CalVal Envisat

# Envisat RA2/MWR ocean data validation and cross-calibration activities. Yearly report 2010.

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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 Ephemeris |
| 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 2010. It is basically concerned with long-term monitoring of the Envisat altimeter system over ocean.

Envisat GDR data are 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 ° 60453/00 - lot2.C). In this frame, besides continuous analysis in terms of altimeter data quality, Envisat GDR Quality Assessment Reports (e.g. Faugere et al. 2003 [30]) are routinely produced in conjunction with data dissemination.

Data from GDR cycles 9 through 93 spanning eight years (from 24-09-2002 to 18-10-2010) have been used for this analysis. All relevant altimeter parameters deduced from Ocean 1 retracking, radiometer parameters and geophysical corrections are evaluated and tested.

Some of the results described here were presented at the OSTST meeting (Lisbon, September 2010) and at the Quality Working Group (QWG) meetings (Reading, May 2010 and Roma, November 2010).

The work performed in terms of data quality assessment also includes cross-calibration with Jason-1, ERS-2 (for the beginning of the mission up to november 2005 only, due to contractual reasons) and Jason-2. 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. The full reprocessing of Jason-1 products in GDR C version was completely finished in January 2010. Concerning Envisat, a full reprocessing in v2.1 version has started in 2011. And yet, a new orbit was delivered on GDR-C/v2.1 standard and has been analysed through some particular studies (notably Mean Sea Level studies).

Since July 2008, Jason-2 data were also used for the cross-calibration with Envisat in its GDR type version. The various comparisons performed between both missions show a very good consistency with a standard deviation of cross-over differences of around 3.8 cm. The geographically correlated biases between Envisat and Jason 2 also show a very good agreement of both data sets. These results are encouraging for insuring a good continuity on the long term monitoring already initiated with Jason-1 since 2002.

After a preliminary section describing the data used, the report is split into 5 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) bias is analyzed. Finally, an additional part presents the particular investigations that have been performed during this year:
- particular studies about long term stability issues, through comparisons with other models and missions, notably:
o concerning Envisat's MSL (and more specifically the wet tropospheric correction post)
o concerning Envisat's wind

- an extensive study on cross calibration results highlighting East/Weast biaises increasing in time and probably correlated to the gravity field through the orbit.
- a particular study concerning the comparison of the bifrequency ionospheric correction on Jason-1 and Envisat compared to GIM model. The aim of this study was to evaluate the degradation of the S-Band loss on the comming years of increasing solar activity. It also proposes a new model correction fitted on Jason-1.

# 2. Quality overview

**Ra-2 instrumental status**:
Due to the permanent RA2 S-band power drop which occured 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 unrelevant 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 is still in a low period, therefore thanks to the GIM model correction used instead of the dual-frequency correction in the SSH equation, data were weakly impacted in terms of variance. In 2010 the solar activity is starting to increase again. To estimate the degradation of the S-Band loss through this correction, a particular study was performed to compare ionospheric correction from different models and missions (see part 7.3.).

No **USO anomaly** were noticed during 2010.
However, it affected intermittently (see Figure 3) Ra-2 data from cycle 46 to cycle 65 pass 451 (2008/01/23). To correct the effect of the USO anomaly, ESA proposed auxiliary files, so that Envisat Ra-2 data remain at the same high level of accuracy.
Users are strongly advised NOT to use the range parameter in Ku and S Band without this correction, even for the non-anomalous periods, in order to correct the range from the long term drift of the USO device. More information is available on http://earth.esa.int/pcs/envisat/ra2/auxdata/
**In the v2.1 version,** used for reprocessing (IPF processing chain 6.04 and CMA Reference Software 9.3_05), the range is now corrected from the proper USO Period and therefore, from cycle 93 onwards (and for the reprocessed data), **no more USO auxiliary file is needed.**

**Missing measurements**:
The unavailability of data over ocean for year 2010 is very low, about 1.3% in average.
The MWR unavailability is also very stable and very low around 0.4%.

**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.

The MWR performances are very good. Note that since the beginning of the mission, the instrumental parameters at 36.5 GHz were known to be slighly drifting. Moreover from cycle 46 onwards, the comparison to ECMWF model is hardened by the numerous improvements of this operational model inducing (around 1.5mm) jumps in the time series.
This year, a particular study was performed to better characterise the stability of MWR compared to other models and missions (see part 7.2.).

**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 long Jason-1 reprocessed time series.
- an updated data series using as homogeneous terms as possible before the reprocessing campain: Envisat POD orbit already reprocessed from cycle 15 onwards, geophysical corrections see 3.2.2.... 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 (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 detailled in part 7.1..
- In addition, a new type of comparison can now be carried on thanks to in situ dataset (Argo TS profile and Tide gages) ingested to provide an external source of calibration. These activities are developped in [11] and [12].

Conclusions are that missions still show significant differences before September 2005 and after 2008. Differences between both missions can be analysed more and more precisely. Wet tropospheric correction still remains a large 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. On the other hand, the inhomogeneity of radiometric processing (drift corrections, side lobe effects correction...) also induces long term unstability. But the most probable suspicious points are currently being instrumental origins (instrumental corrections baddly taken into account). Reprocessed data should hopefully help to clarified these suspicions.

# 3. Data used and processing

## 3.1. Data used

Envisat Geophysical Data Records (GDRs) from cycle 10 to cycle 93 have been used to derive the results presented in this report. This corresponds to nearly eight-years spanning from September 30th 2002 to November 18th 2010. The routine production started on September 2003 with cycle 15. In parallel, a backward reprocessing of cycles 14 to 9 was implemented. With only 7 days of available data, cycle 9 has not been used in this report.

The Envisat GDR data are generated using two softwares: the IPF, from Level0 to Level1B, and the CMA, from Level1B to Level2. As shown in Table 1 several IPF processing chain and CMA Reference Software have been used to produce all the GDR cycles. Tables 2 and 3 describe the main evolutions respectively associated with the IPF and CMA versions.

| Cycles | IPF version | CMA version |
|---|---|---|
| 9 to 10 | 4.58 | 6.3 |
| 11 to 12 | 4.57 | 6.3 |
| 13 to 14 | 4.56 | 6.3 |
| 15 to 21 | 4.54 | 6.1 |
| 22 to 24 | 4.56 | 6.2 |
| 25 to 26 | 4.56 | 6.3 |
| 27 to 28 | 4.57 | 6.3 |
| 29 to 40 | 4.58 | 6.3 |
| 38 to 40 | 5.02 | 7.1 |
| 41 to 47 pass 790 | 5.02 | 7.1 |
| 47 to 48 pass 849 | 5.06 | 9.0 |
| 48 to 51 pass 7 | 5.02 | 7.1 |
| 51 to 58 pass 843 | 5.03 | 8.0 |
| 58 to 64 | 5.06 | 9.0 |
| 65 to 67 | 5.06 | 9.1 |
| 68 to 85 | 5.06 | 9.2 |
| 85 to 92 | 6.02 | 9.3 |
| 93 | 6.04 | 9.3 |
| | | .../... |

| Cycles | IPF version | CMA version |
|---|---|---|

Table 1: IPF/CMA Processing versions

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).

| Version | Changes |
|---|---|
| IPF 4.56 | -Extrapolation of AGC value to the Waveform center (49.5) for both Ku- and S-Band<br>-Correction for an error found in the evaluation of S band AGC |
| IPF 4.57 | No impact on data |
| IPF 4.58 | -Addition of a Pass Number Field in Fast Delivery Level 2 products<br>No impact on GDR data |
| | |
| IPF 5.02 | -MWR Side Lobe correction upgrade<br>-USO clock period units correction<br>-Rain Flag tuning to compensate for the increase of the S band Sigma0<br>-Monthly IF mask taken into account<br>-DORIS Navigator CFI upgrade (RA-2 and MWR)<br>-S-band anomaly flag |
| IPF 5.03 | -Correction for an error found in the Channel 2 brightness temperature<br>-Correction for an error in the window delay (for the 80 and 20 MHz bandwidths)<br>-S-band anomaly flag upgrade, now properly implemented<br>-Correction of Rx-Fine parameter<br>-MWR second channel corrected (Side Lobes correction) |
| IPF 5.06 | No impact on data |
| IPF 6.02 | Introduction of USO correction directly in the range at the L1b level (with error in the IPF implementation) |

.../...

| Version | Changes |
|---|---|
| | Improvement of the Point Target Response (PTR) resolution from 3cm to 1.8mm<br>MWR new caracterisation files |
| IPF 6.04 | USO clock period implementation corrected (no more auxiliary file needed) and constant value applied per product outside from abnormal periods.<br>Slope models updated for Antartica and Greenland |

Table 2: *I*PF changes impacting the Envisat GDR or Level2 data

| Version | Changes |
|---|---|
| CMA 6.1 | MSS CLS01<br>Rain flag<br>MWR neural algorithm<br>Sea Ice tuning<br>Sea State Bias Table file<br>GOT00.2 Ocean Tide Sol 1 Map file<br>FES 2002 Ocean Tide Sol 2 Map file<br>FES 2002 Tidal Loading Coeff Map |
| CMA 6.2 | No impacts on Envisat products |
| CMA 6.3 | Updated OCOG retracking thresholds Ice1 Conf file<br>Increased GDR data coverage by the use of both consolidated and nonconsolidated data prods in inputs. |
| CMA 7.1 | Improving the mispointing estimation<br>Addition of square of the SWH in Ku and S band<br>Addition of GOT2000.2 loading tide<br>FES2004 tide and loading tide<br>New DEM AUX file (MACESS) merge of ACE land elevation data and Smith and Sandwell ocean bathymetry |
| | .../... |

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| Version | Changes |
|---|---|
| | New orbit standards<br>New SSB solution<br>new wind table<br>Mog2D upgraded<br>New S1S2 wave model in dry troposphere<br>GOT00.2 includes two extra waves, S1 and S2<br>GIM model ionospheric correction added in the products |
| CMA 8 | No impacts |
| CMA 9 | Correction of an anomaly in the relative orbit field inside the product header. No scientific impact. |
| CMA 9.1 | Separating the processing of Jason1 and Envisat No scientific impact. |
| CMA 9.2 | New POD orbit configuration.<br>New Dynamic Atmospheric Correction (DAC/MOG2D High Resolution) |
| CMA 9.3 | New rain flag: In the algorithm the coefficients and look-up tables have been updated, in order to set the value of the flag. It is a 6 states flag using MWR, and Ku and S band inputs. [79].<br>New Sea-Ice algorithm includes a 2-state sea ice flag (ice-free ocean and sea-ice) and 4 values indicating the membership of the pixel to each class (ice-free ocean, first-year ice, multi-year ice and wet ice). They are provided as percentages between 0 and 100 in the product.<br>New modelisation of PTR width (SigmaC) impacting SWH value because ($SWH2 = SigmaP2 + SigmaC2$)<br>Evolution on FES2004: new loading tide + K2 and S1 coefficients.<br>New SSB solution, Labroue, 2007 |
| | .../... |

| Version | Changes |
|---|---|
| | Note1: from this version onwards, consolidated data constitute an independant set of data. Convertly, before that, consolidated data replaced non consolidated data in a single data base when available. The cases of available non consolidated data and missing consolidated data did not have any impact on the GDR data availability. |
| | Note2: Change of nomenclature after change of orbite: phase 3 instead of A. |
| | Note3: New slope models were applied for ice sheets applications (no impact on our analysis) from cycle 95. |

Table 3: $C$MA changes impacting the Envisat GDR

The change from IPF 4.58/CMA6.3 to IPF 5.02/CMA7.1 strongly impacted the data. The Sea-State bias table has been recomputed ( [45] ) accounting for the impact of the new orbit and the new geophysical corrections (MOG2D, GOT00 ocean tide correction with the S2 component corrected once only, new wind speed algorithm from Abdalla, 2006 [1]). The new SSB correction is shifted in average by +2.0 cm in comparison with the previous one. New standards are used for the computation of the Envisat Precise Orbit Estimation. One of the main evolutions is the use of the GRACE gravity model EIGEN GC03C. This new model implies a strong reduction of the geographically correlated radial orbit errors. In order to take into account the dynamical effects and wind forcing, a new correction is computed from the MOG2D (Carrere and Lyard, 2003 [13]) barotropic model forced by pressure (without S1 and S2 constituents) and wind. The use of such a correction in the SSH strongly improves the performances. All the corresponding evolutions are detailed in [25].

The change from IPF 5.06/CMA9.1 to IPF 5.06/CMA9.2:
- Change of DAC correction: A new High Resolution Dynamic Atmospheric Correction MOG2D correction was computed and added to the products. Internal studies show that this new correction improves the variance by a gain of 1 to 2cm$^2$ for Jason-1 and Envisat with a greater impact near coasts and in the South pacific area (Bellingshausen basin), see [16].
- Change of orbit: New standards are used for the computation of the Envisat Precise Orbit Estimation (POD GDR-C' configuration including notably a time varying gravity field with no annual and semi annual signal with a long term trend, ...). This version was shown to have an unexpected impact in Jason-1 data and was therefore replaced for Jason-1 reprocessing by a GDR-C standard (same model of gravity field but without the 1st order long term drift). For ENVISAT mission it is used for 3 cycles: 68, 69 and 70.
On cycle 71 the POD containt changed from GDR-C' to the GDR-C standard (same model of gravity field but without the 1st order long term drift). This POD was/is used for JASON-1/ENVISAT reprocessing.

On cycle 85 the simultaneous change of IPF and CMA version from IPF 5.06/CMA9.2 to IPF 6.02/CMA9.3 has a significant impact on the data. It settled the standards of the reprocessing version (V2.1).
The impact on the data is detailled in part 6.4..

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## 3.2. Processing

### 3.2.1. GDR products and quality assesment 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 Centre) tools operated at CLS premises. Each cycle is carefully routinely 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/html/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 27 to 323), ERS-2 (OPRs Cycle 78 to 108) 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 [22]). Since january 2010 a full reprocessing of Jason-1 products in GDR C is fully available. Concerning Envisat, a full reprocessing has also begun in 2011. Therefore, a new homogeneous Envisat/Jason-1 data set will be available next year. The cross-calibration between Envisat, Jason-1 and Jason-2 takes into account Jason-1 and 2 reprocessing. The periods concerned by each version is summed up on Figure 2.

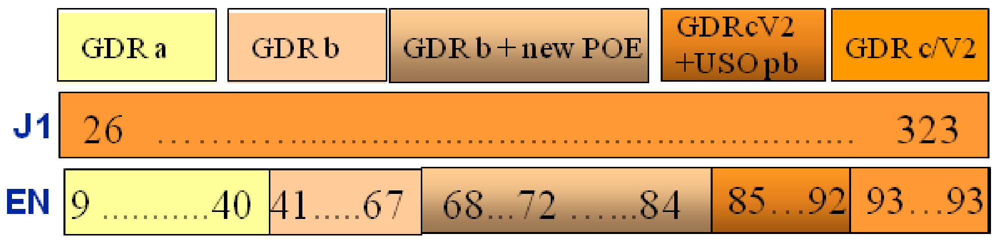


Figure 1: *Status on the GDR versions for Jason-1 and Envisat series.*

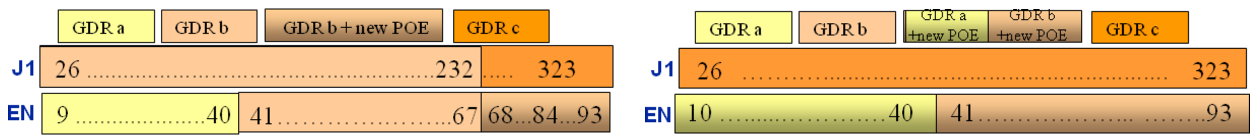


Figure 2: *GDR used in this report for Jason-1 and Envisat comparison. Left:Inhomogeneous version used for current validations. Right: Updated Envisat dataset (including GDRc POE) used for long term analysis (MSL).*

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 detailed in Stum et al. (1998) [75], estimates of the differences are computed using a 120 day running window to keep a constant geographical coverage. ERS-2, flying on same ground track as Envisat only 30 minutes apart, has had a coverage limited to the North Atlantic since the failure of the on-board register in June 2003 (EOHelp message of 4 July 2003). Since May 2008 (cycle 136) additional stations were however added near Indonesia and Tasmania.
To improve the significance of the Envisat/ERS-2 comparison, long term monitoring of altimeter parameters difference is performed on this restricted area all over the Envisat period using a repeat-track method.

### 3.2.2. Particular updates added to the GDR products

Most of this work has been carried out using parameters available in the GDR products. However, a few updates have been necessary to complete the analysis (those are listed in the product disclaimer document available at http://earth.esa.int/dataproducts/availability/ [65]):

- **S-Band anomaly**: A method has been developed to detect data corrupted by S-Band anomaly. It has been applied until cycle 53. From cycle 54 onwards the product flag, available since cycle 51, has been used (see 4.3.1.). Since cycle 60, the cause of the anomaly was found and the anomaly solved. No anomaly occurs anymore since then.
- **Sea ice flag**: A method has been developed to detect data corrupted by sea ice (see 4.3.2.)
- **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, after that, it cannot be computed anymore, due to the S-Band Power drop (17th January 2008) the GIM ionospheric correction is then used.
- **Dual-frequency ionosphere correction**: For cycles 9-40, the sea state bias (SSB) used to correct the S-Band Range was updated in its right S-Band version. The dual-frequency ionosphere correction was therefore recomputed accounting for the S-Band SSB solution on S-Band range. Before that, both S and Ku-Band ranges used here were corrected from the Ku-Band SSB (Labroue (2004 [44])).
- **Geophysical corrections**: The new geophysical correction associated with version CMA7 have been updated on the whole data-set in order to have the most homogeneous time series: wind table, S1S2 wave model in dry troposphere, GOT00.2 with two extra waves S1 and S2, FES2004.

  **GOT 4.7**: A new tidal model was available during 2009 (see [8]). It replaces the GOT00.2 correction in some studies (mean sea level trends).

  **SSB 2007**: A new SSB model was also available during 2009 (see [8]). It is now available in the v2.1 reprocessing version and from cycle 86.

- **MOG2D HR**: The new High resolution DAC implemented into the CMA 9.2 from cycle 69 on Envisat (see Table 3 and [8]) was also updated on the whole data-set.

- **Inverse barometer and dry troposphere corrections**: Pressure values used to compute the inverse barometer and the dry troposphere corrections have been derived from the ECMWF gaussian grids. Indeed, errors due to the topography, up to several centimeters near the coasts, significantly impact the accuracy the so-called Gaussian grids used as input of the Envisat (and Jason-1) ground processing (e.g. Dorandeu et al., 2004b [22]).

- **GIM/IRI ionosphere corrections**: Jason-1 doesn't fly at the same altitude as Envisat which means that ionosphere corrections are not comparable. Moreover, ERS-2 has a mono-frequency altimeter on-board. Therefore it is not possible to use these satellites to assess the Envisat ionosphere path delay. Thus the JPL GPS-based global Ionospheric Maps (GIM) containing the vertical ionospheric total electron content are used here. Note that GIM maps contain the vertical ionospheric total electron content in the 0-1400km altitude range. As Envisat flies around 800km, the International Reference Ionosphere (IRI) model is uses to estimate the GIM correction at the altitude of Envisat:
$GIM_{[0-800]} = GIM_{[0-1400]} \times \frac{IRI_{[800]}}{IRI_{[1400]}}$. Since the S-Band loss (17th January 2008) this correction is used for the SSH computation. Also note that since cycle 41 onwards, this GIM ionosphere correction is available in the GDR products. A particular study was performed to compare ionospheric correction from different models and missions (see part 7.3.).

- **USO correction**: The range needs to be corrected for the Ultra-Stable Oscillator (USO) clock period variations. From the beginning of the mission it underwent several behaviors and the way it is corrected depends on the cycle. It is detailled hereafter in part 3.2.3.. Yet, it is now directly corrected in the range for the v2.1 reprocessing version and from cycle 93.

### 3.2.3. USO correction's specificities

The USO clock period is used to performs the computation of the Ra-2 window time delay and the range needs to be corrected :
- on the whole period, from a drift due to the aging of the device
- during some periods (detailed in Figure 3), from a strong anomaly detailed hereafter.

Description of the USO anomaly:
On the 1st of February 2006 (12:05:36), at the end of cycle 44, for an unknown reason a change of behavior of the USO device occurred. This anomaly, already observed for a short period during cycle 30, created a 5.5m jump on the range parameter and oscillations of about 20-30cm of amplitude at the orbital period. The anomaly became permanent on cycle 46 to 56. On the 1st of March 2007, the USO recovered in a non-anomalous mode. Between cycles 56 and 61, Ra2 data was not affected by the anomaly. On the 27th of September 2007 (cycle 62), a new change of behavior of the Ultra Stable Oscillator (USO) clock frequency occurred. A short break in the anomaly occurred between cycles 63 and 64, followed by another one on the 23th of January which was permanent over the whole year 2008. The anomaly and associated correction is detailed in [54]. The quality assessment of these data has been performed using the USO temporary correction provided by ESA. Users are strongly advised not to use the range parameter in Ku and S Band

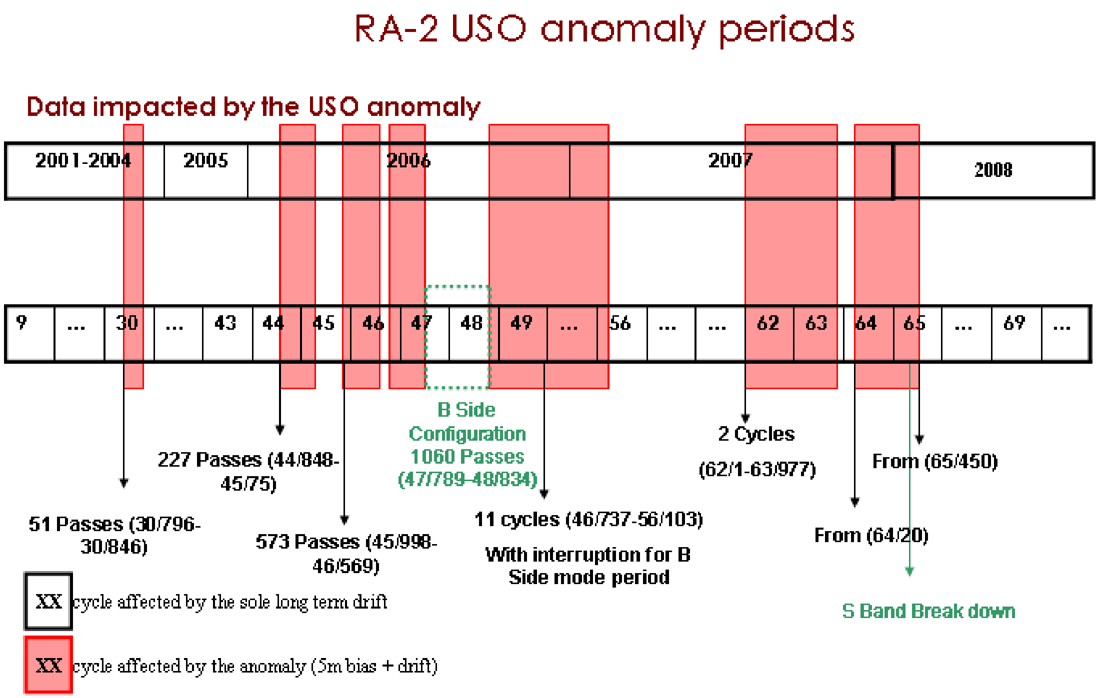


Figure 3: *Chronology of USO Correction anomaly.*

without this correction during the anomaly periods.

The correction of the Ultra-Stable Oscillator (USO) clock period variation applied to the range depends on the cycle considered. This is detailed hereafter:

For cycle 9 to 40, except for anomaly period (cycle 30): The method to correct the USO clock period is described in Celani (2002 [18]). The correction is regularly updated in the IPF ground processing via an Auxiliary data file. However, due to an anomaly in the ADF format, the correction was not taken into account (Martini, 2003 [54]) in the products for cycles lower or equal to 40. ESA supplies auxiliary files to allow users correcting their own database (Martini, 2003 [54]). The distributed auxiliary corrections containing the drift + bias have to be used. The supplied correction has to be subtracted from the original altimetric range (EOP-GOQ and PCF team, 2005) and consequently added to SSH.
**For all products**: Available on a daily basis (1Hz) at the following adress:
http://earth.esa.int/pcs/envisat/ra2/auxdata/OldCorrection.html
Note that for our database, the distributed auxiliary correction was smoothed over a 1-month period to filter peaks and short period variations.

For cycle 41 to 45, (outside of the anomaly periods during cycle 44 and 45): The USO drift + bias is already taken into account in the products. No additional auxiliary correction has to be used.

From cycle 45 to 85, and for all the previous anomaly periods (during cycles 30 and 44): ESA supplies auxiliary files to allow users correcting their own database (Martini, 2003 [54]).
The distributed auxiliary corrections containing the drift + anomaly correction have to be used:
**For FDGDR products**: Available on a product basis (1Hz) at the following adress :
Available on http://earth.esa.int/pcs/envisat/ra2/auxdata/NewCorrection.html.
**For IGDR products**: Available on a daily basis (1Hz) at the following adress :
ftp://diss-nas-fp.eo.esa.int
under the directory : igdr_ous_corr
**For GDR and SGDR products**:Available on a cyclic basis (1Hz) at the following adress :
ftp://diss-nas-fp.eo.esa.int
under the directory : gdr_ous_corr
Note that for these correction a ESA software has to be used and downloaded from http://earth.eo.esa.int/pcs/envisat/ra2/auxdata/software/ENPdsAddUSOCorrection. It applies to 1Hz and 20Hz products.

Between cycle 86 and 92: ESA supplies auxiliary files to allow users correcting their own database. The distributed auxiliary corrections containing a correction of the USO correction badly implemented in IPF6.02 chain.
**For FDGDR**: Not distributed.
**For IGDR**: Not distributed.
**For GDR and SGDR products**: Available on a cyclic basis (1Hz) at the following adress :
ftp://diss-nas-fp.eo.esa.int
under the directory : gdr_ous_corr

After 93 and for v2.1 reprocessed data: No more auxiliary files needed: the USO drift is now directly/properly corrected in the range.

# 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 4. The measurement unavailability over the whole mission is about 5% in average. Eleven cycles have more than 10% of unavailability, notably from cycle 13 to cycle 17. 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 13, 14, 16, 17, 22, 34, 51, 53, 55, 56, 59, 62 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.

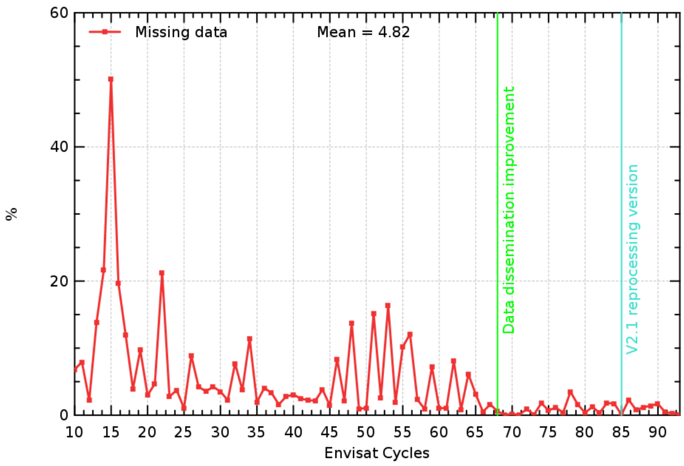


Figure 4: *Monitoring of the percentage of missing measurements relative to what is theoretically expected over ocean*

Figure 5 shows an example of missing measurements for cycle 93 . 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.

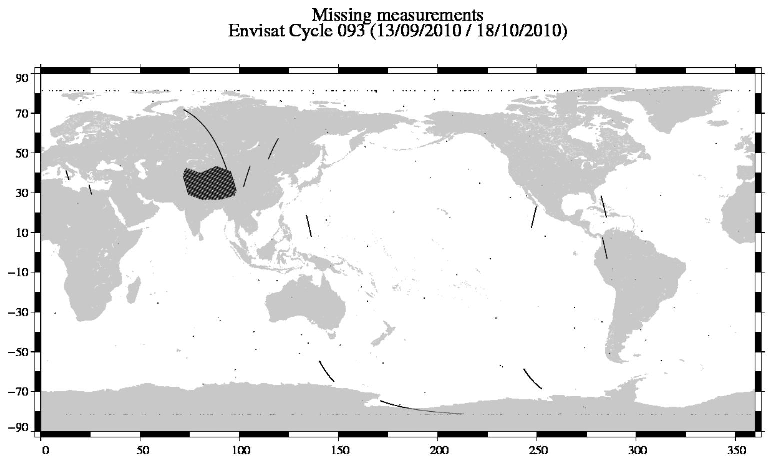


Figure 5: *Envisat missing measurements for cycle 93.*

It has been noticed that some pass segments were regularly missing. Figure 6 shows the pass segments missing more than 5 times over the 11 last cycles. 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).

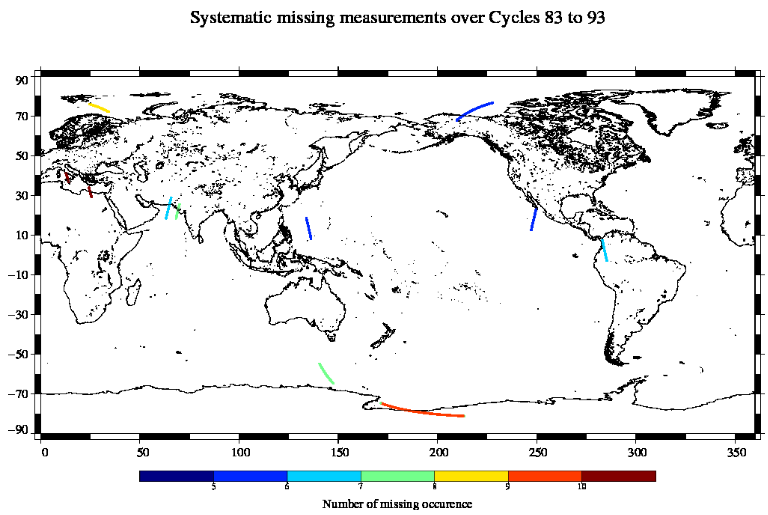


Figure 6: *Pass segments unavailable more than 5 times between cycles 83 and 93 . The color indicates the occurrence of unavailability*

Finally, the list of instrument and platform events is available in Part 10.1.. 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 7. The radiometer unavailability is not constant: it is greater than 4% for cycles 14 to 19 and for cycles 58 and 60, and lower than 2% elsewhere.
After 2008, the MWR unavailability is very stable and very low except for cycle 90 where 8 passes are missing.

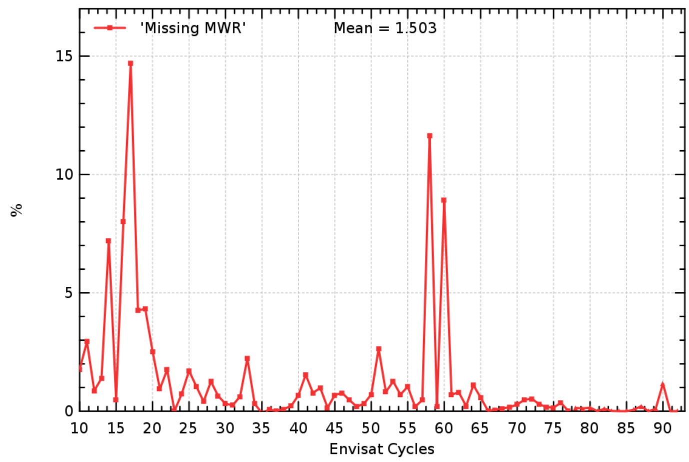


Figure 7: *Cycle per cycle percentages of missing MWR measurements*

## 4.3. Edited measurements

Data editing is necessary to remove altimeter measurements having lower accuracy. It consists in:
- First: removing data impacted by the S-Band anomaly. Note that this step is not necessary anymore from cycle 60 onwards, when the source of the anomaly was solved.
- Then removing of data corrupted by sea ice.
- Then, removing measurements out of thresholds tuned for several parameters.
- The fourth 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 S-Band anomaly

During the Commissioning Phase, it has been discovered that the RA-2 data are affected by the so-called S-Band anomaly. The anomaly results in the accumulation of the S-Band echo waveforms (Laxon and Roca, 2002 [47]). It happens randomly after an acquisition sequence and is only stopped by switching the Ra-2 in a Stand-By mode. When this anomaly occurs, the S-Band waveforms are not meaningful. Consequently, all the S-Band parameters and the Dual Frequency ionosphere correction are not reliable. Notably, the S-Band Sigma0 is unrealistically high during these events. Thus applying a threshold of 5 dB on the (Ku-S) Sigma0 differences is very efficient for detecting the impacted data over ocean. The ratio of flagged measurements over ocean is plotted in Figure 8. A method has been developed to flag the impacted data over all surfaces (Martini et al., 2005 [55]). This flag is available in the GDR product since cycle 51 and has been applied in our internal data base from cycle 54 onwards.

Except from cycle 10 where 33% of the data are impacted (before any solution as found), between 0 and 8% of the data are affected by the S-Band anomaly. From cycle 31 onwards, some modifications have been performed by ESA to decrease the duration of these events: instrument switch-offs (Heater 2 mode) were performed twice a day over the Himalayan and Rocky mountain region. This prevents the S-Band anomaly from lasting more than half a day. Thanks to this procedure the ratio of impacted data decreased from 4.2% (cycles 11 to 30) to 2.2% (cycles 31 to 38). On the 27th of June 2007 (cycle 60) an on-board patch solving the problem has been successfully uploaded. Since then and until the S-Band loss, no occurrences of the anomaly have been detected.

Finally, an algorithm for the S-Band waveform reconstruction has been developed which will enable recovery of data affected by the anomaly. The correction is implemented in the full mission reprocessing began in 2011.

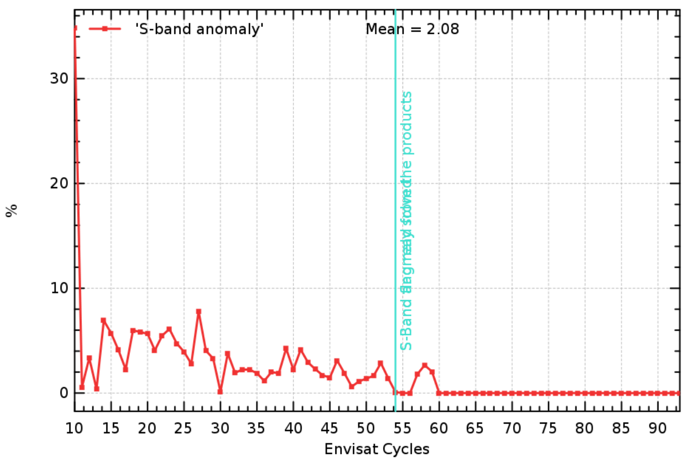


Figure 8: *Cycle per cycle percentages of data impacted by the S-Band anomaly and major events concerning the band.*

### 4.3.2. Measurements impacted by Sea Ice

Since Envisat operates between 82N and 82S of latitude, sea ice detection is an important issue for oceanic applications. For the historical data, no ice flag is available in the Envisat products (their is one in the reproccessed ones), therefore alternate sea ice detection techniques are used in order to retain only open ocean data. 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 [31]). We employ the Peakiness parameter (Lillibridge et al, 2005 [51]) 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 9

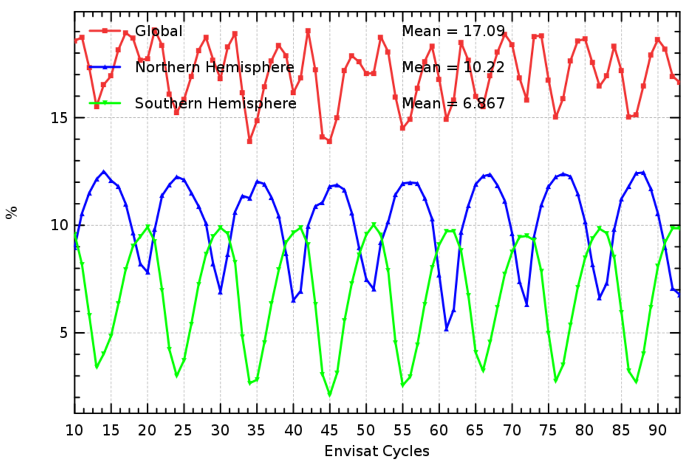


Figure 9: *% of edited points by sea ice flag over ocean*

In September 2007, a record-breaking minimum of flagged data for the Northern Hemisphere zone around cycles 61-63 see Figure 9, due to a low ice extend record. This was observed by different Envisat instruments including its altimeter RA2. 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 these low SLA performances. See further details on 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, a record-breaking minimum of flagged data also occured for the Southern Hemisphere zone around cycles 45 see Figure 9.

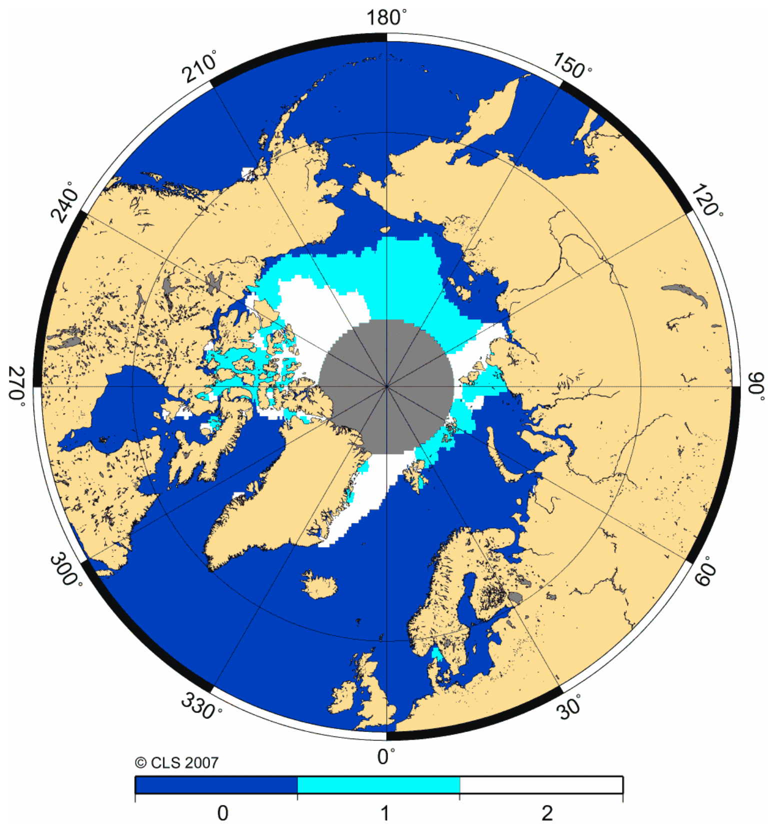


Figure 10: *Sea ice coverage seen by Envisat RA-2, averaged 1° by 1° over September 2007 and compared to an average over the previous years (2003-2006). Dark blue = open ocean, White = usual ice coverage, Light blue = open ocean seen in 2007 where sea ice was observed previously.*

### 4.3.3. 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 4.

| 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 |
| | | .../... |

| Parameter | Min thresholds | Max thresholds |
|---|---|---|
| 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 4: *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 11. These ratios are impacted by successive changes/events in the data processing. The RMS of elementary measurements has the strongest ratio among the altimeter parameters, more than 1% in average with an increase during cycles 86 to 95, probably due to the uso problem solved in v2.1 reprocessing version. On cycle 47, a special operation was executed to limit RA-2 Chirp Bandwidth to 80MHz. It has impacted this parameter as well as the dual frequency ratio. A slight seasonal signal is visible on the curve, mostly due to sea state seasonal variations. The number of elementary measurements has a surprisingly low ratio, except for cycles 14 and 20 when wrong configuration files were uploaded on-board after a RA-2 event. A slight increase is noticed from cycle 54 onwards due to the use of the product S-Band anomaly flag instead of the criteria based on KU/S Sigma0 difference. The square of the off-nadir angle derived from waveforms leads to very stable editing ratio but with a drop on cycle 41, due to a change of the algorithm in CMA7.1. 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. The dual frequency ratio shows a slight increasing trend between cycles 15 and 28 which cannot be considered as significant, given the scatter of the curve. The Ku-band SWH, sigma0 also present a slight increase, mainly since cycle 41. Concerning MWR ratios it is very stable and low before cycle 41 and still low but more cahotic afterwards.

After cycle 85, corresponding to the change of IPF and CMA to version v2, a significant increase is observed on the number of data edited on Rms of 20 Hz range measurements > 25 cm (from 1 to 1.5%), Number of 20-Hz range measurements < 10 and backscatter coefficient out of the [7 dB, 30 dB] range. This is likely due to the USO problem noticed in IPF 6.02 version solved by the IPF 6.04 (in v2.1) version.

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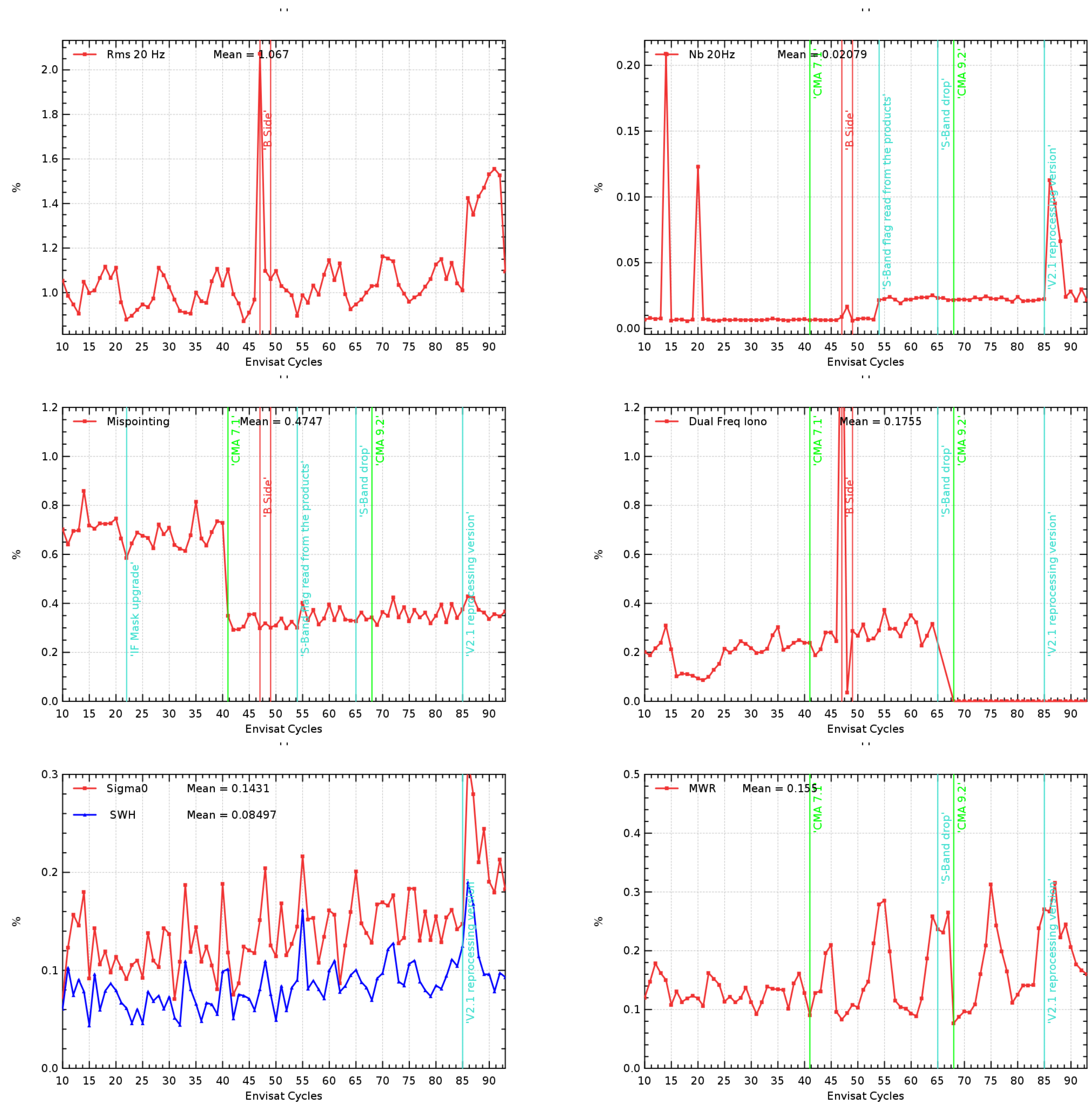



Figure 11: *Cycle per cycle percentages of edited measurements by the main Envisat altimeter and radiometer parameters:* ***Top-Left)*** *Rms of 20 Hz range measurements > 25 cm,* ***Top-Right)*** *Number of 20-Hz range measurements < 10,* ***Middle-Left)*** *Square of off-nadir angle (from waveforms) 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 outside > 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.*

### 4.3.4. 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, ses 12) 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.

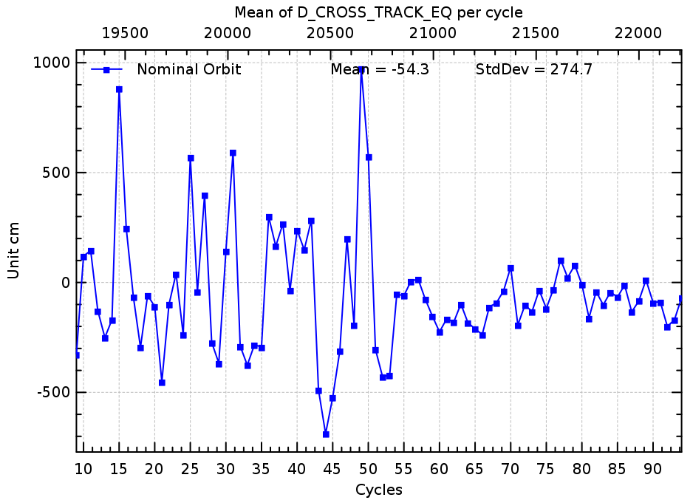



Figure 12: *Cross track deadband measured at equator by comparison to a theoretical track.*

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 detailed is:

- 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 °, 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:
**$1^{st}$ criteria**:
for small portion of pass (less than 200 points) the sample is not big enough to compute reliable statistic. The selection must not be severe: Selected areas: |latitude|<66 °, variability<30cm,

bathymetry>1000m, distance to coast>100km Threshold: 30 cm on mean and standard deviation
**$2^{nd}$ criteria**:
for other passes Selected areas: |latitude|<66°, variability<10cm, bathymetry>1000m, distance>100km Threshold: 15 cm on mean and standard deviation

The percentage of edited measurements over ocean on these criteria has been plotted in Figure 13. 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 mentioned previously impacted the SSH editing ratio on cycle 47. 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.
A significant decrease is observed on the number of data edited on SLA criteria after cycle 85, corresponding to the change of IPF and CMA for V2 reprocessing version (exept for USO remaining anomaly). This is due to a relatively higher amount of data edited on other criteria (see above). The global amount of data remaining globally stable (around 23% edited).

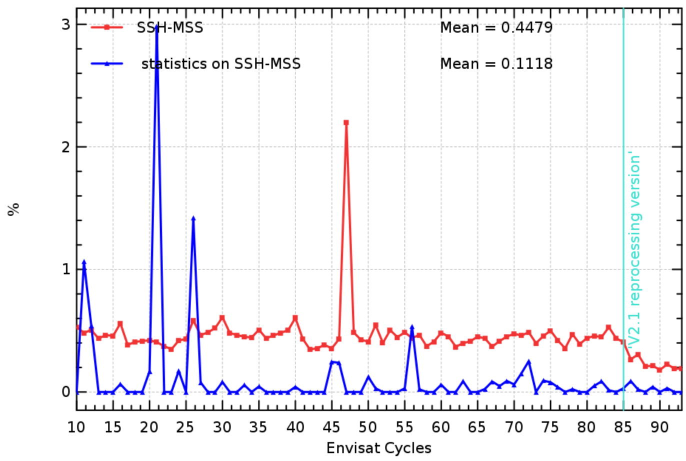


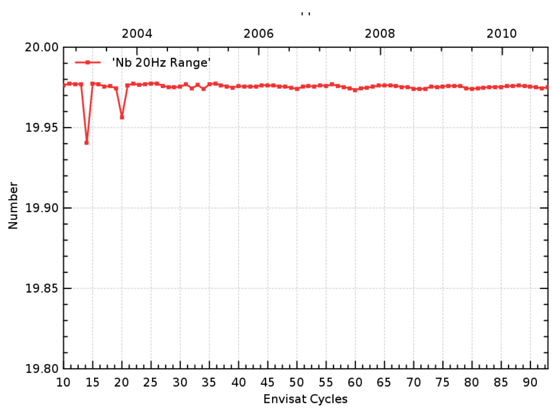

Figure 13: *SSH-MSS out of the [-2, 2m] and edited using thresholds on the mean and standard deviation of SSH-MSS on each pass*

# 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, only the main Ku-band parameters are 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.
Note that this part contains Envisat/ERS-2 comparisons. For those plots be aware that:
- ERS data concern the sole North Atlantic ocean (since july 2003, see 3.2.2.). Since May 2008 (cycle 136) additional stations were added near Indonesia and Tasmania. Therefore, to improve the significance of the Envisat/ERS-2 comparison, long term monitoring of altimeter parameters difference is performed on this restricted area all over the Envisat period using a repeat-track method.
- For contractual reasons the monitoring of the cross validation with ERS stops in november 2005.

## 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 14. 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 and 20 are due to wrong setting of the RA-2 just after recovery. 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 9.0 cm. This value represents a rough estimation of the 20 Hz altimeter noise (Zanifé et al. 2003 [83], Vincent et al. 2003a [81]). 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.



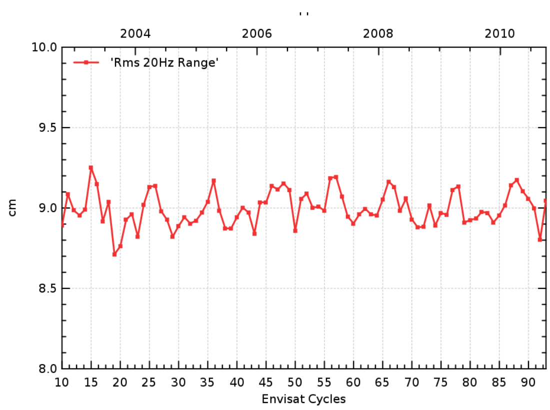




Figure 14: ***left****) Mean per cycle of the number of 20 Hz elementary range measurements used to compute 1 Hz range.* ***right****) Mean per cycle of the standard deviation of 20 Hz measurements.*

The corresponding S-Band parameters have a less stable behaviour (see figure 15). The S-Band mean number and RMS of 20Hz measurements have respectively an increasing and decreasing trend. Moreover jumps are noticed on the two plots on cycle 41 due to a change in the IPF Level 1 processing chain (Rx dist Fine). Moreover, from this cycle, the ascending and descending values are slightly different on the S-Band mean RMS of 20Hz measurements.

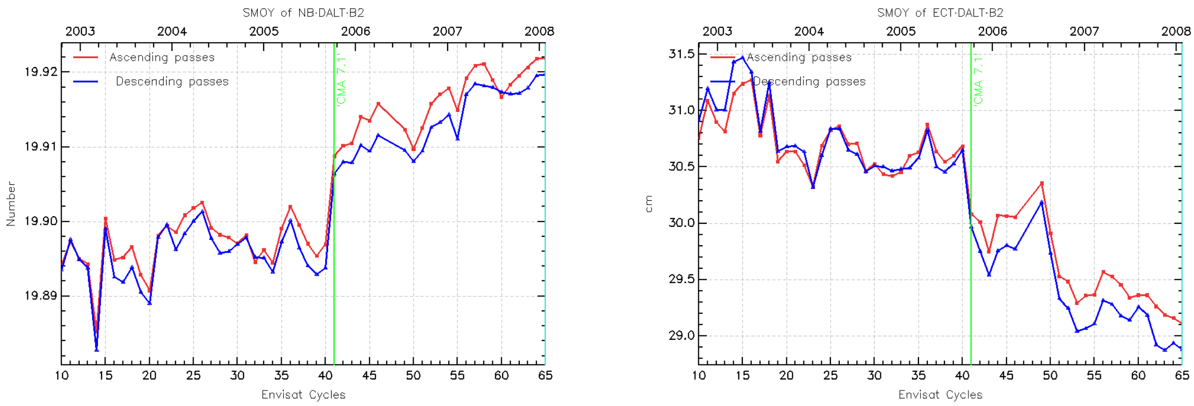



Figure 15: ***left****) Mean per cycle of the S-Band average of 20 Hz measurements separating ascending and descending passes (cm).* ***right****) Mean per cycle of the S-Band standard deviation of 20 Hz measurements separating ascending and descending passes (cm)*

The histogram of RMS of Ku Range on cycle 93 is plotted in figure 16.

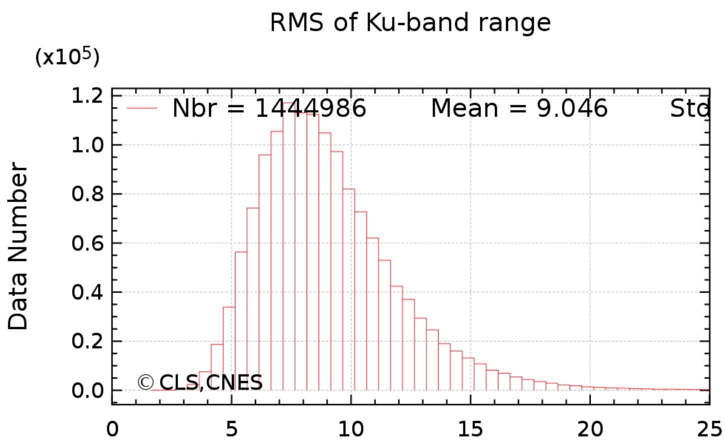



Figure 16: *Histogram of RMS of Ku range (cm). Cycle 93 .*

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## 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 17. The mean value is between 0.02 deg2 and 0.03deg2 before cycle 41. There is a slight rising trend over this period and a 0.005 deg2 jump between cycles 21 and 22 which is due to the upgrade of the IF mask filter auxiliary data file. The mean value observed during this period is not significant in terms of actual platform mispointing. This is due to the way the slope of the waveform trailing edge is computed. On cycle 41, a 0.02 deg2 drop occurs, due to an improvement of the mispointing estimation in CMA v7.1. The mispointing was estimated through the waveform trailing edge slope using an adaptative window that defines the beginning and the end of the slope. To avoid the filter bump effect that leads to high value of the mispointing, an optimum and fixed gate was estimated and implemented. Note that the rising trend observed previously desappeared. This is probably an effect of the regular update of the IF filter since cycle 41. Finally, a smaller value is noticed for the cycle 48, for which altimeter was turned to its B-Side for a short period (cf. details in part 3.1.).

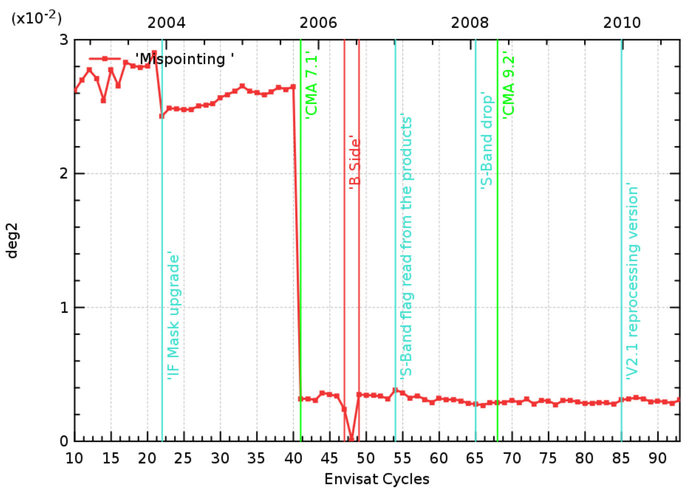



Figure 17: *Mean per cycle of the square of the off-nadir angle deduced from waveforms (deg$^2$).*

The histogram of the squared mispointing is plotted in figure 18.

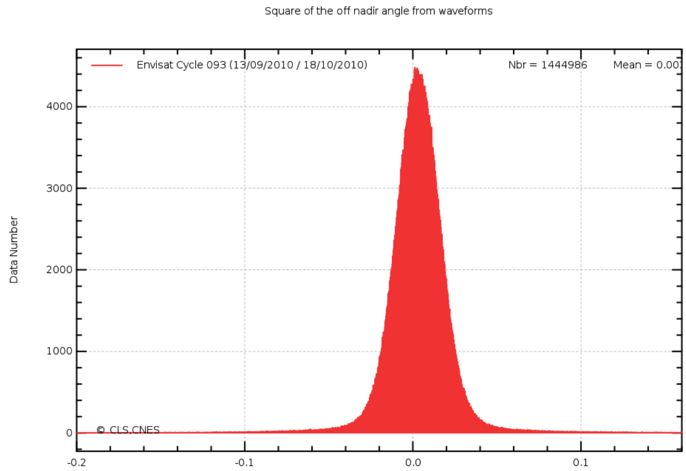



Figure 18: *Histogram of off-nadir angle from waveforms (deg²). Cycle 93 .*

## 5.3. Significant Wave Height

The cycle by cycle mean and standard deviation of Ku and S-Band SWH are also plotted in figure 19. The curve reflects sea state variations. The mean value of Ku SWH is 2.66 m. The S-Band mean SWH is drifting and rather lower mainly after cycle 50. The cycle by cycle mean of Envisat-Jason-1 differences and ERS-2-Envisat differences are plotted in Figure 19.
These differences are quite stable. Envisat SWH is respectively 14 cm and 22 cm higher than Jason-1 and ERS-2 SWH. As for range parameters, some strange behaviours on S-Band SWH are also noticed (see Figure 20): jumps occurred during the S-Band time series (cycle 41 and 51) due to a change in the IPF Level 1 processing chain (Rx dist fine), and inconsistencies between ascending and descending passes.

The histograms of Ku SWH is plotted in figure 21.

The Ku SWH histogram has changed on cycle 85 during the change of version (IPF 6.2 and CMA9.3). Due to the change of SigmaP in Level 0 processing, the SWH estimation changed.
SWH is defined as a function of a constant (related to the PTR width) SigmaP and SigmaC, the slope of the wave form leading edge as:
SWH=2c$\sqrt{SigmaC^2 - SigmaP^2}$.
Mean SWH values are now approximately reduced by 12cm with a SWH dependancy due to the above relation.

Due to this reduction and regarding the noise level of low values of SWH, null value are over represented on the right hand histogram.
However, the new mean values of SWH are more in line with Jason1 and 2 values as well as with ECMWF models.

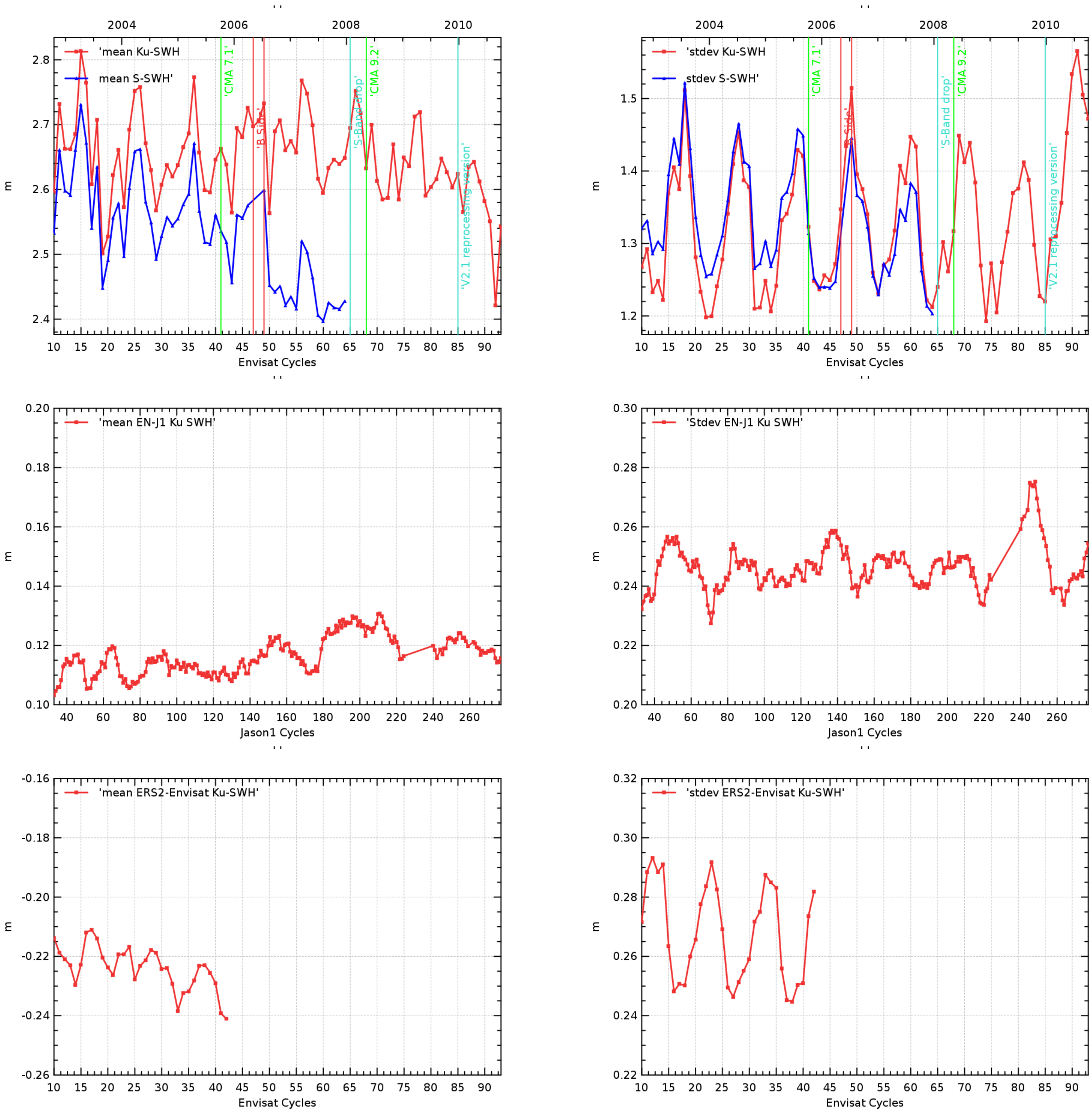



Figure 19: *Global statistics (m) of Envisat Ku and S SWH* ***top)*** *Mean and Standard deviation.* ***middle)*** *Mean Envisat-Jason-1 Ku SWH differences at 3h EN/J1 crossovers.* ***bottom)*** *Mean and Standard deviation of ERS-2-Envisat Ku SWH collinear differences over the Atlantic Ocean.*

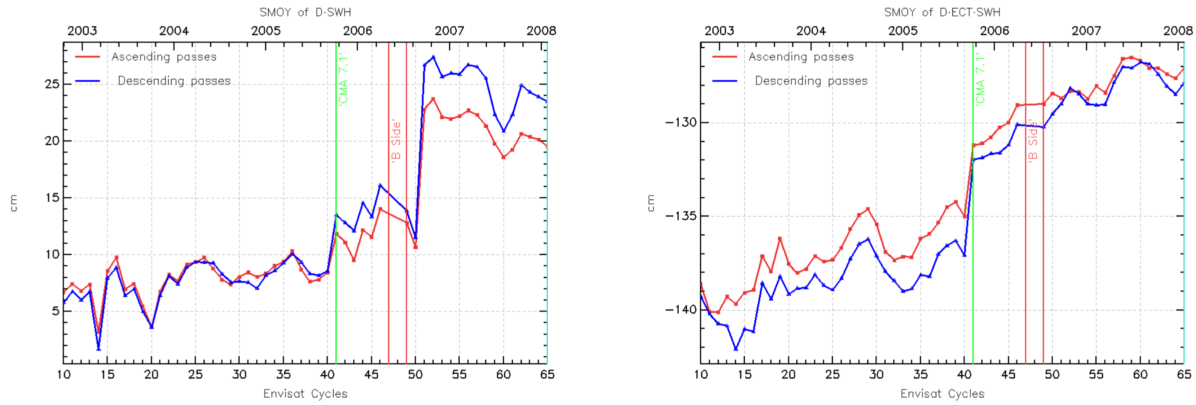



Figure 20: ***left)*** *Mean per cycle of SWH(Ku)-SWH(S).* ***right)*** *Mean per cycle of RMS20Hz[SWH(Ku)]-RMS20Hz[SWH(S)].*

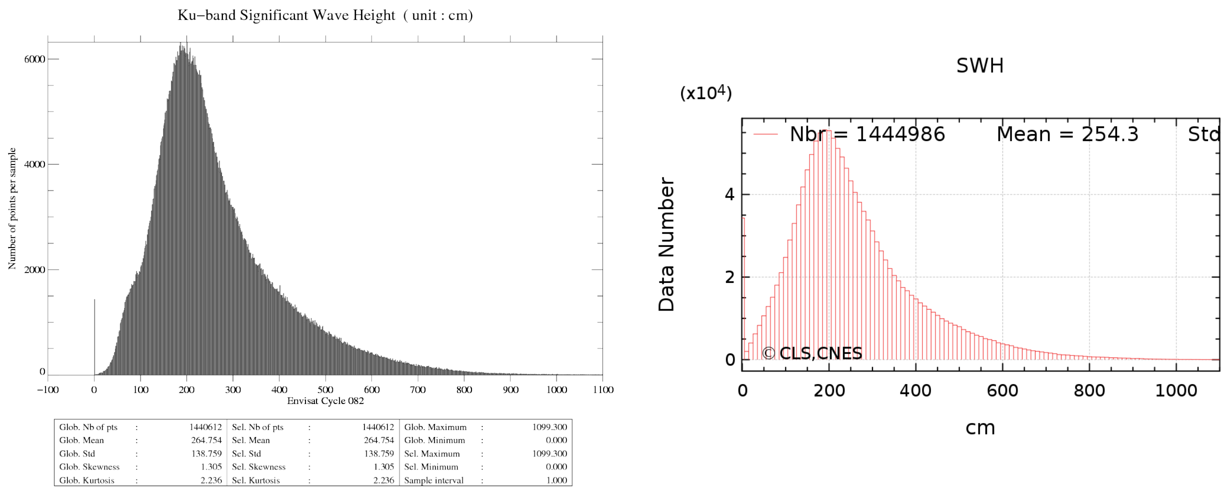



Figure 21: *Histogram of Ku SWH (m) before Cycle 85 (here cycle 82) and after cycle 85. Cycle 93 .*

## 5.4. Backscatter coefficient

The cycle by cycle mean and standard deviation Ku and S-Band Sigma0 are plotted in Figure 23. Note that a -3.5 dB bias has been applied (Roca et al., 2003 [67]) on the Ku-band Sigma0 in order to be compliant with the wind speed model (Witter and Chelton, 1991 [82]). The mean values in Ku band are stable, around 11.1 dB. Two 0.66 dB jumps are visible on the S-Band on cycles 14 and 22. They are due to a correction of the AGC evaluation. This modification has been included in IPF version 4.56, used from cycle 22 onwards for the current processing and for all the reprocessed cycles. The cycle by cycle mean of Envisat-Jason-1 differences and ERS-2-Envisat differences are plotted in figure 23. The mean difference between Envisat and Jason-1 Ku-band Sigma0 is -2.9 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 a homogenous 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... This potential trend, though slight, has to be closely monitored.

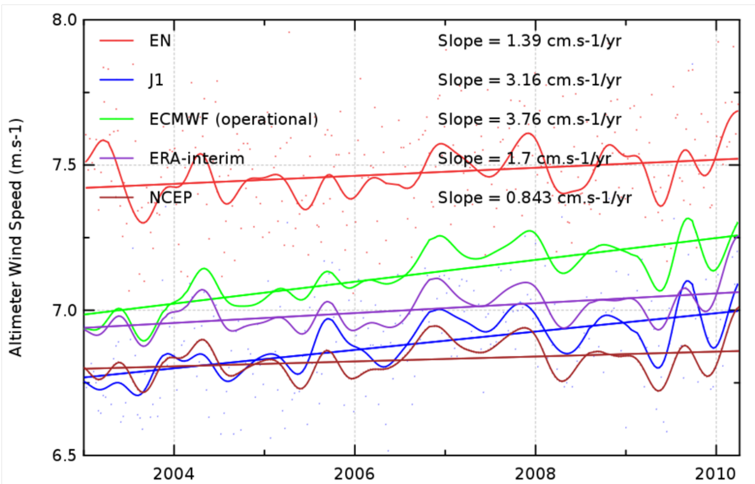



Figure 22: *Wind speed from different sources (EN, J1, ECMWF, NCEP).*

The mean ERS-2-Envisat Ku-band Sigma0 difference is 0.05 dB. However, this mean value accounts for the calibration correction applied in the ground processing to be compliant with the wind speed algorithm (Witter and Chelton, 1991 [82]). The monitoring of (ERS-2 - Envisat) Sigma0 differences exhibits a 0.1 dB jump between cycles 38 and 39. This jump occurs at the end of cycle 38, on the 4th July 2005 11:29 UTC. Since no jump is observed on the Envisat/Jason-1 differences (see previous yearly report), it may be attributed to ERS-2.

Histograms of Ku Sigma0 is plotted in figure 24. The Ku Sigma0 histogram has a good shape.

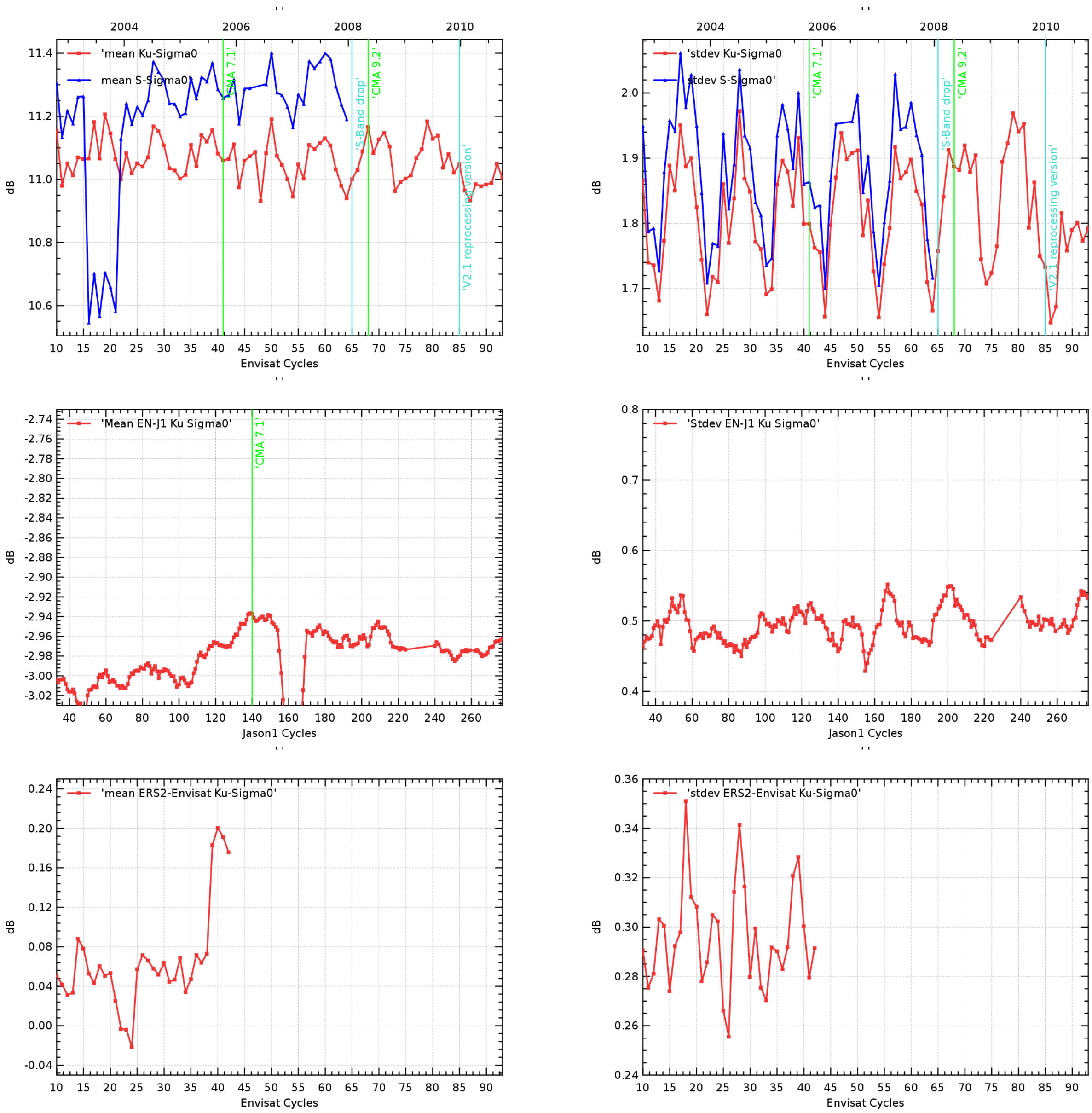



Figure 23: *Global statistics (dB) of* ***top****) Envisat Ku and S Sigma0 Mean and Standard deviation.* ***middle****) Mean Envisat-Jason-1 Ku Sigma0 differences at 3h EN/J1 crossovers.* ***bottom****) Mean and Standard deviation of ERS-2-Envisat Ku Sigma0 collinear differences over the Atlantic Ocean.*

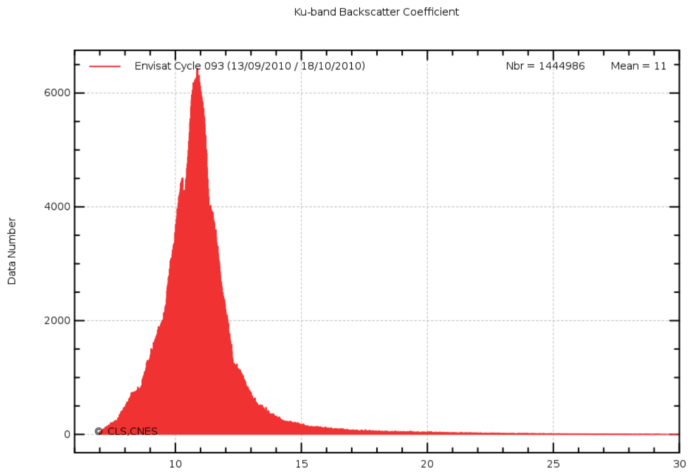



Figure 24: *Histogram of Ku Sigma0 (dB). Cycle 93 .*

## 5.5. Dual frequency ionosphere correction

As performed on TOPEX (Le Traon et al. 1994 [48]) and Jason-1 (Chambers et al. 2002 [19]) 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. As previously mentioned, the JPL GIM ionosphere corrections are computed to assess the dual frequency altimeter based ionosphere correction. The cycle by cycle mean of dual frequency and JPL GIM ionosphere correction are plotted in figure 25. The mean value of the two corrections is clearly decreases from the beginning of Envisat mission due to inter-annual reduction of the solar activity. Since late 2009 it increases again as the solar activity rises (11 year solar cycle). The mean differences (GIM-Dual frequency), plotted in figure 25, is stable around -0.8 cm. It is stronger in absolute value for high ionosphere corrections, for descending passes (in the daytime). The standard deviation of the difference is plotted in figure 25. Low values, less than 2 cm, indicate a good correlation between dual-frequency and GIM corrections. Notice that, in the GDR products, the same sea state bias (SSB) has been used to correct the Ku and S-Band Ranges for cycles 9-40. Since cycle 41, a suitable Ku and S-Band SSB correction is used on the two bands before computing the dual frequency ionosphere correction from Ku and S-Band ranges (Labroue 2004 [44]). In this analysis, the sea state bias (SSB) used to correct the S-Band Ranges for cycles 9-40 is updated in its right S-Band version. The differences with the GDR correction are very small with no impact on the global statistics and only small geographic variations between -1 mm and +1.5 mm (Labroue 2004 [44]). However, the update was done because the impact was shown to be significant in the Mean Sea Level Trend estimation of around 0.4 mm/year (Particular investigation MSL of Yearly report 2008).

Since the S-Band loss, this correction is not available anymore. As written before, the GIM Ionospheric correction is used instead. 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 25. Different trends are observed on the two curves.
Concerning the discrepencies between both missions, note that, in terms of noise, the higher noise for Jason-1 is due to a higher noise in the C band (used for Jason-1 bifrequency ionophere) than in S-Band (used for Envisat one). The filtering step applied on both ionospheres from the products anable 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 dependancy between the absolute value and the bias on this correction (observed on Jason-1). This would deserve more investigation.

This year analysis concerning stability of the ionospheric correction were performed. The results are synthetized in a technical note summed up in part 7.3. and proposed the implementation of a new GIM model ionospheric correction corrected by Jason-1 bifrequency correction. This, mainly in the aim of having a more accurate correction after S-Band loss for the higher solar activity period to come.

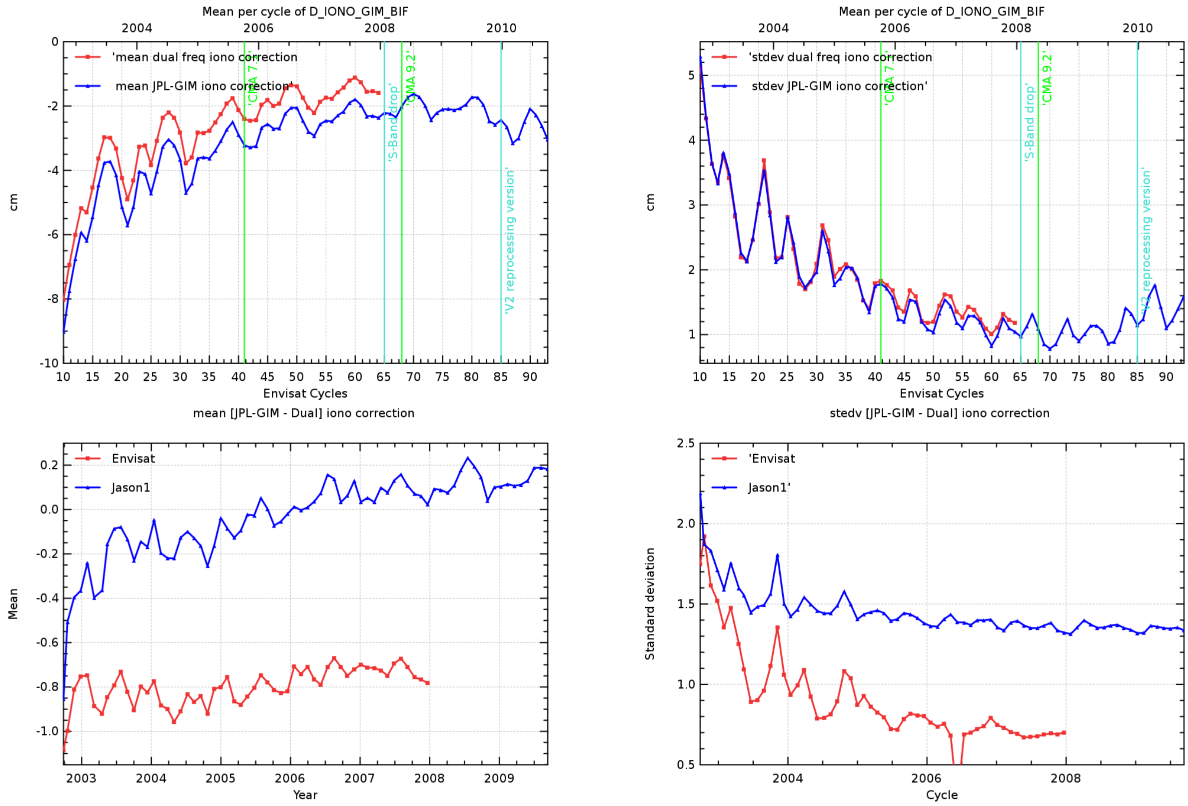



Figure 25: *Comparison of global statistics of Envisat dual-frequency and JPL-GIM ionosphere corrections (cm).* ***top****) Mean and standard deviation per cycle of Dual Frequency and GIM correction.* ***bot****) Mean and standard deviation of the differences for Envisat and Jason-1*

## 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 [61]). As an example, the scatter plot of MWR correction according to ECMWF model for cycle 93 is given in figure 26.

Since the beginning of the mission, the instrumental parameters at 36.5 GHz have been drifting and investigations are in progress to identify the source for these drifts. In particular, different behavior is observed depending on the brightness temperature values. Mean and standard deviation of (MWR-ECMWF model) differences are plotted in figure 27. The difference is not really stable, though the global mean remains small. An annual signal of about 1.5mm of amplitude seems to appear around cycle 40-45. This annual signature was previously attributed to successive jumps on the ECMWF side as explained into S. Abdalla's presentation (QWG 2008), because similar paterns could be seen when comparing the difference of correction radiometric - model on Jason-1(see 27). On the plot, the main model changes are marked out by vertical lines on the plots (see ECMWF web site [24]). Today, the hypothesis of a real annual cycle is rehabilitated. Actually, this signal becomes really clear and uncorrelated to the ECMWF updates when separating Ascending and Descending tracks (see Yearly report 2009). Furthermore, selections per values of wet troposphere also enlights this annual signal. Therefore, it would likely be a difference of behavior between model and radiometer in some conditions. This signal is currently under investigation and would

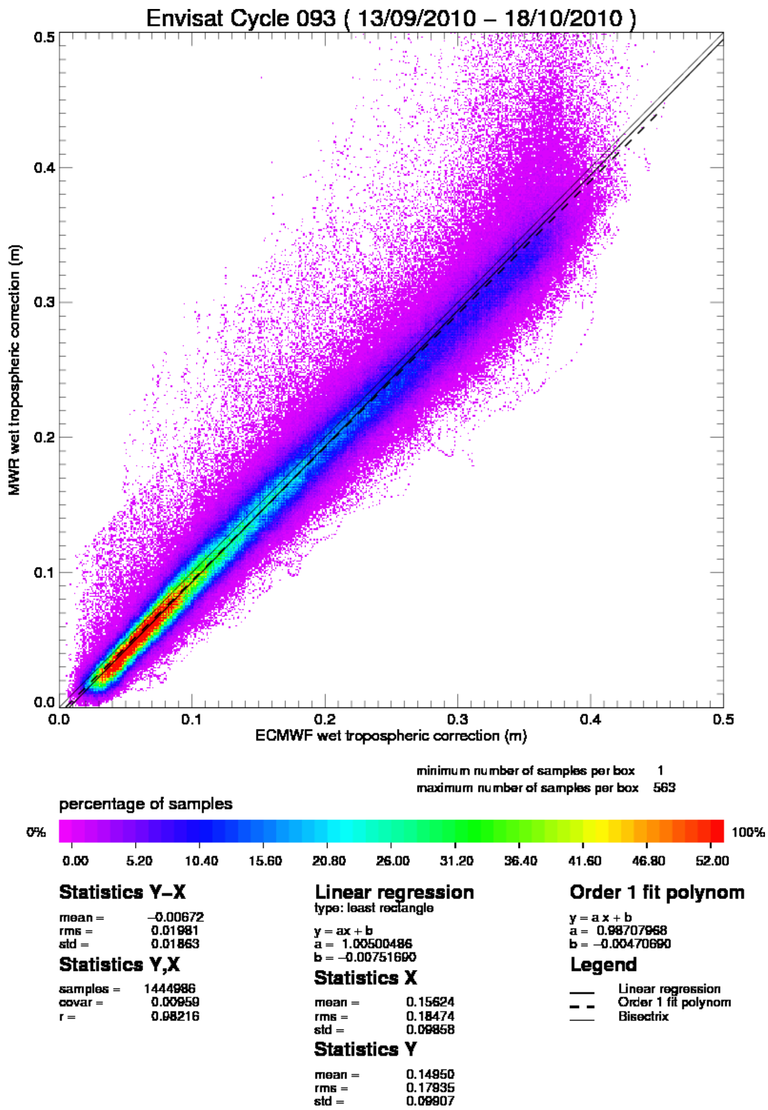



Figure 26: *Scatter plot of MWR correction according to ECMWF model (m)*

be attributed to the side lobe correction introduced on cycle 41 that better takes into account the coastal polution on MWR tropospheric correction.
The standard deviation is also very variable throughout the mission. It drops down by 2 mm from cycle 13, decreases afterwards linearly from cycles 14 to 41 and adopts a cahotic behavior until cycle 65 where it stabilizes around 1.5 cm. This decrease cohincidates with another change of model but because MWR seems to undergo a biger jump than ECMWF series, it could also be due to a larger amount of data taken into acount at the end of the mission (see part 4.3.4..) In 2010 it increases again to 1.7cm on the 26/01/2010 this time probably not due to another ECMWF change (because no such impact seen on Jason-1.
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/ ([64]).

This year analysis concerning stability of the wet tropospheric correction were performed. The results are synthetized in a technical note sumed up in part 7.2..

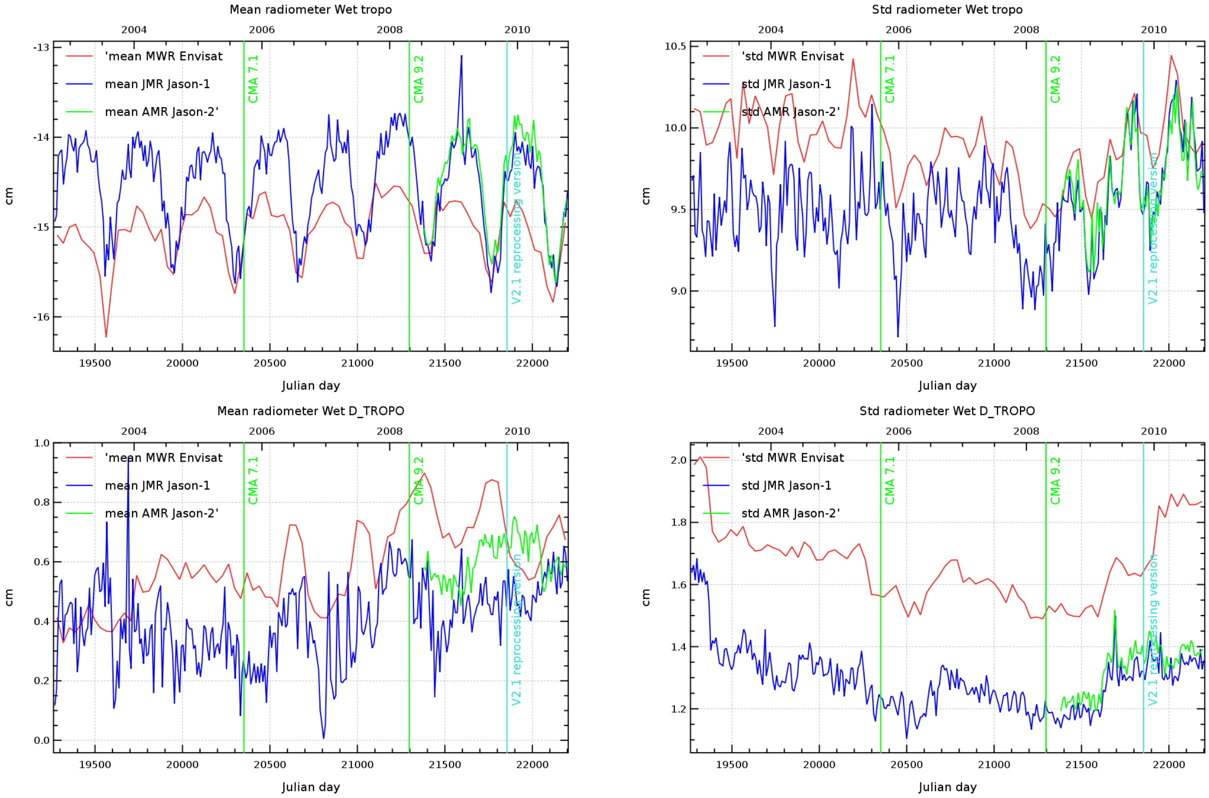



Figure 27: *Comparison of global statistics of Envisat MWR and ECMWF wet troposphere corrections (cm).* ***top)*** *Mean and standard deviation per cycle of MWR, JMR and AMR corrections* ***bot)*** *Mean and standard deviation of the differences versus ECMWF model. Vertical lines represent the major events.*

Note that the 1.5 mm jump around Mai 2010 noticed on Jason2 mean difference of tropospheric correction (AMR-ECMWF) is explained and due to new calibration coeficients.

The (ERS-2 -Envisat) cyclic 23.8 GHz brightess temperatures differences over the Atlantic area are plotted on figure 28. The ERS-2 drift proposed by Eymard et al., 2003 [27] is applied. The correction of the drift proposed by Scharroo et al., 2004 [73], should decrease the mean difference by 0.8K as described in Mertz et al., 2004 [58]. Nevertheless, the mean difference variations are more steady for the period after cycle 21. The (ERS-2 -Envisat) TB36.5 GHz values are also reported in figure 28. The differences before and after cycle 18 have a different behaviour: one observes a great decrease from -2 to -4 K between cycles 13 and 17 whereas the curve seems to be steadier after cycle 18. This is not an impact of the coverage of the data since in the restricted area, the statistics reveals the same features. They also show an unusual behaviour of the TB values during that period. Note that this behaviour is not visible on hottest or coldest values but mainly on the mean values. The impact of the drift of the TB36.5 on (ERS-2 -Envisat) wet troposphere correction differences is visible in figure 29.

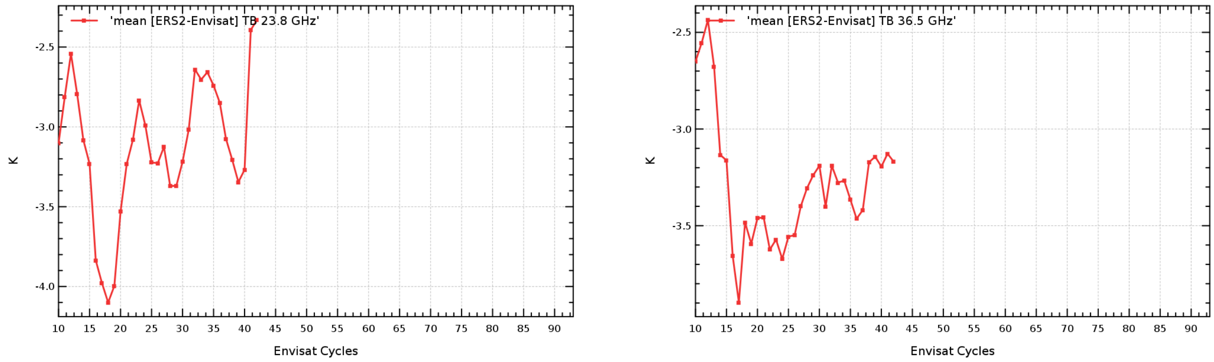



Figure 28: *Monitoring of the (ERS-2 - Envisat) brightness temperatures*

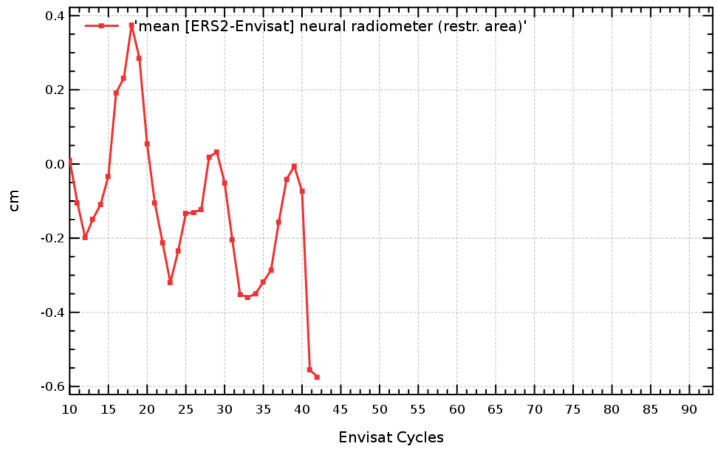



Figure 29: *Monitoring of the (ERS-2 - Envisat) wet troposphere correction*

# 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.

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

$$\begin{aligned}
\sum_{i=1}^{n} Correction_i \quad = \quad & Dry\ troposphere\ correction : new\ S1\ and S2\ atmospheric\ tides\ applied \\
+ \quad & Combined\ atmospheric\ correction :\ MOG2D\ and\ inverse\ barometer \\
+ \quad & Radiometer\ wet\ troposphere\ correction \\
+ \quad & Filtered\ dual\ frequency\ ionospheric\ correction\ /GIM\ model\ after\ cycle\ 64 \\
+ \quad & Non\ parametric\ sea\ state\ bias\ correction \\
+ \quad & Geocentric\ ocean\ tide\ height,\ GOT\ 2000 :\ S1\ atmospheric\ tide\ is\ applied \\
+ \quad & Solid\ earth\ tide\ height \\
+ \quad & Geocentric\ pole\ tide\ height
\end{aligned}$$

As said in 3.2.1., the new geophysical correction associated with version CMA7 have been updated on the whole data-set in order to have the most homogeneous time series. For Envisat, the discontinuities identified in our dataset are (see [7]) :

- Around cycle 30, 40 and 68, due to the orbit, computed using:
  - UnChained mode before cycle 30
  - GRIM5 gravity model for cycles 9 to 40
  - EIGEN-CG03C from cycle 41 to 68.
- Around cycle 40 due to: - the retracking (IF monthly estimations from cycle 41 onwards).
  - the side lobe correction on MWR wet tropo correction

The USO auxiliary correction distributed by ESA are used in Envisat SSH computation.

## 6.2. Single crossover mean

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. 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.

The time invariant errors and the impact of different corections was extensively studied in the 2008 yearly report ([7]).
More recent studies had shown in 2009 that using homogeneous GDR-C orbits homogenized a lot the crossovers. A EastWest bias is remaining on the comparisons between Envisat and Jason-1 or 2. This was studied this year and the time variation of this bias was extensively studied. They are summarized in part 7.1..

Besides the systematic ascending-descending 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 30. 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 is evidenced on the 3 curves. Its amplitude is approximately 1 cm.

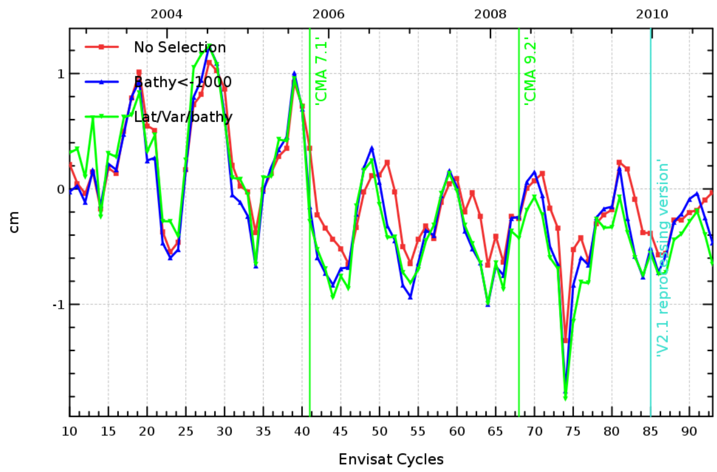



Figure 30: *Time varying 35-day crossover mean differences (cm). Cycle per cycle Envisat crossover mean differences. An annual cycle is clearly visible. Blue: shallow waters (1000 m) are excluded. Green: shallow waters excluded, latitude within [-50S, +50N], high ocean variability areas excluded*

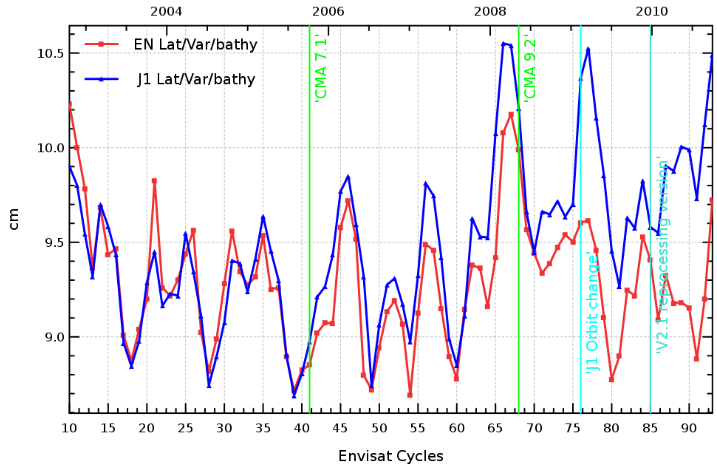
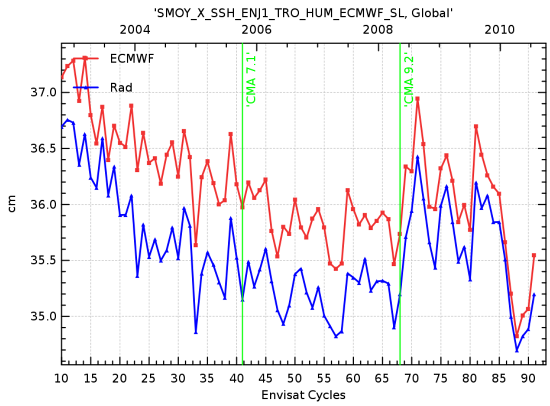



Figure 31: *Standard deviation of along track SLA (m), shallow waters excluded, latitude within [-50S, +50N], high ocean variability areas excluded*

Figure 31 is another way to show that both altimeters have very similar performances. It shows that Envisat and Jason-1 have similar standard deviation of along track SLA before cycle 41 and that Envisat's curve stands around 1mm under Jason's afterwards. This improvement is due to the CMA/IPF V2.1 version. Note that the relative position of Envisat below Jason-1 was shown to be due to the different geographic density of points, which is over estimated at high latitudes for Jason-1 compared to Envisat. To avoid that, statistics averaged per boxe will be provided in the future.



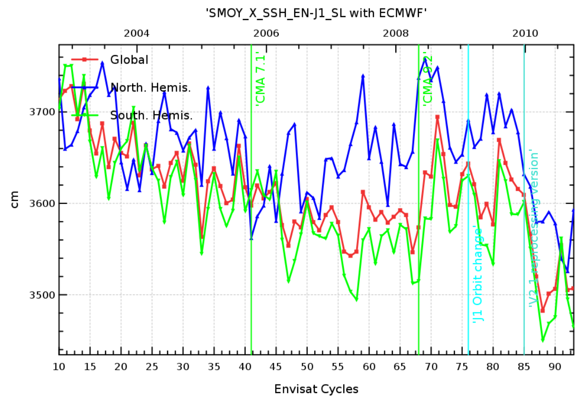




Figure 32: *Mean EN-J1 SSH differences at dual crossovers (cm) for Envisat on global ocean (**left**), and separating Northern and Southern hemispheres (**right**).*

Figure 32 shows a good consistency after mid 2005. Note that the reduction observed after cycle 86 is due to the bias introduced by the CMA/IPF version V2.1 change (details of the bias in 6.4.).

## 6.3. Variance at crossovers

The variance of crossover differences conventionally gives an estimate of the overall altimeter system performance. Indeed, it gathers error sources coming from orbit, geophysical corrections, instrumental noise, and part of the ocean variability. The standard deviation of the Envisat SSH crossover differences has been plotted in Figure 33, depending on three data selection criteria. 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. Cycles 15 and 48 are strongly different because of the low number of crossover points. There are less than 10000 crossovers whereas other cycles lead to more than 20000. Cycles 21 and 26 have higher values because of bad orbit quality over a few passes related to out-of-plane maneuvers. Cycle 21 has a strong value (7 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. Cycle 11 has a relative high value because of missing Doris data. No degradation of the performances have been noticed since the beginning of the USO anomaly on cycle 46. This shows that the correction provided by ESA allows Envisat Ra2 data to maintain the same level of quality.

Similarly, no degradation of the performances have been noticed since the S Band power drop, thanks to the efficient use of the GIM ionospheric correction instead of the missing bifrequency correction. To avoid any jump, the GIM correction is applied with a 8mm bias computed on the last 40 days of SLA difference with GIM and bifrequency corrections (see Figure 25 in part 5.5.). Therefore, the GIM ionospheric correction can be considered to have a good quality for this period of low solar activity. Further studies should be made to evaluate its impact on a higher solar activity period.

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. Performances at crossovers are compared, for the two satellites on Figure 34. The standard deviation of Envisat/Envisat and Jason-1/Jason-1 SSH crossover differences are respectively 6 cm and 5.7 cm. The use of MLE4 retracking on Jason-1 leads to slightly lower than Envisat standard deviation at crossovers. A slight decrease is visible on Envisat plot at cycle 41, thanks to the new standards used for the POE orbit. From cycle 41 onwards, the performances of the two missions are very close.

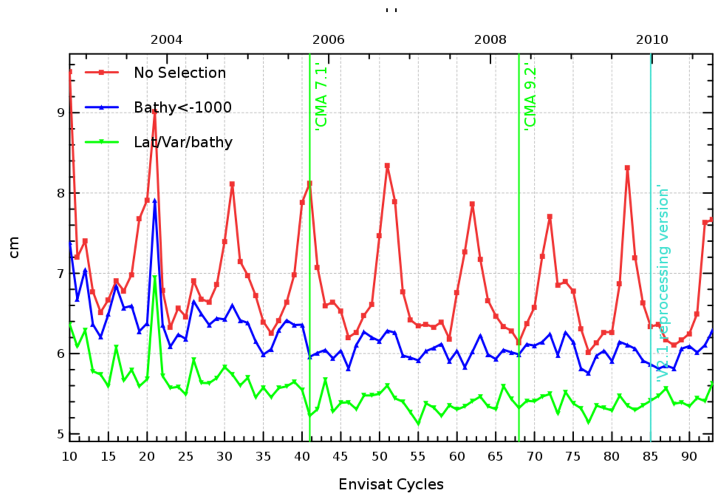



Figure 33: *Standard deviation (cm) of Envisat 10-day SSH crossover differences depending on data selection (with a maximum time lag of 10 days). Red: without any selection. Blue: shallow waters (1000 m) are excluded. Green: shallow waters excluded, latitude within [-50S, +50N], high ocean variability areas excluded.*

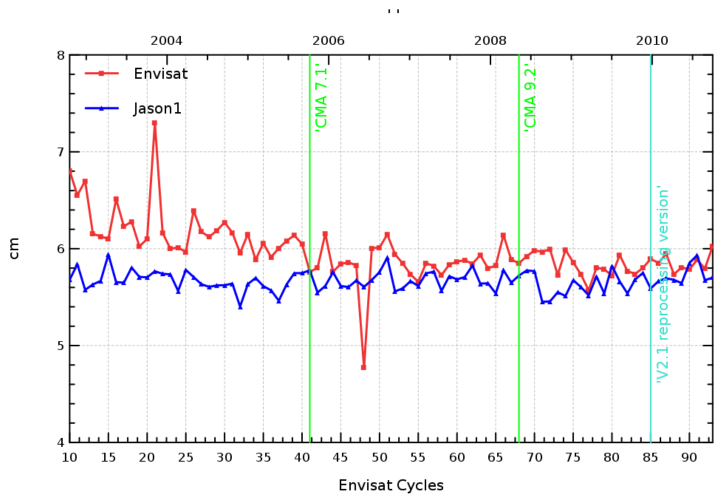



Figure 34: *Comparison of standard deviation (cm) of Envisat (red) and Jason-1 (blue) 35-day SSH crossover differences*

## 6.4. Impact of V2.1 version on data

The following pages are available on the ftp://diss-na-fp.eo.esa.int in a document diffused to users under the name: V2_1_reprocessing_impact_on_altimetric_parameters.pdf

# 1 CalVal status on the Envisat V2.1 reprocessing impact on main altimetric parameters - A. Ollivier - J.F. Legeais - N. Granier - Y. Faugere - F-PAC Calval Team

# 2 Introduction

This comparison analysis was conducted between **V2.1 (IPF V6.04 and CMA 9.3_05)** reprocessing version and the previous version **(IPF V5.06 and CMA 9.2_03)**. It has been done on cycle 85 products and focuses on the main altimetric parameters over ocean.

All GDR and SGDR data are available on the following adress :
ftp://diss-nas-fp.eo.esa.int
under the directory : altimetry_dataset_v2.1.

No USO anomaly is noticed on that cycle and no S Band parameter is available (cycle 85 data are dated after January 17th, 2008). The associated parameters can therefore not be estimated (ex rain flag, bifrequency ionospheric correction...).

# 3 Major changes

## Instrumental corrections impacting the range

Two major changes were performed in the new IPF chain :

- The introduction of USO correction directly in the range at the L1b level. Users are advised NOT to correct any more the range with the auxiliary data provided in the past.

- The improvement of the PTR resolution. This has 2 impacts on the data :
  - A direct impact on the Calibration factors included in the Level2 Instrumental Corrections :
  o On the range through the Time Delay Calibration Factor.
  o On the sigma0 through the Sigma0 Calibration Factor.
  - An undirect impact on the data provided that the retracking is performed on a slighlty modified waveform :
  o On all retracked parameters (Range through Epoch, SWH through SigmaC2, Wind through Sigma0, Mispointing, Peakiness)

## Changes impacting SWH and SSB correction

2 changes were performed impacting the SSB correction :

- The Sea-State bias table has been recomputed (Labroue, 2007) accounting for the impact of the new orbit and the new geophysical corrections (MOG2D, GOT00 ocean tide correction with the S2 component corrected once only, new wind speed algorithm from Abdalla, 2006). The new SSB correction is shifted in average by +2.0 mm in comparison with the previous one.
- Furthermore, the improvement of the PTR SigmaC estimation has an impact on the SWH value ($SWH^2 = SigmaP^2 + SigmaC^2$). It has a mean impact of -13cm with a slight dependence in SWH.

## New MWR

Changes were performed on the MWR characterisation files with an impact on the brightness temperatures. These changes have a small impact for users on the wet tropospheric correction.

## New/Updates quality flags

- Updated Rain flag : In the algorithm the coefficients and look-up tables have been updated, in order to set the value of the flag. It is a 6 states flag using MWR, and Ku and S band inputs. It is thus not possible to validate this flag for cycle 85 (No S band data). Note that the method was presented in a paper ("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).
- New Sea-Ice algorithm includes a 2-state sea ice flag (ice-free ocean and sea-ice) and 4 values indicating the membership of the pixel to each class (ice-free ocean, first-year ice, multi-year ice and wet ice). They are provided as percentages between 0 and 100 in the product.

## Ocean Tide and Tidal Loading

Evolution on FES2004 : new loading tide + K2 and S1 coefficients. This has no impact on our analysis as we used the GOT tidal model.

## Slope model used over ice sheets

New slope models have been implemented. This has no impact on our analysis as this is only applicable over ice sheets.

# 4 Total bias evaluated on the SLA monitoring

The global impact noticed on the SLA monitoring due to the new IPF+CMA versions consists of the sum of :

– Around **-6.4mm** due to the increase of the PTR resolution (included in the range instrumental correction)
– Around **-4.3mm** due to the new SSB solution (algorithm part : +2mm and 4 to 5% of 13cm SWH bias part)

==> Resulting in a **-10.7 mm jump** with geographical patterns (see map of figure **??**).

Note that those statistics result from the comparison of the previous SLA corrected from USO with auxiliary files with a SLA using a range now directly corrected from USO.

Impact is also noticed on SWH monitoring :
- Around **-13cm** biais on the SWH due to the PTR width modification

Due to this global reduction of SWH, the population of null SWH increases. The managing of those null values has slighly changed between the previous and new SSB model. Users must be advised that this might cause a slight over editing due to the SSB if thresholds are not updated accordingly.
Thus,we suggest to relax the thresholds on this parameter (ex, for DUACS processing, this threshold was relaxed from [-50cm,0] to [-50cm,1cm]).

Other parameters are not or slighly impacted (weak impact on the range of the MWR new caracterisation files).

| | |
|---|---|
| Sigma0 : | +0.016dB through Atmospheric attenuation + resolution noise from the sigma0 calibration factor. |
| Atmospheric attenuation : | +0.016dB |
| Wind : | -0.05m/s |
| Brightness Temperature 23.8 GHz : | +0.9K (0.5K expected on all surfaces) |
| Brightness Temperature 36.5 GHz : | +2.7K (1K expected on all surfaces) |
| Radiometer wet correction : | +0.3mm |

# 5 Geographic and temporal differences of New and Old versions

This part shows the temporal difference of daily statistics. Note that these statistics do not take into account the fact that the number of point might not be the same in both versions.
However, the difference is minor and does not affect the statistics in a significant way.
Note that the first and last days of daily differences monitorings are systematically excluded since they are not associated with the same number of data (the previous version included data for the days across the previous and following cycles). Moreover, maps of geographic differences are point to point differences. The statistics enlighted are read from the point to point differences (sometime different from the difference of daily average due to slight discrepencies in the data coverage).

## Impact of IPF/CMA version on Sea Level and range related parameters

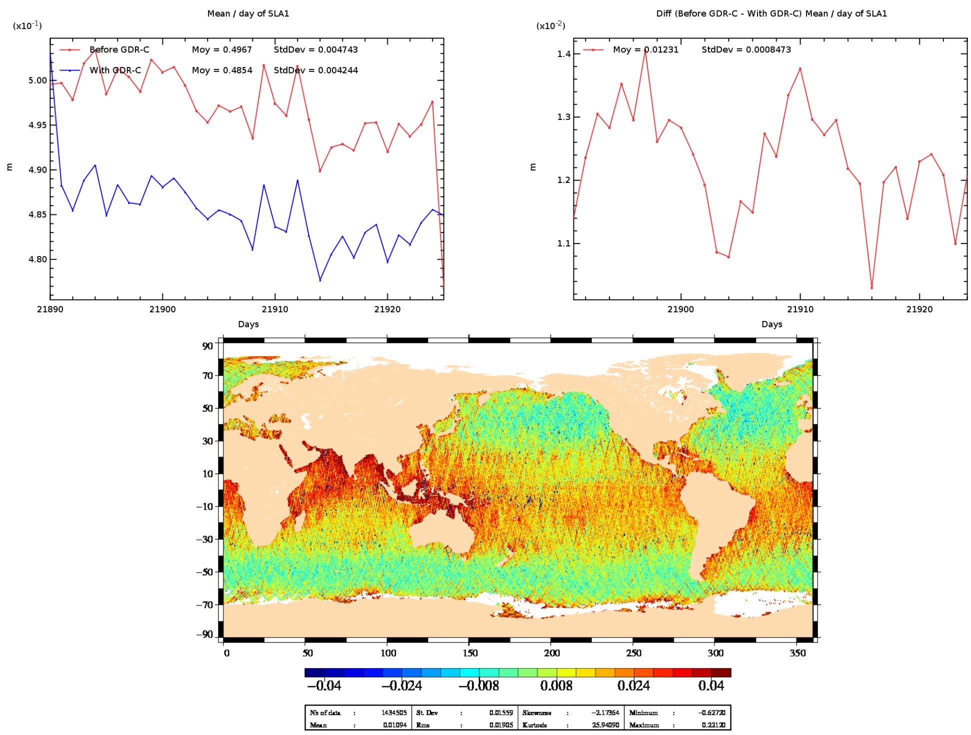



FIG. 1 – **Total Corrected SLA : Monitoring per day of each version (left)/ Difference Old - New version (right) in meters. Bottom : Geographical difference. Total of -10.9mm global bias (average on the geographical point to point difference : map).**

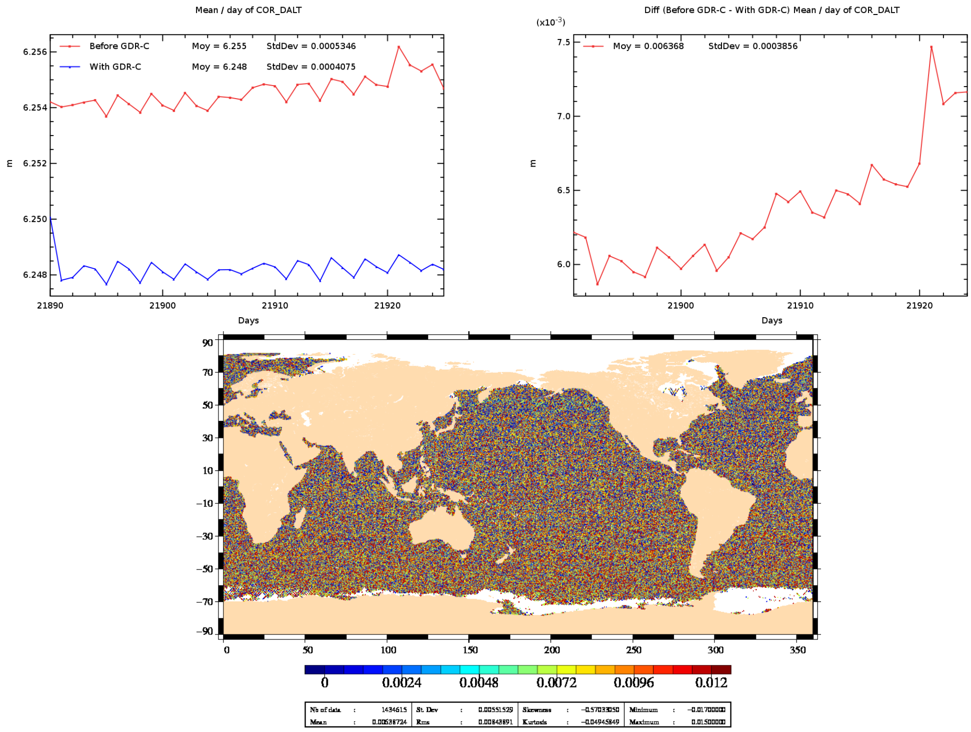



FIG. 2 – **Instrumental Range Correction : Monitoring per day of each version (left)/ Difference Old - New version (right) in meters. Bottom : Geographical difference. Global bias of -6.4mm - related to PTR processing evolution.**

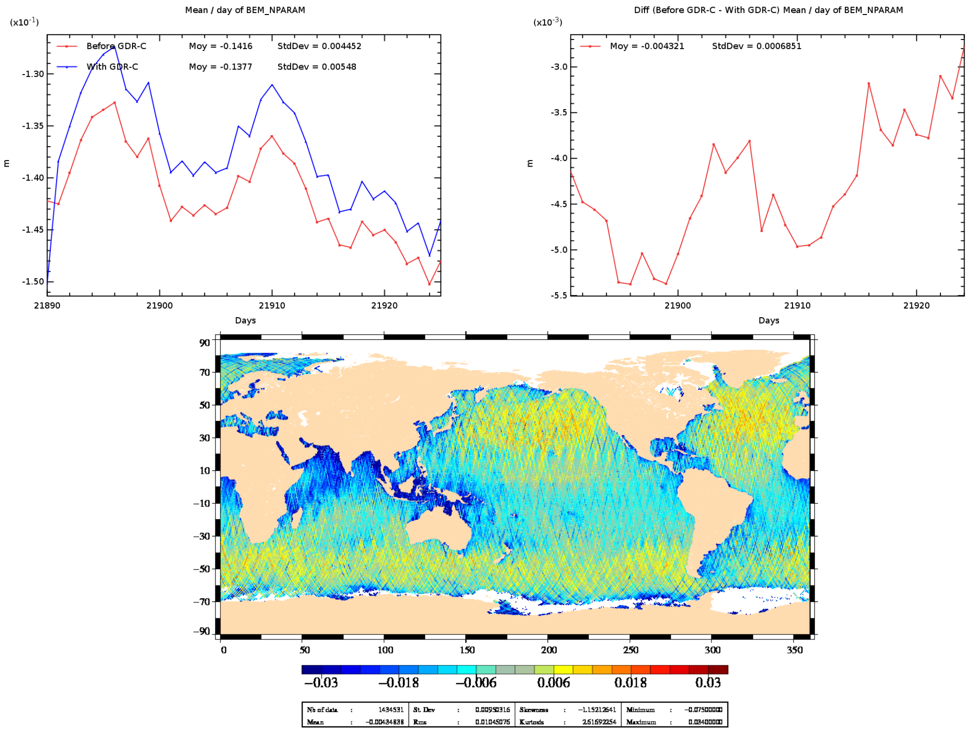



FIG. 3 – **Sea State Bias : Monitoring per day of each version (left)/ Difference Old - New version (right) in meters. Bottom : Geographical difference. Global bias of +4.3mm on sea level height.**

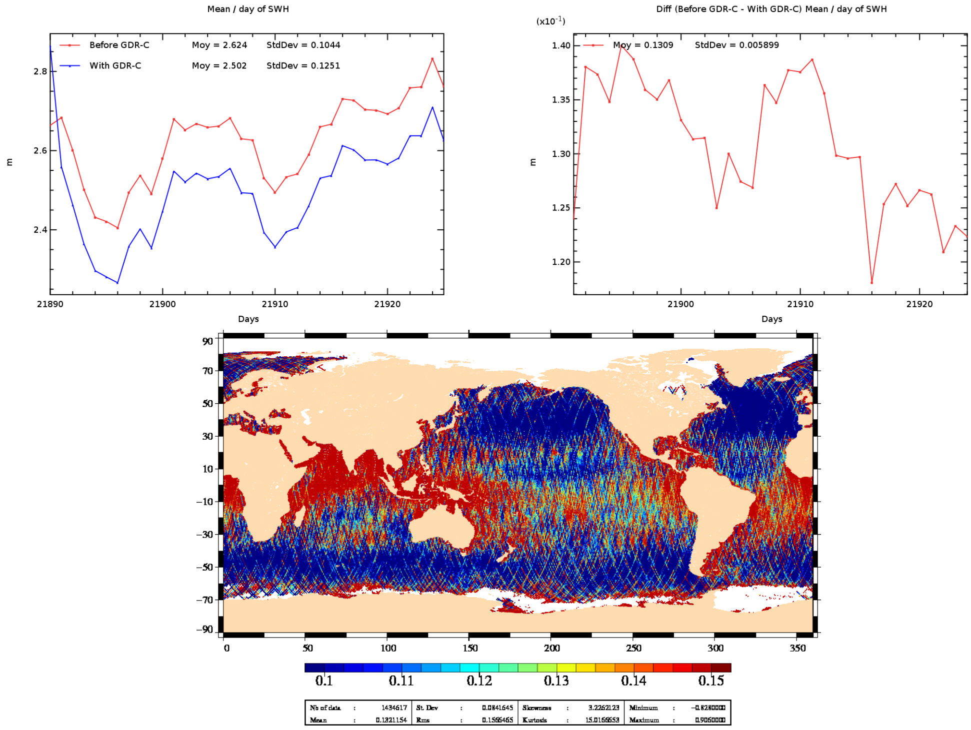



FIG. 4 – **SWH : Monitoring per day of each version (left)/ Difference Old - New version (right) in meters. Bottom : Geographical difference. The global -13.1cm bias observed explains a part of the SLA jump through SSB (theoretical 4 to 5% of SWH bias).**

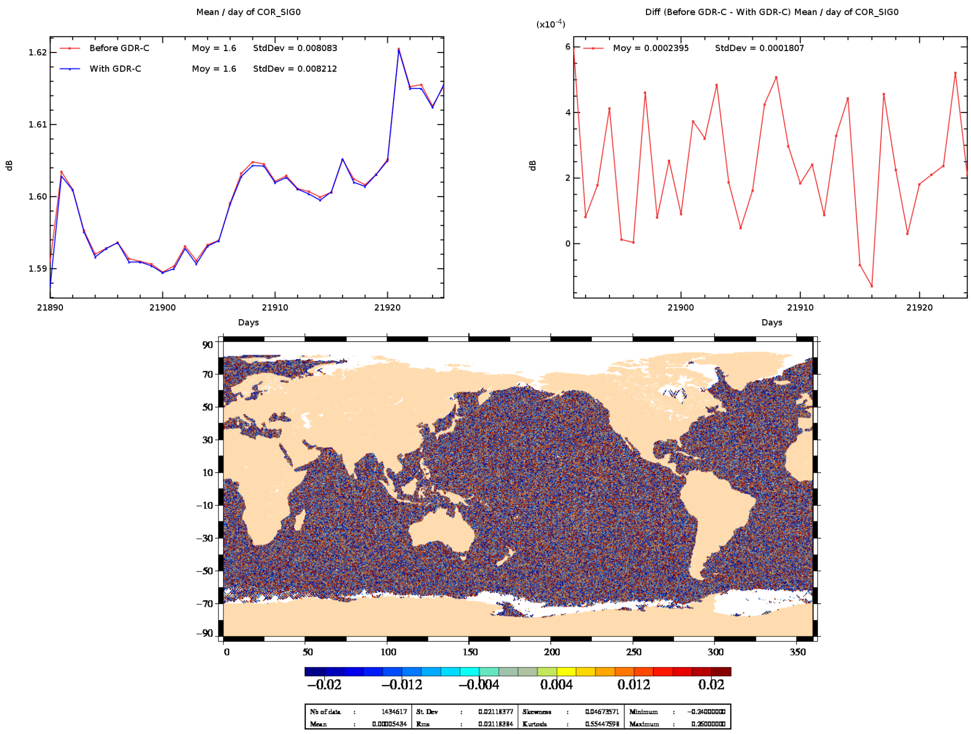



FIG. 5 – **Instrumental Sigma0 corrections : Monitoring per day of each version (left)/ Difference Old - New version (right) in dB. Bottom : Geographical difference. No bias detected but the resolution has increased.**

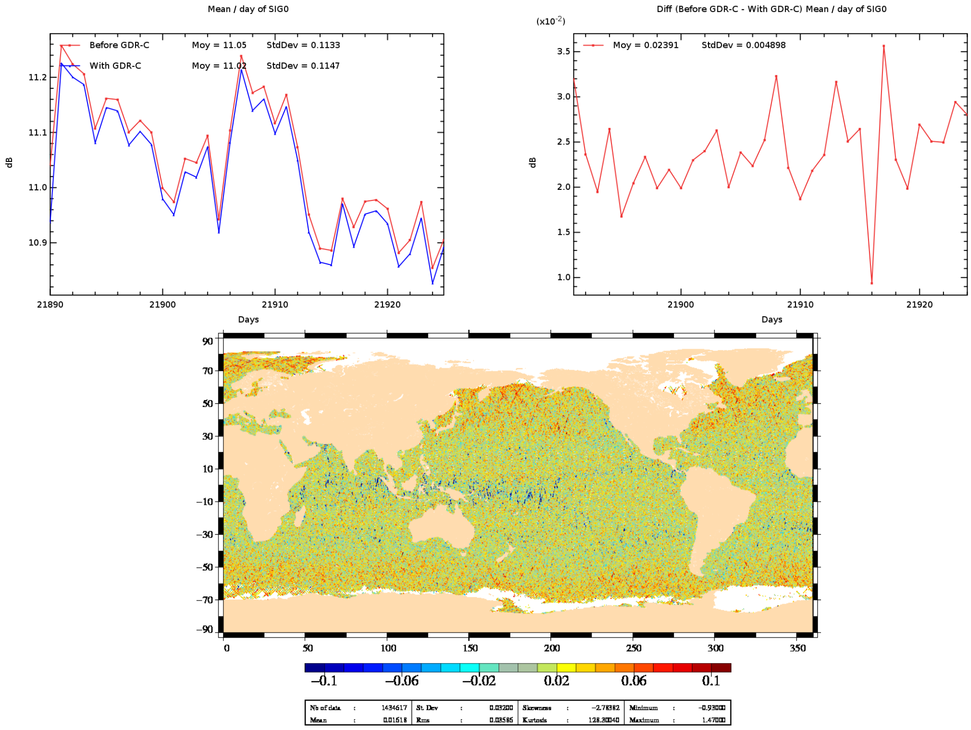



FIG. 6 – **Sigma0 : Monitoring per day of each version (left)/ Difference Old - New version (right) in dB. Bottom : Geographical difference. Weak -0.024dB global bias.**

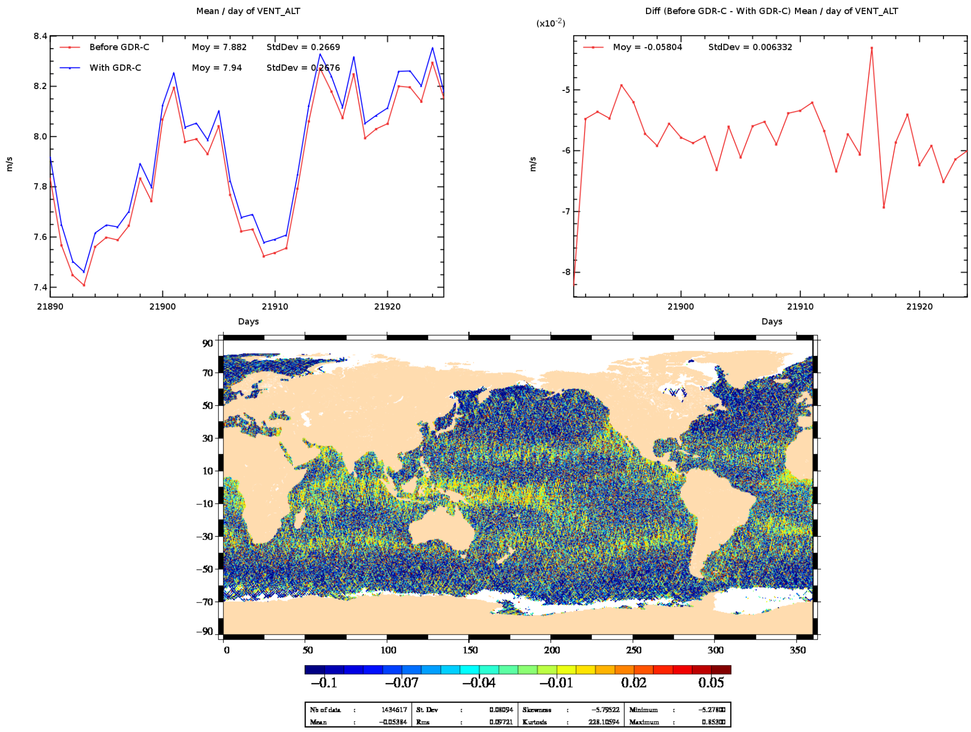



FIG. 7 – **Wind : Monitoring per day of each version (left)/ Difference Old - New version (right) in m/s.Bottom : Geographical difference. Weak 0.06m/s global bias.**

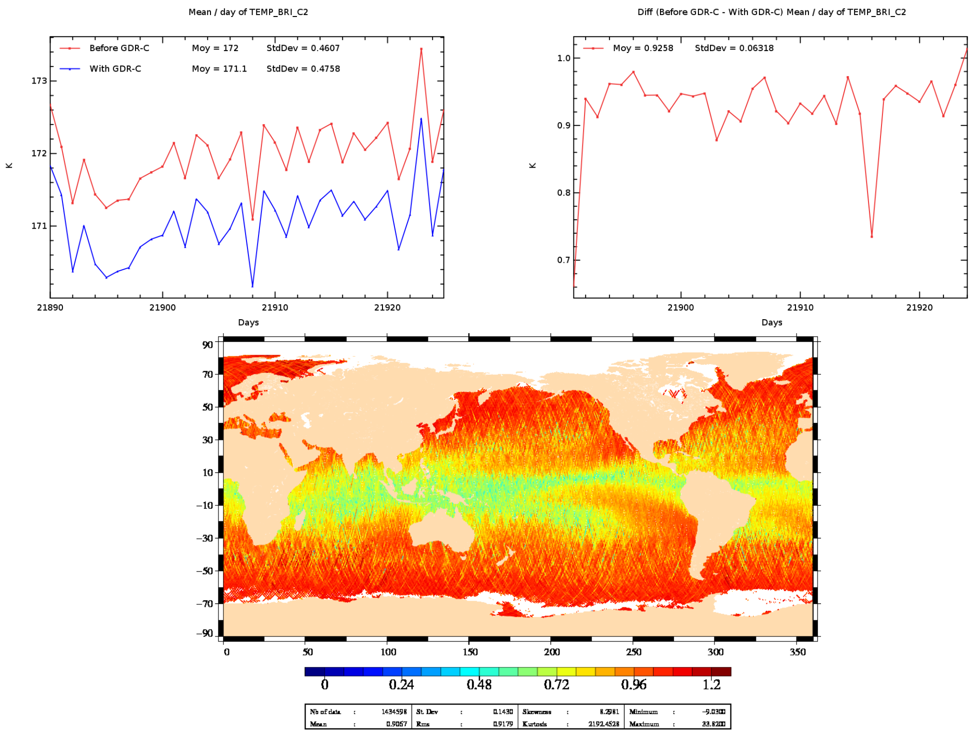
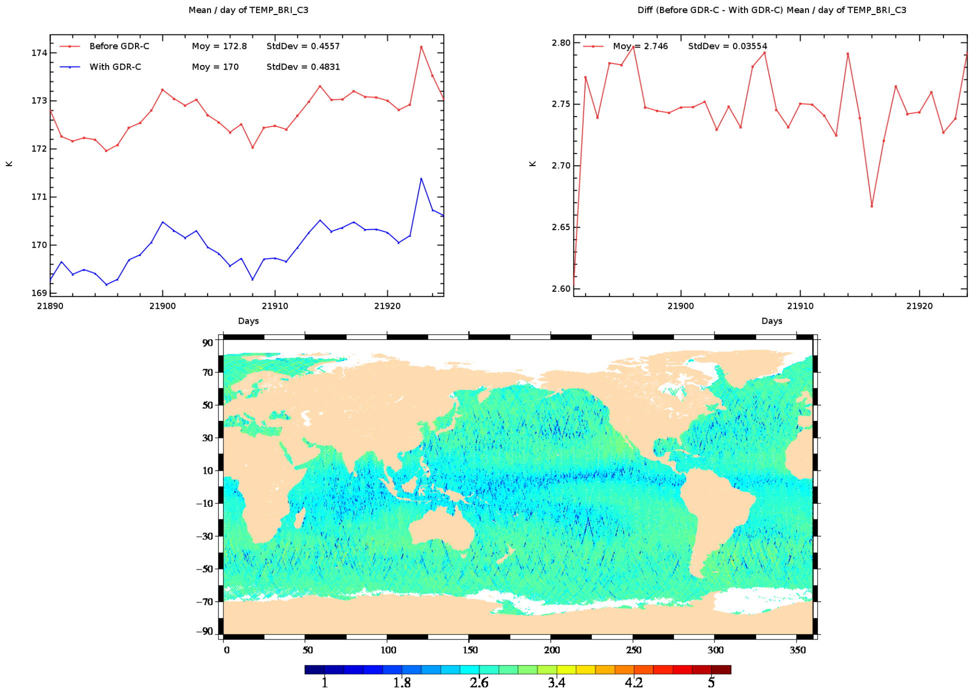
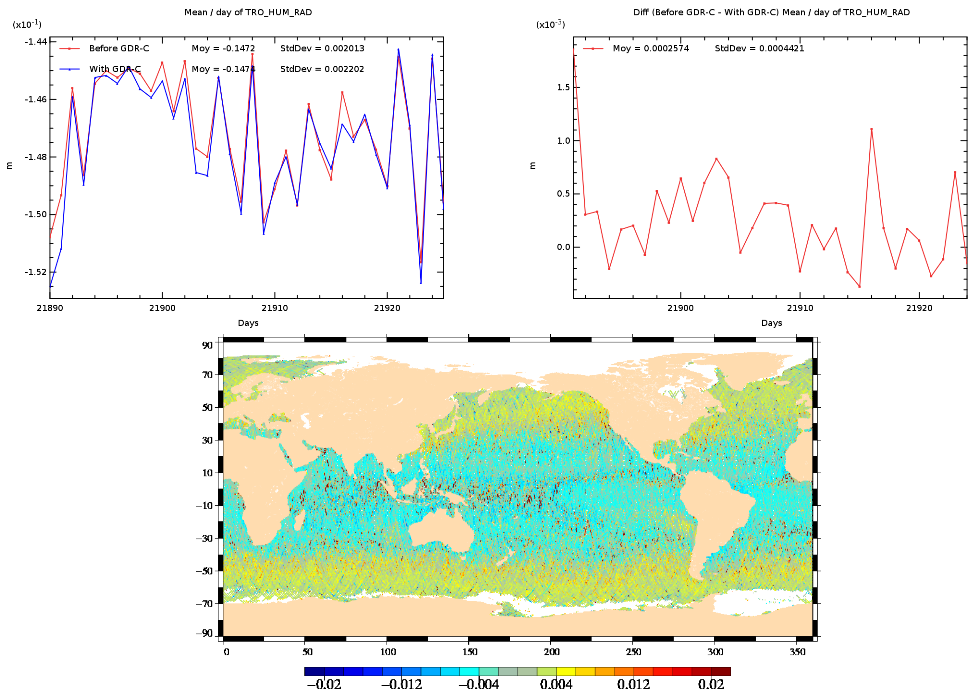



FIG. 8 – **Brightness Temperature 23.8GHz : Monitoring per day of each version (left)/ Difference Old - New version (right) in Kelvin. Bottom : Geographical difference. -0.9K global bias.**




| | | | |
|---|---|---|---|
| Nb of data : 1434598 | St. Dev : 0.2522 | Skewness : 0.6738 | Minimum : −6.3700 |
| Mean : 2.7201 | Rms : 2.7318 | Kurtosis : 416.0347 | Maximum : 39.9900 |

FIG. 9 – **Brightness Temperature 36.5GHz : Monitoring per day of each version (left)/ Difference Old - New version (right) in Kelvin. Bottom : Geographical difference. -2.7K global bias.**




| | | | |
|---|---|---|---|
| Nb of data : 1434598 | St. Dev : 0.0101436 | Skewness : 11.4672420 | Minimum : −0.1790000 |
| Mean : 0.0003003 | Rms : 0.0101481 | Kurtosis : 185.8599308 | Maximum : 0.4540000 |

FIG. 10 – **MWR Wet Tropospheric Correction : Monitoring per day of each version (left)/ Difference Old - New version (right) in m. Bottom : Geographical difference. Weak submilimetric global bias (-0.3mm).**

# 7. Particular investigations

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

## 7.1. Study on ENVISAT Mean Sea Level Trend

### 7.1.1. Introduction

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 cycle 22 and even more significantly after cycle 41 is very encouraging.

In 2010, Envisat MSL was made available on Aviso web page at: http://www.aviso.oceanobs.com/en/news/ocean-indicators/mean-sea-level/products-images/index.html.
3 subject related to the climate related parameters were also studied and presented in the OSTST:
- Wet tropospheric content available at http://www.aviso.oceanobs.com/fileadmin/documents/OSTST/2010/oral/19_Tuesday/OBLIGIS.pdf,
- wind speed and sea surface heigth available at http://www.aviso.oceanobs.com/fileadmin/documents/OSTST/2010/oral/19_Tuesday/Tuesday_afternoon/ABLAIN.pdf,
- and the Mean Sea Level itself.
This part is a summary of last year studies on this latest subject.

It is organized in 2 parts:
- A status on the current MSL seen by Jason-1 and Envisat missions including comparisons to In situ tide gauge data.
- Particular investigations concerning the possible sources of error.

### 7.1.2. Multimission Mean Sea Level trends

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.

#### 7.1.2.1. 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 2°x2° boxes and then by computing a global average with a weighting depending on the latitude (between 66° N/S) following Dorandeu and Le Traon 1999 [20]. 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 :

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

According to the periods, the geophysical corrections provided in the GDR products used are not the same. A table available at the url cited above details the standards of the different terms used throughout the mission.

**Specificities of Envisat:**
- The ionospheric correction used in Envisat SSH computation is the filtered dual frequency before 64, the GIM JPL model afterward.
- The USO auxiliary correction distributed by ESA are used in Envisat SSH computation.

Note that the composite wet troposphere is computed using radiometer further than 50 km from the coasts and ECMWF model for distances between 10 and 50 km.

**Updates of 2010:**
A freezed version was established at the time MSL studies and data were made available on Aviso web page. It includes:
- Ocean tide GOT4.7 updated on the series.
- Composite wet troposphere correction updated on the series.
- GDR-C orbit updated on the whole time series except for cycles before 15.
- A bias was also computed in order to remove the jump introduced by the V2.1 version.

#### 7.1.2.2. MSL time series

Envisat's MSL has various behaviors during its lifetime, including 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<50° and oceanic variability lower than 20cm) shows that the series can be split into 2 major parts (Figure 35):
- Before cycle 22, the annual signal is poorly returned and the slope is clearly negative whereas
- After cycle 22, the annual signal is clearly visible (mainly after cycle 41) and the slope increases again, as expected.
- After cycle 85, the jump introduced by the change of verions V2.1 is corrected in the msl time series.

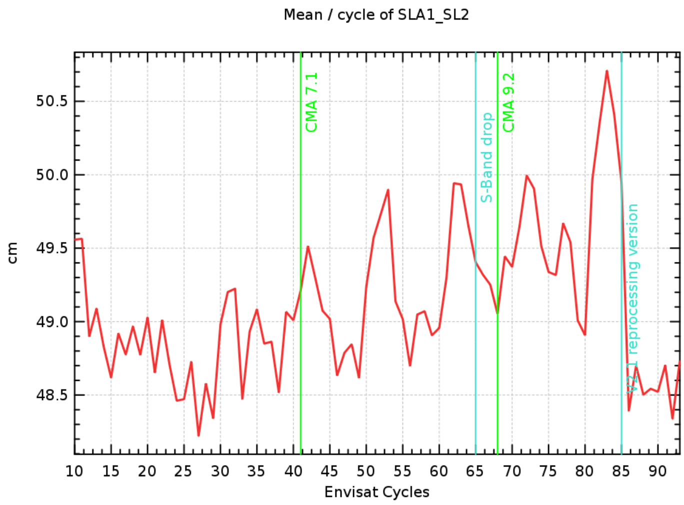



Figure 35: *Envisat SLA per cycle over global ocean for Lat<50° and oceanic variability lower than 20cm with ECMWF Wet tropospheric model.*

This first observation can be refined by a more adapted analysis (see SLA recipe in part 7.1.2.1.), linked to a comparison with Jason-1's MSL (see Figure 36). The period before cycle 22 (January 2004) and the possible reason of anomaly were devellopped in the 2008 Yearly report. It is not taken into account in the trends computation.

Envisat and Jason-1 MSL between 2004 and 2010 present similar behaviors with still a slight underestimation of Envisat slope (see 36 Presented at QWG14).

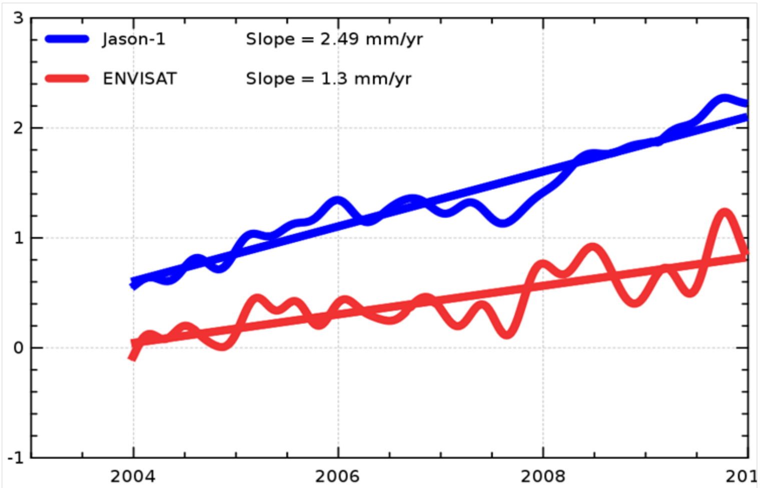



Figure 36: *Envisat and Jason-1 MSL using Radiometer Wet tropospheric model.*

Calibration work are performed to compare altimetric missions (including Envisat) to in situ tide gauges measurement. The results are detailed in [11] available at http://www.aviso.oceanobs.com/fileadmin/documents/calval/validation_report/insitu/annual_report_insitu_2010.pdf. They were consolidated this year and enabled to quantify better the drifts of different missions by providing an external reference.
They conclude that drifts for Jason-1 and TOPEX/Poseidon have been respectively estimated to 0.1 mm/year and 0.7 mm/year, within the error of the method ( 0.5 mm/yr). In the meantime an Envisat MSL drift close to -1.6 mm/yr is detected.

The impact of the wet tropospheric choice and the comparison to Jason-1 and to tide gauges external source are summed up in the table below:

| Global MSL Trend | Period 2004-2010 |
|---|---|
| EN MSL using MWR | 1.3mm/year |
| J1 MSL using JMR | 2.5mm/year |
| EN-J1 (using radiometers) | 1.2mm/year |
| EN-J1 (using ECMWF) | 1.9mm/year |
| EN-Tide gauge | -1.6mm/year |
| J1-Tide gauge | -0.1mm/year |

Table 5: $M$SL trends in mm/year

### 7.1.3. Recent updates and sensitivity studies /Possible sources of error

Last studies (see 2008 Yearly Report) already show the sensitivity of MSL trend to wet tropospheric correction, orbit standards and instrumental corrections.
This year work was performed on those 3 types of error:
- Wet tropospheric correction (through investigation on the MWR stability (presented at OSTST) see part 7.2..
- Instrumental purpose through the PTR drift analysis see hereafter
- and the orbit impact in margin of Est West biais studies see hereafter
They are presented here.

#### 7.1.3.1. In Flight Time Delay / PTR drift

Recent studies were carried out concerning the Point Target Response's drift (PTR) monitored and corrected by the In Flight Time Delay calibration factor. The PTR (more or less a "sinc" signal) was found to be too poorly sampled to enable a meaningful drift analysis.
Monica Roca shows in [68] that "the resolution that can be provided by performing the FFT with the 128 samples of the nominal RA-2 filter bank is not enough to appreciate the real PTR variability". She also shows that a better sampling of the PTR could highlight a 4.5mm drift over the whole mission (around 1mm/year drift).
Calval monitoring showed that the poor resolution of the sum of instrumental correction introduced a jump on the data series around september 2008 (see plot 37) traduced by a 1mm/year effect on the whole data series.
This result was confirmed by in situ tide gauges diagnostics (see [11] and plot 37 right.)

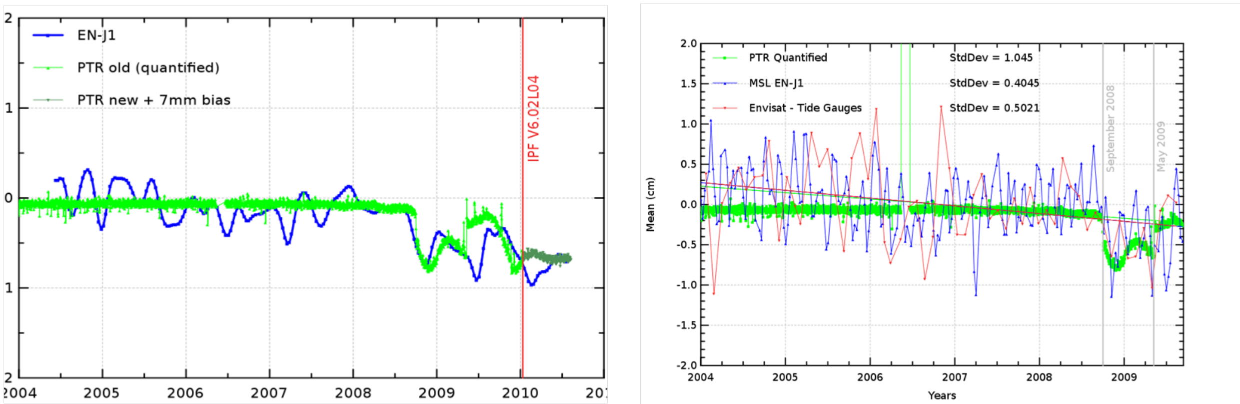



Figure 37: *Difference of PTR with 2 different resolutions compared to Envisat-Jason-1 SLA difference (left), compared to tide gauge height (right).*

This was presented at the QWG14 and at the OSTST in a presentation available at: http://www.aviso.oceanobs.com/fileadmin/documents/OSTST/2010/oral/19_Tuesday/Tuesday_afternoon/faugere.pdf It was also shown that the quantification effect will be cancelled in the reprocessed time series but not the drift. On the contrary it was shown that the way it is applied will increase the difference between both missions.
Instrument orientated discussions conclude on that subject in early 2011 that the correction is currently applied with a wrong sign. This should be solved by the end of the reprocessing.

#### 7.1.3.2. Errors on orbit determination

Since GDR-c orbit update on the whole time series, Envisat and Jason-1 and 2 are much more consistent in terms of cross overs (see Envisat Yearly report 2008) and in terms of local Mean Seal level trends.
Cross comparisons between Envisat and Jason-1 reveal some remaining East West bias varying (increasing) in time.

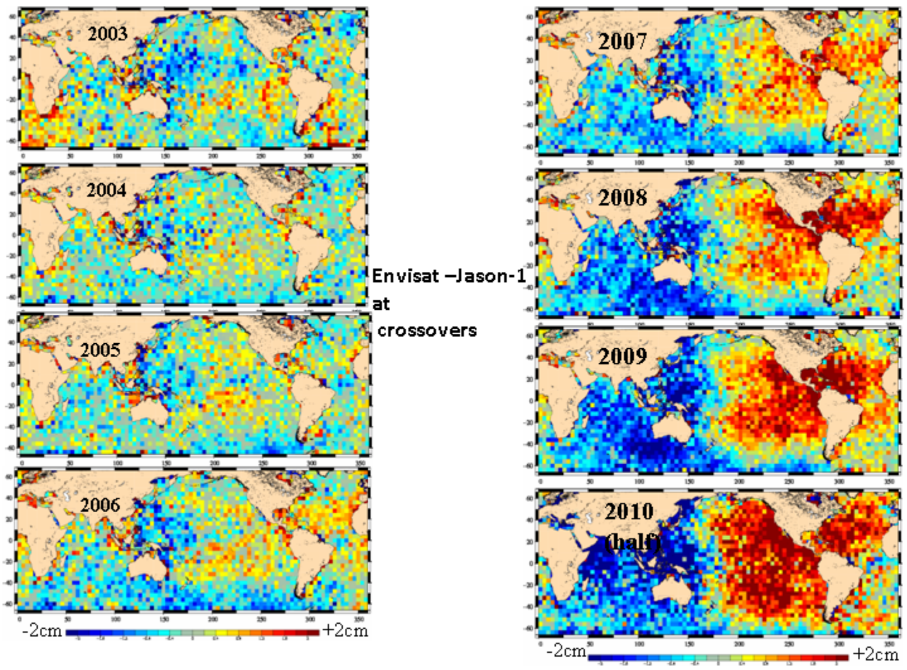



Figure 38: *Average difference of Envisat - Jason-1 SSH at crossovers per year.*

This year, these discrepncies were shown to be due to a different impact of the gravity field taken into account in the orbit models for both missions (OSTST and POD Meeting at CNES see http://www.aviso.oceanobs.com/fileadmin/documents/OSTST/2009/oral/Cerri_gravity_field.pdf).

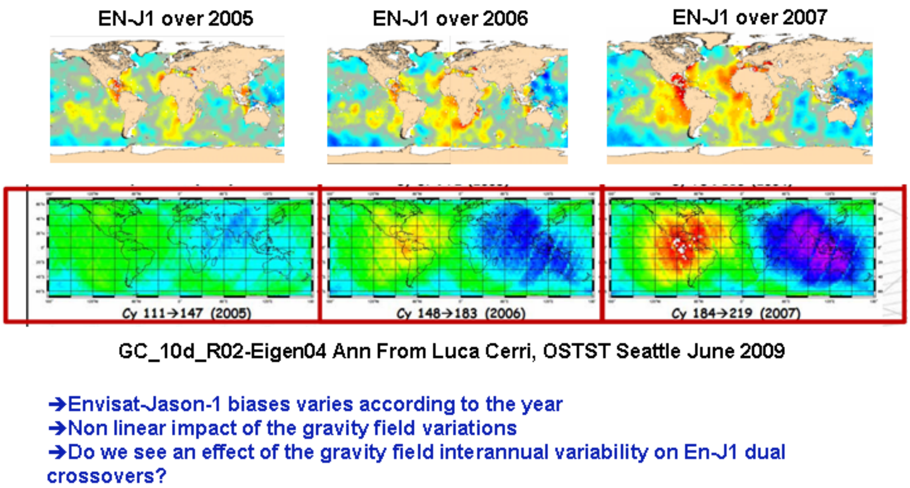



Figure 39: *Average difference of Envisat - Jason-1 SSH at crossovers per year (from L. Cerri, OSTST 2009).*

Further analysis using GDR-C standards enabled to show that the East West bias observed when comparing Envisat and Jason-1 crossovers had a signature on the geographical MSL trends (see 40).

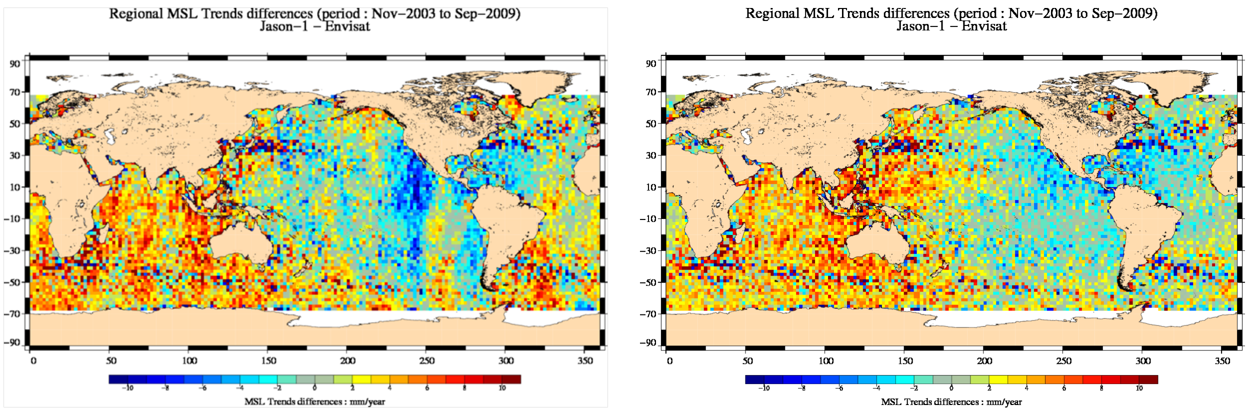



Figure 40: *Geographical difference of Envisat-Jason-1 MSL using GDRA-B-C (left) and homogeneous GDR-C (right) orbit solution between 2004 and 2010.*

Here again, in situ external data helped understanding better the source of the bias. ARGO Mean profilers in situ data set ([12]) enabled to show that the error was present on both Jason-1 and Envisat but in a more important way for Envisat (see 41).
This was presented at the OSTST in a presentation available at: http://www.aviso.oceanobs.com/fileadmin/documents/OSTST/2010/oral/ABLAIN.pdf

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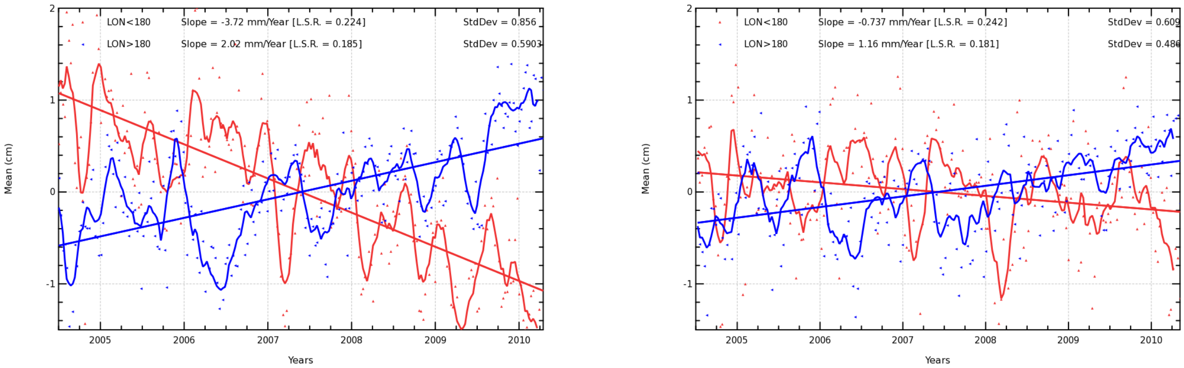


Figure 41: *Mean difference of the SLA - equivalent contain seen by profilers over East (0° and 180°) and West (180° and 270°for Envisat (left) and Jason-1 (right)*

These studies enlighted the importance of the gravity field modelling in the orbit solution and the bias observed should be reduced by a new Gravity field solution developped for GDR-D products available in 2011.
This analysis drove to show the importance of the gravity field solution for the orbit long term consistency and further, to the elaboration of a new standard of orbit using a new Gravity field estimation. This is currently under study.

### 7.1.4. Conclusion

This year, sensitivity studies were performed on Envisat's MSL.
They enabled:
- to explain around 1mm/year in Envisat drift compared to Jason-1. This should be possible to correct by the end of Envisat reprocessing.
- to show the importance of the gravity field model in the orbit solution, notably on geographical trends. This sould also be possible to correct with a future GDR-D like solution and will also benefit to other missions such as Jason-1 or 2.
- to further analyse the wet tropospheric correction stability in order to better quantify the error budget remaining in the MSL estimation.

An effort was also provided to make Envisat MSL available to users in order to prove its pertinence in climate orientated studies.

Envisat MSL behavior should be further studied and better understood next year, thanks to the full mission reprocessing planned for 2011. Note that a whole project initiated early 2011 (CCI: Climate Change Initiative) should also consolidate our knowledge on that subject.

## 7.2. Study on ENVISAT wet tropo comparison

### 7.2.1. Summary of the Study

A study was performed this year on the evolution of the wet tropospheric correction for altimetric use from radiometers, ECMWF and NCEP models and by comparison with in-situ data.

The work needs to be carried on but the first conclusions were the following:
Both JMR and MWR radiometers from Jason-1 and Envisat missions respectively see a drought of the wet troposphere at the end of 2007 / beginning of 2008 which is not seen by the modeled correction from ECMWF.
Both radiometer corrections were of the same order of magnitude before the beginning of 2004 and after the end of 2009 but values are more different in between (JMR higher than MWR).
On a 7 year period, trends of the correction vary between -0.3mm/y (MWR), 0.0mm/y (JMR) and +0.3mm/y (ECMWF).
We have shown the difficulty to obtain accurate time data series in terms of global trend. The natural increase of the wet vapor content is not negligible (+0.2 mm/year) and could be associated with climate warming.
As far as mean sea level calculation is concerned, the strong uncertainty on the evolution of the wet vapor content impacts directly the global MLS trend. It is the main source of error on the MSL calculation. Indeed, drift and jumps are detected on radiometer corrections and moreover, models (reanalyzes included) do not well represent the inter-annual variability. So is it also true for the long-term trend? If the wet vapor content increase is true, it has to be taken into account in the MSL closure budget, which is not the case at the moment.
Spectral analyses show a bump of Jason-2 spectrum between 30km and 110km when compared with radiometric measurements from Jason-1 and Envisat measurements.
Comparison of altimetric SLA with tide gauges measurements reveals incoherence between Jason-1 and Envisat data when compared with global analyses, concerning the drought event of 2008. But this could be explained by the fact that radiometers on Jason-1 and Envisat missions are different and also because the sampling of the ocean by tide gauges doesn't provide same results (especially concerning linear trends) as global analyses. Comparison with Argo dynamic heights (which are provided in the open ocean) shows linear trend a bit higher than when comparing with tide gauges measurements (which are provided in coastal areas). This would suggest that the evolution of the wet troposphere varies spatially. Amplitude of signals prevents us from concluding whether radiometer or model leads to more coherent SLA with in situ data.

The whole study can be available at CLS (CLS-DOS-NT-11-033CLS-DOS-NT-11-033 "On the stability of the altimetric wet tropospheric correction" JLegeais).

### 7.2.2. Presentation of the work at OSTST 2010- Lisbon E. Obligis

Available at http://www.aviso.oceanobs.com/fileadmin/documents/OSTST/2010/oral/19_Tuesday/OBLIGIS.pdf

## 7.3. Analysis of the GIM ionosphere correction stability

Bi-frequency ionosphere correction is calculated from the difference between altimetric distances in main band and auxiliary band (S band on ENVISAT), after correction of the Sea Surface Bias and other instrumental corrections.

Envisat lost the S-Band on 17th January 2008 (cycle 65) so the bi-frequency ionosphere correction is not available anymore. Thus, since cycle 65, the JPL GPS-based global Ionosphere Maps (GIM) containing the vertical ionosphere total electron content has been used. It is corrected of altitude by IRI95 model solution.

The aim of this study is to analyze the GIM ionosphere correction stability and to study the feasibility of correcting the Envisat GIM correction based on the altimeter ionospheric correction measured by Jason-1.

See Report CLS-DOS-NT-20-241 SALP-NT-P-EA-21877-CLS for further details on method and results.

### 7.3.1. Characteristics

#### 7.3.1.1. Global characterisation

Ionosphere correction has a specific and complex geographical distribution based on conduction electron content repartition in atmosphere (figure 42).

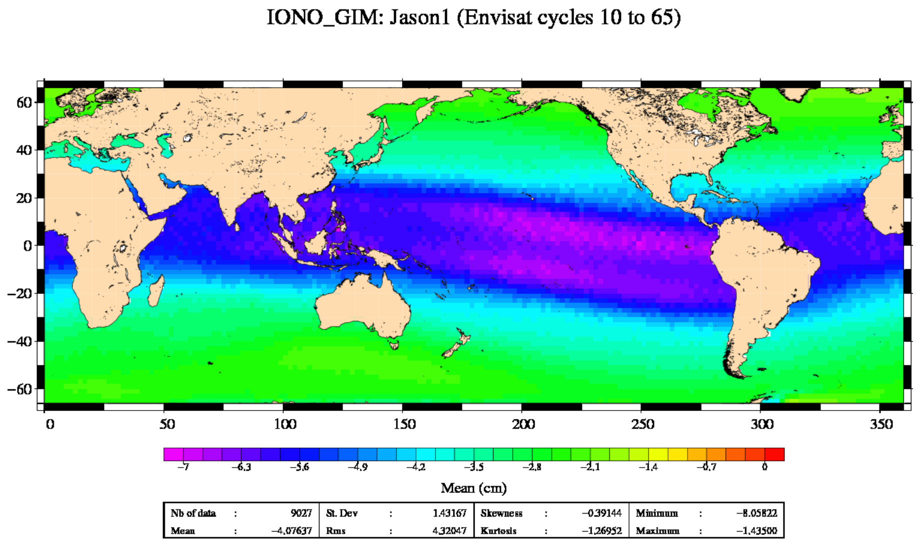


Figure 42: *GIM ionosphere correction mean for Jason-1.*

Furthermore, its level depends on solar activity whose cycle is about 11 years-long. It evolves from -2/-3 cm on weak solar activity period (from 1994 to 1997 and since 2006) to less than -10cm on high solar activity period (2000-2002). Its variability is much more important in high solar activity phases than in weak ones. The decrease of the ionosphere correction (in absolute value) associated with the decrease of the solar activity is stronger on GIM. Consequently the use of GIM lowers the Mean Sea Level rates. This effect depends obviously on the position in the solar cycle. This might well be the contrary in the coming years when solar activity will increase.

#### 7.3.1.2. Long term variations

#### 7.3.1.3. Global trends

The long term variation of the GIM correction over the Envisat period (until S-Band loss) is sensitively different from the Envisat and Jason-1 dual frequency correction. Linear trend differences have been estimated to measure the impact of this difference on the Mean Sea Level trend: the [dual-GIM] difference obtained is -0.5mm/year for Envisat and -1mm/year for Jason-1 (figure 43).

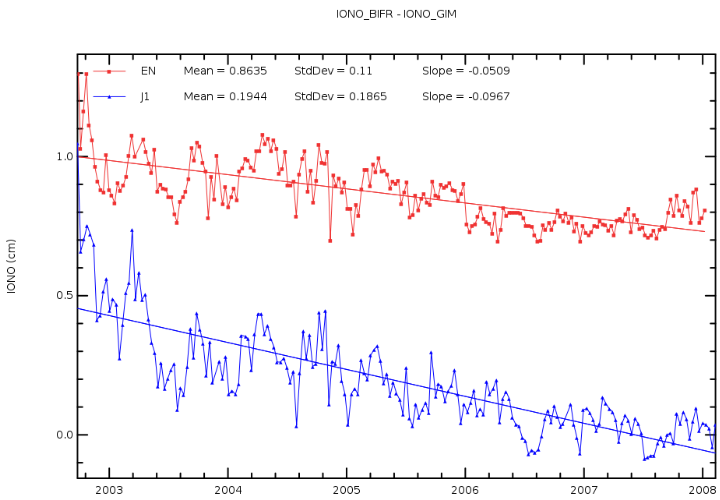


Figure 43: *Temporal evolution of the difference between both ionosphere corrections for Envisat and Jason-1.*

#### 7.3.1.4. Local trends

Temporal evolution of GIM model and dual-frequency ionosphere correction is not homogeneous in space (figure 44). The Envisat [dual-GIM] trend difference can reach - or +3 mm/year near the equator.

### 7.3.2. To a corrective based on Jason-1 bi-frequency ionosphere correction

#### 7.3.2.1. Method developped

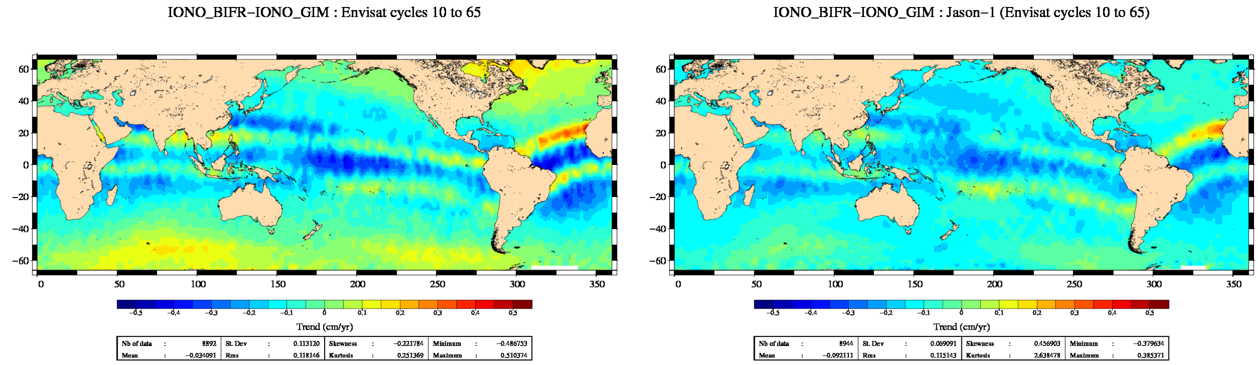


Figure 44: *Geographical trends of the difference between ionosphere corrections: bi-frequency ionosphere correction (IONO_BIFR) and the GIM modeled ionosphere correction (IONO_GIM) for Envisat (left) and Jason-1 (right).*

Long term stability of GIM ionospheric correction does not seem to be insured, notably for high solar activities periods. Considering that the bifrequency correction (notably Jason-1's) is more reliable for long term purposes, we thus propose a correction based on cross-calibration method with Jason-1. The low frequency component of the Jason-1 dual frequency correction selected at particular time is estimated and injected in the GIM Envisat correction.

$$GIM_{EN}Cor = GIM_{EN} - [GIM_{EN}]_{BF} + [BIFR_{J1}]_{BF} + [GIM_{EN} - GIM_{J1}]_{BF}$$

where:

- $GIM_{EN}Cor$ corresponds to the corrected GIM proposed
- $GIM_{EN}$ corresponds to the actual correction
- $[GIM_{EN}]_{BF}$ corresponds to the low frequency component (less to 1 year) of the GIM correction for Envisat
- $[BIFR_{J1}]_{BF}$ corresponds to the low frequency component (less to 1 year) of the BIFR correction for Jason-1
- $[GIM_{EN} - GIM_{J1}]_{BF}$ is the low frequency component of the differences between Jason-1 and Envisat altitudes. It corresponds to applying a trend and a biais to the correction.

This allows correcting the GIM ionosphere correction by +0.5mm/yr.

#### 7.3.2.2. Impact on temporal stability and on Mean Sea Level trends

To complete these investigations, we have studied the impact of applying a corrective term to the ionosphere GIM model to the Mean Sea Level (MSL)(figure 47). For the moment, MSL is calculated with the bi-frequency ionosphere correction until 2008 (S-Band loss). Then, the GIM ionosphere model is used with an 8mm shift. We can note the impact of time period on the slope. As for AVISO data, data prior 2004 are not taken into account in this calculation. Thus, on the period 2004-2010, using a corrected ionosphere GIM model rather than the GIM model would increase of 0.44mm/yr the MSL. Compared to the curve proposed by AVISO (bi-frequency and

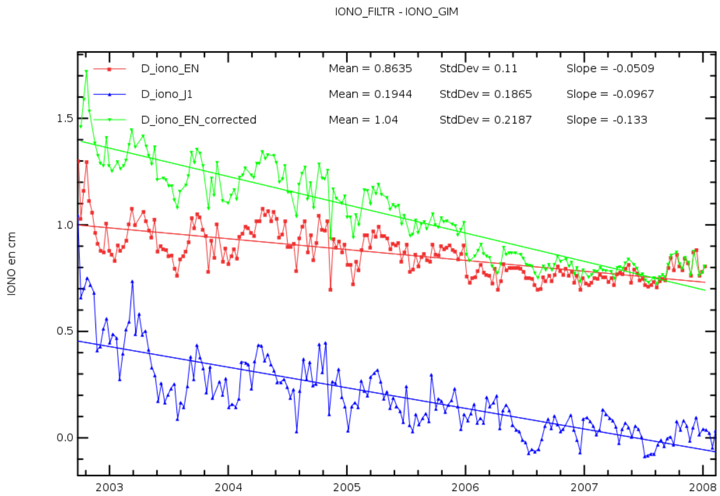


Figure 45: *Temporal evolution of the difference between both ionosphere corrections for Envisat and Jason-1. The third curve (green) represents the same difference taking into account a corrected GIM.*

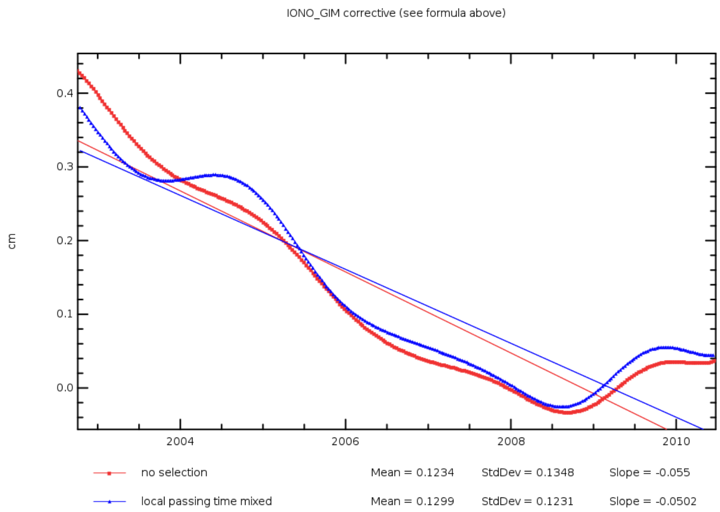


Figure 46: *Temporal evolution of the resultant corrective to the GIM model.*

GIM ionosphere correction), on the period 2004-2010, using homogeneously the corrected GIM model would not modify the MSL trend.

This corrective method is a first step to improve the stability of the GIM correction and thus of the Mean Sea level but it can be improved. Other methods than Jason-1 based method could also be tested. For example, a climatology of the Envisat [dual-GIM] could be established on a 6 years period. Statistics on past [dual-GIM] computed as a function of the solar activity, local time and geographical position could help us to improve the GIM correction. Thus, it could be interesting to test the GPS-based ionosphere climatology (NIC09) proposed by Remko et al.

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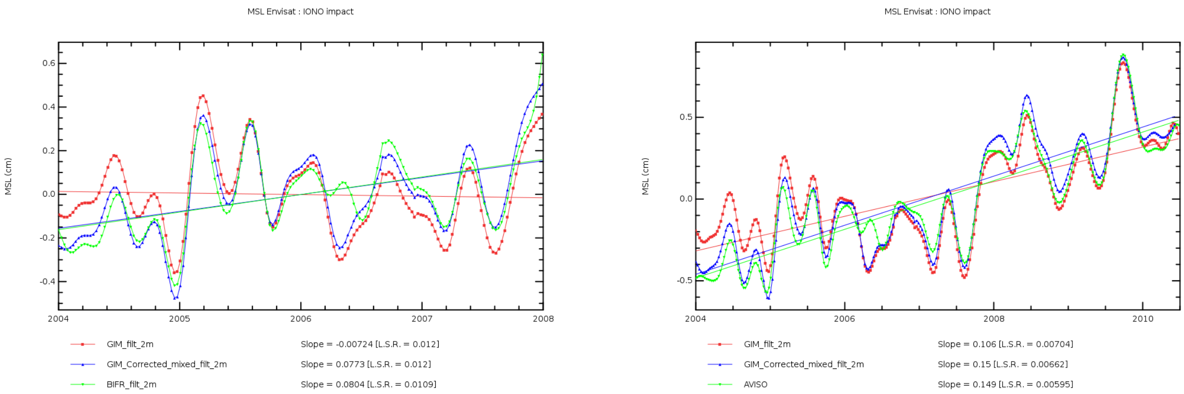



Figure 47: *Mean Sea Level calculated with different ionospheric corrections (bi-frequency and GIM model) for period 2004-2008 for Envisat (left) and compared with AVISO results for period 2004-2010 (right) filtered above 2 months. Annual and semi-annual signals have been removed. Curves are centered on zero. AVISO corresponds to the MSL proposed on AVISO website (www.aviso.oceanobs.com).*

## 7.4. Minicommissionning phase validation

### 7.4.1. Introduction

At the end of October 2010 Envisat shifted to its "drifting phase" or "Extended Mission" mode in order to increase its life time by reducing the maneuvers.
Its orbit is now 17 km lower and its ground track will now shift around the "fixed nodes" of the orbit at 38 degrees N on the descending tracks and 38 degrees S on the ascending tracks instead of the previous plan to have them both at the equator (see figure 48 from http://earth.esa.int/download/envisat/Impact-of-Envisat-Mission-Ext-SAR-data-aug10.pdf).
The global behavior is confirmed by the real plot shown 49 where one can observe that the ascending passes vary more than the descending ones at this latitude.
Quantitatively, theoretical drift is maximum (at +/-50° depending on ascending or descending passes) around 24km in 40 cycles that is to say **600m drift per cycle maximum or around 0.006° par cycle at this latitude**.

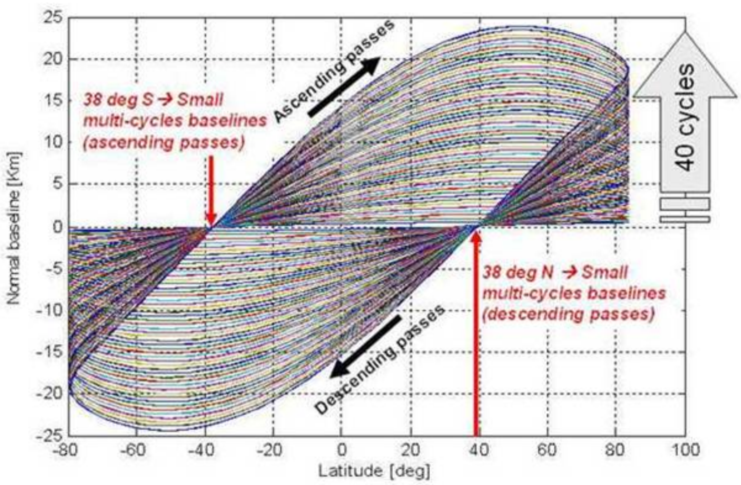



Figure 48: *Theoretical evolution of the perpendicular distance between a track of 1st cycle and the same track for the successive 40 cycles, as a function of latitude and time (40 cycles, i.e. 40 months starting in November 2010)*

Concerning L2 altimeter products validation, mean profile nor theoretical tracks are available anymore. Therefore:
- new methods had to be developped to compute the missing points (which cannot be referenced to a theoretical track anymore).
- the SLA is computed relatively to a MSS out of the repeat track instead of the mean profile.

Concerning the performances themselves, they were analysed deeply during the mini commissioning phase on IGDR products and the particular investigation concerning the potential impact of the MSS degradation outside from the repeat ground track can now be completed on GDR products.

### 7.4.2. IGDR product validation

During the minicommissionning phase (from 27th October 2010 to 14th January 2010) weekly analysis were performed to check the validity of the main parameters.
The analysis are reported hereafter concerning the L2 altimetry products over ocean.

# 1 Introduction

The aim of this document is to report the major features of the data quality from the Envisat mission concerning new IGDR products since Envisat orbit lowering manoeuvres.
It consists in :

- Monitoring the quality of relevant physic parameters (from altimeter and radiometer) over oceans.
- Monitoring of the RA2/MWR availability over oceans.

This report summarizes the main results computed since the $27^{\text{th}}$ October. Note that the number of RA2 measurements used to monitor global statistics until today is displayed in the figure below. This shows the temporal sampling of data measurements available in the CalVal computation.

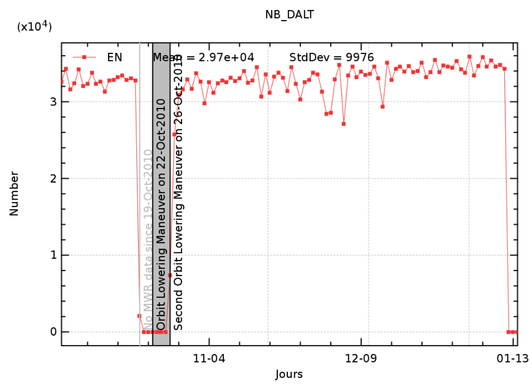



Figure 1: *Monitoring of the number of RA2 measurements over the globe*

## 2 Product performance

This part consists of an overview of the missing measurements, a point on the selection applied on data over ocean and a monitoring of the main altimeter and radiometer parameters concerning the selected data.

For the parameters monitoring:
- when it is relevant, Envisat IGDR monitoring (in red) has been overploted to Jason-1 and Jason-2 ones.

### 2.1 Coverage

#### 2.1.1 RA2 missing measurements

- 32 IGDR passes have been delivered for cycle 95 (starting on pass 818) (26 Oct - 27 Nov 2010)
- 859/862 IGDR passes have been delivered since the beginning of cycle 96 (27 Oct - 26 Nov 2010)
- 856/862 IGDR passes have been delivered since the beginning of cycle 97 (26 Nov - 26 Dec 2010)
- 433/433 IGDR passes have been delivered since the beginning of cycle 98 (26 Dec - 11 Jan 2010)

On cycle 96, note that passes 7, 204 and 862 are completely missing and passes 6, 8, 48, 49, 117, 203, 352, 555, 556, 815 and 816 are partially missing.

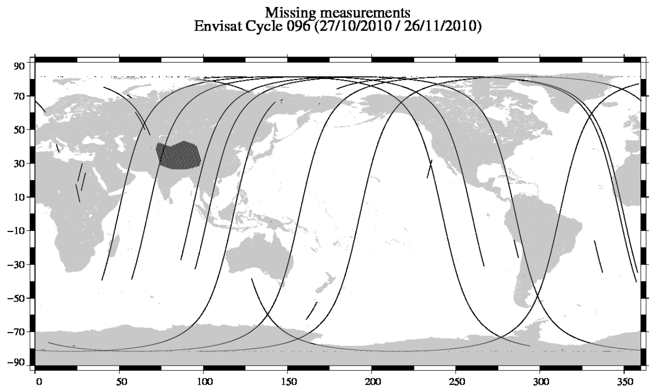



Figure 2: *Cycle 96 map of RA2 missing measurements over the globe*

On cycle 97, 6 pass are completely missing:
- passes 92-93: Scheduling anomaly (telemetry downlink pb)
- 174 acquisition pb at ESRIN

- 237 antenna pb: orbit not acquired at ESRIN.
- 513-514 (14/12) Bad data acquired at Kiruna EOFC

Moreover passes 91, 173, 235 are partially missing.

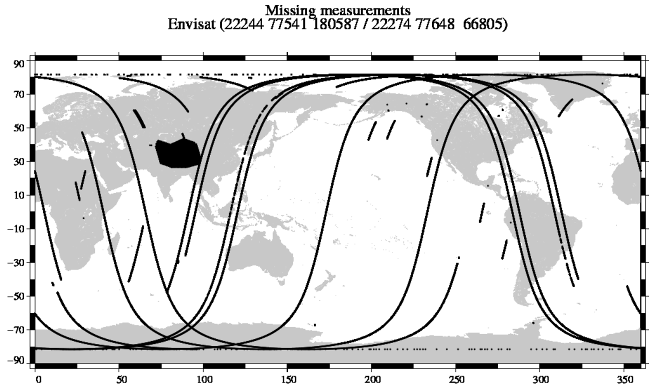



Figure 3: *Cycle 97 map of RA2 missing measurements over the globe*

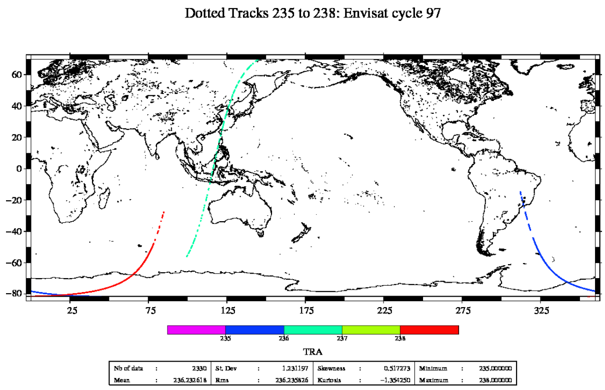



Figure 4: *Tracks 235 to 238 cycle 97, missing with a dotted behavior.*

On cycle 98, no track completely missing.

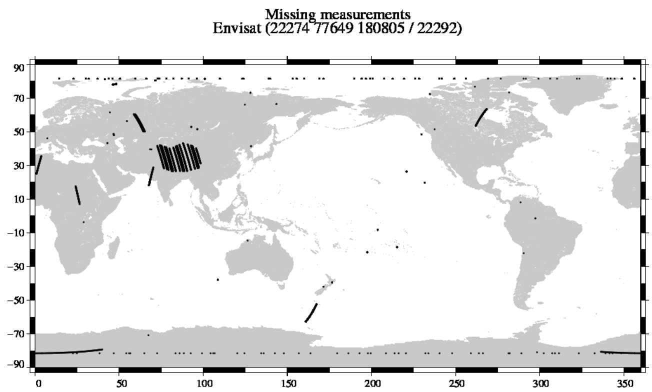



Figure 5: *Cycle 98 map of RA2 missing measurements over the globe*

### 2.1.2 MWR missing measurements

For Cycle 96: 1 pass is entirely edited on radiometer land flag since the beginning of cycle 96. Indeed passes 613 has no radiometer.
Moreover, passes 45, 242, 270, 298 and 614 are partially edited on radiometer land flag on cycle 96.

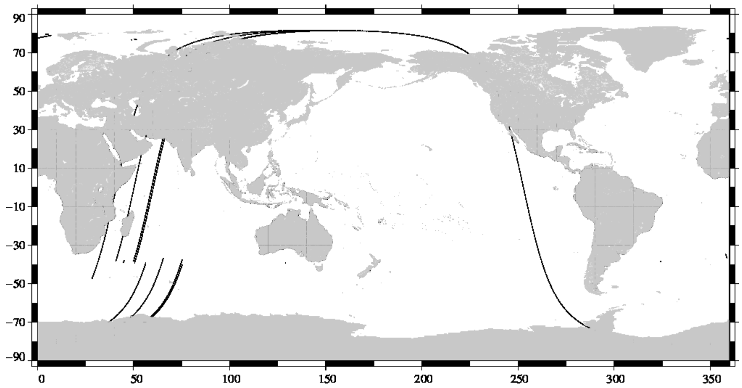



Figure 6: *Cycle 96 map of missing MWR measurements over the globe*

For Cycle 97: Pass 236,238,239 have no radiometer available.
Moreover, note that passes 235 to 238 cycle 97, missing with a dotted behavior also have no radiometer.

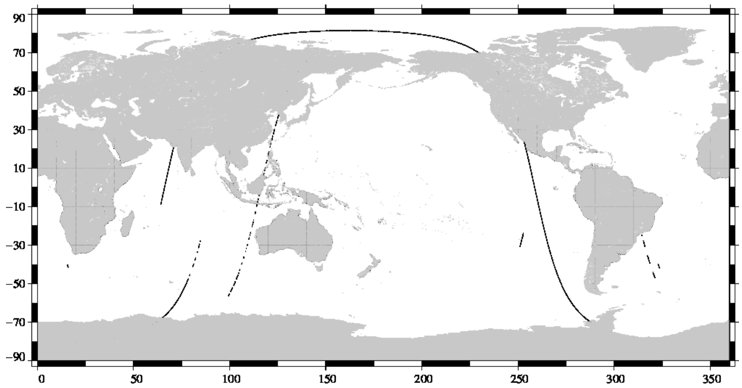



Figure 7: *Cycle 97 map of missing MWR measurements over the globe*

For Cycle 98: no pass entirely whithout radiometer.

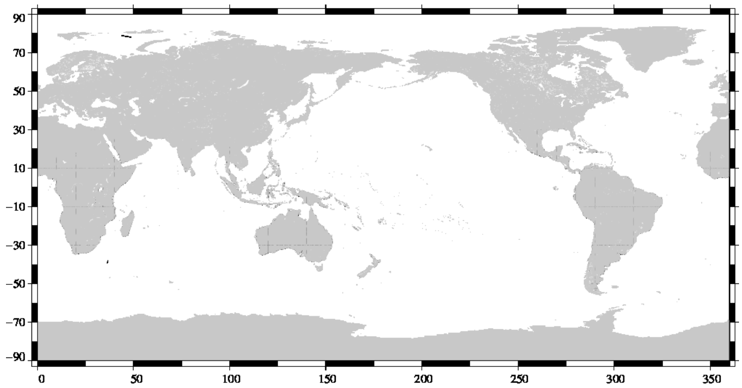



Figure 8: *Cycle 98 map of missing MWR measurements over the globe*

## 2.2 Data edited for the monitoring over oceans

The monitoring of altimeter/radiometer parameters is performed on valid data over ocean only. Below, a map of the data removed by this selection is reported: basically, it consists in land, ice surfaces as well as spurious zones in terms of particular flags or thresholds criteria.

For Cycle 96: note that pass 230 is entirely edited due to a maneuver executed on 4th November 2010.
Moreover, pass 613 with no radiometer is corresponding to the radiometer land flag editing.

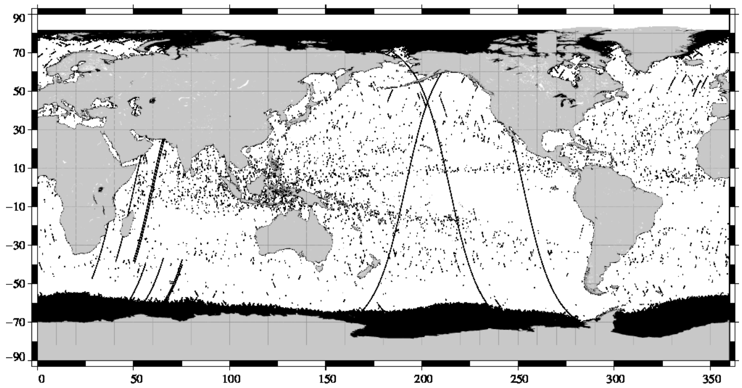



Figure 9: *Cycle 96 data edited for the monitoring over ocean*

For Cycle 97: note that pass 144 to 148 are entirely edited due to a maneuver executed on 1st December 2010.
Pass 236,238,239 have no radiometer available.
Moreover, note that passes 235 to 238 cycle 97, missing with a dotted behavior also have no radiometer.

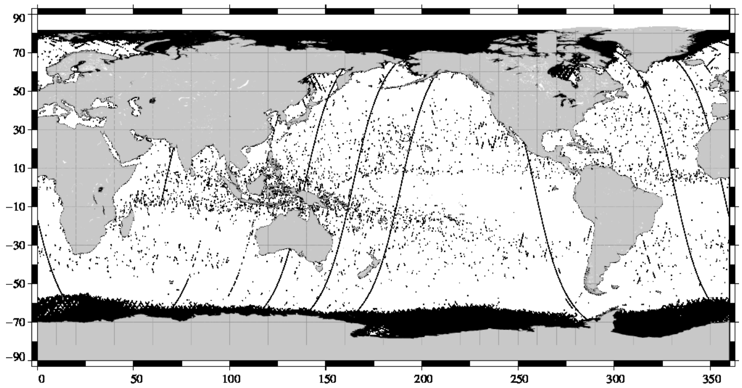



Figure 10: *Cycle 97 data edited for the monitoring over ocean*

For Cycle 98: no pass entirely edited.

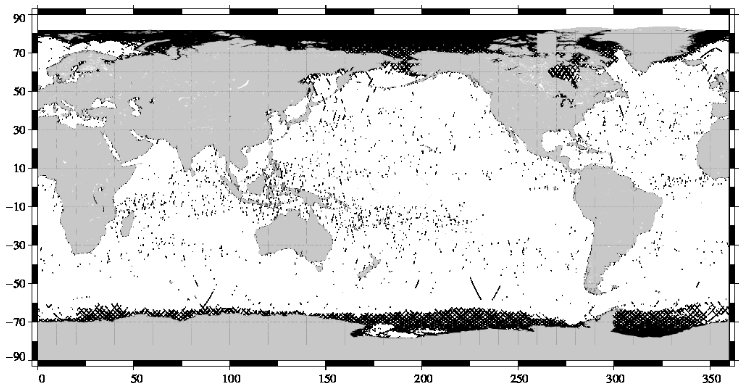



Figure 11: *Cycle 98 data edited for the monitoring over ocean*

## 2.3 Altimeter parameters monitoring over ocean from 27th October to today

Hereafter, the main altimeter parameters monitoring since 27th October 2010 are reported. Note that concerning the monitorings of Envisat, Jason-1 and Jason-2, latitudes are considered between -66 and 66 degrees so as to be compared.

### 2.3.1 Backscatter coefficient

Figures 12 and 13 show the monitoring per day of KU band Sigma_0 .

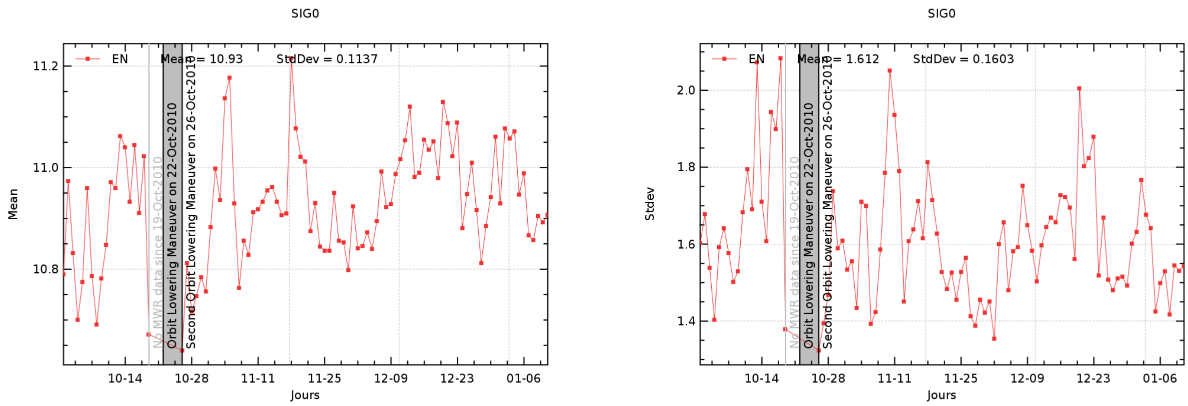



Figure 12: *KU band Sigma0 : mean and standard deviation per day*

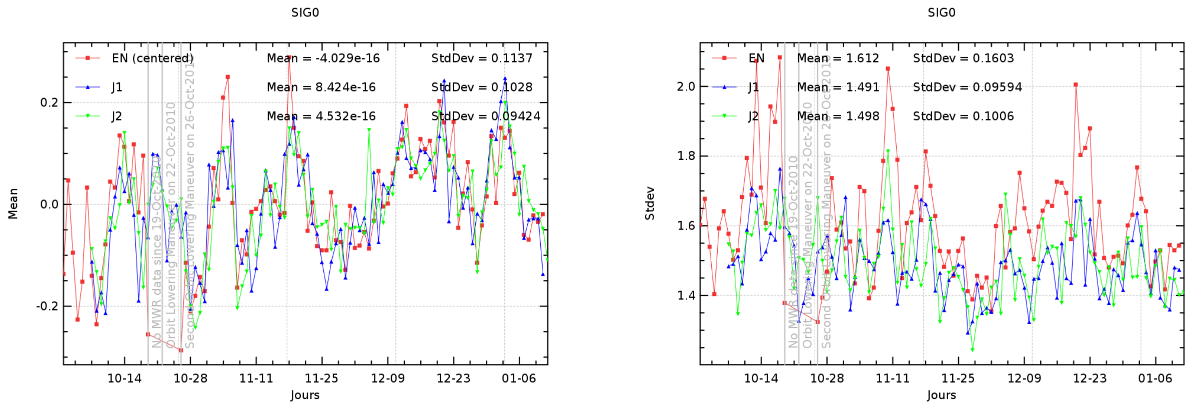



Figure 13: *Multi-mission monitoring of KU band Sigma0 : mean and standard deviation per day*

### 2.3.2 Significant Wave Height

Figures 14 and 15 show the monitoring per day of KU band Significant Wave Height.

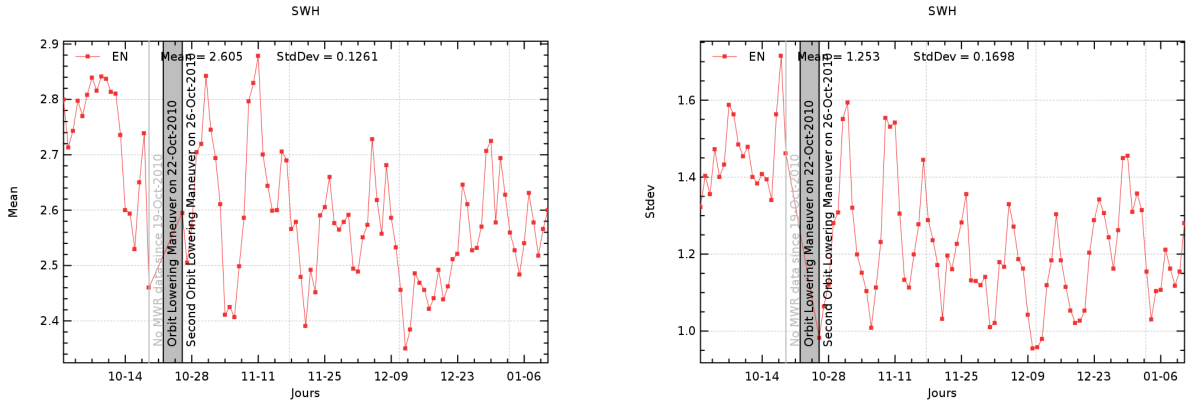



Figure 14: *KU band Significant Wave Height : mean and standard deviation per day*

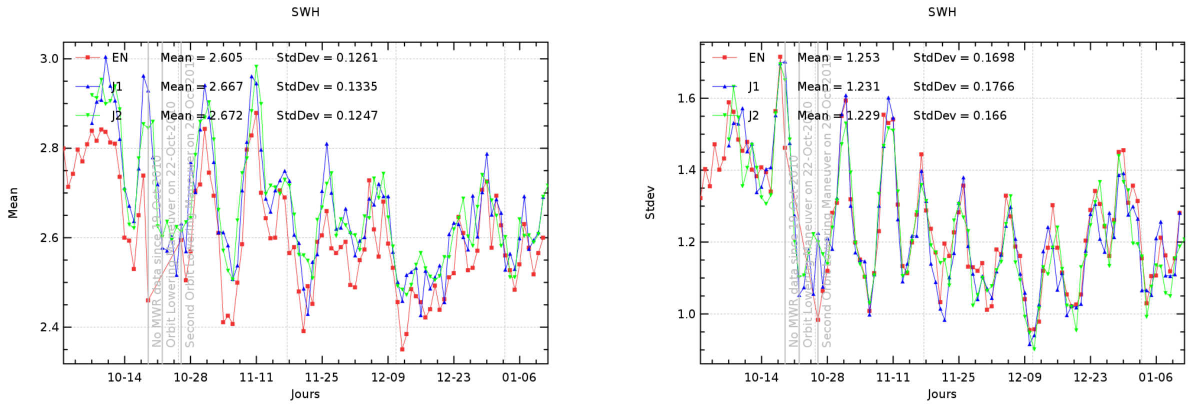



Figure 15: *Multi-mission monitoring of KU band Significant Wave Height : mean and standard deviation per day*

### 2.3.3 Wind

Figures 16 and 17 show the monitoring per day of KU band Wind.

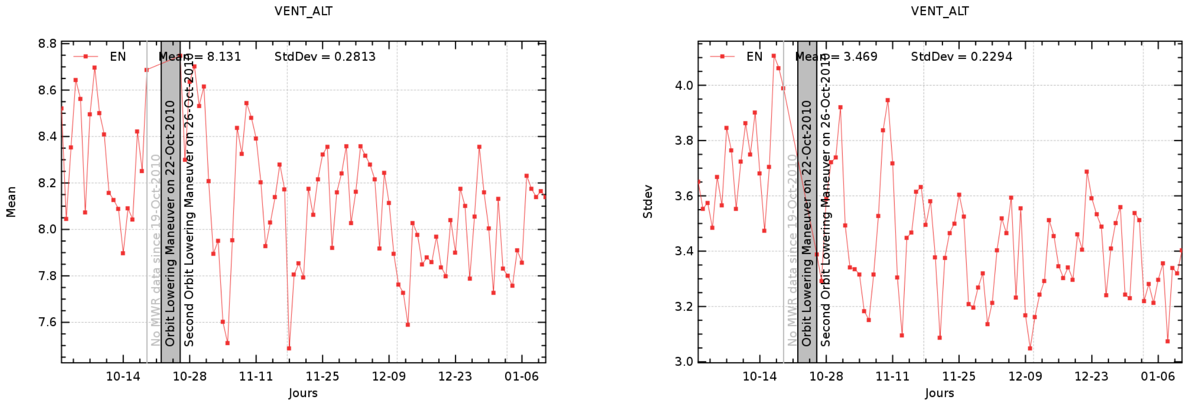



Figure 16: *KU band Wind : mean and standard deviation per day*

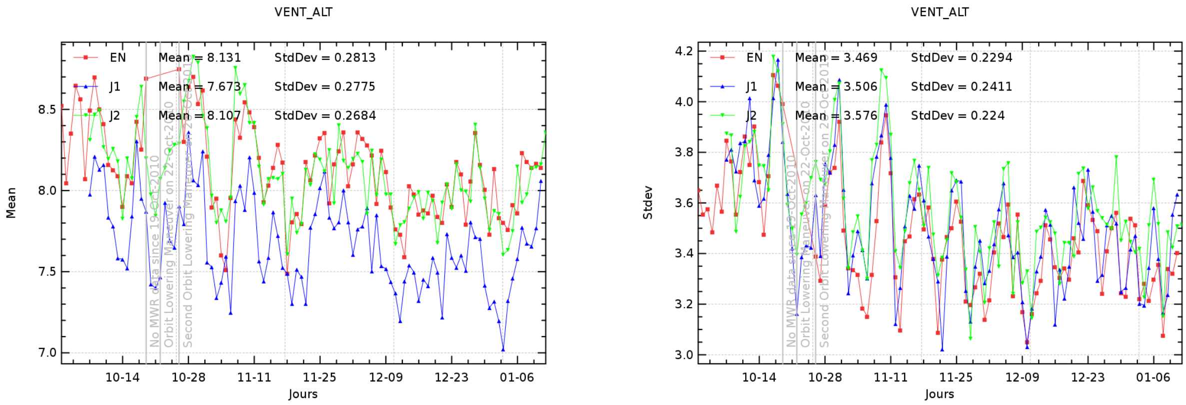
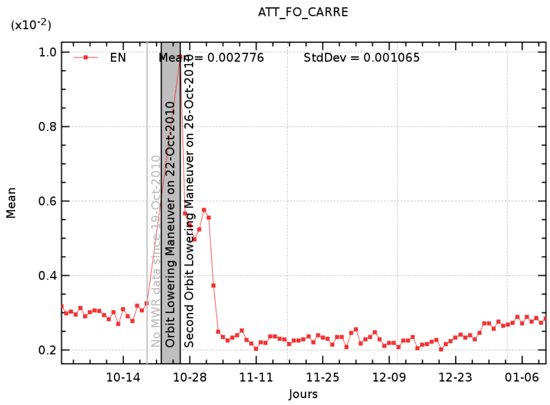



Figure 17: *Multi-mission monitoring of KU band Wind : mean and standard deviation per day*

### 2.3.4 Mispointing

Figure 18 shows the monitoring per day of KU band mispointing.



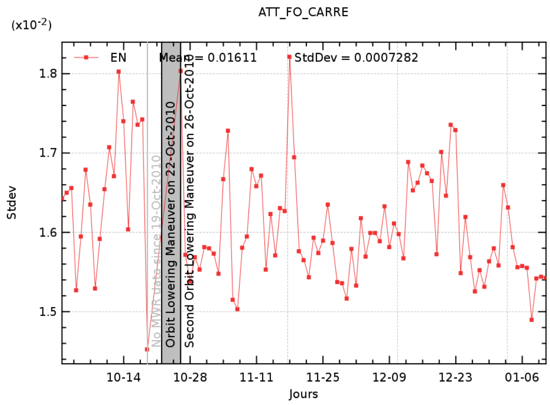




Figure 18: *KU band mispointing : mean and standard deviation per day*

Note a slight and not alarming increasing of the mispointing after december the 26th (included in the nominal dynamic observed on this parameter).

### 2.3.6 Instrumental DALT correction

Figure 21 shows the monitoring per day of instrumental DALT correction.

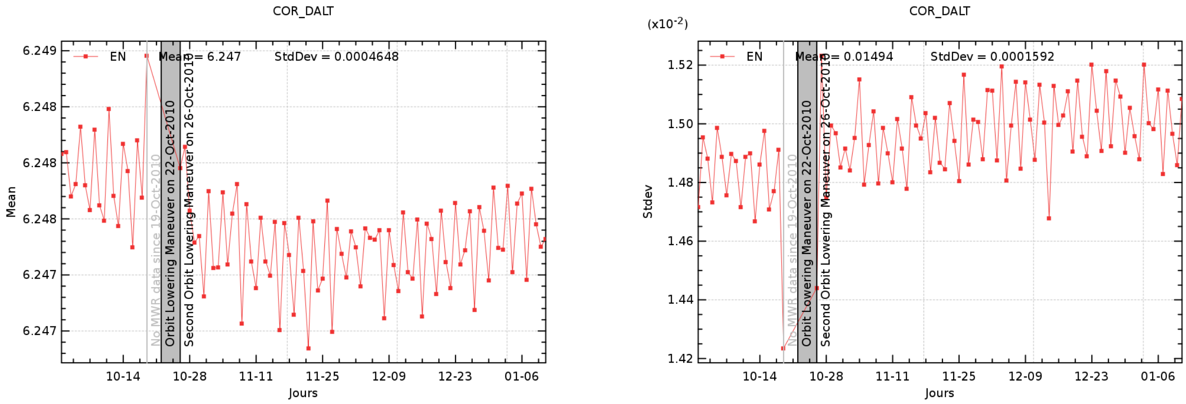



Figure 21: *KU band instrumental DALT correction : mean and standard deviation per day*

### 2.3.7 Corrected Sea Level Anomaly

Figures 22 and 23 show the monitoring per day of the Corrected Sea Level Anomaly.

The Ku Band SLA has been computed with the following terms:

- Ku range (ocean retracking)
- Doris navigator orbit (using the sole interpolated mode)
- GIM model ionospheric correction. Due to the S Band Power drop anomaly, started on the 17th of January, the bi-frequency ionospheric correction can not be used anymore see section *Particular Investigation* in the ECAR from Cycle 72 onward.
- MWR derived wet troposphere correction
- ECMWF dry tropospheric correction
- Non parametric sea state bias
- Inverted barometer
- Total geocentric GOT00 ocean tide height
- Geocentric pole tide height
- Solid earth tide height
- Mean Sea Surface height (CLS01)

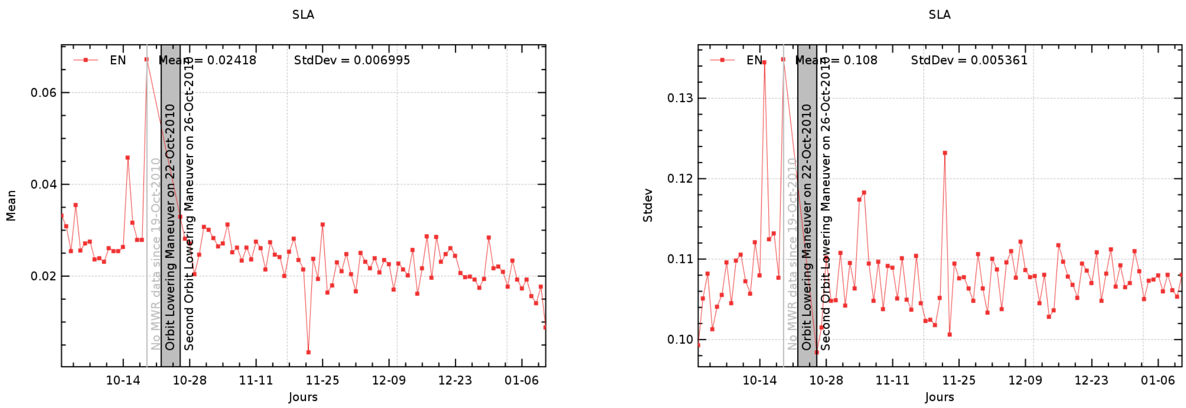



Figure 22: *KU band Corrected Sea Level Anomaly : mean and standard deviation per day*

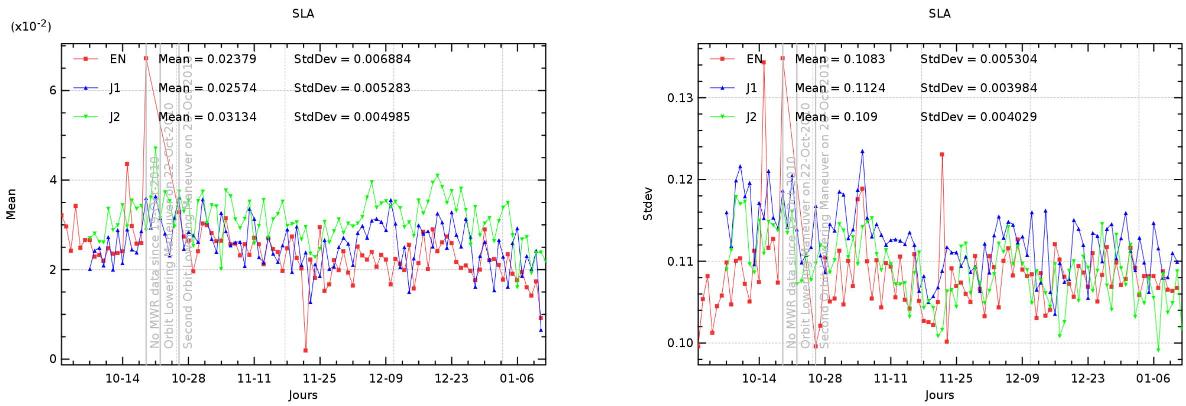



Figure 23: *Multi-mission monitoring of KU band Corrected Sea Level Anomaly : mean and standard deviation per day*

Note an anomaly of SLA on the 22th of November: probable impact of a manoeuver. To be checked with POE orbit in GDR.

## 2.4 Radiometer parameters monitoring over ocean

Hereafter, the main radiometric parameters performance monitorings for almost 3 cycles are reported.

### 2.4.1 Radiometer - ECMWF model's wet tropospheric correction

Figures 24 and 25 show the monitoring per day of the differences between radiometer and ECMWF model's wet tropospheric correction.

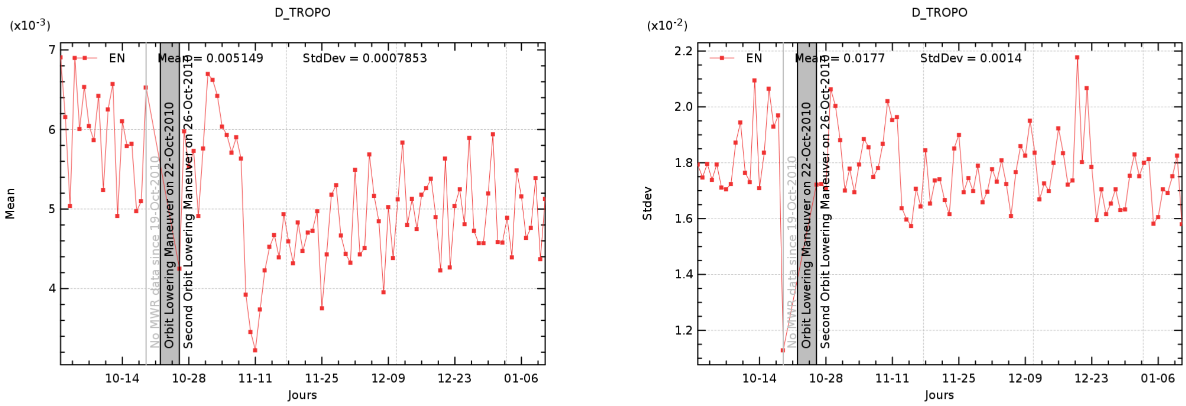



Figure 24: *Difference of radiometer and model wet troposheric corrections : mean and standard deviation per day*

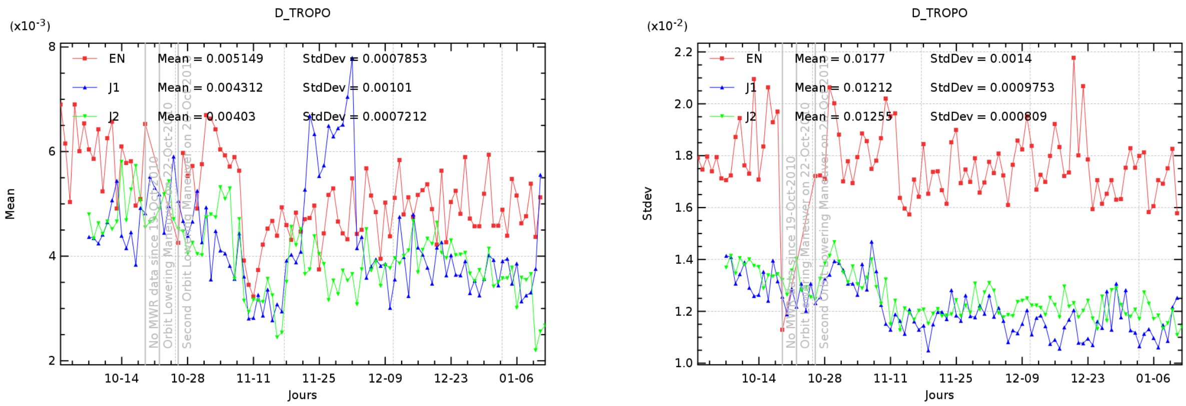



Figure 25: *Multi-mission monitoring Difference of radiometer and model wet troposheric corrections : mean and standard deviation per day*

Note that radiometer wet troposphere differences with ECMWF model display a jump of about 2 mm on 9$^{th}$ November 2010, linked to the evolution of the ECMWF model itself. This jump is more significant on J1 and J2 than on Envisat. This implies, as seen on the monitoring of radiometer and model differences, a decrease of the mean value of the standard deviation to less than 1.2 cm whereas it remains constant around 1.8cm on Envisat.
Also note that on the 22$^{th}$ November and 5$^{th}$ December, a yaw flip induces 2 jumps on the J1 monitorings.

### 2.4.2 Brightness temperatures difference

Figures 26 and 27 show the monitoring per day of the two MWR brightness temperatures (channel 23.8GHz - 36.5GHz).

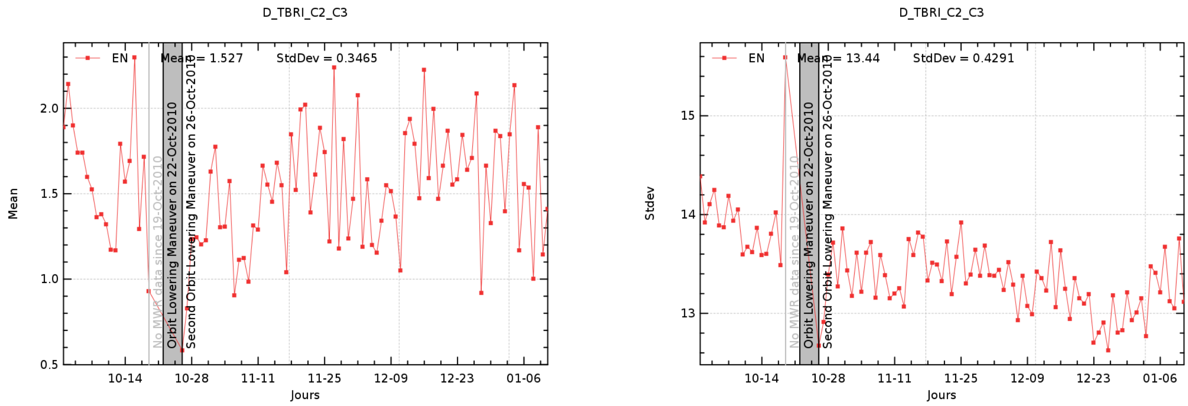



Figure 26: *Difference of MWR brightness temperatures : mean and standard deviation per day*

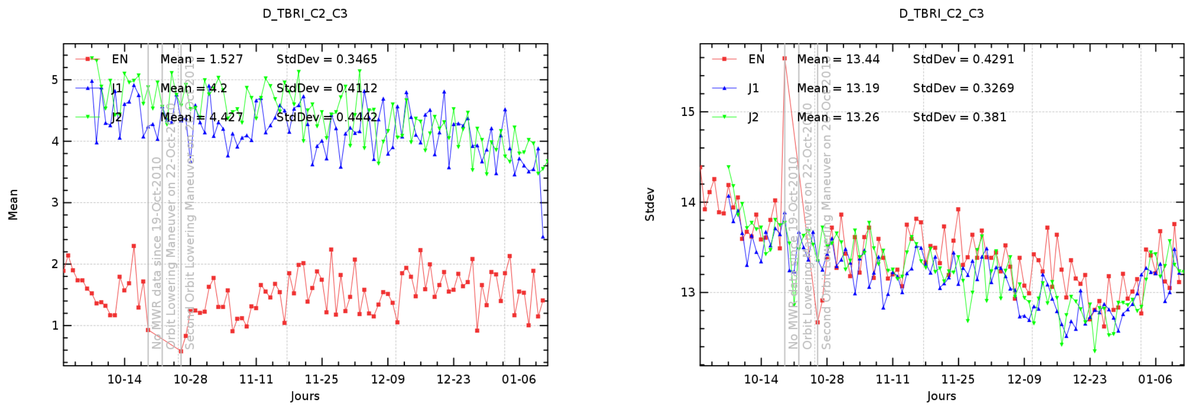



Figure 27: *Multi-mission monitoring Difference of radiometer brightness temperatures : mean and standard deviation per day*

# 3 Investigations

## 3.1 Results concerning the new theoretical track

Figure 28 shows an example of the spatial sampling of the new Envisat tracks in North Atlantic. Although passes seem to be sometimes surimposed, they don't correspond. This is displayed in figure 29 presenting the sampling for pass 600 of Envisat.

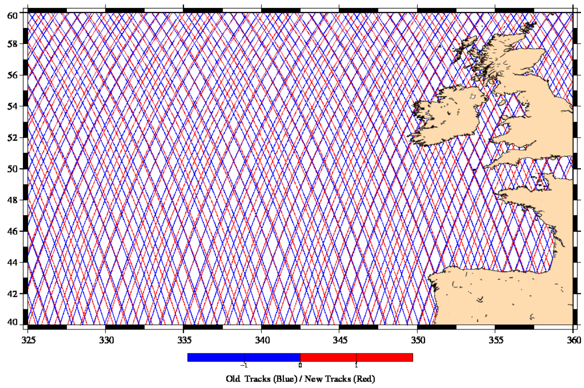



Figure 28: *Example of the spatial sampling of the old (blue) and new (red) tracks on Envisat*

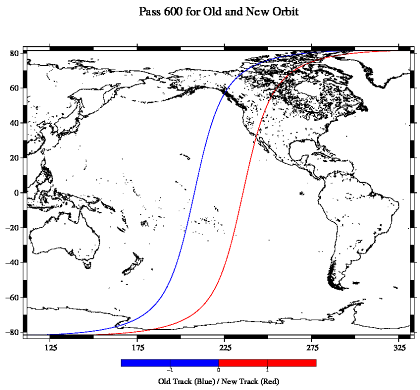



Figure 29: *Envisat pass 600 old (blue) and new (red) locations*

## 3.2 Potential impact of the MSS degradation

Figure 30 shows the monitoring per day of the Corrected Sea Level Anomaly. Concerning the SLA standard deviation, no degradation due to the MSS outside of the repeat track can be noticed. After Jason-1 ground track shift (2009) a degradation of around 2cm rms was noticed on SLA standard deviation (referenced to Jason-2 which remained on the initial track). Here, the degradation is hidden by the absolute SLA variability around 10cm rms: (we compare 100cm$^2$ to 100+4cm$^2$).

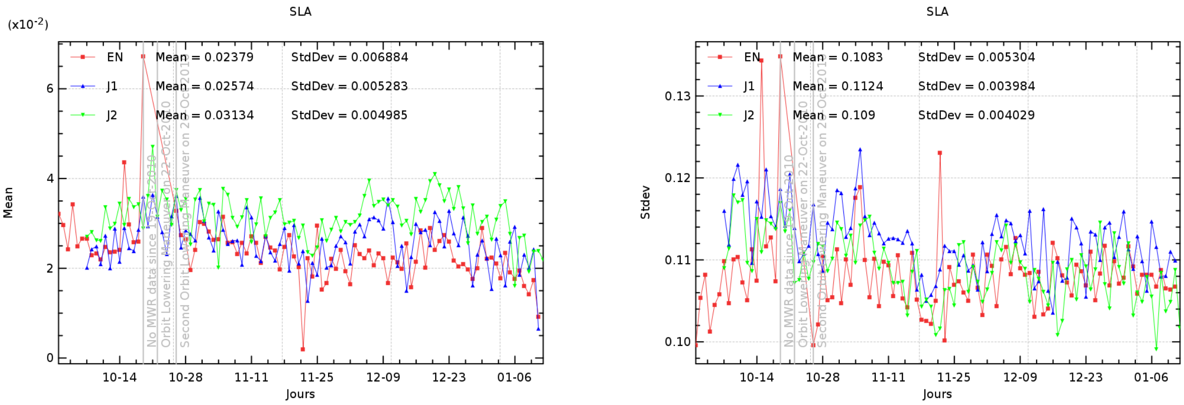



Figure 30: *Multi-mission monitoring KU band Corrected Sea Level Anomaly : mean and standard deviation per day*

# 4 Summary

The Envisat IGDR data from 27th October 2010 have been analysed in this report.

**On cycle 96 (27 Oct 2010 - 26 Nov 2010)**, note that passes 7, 204 and 862 are completely missing and
passes 6, 8, 48, 49, 117, 203, 352, 555, 556, 815 and 816 are partially missing.

**On cycle 97 (26 Nov 2010 - 26 Dec 2010)**, 6 pass are completely missing:
- passes 92-93: Scheduling anomaly (telemetry downlink pb)
- 174 acquisition pb at ESRIN
- 237 antenna pb: orbit not acquired at ESRIN.
- 513-514 (14/12) Bad data acquired at Kiruna EOFC

Moreover passes 91, 173, 235 are partially missing.
- Note: P456 is not missing anymore.

**On cycle 98 (26 Dec 2010 - 11 Jan 2010)**, no track completey missing nore edited are noticed.

Since 27 October 2010, the main comments are:

- Apparent squared mispointing is slightly weaker than its value before the maneuver but its dynamic remains within the nominal values currently observed.
- SLA standard deviation: The quality of IGDR products is very good, no strong degradation is visible on results probably hidden by the absolute SLA variability around 10cm rms: (we compare $100cm^2$ to $100+4cm^2$).
- Note that radiometer wet troposphere differences with ECMWF model seem to be pretty high until the 9th of November and then tend to decrease to a mean value of 3.5 mm, consistent with Jasons' results and linked with the evolution of the ECMWF model. This jump is more significant on J1 and J2 than on Envisat. This implies, as seen on the monitoring of radiometer and model differences, a decrease of the mean value of the standard deviation to less than 1.2 cm whereas it remains constant around 1.8cm on Envisat.
- No visible impact is noticed on the other main parameters: SLA bias, SWH, Sigma0, MWR correction, rms of 20Hz range...
- Some jumps are noticed on some parameters as the SWH standard deviation/day but cross comparison to other altimeters shows that it is linked to natural ocean variability.
- Finally, as shown on figure 32 and 33, results obtained on crossover mean differences for cycles 96 and 97 are in agreement with previous cycles (figure 31) with comparable patterns of mean differences on the different basins of the global ocean.

Note that due to ground tracks geometry change, crossovers are now missing from some thin bands of latitudes.

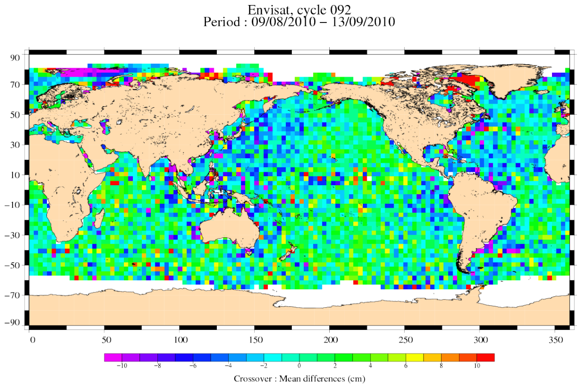



Figure 31: *Crossover : Mean differences for cycle 92- Before orbit change (cm)*

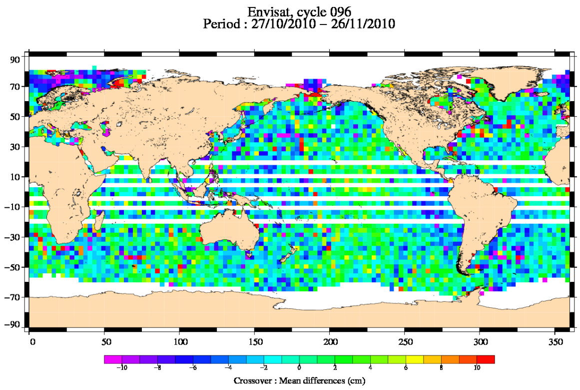



Figure 32: *Crossover : Mean differences for cycle 96 (cm)*

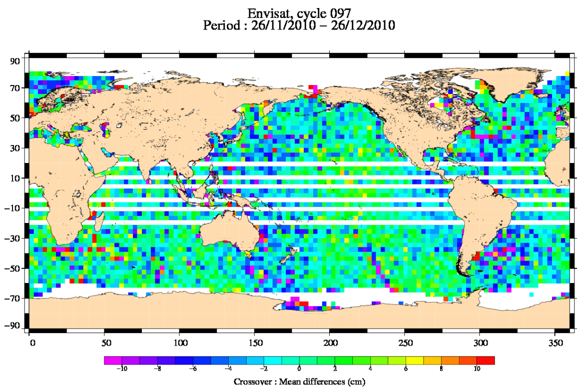



Figure 33: *Crossover : Mean differences for cycle 97 (cm)*

### 7.4.3. GDR aditionnal product validation

First, qualitatively, the theoretical drift of tracks can now be confirmed by GDR position plots. This is illustrated by the real plot shown figure 49 where one can observe that the ascending passes vary more than the descending ones at this latitude (54°.
However, quantitatively, the drift read on the map is around 0.1 ° in 6 cycles that is to say 0.02° par cycle where 0.006° was expected theoretically... Converted in km at this latitude, the drift is around 10km in 6 cycles whereas around 3.6km were expected.
This should therefore monitrored carefully.

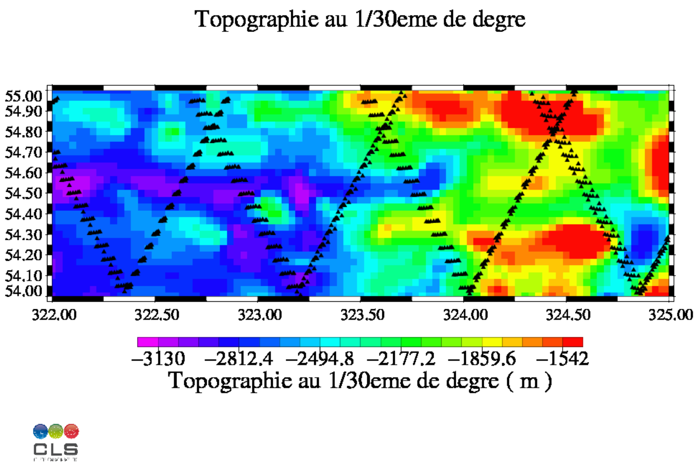



Figure 49: *Real evolution of the distance between tracks for 10 cycles (96 to 101), around 54° latitude*

After Jason-1 ground track shift (2009) a degradation of around 2cm rms was noticed on SLA standard deviation (referenced to Jason-2 which remained on the initial track). For Envisat IGDR products no degradation could be observed on the SLA performence.
Actually, for IGDR products, the degradation is hidden by the absolute SLA variability around 10cm rms: (we compare 100cm2 to 100+4cm2).
Some cycles after the change of orbit, however, additionnal investigations could be performed on GDR products concerning the expected slight degradation due to the MSS outside of the repeat track as reference of SLA computation.
For GDR products the variability is globally lower (mainly thanks to the better POD orbit restitution) and the degradation is visible on the standard deviation monitoring (see plot 50).
Note that the degradation reaches the level observed for cycle 65 were a particularly hot summer had uncovered for the first time oceans above North East Siberia during September-October 2007 leading to a degraded MSS (see Part ).
This result is expected.

Concerning the apparent squared mispointing slightly weaker than its value before the maneuver, the observation is maintained when looking at the GDR products (see plot 51). This is under

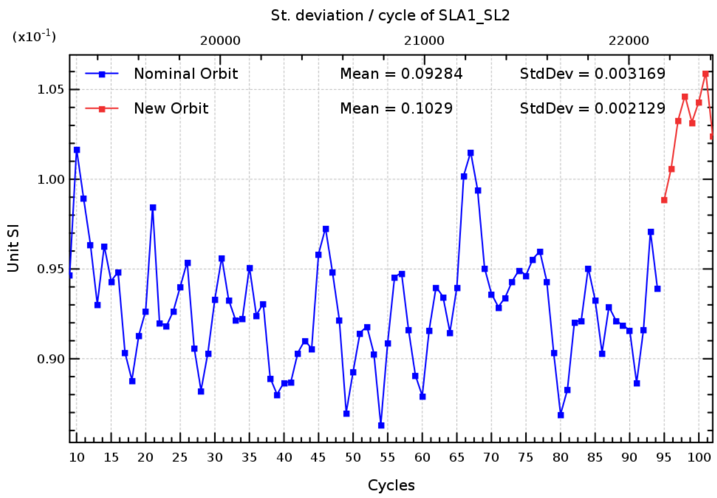



Figure 50: *Standard deviation of Envisat GDR SLA monitoring.*

investigation.

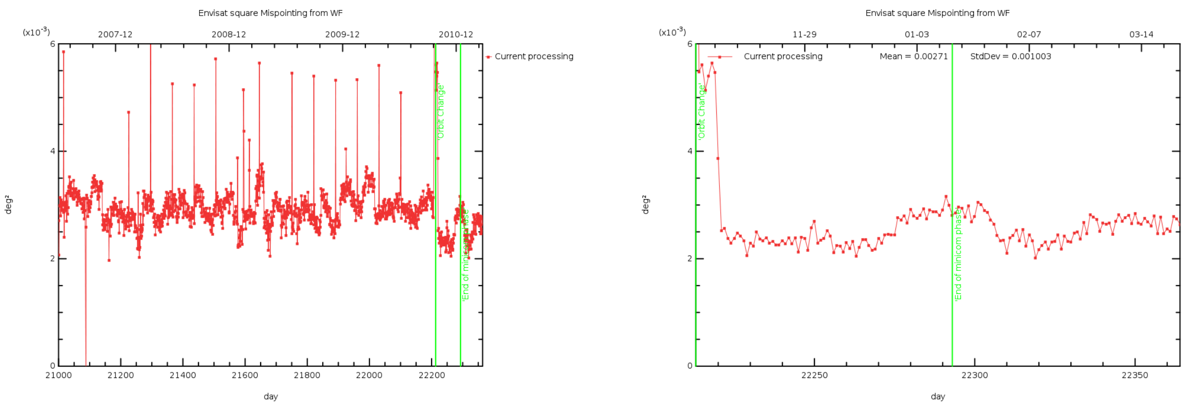



Figure 51: *Daily mean apparent mispointing estimated from waveform. Left: from 2007 to 2010. Right: Zoom after orbit change.*

#### 7.4.4. Conclusion

Performences of Envisat are therefore still very good after the change of orbit exept for the slight degradation due to the MSS quality outside of the repeat track.
Note that this year extensive studies were performed to estimate a new MSS from new mean profiles estimated on the longest time series available (15 years) and using recent standards. This should improve the quality of the MSS everywhere and notably out from the repeat track were Envisat is drifting. Results were presented at the OSTST meeting in the presentation available at: http://www.aviso.oceanobs.com/fileadmin/documents/OSTST/2010/oral/19_Tuesday/Schaeffer.pdf.

# 8. Conclusion

A statistical evaluation of Envisat altimetric measurements over ocean has been presented in this report. With more than eight years of data now available in Geophysical Data Record (GDR) products, Envisat altimetric measurements show good general results:

- A very good **availability** of Envisat data on the last 18 months was noticed thanks to an improvement of the data dissemination since May 2008.

- The **S-Band loss** is considered to be permanent and all the S-band parameters MUST NOT be used anymore. The dual ionospheric correction could efficiently be replaced by the JPL GIM Ionospheric correction with no visible impact on the data quality, presumably thanks to the low solar activity period when it occured. However, this could be problematic for MSL studies regarding the instabilities noticed on the GIM correction.

- The **USO anomaly** still did not affect Ra-2 this year and since January the 23th 2008. Auxiliary files correction allows Envisat Ra-2 data to recover their nominal quality during anomaly period. They are also recommended to be used in previous non anomaly periods as well in order to take into account the long term aging drift. After 93 though, and for v2.1 reproccessed data, no more auxiliary files are needed anymore the range is now directly/properly corrected.

- The **SLA performance** is very good, at the same level as Jason-1 with geographical differences between Envisat and Jason-1 reaching the cm level using recent (September 2005's IPF/CMA update) orbit and geophysical correction. The current v2.1 standards (orbit configuration, instrumental and geophysical correction) used since September 2005 in the IPF/CMA, allow Envisat products to have a higher geophysical quality.

- The**altimeter and radiometer parameters** are consistent with expected values. However, differences between MWR and ECMWF wet troposphere correction are still periodically noticed due to version changes of the ECMWF Model with a strong impact on the MSL trend. Homogeneous model time series would be very useful. Furthermore investigation on the MWR stability should be carried on.

- Very good consistency was found between Envisat and **Jason-2** data with the longer and longer time series. This is encouraging for insuring a good continuity on the long term monitoring already initiated with Jason-1 since 2002.

- The Envisat **Mean Sea Level trend** is still an issue and was studied again this year. It is unfortunatly still unusable at the beginning of the mission (until cycle 22). However, this year, after the extensive studies performed on all the terms of SLA we could update (including the new official GDRC Orbit), a particular care was brought to instrumental calval monitoring. A term of the instrumental correction is being suspected to be wrongly applied on the data which could introduce errors in Envisat's MSL time series. Investigations are carrying on to prove that the correction of such instrumental term could significantly reduce MSL discrepencies with Jason-1.

- Extensive studies of comparison to in situ data (Tide gages and TS profile) were performed this year, helping to characterise the differences between Jason-1 and Envisat missions. They enabled for instance to evidence East/west discrepencies probably due to a different impact of the time variable gracvity field in both mission.

- A **reprocessing** of the whole Envisat altimetric mission began in 2010. The major evolutions are a new precise orbit based on recent Grace data and new ITRF model (validated this year from cycle 15 onwards), new geophysical and instrumental (USO) corrections, new SSB correction, updated wet tropospheric correction. A first Calval analysis of the data reveled an implementation problem on IPF side and the reprocessing was then blocked from March to November 2010, to get the problem solved. Meanwhile, a temporary solution was developped in order to maintain the current cycles production. The reprocessing is going on and should be finished early 2012. Besides it is planned to re-process ERS-2 data with similar algorithms (REAPER project).
These new products will further improve the high quality level of the Envisat altimetric mission and will make easier the data merging for multi-mission altimetry, as it is essential for oceanography and applications.

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# 10. Appendix 1: Instrument and plateform status

## 10.1. 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

## 10.2. Cycle 010

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

## 10.3. 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)

## 10.4. 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)

## 10.5. 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)

## 10.6. 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)

## 10.7. 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)

## 10.8. 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

## 10.9. Cycle 017

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

## 10.10. 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)

## 10.11. 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)

## 10.12. 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)

## 10.13. 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)

## 10.14. 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)

## 10.15. 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))
- .

## 10.16. 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)

## 10.17. Cycle 025

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

## 10.18. 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)

## 10.19. 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)

## 10.20. 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)

## 10.21. 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)
- .

## 10.22. 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)

## 10.23. 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)

## 10.24. 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)

## 10.25. 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)

## 10.26. 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)

## 10.27. 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)

## 10.28. 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 )

## 10.29. 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 )

## 10.30. 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 )

## 10.31. 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)

## 10.32. 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)

## 10.33. 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)

## 10.34. 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)

## 10.35. 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)

## 10.36. 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)

## 10.37. 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))

## 10.38. 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 Manoeuvre (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 bandwith 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)

## 10.39. 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)

## 10.40. 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)

## 10.41. Cycle 049

- none

## 10.42. 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)

## 10.43. 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)

## 10.44. 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)

## 10.45. 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)

## 10.46. Cycle 054

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

## 10.47. 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)

## 10.48. Cycle 056

- No event

## 10.49. 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)

## 10.50. 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)

## 10.51. 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)

## 10.52. 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)

## 10.53. 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)

## 10.54. 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)

## 10.55. 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)

## 10.56. 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)

## 10.57. 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.

## 10.58. Cycle 066

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

## 10.59. Cycle 067

- None

## 10.60. Cycle 068

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

## 10.61. Cycle 069

- None

## 10.62. Cycle 070

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

## 10.63. Cycle 071

- None

## 10.64. 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.
- .

## 10.65. 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.

## 10.66. 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)

## 10.67. Cycle 075

- None

## 10.68. 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)

## 10.69. Cycle 077

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

## 10.70. 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

## 10.71. Cycle 079

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

## 10.72. Cycle 080

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

## 10.73. 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)

## 10.74. Cycle 082

- None

## 10.75. 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)

## 10.76. 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)

## 10.77. 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)

## 10.78. 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)

## 10.79. 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)

## 10.80. 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)

## 10.81. 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)

## 10.82. 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

## 10.83. 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)

## 10.84. Cycle 092

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

## 10.85. 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)