Estimation of the Absolute Orbit Accuracy of Envisat

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Introduction

This paper presents the results of the orbit comparison campaign conducted at the European Space Operations Centre (ESOC) in May 2003. The goal of the comparison is to better quantify the absolute orbit accuracy of ENVISAT. For this comparison cycle 12 of ENVISAT was selected which corresponds to a period of 35 days starting at 10.12.2002 and ending at 13.01.2003. Two days, 18 and 19 December, were excluded within this period from the comparison. These days were selected because of the large inclination manoeuvre on 18 December and the resulting loss of DORIS and SLR tracking data for nearly a day.
Six different centers contributed their POD solution to the comparison. The CNES POD solution used in this comparison is the same solution as the one that is found on the ENVISAT altimeter GDR. The JPL-DORIS solution only uses the DORIS tracking dataset and is based on the EGM-96 gravity field where all the other centers use DORIS and SLR data and the GRIM5-C1 field. Three complementary analysis methods where applied to all contributions, namely pair-wise orbit comparison, SLR tracking data analysis and altimeter crossover analysis.

Pair-wise orbit comparison

Table 1 provides the pair-wise total and radial orbit difference for all solutions. The top triangle shows the RMS difference and the bottom triangle provides the order within the total set of comparison pairs. The RMS of differences between the orbit solution and the true ENVISAT orbit can be seen as a measure for the orbit error, denoted as RMS_A and RMS_B for two solutions A and B respectively. If the two solutions are independent, their two orbit error signals are fully uncorrelated. The pair-wise error value RMS_{AB} follows from:

$$RMS_{AB} = \sqrt{RMS_A^2 + RMS_B^2}$$

The pair-wise orbit error should be the value that is observed in the form of the orbit difference RMS from Table 1. It is possible that the same systematic error is present in two or more orbit solutions, for instance the same systematic gravity field errors or a bias in the DORIS tracking dataset. Similarly, two orbit solutions can be insufficiently uncorrelated if two centers use the same POD software. In both cases the pair-wise differences from Table 1 will be smaller than what they should be. The observed RMS of orbit differences provides an upper bound to the actual pair-wise orbit error.

Radial (cm)	NCL	CNES	DEOS	ESOC	GFZ	JPL-DORIS
NCL		2.13	1.18	1.73	1.52	3.93
CNES	7		2.45	2.19	2.41	3.87
DEOS	1	10		1.90	1.77	4.12
ESOC	3	8	6		1.90	4.01
GFZ	2	9	4	5		4.06
JPL-DORIS	12	11	15	13	14	

Total (cm)	NCL	CNES	DEOS	ESOC	GFZ	JPL-DORIS
NCL		7.22	6.25	8.07	9.23	18.82
CNES	2		8.76	8.47	9.80	18.33
DEOS	1	6		8.30	10.50	20.40
ESOC	3	5	4		10.44	20.18
GFZ	7	8	10	9		19.48
JPL-DORIS	12	11	15	14	13	

Table 1 Pair-wise comparisons, RMS of radial and total difference between orbits in cm (top triangle) and index wi thin the total set of comparison pairs (bottom triangle: 1 = smallest overall RMS, etc.)

SLR analysis

Because of the very low noise level of the SLR tracking dataset the SLR residuals can give an indication of the lower bound of the orbit error. To correctly evaluate the SLR residuals the processing software and the SLR dataset are exactly identical for all solutions, so that any difference in the residuals can only be caused by differences in the input orbit. All available orbit solutions were separately input into the ESOC POD software, in order to compute RMS laser residuals by means of the following procedure:

- All SLR observations are processed for every orbit solution separately, without rejecting any data.
- A single table can now be created with all 1-way SLR residuals, *i.e.*, one row per SLR measurement and one column for every orbit solution.
- Two further columns are added to the table with the number of accepted/rejected residuals (per observation) after applying a +/- 7.5 cm rejection window (equivalent to roughly a 3-sigma rejection level).
- An observation is accepted if at least 4 of the available solutions show a residual within the 7.5 cm window. If the observation is accepted, it is accepted for all solutions, even for those that have a residual outside the rejection window.
- If an observation is not accepted on the above criterion, it is rejected for all solutions.

As a consequence, exactly the same subset of SLR measurements is accepted for all solutions. The mean, RMS and sigma over the accepted residuals are shown in Table 2. It should be noted that the ESOC solution was obtained from the same POD software that is used here to compute the SLR residuals. The POD process for this solution is based on DORIS and SLR, so that the SLR results for ESOC may be biased in a favorable way.

Solution (cm)	nr obs	RMS	Mean	Sigma
ESOC	4527	1.43	0.10	1.42
NCL	4527	1.88	0.07	1.88
DEOS	4527	1.97	0.51	1.90
CNES	4527	2.93	0.32	2.90
GFZ	4527	3.14	-1.45	2.79
JPL-DORIS	4527	10.66	0.41	10.65

Table 2 Overall SLR residual statistics for each orbit solution in cm. The solutions have been sorted in order of RMS over the accepted data points.

Altimeter crossovers

As the SLR data is used for all POD solutions, except the JPL solution, this measurement type no longer gives an independent assessment of the orbit accuracy. But none of the solutions in this analysis used the altimeter instrument in their orbit solution. Thus the altimeter dataset is completely independent from all solutions. Again as with the SLR analysis the same software and dataset is used so that any differences in the residuals can only be due to the orbit.
The crossovers are based on data from 10.12.2002 – 13.01.2003, excluding December 18 and 19. In order to reduce the sea-height variability contribution to the crossover differences and thereby enhance the orbit differences in these statistics, crossover locations are over open ocean only, and the maximum time difference between two passes is 5 days. No outlier editing has been performed on the crossovers. The crossovers are estimated using altimeter data from the DEOS RADS database. The JPL-GIM ionosphere correction and ECMWF wet troposphere correction replace the dual-frequency and MWR values, in order to maximize the number of valid data points in the dataset. Table 3, list for all solutions the altimeter crossover residuals for cycle 12.

Solution (cm)	nr obs	RMS	Mean	Sigma
DEOS	5782	6.46	-0.23	6.46
NCL	5782	6.47	-0.50	6.45
GFZ	5782	6.58	0.07	6.58
ESOC	5782	6.86	-0.63	6.83
CNES	5782	7.03	-0.89	6.46
JPL-DORIS	5782	8.05	-0.55	8.03

Table 3 Altimeter crossover residuals (in cm) for each solution. The solutions have been sorted in order of RMS over the accepted data points.

Orbit Accuracy estimation

The orbit comparisons apply to a pair of two solutions, the residuals apply to one single solution. If the RMS of pair-wise orbit differences is interpreted as the pair-wise orbit error it is reasonable to compute an equivalent pair-wise RMS of tracking residuals from the RMS of residuals for the separate solutions, according to the same relationship for a pair-wise RMS:

$$RMS(A,B) = \sqrt{RMS^2(A) + RMS^2(B)}$$

Again, this is only possible under the condition that the two solutions have independent RMS values for their tracking residuals, otherwise a common component would disappear from the pair-wise RMS. This does not add a new condition, because the further analysis already required the two compared solutions to have independent error signals.
We can now consider the ratio D which is defined as the pair-wise RMS of orbit error (= the RMS of orbit differences), divided by the pair-wise RMS of tracking residuals as computed above. From statistical analysis it follows that if this ratio D is found to be constant for all compared pairs, the same constant will also define the ratio between the RMS of orbit error and the RMS of tracking residuals for a single solution.
Based on the results from the pair-wise orbit comparisons and the pair-wise tracking data residuals, the factor D can be computed for every compared pair of orbits. The ratio D turns out to be reasonably constant, and the mean factor D is then adopted as the 'Dilution of precision' factor for that tracking data type.
Such an analysis for ENVISAT suggests a total orbit error of 4-7 cm for all, except the JPL, solutions in this comparison. Likewise, radial orbit error is estimated to be as low as 2-2.5 cm. Real values for ENVISAT are likely to be higher. The reason for this is that the used solutions in

this comparison do not seem to be fully independent of each other *e.g.*, the NCL and DEOS solution show very similar behavior. Further all solutions, except JPL, use the same gravity field and the same tracking dataset (DORIS+SLR), which means that any systematic error in the gravity field or the tracking dataset will not show up in the pair-wise comparison. But, several centers do use different software, number of estimated parameters and non-conservative force models, which enhance the independent nature of their solution.
Concluding, the authors feel that a more realistic total orbit error for the presented ENVISAT solutions in this comparison is around 10 cm. with a radial orbit accuracy of 3 cm.

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