Gravity field determination at the AIUB based on GPS data

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Abstract

We use GPS-derived kinematic LEO satellite positions as pseudo-observations in order to solve for the spherical harmonic (SH) coefficients of the Earth's gravity field in a generalized orbit determination problem (Celestial Mechanics Approach). Apart from the (SH) coefficients, each daily arc is characterized by a set of initial conditions, dynamical orbit parameters, and pseudo-stochastic pulses. The daily solutions are combined on the normal equation level.
The gravity field model AIUB-CHAMP01S (Prange et al., 2008), based on one year of CHAMP kinematic orbit positions (Jäggi et al., 2006), was generated using the described Celestial Mechanics Approach without making use of accelerometer data. External validations show that our results are comparable in quality with the best alternative approaches based on GPS data only. Experiments with real data revealed that our results do not improve when including CHAMP accelerometer data in our analysis. This empirical finding is supported by a simulation study presented here.
Last but not least the latest efforts in GPS-based gravity field determination at the AIUB are outlined.

AIUB-CHAMP01S fact sheet

Maximum degree:	90
Method:	orbit determination by numerical integration of variational equations
Parametrization:	along-track polynomial, empirical 1/rev coefficients, pseudo-stochastic pulses (interval: 5 / 15 minutes), initial conditions
Orbit arc length:	1 day
Regularization:	none
Data:	CHAMP kinematic orbit positions (March 2002-March 2003, 943 235 observation epochs), no accelerometer data

Internal validation

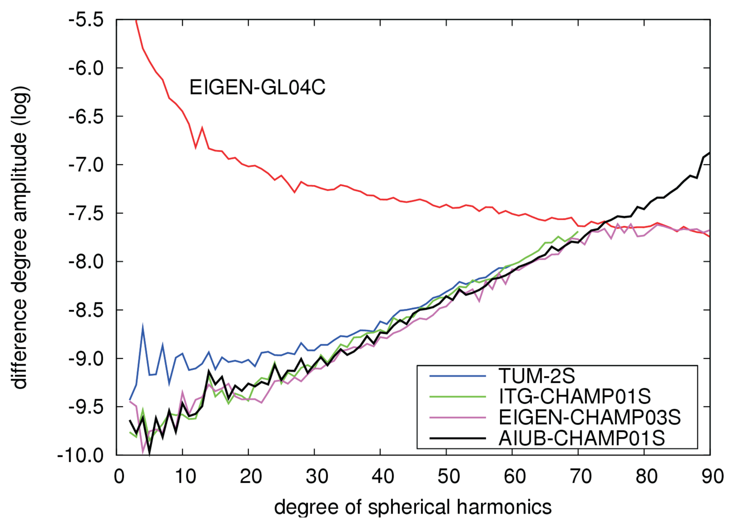

Fig. 1 Differences of the AIUB-CHAMP01S and other well known CHAMP gravity field solutions w.r.t. EIGEN-GL04C. The ITG-CHAMP01S is the best comparable model, because it is based on a similar approach, the same data set of one year CHAMP GPS data, and it is also not affected by regularization.

Compared models	Type of comparison		Spectral range of SH coefficients 0-30	0-50	0-70
EGM96 – EIGEN-GL04C	undulation [cm]:	RMS	8.2	16.7	22.4
		max.	111.5	375.4	631.3
		min.	-93.3	-248.5	-417.2
	anomaly [mGal]:	RMS	0.29	0.97	1.69
ITG-CHAMP01S – EIGEN-GL04C	undulation [cm]:	RMS	1.3	5.5	26.4
		max.	6.7	31.2	153.9
		min.	-6.2	-31.1	-161.2
	anomaly [mGal]:	RMS	0.04	0.37	2.57
AIUB-CHAMP01S – EIGEN-GL04C	undulation [cm]:	RMS	1.4	5.2	22.2
		max.	7.7	30.5	137.6
		min.	-7.6	-32.9	-127.3
	anomaly [mGal]:	RMS	0.05	0.35	2.15

Tab. 1 Comparison of selected gravity field models with EIGEN-GL04C on a latitude-weighted 1x1 degree grid (gravity anomaly and geoid height differences).

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External validation

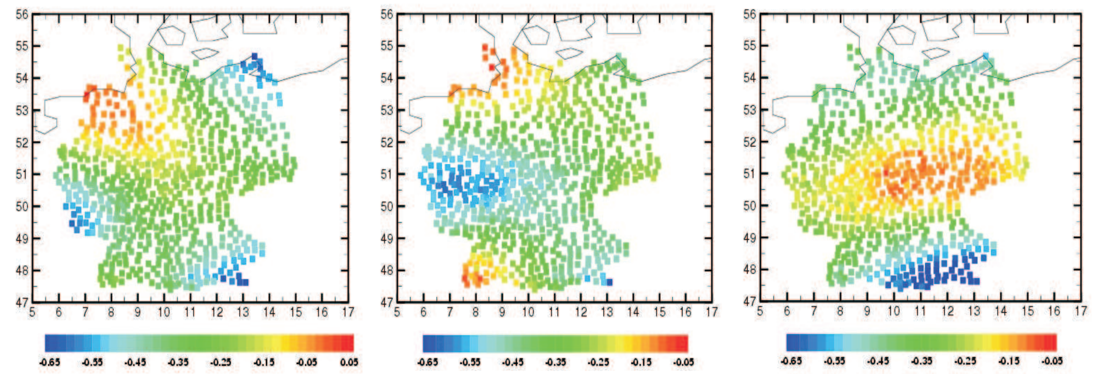


Fig. 2 Differences between terrestrial measured geoid heights and geoid heights derived from different gravity field models (**left:** TUM-2S, **middle:** AIUB-CHAMP01S, **right:** ITG-CHAMP01E) in Germany. Cutoff degree: 60. Unit: m.

Dataset	Points	GRIM-5C1	TUM-2S	ITG-CHAMP01S	ITG-CHAMP01E	AIUB-CHAMP01S	ITG-GRACE02S	AIUB-GRACE01Sp
EUREF GPS	180	37.3	28.0	25.9	24.8	24.5	23.1	23.0
BRD EUVN	87	24.8	13.7	13.6	14.1	11.9	03.2	03.4
BRD GPS	675	27.9	13.6	13.5	15.1	12.1	03.5	03.6
Canada GPS 1998	1443	28.9	26.3	24.2	22.7	24.8	19.8	19.6
Canada GPS 2007	430	22.8	24.4	21.4	17.5	20.4	14.7	14.5
Australia GPS	197	29.6	30.7	31.0	25.4	28.4	24.1	24.1
Japan GPS	837	28.8	16.3	17.9	12.6	18.5	11.6	11.6
USA GPS	5168	37.5	37.9	37.5	34.4	35.1	33.3	33.3

Tab. 2 RMS errors (in cm) of the differences between geoid heights derived from gravity field models and different terrestrial height data sets (up to degree 60).

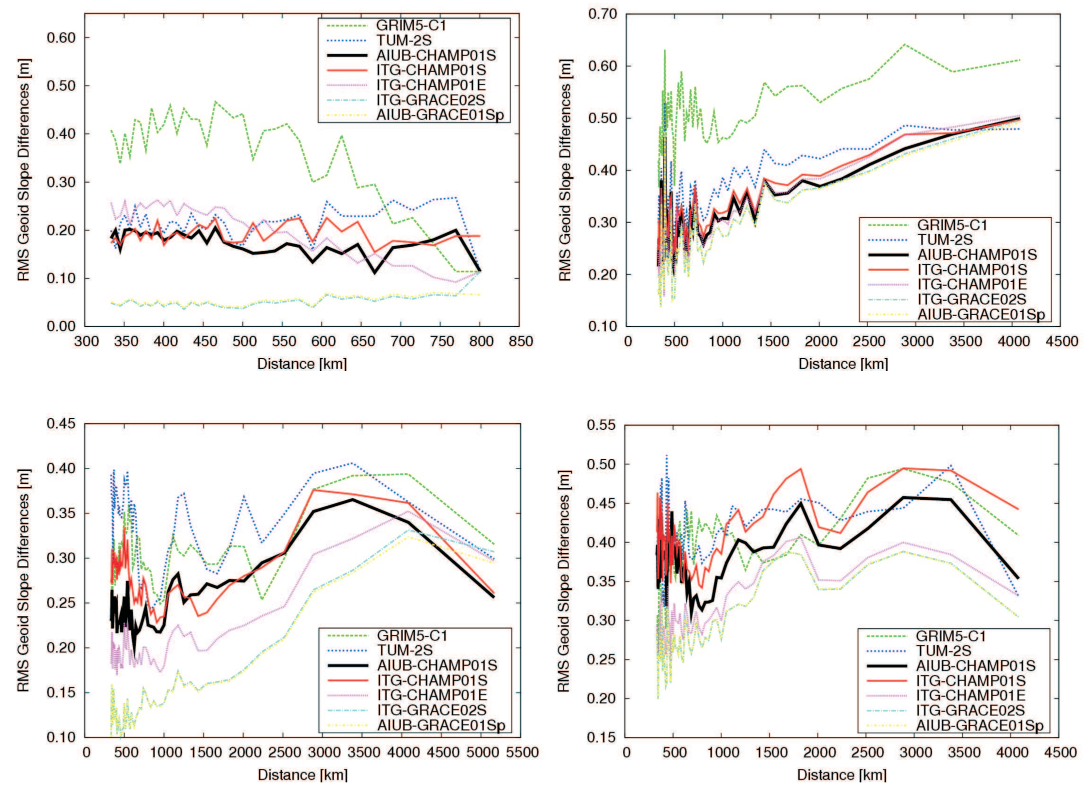


Fig. 3 Differences between geoid slopes derived from different gravity field models and terrestrial height data sets up to degree 60 (**top left:** BRD EUVN, **top right:** EUREF GPS, **bottom left:** Canada GPS, **bottom right:** Australia GPS).

The AIUB-CHAMP01S was, together with other gravity field models, externally validated by Thomas Gruber from IAPG in Munich. From the terrestrial height data sets as well as from the gravity field models geoid heights and geoid slopes have been derived and compared. For further details concerning the method we refer to Gruber (2004). The external validation confirms the results of the internal validation and shows that the AIUB-CHAMP01S is one of the best gravity field models using only CHAMP data of one year (see comparison to the ITG-CHAMP01S).
The results also show the strong impact of regularization (see ITG-CHAMP01E, which is regularized to the EGM96 model). Table 2 also indicates the limitations of the terrestrial height data sets used for validation: For some terrestrial data sets the RMS error does not differ greatly when compared to very different gravity field models, e.g. models based on SLR, CHAMP or GRACE data.

Simulation study

In order to get more insight into our gravity field estimation technique and to study the influence of different error sources, a simulation study was performed. CHAMP orbit positions were simulated for a time interval of 20 days. The gravity field model EIGEN-GL04C up to degree 120 served as truth. Different versions of the orbit positions have been generated with noise or non-gravitational accelerations being switched on or off. The non-gravitational forces were taken from real accelerometer data. From the simulated positions orbits (see Tab. 3) and gravity field parameters have been estimated using different parameterizations. In the gravity field estimation process different model defects have been "activated" to study their impact on the solutions:
Scenario 1: omission errors only
Scenario 2: unmodeled non gravitational accelerations only
Scenario 3: Scenario 1 + Scenario 2
Scenario 4: Scenario 3 + noise (RMS of position: 2 cm)

model deficiency	RMS of orbit estimation (initial conditions only)	additional parameters	RMS (with additional parameters)
-	0.0 mm	-	0.0 mm
inconsistent solid earth tide model	0.1 mm	-	0.1 mm
inconsistent nutation model	2.0 mm	dynamical parameters	1.3 mm
inconsistent meanpole	3.0 mm	dynamical parameters	2.0 mm
inconsistent ocean tide model	45.0 mm	dynamical parameters pulses 30 min pulses 15 min	34.0 mm 2.3 mm 1.0 mm
inconsistent gravity field model	125.0 mm	dynamical parameters pulses 30 min pulses 15 min	51.0 mm 3.5 mm 2.1 mm
error of omission (cutoff degree of gravity field=70 instead of 120)	445.0 mm	dynamical parameters pulses 30 min pulses 15 min	309.0 mm 17.0 mm 5.0 mm
non-gravitational accelerations	149360.0 mm	dynamical parameters pulses 30 min pulses 15 min	207.0 mm 5.5 mm 2.0 mm

Tab. 3 Orbit estimation from error free satellite positions in the presence of different error sources. The estimation of additional orbit parameters reduces the error of orbit estimation significantly.

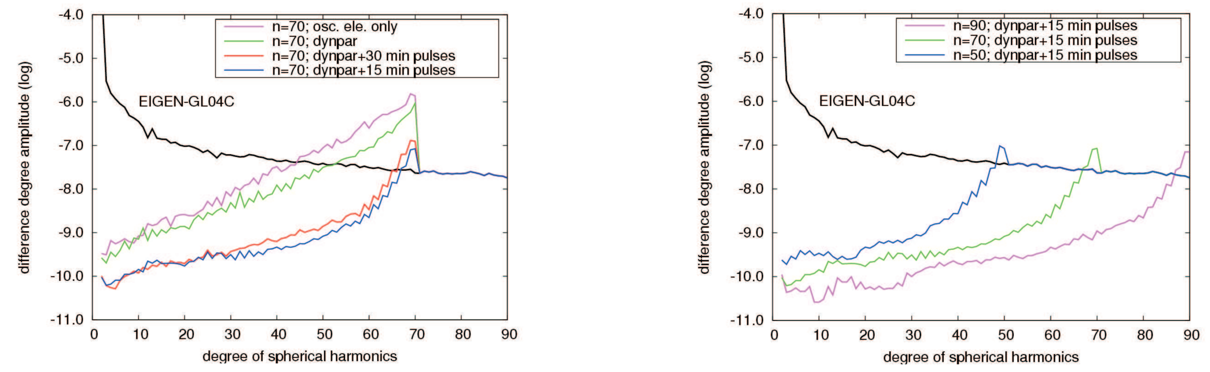


Fig. 4 Gravity field recovery: Scenario 1: **Left**: Reduction of omission errors with different orbit parameterizations. **Right**: Omission errors when using different cutoff degrees.

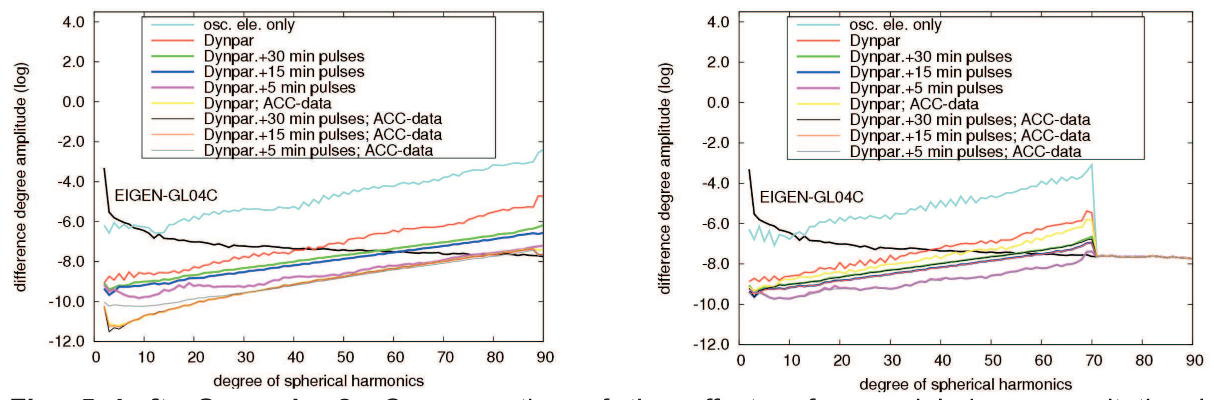
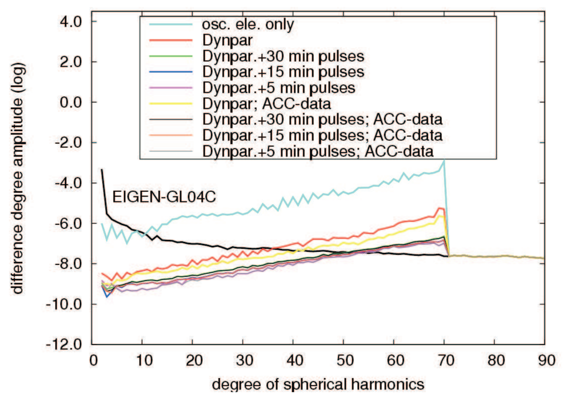


Fig. 5 Left: Scenario 2: Compensation of the effects of unmodeled non-gravitational accelerations by orbit parameters only / a combination of accelerometer data and orbit parameters. **Right: Scenario 3** with the same parameterization.

Fig. 6 Right: Scenario 4 with the same parameterization as used in scenario 2 and 3 (see Fig. 5). In the presence of omission errors, non-gravitational accelerations and noise, the gravity field recovery results looks quite realistic for the different parameterizations.



The simulation study showed, how dynamical (without acc. data: constant acceleration and coefficients of a periodic function in radial, along-track and cross-track direction plus polynomial in along-track direction; with acc. data: acc. calibration parameters) and pseudo-stochastic orbit parameters compensate for unmodeled gravitational and non-gravitational effects. In order to compensate for the omission errors, the estimation of many orbit parameters is necessary for our approach. However, the orbit parameters cannot completely absorb this effect. In a realistic scenario (presence of omission errors and observation noise) the impact the of non-gravitational accelerations is dominated by the other effects. The remaining non-gravitational effects can be sufficiently absorbed by the orbit parameters, which have to be estimated anyway in order to compensate for the omission errors. This renders the effect of accelerometer data negligible in a realistic scenario.

GPS orbit and clock reprocessing

With support of the CODE IGS analysis center, located at the AIUB, a reprocessing of the GPS satellite orbits and clock corrections has been initiated. The reprocessing incorporates the latest IGS standards and model changes. The goal is to have a fully consistent up-to-date set of GPS orbit and clock products for the years 2002 to 2007. This allows the computation of consistent CHAMP and GRACE orbits, which will be the basis for future multi-year gravity field solutions. Based on these reprocessed GPS products the generation of GPS satellite clocks with the higher sampling rate of 10s is performed, allowing us to benefit from the full sampling rate of the CHAMP and GRACE GPS receivers.

Summary

We use the Celestial Mechanics approach for gravity field determination at the AIUB. Our first official solution AIUB-CHAMP01S is based on one year of CHAMP kinematic positions. The external validation confirmed the results of our internal validation: The AIUB-CHAMP01S is comparable in quality with the best gravity field models using the same GPS only data set. As the AIUB-CHAMP01S was produced without the use of accelerometer data, we accomplished a simulation study, which clearly showed that the estimation of many pseudo-stochastic orbit parameters not only compensates for omission errors and modeling deficiencies, but also for unmodeled non-gravitational effects. The validation and the simulation study proved the suitability and good performance of the Celestial Mechanics Approach for gravity field determination based on kinematic orbit positions. Our current activities concentrate on the generation of a consistent set of GPS orbits and clock corrections using the up-to-date standards of the IGS. This data set will be the basis for multi-year gravity field models using CHAMP and GRACE GPS data.

References

Beutler, G. (2005) "Methods of Celestial Mechanics", Astronomy and Astrosphysics Library, Springer.
Förste, C. et al. (2006) "The GeoForschungsZentrum Potsdam/Groupe de Recherche de Geodesie Spatiale satellite-only and combined gravity field models: EIGEN-GL04S1 and EIGEN-GL04C", Journal of Geodesy, DOI 10.1007.
Gruber, T. et al. (2000) "GRIM5-C1: Combination solution of the global gravity field to degree and order 120", Geophysical Research Letters, Vol. 27 No. 24, p.4005-4008
Gruber, T. (2004) "Validation Concepts for Gravity Field Models from New Satellite Missions",In: Proceedings of Second International GOCE User Workshop "GOCE, The Geoid and Oceanography", ESA-ESRIN, Frascati, Italy.
Hugentobler, U. et al. (2006) "CODE IGS Analysis Center Technical Report 2003/2004", In: International GPS Service 2003-2004.
Jäggi, A. et al. (2006): Kinematic and highly reduced-dynamic LEO orbit determination for gravity field estimation. Dynamic Planet - Monitoring and Understanding a Dynamic Planet with Geodetic and Oceanographic Tools, edited by C. Rizos et al., pp. 354-361, Springer.
Jäggi, A. et al. (2008) "GRACE Gravity Field Determination using the Celestial Mechanics Approach - First Results", this meeting
Lemoine, F.G. et al. (1998) "The development of the joint NASA GSFC and the National Imagery and Mapping Agency (NIMA) geopotential model EGM96", NASA Technical Paper NASA/TP-1998-206861, Goddard Space Flight Center, Greenbelt, USA.
Mayer-Gürr, T. et al. (2005) "ITG-CHAMP01: a CHAMP gravity field model from short kinematic arcs over a one-year observation period", Journal of Geodesy, 78 (7-8), 462-480.
Mayer-Gürr, T. (2006) "Gravitationsfeldbestimmung aus der Analyse kurzer Bahnbögen am Beispiel der Satellitenmissionen CHAMP und GRACE", PhD thesis, University of Bonn
Prange, L. et al. (2008) "Gravity Field Determination at the AIUB - the Celestial Mechanics Approach", submitted to the Proceedings of the IUGG General Assembly in Perugia.
Reigber, C. et al. (2004) "Earth Gravity Field and Seasonal Variability from CHAMP", In: Earth Observation from CHAMP - Results from Three Years in Orbit, Springer , Berlin, 25-30, 2004.
Wermuth, M. et al. (2004) "A gravity field model from two years of CHAMP kinematic orbits using the energy balance approach", Geophysical Research Abstracts, Vol. 6, European Geosciences Union.