

SLR Tracking of Envisat Past its End of Life

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Abstract. *After more than twice of the scheduled life-time, contact to the Envisat satellite was lost in April 2012. Since then, the satellite has been moving uncontrolled in a Sun-synchronous orbit of about 770 km altitude. In the absence of telemetry and active tracking, satellite laser ranging measurements provide an important means for monitoring both the orbit and attitude of Envisat. Since public orbit information (in the form of Two-Line Elements) is generally too coarse to enable a seamless SLR tracking, DLR has taken initiative to determine the orbit of Envisat from SLR tracking and to generate station predicts for the ILRS. Starting from a small initial set of tracking points collected by the Graz laser station after visual search and acquisition of Envisat, a routine processing chain has been established in May of this year. This has enabled a large number of volunteer stations to contribute Envisat observations, which in turn supported a routine orbit processing. The paper focuses on the assessment of the orbit determination and prediction performance and relates it to the achieved SLR coverage. It complements other presentations addressing the benefit of SLR tracking for studies of Envisat attitude behaviour.*

Introduction

The paper is structured in the following way: First, a quantitative assessment of the observations provided by the International Laser Ranging Service (ILRS) is performed. The presented data set of satellite laser ranging (SLR) measurements has served as the basis for orbit determination of Envisat. The methodology and settings for orbit prediction and analysis are threaded thereafter. The most important parameter of influence on the orbit prediction accuracy is the atmospheric drag modelling error. Therefore, the analysis will focus on atmospheric drag coefficient estimation and the dependency of predicted position errors from solar and geomagnetic activity.

Course of the Tracking Campaign

The analysis time period extends over half a year from 2013/05/01 until 2013/10/31. Within this time frame, 19 SLR stations have collected ranging measurements on an average number of 2.87 station passes have been tracked per day (cf. Table 1 for detailed station statistics). This great response from the ILRS network has ensured a constant observations stream and subsequent regular orbit determination and prediction by GSOC. Processing and monitoring of results has been performed manually and during office times. Predictions have been usually updated on Monday, Wednesday and Friday. A total number of 64 prediction files in CPF format spanning seven days into the future have been published on the IRLS website.

Orbit Prediction Analysis

The SLR measurements have been used for a routine batched least-square orbit determination (OD) and subsequent orbit prediction (OP) [3]. All normal points (NPT) from station tracks within a

Table 1. Envisat ILRS observation statistics for tracking period from 2013/05/01 to 2013/10/31

Site Code	# Tracks	# Normal Points	MEAN Range Residuals [m]	STD Range Residuals [m]
GRZL	112	2104	0.027	1.579
CHAL	76	353	-0.149	1.772
YARL	47	352	-0.135	1.927
STL3	46	488	0.088	1.326
SIML	42	455	-0.191	3.133
ZIML	37	103	0.153	2.861
WETL	31	101	1.283	2.021
POT3	27	221	0.020	1.622
SHA2	25	189	0.486	2.785
MATM	20	203	-0.058	1.362
KTZL	13	101	0.823	1.563
RIGL	12	127	0.400	1.622
GLSL	12	176	-0.484	2.973
SISL	7	52	-2.921	1.009
ARKL	7	8	5.365	1.788
GRSM	3	18	0.137	0.929
BEIL	3	13	-0.033	3.127
BADL	2	2	2.332	-
HERL	1	4	0.192	0.591

maximum observation arc length of seven days into the past have been included into a single OD run. Observations have been equally weighted for all stations with 1-sigma a priori measurement accuracy of one meter. The underlying orbit dynamic model settings for OD and OP are listed in Tab. 2. In the same way, an a posteriori orbit solution is computed that incorporates best knowledge information on solar flux and geomagnetic indices derived from past space weather measurements instead of forecasts. The a posteriori orbit fits serve for an evaluation of measurement residuals in the first step, also listed in Tab. 1. The range residual standard deviation (STD) is in the order of a few meters. Due to the uncontrolled attitude of the satellite the laser ranging reflector position exhibits an oscillation in range of a few meters which can be directly seen from the raw measurements [1]. The range residuals mean values (MEAN) are smaller than the standard deviation for all contributing SLR stations. A minority of SLR stations has collected range measurements over full station passes. Most stations have generated a small number of normal points per track that do not cover the apparent spin period of Envisat [2]. In this case, averaging the sine-shaped range residuals over one pass is not possible which deteriorates the station residuals statistic and more severe corrupts orbit determination and prediction accuracy.

Table 2. Orbit Dynamic Model applied for Orbit Determination and Prediction

Earth Gravity Field	30x30 GGM01S
Atmospheric Drag	Jaccia 1971, Cd-Coefficient Estimation
Solar Radiation Pressure (SRP)	Cr-Coefficient Estimation
Satellite Shape & Attitude	Cannonball Model
Third Body Attraction	Sun and Moon with Analytical Ephemeris

Force Model Parameter Estimation

Estimation results for atmospheric drag and solar radiation pressure (SRP) are shown in Fig. 1. The estimated coefficients correspond to a constant cross section of 26 m^2 for atmospheric drag calculation and 20 m^2 for solar radiation pressure calculation respectively. No correlation can be found with solar activity for both coefficients. A correlation would indicate systematic force modelling errors. The drag coefficients (C_d) present mostly small estimation uncertainties, which can be explained by the relative long observation arcs of up to seven days that allow measuring the effect of perturbation accelerations. A time variation of around 25-30% may partly be induced by atmospheric density modelling errors and partly by changes in the average drag cross section. Due to the smaller acceleration of solar radiation pressure compared to the acceleration of atmospheric drag at the orbital altitude of Envisat, the SRP coefficients (C_r) present a larger estimation uncertainty. The strong time variation needs to be further analyzed. Utilization of information on spin axis orientation may be useful for this purpose [2].

Position Prediction Error

The position errors of the predicted orbits from the a posteriori orbits are plotted in Fig. 2 superposed for all OD+OP runs. Maximum values of prediction errors can be read: 20 m for the radial position component and almost constant over time, increasing position errors in tangential and normal direction, starting at a comparable level as in radial direction and exceeding 1 km in along-track direction and 100 m in cross-track direction for the worst cases and prediction times longer than five to six days. Interestingly, the mean position error from all OD+OP runs shows a clear negative trend in along-track direction over prediction time. Data on solar and geomagnetic activity are required for orbit determination and prediction under the influence of atmospheric drag. For this purpose F10.7 solar flux indices and geomagnetic ap and kp indices are downloaded daily

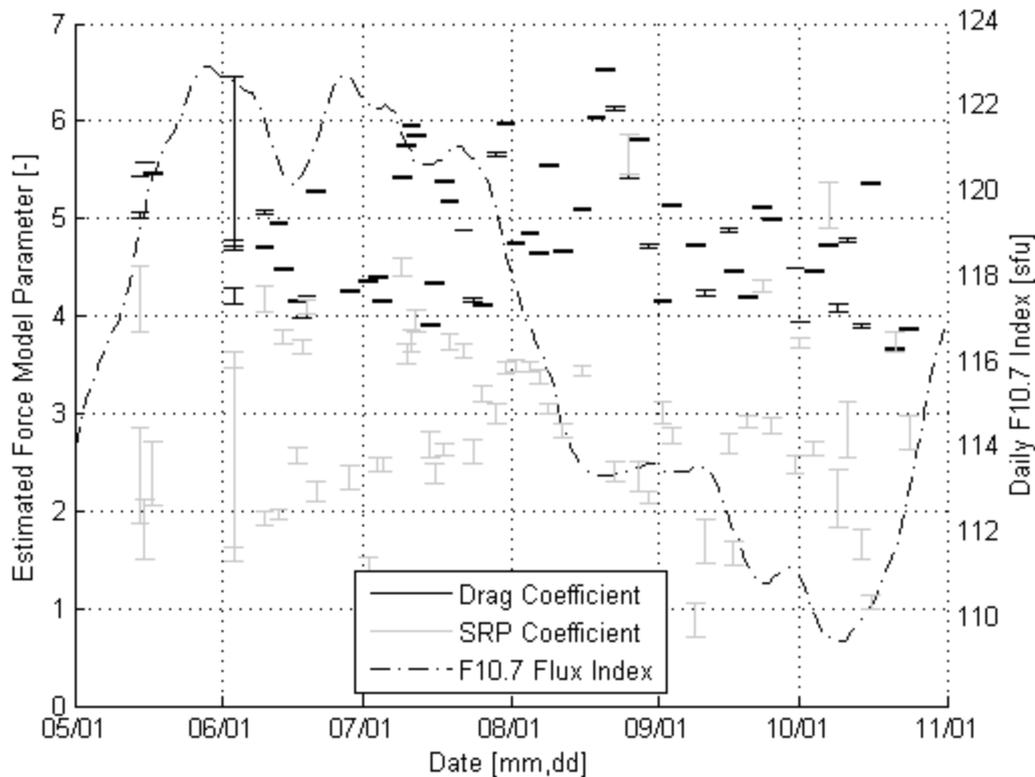


Figure 1. Atmospheric drag and solar radiation pressure estimation results, one-sigma estimation uncertainty indicated by error bars

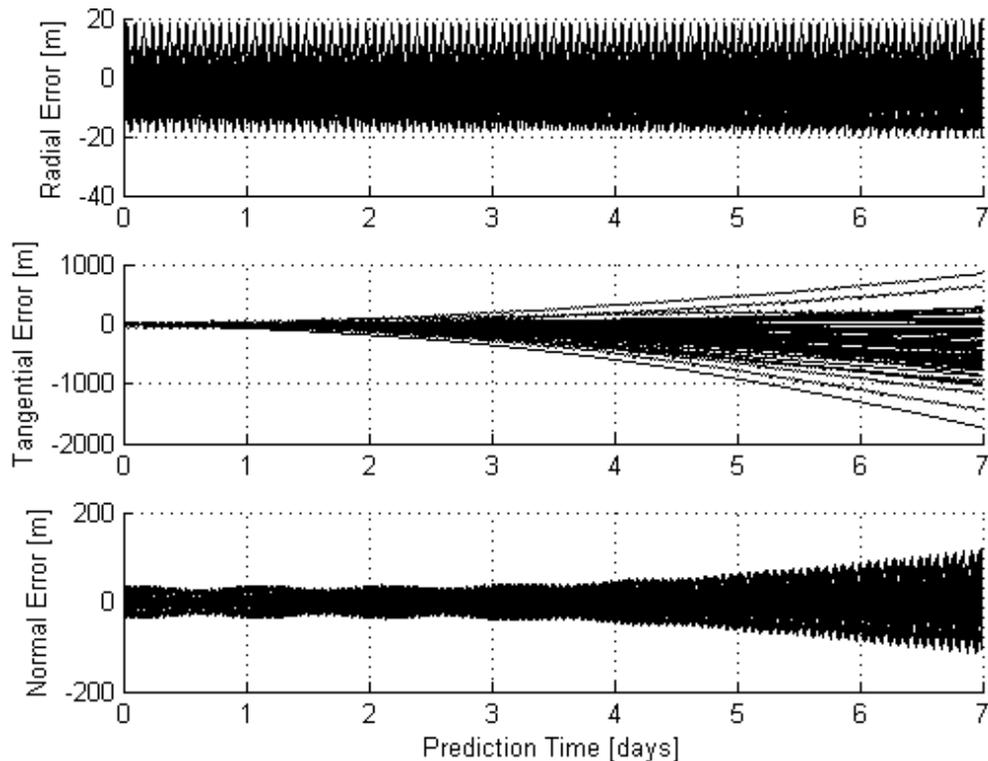


Figure 2. Position prediction error for all OD&OP runs

from a FTP- Server at the European Space Operations Centre of ESA. Till the end of July 2013 orbit predictions have been generated with essentially no information on future solar and geomagnetic activity. The last index data from the current date have been used for orbit propagation. Also shown in Fig. 1 is a graph of daily F10.7 solar flux indices obtained after the end of the tracking campaign. For the majority of OD+OP runs the week long prediction intervals are characterized by decreasing solar activity. By always taking the current index data the solar and geomagnetic activity and therefore the atmospheric drag during prediction has been overestimated in most cases. Predicted index data are obtained from the same source and applied for orbit prediction of Envisat satellite since August 2013 [2]. A statistic over all OD+OP runs before and after incorporation of predicted solar and geomagnetic activity is given in Fig. 3 and Fig. 4. The indices predictions compensate for most of the mean position errors in tangential direction. Moreover, the position error standard deviation slightly improves for the radial and normal component. The results are averaged over single orbital revolutions.

Conclusion

The most important lesson learned is that application of appropriate predictions on solar and geomagnetic activity greatly improved the orbit prediction accuracy by cancelling out mean position errors. The prediction error stays below 3 m in radial direction (1-sigma) and is almost constant over the prediction time. Position errors in cross-track direction start at a comparable low level and steadily increase up to 25 m (1-sigma) after 7 days of orbit prediction. Also the along-track error is steadily growing. A typical error was ~ 200 m after 48 hours of orbit prediction for the six month long analysis period with moderate space weather. The orbit prediction accuracy is sufficiently accurate for SLR acquisition after few days and comparable to predictions generated from dedicated radar tracking campaigns [5]. Based on the findings of this work automated processing will start in December 2013. This will lead to more frequent, daily orbit predictions generated from SLR tracking of the Envisat satellite.

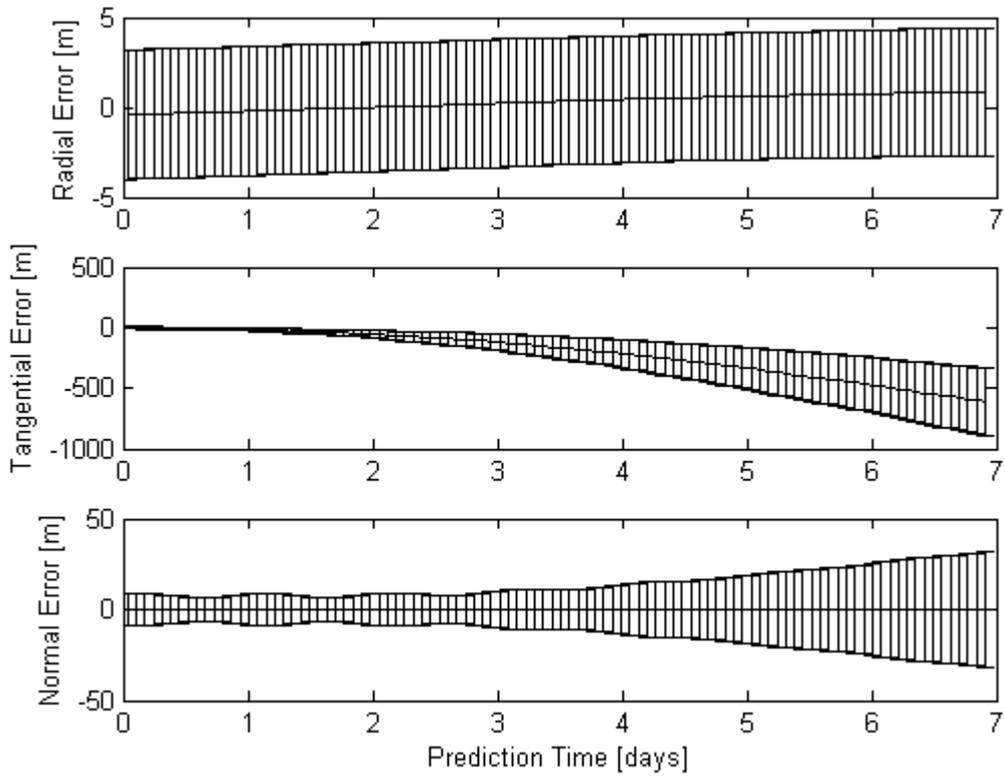


Figure 3. Position prediction error statistic over single orbital revolutions and all prediction generated without application of solar flux predictions

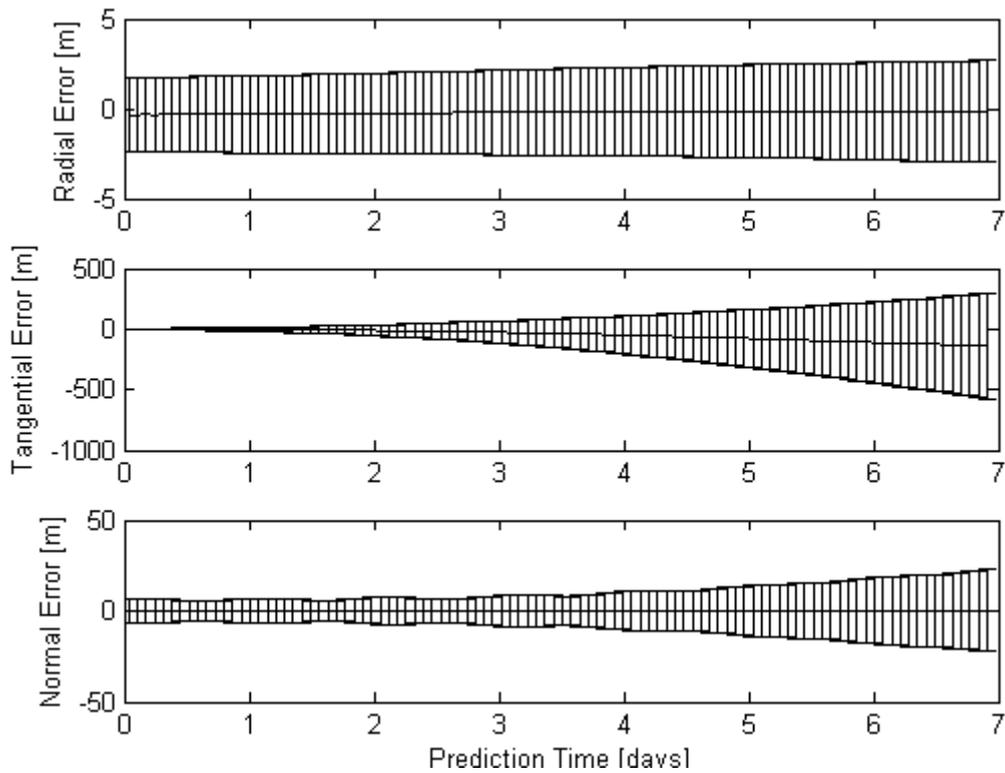


Figure 4. Position prediction error statistic over single orbital revolutions and all predictions generated with application of solar flux predictions

References

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