dynamic methods of estimation
- •Improvement of solar radiation pressure on solar pannels
- •Digital Terrestrial Model 2013
- •Introduction of hydraulic charge at station positions



SSH variance reduction at crossovers, using MWR V2.2 compared to ECMWF model

2 New wet tropospheric corrections

Future Wet tropo

- •New Side Lobes consideration
- •New in flight calibration
- •New parameters in entries of neural network (Gamma/SST)

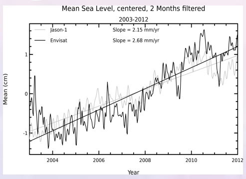
+ Additionnal MWR derived fields: ice flags, atmospheric attenuation

Next reprocessing upgraded fields and expected impacts at different scales

Upgraded Fields	Orbit GDR-E standards (1)	MWR wet tropospheric correction (2)	MWR derived fields (ice flags, atmospheric attenuation...) will also be upgraded	SSB computed with all upgraded corrections	PTR Internal Path Delay drift (3)	Look Up Tables for small waves correction (4)	L1b reprocessing: ICU, USO, IF mask...)	Ocean Tide: MAR_GOT_4V10 FES_2014	Non equilibrium long period ocean tide	Updated MSS (CNES/CLS 2012)	New iono. filetring method (5)
Expected impact	Climate scales geographical variations Short scales error reduction (crossovers)	Coastal areas Short scales error reduction (crossovers) Reduction of difference with model	Mesoscale	Mesoscale	Climate scale	Reduction of altimetry/ERA-Interim model dependency for Envisat small waves.	Climate scale + punctual effects expected?	Mesoscale	Mesoscale	Regional scale	Number of SLA valid data increase. Short scales error reduction (crossovers) Independant from editing step

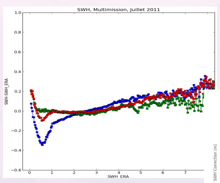
Instrumental corrections, new algorithms: a various panel of improvements

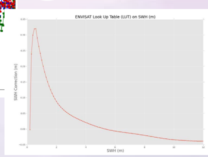
3 Internal Path delay correction



With an homogenized V2.1 dataset, and after correction of the Internal Path Delay drift (PTR), the consistency of Envisat Mean Sea Level with Jason-1 and in-situ data is clearly increased.

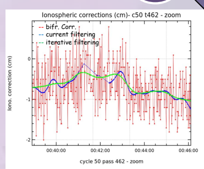
4 Small waves correction





RA-2 small waves are underestimated for Envisat, as visible on the comparison with ERA model (left). For Jason's missions, waves are corrected in the products by correction tables

5 New bifrequency ionospheric correction filtering method



Currently, ionospheric correction filtering method is too restrictive. A new filtering solution is proposed, based on an iterative filtering coupling a Lanczos filter and a median filter. This method allows to recover valid ionospheric correction data usable in SLA computation

New fields available !!

Current Homogeneous dataset available on:
ftp://diss-nas fp.eo.esa.int
under the directory altimetry_dataset_v2.1.
Envisat Corrected SSH products now available on ODES portal:
http://odes.altimetry.cnes.fr

- ✓ ERA Interim meteo. Fields (dry/wet tropospheric corrections)
- ✓ 2 new wet tropospheric corrections
- ✓ ACE2
- ✓ LEGOS Echo and Geo correction over ice shelves
- ✓ EGM 2008
- ✓ MSS DTU-10...

GDR will be available in NetCDF format S3 compliant

8.2. Other analysis performed in 2014

8.2.1. Remaining issues observed on Envisat dataset: refined analysis of Envisat Mean Sea Level

Following slides present the complete analysis performed on Envisat MSL suspicious behaviours, presented at the QWG21, Esrin 2014.

Overview - details

Suspicious behaviors on **Envisat Mean Sea Level** raise questions:
⇒ Signature at mesoscale?
⇒ Causes of the different behavior observed? Suspected parameters?
⇒ Possible correction of these behaviors … next reprocessing …

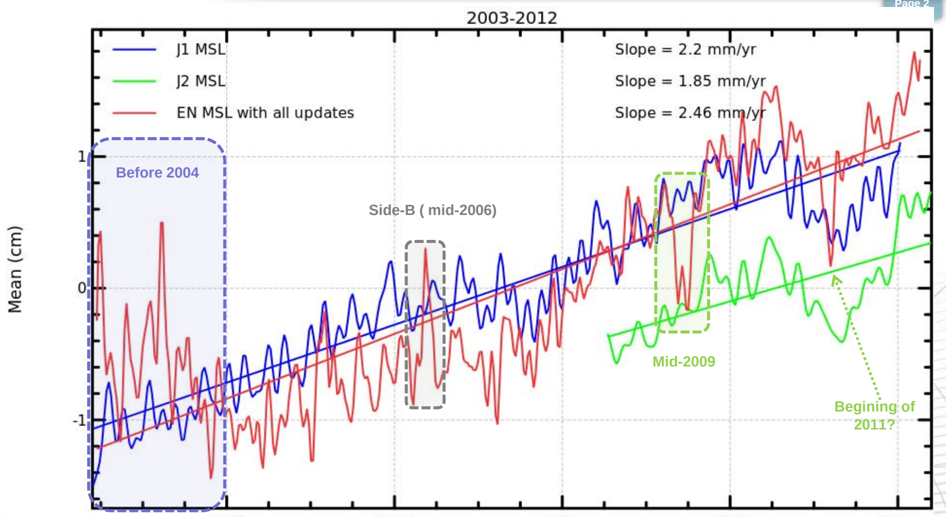
What happens on 2002/2003?
- **Drift on Mean Sea level at the beginning of the Envisat period**
- **Behavior of RA2 parameters, waveform parameters, …(QWG#18)**

Suspicious S-Band behavior
- **QWG#18: Statistics on S-Band waveform parameters are suspicious**
- **Impact on ionospheric correction? Other parameters impacted?**

Other remarks
- **Jump mid-2009 observed on Envisat Mean Sea Level ?**
- **Other remarkable periods**

Suspicious Side-B period
- **Exhaustive list of observed bias for Side-B period.**
- **Difference of treatment Side-A/Side-B?**

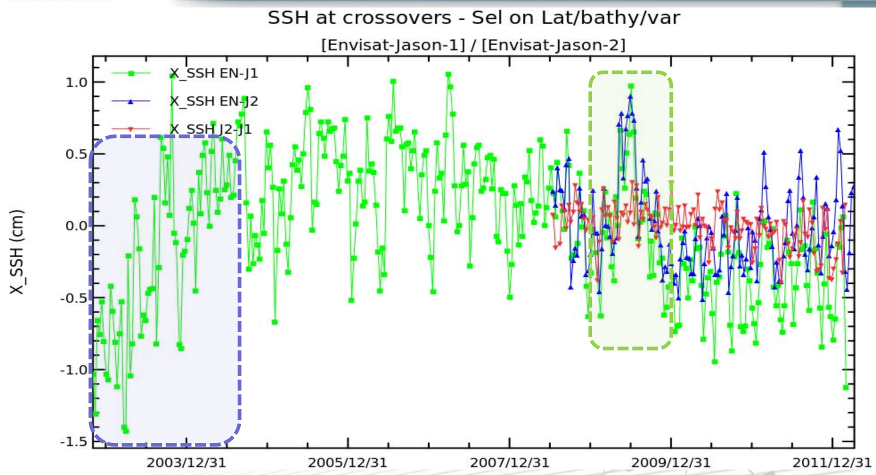
Signature on Mean Sea Level
(with MWR wet tropo V2.2 /PTR/GDR-D Orbit)



6 … 32	…	47 48	…	78 80		94	…

Signature at mesoscale – multimission comparison

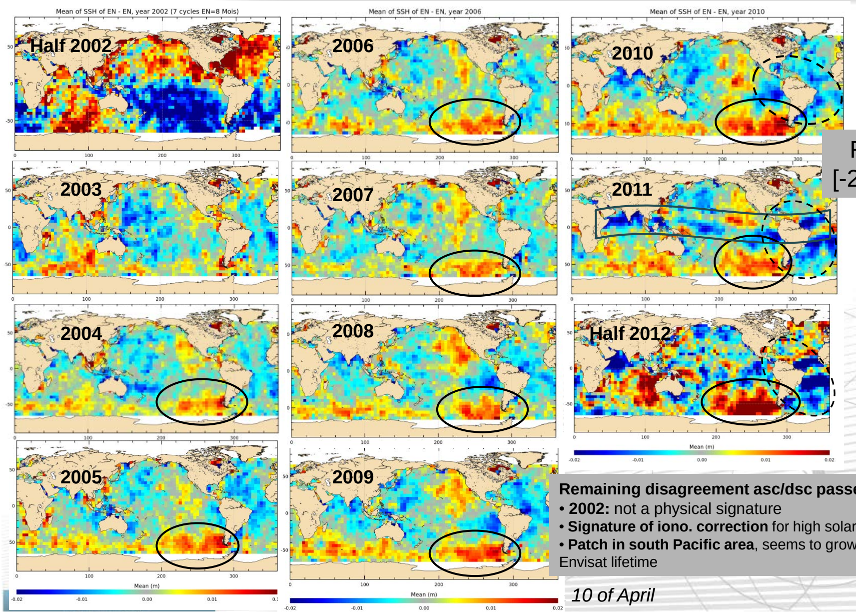
(EN: with MWR wet tropo V2.2 /PTR/GDR-D Orbit)



- Before 2004: the signature at mesoscale is clearly visible, as on MSL
- We recover the jump in the first part of year 2009, without explanation yet.
- A weak annual signal seems to appear after 2010 on Envisat-Jason2 difference at crossovers.

Envisat SSH at crossovers per year with

MWR wet tropo V2.2 /PTR/EIGEN6S2 Orbit/Filtered Iono (centered maps)

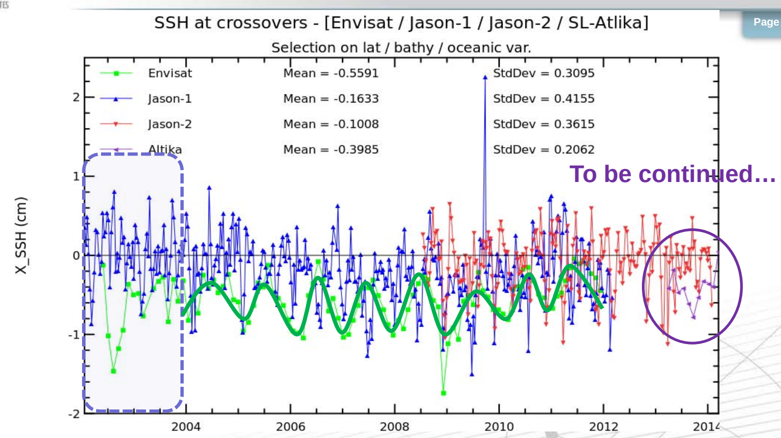


Range : [-2cm,2cm]

Remaining disagreement asc/dsc passes:
- **2002:** not a physical signature
- **Signature of iono. correction** for high solar activity period
- **Patch in south Pacific area**, seems to grow throughout Envisat lifetime

SSH at monomission crossovers

(EN: with MWR wet tropo V2.2 /PTR/GDR-D Orbit)



- **Annual signal observed on Envisat**, except for 2002/2003 => heliosynchronism ? (analysis of Altika)
- Behavior **before 2004** is confirmed as **suspicious** on Envisat monomission crossovers…
- Mean difference of SSH computed at crossovers: centered on -5mm for Envisat (-1mm for the Jason's.)
- Jump in 2009 visible in multimission crossovers not visible here.

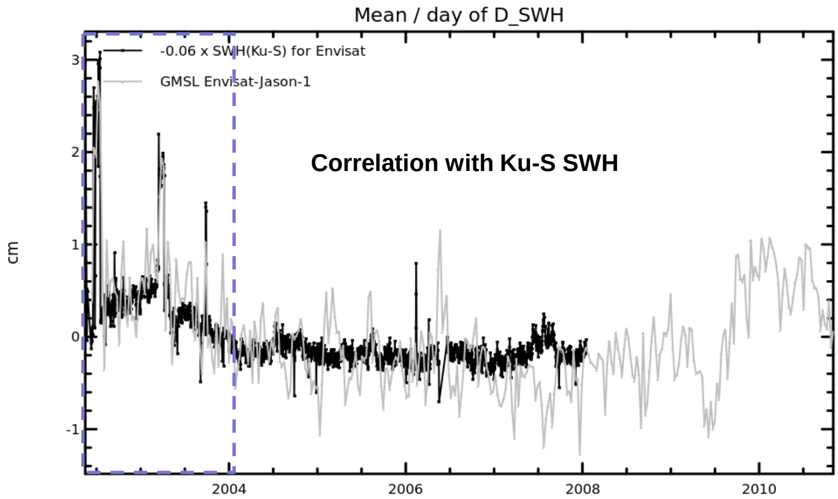
Remaining issues – Before 2004

List extracted from QWG#18

Parameter	Signature before 2004
ICU/UTC drift estimation	Extract from ECAR monitoring Change of behavior at the beginning of the period
Precise orbit solution	Unchained mode of DORIS for POD at the beginning of the period => DORIS on board inhomogeneities
MWR related parameters	Mean of brightness temp, attmospheric attenuation seems suspicious
Mean and Std deviation of Filtered –GIM ionospephric corr.	The mean difference of ionospheric corrections is biased before 2004, over 3mm over 2003.
Mean of S-Band 20Hz range standard deviation	before cycle 20: a particular trend is noticed before 2004 (-5mm/y)
Standard deviation of S-Band 20Hz range standard deviation	before cycle 20: a particular trend is noticed before 2004 (-5mm/y)
Mean of S-Band SWH	before cycle 20: a particular trend is noticed before 2004 (-10cm/y)
Standard deviation of S-Band SWH	Suspicious before cycle 20: a particular trend is noticed before 2004 (-6.6cm/y) compared to after 2004 (-1.6cm/y)
Attitude of the satellite	Unstability under cycle 25: Jumps are noticed cycle 7/14/15

MSL before 2004

=> Ku – S SWH seems to provide us a direction of possible investigations



S-Band suspicious signature before 2004

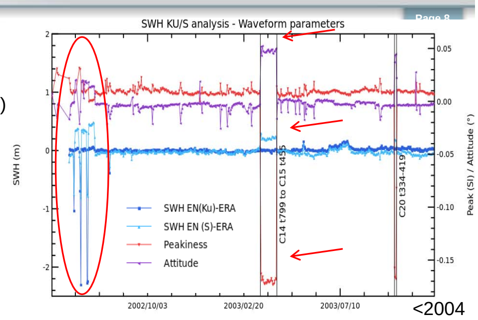
•Jumps are observed for wrong RA2 parameters settings periods
(No or wrong CTI table uploaded on board)

- 10/07/2002 - 18/07/2002 (cycle 7 track 360 to 780)
- 16/03/2003 - 08/04/2003
(cycle 14 track 799 to cycle 15 track 455)
- 27/09/2003 - 30/09/2003
(cycle 20 track 334 to 419)
- Bandwidth shift tests cycle 7:
2002/06/18 and between 2002/06/26 and 2002/06/29

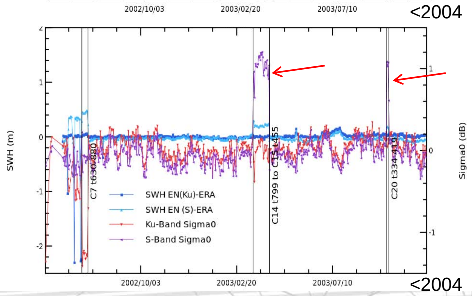
⇒Waveform mispointing and peakiness are impacted

⇒ Ku-S Sigma0 / Ku-S SWH are impacted too but only mainly S-Band

⇒ Wrong CTI tables DO have an impact on many altimeter parameters including MSL (cm jumps) : why?



<2004



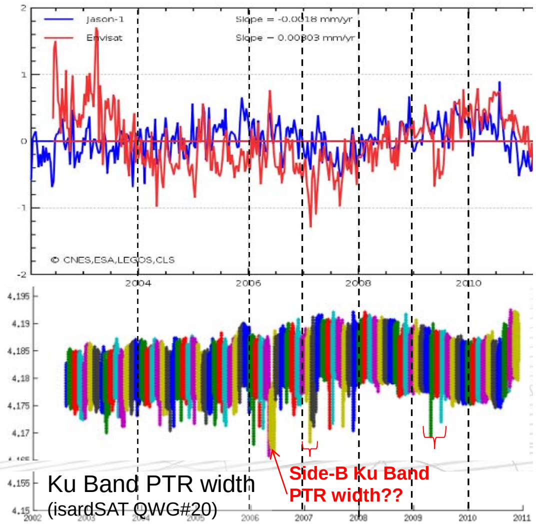
<2004

Other remarkable behaviors

- Elsewhere, remaining jumps are still observed with no obvious link with any physical corrections…
- Strong suspicion of instrumental events badly taken into account in instrumental corrections.
  - PTR?
  - IF Mask?
  - ICU?

  By now, we could not evidence the exact cause through the analysis of isardSAT plots presented in QWG…

  ➔What can we expect of reprocessing about that?



Side B remaining issues

Events:

Radio Frequency Module was switched to its B-side
(2006/05/15 ,14:21:50 (c47p794) to 2006/06/21, 11:37:32 (c48 p847))

During Side-B period, S-Band power drop occurred
(2006/05/21, 13:24:57 (c47 p936) to 2006/06/21, 11:37:32 (c48 p847))

Envisat GDR products

V1=> side-B data are **computed with Side A configuration** of the Ground Segment Chain

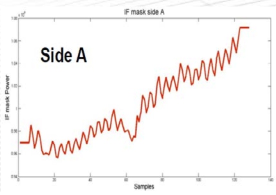
V2.1 => side-B data are **computed with real Side-B configuration** of the Ground Segment Chain

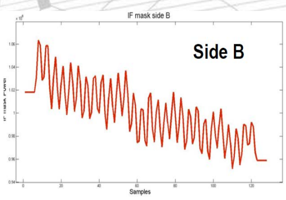
→ **Impact on waveform parameters** presented during QWG#7 and #10

→ QWG#18: The characterisation files are used (depending on parameters) at L1b or L2 processing. After investigation, the origin of the differences were attributed to L1b step:

→ **A-Side/B-Side IF Mask impact on L1B corrected WF?**

impact of the **reversed** slope?

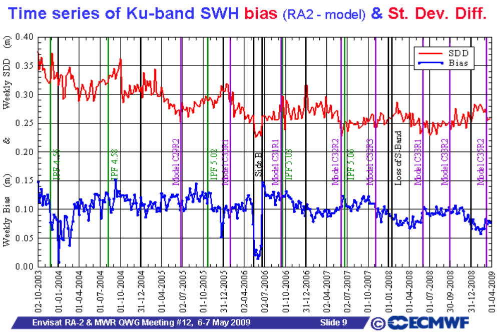




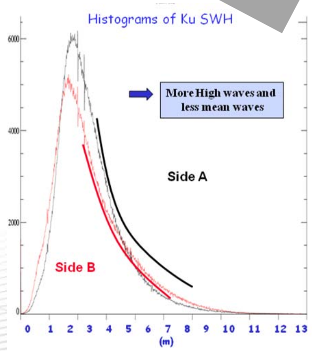
From S. Urien's talk QWG#18

ECMWF :

Best ever SWH when B-side processed in A-side
(in terms of bias and std)



With **Side-A configuration** applied on Side-B



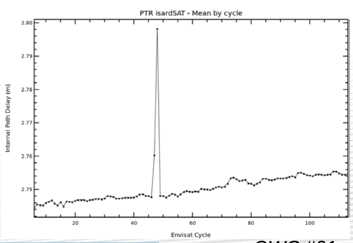
With **Side-B configuration** applied on Side-B:
- std dev of SWH similar to Side-A
- SWH distribution changes

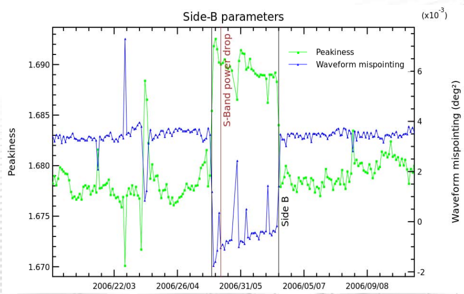
Bias observed with Side-A for Side-B data computed with …

Side-A test period: cycle 46 to 49 in Side-A conf.

Parameter	… Side-A configuration	… Side-B configuration (V2.1)
Mean/ std. dev of Ku SWH	-10cm/-4 cm	similar / similar
Std dev of Ku Range	-5 mm	similar
Mean of Sigma0	similar	-0.1 dB (0.5m/s on wind)
Peakiness	+0.07	+0.01
Mispointing	-0.03°2	-0.004°2
Mean of SLA (Open ocean)	+4.4cm	+8mm

- Altimeter range : bias of 8mm
- isardSAT PTR: bias of 5cm for the Side-B





Conclusion and perspectives

Tentative correlations established between jumps on MSL and Instrumental parameters

- Before 2004:
  - Jumps and drift observed
  - S-Band parameters ?
    - **Why such a visible impact on Mean Sea Level??**
    - **Impact of ponctual events on the particular trend of Envisat MSL before 2004?? Why? How?**
  - Problems of CTI tables for this period / Bandwidth shift tests ?…
- Side-B:
  - Biases on peakiness, waveform mispointing (weak on Sigma0) and range
  - But also discontinuity on SLA and on SWH distribution
  - Why a **reversed IF mask**? **Why impact on geophysical parameters as well?**
  - **Possible errors in Side-B processing?**
- In 2009 and elsewhere
  - still under investigations

➔ Hope to correct some of these events with the next reprocessing updates?

Backup slides

QWG #21 – ESRIN - 2014, 9 & 10 of April

Overview of Envisat lifetime events

➔ *Homogeneous available dataset*

Communication loss on 8 April 2012

6		9	10	…	22	…	41	…	47/48	…	60	…	65	…	80	…	85	…	92	…	94/95	…	113

First cycles available in V2.1 version

Cycles 47/48 •t794/t847: Side-B period •t936/t847: S-Band power drop

S-Band power drop 2008, 17th January => Use of GIM iono. corr. afterward

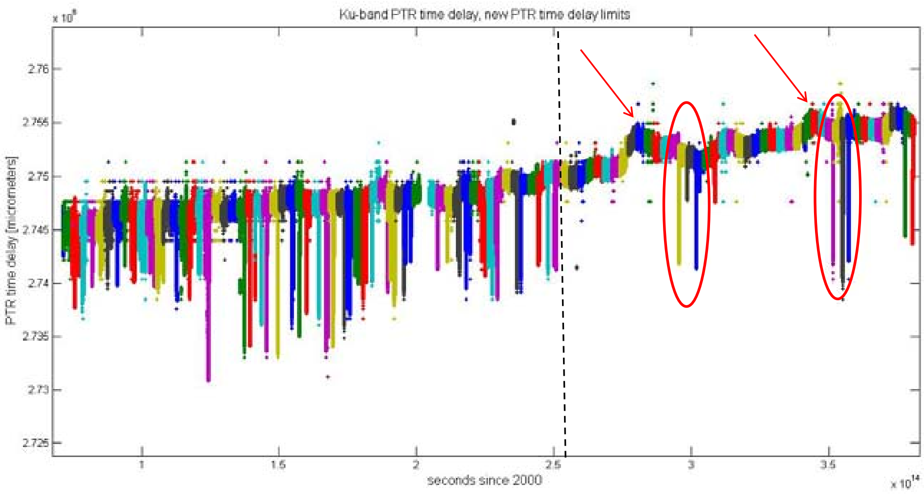
Drifting phase, 22-26th Nov 2006 Pseudo-cycle 35d

Homogeneous data set available on:
ftp://diss-nas-fp.eo.esa.int
under the directory :
altimetry_dataset_v2.1.

++ Already available:
Instrument correction (PTR) from isardSAT
Orbit GDR-D,
New MWR

- For the first time the whole data set was reprocessed and made available to users in January 2012
- A **future reprocessing** is planned, including improvements at different scales (New POD, instrumental correction insuring climate scales relevance, new Radiometer wet tropo…)
- Do these events sign on climatic scale? On mesoscale?

Which remarkable behavior can be linked to these events?
Which observed anomaly remains without explanation yet?



8.2.2. Editing improvement for Duacs multimissions process: how to wisely use data near coasts?

In SLA multimission products, some residual errors were noticed near coasts resulting in a pollution of multimissions maps. These values were attributed to drifting missions, in particular to Cryosat-2. The corresponding SLA seemed to be erroneous and the causes were not clearly defined. Oceanic tide model could be in cause, but Mean Sea Surface definition seemed to be a great source of error too.
As a consequence a palliative but drastic solution is currently used in DUACS products: data providing by drifting missions under 20km from coasts are not used in SLA multimission maps generation.
This solution is not really satisfactory, a significant number of data is not considered whereas SLA could be valid and usable for multimissions analysis and products generation.

Knowing this palliative solution, an effort was made in 2014 to define a new solution which allows to refine the validation of SLA near coasts.
This solution consists in an iterative filtering of SLA data directly after the classical editing process. For drifting missions, this solution adds therefore a step in the global editing process and allows to determine a SLA which is valid very close to shore.
After the classic editing process a median filter is applied on the whole dataset of valid SLA, using a window of 60 points (400km). This filtering method give a specific validity flag for each SLA data. After this filtering step, this specific flag is taken into account in the band of 30km near coasts.

SLA is therefore considered as valid if:

- beyond 30km from coasts, SLA value is validated by the classical editing process;
- below 30km from coasts, SLA value is validated:
  - by the classical editing process AND
  - by the iterative median filter (statistics in 3σ) directly applied after the classical editing process.

The optimal distance to be used could be adapted depending on the application needs.
The iterative process allows to give robustness to statistics and the filtering parametrization allows to remove only the spurious values of SLA very close to shores.

Figure 29 presents for cycle 112 the current solution used for Envisat in Duacs production system (on the left) and the new solution proposed for a better consideration of SLA near coasts for drifting phase (on the right). The zoom is made on Egean Sea because of the multitude of islands in this area.

We easily sea the gain of data very close to coasts. These SLA data are now considered as valid and can be used in multimission process.

.

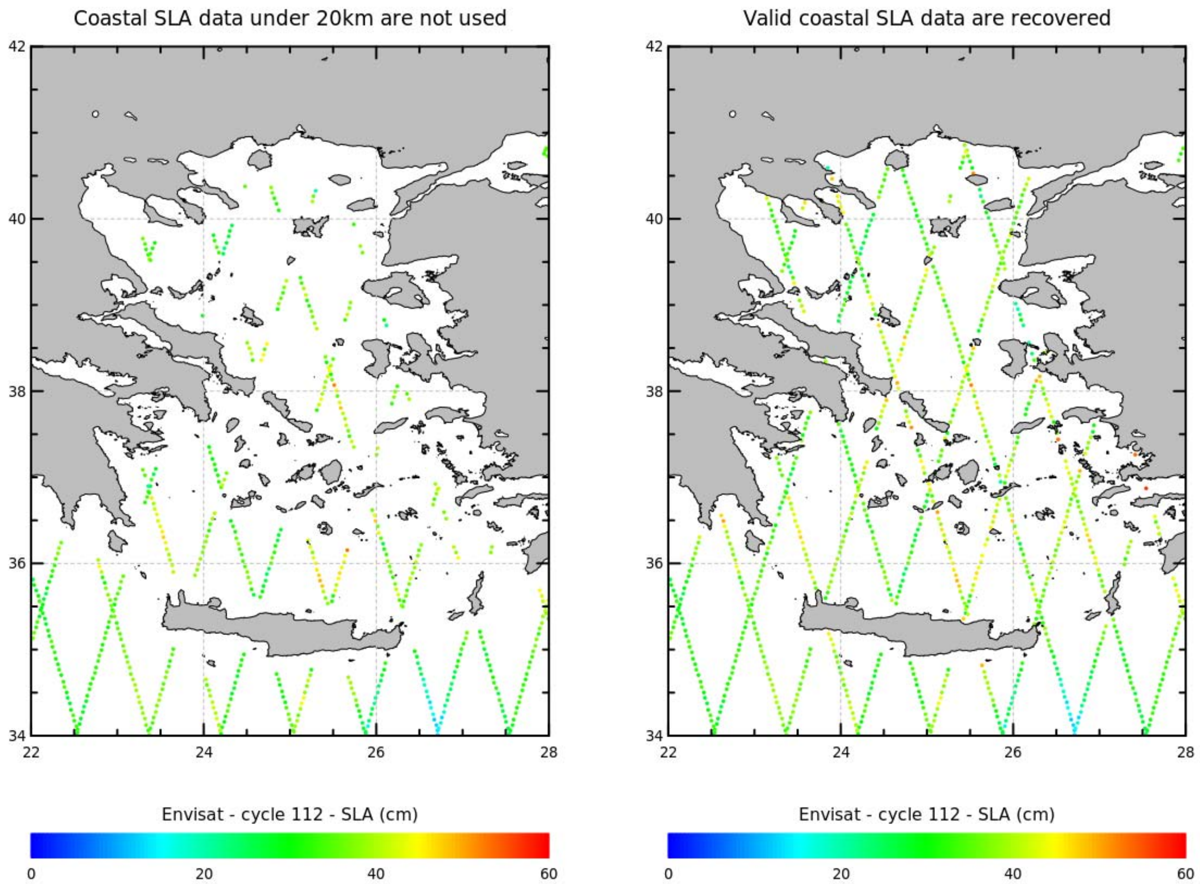


Figure 29: *Envisat cycle 112,* ***Left:*** *Data under 20km are removed for drifting missions - Current DUACS solution* ***Right:*** *Data near coasts are recovered with filtering solution directly applied on Sea Level Anomaly (result of filtering is here considered under 30km)*

9. Conclusion

This report gathers the statistical evaluation of Envisat altimetric measurements on the whole dataset, corresponding to 10 years of data now available. Results presented here are based on GDR in V2.1 version and the last updates devolopped in 2013 and 2014. The major part of these updates are anticipated to prepare the next reprocessing. Such analysis will continue in 2015 notably with two new versions of radiometer wet tropospheric corrections.

With 10 years of available data and after 2 more years of analysis, we have now a very good knowledge of the quality of Envisat Mean Sea Level as a relevant indicator, refined this year by new analysis; possible correlations are established between spurious behaviours, notably at the beginning of the Envisat period, and instrumental events or configuration used. This is an important evolution in our approach of Envisat Mean Sea Level relevance.

At the end of this year, we underline the following major elements:

- A very good availability of Envisat data on the last 2.5 years (from cycle 68) was noticed thanks to an improvement of the data dissemination since May 2008. Over the 10 years the availability of data is remarkable, reaching 94%.

- This year some studies were carried out in order to improve the quality of Envisat dataset. Ocean tide models were analysed and will be used for the next reprocessing. This task will continue with the analyse of two new radiometer wet tropospheric corrections.

- After the loss of Envisat, the efforts concerning the computation of Envisat Mean Sea Level trend on the whole time series have been carried on. Sensitivity studies have been performed and many improvements and updates over the whole time series allows to show similarity with Jason-1's MSL and tide gauges, as demonstrated in 2013.
  Efforts were made this year to refine the analysis of misunderstood behaviours of Envisat MSL. The Envisat MSL trend for its first year of life remains very suspicious, but potential correlations are established between the jumps and trends observed and instrumental effects or configuration used. The S-Band parameters on this period have notably been detected as suspicious for this period. Other period have been finely analysed, such as Side-B period (mid-2006) for which associated jump is visible on Mean Sea Level trend.
  Continuing such focused analysis is an important issue for the Envisat Mean Sea Level understanding.

- A new solution for data near coasts validation has been developped notably on Cryosat-2 data and were successfully tested on Envisat too. Editing process remains a major question in validation process, for all the missions; analysis performed this year will be continued in the future to improve this first step of altimetric data validation.

Efforts must continue to be performed to analyse the residual strange behaviors of Envisat dataset comparing to other missions in terms of SSH quality or relevant Mean Sea Level computation. This remains important to refine our knowledge of the data and to well prepare future reprocessing.

10. Bibliography

References

[1] Abdalla, S., "A wind retrieval algorithm for satellite radar altimeters", ECMWF Technical Memorandum, in preparation, 2006.

[2] Ablain, M., G. Pontonnier, B. Soussi, P. Thibaut, M.H. de Launay, J. Dorandeu, and P. Vincent. 2004. Jason-1 GDR Quality Assessment Report. Cycle 079. SALP-RP-P2-EX-21072-CLS079, May.

[3] M. Ablain., S. Philipps, Dorandeu J., 2006: Jason-1 validation and cross calibration activities. Yearly report. Technical Note CLS.DOS/NT/06-302, Contract N° 03/CNES/1340/00-DSO310 - lot2.C http://www.jason.oceanobs.com/documents/calval/validation_report/annual_report_j1_2006.pdf

[4] M. Ablain., S. Philipps, 2007: Jason-1 validation and cross calibration activities. Yearly report. Technical Note CLS.DOS/NT/06-302, Contract N° 03/CNES/1340/00-DSO310 - lot2.C http://www.jason.oceanobs.com/documents/calval/validation_report/annual_report_j1_2007.pdf

[5] Ablain M., A. Cazenave, G. Valladeau, and S. Guinehut. 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.

[6] M. Ablain., S. Philipps, G. Valladeau, J.F. Legeais, H. Roinard 2011: Jason-1 validation and cross calibration activities. Annual report 2011. Technical Note CLS.DOS/NT/12-017, Contract N° SALP-RP-MA-EA-22056-CLS

[7] M. Ablain., S. Philipps, G. Valladeau, J.F. Legeais 2011: Jason-2 validation and cross calibration activities. Annual report 2011. Technical Note CLS.DOS/NT/12-005, Contract N° SALP-RP-MA-EA-22042-CLS

[8] Ablain M., Cazenave A., Guinehut S., Valladeau G., (submitted for publication), A new assessment of global mean sea level from altimeters highlights a reduction of global slope from 2005 to 2008 in agreement with in-situ measurements, submitted to Ocean Sciences.

[9] Ablain, M., A. Cazenave, G. Valladeau, and S. Guinehut. 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.

[10] 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 Vol 35.

[11] Faugere Y., Granier N., Ollivier A., 2007: Envisat RA-2/MWR ocean data validation and cross-calibration activities. Yearly report. Technical Note CLS.DOS/NT/08.006, Contract N° SALP-RP-MA-EA-21516-CLS

[12] Ollivier A.,Faugere Y., 2008: Envisat RA-2/MWR ocean data validation and cross-calibration activities. Yearly report. Technical Note CLS.DOS/NT/09.040, Contract N° SALP-RP-MA-EA-21633-CLS

[13] Ollivier A.,Faugere Y., 2009: Envisat RA-2/MWR ocean data validation and cross-calibration activities. Yearly report. Technical Note CLS.DOS/NT/10.018, Contract N° SALP-RP-MA-EA-21800-CLS http://www.aviso.oceanobs.com/fileadmin/documents/calval/validation_report/EN/annual_report_en_2009.pdf

[14] Ollivier A.,Faugere Y., 2010: Envisat RA-2/MWR ocean data validation and cross-calibration activities. Yearly report. Technical Note CLS.DOS/NT/10.018, Contract N° SALP-RP-MA-EA-21920-CLS http://www.aviso.oceanobs.com/fileadmin/documents/calval/validation_report/EN/annual_report_en_2010.pdf

[15] Ollivier A., Guibbaud M., 2011: Envisat RA-2/MWR ocean data validation and cross-calibration activities. Yearly report. Technical Note CLS.DOS/NT/12.021, Contract SALP-RP-MA-EA-22062-CLS http://www.aviso.oceanobs.com/fileadmin/documents/calval/validation_report/EN/annual_report_en_2011.pdf

[16] Ollivier A., Guibbaud M., 2012: Envisat RA-2/MWR ocean data validation and cross-calibration activities. Yearly report. Technical Note CLS.DOS/NT/12.292, Contract SALP-RP-MA-EA-22163-CLS http://www.aviso.oceanobs.com/fileadmin/documents/calval/validation_report/EN/annual_report_en_2012.pdf

[17] Ollivier A., Guibbaud M., 2013: Envisat RA-2/MWR ocean data validation and cross-calibration activities. Yearly report. Technical Note CLS.DOS/NT/13.290, Contract SALP-RP-MA-EA-22293-CLS http://www.aviso.oceanobs.com/fileadmin/documents/calval/validation_report/EN/annual_report_en_2013.pdf

[18] Commien L., S. Philipps, M. Ablain., 2008: Jason-1 validation and cross calibration activities. Yearly report. Technical Note CLS.DOS/NT/09-006, Contract N° 60453 - lot2.C http://www.jason.oceanobs.com/documents/calval/validation_report/annual_report_j1_2008.pdf

[19] Valladeau G. and Prandi P., 2013:Validation of altimeter data by comparison with tide gauge measurements for TOPEX/Poseidon, Jason-1, Jason-2 and Envisat (Annual report 2013). [SALP-NT-MA-EA-xxxxx-CLS, CLS.DOS/NT/13-262].

[20] Legeais J.F. and Ablain M., 2013: Validation of altimetric data by comparison with in-situ T/S Argo profiles (Annual Report 2013) [SALP-RP-MA-EA-22281-CLS, CLS.DOS/NT/13-256]

[21] Beckley, B. D., F. G. Lemoine, S. B. Luthcke, R. D. Ray, and N. P. Zelensky A reassessment of global and regional mean sea level trends from TOPEX and Jason-1 altimetry based on revised reference frame and orbits, Geophys. Res. Lett., 34, L14608, 2007, doi:10.1029/2007GL030002.

[22] Valladeau G., Ablain M., Validation of altimetric data by means of tide gauge measurements for TOPEX/Poseidon, Jason-1 and Envisat, Reference : CLS.DOS/NT/10-289, Nomenclature : SALP-NT-MA-EA-21922-CLS

[23] Legeais JF, Ablain M., Validation of altimetric data by comparison with in-situ T/S Argo profiles, Reference : CLS.DOS/NT/10-308, Nomenclature : SALP-NT-MA-EA-21921-CLS

[24] Carrère, L., and F. Lyard, Modeling the barotropic response of the global ocean to atmospheric wind and pressure forcing - comparisons with observations. 2003. Geophys. Res. Lett., 30(6), 1275, doi:10.1029/2002GL016473.

[25] Commien, L., 2009. Différences entre l'orbite des GDR-C et GDR-B Jason-1, NT08.338

.

[26] Commien, L., S. Philipps, M. Ablain, and N. Picot, 2008. SSALTO CALVAL Performance assessment Jason-1 GDR "C" / GDR "B". Poster presented at OSTST meeting, Nice, France, 09-12 November 2008. Available at: http://www.aviso.oceanobs.com/fileadmin/documents/OSTST/2008/commien.pdf

[27] Legeais JF. and Carrere L, July 2008, Complement de validation de la DAC_HR par rapport à la DAC , en zone cotiere, Technical Note CLS.DOS/08.189.

[28] Cazenave, A., et al.,1999: Sea Level Change from Topex/Poseidon altimetry and tide gauges, and vertical crustal motions from DORIS, G. Res. Let., 26, 2077-2080.

[29] Cazenave, A. and Nerem, R. S.: Present-day sea level change, Observations and causes, Rev. Geophys., 42, RG3001, doi:10.1029/2003RG000139, 2004.

[30] Celani C., B. Greco, A. Martini, M. Roca, 2002: Instruments corrections applied on RA-2 Level-1B Product. 2002: Proceeding of the Envisat Calibration Workshop.

[31] Cerri L., Berthias P., Bertiger W.I., Haines, B.J. Lemoine F.G., Mercier F., Ries J.C., Willis P., Zellensky P. and Ziebart M. Precision Orbit Determination Standards for the Jason Series of Altimeter Missions, Marine Geodesy Vol 33., 2010

[32] Cerri L., Couhert A., Houry S., Mercier F., OSTST 2011 presentation available at http://www.aviso.oceanobs.com/fileadmin/documents/OSTST/2011/oral/02_Thursday/Splinter%203%2

[33] Chambers, D., P., J. Ries, T. Urban, and S. Hayes. 2002. Results of global intercomparison between TOPEX and Jason measurements and models. Paper presented at the Jason-1 and TOPEX/Poseidon Science Working Team Meeting, Biarritz (France), 10-12 June.

[34] Dorandeu, J. and P.Y. Le Traon, 1999: Effects of Global Atmospheric Pressure Variations on Mean Sea Level Changes from TOPEX/Poseidon. J. Atmos. Technol., 16, 1279-1283.

[35] Dorandeu J., Y. Faugere, F. Mertz, F. Mercier, N. Tran, 2004a: Calibration / Validation Of Envisat GDRs Cross-calibration / ERS-2, Jason-1 Envisat and ERS Symposium, Salzburg, Austria.

[36] Dorandeu, J., M. Ablain, Y. faugere, F. Mertz, B. Soussi, 2004b, Jason-1 global statistical evaluation and performance assessment. Calibration and cross-calibration results Mar. Geod. 27(3-4): 345-372.

[37] Doornbos E., Scharroo R., 2005: Improved ERS and Envisat precise orbit determination, Proc. of the 2004 Envisat and ERS Symposium, Salzburg, Austria.

[38] ECMWF, The evolution of the ECMWF analysis and forecasting system Available at: http://www.ecmwf.int/products/data/operational_system/evolution/

[39] EOO/EOX, October 2005, Information to the Users regarding the Envisat RA2/MWR IPF version 5.02 and CMA 7.1 Available at http://earth.esa.int/pcs/envisat/ra2/articles/

[40] EOP-GOQ and PCF team, 2005: Envisat Cyclic Altimetric Report, Technical Note ENVI-GSOP-EOPG-03-0011 Available at: http://earth.esa.int/pcs/envisat/ra2/reports/pcs_cyclic/

[41] Eymard L., E. Obligis, N. Tran, February 2003, ERS2/MWR drift evaluation and correction, CLS.DOS/NT/03.688

[42] http://earth.esa.int/brat/html/alti/dataflow/processing/pod/orbit_choice_en.html

[43] Envisat RA-2 Range Instrumental correction: USO clock period variations and associated auxiliary file, ENVI-GSEG-EOPG-TN-03-0009

[44] Faugere Y., Mertz F., Dorandeu J., 2003: Envisat GDR quality assessement report (cyclic), Cycle 015. SALP-RP-P2-EX-21072-CLS015, May. Available at http://www.aviso.oceanobs.com/html/donnees/calval/validation_report/en/welcome_uk.html

[45] Faugere Y., Mertz F., Dorandeu J., 2003: Envisat validation and cross calibration activities during the verification phase. Synthesis report. Technical Note CLS.DOS/NT/03.733, ESTEC contract N°16243/02/NL/FF WP6, May 16 2003 Available at http://earth.esa.int/pcs/envisat/ra2/articles/Envisat_Verif_Phase_CLS.pdf

[46] Faugere Y., Mertz F., Dorandeu J., 2004: Envisat RA-2/MWR ocean data validation and cross-calibration activities. Yearly report. Technical Note CLS.DOS/NT/04.289, Contract N° 03/CNES/1340/00-DSO310 Available at http://earth.esa.int/pcs/envisat/ra2/articles/Envisat_Yearly_Report_2004.pdf

[47] Faugere Y., Estimation du bruit de mesure sur jason-1, December 2002, CLS.ED/NT.

[48] Y.Faugere, J.Dorandeu, F.Lefevre, N.Picot and P.Femenias, 2005: Envisat ocean altimetry performance assessment and cross-calibration. Submitted in the special issue of SENSOR 'Satellite Altimetry: New Sensors and New Applications'

[49] Yannice Faugere, JoÃ«l Dorandeu, Fabien Lefevre, Nicolas Picot and Pierre Femenias, Envisat Ocean Altimetry Performance Assessment and Cross-calibration, Special Issue on 'Satellite Altimetry: New Sensors and New Application' Edited by Ge Chen and Graham D. Quartly, March 2006

[50] Faugere Y., Mertz F., Dorandeu J., 2005: Envisat RA-2/MWR ocean data validation and cross-calibration activities. Yearly report. Technical Note CLS.DOS/NT/04.289, Contract N° 03/CNES/1340/00-DSO310 http://www.jason.oceanobs.com/documents/calval/validation_report/en/annual_report_en_2005.pdf

[51] Faugere, Y., J. Dorandeu, N. Picot, P. Femenias. 2007. Jason-1 / Envisat Cross-calibration, presentation at the Hobart OSTST meeting

[52] Faugere, Y., Ollivier, A., 2007, Investigation on the differences between CLS and Altimetrics Envisat MSL trend, CLS.DOS/NT07-261

[53] Faugere, Y., Ollivier, A., 2008, Investigation on the High frequency content of Jason and Envisat, CLS.DOS/NT08-119

[54] Dibarbour, G., Bruit Jason et Analyse spectrale, March 2001, CLS.ED/NT

[55] G.Dibarboure, P.Schaeffer, P.Escudier, M-I.Pujol, J.F.Legeais, Y.Faugère, R.Morrow, J.K.Willis, J.Lambin, J.P.Berthias, N.Picot - Finding desirable orbit options for the "Extension of Life" phase of Jason-1 Submitted to Marine Geodesy - Jason-2 Special Issue Volume 3 - May 2011

[56] Imel, D., Evaluation of the TOPEX/POSEIDON dual-frequency ionosphere correction, J. Geophys. Res., 99, 24,895-24,906, 1994

[57] Labroue, S. and P. Gaspar, 2002: Comparison of non parametric estimates of the TOPEX A, TOPEX B and JASON 1 sea state bias. Paper presented at the Jason 1 and TOPEX/Poseidon SWT meeting, New-Orleans, 21-12 October.

.

[58] Labroue S. and E. Obligis, January 2003, Neural network retrieval algorithms for the ENVISAT/MWR, Technical note CLS.DOS/NT/03.848

[59] Labroue S., 2003: Non parametric estimation of ENVISAT sea state bias, Technical note CLS.DOS/NT/03.741, ESTEC Contract n°16243/02/NL/FF - WP3 Task 2

[60] Labroue S., 2004: RA-2 ocean and MWR measurement long term monitoring, Final report for WP3, Task 2, SSB estimation for RA-2 altimeter, Technical Note CLS-DOS-NT-04-284

[61] Labroue S., 2005: RA2 ocean and MWR measurement long term monitoring 2005 report for WP3, Task 2 SSB estimation for RA2 altimeter, Technical Note CLS-DOS-NT-05-200

[62] Labroue S., 2006: Estimation du Biais d'Etat de Mer pour la mission Jason-1, Technical note CLS-DOS-NT-06-244

[63] Labroue S., MH. Rio, Y. Faugere, A. Ollivier - Tâche 1.1 - Résolution des produits et filtrage SALP-NT-P-EA-21665-CLS

[64] Laxon and M. Roca, 2002: ENVISAT RA-2: S-BAND PERFORMANCE, S., Proceedings of the ENVISAT Calibration Workshop, Noordwijk

[65] Legeais J.F., Ablain M. 2011: Cal/Val in-situ annual report Altimetry / Argo T/S profiles. Validation of altimeter data by comparison with in-situ T/S Argo profiles. Ref. CLS/DOS/NT/11-305. SALP-RP-MA-EA-22045-CLS.

[66] Le Traon, P.-Y., J. Stum, J. Dorandeu, P. Gaspar, and P. Vincent, 1994: Global statistical analysis of TOPEX and POSEIDON data. J. Geophys. Res., 99, 24619-24631.

[67] Le Traon, P.-Y., , F. Ogor, 1998: ERS-1/2 orbit improvement using TOPEX/POSEIDON: the 2 cm challenge. J. G. Res., VOL 103, p 8045-8057, April 15, 1998.

[68] Le Traon P.Y. Y. Faugere, F. Hernandez, J.Dorandeu, F.Mertz, and M. Can We Merge GEOSAT Follow-On with TOPEX/Poseidon and ERS-2 for an Improved Description of the Ocean Circulation? ; June 2003, American Meteorological Society

[69] Lefèvre, F., and E. Sénant, 2005: ENVISAT relative calibration, Technical Note CLS-DOS-NT-05.074.

[70] Lillibridge J, R. Scharroo and G. Quartly, 2005: rain and ice flagging of Envisat altimeter and MWR data, Proc. of the 2004 Envisat and ERS Symposium, Salzburg, Austria

[71] Luthcke. S. B., N. P. Zelinsky, D. D. Rowlands, F. G. Lemoine, and T. A. Williams. 2003. The 1-Centimeter Orbit: jason-1 Precision Orbit Determination Using GPS, SLR, DORIS, and Altimeter Data. Mar. Geod. 26(3-4): 399-421.

[72] Martini A. and P. Féménias, 2000: The ERS SPTR2000 Altimetric Range Correction: Results and Validation. ERE-TN-ADQ-GSO-6001. 23 November 2000.

[73] Martini A., 2003: Envisat RA-2 Range instrumental correction : USO clock period variation and associated auxiliary file, Technical Note ENVI-GSEG-EOPG-TN-03-0009 Available at http://earth.esa.int/pcs/envisat/ra2/articles/USO_clock_corr_aux_file.pdf http://earth.esa.int/pcs/envisat/ra2/auxdata/

[74] A. Martini, P. Feminias, G. Alberti, M.P.Milagro-Perez, 2005: RA-2 S-Band Anomaly: Detection and waveform recontruction. Proc. of 2004 Envisat & ERS Symposium, Salzburg, Austria. 6-10 September 2004 (ESA SP-572, April 2005).

[75] Mertz, F., Y. Faugere and J. Dorandeu, 2003: Validation of ERS-2 OPR cycle 083-086. CLS.OC.NT/03.702 issue 083-086.

[76] Mercier, F., L.Cerri, S. Houry, A. Guitart, P. Broca, C. Ferrier, J-P. Berthias, 2006: DORIS 1b Product evolution, Symposium 15 Years of progress in radar altimetry, Venice.

[77] Mertz F., J. Dorandeu, N. Tran, S. Labroue, 2004, ERS-2 OPR data quality assessment. Long-term monitoring - particular investigations, Report of task 2 of IFREMER Contract n° 04/2.210.714. CLS.DOS/NT/04.277.

[78] Mitchum, G., 1994: Comparison of TOPEX sea surface heights and tide gauge sea levels, J. Geophys. Res., 99, 24541-24554.

[79] Mitchum, G., 1998: Monitoring the stability of satellite altimeters with tide gauges, J. Atm. Oceano. Tech., 15, 721-730.

[80] Obligis E., L. Eymard, N. Tran, S. Labroue, 2005: Three years of Microwave Radiometer aboard Envisat: In-flight Calibration, Processing and validation of the geophysical products, submitted

[81] Ollivier A.,Y. Faugere, P. Thibaut, G. Dibarboure, J. Poisson, 2008: Investigation on the high frequency content of Jason-1 and Jason-2, Technical note CLS-DOS-NT-09-027

[82] Ollivier, A., Y. Faugere and N. Picot, P. Femenias 2008. ENVISAT Jason-2 Cross calibration. Poster presented at OSTST meeting, Nice, France, 09-12 November 2008. Available at: http://www.aviso.oceanobs.com/fileadmin/documents/OSTST/2008/ollivier.pdf

[83] Ollivier A., Y.Faugere, N. Picot, M. Ablain, P. Femenias and J. Benveniste, 2012, Envisat ocean altimeter becoming relevant for Mean Sea Level Trend Studies, Marine Geodesy Vol 35

[84] Ollivier A., J.F. Legeais - N. Granier - Y.Faugere - F-PAC Calval Team CalVal status on the Envisat V2.1 reprocessing impact on main altimetric parameters, available on the ftp://diss-na-fp.eo.esa.int in a document distributed to users under the name: V2 1 reprocessing impact on altimetric parameters.pdf

[85] Ollivier A., M. Guibbaud - Envisat V2.1 reprocessing impact on ocean data, Technical Note CLS.DOS/NT/12.064, http://www.aviso.oceanobs.com/fileadmin/documents/calval/validation_report/EN/EnvisatReprocessingReport.pdf

[86] Pascual A., FaugÃ¨re F., Larnicol G., Le Traon P.Y, 2006, Improved description of the ocean mesoscale variability by combining four satellite altimeters, Geophys. Res. Let., Vol 33, L02611

[87] Picard B., M-L Frery, E. Obligis: ENVISAT Microwave Radiometer Assessment Report Cycle 039, Technical Note CLS.DOS/NT/05.147 Available at http://earth.esa.int/pcs/envisat/mwr/reports/

[88] Product disclaimer available on http://earth.esa.int/dataproducts/availability/

[89]

[90] Ray, R. (1999) - A global ocean tide model from Topex/Poseidon altimetry: GOT 99.2 - NASA Tech Memo 209478.

[91] R D Ray and R M Ponte, 2003: Barometric tides from ECMWF operational analyses, Annales Geophysicae, 21: 1897-1910.

[92] Roca M., A. Martini, 2003: Level 1b Verification updates, Ra2/MWR CCVT meeting, 25-26 March 2003, ESRIN, Rome

[93] Roca M., A. Martini, PTR Study, QWG meeting, November 2008, ESRIN, Rome

[94] H. Roinard, S. Philipps, Jason-2 reprocessing impact on ocean data (Cycle 001 to 145), CLS.DOS/NT/12.138

[95] Rudolph A., D.Kuijper, L.Ventimiglia, M.A. Garcia Matatoros, P.Bargellini, 2005: Envisat orbit control - philosophy experience and challenge, Proc. of the 2004 Envisat and ERS Symposium, Salzburg, Austria

[96] Salstein, D. A., Ponte, R. M., and Cady-Pereira, K.: Uncertainties in atmospheric surface pressure fields from global analyses, J. Geophys. Res., 113, D14107, doi:10.1029/2007JD009531, 2008.

[97] R. Scharroo and P. N. A. M. Visser, 1998: Precise orbit determination and gravity field improvement for the ERS satellites, J. Geophys. Res., 103, C4, 8113-8127

[98] Scharroo R., A decade of ERS Satellite Orbits and Altimetry, 2002: Phd Thesis, Delft University Press science

[99] Scharroo R., December 12, 2002, Routines for iono corrections, internet communication to the CCVT community

[100] Scharroo R., J. L. Lillibridge, and W. H. F. Smith, Cross-Calibration and Long-term Monitoring of the Microwave Radiometers of ERS, TOPEX, GFO, Jason-1, and Envisat, **Marine Geodesy, 27:279-297**, 2004.

[101] Scharroo, R., W.H.F.Smith - A global positionning system-based climatology for the total electron content in the ionosphere - October 2010

[102] Scharroo, R., RA-2 USO Anomaly: predictive correction model, Tech. Rep. N1-06-002, Altimetrics LLC, Cornish, New Hampshire, May 2006.

[103] Stum J., F. Ogor, P.Y. Le Traon, J. Dorandeu, P. Gaspar and J.P. Dumont, 1998: "An intercalibration study of TOPEX/POSEIDON, ERS-1 and ERS-2 altimetric missions", Final report of IFREMER contract N_97/2 426 086/C CLS.DOS/NT/98.070.

[104] Surface Topography Mission (STM) End to End Performance Budgets (SY-6) CLS-DOS-NT-08-2173-0 of 24/02/2010 - S3-TN-CLS-SY-00049

[105] Thibaut P., New assessment of the RA-2 instrumental corrections and impact on the Mean Sea Level P.Thibaut, J.C.Poisson, M.Roca, P.Nilo Garcia, Y.Faugere N.Picot, J.Benveniste, P.Femenias http://www.aviso.oceanobs.com/fileadmin/documents/OSTST/2011

[106] Tran, N., D. W. Hancock III, G.S. Hayne. 2002: "Assessment of the cycle-per-cycle noise level of the GEOSAT Follow-On, TOPEX and POSEIDON." J. of Atmos. and Oceanic Technol. 19(12): 2095-2117.

[107] Tran N. and E. Obligis, December 2003, Validation of the use of ENVISAT neural algorithm on ERS-2. CLS-DOS-NT-03.901.

[108] Tran N., E. Obligis and L. Eymard, 2006, Envisat MWR 36.5 GHz drift evaluation and correction. CLS-DOS-NT-05.218.

.

[109] Tran N. et al. Validation of Envisat Rain Detection and Rain Rate Estimates by Comparing With TRMM Data" N. Tran et al. IEEE Geoscience and Remote Sensing Letters, oct 2008

[110] Valladeau G., Ablain M., Validation of altimetric data by means of tide gauge measurements for TOPEX/Poseidon, Jason-1 and Envisat, Reference : CLS.DOS/NT/08-256, Nomenclature : SALP-NT-MA-EA-21589-CLS

[111] Valladeau G. 2011: Cal/Val in-situ annual report Altimetry / tide gauges. Validation of altimeter data by comparison with tide gauges measurements. Ref. CLS/DOS/NT/12-016. SALP-RP-MA-EA-22046-CLS.

[112] Valladeau G., Ablain M., Validation of altimetric data by comparison with tide gauge measurements for TOPEX/Poseidon, Jason-1 and Envisat, Reference : CLS.DOS/NT/09-115, Nomenclature : SALPNT-MA-EA-21691-CLS

[113] Valladeau G. and J.-F. Legeais, M. Ablain, S. Guinehut and N. Picot, Altimeter and in-situ sea level comparisons with tide gauges and ARGO profiles Marine Geodesy 2012, submitted

[114] Valladeau G. and J.-F. Legeais, M. Ablain, S. Guinehut and N. Picot, Comparing altimetry with tide gauges and Argo profiling floats for data quality assessment and Mean Sea Level studies, Marine Geodesy Vol 35.

[115] Thibaut P., Lasne Y., Poisson J.C, Numerical Retracking techniques applied on Envisat data, 2013-11-26, CLS-DOS-NT-12-143

[116] Vincent, P., S. D. Desai, J. Dorandeu, M. Ablain, B. Soussi, P. S. Callahan, and B. J. Haines 2003. Jason-1 Geophysical Performance Evaluation. Mar. Geod. 26(3-4): 167-186.

[117] Witter, D. L., D. B. Chelton, 1991: "A Geosat altimeter wind speed algorithm development", J. of. Geophys. Res. (oceans), 96, 8853-8860, 1991.

[118] Zanife, O. Z., P. Vincent, L. Amarouche, J. P. Dumont, P. Thibaut, and S. Labroue, 2003. Comparison of the Ku-band range noise level and the relative sea-state bias of the Jason-1, TOPEX and Poseidon-1 radar altimeters. Mar. Geod. 26(3-4): 201-238.

.