Validation of Earth's gravity field models using LAGEOS

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K. Sośnica, D. Thaller, A. Jäggi, R. Dach, and G. Beutler
Astronomical Institute, University of Bern, Bern, Switzerland

Introduction

Precise orbit determination is an essential task for processing SLR data. The quality of the satellite orbits strongly depends on models and parameters used in the dynamic orbit determination. The Earth's gravity field model has a crucial impact on the quality and accuracy of estimated and predicted satellite orbits. The influence of different gravity field models on LAGEOS-1 and LAGEOS-2 orbit determination is discussed. We show that not only the type of gravity field model but also the proper choice of the maximum degree of the gravity field model is essential.

The quality of the estimated orbit can be validated in two ways: On one hand by investigating the mean error of the solution based on SLR observations. On the other hand by comparing the orbit predictions with the orbits estimated based on real measurements. Additionally, orbits resulting from solutions using different gravity field models may directly be compared.

Precise orbit determination based on SLR data as well as the orbit prediction and comparisons for the two LAGEOS satellites were performed using the Bernese Software v.5.1.

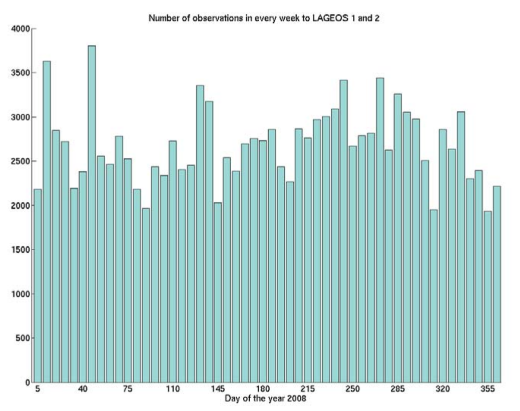
Gravity field model	Year	Max. degree	SLR	CHAMP	GRACE	GOCE	Ground data
JGM3	1996	70	Y				Y
EIGEN-GL04C	2006	360	Y		Y		Y
EGM2008	2008	2190			Y		Y
EIGEN51C	2010	359	Y	Y	Y		Y
ITG-GRACE2010S	2010	180			Y		
AIUB-CHAMP03S	2010	100		Y			
AIUB-GRACE03S	2011	160			Y		
GOCE SST-only	2011	120		Y		Y	

Tab. 1: List of used Earth gravity field models

Models and data

We selected eight gravity field models for the comparison (see Tab.1): JGM3 (based on SLR observations, satellite altimetry and ground data), three models included CHAMP data, five included GRACE, and one model which achieved due to GOCE-GPS observations. Only three gravity field models were obtained considering SLR observations (JGM3, EIGEN-GL04C and EIGEN51C).

7-day arc in 2008 were generated using the SLR measurements to both LAGEOS satellites. For orbit determination we used different gravity field models up to degree and order 70 (for models including drifts, these values were taken into account, as well). For every solution the same set of observations was used (data were previously screened using uniquely merged normal points data from CDDIS and EDC). 139,000 SLR observations were available in 2008, within the all weeks the number of normal point varied between 1932 and 3804 (see Fig. 1a,b).



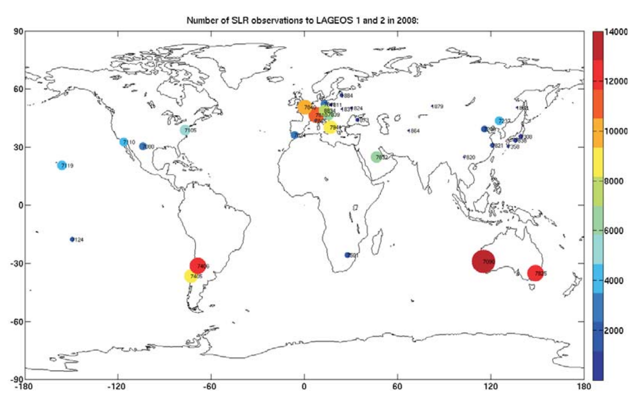


Fig. 1a,b: Number of SLR observations to LAGEOS1 and 2 in 2008

References

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Astronomical Institute, University of Bern, Bern
krzysztof.sosnica@aiub.unibe.ch

Comparison of gravity field models

The RMS of the observation residuals from weekly solution is the first indicator of the quality of the gravity field model. The RMS for two models, i.e., JGM3 and ITG-GRACE2010S (see Fig. 2) are significaly larger than for other models (mean value: 7.42 and 7.32mm, respectively). RMS of residuals for CHAMP-based models are 7.21 and 7.22mm (for GOCE-SST and AIUB-CHAMP03S, respectively). The GRACE-based models show more or less similar patterns (see Tab. 2). The smallest RMS is observed for EGM2008, AIUB-GRACE03S, EIGEN51C, EIGEN-GL04C (7.13, 7.15, 7.16, and 7.17mm, respectively). The RMS of the observation residuals was reduced to 7.18mm for ITG-GRACE2010, after setting gravity field coefficients C_{10}, C_{11} and S_{11} to zero (due to recommendations). This modified model is indicated in Tab. 2 as ITG-GRACE10 mod.

The second way to validate the satellite orbits is to compare the estimated orbit with the prediction of the orbit from the previous week. One comparison was computed with estimating 7 Helmert transformation parameters (see Tab. 2) and the second comparison without Helmert parameters (see Fig. 3).

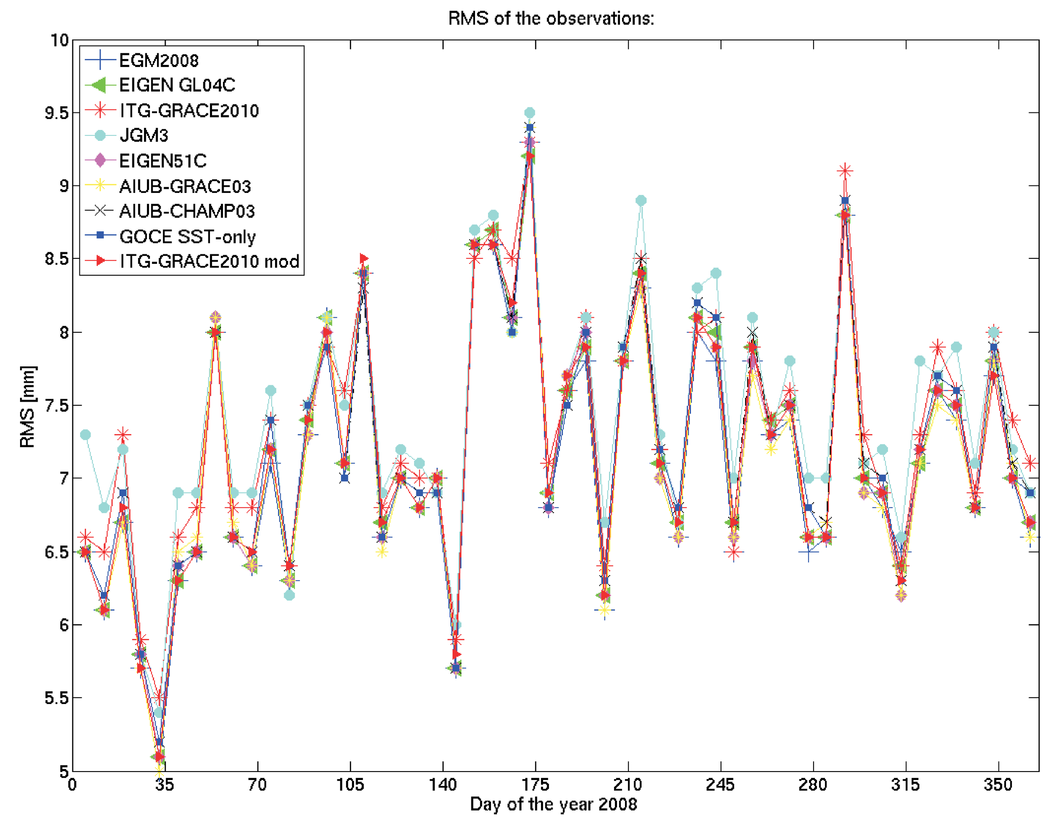
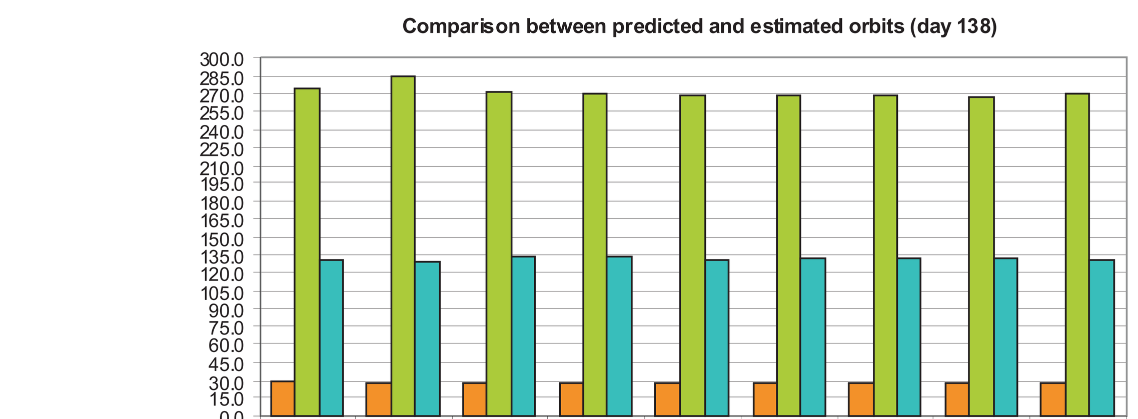


Fig. 2: RMS of the observations in weekly LAGEOS solution

Gravity field model	RMS of observation residuals [mm]	Comparison of estimated and predicted orbits			
		Scale [ppb]	RMS radial prediction [mm]	RMS along-track prediction [mm]	RMS out-of-plane prediction [mm]
JGM3	7.42	-0.05	29.7	398.6	199.1
ITG-GRACE2010S	7.32	-0.03	29.9	396.8	198.6
AIUB-CHAMP03S	7.22	-0.04	29.7	398.0	199.2
GOCE SST-only	7.21	-0.04	29.7	397.9	199.1
ITG-GRACE10 mod	7.18	-0.04	29.7	298.0	199.2
EIGEN-GL04C	7.17	-0.04	29.7	397.6	198.9
EIGEN51C	7.16	-0.04	29.7	397.9	199.2
AIUB-GRACE03S	7.15	-0.04	29.7	397.8	198.9
EGM2008	7.13	-0.03	29.7	398.0	199.2

Tab. 2: The quality of LAGEOS weekly solutions sorted in descending order of the mean RMS of residuals (mean values for 2008)



	JGM3	ITG-GRACE2010	AIUB-CHAMP03S	GOCE SST	ITG-GRACE10 mod	EIGEN-GL04C	EIGEN51C	AIUB-GRACE03S	EGM2008
RMS radial prediction [mm]	28.1	27.0	27.2	27.2	27.2	27.3	27.3	27.7	27.3
RMS along-track prediction [mm]	273.4	285.0	271.7	270.9	268.2	268.4	268.0	267.3	270.3
RMS out-of-plane prediction [mm]	130.4	129.0	132.8	132.7	131.4	131.6	131.8	132.1	131.2

Fig. 3: The comparison between the estimated and predicted orbits (without estimating Helmert transformation parameters)

Maximum degree and order

We studied the impact of the maximum degree and order of gravity field model on orbit determination of LAGEOS 1 and 2. EGM2008 model was used for this purpose. Fig. 4 shows that the LAGEOS satellites are very sensitive up to degree and order 14 (semi-major axes of LAGEOS satellites orbits are about 12,200km). Differences between solutions based on degree 12 and 14 are extremely large. Small differences between degree of 14 and 20 are still visible (on the level of about 0.5 mm). Increasing the degree of gravity field model above 20 has no significant impact on the resulting satellite orbit, the differences are at the level of 0.01 mm (see Tab.3, Fig.5).

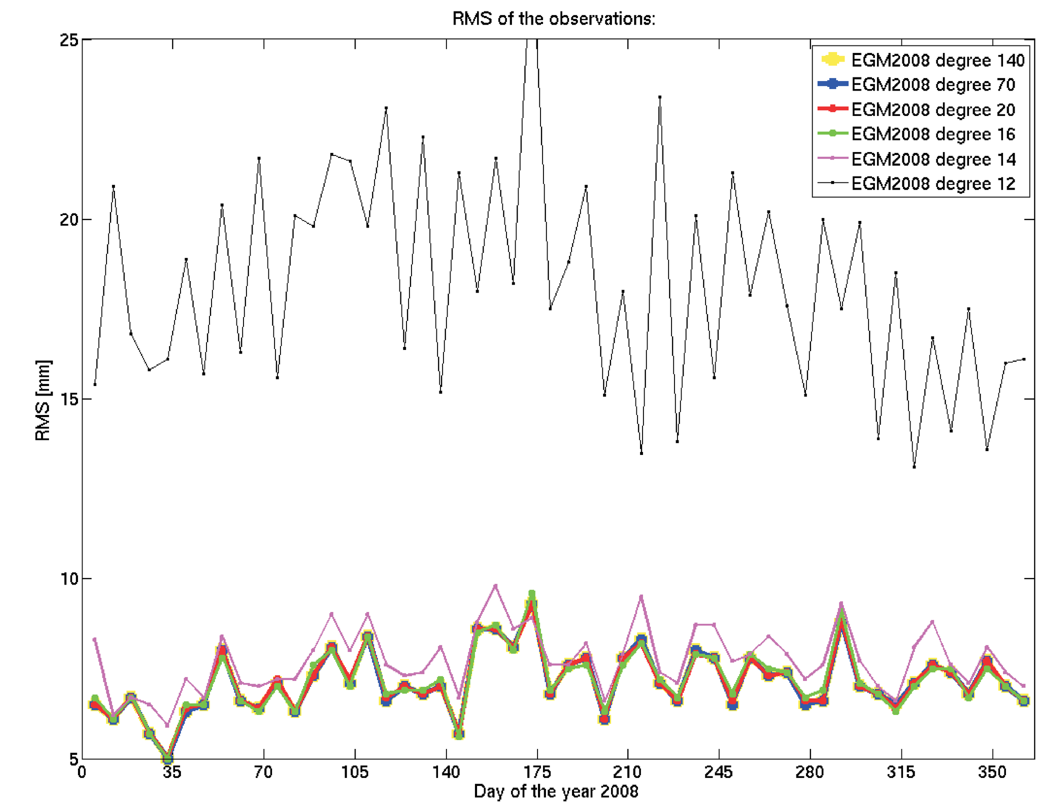


Fig. 4: The RMS of weekly solutions for different degrees and orders of gravity field models

EGM2008 up to degree and order:	RMS of observation residuals [mm]	Comparison of predicted and estimated orbits			
		Scale [ppb]	RMS radial prediction [mm]	RMS along-track prediction [mm]	RMS out-of-plane prediction [mm]
140	7.13	-0.03	29.7	398.0	199.2
70	7.13	-0.03	29.7	398.0	199.2
20	7.14	-0.04	29.7	399.2	199.6
16	7.16	-0.03	29.9	411.0	205.0
14	7.73	-0.05	31.0	448.8	222.4
12	18.19	0.19	41.6	1522.1	769.8

Tab. 3: The quality of the estimated and predicted LAGEOS orbits (mean values for 2008)

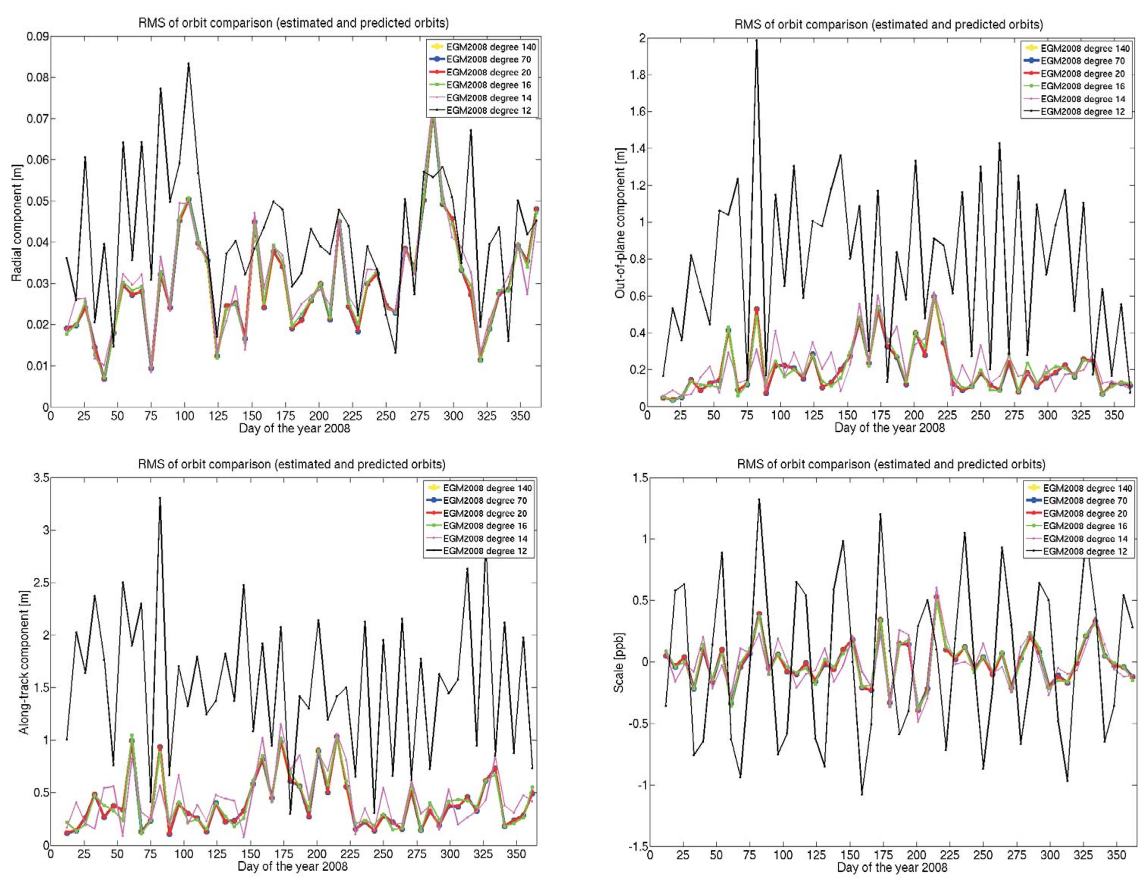


Fig. 5: RMS of the Helmert transformation between estimated and predicted orbits for radial, along-track, out-of-plane components and scale parameter

Orbit comparison

Table 4 shows the comparison between orbits estimated using different gravity field models. The RMS for the orbits based on ITG-GRACE2010C model is the largest w.r.t. other orbits. For ITG-GRACE2010C the RMS exceeds 14mm in every case. The difference is mainly caused by orbit translation in Z-direction w.r.t. geocenter. This effect may be significantly reduced by setting C_{10}, C_{11} and S_{11} to zero (like in ITG-GRACE-10 mod). The model with the second largest differences to the others is JGM3 with values larger than 6mm. EGM2008 differs slightly with other GRACE-based and significantly with CHAMP-based models (see Fig. 6). Orbits using AIUB-GRACE03S, ITG-GRACE10 mod, EIGEN04 and EIGEN51C models are of the comparable quality (all these models are GRACE-based, see Fig. 7). The RMS of orbit comparison reaches the smallest value for the AIUB-CHAMP03S and GOCE SST (the second model is the extension of the AIUB CHAMP-based model with GPS measurements from GOCE).

Gravity field model	EIGEN-GL04C	EGM2008	EIGEN51C	ITG-GRACE2010S	GOCE SST	AIUB-CHAMP03S	AIUB-GRACE03S	ITG-GRACE10 mod
JGM3	8.5	11.2	7.6	15.6	6.7	6.6	8.8	7.6
EIGEN-GL04C		3.8	2.1	14.3	6.2	5.9	1.8	1.2
EGM2008			5.6	15.3	9.8	9.5	3.7	4.3
EIGEN51C				14.1	4.4	4.2	2.4	1.9
ITG-GRACE2010S					14.7	14.6	14.5	14.1
GOCE SST						0.6	6.6	5.8
AIUB-CHAMP03S							6.4	5.5
AIUB-GRACE03S								2.2

Tab. 4: Comparison between estimated orbits based on different gravity field models: RMS of orbit differences (mean for 2008, in mm)

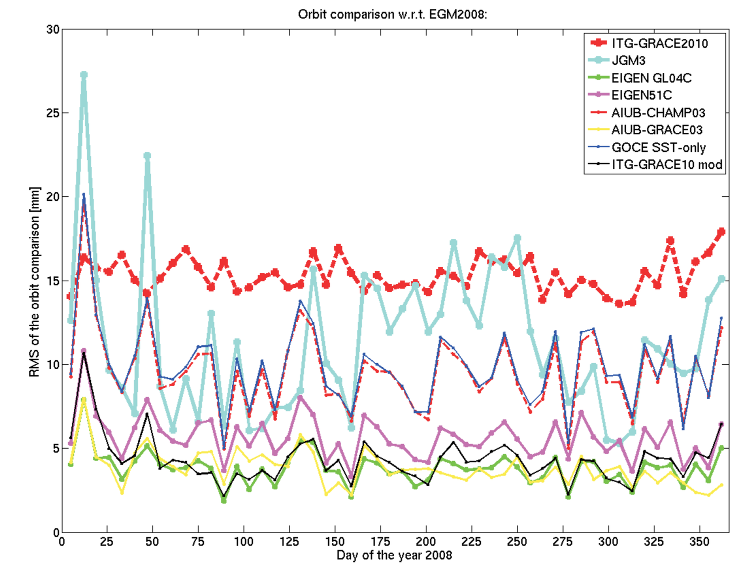


Fig. 6: The comparison between the orbits based on EGM2008 model and other gravity field models

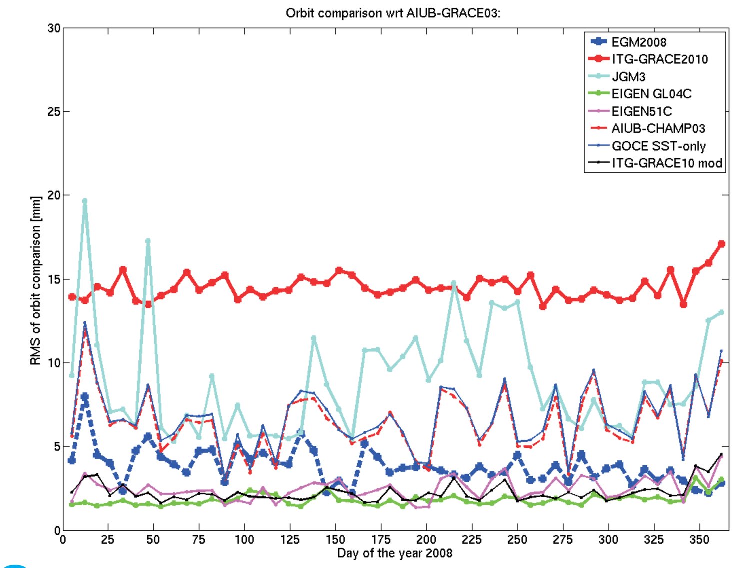


Fig. 7: The comparison between the orbits based on AIUB-GRACE03S model and other gravity field models

Summary

- The smallest RMS of the solution is observed for EGM2008 and AIUB-GRACE03S gravity field models,
- Orbits based on JGM3 model differ the most w.r.t. orbits based on other models. The same effect is observed for ITG-GRACE2010, when the coefficients of degree one are not set to zero,
- LAGEOS satellites are sensitive up to degree 20 of the used gravity field models.

Contact address

Krzysztof Sośnica
Astronomical Institute, University of Bern
Sidlerstrasse 5
3012 Bern (Switzerland)
Krzysztof.sosnica@aiub.unibe.ch