EIGEN-6

A new combined global gravity field model including GOCE data from the collaboration of GFZ-Potsdam and GRGS-Toulouse

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Data used for EIGEN-6C/S

LAGEOS-1/2 SLR dat

GRACE GPS-SST and K-band range-rate data:

- **January 2003 … June 2009 (6.5 years)**
- **within the GRGS RL02 GRACE processing**
- **normal equations including 5 time variable parameters for each spher. harm. coeff. up to d/o 50:**

$$G(t)=\mathbf{G}(t_0)+\mathbf{DOT}*(t-t0)+\mathbf{C1A}*\cos(\omega a*(t-t0))+\mathbf{S1A}*\sin(\omega a*(t-t0))$$
$$+\mathbf{C2A}*\cos(\omega sa*(t-t0))+\mathbf{S2A}*\sin(\omega sa*(t-t0))$$

with t_0=2005.0 = reference epoch

where:			
	DOT	=	drift
	C1A, S1A	=	annual terms
	C2A, S2A	=	semi-annual terms

GOCE:

- **GOCE SGG data: Txx, Tyy and Tzz**
- **processed by the direct approach (GFZ/GRGS within GOCE-HPF)**
- **individual normal equations for each SGG component**
- **application of a (100 – 8) sec band pass filter for all three SGG components**
  - ☞ **The SGG signal is filtered-out below degree ~ 50**

Terrestrial data:

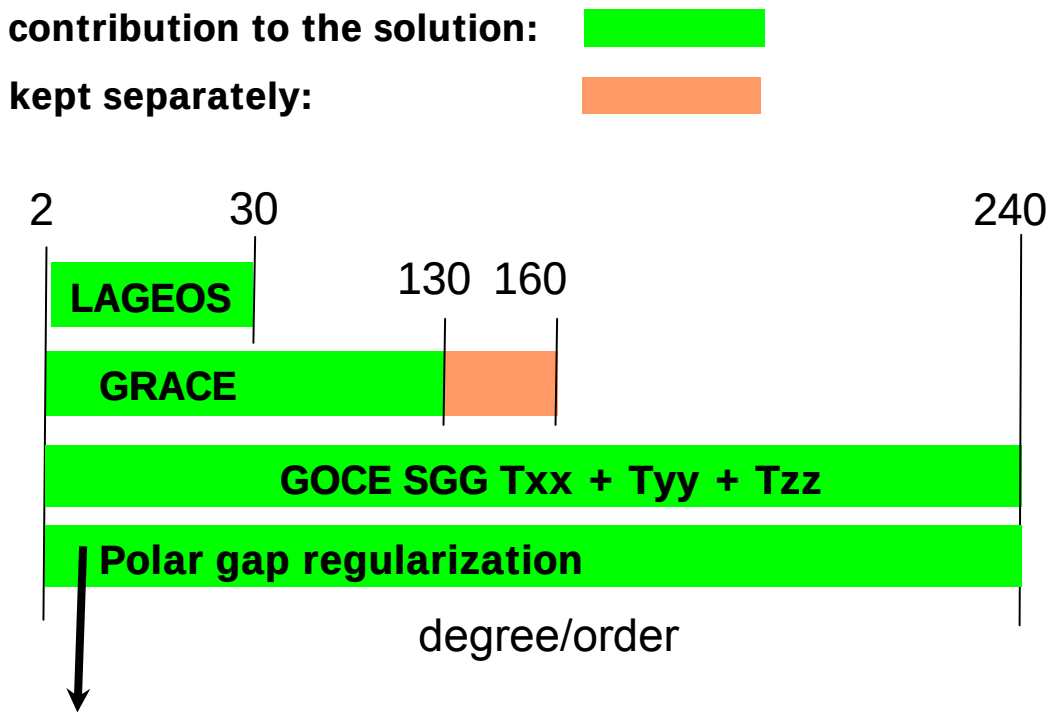
DTU10 global gravity anomaly grid (Andersen, Knudsen and Berry 2010 & Anderson 2010)

☞ **This is obtained from altimetry over the oceans and EGM2008 over land**

The combination of the different satellite and surface parts has been done done by a band-limited combination of normal equations, which are obtained from observation equations for the spherical harmonic coefficients.

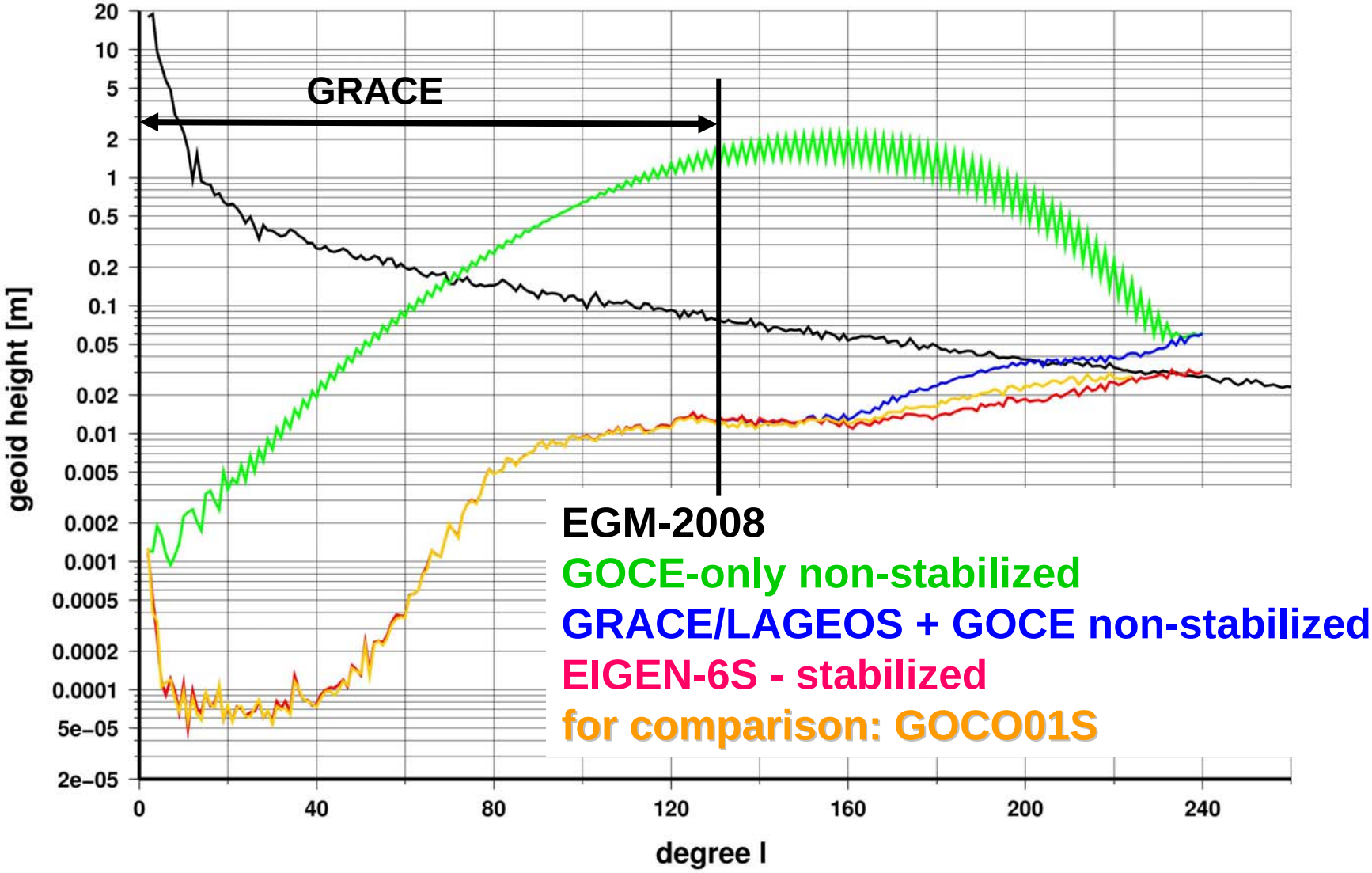
The satellite-only model EIGEN-6S

Combination scheme of EIGEN-6S (satellite-only)

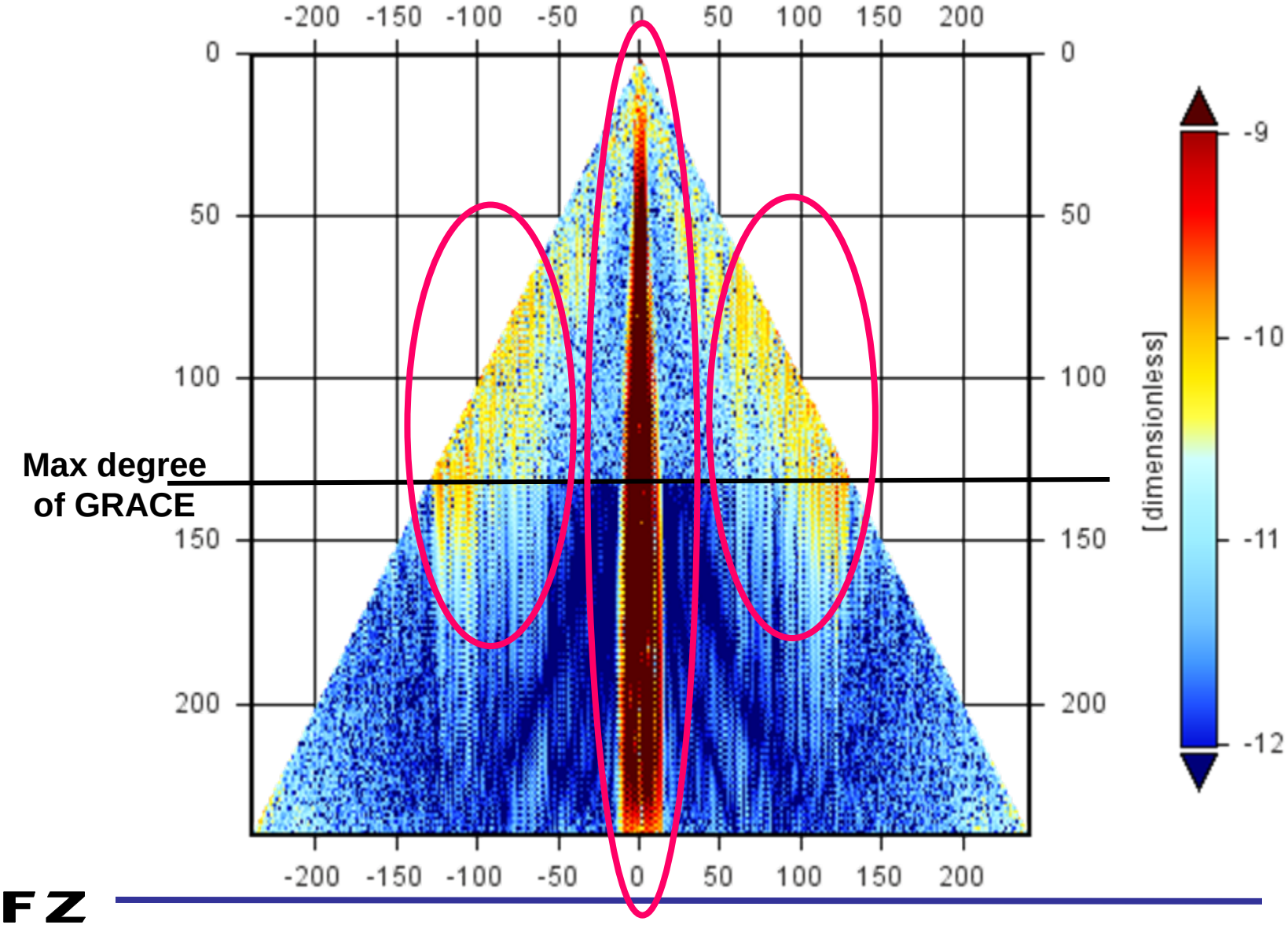


Application of external gravity field information over the polar gaps
For EIGEN-6S: GRACE/LAGEOS to d/o 130 + zero coefficients to d/o 240
Algorithm: **Spherical cap regularization** (Metzler & Pail 2005)

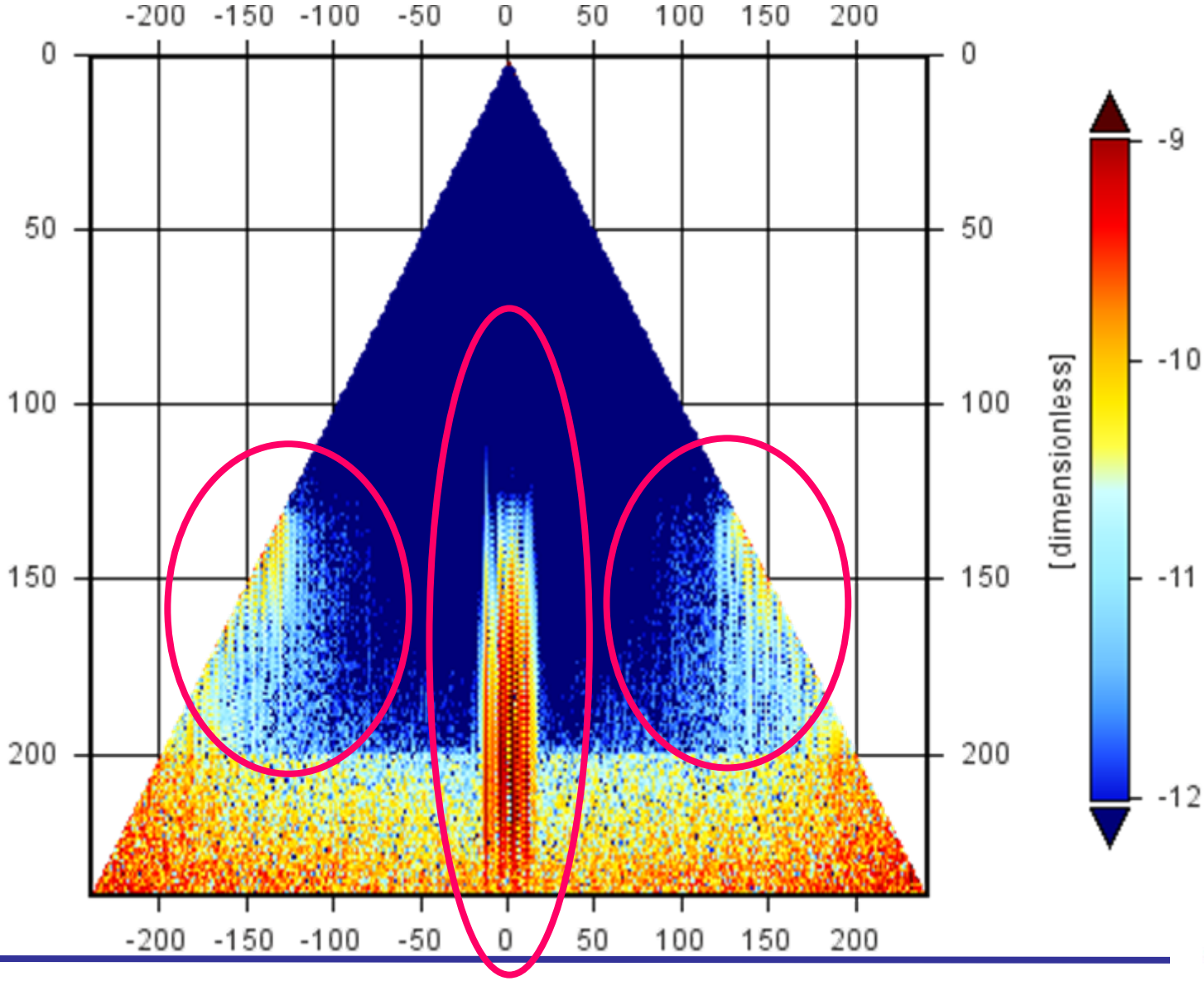
EIGEN-6S: GOCE Polar Gap stabilization for GRACE + GOCE
The effect of the stabilization in the spectral domain



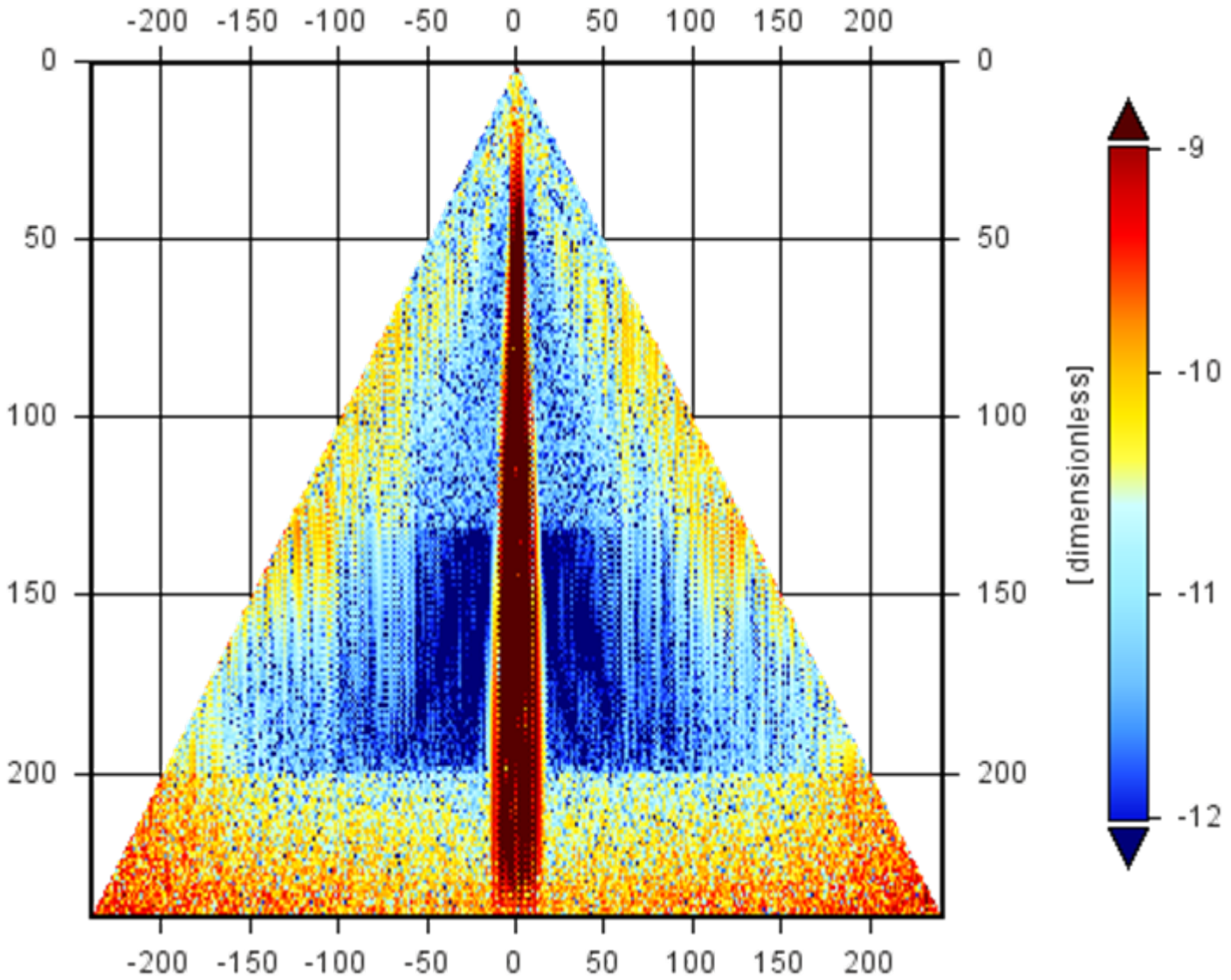
The effect of the stabilization of GRACE on GOCE: GOCE-only vs. GRACE+GOCE, both non-stabilized



The effect of the stabilization on the spherical hermonic coefficients: GRACE+GOCE-only non-stabilized vs. EIGEN-6S



The effect of the stabilization on the spherical hermonic coefficients: GOCE-only non-stabilized vs. EIGEN-6S



The combined model EIGEN-6C

Combination scheme of EIGEN-6C

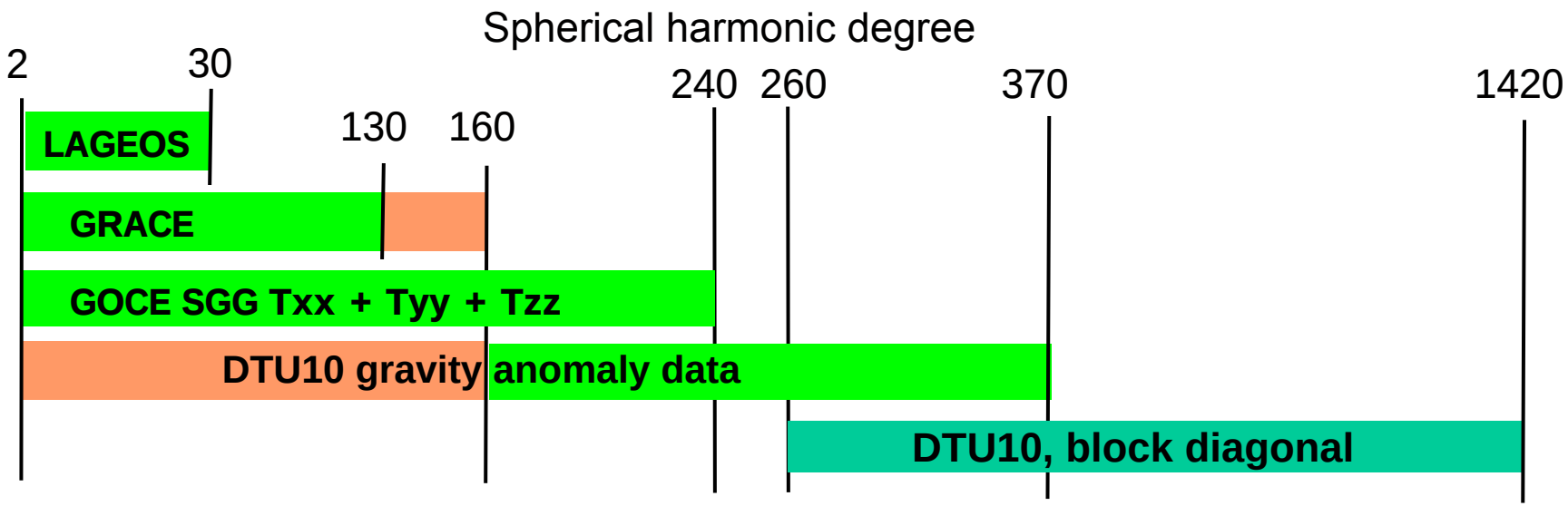
Accumulation of a full normal matrix up to d/o 370:

~200.000 parameters, ~ 250 GByte

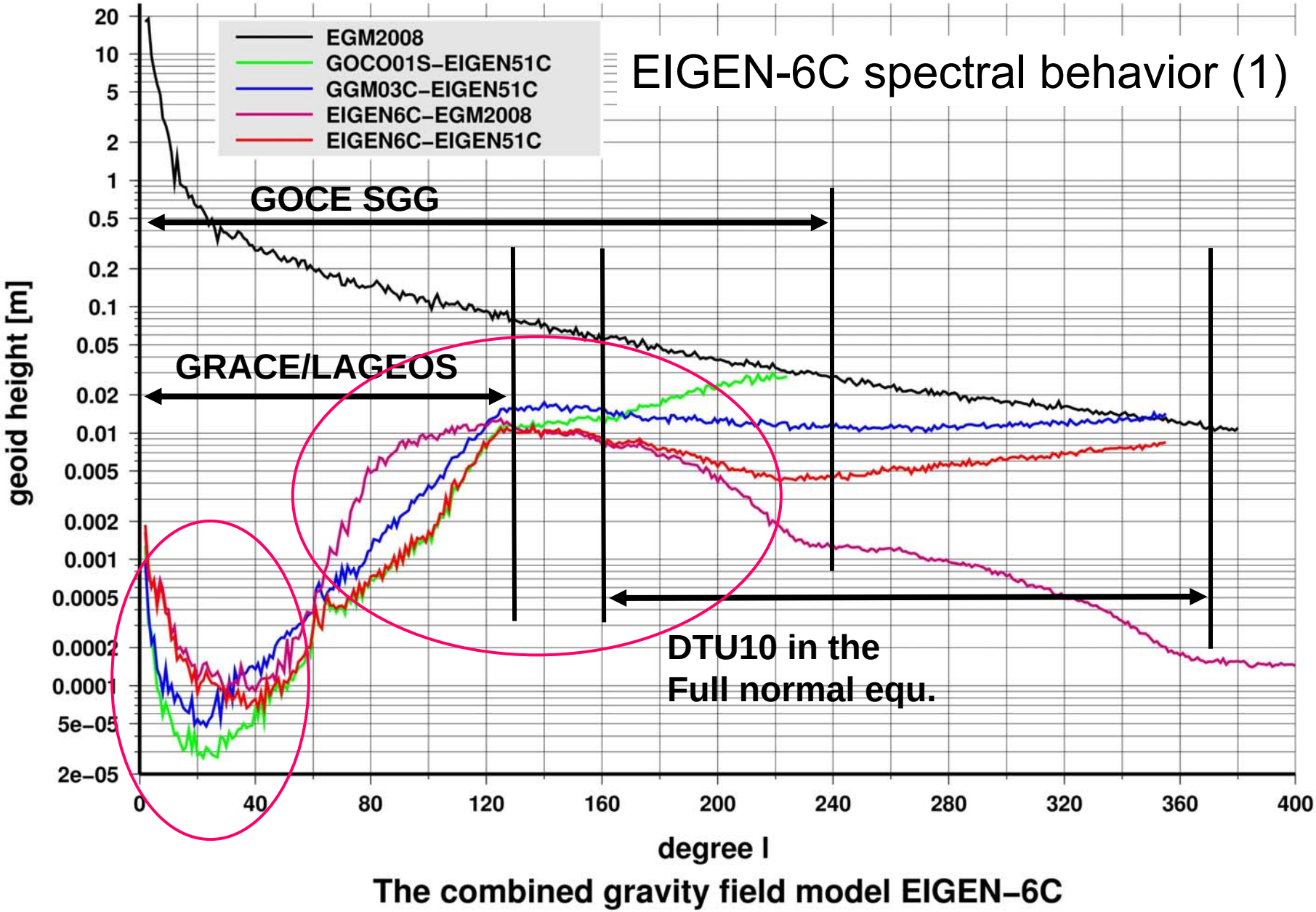
contribution to the solution:

kept separately:

Separate block diagonal solution:

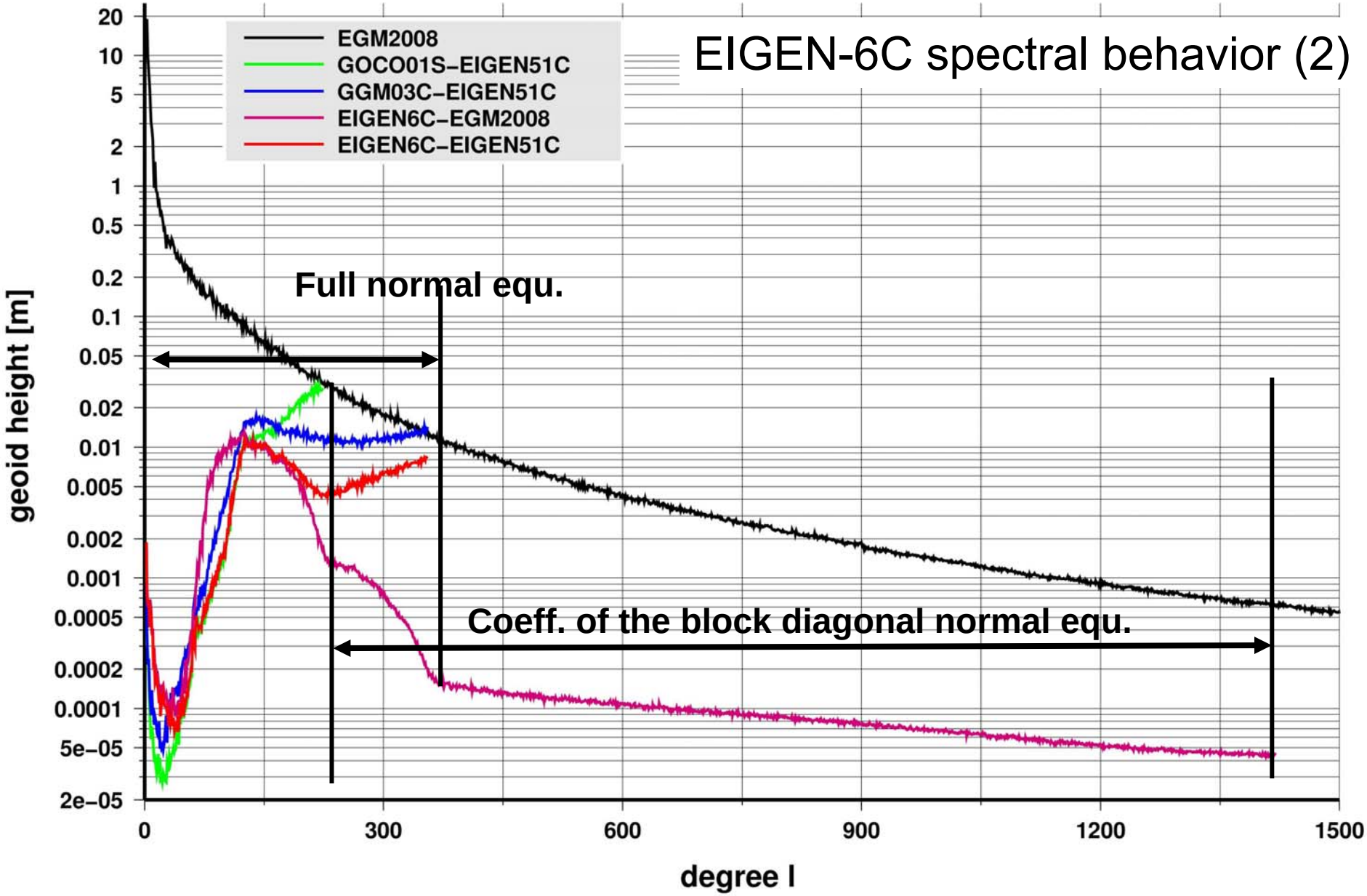


EIGEN-6C spectral behavior (1)



The combined gravity field model EIGEN–6C

EIGEN-6C spectral behavior (2)



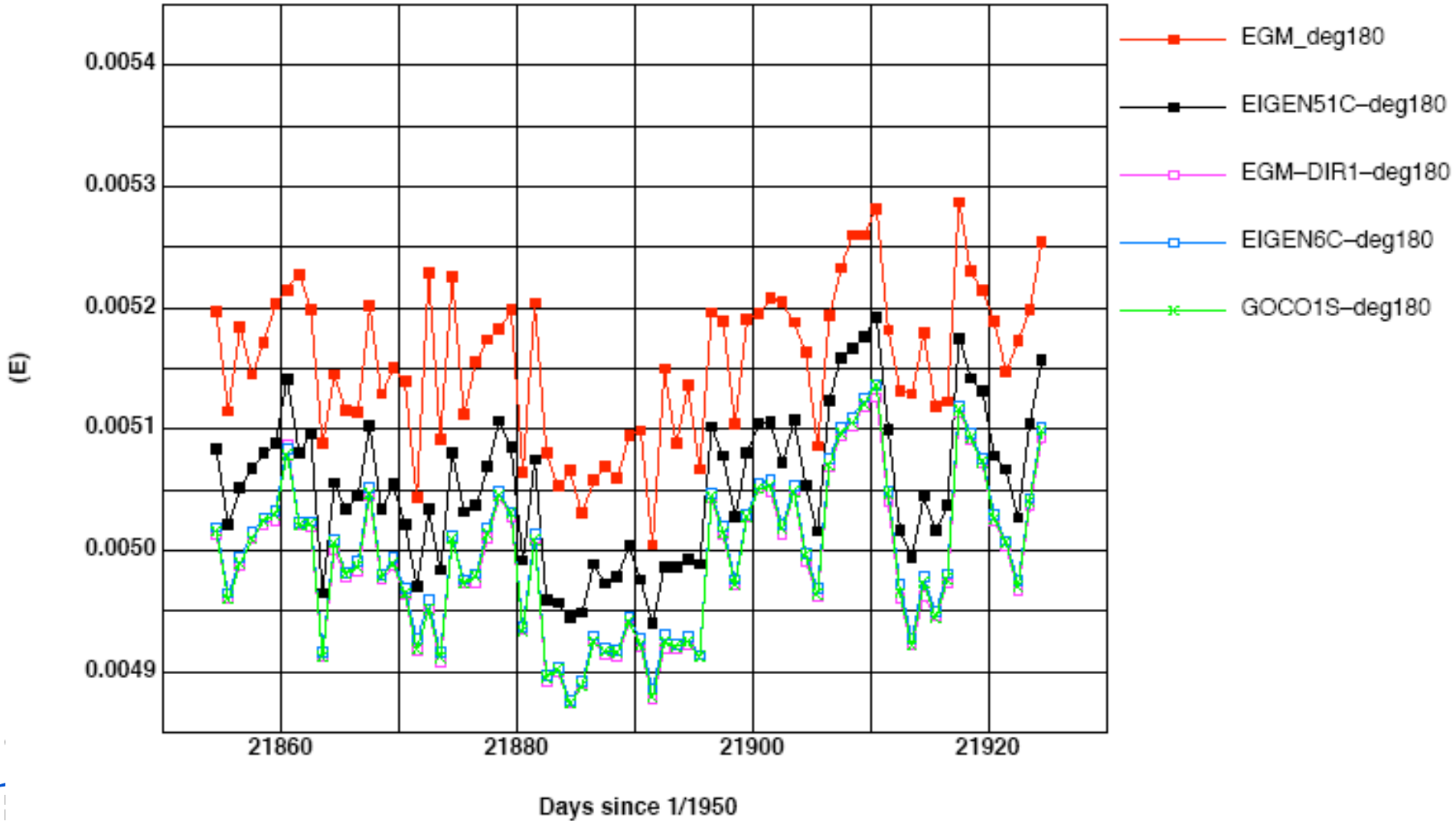
The combined gravity field model EIGEN–6C

Evaluation Results

Evaluation by computation of residuals

RMS of filtered SGG residuals: GOCE measurements (cycle 1) - model

GOCE models - Improvement with GOCE compared to GRACE



GOCE Orbit adjustment tests

- Observations: **GO_CONS_SST_PKI_2I** (kinematic GOCE orbit positions)
- Dybamic orbit computation
- **60 arcs** (01.11. – 31.12.2009), Arclength = **1.25 days**
- Parametrization:
  - Accelerometer **biases**: 2/rev for cross track / radial / along track
  - Accelerometer **scaling factor**: along track fixed (set to 1.0), 1/arc for cross track / radial

Rms values [cm] of the orbit fit residuals (mean values from the 60 arcs)

1) Orbit computation with different spher. harm. max. degree

Gravity field model / max. d/o	120x120	150x150	180x180
EGM2008	4.0 →	2.9 →	2.8
GGM03C	3.6 →	2.4 →	2.3
EIGEN-5C	3.4 →	2.3 →	2.2
EIGEN-51C	3.2 →	2.0 →	1.8
ITG-GRACE2010S	3.3 →	1.8 →	1.7
GO_CONS_GCF_2_DIR	3.9 →	2.6 →	2.4
GOCO01S	3.3 →	1.8 →	1.6
EIGEN-6S (epoch 01.12.2009)	3.2 →	1.6 →	1.5
EIGEN-6C (epoch 01.12.2009)	3.2 →	1.6 →	1.5

☞ **The best orbit fits for max deg. 180 for all models**

GOCE Orbit adjustment tests

- Observations: **GO_CONS_SST_PKI_2I** (kinematic GOCE orbit positions)
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Rms values [cm] of the orbit fit residuals (mean values from the 60 arcs)

2) Obit fits without and with GOCE-contaning models

Gravity field model / max. d/o	180x180	
EGM2008	2.8	GRACE
GGM03C	2.3	
EIGEN-5C	2.2	
EIGEN-51C	1.8	
ITG-GRACE2010S	1.7	
GOCE TIM-2	4.2	GOCE-only
GOCE DIR-2	2.4	
GOCO01S	1.6	GOCE+GRACE
EIGEN-6S (epoch 01.12.2009)	1.5	
EIGEN-6C (epoch 01.12.2009)	1.5	

☞ GOCE-only models are not better than most of the GRACE models
GOCE-GRACE models give better results than GRACE models

GPS/Levelling test with EIGEN-6C

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).

Maximum d/o 360 ☞

	GGM03C	EIGEN-GL04C	EIGEN-5C	EIGEN-51C	EIGEN-6C	EGM2008 (till d/o 360)
Europe (1234)	33.3	33.6	30.2	28.8	27.5	26.9
Germany (675)	18.8	17.8	15.2	14.8	15.4	14.2
Canada (1930)	27.8	25.3	25.1	24.4	22.9	22.9
USA (6169)	34.5	33.9	33.9	33.3	31.6	31.8
Australia (201)	25.8	24.4	24.3	23.3	23.6	23.6

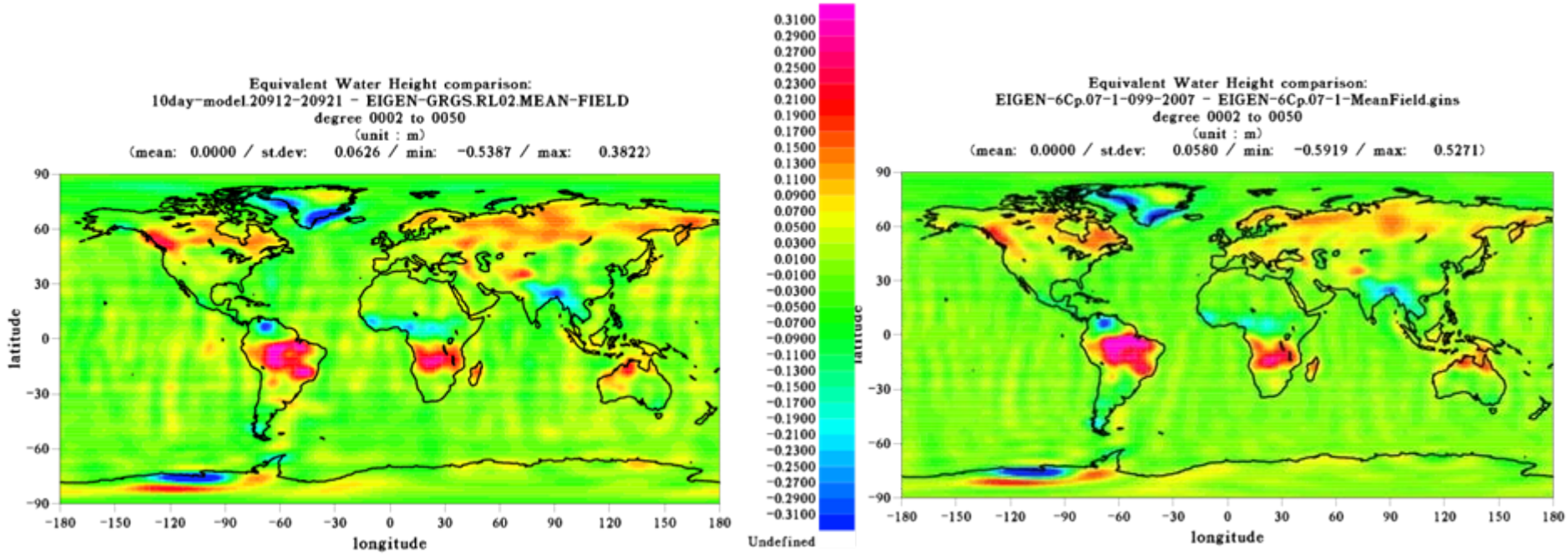
Used GPS/Leveling data sets:
- **USA**: (Milbert, 1998)
- **Canada:** (M. Véronneau, personal communication 2003, Natural Resources Canada)
- **Europe/Germany:** (Ihde et al., 2002)
- **Australia:** (G. Johnston, Geoscience Australia and W. Featherstone, Curtin University of Technology, personal communication 2007)

Comparison of independend GRACE time series and the time variable coefficients from EIGEN-6C (max d/o 50)

10-day model at

Mean model EIGEN-6C interpolated to

April 2007



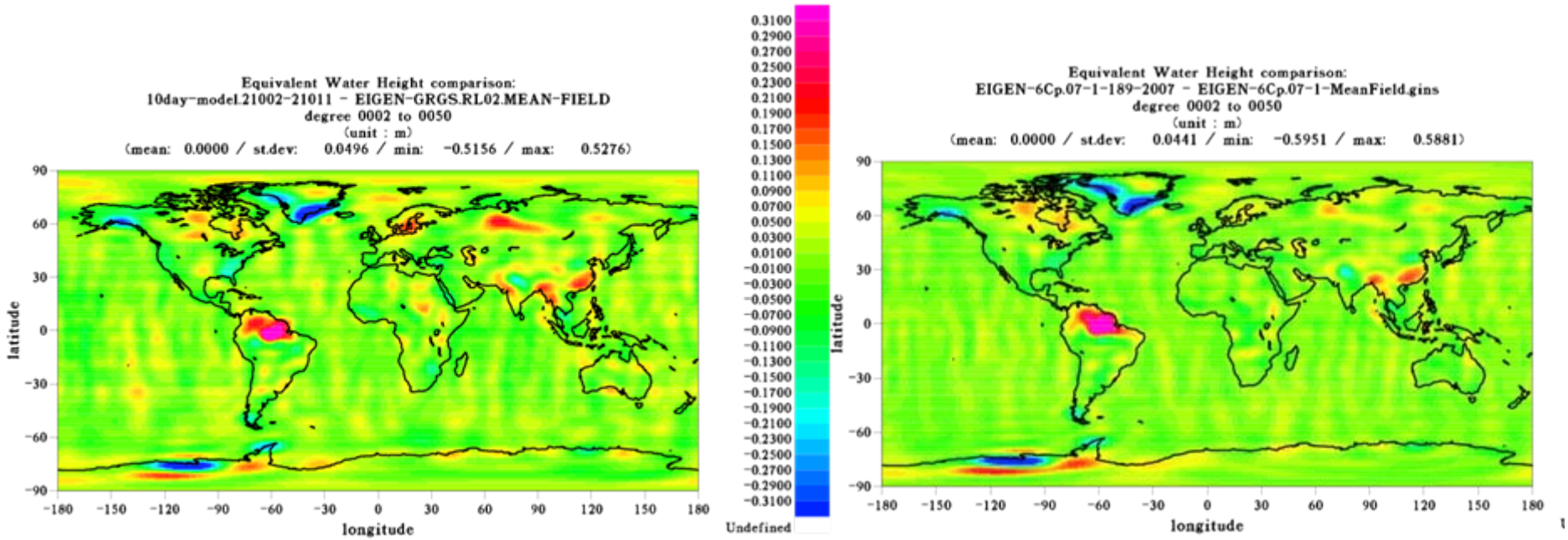
Geoidheight differences
between the time variable gravity field at the epoch and the corresponding mean field expressed in equivalent water heights (meter)

Comparison of independend GRACE time series and the time variable coefficients from EIGEN-6C (max d/o 50)

10-day model at

Mean model EIGEN-6C interpolated to

July 2007



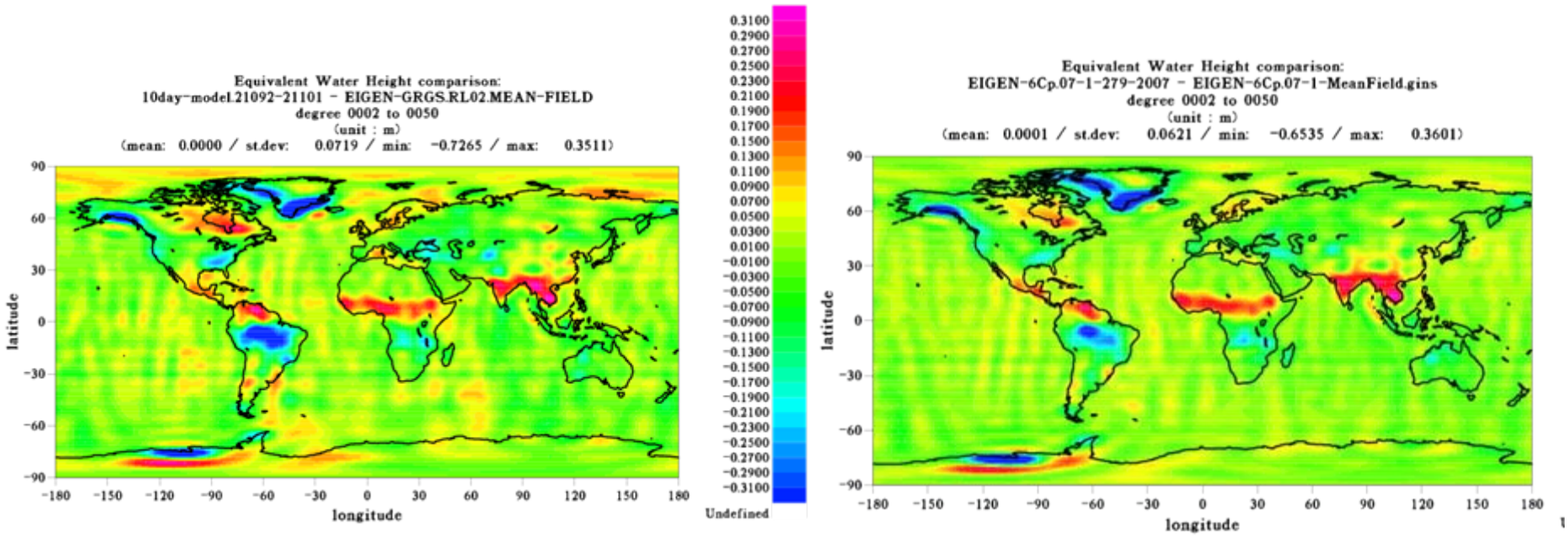
Geoidheight differences between the time variable gravity field at the epoch and the corresponding mean field expressed in equivalent water heights (meter)

Comparison of independend GRACE time series and the time variable coefficients from EIGEN-6C (max d/o 50)

10-day model at

Mean model EIGEN-6C interpolated to

October 2007



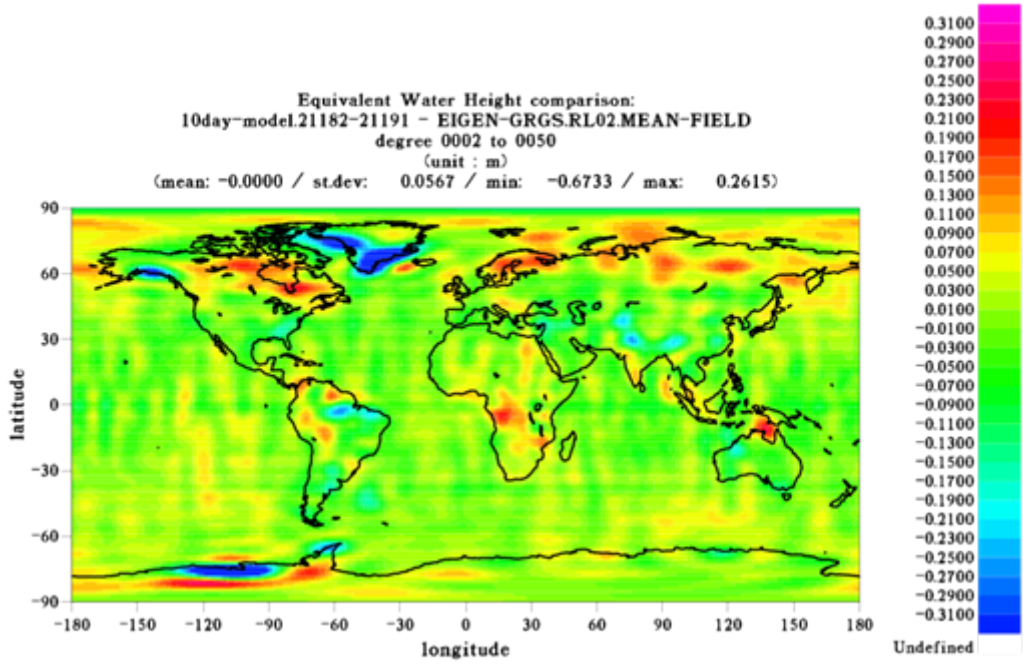
Geoidheight differences
between the time variable gravity field at the epoch and the corresponding mean field expressed in equivalent water heights (meter)

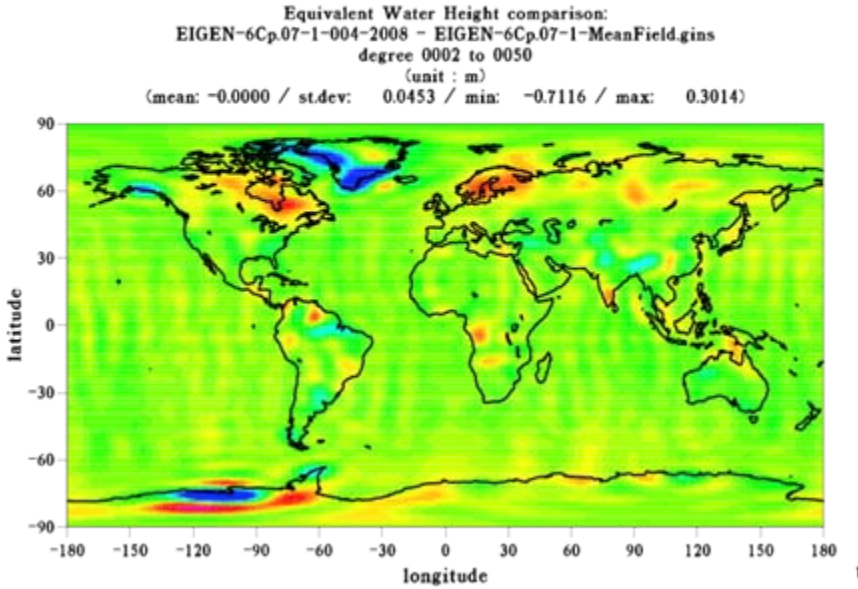
Comparison of independend GRACE time series and the time variable coefficients from EIGEN-6C (max d/o 50)

10-day model at

Mean model EIGEN-6C interpolated to

January 2008





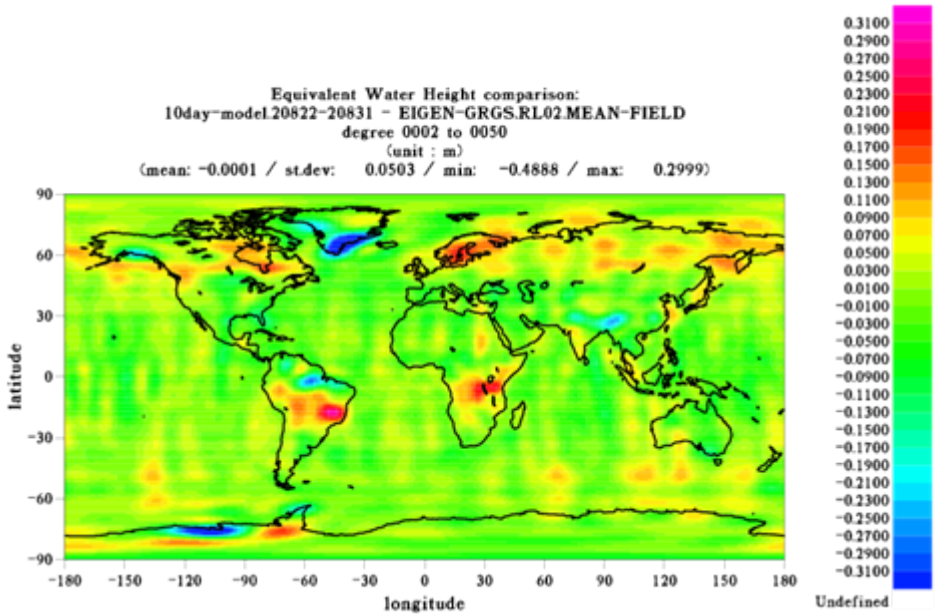
Geoidheight differences between the time variable gravity field at the epoch and the corresponding mean field expressed in equivalent water heights (meter)

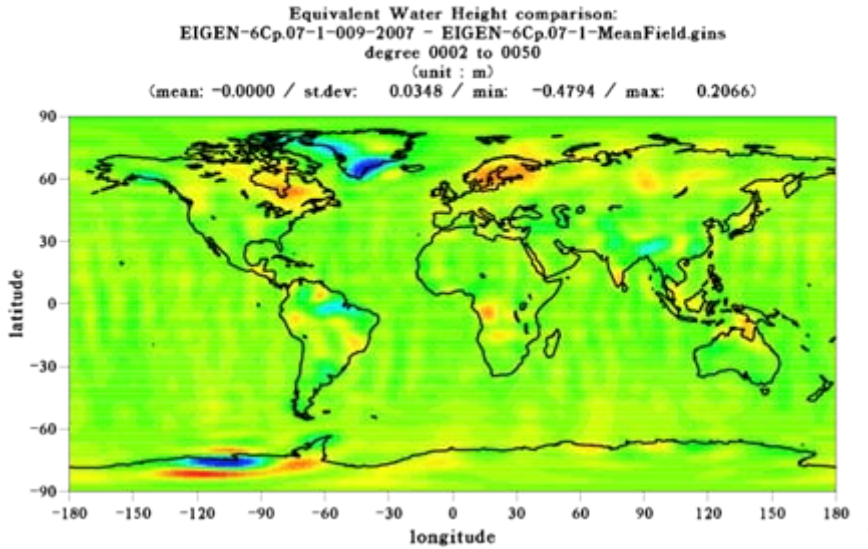
Comparison of independend GRACE time series and the time variable coefficients from EIGEN-6C (max d/o 50)

10-day model at

Mean model EIGEN-6C interpolated to

January 2007





Geoidheight differences between the time variable gravity field at the epoch and the corresponding mean field expressed in equivalent water heights (meter)

The impect of time variable models in satellite orbit computation:

GOCE orbit adjustment fit: Static vs. Time variable Gravity model

- **Dynamic orbit computation**
- Observations: **GO_CONS_SST_PKI_2I** (kinematic GOCE orbit positions)
- **60 arcs** (01.11. – 31.12.2009), Arclength = **1.25 days**
- Rms values **[cm]** of the orbit fit residuals (mean values from the 60 arcs)
- Parametrization:
  Accelerometer **biases**: 2/rev for cross track / radial / along track
  Accelerometer **scaling factor**: along track fixed (set to 1.0), 1/arc for cross track / radial

Gravity field model / max. d/o	150x150
GRACE 2003-2010 (static)	2.1 ± 0.7
GRACE 2003-2010 (at epoch 20091201)	1.8 ± 0.7
GRACE 2003-2009.5 (static)	2.0 ± 0.7
GRACE 2003-2009.5 (at epoch 20091201)	1.7 ± 0.7
EIGEN-6C (static)	1.8 ± 0.8
EIGEN-6C (at epoch 01.12.2009)	1.6 ± 0.7

Summary / Conclusion

- **EIGEN-6S** is new satellite-only model from the combination of LAGEOS/GRACE & GOCE.
- **EIGEN-6C** is a new combined gravity field model from the EIGEN-6S satellite data and the DTU10 global gravity anomaly grid of a **maximum degree 1420**.
- **Over land and beyond degree 240**, EIGEN-6C is in principle a reconstruction of EGM2008 (Due to the inclusion of DTU10)
- EIGEN-6C/S contain **time variable parameters** for all spher. harm. coeff. **up to degree 50** (drift, annual and semiannual terms).

- GOCE-only models are not as good as GRACE models for **GOCE orbit computation**. The best GOCE orbit fit results are obtained with combined **GRACE+GOCE models.** Thereby, the maximum degree should be taken **up to 180**.
- The application of **time variable gravity field components** in GOCE orbit computations gives a futher improvement in the orbit fit results (best results with EIGEN-6C).
- Thus, **time variable gravity field components** should be used in satellite orbit computations generally

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- **GPS/Leveling comparisons** show an improvement of EIGEN-6C compared to the previous EIGEN-models. The EIGEN-6C results are comparable with EGM2008
- Meanwhile the generation and **inversion of normal equations > 300 Gbyte** of more than 200.000 parameters is technically feasible

- EIGEN-6C/S will be published on the ICGEM data base at GFZ Potsdam within the next weeks

http://icgem.gfz-potsdam.de

Thank you for your attention