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# A case study on the potential of robust decorrelation filter design for a reprocessing of a gravity field model from GOCE data



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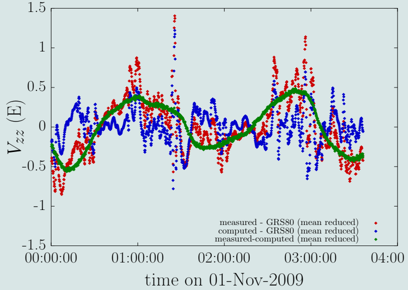
# Outline

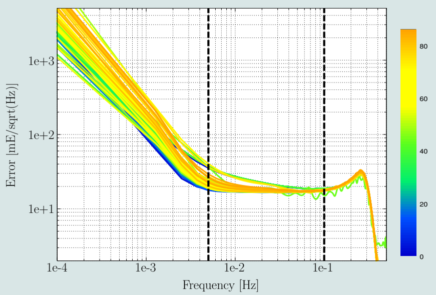
Within the GOCE **time-wise approach** (EGM_TIM gravity field models)

- SGG observations are treated as time series along the orbit
- partioned into gapless parts of time series (segments)
- gradient components $V_{XX}$, $V_{XZ}$, $V_{YY}$ and $V_{ZZ}$ are separately analyzed
- gradiometer noise is approximated by an ARMA process
- are assumed to be uncorrelated
- inverse process is used as complete decorrelation filter






observations as time series

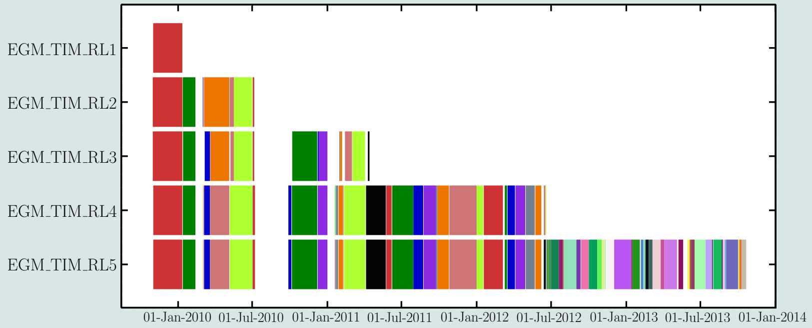



decorrelation filters for $V_{ZZ}$

# Timeline of EGM_TIM Models







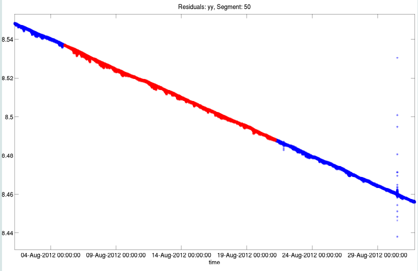

| release | timespan | d/o | $U$ | $S$ | epochs |
|---|---|---|---|---|---|
| EGM_TIM_RL01 | 11/2009–01/2010 | 2–224 | 50 172 | 1 | 6 161 834 |
| EGM_TIM_RL02 | 11/2009–07/2010 | 2–250 | 62 997 | 9 | 19 477 946 |
| EGM_TIM_RL03 | 11/2009–04/2011 | 2–250 | 62 997 | 16 | 31 289 605 |
| EGM_TIM_RL04 | 11/2009–06/2012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

For entire mission data set as in EGM_TIM_RL05: $4 \times 87 = \mathbf{348}$ filters adjusted

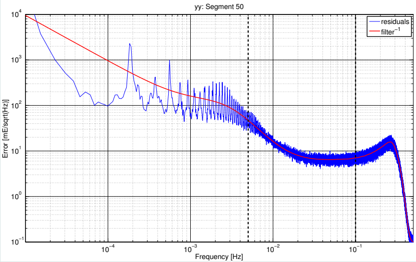
Starting point are gradient residuals (per component $c$, per segment $s$)

$$\mathbf{v}_{c,s} = \mathbf{A}_{c,s}\tilde{\mathbf{x}} - \mathbf{l}_{c,s} \qquad (1)$$

## Time domain




## Frequency domain




- manual selection of a part without gross errors (red)
- least squares estimation of ARMA process (requires equidistant data)
- outliers, non-stationarity of time series are ignored for the estimation of filters, outlier detection separately

⇒ effects may smear into filter (and spectrum)

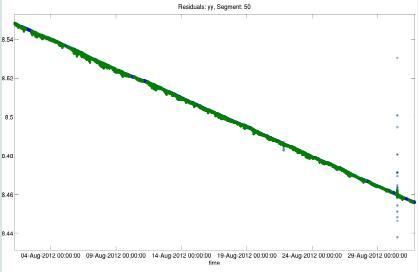
# Filter estimation procedure (new)



Starting point are gradient residuals (per component $c$, per segment $s$)

$$\mathbf{v}_{c,s} = \mathbf{A}_{c,s}\tilde{\mathbf{x}} - \mathbf{l}_{c,s} \qquad (2)$$

## Time domain

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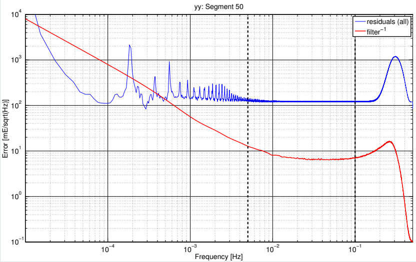


- use of entire segment, robust estimation of AR process (L1 norm)
- details: Fri. 15:30, EGU2015-13050, Schuh etal. *Correlation analysis for long time series by robustly estimated autoregressive stochastic processes*
- outliers directly an output from filter estimation (green)

$\Rightarrow$ more outliers, stable filter estimate

# Real data used for first analysis



Three long segments of lower orbit campaign for case-study

| segment | start | end | # observations | note |
|---|---|---|---|---|
| 50 | 01-Aug-2012 | 31-Aug-2012 | 2 645 205 | first decay phase |
| 58 | 02-Dec-2012 | 13-Jan-2013 | 3 632 149 | |
| 76 | 17-Jun-2013 | 13-Jul-2013 | 2 325 772 | |

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## outlier statistics

| segment | $XX$ | | $XZ$ | | $YY$ | | $ZZ$ | |
|---|---|---|---|---|---|---|---|---|
| | # | % | # | % | # | % | # | % |
| 50 old | 70 600 | 2.7 | 35 036 | 1.3 | 5 531 | 0.2 | 42 879 | 1.6 |
| 50 new | 707 381 | 26.7 | 613 017 | 23.2 | 298 166 | 11.3 | 33 839 | 1.3 |
| 58 old | 51 335 | 1.4 | 100 429 | 2.8 | 10 129 | 0.3 | 40 089 | 1.1 |
| 58 new | 28 066 | 0.8 | 15 704 | 0.4 | 398 071 | 11.0 | 6 924 | 0.2 |
| 76 old | 78 006 | 3.4 | 102 083 | 4.4 | 221 230 | 9.5 | 13 149 | 0.6 |
| 76 new | 160 428 | 6.9 | 61 415 | 2.6 | 584 366 | 25.1 | 141 187 | 6.1 |

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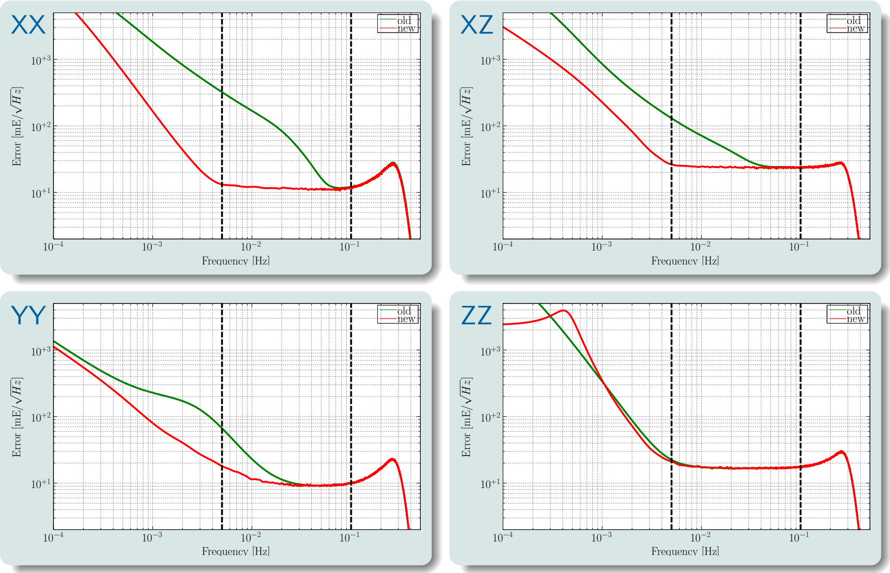
$\Rightarrow$ new method is more aggressive w.r.t. outliers

$\Rightarrow$ selects highest quality data for filter estimation

# Estimated filters: $s = 50$

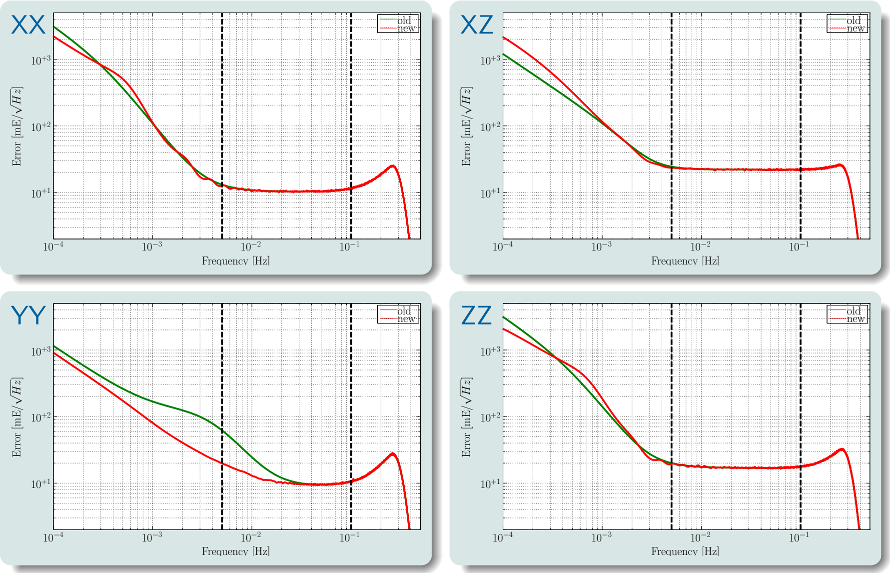







new filter estimates: flat behavior in measurement band (XX, XZ and YY)

# Estimated filters: $s = 58$

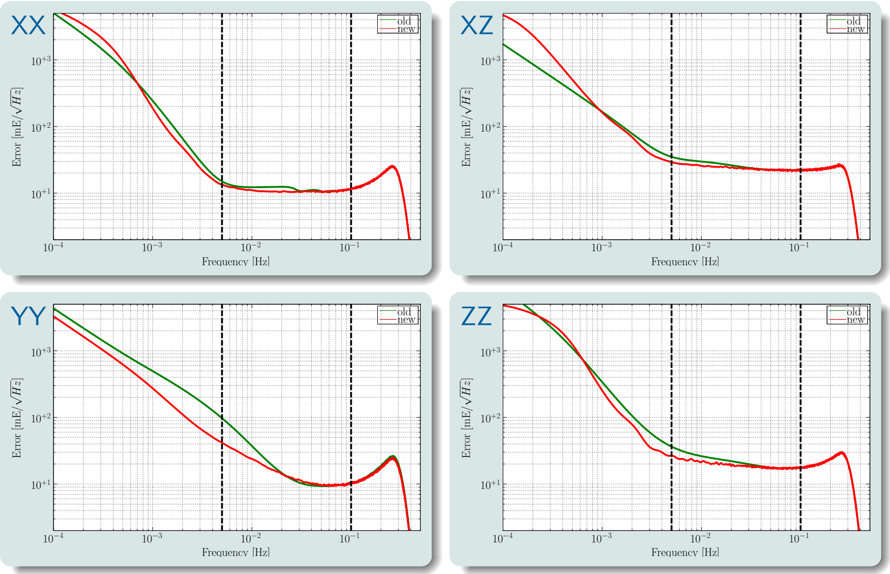



new filter estimates: flat behavior in measurement band (YY)

# Estimated filters: $s = 76$








new filter estimates: slightly flatter behavior in measurement band (all)

# Preliminary conclusions



New filters suggest that data is more accurate than old filters assume

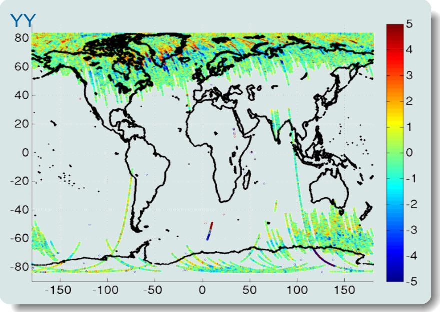
- especially the low orbit data looses stationarity (higher noise at special locations)
- degradation of "old" filters by non-stationarity

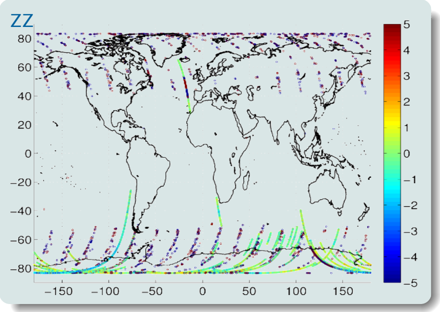
⇒ concentrate on stationary data for filter estimation

⇒ drawback: data which does not agree with filter model are marked as outliers

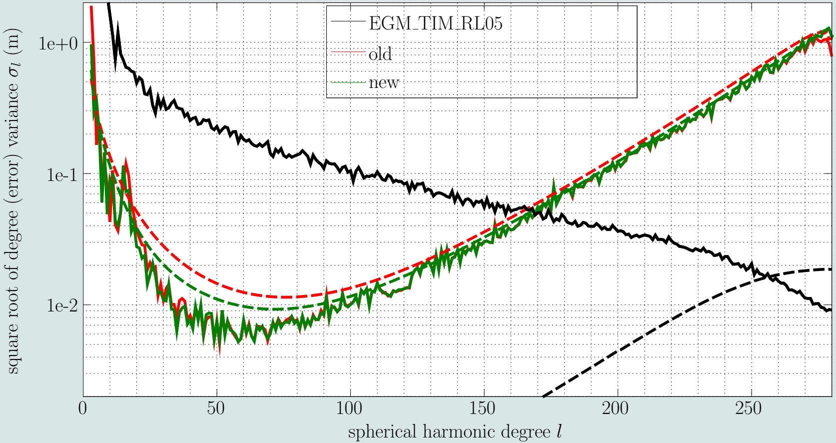
- Do the new filter yield more accurate gravity fields?

⇒ Case study for the three selected segments



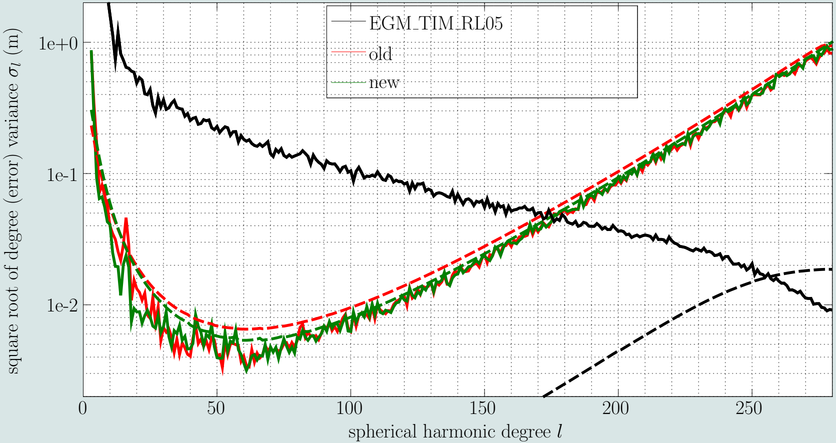



SGG-only gravity field solution from single component & single segment ($s = 76$, $c = XX$)



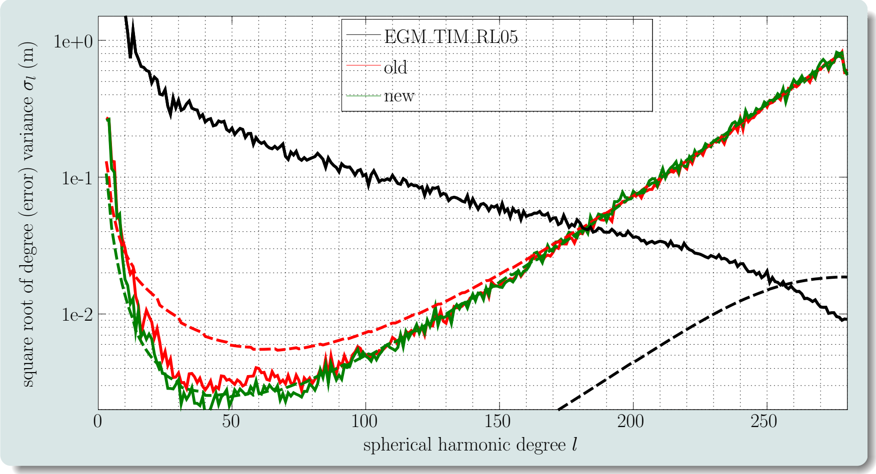

- red: old solution, green: new solution, solid: difference, dashed: formal errors
- Difference to reference model more or less the same
- Formal errors closer to empirical difference

SGG-only gravity field solution from single component & single segment ($s = 76$, $c = XZ$)



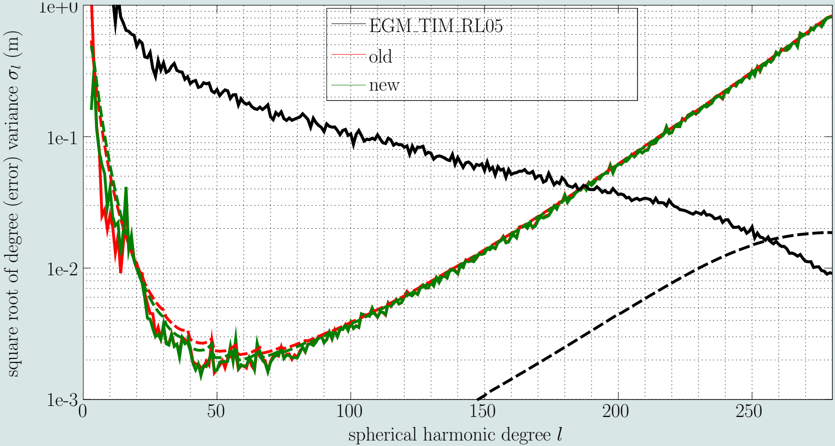

- red: old solution, green: new solution, solid: difference, dashed: formal errors
- Difference to reference model more or less the same
- Formal errors closer to empirical difference

SGG-only gravity field solution from single component & single segment ($s = 58$, $c = YY$)




- red: old solution, green: new solution, solid: difference, dashed: formal errors
- Difference to reference model improved for degree 15 – 80
- Formal errors closer to empirical difference

SGG-only gravity field solution from single component & single segment ($s = 50$, $c = ZZ$)

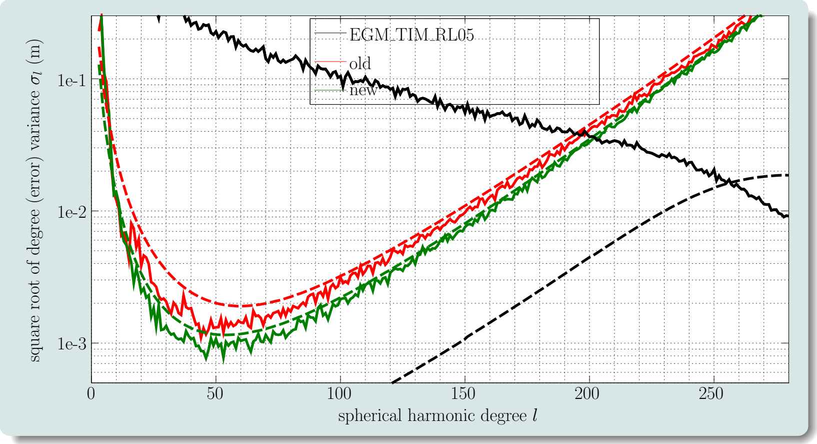



- red: old solution, green: new solution, solid: difference, dashed: formal errors
- Difference to reference model more or less the same
- Formal errors more or less the same

# Segment solutions



SGG-only gravity field solution from single segment ($s = 50$, $c = ZZ, XZ, YY, ZZ$)

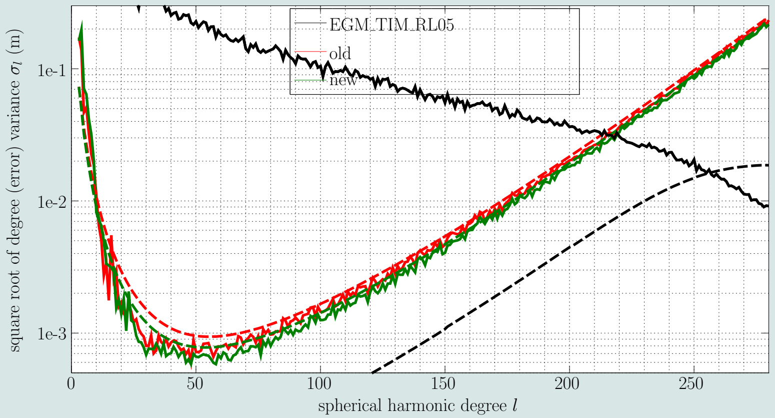



- red: old solution, green: new solution, solid: difference, dashed: formal errors
- difference to reference model becomes smaller for whole spectrum
- formal errors smaller and more consistent to difference
- cumulative formal error: deg. 30–200 → reduction 24%; deg. 30–280→reduction 16%
- cumulative empirical error: deg. 30–200 → reduction 20%; deg. 30–280→reduction 9%

# Segment solutions



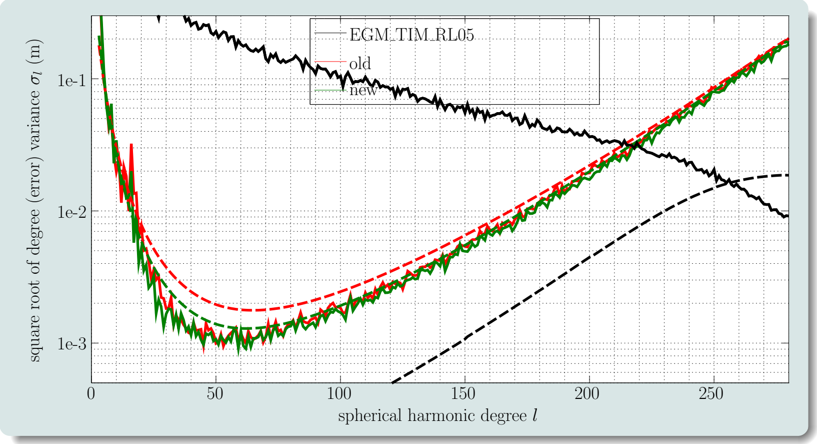
## SGG-only gravity field solution from single segment ($s = 58$, $c = ZZ, XZ, YY, ZZ$)




- red: old solution, green: new solution, solid: difference, dashed: formal errors
- Difference to reference model becomes smaller for whole spectrum
- Formal errors smaller and more consistent to difference
- cumulative formal error: deg. 30–200 → reduction 12%; deg. 30–280→reduction 8%
- cumulative empirical error: deg. 30–200 → reduction 10%; deg. 30–280→reduction 6%

# Segment solutions

SGG-only gravity field solution from single segment ($s = 76$, $c = ZZ, XZ, YY, ZZ$)



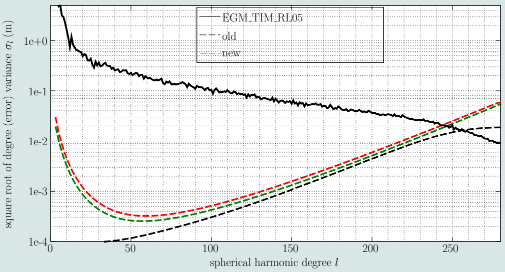

- red: old solution, green: new solution, solid: difference, dashed: formal errors
- Difference to reference model becomes smaller for whole spectrum
- Formal errors smaller and more consistent to difference
- cumulative formal error: deg. 30–200 → reduction 13%; deg. 30–280→reduction 7%
- cumulative empirical error: deg. 30–200 → reduction 7%; deg. 30–280→reduction 5%

# Summary



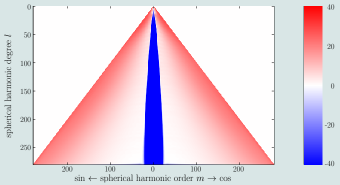
Gravity field solutions (for individual segments & components) with robustly estimated filters show the remaining potential in GOCE data

- case study has shown: positive effect for lower orbit data
- strong impact when combining components and segments (improved relative weighting due to more realistic formal errors)
- strengths of individual components are better kept in combination
- although less observations are used, no negative effect visible in new solutions, improvements for entire spectrum
- improvements for individual segments in the range of 5 – 20%




data from 06/2012 to 10/2013
cumulative formal error

deg. 30 – 200: reduction → 15%
deg. 30 – 280: reduction → 11%



# Conclusions and outlook



- reanalysis of entire mission data seems promising
- effect for nominal data (more stationary) not yet clear
- detailed residual analysis has to be performed
- adjust threshold for outlier detection: e.g. low for filter estimation, higher for gravity field determination (to use more data)
- target date for update of EGM_TIM_RL05, probably as EGM_TIM_RL06: IUGG Prague
- will additionally include improvements for SST part

## Related presentations

- Thu, 16 Apr, 14:45–15:00, EGU2015-10477 *Mitigation of ionospheric scintillation effects in kinematic LEO precise orbit determination*, Norbert Zehentner and Torsten Mayer-Gürr
- Tue, 14 Apr, 17:30–19:00, EGU2015-12092 *GOCE gravity field models following the time-wise approach*, Jan Martin Brockmann, Eduard Höck, Ina Loth, Torsten Mayer-Gürr, Roland Pail, Wolf-Dieter Schuh, and Norbert Zehentner
- Fri, 17 Apr, 15:30–15:45, EGU2015-13050 *Correlation analysis for long time series by robustly estimated autoregressive stochastic processes*, Wolf-Dieter Schuh, Jan-Martin Brockmann, and Boris Kargoll