GOCE gravity field models following the time-wise approach

Jan Martin Brockmann[1], Eduard Höck[2,4], Ina Loth[1], Torsten Mayer-Gürr[2], Roland Pail[3], Wolf-Dieter Schuh[1] and Norbert Zehentner[2]

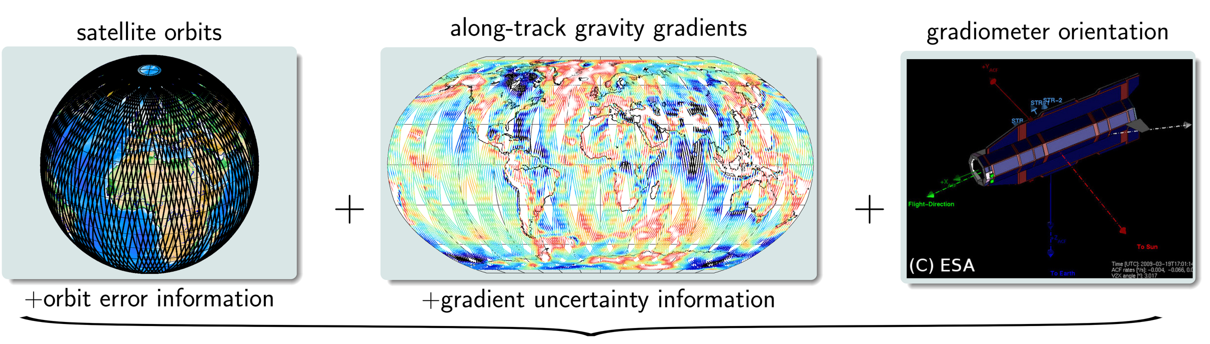
[1] IGG-TG, University of Bonn; [2] IfG, TU Graz; [3] IAPG, TU München; [4] IWF, Austrian Academy of Sciences

Abstract and Motivation

Since the launch of ESA's GOCE satellite in 2009 and its end in 2013, a sequence of official GOCE gravity field models was released. One of the series of models follows the so called time-wise approach (EGM_TIM). They are purely based on GOCE observations such that they are independent of other gravity information and describe the Earth's gravity field as seen by GOCE. The models of the time-wise series were computed within the ESA funded High-level Processing Facility (HPF) and are part of the official ESA GOCE products. Gravity gradients in the gradiometer reference frame and the satellite positions as derived by GPS measurements entered the solutions as observations. Together with the spherical harmonic coefficients, a realistic and full covariance matrix is provided reflecting the model quality.

This contribution summarizes the gravity field models derived with the time-wise approach. The progress along the five releases is highlighted. Special focus is put on the final release 5. This model, parameterized as 78 957 spherical harmonic coefficients (spatial resolution of 71 km), was determined from $4 \times 109\,799\,264$ gravity gradient measurements and 108 754 709 three dimensional positions within a joint least squares adjustment procedure. As this gravity field models only depend on GOCE observations, the gain of GOCE compared to other missions and other gravity field products can be clearly demonstrated. With release 5 of the time-wise model, a pure GOCE based model with a mean global accuracy of 2.4 cm at a spatial resolution of 100 km for the geoid (0.7 mGal for gravity anomalies) is available.

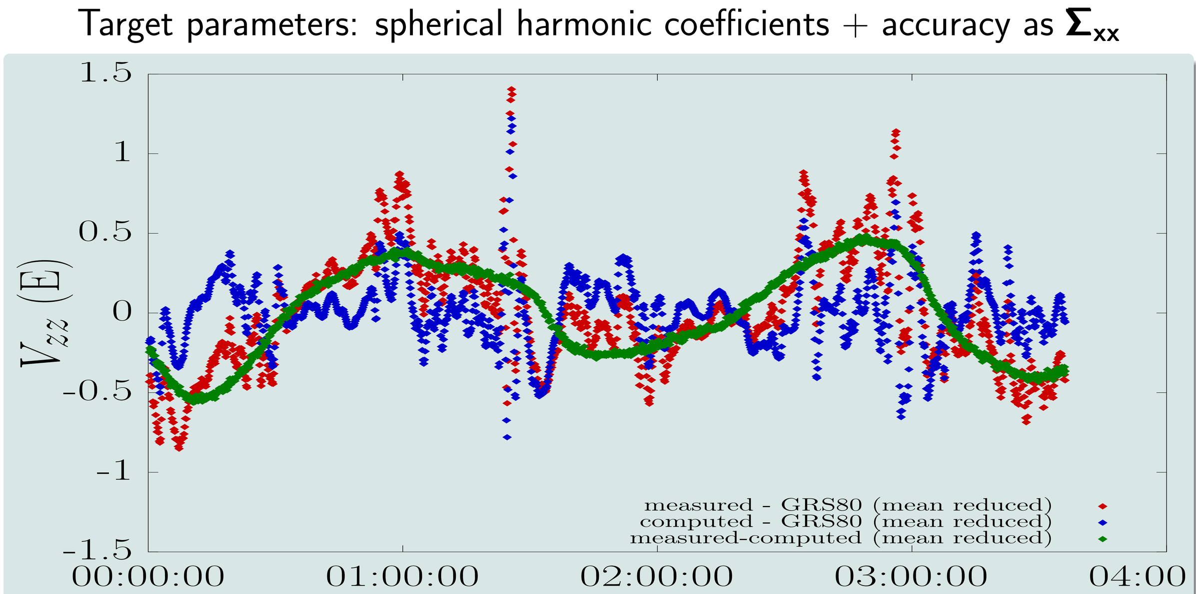
The time-wise approach



$$V(r,\theta,\lambda) = \frac{GM}{a}\sum_{l=0}^{l_{\max}}\left(\frac{a}{r}\right)^{l+1}\sum_{m=0}^{l}\left(c_{lm}\cos(m\lambda) + s_{lm}\sin(m\lambda)\right)P_{lm}(\cos\theta),$$

GOCE-only gravity field model independent of other gravity data

Target parameters: spherical harmonic coefficients + accuracy as $\boldsymbol{\Sigma}_{\mathbf{xx}}$



SST processing:

- short arc integral equation approach
- stochastic model: position covariance + empirical cov. function
- least squares normal equations

SGG processing:

- gravity gradients in GRF as time series
- components used V_{xx}, V_{xz}, V_{yy} and V_{zz}
- stochastic model: individually adjusted ARMA filters
- iterative outlier detection
- least squares normal equations

Constraints:

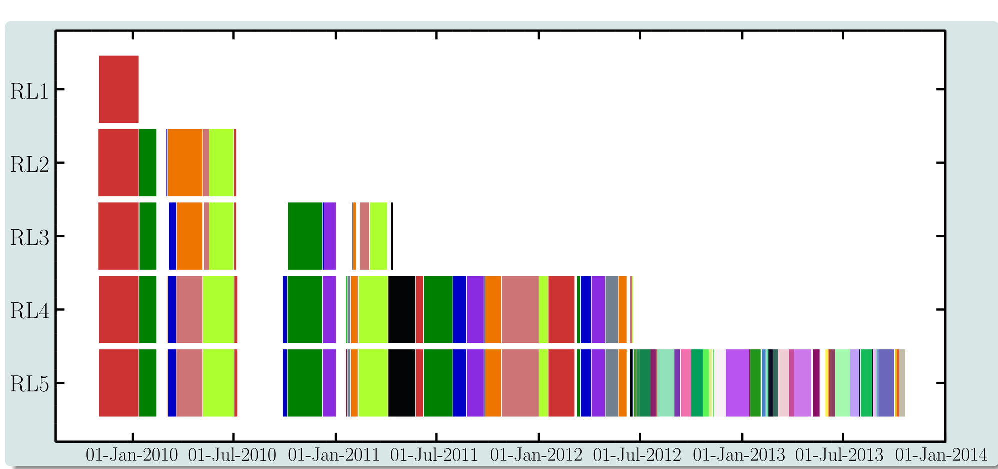
- Kaula for (near) zonal coefficients (polar gap)
- Kaula for high degree coefficients

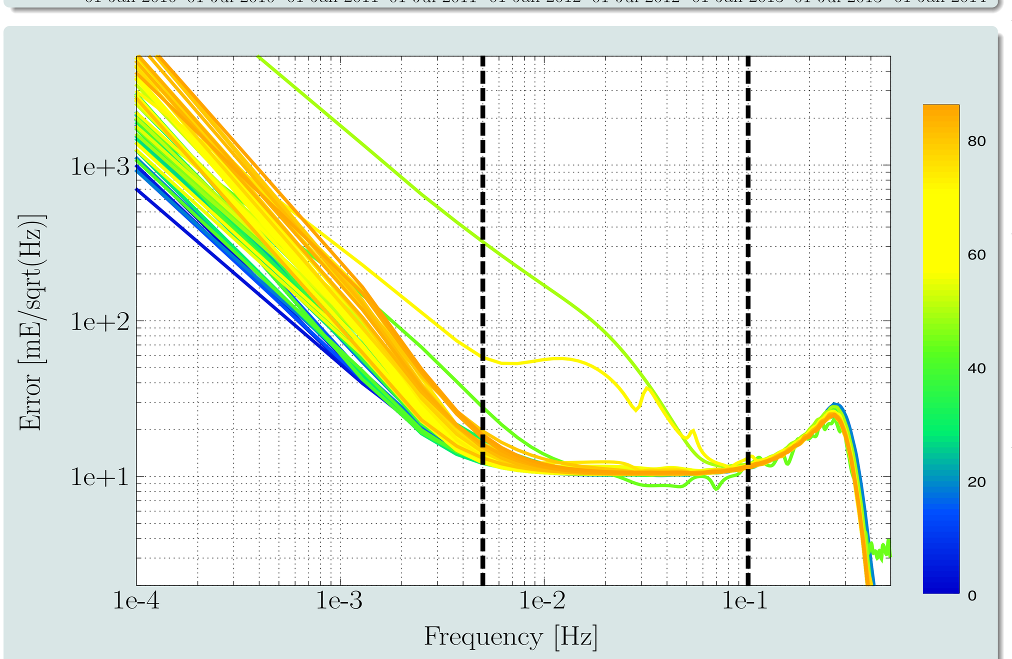
Combined solution:

- solution of weighted combined normal equations
- weights derived by variance component estimation

$$\left(\frac{1}{\sigma^2_{\mathrm{sst}}}\mathbf{N}_{\mathrm{sst}} + \sum_r \frac{1}{\sigma^2_r}\mathbf{N}_r + \sum_g \sum_{s=0}^{S-1} \frac{1}{\sigma^2_{g,s}} \mathbf{A}^T_{g,s}\mathbf{Q}^{-1}_{\ell_{g,s}\ell_{g,s}}\mathbf{A}_{g,s}\right)\mathbf{x} = \frac{1}{\sigma^2_{\mathrm{sst}}}\mathbf{n}_{\mathrm{sst}} + \sum_r \frac{1}{\sigma^2_r}\mathbf{n}_r + \sum_g \sum_{s=0}^{S-1} \frac{1}{\sigma^2_{g,s}} \mathbf{A}^T_{g,s}\mathbf{Q}^{-1}_{\ell_{g,s}\ell_{g,s}}\boldsymbol{\ell}_{g,s}$$

Data used in the EGM_TIM models

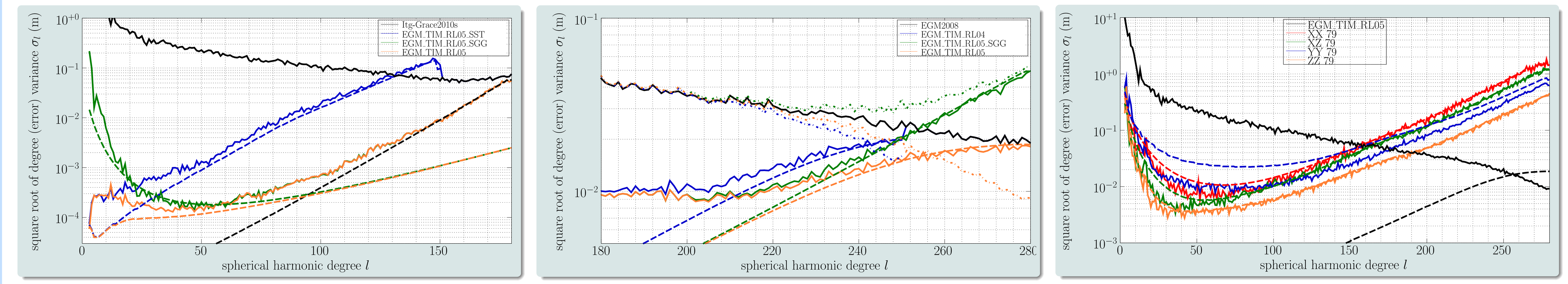




release/type		input/info	time series	(d/o)	# obs
EGM_TIM_RL01		SST, SGG, REG	11/2009–01/2010	2–224	24 524 268
	SST	energy balance, in-flight velocity	pointwise	2–100	6 013 954
	SGG	V_{XX}, V_{YY}, V_{ZZ}	1 gapless segment	2–224	$3 \times 6\,161\,834$
	REG	zonal coefficients	–	$m < \theta_0 l$	5 490
	REG	high degree coefficients	–	170–224	19 322
EGM_TIM_RL02		SST, SGG, REG	11/2009–07/2010	2–250	82 696 288
	SST	energy balance, in-flight velocity	pointwise	2–100	24 228 376
	SGG	V_{XX}, V_{YY}, V_{ZZ}	9 gapless segments	2–250	$3 \times 19\,477\,946$
	REG	zonal coefficients	–	$m < \theta_0 l$	6 866
	REG	high degree coefficients	–	180–250	27 208
EGM_TIM_RL03		SST, SGG, REG	11/2009–04/2011	2–250	$\approx 215\,000\,000$
	SST	energy balance, in-flight velocity	pointwise	2–100	$\approx 3 \times 30\,000\,000$
	SGG	V_{XX}, V_{YY}, V_{ZZ}, V_{XZ}	16 gapless segments	2–250	$4 \times 31\,289\,605$
	REG	zonal coefficients	–	$m < \theta_0 l$	6866
	REG	high degree coefficients	–	180–250	27 208
EGM_TIM_RL04		SST, SGG, REG	11/2009–06/2012	2–250	480 719 445
	SST	short arcs, 3-D positions	35 min arcs	2–130	$3 \times 69\,692\,004$
	SGG	V_{XX}, V_{YY}, V_{ZZ}, V_{XZ}	41 gapless segments	2–250	$4 \times 67\,305\,785$
	REG	zonal coefficients	–	$m < \theta_0 l$	6 866
	REG	high degree coefficients	–	180–250	27 208
EGM_TIM_RL05		SST, SGG, REG	11/2009–10/2013	2–280	765 504 101
	SST	short arcs, 3-D positions	35 min arcs	2–150	$3 \times 108\,754\,709$
	SGG	V_{XX}, V_{YY}, V_{ZZ}, V_{XZ}	87 gapless segments	2–280	$4 \times 109\,799\,264$
	REG	zonal coefficients	–	$m < \theta_0 l$	8 644
	REG	high degree coefficients	–	201–280	34 274

The latest solution EGM_TIM_RL05

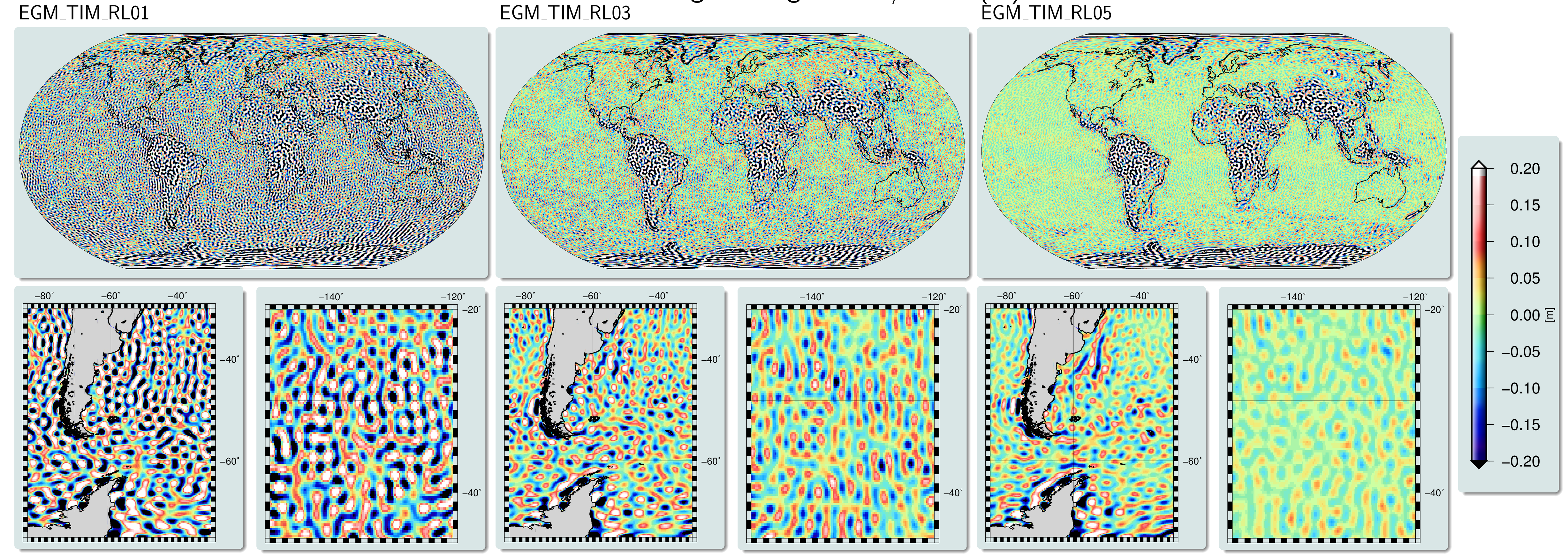
EGM_TIM_RL05 and contributers compared to others models (solid: differences, dashed: formal errors)



Comparison of lower degrees to ITG-Grace2010s — Comparison of higher degrees to EGM2008 — Seg. 79 (21 days), consistent error estimates except for YY

Progress along the releases

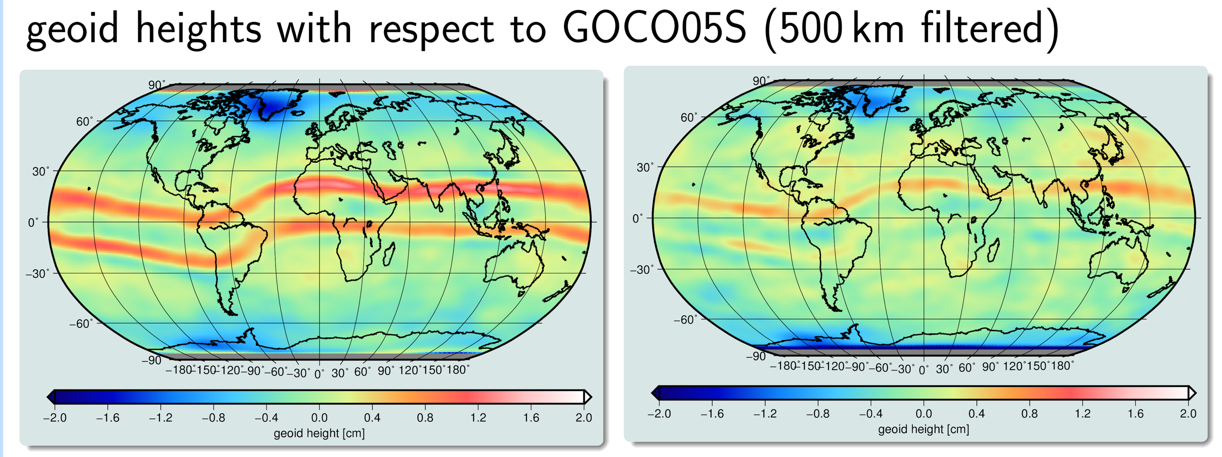
Difference of EGM_TIM releases and EGM2008 in terms of geod heights at d/o 200 (m)



	EGM_TIM_RL01	EGM_TIM_RL03	EGM_TIM_RL05
geoid heights (cm):	$\sigma_{\mathrm{RMS}} = 13.1$, $\sigma_{\mathrm{VCM}} = 14.0$	$\sigma_{\mathrm{RMS}} = 6.5$, $\sigma_{\mathrm{VCM}} = 6.5$	$\sigma_{\mathrm{RMS}} = 2.8$, $\sigma_{\mathrm{VCM}} = 2.8$
gravity anomalies (mGal):	$\sigma_{\mathrm{RMS}} = 3.6$, $\sigma_{\mathrm{VCM}} = 3.9$	$\sigma_{\mathrm{RMS}} = 1.8$, $\sigma_{\mathrm{VCM}} = 1.8$	$\sigma_{\mathrm{RMS}} = 0.8$, $\sigma_{\mathrm{VCM}} = 0.8$

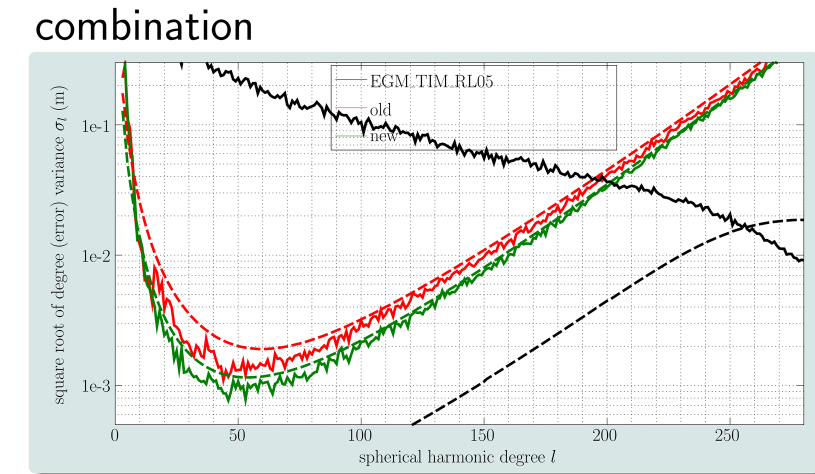
Outlook and future work

SST updates: reduce magnetic equator effect
geoid heights with respect to GOCO05S (500 km filtered)



EGM_TIM_RL05_SST — improved SST solution

SGG updates: outlier detetection, robust filter estimation, relative combination



- SGG-only solution, $s = 50$
- 30 days data
- cumulative formal error (l 30–280): reduction 16%
- cumulative empirical error (l 30–280): reduction 9%

Summary and Conclusions

- five releases of the time-wise models are available
- current mean global accuracy at d/o 200: 0.7 mGal, 2.4 cm
- full covariance matrix is an essential part of the model
- GOCE EGM_TIM_RL05 normal equations are used in the combined satellite-only model GOCO05S
- although all data is used in EGM_TIM_RL05 remaining potential in GOCE data was identified
- reanalysis of the whole data set as an update for EGM_TIM_RL05 or a release 6 is planned (IUGG 2015)

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Institute of Geodesy and Geoinformation
Department of Theoretical Geodesy
University of Bonn

Contact:
Jan Martin Brockmann
brockmann@geod.uni-bonn.de

Nussallee 17
D-53115 Bonn
www.igg.uni-bonn.de/tg/