5th GOCE User Workshop 2014

A Gravity Field Model From the Entire GOCE Mission: EGM_TIM_RL05

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] Institute of Geodesy and Geoinformation · Theoretical Geodesy · University of Bonn
[2] Institute of Theoretical Geodesy and Satellite Geodesy · TU Graz
[3] Institute for Astronomical and Physical Geodesy · TU München
[4] Space Research Institute · Austrian Academy of Sciences

GUW 2014, Paris, 25.11.2014

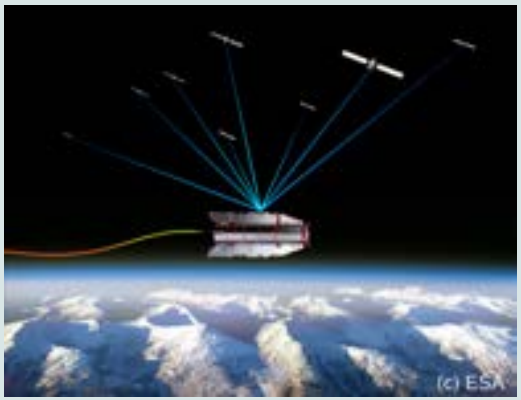
Content

Sensors for Gravity Field Determination

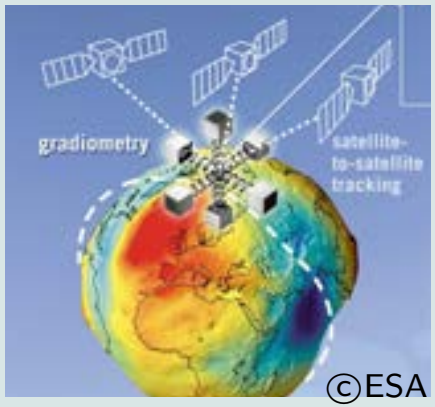
The whole GOCE satellite is the sensor!

Three main sensor observations have to be scientifically processed for gravity field determination:

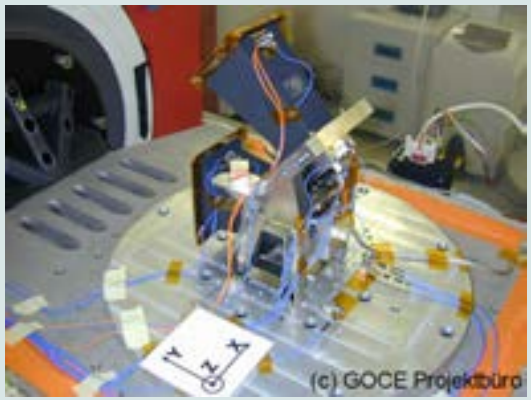
GPS tracking (SST)



Gradiometry (SGG)



Star tracker (STR)

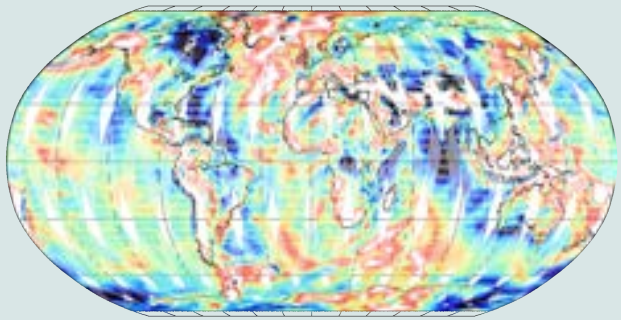


From Observations to the Gravity Field

kinematic satellite orbits

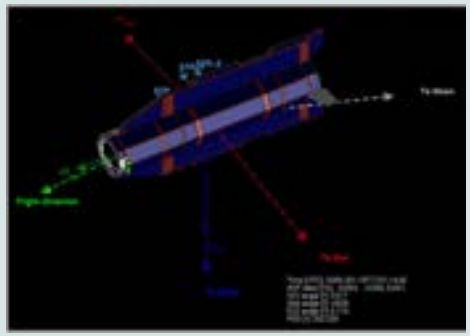
+

geolocated gravity gradients



+

gradiometer orientation



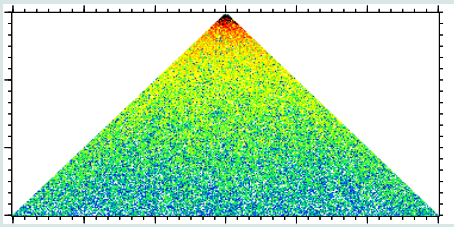
+orbit error information

+gradient error information

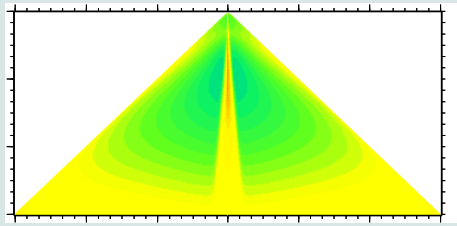
$$V(r,\theta,\lambda) = \frac{GM}{a}\sum_{l=0}^{l_{max}}\left(\frac{a}{r}\right)^{l+1}\sum_{m=0}^{l}\left(c_{lm}\cos(m\lambda) + s_{lm}\sin(m\lambda)\right)P_{lm}(cos\theta), \quad (1)$$

GOCE-only gravity field model independent of any other gravity field information

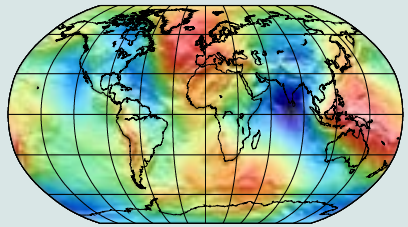
spherical harmonic coefficients



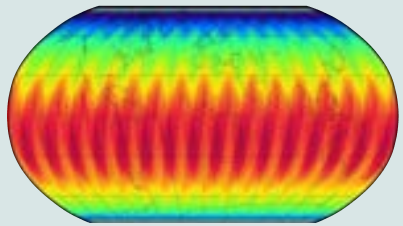
+ accuracies as full VCM



geoid heights

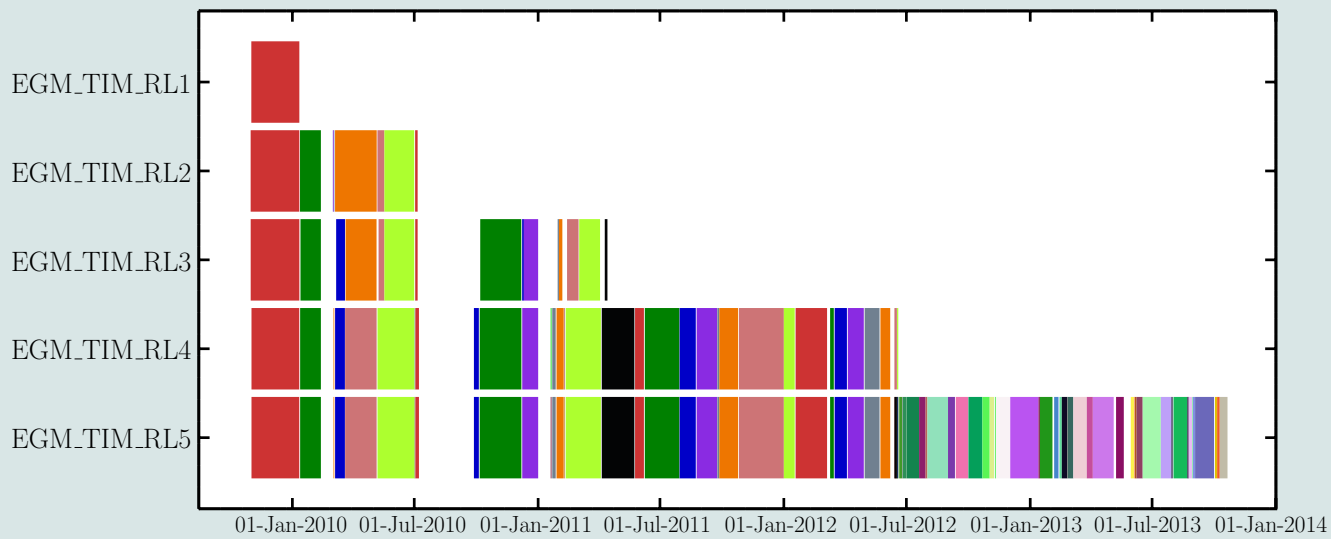


+ accuracies



Timeline of EGM_TIM Models

Five releases of the time-wise method are derived



release	timespan	d/o	U	S	epochs
EGM_TIM_RL01	11/2009–01/2010	2–224	50 172	1	6 161 834
EGM_TIM_RL02	11/2009–07/2010	2–250	62 997	9	19 477 946
EGM_TIM_RL03	11/2009–04/2011	2–250	62 997	16	31 289 605
EGM_TIM_RL04	11/2009–06/2012	2–250	62 997	41	69 692 004
EGM_TIM_RL05	11/2009–10/2013	2–280	78 957	87	109 799 264

Time-Wise Approach

SST processing:

- 3D positions as observations
- Setup of least squares NEQs

SGG processing:

- gravity gradients in GRF as time series per component
- Least squares NEQs per component

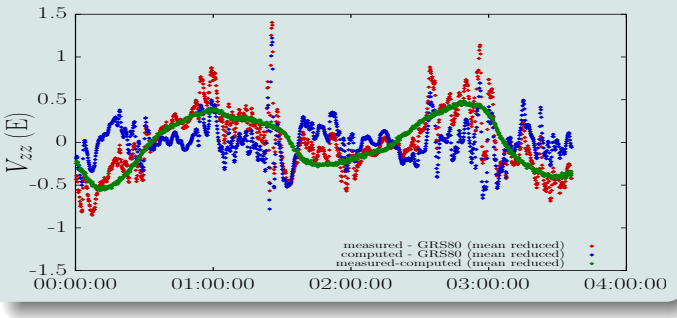
Constraints: Kaula

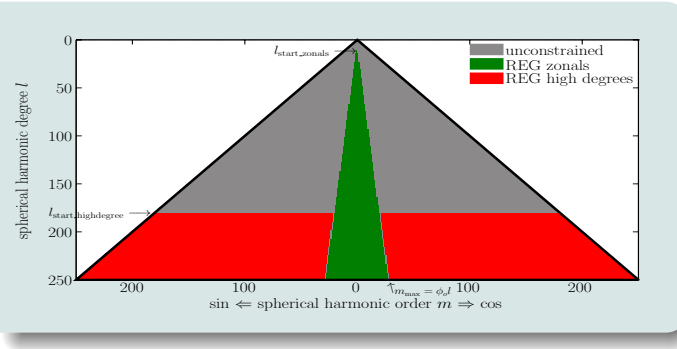
- for (near) zonal coefficients (polar gap)
- for high-degree coefficients

Combined solution:

- solution of weighted combined NEQs
- weights derived by VCE

$\Rightarrow$ time-wise models are only based on GOCE

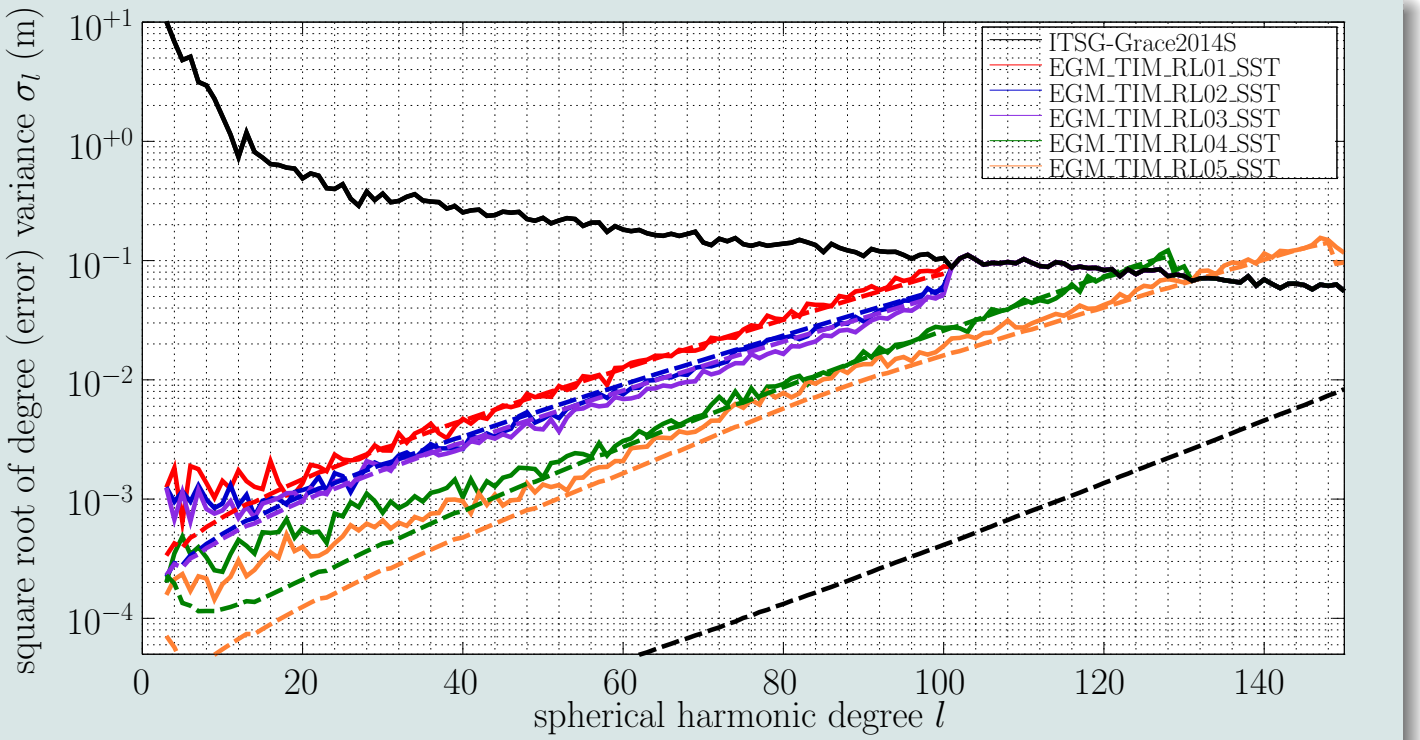




$$\left(\frac{1}{\sigma^2_{\text{sst}}}\mathbf{N}_{\text{sst}} + \sum_r \frac{1}{\sigma^2_r}\mathbf{N}_r + \sum_g \sum_{s=0}^{S-1} \frac{1}{\sigma^2_{g,s}} \mathbf{A}^T_{g,s} \mathbf{Q}^{-1}_{\boldsymbol{\ell}_{g,s}\boldsymbol{\ell}_{g,s}} \mathbf{A}_{g,s}\right) \mathbf{x}$$
$$= \frac{1}{\sigma^2_{\text{sst}}}\mathbf{n}_{\text{sst}}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

SST Part of the Models

- Functional model: RL01-03 energy balance approach, RL04-05 short arc integral equation approach, 3D positions as observations
- Stochastic model: RL01-03 position covariance, RL04-05 position covariance + empirical covariance function
- Least squares normal equations



- Progress clearly visible
- Remaining systematic errors in long wavelengths
- for RL05: S/N ratio equals 1.0 at d/o 130

SGG Part of the Models

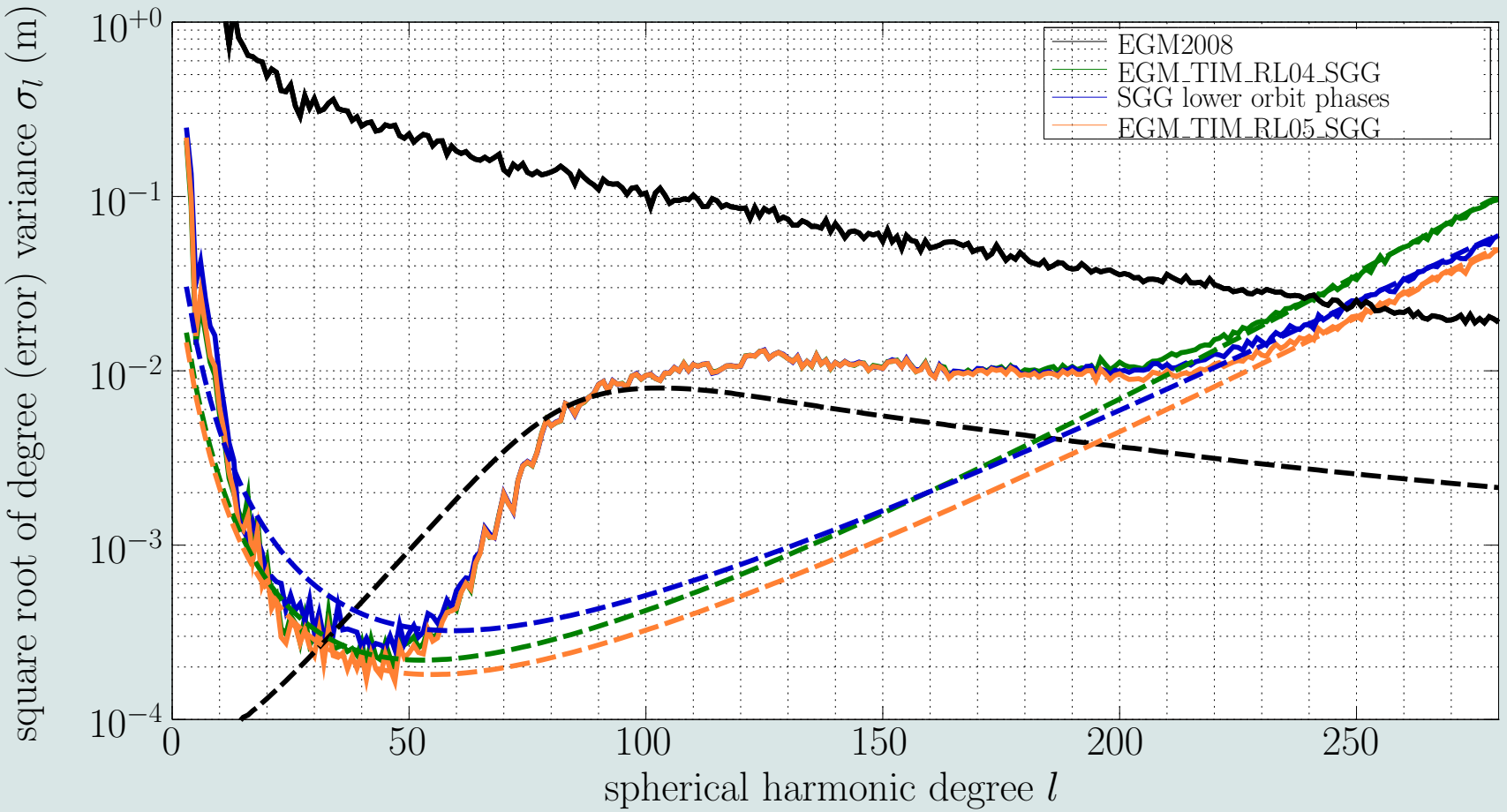
- Functional model: gravity gradients in GRF as time series for gap less segments of the time series
- Components used: V_{xx}, (V_{xz}), V_{yy} and V_{zz}
- Stochastic model: individually adjusted ARMA filters
- Iterative outlier detection

rel.	input/info	time series	(d/o)		# observ.	# flags
RL01	XX, YY, ZZ	1 segments	224	3·	6 161 834	$1.0 \cdot 10^4$
RL02	XX, YY, ZZ	9 segments	250	3·	19 477 946	$5.5 \cdot 10^5$
RL03	XX, YY, ZZ, XZ	16 segments	250	4·	31 289 605	$4.6 \cdot 10^5$
RL04	XX, YY, ZZ, XZ	41 segments	250	4·	67 305 785	$2.0 \cdot 10^6$
RL05	XX, YY, ZZ, XZ	87 segments	280	4·	109 799 264	$4.5 \cdot 10^6$

Comments

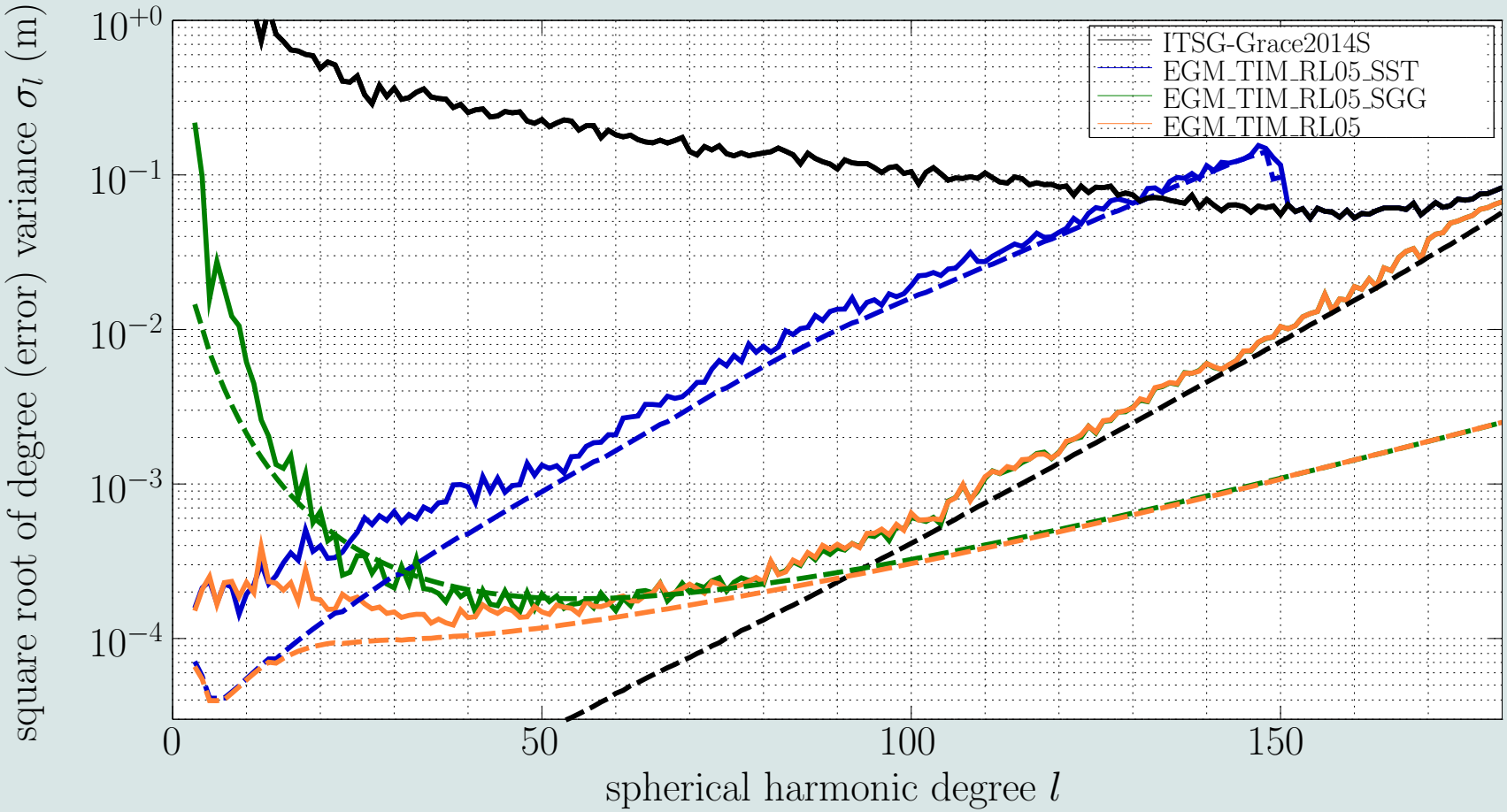
- # flagged outliers: approximate values for flagged epochs
- for data after RL04: individual flags per component (complex data characteristics) additional weights (variance components) per component and segment
- RL04 period in RL05: reprocessed NEQs with RL04 setup but to d/o 280
- $4 \cdot 87 = 384$ adjusted filters for RL05

Impact of Lower Orbit Data on Solution



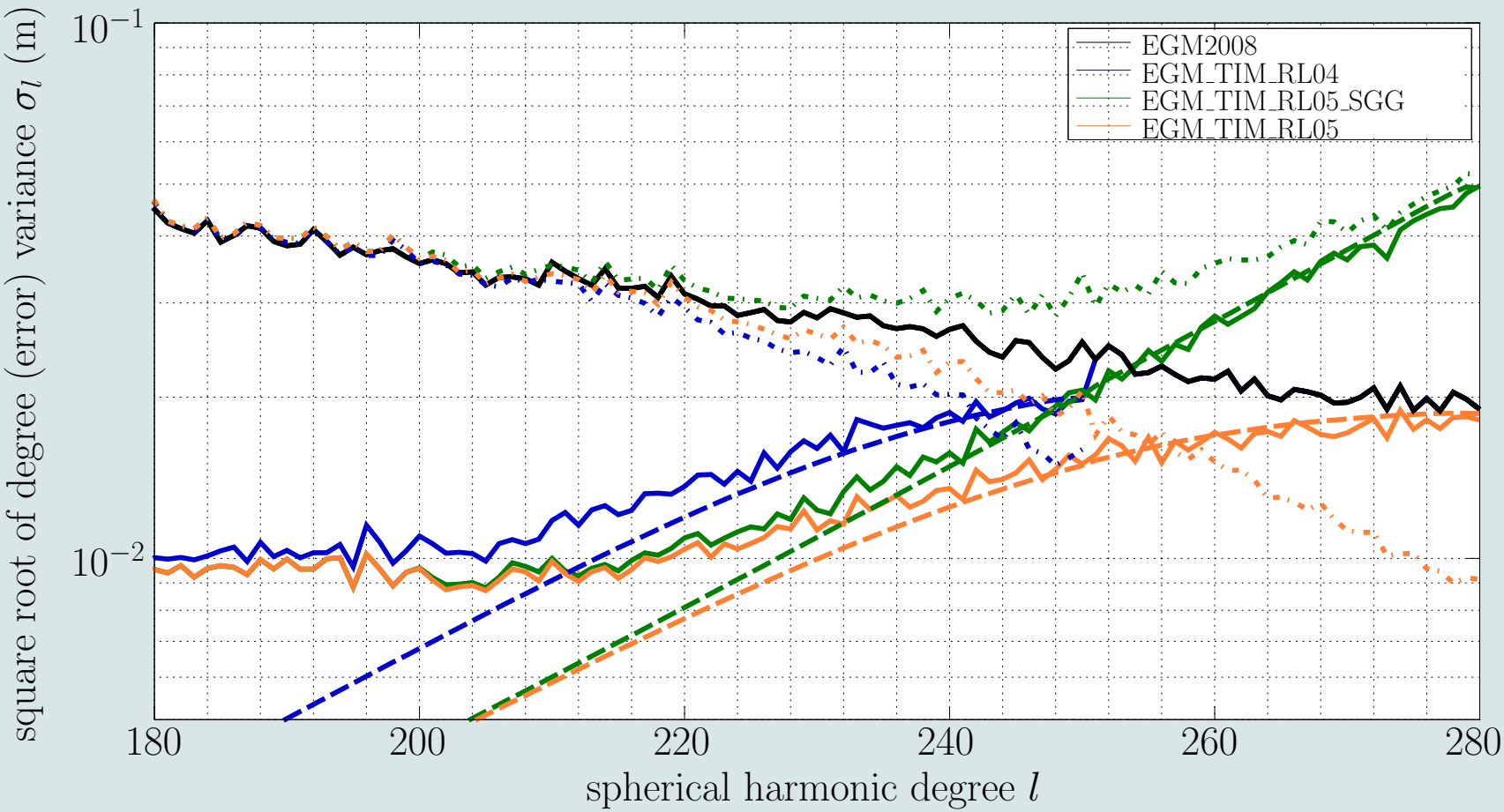
SGG lower orbit phases contain only 63 % of the data volume of RL04 period,
solution is significantly better above d/o 170 $\Rightarrow$ Low orbit impact
$\Rightarrow$ tilt of the formal errors demonstrate the effect

Combined Solution – Low Degrees



- Major SST contribution to d/o 20
- Contributions above d/o 50 visible
- GRACE error budget visible at d/o 80 for recent models

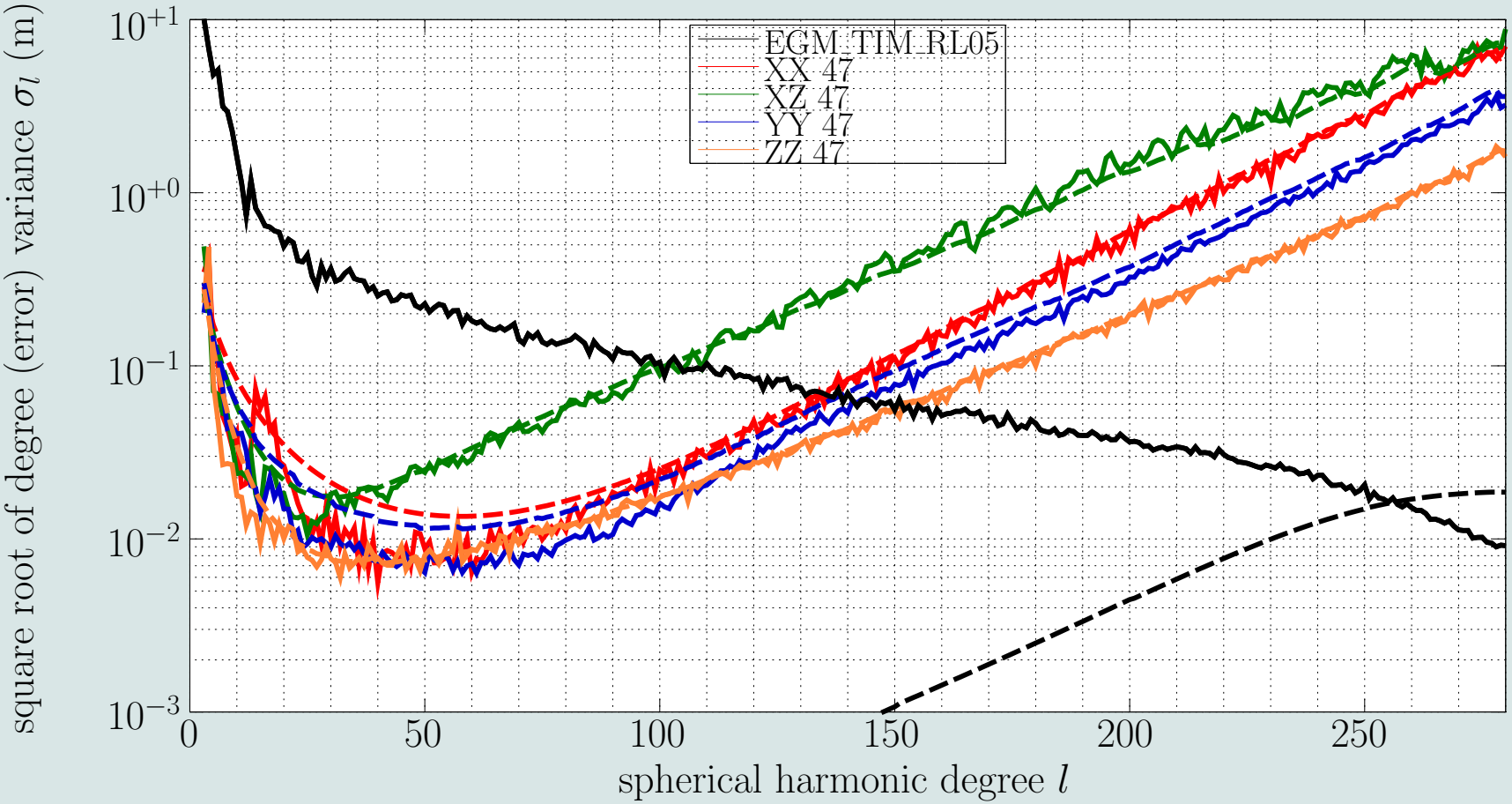
Combined Solution – High Degrees



- For RL05: Kaula for near zonals and $l > 200$
- S/N = 1 for unconstrained solution at degree 254
- Signal is increasing for high degrees
- Noise is decreasing from RL04 to RL05

Combined Solution – Consistency

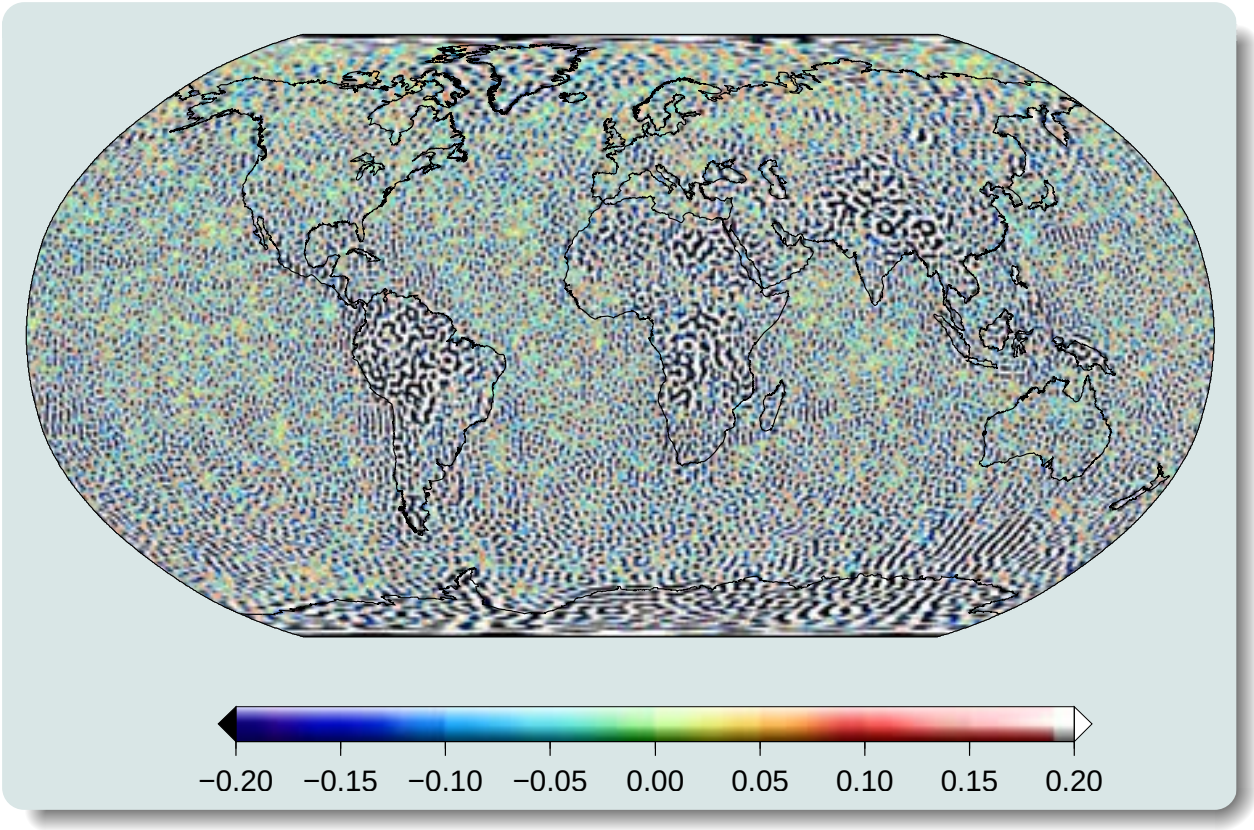
Degree variances of partial solutions w.r.t. finally combined EGM_TIM_RL05



Seg. No: 47 (01.07.2012–19.07.2012), # observations: $1.6 \cdot 10^6$, VCs not applied

$\Rightarrow$ Consistent error estimates, slightly to pessimistic (low degrees)

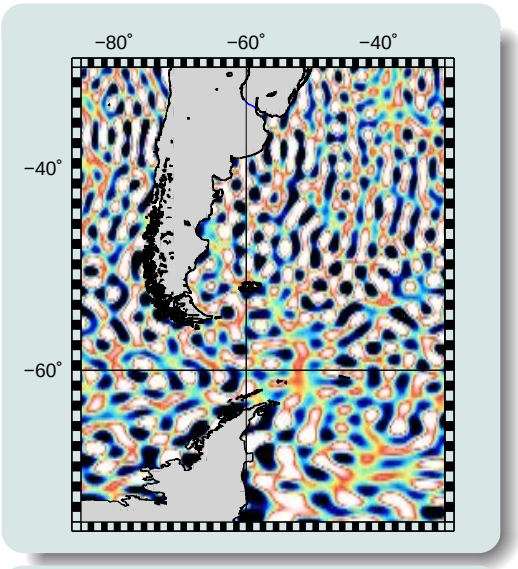
EGM_TIM: Comparison to EGM2008

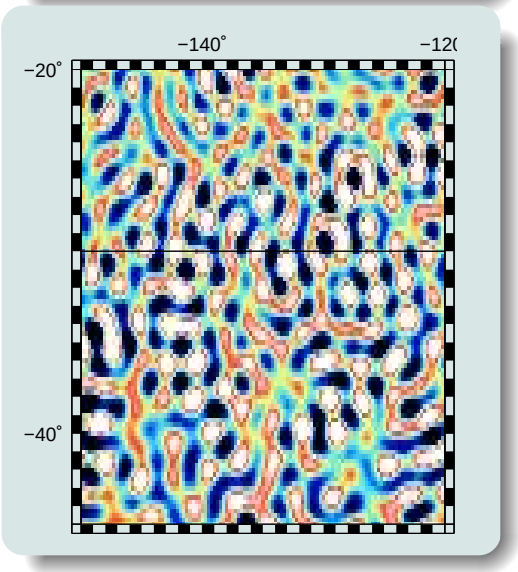


RL	RMS cm	VCM cm	RMS mGal	VCM mGal
01	13.1	14.0	3.6	3.9

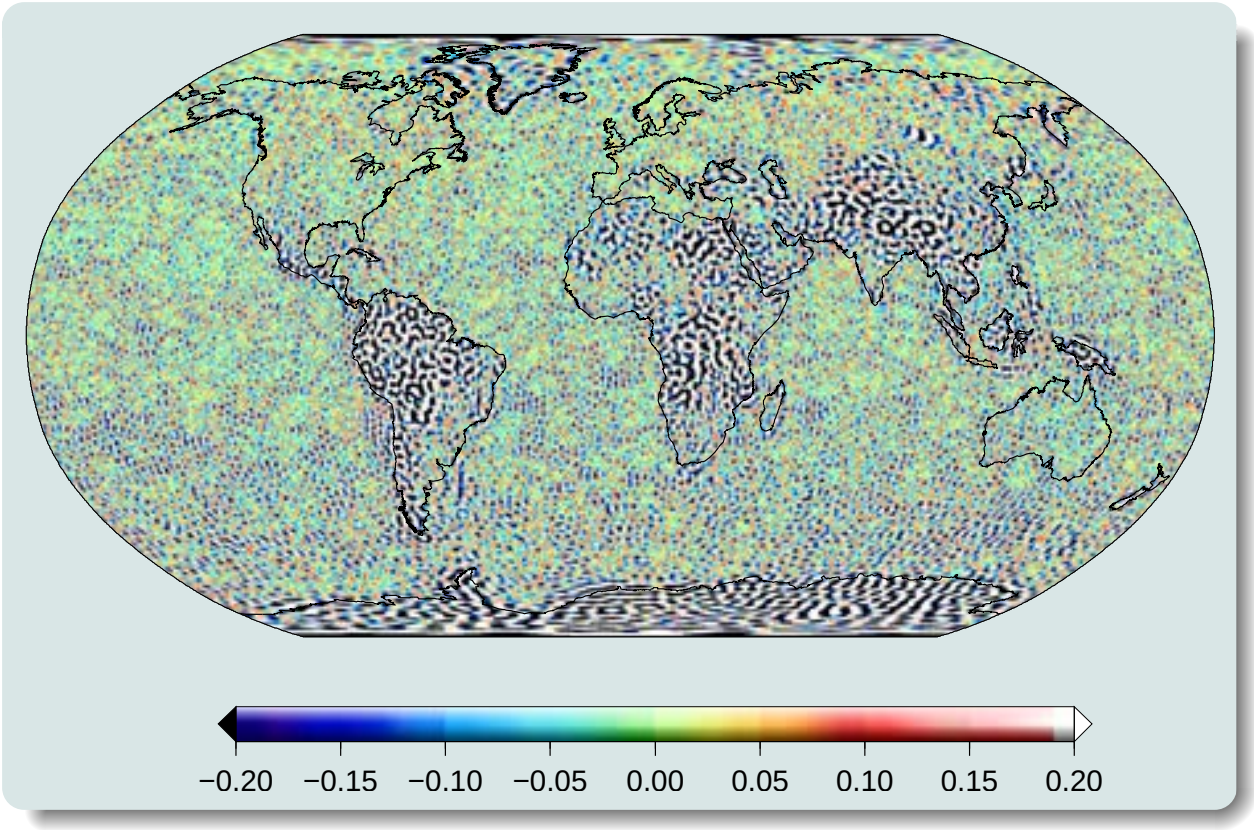
Images: Geoid to d/o 200 (m)
Statistics: smooth area in South Pacific
RMS: regional accuracy w.r.t. EGM2008
VCM: accuracy from variance propagation

EGM_TIM_RL01

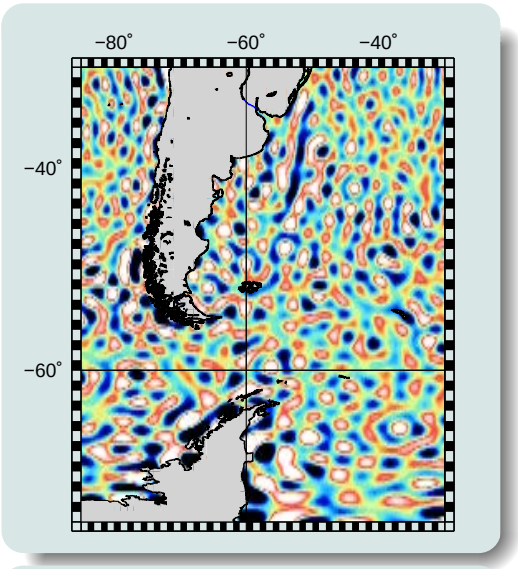


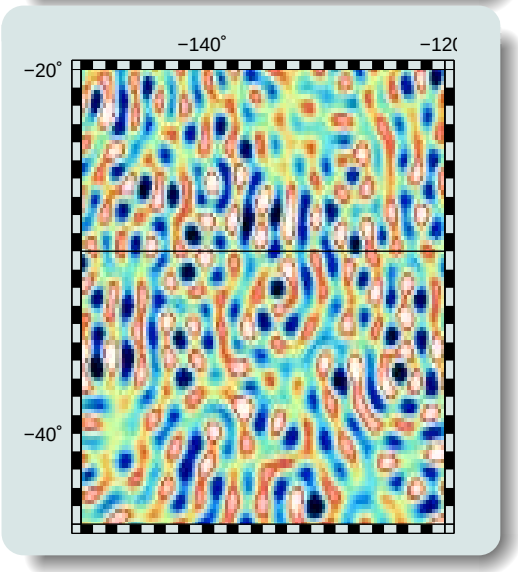


EGM_TIM: Comparison to EGM2008



EGM_TIM_RL02

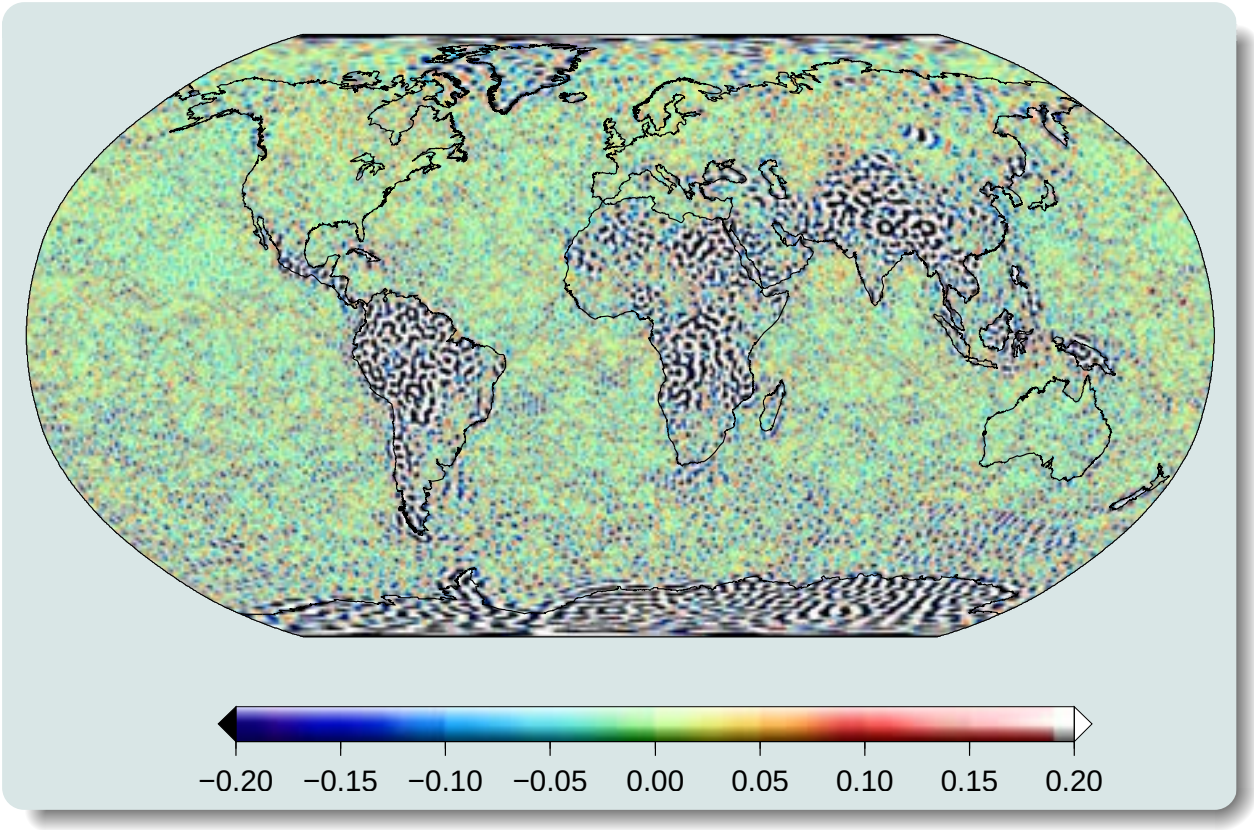




RL	RMS cm	VCM cm	RMS mGal	VCM mGal
01	13.1	14.0	3.6	3.9
02	9.0	8.3	2.5	2.3

Images: Geoid to d/o 200 (m)
Statistics: smooth area in South Pacific
RMS: regional accuracy w.r.t. EGM2008
VCM: accuracy from variance propagation

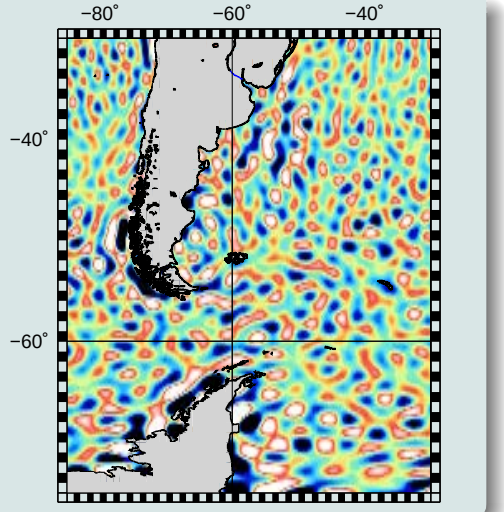
EGM_TIM: Comparison to EGM2008

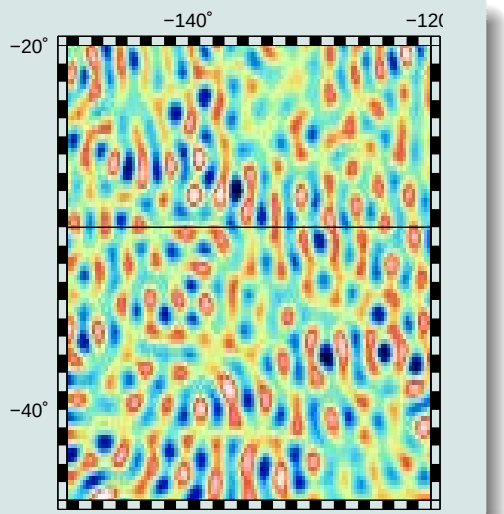


RL	RMS cm	VCM cm	RMS mGal	VCM mGal
01	13.1	14.0	3.6	3.9
02	9.0	8.3	2.5	2.3
03	6.5	6.5	1.8	1.8

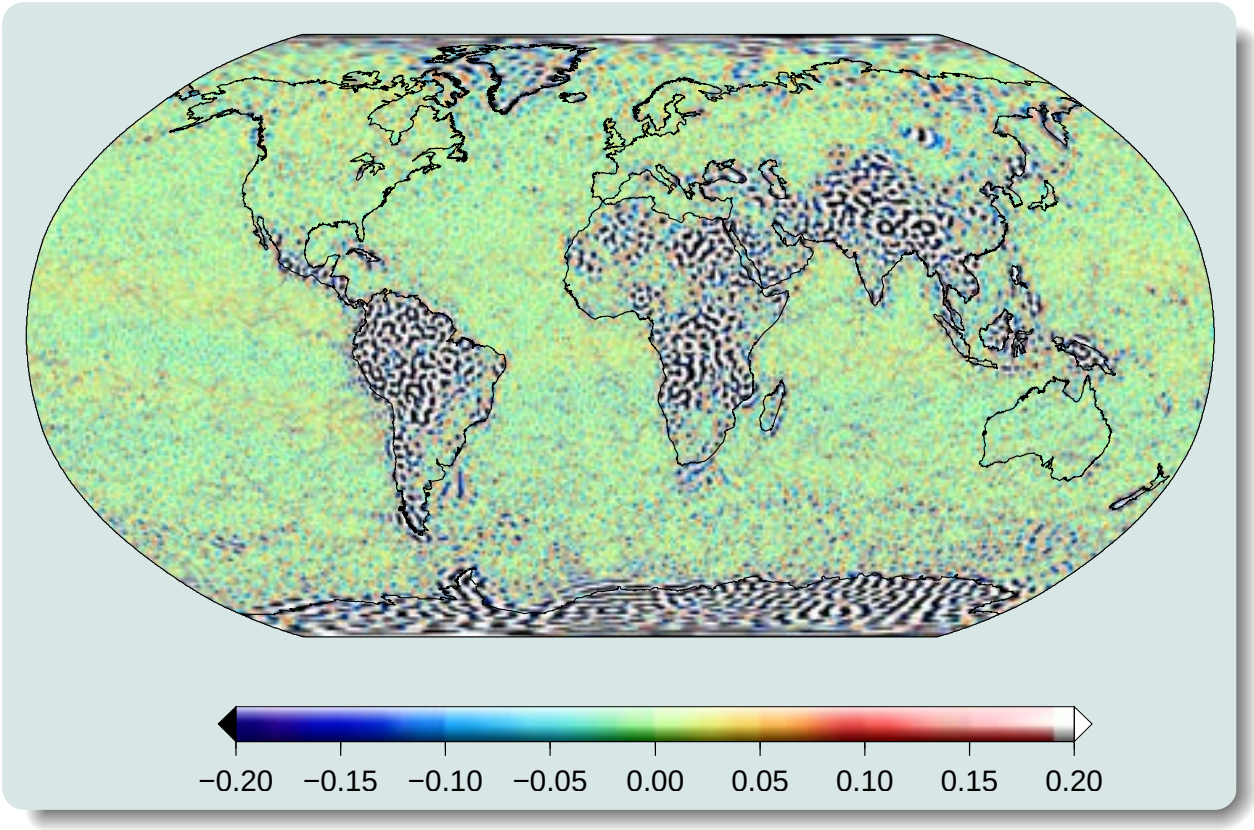
Images: Geoid to d/o 200 (m)
Statistics: smooth area in South Pacific
RMS: regional accuracy w.r.t. EGM2008
VCM: accuracy from variance propagation

EGM_TIM_RL03

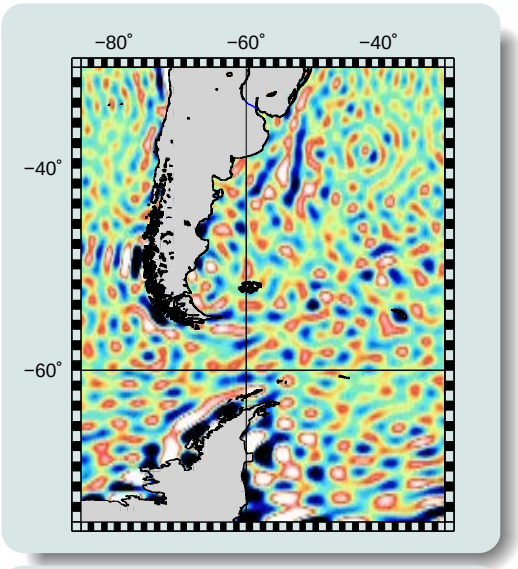


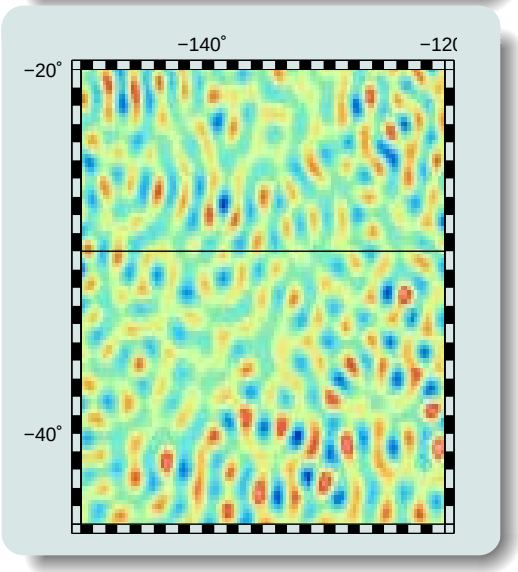


EGM_TIM: Comparison to EGM2008



EGM_TIM_RL04

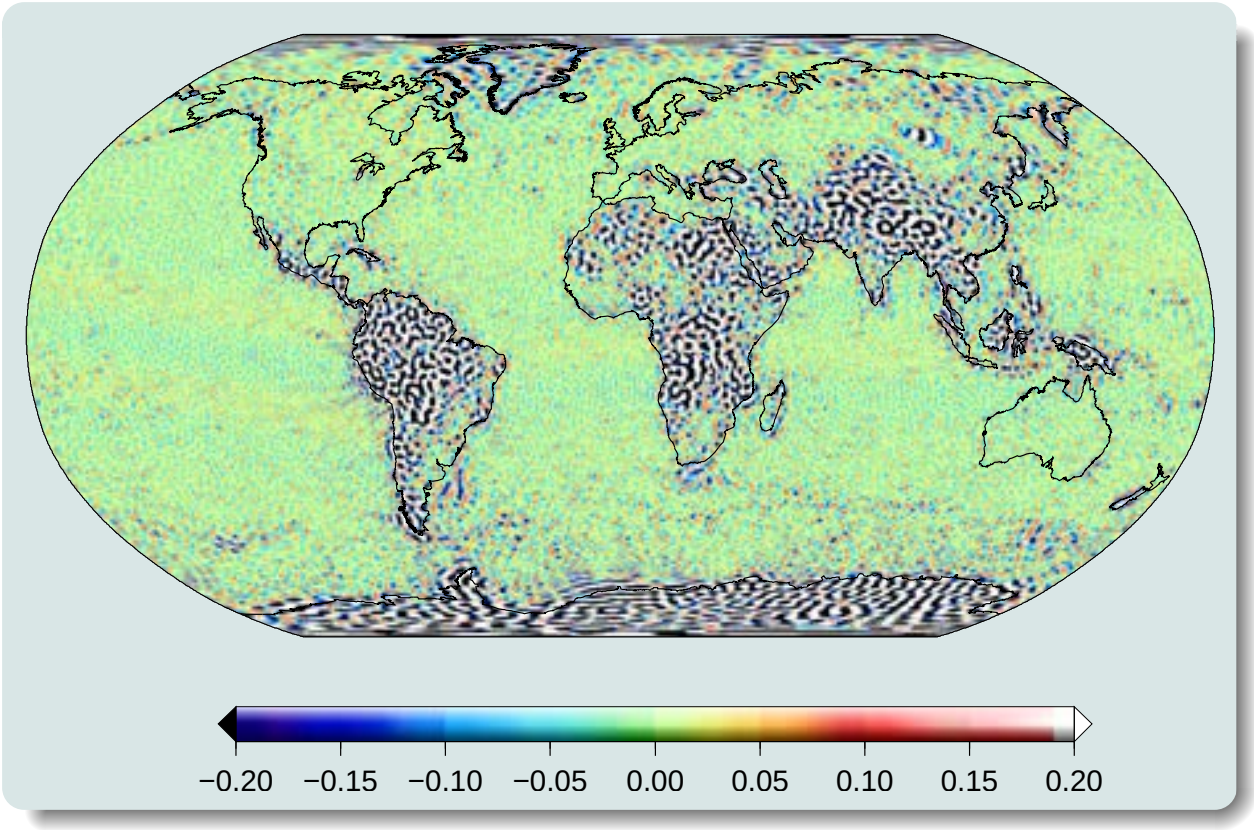




RL	RMS cm	VCM cm	RMS mGal	VCM mGal
01	13.1	14.0	3.6	3.9
02	9.0	8.3	2.5	2.3
03	6.5	6.5	1.8	1.8
04	4.1	4.1	1.1	1.2

Images: Geoid to d/o 200 (m)
Statistics: smooth area in South Pacific
RMS: regional accuracy w.r.t. EGM2008
VCM: accuracy from variance propagation

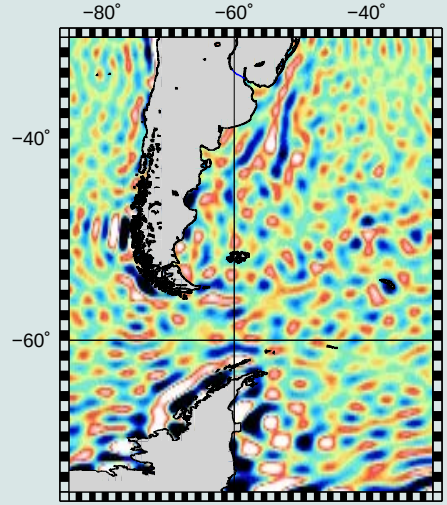
EGM_TIM: Comparison to EGM2008

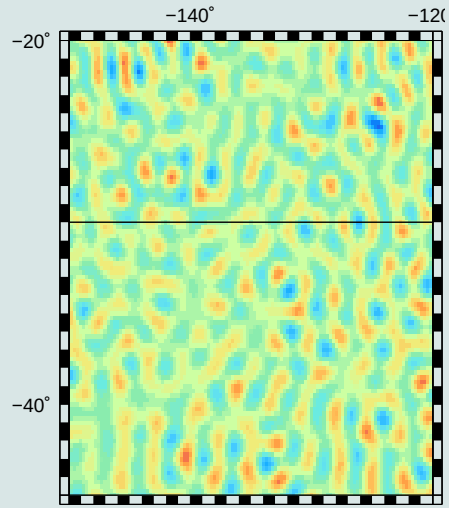


RL	RMS cm	VCM cm	RMS mGal	VCM mGal
01	13.1	14.0	3.6	3.9
02	9.0	8.3	2.5	2.3
03	6.5	6.5	1.8	1.8
04	4.1	4.1	1.1	1.2
05	2.8	2.8	0.8	0.8

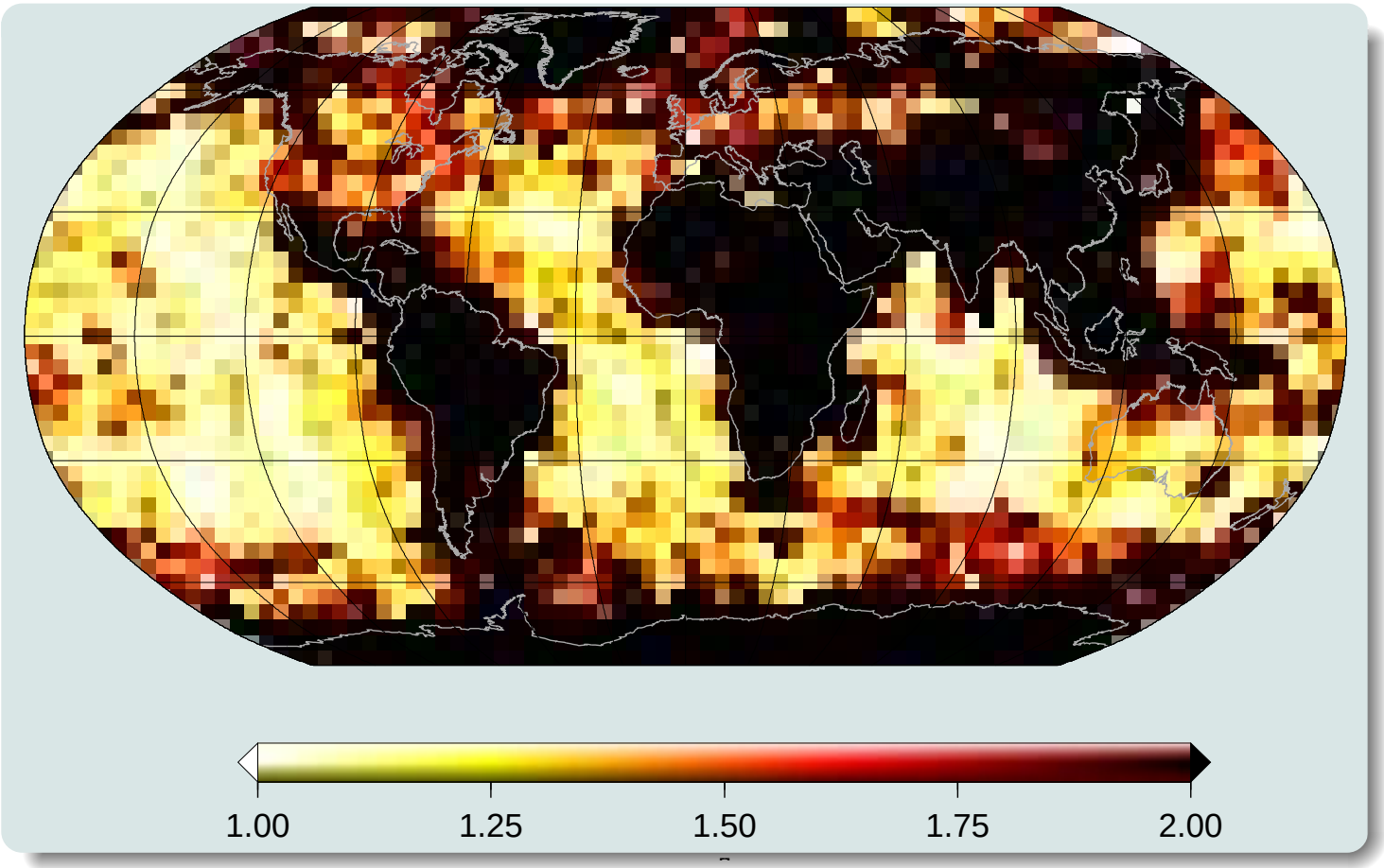
Images: Geoid to d/o 200 (m)
Statistics: smooth area in South Pacific
RMS: regional accuracy w.r.t. EGM2008
VCM: accuracy from variance propagation

EGM_TIM_RL05





Significant Differences to EGM2008

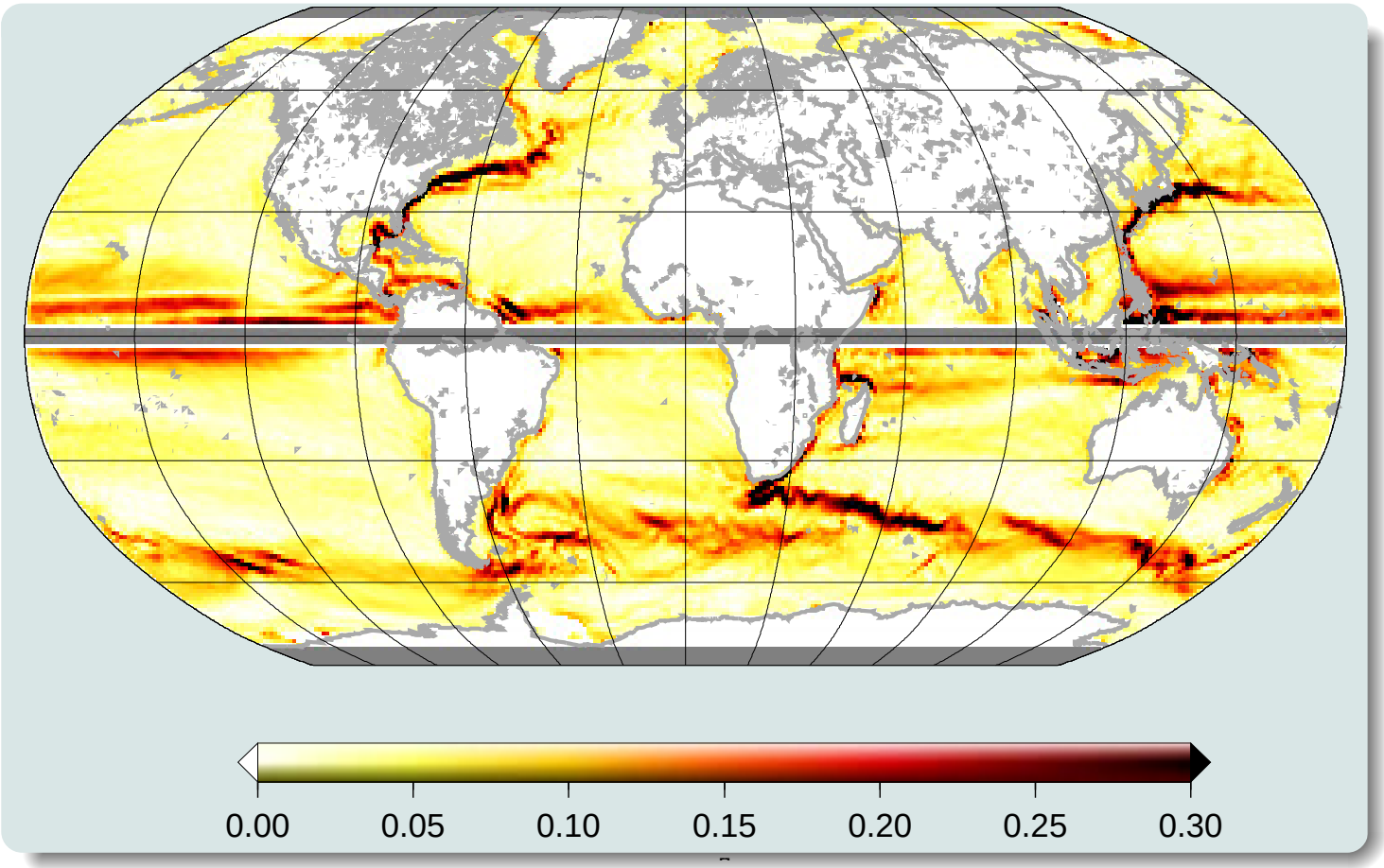


EGM_TIM_RL05

Ratio of rms w.r.t. EGM2008 and propagated geoid height standard deviations

- $4^\circ \times 4^\circ$ blocks, rms w.r.t. EGM08/ mean propagated standard deviation
- white means: consistency of EGM08 and TIM_RL05 within GOCE error level
- black means: difference of TIM_RL05 and EGM08 significant outside error predicted by GOCE
- orange/red it is very likely, that differences are significant

Comparison to Ocean Currents



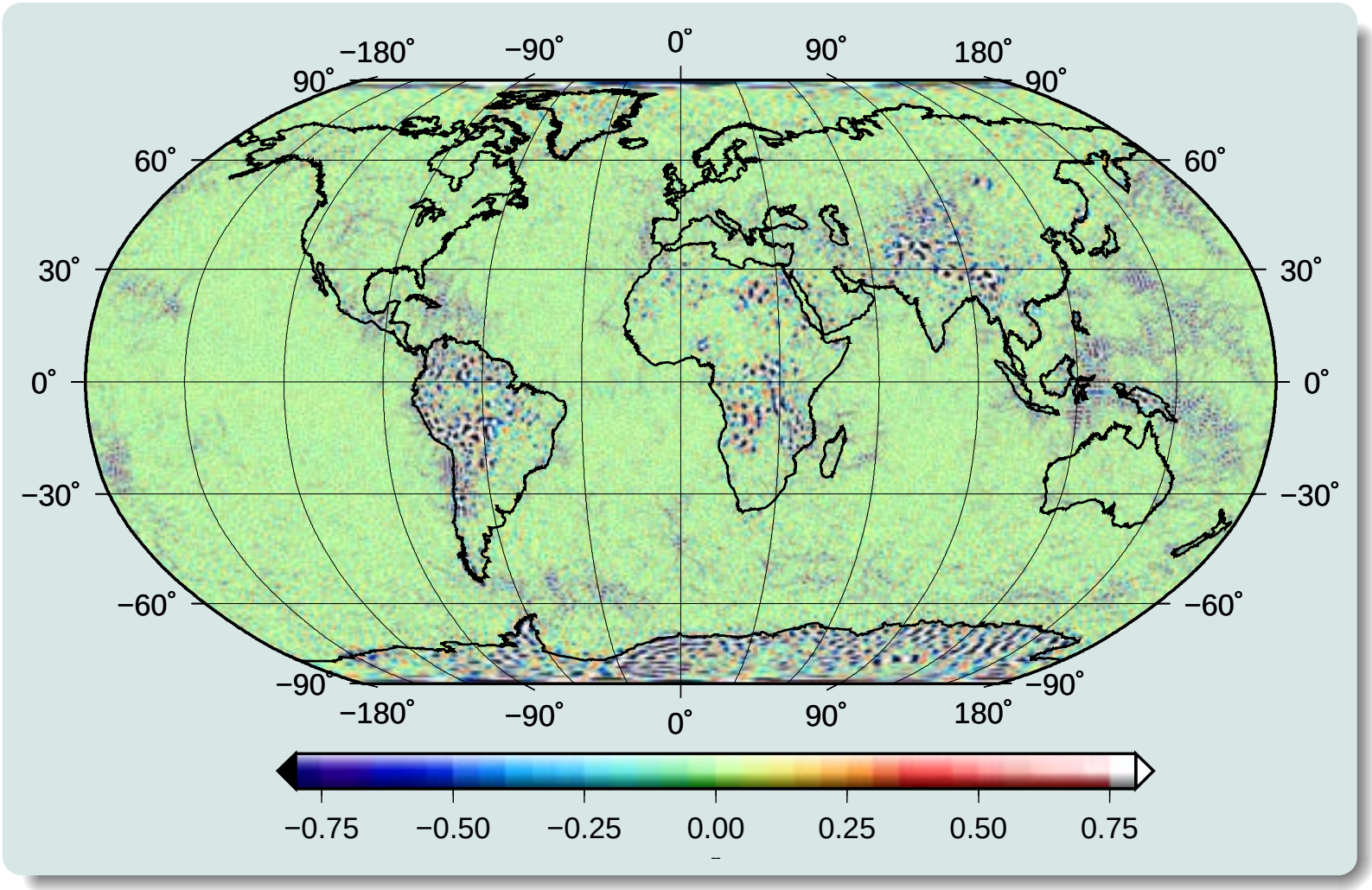
CLS09 velocity amplitudes

Amplitudes of velocities computed from CLS09

- Significant differences correlate to currents

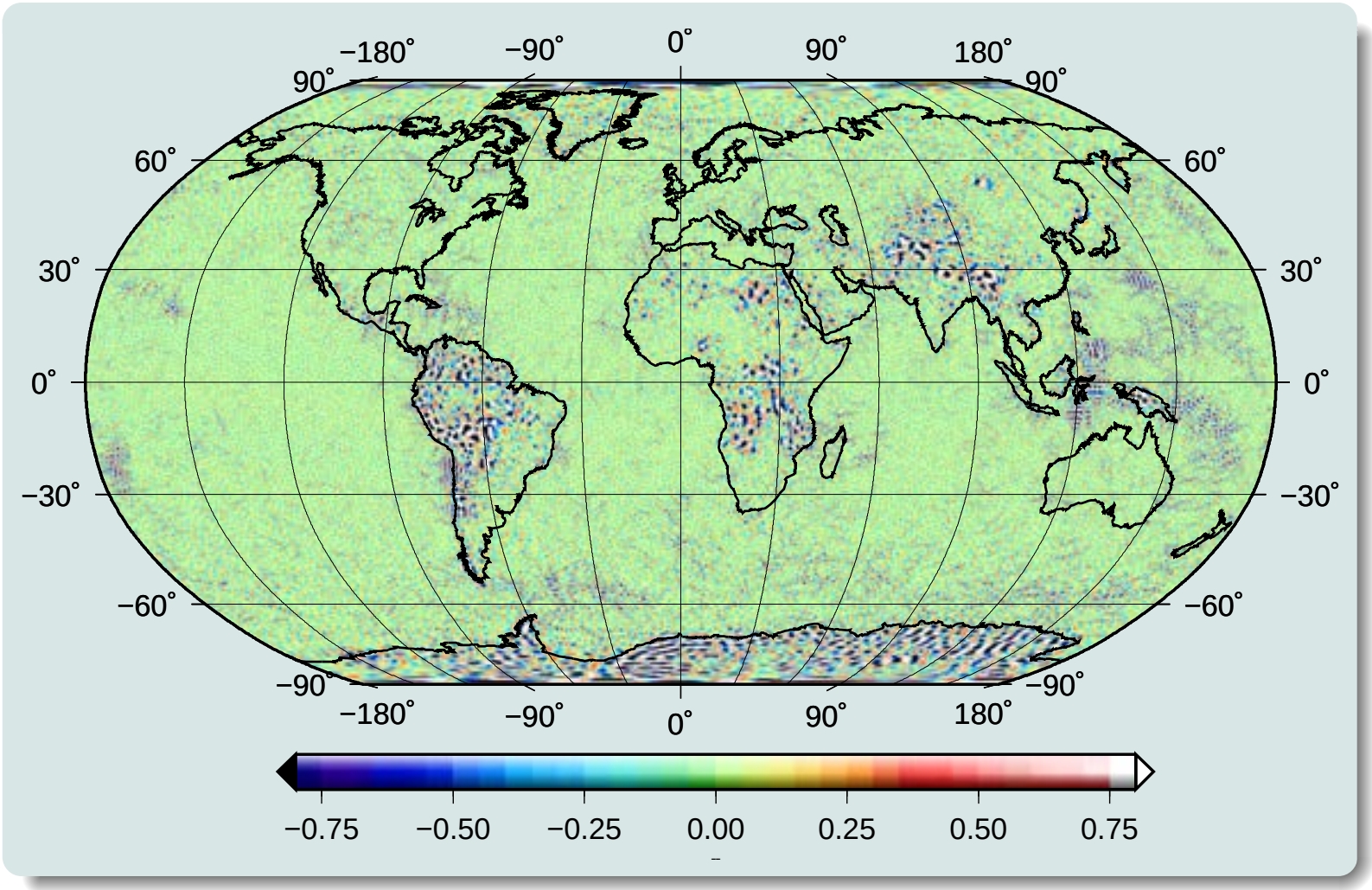
High-Degree Signal in EGM_TIM_RL05

Geoid heights EGM_TIM_RL05 (d/o 260) – EGM280 (d/o 280)



High-Degree Signal in EGM_TIM_RL05

Geoid heights EGM_TIM_RL05 (d/o 280) – EGM280 (d/o 280)



- Differences are significantly reduced
- There is geoid signal above degree 260 in EGM_TIM_RL05!

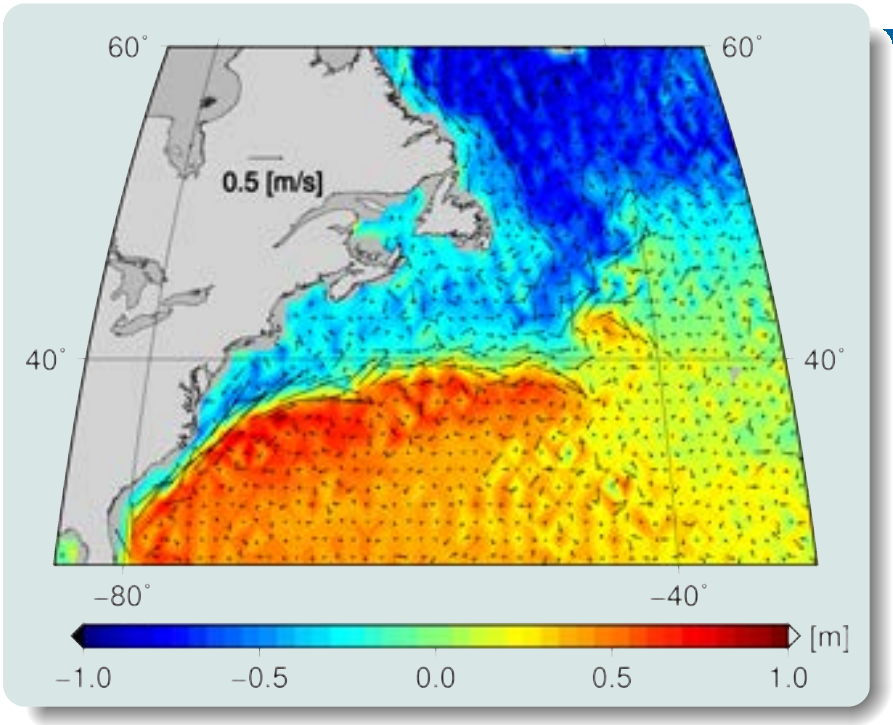
Summary and Conclusions

Summary on EGM_TIM_RL05:

- 5th release of GOCE time-wise gravity field model finalized
- Consistent set of spherical harmonic coefficients d/o 2-280
- Realistic covariance matrix
- GRACE improvement d/o 80+
- EGM08 improvement d/o 40–220
- Significant contribution from low orbit data
- Mean global accuracy at d/o 200: **0.7 mGal, 2.4 cm**
- Unconstraint version available on request!
- Ready to use! Please provide feedback!

Reference: Brockmann, J. M.; Zehentner, N.; Höck, E.; Pail, R.; Loth, I.; Mayer-Gürr, T. and Schuh, W.-D.: *EGM_TIM_RL05: An Independent Geoid with Centimeter Accuracy Purely Based on the GOCE Mission*, Geophys. Res. Lett., 2014, DOI 10.1002/2014GL061904

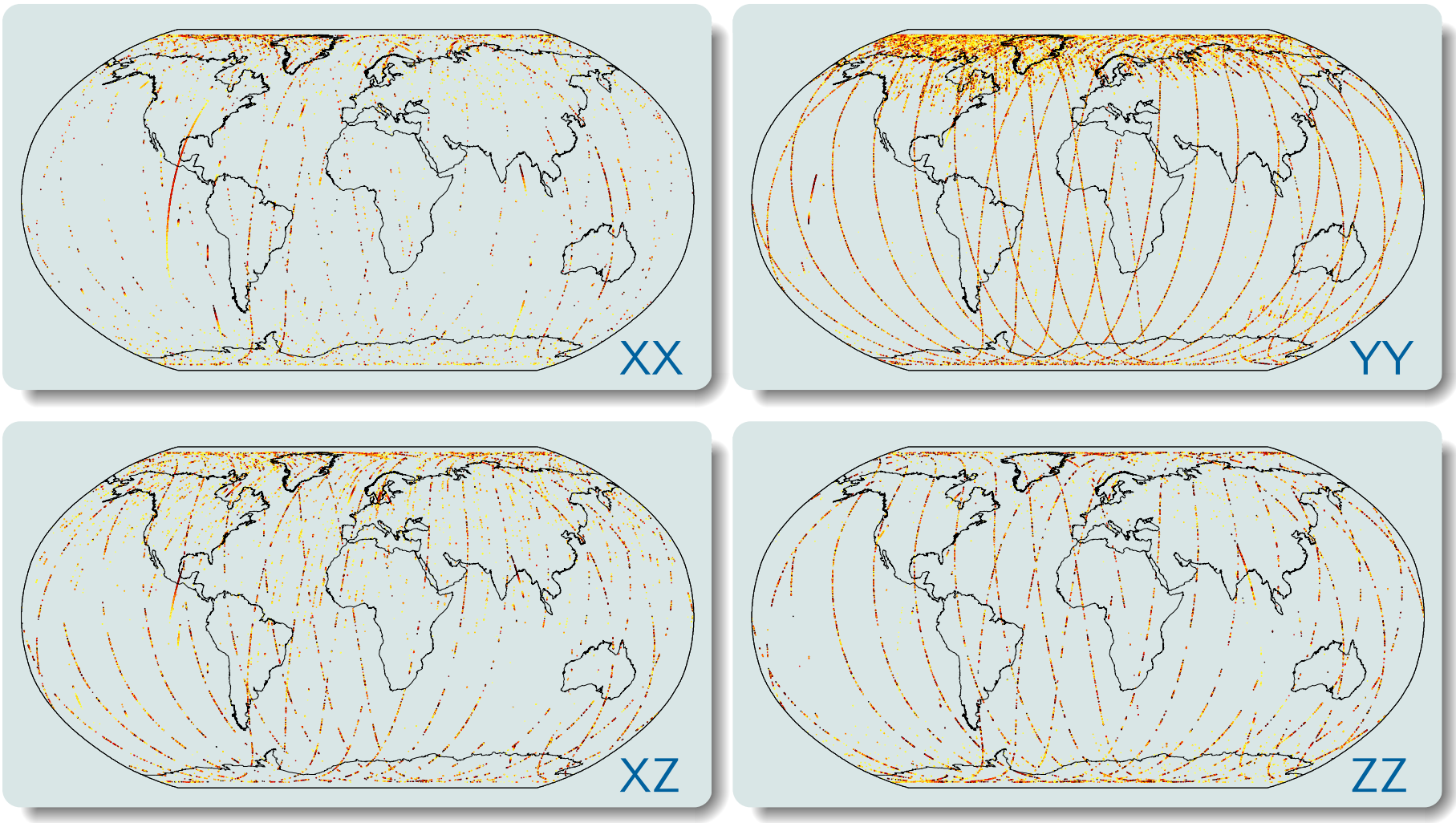
MDT estimated only from GOCE and along track altimetry EGM_TIM_RL05:



Following: Becker, S., J. M. Brockmann, and W.-D. Schuh (2014), Mean dynamic topography estimates purely based on GOCE gravity field models and altimetry, Geophys. Res. Lett., 41, 2063–2069, doi:10.1002/2014GL059510.

Outlier Distribution – End of Mission

Small outliers (7-15 σ) within the Last $20 \cdot 10^6$ observations (end of mission)



$\Rightarrow$ Individual flags for different components useful!