CalVal Envisat

Envisat RA2/MWR ocean data validation and cross-calibration activities. Yearly report 2012.

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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)
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 validation and cross calibration studies carried out at CLS during year 2012. It is basically concerned with long-term monitoring of the Envisat altimeter system over ocean.
The main event of this year was the loss of Envisat, on the 8th of April. 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).
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. All relevant altimeter parameters deduced from Ocean 1 retracking, radiometer parameters and geophysical corrections are evaluated and tested.
Note that the cycle 113 is uncomplete because of the loss of Envisat on 8th of April. This report contains also studies focused on the last update of Envisat data concerning GDR-D orbits standard, the instrumental correction PTR (Point Target Response) and the update of wet tropospheric correction after reprocessing.
For further information about the original GDR data before reprocessing, please refer to [13].
A document concerning the impact of reprocessing on the data is also available in the frame of the reprocessing activities (see [81]).

Some of the results described here were presented at the OSTST meeting (Venice, September 2012) and at the Quality Working Group (QWG) meetings (Propriano, May 2012 and Roma, November 2012).

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. Note that ERS-2 mission is over from July 2011 and no additional cross calibration with this mission was performed and shown in this report.

The various comparisons performed between the 4 missions cited above show a very good consistency with a standard deviation of cross-over differences of around 5.9 cm on the whole period. The geographically correlated biases between Envisat and Jason 2 also show a very good agreement of both data sets. The East West bias increasing in time observed in the past yearly reports is today reduced by the use of a new orbit standard.

Furthermore, methods of comparison to in situ dataset are also used to provide an external reference, complementary to the usual satellite cross comparisons.
Using these methods, particular studies were extensively carried on this year (notably Mean Sea Level studies) to show how the Envisat data can be further improved after the end of reprocessing in terms of global stability and regional biases.

After a preliminary section describing the data used, the report is split into 6 main sections: first, **data coverage** and measurement validity issues are presented. Second, a **monitoring of the main altimeter and radiometer parameters** is performed, describing the major impact in

terms of data accuracy. Then, **performances** are assessed and discussed with respect to the major sources of errors. Then, Envisat **Sea Surface height** (SSH) differences at cross-overs and the SLA computed with **MSL** standards is monitored. Finally, an additional part presents the **particular investigations** that have been performed during this year:
- A particular study was carried out on the external correction of PTR (Point Target Response) provided by IsardSAT. This instrumental correction was compared to the F-PAC PTR (expertise correction) in terms of availability, coverage and performances improvements.
- The increase of performances using new GDR-D standards are also presented. A particular point is added concerning the beginning of the Envisat period: for a few cycles before 2003, the behaviour of official GDR-D standards seems to be degraded and not consistent from that observed with preliminary GDR-D standards.
- A new filtering method for ionospheric correction was analysed also this year. Unlike what is made in the current filtering method, this iterative process is not linked with the classic SLA validation process, and filtered values can be computed even if the SLA is invalid. Moreover, the filtered correction can be computed wherever the dual-frequency ionospheric correction is defined. So, the iterative process is independent from the SLA validation process and the number of filtered ionospheric correction data increased. Other improvements are described in the dedicated part, notably concerning the performances at crossovers.
- This year, the behaviour of a composite wet tropospheric correction was studied, in terms of performance comparing with a radiometer wet troposheric correction. The composite correction is computed using a combination of ECMWF model near coasts and radiometer data somewhere else. Then, the behaviour of this correction was analysed for Envisat and Jason-1.
- A part is dedicated to the radiometer wet tropospheric correction and its behaviour after reprocessing compared to previous GDR. Investigations have been carried out to analyse the observed degradation, and an updated version, not available for users, was proposed to reduce this degradation.
- A new sea state bias was computed, using data after reprocessing and an updated wet tropospheric correction. A final part is dedicated to the Envisat error budget synthesis written in 2012 and estimated over the whole mission. This estimation is made by comparing altimeter data to other sources (models, in situ data).

2. Quality overview

All the information concerning the historical data is available in 2011 Yearly Report. This year report only concerns the routine after V2.1 update.

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. A warning was sent to the community to warn about the mid wave length signal degrading the data since cyclic report 107 (October 2011).

No **USO anomaly** was noticed during 2012.
Yet, 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:
This year, Envisat was entirely on its drifting phase. The 35 day cycle is now 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. This year, with more GDR data available, the impact on the data could be investigated further. 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.

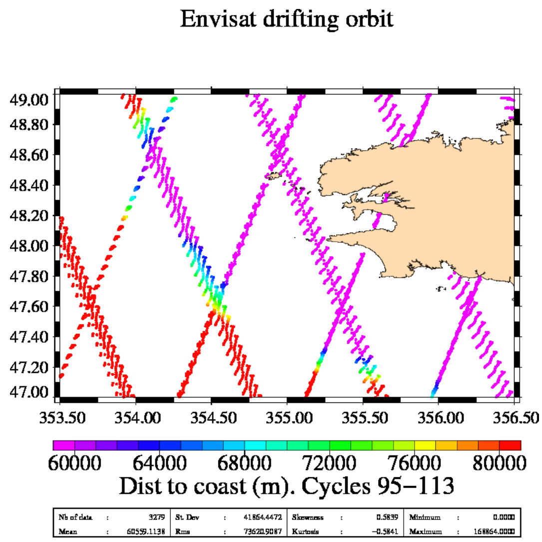

Figure 1: *Effect of the drifting phase near French coast. Cycles 95 to 113.*

Missing measurements:
The unavailability of data over ocean for year 2012 is very low, about 3% in average.
The MWR unavailability is also rather stable and low, in average around 2% on the 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 MWR, a degradation is noticed using the MWR after reprocessing in SLA computation. This degradation is systematic for all cycles. Some investigations are in progress in order to understand this degradation and to find solutions.

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 [18] and [19].
- Particular focus was also made on the Time Delay Calibration Factor (position of the Point Target Response : PTR) an instrumental correction badly taken into the official products before reprocessing (lack of precision in the quantification step + error in the sign of the correction) which could introduce an unexpected drift affecting Envisat MSL data. This is detailed in part .

Conclusions are that provided an appropriated correction for 3 errors (PTR, the POE standard and the wet tropospheric correction), Envisat reprocessed data enable 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

alimetric parameters. 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 comaprisons. On the other hand, the radiometric correction shows some long term instability (even with the homogenized V2.1 time series) which should be investigated.

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.
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]).

Note that for cycle 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).

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 is 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.oceanobs.com/donnees/calval/validation_report/en/welcome_uk.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 [32]). 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) [97], 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]).

- **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 be sure to get rid of any 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) the GIM ionospheric correction is used. In 2012 a new method of computation was developped, based on an iterative filtering process. The results are presented in part 8.5.1.

The few updates still necessary to complete the analysis are listed in the product disclaimer document available at http://earth.esa.int/dataproducts/availability/ [84]. 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 can 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]).

- **Note:**
  In this report, the named V2.1+ data set corresponds to the version after reprovessing, updated by:
  - the F-PAC PTR correction;
  - the GDR-D orbit standards;

- the updated wet tropospheric correction;
- the updated Sea Surface State.
The impact of this last version of GDR is developped in Part in term of Mean Sea Level computation. The impact on SSH variance at crossovers is summarized in Part 6.2.1..

Particular investigations have been carried out this year, analysing different aspects of this new dataset. Analysis using V2.1+ dataset are listed below:
- Use of IsardSAT Internal Path Delay correction in SLA computation (see 8.2.1.);
- Use of GRD-D orbit standards in SSH computation (see 8.3.1.);
- Impact of reprocessed wet tropospheric correction at crossovers (see 8.3.3.);
- Computation of a new Sea State Bias for Envisat V2.1+ dataset (see 8.3.2.);
- A new approach for dual-frequency ionospheric correction filtering (see 8.5.1.);
- Impact of Jason-2 reprocessing on intercalibration with Envisat (see 8.6.1.).

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. Passes 1 to 452 of cycle 15 have not been delivered because of a wrong setting of RA-2. 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 short 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.

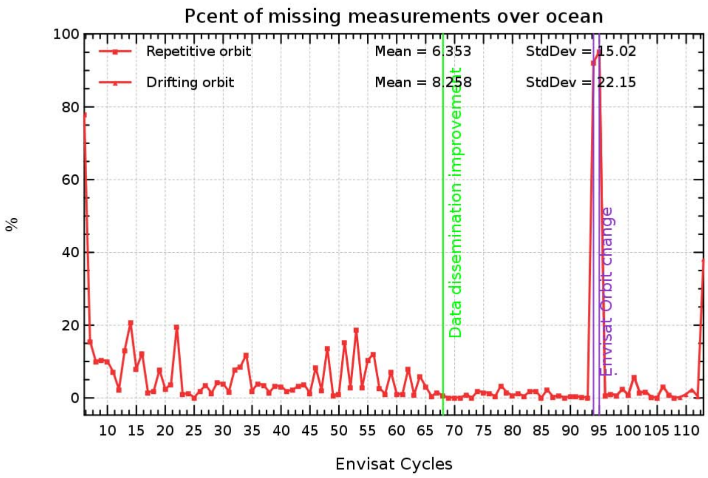

Figure 2: *Monitoring of the percentage of missing measurements relative to what is theoretically expected over ocean*

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.

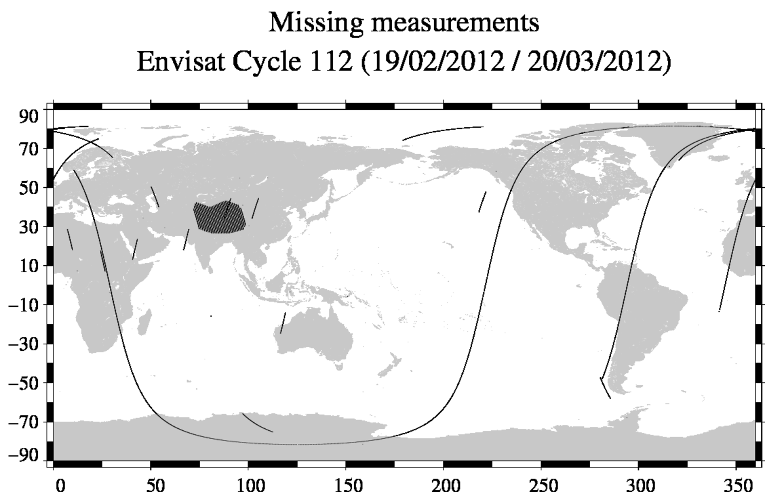

Figure 3: *Envisat missing measurements for the last entire cycle (112)*

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.

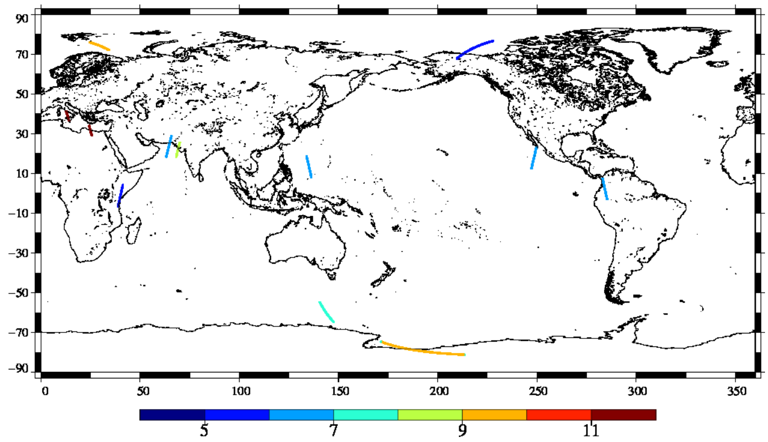

Figure 4: *Pass segments unavailable more than 5 times between cycles 82 and cycle 92. The color indicates the occurrence of unavailability*

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.
During cycles 101 and 102, some instrument anomalies prevent from the MWR radiometer correction:
- Cycle 101: 18 passes (252-269)
- Cycle 102: 72 passes (724 to 795)
During cycle 110, 162 passes (1 to 10, 16 to 167) are entirely rejected because MWR correction is missing (from 2011/12/20 14:43 TU to 2011/12/27 17:37 TU)

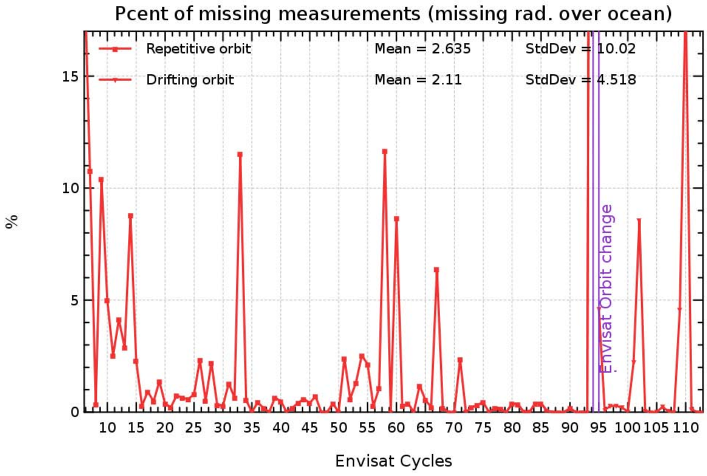

Figure 5: *Cycle per cycle percentages of missing MWR measurements*

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 value.

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 [41]). We employ the peakiness parameter (Lillibridge et al, 2005 [66]) 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 2011, similarly to September 2007, a record-breaking minimum of flagged data for the Northern Hemisphere zone around cycles 105-106 see blue curve Figure 6, due to a low ice extend record. 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

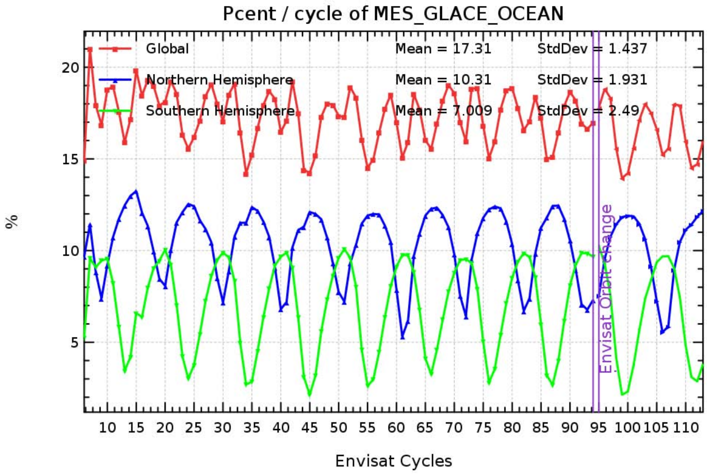

Figure 6: *% of edited points by sea ice flag over ocean*

http://www.aviso.oceanobs.com/en/applications/glace/glaces-de-mer/l-etendue-des-glaces-de-l-arctique-vue-par-l-altimetre-d-envisat/index.html.

Note that similarly, in February 2006 and February 2011, a record-breaking minimum of flagged data also occurred for the Southern Hemisphere zone around cycles 45 and 99, 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 really 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.

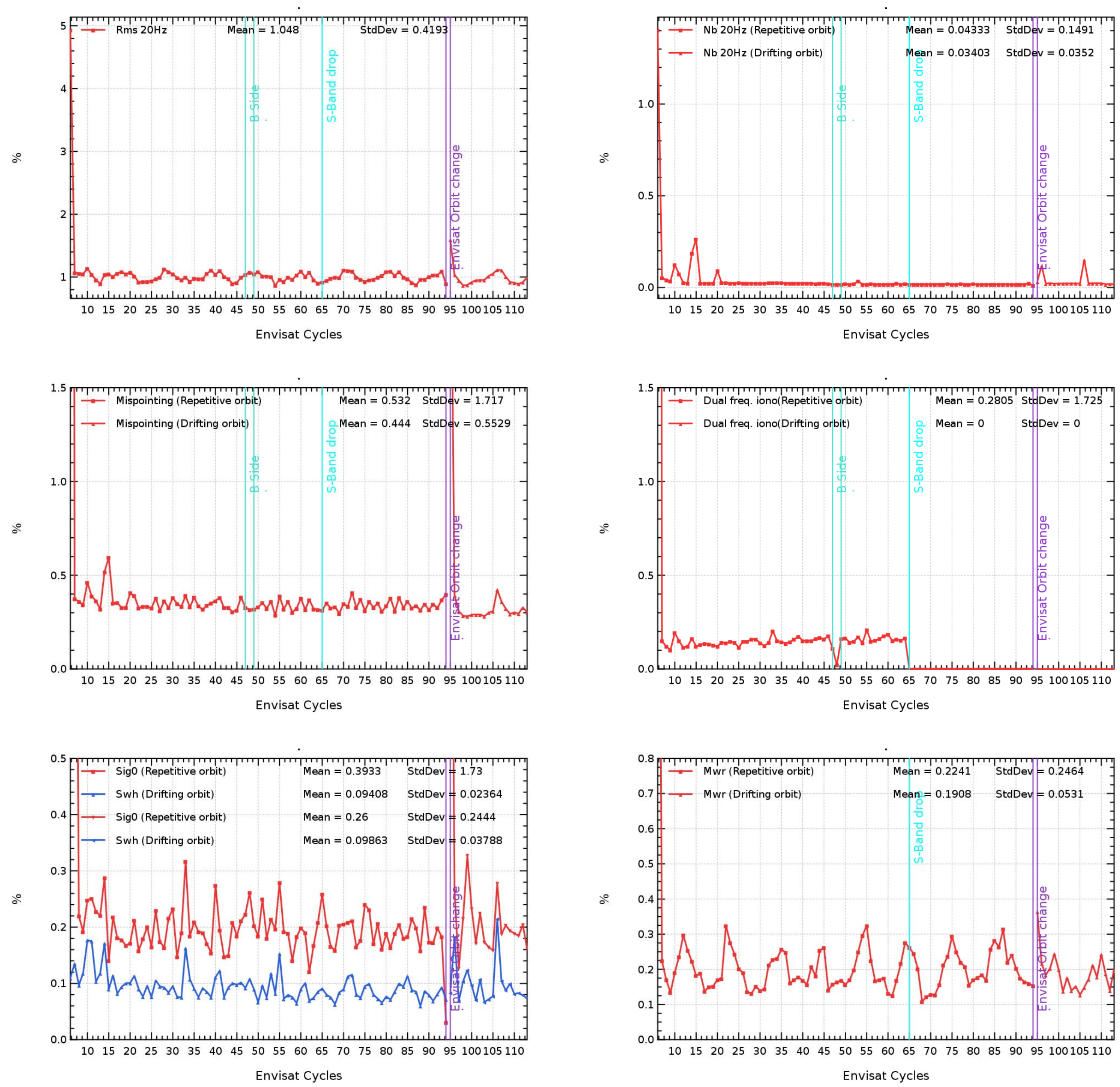

Figure 7: *Cycle per cycle percentages of edited measurements by the main Envisat altimeter and radiometer parameters:* ***Top-Left)*** *Rms of 20 Hz range measurements > 25 cm,* ***Top-Right)*** *Number of 20-Hz range measurements < 10,* ***Middle-Left)*** *Square of off-nadir angle (from waveforms) 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 has been 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 figure 8 could not be completed for the drifting phase due to the method based on a theoretical track (which does not exist anymore).

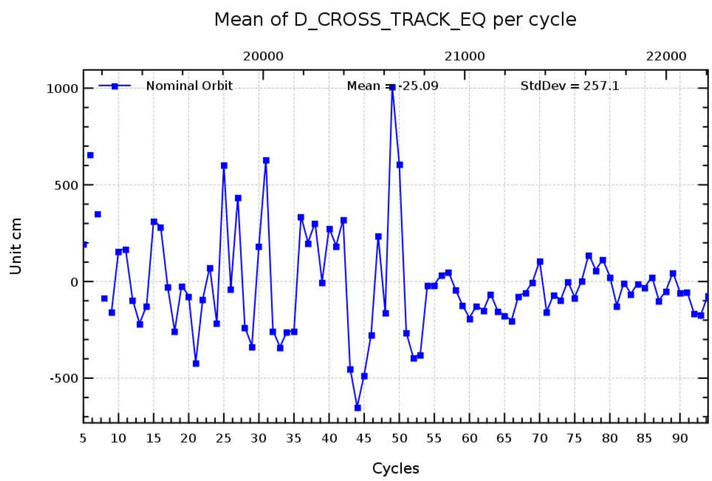

Figure 8: *Cross track deadband measured at equator by comparison to a theoretical track before the drifting phase.*

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 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 $^{\circ}$, 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 $^{\circ}$, 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.

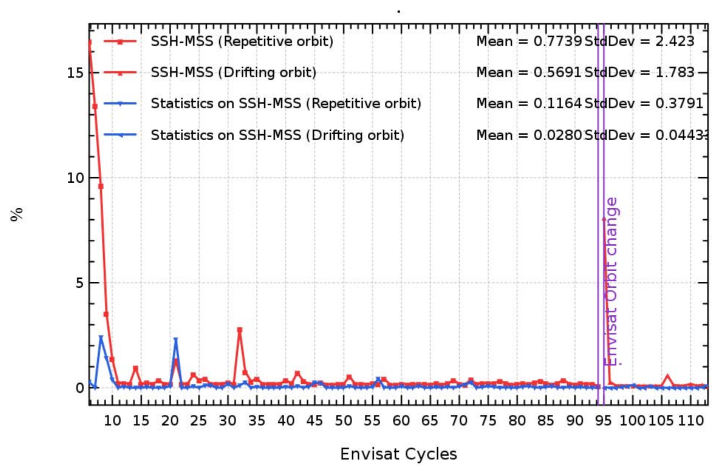

Figure 9: *SSH-MSS out of the [-2, 2m] and edited using thresholds on the mean and standard deviation of SSH-MSS on each pass*

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

For cycle 6 to 9, different tunnings 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 workable 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 this 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 occurred, 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).

5. Long term monitoring of altimeter and radiometer parameters

All GDR fields are 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 [111], Vincent et al. 2003a [109]). 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.

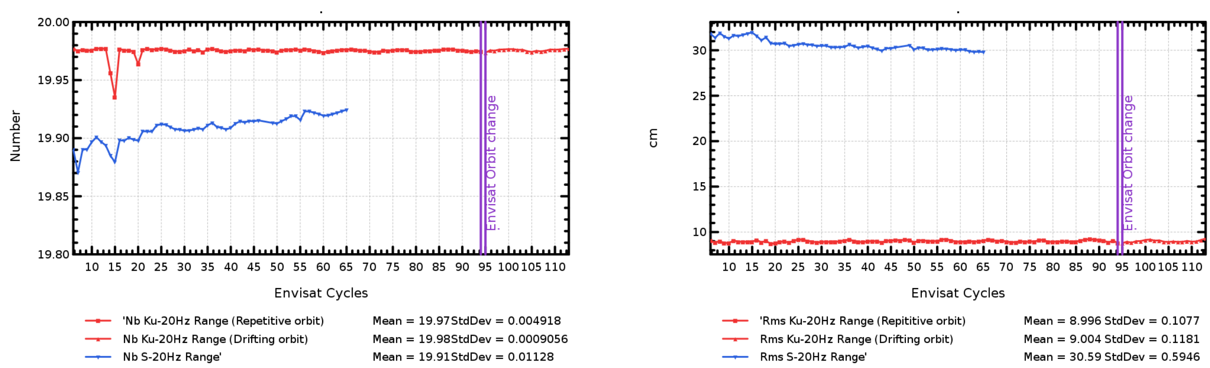

Figure 10: ***left)*** *Mean per cycle of the number of 20 Hz elementary range measurements used to compute 1 Hz range.* ***right)*** *Mean per cycle of the standard deviation of 20 Hz measurements.*

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.

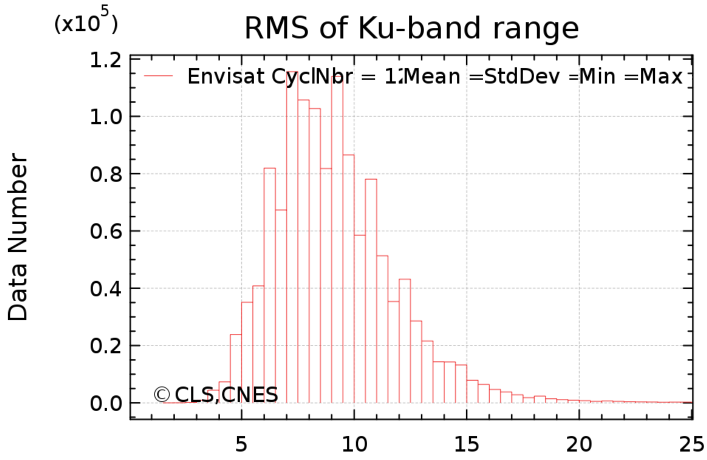

Figure 11: *Histogram of RMS of Ku range (cm). Cycle 112 .*

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).
At the end of the period, as noticed during the mini commissionning phase and QWG 17 the mispointing stabilises at a slightl 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.

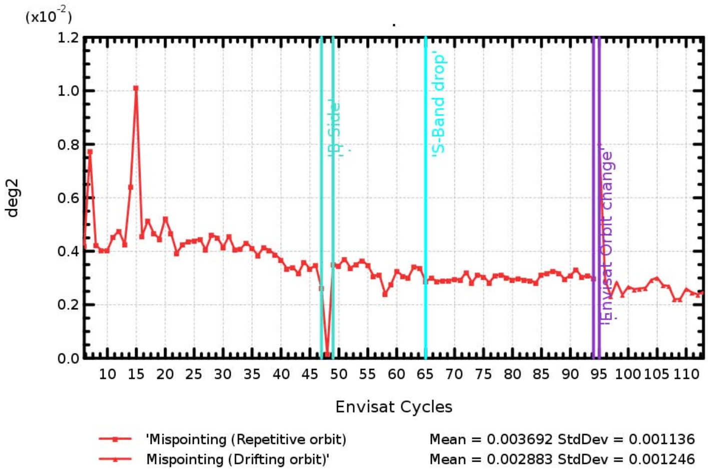

Figure 12: *Mean per cycle of the square of the off-nadir angle deduced from waveforms (deg^2).*

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

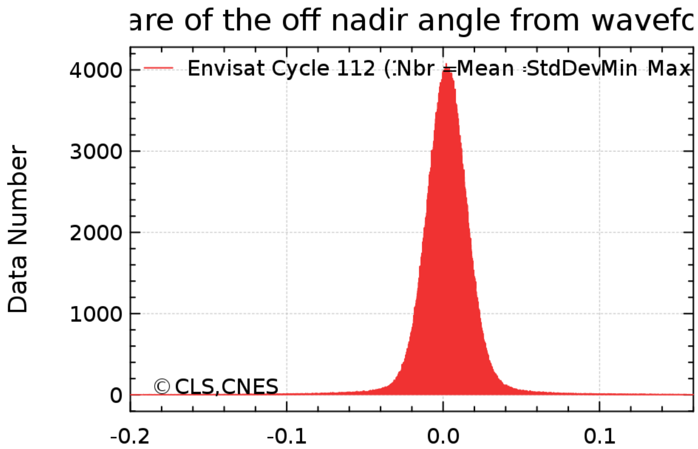

Figure 13: *Histogram of off-nadir angle from waveforms (deg²). Cycle 112 .*

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.

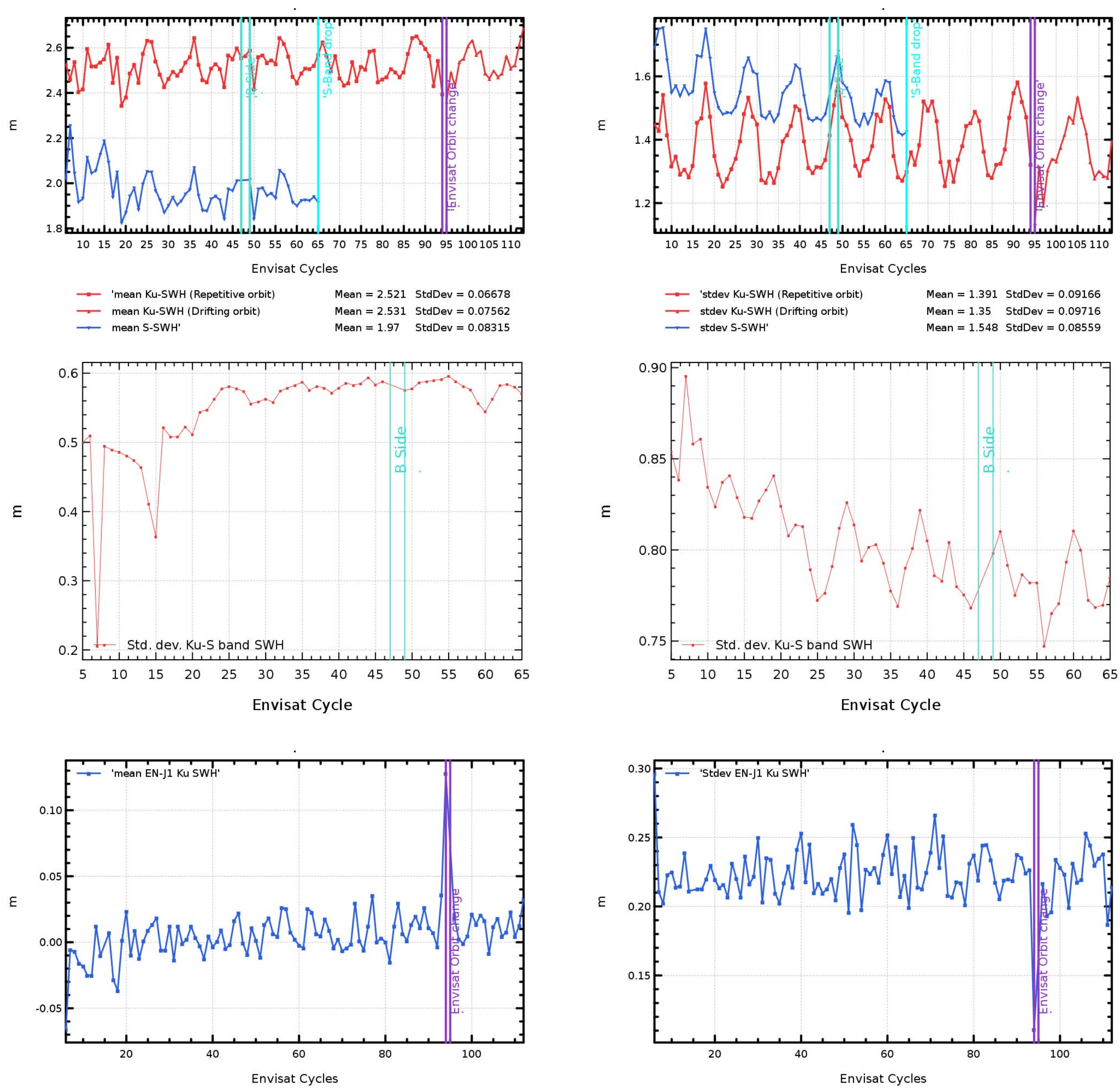

Figure 14: *Global statistics (m) of Envisat Ku and S SWH* ***top)*** *Mean and Standard deviation.* ***Middle:*** *Mean and standard deviation of Ku-S band SWH* ***bottom)*** *Mean Envisat-Jason-1 Ku SWH differences at 3h EN/J1 crossovers.*

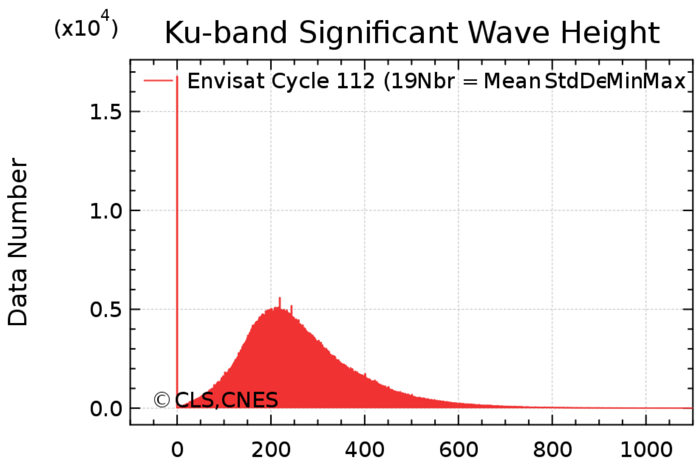

Figure 15: *Histogram of Ku SWH (m) Cycle 112 .*

5.4. Backscatter coefficient

The cycle by cycle mean and standard deviation Ku and S-Band Sigma0 are plotted in Figure 17, until end of 2010. Note that a -3.5 dB bias has been applied (Roca et al., 2003 [86]) on the Ku-band Sigma0 in order to be compliant with the wind speed model (Witter and Chelton, 1991 [110]). 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 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... The global stability of this parameter was extensively studied in Ablain et al. 2012 submitted in Marine Geodesy (see [10]) and summurized 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.

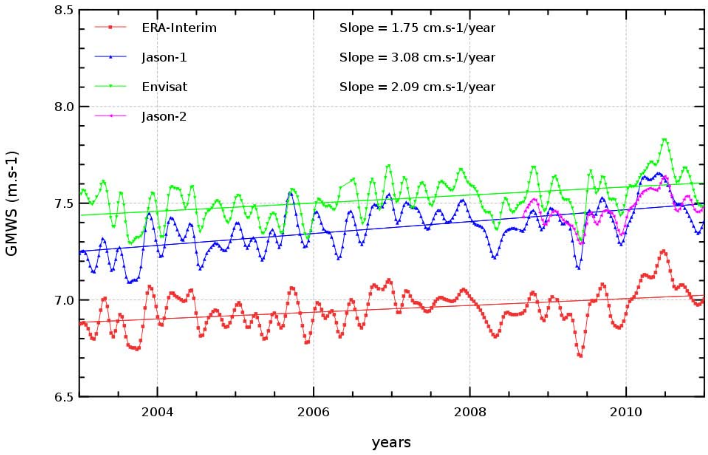

Figure 16: *Wind speed from different sources (EN, J1, ECMWF, NCEP).*

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

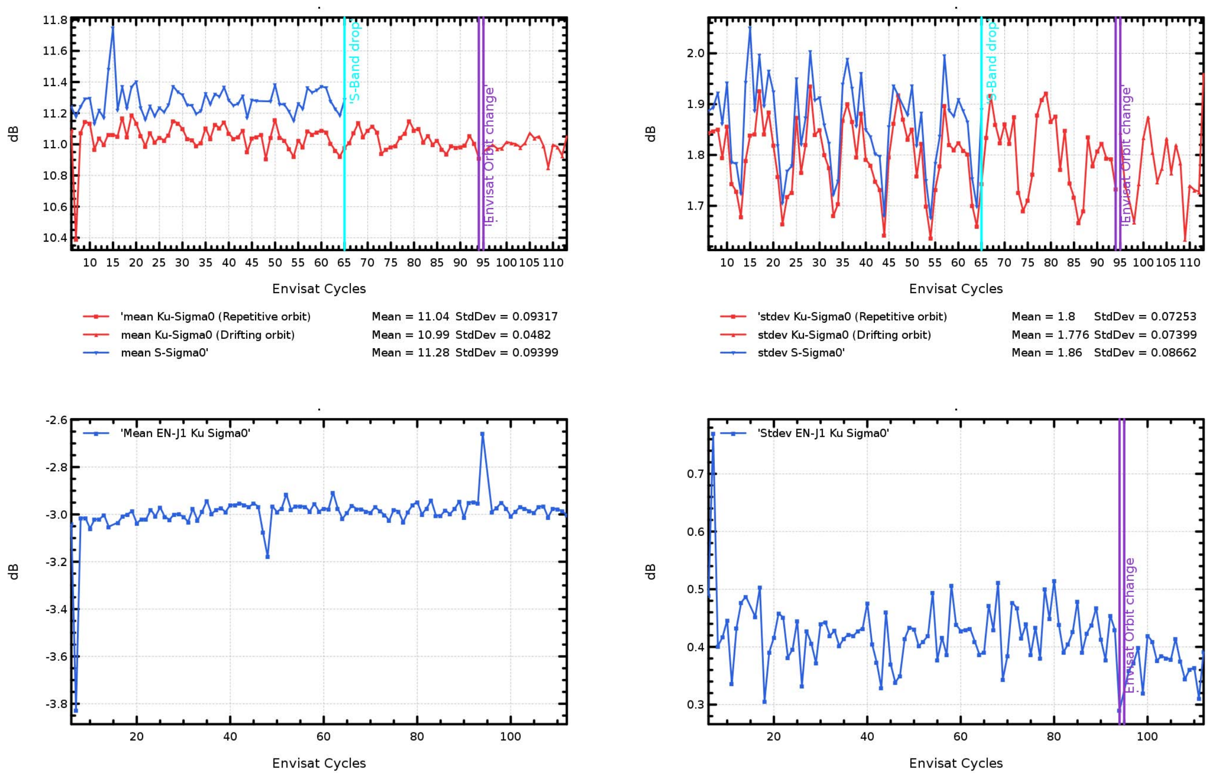

Figure 17: *Global statistics (dB) of **Top**) Envisat Ku and S Sigma0 Mean and Standard deviation. **Bottom**) Mean Envisat-Jason-1 Ku Sigma0 differences at 3h EN/J1 crossovers.*

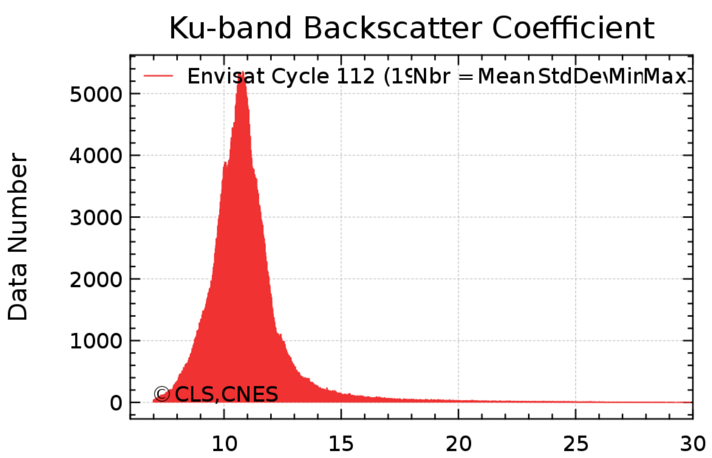

Figure 18: *Histogram of Ku Sigma0 (dB). Cycle 112 .*

5.5. Dual frequency ionosphere correction

As performed on TOPEX (Le Traon et al. 1994 [62]) and Jason-1 (Chambers et al. 2002 [29]) 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 developped in part 8.5.1. and could enable to add this filtered field directly in the GDR, 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 to replace the bifrequency correction for its better performences. 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 (GIM-Dual frequency), plotted in figure 19, 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 [56]).

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.

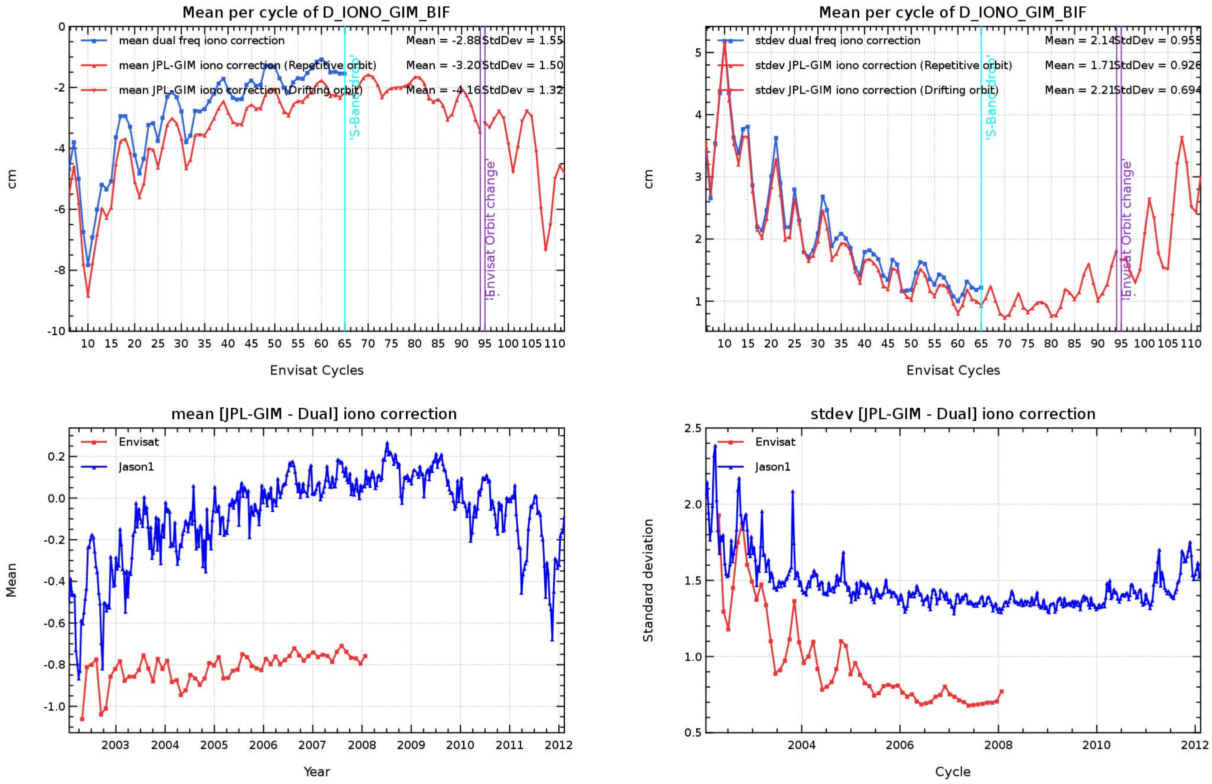

Figure 19: *Comparison of global statistics of Envisat dual-frequency and JPL-GIM ionosphere corrections (cm).* ***Top****) Mean and standard deviation per cycle of Dual Frequency and GIM correction.* ***Bottom****) Mean and standard deviation of the differences for Envisat and Jason-1*

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 [76]). 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.

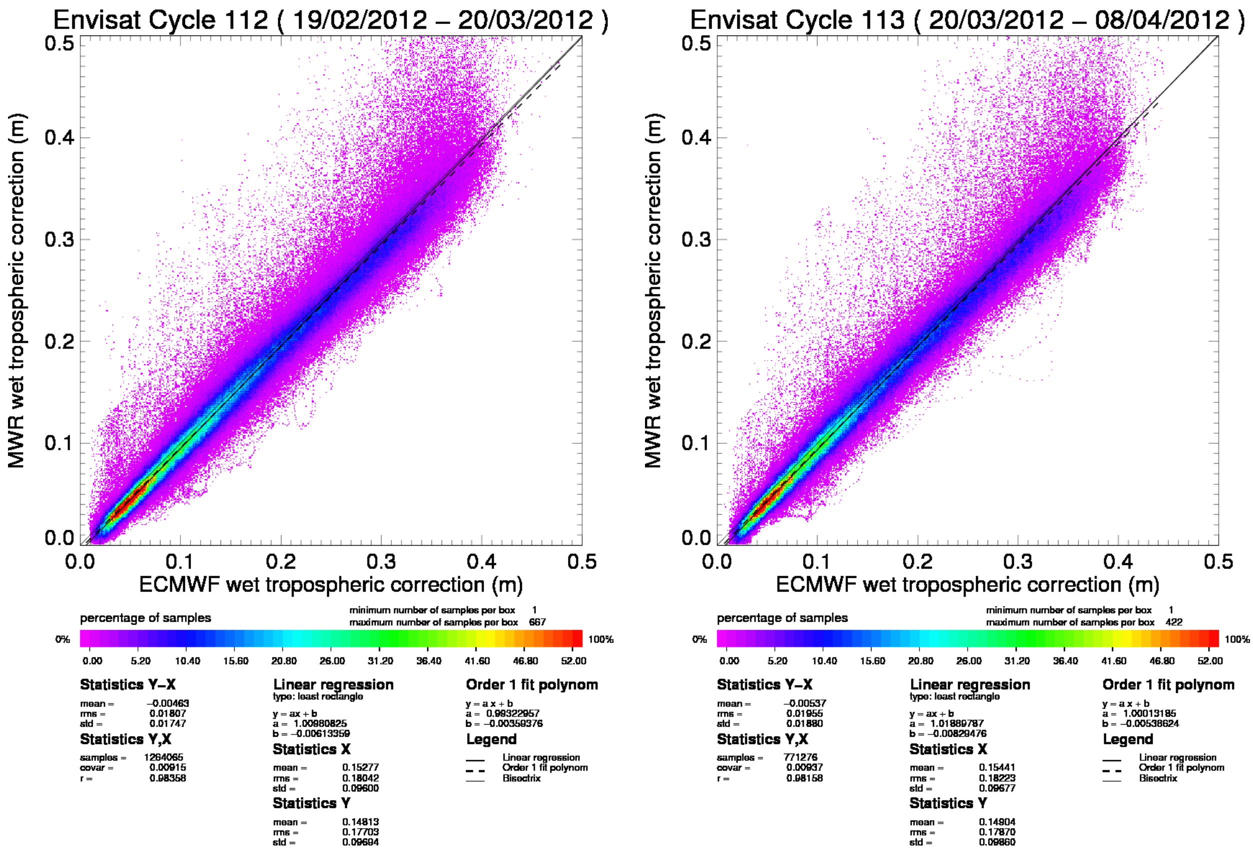

Figure 20: *Scatter plot of MWR correction according to ECMWF model (m) (cycle 112 & 113)*

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/ ([83]). 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 [34])) 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 daviation is greater than the value obtained before the reprocessing

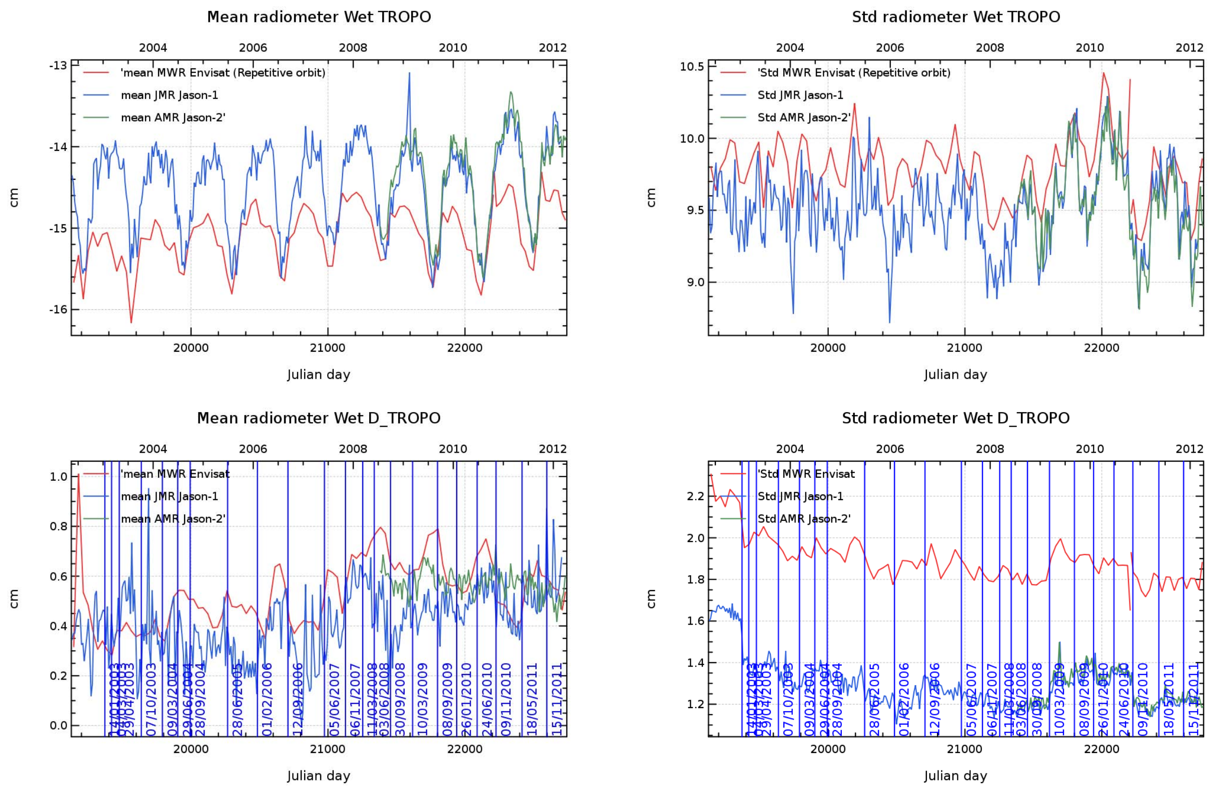

Figure 21: *Comparison of global statistics of Envisat MWR and ECMWF wet troposphere corrections (cm).* ***top****) Mean and standard deviation per cycle of MWR, JMR and AMR corrections* ***Bottom****) Mean and standard deviation per cycle of the differences versus ECMWF model. Vertical lines represent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

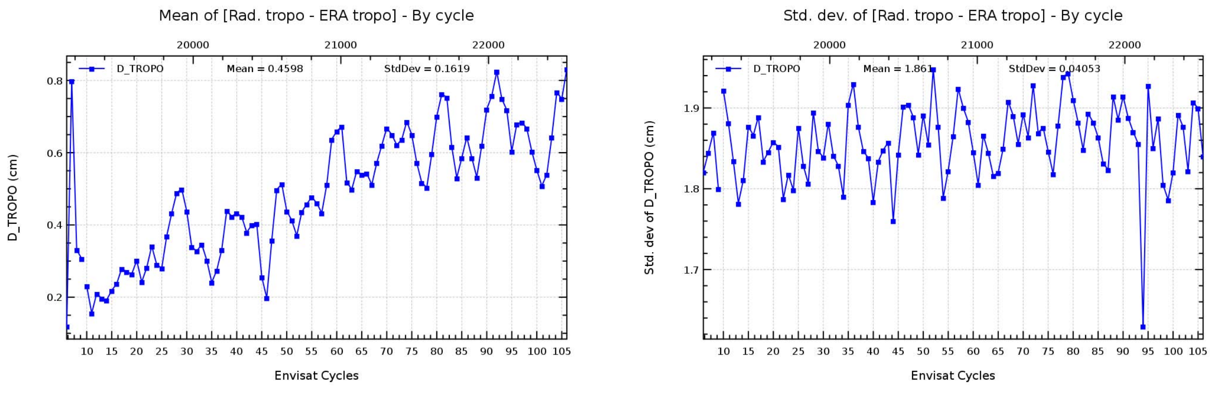

Figure 22: *Mean and standard deviation per cycle of the differences of MWR correction versus ERA-Interim*

(1.6cm). In fact, the analysis made after reprocessing enabled to evidence a degradation of this correction visible on SSH performance at crossovers; studies have been made at the end of 2012 to highlights this degradation (see 8.3.3.).

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.

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

$$\begin{aligned}\sum_{i=1}^{n} Correction_i \quad = \quad & Dry\ troposphere\ correction : new\ S1\ and\ S2\ atmospheric\ tides\ applied \\ + \quad & Combined\ atmospheric\ correction :\ MOG2D\ and\ inverse\ barometer \\ + \quad & Radiometer\ wet\ troposphere\ correction \\ + \quad & Filtered\ dual\ frequency\ ionospheric\ correction\ /GIM\ model\ after\ cycle\ 64 \\ + \quad & Non\ parametric\ sea\ state\ bias\ correction \\ + \quad & Geocentric\ ocean\ tide\ height,\ GOT\ 4.7 : is\ applied \\ + \quad & Solid\ earth\ tide\ height \\ + \quad & Geocentric\ pole\ tide\ height\end{aligned}$$

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.

6.2. Improved performances of GDR

SSH crossover differences are computed on a one-cycle basis, with a maximum time lag of 10 days, in order to reduce the impact of ocean variability which is a source of error in the performance estimation. The mean of crossover differences represents the average of SSH differences between ascending and descending passes. This difference can reflect orbit errors or errors in geophysical corrections but also includes geophysical variability. The fact that Envisat is Sun-synchronous can play a role since the ascending passes and descending passes respectively cross the equator at 10pm local time and 10am local time. Thus all the parameters with a daily cycle can induce errors resulting in ascending/descending differences. The error observed at crossovers can be split into two types: the time invariant errors and the time varying errors.

This year V2.1 reprocessed dataset was enhanced on several aspects. Last year studies had evidenced some perfectible aspects which are actually solved this year.
The V2.1+ dataset was upgraded with four corrections:
- 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.);

- Radiometer wet tropospheric correction with an impact on performances at crossovers (see 8.3.3.);
- Sea Surface Bias with an impact on performances at crossovers and on mean of SLA (see 8.3.2.).

The global impact of those four updates is estimated on figures 23 and 24 with reference to V2.1 and V1 respectivelly.
The variance of SSH at crossovers is globally descreased on the dataset with the V2.1+ updates; the gain is close to 0.7cm^2 compared to the data set V2.1 after reprocessing (for a selection far form coasts, latitudes$<$ 50 deg and low oceanic variability). We can notice a slight degradation around 50°S/50°N, due to the use of the wet tropospheric correction updated version (see 8.3.3.).

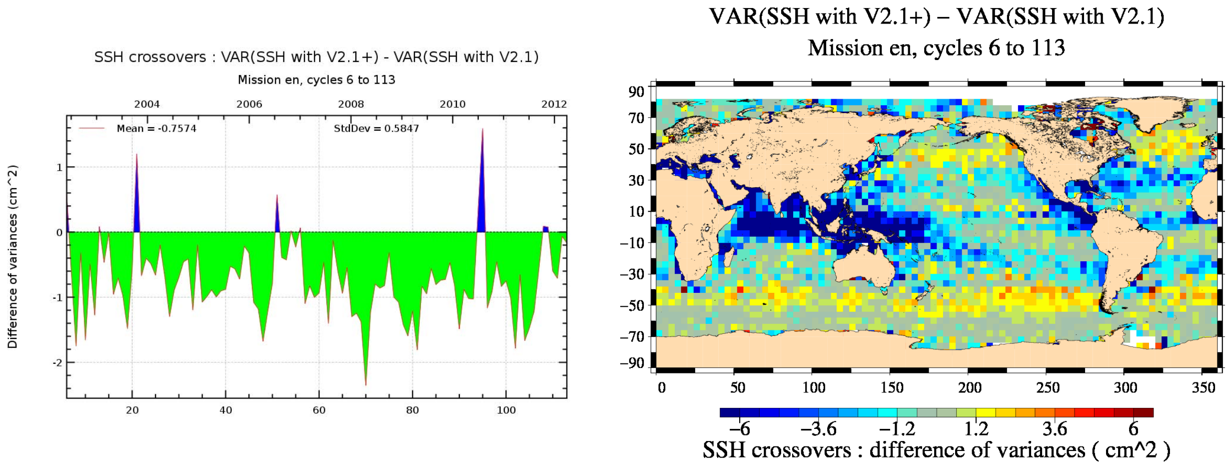

Figure 23: *Difference of variance of SSH at crossovers, comparing V2.1+ version (GDR-D orbits, F-PAC PTR, updated wet tropospheric correction) to V2.1 version (after reprocessing)*

The comparison to GDR before reprocessing (V1) is showed on Figure 24. In this case, the gain is close to 3cm^2 for the same selection, and globaly distributed. This gain is significant and takes into account all the evolutions applied during reprocessing period and the last updates.

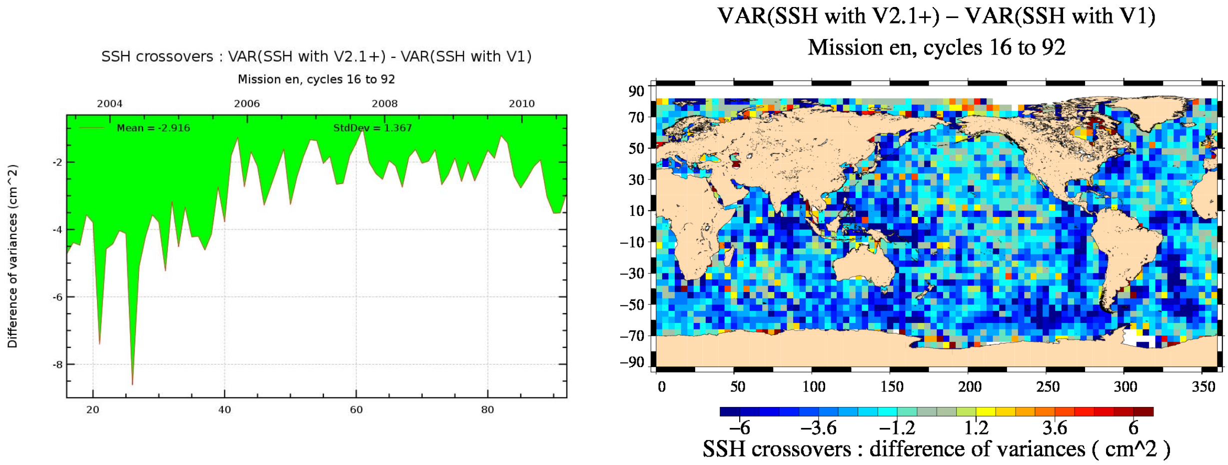

Figure 24: *Difference of variance of SSH at crossovers, comparing V2.1+ version (GDR-D orbits, F-PAC PTR, updated wet tropospheric correction) to V1 version (before reprocessing)*

Figure 25 presents the difference of SSH at crossovers for Envisat using V2.1+ dataset, by year since 2003. The next figure 26 takes into account dual-crossovers Envisat/Jason-1, with V2.1+ dataset for Envisat and GDR-D orbit standard for Jason-1. We easily see the effect of GDR-D

POE standard on the difference Envisat/Jason-1, reducing the geographical biases. The remaining biases (North/South) are linked to the different SSB model used for each mission.

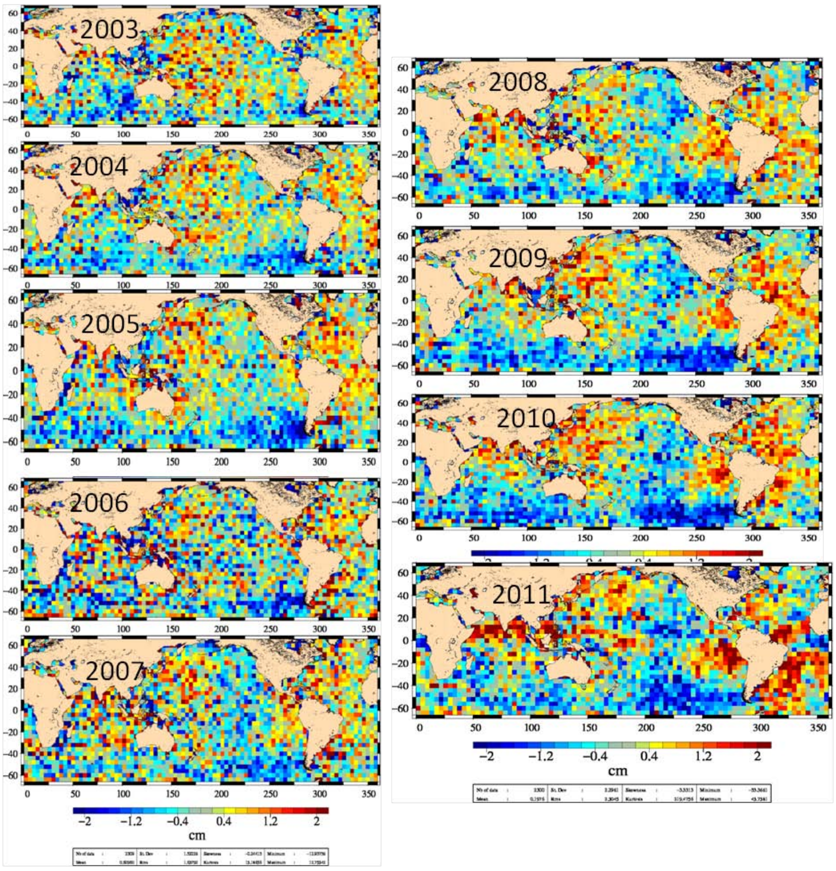

Figure 25: *Envisat difference of SSH at crossovers (monomission) by year since 2003 using V2.1+ dataset*

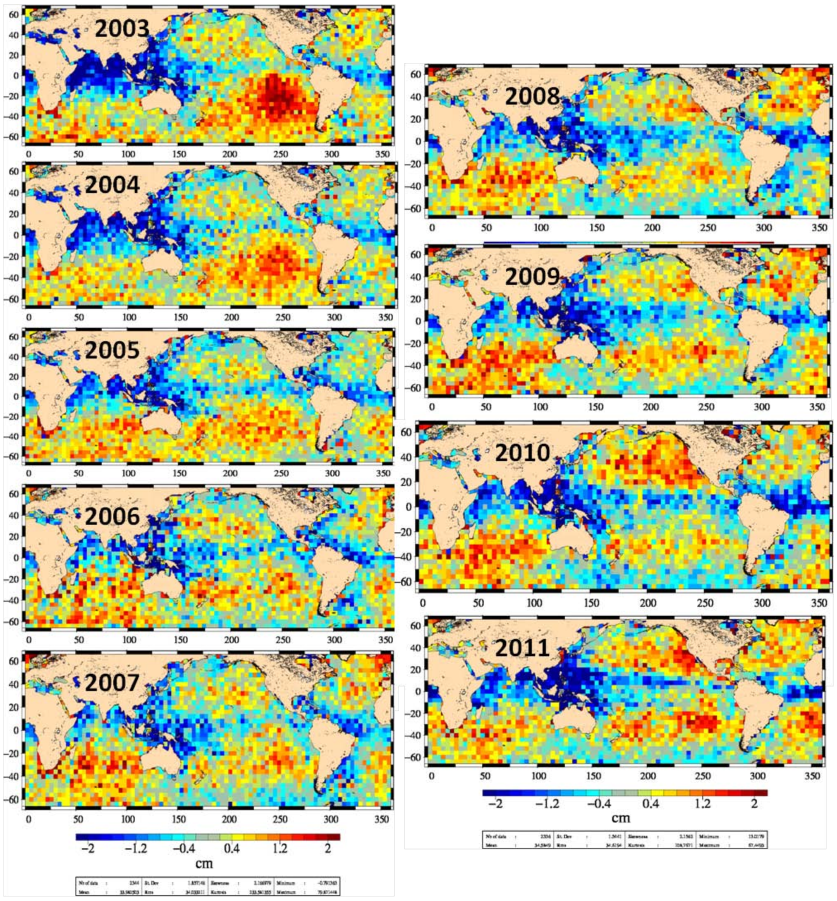

Figure 26: *Envisat/Jason-1 difference of SSH at dual-crossovers by year since 2003 using V2.1+ dataset for Envisat and GDR-D for Jason-1*

6.2.1. Time varying SSH differences at crossovers

Besides the systematic East/West errors, a time varying error can also be observed at crossovers. The cyclic mean ascending-descending SSH differences at crossovers shows this error in Figure 27. The cyclic mean crossover differences have been plotted in three different configurations: full data set, deep ocean data, and deep ocean data with low variability, and excluding high latitudes. A strong annual signal (decreased by reprocessing but still present) is evidenced on the 3 curves. Its amplitude is approximately 1 cm and the mean value, slightly negative.
Note that for the very first cycles (before cycle 10) a bias is noticed, probably in relation with the small amount of valid data for these cycles.

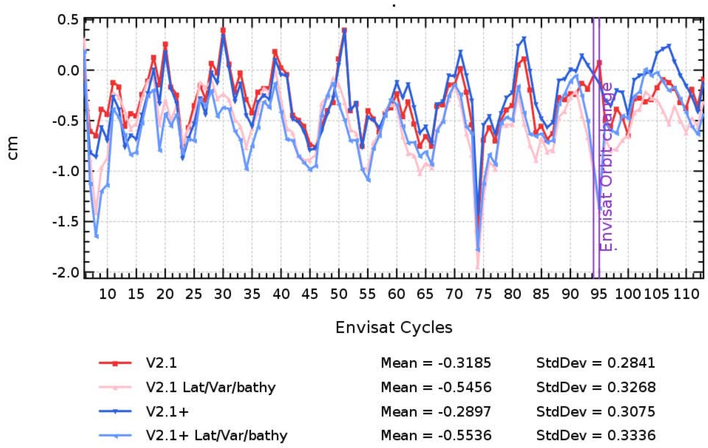

Figure 27: *Time varying crossover mean differences (cm). Cycle per cycle Envisat crossover mean differences. An annual cycle is clearly visible. (Lat/var/bathy: shallow waters excluded, latitude within [-50S, +50N], high ocean variability areas excluded)*

Figure 28 shows a global bias of 35cm between Envisat and Jason-1, in agreement with the absolute calibration studies (see for instance Bonnefond et al. OSTST). A rather good consistency is observed on the whole period even if some discrepancies are observed.

On Envisat/Jason-1 differences (see 28), an interannual long wave signal is visible, notably before 2004 where a strong drift is observed (before cycle 20). On the Envisat/Jason-2 difference, the impact of Jason-2 reprocessed dataset and PTR correction are visible:
- In terms of mean, the difference observed between Envisat and Jason-2 was 28cm (46.5cm for Envisat, 18.5cm for Jason-2);
After Jason-2 reprocessing, this 18.5cm bias is explained and so removed on Jason-2 side to have a mean difference of 46.5cm now.
For detailled results concerning the Jason-2 reprocessing, please refer to [88].
- The stability of Envisat/Jason-2 SSH difference at crossovers is improved with Jason-2 reprocessed dataset.
- In term of trends, the negative drift around 2cm concerning EN-J2 observed with the V2.1

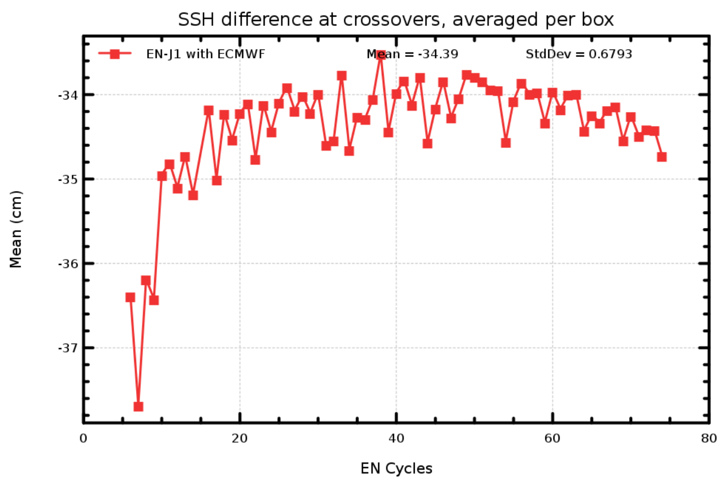

Figure 28: *Mean of J1-EN (V2.1+) SSH differences at dual crossovers (cm) on global ocean*

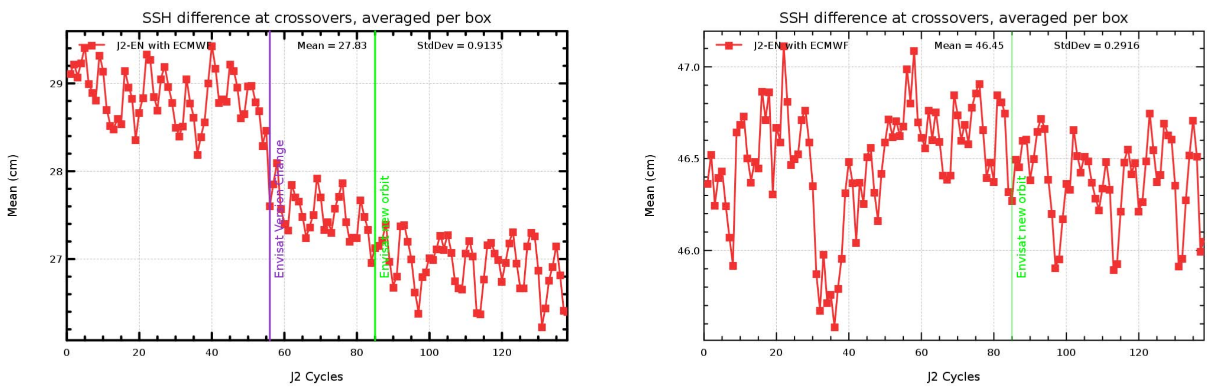

Figure 29: *Mean of EN-J2 SSH differences at dual crossovers (cm) on global ocean* ***Left:*** *Before Jason-2 reprocessing/Envisat V2.1 (+ GDR-D POE & PTR)* ***Right:*** *After Jason-2 reprocessing/Envisat V2.1 (+ GDR-D POE & PTR)*

dataset (after reprocessing) over the whole period is now corrected with V2.1 dataset. This effect had been shown to be related to the PTR instrumental correction accounted for in the reprocessed data with a more accurate resolution but applied with a wrong sign on Envisat side.
The PTR effect is now corrected using the last updates of Envisat dataset. This fact was evidenced and detailed in a climate orientated study and a paper (Ollivier et al., 2012) and consists in a major step towards the understanding of Envisat long term stability.

A drift is also present for the first part of the mission (before 2004, cycle 22) on Envisat-Jason-1 difference (see 28). This point is also identified also to be the next challenge to be taken up for MSL purposes (see part 7).

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 30. 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.

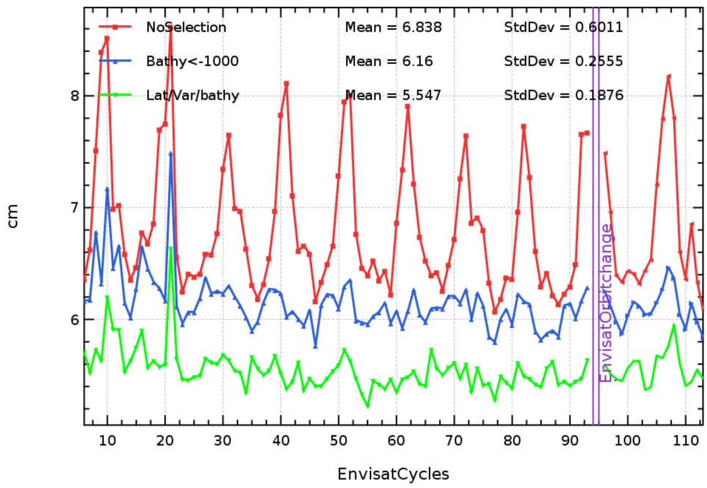

Figure 30: *Standard deviation (cm) of Envisat 10-day SSH crossover differences depending on data selection (with a maximum time lag of 10 days). Red: without any selection. Blue: shallow waters (1000 m) are excluded. Green: shallow waters excluded, latitude within [-50S, +50N], high ocean variability areas excluded.*

In order to compare Envisat and Jason-1 performances at crossovers, Envisat and Jason-1 crossovers have been computed on the same area excluding latitude higher than 50 degree, shallow waters and using exactly the same interpolation scheme to compute SSH values at crossover locations. A step of average per box is also performed. Performances at crossovers are compared, for the two satellites on Figure 31. The standard deviation of Envisat/Envisat and Jason-1/Jason-1 SSH crossover differences are respectively 6 cm and 5.7 cm along track and 2.6cm and 3cm after an average per box.

Note that Jason-1 consistency at crossovers seems to degrade slightly whereas it improves for Envisat at the end of the series. The performances of the two missions are anyway very good and close.

The same comparison is made for Envisat and Jason-2 before and after Jason-2 reprocessing, as presented on Figure 32.

For Envisat, the two cross comparisons give different results (see Figures 31 and 32) in terms of standard deviation of mean SSH difference at crossover per box. For these two processings, the crossovers are taken into account in a limit of 10 days. Then, for Envisat/Jason-1 cross comparison, the mean of X-SSH at crossovers is computed over 35 day; for Jason-2/Envisat, this

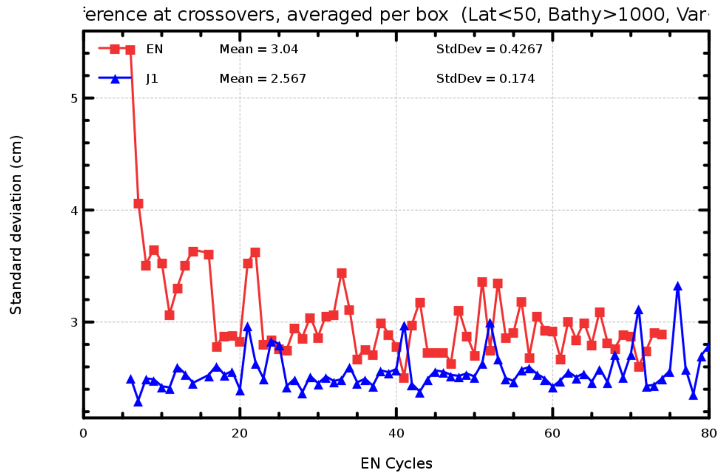

Figure 31: *Standard deviation (cm) of Envisat/Jason-1 on 10-day SSH crossover differences with 4 by 4 average per box and shallow waters excluded, latitude within [-50S, +50N], high ocean variability areas excluded.*

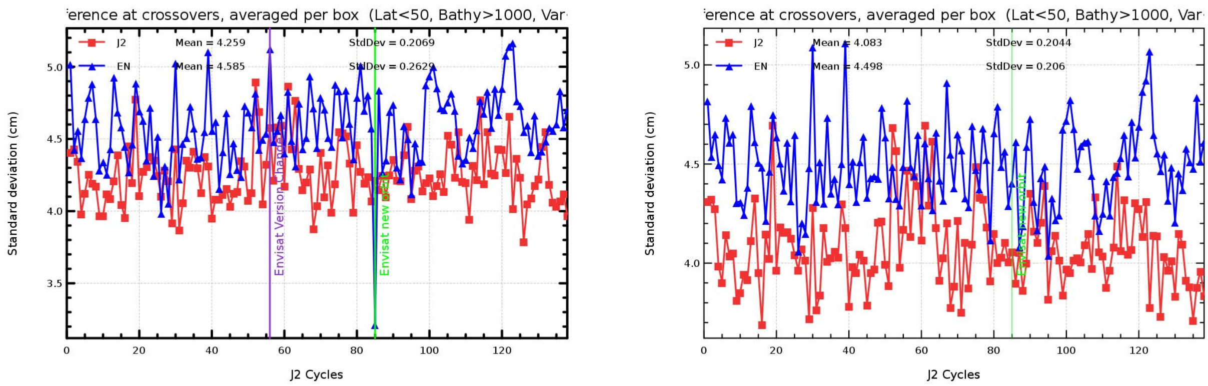

Figure 32: *Standard deviation (cm) of Envisat/Jason-2 (**Left:** Jason-2 Before rep./Envisat V2.1 dataset **Right:** Jason-2 After rep./Envisat V2.1+ dataset) on 10-day SSH crossover differences with 4 by 4 average per box and shallow waters excluded, latitude within [-50S, +50N], high ocean variability areas excluded.*

mean is computed over 10 days, which has an influence on the mean of standard deviation by cycle.
Figure 33 presents the maps of X-SSH mean per box for the Envisat cycle 100, computed on 35 days (cross comparison with Jason-1) or 10 days (cross comparison with Jason-2). We note that this mean per box can really differ from one box to the other, this phenomenon is notably visible on the mean computed over 10 days (33, right). With a mean over 35 days, long wave length effects are more visible and the standard deviation of X-SSH mean per box is lower than the one computed over 10 days, as seen on figures 31 and 32

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

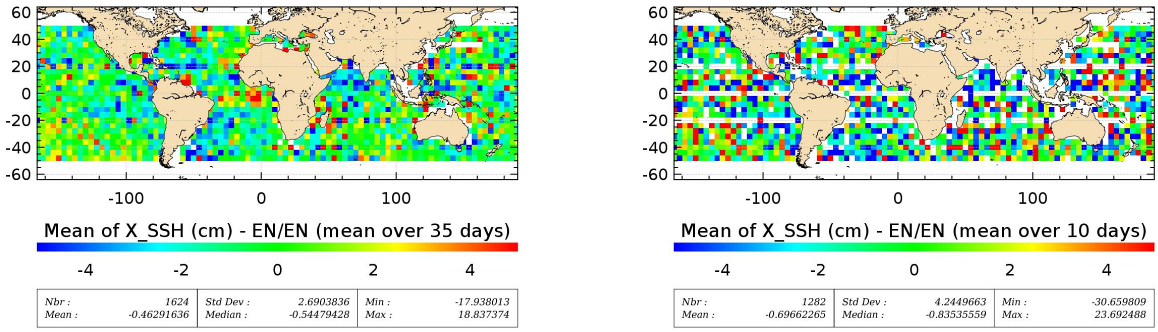

Figure 33: *Mean (cm) of X-SSH Envisat/Envisat, cycle 100,* ***Left****: from Envisat/Jason-1 cross-comparison (mean on 35 days)* ***Right:*** *from Jason-2/Envisat cross-comparison (mean on 10 days), with 4 by 4 average per box and shallow waters excluded, latitude within [-50S, +50N], high ocean variability areas excluded.*

months on figure 34.

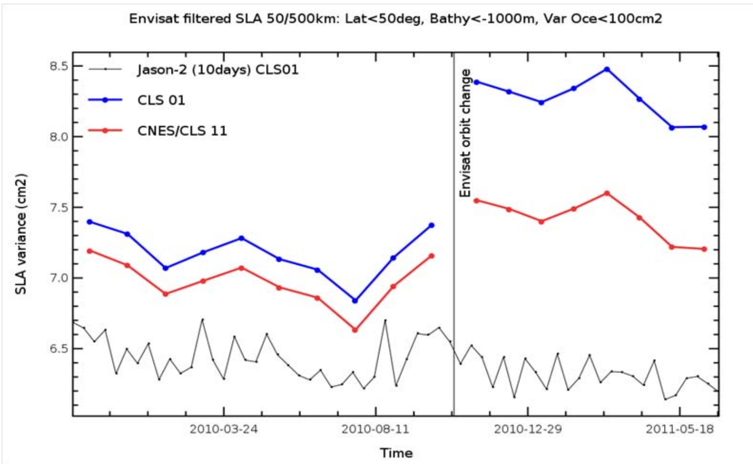

Figure 34: *Impact of the SLA reference out of the repeat track on the wavelength between 50km and 500km.*

6.3. Cross comparison with Jason-1/Jason-2

The previous plots underline the fact that monomission analysis are very much improved with the V2.1+ updated dataset. In terms of comparison to other missions the agreement is also better. The maps in Figure 35 (center) show the consistency between Envisat and Jason-1 once both missions updated.

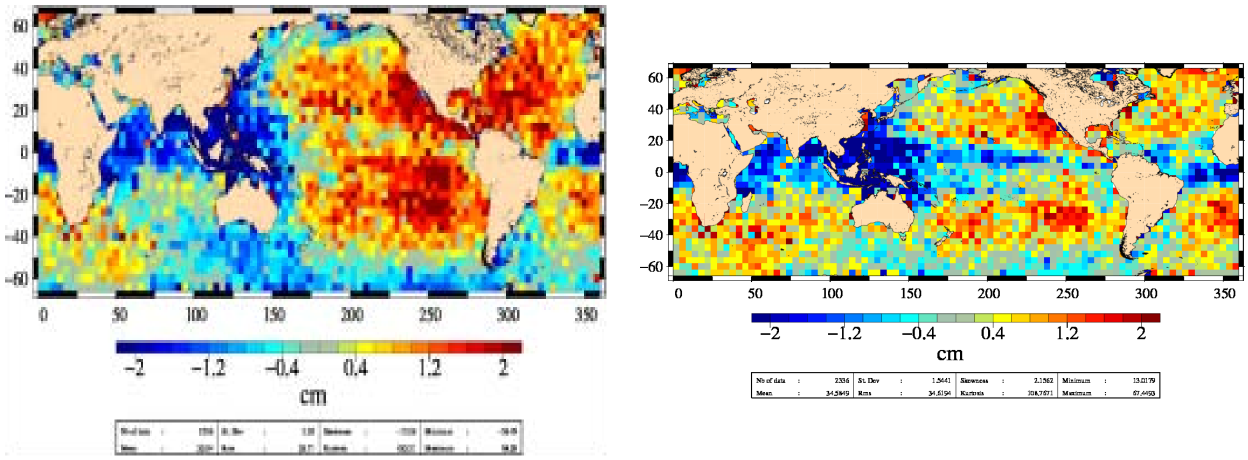

Figure 35: *Difference of variance of SSH at crossovers for 2011 using* ***Left:*** *Envisat V2.1/GDR-C orbit standard for Jason-1* ***Right:*** *Envisat V2.1+/GDR-D orbit std. for Jason-1*

The similar comparison is made between Envisat and Jason-2. The results are presented in Figure 36, using model wet tropospheric correction.
The remaining North/South observed with GDR-D standards bias (Figure 36, right) comes from the different SSB model used for the two missions.

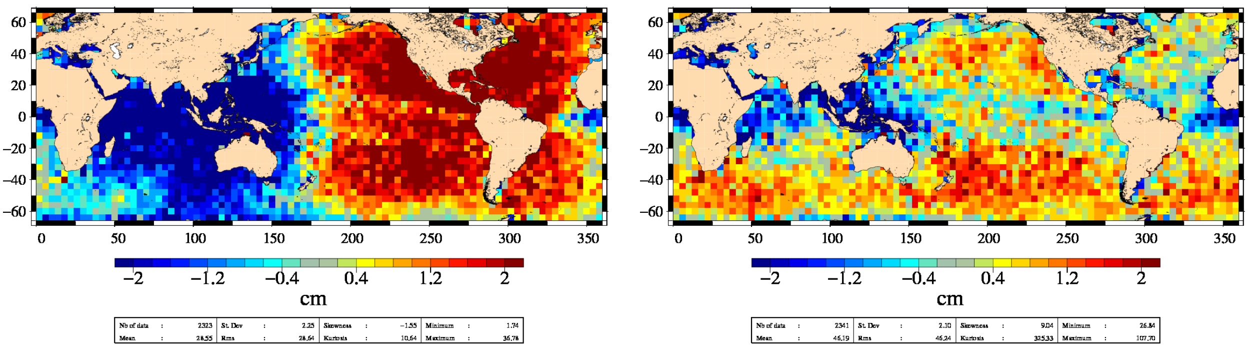

Figure 36: *Difference of variance of SSH at crossovers for 2011 using* ***Left:*** *GDR-C/GDR-C orbit for Jason2 after rep./Envisat* ***Right:*** *Envisat V2.1+/reprocessed Jason-2 dataset*

The East/West bias visible with GDR-C orbits is now reduced between Envisat, Jason-1 and Jason-2. Once these descrepencies removed, cross comparisons between missions enable to detect other differences and enhance the confidence in all altimetric dataset.

6.4. Cross comparison with Cryosat-2

With the loss of Envisat in April 2012, an important part of the global altimetric network disappeared. Notably at high latitudes and between Jason-1 and Jason-2 data tracks, we focused on the potential of Cryosat-2 to constitute a new reference for multimissions studies. Available Cryosat-2 data are provided by CNES CPP delayed time reprocessing, in LRM mode. Results are promising; Figure 37 shows the SLA computed for Envisat, Jason-1, Jason-2 and Cryosat-2 for 2010/2011. The patterns are similar for all the missions, showing that Cryosat-2 could be used for studies in complement of Envisat. The Figure 38 shows as well that the difference of variance of SSH at crossovers for Jason-2/Cryosat-2 has an order of magnitude comparable or even lower than the one obtained with Envisat/Jason-1 cross-comparison (see 38 and 35 right).

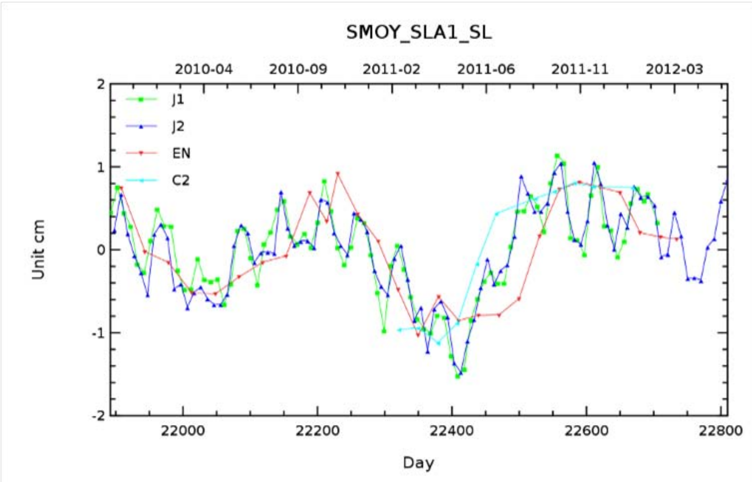

Figure 37: *Comparison of SLA for Envisat, Jason-1, Jason-2 and Cryosat-2 (selection on bathymetry, latitudes and oceanic variability)*

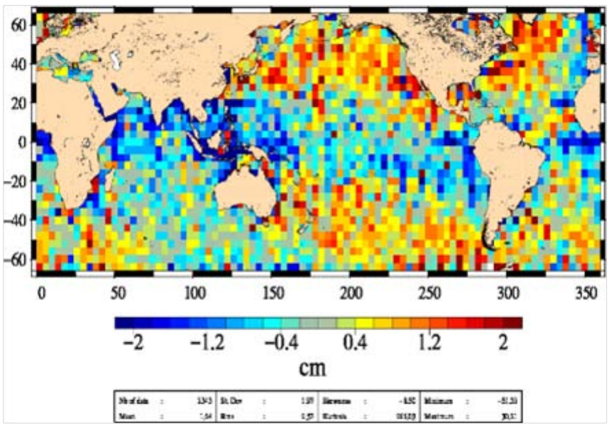

Figure 38: *Difference of SSH variance for multimission crossovers: Cryosat-2/Jason-2*

The cross-comparison between Cryosat-2 and Jason-2 allows to be confident in use of Cryosat-2 as a new reference solution for multimissions studies.

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7. ENVISAT Mean Sea Level Trend

Observing and understanding our 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 [25], 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) and Envisat (onwards from 2002) have been successively launched, providing a precious and precise complementary data set to the NASA/CNES missions. ERS1, ERS2, Geosat-Follow-On (GFO), and Envisat enables 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 [82], Le Traon et al. 2003 (see [64])).
Up to now, the quality and performances of ENVISAT mission were shown to be very good (Faugere et al 2006, see [45]) 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. Dedicated updates and post processing enable to obtain a homogeneous data set. 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 [79])) 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 extensiveley developped in [15], 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.oceanobs.com/en/news/ocean-indicators/mean-sea-level/products-images/index.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.oceanobs.com/en/news/ocean-indicators/mean-sea-level/processing-corrections/index.html.

7.2. MSL recipe

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 [30]. 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.

$$SLA = Orbit - Altimeter\ Range - MSS\ CLS01 - \sum_{i=1}^{n} Correction_i$$

with :

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

This year, the geophysical corrections provided in the GDR products are totally homogeneous and described in part 3.2.2.. Reprocessed data (from cycle 6 to 92) were concatenated to the current data from 93 to 113 .

	Cycles 6-64	Cycle 65-94	Cycle 95 onwards
Orbit	GDR-D		
Range	From GDR + PTR correction (V2.1+)		
DAC	MOG2D-HR		
			.../...

.

	Cycles 6-64	Cycle 65-94	Cycle 95 onwards
Iono corr	Dual-Frequency with S-Band SSB	GIM+bias	
MWR Wet tropo	Composite Corrected from side lobes		MWR Corrected from side lobes
MWR Dry tropo	Gaussian grids S1-S2 atmospheric tides applied		
SSB	Homogeneous to GDR-C		
Solid Tides	From GDR		
Pole Tides	From GDR		

Table 2: *G*eophysical corrections used following the periods

The updated version here named "V2.1+" is based on V2.1 version (after reprocessing) and includes the 3 updates cited below:
- The F-PAC PTR (see Part 8.2.1.);
- The new wet tropospheric correction (see Part 8.3.3.);
- the GDR-D orbit standards.(see Part 8.3.1.).

7.3. MSL global time series

The global MSL is presented here after. The V2.1+ evolution enables to improve data (Figure 41). But the effect on global MSL is largely dominated by the PTR evolution (see impact of PTR alone in [15]).

Envisat MSL now exhibits a 2.3mm/yr trend (not taking into account the GIA post rebound of around 0.3mmyr usually considered in the litterature). The difference between Envisat and Jason-1 is now reduced to 0.2mm/y on the whole Envisat period, as seen on the Figure 39 and Table 3. 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. Actually, in a dedicated part (8.1.1.), the exercice was carried on to list all the potential terms suspected for a bad estimation of the MSL during the first year.

The comparison to in-situ data is presented in table 3.
The studies are also detailed in [108] to evaluate the different impacts of the standards on the comparison to Tide Gauges and TS profiles.
It shows complient results in terms of drift on the whole mission period but when removing the first year, the trend seems to be slighly higher on Envisat side than on Jason-1 side.

When comparing with tide gauges from January 2004 onwards (figure 40 right and last column of table 3), the altimeter MSL drift is greater for one of these missions than the other (0.9 mm/yr difference close to 1.0 mm/yr). The associated error over this period is estimated to be ± 0.7 mm/yr, taking into account the spatial sampling restricted to coastal areas and the terrestrial crustal movements. Considering both Jason-1 and Envisat time series, the comparison with tide

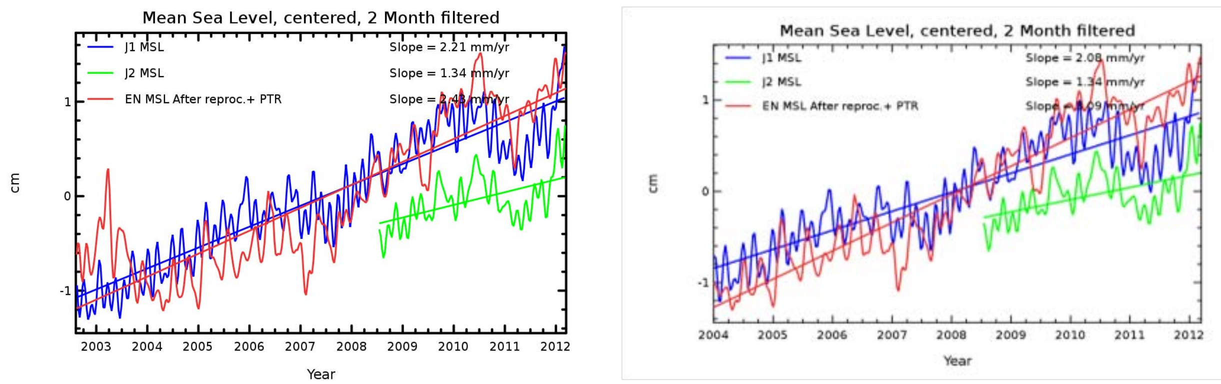


Figure 39: *MSL computed with last upadtes: PTR, updated tropo. correction and GDR-D orbit for the period* ***Left****: 2003-2012* ***Right****: 2004-2012*

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

Table 3: *Altimeter MSL trends of Jason-1 and Envisat and MSL drifts compared with in-situ measurements over the period 2004 / January 2012.*

gauges suggests that the drift is greater for Envisat mission (0.8 vs -0.1 mm/yr).

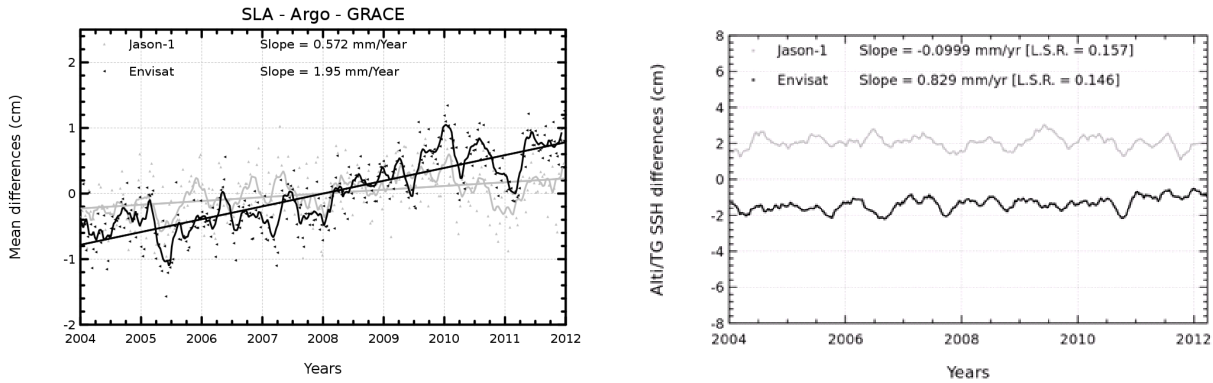


Figure 40: *Altimeter MSL trends of Jason-1 and 2 and Envisat over 2004-2012 without the GIA contribution (+0.3mm/yr) (top). MSL drift of Jason-1 and Envisat compared with Argo+GRACE (left) and tide gauges (right) over the same period (GIA included) and without annual and semi-annual signals and after 2-month filtering.*

Furthermore, to explain this difference of sensitivity, a study was performed to estimate the impact of coastal selection on the altimeter dataset. This enables to demonstrate that the proximity modifies greatly the trend on altimetry side (approximately +/- 0.3 mm/yr depending on the standard, see table 4) and, in absolute, using MWR instead of ECMWF give more consistent trends between altimetry and tide gauge MSL. Thus, these analyses show the sensitivity of the method and results should be further investigated in coastal areas.

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

Table 4: *Effect of the coastal selection on altimeter Envisat - Jason-1 MSL and compared with in-situ measurements over the period 2003 / January 2012.*

Finally, to complete this study in open ocean and make the results reliable, the altimeter MSL is then compared with Argo and GRACE data over the same period (figure 40 left and 3rd column of table 3, see Altimetry/Argo T/S profiles 2012 annual report [108]). Again, the altimeter MSL drift is greater for one of these missions than the other (1.4 mm/yr difference close to 1.0 mm/yr global difference). Note that the error over this period is estimated to be around ±0.8 mm/yr, taking into account the errors associated with both types of data, their processing and the colocation process. Moreover, absolute MSL drifts referenced to Argo and GRACE data also suggest that the Envisat MSL drift is greater than the one of Jason-1 (2.0 vs 0.6 mm/yr).

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

7.4. MSL regional time series

The regional MSL is presented here after. The V2.1+ evolution enables to improve V2.1 data (Figure 41). But the effect on regional MSL is largely dominated by the orbit standard evolution (see impact of Orbit alone in [15]).

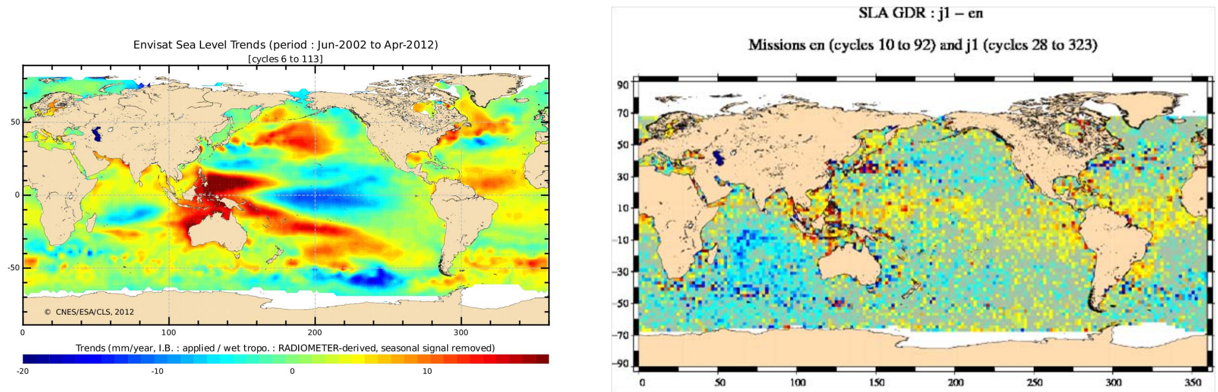


Figure 41: *Left: Regional absolute MSL for EN. Right: Difference EN/J1 After reprocessing with updates (V2.1+)*

The impact of updating Envisat data series is observed on Figure 41. Geographic trends differences are now homogeneous with few geographical patches (excepts a slight difference in the Indian Ocean (blue) and along the magnetic equator (yellow)).

7.4.1. Impact of wet tropospheric correction

Tests were performed this year, notably concerning the wet tropospheric correction used in MSL computation. ECMWF and ERA-Interim model have been used to highlights the observed discrepencies between radiometer and model. ERA Interim model was notably tested as a reference on the long term stability. Observed results are described in the next table (Table 5). Figure 42 shows the MSL trends for the different configurations:

Correction used	Global MSL Trend
MWR-ECMWF	0.2mm/yr (0.6mm/yr before rep.)
MWR-ERA Interim	0.4mm/yr
MWR	2.42mm/yr
ERA Interim	2.86mm/yr

Table 5: MSL trends in mm/year

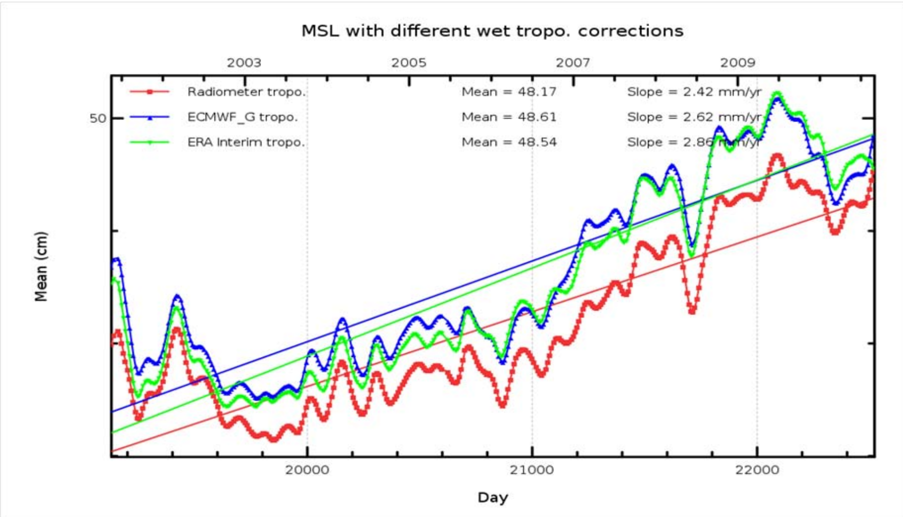


Figure 42: *MSL computed with wet tropospheric corrections (Radiometer, ECMWF model and ERA-Interim model)*

The difference of trends between ERA-Interim and radiometer tropospheric correction is more important than the difference between the ECMWF and radiometer tropospheric correction (0.4mm/y against 0.2mm/y). But the long term stability is by construction more reliable for ERA-Interim.

8. Particular investigations

This year investigations were carried on. This part is dedicated to them.

8.1. MSL

8.1.1. Remaining residual errors of MSL: before 2004

Envisat's MSL has various behaviors during its lifetime (even with reprocessed data) notably, a very odd decreasing trend at the beginning of the mission.
A first look at the raw (unfiltered and with annual, bi-annual and 60 days signal) SLA monitored on the whole time series with a severe selection on purely oceanic data (Lat<50deg and oceanic variability lower than 20cm) shows that the series can be split into 2 major parts:
- Before 2004 (cycle 22), the slope is clearly negative whereas
- After 2004 (cycle 22), the slope increases again, as expected.

During QWG 18 and to follow a work initiated in the yearly report 2008 [12], a synthetis of the suspicious terms of the MSL at the begining of the period was performed. This is summarized in the following view graphs.

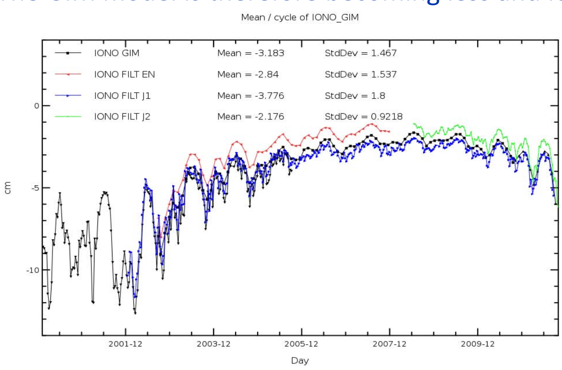
Remaining issues not to forget

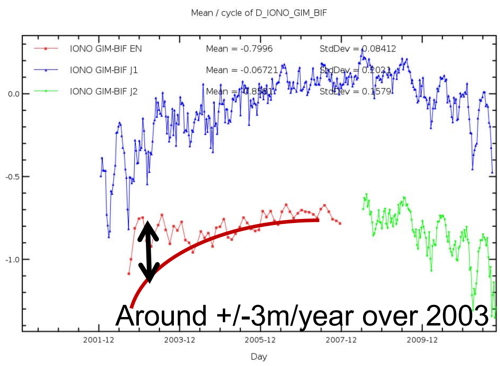
- Regional estimates are impacted by a larger error (on other missions as well): still things to analyse more accurately:
  - Coastal areas
  - High latitudes

  Under investigation / Tide Gauges comparison
- Interannual behavior differences with other missions and in situ still to be understood (mainly beginning of the period: before 2004)
- Stability of Wet Tropospheric Correction: Discrepencies Radiometer/ECMWF
- ➔Impact of Ionospheric correction (GIM quality/S-Band Quality?)

Long term monitoring of ionospheric correction

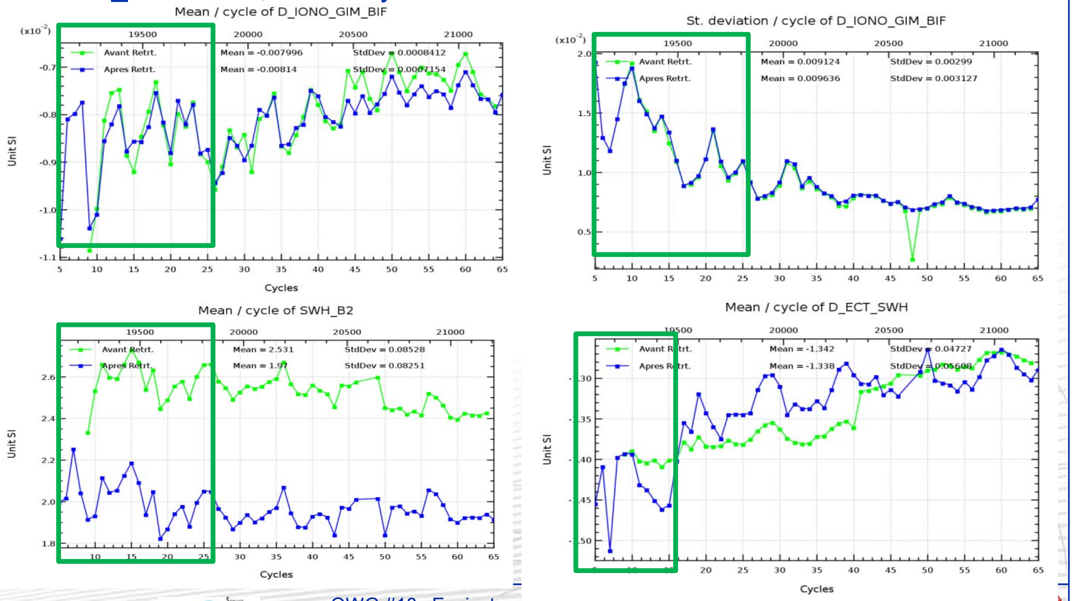
Since the S-Band loss, Envisat iono correction was efficiently replaced by the JPL GIM model. But the solar activity (represented by a higher value of the mean correction) is increasing again since mid 2009 following a 11 year period signal (see left hand plot).
The monitoring of the difference iono GIM-Bifrequency correction on Jason-1 and Jason-2 (see right hand plot) enlights that the error on the model is higher when the solar activity increases (around 5mm more than in 2008).
The GIM model is therefore becoming less and less efficient for Envisat.





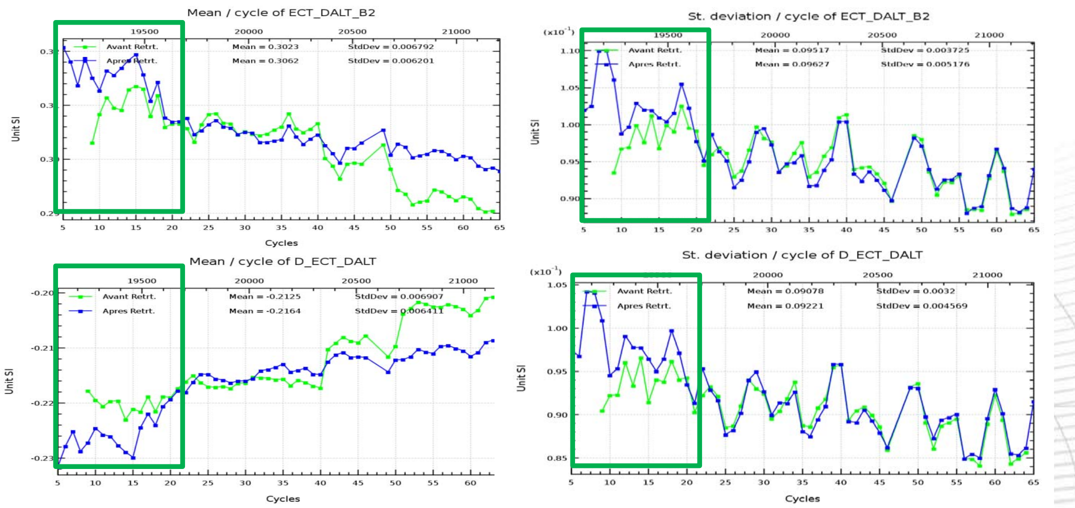
Envisat parameters: odd behavior before 2004

Suspicious behaviour of:
- Mean and Std of Filtr –GIM and Mean SWH S-Band before cycle 25
- Mean of D_ECT SWH, before cycle 15



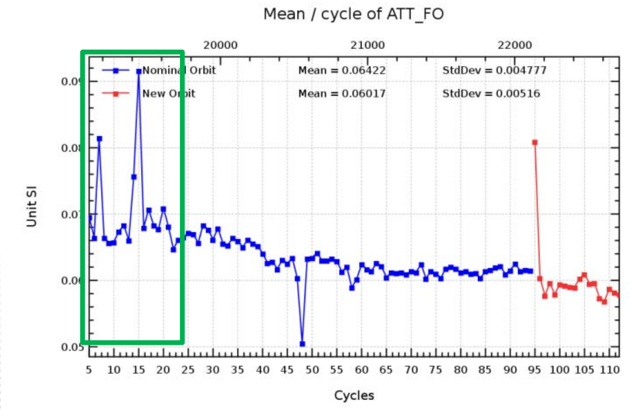
Envisat parameters: odd behavior before 2004

Suspicious behaviour of:
- Mean and Std of S-Band ECT_DALT before cycle 22
- Mean of D_ECT SWH, before cycle 15



Waveform parameters

- Attitude of the satellite, estimated thanks to the waveform mispointing in Ku Band is also suspicious before cycle 22 even after reprocessing…



Remaining issues not to forget

- Regional estimates are impacted by a larger error (on other missions as well): still things to analyse more accurately:
  - Coastal areas
  - High latitudes

  Under investigation / Tide Gauges comparison
- Interannual behavior differences with other missions and in situ still to be understood (mainly beginning of the period: before 2004)
- Stability of Wet Tropospheric Correction: Discrepencies Radiometer/ECMWF
- Impact of Ionospheric correction (GIM quality/S-Band Quality?)

➔ Odd to observe that MWR+ S band + Ku band waveform parameters have a particular behavior

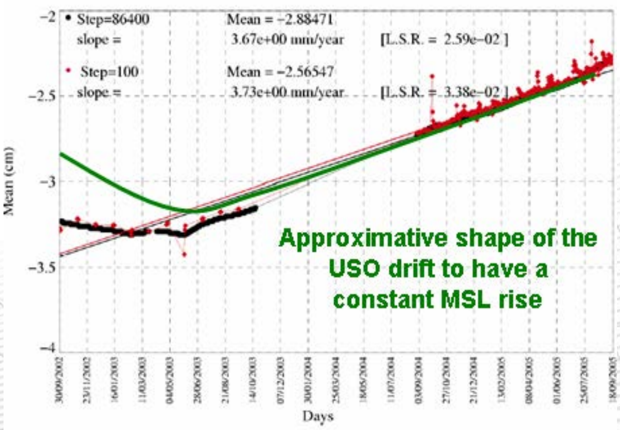
➔ What is common to all this? Time management? Other?

Uncertainties on instrumental corrections

USO drift estimation

+Extracted from QWG Nov 2008

- Change of behavior around cycle 22 as the MSL but
- Analyse with the reprocessed USO (long term drift already analysed)
- No obvious link between both drift



Uncertainties on instrumental corrections

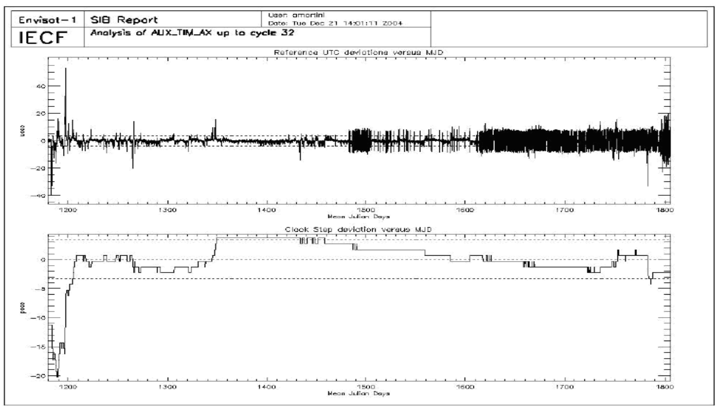
ICU/UTC drift estimation

+Extracted from QWG Nov 2008

- Extract from ECAR monitoring
- Change of behavior at the beginning of the period➔?

Reference UTC deviation versus MJD

Clock step deviation versus MJD

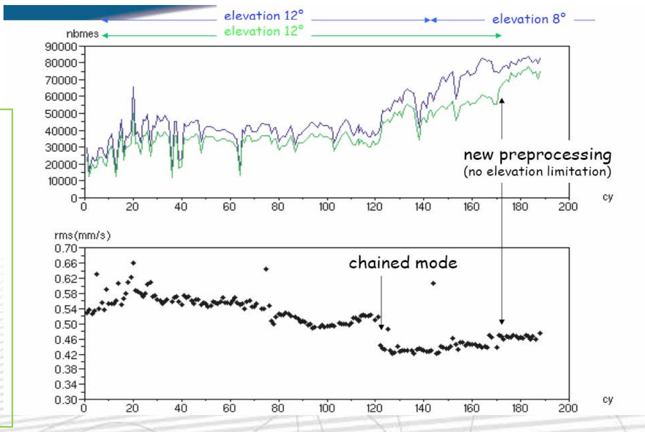


Uncertainties on orbital terms

DORIS/Laser processing

+Extracted from QWG Nov 2008

- DORIS on board inhomogeneity
- DORIS ground processing modes➔ Tests to be done



Gravity field

Need to regenerate POD solution with updated Grace data to monitor properly (for other missions)

Conclusion

- Hudge efforts/improvements were made to improve MSL relevance on global and regionally
- Enables to enhance to mission's quality but also to better quantify the senstivity of MSL for other missions
- Still some things to be understood/improve
  - At the beginning of the period concerning the global MSL with a particular point of wet tropo and iono corrections
  - Is it a combination of many points or rather an external common cause of error?
  - ➔Cumulated effect of all planned improvements (V2.2), including IsardSat PTR to be tested…
  - ➔It would be very usefull to analyse the regional paterns of Cross Cal results on this first year
  - ➔Investigations must go on.

8.1.2. Remaining residual of MSL: interannual errors

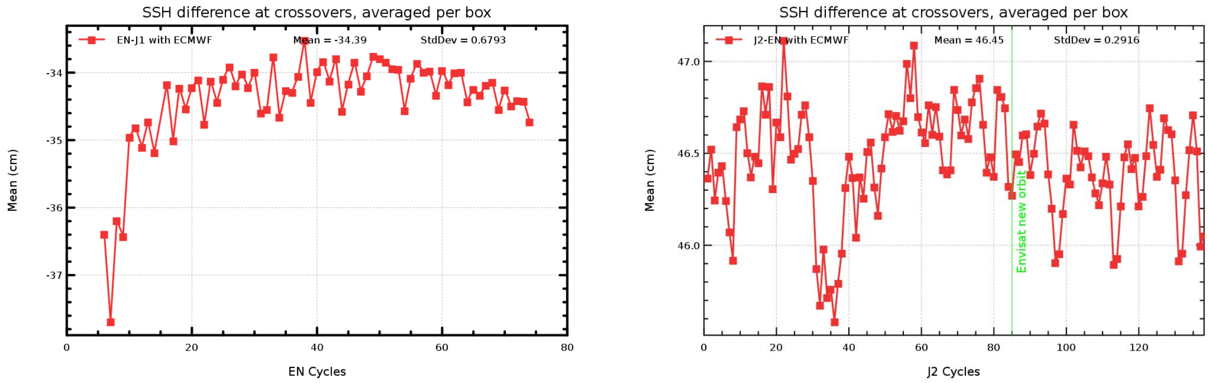
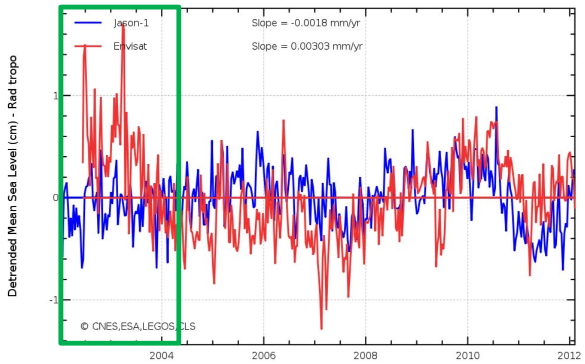


Figure 43: *Mean EN-J1* ***Left:*** *and J2-EN* ***Right:*** *SSH differences at dual crossovers (cm) on global ocean after EN and J2 reprocessing.*

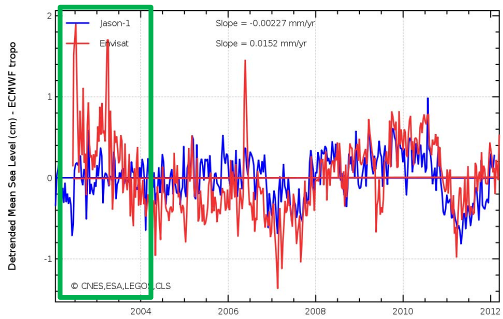
After the beginning of the period, the new Envisat MSL trend seems well correlated to Jason-1's MSL in terms of interannual signal. Yet, some reamining jumps can be identified and are suspected not to have any physical reason (jumps at beginning of 2007, mid 2007, mid 2009 and beginning of 2011 notably...). These jumps are observed on the mean difference at cross overs shown 43 as well as on the detrended MSL (using either ECMWF or MWR wet tropospheric correction) shown hereafter:

Interannual signal and BOM

Detrended MSL signal highlights the remaining dicrepencies between EN and J1:
The beginning of the mission remains particulary suspicious…



Similar behavior observed with ECMWF Wet Tropo



To investigate this point, note that similarities between IFF slope (from isardSAT P. Nilo's talk) and those abnormal jumps in MSL time series was noticed during QWG 19.
Of course the link cannot be established directely because a slope of IF Mask slope (or an the altimetric waveform) is far from being directly converted into range but this correlation could be further investigated on intrument side...

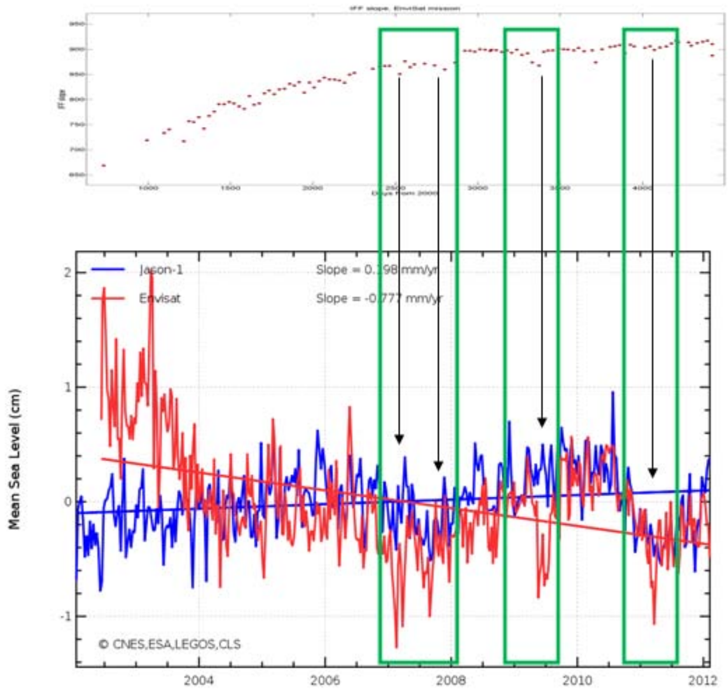


Figure 44: *Similarities between IFF slope and Envisat global MSL trends*

8.1.3. Sensitivity tests on residual errors of MSL

8.1.3.1. Test with a POE built with a 10 day-gravity field: Grace-10Days

The studies concerning the GDR-D orbit standard instead of GDR-C evidenced the fact that the Gravity field and the models used for POD purposes have a big impact on regional MSL long term trend.
Those standards are computed from a 10 day- gravity field with different long term evolution models fitted on it (annual semiannual terms + linear trend for GDR-D standard only).

At OSTST 2012, questions were raised concerning the divergence between the 'Real' Gravity field and the models used for POD purposes when extrapolated before and after the period of estimation of the variable terms of the model.
Now that Envisat mission is finished, this divergence could be estimated on the whole period in terms of long term trend. A new MSL computation was therefore tested in order to analyse the impact of a POE built (L. Cerri, CNES-POD) with a GDR-D POE and a 10 day- gravity field.

The Figure 45 shows the obtained results:
The conclusion of this study is that the impact is negligible on global MSL: indeed, the difference

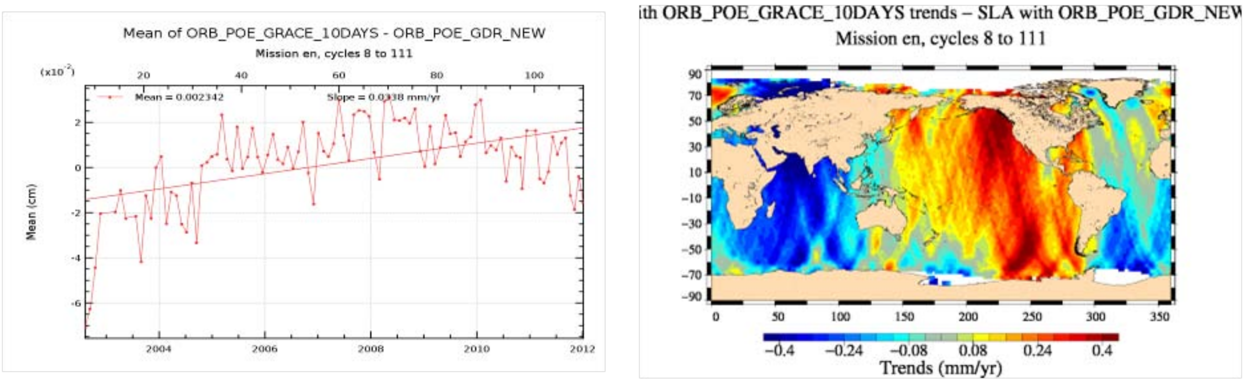


Figure 45: ***Left****: Mean of difference between GDR-D standard and 10-Day GRACE orbit* ***Right****: Impact on regional MSL*

of trends is close to 0.04mm per year whereas the precision on this parameter is usually estimated to 0.5mm/yr (Ablain et al 2009). And on regional MSL, the impact is very weak. The difference is less than 0.5mm per year for an estimated precision of 3mm/yr on this parameter.
However, for both global and regional MSL, the features do present geographical biases and interesting non random signal. They could be of interest in some years when the precision of the altimetric system will have been improved.

8.2. Internal Path Delay

8.2.1. Use of IsardSAT Internal Path Delay correction in SLA computation

This year and after the end of the reprocessing, the question of the instrumental correction to use in Mean Sea Level computation appeared. Before reprocessing, errors were identified on the PTR correction (In Flight Time Delay Calibration): a quantification step and the wrong sign for the application of the correction. Then, after reprocessing the data were properly resolved but the sign was still uncorrect, and the MSL trend was strongly impacted by this error (see Yearly Report 2011).
The problem was to find an appropriate solution to correct data afterwards, at Level 2 processing. The chosen solution was to provide to users an external correction for direct application at Level2. Two solutions were considered:
* The F-PAC PTR correction (provided by an extraction of L1B product) applied as 2*F-PAC PTR at level 2; this is the solution used for the validation of the files provided to users.
* To compute a new PTR correction, and then give users only the delta between F-PAC PTR and IsardSat PTR instead of 2*F-PAC PTR as a rythm of one value per second. This solution is provided as Netcdf file, one by cycle.

The main observation is the slight gain in term of difference of variance of SSH at crossovers; the SSH computed with IsardSAT PTR seems to be more coherent at crossovers than the SSH computed with F-PAC PTR.
This phenomenon is more visible near coasts.

Considering only side A data (all cycles except cycle 47 and 48), a weak difference on MSL is observed, using IsardSat or F-PAC one in the MSL computation. The global trend of MSL reaches 2.52 mm per year whereas the trend for MSL computed with F-PAC PTR is 2.47 mm per year.
For side B period (cycle 47 and 48), a bias of 3.5cm is observed on Mean Sea Level.

8.2.2. Significant points

Several points have been highlihgted:
The split by cycle is not coherent with the one normally used: each cycle of PTR file starts at track n°2 of the official GDR division used.
A 3 minutes overlap was observed between each correction cyclic file. During this overlap, locally the error at the beginning of the cycles reached more than 2mm whereas the absolute value of the correction delivered to users took values between 0.5 and 1.5mm.
Coverage lacks are observed on IsardSat PTR new correction compared to the F-PAC Reference (mainly before cycle 50): many tracks per cycles are uncomplete and 2-3 hours data gaps are observed ponctually.

For side A and side B, the standard deviation of PTR IsardSat correction is decreased comparing to F-Pac PTR. For side A, a similar behaviour is observed in term of trends.

Provision to users was accompanied by a technical note written to warn users of the different points cited above, notably concerning the side B data, considered as not validated yet.
See the dedicated page on ESA web site:

https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/envisat/news/-/asset_publisher/x9cY/content/improvement-of-envisat-ra-2-reprocessed-data-v2-1
The PTR cyclic files are available here:
ftp://diss-nas-fp.eo.esa.int/altimetry_dataset_v2.1/PTR_external_correction_file

The following slides summarizes the study performed.

IsardSAT PTR analysis

M. Guibbaud, A. Ollivier – CLS

OverView

- Error identified on PTR correction (In Flight Time Delay Calibration Factor) before reprocessing:
  - Quantification/resolution step
  - Sign
- Reprocessed data are properly resolved but the sign is still uncorrect➔ MSL trend strongly impacted by this
- Problem: How to correct data afterwards the information is on L1b only and not in L2

OverView

- Solution:
  - Compute a new PTR solution: best ever on theoretical point of view including other improvement on IsardSat Side (IF Mask…): ⇨ **isardSAT_PTR**
  - Extract L1b information and add 2PTR at level2: anticipated on F-Pac Side since the beginning of the reprocessing: **F-Pac_PTR**

- Open Issues:
  - On what point are the 2 corrections different?
  - It was decided by ESA to provide to users:
    - The difference isardSAT_PTR -F-Pac_PTR instead of 2 F-Pac_PTR correction to change only the sign.
    - At a rythm of One value per second

Plan

The study consisted in :

- Ingesting both corrections (Ku) in an altimetry database
- Comparing F-Pac PTR reference (from L1b official outputs from IPF) and the old /new isardSAT and Delta correction in terms of Availability/coverage
- Analysing the local behaviors of isardSAT correction overlaps
- Comparing the behavior of the F-Pac PTR (applied with the good sign as for Aviso web site) and the Delta Correction proposed by isardSAT over ocean in terms of:
  - Impact on SSH performances
  - Impact on global and regional MSL

IsardSAT PTR correction

Best solution on theoretical point of view including other improvement on isardSAT Side (IF Mask…)
+ improvement of consistency between Proto and real IPF (gestion of outliers)
See Monica/Pablo's presentation

Data Provision:
- First version provided to CLS on 20th of May => flag of PTR value (Ku,Ku,Ku,S band) => missing PTR data for one data on four approximatively. Inconsistent with the aim of delivery to users (expected one data per second).
- Corrected version provided to CLS on 29th of June
- Repeated products found in cycle 5,16 and 54 files, corrected files provided on 7th of July.
- Correction of Side-B bias provided for cycle 47 et 48 at the beginning of August.

IsardSAT PTR correction: furnitures

• One file by cycle available on the isardSAT FTP site

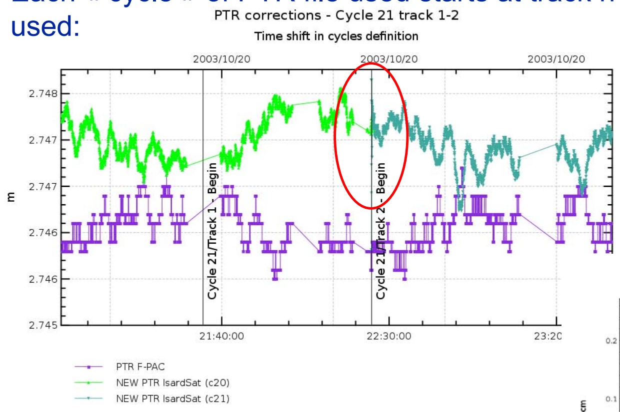
• Contents:
  o time: in microseconds since 2000/01/01
  o flag: indicates the Band and Chain of the measurements
  o new__ptr_time_delay_Ku: New PTR time delay for Ku Band
  o new__ptr_time_delay_S: New PTR time delay for S Band
  o old__ptr_time_delay_Ku: OldPTR time delay for Ku Band
  o old__ptr_time_delay_S: Old PTR time delay for S Band
  o delta__ptr_time_delay_Ku: delta of the PTR time delay for Ku Band (new-old) – The external correction
  o delta__ptr_time_delay_S: delta of the PTR time delay for S Band (new-old) – The external correction

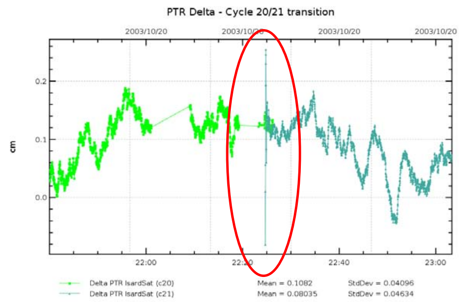
• Units: micrometers

First observations

- The division by cycle is not coherent with the normally used => has no impact in our analyse **BUT needs to be reported to users.**

  Each « cycle » of PTR file used starts at track n°2 of the official GDR division used:





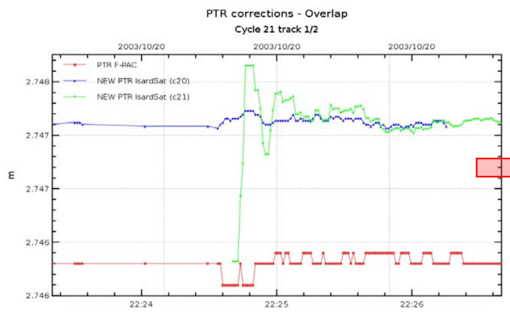
- 3 min. overlaps between each correction cyclic file

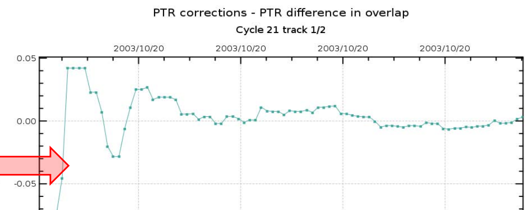
  Behaviour ?

  Impact on PTR new/old correction?

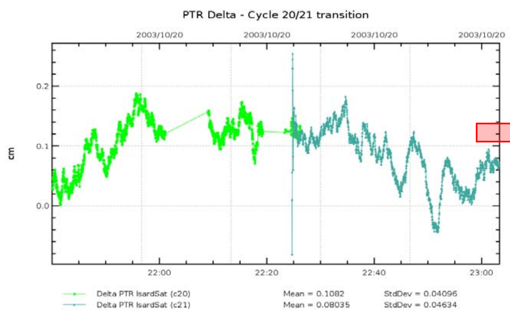
  Impact on the PTR delta correction?

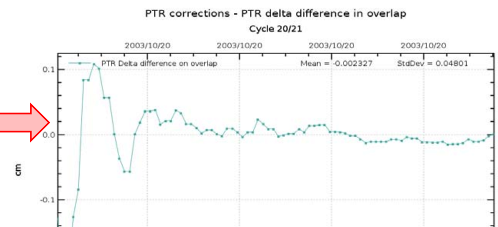
Overlap





Difference between the 2 overlapped NEW PTR isardSAT correction on overlap period : **locally more than 1mm**



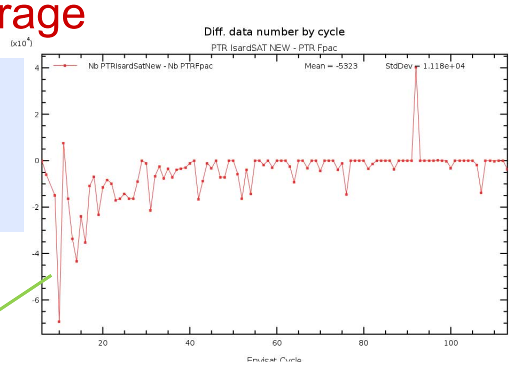


Difference of delta PTR correction on overlap period : **locally more than 2mm**

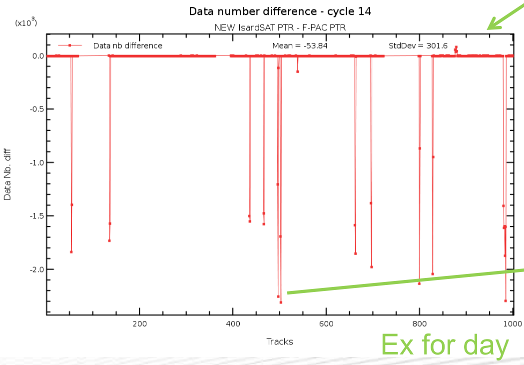
➔ Loccally the error at the beginning of the cycles reaches more than 2mm whereas the absolute value of the delta (to deliver to users) takes values between 0.5 and 1.5mm (beginning and end of the series)…

Coverage

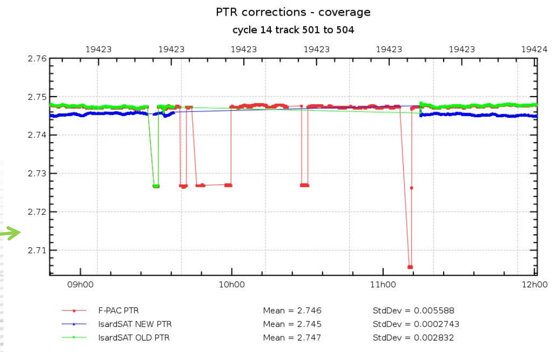
➔We observe coverage lacks on isardSAT PTR new correction compared to the F-PAC Reference (mainly before cycle 50).
➔Many tracks per cycles are uncomplete
➔ 2-3 hours data gaps are observed ponctually



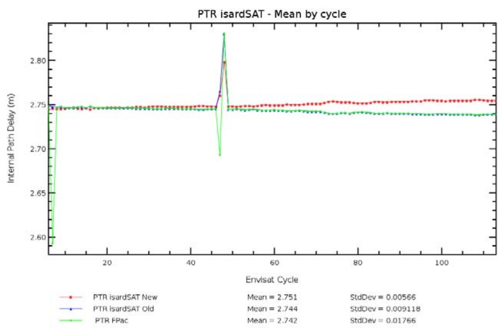
Ex for Cycle 14



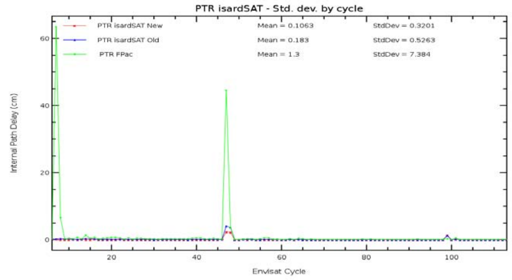
Ex for day 19423



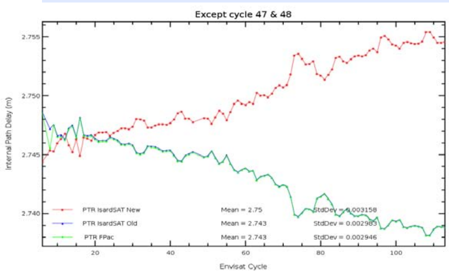
Statistics by cycle

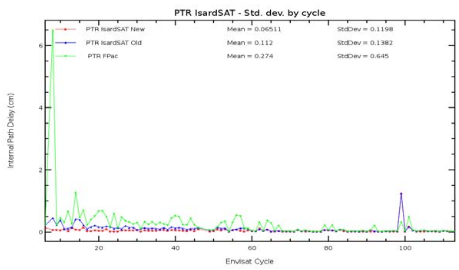


Std deviation of PTR is reduced for Side-B



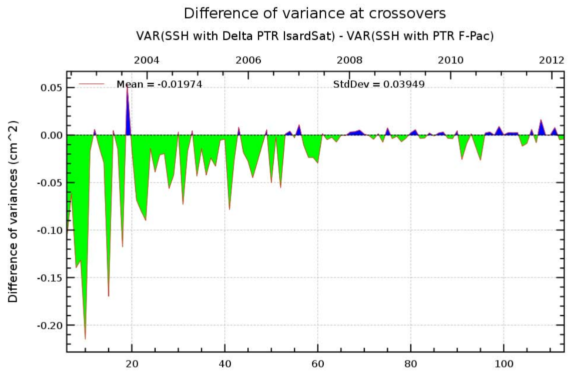
For Side A only:
➔Similar behavior in term of trends
➔Smaller standard deviation for isardSAT PTR (old and new) than FPAC one=>better?

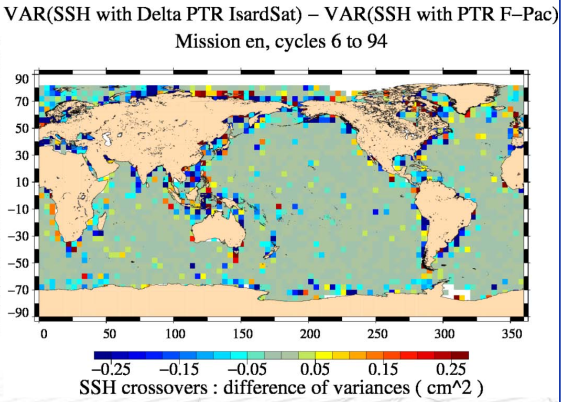




Impact on SSH at crossovers

without side-B





➔Slight gain on SSH variance difference at crossovers : SSH corrected from isardSAT Delta better than SSH corrected from F-Pac PTR (mainly near coasts)

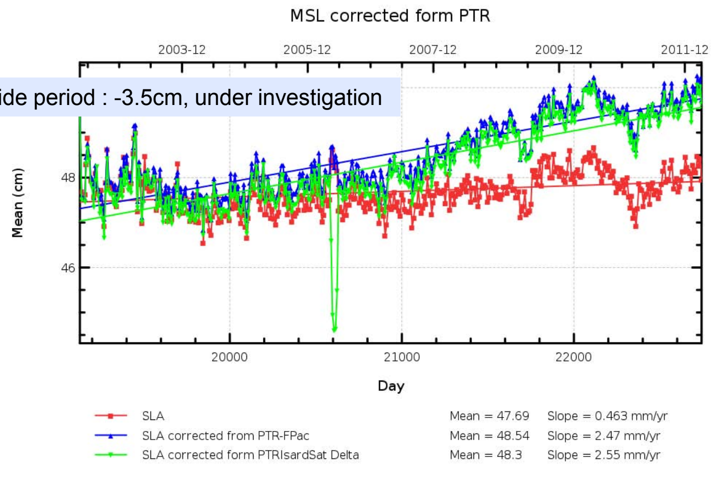
IsardSAT PTR in MSL

- Until now in MSL available on Aviso (using FPAC correction):
  - Side-A: SSH corrected from (-2*PTR_FPAC) + 5.495m
  - Side-B: SSH corrected from (-2*PTR_FPAC) + 5.694m

20cm bias

- Now, compared with:
  - SSH corrected from **delta__ptr_time_delay_Ku**

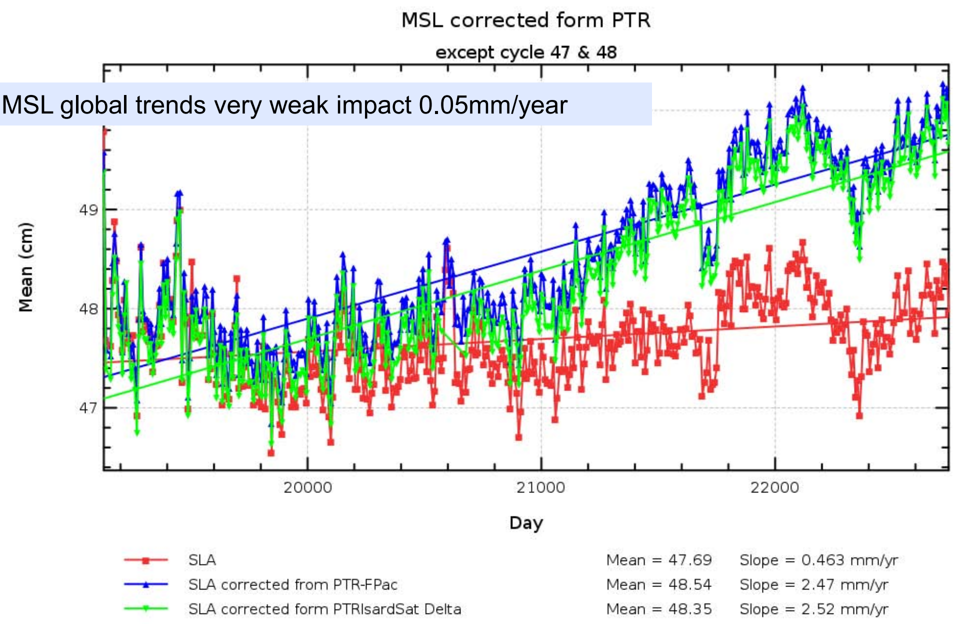
➔Bias on MSL on B-side period : -3.5cm, under investigation



Impact on global Envisat MSL

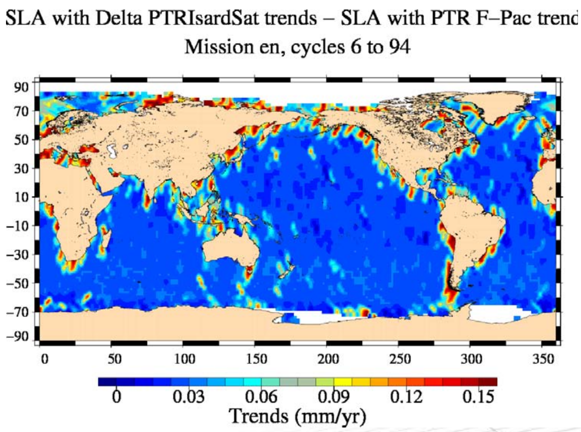
without side-B

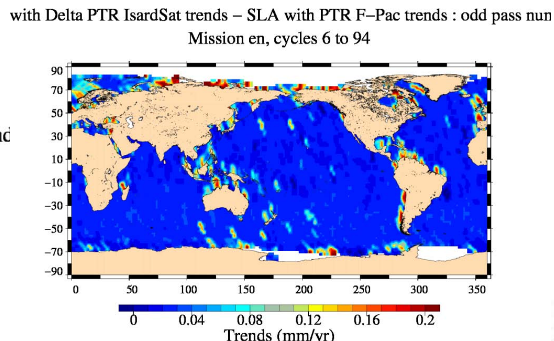
➔MSL global trends very weak impact 0.05mm/year

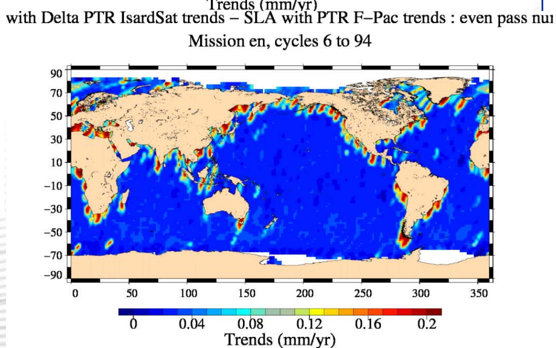


MSL trends differences

without side-B







➔MSL regional trends very weak impact but slighlty impacted near coasts

Conclusions & prospects

Gaps and overlaps:

• 3 mins overlap between each cyclic correction file => locally high (relatively to what we correct for) error on delta PTR.

• Some coverage gaps on isardSAT PTR new correction compared to the F-PAC Reference (mainly before cycle 50). Uncomplete tracks.

SLA behavior:

• New isardSAT PTR correction Side B period is biased (around 3.5cm) (reported to user on Aviso web site)

• Smaller variance of SSH at crossovers with PTR Delta than the PTR F-Pac correction => better (B Side period excepted)

• Similar behavior in terms of trends (B Side period excepted)

• Better behaviour near gaps and coasts.

➔Decision end of July to deliver the data to users (with release note):

➔Available on ESA ftp server since 28/08/2012:

https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/envisat/news/-/asset_publisher/x9cY/content/improvement-of-envisat-ra-2-reprocessed-data-v2-1

8.3. Performance gain of new standards

GDR-D POE, updated wet tropospheric correction and associated SSB

8.3.1. GDR-D POE standard

8.3.1.1. Description of GDR-D standards

In 2011, a first validation was made in preliminary GDR-D orbit standard. It has been shown that the use of this new standard reduced the East West bias increasing in time. These standards includes the gravity field EIGEN-GRGS-Release2bis (detailed in (Cerri et al. 2011)), which results from a modeling on 8 years (2002-2011) instead of 3 years (2003-2005 for the EIGEN-GL04S (see Table 41)). It includes a semi-annual and annual time variability field as well as a long term drift term which was shown to appears with a different sign and amplitude on Envisat and Jason-1 data, and consequently in a greater way in the difference Envisat minus Jason-1.

The use of this standard in GDR was analysed this year for Envisat, Jason-1 and Jason-2. In fact, the quality of Precise Orbit Ephemeris is crucial for the quality of altimeter data. Inversely, studies using Sea Surface Height calculation from altimeter or in-situ data enable to give insight in orbit quality for the different missions, to compare different orbit solutions for one mission and to compare the behavior of an orbit standard on different missions.

8.3.1.2. Temporal behavior of GDR-C and GDR-D POE

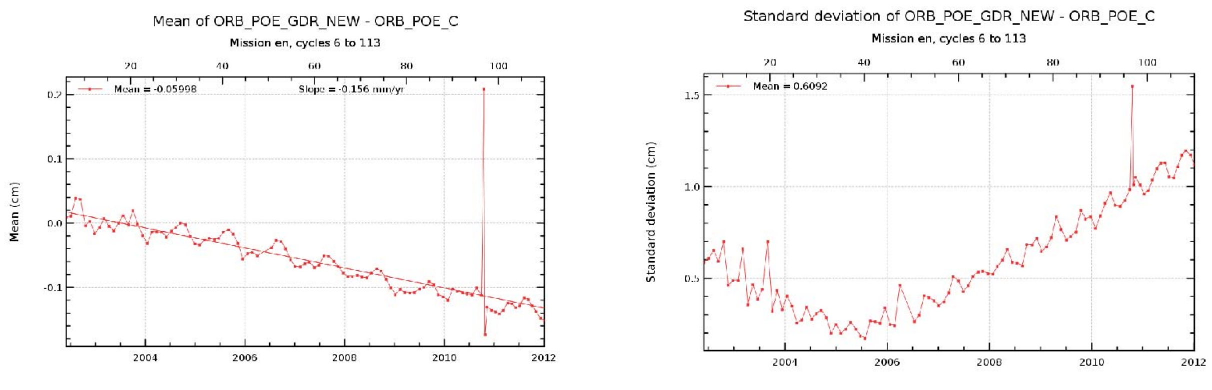


Figure 46: *Mean and std. deviation of difference of GDR-D and GDR-C standards*

Figure 46 left is the mean difference of CNES GDR-C and GDR-D orbits per cycle. The drift observed is the signature of the long term drift modeled in the GDR-D. It is the main difference in the associated gravity field models EIGEN-GRGS-Release2bis and EIGEN-GL04S. The global slope of the difference is -0.17mm/year. This result was expected after GDR-D preliminary orbit analysis and is observed on MSL computation (see figure 47).

Figure 46 right is the Standard deviation of the difference of CNES GDR-C and GDR-D orbits per cycle. The minimum on year 2005 is the signature of the fact that the new gravity field is estimated over 8 years (2002-2011) instead of 3 years (2003-2005) for the EIGEN-GL04S centered in 2005.

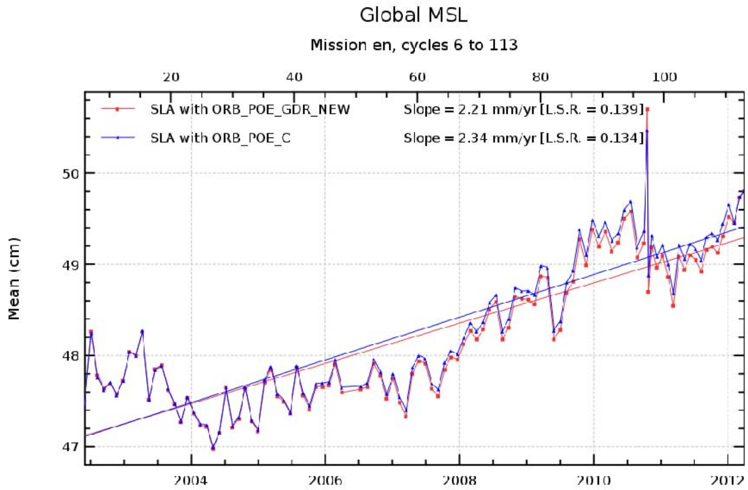


Figure 47: *Impact of the GDR-D orbit standard instead of GDR-C standard on the Mean Sea Level trend*

For Envisat, the impact of using GDR-D orbit standard reaches 0.13mm/y, which is significant.

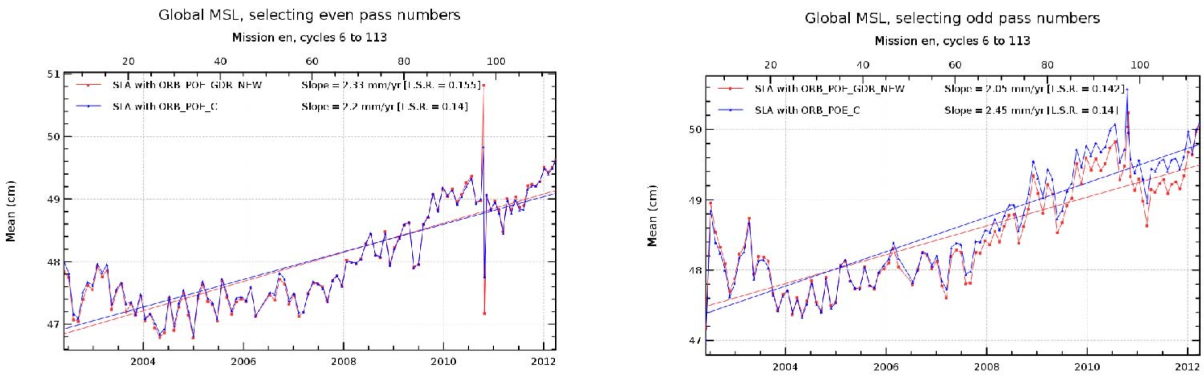


Figure 48: *Impact of the GDR-D orbit standard instead of GDR-C standard on the Mean Sea Level trend for ascending/descending passes*

The discrepancy between ascending/descending passes is now reduced from around 0.45 mm/y to -0.18 mm/y using the GDR-D (see figure 48). This result was already demonstrated in the preliminary study (see [15]). The change in the time varying field used in GDR-C and GDR-D standards corrects for effects varying with a large time dependency: this has a signature on the regional Mean Sea Level trends. The figure 49 (right) presents the centered difference of regional Mean Sea Level trends between Jason-1 and Envisat using GDR-D orbit standards.

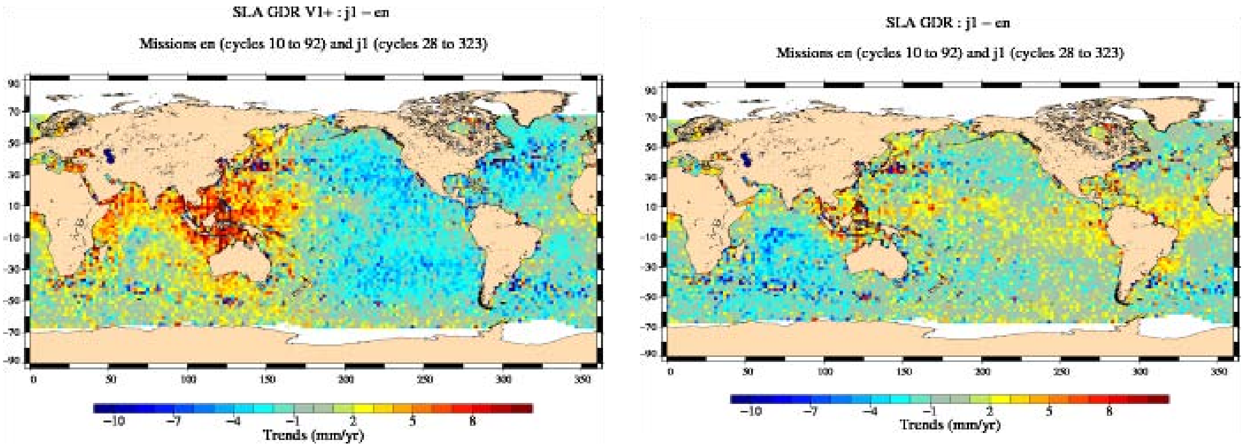


Figure 49: *Regional Mean Sea Level of dual crossovers Envisat (V2.1)/Jason-1 using GDR-C or GDR-D standards*

8.3.1.3. Performance at crossovers

The quality of the Envisat CNES preliminary GDR-D orbit in terms of SSH performance is tested through the variance gain at crossovers (compared to GDR-C orbit), as visible on figure 50 for Envisat.
The variance of SSH at crossovers is decreased for Envisat from 0.07cm^2 compared to GDR-C orbit standard.

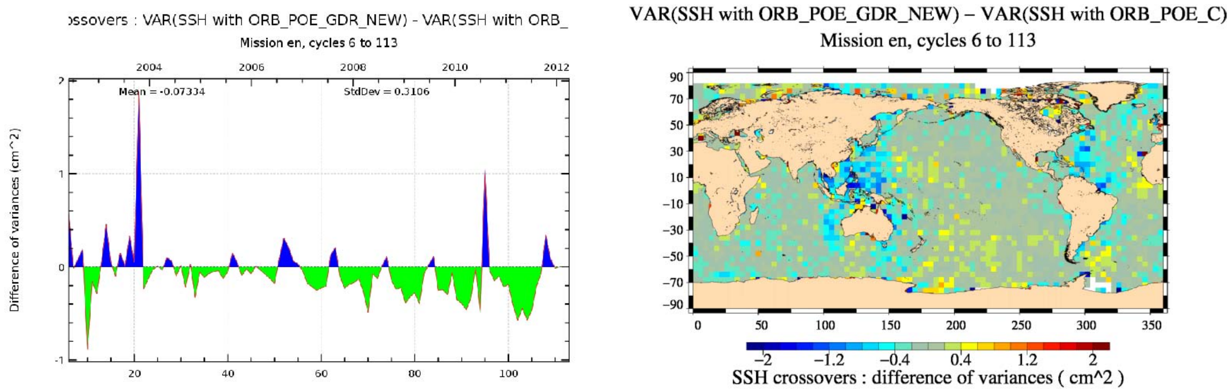


Figure 50: *Variance difference of SSH at croossovers using GDR-D compared to GDR-C standard for Envisat*

For the three missions, the GDR-D standard reduces the variance of SSH at crossovers, which is a good indication of quality for mesoscale scales (lower than 10days), as shown on figure 51.

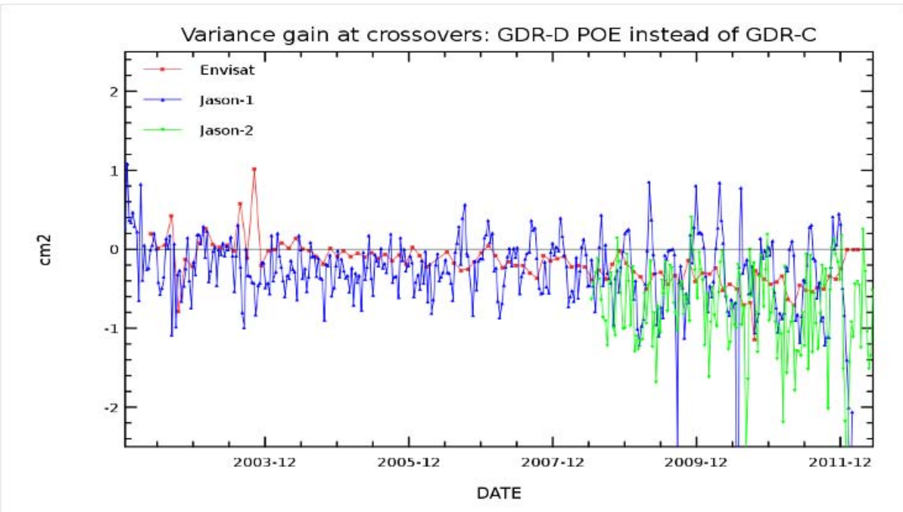


Figure 51: *Variance difference of SSH at croossovers, using GDR-D compared to GDR-C standard for Envisat, Jason-1 and Jason-2*

In terms of mean of SSH difference at crossovers, the reduction is noticed for the three missions too.

Systematic geographical biaises between ascending/descending passes behavior are largely reduced, as seen on figures 52 and 53 for Envisat and Jason-2.

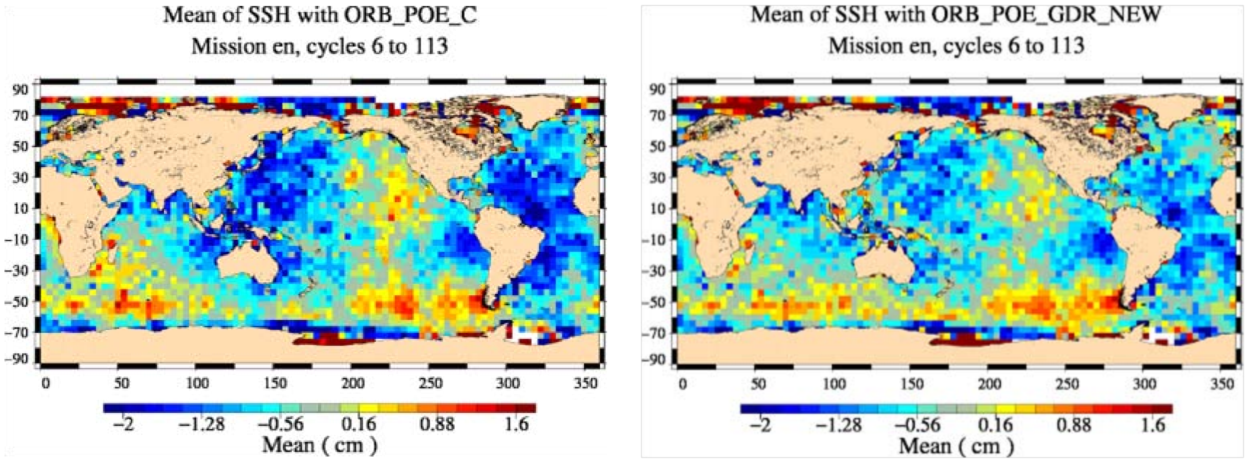


Figure 52: *Maps of mean of SSH at crossovers over the entire Envisat dataset, with GDR-C or GDR-D orbit standard*

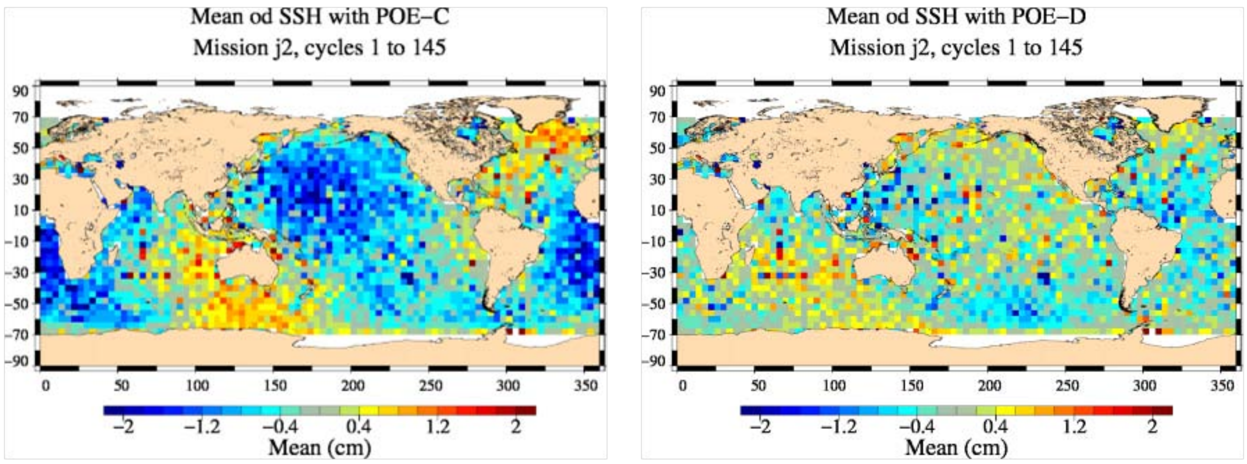


Figure 53: *Maps of mean of SSH at crossovers over the entire Jason-2 dataset, with GDR-C or GDR-D orbit standard*

The strong geographical East/West bias signature, in relation with the gravity field included in the orbit solution, which was shown as increasing with time is now strongly reduced using GDR-D solution.
GDR-D standard improve consistency of each mission, compared to GDR-C standard, with a stronger impact on Envisat but all the missions gain better consistency in therms of SSH at crossovers. It improve the consistency between each mission too, removing the error linked with each mission, as presented on figure 54.

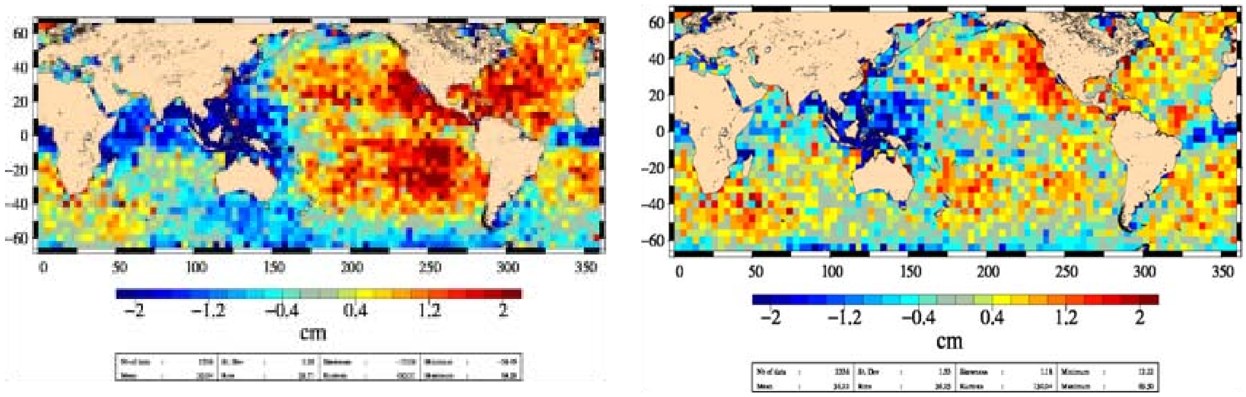


Figure 54: *Mean difference Envisat (V2.1)-Jason-1 of SSH at crossovers over 2011 (with wet tropo. model) using* ***Left:*** *GDR-D for Envisat/GDR-C for Jason1* ***Right:*** *GDR-D for both missions*

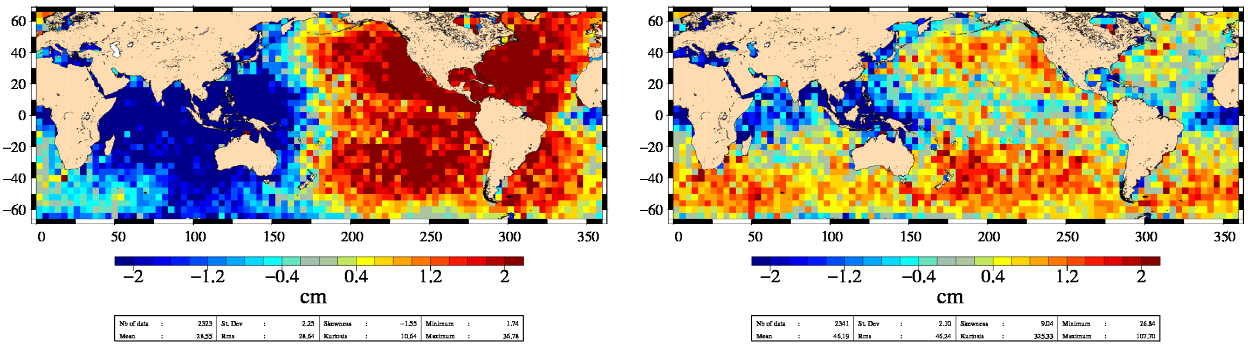


Figure 55: *Mean difference Jason2-Envisat at crossovers over 2011 (with wet tropo. model) using* ***Left:*** *GDR-C orbit standard for both missions* ***Right:*** *GDR-D orbit standard for both missions*

Figure 55 presents the mean difference of SSH at crossovers for Jason-2 using GDR-C or GDR-D orbit standards. The reduction of East/West bias is significant, as for the two other missions.

8.3.1.4. Particular degradation

Now let us consider only the period before 2003; on the figure 56, we observe a supsicious behaviour in the difference of variance of SSH at crossovers using GDR-C or GDR-D standard.

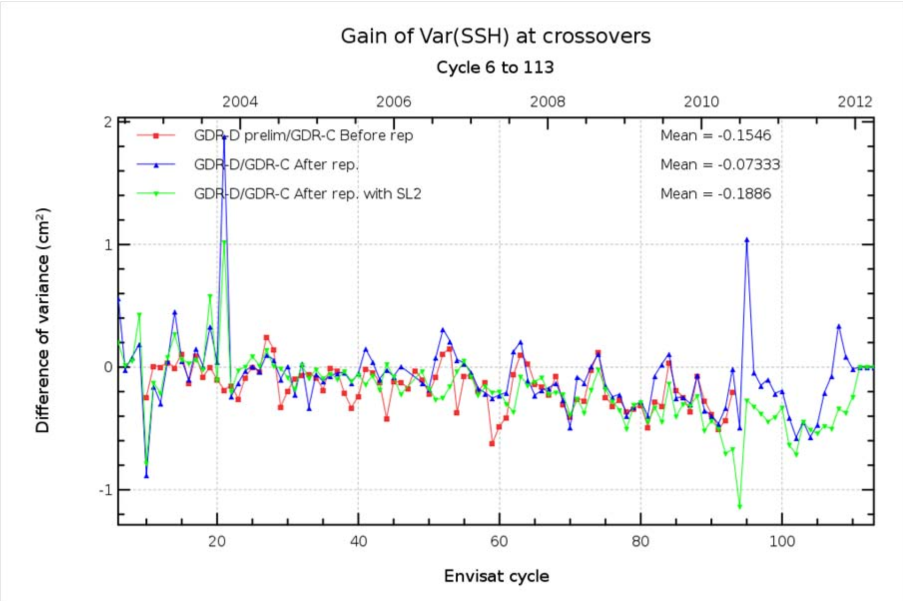


Figure 56: *Difference of SSH variance at crossovers using preliminary GDR-D/GDR-C before reprocessing (red), GDR-D/GDR-C after reprocessing (blue) and the same with selection (shallow waters excluded, latitude within [-50S, +50N], high ocean variability areas excluded)*

We can notice a degradation of SSH variance at crossovers with GDR-D orbits after reprocessing, before cycle 30, especially for cycles 9,14,19 and 21.
The selection applied globaly improve the performance (-0.19cm^2 against -0.07cm^2) but the degradation at the beginning of the serie persists.
Note that in red, preliminary GDR-D orbits did not present this effect.

For the two impacted cycles 19 and 21, the figure 57 shows the geographical degradation at crossovers for SSH computed with GDR-D standard.

For some tracks the degradation is important, and the corresponding difference of orbit field seems suspicious too.
The next figure (58) highlights this difference.
In conclusion, some isolated tracks are actually different for some cycles at the beginning of the mission. These tracks do degrade the performances at crossovers in GDR-D compared to GDR-C standard, which is under investigation.

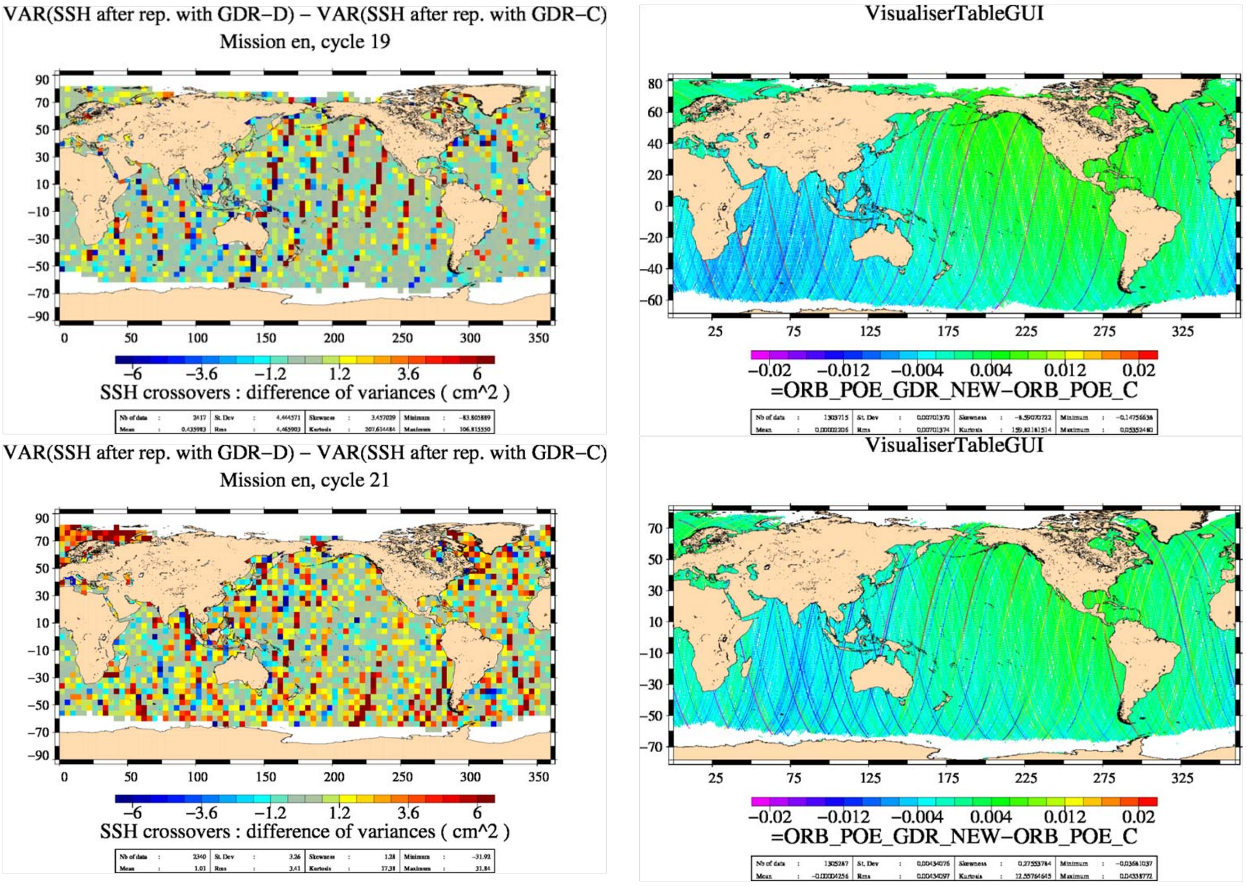


Figure 57: *Left: Difference of variance of SSH at crossovers, Right: Mean of difference of GDR-D and GDR-C standards. Top: Cycle 19, Bottom: Cycle 21*

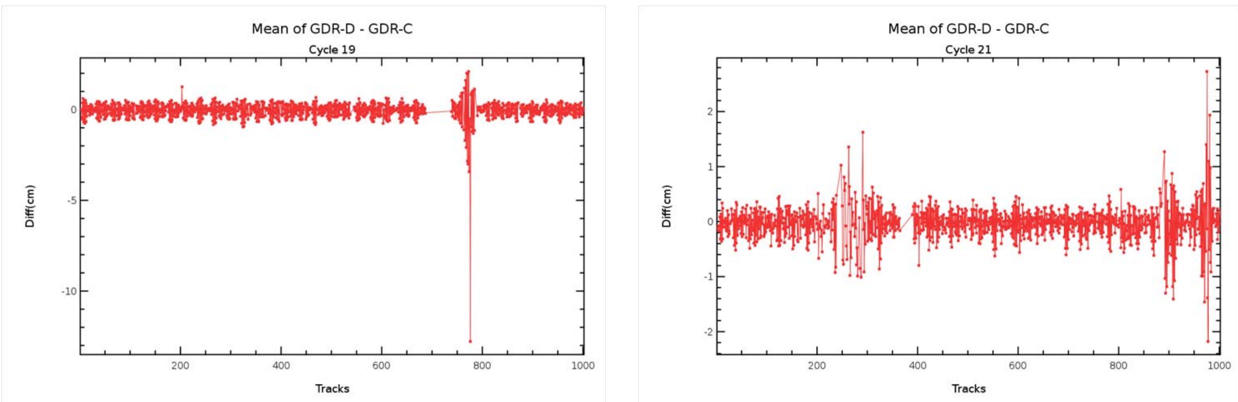


Figure 58: *Mean of difference of GDR-D and GDR-C standards Left: Cycle 19 Right: Cycle 21*

8.3.2. Sea Surface Bias

In 2012, a new SSB was computed, based on V2.1 reprocessed dataset and taken into account the updated wet tropospheric correction. This bias was analysed and the impact on SSH at crossovers and on SLA for Envisat dataset is developped here. The computation details of this new Sea Surface Bias are available in (Tran et al. OSTST 2012).

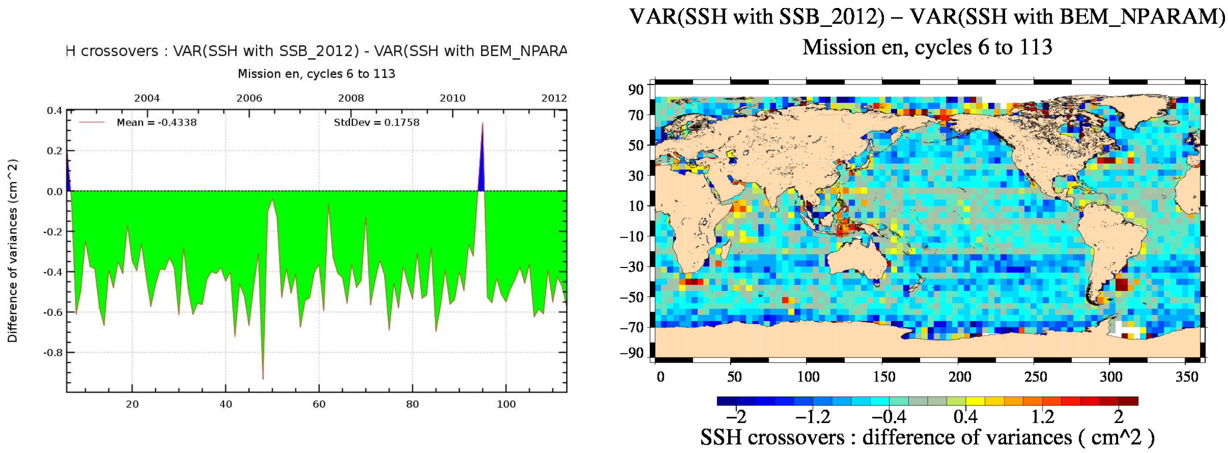


Figure 59: *Variance difference of SSH at crossovers, using the new SSB compared to the previous version*

The gain of variance on SSH at crossovers reaches a mean of -0.4cm^2, and is global on the whole serie, except for the first 2 cycles, where a tiny degradation is observed; this degradation is lower than 0.2cm^2, and at the time of orbit change. The gain is globally distributed.

8.3.3. Wet tropospheric correction

This year and after reprocessing, particular study has been made on the degradation on SSH at crossovers due to wet tropospheric correction. Once characaterized the errors were analysed and experts computed a new wet tropospheric correction (summer 2012); the impact of this updated correction is here analysed in terms of variance of SSH at crossovers and MSL.

The degradation of the V2.1 MWR wet tropospheric correction compared to the one used before reprocessing is near 1.5cm^2 when avoiding the high latitudes, low bathymetry and high oceanic activity, as seen on figure 60 left,and it can reach locally 5cm^2 in wet areas (figure 60, right). After investigations, radiometer experts have computed a new MWR correction, which improves results compared to the V2.1 reprocessed dataset. This improvement is near 0.8cm^2, and localized in wet areas, where the degradation was the most important, see Figure 61.

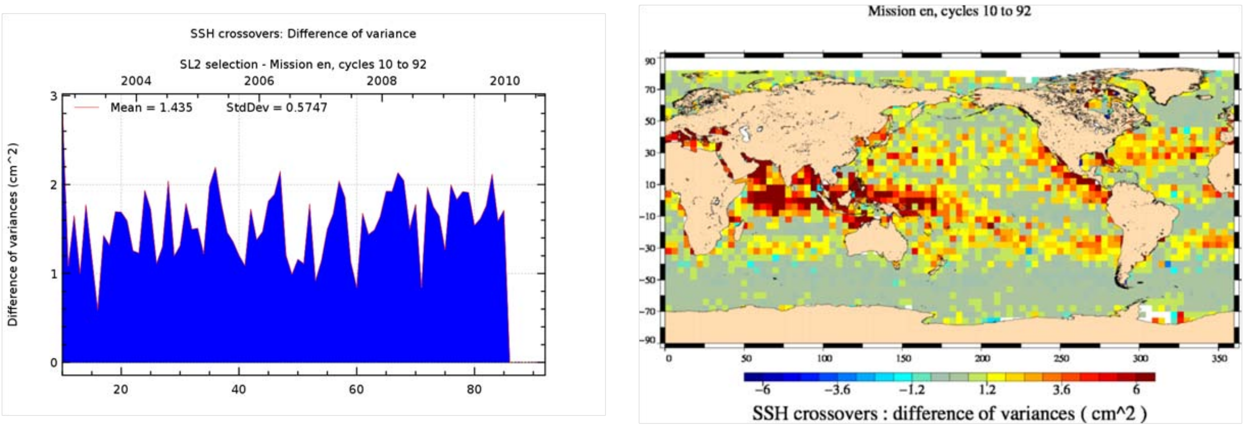


Figure 60: *Left: Variance difference of SSH at crossovers per cycle: impact of the MWR correction in V2.1 against routine GDR (before rep.),* ***Right****: Map of this difference over cycles 10 to 92.*

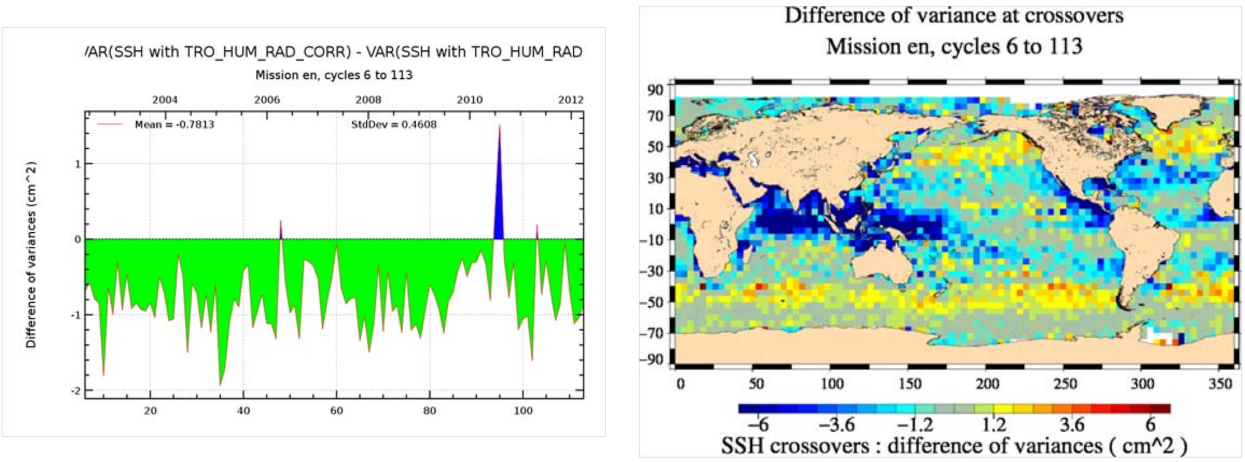
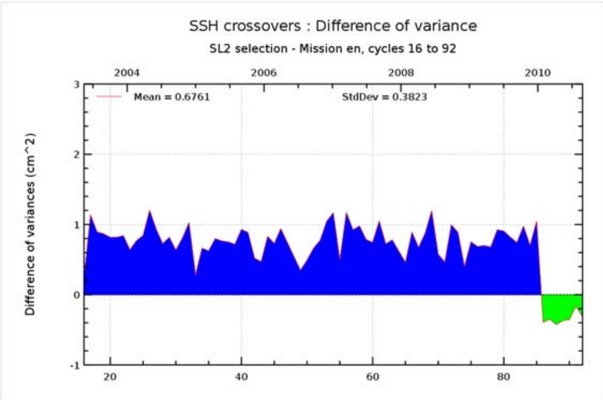


Figure 61: *Left: Variance difference of SSH at crossovers per cycle: impact of the MWR correction in V2.1+ against V2.1,* ***Right****: Map of this difference over cycles 6 to 113.*

.

This gain is significant but still degrades the MWR data if compared to routine GDR, as we can see on Figure 62. Note that the improvement after cycle 85 is relevant from the fact that the routine GDR was already in V2.1 standard. For this period, the gain corresponds to the "V2.1+"-"V2.1" gain.



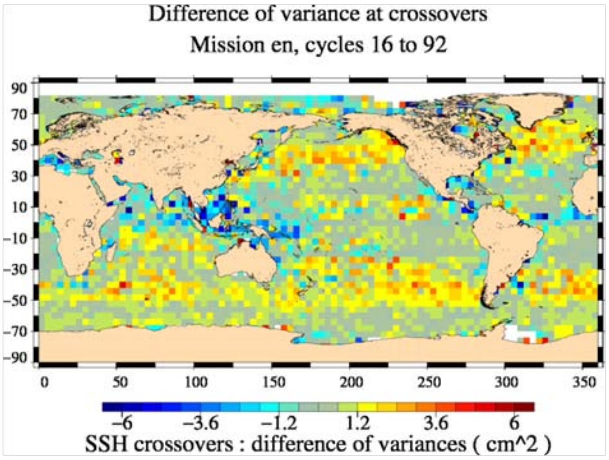


Figure 62: *Left: Variance difference of SSH at crossovers per cycle: impact of the MWR correction in V2.1+ against routine GDR , Right: Map of this difference over cycles 16 to 92.*

Using the updated MWR correction reduces the degradation from 1.5cm^2 to 0.67cm^2, in comparison with routine GDR. We can notice that a slight gain is obtained in wet areas, whereas the slight degradation is centralized on 50°S/50°N bands.
This degradation is still under investigation on radiometer expert side in order to compute a more accurate radiometer correction.

8.4. Performances of composite wet tropospheric correction

Radiometer content is known to be polluted and less relevant near coasts. To improve data near coasts, a composite correction was computed using model data near coasts and radiometer data elsewhere. For this, a classification of transition areas is defined: small gaps (< 200km), big gaps (> 200km),... with a dedicated processing adapted to each case. For the small gaps, the computed values result from a linear interpolation of radiometer data. For the transition zone, the wet tropospheric correction is a combination of model data and radiometer data, based on the difference between the two corrections. For each defined zone, a different algorithm is applied in order to extend the wet tropospheric correction data,validated in 2005. This year a performance analysis was carried on to estimate the real improvement of such strategy.

The first observation we made is on difference of variance of SSH at crossovers: we compare a SSH computed with the composite correction to a SSH computed with the radiometer data. We observe also the variance gain or degradation directly linked to the use of this composite correction. The results for Envisat and Jason-1 are potted below, on Figure 63. The plots Figure 64 are computed with the selection only on $|lat| < 50^\circ$.

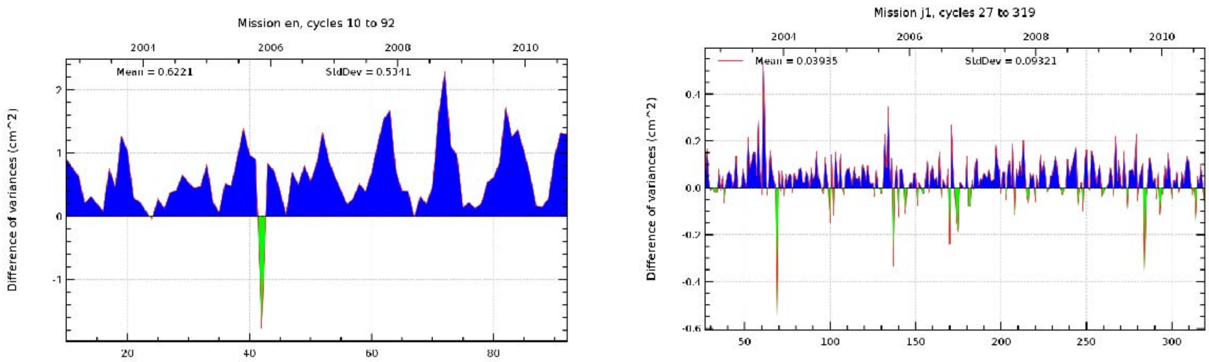


Figure 63: *Difference of variance of SSH at crossovers for composite wet tropo. correction/wet radiometer correction - Envisat (**Left**) and Jason1 (**Right**)*

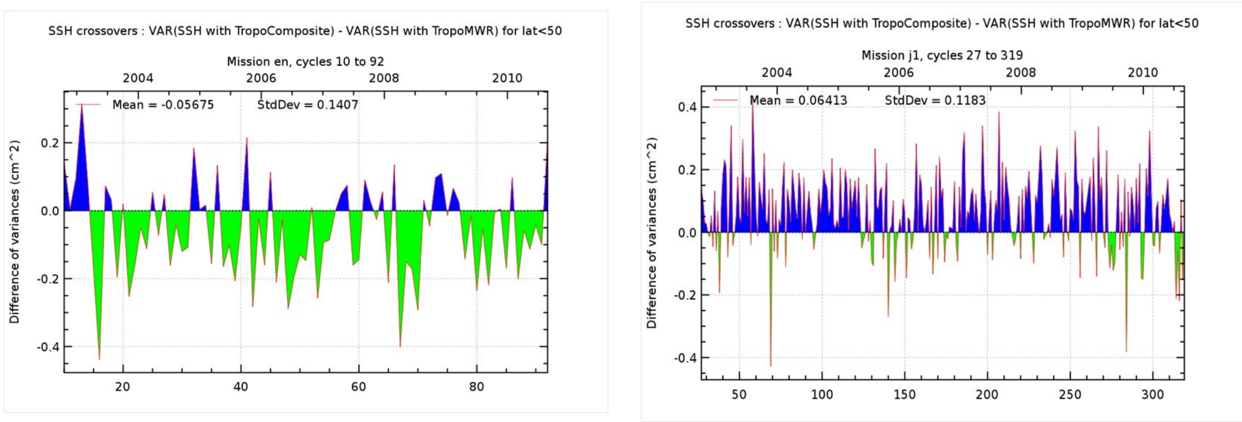


Figure 64: *Difference of variance of SSH at crossovers for composite wet tropo. correction/wet radiometer correction - Envisat (**Left**) and Jason1 (**Right**) - with selection on latitudes*

The degradation is reduced for $|lat| < 50^{\circ}$, but this degradation is still significant for a great number of cycles, especially for Jason1.
This degradation is also visible geographically, for the two missions, in Figure 65.

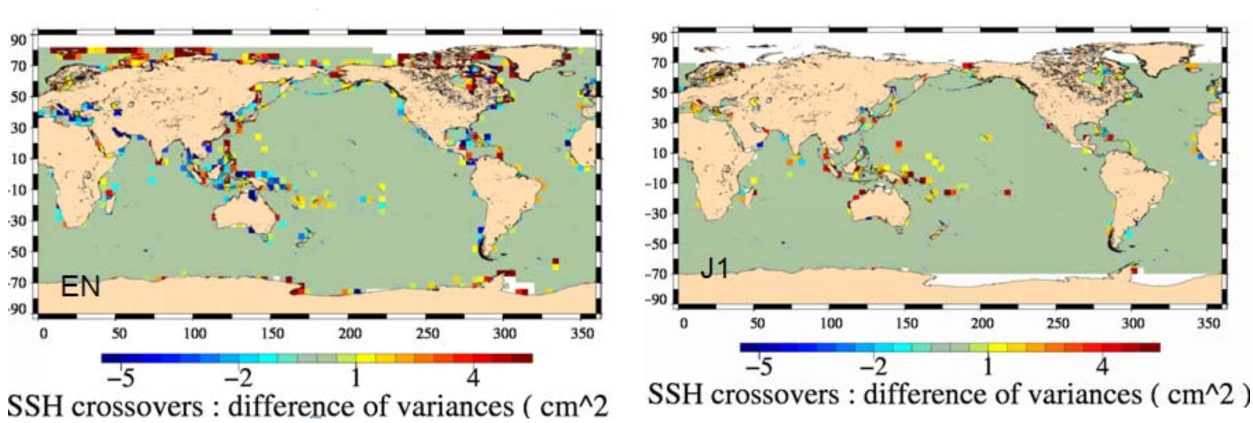


Figure 65: *Geographical repartition - Difference of variance of SSH at crossovers for composite wet tropo. correction against wet radiometer correction - Envisat (**Left**) and Jason1 (**Right**)*

For Envisat, we notice a great degradation on high latitudes using the composite wet tropospheric correction, probably due to ice areas. The most important thing shown by these two maps is the inconsistency between the results of two adjacent boxes; typically for Envisat in Indonesia area, the repartition of gain seems suspicious.
Some tests have been made to study this difference at crossovers for defined areas: ocean, little ($< 200km$) and big hole (islands areas), transition ($< 50km$) area and coasts. These different areas are used in the computation of composite correction, with an dedicated algorithm in each of them. This algorithm takes into account a part of radiometer correction and a part of model, function of the concerned area. The different results obtained in these areas don't allow to conclude that one area is particularly concerned by a degradation of performances. As it is, this study don't explain the variance degradation, which does not seem to be linked to the coastal zone division and then to the different algorithm applied in each zone.

The difference of variance of SSH at crossovers was computed with a composite correction using ERA-Interim wet tropospheric correction data too. And the results were similar: a global degradation is noticed for Envisat and Jason1.

8.5. Dual-frequency ionospheric correction filtering

8.5.1. A new approach for dual-frequency ionospheric correction filtering

This year, a study was carried out on possible improvement of the ionospheric correction filtering method. Envisat dual-frequency ionospheric correction is very noisy and needs to be filtered before being used to correct SLA. Presently, users are advised to filter frequencies lower than 300km before using it in the SLA computation. In the delivered products, the dual-frequency ionospheric correction is provided without any filter.
In the current method, dual-frequency ionospheric correction data are filtered after the CalVal editing process, which brings together a selection of data on different criterion: flag,thresholds, statistics on SLA along tracks,... After the complete validation process, dual-frequency ionospheric correction data are considered as valid if all the described criterion are respected, which create a strong dependency between ionospheric terms and other corrections or SSH which has no reason to be.
Valid values of dual-frequency ionospheric correction can be rejected because of SSH, and as a consequence, no associated filtered values can be computed.

The main advantage of the proposed new filtering method is to suppress this dependancy.
The first difference is the data selection step; in this iterative method, the selection is made only on range standard deviation and elementary data number. A selection is also made to suppress ice data. Thus this selection allows to apply the iterative filtering on a larger number of data.

The method is based on an iterative process: between each iteration, selection of valid data is based on difference between filtered data and not filtered data. Data are conserved if they respect a statistic criteria calculated from standard deviation of previous iteration filtered data. After the filtering step, an interpolation is made to fill potential gaps in filtered correction.
As well, filtered values are available wherever the dual-frequency correction is defined.

The increase of filtered ionospheric correction data number reaches more than 6% for Envisat, compared to filtered value selected after validation process.
For Jason-1 and Jason-2, this percentage is around 5%.

In terms of performance, the variance of SSH at crossovers is decreased using the iterative filtered ionospheric data compared to the dual-frequency ionospheric data for Jason-1 and Jason-2, and overall similar for Envisat. Indeed for Envisat we observe a slight degradation of this difference of variance for few cycles before 20. Geographically, this degradation is visible in high ionospheric content areas. After investigations, a different behaviour appears on even tracks and odd tracks, particularly for the beginning of the Envisat serie.
The degradation seems to be more important for odd tracks (night), probably linked to the characteristics of orbit (heliosynchroneous).

This new filtered correction will be used for Duacs Delayed Time reprocessing 2013. The feasibility of adding this correction in GDR will be assessed by ESL team.

.

A new approach for dual-frequency ionospheric correction filtering

M. Guibbaud, A. Ollivier, M. Ablain

Overview

Dual-frequency ionospheric correction is very noisy and needs to be filtered before correcting for SLA ➔ Users are advised to filter frequencies lower than 240km.

But in the products, this filter is not provided.

Current method :

Done during CalVal process AFTER editing step (= selection of data on different criteria, flag, thresholds and statistics on SLA terms, …)

➔ Introduce a dependancy between ionospheric correction and SSH which has no reason to be

➔ No filtered ionospheric correction for SLA rejected data, whatever the reason of rejection

New filtering method:

Possibly done in the product generation chains (for implementation, see ESL team)

➔ Reducing the dependancy between ionospheric correction an data selection based on SLA

➔ Keeping filtered values wherever the dual-frequency correction is defined

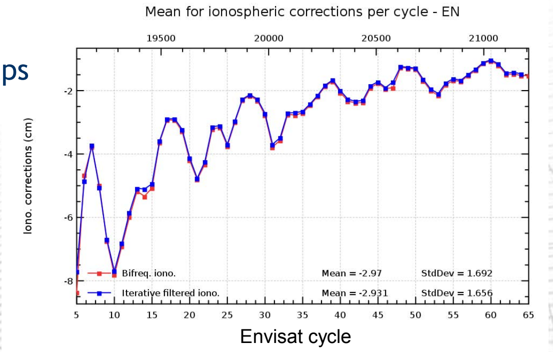
The new filtering method

1st STEP : Very light selection : Selection only on ice, range standard deviation and data number.

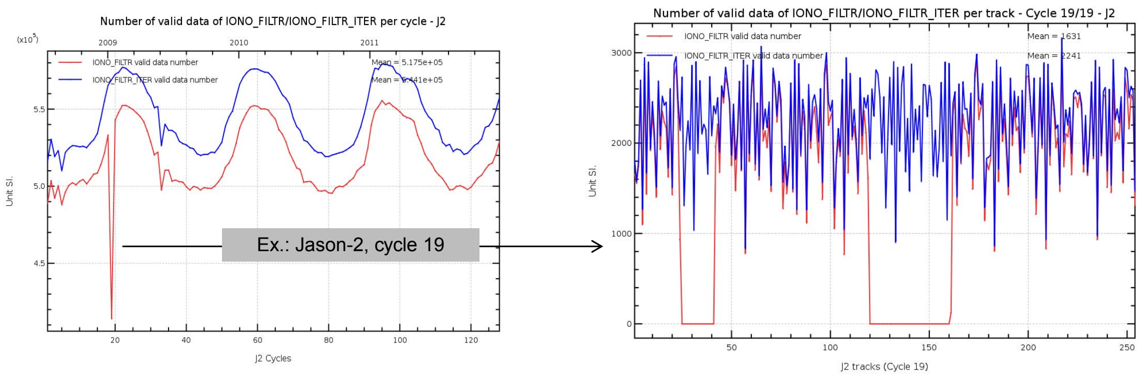
2nd STEP : Iterative filtering process: between each iteration, selection of valid data is based on difference between filtered data and not filtered data.

Use of a Median filter,
then a Lanczos filter

3rd STEP : Interpolation by spline: to fill the gaps



1- valid data number increase



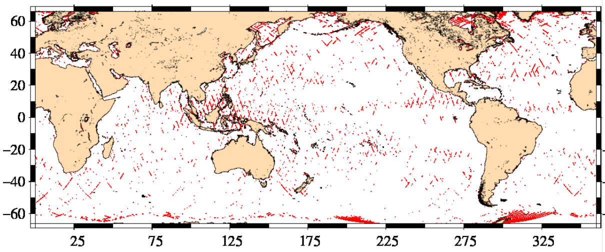
➔ Cycle 19: No MWR correction for tracks 24 to 42, and 119 to 161 => validation flag is « false » => no current ionospheric correction for this period, but existing iterative iono. correction

Recovery of iono for over edited SLA

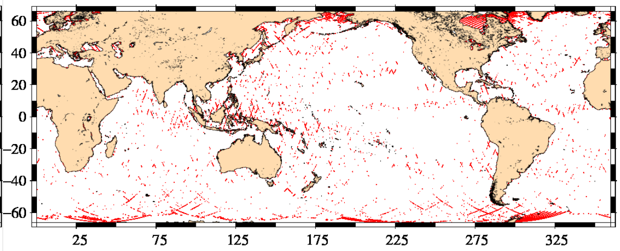
Statistics/Mission	Jason-1 (c 1 to c368)	Jason-2 (c 1 to 128)	Envisat (c 1 to 64)
% of data gained/cycle	+ 4.7%	+5.1%	+6.2%

1- valid data number increase: geographical coverage

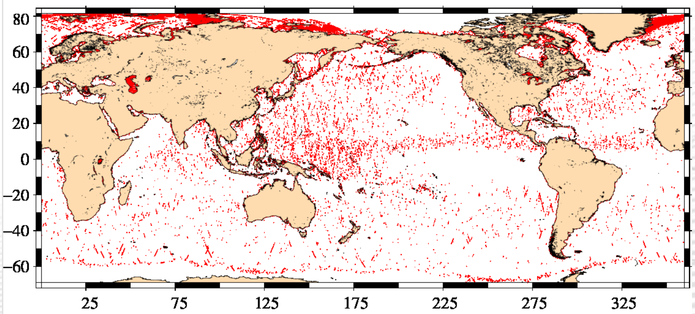
Jason1 – Iterative iono correction
Data gained, compared to current filtering method – c200



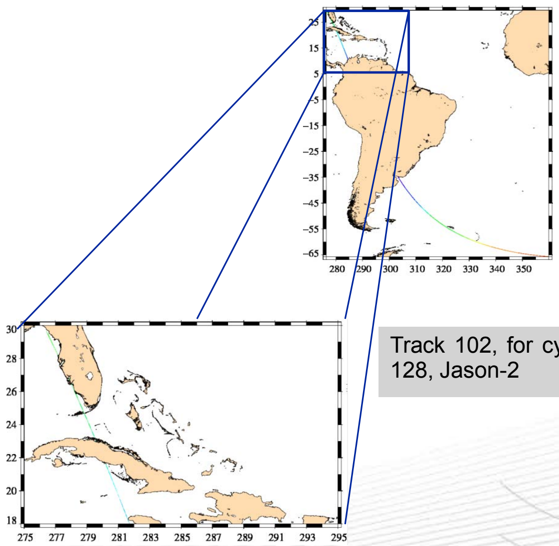
Jason2 – Iterative iono correction
Data gained, compared to current filtering method – c70



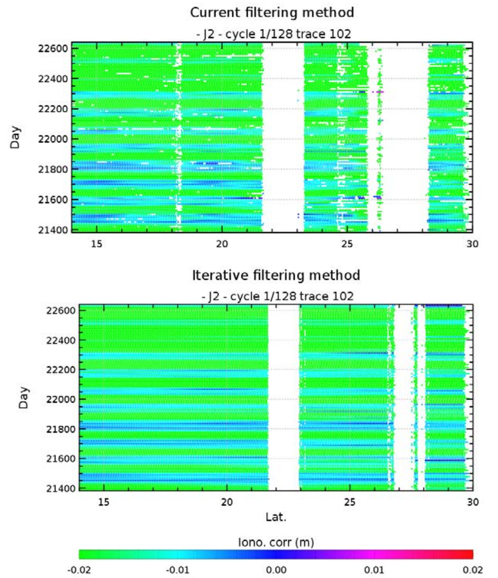
Envisat – Valid iterative iono. correction
Data gained, compared to current filtering method –c50



1- valid data number increase

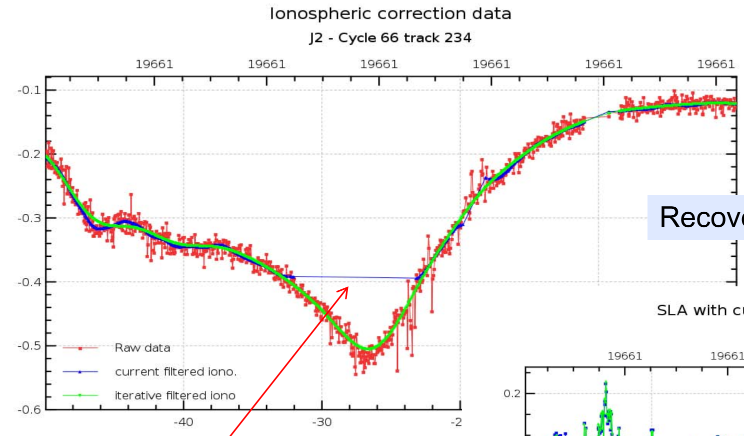


Track 102, for cycle 1 to 128, Jason-2

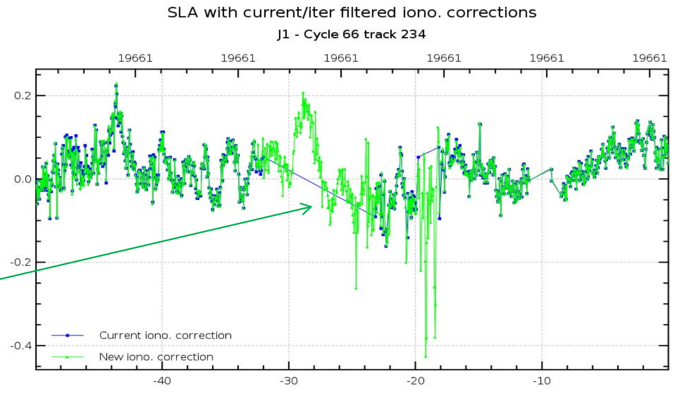


Better coverage in coastal areas

1- valid data number increase

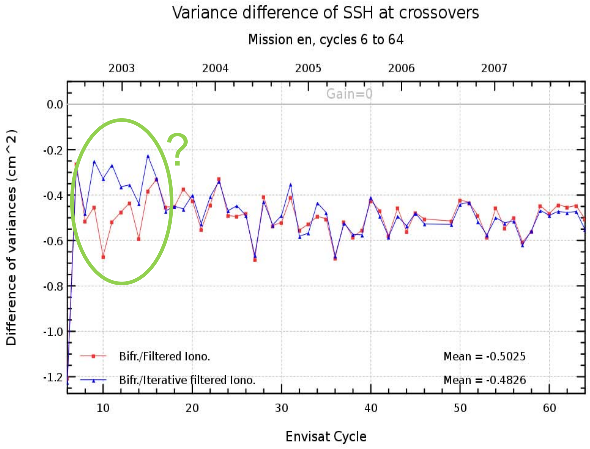


Recovery of SLA for over edited iono

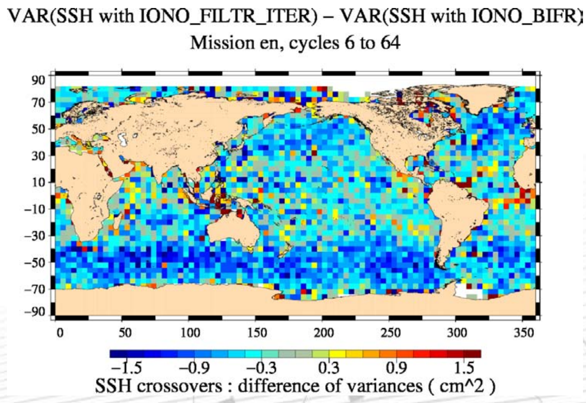


Current filtered iono. correction is not defined => *SLA is not defined*
BUT
With iter. filtering method, iono. correction is defined => SLA exists and is valid

2- Performances improvement



Case of Envisat



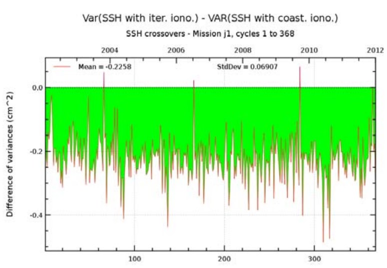
- Gain of SSH variance at crossovers for the filtered methods (0.5cm² by cycle)
- Global geographical improvement with filtered ionospheric correction.

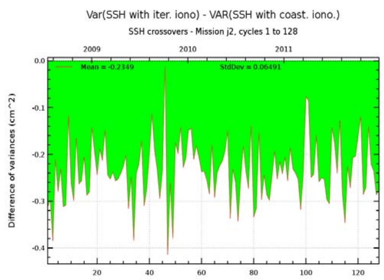
- Why the improvement is more pronounced for current filtering method between cycle 8 & 15 (04/2003)?

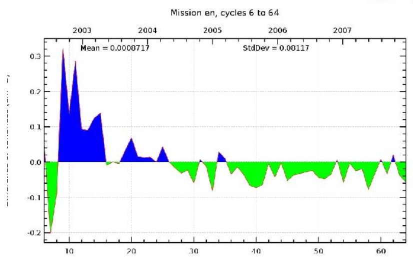
2- Performances improvement

Statistics on SSH at crossovers for Jason1/Jason2/Envisat
Current filtering method Versus *Iterative Filtering method*

Statistics/Mission	Jason-1 (c 1 to c368)	Jason-2 (c 1 to 128)	Envisat (c 1 to 64)
SSH variance difference at crossovers	-0.22 cm²	-0.23cm²	0cm²





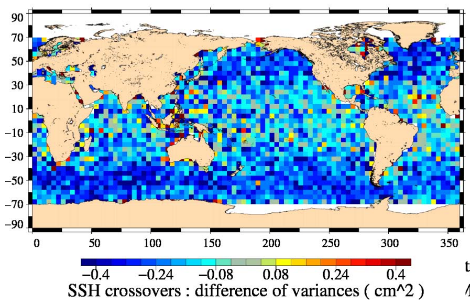


For Envisat:
▪Very light degradation (0.2cm²) for high solar activity period ➔ why?

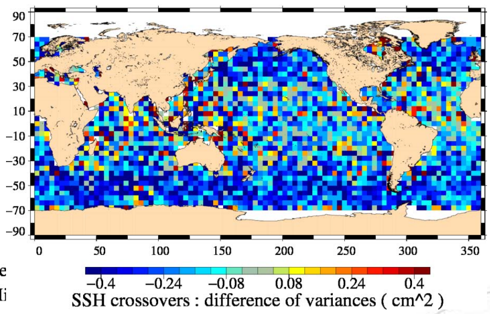
2- Performances improvement

Geographical impact on SSH at crossovers – Jason-1/Jason-2/Envisat

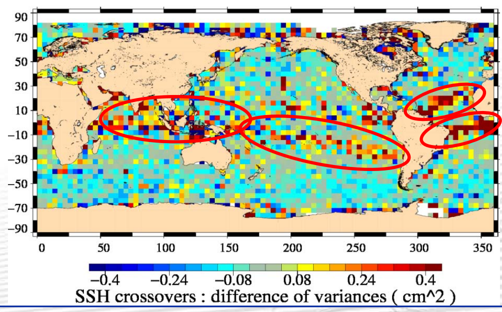
Var(SSH with iter. iono.) – Var(SSH with current iono.)
Mission J1, cycle 1 to 368



Var(SSH with iter. iono) – Var(SSH with current iono.)
Mission j2, cycles 1 to 128



J1/J2: Decrease of variance of SSH at crossovers

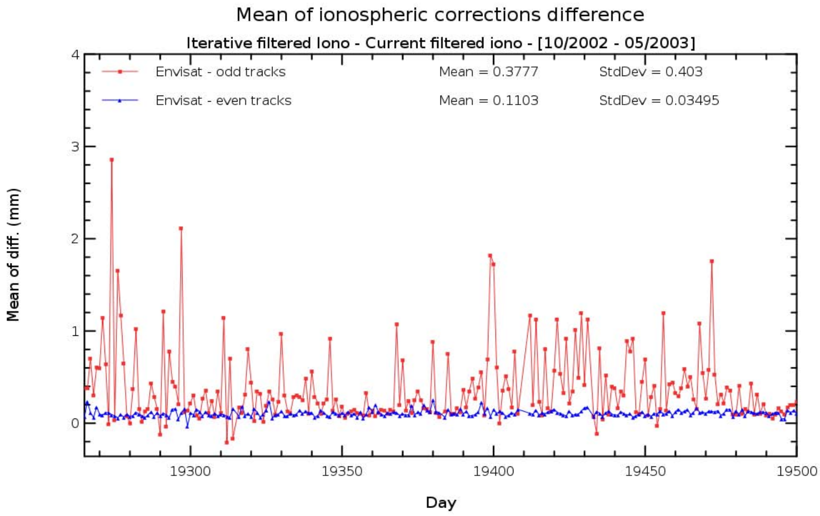


Envisat: degradation in high solar activity areas

3- Envisat: particular investigations

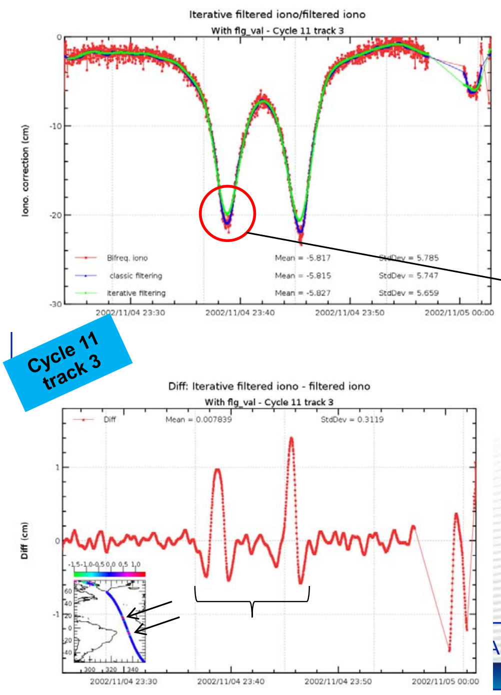
Envisat = heliosynchroneous mission: different behavior on even/odd tracks

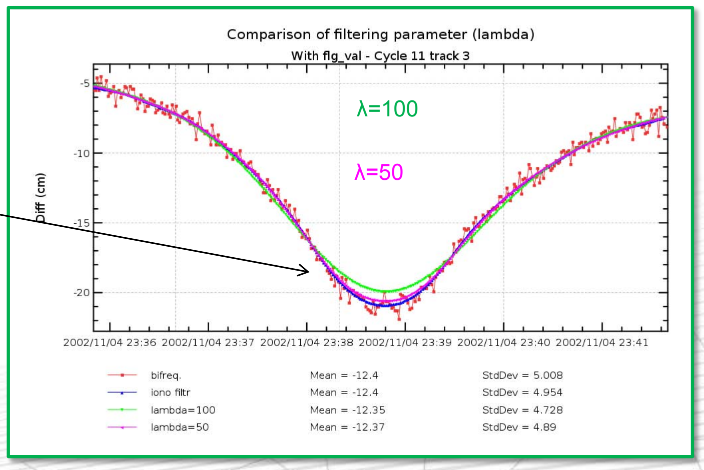
Behavior different from Jason-1: specific study needed.



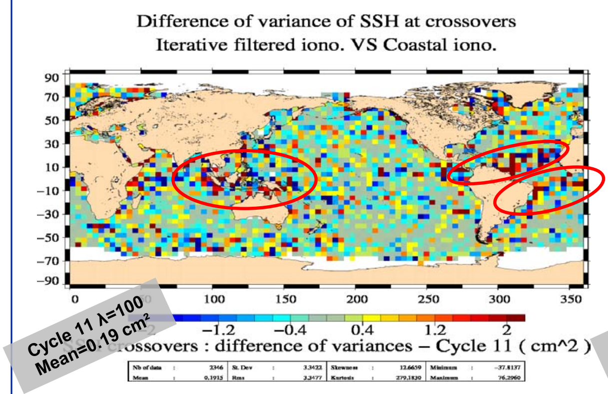
Analysis of observed degradation on variance at crossovers before cycle 25 for Envisat

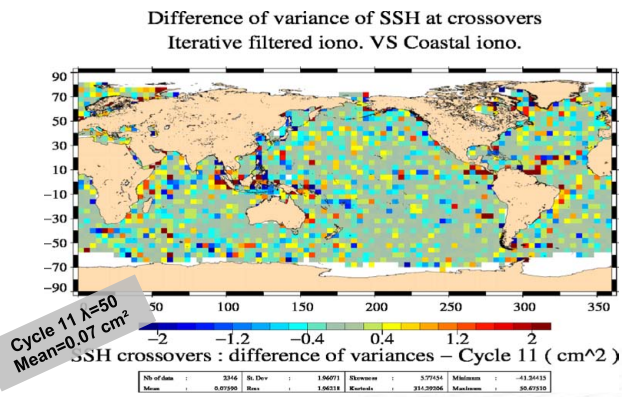
Analysis of track 3 of cycle 11 (degraded variance at crossovers)

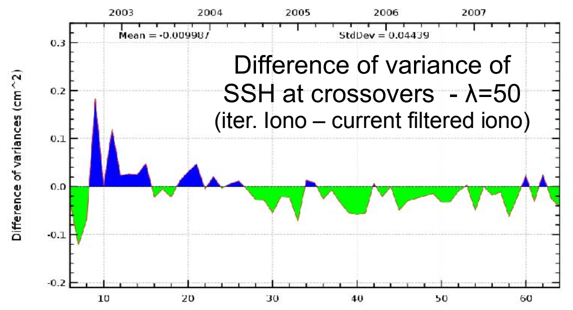




Envisat: example on cycle 11







For λ=50, the global gain on the whole period is very slightly positive.

The degradation is reduced for cycles in high solar activity period without degrading the slight gain observed for the rest of the period.

Conclusion and prospects

- Gain of ionospheric correction valid data:

➔ Increase of valid data number for filtered ionospheric correction with the iterative method (wherever the dual-frequency ionospheric correction is defined, typically if MWR is missing)
➔ Increase of SLA potentially valid data number

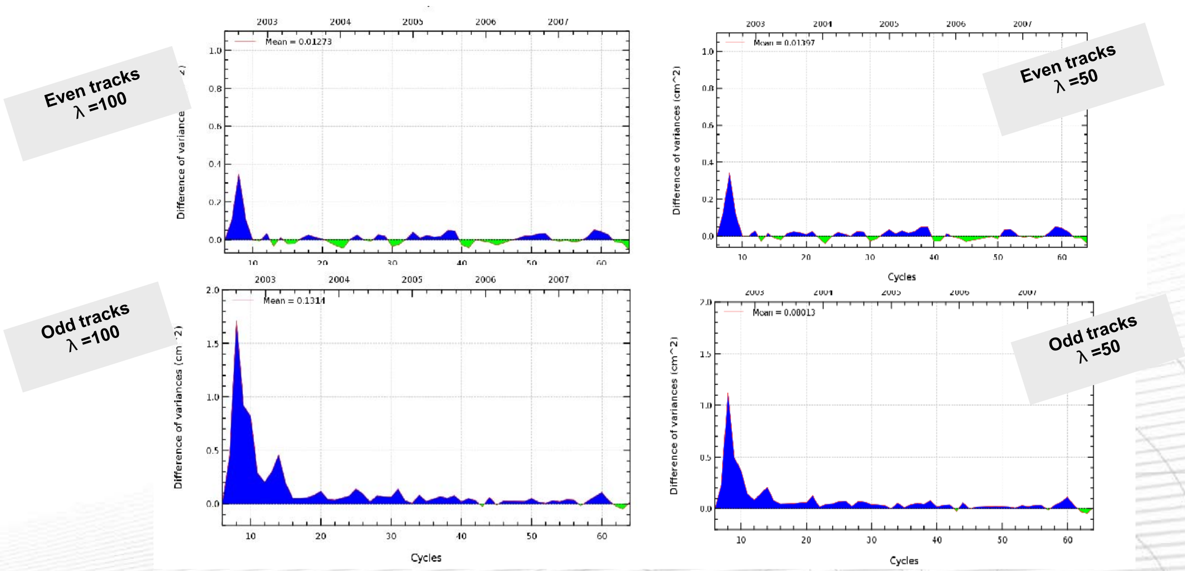
- Performances of the system increased:

➔ Significant gain in SSH consistency at crossovers compared to :
  - bifrequency ionospheric correction: improved for the 3 missions
  - current filtered ionospheric correction: improved for Jason-1 and 2, similar for Envisat (heliosynchroneous and lower altitude).

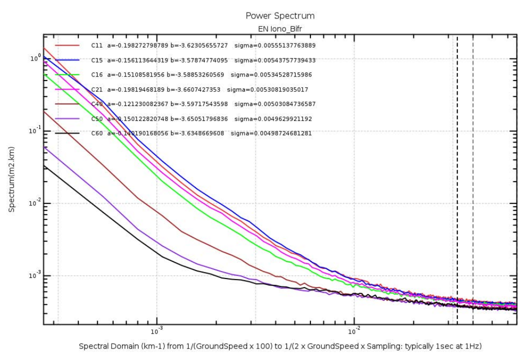
Will be used for Duacs Delayed Time reprocessing 2013.
Feasibility of introduction in GDR to assess by ESL team.

Appendix 1: Envisat: Asc./Dsc. tracks analysis

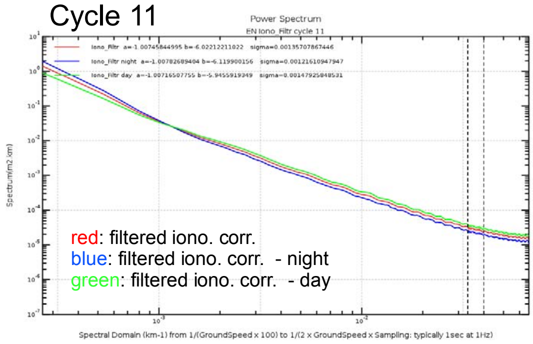
Difference of variance of along track SLA



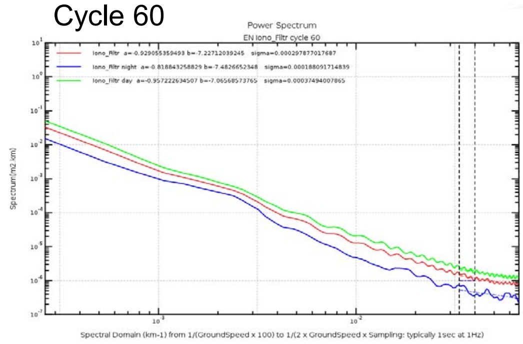
Appendix 2: Power spectrum for ionospheric corrections



Cycle 11



Cycle 60



8.6. Impact of Jason-2 reprocessing on intercalibration with Envisat

This year the mission Jason-2 was reprocessed for cycle 1 to 145 (July 2008 to June 2012). The reprocessing of GDR data has an impact on the current comparisons with other missions, notably on Envisat. This impact is quantifiable using the different results produced by intercalibration between the two missions. These new comparisons can allow to show new finer results on Envisat, notably on jumps visible on MSL after computation with V2.1+ version.

8.6.1. What is new on Jason-2?

The Jason-2 reprocessed data contains new evolutions, listed below:

- The main improvement in Jason-2 reprocessed version is its new orbit. The use of GDR-D standard very much improves the coherence of ascending/descending SSH differences. It also improves the coherence between Jason-2 and Envisat as there are no longer east/west biases, as seen in part .
- The pseudo time-tag bias (-0.29ms for Jason-2 GdrT) has been corrected and is now close to zero. Consequently, the small north/south hemispheric differences on Jason-2 SSH crossovers differences are reduced.
- Radiometer parameters have been enhanced in coastal regions, and an anomaly in 34GHz channel has been corrected. New AMR calibration coefficients are also used.
- The expected modifications with the update of the altimeter characterization file, corrected pole tide solution, altimeter wind speed, global tide model are observed.
- GdrD sea state bias is calculated with a different approach for low sea states. Main difference are observed in these areas (as the editing method has changed) and seems not to be better than the previous one. Note that an updated version of SSB model (based on Gdr-d data) was presented at OSTST2012

All the information conerning Jason-2 reprocessing are described in the Jason-2 Reprocessing Report ([88]).

8.6.2. Intercalibration with Envisat

For this comparison, V2.1+ dataset was used to compare to Jason-2, using the last updates:
- POE orbit standard: GDR-D;
- GOT 4.8 ocean tide;
- Mean Sea Surface CNES_CLS_2011
- Use of PTR computed by F-Pac team, similar to the one available from isardSAT computation at the following address: ftp://diss-nas-fp.eo.esa.int under the directory : altimetry_dataset_v2.1 (see)
The other corrections used are in V2.1 standard.

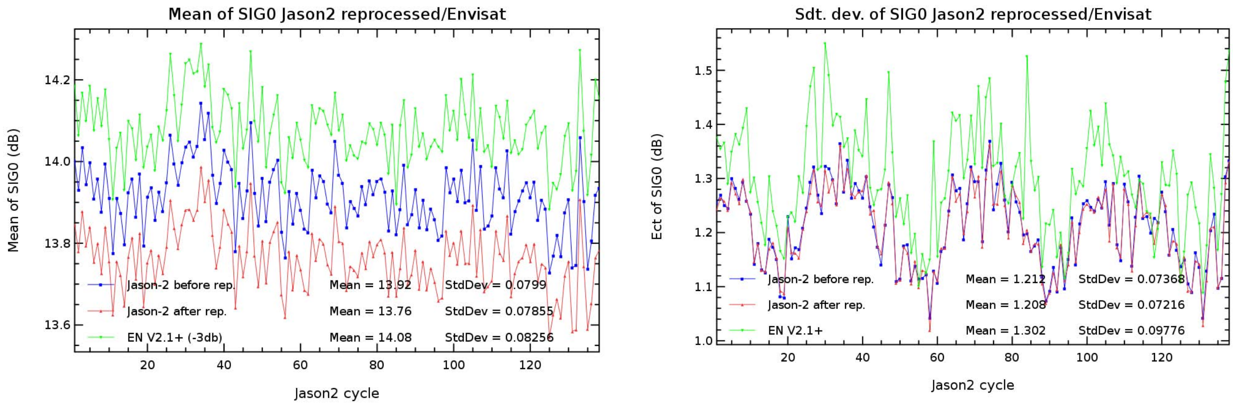


Figure 66: *Mean and standard deviation of Jason-2 reprocessed dataset/Envisat V2.1+ dataset Backscatter coefficient*

Figure 66 presents backscatter coefficient long term monitoring for Jason-2 reprocessed and Envisat V2.1+ datasets.
The mean of backscatter coefficient is reduced with reprocessed data from 0.16dB. the standard deviation before and after reprocessing are similar, lower than obtained for Envisat.

Figure 67 presents long term monitoring of significant wave height for Jason-2 reprocessed and Envisat V2.1+ datasets.

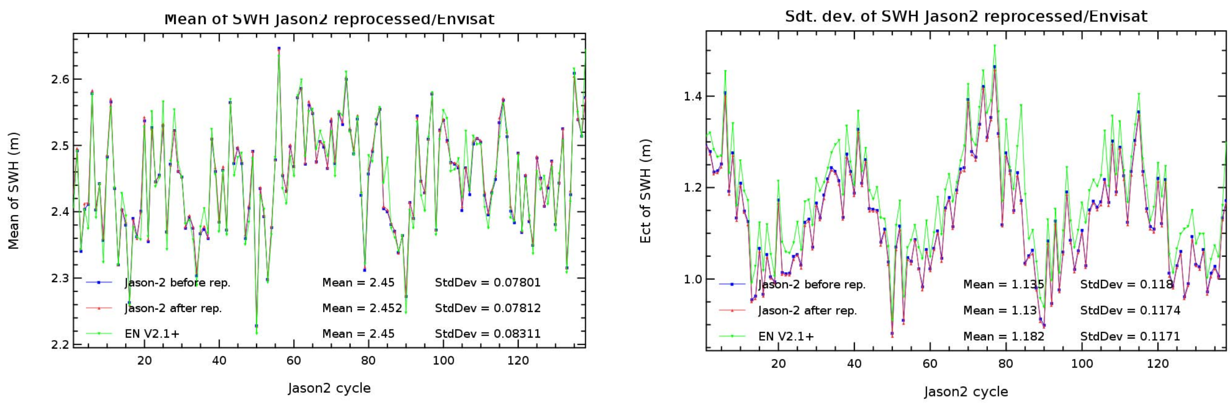


Figure 67: *Mean and standard deviation of Jason-2 reprocessed dataset/Envisat V2.1+ dataset Significant Wave height*

Figure 68 presents the difference between wet tropospheric correction and ECMWF model for the two missions.

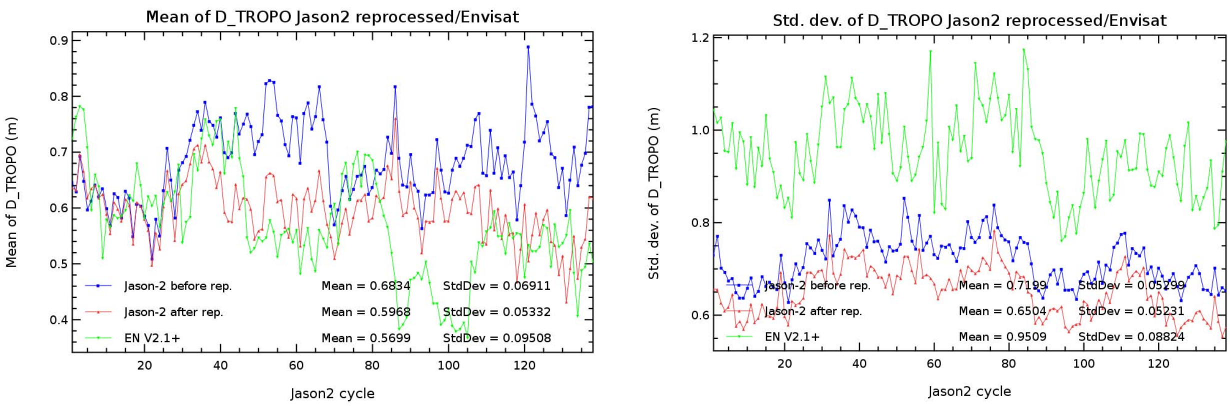


Figure 68: *Monitoring of mean **(Left)** and standard deviation **(Right)** of difference of wet tropo. correction for Jason-2 and Envisat.*

On figure 69 is plotted the standard deviation of SSH at crossovers for Jason-2 and Envisat. The standard deviation is more important for Envisat and reaches 4.5cm. In term of residual errors on MSL, comparisons between Envisat and reprocessed Jason-2 dataset are presented in 8.1.2..

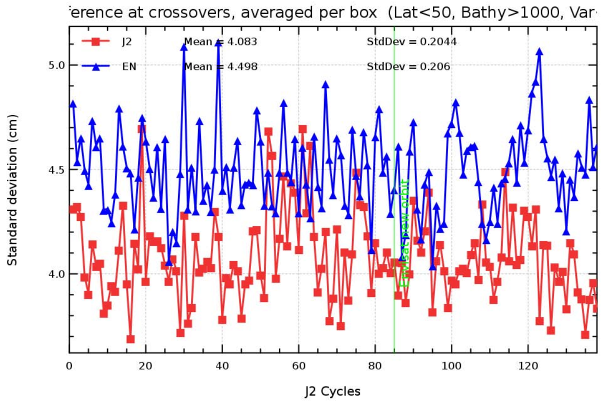


Figure 69: *Std. deviation of SSH at crossovers for reprocessed Jason-2 and Envisat (selection on bathymetry, shallow water and latitudes)*

Figure 70 shows monitoring of multi-mission crossovers (between Jason-2 and Envisat) using GdrT/V1 Envisat dataset for Jason-2/Envisat (red curve) or GdrD standard for Jason-2 and V2.1+ Envisat dataset for the blue curve.
In order to allow comparison, the green curve represents cyclic mean of difference at crossovers computed with GdrC updated Jason-1 data and GdrD Jason-2 data.
Note that there were geographical patterns on difference of SSH at J2/EN crossovers that are greatly reduced using the most recent standards. This improvement is mainly due to the POE-D orbit solutions.

The effet of PTR is observed on the mean of SSH difference at crossovers for Envisat V2.1+ dataset. The two missions are now more homogeneous considering the Jason-2 reprocessing.
Concerning the standard deviation at crossovers (Figure 70,right), the difference between the two missions is reduced from 3.6mm. The increase observed on this difference with old standards is now removed.

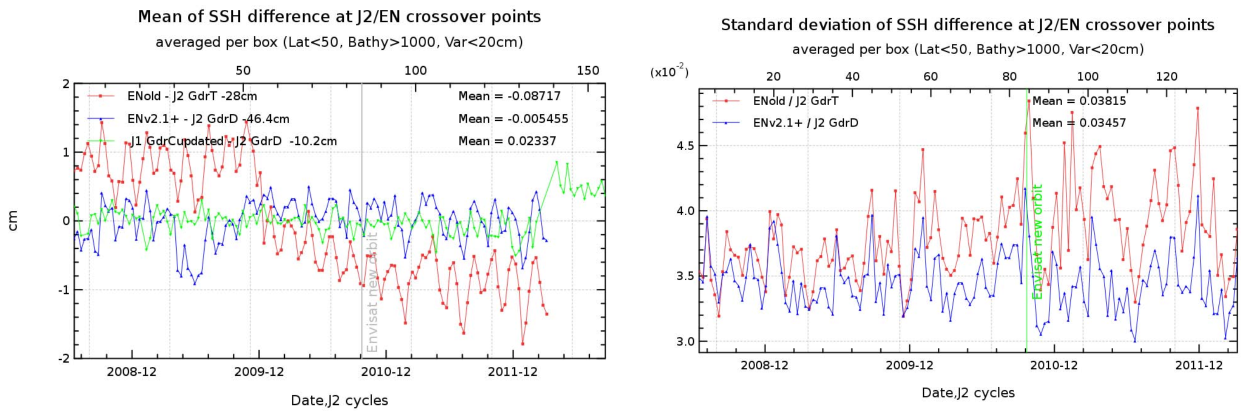


Figure 70: *Monitoring of mean **(left)** and standard deviation **(right)** of JA2-EN SSH crossovers.*

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All the results concerning the impact of Jason-2 reprocessing on ocean data are described in the Jason-2 Reprocessing Report ([88]).

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8.7. Investigation on oustanding tracks in Pacific

Following the presentation of ECMWF during QWG18, investigations were carried out to determine the reason of oustanding tracks visible on mean per year of ERA wind maps. After investigations, these outliers were observed on range parameters: waveform mispointing, basckscatter coefficient,waves and also wind. During CalVal validation process, these tracks were rejected by threshold or by statistics on tracks. This phenomenon corresponds to tracks during which orbit inclination maneuvers happened. In fact, before cycle 50, all the orbit inclination maneuvers take place in the Pacific area. After cycle 50, track 9 is particularly impacted (approximately one cycle on two). Finally, without rejecting these tracks, along tracks and at crossovers statistics are necessarily disturbed.

Analysis of difference Altimeter – ERA INTERIM wind: outstanding tracks in Pacific

M. Guibbaud, A. Ollivier – CLS

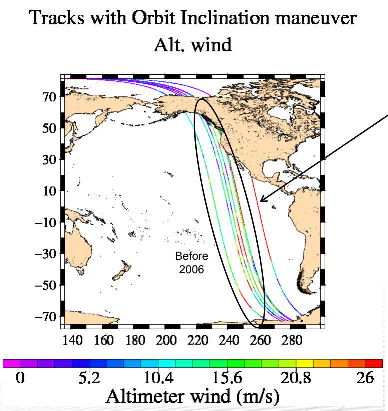
Problem

- QWG#18 - Abdallah Salleh:

‘observation of a bias between altimeter wind and ERA model wind mean for tracks 9 and 523 (Pacific) until 1m/s’

- Investigations:
  - o Statistics by cycle/by year for incriminated tracks? geographical outstanding tracks?
  - o Behaviour before/after editing?

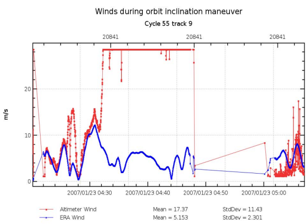
Investigations



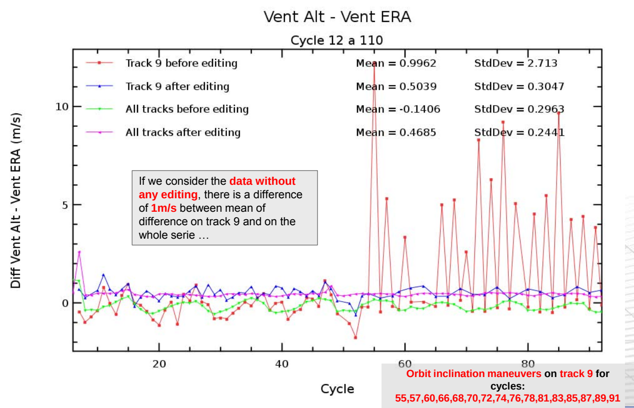
- During Envisat life, all the orbit inclination maneuvers took place in Pacific area.

- After 2006, all the orbit inclination maneuvers occured only on track 9

➔ If no editing is performed on these tracks, impacts are observed on statistics



Investigations – zoom on track 9



9. Conclusion

This report gathers the statistical evaluation of Envisat altimetric measurements on the whole dataset; with the loss of Envisat on the 8th of April, 2012, 10 years of data are now available. This report presents results based on GDR in V2.1 version and the last updates named V2.1+ version.

The major event of this year is the loss of Envisat on the 8th of April. In spite of efforts to resume contact with the satellite, the end of the mission's operations was declared by European Space Agency on the 9th of May 2012.
Then 10 years of data are available and provided to users. These data are homogeneous and allows to improve the computation of Envisat MSL.

The major points to underline are:

- A very good availability of Envisat data on the last 2.5 years 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 in V2.1 version, notably:

  * A solution of PTR correction (Internal Path Delay) was studied and compared to the F-PAC PTR solution. This IsardSAT PTR correction mainly improves performances of SSH at crossovers, which is more visible near coasts. But some points have been highlighted concerning overlaps between cycles and ponctually uncomplete tracks. In terms on MSL, a weak difference is observed (0.05mm/y) for side A, MSL for side B is impacted by a bias.

  * The degradation of quality due to the wet tropospheric correction was studied, and a new correction was proposed to reduce this degradation. The improvement is observed compared to GDR in V2.1 version but the degradation remains compared to the routine GDR (before reprocessing). This remaining degradation is under investigation, which will allow to compute a more accurate radiometer correction. Note that an associated Sea State Bias will be provided.

  * The GDR-D POE standard is now used in SSH computation. The variance of SSH at crossovers is decreased and systematic geographical biases are largely reduced for Envisat but also for Jason-1 or Jason-2. The impact on Mean Sea Level trend is significant.

With these evolutions, the variance of SSH at crossovers is globally decreased. In spite of the degradation due to the wet tropospheric correction, the SSH performance is improved for Envisat. Cross comparisons was developped with Jason-1 and Jason-2, and also with Cryosat-2, which represents a new potential reference at high latitudes after the loss of Envisat. The behaviour of Cryosat-2 in terms of cross comparison allows to be confident in its use as a new reference solution for multimissions studies.

- Extensive studies of comparison to in situ data (Tide gages and TS profile) were performed this year again, helping to characterize the differences between Jason-1 and Envisat missions. They also enabled to show the great improvement on global MSL trend (see [108]).

- 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, which is very encouraging. In 2012, Envisat time series was updated notably with the PTR instrumental correction and the GDR-D POE standard, which insures a better consistency between other missions and in situ dataset (this drove to 2 official publications in Marine Geodesy: Ollivier et al. 2012 and Valladeau et al. 2012). Other studies were also performed notably to estimate the impact of MSL of a coastal selection on altimeter dataset, to compare to in situ dataset, which highlights the sensitivity of the method and the need to continue to investigate on this point. These comparisons indicates that the Envisat MSL drift is greater than the one of Jason-1 over the period 2004/2012.
In terms of regional MSL, the effect of V2.1+ dataset is dominated by the GDR-D POE standard use. The geographical patterns on trend maps observed previously are now reduced.
An effort was made to analyse MSL for the beginning of the period (before 2004). During this period, a great decreasing trend is observed. Some altimetric parameters have been shown as suspicious before 2004 (standard deviation of GIM/Bifrequency ionospheric correction, S-Band parameters, Ku-Band waveforms). The question of impact on MSL is still unresolved and should be carried on.
Finally, the comparison with Jason-1 MSL trend after 2004 allowed to identify some jumps, which were suspected not to have physical reason. Similarities appeared with IFF slope form IsardSAT. A potential correlation could be further investigated on instrument side.

10. Error budget of Envisat Altimetry Mission - October 2012 update - V2.1 reprocessing version

1. Introduction

This document is a synthesis of the error budget estimated for the whole mission for Envisat altimeter (RA-2) level 2 OFL products. This takes into account the homogeneous reprocessed data set, achieved in January 2012. Estimating the error budget in altimetry is a hard work principally because of the lack of absolute reference. It can however be estimated by comparing corrections from different sources of estimation (typically measurements/models or measurements/in situ data,...).

The global Envisat altimeter error budget (for level 2 OFL products) changed during the mission lifetime considering corrections improvements (this effect is much reduced thanks to the reprocessing exercise), on aging of devices or geophysical interannual effects. The table hereafter sums up the Envisat altimeter error budget for year 2012 compared to the specifications allowed budget. Each figure of the table is associated to a small paragraph including:

- comments on the method used to quantify them
- comments on the stability of the given value.
- reference documents.

Particular events:

- In 2012, Envisat was entirely on its drifting phase. The 35 day cycle reduced to a 30day pseudo cycle with a small drift estimated to +/-1.7km per cycle maximum at respectively 50deg Latitude N/S, whereas it does not drift at 38deg N and S. Note that the drift was observed to be higher than the one theoretically expected (+/-600m per cycle maximum was expected). 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 (see [5]).
- The Envisat whole mission reprocessing ended on January 2012. The ground processing chains had been upgraded to support reprocessing, this new standard is called V2.1. The impact of this new version is detailed in [9]. For the current processing, this standard was adopted in october 2010. Therefore, the impact was already estimated in the 2011 Error Budget document. For the first time this year, the Error budget estimation presented hereafter is computed with this reprocessing version on the whole mission.
- On April, 8th 2012, the communication with Envisat mission was definitively lost. Its data quality remained stable and very good until the end. The end of operation was announced in May 2012; this Error Bugdet document has been updated after the end of the mission, thanks to delayed time future reprocessing and improvement of the global altimetric system.

2. Term by term altimetric error budget

2.1. a/ Altimeter noise

A slight seasonal signal is visible on the mean RMS of Ku 20Hz. Higher values correspond to higher waves occurring during the austral winter. The mean value is about 9.1 cm. This value represents a rough estimation of the 20 Hz altimeter noise (Zanife et al. 2003 [16], Vincent et al. 2003a [15]). Assuming that the 20Hz measurements have uncorrelated noise, it corresponds to a noise of about 2 cm at 1Hz.

The High frequency content of range parameter (noise level) reaches its maximum during the last cycle, but remains stable in 2012.

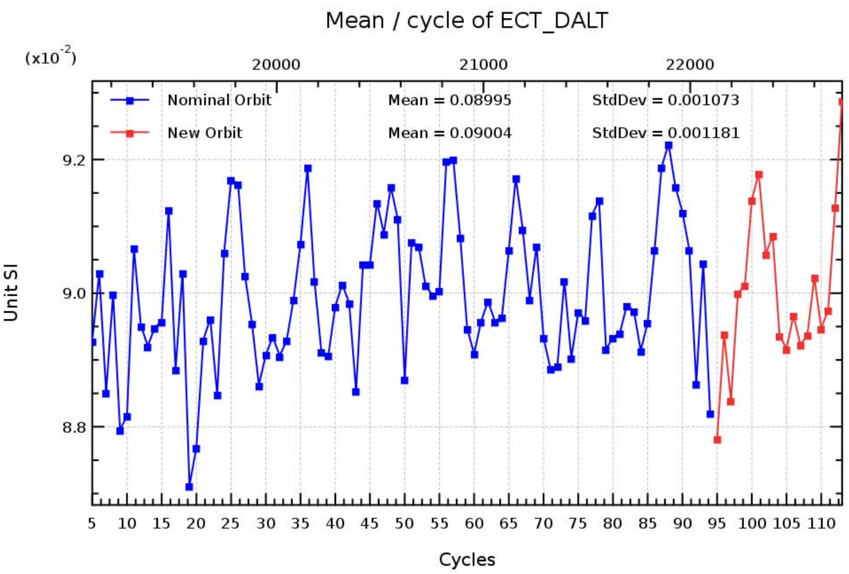


Figure 1: *Mean of range sdt. deviation, by cycle*

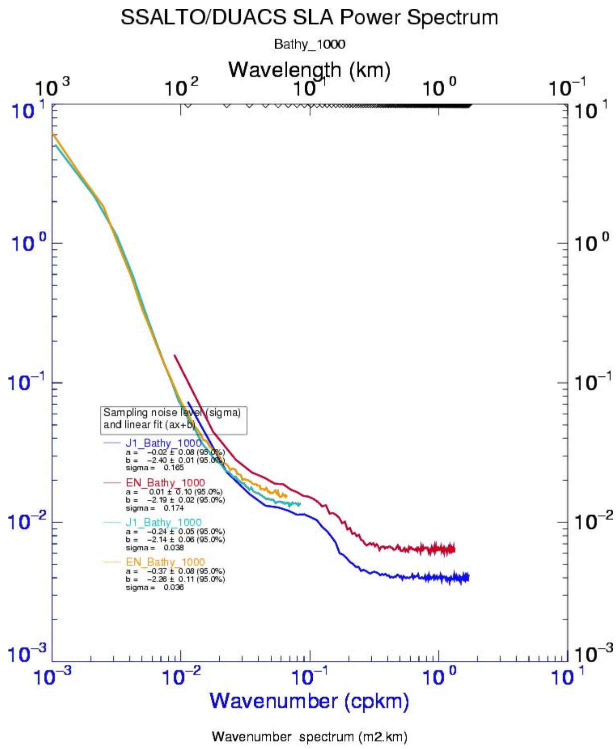


Figure 2: *A COMMENTER*

2.2. b/ Sea State Bias

Estimating the absolute sea state bias correction error is relatively difficult (see [12]). Since most SSB estimators are computed as a function of SWH and altimeter Wind Speed, the first approach is to use a Gaussian assumption, and a direct dependence between the random noises on the input parameters. Our current knowledge on SWH and SIG0 is synthesized in chapter 5.3 and 5.4 of [12].

This don't represent an absolute reference but long term monitoring mean and standard deviation of SSB give information on stability of this parameter. Studies concerning the SSB noise was also performed and explained during SLOOP project ([4]). This sea state bias mean is stable around -14cm with an annual cycle linked to the seasonal repartition of high/small waves. The standard deviation of SSB (including ocean variability) is now homogeneous on the whole time series, using the 2007 Labroue Non Parametric Bias. The standard deviation is between 6cm and 7.5cm according to a seasonnal signal and 6.3cm for 2012. A part of this standard deviation is linked to a slight degradation of the average SWH in the reprocessed version (see §3.2).

In 2012, a new SSB has been computed (Tran et al. OSTST 2012), not included in products yet. The differences of computation change correlation between SSB and SWH.

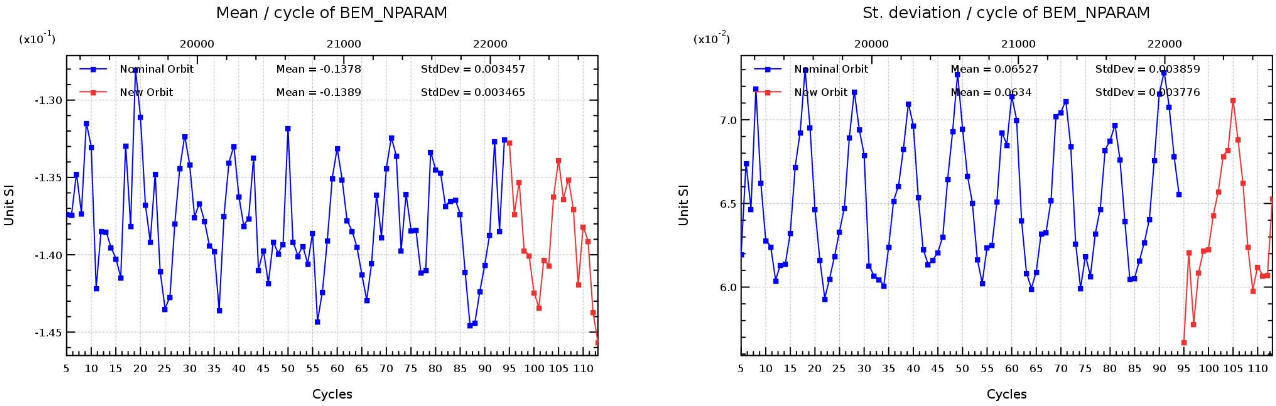


Figure 3: *Mean and Std. Dev of Sea State Bias by cycle*

2.3. c/ Ionospheric correction

Due to the S-Band loss on January 17th 2008, the bifrequency ionospheric correction is no longer available. A comparison to the GIM model ionospheric correction during 2007 and a cross comparison between Envisat and Jason-1/2 and the GIM model during 2010 enables to get an acceptable value. The comparison to the GIM model ionospheric correction during year 2007 gives a standard deviation of 0.7 cm. As described in Envisat Yearly report 2010, a 280km Lanczos Low pass filter enables to reduce this variability to 0.4 cm. Cross comparison of bifrequency ionosphere to the same GIM model ionospheric correction for Jason-1/2 shows that the statistics are rising slowly. This is related to the slight increase of solar activity.
The ionosphere quality is affected by the S-Band loss from January 2008 onwards. In 2012, the quality of the GIM ionosphere correction continues to be slightly degraded whereas it was stable until 2011. In fact, the degradation starts to be observable at crossovers as seen on figure 7.

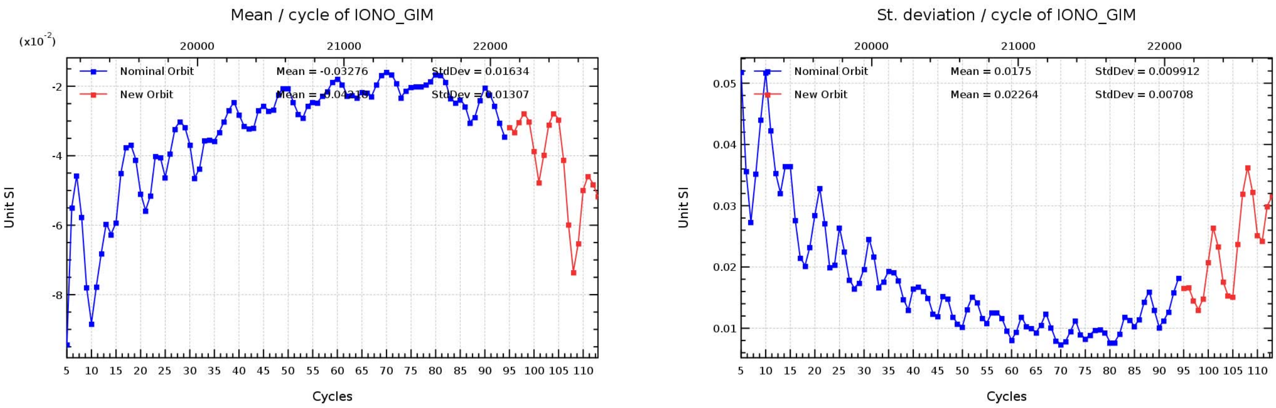


Figure 4: *Mean and Std. Dev of GIM ionospheric correction by cycle*

Since the S-Band loss, Envisat iono correction was efficiently replaced by the JPL GIM model. But the solar activity (reprensented by a higher value of the mean correction) is increasing again since mid 2009 following a 11 year period signal (see 5 left hand plot). The monitoring of the difference iono GIM-Bifrequency correction on Jason-1 and Jason-2 (see 5 right hand plot) enlights that the error on the model is higher when the solar activity increases (around 5mm more than in 2008). The GIM model is known to be less efficient at the end of the Envisat data set as observed on the signature on 6 plot compared to 7.

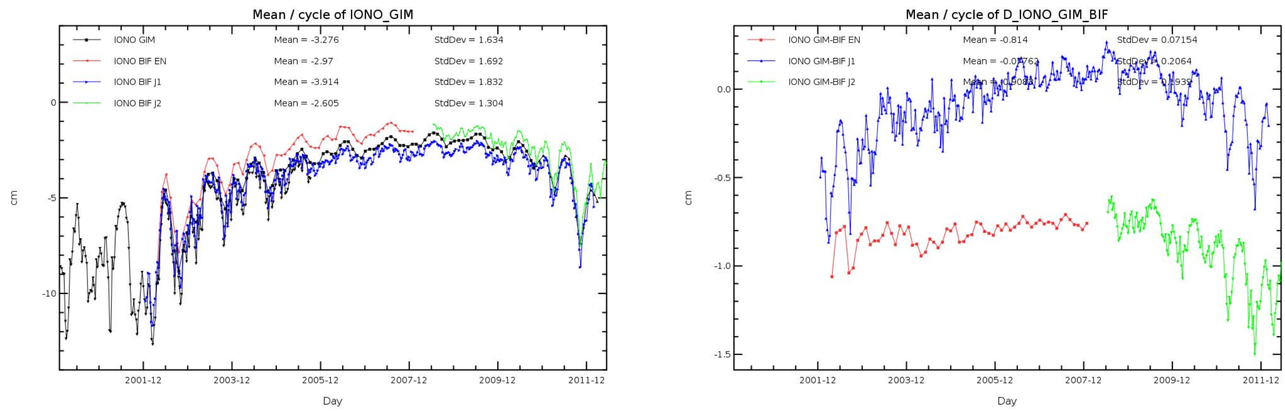


Figure 5: *Ionospheric content over the 11 last years observed by different missions (left). Difference to GIM reference (right).*

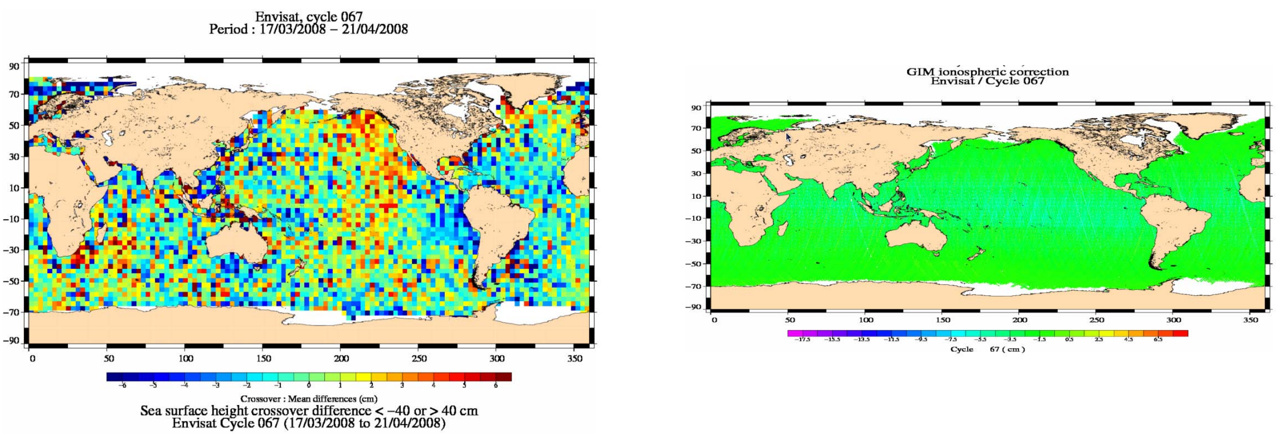


Figure 6: *Cycle 67, March 2008: SSH at crossovers (left). GIM ionospheric correction (right).*

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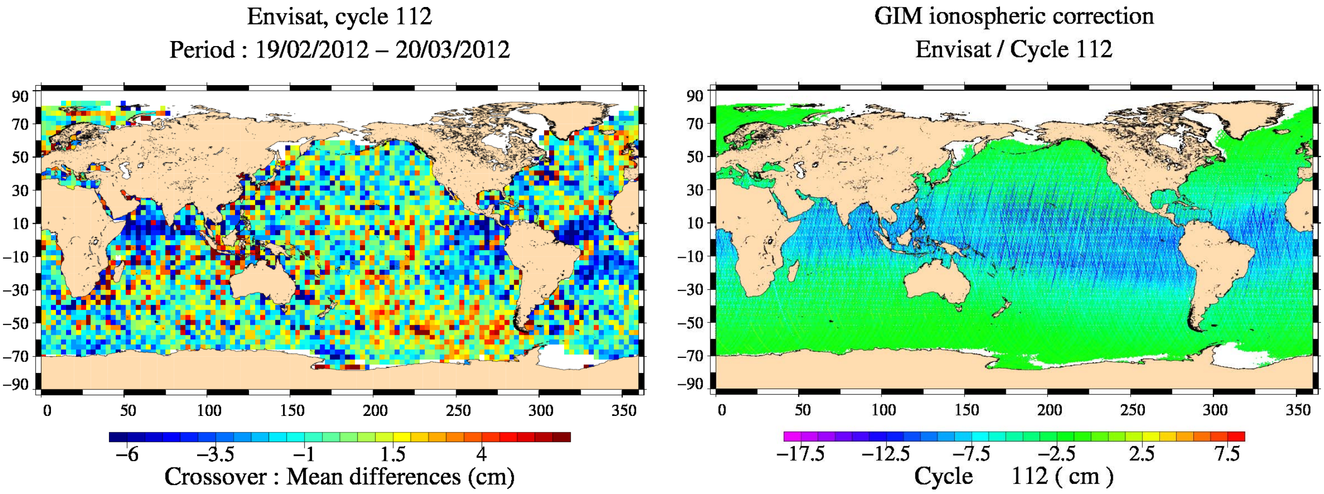


Figure 7: *Cycle 112, mars 2012: SSH at crossovers (left). GIM ionospheric correction (right).*

2.4. d/ Dry troposphere

See Salstein et al. (2008) [10].

2.5. e/ Wet troposphere

The standard deviation of the difference between MWR and ECMWF is variable throughout the mission. This variability can include the effect of the MWR ageing but it also includes ECMWF model changes. For the major part of the mission, it is rather stable around 1.8cm, whith slightly higher values (2cm) before cycle 12 (beginning 2003) and following an upgrade of the ECMWF model version on cycle 77 (end 2007). To prove this, a comparison to ERA Interim reprocessing ECMWF model is performed (see 10): no jumps are noticed. Convertely, a drift is observed on the difference of both corrections (0.5mm/year). Globally, the MWR performences are better than ECMWF (0.6cm^2) as illustrated by the graph 8. This year, studies showed that this could be improved (Ollivier et al., OSTST 2012). But feasability of a final improve of 1.1cm^2 has been shown too. Concerning the average stability, it is responsible for a non negligieble part of the Mean Sea Level uncertainty (Ablain et al. 2010 [1]), around 0.6mm/year on Envisat as explained in ([6]).

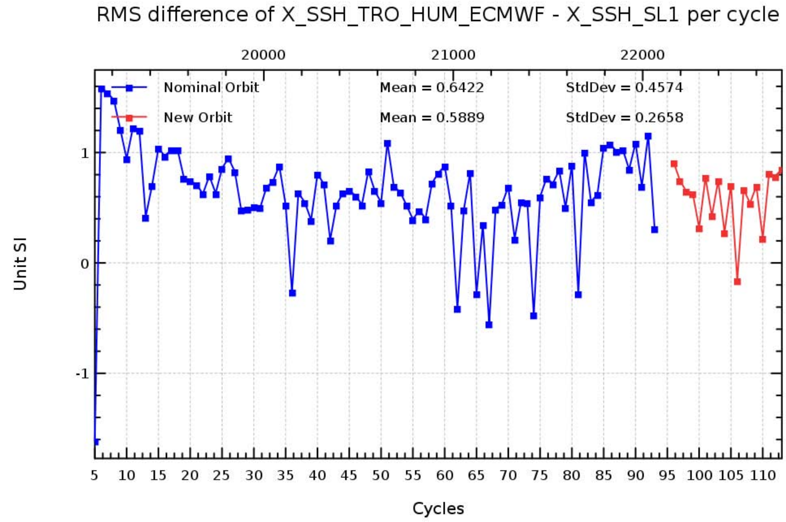


Figure 8: *RMS loss using ECMWF instead of MWR at crossovers, monitored by cycle*

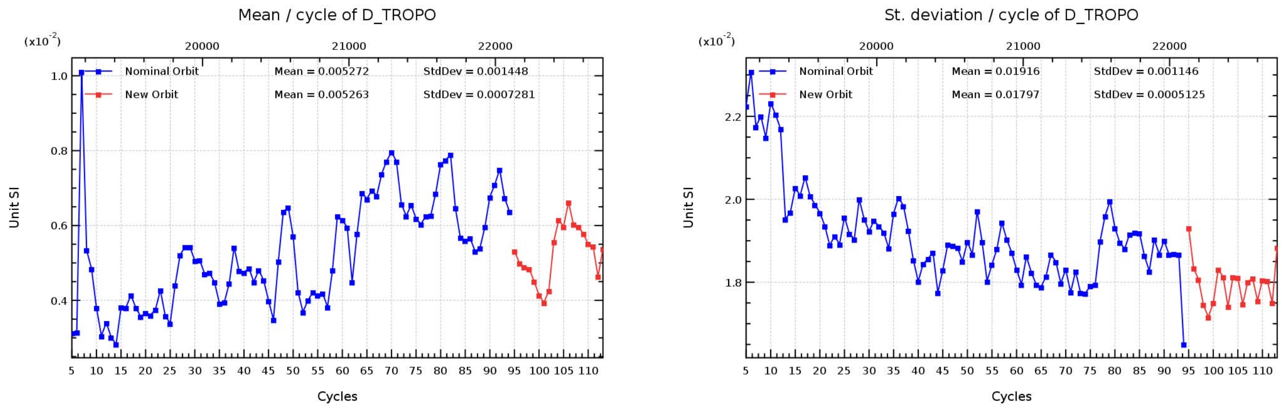


Figure 9: *Mean and Std. Dev of [radiometer-model] correction by cycle*

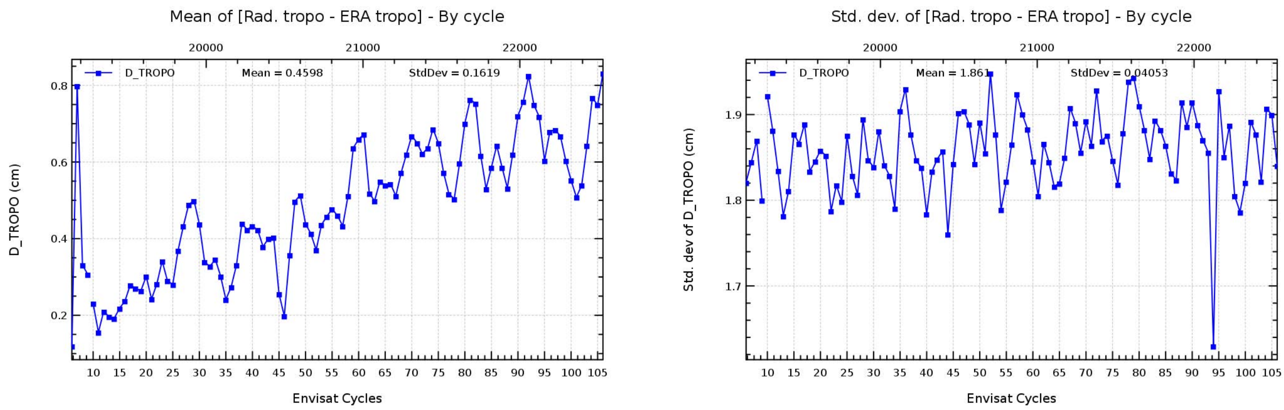


Figure 10: *Mean and Std. Dev of [radiometer-ERA model] correction by cycle*

2.6. f/ Range drift/SSH

Extensive description of the in situ comparison is available in [13]. Note that a study was performed this year concerning the new sources of errors identified in Envisat RA2 system, notably concerning a wrong instrumental correction (PTR) with a 1 to 2mm/year impact on the global trend estimation. Also note that the errors are now monitored with a regional approach detailed in [5], §7.1.
Thanks to the recent updates, the accuracy of Envisat Mean Sea Level trend is now more realistic as detailled in Ollivier et al. 2012 [7]. The stability of the SSH stability can also be assessed by in situ data, as described in Valladeau and Leageais et al, 2012 [14].

2.7. g/ Radial Orbit Error

Absolute orbit quality is hard to determine, a criteria is the rms based on laser data. After the increase of 2010 (from around 1.5 to 1.9cm), the rms slightly decreased at the beginning of 2011 but increased to the end to reach 1.8cm. In 2012, the same phenomenon is observed, a slight decresase, reaching 1.2cm.
This increase could be due to a quality degradation of some stations included in the laser network. Furthermore, an internal quality criteria can also be given, based on consecutive orbits overlap comparison. This rms is reduced to around 0.6 cm for 2010 (1cm in 2009). The rms based on high elevation laser data gives a more reliable metric to assess the orbit quality. Orbit quality is stable despite the change to the drifting phase orbit and the slight increase of the solar activity.

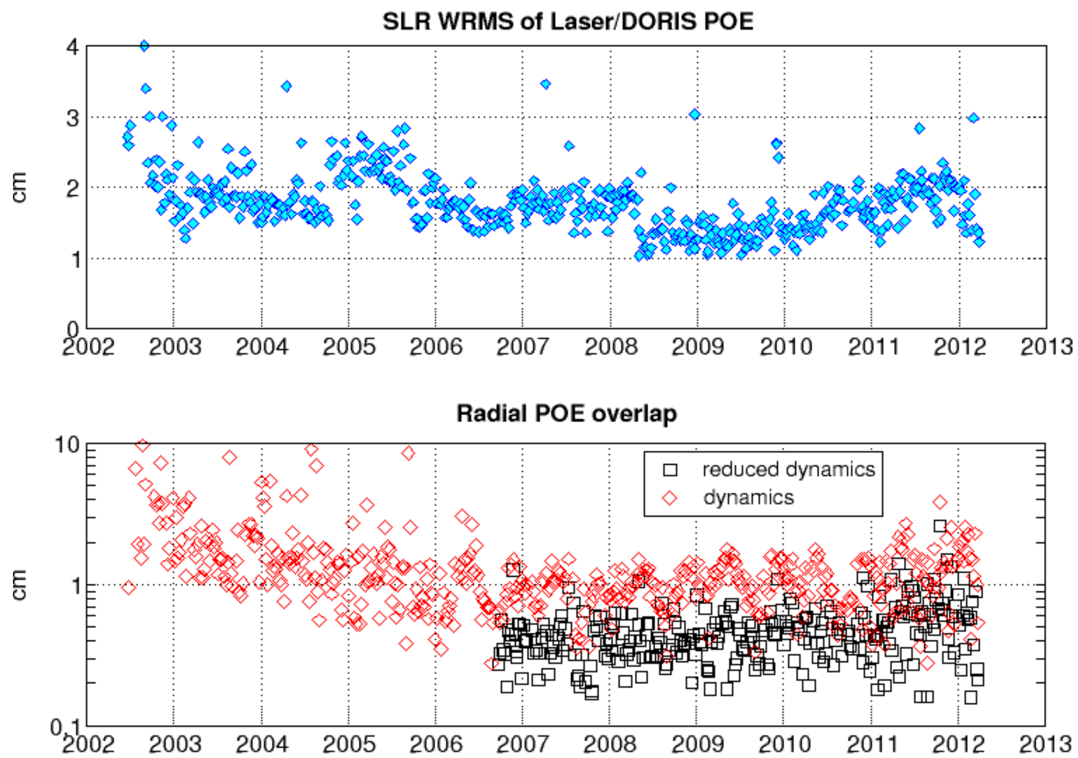


Figure 11: *Intrinsic POD quality criterion for Envisat (courtesy P. Yaya)*

2.8. h/ Significant Wave Height

See with Saleh Abdallah for ECMWF WAM outputs. In V2.1 version, the change of instrumental constant SigmaP has a direct impact on the SWH estimation, due to the following relation: $SWH = 2c\sqrt(\sigma c^2 - \sigma p^2)$
The SWH in V2.1 dataset is globally more complient to buoys except for small waves, and to WAM model too. But both see stronger bias, around -13cm mean SWH bias, and a standard deviation degradation for SWH less than 3m. The noise increases from less than 7cm to 25cm for waves lower than 1m. This is presented in Figure 12. On figure 13 left, the blue curve corresponds to the chosen value of SigmaP, and the change of SWH behavior can be explained theoretically as a consequence of the non linear relation between SWH and SigmaP. Theoretical analysis based on a numerical retracking are planed to be carried on. This was explained in QWG_17 (A.Ollivier talk on SWH issue) and is still under investigations on instrument expert side.

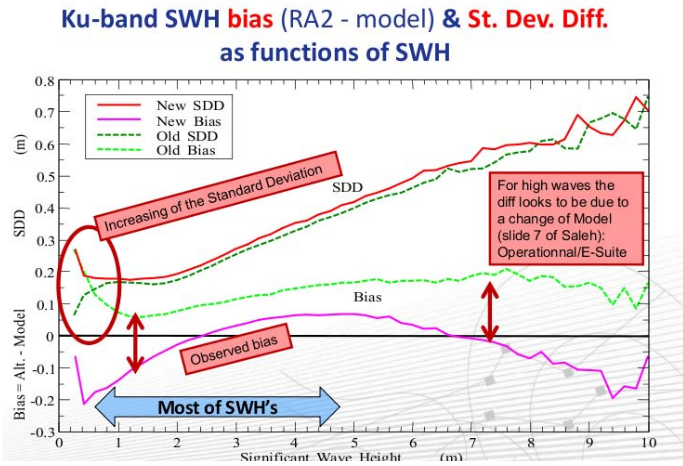
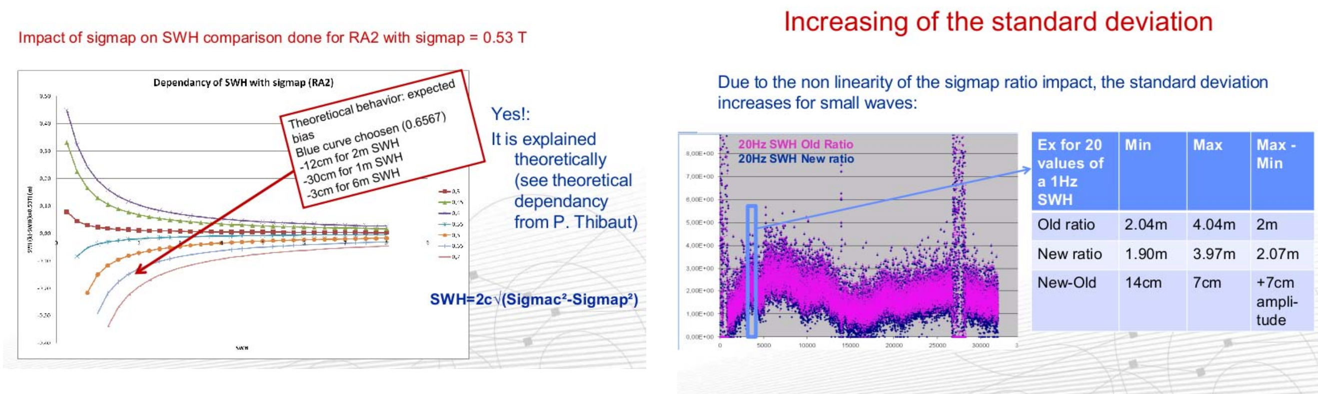


Figure 12: *Ku-band SWH bias and standard deviation difference as functions of SWH*



Ex for 20 values of a 1Hz SWH	Min	Max	Max - Min
Old ratio	2.04m	4.04m	2m
New ratio	1.90m	3.97m	2.07m
New-Old	14cm	7cm	+7cm amplitude

Figure 13: ***Left:*** *Dependancy of SWH with SigmaP* ***Right:****Standard deviation increase for small waves*

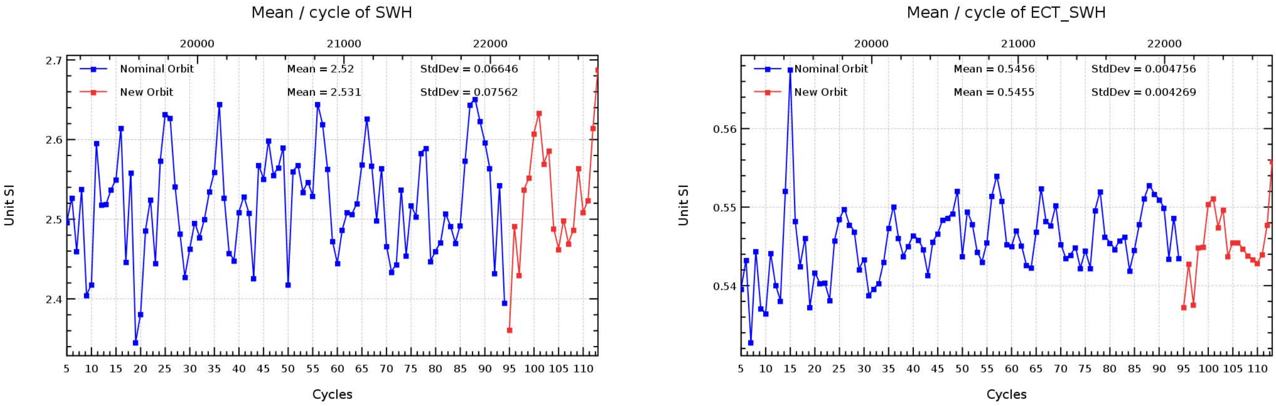


Figure 14: *Left) Mean Wave Height by cycle Right) Sdt. dev. of Wave Height by cycle*

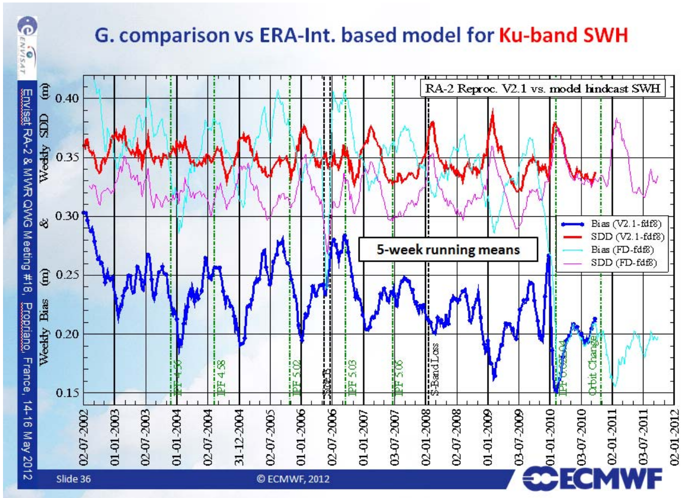


Figure 15: *Time series of Ku-Band SWH bias (RA2-model) and standard deviation difference (courtesy S. Abdalha ECMWF)*

2.9. i/ Wind speed

Obtained from a comparison between Sigma0 derived winds obtained with v1.0 tables and ECMWF gaussian grids wind outputs, with ocean data only (see editing specifications in Envisat Yearly report 2010 [5]). In 2012, a paper was also written on the stability of this parameter, evidencing a drift at the beginning of Envisat's period (Ablain et al. 2012 [2]).

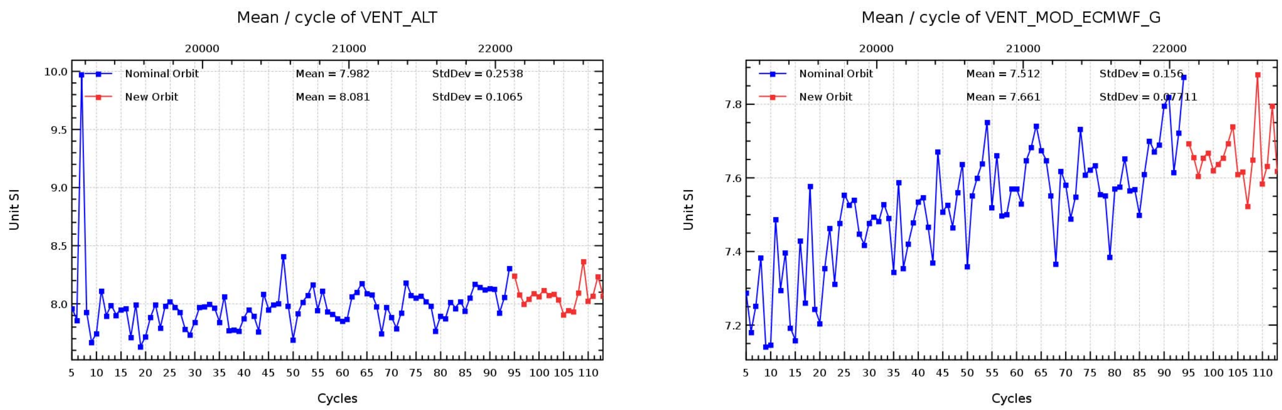


Figure 16: *Mean of Left) Altimetric Wind Speed Right) ECMWF Gaussian Wind Model, by cycle*

Envisat Altimetry	Specified	Observed	Comments
Altimeter noise	4.5cm	2cm	Altimeter noise computed on post launch data (see a/)
Sea State Bias	2cm	0.5cm	SSB error estimated from differences between different empirical models. Value at 2 m SWH. (see b/)
Ionosphere	0.2cm	0.7cm	Derived from cross-sensor comparisons (see c/)
Dry troposphere	0.7cm	0.7cm	From uncertainties in ECMWF atmospheric fields used to derive the correction. Value at 2-3 hPa sea level pression. (see d/)
Wet troposphere	1.4cm	1.8cm	Comparisons with ECMWF correction. (see e/)
Total range error (TRE): $\sqrt{\sum Terms^2}$	**5cm**	**2.9cm**	
Range drift/SSH	< 0.5cm/y	0.2cm/y	From in situ tide gauge comparison over 2005-2010 (see f/)
Radial Orbit error (ROE)	2cm	1.7cm	From POD operational monitoring (see g/)
Sea height error: $\sqrt{(TRE)^2 + (ROE)^2}$	**5.4cm**	**3.5cm**	
Significant Wave Height	5% or 25 cm	25cm	Comparison versus ECMWF WAM global value (see h/)
Wind Speed	2.0m/s	1.3m/s	Comparison versus ECMWF global fields (see i/)

11. Appendix: Instrument and platform status

11.1. ACRONYMS

The main acronyms used to describe the events are explained below.
CMA: Centre Multimission Altimetrique
CTI tables: Configuration Table Interface. They contain the setting of the instruments and are uploaded on board after a switch off, a reset
HTR Refuse: Heater Refuse
ICU: Instrument Control Unit, a part of the distributed command and control function implemented on ESA spacecraft. The unit receives, decodes and executes high-level commands for its instrument, and autonomously performs health-checking and parameter monitoring. In the event of anomalies it takes autonomous recovery actions.
IPF: Instrument Processing Facilities
MCMD: Macrocommand
OBDH: On Board Data Handling
OCM: Orbit Controle Mode/maneuvre
P/L SOL: Payload Switch Off Line
SEU: Single Event Upset
SM-SOL by PMC: SM Switch Off Line by Payload Main Computer
SW: Software
TM: Telemetry
USO: Ultra Stable Oscillator

11.2. EVENTS

Cycle 006

- Doris Doppler Instrument nominal mode with median frequency bandwidth pre-positionning (required for DORIS incident recovery) (2002/05/16 00:00:00 to 2003/05/19 12:00:00 TAI)
- Payload anomaly, DORIS MVR switch OFF (2002/05/27 01:38:37 to 2002/06/03)
- Orbit Maintenance Maneuver (2002/06/01 10:26:20 to 2002/06/01 13:16:46 TAI)
- Doris Doppler Instrument nominal mode with median frequency bandwidth pre-positionning (required for DORIS incident recovery) (2002/06/03 00:00:00 to 2003/06/11 12:00:00 TAI)

Cycle 007

- Orbit Maintenance Maneuver (2002/07/06 03:47:52 to 2002/07/06 06:38:14 TAI)
- Interface Control Unit anomaly (2002/07/06 08:02:00 to 2002/07/09 14:00:00)

Cycle 008

- Orbit Maintenance Maneuver (2002/08/06 03:38:08 to 2002/08/06 06:28:33 TAI)
- Orbit Maintenance Maneuver (2002/08/26 17:07:44 to 2002/08/26 19:58:09 TAI)

Cycle 009

- Payload switch down to load new software (2002/09/08 06:46:03 to 2002/09/10)
- Orbit Inclination Maneuver (2002/09/09 23:35:34 to 2002/09/10 01:48:59 TAI)
- Orbit Maintenance Maneuver (2002/09/11 01:55:32 to 2002/09/11 03:55:38 TAI)
- Interface Control Unit anomaly (2002/09/15 02:53:00 to 2002/09/17 10:56:00)

Cycle 010

- RA-2 went to STBY/Refuse (2002/10/09 09 13:34:22 to 2002/10/10 08:56:53)

Cycle 011

- Ra2 switch-down - Planned SM-SOL by PMC1 (2002/11/18 04:38:00 to 2002/11/19 19:19:21,Pass 382-429)
- DORIS Navigator switch-down - Planned SM-SOL by PMC1 (2002/11/18 04:38:02 to 2002/11/22 12:40:00, Pass 382-505)
- MWR switch-down - Planned SM-SOL by PMC1 (2002/11/18 04:37:59 to 2002/11/20 12:20:06, Pass 382-448)
- Orbit Maintenance Maneuver (2002/11/07 18:15:51 to 2002/11/07 21:06:17,Pass 83-85)
- Orbit Maintenance Maneuver (2002/11/29 03:35:30 to 2002/11/29 06:25:57,Pass 696-698)

Cycle 012

- RA-2 went to HTR-0 Refuse (2002/12/21 04:31:26 to 2002/12/21 12:52:00, Pass 325-333)
- Orbit Inclination Maneuver (2002/12/18 04:28:18 to 2002/12/18 06:36:46, Pass 238-240)
- Orbit Maintenance Maneuver (2002/12/18 22:17:22 to 2002/12/19 00:17:34, Pass 259-261)

Cycle 013

- RA-2 went to HTR-0 Refuse (2003-01-16 01:52:36 to 2003-01-17 17:00:35)
- RA-2 went to suspend mode (2003-01-25 23:56:36 to 2003-01-27 19:54:02)
- Orbit Maintenance Maneuver (2003/01/14 00:55:17 to 2003/01/14 03:45:42 TAI)
- Orbit Maintenance Maneuver (2003/02/11 23:04:49 to 2003/02/12 01:04:57 TAI)

Cycle 014

- SEU's caused a Software Anomaly (2003/03/02 02:46:44 to 2003/03/03 16:46:35).
- Subsystems unavailable - Autonmous P/L switch-off (2003/03/15 04:21:08 to 2003/03/17 19:00:13)
- RA2 in HTR0/Refuse due to HPA primery bus undercurrent (2003/03/17 21:09:32 to 2003/03/18 18:50:40)
- Orbit Maintenance Maneuver (2003/02/21 03:42:57 to 2003/02/21 05:53:24)
- Orbit Maintenance Maneuver (2003/03/03 23:51:14 to 2003/03/04 01:51:22)

Cycle 015

- Wrong setting of Ra2 parameters (no CTI tables have been up-loaded on-board) from 18 Mar 2003 18:50:40 to 9 Apr 2003 17:12:24, Pass 1 to 452
- RA-2 unavailability (Format Header Error forcing ICU to RS/WT/INI) from 8 Apr 2003 15:08:57.000 to 9 Apr 2003 17:12:24.000, Pass 437 to 452
- RA-2 unavailability (Format Header Error forcing ICU to RS/WT/INI) from 8 Apr 2003 15:08:57.000 to 9 Apr 2003 17:12:24.000, Pass 613 to 624
- RA-2 unavailability: Multiple SEU caused ICU switchdown (2003/04/24 13:20:09 to 2003/04/25 09:15:36,879 to 901)
- Orbit Maintenance Maneuver (2003/04/04 00:40:48 to 2003/04/04 02:40:56 TAI)

Cycle 016

- RA2 unavailability (known SEU failure) (from 5 May 2003 12:30:17.000 to 6 May 2003 10:01:10.000, Pass 191 to 215)
- RA-2 unavailability (ICU in SUSPEND due to TM FMT Error when a Reduced FMT was requested) (from 11 May 2003 11:06:33.000 to 12 May 2003 10:14:35.726, Pass 361 to 387)
- Orbit Maintenance Maneuver (from 2003/05/14 22:40:13 to 2003/05/15 00:40:19 TAI, Pass 460 to 462)
- RA-2 unavailability (Switch-down for PMC SW upgrade and OCM) from 18 May 2003 06:25:17.000 to 19 May 2003 15:59:28.000, Pass 548 to 602)
- MWR unavailability (Switch-down for PMC SW upgrade and OCM) from 18 May 2003 06:25:24.000 to 19 May 2003 14:45:40.000, Pass 548 to 602)
- DORIS unavailability (Switch-down for PMC SW upgrade and OCM) from 18 May 2003 06:25:25.000 to 19 May 2003 13:21:28.000, Pass 548 to 602)
- Orbit Inclination Maneuver (from 2003/05/20 04:11:53 to 2003/05/20 06:23:31 TAI, Pass 610 to 612)
- RA-2 unavailability (ICU went to RS/WT/INI) from 1 Jun 2003 14:36:40.000 to 2 Jun 2003 09:20:35.000, Pass967 to 987

Cycle 017

- Orbit Maintenance Maneuver (from 2003/06/07 01:08:16 to 2003/06/07 03:08:23 TAI, Pass 119 to 122)

Cycle 018

- Orbit Maintenance Maneuver (from 2003/07/11 0:58:45 to 2003/07/11 03:49:08 TAI, Pass 90 to 94)
- RA2 unavailability (RA-2 in STBY/REF due to MCMD timeout) (from 26 Jul 2003 15:28:11 to 26 Jul 2003 17:25:35, Pass 538)
- RA2 unavailability (RA-2 picked up Mission Planning schedule) (from 31 Jul 2003 16:11:02 to 31 Jul 2003 18:06:30, Pass 682)

- Orbit Maintenance Maneuver (from 2003/07/11 0:58:45 to 2003/07/11 03:49:08 TAI), Pass 91 to 94)

Cycle 019

- Orbit Maintenance Maneuver (from 2003/08/15 1:31:29 to 2003/08/15 03:31:35 TAI, Pass 91 to 93)
- RA-2 went to STBY/Refuse due to Individual Echoes MCMD Timeout (from 2003-08-15 16:40:21 to 2003-08-15 18:35:35, Pass 110)
- RA-2 went to STBY/Refuse due to Individual Echoes MCMD Timeout (from 2003-08-30 15:28:00 to 2003-08-30 20:47:35, Pass 538 to 543)
- PLSOL . Instrument Switch OFF/ON (from 2003-09-04 22:52:52 to 2003-09-06 16:41:09, Pass 689 to 738)

Cycle 020

- RA-2 in STANDBY / REFUSE MODE (from 2003-09-21 15:36:40 to 2003-09-21 17:33:30, Pass 166 to 167)
- RA-2 is in RS/WT/INT mode (from 2003-09-27 00:28:08 to 2003-09-27 12:52:00, Pass 320 to 333)
- Wrong setting of Ra2 parameters (no CTI tables have been up-loaded on-board) (from 2003-09-27 12:52:00 to 2003-09-30 12:45:00, Pass 334 to 407)
- Orbit Maintenance Maneuver (2003/09/30 00:40:53 to 2003/09/30 02:41:00 TAI, Pass 405 to 407)

Cycle 021

- Orbit Inclination Maneuver (2003/10/28 04:56:18 to 2003/10/28 07:09:44 TAI, Pass 210 to 212)
- RA-2 is in RS/WT/INT mode. 29 Oct 2003 06 :47 :04 to 29 Oct 2003 12 :58 :35, Pass 242 to 247)
- Orbit Maintenance Maneuver (2003/10/31 01:13:10 to 2003/10/31 03:13:25 TAI, Pass 291 to 293)
- RA-2 is in RS/WT/INT mode. TM format header error (02 Nov 2003 15 :16 :56 to 03 Nov 2003 12 :08 :35, Pass 366 to 389)
- Orbit Maintenance Maneuver (2003/11/18 23:02:30 to 2003/11/19 01:52:55 TAI, Pass 833 to 835)

Cycle 022

- RA-2 is in RS/WT/INT mode (2003-11-26 13:31:20 to 2003-11-26 19:39:35, Pass 49 to 54)
- RA-2 PLSOL . Instrument Switch OFF/ON (2003-12-03 07:18:43 to 2003-12-05 16:35:05, Pass 241 to 308)
- MWR PLSOL . Instrument Switch OFF/ON (2003-12-03 07:18:43 to 2003-12-04 18:45:41)

- RA-2 is in RS/WT/INT mode. (2003-12-06 15:55:52 to 2003-12-10 19:16:36, Pass 338 to 455)
- Orbit Maintenance Maneuver (2003/12/15 21:02:28 to 2003/12/15 23:02:36, Pass 601 to 603)
- Orbit Maintenance Maneuver (2003/12/26 21:03:30 to 2003/12/26 23:03:34, Pass 916 to 918)

Cycle 023

- Orbit Maintenance Maneuver (2004/01/21 23:54:27 to 2004/01/22 01:54:37))
- Orbit Maintenance Maneuver (2004/01/26 22:26:07 to 2004/01/27 00:26:11))

Cycle 024

- Orbit Inclination Maneuver (2004/02/04 04:46:39 to 2004/02/04 06:58:05)
- Orbit Maintenance Maneuver (2004/02/05 11:17:21 to 2004/02/05 13:17:23)
- Orbit Maintenance Maneuver (2004/02/24 11:48:39 to 2004/02/24 13:48:45)

Cycle 025

- Orbit Maintenance Maneuver (2004/04/07 20:05:30 to 2004/04/07 22:05:34)

Cycle 026

- RA-2 in STANDBY/REF DUE TO MCMD H202 FAILURE (2004-22-04 15:15:36 2004-22-04 17:07:05)
- RA-2 Switch down to RESET/WAIT due to too many SEU's reported. (2004-05-10 02:06:31 2004-05-10 11:27:30)
- Orbit Inclination Maneuver (2004/04/14 04:43:02 2004/04/14 06:55:00)
- Orbit Maintenance Maneuver (2004/05/07 01:08:56 2004/05/07 03:09:04)

Cycle 027

- RA2 went to suspend owing to repeated type 10 entries in report format (2004/05/31 02:45:27 to 2004/05/31 12:01:50)
- No DORIS data from 2004/06/06 13:00:00 to 2004/06/14 14:52:00. Following an onboard incident, Doris instrument has been switched to the redundant chain. Doris data are unavailable from June, 6th to June, 14th. To allow GDR production, POE with laser only data have been produced during this period.
- RA2 in SUSPEND Mode (2004/06/21 14:47:51 to 2004/06/21 19:24:30, Pass 995 to 999)

Cycle 028

- RA2 in ICU rs/wt/ini (2004/07/18 13:47:03 to 2004/07/18 19:59:00, Pass 765 to 771)
- Orbit Maintenance Maneuver (2004/06/30 08:08:29 to 2004/06/30 10:08:35, Pass 242 to 244)

Cycle 029

- RA2 in ICU RS/WT/INI. (SDU problem in RAM) (2004/08/10 15:00:39 to 2004/08/11 10:59:30, Pass 423 to 445)

- Orbit Maintenance Maneuver (2004/08/17 02:04:20 to 2004/08/17 04:04:26 , Pass 607 to 609)

Cycle 030

- RA2 in ICU RS/WT/INI. (SDU problem in RAM) (2004/09/26 13:39:50 to 2004/09/27 16:23:30, Pass 765-795)
- Abnormal behaviour of the RA-2 sensor (2004/09/27 16:23:30 to 2004-09-29 10:21:07, Pass 796-846)
- Collision avoidance Maneuver (2004/09/01 22:52:27 to 2004/09/02 00:52:37, Pass 60-62)
- Collision avoidance Maneuver (2004/09/02 23:44:27 to 2004/09/03 01:44:37, Pass 89-91)
- Orbit Inclination Maneuver (2004/09/21 04:14:37 to 2004/09/21 06:29:19, Pass 610-612)
- Orbit Maintenance Maneuver (2004/09/24 03:53:38 to 2004/09/24 05:53:46, Pass 695-697)

Cycle 031

- Collision avoidance Maneuver (2004/10/22 03:20:22 to 2004/10/22 07:00:41, Pass 495-498)
- High solar activity (Pass 974-1002)

Cycle 032

- RA2 in RS/WT/INI. 2004/11/23 13:25:58 to 2004/11/24 14:10:10, Pass 421-449
- RA2 Format header error. 2004/12/01 10:22:30 to 2004/12/01 15:34:29, Pass 647-651
- Orbit Maintenance Maneuver (2004/11/12 01:07:57 to 2004/11/12 03:08:06,Pass 91-93)

Cycle 033

- RA-2 went to RS/WT/INI due RBI (2004/12/27 02:49:10 to 2004/12/27 13:49:30, 380 to 391)
- Orbit Maintenance Maneuver (2004/12/17 01:03:48 to 2004/12/17 03:03:52, 91 to 93)
- Orbit Maintenance Maneuver (2005/01/05 23:10:28 ro 2005/01/06 01:10:36, 661 to 663)
- Orbit Inclination Maneuver (2005/01/07 04:25:17 to 2005/01/07 06:38:53, 696 to 698)

Cycle 034

- RA-2 went to RS/WT/INI Mode (2005/01/26 15:50:30 to 2005/01/26 21:07:30, 252 to 257)
- Orbit Maintenance Maneuver (2005/02/18 01:23:24 to 2005/02/18 03:23:28, 893 to 894)

Cycle 035

- RA-2 went to RS/WT/INI Mode (2005/03/18 04:35:34 to 2005/03/18 12:58:00, 697 to 705)
- Orbit Maintenance Maneuver (2005/03/17 04:51:26 to 2005/03/17 07:06:31, 668 to 669)

Cycle 036

- RA-2 went to RS/WT/INI mode (2005/04/18 05:01:10 to 2005/04/18 13:22:32, 583 to 591)
- RA-2 went to RS/WT/INI mode (2005/04/18 37:58:10 to 2005/04/24 11:42:30, 742 to 761)

Cycle 037

- RA-2 went to ICU in RS/WT/INI (RBI ERR 71) (2005/05/14 23:56:37 to 2005/05/15 10:53:45, 348 to 359)
- RA-2 went to ICU in RS/WT/INI (2005/05/21 00:10:45 to 2005/05/21 10:55:35, 520 to 531)

Cycle 038

- RA-2 went to ICU in RS/WT/INI (2005/07/04 04:41:10 to 2005/07/04 11:19:39, 783 t0 789)

Cycle 039

- RA-2 went to ICU in RS/WT/INI (2005/07/16 13:32:21 to 2005/07/16 19:58:52,135 to 141)
- RA-2 went to ICU in RS/WT/INI (2005/07/17 14:43:49 to 2005/07/17 19:20:30,165 to 169)
- RA-2 went to ICU in RS/WT/INI (2005/07/29 00:41:41 to 2005/07/29 09:58:30,492 to 501)
- Orbit Maintenance Maneuver (2005/08/09 22:45:44 to 2005/08/10 00:45:50 TAI)

Cycle 040

- RA-2 went to ICU in RS/WT/INI (2005/08/16 16:41:57 to 2005/08/16 20:22:30,24 to 27)
- RA-2 went to ICU in RS/WT/INI (2005/08/30 16:01:25 to 2005/08/30 19:43:00,424 to 427)
- RA-2 went to ICU in RS/WT/INI (2005/09/12 15:53:09 to 2005/09/12 19:47:00,796 to 799)
- Orbit Maintenance Maneuver (2005/09/07 05:19:53 to 2005/09/07 07:36:31 TAI)

Cycle 041

- RA-2 went to ICU in RS/WT/INI (2005/09/20 12:19:17 to 2005/09/20 18:56:00,19 to 25)
- RA-2 went in RS/WT/INI (2005/10/04 12:47:33 to 2005/10/04 16:35:30,420 to 423)
- Orbit Maintenance Maneuver (2005/10/06 02:19:10 to 2005/10/06 02:19:14 TAI)

Cycle 042

- RA-2 went in RS/WT/INI following Uncontrolled S/W Action (2005/10/28 05:34:13 to 2005/10/28 10:39:00,97 to 101)

Cycle 043

- RA-2 went in RS/WT/INI following Uncontrolled S/W Action (2006/01/02 12:56:35 2006/01/02 18:09:30,993 to 997)

Cycle 044

- RA-2 went in RS/WT/INI following Multiple SEU Anomaly (ref AR-614) (2006/01/12 14:20:35 to 2006/01/12 19:12:30,279 to 283)
- RA-2 went in RS/WT/INI(2006/01/30 02:07:15 to 2006/01/30 11:29:00,780 to 789)

- RA-2 went in RS/WT/INI following Uncontrolled S/W Action (2006/02/01 05:17:56 to 2006/02/01 12:04:30,841 to 847)
- RA-2 went in RS/WT/INI following Uncontrolled S/W Action (2006/02/01 16:30:28 to 2006/02/01 18:36:30,854 to 855)
- Orbit Inclination Maneuver (2006/01/10 05:54:24 to 2006/01/10 06:11:24)

Cycle 045

- RA-2 went in RA2 back to operations following TM format anomaly (2006/03/13 09:36:51 to 2006/03/13 17:40:00,989 to 997))

Cycle 046

- RA-2 switch to STBY and back to measurement to get useful telemetry related to USO (2006/03/17 12:04:00 to 2006/03/17 13:26:00,104 to 107)
- Orbit Inclination Maneuver (2006/03/28 05:33:20 to 2006/03/28 05:52:11 TAI)
- Payload anomaly DORIS MVR switch off (no data from) (2006/04/06 02:09:00 to 2006/04/08 12:40:00 TAI)
- RA2 back to operations following TM format anomaly (2006/04/06 12:31:00 to 2006/04/08 12:31:00,664 to 735)
- Doris Doppler Instrument nominal mode with median frequency bandwidth pre-positionning (required for DORIS incident recovery) (2004/04/08 12:40:00 to 2006/04/14 09:00:00 TAI)
- Payload anomaly DORIS Reset (2006/04/14 09:00:09)

Cycle 047

- On 12th-13th May, a special operation was executed to limit RA-2 Chirp Bandwidth to 80MHz (starting from 12/05/2006 at 15:51:37, pass 710) and then 20 MHz (starting from 13/05/2006 at 03:57:57, Pass 724). The instrument was returned to 320MHz on 13/05/2006 at 15:10:17, Pass 738. Users are strongly advised not to use passes 710-738
- The instrument sub-system Radio Frequency Module (RFM) was switched to its B-side on 15 May 2006 at 14:21:50, Pass 790
- RA-2 BACK TO OPERATIONS AFTER 2 CONSECUTIVE SEU ANOMALIES (19 May 2006 09:24:32 and 19 May 2006 19:13:00)

Cycle 048

- RFM switched to its nominal configuration side (A-side) on the 2006/06/21 at 13:20:15, Pass 850
- RA-2 Back to Measurement following Uncontrolled S/W Action (2006/06/25 15:01:36 to 2006/06/25 19:46:00, passes 967-971)

Cycle 049

- none

Cycle 050

- RA-2 Back to Measurement following Multiple SEU Anomaly (2006/08/01 01:14:40 to 2006/08/01 08:54:30,6 to 13)
- Foccserver have been re-booted and is up and running. The problem was probably due to a HW failure at ESRIN (IECF) which caused all the user slots to be occupied(2006/08/17 00:00:41 to 2006/08/17 11:10:00,TAI)

Cycle 051

- RA-2 Back to Measurement following a Service Module Anomaly (2006/09/7 16:40:30 to 2006/09/10 15:47:30,80 to 166)
- Orbit Inclination Maneuver (2006/09/13 05:22:17 to 2006/09/13 05:40:29)
- Interruption of the Envisat data transmission via the ESA Data Relay Satellite Artemis (anomaly with Envisat Ka-band antenna) from 2006/09/26 until 2006/10/1,630 to 641, 658 to 669, 686 to 697, 716 to 725, 744 to 755)

Cycle 052

- RA-2 Back to Measurement following a Service Module Anomaly (2006/10/26 04:02:43 to 2006/10/26 10:32:00,467 to 473)
- RA-2 Back to Measurement following a Service Module Anomaly (2006/11/02 15:20:19 to 2006/11/02 20:07:00,681 to 685)

Cycle 053

- RA-2 Back to Measurement following Multiple SEU Anomaly (2006/11/26 08:01:06 to 2006/11/26 17:32:00, 358-367)
- Available again in Measurement after SM Memory Maintenance (2006/11/28 07:40:00 to 2006/11/29 17:23:00,413-469)
- The entire payload switched off (Due to a LVL 3 PROTOCOL ERROR AND INTERRUPT) (2006/12/12 18:02:17 to 2006/12/15 15:54:00,826-909)

Cycle 054

- HSM input reset (2006/12/27 14:18:50 to 2006/12/28 10:51:48)

Cycle 055

- Orbit Inclination Maneuver (2007/01/23 04:33:06 to 2007/01/23 04:51:50; 9)
- RA-2 recovered from STANDBY / REFUSE MODE and back to MEASUREMENT (2007/02/01 15:15:30 to 2007/02/01 17:11:30, 280-281)
- RA-2 return to operation from RESET/WAIT due to MCMD Transfer Acknowledge Error (2007/02/16 00:47:49 to 2007/02/16 11:07:00, 692-703)
- RA-2 return to operation from HT0/REF due to low HPA PBC current (2007/02/17 00:45:47 to 2007/02/19 11:11:00, 721-789)

Cycle 056

- No event

.

Cycle 057

- Orbit Inclination Maneuver (2007/04/03 04:34:42 to 2007/04/03 04:50:14)
- RA-2 Return to Mesurement from HEATER 0 / REFUSE MODE due to HPA bus current OOL (2007/04/03 12:37:27 3 to 2007/04/03 13:48:00)
- RA-2 Return to Measurement after HEATER 0 / REFUSE MODE due to HPA bus current OOL (2007/04/04 09:49:12 to 2007/04/04 11:30:00)
- RA-2 back to measurement from STBY/REFUSE following HTR0/REFUSE MODE (2007/04/09 05:08:51 to 2007/04/09 10:36:30)

Cycle 058

- The MWR instrument switched into Stand-by/Refuse mode following an on-board anomaly (2007/05/26 13:20:29 to 2007/05/30 13:41:06, 535-649)

Cycle 059

- RA-2 recovered back to measurement from HTR1/REF0 (2007/06/30 00:37:55 to 2007/06/02 09:51:00,520-587)

Cycle 060

- RA-2 returned to Measurement from HTR1/REF due to a Telemetry error.(2007/07/19 01:08:026 to 2007/07/19 07:38:00,63-69)
- Orbit Inclination Maneuver (2007/07/17 04:41:26 to 2007/07/17 04:43:42,9)

Cycle 061

- Payload switch-off due to Service Module Anomaly (Global AOCS Surveillance triggered) (24 Sep 2007 12:27:00 to 27 Sep 2007 11:13:30,993-1002)

Cycle 062

- Payload switch-off due to Service Module Anomaly (Global AOCS Surveillance ered).(24 Sep 2007 12:27:00 to 27 Sep 2007 11:13:30,1-7)
- Orbit Inclination Maneuver (27 Sep 2007 05:16:25 to 27 Sep 2007 05:31:15)
- MCMD Transfer Acknowledge Error caused the ICU to be put into Reset/Wait Mode. This is one of the expected anomalies and RA-2 was back to measurement on the same day. (2 Oct 2007 16:15:55 to 2 Oct 2007 20:09:30,224-227)

Cycle 063

- The instrument was switched to Suspend by the PMC following consecutive TM format errors, the mode was commanded back to Measurement on the same day.(8 Nov 2007 13:31:47 to 8 Nov 2007 17:24:30)

Cycle 064

- Planned payload unavailability for OCM and Maintenance (3 Dec 2007 22:00:00 to 4 Dec 2007 13:50:00, passes 2 to 21)

- Orbit Inclination Maneuver (4 Dec 2007 04:34:54 to 4 Dec 2007 04:49:55)
- RA-2 Back to Measurement following TM Format Anomaly (9 Dec 2007 20:45:11 to 10 Dec 2007 09:14:30, passes 172 to 187)
- RA-2 was switched down into Standby for the System Memory Test (13 Dec 2007 06:44:00 to 13 Dec 2007 12:39:30, passes 270 to 277)

Cycle 065

- On 16th January an anomaly occurred in the HSM from 16 Jan 2008 16:11:00 to 17 Jan 2008 10:35:21, passes 253 to 276
- Envisat RA-2 (A-Side) S-band transmission power suddenly dropped on 17 January 2008, 23:23:40, UTC. Consequently, all S-band parameters as well as the dual ionospheric correction are not relevant anymore and must not be used from this date onwards.

Cycle 066

- Orbit Inclination Maneuver (2008/02/12 03:35:23 to 2008/02/12 05:49:28, 9)

Cycle 067

- None

Cycle 068

- Orbit Inclination Maneuver (2008/04/22 start : 04:37:04 TAI, end : 04:47:48 TAI).

Cycle 069

- None

Cycle 070

- Orbit Inclination Maneuver (2008/07/01 from 04:41:17 to 04:43:49 TAI).

Cycle 071

- None

Cycle 072

- Orbit Inclination Maneuver (2008/09/09 from 04:34:21 to 2008/09/09 04:50:26 TAI).
- From 2008/09/11 18:59:00 TAI to 2008/09/12 01:13:00 TAI, ARTEMIS (ENVISAT relay satellite) was unavailable due to ATV operation. This impacted the data availability from pass 86 to 90.

Cycle 073

- During the period covered by cycle 073 one SFCM maneuvre was executed as planned on the 7th of September at 01:36:05.

Cycle 074

- 2008/11/18 04:35:33 Orbit Inclination Maneuver (end : 2008/11/18 04:49:13 TAI)

- 2008/11/30 20:25:00 Artemis acquisition antenna was damaged by a strong hail. No data from 2008/11/30 20:25:00 TAI to 2008/12/01 07:14:00 TAI
- 2008/12/19 03:12:32 Orbit Maintenance Maneuver (end : 2008/12/19 03:12:34 TAI)

Cycle 075

- None

Cycle 076

- 2009/01/27 03:35:18 Orbit Inclination Maneuver (end : 2009/01/27 05:49:30 TAI)
- 2009/01/28 01:26:31 Orbit Maintenance Maneuver (end : 2009/01/28 03:26:37 TAI)
- 2009/02/17 03:27:51 Orbit Maintenance Maneuver (end : 2009/02/17 03:27:54 TAI)

Cycle 077

- 2009/03/13 03:06:29 Orbit Maintenance Maneuver (end : 2009/03/13 03:06:31 TAI)

Cycle 078

- 2009/04/07 04:34:26 Orbit Inclination Maneuver (end : 2009/04/07 04:50:21 TAI)
- 2009/04/15 22:16:36 Orbit Maintenance Maneuver (end : 2009/04/15 23:56:44 TAI)
- 2009/04/21 02:50:33 Orbit Maintenance Maneuver (end : 2009/04/21 02:50:35 TAI)
- 2009/04/28 13:04:50 Failure of the HSM (High Speed Mutliplexer), no data from 2009/04/28 13:04:50 TAI to 2009/04/29 14:57:28 TAI

Cycle 079

- 2009/05/20 01:32:33 Orbit Maintenance Maneuver (end : 2009/05/20 03:13:11 TAI)

Cycle 080

- 2009/07/09 03:01:12 Orbit Maintenance Maneuver (end : 2009/07/09 03:01:16 TAI)

Cycle 081

- 2009/07/21 04:40:21 Orbit Inclination Maneuver (end : 2009/07/21 04:44:35 TAI)
- 2009/07/23 02:00:32 Orbit Maintenance Maneuver (end : 2009/07/23 02:50:50 TAI)

Cycle 082

- None

Cycle 083

- 2009/09/29 04:33:42 Orbit Inclination Maneuver (end : 2009/09/29 04:51:00 TAI)
- 2009/10/15 01:56:42 Orbit Maintenance Maneuver (end : 2009/10/15 01:56:44 TAI)

Cycle 084

- 2009/11/04 07:51:36 Orbit Maintenance Maneuver (end : 2009/11/04 09:32:30 TAI)

- 2009/11/06 02:35:08 Orbit Maintenance Maneuver (end : 2009/11/06 02:35:10 TAI)
- 2009/12/03 03:04:03 Orbit Maintenance Maneuver (end : 2009/12/03 03:04:06 TAI)

Cycle 085

- 2009/12/08 04:34:40 Orbit Inclination Maneuver (end : 2009/12/08 04:59:57 TAI)
- 2009/12/09 22:18:47 Orbit Maintenance Maneuver (end : 2009/12/09 22:18:53 TAI)
- 2009/12/18 02:24:03 Orbit Maintenance Maneuver (end : 2009/12/18 02:24:05 TAI)

Cycle 086

- 2010/01/21 01:03:29 Orbit Maintenance Maneuver (end: 2011/01/21 04:44:32 TAI)
- 2010/01/22 01:52:33 Orbit Maintenance Maneuver (end: 2011/01/22 01:52:38 TAI)
- 2010/01/23 17:02:10 Diode software failure (end : 2010/01/26 21:03:30 TAI)
- 2010/01/23 17:03:20 DORIS instrument in Fixed-Frequency Doppler Search mode (so-called : waiting mode) from 2010/01/23 17:03:20 TAI to 2010/01/26 21:00:48 TAI
- 2010/01/27 20:15:28 DORIS instrument in Fixed-Frequency Doppler Search mode (so-called : waiting mode) from 2010/01/27 20:15:28 TAI to 2010/01/29 14:04:48 TAI
- 2010/01/27 20:13:30 Diode software failure (end : 2010/01/29 14:26:10 TAI)

Cycle 087

- 2010/02/16 04:33:58 Orbit Inclination Maneuver (end : 2010/02/16 04:50:39 TAI)
- 2010/02/22 21:13:54 Orbit Maintenance Maneuver (end : 2010/02/22 22:04:15 TAI)
- 2010/03/17 17:24:29 Orbit Maintenance Maneuver (end : 2010/03/17 19:05:15 TAI)

Cycle 088

- 2010/04/11 01:09:00 Not acquired at Esrin due to a scheduled USV-2 TL-72H launch. No data from 2010/04/11 01:09:00 TAI to 2010/04/11 07:28:00 TAI
- 2010/04/17 03:03:27 Orbit Maintenance Maneuver (end : 2010/04/17 04:44:06 TAI)

Cycle 089

- 2010/04/27 04:37:05 Orbit Inclination Maneuver (end : 2010/04/27 04:47:30 TAI)
- 2010/05/28 02:35:15 Orbit Maintenance Maneuver (end : 2010/05/28 04:15:53 TAI)

Cycle 090

- 2010/06/25 03:22:57 Orbit Maintenance Maneuver (end : 2010/06/25 03:23:01 TAI)
- 2010/06/30 23:06:08 DORIS instrument in Fixed-Frequency Doppler Search mode (so-called : waiting mode) from 2010/06/30 23:06:08 TAI to 2010/07/01 01:56:48 TAI
- 2010/07/02 07:43:28 DORIS instrument in Fixed-Frequency Doppler Search mode (so-called : waiting mode) from 2010/07/02 07:43:28 TAI to 2010/07/02 21:48:28 TAI

Cycle 091

- 2010/07/06 04:37:29 Orbit Inclination Maneuver (end : 2010/07/06 04:47:06 TAI)
- 2010/07/07 02:03:35 Orbit Maintenance Maneuver (end : 2010/07/07 02:03:37 TAI)
- 2010/07/30 05:20:14 Orbit Maintenance Maneuver (end : 2010/07/30 05:20:17 TAI)

Cycle 092

- 2010/08/23 21:41:33 Orbit Maintenance Maneuver (end : 2010/08/23 21:41:36 TAI)

Cycle 093

- 2010/09/24 03:39:33 Orbit Maintenance Maneuver (end : 2010/09/24 03:39:35 TAI)
- 2010/10/15 03:03:25 Orbit Maintenance Maneuver (end : 2010/10/15 05:03:28 TAI)

Cycle 094

- 20-10-2010 23:52:00 to 21-10-2010 06:34:22 - KBS-2 down due to EPC2 power relay status OFF

Cycle 095

- Up to 26-10-2010 07:56: planned interruption during change of orbit
- 2010/10/26 13:49:13 Orbit Maintenance Maneuver (end : 2010/10/26 16:42:43 TAI)

Cycle 096

- 2010/11/25 03:16:03 Orbit Maintenance Maneuver (end : 2010/11/25 04:56:20 TAI)
- 2010/11/22 07:02:12 Orbit Maintenance Maneuver (end : 2010/11/22 08:42:30 TAI)
- 2010/11/04 20:40:53 Orbit Maintenance Maneuver (end : 2010/11/04 21:31:14 TAI)

Cycle 097

- 2010/12/17 06:12:15 Orbit Maintenance Maneuver (end : 2010/12/17 06:12:19 TAI)
- 2010/12/01 20:51:28 Orbit Maintenance Maneuver (end : 2010/12/02 00:12:08 TAI)

Cycle 098

- 2011/01/14 01:58:18 Orbit Maintenance Maneuver (end : 2011/01/14 01:58:22 TAI)

Cycle 099

- 2011/02/18 05:10:16 Orbit Maintenance Maneuver (end : 2011/02/18 05:10:20 TAI)
- RA2 instrument down [EOFC 59618 (1PN) EN-UNA-2011/0026] (2011/02/21, from 16:29:39 to 21:15:38)

Cycle 100

- 2011/03/17 00:51:32 Orbit Maintenance Maneuver (end : 2011/03/17 02:31:50 TAI)
- ATV-2 Envisat Emergency activity [EOFC 60464] (2011/03/22, from 02:21:59 to 07:06:28)

Cycle 101

- RA2 in RS/WT/INI due to TM Format Anomaly (2011/04/0, from 00:19:00 to 10:54:37)
- [RA2] Payload /PEB Switch-off due to Service Module Anomaly (2011/04/03, from 15:50:32 to 2011/04/04 15:39:37)
- 2011/04/08 09:43:20 Orbit Maintenance Maneuver (end : 2011/04/08 09:43:28 TAI)
- 2011/04/16 14:17:07 Orbit Maintenance Maneuver (end : 2011/04/16 14:17:11 TAI)

Cycle 102

- ICU anomaly (2011/04/27, from 03:25:47 to 10:03:38)
- 2011/05/05 01:02:53 Orbit Maintenance Maneuver (end : 2011/05/05 01:03:01 TAI)
- No data from 2011/05/21 00:53:11 TAI to 2011/05/23 10:24:32 TAI - DORIS Instrument Failure
- ARTEMIS : Service rejected by emergency ATV (2011/05/23, from 20:10:41 to 23:02:09)

Cycle 103

- 2011/06/01 02:41:56 Orbit Maintenance Maneuver (end : 2011/06/01 03:32:01 TAI)
- 2011/06/16 04:00:10 Orbit Maintenance Maneuver (end : 2011/06/16 05:40:28 TAI)

Cycle 104

- 2011/07/13 01:08:17 Orbit Maintenance Maneuver (end : 2011/07/13 04:48:34 TAI)
- 2011/07/14 03:24:16 Orbit Maintenance Maneuver (end : 2011/07/14 07:04:48 TAI)

Cycle 105

- 2011/08/11 00:55:16 Orbit Maintenance Maneuver (end : 2011/08/11 02:35:32 TAI)
- 2011/08/17 22:46:22 Orbit Maintenance Maneuver (end : 2011/08/18 00:26:59 TAI)
- 2011/08/23 00:38:33 Orbit Maintenance Maneuver (end : 2011/08/23 00:38:35 TAI)

Cycle 106 Nothing to report.

Cycle 107

- 2011/09/23 01:19:06 Orbit Maintenance Maneuver (end : 2011/09/23 02:59:24 TAI)
- 2011/09/30 03:37:33 Orbit Maintenance Maneuver (end : 2011/09/30 04:27:39 TAI)
- 2011/10/14 03:11:18 Orbit Maintenance Maneuver (end : 2011/10/14 03:11:26 TAI)

Cycle 108

- 2011/10/28 02:46:03 Orbit Maintenance Maneuver (end : 2011/10/28 02:46:15 TAI)
- 2011/11/06 14:58:25 Orbit Maintenance Maneuver (end : 2011/11/06 18:19:11 TAI)
- 2011/11/11 03:08:07 Orbit Maintenance Maneuver (end : 2011/11/11 03:58:14 TAI)

- 2011/11/17 02:44:59 Orbit Maintenance Maneuver (end : 2011/11/17 02:45:10 TAI)

Cycle 109

- 2011/11/25 02:45:37 Orbit Maintenance Maneuver (end : 2011/11/25 02:45:47 TAI)
- 2011/12/08 02:58:04 Orbit Maintenance Maneuver (end : 2011/12/08 02:58:16 TAI)

Cycle 110

- 2011/12/23 03:24:54 Orbit Maintenance Maneuver (end : 2011/12/23 05:25:02 TAI)
- 2011/12/25 02:20:34 Orbit Maintenance Maneuver (end : 2011/12/25 02:20:40 TAI)
- 2011/12/27 13:50:00 No data from 2011/12/27 13:50:00 TAI to 2011/12/27 17:37:38 TAI (Instrument Failure)
- 2012/01/13 03:43:39 Orbit Maintenance Maneuver (end : 2012/01/13 03:43:45 TAI)

Cycle 111

- 2012/02/01 01:53:44 Orbit Maintenance Maneuver (end : 2012/02/01 01:53:52 TAI)

Cycle 112

- 2012/02/24 03:17:26 Orbit Maintenance Maneuver (end : 2012/02/24 05:17:39 TAI)
- 2012/03/01 02:29:11 Orbit Inclination Maneuver (end : 2012/03/01 04:49:18 TAI)
- 2012/03/06 02:47:37 Orbit Maintenance Maneuver (end : 2012/03/06 04:47:41 TAI)
- 2012/03/15 03:11:59 Orbit Maintenance Maneuver (end : 2012/03/15 03:12:09 TAI)

Cycle 113

- 2012/04/05 04:18:16 Orbit Maintenance Maneuver (end : 2012/04/05 04:18:24 TAI)
- 2012/04/08 10:54:00 No data since 2012/04/08 10:54:00 TAI (Safehold entry)

End of Envisat Mission

On Sunday 8th April afternoon, the communication links with Envisat was suddenly lost, preventing re- ception of telemetry data. An extended network of ground stations was immediately activated to send commands to the satellite. While it is known that Envisat remained in a stable orbit around Earth, efforts to resume contact with the satellite were unsuccessful.
The end of the mission's operations was declared by European Space Agency on the 9th of May 2012.

12. 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] 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

[17] 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.

[18] 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

[19] 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

[20] 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.

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

[22] 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

[23] 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.

[24] 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.

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

[26] 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.

[27] 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

[28] 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

[29] 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.

[30] 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.

[31] 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.

[32] 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.

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

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

[35] 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/

[36] 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/

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

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

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

[40] 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

[41] 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

[42] 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

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

[44] 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'

[45] 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

[46] 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

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

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

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

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

[51] 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

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

[53] 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.

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

[55] 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

[56] 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

[57] 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

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

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

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

[61] 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.

[62] 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.

[63] 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.

[64] 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

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

[66] 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

[67] 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.

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

[69] 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/

[70] 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).

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

[72] 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.

[73] 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.

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

.

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

[76] 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

[77] 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

[78] 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

[79] 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

[80] 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

[81] 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

[82] 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

[83] 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/

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

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

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

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

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

[89] 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

[90] 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.

[91] 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

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

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

[94] 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.

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

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

[97] 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.

[98] 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

[99] 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

[100] 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.

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

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

[103] 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

[104] 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

[105] 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.

[106] 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

[107] 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

[108] 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.

[109] 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.

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

[111] 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.