Living Planet Symposium 2019

An improved global gravity field model of the Earth derived from reprocessed GOCE observations with the time-wise approach

Jan Martin Brockmann[1], Till Schubert[1], Wolf-Dieter Schuh[1], Andreas Kvas[2] and Torsten Mayer-Guerr[2] + GOCE HPF Team

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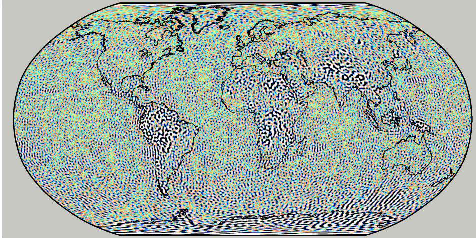
May 13, 2019

Motivation: GOCE mission

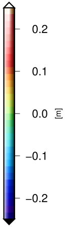
10 years ago – launch

5.5 years ago – re-entry

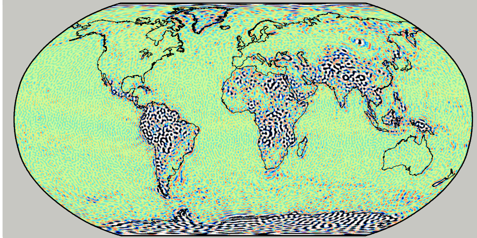
9 years ago – EGM_TIM_RL01 solution



geoid w.r.t EGM2008



4.5 years ago – EGM_TIM_RL05 solution



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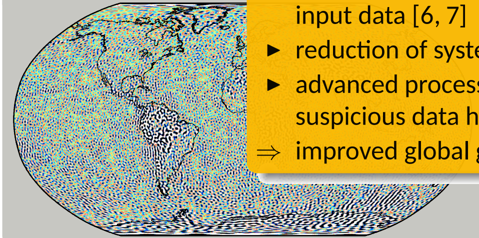

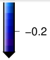

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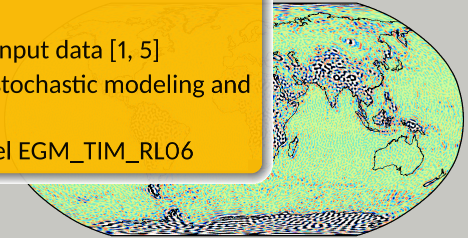


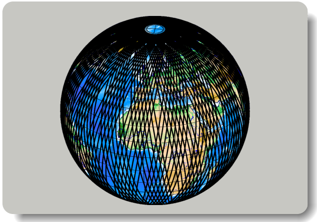
Reprocessing 10 years after launch

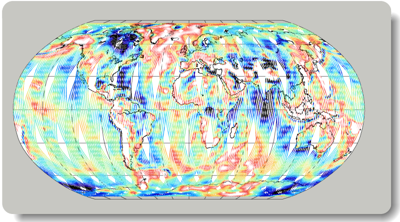
- GOCE HPF reprocessing campaign of entire GOCE mission data set
- reprocessed L1B gravity gradients: improved calibration of input data [6, 7]
- reduction of systematic effects in input data [1, 5]
- advanced processing algorithms: stochastic modeling and suspicious data handling [5]

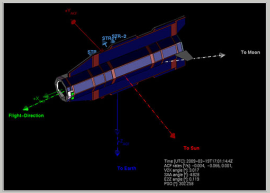
⇒ improved global gravity field model EGM_TIM_RL06

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

kinematic satellite orbits + geolocated gravity gradients (GRF) + gradiometer orientation







+orbit error information

+ advanced gradient error model

high dimensional joint least squares estimation

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

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

EGM_TIM GOCE gravity field models

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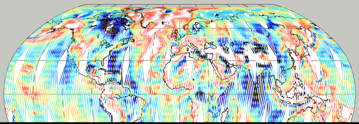
kinematic satellite orbits

$+$

geolocated gravity gradients (GRF)



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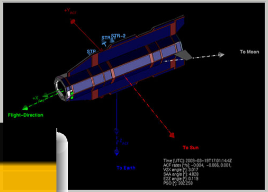

$+$orbit error inform... ...ror model

high dimensional joint least squares estimation

Focus today

The new solution: EGM_TIM_RL06 computed from

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

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

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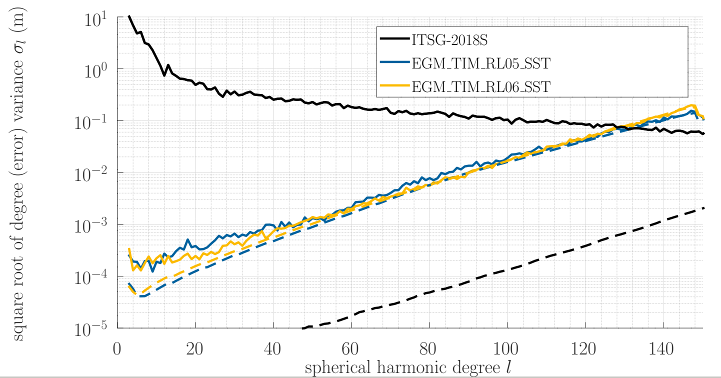
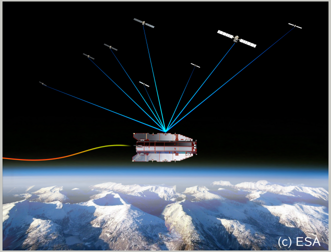
High-Low SST: Normal equations assembled by IfG @ TU Graz

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

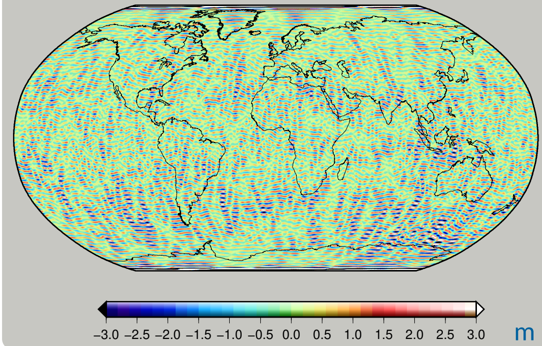




- reduction of systematic effects (magnetic equator) $\Rightarrow$ poster B-174 (Fr 12:20): Arnold et al. *'Reprocessing of GOCE Precise Science Orbits'*
- compared to RL05: small improvements lower degrees

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

GO_EGM_TIM_RL05_SST



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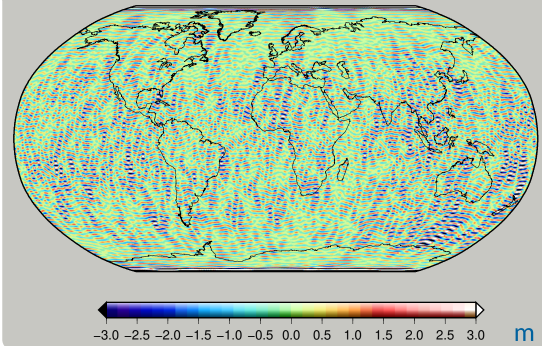


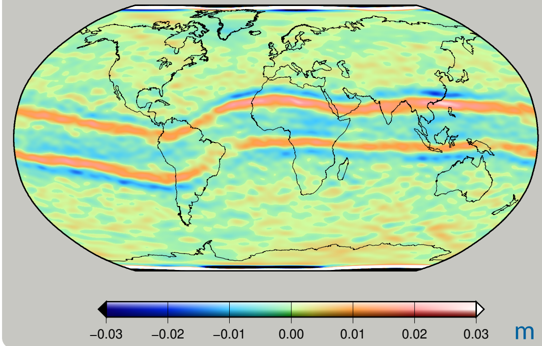
RMS: 0.79 m

RMS: 0.86 m

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

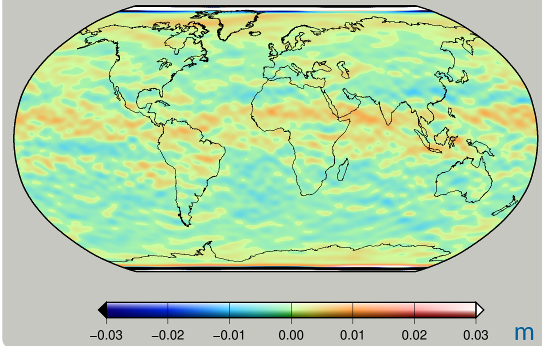
Geoid w.r.t. ITSG-Grace2018s (m) at d/o 150, 300 km Gaussian Filter applied

GO_EGM_TIM_RL05_SST



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

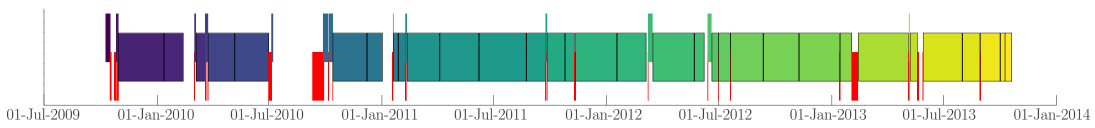
GO_EGM_TIM_RL06_SST



RMS: 2.5 mm, RANGE: $\pm$1.0 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

$\Rightarrow$ gravity gradients are highly correlated in time

Data-adaptive correlation modeling and detection of suspicious data along the orbit for

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

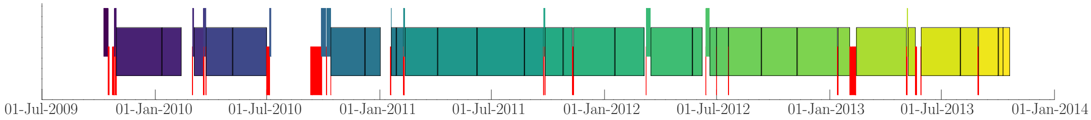
compared to RL05: improved processing — robustification & suspicious data identification [2, 5]

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

$\Rightarrow$ improved L1B input gradients

Gravity gradient processing

Used gravity gradient data: partioned into gapless and equidistant segments



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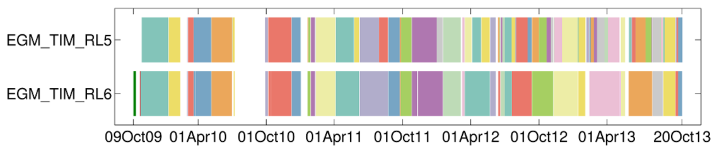
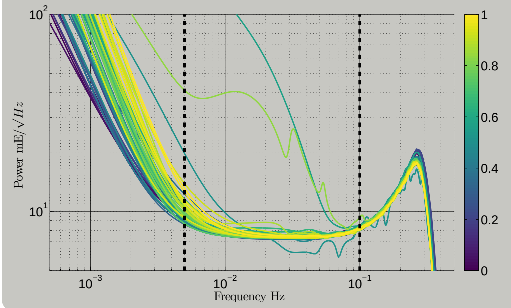
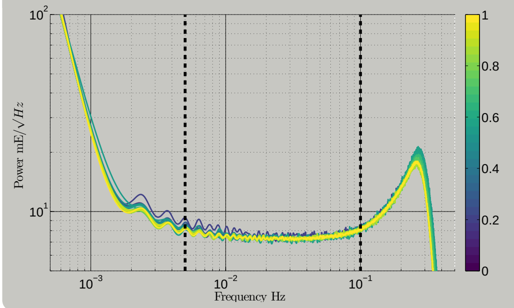
With robustified estimation: stable filters from longer segments possible RL05 vs RL06



RL05 V_{XX}



RL06 V_{XX}



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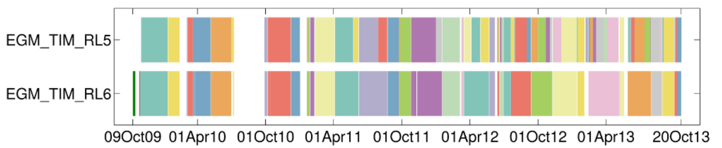
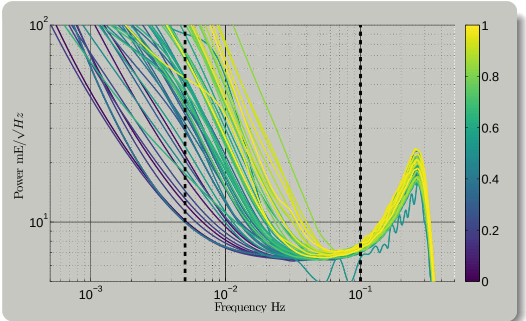
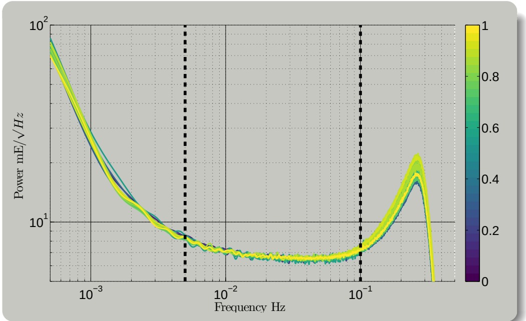


RL05 V_{YY}

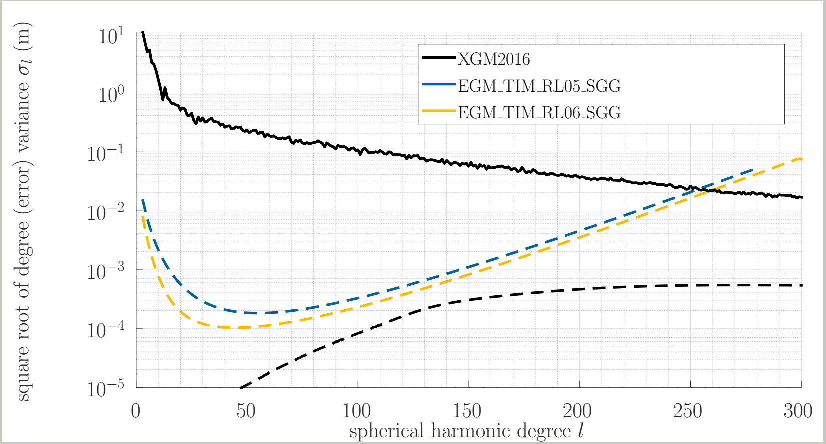


RL06 V_{YY}



Gradient only solution vs. XGM2016

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



dashed: formal from covariance, near zonal coefficients excluded

Combined solution EGM_TIM_RL06

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

Computational challenging

requires assembly & solution of a dense overdetermined system of equations with 440 000 000 correlated equations with 90 000 unknowns

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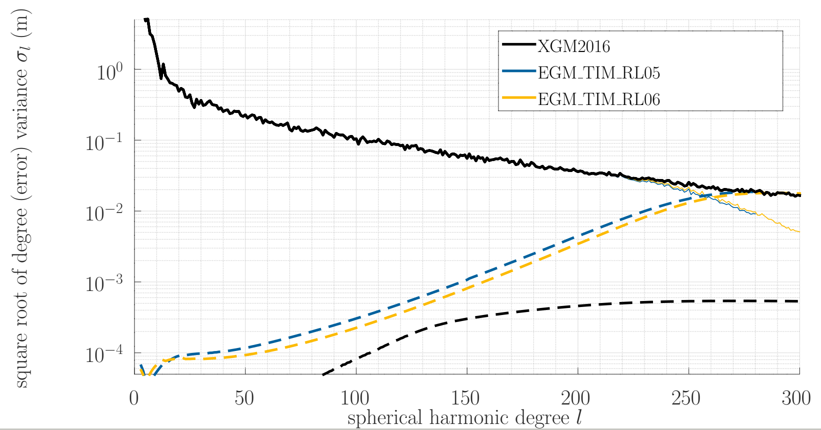
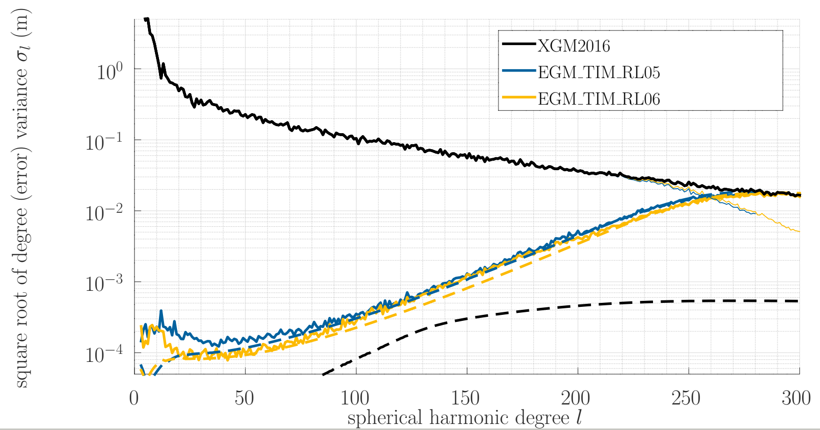


solid: empirical from difference, dashed: formal from covariance, near zonal coefficients excluded

EGM_TIM_RL06 compared to XGM2016



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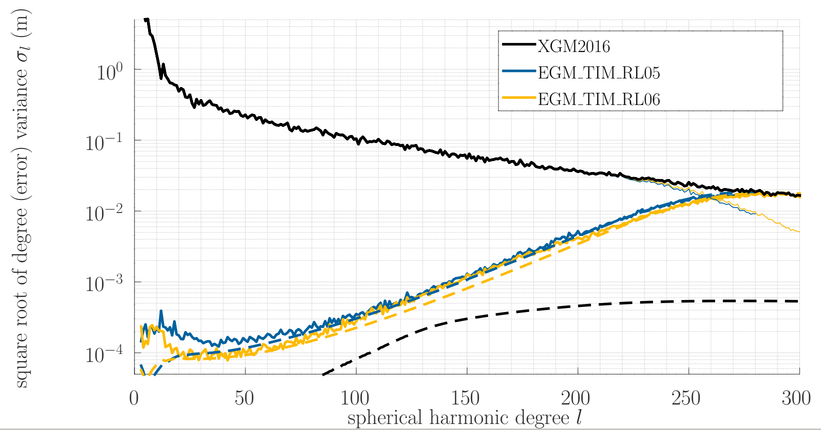
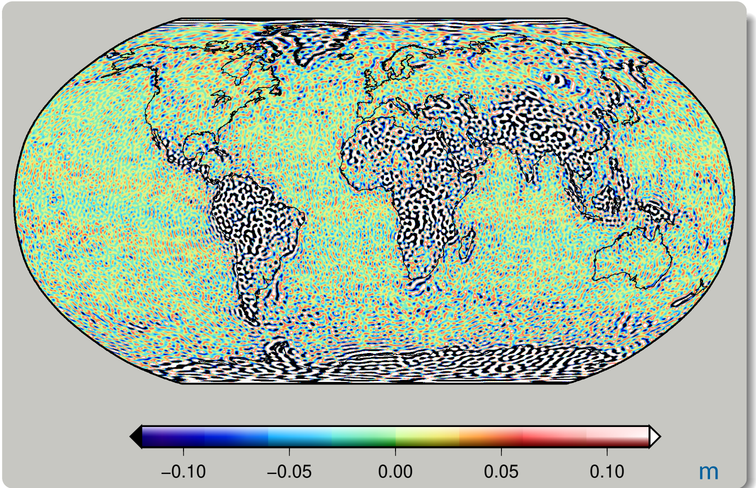
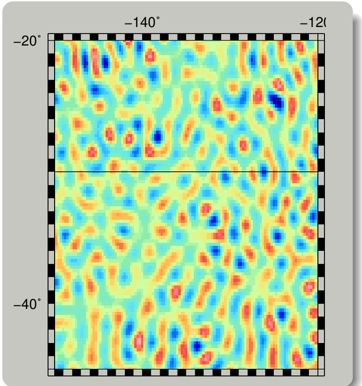


Improvements for entire spectrum, RL05 errors in XGM2016 visible (XGM includes EGM_TIM_RL05)



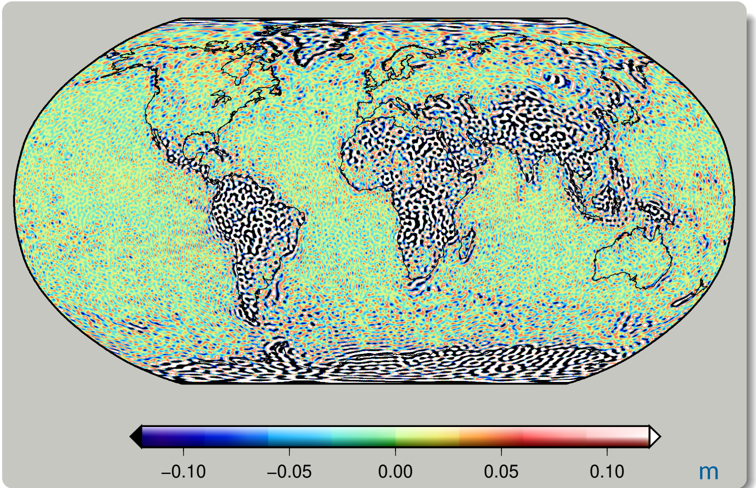
EGM_TIM_RL05



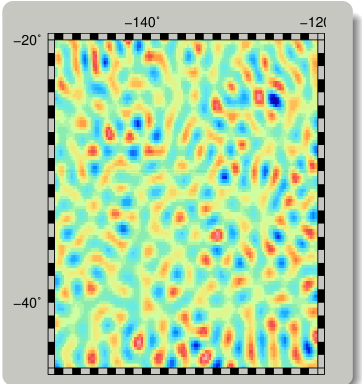
RMS: 2.8 cm

Larger differences constant: signal made visible by GOCE

Geoid compared to EGM2008 @ d/o 200

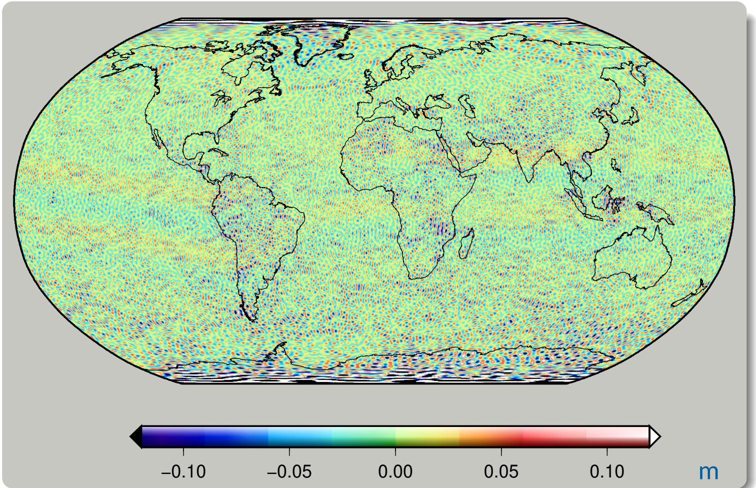


EGM_TIM_RL06

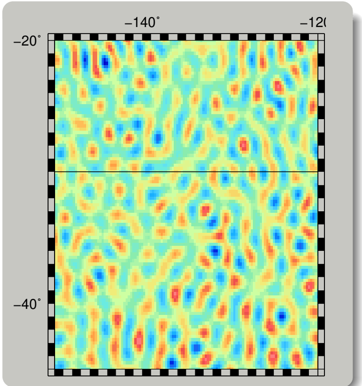


RMS: 2.4 cm

Larger differences constant: signal made visible by GOCE



EGM_TIM_RL05



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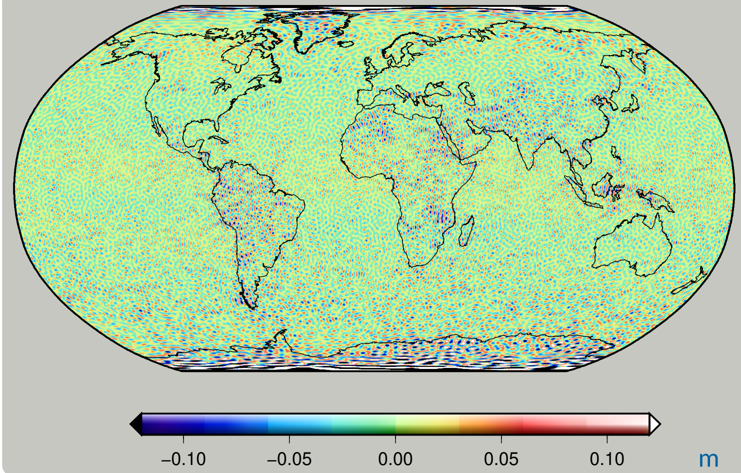
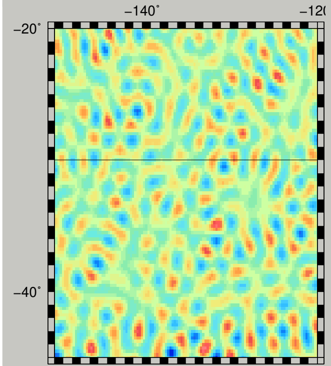
Geoid compared to XGM2016 @ d/o 200

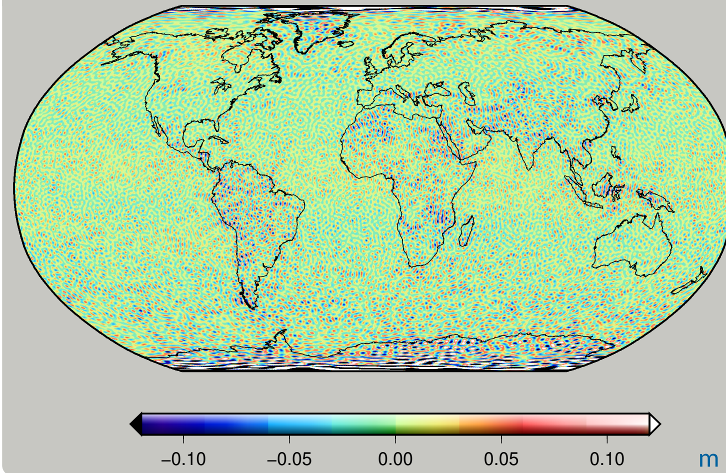


EGM_TIM_RL06



RMS: 2.1 cm

Geoid compared to XGM2016 @ d/o 200



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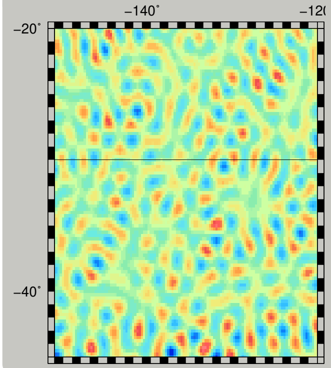

RMS: 2.1 cm

Although XGM2016 includes RL05, RL06 is more consistent!

Conclusions

- EGM_TIM_RL06: improved global gravity field model purely 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: accuracy level at 1.0 cm to 1.7 cm @ 100 km

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Outlook

- model & covariance will be available end of May (ESA/ICGEM)
- unconstraint versions (SST-/SGG-only) on request

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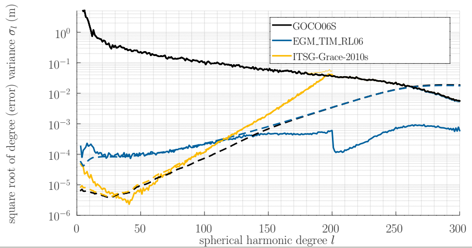
GOCO06S: Combined satellite-only model [3]

- GOCE: EGM_TIM_RL06
- GRACE: ITSG-Grace2018s [4]
- HL-SST: CHAMP, SWARM, TerraSAR-X,...
- SLR: LAGEOS1/2, Ajisai, Stella, Starlette, LARES, LARETS, Etalon1/2, BLITS



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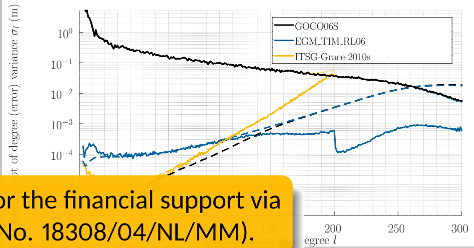

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References I

[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] Andreas Kvas, Torsten Mayer-Gürr, Sandro Krauß, Jan Martin Brockmann, Till Schubert, Wolf-Dieter Schuh, Roland Pail, Thomas Gruber, Adrian Jäggi, and Ulrich Meyer. The satellite-only gravity field model GOCO06s, 2019.

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