GRACE processing at TU Graz

Torsten Mayer-Gürr, Saniya Behzadpour, Andreas Kvas, Matthias Ellmer, Beate Klinger, Norbert Zehentner, and Sebastian Strasser

Institute of Geodesy
Graz University of Technology

COST-G meeting, Bern
2019-01-14
ITSG-Grace2018

(Almost) complete reprocessed GRACE time series.

- Static gravity field
  - degree/order 200
  - trend + annual signal
  - full normal equations in SINEX format

- Unconstrained monthly solutions
  - degree/order 60, 96, 120
  - full normal equations in SINEX format

- Daily Kalman filtered solutions
  - degree/order 40

- ifg.tugraz.at

Level 2: Monthly gravity fields

Postfit residuals

Least squares adjustment

\[ \Delta \hat{x} = (A^T (\sum^{-1}_{ii} A))^{-1} A^T \sum^{-1}_{ii} \Delta l \]

Reduced observations: Observed – computed (Background models)

Design matrix: Parametrization

Weight matrix: Inverse of the covariance matrix of reduced observations
Processing at TU Graz

Level2: Monthly gravity fields

Postfit residuals

Least squares adjustment

\[ \Delta \hat{x} = \left( A^T \sum^{-1} A \right)^{-1} A^T \sum^{-1} \Delta l \]

Reduced observations: Observed – computed (Background models)

Design matrix: Parametrization

Weight matrix: Inverse of the covariance matrix of reduced observations
Covariance matrix of reduced observations
Time series of postfit residuals

Residuals are clearly correlated!
Covariance matrix of reduced observations

Size: ca. 2 TerraByte

⇒ Divide into smaller blocks (max. 3 hours length = 2160 epochs)

⇒ Correlations between blocks are ignored
Covariance matrix of reduced observations

\[ \Sigma(\Delta l) = \Sigma_{KBR} + B \Sigma_{SCA} B^T + A \Sigma_{AOD} A^T \]

KBR & ACC noise (stationary)

SCA noise
Variance propagated to range rates

Background models uncertainties
Variance propagated to range rates
Covariance matrix of reduced observations

Covariance matrix

$$\Sigma(\Delta l) = \Sigma_{KBR} + B\Sigma_{SCA}B^T + A\Sigma_{AOD}A^T$$

- KBR & ACC noise (stationary)

Iterative procedure
1. Apriori covariance matrix
2. Solution via Least Squares Adjustment
3. Variance factor (amplitude) for each frequency via Variance Component Estimation (VCE)

Toeplitz matrix  ↔  Covariance function  ↔  Power Spectral density (PSD)
Covariance matrix of reduced observations

\[ \Sigma(\Delta l) = \Sigma_{KBR} + B\Sigma_{SCA}B^T + A\Sigma_{AOD}A^T \]

KBR & ACC noise (stationary)

Iterative procedure
1. Apriori covariance matrix
2. Solution via Least Squares Adjustment
3. Variance factor (amplitude) for each frequency via Variance Component Estimation (VCE)

Ellmer, Matthias (2018): Contributions to GRACE Gravity Field Recovery, Doctoral dissertation, Graz University of Technology, Graz, Austria. DOI: 10.3217/978-3-85125-646-8
Covariance matrix of reduced observations

Covariance matrix

$$\Sigma(\Delta l) = \Sigma_{KBR} + B \Sigma_{SCA} B^T + A \Sigma_{AOD} A^T$$

- Antenna offset correction
  - computed using level-1B orientation data (RL03).
  - increase opening angle $\alpha$: increase noise

- Variance propagation
  - Stationary noise for star camera observations.
  - Orientation uncertainties propagation to antenna offset correction.

Ellmer, Matthias (2018): Contributions to GRACE Gravity Field Recovery, Doctoral dissertation, Graz University of Technology, Graz, Austria. DOI: 10.3217/978-3-85125-646-8
Covariance matrix of reduced observations

Covariance matrix

\[
\Sigma(\Delta l) = \Sigma_{KBR} + B\Sigma_{SCA}B^T + A\Sigma_{AOD}A^T
\]

AOD1B is given as series of spherical harmonics (degree 180) every 3 hours

For variance propagation: Only daily mean (degree 40) are considered

Vector of daily spherical harmonics

\[
\mathbf{x}_{AOD} = \begin{pmatrix}
    x_1 \\
    x_2 \\
    \vdots \\
    x_{31}
\end{pmatrix}
\]

Covariance matrix: block Toeplitz matrix

\[
\Sigma_{AOD} = \begin{pmatrix}
    \Sigma_{11} & \Sigma_{12} & \Sigma_{13} \\
    \Sigma_{12}^T & \Sigma_{11} & \Sigma_{12}^T \\
    \Sigma_{13}^T & \Sigma_{12}^T & \Sigma_{11}
\end{pmatrix}
\]

Background models uncertainties

Variance propagation to range rates
The Updated ESA Earth System Model

Dobslaw et al. 2015
www.gfz-potsdam.de/section/earthsystemmodelling/services/esa-esm/

+ estimation of the errors in the AO component
The Perturbed De-Aliasing Model for ESA ESM

Dobslaw et al. 2015
www.gfz-potsdam.de/section/earthsystemmodelling/services/esa-esm/
The Perturbed De-Aliasing Model for ESA ESM

Estimation of signal/error covariance matrix from 10 years of simulated data

\[ \Sigma_{AOD} = \frac{1}{n} \sum_{i=1}^{n} x_i x_i^T \]

- Assumption of stationary noise
- Temporal correlations are modelled as autoregressive (AR) process of order 3

Dobslaw et al. 2015
www.gfz-potsdam.de/section/earthsystemmodelling/services/esa-esm/
Covariance matrix of reduced observations

Covariance matrix

\[ \Sigma(\Delta l) = \Sigma_{KBR} + B \Sigma_{SCA} B^T + A \Sigma_{AOD} A^T \]

- AOD1B is given as series of spherical harmonics (degree 180) every 3 hours
- For variance propagation: Only daily mean (degree 40) are considered

Vector of daily spherical harmonics

\[ \mathbf{x}_{AOD} = \begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_{31} \end{pmatrix} \]

Covariance matrix: block Toeplitz matrix

\[ \Sigma_{AOD} = \begin{pmatrix} \Sigma_{11} & \Sigma_{12} & \Sigma_{13} \\ \Sigma_{12}^T & \Sigma_{11} & \Sigma_{12}^T \\ \Sigma_{13}^T & \Sigma_{12}^T & \Sigma_{11} \end{pmatrix} \]

- For variance propagation: Integration of spherical harmonics to range rates (Design matrix \( A \))
Evaluation Using GRACE Data

Quiet ocean RMS:
- No model uncert.: 21.2 cm EWH

\[ \Sigma(\Delta l) = \Sigma_{KBR} + B \Sigma_{SCA} B^T + A \Sigma_{MOD} A^T \]
Evaluation Using GRACE Data

Quiet ocean RMS:
- No model uncert.: 21.2 cm EWH
- Model uncert. considered: 13.3 cm EWH

→ 37% RMS reduction

\[ \Sigma(\Delta l) = \Sigma_{KBR} + B\Sigma_{SCA}B^T + A\Sigma_{AOD}A^T \]
Covariance matrix of reduced observations

Covariance matrix

$$\Sigma(\Delta t) = \Sigma_{KBR} + B \Sigma_{SCA} B^T + A \Sigma_{AOD} A^T$$

- AOD1B is given as series of spherical harmonics (degree 180) every 3 hours
- For variance propagation: Only daily mean (degree 40) are considered

Vector of daily spherical harmonics

$$\mathbf{x}_{AOD} = \begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_{31} \end{pmatrix}$$

Covariance matrix: block Toeplitz matrix

$$\Sigma_{AOD} = \begin{pmatrix} \Sigma_{11} & \Sigma_{12} & \Sigma_{13} \\ \Sigma_{12}^T & \Sigma_{11} & \Sigma_{12}^T \\ \Sigma_{13}^T & \Sigma_{12}^T & \Sigma_{11} \end{pmatrix}$$

- For variance propagation: Integration of spherical harmonics to range rates (Design matrix \(A\))
Incorporation of Background Model Uncertainties into the Gravity Field Recovery Process

Andreas Kvas, Saniya Behzadpour, Matthias Ellmer, Beate Klinger, Sebastian Strasser, Norbert Zehentner, Torsten Mayer-Gürr

Institute of Geodesy
Graz University of Technology

GSTM 2018
2018-10-10, Potsdam
Gravity Field Recovery with Model Errors

- \( x \) ... gravity field parameters
- \( y \) ... model parameters

\[ l = f(x, y) \]

- evaluated using model output contaminated with (random) errors

\[ l = f(x, y_m) = f_m(x) \]

\[ y_m = y_t + y_e \quad y_e \sim N(0, \Sigma(y_m)) \]

- linearization wrt to \( x \)

\[ l = f_m(x_0) + \frac{\partial f_m}{\partial x} \bigg|_{x_0,y_m} (x - x_0) + \ldots \]

- observation equations

\[ l - f_m(x_0) = A\Delta x + e \]

\[ \Sigma(e)? \]

- covariance propagation

\[ \Sigma(e) = \Sigma(l) + B\Sigma(y_m)B^T \]

- least squares adjustment

\[ \hat{x} = x_0 + (A^T PA)^{-1} (A^T P\Delta l) \]

\[ P = (\Sigma(l) + B\Sigma(y_m)B^T)^{-1} \]
Gravity Field Recovery with Model Errors – Alternative Approach

\[ l = f(x, y) \]

linearization wrt to \( x \) and \( y \)

\[ l = f(x_0, y_m) + \frac{\partial f}{\partial x} (x - x_0) + \frac{\partial f}{\partial y} (y - y_0) + \cdots \]

add pseudo-observations

\[
\begin{align*}
l - f(x_0, y_m) &= A\Delta x + B\Delta y + e \\
0 &= l\Delta y + v
\end{align*}
\]

\[
\begin{align*}
\Sigma(e) &= \Sigma(l) \\
\Sigma(v) &= \Sigma(y_m)
\end{align*}
\]

blocked normal equations

\[
\begin{bmatrix}
A^T \Sigma(l)^{-1} A & A^T \Sigma(l)^{-1} B \\
B^T \Sigma(l)^{-1} B + \Sigma(y_m)^{-1}
\end{bmatrix}
\begin{bmatrix}
\Delta x \\
\Delta y
\end{bmatrix}
= \begin{bmatrix}
A^T \Sigma(l)^{-1} \Delta l \\
B^T \Sigma(l)^{-1} \Delta l
\end{bmatrix}
\]

least squares adjustment

\[ \hat{x} = x_0 + (A^T PA)^{-1} (A^T P \Delta l) \]

\[ P = (\Sigma(l) + B\Sigma(y_m)B^T)^{-1} \]

some tedious matrix algebra
Gravity Field Recovery with Model Errors

- Model uncertainties can be incorporated on both observation and parameter level
  - Either augmentation of the covariance matrix of observations,
  - or extension of the parameter space to include model corrections

\[
\Delta l = A \Delta x + e \\
\Sigma(e) = \Sigma(l) + B \Sigma(y_m) B^T
\]

\[
\equiv \\
\Delta l = A \Delta x + B \Delta y + e \\
\Sigma(e) = \Sigma(l) \\
0 = I \Delta y + v \\
\Sigma(v) = \Sigma(y_m)
\]

- For \( y_e \) ... assumed stationary \( \Rightarrow \Sigma(y_m) \) has Toeplitz structure
  - \( B y_e \) ... (observation level) non-stationary, depends on satellite position

- In this study, only dealiasing model errors are considered
  - Stochastic properties are drawn from the ESA ESM aoError sample time series
  - Covariance structure is approximated by fitting an autoregressive model (AR) of order three to the time series

AOD errors as additional term in the covariance matrix

<= identical result =>

Co-estimation of daily solutions with \( \Sigma_{AOD} \) as constraint
Processing at TU Graz

Level2: Monthly gravity fields

Least squares adjustment

\[ \Delta \hat{x} = \left( A^T \sum_{ii}^{-1} A \right)^{-1} A^T \sum_{ii}^{-1} \Delta l \]

Design matrix: Parametrization

Weight matrix: Inverse of the covariance matrix of reduced observations

Reduced observations: Observed – computed (Background models)

Postfit residuals
Level2: Monthly gravity fields

Least squares adjustment

\[ \Delta \hat{x} = \left( A^T \sum_{ii}^{-1} A \right)^{-1} A^T \sum_{ii}^{-1} \Delta l \]

Reduced observations:
Observed – computed
(Background models)

Design matrix:
Parametrization

Weight matrix:
Inverse of the covariance matrix
of reduced observations

Postfit residuals
Updated background models
# Background models

<table>
<thead>
<tr>
<th>Force models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static field + annual + trend</td>
</tr>
<tr>
<td>Atmosphere + Ocean</td>
</tr>
<tr>
<td>Hydrology</td>
</tr>
<tr>
<td>Astronomical tides</td>
</tr>
<tr>
<td>Earth tides</td>
</tr>
<tr>
<td>Ocean tides</td>
</tr>
<tr>
<td>Atmospheric tides</td>
</tr>
<tr>
<td>Pole tides</td>
</tr>
<tr>
<td>Ocean pole tides</td>
</tr>
<tr>
<td>Non-Conservative forces</td>
</tr>
<tr>
<td>Relativistic effects</td>
</tr>
</tbody>
</table>
### Background models

<table>
<thead>
<tr>
<th>Force models</th>
<th>ITSG-Grace2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static field + annual + trend</td>
<td>GOCO05s</td>
</tr>
<tr>
<td>Atmosphere + Ocean</td>
<td>AOD1B RL05</td>
</tr>
<tr>
<td>Hydrology</td>
<td>-</td>
</tr>
<tr>
<td>Astronomical tides</td>
<td>JPL DE421</td>
</tr>
<tr>
<td>Earth tides</td>
<td>IERS2010</td>
</tr>
<tr>
<td>Ocean tides</td>
<td>EOT11a</td>
</tr>
<tr>
<td>Atmospheric tides</td>
<td>van Dam, Ray 2010 (S1, S2)</td>
</tr>
<tr>
<td>Pole tides</td>
<td>IERS2010</td>
</tr>
<tr>
<td>Ocean pole tides</td>
<td>Desai 2004</td>
</tr>
<tr>
<td>Non-Conservative forces</td>
<td>Accelerometer L1B</td>
</tr>
<tr>
<td>Relativistic effects</td>
<td>IERS2010</td>
</tr>
</tbody>
</table>
## Background models

<table>
<thead>
<tr>
<th>Force models</th>
<th>ITSG-Grace2016</th>
<th>ITSG-Grace2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static field + annual + trend</td>
<td>GOCO05s</td>
<td>Internal GRACE+GOCE 2017</td>
</tr>
<tr>
<td>Atmosphere + Ocean</td>
<td>AOD1B RL05</td>
<td>AOD1B RL06</td>
</tr>
<tr>
<td>Hydrology</td>
<td>-</td>
<td>LSDM (submonthly part)</td>
</tr>
<tr>
<td>Astronomical tides</td>
<td>JPL DE421</td>
<td>JPL DE421</td>
</tr>
<tr>
<td>Earth tides</td>
<td>IERS2010</td>
<td>IERS2010</td>
</tr>
<tr>
<td>Ocean tides</td>
<td>EOT11a</td>
<td>FES2014b + GRACE estimates</td>
</tr>
<tr>
<td>Atmospheric tides</td>
<td>van Dam, Ray 2010 (S1, S2)</td>
<td>AOD1B RL06</td>
</tr>
<tr>
<td>Pole tides</td>
<td>IERS2010</td>
<td>IERS2010 (linear mean pole)</td>
</tr>
<tr>
<td>Ocean pole tides</td>
<td>Desai 2004</td>
<td>Desai 2004 (linear mean pole)</td>
</tr>
<tr>
<td>Non-Conservative forces</td>
<td>Accelerometer L1B</td>
<td>Accelerometer L1B</td>
</tr>
<tr>
<td>Relativistic effects</td>
<td>IERS2010</td>
<td>IERS2010</td>
</tr>
</tbody>
</table>
## Background models

<table>
<thead>
<tr>
<th>Force models</th>
<th>ITSG-Grace2016</th>
<th>ITSG-Grace2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static field + annual + trend</td>
<td>GOCO05s</td>
<td>Internal GRACE+GOCE 2017</td>
</tr>
<tr>
<td>Atmosphere + Ocean</td>
<td>AOD1B RL05</td>
<td>AOD1B RL06</td>
</tr>
<tr>
<td>Hydrology</td>
<td>-</td>
<td>LSDM (submonthly part)</td>
</tr>
<tr>
<td>Astronomical tides</td>
<td>JPL DE421</td>
<td>JPL DE421</td>
</tr>
<tr>
<td>Earth tides</td>
<td>IERS2010</td>
<td></td>
</tr>
<tr>
<td>Ocean tides</td>
<td>EOT11a</td>
<td></td>
</tr>
<tr>
<td>Atmospheric tides</td>
<td>van Dam, Ray 2010 (S1, S2)</td>
<td></td>
</tr>
<tr>
<td>Pole tides</td>
<td>IERS2010</td>
<td></td>
</tr>
<tr>
<td>Ocean pole tides</td>
<td>Desai 2004</td>
<td>Desai 2004 (linear mean pole)</td>
</tr>
<tr>
<td>Non-Conservative forces</td>
<td>Accelerometer L1B</td>
<td>Accelerometer L1B</td>
</tr>
<tr>
<td>Relativistic effects</td>
<td>IERS2010</td>
<td>IERS2010</td>
</tr>
</tbody>
</table>

**LDSM Hydrology model**
- reduced by annual, trend
- reduced by monthly mean
⇒ only submonthly part used as dealiasing

⇒ Definition of GRACE monthly not changed (contains full monthly hydrological signal)
### Background models

<table>
<thead>
<tr>
<th>Force models</th>
<th>ITSG-Grace2016</th>
<th>ITSG-Grace2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static field + annual + trend</td>
<td>GOCO05s</td>
<td>Internal GRACE+GOCE 2017</td>
</tr>
<tr>
<td>Atmosphere + Ocean</td>
<td>AOD1B RL05</td>
<td>AOD1B RL06</td>
</tr>
<tr>
<td>Hydrology</td>
<td>-</td>
<td>LSDM (submonthly part)</td>
</tr>
<tr>
<td>Astronomical tides</td>
<td>JPL DE421</td>
<td>JPL DE421</td>
</tr>
<tr>
<td>Earth tides</td>
<td>IERS2010</td>
<td>IERS2010</td>
</tr>
<tr>
<td>Ocean tides</td>
<td>EOT11a</td>
<td></td>
</tr>
<tr>
<td>Atmospheric tides</td>
<td>van Dam, Ray 2010 (S1, S2)</td>
<td>AOD1B RL06</td>
</tr>
<tr>
<td>Ocean pole tides</td>
<td>Desai 2004</td>
<td>Desai 2004 (linear mean pole)</td>
</tr>
<tr>
<td>Non-Conservative forces</td>
<td>Accelerometer L1B</td>
<td>Accelerometer L1B</td>
</tr>
<tr>
<td>Relativistic effects</td>
<td>IERS2010</td>
<td>IERS2010</td>
</tr>
</tbody>
</table>
Estimated ocean tides from GRACE data

- Complete GRACE time series
- Full normals: tides+daily+annual+trend
- Constrained towards FES2014b
- Contains atmospheric and ocean tides
- Introduced as new background model

Mm
Mf
Mtm

Q1
O1
P1
S1
N2
M2
S2

cos
sin

-5 mm 0 mm 5 mm

-10 mm -5 mm 0 mm 5 mm 10 mm

-20 mm -10 mm 0 mm 10 mm 20 mm

equivalent water height
Estimated ocean tides from GRACE data

- Complete GRACE time series
- Full normals: tides+daily+annual+trend
- Constrasted towards FES2014b
- Contains atmospheric and ocean tides
- Introduced as new background model

### M2 (GRACE estimates relative to FES2014b)

- $m_2 \cos \theta$
- $m_2 \sin \theta$

Equivalent water height:

- $-20$ mm
- $-10$ mm
- $0$ mm
- $10$ mm
- $20$ mm
Estimated ocean tides from GRACE data

- Complete GRACE time series
- Full normals: tides+daily+annual+trend
- Constraining towards FES2014b
- Contains atmospheric and ocean tides
- Introduced as new background model

\[ S1 \text{ (GRACE estimates relative to FES2014b)} \]
# Background models

<table>
<thead>
<tr>
<th>Force models</th>
<th>ITSG-Grace2016</th>
<th>ITSG-Grace2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static field + annual + trend</td>
<td>GOCO05s</td>
<td>Internal GRACE+GOCE 2017</td>
</tr>
<tr>
<td>Atmosphere + Ocean</td>
<td>AOD1B RL05</td>
<td>AOD1B RL06</td>
</tr>
<tr>
<td>Hydrology</td>
<td>-</td>
<td>LSDM (submonthly part)</td>
</tr>
<tr>
<td>Astronomical tides</td>
<td>JPL DE421</td>
<td>JPL DE421</td>
</tr>
<tr>
<td>Earth tides</td>
<td>IERS2010</td>
<td>IERS2010</td>
</tr>
<tr>
<td>Ocean tides</td>
<td>EOT11a</td>
<td>FES2014b + GRACE estimates</td>
</tr>
<tr>
<td>Atmospheric tides</td>
<td>van Dam, Ray 2010 (S1, S2)</td>
<td>AOD1B RL06</td>
</tr>
<tr>
<td>Pole tides</td>
<td>IERS2010</td>
<td>IERS2010 (linear mean pole)</td>
</tr>
<tr>
<td>Ocean pole tides</td>
<td>Desai 2004</td>
<td>Desai 2004 (linear mean pole)</td>
</tr>
<tr>
<td>Non-Conservative forces</td>
<td>Accelerometer L1B</td>
<td>Accelerometer L1B</td>
</tr>
<tr>
<td>Relativistic effects</td>
<td>IERS2010</td>
<td>IERS2010</td>
</tr>
</tbody>
</table>
Processing at TU Graz

Level2: Monthly gravity fields

Least squares adjustment

\[ \Delta \hat{x} = \left( A^T \sum_{ii}^{-1} A \right)^{-1} A^T \sum_{ii}^{-1} \Delta l \]

Reduced observations: Observed – computed (Background models)

Design matrix: Parametrization

Weight matrix: Inverse of the covariance matrix of reduced observations

Postfit residuals
Processing at TU Graz

Level 2: Monthly gravity fields

Postfit residuals

Least squares adjustment

\[ \Delta \hat{x} = \left( A^T \sum_{ii}^{-1} A \right)^{-1} A^T \sum_{ii}^{-1} \Delta l \]

Design matrix: Parametrization

Weight matrix: Inverse of the covariance matrix of reduced observations

Reduced observations: Observed – computed (Background models)
Parametrization
Parametrization

- Gravity field
  - Monthly spherical harmonics (degree = 60, 96, 120)
  - Daily spherical harmonics (degree = 40), constrained

- Orbit
  - Daily satellite state (position, velocity)

- Accelerometer
  - Bias per axis: cubic splines with 6 hour knot interval
  - Daily full 3x3 scale matrix: scale, rotation, shear

- KBR antenna center (x, y)
  - Monthly

Beate Klinger and Torsten Mayer-Gürr (2016): The role of accelerometer data calibration within GRACE gravity field recovery: Results from ITSG-Grace2016, Advances in space research, 1597, DOI 10.1016/j.asr.2016.08.007
Parametrization

- Gravity field
  - Monthly spherical harmonics (degree = 60, 96, 120)
  - Daily spherical harmonics (degree = 40), constrained

- Orbit
  - Daily satellite state (position, velocity)

- Accelerometer
  - Bias per axis: cubic splines with 6 hour knot interval
  - Daily full 3x3 scale matrix: scale, rotation, shear

- KBR antennca center (x, y)
  - Monthly

- Parametrization of special events
  (sun-shadow crossing, sun intrusion into star camera)
  - Signal events are identified beforehand in the monthly time series.
  - For each event the middle time is selected + Time margin.
  - disturbance range rate signals at each event using polynomial (degree 11).
  - The monthly variation of each signal: uniform cubic B-splines

Beate Klinger and Torsten Mayer-Gürr (2016): *The role of accelerometer data calibration within GRACE gravity field recovery: Results from ITSG-Grace2016*, Advances in space research, 1597, DOI 10.1016/j.asr.2016.08.007

GSTM-2018:
Saniya Behzadpour et. al.: *Reducing systematic errors in the GRACE observations using parametric models*

Paper is in preparation
Residuals (argument of latitude versus time)

One revolution

Equator

North pole

Equator

South pole

Equator

Time

June 2012

Derivation filtered residuals

[Color scale: -2 to 2 nm/s^2]
Residuals (argument of latitude versus time)
Residuals (argument of latitude versus time)

derivation filtered residuals

Sun intrusion into star camera baffle

Sun – shadow crossing
Residuals (argument of latitude versus time)

derivation filtered residuals

argument of latitude

June 2012

models
Residuals (argument of latitude versus time)
Residuals (argument of latitude versus time)
Residuals (argument of latitude versus time)
Processing at TU Graz

Level2: Monthly gravity fields

Postfit residuals

Least squares adjustment

\[ \Delta \hat{x} = \left( A^T (\sum_{\|}^{-1}) A \right)^{-1} A^T (\sum_{\|}^{-1}) \Delta l \]

Reduced observations: Observed – computed (Background models)

Design matrix: Parametrization

Weight matrix: Inverse of the covariance matrix of reduced observations
References

- Matthias Ellmer (2018): *Contributions to GRACE Gravity Field Recovery*, Doctoral dissertation, Graz University of Technology, Graz, Austria. DOI: 10.3217/978-3-85125-646-8


- Beate Klinger and Torsten Mayer-Gürr (2016): *The role of accelerometer data calibration within GRACE gravity field recovery: Results from ITSG-Grace2016*, Advances in space research, 1597, DOI 10.1016/j.asr.2016.08.007