POD-4

TOWARD EIGEN-05: GLOBAL MEAN GRAVITY FIELD MODELS FROM COMBINATION OF SATELLITE MISSION AND ALTIMETRY/GRAVIMETRY SURFACE DATA

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Introduction

Global mean high-resolution gravity field models can be derived from the combination of satellite data and surface gravity data, because surface gravity data from altimetry and gravimetry are globally available and provide a higher resolution than pure satellite data but lacking the high precision in the long-wavelength part. 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 (**E**uropean *I*mproved **G**ravity model of the Earth by New techniques) processing activities (see for instance Reigber et al. 2002 and Reigber et al. 2005). The satellite-based data were combined with partially newly released surface gravity data sets on the basis of normal equations to derive a global high-resolution gravity field 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.

During the last two years, a series of combined models was computed from the combination of CHAMP, GRACE and LAGEOS satellite data with various gravity anomaly and altimetry surface data sets. The degree range of all these models is up to 360, but the amount of included satellite data has been continuously increased. For instance the amount of GRACE data from 200 days for earlier EIGEN-CG01C to 34 months for the most recent EIGEN-GL05Cp.

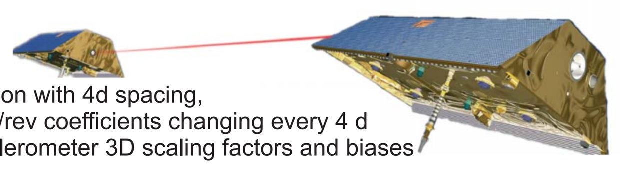
This poster focuses on the two latest models of this series:

- The model **EIGEN-GL04C** (Förste et al., 2006) was published in spring 2006 and is available on the ICGEM data base at GFZ Potsdam. In contrast to the precursor models EIGEN-CG01C and -CG03C, GFZ-processed altimetry data were included.
- The preliminary model **EIGEN-GL05Cp** is an unpublished update of EIGEN-GL04C. EIGEN-GL05Cp was generated in preparatory studies for a future combined EIGEN-05 model. This new model should be available beginning of 2007 after a new reprocessing of the GRACE data, based on improved processing standards.

GRACE and LAGEOS satellite data for EIGEN-GL04C and EIGEN-GL05Cp

Data Period:
CNES (for GRACE and LAGEOS): February 2003 – February 2005
GFZ (for GRACE): February 2003 - July 2005 [for EIGEN-GL04C]
GFZ (for GRACE): February 2003 - Febr. 2006 [for EIGEN-GL05Cp]

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



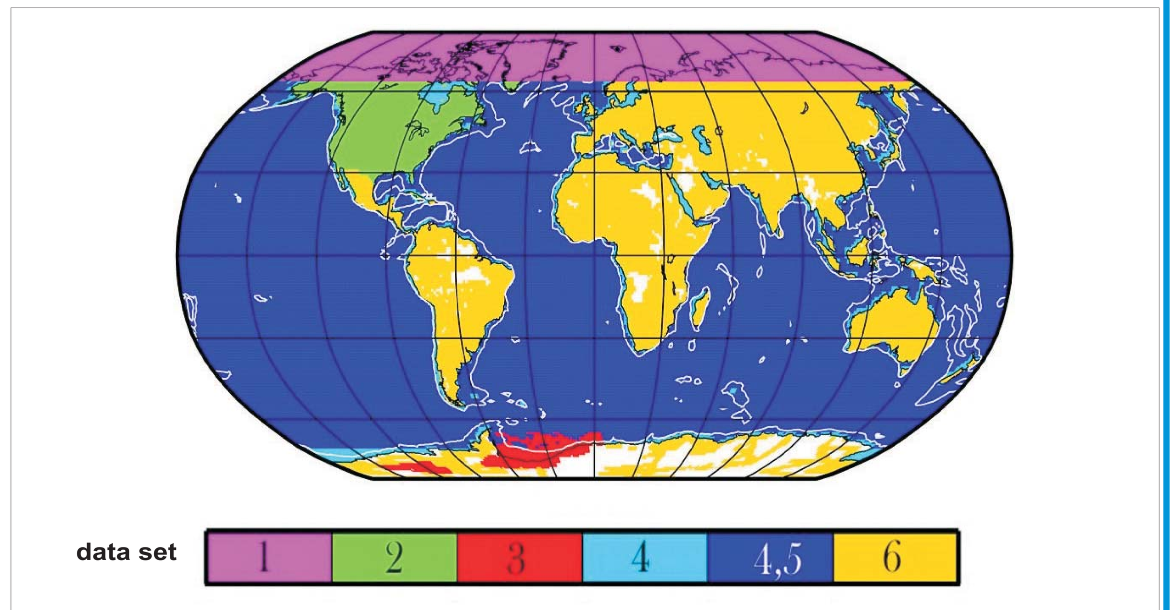
Dynamical Parametrization:
LAGEOS: emp. coefficients, along-track polygon with 4d spacing, along-track and cross-track emp. 1/rev coefficients changing every 4 d
GRACE: K-band empirical coefficients, accelerometer 3D scaling factors and biases at begin and end of the arc

Processing Standards:
Gravity Field: EIGEN-CG03C (150x150) Ocean Tides: FES2004 (80x80)
Earth Tides: IERS2003 Solid Earth Pole Tide: IERS2003
De-aliasing: ECMWF, OMCT(GFZ)/MOGD2D(GRGS)
Ocean Pole Tide: Desai 2002 (80x80)

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

(1) Arctic Gravity Project (ArcGP) gravity anomalies (Forsberg, Kenyon 2004; Forsberg 2006), 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 (Esselborn et al. 2006) 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 set 7 which was 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

Combined gravity field models released by GFZ Potsdam and GRGS Toulouse since 2004

		EIGEN-CG01C	EIGEN-CG03C	EIGEN-GL04C	EIGEN-GL05Cp
	released:	May 2004 (Reigber 2006)	March 2005 (Förste 2005)	March 2006 (Förste 2006)	preliminary (not for publication)
	Resolution:	360 x 360	360 x 360	360 x 360	360 x 360
Main differences:					
Satellite data:	CHAMP	**33 months**: 10/2000 - 06/2003		----	---
	GRACE	**200 days**: 04/2002 - 11/2003	**16 months**: 02/2003 - 07/2004	**30 months**: 02/2003 - 07/2005	**34 months**: 02/2003 - 02/2006
	LAGEOS	----	----	24 months: 02/2003 - 02/2005	24 months: 02/2003 - 02/2005
Ocean data (direct altimetry)		**CLS01** sea surface heights		**GFZ** mean sea surface heights	
Max. degree of the the full normal matrix		140	140	179	200
Overlapping range [deg] between satellite and terrestrial data:		70 ... 109	70 ... 120	70 .. 115	70 ... 150 using constraints
Terrestrial data: Grid size for the full normal equations		1° x 1°	1° x 1°	30' x 30'	30' x 30'

Comparison with geoid heights determined point-wise by GPS positioning and levelling:

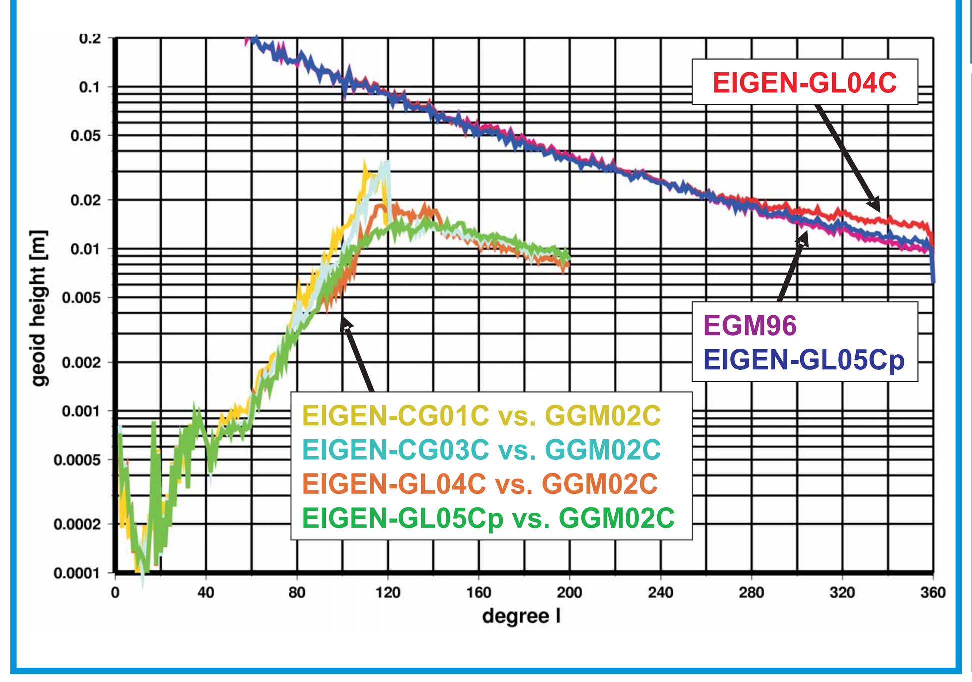
Root mean square (cm) about mean of GPS-Levelling minus model-derived geoid heights (number of points in brackets)

	EGM96	GGM02C/ EGM96*	E I G E N CG01C	CG03C	GL04C	GL05Cp
Europe (186)	44.6	29.8	39.7	38.4	34.0	34.7
Germany (675)	27.6	16.3	21.7	19.7	18.1	18.3
Canada (1930)	37.3	31.1	31.7	35.0	31.1	30.4
USA (669)	46.5	42.8	44.1	43.6	43.5	42.7

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

* GGM02C up to n=m=200; EGM96 for n,m > 200

EIGEN-GL05Cp: Geoid Degree Amplitudes



Algorithms and steps for the adjustment of the combined solution EIGEN-GL05Cp:

Composition of the solution from three separate solutions:

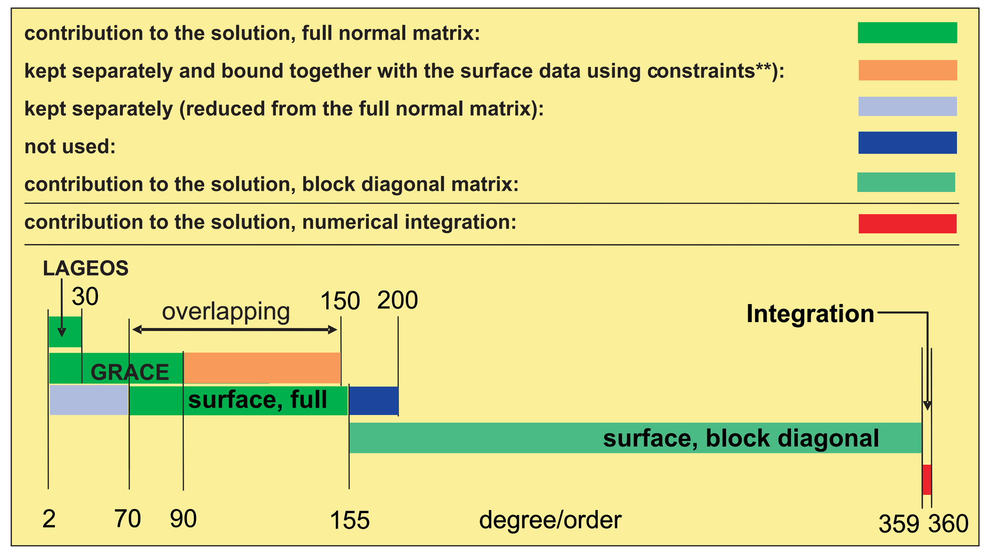
1) GRACE + LAGEOS: full normal matrix (lmax = 150), weight = 1
GRACE: lmax = 150, LAGEOS: lmax = 30

surface full: terrestrial gravity anomalies (continents, polar regions and coast lines) + altimetric geoid undulations (oceans), based on 30' x 30' gridded data
weight = 0.0125 · indiv. weighting (for the different data sets)
full normal equation system, added to the satellite normal matrix

2) surface block diagonal: terrestrial gravity anomalies plus altimetric gravity anomalies, block-diagonal normal equation system, solved separately, based on 30' x 30' gridded data

3) Integration: terrestrial gravity anomalies plus altimetric gravity anomalies, separate numerical integration, based on 30' x 30' gridded data

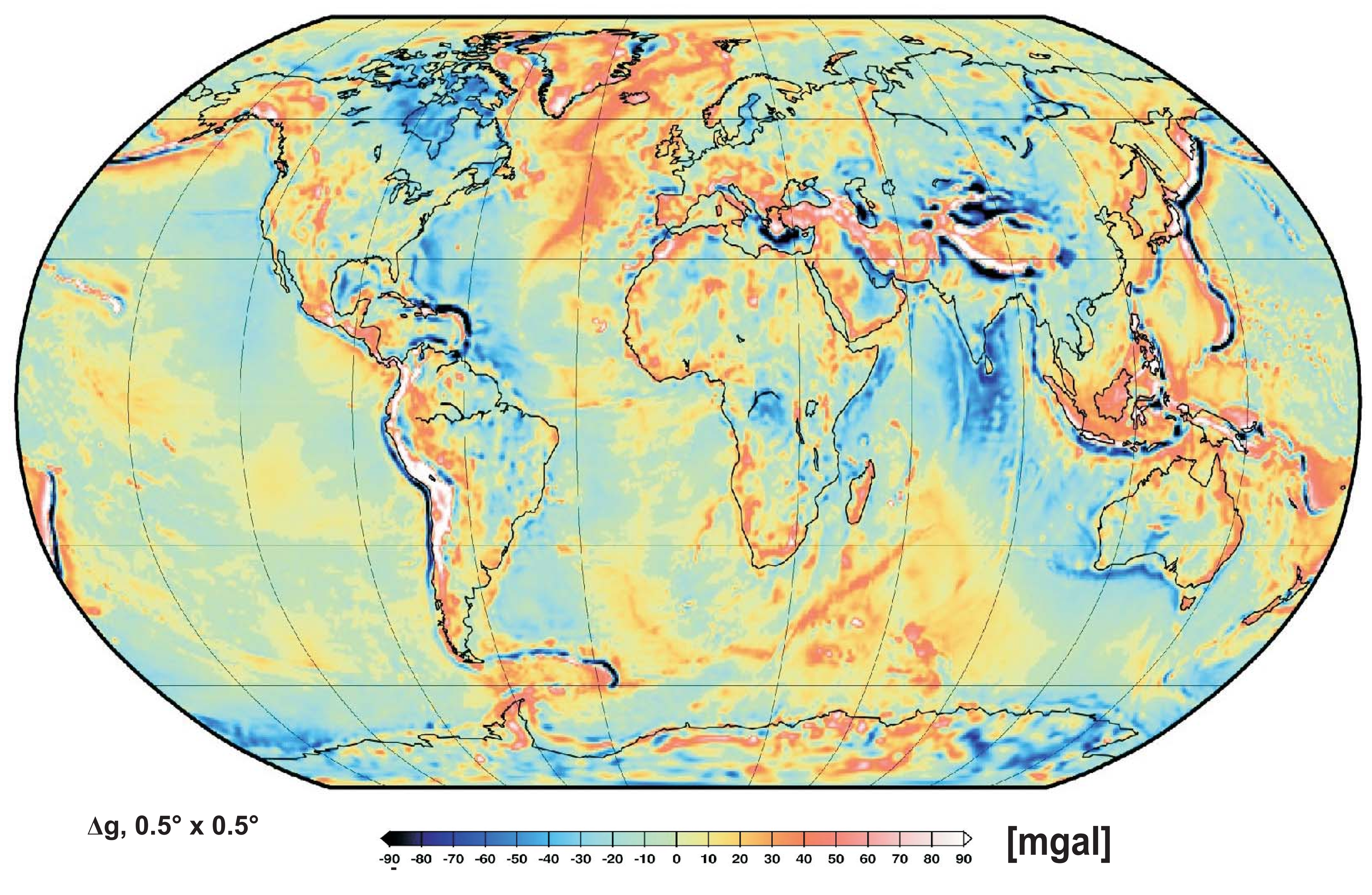
Combination scheme of the EIGEN-GL05Cp components:



**) constraints (pseudo observations), applied between degree 90 and 150:

$$C/S_{n,m,\mathrm{Surface}} \quad C/S_{n,m,\mathrm{GRACE}} \quad _{\mathrm{LAG.}} = 0 \pm \sigma \qquad \sigma = 0.8696 \quad 10^{10} \quad e^{\frac{l \;\; 90}{24.6}}$$

EIGEN-GL05Cp gravity anomalies



Comparison of Orbit adjustment tests (1)

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 (1)	GGM02C (2)	EIGEN-CG01C (1)	EIGEN-CG01C (2)	EIGEN-CG03C (1)	EIGEN-CG03C (2)	EIGEN-GL04C (1)	EIGEN-GL04C (2)	EIGEN-GL05Cp (1)	EIGEN-GL05Cp (2)
CHAMP	SLR	5.19	5.51	5.48	5.58	5.58	5.45	5.44	5.41	5.61	5.58
	GPS P-Code	53.42	53.5	52.99	52.97	52.97	52.85	52.96	52.99	52.96	52.97
	GPS Phase	0.56	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54
GRACE	SLR	5.50	5.54	5.22	5.22	5.79	5.80	5.25	5.24	5.24	5.24
	K-Band-RR	1.40	1.40	1.47	1.47	1.53	1.53	1.53	1.53	1.54	1.54
	GPS P-Code	52.15	52.15	51.97	51.97	51.95	51.94	51.97	51.96	51.98	51.97
	GPS Phase	1.21	1.21	1.11	1.11	1.13	1.13	1.10	1.10	1.11	1.11

Comparison of Orbit adjustment tests (2)

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-GL04C	EIGEN-GL05Cp
GFZ-1	5 x 3 days	SLR	14.30	15.06	15.10	13.79	13.96
STELLA	5 x 3 days	SLR	3.23	3.02	3.06	2.98	2.98
STARLETTE	5 x 3 days	SLR	2.44	2.63	2.61	2.58	2.57
AJISAI	5 x 3 days	SLR	3.18	3.17	3.16	3.14	3.13
LAGEOS-1	5 x 6 days	SLR	1.14	1.15	1.11	1.11	1.11
LAGEOS-2	5 x 6 days	SLR	1.04	1.10	1.04	1.03	1.03
ERS-2	6 x 6 days	SLR PRARE PRARE-Doppler	6.03 3.00 0.378	5.50 3.64 0.351	5.34 3.55 0.345	5.33 3.55 0.345	5.33 3.55 0.344
ENVISAT	7 x 4...8 days	SLR DORIS	4.32 0.495	4.97 0.499	4.29 0.495	4.94 0.497	4.94 0.497
WESTPAC	5 x 6 days	SLR	4.24	4.00	3.99	4.01	4.01

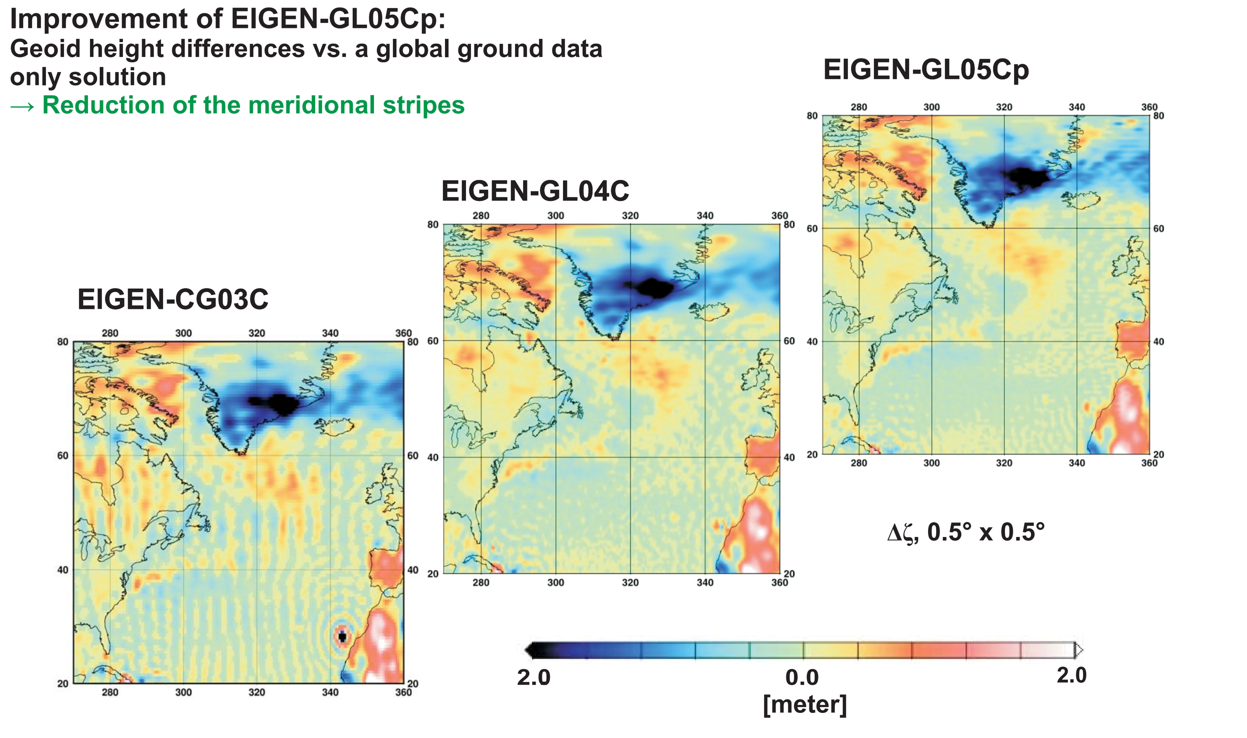
Latitude-weighted root mean square of geoid- and gravity anomaly differences between gravity field models and altimetry based data sets, formed on 1° x 1° grids of the compared data sets, after filtering with different filter lengths.

gravity field model / altimetry based data set	Filter-length	EGM96	GGM02C	EIGEN-CG01C	EIGEN-CG03C	EIGEN-GL04C	EIGEN-GL05Cp
NIMA *) [mgal]	3°		4.165	4.256	4.261	4.191	4.109
	5°		1.008	1.107	1.105	1.027	1.000
	10°		0.313	0.313	0.313	0.313	0.313
CLS-ECCO **) [m]	3°	0.176	0.171	0.182	0.183	0.174	0.169
	5°	0.131	0.129	0.133	0.133	0.129	0.128
	10°	0.115	0.117	0.116	0.119	0.117	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)

Improvement of EIGEN-GL05Cp:

Geoid height differences vs. a global ground data only solution
→ Reduction of the meridional stripes



Summary and Outlook

The quality of the **EIGEN-GL04C** model was recently appreciated by adopting it as a standard for the reprocessing of the **Jason** and **TOPEX/Poseidon data,**

The **EIGEN-GL04C** coefficients are available for download at the **ICGEM*** data base at **GFZ Potsdam**:
http://icgem.gfz-potsdam.de/ICGEM/ICGEM.html

Further improvements of the current **EIGEN-GL05Cp** model are planned for the upcoming **EIGEN-05** gravity field model:

- reprocessing (new release) of all GRACE (and CHAMP) data
- inclusion of CHAMP
- extension of the full ground data based normal equations to higher degrees (n,m=250 or more)
- usage of new/updated ground data sets

*ICGEM = The **I**nternational **C**enter of **G**lobal **E**arth **M**odels at **GFZ Potsdam** is one of the six data centers of the **International Gravity Field Service** (**IGFS**) of the **IAG**

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