GOCESeaComb

External calibration/validation of ESA's GOCE mission and contribution to DOT and SLA determination through stochastic combination with heterogeneous data

Newsletter Issue 7/31.08.2013

GOCESeaComb

The **GOCESeaComb** project is funded by the European Space Agency (ESA) within its Scientific Experiment Development Program (PRODEX) following a successful application to the General Secretariat for Research & Technology (GSRT) after an invitation to the Greek scientific community in response to the 1st PRODEX Programme Call for Greece.

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GOCESeaComb

The GOCESeaComb Project Logo

GOCESeaComb validation in the spectral domain and external validation with terrestrial data

During the period of this newsletter and since the last newsletter in June 2013, all project activities are going according to schedule. These refer to the completion of the actual validation of the available GOCE/GRACE GGMs in terms of the GOCE contribution brought to gravity field and geoid approximation.

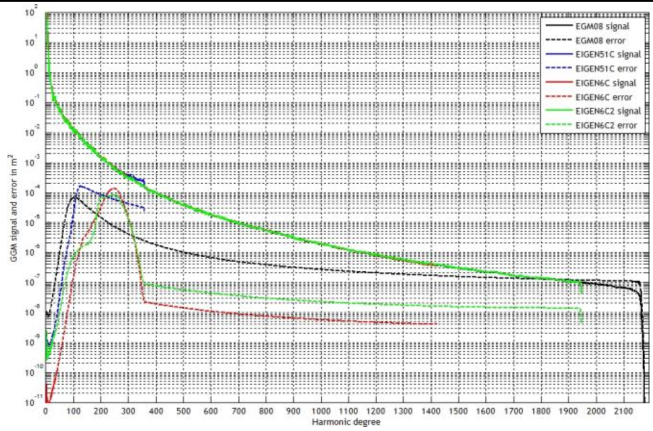
GOCESeaComb spectral Validation of GOCE/GRACE GGMs

GOCE data validation is performed following three main approaches. ***The first one*** refers to the evaluation of the GOCE/GRACE based GGMs signal and error in the form of the provided degree and error variances. ***The second*** refers to an external evaluation of the GGMs against the local gravity and GPS/Leveling data for various degrees of GGM expansion. ***The third one*** will be based on the evaluation of the spectral content of the GOCE/GRACE GGM via a wavelet-based and FFT-based multi-resolution analysis.

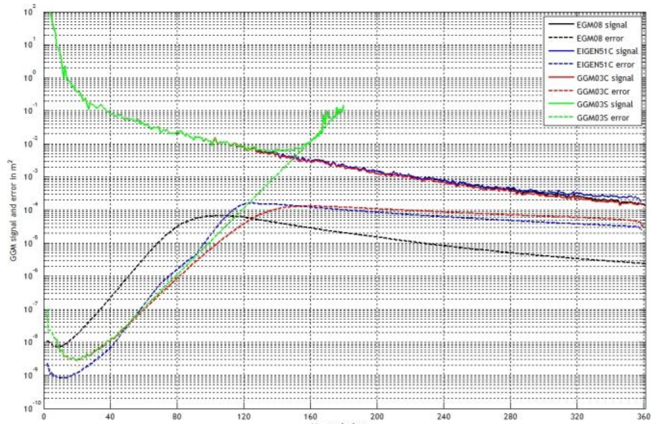
In a first step, we evaluated the GGM spectrum with the coefficients and their errors as provided from the GRACE-only, GOCE-only, and combined GGMs. In all cases the EGM2008 signal and error were be used as reference. Against EGM2008 we also determined the GOCE-based GGM gain in 2D and 1D (per degree). The same was be performed for anomaly error degree variances for the same models, so that the corresponding RMS anomaly differences per degree was computed. In this process, the spherical harmonic coefficients and their errors were used to determine signal power, error, rms signal power and rms signal error by degree and cumulatively for all GGMs.

Within the same frame, the harmonic coefficients and their errors for each GGM were evaluated as well in terms of a normalized log plot. The evaluation refers to all available TIM, DIR, GOCO, EIGEN, SPW and GRACE models available today. An example of this evaluation is presented in Figure 1 below, where the TIM R4, DIR-R4, coefficients are depicted along with their errors. The signal degree variances represent the amount of the signal contained in each degree or up to a specific degree (if computed cumulatively), while the error degree variances represent the error of the model up to a specific degree.

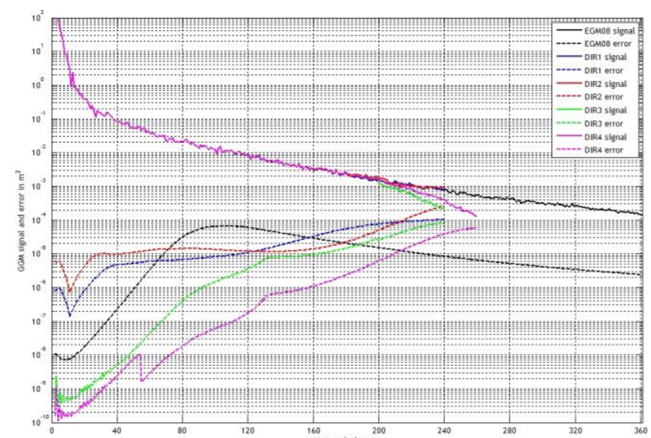
An example is shown in the figure on the left panel (Figure 2) where the geoid signal and error degree variances are depicted (by degree) for various GOCE, GOCE/GRACE and combined GGMs. Furthermore, Figure 3 depicts the cumulative geoid errors for the latest TIM-R4, DIR-R4, GOCO03S, and EIGEN6C2 models.



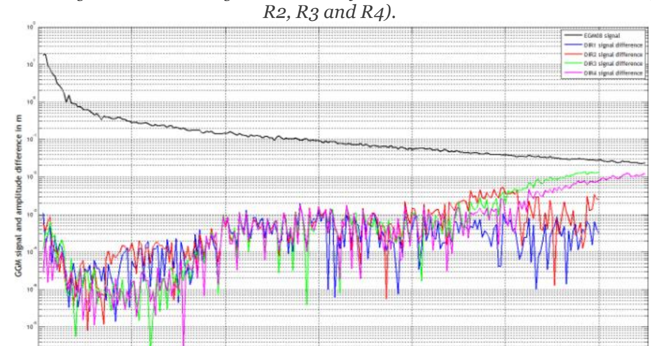
Geoid degree and error degree variances for the EGM08, EIGEN51C, EIGEN6C and EIGEN6c models.



Geoid degree and error degree variances for the EGM08, EIGEN51C, GGM03C and GGM03S models.



Geoid degree and error degree variances for the EGM08 and DIR models (R1, R2, R3 and R4).



Geoid height amplitude differences for the DIR models (R1, R2, R3 and R4), w.r.t., EGM08.

Figure 2: *Spectral evaluation of GOCE/GRACE GGMs*

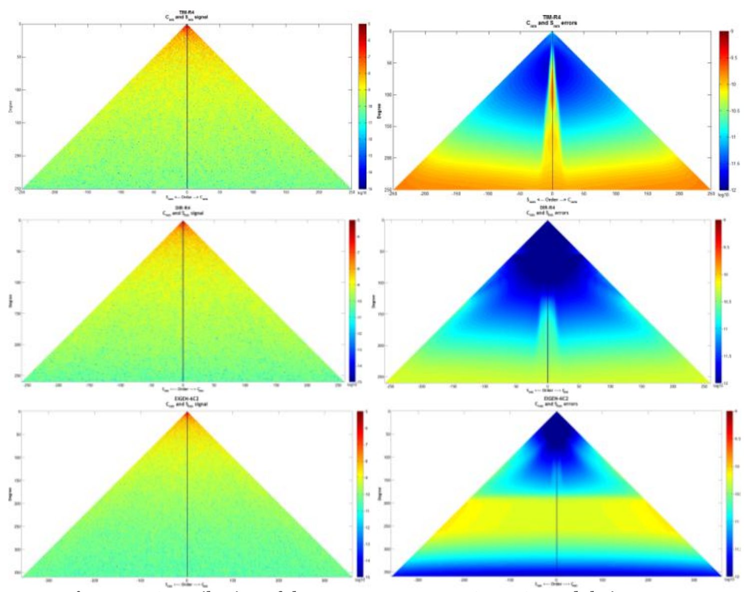
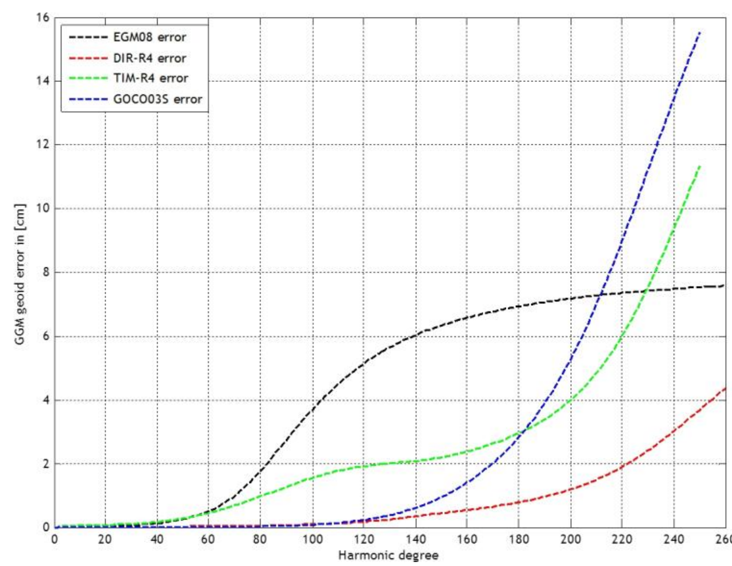


Figure 1: *Contribution of the TI-R4, DIR-R4, EIGEN6C2 and their errors.*



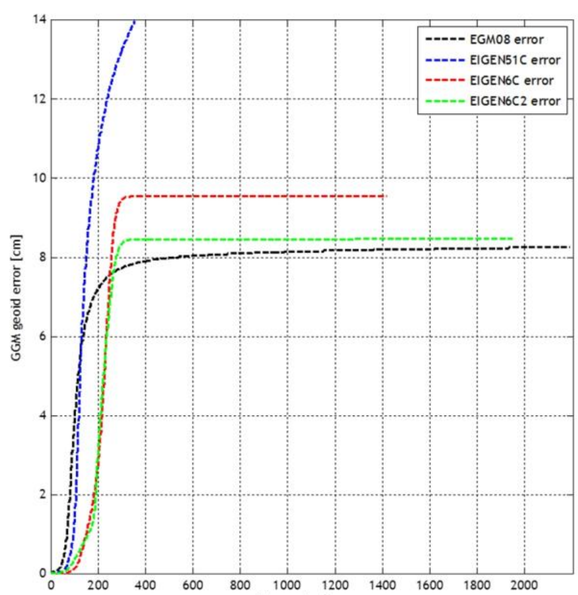
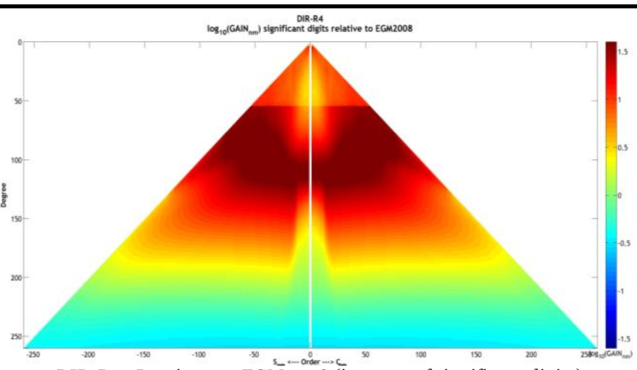
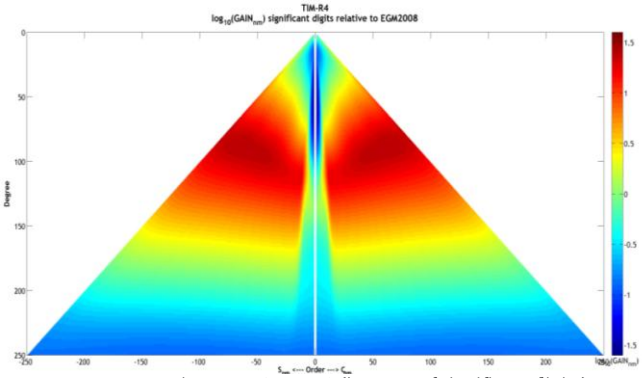


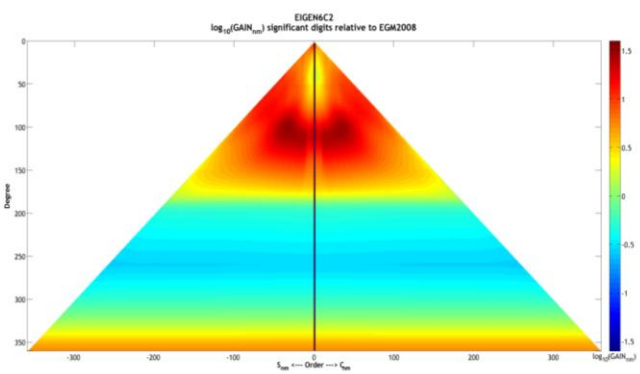
Figure 3: *Cumulative geoid errors from TI-R4, DIR-R4, GOCO03S and EIGEN6C2.*



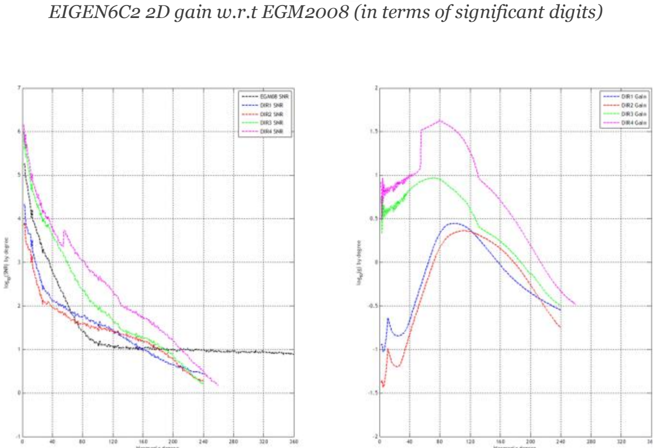
DIR-R4 2D gain w.r.t EGM2008 (in terms of significant digits)



TIM-R4 2D gain w.r.t EGM2008 (in terms of significant digits)



EIGEN6C2 2D gain w.r.t EGM2008 (in terms of significant digits)



DIR-R4 1D SNR and gain w.r.t EGM2008 (in terms of significant digits)

Figure 4: *Gain and SNR for GOCE/GRACE GGMs.*

Moreover, difference degree variances have been determined between coefficients from CHAMP-only, GRACE-only and GOCE-only GGMs with the coefficients provided by EGM008 as reference. An example of the evaluation of the amplitude differences is shown in Figure 2 (bottom) where the geoid signal differences, relative to EGM2008, for all DIR models (DIR1, DIR2, DIR3 and DIR4) are presented. Additionally, the gain offered by the GOCE GGMs, in terms of significant digits, compared to EGM2008 has been evaluated in both a 2D and 1D mode. Figure 4 depicts the results from this analysis for the DIR-R4, TIM-R4 and EIGEN6C2 models.

The second validation methodology refers to an external evaluation of the GGMs against the local gravity, deflection of the vertical and GPS/Leveling data for various degrees of GGM expansion. In this process we evaluated both absolute as well as relative differences of the GPS/Leveling geoid heights and GGM geoid heights in order to evaluate the performance of the latter within the well-known leveling by GPS scheme. An example of such this analysis is shown in Figure 5, where absolute and relative geoid height differences are plotted as a function of the baseline length. Within the same frame, the GOCE-based GGMs have been evaluated per-degree with fill-in information from EGM2008 and RTM effects, corresponding to a maximum degree of expansion equal to 216,000. From this analysis, the useful waveband of the GOCE-based GGMs has been determined, showing a 2 cm improvement relative to EGM2008. Figure 6, 7 and 8 depict the results acquired for the DIR, TIM and EIGEN models in terms of the std of the differences with GPS/Leveling geoid heights. Note that the latter, i.e., EIGEN6C2 is consistently better than EGM2008 for the entire spectrum. The same analysis has been carried out for the comparison with the local gravity data, where combined GGMs (augmented with EGM2008 and RTM effects) have been compared with terrestrial gravity data over Greece. The results, in terms of the std of the reduced fields are presented in Figure 9.

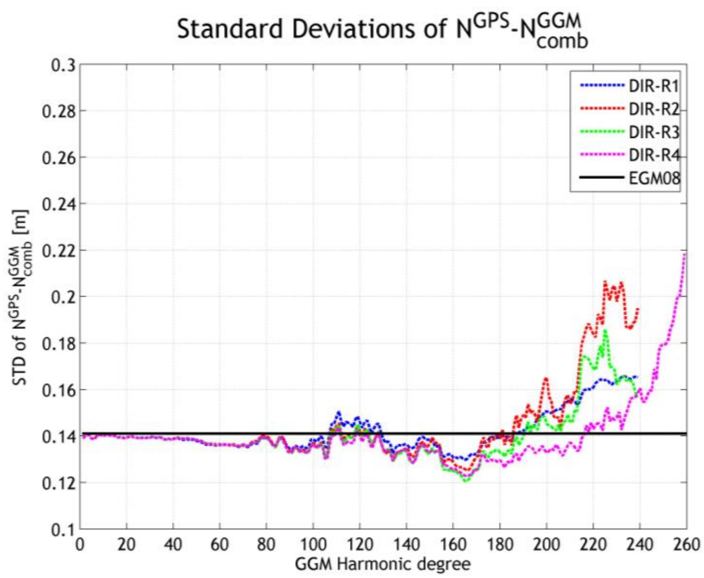
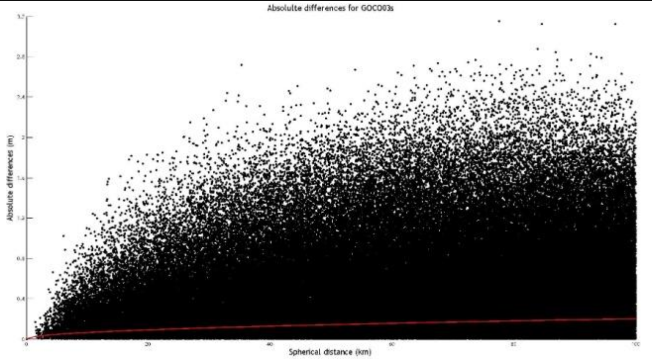
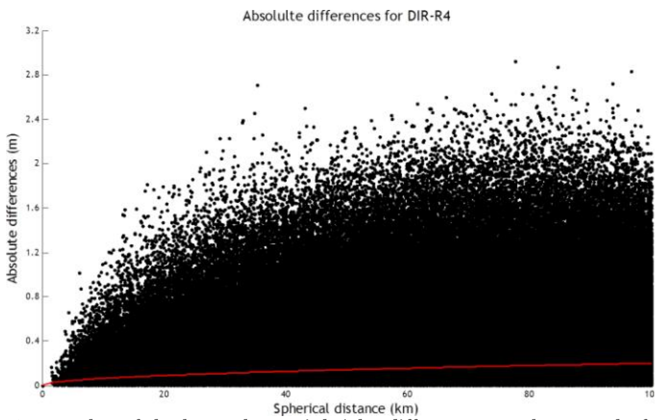


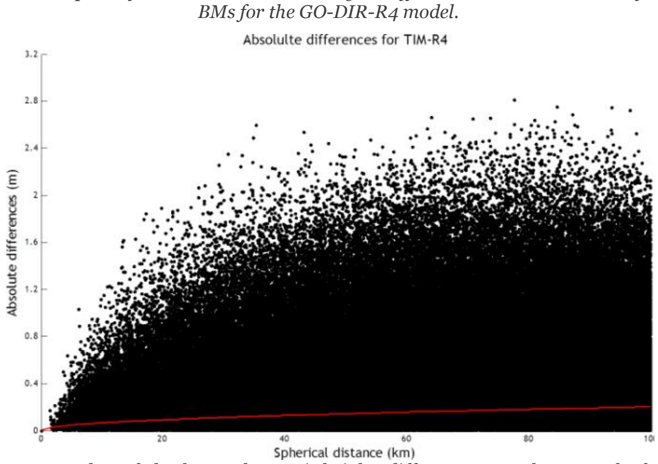
Figure 6: *std's of geoid height differences between combined DIR GGMs and GPS/Leveling geoid heights.*



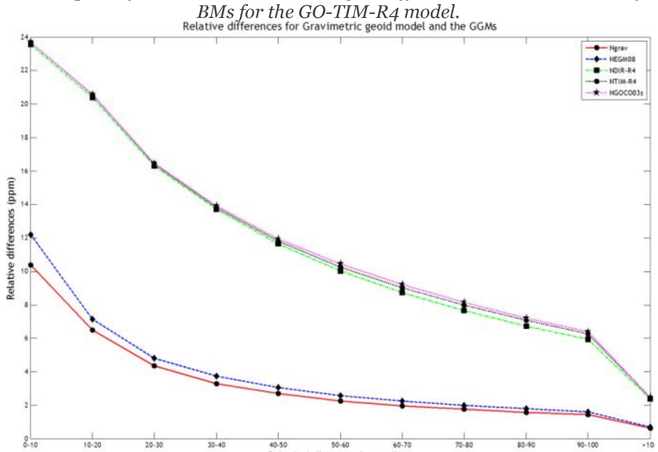
Scatter plot of absolute orthometric heights differences over the network of Greek BMs for the GOCO03S model



Scatter plots of absolute orthometric heights differences over the network of BMs for the GO-DIR-R4 model.



Scatter plots of absolute orthometric heights differences over the network of BMs for the GO-TIM-R4 model.



Relative geoid heights differences over the network of BMs for the EGM08, DIR-R4, TIM-R4, GOCO03S and local models.

Figure 5: *External validation of GOCE/GRACE GGMs.*

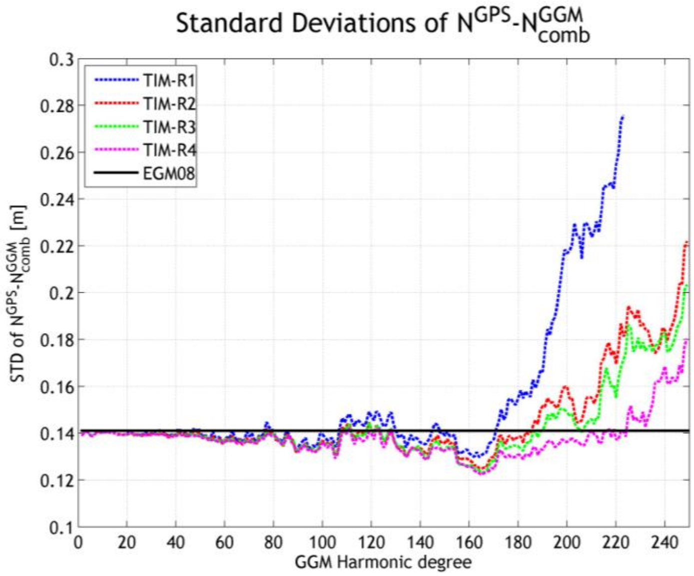


Figure 7: *std's of geoid height differences between combined TIM GGMs and GPS/Leveling geoid heights.*

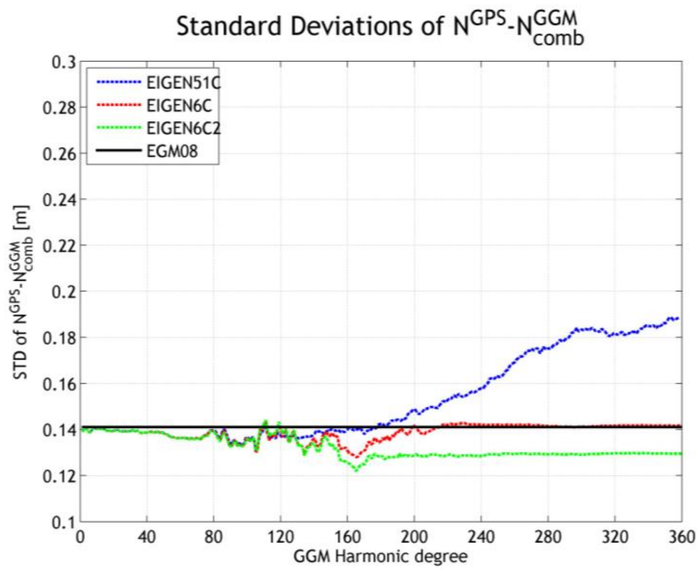


Figure 8: *std's of geoid height differences between combined EIGEN GGMs and GPS/Leveling geoid heights.*

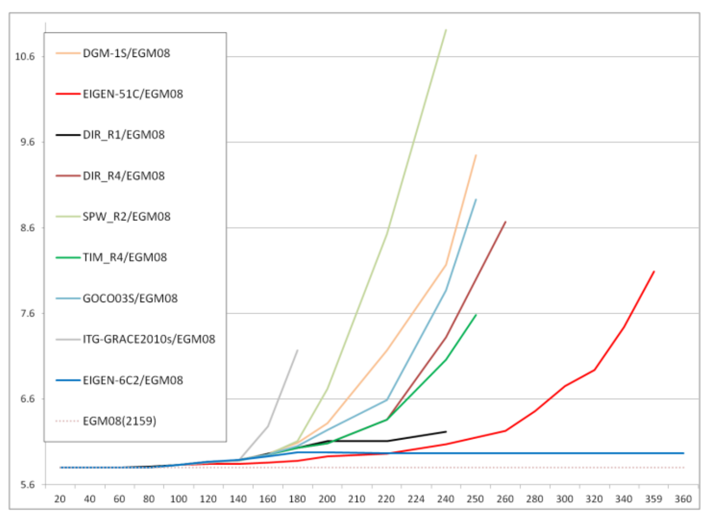
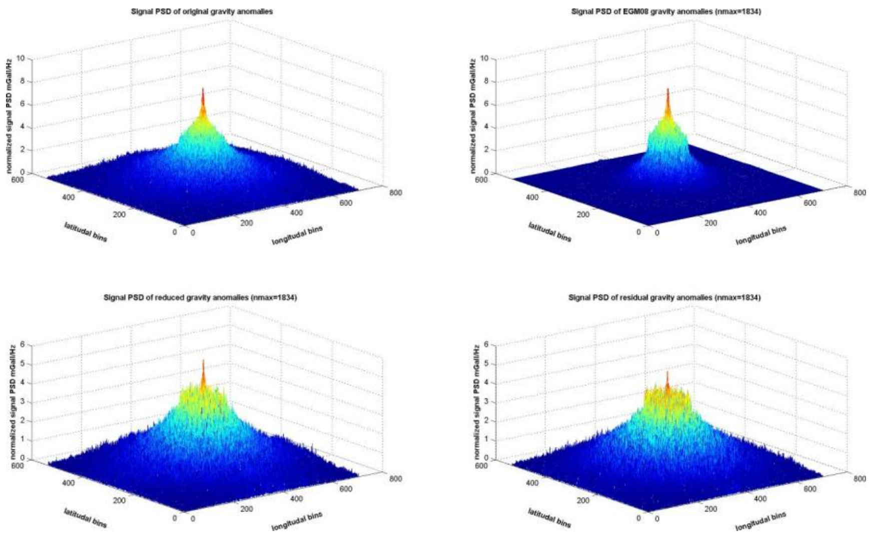
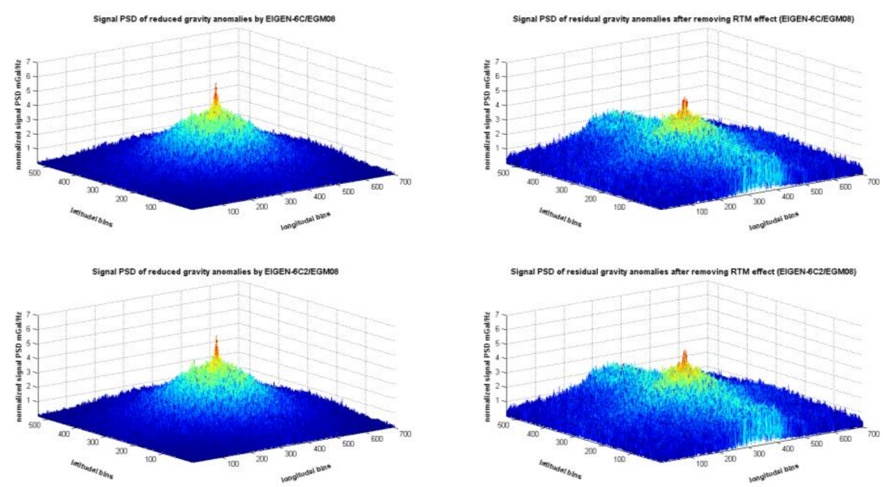


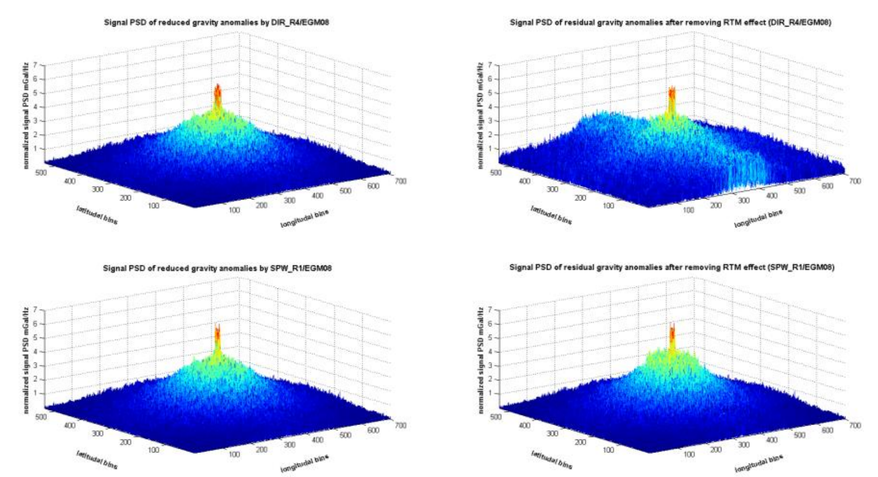
Figure 9: *std's of reduced gravity anomalies for the GOCE-based combined GGMs and EGM2008.*



Signal PSDs for the original gravity data (top left), EGM08 (n_{max}=1834) contribution (top right), reduced gravity (bottom left) and residual field after the RTM reduction



Signal PSDs of: Reduced gravity anomalies by EIGEN-6C (top-left), Residual gravity anomalies after removing EIGEN-6C and RTM effects (top-right), Reduced gravity anomalies by EIGEN-6C2 (bottom-left) and Residual gravity anomalies after removing EIGEN-6C2 and RTM effects (bottom-right).



Signal PSDs of: Reduced gravity anomalies by DIR-R4 (top-left), Residual gravity anomalies after removing DIR-R4 and RTM effects (top-right), Reduced gravity anomalies by SPW-R1 (bottom-left) and Residual gravity anomalies after removing SPW-R1 and RTM effects (bottom-right).

Figure 10: *FFT-based evaluation of the GOCE/GRACE GGMs.*

The third methodology was based on spectral methods and consists of two parts, one based on FFT and another on wavelets. Within the FFT concept, an estimation of the anomaly degree variances from the power spectral density (PSD) of the differences between the GGMs from each satellite and EGM08, as well as the local (terrestrial and marine) gravity data will be performed. This follows the well-known remove-compute-restore scheme, where the medium frequencies will be modeled with the GOCE/GRACE GGMS. It should be noted that the contribution of CHAMP, GRACE and GOCE models was again validated for various degrees of expansion, so that an external estimate of the total commission and omission errors can be performed as well. An example of the results acquired are presented in Figure 10 to the left, where the signal PSDs for the original, reduced to EGM08 (n_{max}=1834) and RTM reduced gravity data are depicted along with the reduced and residual fields for DIR-R4, TIM-R4 and EIGEN6C2.

Finally, the idea behind the multi-resolution analysis (MRA) with wavelets is that the two-dimensional wavelet transform can give wavelet coefficients at different spatial scales L_i, while these scales are connected and directly related to the signal frequencies, i.e., harmonic degrees of expansion. Therefore, for each scale of analysis the signal can be analyzed in an approximation and three detail coefficients (horizontal, vertical and diagonal), so that extreme values in the latter coefficients can allow, through the 2D-MRA, to localize the magnitude of the difference, its wavelength and structure. Given these, the improved gravity field representation of GOCE will be viewed through the 2D-MRA using the finer representation of known signals in the area under study, that cannot be represented by CHAMP, GRACE or even combined models. As far as the wavelet transforms are concerned our results were based on the Daubechies 10 (db10) wavelet. This analysis has been carried out for all GOCE-based GGMs, and an example is presented in Figure 11 below, where geoid heights from the TIM-R4 model are presented in the wider area under study. This field is then analyzed with Daubechies 10 (db10) wavelet, which is actually a good choice for potential field data since it indicates that p to the 10th moment (derivative) of the field will be zero. The analysis is presented for an L13 decomposition level. It is interesting to notice the MRA aspects offered by WLs by increasing level of analysis, given the representation of the approximation and detail coefficients. Table 1 below summarizes the decomposition levels used for the wavelet analysis along with the combined models developed by selective reconstruction of the GOCE-based GGMs (Table 2).

Table 1: Resolution limits for each level of wavelet

# WL level	Resolution [km]
1	22-44
2	44-88
3	88-176
4	176-352
5	352-704
6	704-1408
7	1408-2816
8	2816-5632
9	5632-11264
10	11264-22528
11	22258-45056
12	45056-90112
13	90112-180224

Table 2: Combined models and their coefficients

# model	name of model	coefficients of models at levels	# model	name of model	coefficients of models at levels
1	egm_dir_1	1-6, 9-13 EGM2008 and 7,8 DIR_1	**12**	dir_1_egm	1-6 EGM2008 and 7-13 DIR_1
2	egm_dir_2	1-6, 9-13 EGM2008 and 7,8 DIR_2	**13**	dir_2_egm	1-6 EGM2008 and 7-13 DIR_2
3	egm_dir_3	1-6, 9-13 EGM2008 and 7,8 DIR_3	**14**	dir_3_egm	1-6 EGM2008 and 7-13 DIR_3
4	egm_dir_4	1-6, 9-13 EGM2008 and 7,8 DIR_4	**15**	dir_4_egm	1-6 EGM2008 and 7-13 DIR_4
5	egm_tim_1	1-6, 9-13 EGM2008 and 7,8 TIM_1	**16**	tim_1_egm	1-6 EGM2008 and 7-13 TIM_1
6	egm_tim_2	1-6, 9-13 EGM2008 and 7,8 TIM_2	**17**	tim_2_egm	1-6 EGM2008 and 7-13 TIM_2
7	egm_tim_3	1-6, 9-13 EGM2008 and 7,8 TIM_3	**18**	tim_3_egm	1-6 EGM2008 and 7-13 TIM_3
8	egm_tim_4	1-6, 9-13 EGM2008 and 7,8 TIM_4	**19**	tim_4_egm	1-6 EGM2008 and 7-13 TIM_4
9	egm_goco01s	1-6, 9-13 EGM2008 and 7,8 GOCO01S	**20**	goco01s_egm	1-6 EGM2008 and 7-13 GOCO01S
10	egm_goco02s	1-6, 9-13 EGM2008 and 7,8 GOCO02S	**21**	goco02s_egm	1-6 EGM2008 and 7-13 GOCO02S
11	egm_goco03s	1-6, 9-13 EGM2008 and 7,8 GOCO03S	**22**	goco03s_egm	1-6 EGM2008 and 7-13 GOCO04S

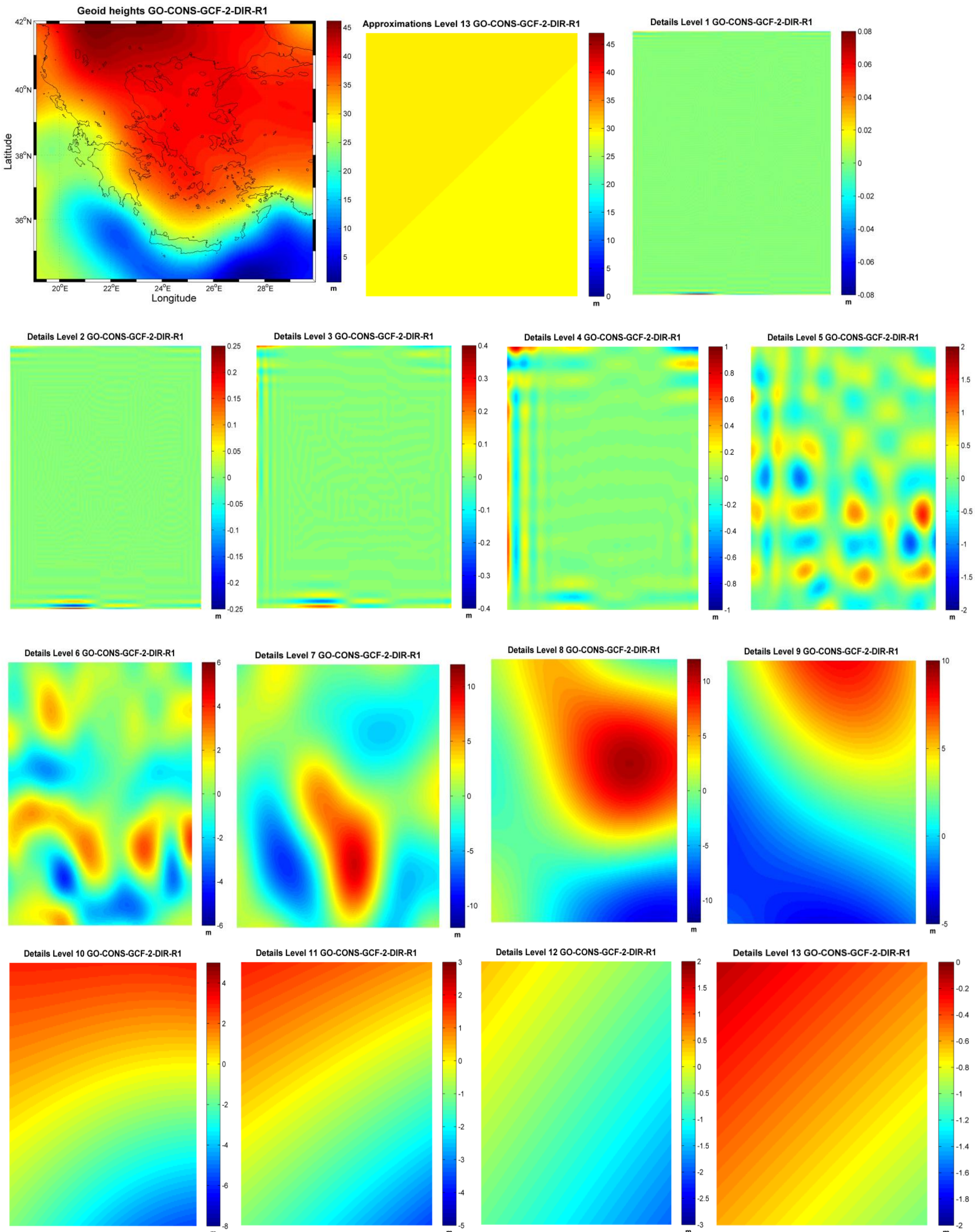


Figure 11: *L13 decomposition of the DIR-R1 geoid heights with db10 wavelet. Original field (top left), approximation coefficients (top right), and detail coefficients for each level are shown.*

Figure 12, presents the EGM2008 differences with DIR-R4 before and after the selective reconstruction, where the improved performance of the DIR model is seen, after the WL analysis. The same has been carried out for the evaluation of the original and reconstructed GOCE models over the network of GPS/Leveling BMs in Greece. An example is shown in Figure 13 and 14, where the differences before and after the WL analysis is presented for DIR-R4 and TIM-R4.

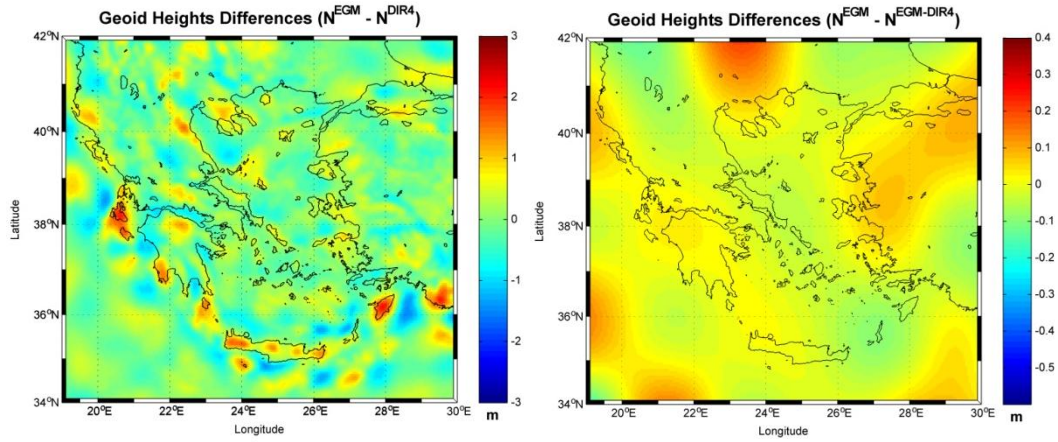


Figure 12: Geoid heights differences between EGM2008 and DIR-R4 before (right) and after (left) the WL analysis.

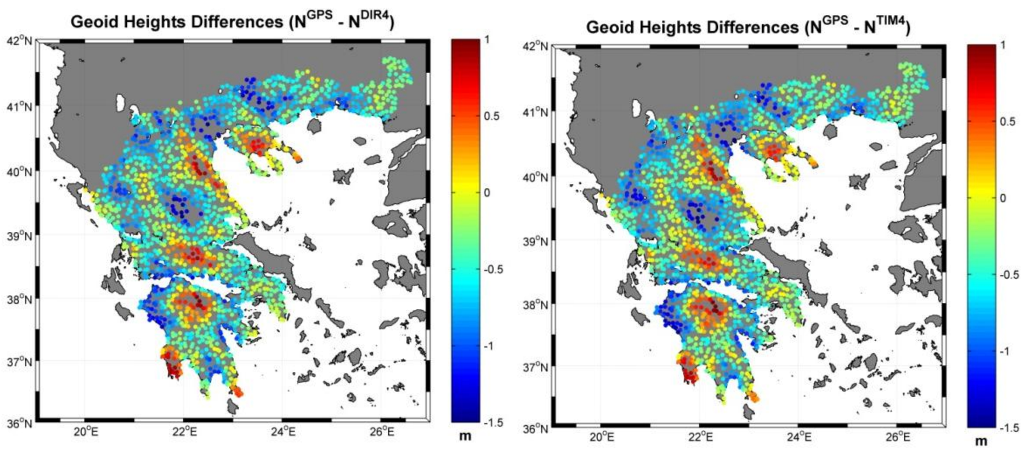


Figure 13: GPS/Leveling geoid heights differences with DIR-R4 and TIM-R4 before (top) the WL analysis.

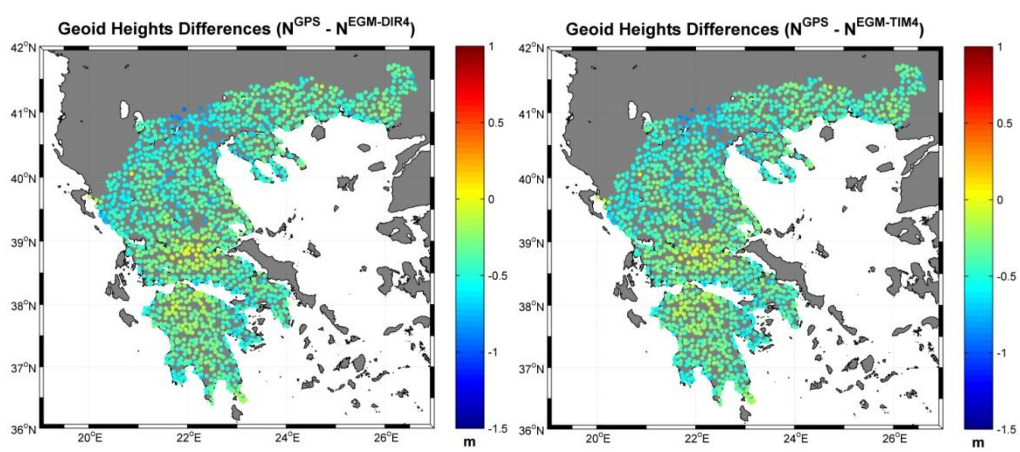


Figure 14: GPS/Leveling geoid heights differences with DIR-R4 and TIM-R4 after (bottom) the WL analysis.

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