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On the Accuracy of ERS-1 Orbit Predictions

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by

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Summary

Since the launch of ERS-1 (first European Remote Sensing Satellite) the D-PAF (German Processing and Archiving Facility) provides regularly orbit predictions for the worldwide SLR (Satellite Laser Ranging) tracking network. The weekly distributed orbital elements are so-called tuned IRVs and tuned SAO-elements. The tuning procedure, designed to improve the accuracy of the recovery of the orbit at the stations, is discussed based on numerical results. This shows that tuning of elements is essential for ERS-1 with the currently applied tracking procedures.

The orbital elements are updated by daily distributed time bias functions. The generation of the time bias function is explained. Problems and numerical results are presented. The time bias function increases the prediction accuracy considerably.

Finally the quality assessment of ERS-1 orbit predictions is described. The accuracy is compiled for about 250 days since launch. The average accuracy lies in the range of 50-100 ms and has considerably improved.

1. Background and Introduction

Since the very first days when ERS-1 began his mission in space, the D-PAF is sending orbit predictions to the SLR community. The orbit predictions are produced in form of the well established IRVs and SAO-elements. The procedure is given in chapter 2. Though these orbital elements are very compressed forms of complicated orbit trajectories, they optimally represent the orbit. The trick to achieve this is called *tuning* of elements. In chapter 3 the problem is illuminated from the numerical point of view.

Very soon after launch it became clear that the ERS-1 trajectory is extremely affected by solar and geomagnetic activities. The orbit predictions lost accuracy mainly in along-track direction. The D-PAF therefore introduced the time bias function which is generated and disseminated daily. Meanwhile the time bias function has become an accepted tool in the SLR community. Some features of the time bias function and related topics are explained in chapter 4.

The extremly high solar activity in the first months of the mission brought extraordinary events such as a geomagnetic storm of nearly singular type. Though SLR tracking was almost lost for two days, the D-PAF orbit prediction system (and the SLR community in turn) gained at the end. The software system got more backup solutions and the quality checks were largely extended. Chapter 5 tells more about quality assessment and quality checks.

Finally the orbit prediction system has developed to a reliable system in SLR tracking. This becomes obvious from the course of the average accuracy of the orbit predictions shown in the more detailed analysis in chapter 5.

2. Generation of Orbit Predictions

In a first step the orbital parameters are estimated by differential orbit correction with the DOGS-OC (DGFI Orbit and Geodetic parameter estimation System - Orbit Computation) software. Laser ranges are mainly used as observations for the least squares procedure and in few cases also RA FD data (Radar Altimeter Fast Delivery) (*Massmann, F.-H. et.al., 1992*). The use of PRARE data (Precise Range And Range rate Equipment) was also planned prior to launch.

Orbit perturbation models used are state of the art ones. The gravitational forces are mainly represented by the GRIM4-S2 gravity field model (*Schwintzer, P. et.al., 1992*). The major non-gravitational perturbations of the low altitude orbit stemm from surface forces. DOGS-OC adopts a macro modell of the surface of ERS-1 for albedo, direct solar radiation and drag. Earth's high atmosphere is represented by the CIRA'86 model where solar and geomagnetic activity is needed as input.

In a second step the orbit is integrated forward by the DOGS-OC software with the parameters derived before. Adopted are the same perturbation models but now solar and geomagnetic activity are predicted for the respectiv time period. And this indeed is the major error source that degrades the accuracy of ERS-1 orbit predictions. Also the ERPs (Earth rotation parameters) are predicted for the time period of the forward integration. The accuracy of ERP predictions is quite good for the lifetime of ERS-1 orbit predictions, the effect can therefore be neglected.

In the third step DOGS-PD (PD for Predictions) compresses the orbit to dedicated forms and formats of orbital elements which can easily be disseminated worldwide via various telecommunication channels. In addition these elements are tuned so that the user will recover the orbit in an optimal way. So-called tuned IRVs (Inter-Range Vectors) and tuned SAO-elements (Smithsonian Astrophysical Observatory) are delivered to the SLR community, PRARE-elements to the PRARE system.

3. Tuning

The orbit is recovered at the SLR sites by simple programs intended for use on low capacity computers. These programs adopt low degree and order gravity fields and do not consider nongravitational forces as drag. The IRVINT integrator written at the university of Texas starts from the IRVs. The ancient AIMLASER program applies analytical orbit theory to recover the orbit from the SAO-elements.

Because of these severe neglections, D-PAF tunes IRVs and SAO-elements. This means that despite of simple perturbation modelling onsite the orbit is recovered in an optimal way. The optimum is a minimum difference in the least squares sense of the recovered orbit to the full perturbation model orbit or reference orbit. The IRVINT and AIMLASER programs have to run then in a defined mode. D-PAF assumes for IRVINT a 60s integration step size and the GEM10N gravity field coefficients up to degree and order 18. The AIMLASER program should run in the RGO version (Royal Greenwich Observatory) with dedicated GEM10B. coefficients.

Fig. 1 shows the along-track error if an un-tuned IRV is integrated by IRVINT. The example holds in general. Due to the missing drag forces modelling the error grows during the day to ca. 1400m in along-track position or ca. 200ms in time bias which would prevent tracking of the satellite.

Fig. 2 displays the error after tuning. Maxima are now ca. 20ms around midnight and around noon. The remaining along-track errors are similar day by day, the maxima are dependent on the solar activity. They could be accounted for by a function giving the error for 24 hours of a day. The more proper way of course would be to model drag in the integrator. Anyway the remaining errors are in a range that can be accepted for tracking.

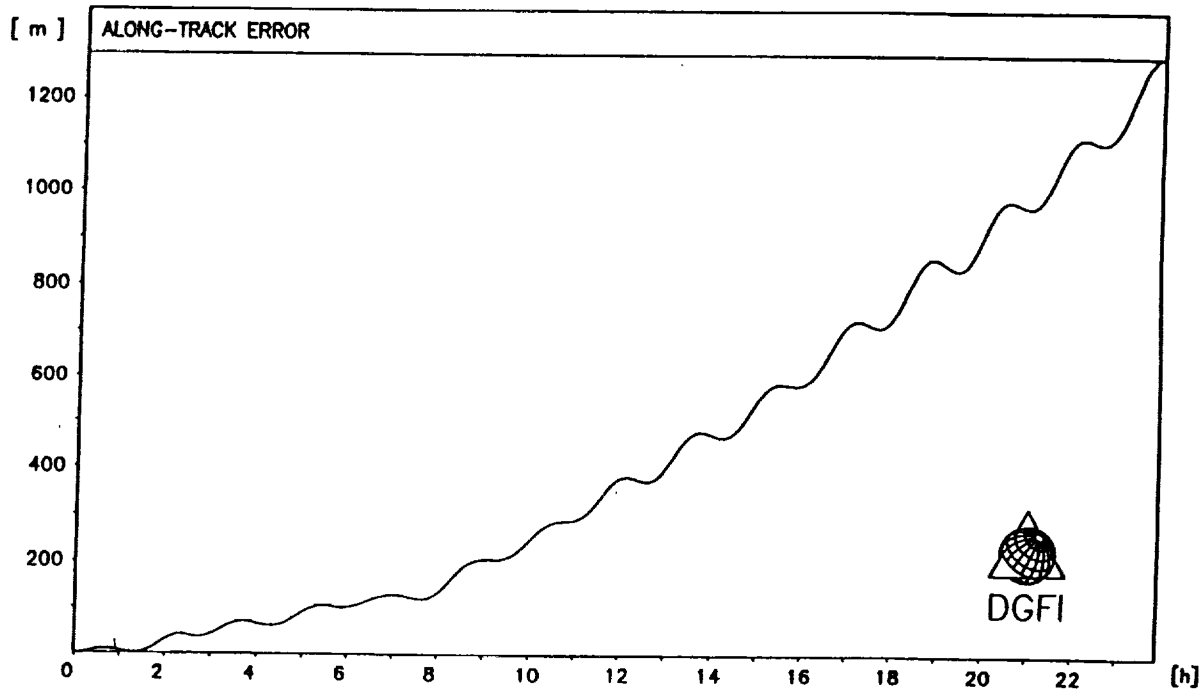

Figure 1 Along-track error from un-tuned IRVs

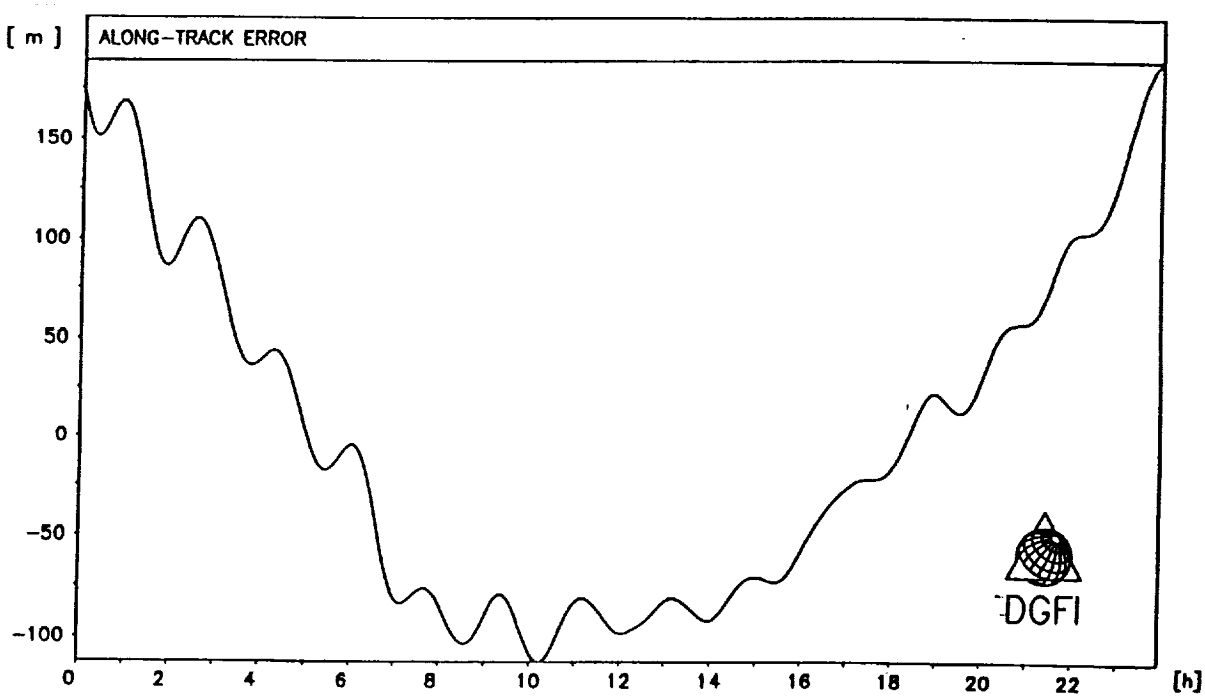

Figure 2 Along-track error from tuned IRVs

The accuracy of tuning, that is the difference of the recovered orbit to the reference orbit, can be seen in Table 1 where the typical differences are given as RMS-values in meters for both types of prediction elements. Again the values are largely dependent on the solar activity.

	IRVs 1d	**SAO-elements** 10d
radial	3-5	10-20
across-track	3	10
along-track	20-60	20-100

Table 1: Tuning accuracy (in m)

The SAO-elements show less accurate recovery because they represent the whole prediction period (normally 10d) whereas the IRVs are given each day. All values are within a range that can be accepted for tracking.

4. Time Bias

D-PAF generates and disseminates weekly prediction sets containing IRVs and SAO-elements. Due to the sensitivity of ERS-1 to variations of the high atmosphere the predictions loose accuracy mainly in along-track direction. This is also known to the stations as so-called time bias i.e. the satellite rises too late or the satellite rises too early. The determination of the time bias provides a quick and simple update of the orbit predictions.

Therefore D-PAF generates and disseminates daily a time bias function from new Q/L (Quick Look) Laser ranges. For every pass over all stations having observed ERS-1, a time bias is computed relative to the last prediction set. A third order function in time is fitted by LS (Least Squares) to these time bias values. In the LS procedure the time bias values are checked for outliers and the parameters are checked for significance leading all in all to a best approximating function. The function fits to the time bias values within 1ms for up to four days.

A typical example of time bias values is given in Fig.3. Fig.4 shows the fitted function after removing the outliers and after the significance check of the parameters.

The time bias function represents the time bias values of the last few days. More important it is capable of predicting the along-track error.

The EDC (European Data Center) provides another important tool to handle the time bias problem. Stations can store the observed time bias immediately after the pass in the data base. Currently Graz, Potsdam, RGO, Santiago de Cuba and Wettzell do so. This time bias is nearly in real-time available to other stations. The stations can then compare the results with their own computations and with the D-PAF time bias function. This all this together should yield to more confidence in the time bias that is going to be used for the next upcoming pass.

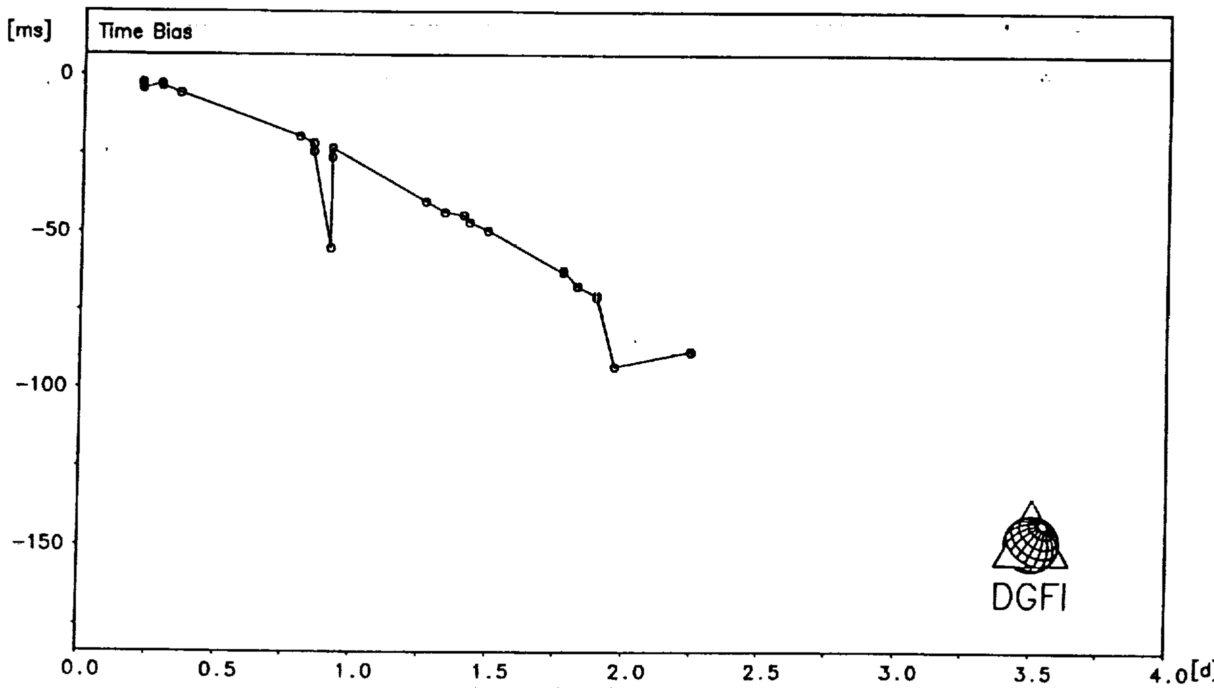

Figure 3 Time bias values

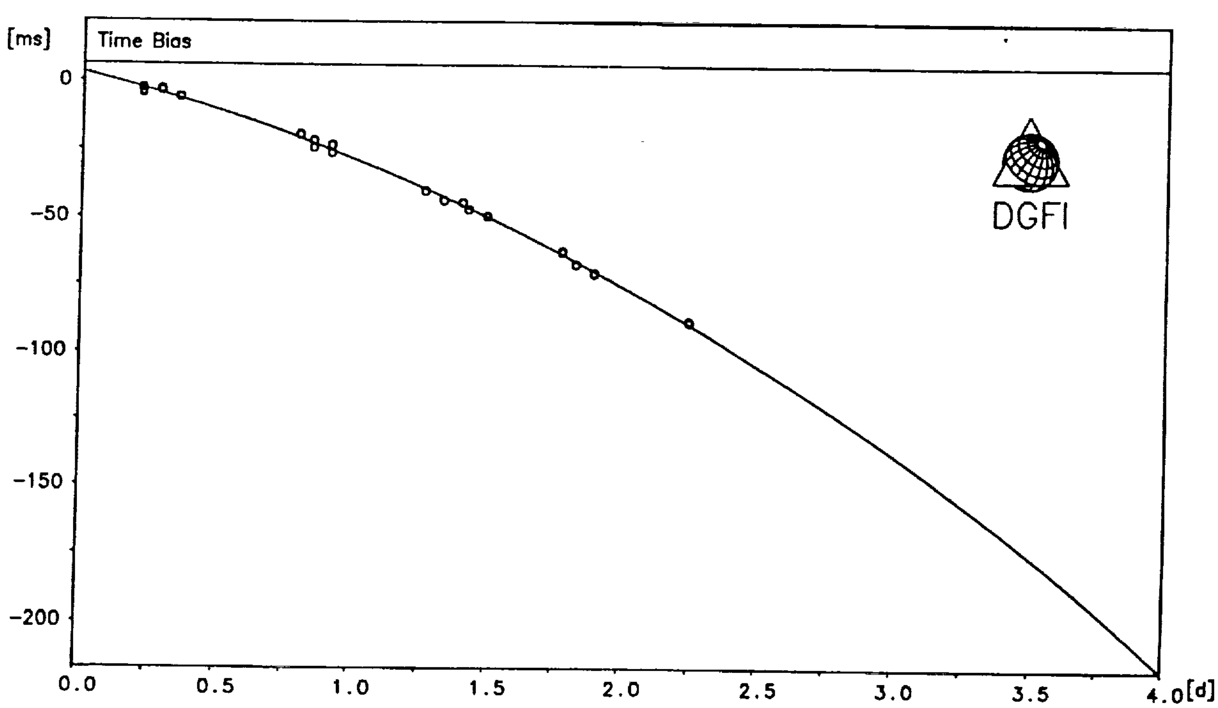

Figure 4 Time bias function

5. Quality

The quality of the ERS-1 prediction products is indicated to the users by a quality flag. In case of orbit predictions the quality flag is computed from the fit of observations in the orbit analysis (step 1 in chapter 2), from the comparison of overlapping arcs and from the tuning accuracy. The quality of the time bias function is assessed from the approximation error of the function and the data coverage.

Of course the quality flag gives only an idea on how the quality of the products can be. By nature predictions go into the future and nobody can determine what will be. Particularly the accuracy of ERS-1 orbit predictions is heavily influenced by unpredictable solar activity. Anyway the quality flag shows the current knowledge of the quality. It convinces the generator that he did a good job and it gives a first indication to the user in case he has problems.

All prediction products are subject to permanent quality checks. Daily the time bias of newly incoming Q/L Laser passes are determined relative to the actual prediction orbit which leads to the time bias function. The prediction orbit is also compared to the MMCC orbit (Mission and Management Control Center). The MMCC orbit is generated by an independent group in ESOC (European Space Operation Center), Darmstadt, from S-band observations and radar altimeter fast delivery ranges. The comparison with such a completely external source provides more confidence in the results.

On a weekly basis when new orbit predictions are generated the new prediction orbit is compared to the old one. The differences in along-track direction should exactly reflect the old time bias function. The differences in radial and across-track direction normally stay within a few meters.

The internal quality checks proceed in a closed loop from prediction set to prediction set. The external checks give an independent judgement. So the reliability of the orbit prediction system has reached a quite high level.

Fig.5 displays the along-track errors of ERS-1 orbit predictions since launch. The first 100d are clearly affected by large solar activities. In addition a manoeuvre was missed. Meanwhile these cases are taken care of. In the right half of Fig.5 it can be seen that the mean accuracy steadily improves, but is clearly degraded by the frequent manoeuvres.

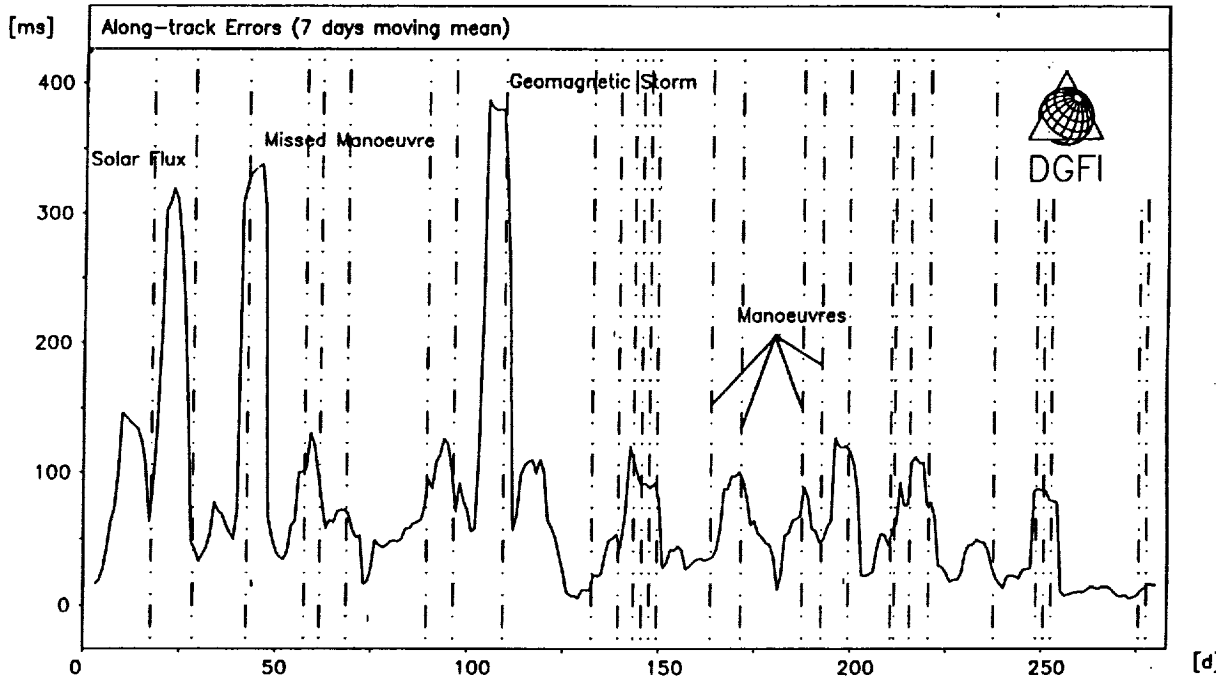

Figure 5 Accuracy of ERS-1 orbit predictions

6. Conclusions

It has been shown that tuning of orbit predictions is essential for ERS-1. D-PAF provides daily time bias functions that account for the along-track error of the predictions. The quality of ERS-1 prediction products is assessed and indicated to the users. The predictions are permanently checked internally and externally. The average accuracy has considerably improved since launch.

7. Literature

Massmann, F.-H., Reigber, Ch., Li, H., König, R., Raimondo, J.C., Rajasenan, C. and M. Vei: *Laser Ranging Network Performance and Routine Orbit Determination at D-PAF*, this proceedings

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