DDK-filter Reassessment using Time Variable Error Covariance Information

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1.2 Global Geomonitoring and Gravity Field

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GRACE - Why time variable filtering?

- Decreasing altitude $\rightarrow$ increasing sensitivity
- Changing ground track pattern $\rightarrow$ changing correlations within parameters
- Varying instrument performance

Upward continuation

$$u = \left( \frac{r_e}{r_e + h_{GRACE}} \right)^{l+1}$$

<table>
<thead>
<tr>
<th>SH degree $l$</th>
<th>$u_{500\ km}/u_{350\ km}$</th>
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<tbody>
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<tr>
<td>60</td>
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more ...
## Reassessing DDK

<table>
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<tr>
<th></th>
<th>DDK</th>
<th>VDK</th>
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<tbody>
<tr>
<td></td>
<td>[Kusche, 2007; Kusche et al. 2009]</td>
<td>DDK reassessment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(cf. Horvath, 2017)</td>
</tr>
<tr>
<td>Error VCM</td>
<td>Constant (based on older VCM; block diagonal)</td>
<td>Time variable (based on actual RL05a VCM; full)</td>
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<tr>
<td>Signal VCM</td>
<td>Constant (based on Hydrological model; SH degree dependent)</td>
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<tr>
<td>Filter parameter</td>
<td>$\frac{\alpha_{DDK1}}{\alpha_{DDK5}} = 1000$</td>
<td>$\frac{\alpha_{VDK1}}{\alpha_{VDK5}} = 1000$</td>
</tr>
</tbody>
</table>
Closed-loop validation

Monthly (bad coverage) residuals in terms of surf. mass dens. in mm ewh.

DDK4

Destriping + 300 km Gaussian

VDK4

Global absolute annual amplitude RMS of truth and residuals with different filters and filter strengths
Conclusions

• Time variable decorrelation filter using the most accurate error (and signal) VCM proposed for GRACE (and GRACE-Follow-On) data in order to account for changing sensitivity

• Candidate filter method for GFZ Level 3 processing (cf. Dahle et al., EGU2018-17878, Poster on the new GFZ Level 3 web portal GravIS)

• Closed-loop simulation results show
  – smallest global residuals for bad coverage months
  – better global retrieval of linear and annual terms than static DDK
  – smaller basin residuals compared to DDK and Destriping+Gaussian

• Real data analyses show a reduction of the total RMS over the oceans for the GFZ RL05a time series around 16% (VDK5 vs. DDK5) and 18% (4)
Introduction

Filter assessment

Filter characteristics

Validation
  • Closed-loop simulation
  • Real data analysis

Conclusions

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Which filter to be applied?

Isotropic

Homo-
geneous

Gaussian

Inhomo-
geneous

Anisotropic

Destriping
[Swenson and
Wahr, 2006]

Regularization
[Kusche, 2007]

[Devaraju, 2015]
Which filter to be applied?

Isotropic

Anisotropic

Homo-
geneous

Inhomo-
geneous

normalized kernel values

distance from kernel center (lon.=lat.=0 ) in km

300 km Gaussian
DDK3, West-East dir.
DDK3, South-North dir.

[Devaraju, 2015]

[Swenson and Wahr, 2006]

[Kusche, 2007]
Reassessing DDK

\[ \mathbf{x}_\alpha = \left( \mathbf{N} + \alpha \mathbf{M} \right)^{-1} \mathbf{N} \mathbf{x} \]

filtered spherical harmonic (SH) coefficients

Inverse error variance-covariance matrix (VCM)

Regularization/Filter parameter

Inverse signal VCM

raw SH coefficients

Filter matrix \( \mathbf{W}_\alpha \)

[Kusche, 2007; Kusche et al. 2009]
## Reassessing DDK

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Filter characteristics

Simulated error VCM (cf. Flechtner et al., 2016):

• 5 years GRACE-like simulation with decreasing altitudes from 490 to 450 km and realistic instrument errors
• Software: GFZ´s Earth Parameters and Orbits System (EPOS)
• Maximum spherical harmonic (SH) degree and order 100

Real data VCM:

• GRACE GFZ RL05a (processed with EPOS)
• Maximum spherical harmonic degree and order 90
Filter kernel of VDK3 (03/2004)
Mean Gaussian radius: VDK3 vs. DDK3

Decreasing altitude $\rightarrow$ decreasing mean Gaussian radius

Bad coverage (08/2003) effect not visible in mean Gaussian radius
Mean Gaussian radius: DDK vs. VDK

Periodic variations in mean Gaussian radius, especially for VDK1.
## Mean Gaussian radius: DDK vs. VDK

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<tr>
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</table>

Significant larger VDK SN radii compared to DDK
Closed-loop simulation

- Five years 01/2002-12/2006 based on GRACE-like mission design
- Initial altitude 490 km, final altitude 450 km
- Realistic instrument and background model errors applied
- Ground truth: ESA Earth system model AOHIS (Dobslaw et al. 2015)
- Software: GFZ’s Earth Parameters and Orbits System (EPOS)
- Maximum SH degree and order 100

Further details in Flechtner et al. (2016): *What Can be Expected from the GRACE-FO Laser Ranging Interferometer for Earth Science Applications?*
Simulated orbit coverage in 2003
Filtered residuals wrt. static reference in 08/2003

Surface mass densities in mm ewh.
Ocean/Land total RMS of the truth and the residuals for Destriping, DDK and VDK filters

- $C_{20}$ neglected
- Reference Gaussian filtered $\rightarrow$ omission error reduction
- 500 km land area extension
- RMS weighted by $\cos$(latitude)
- All months
Ocean/Land total RMS of the truth and the residuals for the different filters

- $C_{20}$ neglected
- Reference Gaussian filtered → omission error reduction
- 500 km land area extension
- RMS weighted by $\cos$(latitude)
- 2 bad months neglected
Ocean/Land total RMS of the truth and the residuals for the different filters

- $C_{20}$ neglected
- Reference Gaussian filtered → omission error reduction
- 500 km land area extension
- RMS weighted by cos(latitude)
- Linear and annual terms subtracted
Ocean/Land monthly RMS of the truth and the residuals for Destriping, DDK3 and VDK3 filters

- Reference 340 km Gaussian filtered → omission error reduction
- 500 km land area extension
- RMS weighted by cos(latitude)
Ocean/Land monthly RMS of the truth and the residuals for Destriping, DDK3 and VDK3 filters

- Reference 340 km Gaussian filtered \(\rightarrow\) omission error reduction
- 500 km land area extension
- RMS weighted by cos(latitude)
- Linear and annual terms subtracted
Ocean/Land total RMS of linear trend for the truth and the residuals for the different filters

- $C_{20}$ neglected
- Reference Gaussian filtered $\rightarrow$ omission error reduction
- 500 km land area extension
- RMS weighted by $\cos$(latitude)
Ocean/Land total RMS of annual amplitude for the truth and the residuals for the different filters

- $C_{20}$ neglected
- Reference Gaussian filtered → omission error reduction
- 500 km land area extension
- RMS weighted by $\cos$(latitude)
Basin analysis

• 13 basins for large and smaller rivers
• Simple integration mask
• Reference 300 km Gaussian filtered → omission error reduction
• Performance criteria:
  • Raw RMS of the difference wrt. the truth
  • Comparison of linear and annual parameters
  • RMS of linear and annual reduced residuals
### Raw residual RMS in mm ewh.

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<th>Basin #grid points</th>
<th>Basin Name</th>
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<th>DDK2</th>
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<td>14.7</td>
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</tr>
</tbody>
</table>

**Smallest residuals**
Linear and annual terms and residual RMS in mm ewh.

<table>
<thead>
<tr>
<th>Basin #grid points</th>
<th>Basin Name</th>
<th>Linear trend / year</th>
<th>Annual amplitude</th>
<th>Annual phase in day of max.</th>
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<td>450</td>
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</tbody>
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Smallest residuals Not significant
Real data analysis

GRACE GFZ RL05a solutions 2002 – 2017

7 day repeat cycle in 12/2009
Surface mass densities for 12/2009: DDK1/2, VDK1/2
GRACE short repeat cycles

- Altitude in km
- Revolution time in min.
- Equator gaps in km


EGU 2018, Vienna, Austria, 9 April 2018
RMS over ocean/land

Ocean RMS improvement VDK vs. DDK median: VDK5 (16%), VDK4 (18%)
Conclusions

• Time variable decorrelation filter using the most accurate error (and signal) VCM proposed for GRACE (and GRACE-Follow-On) data in order to account for changing sensitivity
• Candidate filter method for GFZ Level 3 processing (cf. Dahle et al., EGU2018-17878, Poster on the new GFZ Level 3 web portal GravIS)
• Closed-loop simulation results show
  – smallest global residuals for bad coverage months
  – better global retrieval of linear and annual terms than static DDK
  – smaller basin residuals compared to DDK and Destriping+Gaussian
• Real data analyses show a reduction of the total RMS over the oceans for the GFZ RL05a time series around 16% (VDK5 vs. DDK5) and 18% (4)
GRACE-like correlation RMS per SH order

Off diagonal correlations
- Parallel to main diagonal
  \( m_i - m_j = \text{const.} \)
- Perpendicular to main diag.
  \( m_i + m_j = \text{const.} \)

[Murböck et al., 2016, GSTM]
GRACE correlations, $m_i - m_j = \text{const.}$
GRACE correlations, $m_i + m_j = \text{const.}$

Effects of resonances for $m < 2 \cdot l_{\text{max}}$

[Source: Murböck et al., 2016, GSTM]