GOCE High Level Processing Facility Technical Note

TIM RL01 gravity field determination with reprocessed EGG_NOM_2 data

Doc. No.: GO-TN-HPF-GS-0301
Issue: 1
Revision: 0
Date: 16 / 05 / 2012

Prepared by: The European GOCE Gravity Consortium
EGG-C

Document Information Sheet

Document Name
TIM RL01 gravity field determination with reprocessed EGG_NOM_2 data

Document ID	Issue	Date
GO-TN-HPF-GS-0301	1.0	16.05.2012

Author	Institute
J.M. Brockmann, W.D. Schuh, I. Krasbutter	ITG
T. Gruber	IAPG
Contributions from	Institute
WP6000 Team	TUG, IAPG

Document Category	Document Class	Document Level

Configuration Item		Confidentiality Level

Appropriate Signatures		
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List	
DIL	NO
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1. ABSTRACT

This technical note summarizes a comparison between the RL 01 gravity field model determined by the time-wise approach EGM_TIM_RL01 with a reprocessed version EGM_TIM_RL01p_REPRO using the reprocessed gravity gradients (EGG_NOM_2 version 0101 products) based on the same data period, i.e. 01. Nov 2009 to 11. Jan 2010. The improvements caused by the L1B reprocessing are shown within the full-scale gravity field determination using the time-wise method. The gain is shown via a comparison to other models (ITG-Grace2010s, GOCO02S, EGM2008 and EGM_TIM_RL03). Significant improvements for all spherical harmonic degrees larger than 20 can be shown.

2. USED DATA

As meanwhile the reprocessed gravity gradient products (EGG_NOM_2 version 0101) are available for the data period which was used in the release 01 GOCE gravity field models, the EGM_TIM_RL01 was reprocessed using the reprocessed EGG_NOM_2 product. A full scale gravity field determination was performed, i.e. estimation of a decorrelation filter, outlier detection, estimation of spherical harmonics coefficients, its accuracies as well as the determination of relative weights (weighting the SST, SGG and the Kaula constraints). Note that the old (i.e. the same) PSO product as well as the same SST solution was used within this computation. Both models, the original release 01 EGM_TIM_RL01 and the reprocessed version EGM_TIM_RL01p_REPRO are summarized with some processing details in Table 2-1.

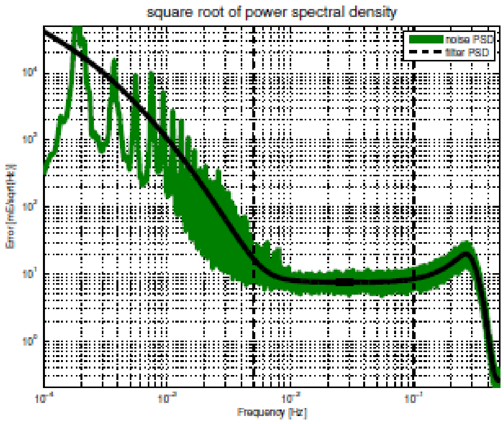
Table 2-1: Details about the observations used in the computation of both RL01 models (EGM_TIM_RL01 and EGM_TIM_RL01p_REPRO).

Model	SST NEQ	SGG Observations	Time Period
EGM_TIM_RL01	Energy Balance RL01	EGG_NOM_2 v00x	01. Nov. 2009-11. Jan. 2010
EGM_TIM_RL01p_REPRO	Energy Balance RL01	EGG_NOM_2 v101	01. Nov. 2009-11. Jan. 2010

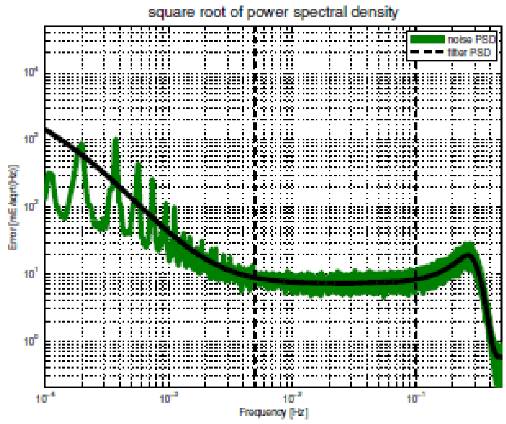
3. STOCHASTIC MODEL COMPARISON

As the data from 01. Nov 2009 to 11. Jan 2010 are gap-less, a single decorrelation filter is estimated for the complete data period for each of the diagonal tensor components. Based on SGG residuals after a full-scale gravity field determination, an ARMA process is adjusted to the residuals. The inverse process – i.e. the filter – is used within a second iteration as complete decorrelation filter within again a full scale gravity field recovery. The procedure is iterated, until the filter estimation does not change. For each component, a filter used in the processing of EGM_TIM_RL01 (left column) and the new filter used in the estimation of EGM_TIM_RL01p_REPRO (right column) is shown in Figure 3-1. The PSD of the adjusted filter is compared to the PSD of residuals. The figure shows the finally converged filters, thus the filters used in the final gravity field adjustment. Figure 3-2 shows the direct comparison of the filters determined for EGG_NOM_2v000x and EGM_TIM_RL01p_REPRO (left column). The strong decrease of noise due to the new L1B processing below the measurement bandwidth is clearly visible for all three components. Especially, for V_{xx} and V_{yy} a significant decrease of the noise within the MBW is visible (cf. Figure 3-2).

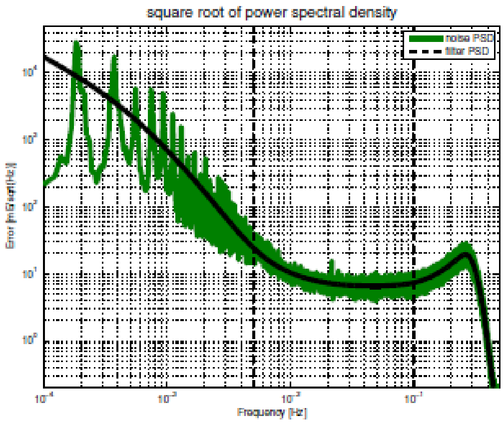
EGM_TIM_RL01 from EGG_NOM_2v000x   EGM_TIM_RL01p_REPRO from EGG_NOM_2v010



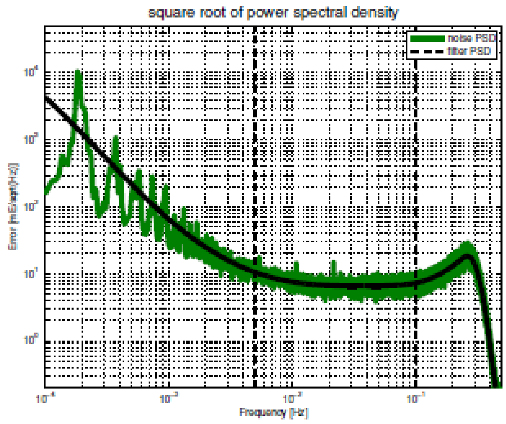
(a) EGM_TIM_RL01: V_{xx} PSD of SGG noise and adjusted filter



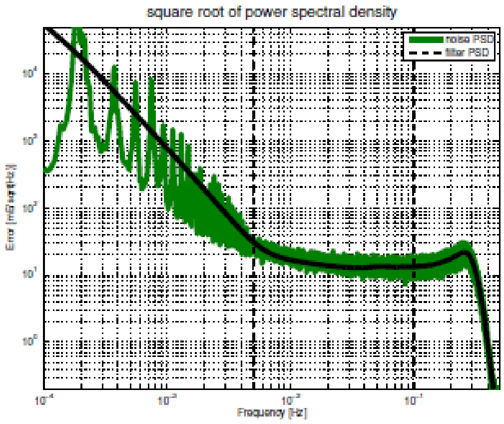
(b) EGM_TIM_RL01p_REPRO: V_{xx} PSD of SGG noise and adjusted filter



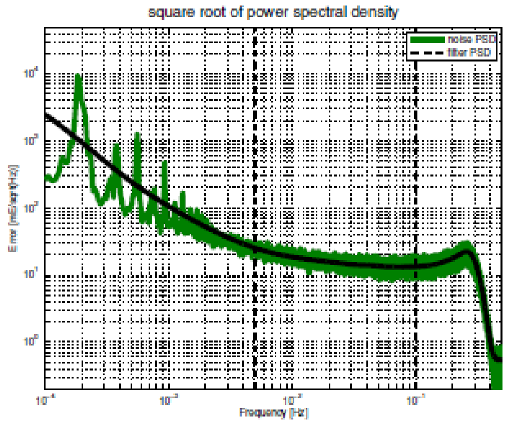
(c) EGM_TIM_RL01: V_{yy} PSD of SGG noise and adjusted filter



(d) EGM_TIM_RL01p_REPRO: V_{yy} PSD of SGG noise and adjusted filter

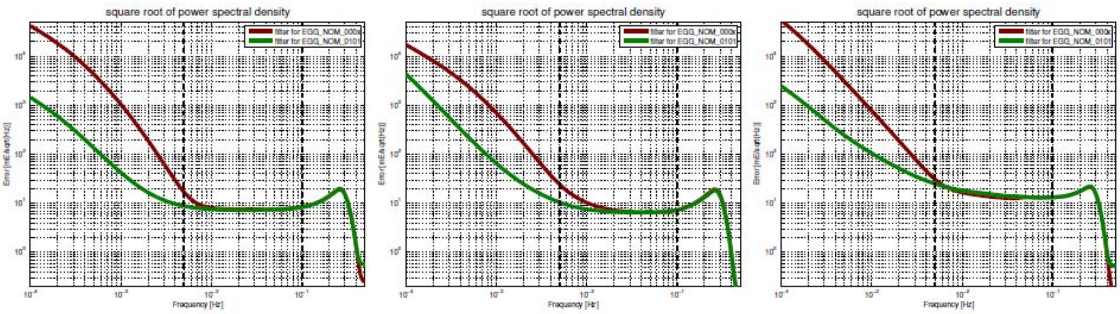


(e) EGM_TIM_RL01: V_{zz} PSD of SGG noise and adjusted filter



(f) EGM_TIM_RL01p_REPRO: V_{zz} PSD of SGG noise and adjusted filter

Figure 3-1: Estimated gradiometer noise from gravity field adjustment for the RL01 solutions from EGG_NOM_2v000x (EGM_TIM_RL01, left column) and EGG_NOM_2v0101 (EGM_TIM_RL01p_REPRO, right column)



(a) Comparision of filters for V_{xx} (b) Comparision of filters for V_{yy} (c) Comparision of filters for V_{zz}

Figure 3-2: Estimated filter model for the gradiometer noise for the RL01 solutions (EGG_NOM_2v000x, used in EGM_TIM_RL01, green) and for the reprocessed solution (EGG_NOM_2v0101, used in EGM_TIM_RL01p_REPRO, dark red)

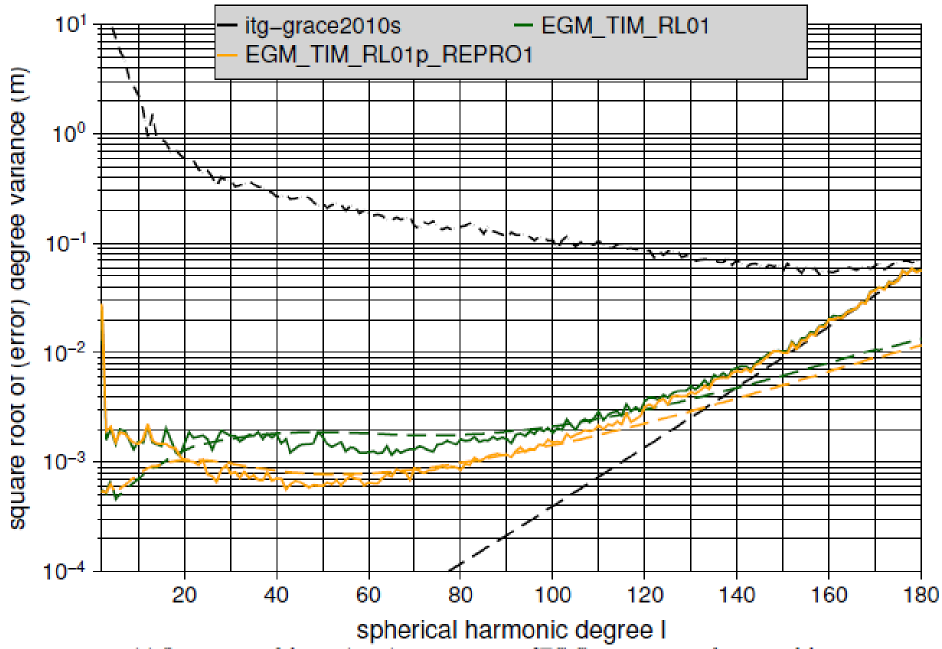
4. FULL SCALE GRAVITY FIELD SOLUTIONS

4.1 COMPARISON ON COEFFICIENT LEVEL

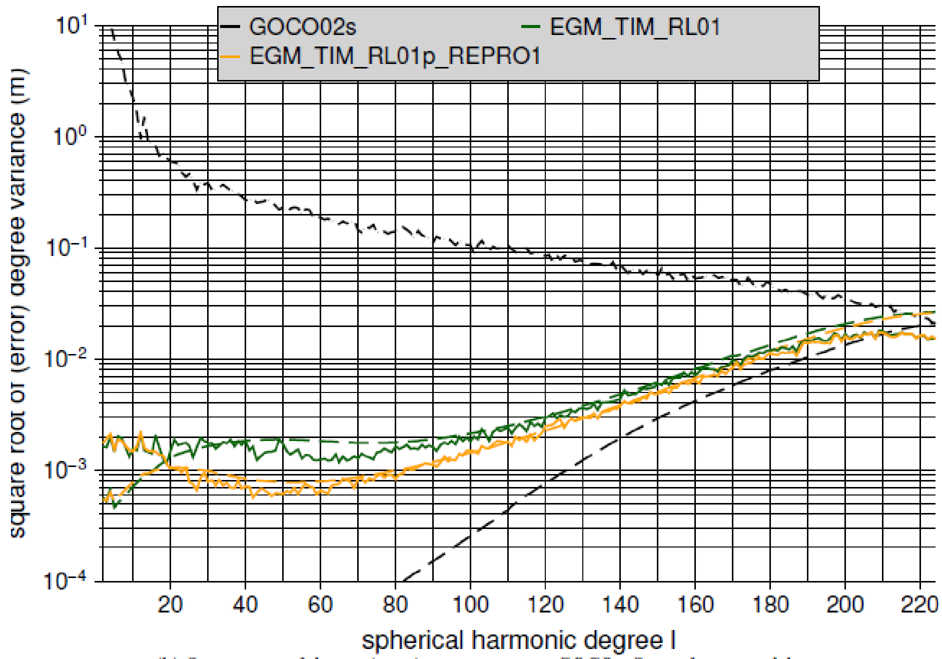
Using the filter iteratively adjusted to the SGG residuals, a final full gravity field solution was obtained. As for the EGM_TIM_RL01 solution, the spherical harmonic degrees 2 to 224 were resolved. The new solution EGM_TIM_RL01p_REPRO and the first release time-wise solution EGM_TIM_RL01 contain the same data period, thus the models are directly comparable. Figure 4-1(a) shows the square root of degree variances of both solutions (EGM_TIM_RL01 and the new EGM_TIM_RL01p_REPRO) with the ITGGrace2010s as reference model and Figure 4-1(b) the square root of degree variances w.r.t. the GOCO02S model. The GRACE model should be superior to both 2-months GOCE solutions for the lower degrees, GOCO02S should be superior for the whole degree range, as in addition to GRACE and CHAMP three times more GOCE data are included. Thus, it is expected to be more accurate also for the high degrees, where no GRACE contributes. Solid lines are the square root of degree variances from the difference to the reference model, dashed lines are the square root of degree error variances obtained from the estimated coefficient accuracies (i.e. the formal errors).

Analyzing Figure 4-1, it can be seen that the new solution EGM_TIM_RL01p_REPRO shows smaller errors w.r.t to the ITG-Grace2010s and w.r.t. the GOCO02S solution for nearly all spherical harmonic degrees. Note that for the new model, limited effort was spent on the estimation of the SST weight. Only the lowest degrees 2-20 which are nearly completely determined by SST do not show a significant change. The focus should be on degrees larger than 20, there the SGG observation mainly contribute. What ever model is used as reference, the decrease of the formal errors is affirmed with the decrease of the difference to the reference model. This again demonstrates the quality of the error estimations within the time-wise method. Figure 4-1 clearly demonstrates, that the reprocessed gradients improve the whole spherical harmonic spectrum (except the SST determined degrees 2-20). This is highlighted in Figure 4-2, which shows the improvement σ_l (EGM_TIM_RL01)/σ_l(EGM_TIM_RL01p_REPRO) in the square root of degree variances per degree. The maximal improvement of a factor of about 2.4 is for the coefficients of degree 50, the square root of degree variances is still a factor 1.19 larger for the first release at degree

169. The numbers for the improvements above degree 170 should be handled with care, as these coefficients are regularized in both solutions and might be very dependent and the convergence of the estimation of the used weight for regularization.



(a) Square root of degree (error) variances using ITG-Grace2010s as refernce model.



(b) Square root of degree (error) variances using GOCO02S as refernce model.

Figure 4-1: Square root of degree (error) variances comparing both models (EGM_TIM_RL01 and EGM_TIM_RL01p_REPRO) to a superior reference model (ITG-Grace2010s and GOCO02S) in terms of the square root of degree (error) variances (m). The near zonal coefficients are excluded in the computations. The solid lines are degree error variances estimated from the difference of the reference solution, the dashed lines are the degree error variances computed from the estimated coefficient accuracies.

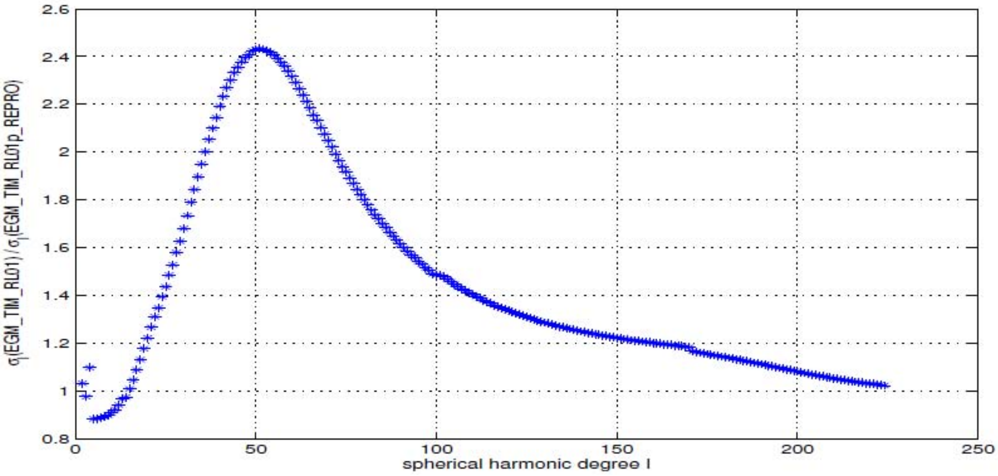
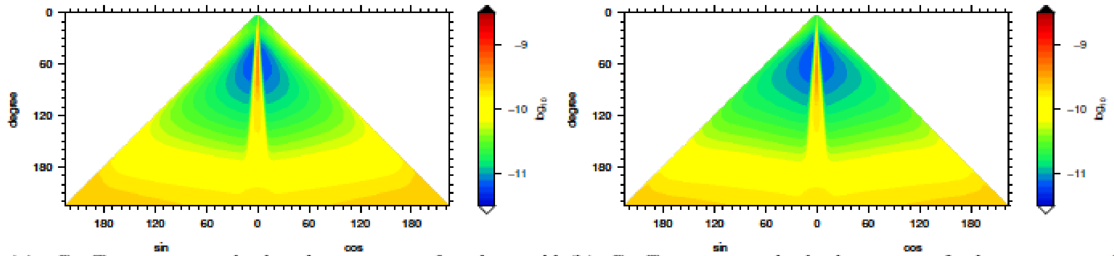


Figure 4-2: Quotient of the square root of degree error variances of EGM_TIM_RL01 and EGM_TIM_RL01p_REPRO. It indicates the mean improvement per degree. A number of 1.5 means that the square root of degree error variances for degree l in EGM_TIM_RL01 is a factor of 1:5 larger as the corresponding value computed from EGM_TIM_RL01p_REPRO.

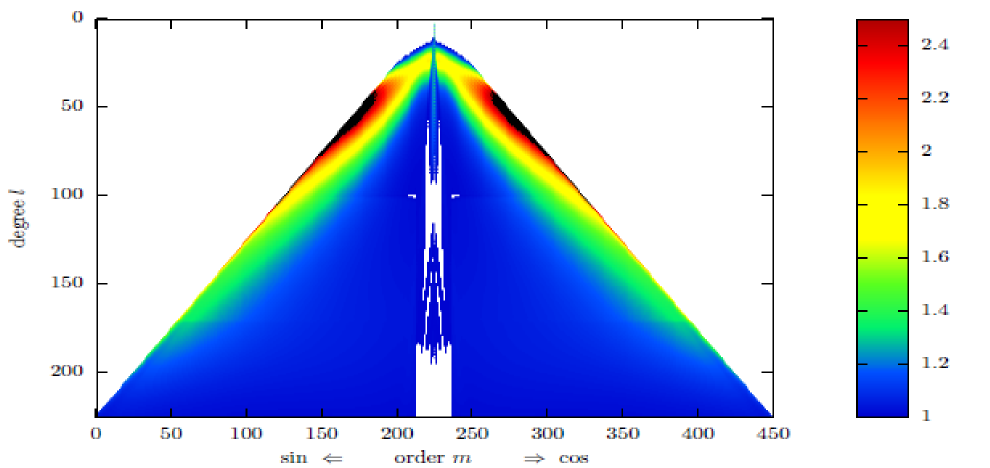
In contrast to the mean values per degree in terms of square roots of degree error variances, Figure 4-3(a) and Figure 4-3(b) show the estimated coefficient standard deviations for both solutions in the coefficient triangle. The ratio $\sigma_{l,m}$(EGM_TIM_RL01)/ $\sigma_{l,m}$(EGM_TIM_RL01p_REPRO) is shown within Figure 4-3. Again, the numbers indicate the improvement achieved from the L1B reprocessing, now in terms of in terms of accuracy for each individual coefficient. Sectorial coefficients are improved most (as they are most dependent of the signal below the MBW and they are most dependent on V_{yy}, which both improved most). The maximal factor which can be found is 3.75. Thus, the standard deviation of the old solution is 3.75 higher than in the reprocessed solution. Thus, it decreased to 25%. Still at degree 200 some the standard deviation of the old model is a factor of 1.2 larger than for the reprocessed one. The largest improvements in accuracies are for the standard deviations of the near sectorial coefficients of degree 20 - 100. The improvements in the estimated accuracies

are validated by Figure 4-3(d) and Figure 4-3(e) which displays coefficient differences to the GOCO02S model for both models. The difference for the sectorial coefficients for EGM_TIM_RL01p_REPRO becomes smaller. In addition, the stripes at orders 16/32/... (related to the peaks in the spectra at multiples of 1/revolution) are reduced in EGM_TIM_RL01p_REPRO, which are slightly visible in the difference to GOCO02S for EGM_TIM_RL01.

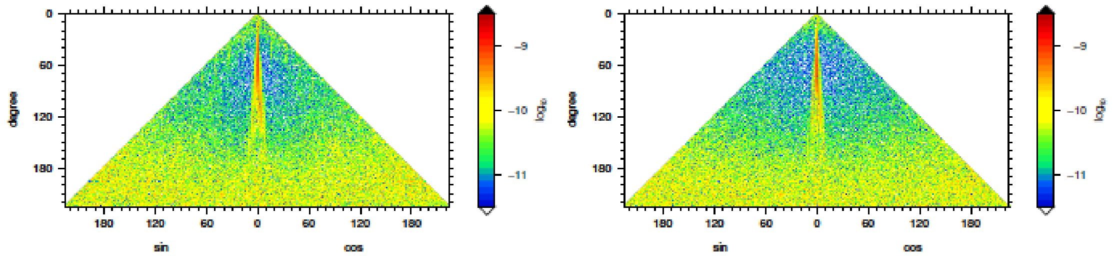


(a) Coefficients standard deviations of the old EGM_TIM_RL01 model.

(b) Coefficients standard deviation of the reprocessed EGM_TIM_RL01p_REPRO model.



(c) Ratio of the coefficients standard deviations $\sigma_{l,m}$(EGM_TIM_RL01)/$\sigma_{l,m}$(EGM_TIM_RL01p_REPRO. It indicates the improvement of each individual coefficients standard deviation. A number of 1.5 means that the standard deviation of a coefficient in EGM_TIM_RL01 is a factor of 1.5 larger as the corresponding value from EGM_TIM_RL01p_REPRO. Black corresponds to improvements lager then a factor of 2.5, white indicates a value smaller 1, corresponding to an increase of the standard deviation in the new EGM_TIM_RL01p_REPRO solution.



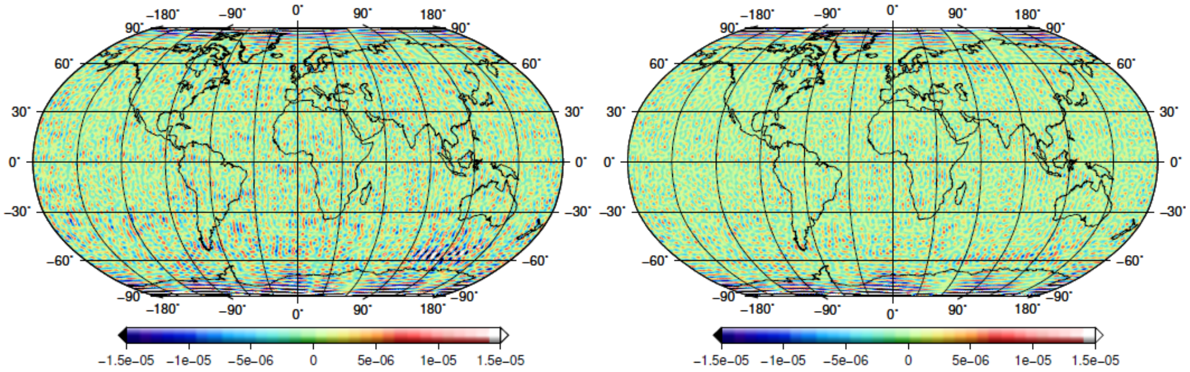
(d) Coefficients differences of the old EGM_TIM_RL01 model to GOCO02S.

(e) Coefficients differences of the old EGM_TIM_RL01p_REPRO model to GOCO02S.

Figure 4-3: Coefficients standard deviations of both models and their ratios plotted in the coefficient triangle. In addition coefficient differences to the GOCO02S model are shown for both models.

4.2 COMPARISON BASED ON GRAVITY FIELD FUNCTIONAL

To show the improvements in the spatial domain, gravity anomaly differences to the ITG-Grace2010s model and the EGM2008 model are computed for both 71day GOCE models (EGM_TIM_RL01 and EGM_TIM_RL01p_REPRO). The differences to ITG-Grace2010 to the spherical harmonic degree 120 are shown in Figure 4-4. The Table summarizes the statistics for both models. The statistics indicate (all values (min, max, rms) in all areas) that EGM_TIM_RL01p_REPRO comes closer to ITG-Grace2010s. The global rms (without the polar areas) reduces from 0.37mgal for EGM_TIM_RL01 to 0.30mgal for EGM_TIM_RL01p_REPRO which is a significant reduction of about 19%. The systematic effects, e.g. the South Australia anomaly are significantly reduced (as expected). In order to study the higher frequencies, gravity anomaly differences to EGM2008 are computed to spherical harmonic d/o 200 for both models. Figure 4-5 shows the differences and the corresponding statistics. The statistics indicate (all values (min, max, rms) in all areas) that EGM_TIM_RL01p_REPRO is more consistent to EGM2008 than EGM_TIM_RL01. In some areas (e.g. Germany 13% or global 6.5%) the rms is significantly reduced from release EGM_TIM_RL01 to the reprocessed model EGM_TIM_RL01p_REPRO. The positive effect of L1B reprocessing is affirmed by the anomaly comparisons to EGM2008 also at degree and order 200.



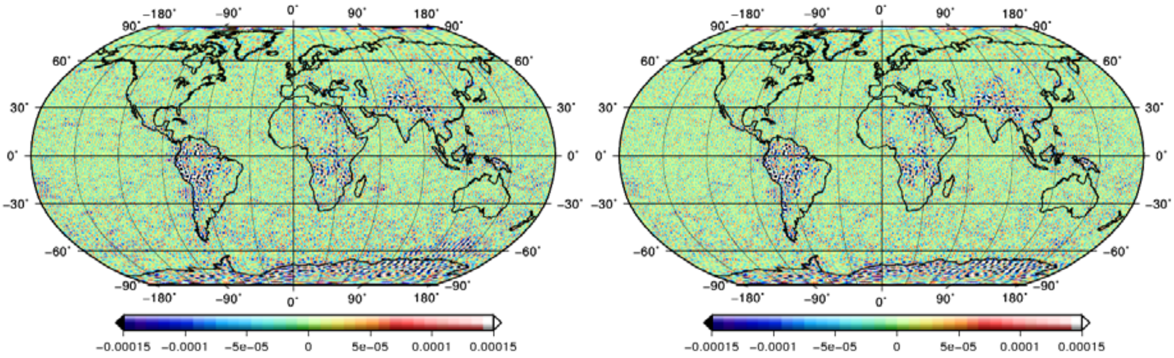
(a) Gravity anomalies (m/s^2) of EGM_TIM_RL01 as a difference to the ITG-Grace2010s model to d/o 120.

(b) Gravity anomalies (m/s^2) of EGM_TIM_RL01p_ REPRO as a difference to the ITG-Grace2010s model to d/o 120.

area	EGM_TIM_RL01 min mgal	max mgal	mean mgal	rms mgal	EGM_TIM_RL01p_REPRO min mgal	max mgal	mean mgal	rms mgal	reduction of rms %
±90°	-41.55	63.94	0.45	5.33	-49.63	62.01	0.01	5.20	2.4
±80°	-2.94	2.84	0.00	0.37	-2.57	2.17	0.00	0.31	18.9
Germany	-0.81	1.01	0.03	0.30	-0.73	0.80	0.00	0.23	23.3
North Atlantic	-1.00	0.84	-0.01	0.29	-0.78	0.64	0.00	0.23	22.4

(c) Statistics for the differences

Figure 4-4: Gravity anomaly differences of both GOCE 71 day models to the ITG-Grace2010s model to d/o 120.



(a) Gravity anomalies (m/s^2) of EGM_TIM_RL01 as a difference to the EGM2008 model to d/o 200.

(b) Gravity anomalies (m/s^2) of EGM_TIM_RL01p_REPRO as a difference to the EGM2008 model to d/o 200.

area	EGM_TIM_RL01				EGM_TIM_RL01p_REPRO				reduction
	min mgal	max mgal	mean mgal	rms mgal	min mgal	max mgal	mean mgal	rms mgal	of rms %
±90°	-74.54	71.26	0.46	7.60	-74.16	63.68	-0.02	7.15	5.8
±80°	-74.54	64.08	0.00	4.76	-74.16	63.68	0.00	4.45	6.5
Germany	-10.65	11.49	0.09	3.92	-10.05	10.9	0.05	3.46	13.3
North Atlantic	-10.84	9.77	0.00	3.13	-10.67	9.32	0.01	3.04	2.9

(c) Statistics for the differences

Figure 4-5: Gravity anomaly differences of both GOCE 71 day models to the EGM2008 model to d/o 200.

5. COMPARISON OF THE EGM_TIM_RL03 TO THE REPROCESSED RL01

To demonstrate the improvement of reprocessing, Figure 5-1 shows the square root of degree error variances of the first and third time-wise releases and the newly reprocessed release 01 to ITG-Grace2010s. A nice conclusion can be drawn: For the spherical harmonic degrees 20-60 the newly processed RL01 (EGM_TIM_RL01p_REPRO) is at least of same quality as the third-generation EGM_TIM_RL03 model (even better for some degrees). Some strange features are removed in the new solution.

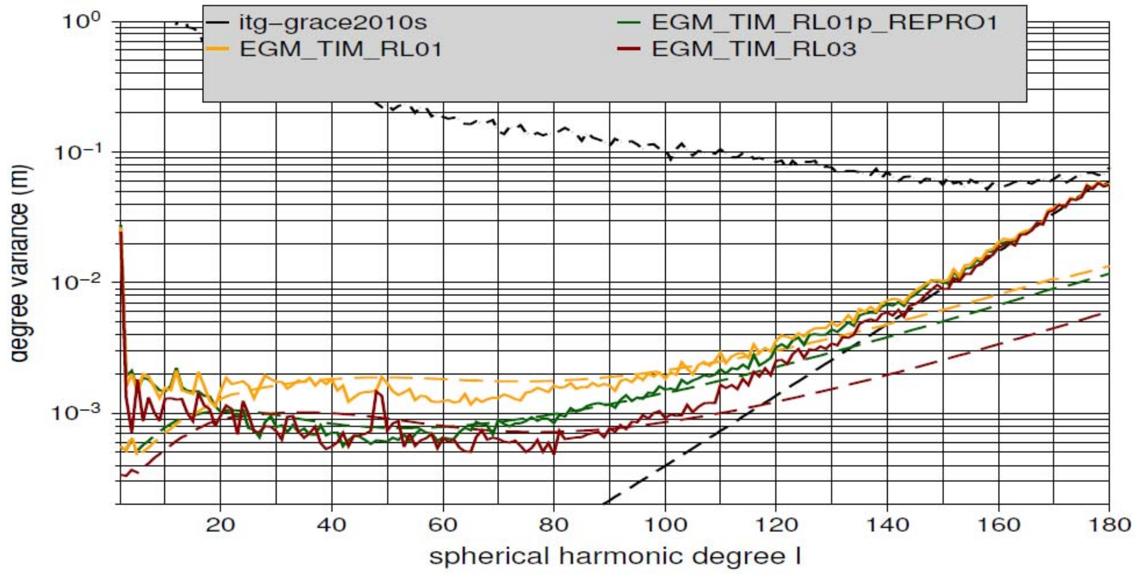


Figure 5-1: Square root of degree (error) variances using ITG-Grace2010s as reference model

6. EXTERNAL VALIDATION OF THE REPROCESSED RL01 MODEL

In order to identify the external performance of the reprocessed RL01 model a few comparisons to external GPS Levelling data in various regions have been performed. Geoid differences to the GPS Levelling data sets were computed for truncations degrees between degree and order 100 and 200 in steps of 10 in order to investigate the behavior of the model for various resolutions. RMS of differences per region were computed and plotted for the different truncation degrees (see Figure 6-1 and Figure 6-2). The omission error basically is estimated from EGM2008. Therefore this model shall be regarded as reference with an identical RMS difference for all truncation degrees. From Figure 6-1 and Figure 6-2 it is obvious that for nearly all regions under test significant improvements could be reached with the reprocessed model compared to the original release 1 model. Even if the reprocessed data mainly improve the low to medium frequencies of the GOCE gravity gradients these improvements are propagated to the higher frequencies as well. One can argue that by improving the long wavelength geoid finally also the total estimated geoid accuracy is increased. This is well visible in Figure 6-1and Figure 6-2 where the release 1 model curves in many cases are quasi parallel at a lower level up to a truncation degree and order 200.

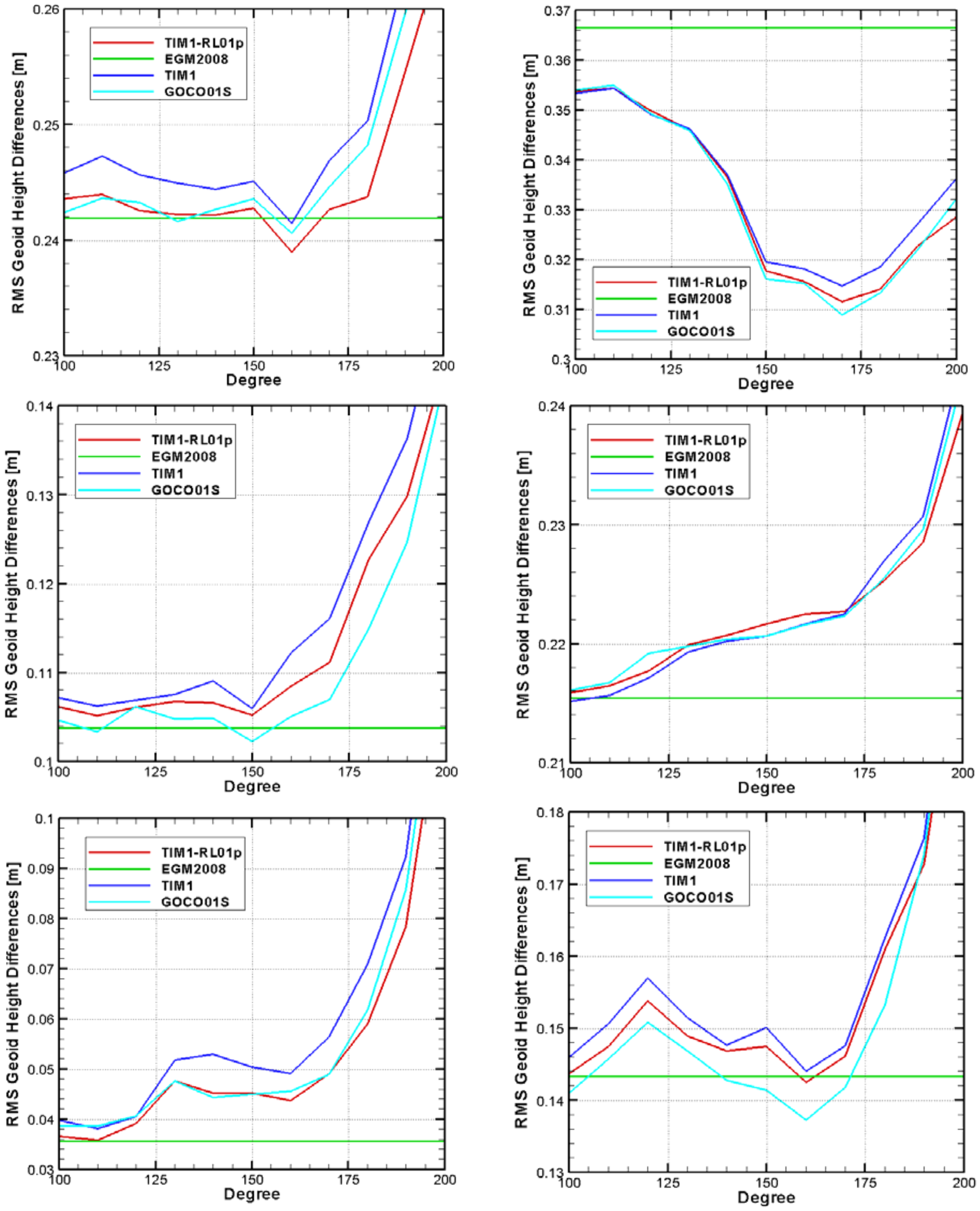


Figure 6-1: RMS of geoid height differences for release 1 gravity fields TIM1-RL01p (reprocessed release 1 model), TIM1 (original release 1 model), GOCO01S (combined TIM1 and ITG-GRACE2010S model) and EGM2008 as reference model for truncation degrees between 100 and 200 (in steps of 10) for various regions. Top left: Australia; top right: Brazil; middle left: Canada; middle right: European unified data set; bottom left: Germany; bottom right: Greece.

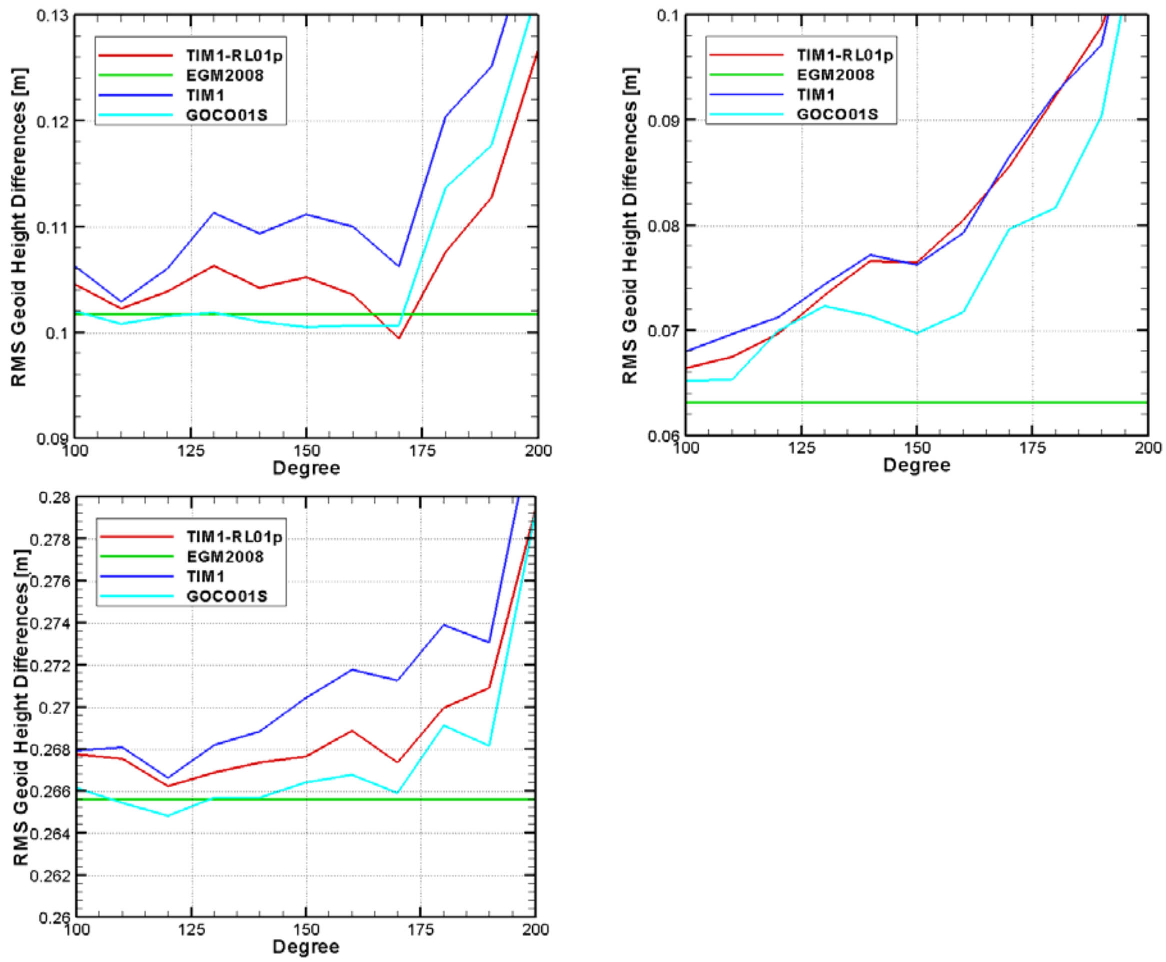


Figure 6-2: RMS of geoid height differences for release 1 gravity fields TIM1-RL01p (reprocessed release 1 model), TIM1 (original release 1 model), GOCO01S (combined TIM1 and ITG-GRACE2010S model) and EGM2008 as reference model for truncation degrees between 100 and 200 (in steps of 10) for various regions. Top left: Japan; top right: United Kingdom; middle left: USA.

7. CONCLUSIONS

Following conclusion can be be drawn for the reprocessing of the first gravity field time-wise release with reprocessed L1B gravity gradients:

- The reprocessed gravity gradients result in a significant improvement of the gravity field for all spherical harmonic degrees.
- The largest improvements can be seen for the spherical harmonic degrees 20-100. The sectorial coefficients improved most, which could have been expected, as they are mainly determined from V_{yy} and the frequencies below the MBW. Both parts of the noise spectra mainly improved in L1B reprocessing.
- For individual coefficients the standard deviation decreases to 1/3.75 = 0.27, $c_{60,60}$) compared to the standard deviation of the coefficients estimated from the old L1B data. Individual coefficients have a brilliant benefit of L1B reprocessing.

- Sectorial coefficients benefit significantly to degree 170, for higher degrees, benefit might be hidden by the regularization starting at 170.
- Improvements in the coefficients are approved also via gravity anomaly comparisons to ITG-Grace2010s (20% rms reduction at d/o 120) and EGM08 (3-13% rms reduction at d/o 200).
- Improvements are confirmed by external validation with independent GPS Levelling geoid data.
- The results approve the time-wise strategy to use the complete gravity gradient spectra within gravity field estimation. The gain is expected to be much smaller, if the focus is just put to the MBW applying band-pass filters.

The results found for the 71-day GOCE-only solution are promising for the complete reprocessing. Nevertheless we should keep in mind that the effects were worst for November and December 2009 data. The shown solution, denoted EGM_TIM_RL01p_REPRO is a first test. There might be additional improvements in optimizing the relative weights (there was made not such much effort within this first attempt), the same holds for outlier detection. Anyway thanks to Claudia Stummer and Christian Siemes and the PDS team, who spent a lot of efforts on the L1B reprocessing.