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A MEAN GLOBAL GRAVITY FIELD MODEL FROM THE COMBINATION OF SATELLITE MISSION AND ALTIMETRY/GRAVIMETRY SURFACE DATA - EIGEN-GL04C

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Introduction

High-resolution global mean gravity field models can be derived from the combination of satellite tracking and surface data. With the CHAMP and GRACE satellite missions, a new generation of such global gravity field models became available. At GFZ Potsdam and GRGS Toulouse, satellite based global gravity models of high resolution are routinely produced in the framework of the EIGEN processing activities (EIGEN = European Improved Gravity model of the Earth by New techniques).

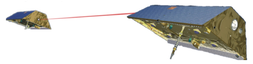
Here the latest result of a new generation of gravity model products generation is presented. This model EIGEN-GL04C was obtained from the processing of GRACE and LAGEOS satellite tracking data. The satellite-based gravity field parameters are the result of a substantial satellite data reprocessing, based on recently improved processing standards and models.

On the other hand, surface gravity data derived from altimetry and gravimetry are globally available, providing a higher resolution than pure satellite data but lacking the high precision in the long-wavelength part. The satellite-based data were combined with partially newly processed surface gravity data sets on the basis of normal equations to derive a global high-resolution gravity field model model, combining the high precision and homogeneity in the long- to medium-wavelength part from the satellite data with the short-wavelength resolution of the surface data. The obtained Earth gravity field parameters are an update of former EIGEN models of a resolution corresponding to a resultion (i.e. half-wavelength) of 50 km and degree/order 360, respectively.

GRACE and LAGEOS satellite data

Data Period:
CNES (for GRACE and LAGEOS): February 2003 – February 2005
GFZ (for GRACE): February 2003 - July 2005 (without January 2004)

Arc Length:
LAGEOS: 7d **GRACE**: 1d



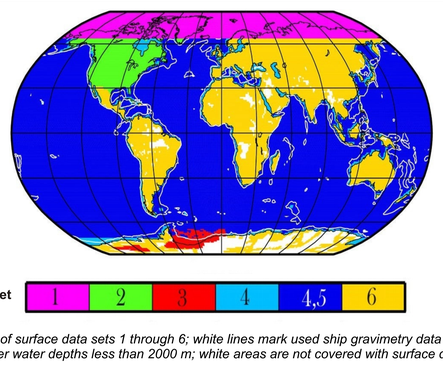
Dynamical Parametrization:
LAGEOS: emp. Coefficients, along-track polygon with 4d spacing, along-track and cross-track emp. 1/rev coefficients changing every 4 d
GRACE: K-band empirical coefficients, accelerometer 3D scaling factors and biases at begin and end of the arc

Processing Standards:
Gravity Field: EIGEN-CG03C (150x150)
Earth Tides: IERS2003
De-aliasing: AOD1B RL03 (ECMWF, OMCT)
Ocean Tides: FES2004 (80x80)
Solid Earth Pole Tide: IERS2003
Ocean Pole Tide: Desai 2002 (80x80)

Surface data used for the combination with the GRACE and LAGEOS satellites' normal equations

(1) Arctic Gravity Project (ArcGP) gravity anomalies (Forsberg, Kenyon 2004), for regions of latitude > 64°,
(2) NRCan gravity anomalies (Véronneau 2003, personal communication), covering North America,
(3) AWI (Studinger 1988) and LDO (Bell et al., 1999) gravity anomalies, over two small areas of Antarctica and adjacent sea ice (AWI),
(4) NIMA altimetric gravity anomalies over the ocean including standard deviations,
(5) Geoid undulations over the oceans derived from GFZ mean sea surface heights (T. Schöne and S. Esselborn 2005, personal communication) minus ECCO simulated sea surface topography (Stammer et al., 2002),
(6) NIMA terrestrial gravity anomalies (if not covered by data sets 1 to 3) including standard deviations, with almost worldwide continental coverage, except for Antarctica and some smaller data gaps, and
(7) NIMA ship-borne gravity anomalies over water depths less than 2000 m.

All data sets are available or averaged to equi-angular 30' x 30' block mean values, except data sets 5 and 7 that are provided with a 1° x 1° resolution. The NIMA data sets (Kenyon, Pavlis 1997) are those already incorporated in the EGM96 solution.



Coverage of surface data sets 1 through 6; white lines mark used ship gravimetry data (data set 7) over water depths less than 2000 m; white areas are not covered with surface data.

4) Algorithms and steps for the adjustment of the combined solution EIGEN-GL04C:

Composition of the EIGEN-GL04C solution from three separate solutions:

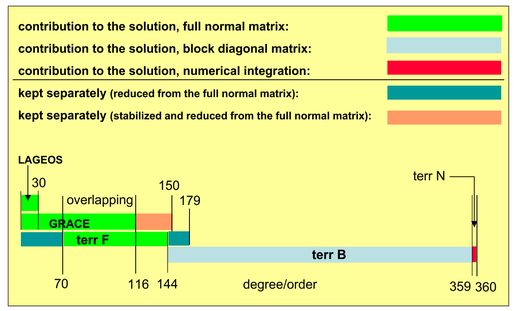
GRACE + LAGEOS: full normal matrix (l_{max} = 150), weight = 1
GRACE: l_{max} = 150, LAGEOS: l_{max} = 30

terr F: terrestrial gravity anomalies (continents, polar regions and coast lines) + altimetric geoid undulations (oceans), l_{max} = 179
weight = 0.0125 · indiv. weighting (for the different data sets)
full normal equation system, based on **30' x 30'** gridded data added to the GRACE+LAGEOS normal matrix

terr B: terrestrial gravity anomalies plus altimetric gravity anomalies (l = 144 ... 359), block-diagonal normal equation system, based on 30' x 30' gridded data solved separately

terr N: terrestrial gravity anomalies plus altimetric gravity anomalies (l = 360), separate numerical integration, based on 30' x 30' gridded data

Combination scheme of the EIGEN-GL04C components:

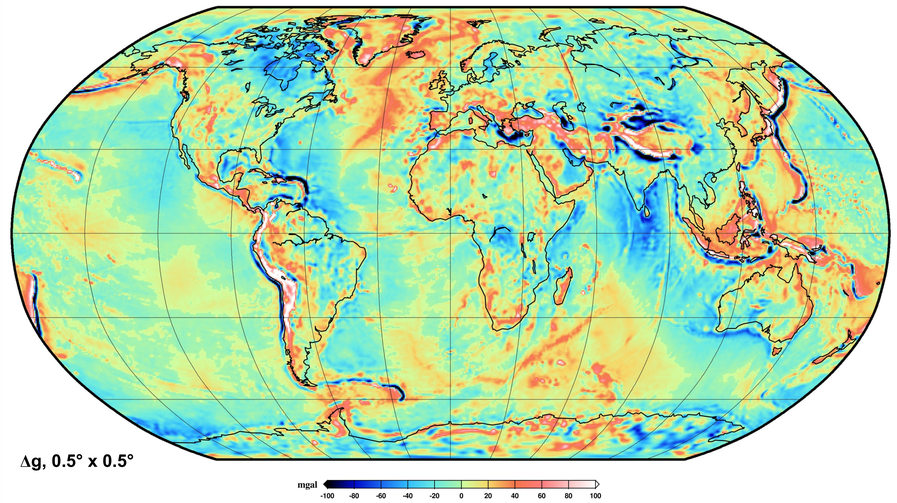


Comparison with geoid heights determined point-wise by GPS positioning and levelling:
- Root mean square (cm) about mean of GPS-Levelling minus model-derived geoid heights (number of points in brackes).

	Europe (186)	Germany	Canada (1930)	USA (6169)
EGM96	44.6	27.6	37.3	46.5
GGM02C	29.8	16.3	31.1	42.8
EIGEN-CG01C	39.7	21.7	31.7	44.1
EIGEN-CG03C	38.4	19.7	35.0	43.6
EIGEN-GL04C	34.1	18.5	31.1	43.5

Used GPS/Levelling data sets:
- USA (Milbert, 1998)
- Canada (Véronneau, personal communication 2003, Natural Resources Canada, GPS on BMs file, update February 2003)
- Europe/Germany (Ihde et al., 2002).

EIGEN-GL04C gravity anomaly



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EIGEN-GL04C: Comparison of Orbit adjustment tests (1)

Mean RMS: SLR and PRARE in cm, PRARE-Doppler and DORIS in mm/sec
All gravity fields truncated to 120x120

Satellite	Data (#arcs)	Data Typ	GGM02C	EIGEN-CG01C	EIGEN-CG03C	EIGEN-GRACE4Sv1 (19 months)	EIGEN-GL04C
GFZ-1	5 x 3 days	SLR	14.30	15.06	15.10	14.11	13.79
STELLA	5 x 3 days	SLR	3.23	3.02	3.06	3.01	2.98
STARLETTE	5 x 3 days	SLR	2.44	2.63	2.61	2.64	2.58
AJISAI	5 x 3 days	SLR	3.18	3.17	3.21	3.16	3.14
LAGEOS-1	5 x 6 days	SLR	1.14	1.15	1.20	1.11	1.11
LAGEOS-2	5 x 6 days	SLR	1.04	1.10	1.14	1.04	1.03
ERS-2	6 x 6 days	SLR PRARE PRARE-Doppler	6.03 3.00 0.378	5.50 3.64 0.351	5.53 3.69 0.354	5.34 3.55 0.345	5.33 3.55 0.345
ENVISAT	7 x 4...8 days	SLR DORIS	4.32 0.495	4.97 0.499	4.43 0.496	4.29 0.495	4.94 0.497
WESTPAC	5 x 6 days	SLR	4.24	4.00	4.09	3.99	4.01

EIGEN-GL04C: Comparison of Orbit adjustment tests (2)

RMS: SLR and GPS-Code in cm, GPS-Phase in cm
Used Data: one 1.5 day arc
gravity fields truncated to: (1) 120 x 120
(2) 150 x 150

Satellite	Data Typ	GGM02C		EIGEN-CG01C		EIGEN-CG03C		EIGEN-GRACE4Sv1 (19 months)		EIGEN-GL04C	
		(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
CHAMP	SLR	5.32	5.19	5.51	5.48	5.58	5.45	5.59	5.64	5.44	5.41
	GPS P-Code	53.21	53.42	53.5	52.99	52.97	52.85	52.97	53.17	52.96	52.99
	GPS Phase	0.55	0.56	0.54	0.54	0.54	0.54	0.54	0.55	0.54	0.54
GRACE	SLR	5.50	5.54	5.20	5.22	5.79	5.80	5.26	5.21	5.25	5.24
	K-Band-RR	1.40	1.40	1.48	1.47	1.53	1.53	1.51	1.49	1.53	1.53
	GPS P-Code	52.15	52.15	51.98	51.97	51.95	51.94	51.89	51.86	51.97	51.96
	GPS Phase	1.21	1.21	1.10	1.11	1.13	1.13	1.09	1.09	1.10	1.10

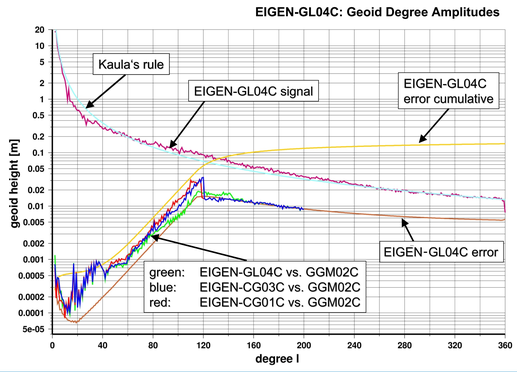
Weighted (cosine of latitude) root mean square (wrms, [m] resp. [mgal]) of geoid resp. gravity anomaly differences between gravity field models and altimetry based data sets, formed on 1° x 1° grids of the compared data sets, after filtering with different filter lengths.

altimetry based data set \ gravity field model	Filter-length	EGM96	GGM02C	EIGEN-CG01C	EIGEN-CG03C	EIGEN-GL04C
NIMA *) [mgal]	2.5°		4.165	4.256	4.261	4.191
	5°		1.008	1.107	1.105	1.027
	10°		0.313	0.313	0.313	0.313
CLS-ECCO **) [m]	2.5°	0.176	0.171	0.182	0.183	0.174
	5°	0.131	0.129	0.133	0.133	0.129
	10°	0.115	0.117	0.116	0.119	0.117

Altimetry based data sets for comparison
*) NIMA altimetric gravity anomalies over the ocean (Kenyon, Pavlis 1997)
**) Geoid undulations over the oceans derived from CLS01 altimetric Sea Surface Heights (Hernandez et al., 2001) and ECCO simulated sea surface topography (Stammer et al., 2002)

Note: GGM02C comparison not independent because combinened with EGM96 field (which consists for n>70 of NIMA)

EIGEN-GL04C: Geoid Degree Amplitudes



Improvement of EIGEN-GL04C: Geoid height differences vs. a global ground data only solution

☞ Reduction of meridional "striations"