AN OPERATIONAL CORRECTION FOR THE RA2 SIDE A USO ANOMALY: METHOD AND PERFORMANCE ASSESSMENT

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ABSTRACT

For an unknown reason a change of behaviour of the Ultra Stable Oscillator (USO) clock frequency occurred on September 2004 lasting 2 days and on February 2006, lasting 9 days. Between March 2006 and March 2007, all the RA-2 A-side data have been impacted by the USO anomaly. Translated into range, the anomaly consists in an oscillating signal with an orbital period and an amplitude of 30cm around a 5.6m mean bias.

This paper presents the method implemented temporarily to correct the anomalous data as well as the assessment of the quality and performance of the corrected data through two analyses: first, an extensive geophysical validation study over ocean, then a comparison of the operational correction method to a predictive model based one.

Auxiliary files are available on all surfaces, for real time and off-line data, at the same time as the products themselves and enable Ra2 data to recover their high level of accuracy. Soon, a finalized correction will be included in the products themselves.

1. INTRODUCTION

For an unknown reason a change of behaviour of the Ultra Stable Oscillator (USO) clock frequency occurred on September 2004 lasting 2 days and on February 2006, lasting 9 days. Between March 2006 and March 2007, all the RA-2 A-side data have been impacted by the USO anomaly.

An operational correction procedure has been implemented by the altimetry Data Processing and Quality Control (DPQC) team. This paper aims at presenting this correction method.

After a description of the anomaly since september 2004, the method used to correct the data is presented. Then, a quality assessment of the corrected data is performed over ocean during the anomaly period. On the same period, a comparison is then performed with another solution, a model based correction. Finally, the method is tested on a stable period in order to check that the proposed method enables to moitor the USO device long term effects. To finish with, the last section deals with the practical details necessary to use the correction.

2. ANOMALY DESCRIPTION

When the anomaly occurs, the USO period increases rapidly during several hours to reach about 12500.090 picoseconds and from then starts to oscillate with a 0.005 ps amplitude. This change of frequency has a direct impact on the altimetric range measurement in both Ku and S bands. Translated into range, the anomaly consists in an oscillating signal with an orbital period and an amplitude of 30cm around a 5.6m mean bias. It is noticeable on the Sea Level Anomaly (SLA) map in Figure 1 that without the correction, all the oceanic structures would be hidden by the anomaly.

The change of behaviour of the Ultra Stable Oscillator (USO) clock frequency occurred on September 2004 lasting 2 days and on February 2006, lasting 9 days as shown in Figure 2. Furthermore, between March 2006 and 2007, the USO correction does not have a stable behaviour concerning its average per day. It varies between 5.2 and 5.8m. Jumps can also be noticed after each platform or instrument event. Since the beginning of March 2007 the USO period bias and orbital variations disappeared, coming back to the nominal behaviour. The reason remains unexplained as well.

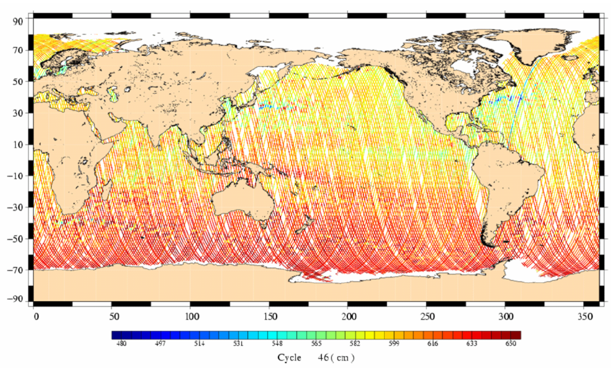

Figure 1. SLA without the USO Correction on cycle 46 affected by the anomaly.

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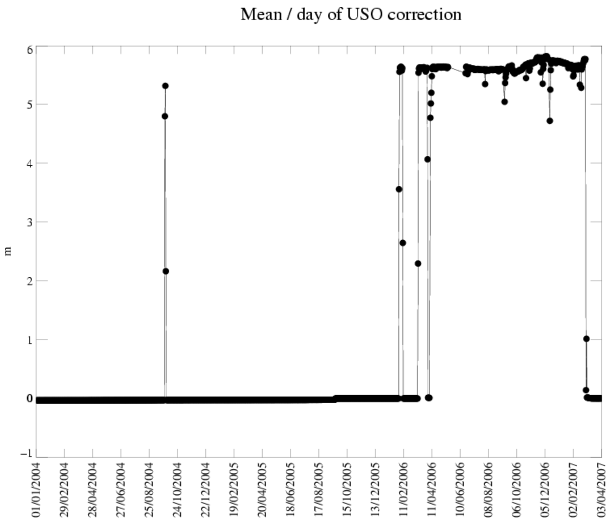


Figure 2. Daily mean Period converted into range (m) since September 1st of 2004

3. USO RANGE CORRECTION METHOD

The proposed method to estimate the true USO period is based on a reference with the on board clock ([1]). The USO period is calculated by finite difference:

$$Period(t) = \frac{OBDH(t - step/2) - OBDH(t + step/2)}{USO_{count}(t - step/2) - USO_{count}(t + step/2)} \quad (1)$$

(1)

Where OBDH is the on-board clock time, USOcount the count of the altimeter clock and step=100s. The method is fully described in [2] and [3]. To compute a corrected tracker range an approximated method is used. The range used comes from an already computed tracker range with a wrong USO clock period (using Level1B data instead of Level0). It is demonstrated in [4], that the error using this method is negligible.

Once calculated the period with the short step, it is noticeable in Figure 3 (top), that a quantification step appears. In order to smooth it, a filter is applied on the raw period (middle) before converting it to a smooth range correction (bottom). a spline regression filter was preferred to a Lanczos filter low pass filter because it presents the strong advantage of filling small gaps of data taking into account the dynamic of the points apart from the gaps. It is shown to give better results than a Lanczos low pass filter near gaps and similar results elsewhere. To choose the spline smoothing factor a comparison between the two filtering methods was performed. The Lanczos cut-off frequency has indeed a real physical meaning, and is thus easier to estimate. Three complementary criteria were then observed to choose the final spline smoothing factor:

• Minimum standard deviation between the data filtered with he two metods

• Absence of strong non physical divergence for the spline

• Absence of local oscillations (this have been detected thanks to a relative comparison with a model method (see chapter on the comparison with the correction proposed by R Scharroo).

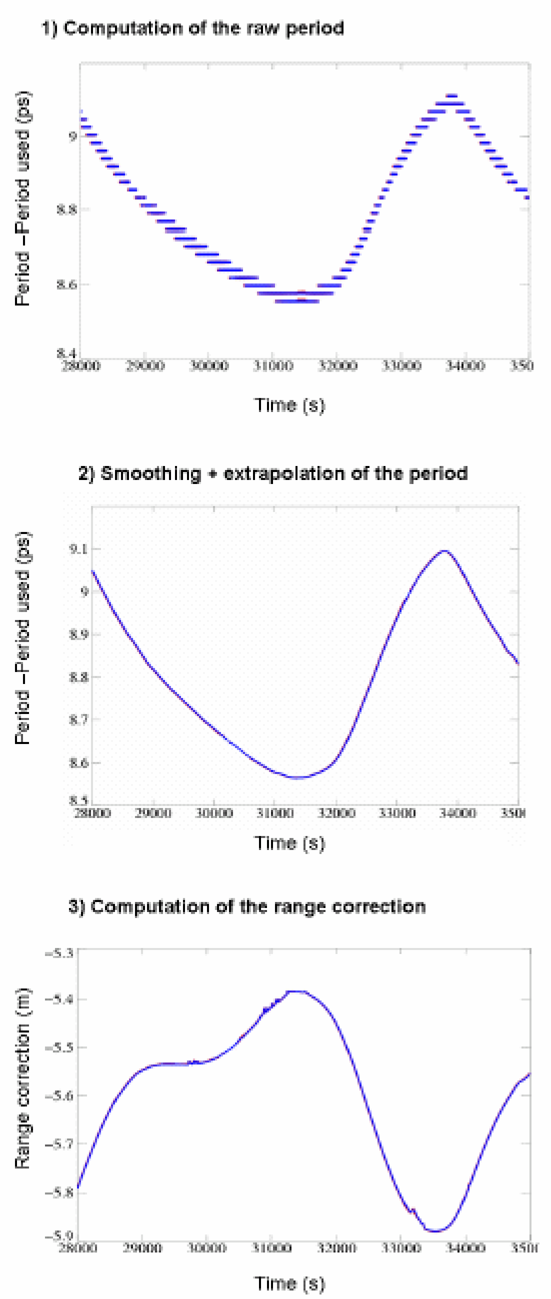


Figure 3. Raw period computation (top), filtering (middle) and conversion to range correction (bottom).

The USO range correction is then computed as follow with the equation:

CorrUSO = Range.[Period(t) – $Period_{GS}$]/Period(t) (2)

where $Period_{GS}$ is the clock period used in the ground segment and equal to 12500ps for IPF versions up to V4.58. For data produced in more recent version before

11/03/2006, it is recomputed every 3 days to take into account the long term variations of USO clock period. After the 11/03/2006, this strategy was no more used and $Period_{GS}$ is set to 12499.999726000 ps.

4. QUALITY EVALUATION OF THE CORRECTED DATA OVER OCEANS

As seen in Figure 1, on the uncorrected SLA map, data are unusable without correction. The following monitoring shows that once corrected, data recover their nominal level of accuracy. Figure 4 shows an example of the SLA after correction. The monitoring of SLA (Figures 5) and SSH at crossovers (Figures 6) statistics shows a good consistency of the performances of corrected data before and after the anomaly. Another way of validating the correction consists in analysing relative performances of different corrections. The following part deals with a comparison between two possible approaches of correction.

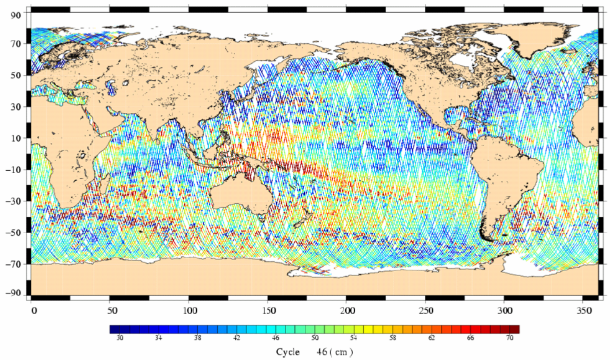
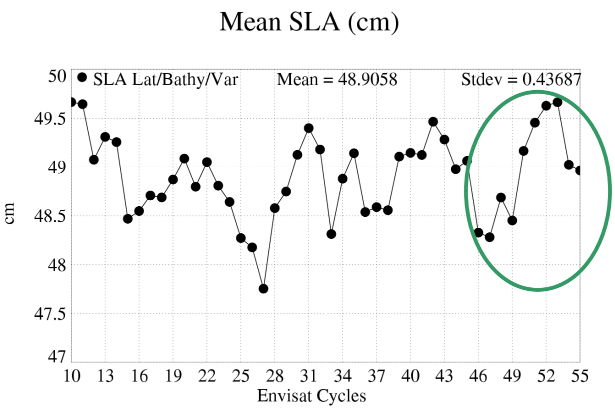


Figure 4. SLA corrected by the USO Correction on cycle 46 affected by the anomaly.



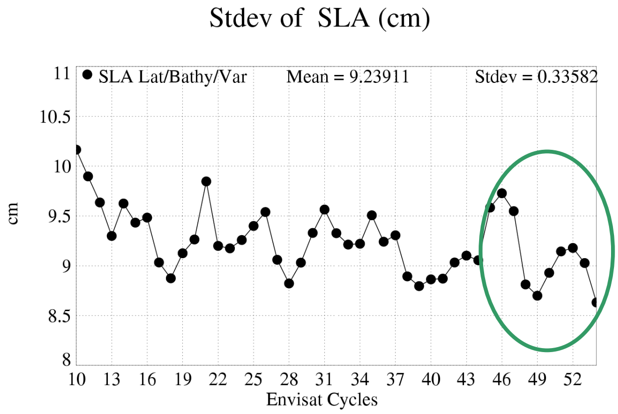


Figure 5. SLA average (top) and standard deviation (bottom) of corrected SLA. Cycles circled in green are affected by the anomaly.

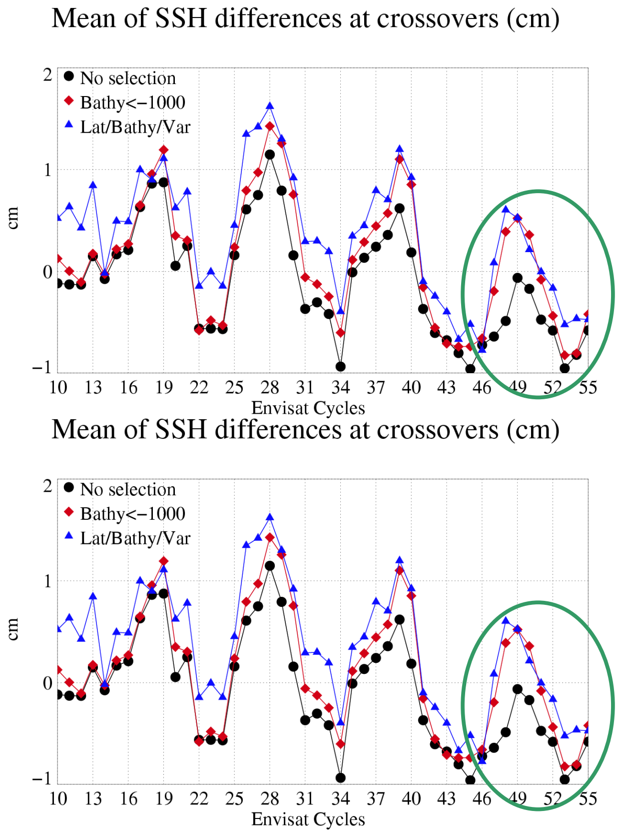


Figure 6. SSH at crossovers average (top) and standard deviation (bottom). Cycles circled in green are affected by the anomaly.

5. COMPARISON TO A MODEL BASED CORRECTION

Here, the operational correction is compared to a method based on a modelling of the USO period oscillation which was found to be strongly linked to the orbital period. It was proposed by Remko Scharroo and is detailed in [5]. This method is predictive, which can be a strong advantage in terms of operations for the generation of real time corrections. Because those

methods are completely different, this relative comparison is a very good way for assessing the performance of the corrections. The performances are compared over the same data set over ocean using GDR data of Cycles 46 and 47. Thanks to either correction, the previously unusable altimetric data now have satisfactory performances. However, some fine differences are still evidenced. Figure 7 shows that the mean differences are weak (around 3mm). However, in case of strong variation of the USO period (after a switch off/on for example) this value can reach 10 cm (Figure 8).
Figure 9 shows that the geographical distribution of the difference between the two corrections is not homogeneous: the operational correction is slightly higher (of about 2-3 mm) than the predictive model's in the northern hemisphere whereas the situation is inverted in the Southern hemisphere. The variance of differences reaches 1cm2 around 40°S of latitude. Some higher values are also noticed along several passes. These passes corresponds to measurements just after a restart.
In order to compare the performance of the two methods, SSH differences at 10-day crossovers are computed. When looking at the mean SSH differences at crossovers, (see table 1), we see that the predictable model correction induces a strong bias compared to usual values whereas no bias is noticed when using the operational correction. This bias is due to some problems in the modelling method around 40°S of latitude. These errors implies systematic ascending/descending differences in these areas. The signature of these errors are also visible in Figure 9 (bottom).

Performance of SSH at crossovers	Operational Correction	Predictive model Correction
Cycle 46		
Number of Points	39406	39406
Mean	-0.74 cm	-1.55 cm
Standard Deviation	8.28 cm	8.41 cm
Mean Quadratic Error	8.31 cm	8.55 cm
Cycle 47		
Number of Points	26723	26723
Mean	-0.67 cm	-1.23 cm
Standard Deviation	7.93 cm	7.90 cm
Mean Quadratic Error	7.96 cm	8.00 cm

Table 1. Performance of SSH at crossovers for both Corrections. Cycles 46 and 47.

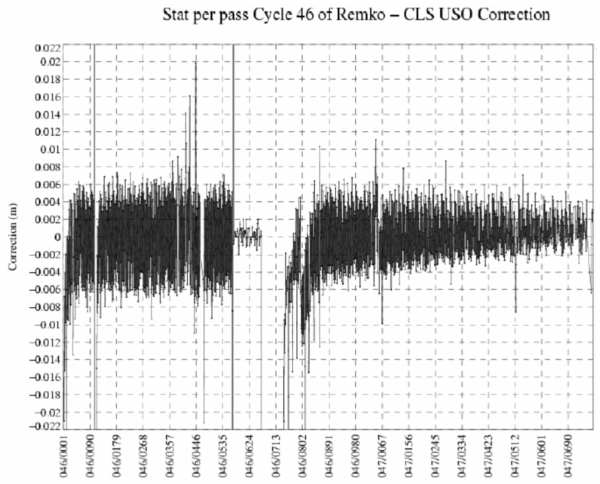


Figure 7. Average USO correction differences per pass for Cycle 46 and 47

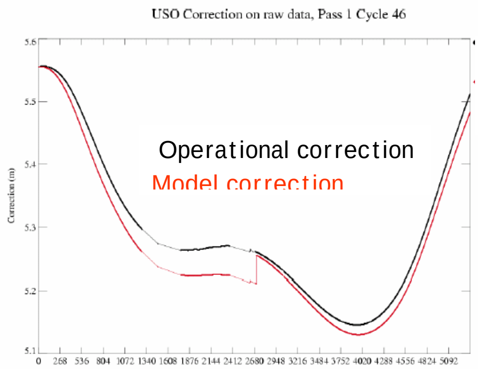


Figure 8. USO correction differences for the pass 1 of cycle 46.

To conclude, although the two corrections studied seem to have similar behaviours and to both provide a good correction of the data oscillations, the analysis presented here enables to lighten some differences. The predictive model, seems to need further tunings in order to better take into account rapid changes of the mean USO value in order to avoid the jumps between consecutive tracks. In addition to that, the bias it introduces between ascending and descending tracks should be further investigated and could probably be over turned with a different tuning of the model. Concerning the operational method, this study enabled to evidence very weak oscillations which drove to a refinement of the spline smoothing factor. After this refinement, the local oscillations are much smoothed and the performances of oceanographic parameters seem quiet close to the ones obtained before the anomaly period.

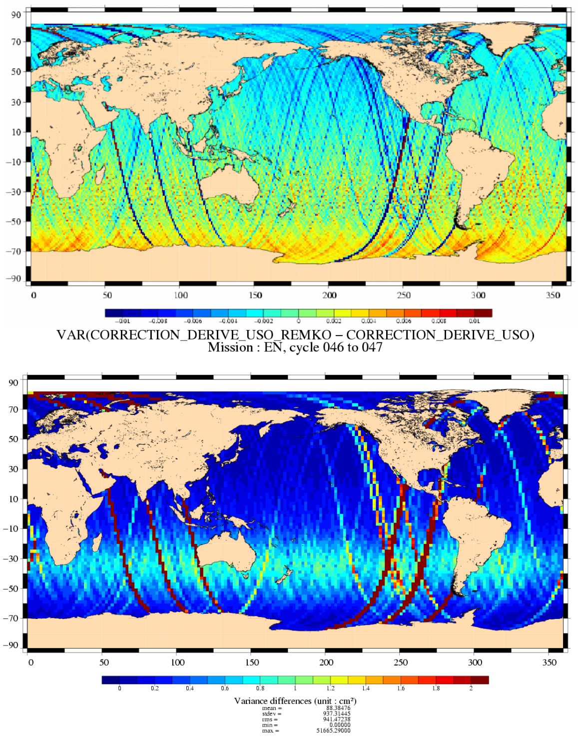


Figure 9. (Predictive model USO Correction - Operational USO Correction) mean differences (top) and standard deviation of differences

6. ANALYSIS OF THE VALIDITY OF THE LONG TERM DRIFT COMPONENT SEEN BY THE NEW CORRECTION

The aim of this section is to compare, on a non anomalous period, two methods of computing the USO corrections: a method using a step of 100s with a spline filter to the previous one, using a step of 86400s ([1]) with a three days interpolation of monthly averages. As expected, the first one is shown to follow more precisely the short terms variations such as recoveries after instrumental events. The other one is very much smoothed and only gives information on the long term drift.

As seen in Figure 10, for the analysed cycles, the drift can be approached by a linear increasing. The slopes of both methods are almost equal. Thanks to this study, it is therefore shown that the global long term drift is the same in both cases and that the short step method enables to recover the long term drift as well as the short term ones. This validates that a shorter step method does not loose any long term information.

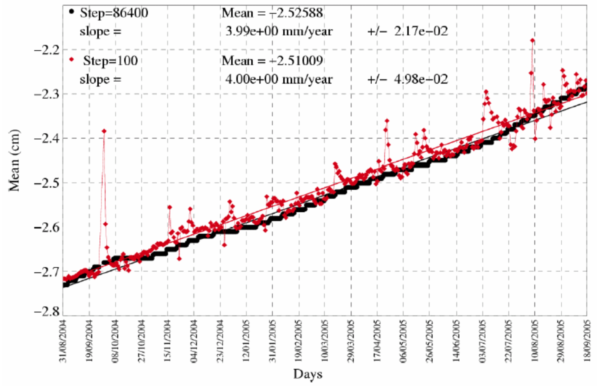


Figure 10. Mean per day of Correction Step=100s and Correction Step=86400s.

7. PRACTICAL USE OF THE TEMPORARY CORRECTION

This correction has been computed and developed operationally and delivered to the users since Cycle 46, see Figure 11). The correction concerning previous anomalies (Cycles 30, 44 and 45) were computed with the same method and also delivered to the users. There are three USO corrections for the different Envisat Level 2 altimetry data products:

• A NRT orbit basis USO correction for FDGDR products, available from http://earth.esa.int/pcs/envisat/ra2/auxdata/. The NRT USO correction is available from July 28, 2006 onwards.

• An Interim daily USO correction for IGDR products, available at the same F-PAC location as for IGDR, in the directory igdr ous corr.

• An OFL cycle USO correction for GDR products, available at the same F-PAC location as for GDR, in the directory gdr ous corr. Information on USO correction filename and format definition is available from: http://earth.esa.int/pcs/envisat/ra2/auxdata/NewCorrection.html. A software can be used to include the correction fields in the product themselves. It is available at the following address: http://earth.esa.int/pcs/envisat/ra2/auxdata/software/

This device is available under SUN and LINUX versions.

Note finally that users are advised to apply the correction auxiliary files even during the non-anomalous period in order to correct for the nominal ageing drift of the USO device.

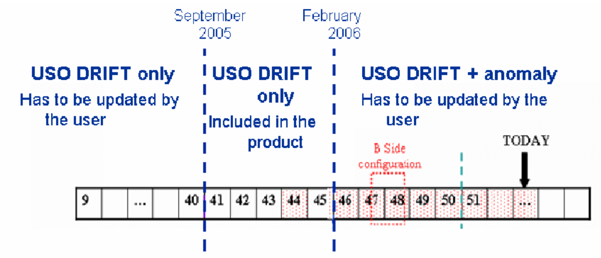


Figure 11. Chronology of USO Correction computation.

8. CONCLUSIONS

The USO anomaly is a major anomaly which strongly impacts the RA-2 quality data quality. An operational correction procedure has been implemented by the altimetry Data Processing and Quality Control (DPQC) team. Thanks to this temporary procedure the correction has allowed Ra-2 data to recover their nominal quality in real time since the 1st of August 2006.

An extensive validation was performed and enabled to show that the corrected data now had a nominal quality. The proposed method has also been validated by comparing to another method, a model based solution.

Soon, a finalized correction procedure will be implemented in the ground segment and the range will be directly corrected in the products themselves.

Acknowledgements

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