<table>
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<tr>
<th><strong>Model name</strong></th>
<th>GO_CONS_GCF_2_TIM_R4</th>
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<tbody>
<tr>
<td><strong>Producer</strong></td>
<td>Graz University of Technology, Institute for Theoretical and Satellite Geodesy University of Bonn, Institute of Geodesy and Geoinformation TU München, Institute of Astronomical and Physical Geodesy</td>
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<tr>
<td><strong>Method</strong></td>
<td>Time-wise</td>
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| **Data period** | 01/11/2009 – 19/06/2012  
Effective data volume: approx. 26.5 months |
| **Max. degree** | 250 |
| **Input data** | **Orbit data:**  
SST_PKI: Kinematic GOCE orbits  
SST_PCV: Covariance Information related to kinematic orbits  
**Gradiometer data:**  
EGG_NOM: Level 2 gravity gradients in Gradiometer Reference Frame (GRF); rotations between inertial and gradiometer frame  
EGG_CCD: common mode accelerations in GRF |
| **Processing strategy** | Least squares solution using full normal equations for GPS-satellite to satellite tracking (SST) and 4 components of gradiometry.  
**GPS-SST:**  
– Full normal equations complete to degree/order 130, based on short-arc integral approach  
– Stochastic modeling: covariance information of kinematic orbits (SST_PCV)  
**Gravity gradiometry:**  
– Full normal equations complete to degree/order 250, based on gradiometer components $V_{XX}$, $V_{YY}$, $V_{ZZ}$, $V_{XZ}$ in the GRF.  
– Stochastic modeling by ARMA filtering of normal equations and right-hand side for the entire spectral range (full de-correlation), i.e. certain spectral components are not filtered out, but properly weighted. Filters adapted separately for 41 individual data segments.  
**Combination & constraints:**  
– Combination of GPS-SST and 4 gradiometer components by addition of normal equations.  
– Kaula regularization for near-zonal coefficients (related to polar gap) and for coefficients > degrees 180 to improve signal-to-noise ratio  
– Optimum relative weighting factors and regularization parameter determined by variance component estimation. |
| **Key characteristics** | – GOCE-only solution in a rigorous sense. No external gravity field information is used, neither as reference model, nor for constraining the solution.  
– SST processing changed from energy integral approach (releases 1 to 3) to short-arc integral method.  
– SGG processing strategy unchanged for all 4 releases of time-wise models.  
– Related variance-covariance information represents very well the true errors of the coefficients  
– Solution can be used for independent comparison and combination on normal equation level with other satellite-only models (e.g. GRACE), terrestrial gravity data, and altimetry.  
– Since in the low degrees the solution is based solely on kinematic GOCE orbits, it is not competitive with a GRACE model. |
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Model characteristics and validation results

One of the key characteristic of the time-wise processing method is the attempt to model the stochastic properties of the input data as realistically as possible. Concerning gravity gradiometry, the total data period from November 2009 to June 2012 is split into 41 segments (cf. Fig 1, bottom) in according to changes in the error behavior. Figure 1 (top) displays the ARMA filters used for building the metric of the normal equations for these 41 sub-segments, showing time-variations of the gradiometer performance mainly below an in the lower measurement bandwidth.

Figure 2 shows cumulative geoid height (left) and gravity anomaly errors (right) of the four TIM releases. The accuracy is about 3.2 cm / 0.9 mGal at degree/order 200 (100 km half wavelength) for the GOCE-TIM4 model.

The TIM models have been externally validated by independent GPS/leveling observations. Fig.3 shows the results for Germany (875 stations) and Japan (873). In Germany the RMS is about 4.5 cm at degree 200. Since GPS/leveling observations have errors of 2 to 3 cm, this number is very consistent with the 3.2 cm “formal” error in Fig. 2. From the results in Japan we can conclude that the pure GOCE-model TIM_R4 performs significantly better than EGM2008, even though the latter contains also terrestrial gravity data.