EGU General Assembly 2019

An improved global gravity field model from the GOCE mission: the time-wise release 6 model

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+ GOCE HPF Team

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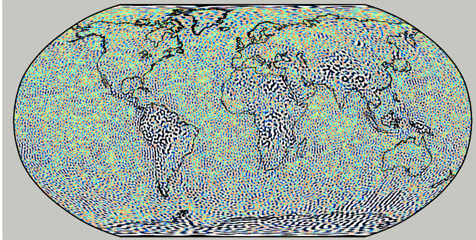
April 11, 2019

Motivation: GOCE mission

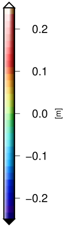
10 years ago
– launch

5.5 years ago
– re-entry

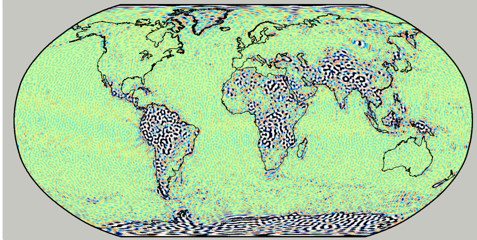
9 years ago – EGM_TIM_RL01 solution



geoid w.r.t
EGM2008



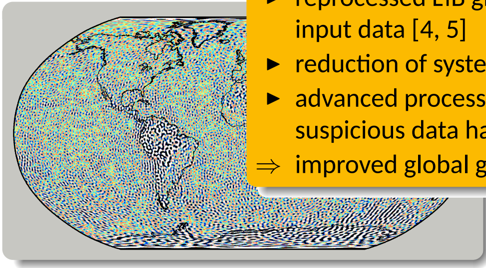
4.5 years ago – EGM_TIM_RL05 solution

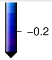


10 years ago – launch

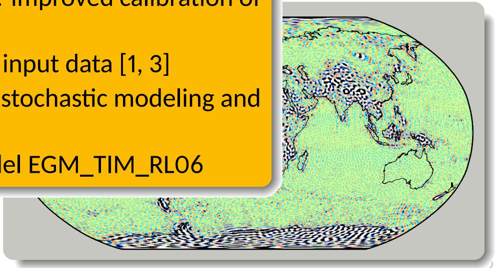
5.5 years ago – re-entry

9 years ago – EGM_TI





M_RL05 solution



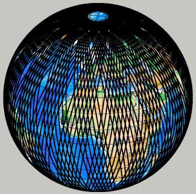
Reprocessing 10 years after launch

- GOCE HPF reprocessing campaign of entire GOCE mission data set
- reprocessed L1B gravity gradients: improved calibration of input data [4, 5]
- reduction of systematic effects in input data [1, 3]
- advanced processing algorithms: stochastic modeling and suspicious data handling [3]

⇒ improved global gravity field model EGM_TIM_RL06

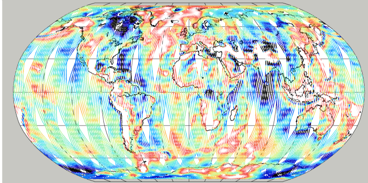
Gravity field models determined with the time-wise approach: **solely based on GOCE observations!**

kinematic satellite orbits



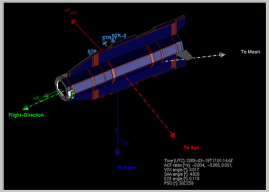
+orbit error information

geolocated gravity gradients (GRF)



+ advanced gradient error model

gradiometer orientation



high dimensional joint least squares estimation

A global mode of the Earth's gravity field (spherical harmonics) + its uncertainty

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

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kinematic satellite orbits

+

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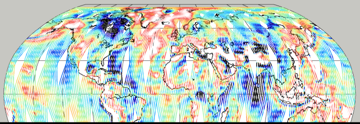
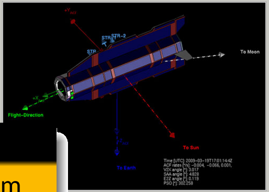


+

gradiometer orientation



+orbit error inform

Focus today

The new solution: EGM_TIM_RL06rc computed from

- GPS tracking observations (SST)
- reprocessed gravity gradients (SGG)
- regularizing prior information (REG)

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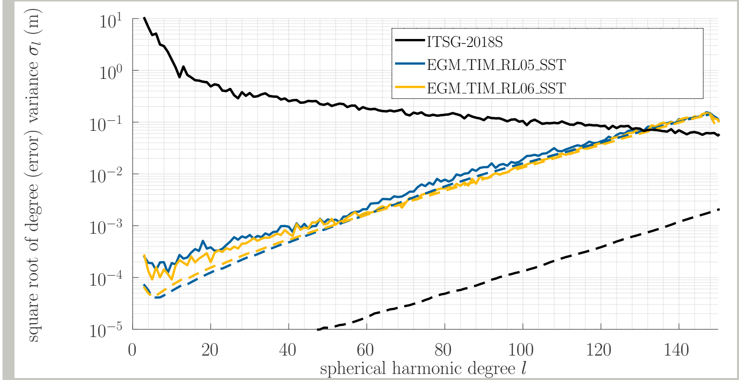
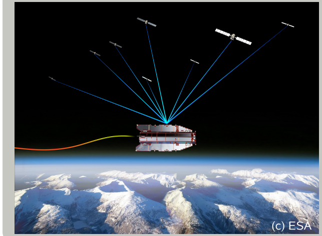
3

High-Low SST: Normal equations assembled by IfG @ TU Graz

- long wave-length gravity field from kinematic orbits
- short arc integral equation approach (as for GRACE, GOCE standards applied)



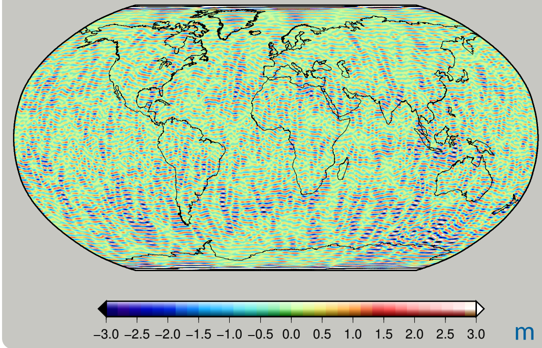


- reduction of systematic effects (e.g. magnetic equator): $\Rightarrow$ ROTI based weighting
- currently in-house orbits with raw observation approach [6]
- compared to RL05: slight improvements

Reduction of errors

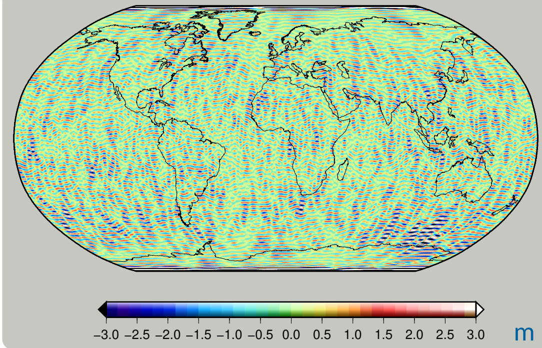
Geoid w.r.t. ITSG-Grace2018s (m) at d/o 150

GO_EGM_TIM_RL05_SST



RMS: 0.79 m

GO_EGM_TIM_RL06_SSTrc

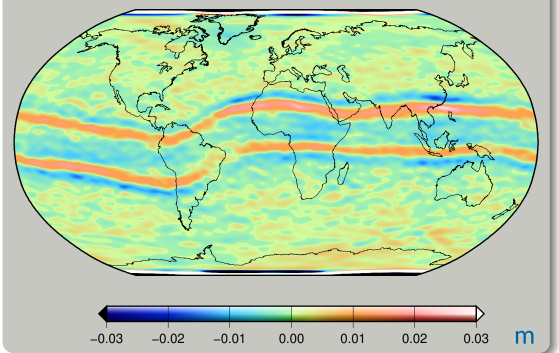


RMS: 0.77 m

⇒ systematic error around magnetic equator reduced: extend and magnitude halved!

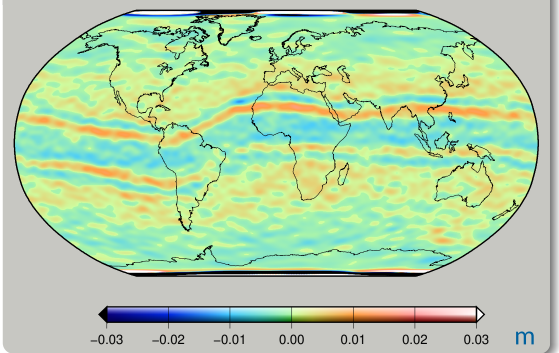
Geoid w.r.t. ITSG-Grace2018s (m) at d/o 150, 300 km Gaussian Filter applied

GO_EGM_TIM_RL05_SST



RMS: 4.1 mm, RANGE: $\pm$2.6 cm

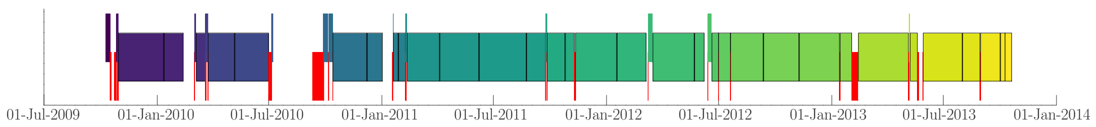
GO_EGM_TIM_RL06_SSTrc



RMS: 2.9 mm, RANGE: $\pm$1.5 cm

$\Rightarrow$ systematic error around magnetic equator reduced: extend and magnitude halved!

Used gravity gradient data: partioned into gapless and equidistant segments



- available epochs: 114.8×10^6, epochs used 110.4×10^6
- the red (shifted down): the 38 segments not used, 4.4×10^6
- the colored (shifted up): 17 short usable segments less then a week
- the others: 32 used segments longer then a week

Iteratively refined robustified AR processes for decorrelation estimated along the orbit for

- each of the segments and each gravity gradient component (V_{XX}, V_{XZ}, V_{YY} and V_{ZZ})

compared to RL05: improved processing — robustification & suspicious data identification [2, 3]

$\Rightarrow$ suspicious data identified by series of hypothesis tests (not used for decorrelation filter & analysis)

$\Rightarrow$ improved L1B input gradients

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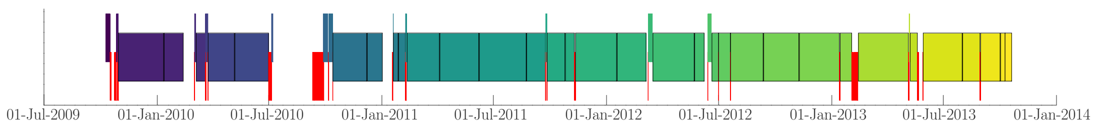

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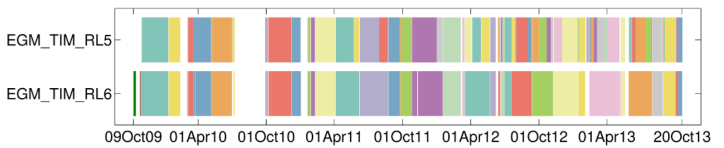
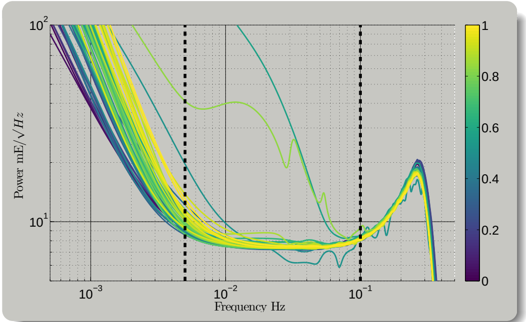
Decorrelation filters

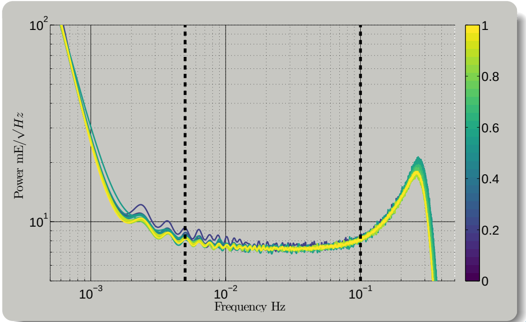
With robustified estimation: stable filters from longer segments possible RL05 vs RL06



RL05 V_{XX}



RL06 V_{XX}



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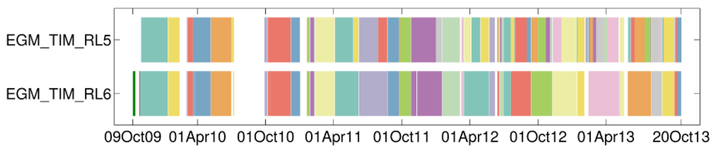
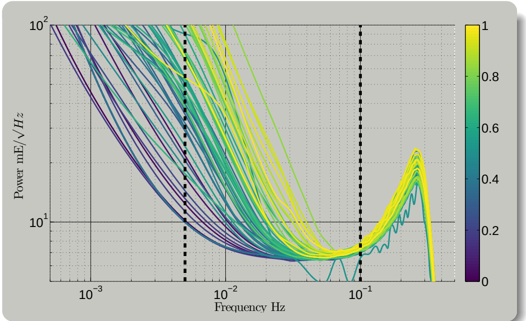
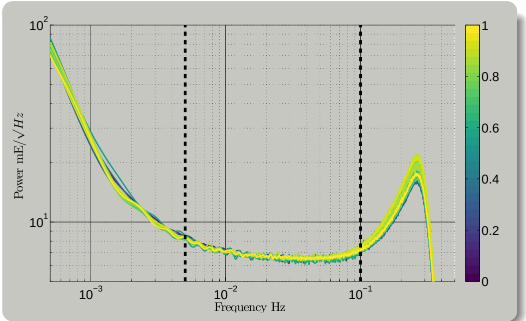


RL05 V_{YY}

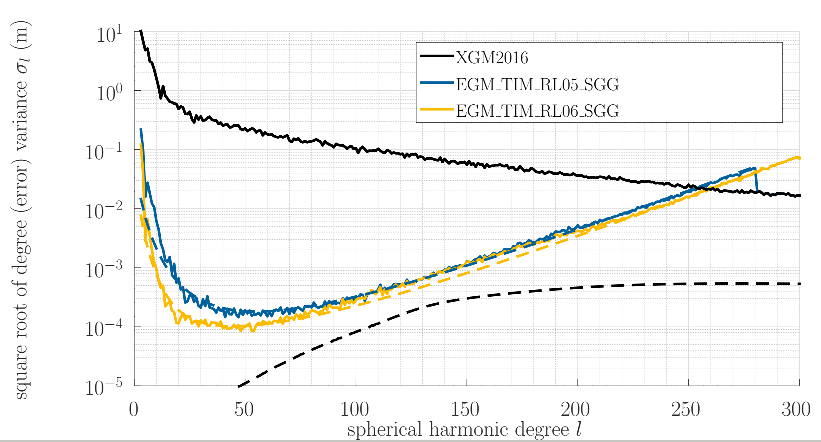


RL06 V_{YY}



Gradient only solution vs. XGM2016

obs V_{XX} 108.3 $\times 10^6$, V_{XZ} 108.6 $\times 10^6$, V_{YY} 109.8 $\times 10^6$, V_{ZZ} 109.7 $\times 10^6$

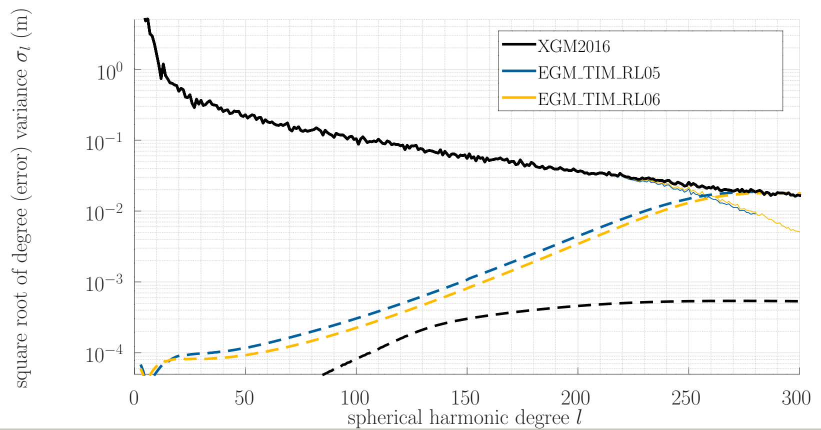


solid: empirical from difference, dashed: formal from covariance, near zonal coefficients excluded

Combined solution EGM_TIM_RL06rc

Combination of all normal equations, weights by variance component estimation (VCE)

- SGG normal equations: of all segments and components (weights in $[0.92\,,\ 1.13]$)
- SST normal equation: weight 1.00
- REG high degrees: diagonal Kaula for degrees $>\ 200$, weight 0.78
- REG polar gaps: normal equations for zero gravity anomalies for degrees 11 to 300, $0.5°$
  - south pole from $-83°$: $\sigma \approx 20$ mGal from VCE
  - north pole from $+83°$: $\sigma \approx 9$ mGal from VCE
  - RL05: extra Kaula for near zonals
- two full iterations for SGG decorrelation filter estimation



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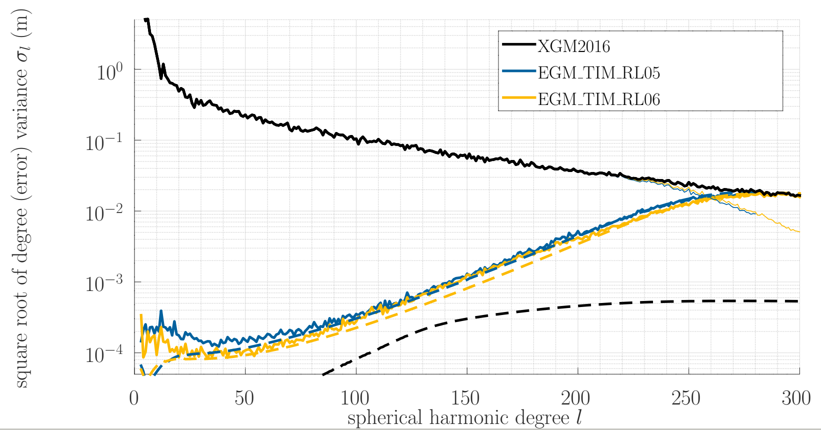
EGM_TIM_RL06rc compared to XGM2016



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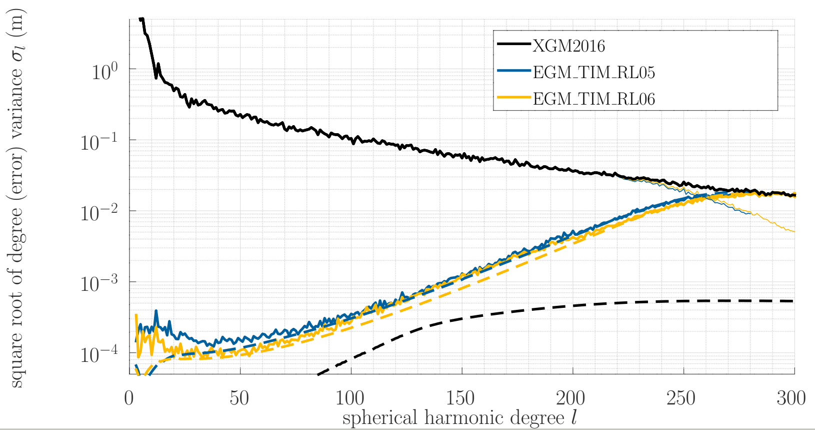
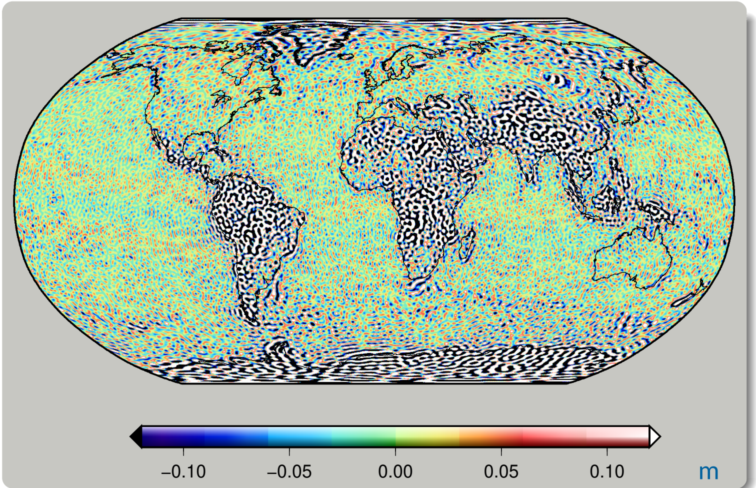
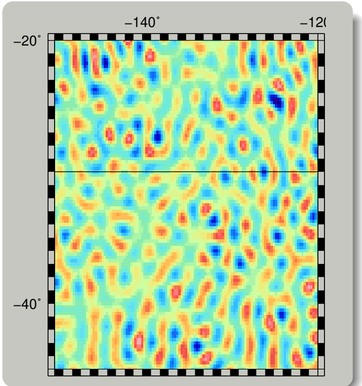


Improvements for entire spectrum, RL05 errors in XGM2016 visible (includes EGM_TIM_RL05)

Geoid compared to EGM2008 @ d/o 200

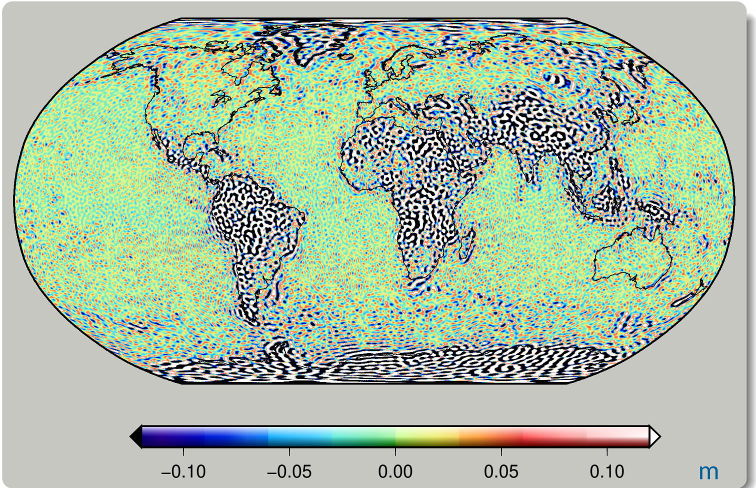


EGM_TIM_RL05

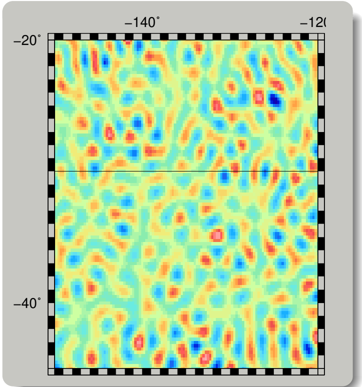


RMS: 2.8 cm

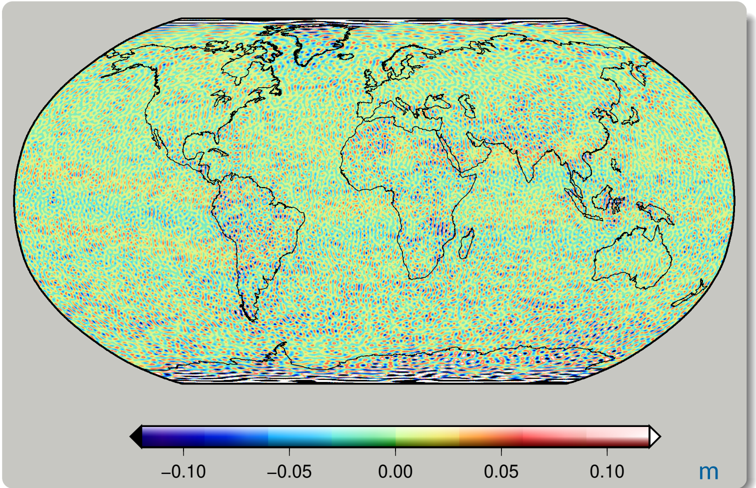
Geoid compared to EGM2008 @ d/o 200



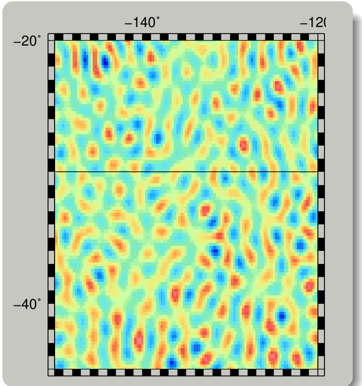
EGM_TIM_RL06rc



RMS: 2.4 cm

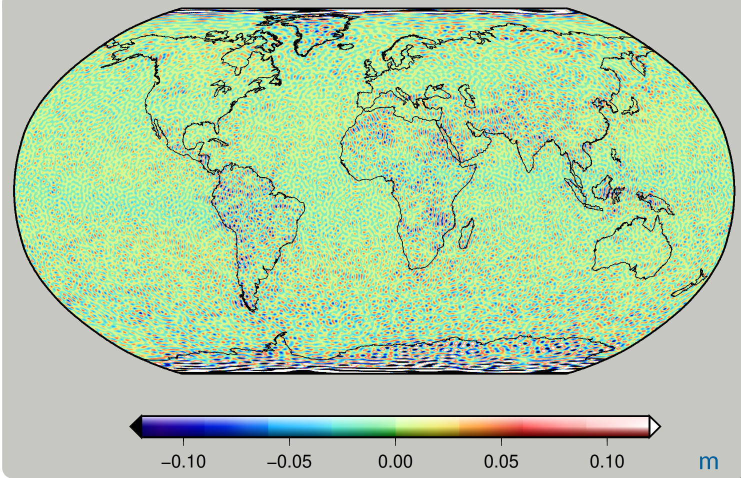


EGM_TIM_RL05

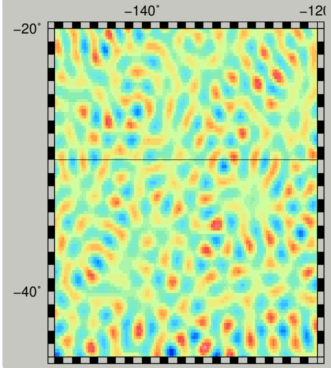


RMS: 2.4 cm

Geoid compared to XGM2016 @ d/o 200

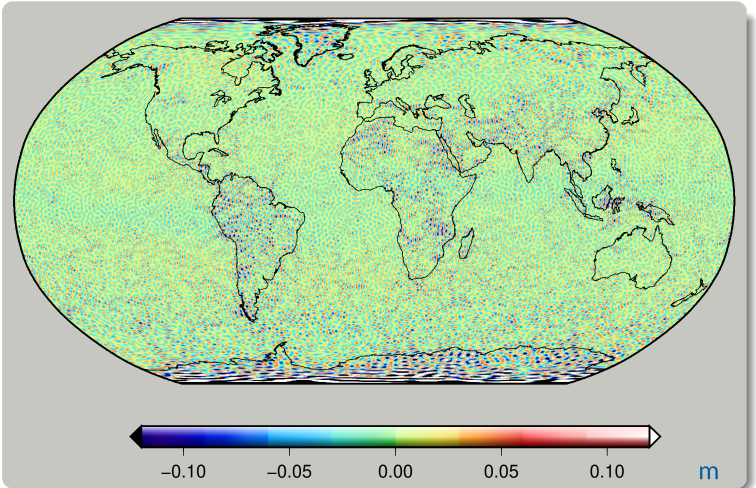


EGM_TIM_RL06rc

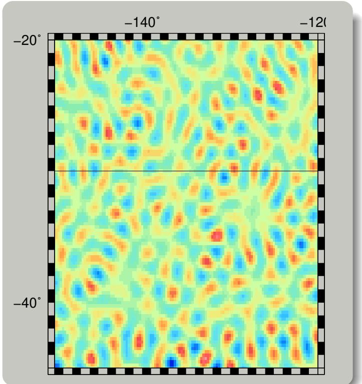


RMS: 2.1 cm

Geoid compared to XGM2016 @ d/o 200



EGM_TIM_RL06rc



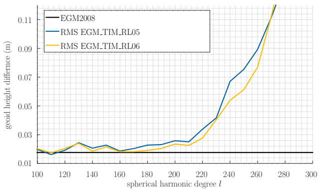
RMS: 2.1 cm

Although XGM2016 includes RL05, RL06 is more consistent!

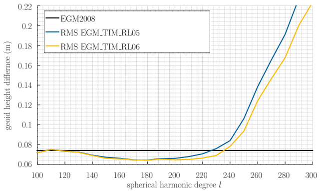
Conclusions

- EGM_TIM_RL06rc: improved global gravity field model only based on GOCE
- use of reprocessed L1B gravity gradients and advanced decorrelation filter estimation
- improvements are threefold
  - ✓ global reduction of errors in range of 15 % to 25 %
  - ✓ reduction of systematic errors at centimeter level
  - ✓ improved/more realistic covariance matrix
- official ESA GOCE HPF GOCE-only model

Germany: GPS/Levelling validation



Japan: GPS/Levelling validation



courtesy: T. Gruber, IAPG, TU München

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Outlook

- model & covariance will be available after LPS19 (ESA/ICGEM)
- update of SST part (cf. Grombein et. al. EGU2019-4384)?
- unconstraint versions (w/o REG) available on request
- input to GOCO06S (next talk: EGU2019-17241 Kvas et. al.)

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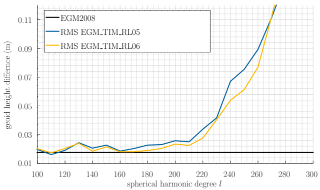

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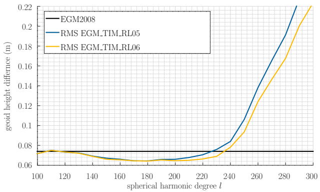
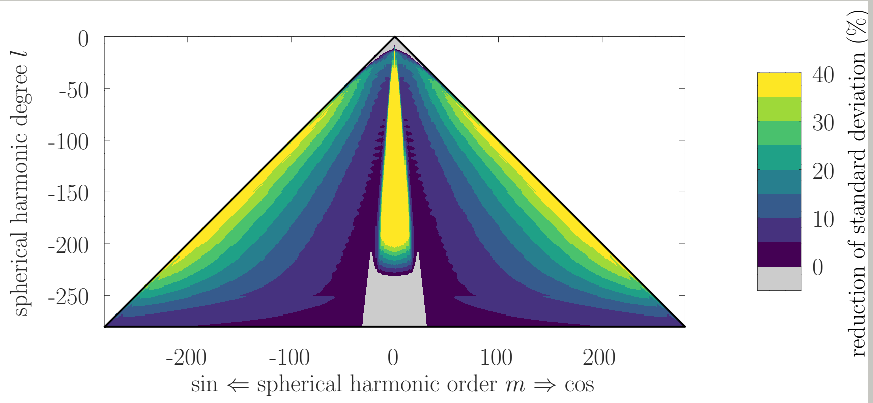


courtesy: T. Gruber, IAPG, TU München

Where are the improvements compared to EGM_TIM_RL05?



- low degrees determined by SST do formally not improve
- sectorials benefit most, up to 40 % reduction of standard deviation

[1] J. M. Brockmann, N. Zehentner, W.-D. Schuh, and Torsten Mayer-Gürr. Studies on the potential of a reprocessing camapign of the GOCE observations inline with the time-wise method. Technical report, University of Bonn, Institute of Geodesy and Geoinformation, Department of Theoretical Geodesy, Bonn, 2016. URL `https://uni-bonn.sciebo.de/index.php/s/CDGSKaqmfPUgWBT`.

[2] Jan-Martin Brockmann, Till Schubert, Wolf-Dieter Schuh, and GOCE HPF Team. Reprocessed GOCE gravity gradients for gravity field recovery: First results with the time-wise approach (talk), 2018. URL `https://presentations.copernicus.org/EGU2018-13217_presentation.pdf`.

[3] Till Schubert, Jan Martin Brockmann, and Wolf-Dieter Schuh. Identification of suspicious data for robust estimation of stochastic processes. In *IX Hotine-Marussi Symposium*, International Association of Geodesy Symposia. Springer, in review.

[4] Christian Siemes. Improving GOCE cross-track gravity gradients. *Journal of Geodesy*, 92(1):33–45, January 2018. ISSN 0949-7714, 1432-1394. doi: 10.1007/s00190-017-1042-x. URL `https://link.springer.com/article/10.1007/s00190-017-1042-x`.

[5] Christian Siemes, Moritz Rexer, and Roger Haagmans. GOCE star tracker attitude quaternion calibration and combination. *Advances in Space Research*, 63(3):1133–1146, February 2019. ISSN 0273-1177. doi: 10.1016/j.asr.2018.10.030. URL `http://www.sciencedirect.com/science/article/pii/S0273117718307993`.

[6] N. Zehentner. *Kinematic Orbit Positioning Applying the Raw Observation Approach to Observe Time Variable Gravity*. PhD thesis, Graz University of Technology, Graz, Austria, 2016.