GOCESeaComb

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

Newsletter Issue 6/30.06.2013

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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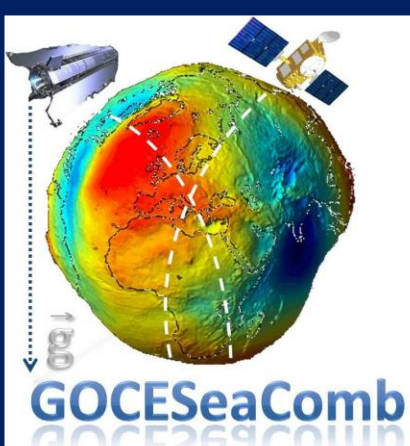


The GOCESeaComb Project Logo

GOCESeaComb methodologies for GOCE validation

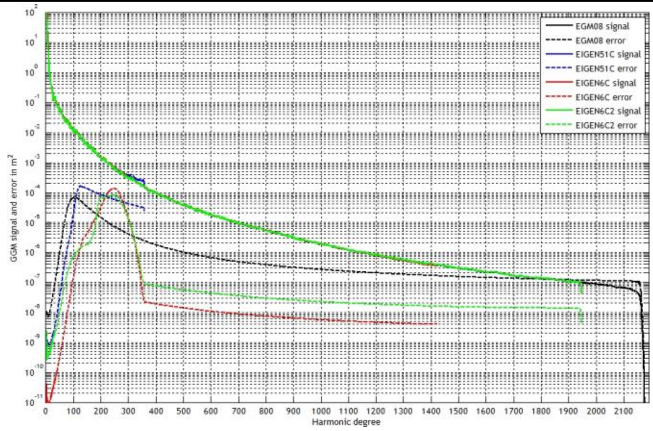
During the period of this newsletter and since the last newsletter in April 2013, all project activities are going according to schedule. These refer to the actual validation of the available GOCE/GRACE GGMs in order to evaluate the GOCE contribution brought to gravity field and geoid approximation.

GOCESeaComb METHODOLOGIES FOR GOCE VALIDATION

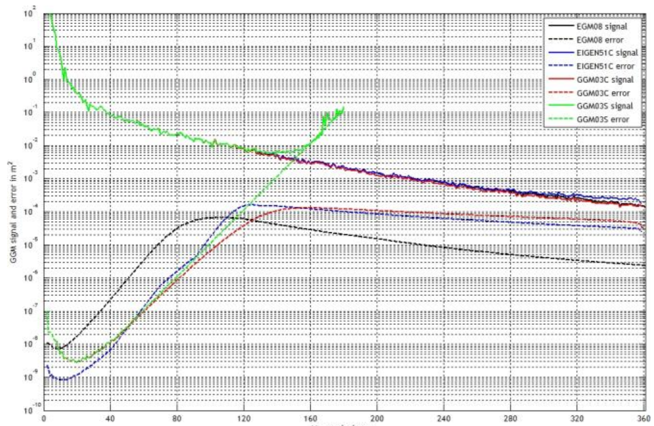
GOCE data validation is performed following three main approaches. ***The first one*** refers to the evaluation of the GOCE/GRACE based GGMs signal and error in the form of the provided degree and error variances. ***The second*** refers to an external evaluation of the GGMs against the local gravity 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, the GGM spectrum will be evaluated 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 will be used as reference. The same will be performed for anomaly error degree variances for the same models, so that the corresponding RMS anomaly differences per degree will be computed. In this process, the spherical harmonic coefficients and their errors will be used to determine signal power, error, rms signal power and rms signal error by degree and cumulatively for all GGMs. It should be noted that the contribution of CHAMP, GRACE and GOCE models will be validated for various degrees of expansion, so that an external estimate of the total commission and omission errors can be performed as well. Since various geopotential models will be available and needed to be compared, it is necessary to scale their harmonic coefficients, so that they will all refer to the surface of a sphere of radius $R=6371\ km$. In that way, the computed signal and error degree variances can be comparable. For this reason, the scaled signal and error degree variances will be computed for all models to be evaluated. Having estimated the disturbing potential degree and error degree variances, we can then estimate the corresponding quantities for geoid heights and gravity anomalies, given that the latter two are of main interest for gravity field approximation.

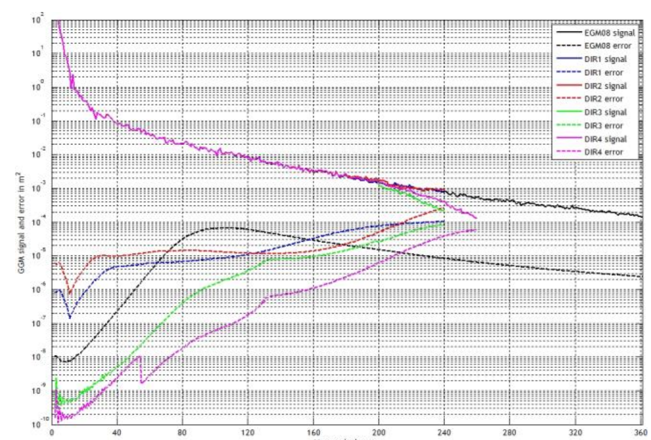
Within the same frame, the harmonic coefficients and their errors for each GGM will be evaluated as well in terms of a normalized log plot. An example of this evaluation is presented in Figure 1 below, where the TIM (R1, R2, R3 and R4) coefficients are depicted along with their errors. The signal degree 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.



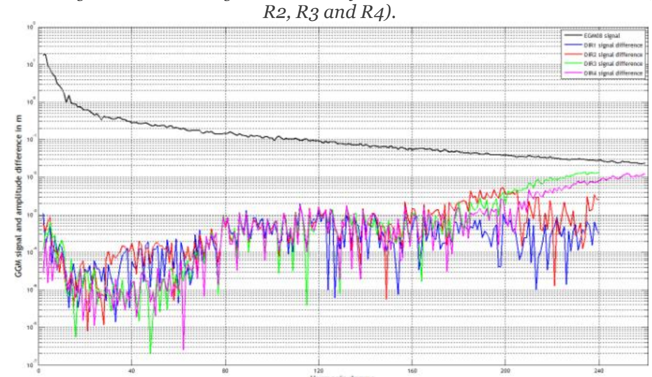
Geoid degree and error degree variances for the EGM08, EIGEN51C, EIGEN6C and EIGEN6c models.



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*

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.

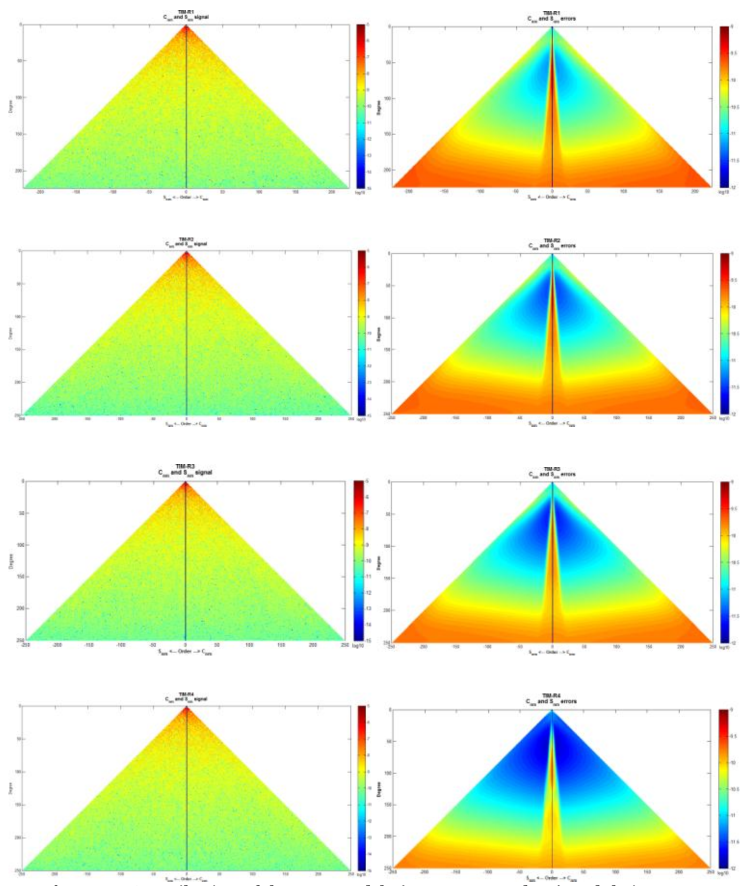
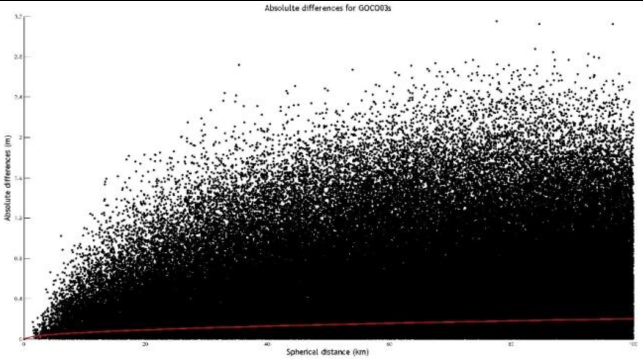


Figure 1: *Contribution of the TIM models (R1, R2, R3 and R4) and their errors.*

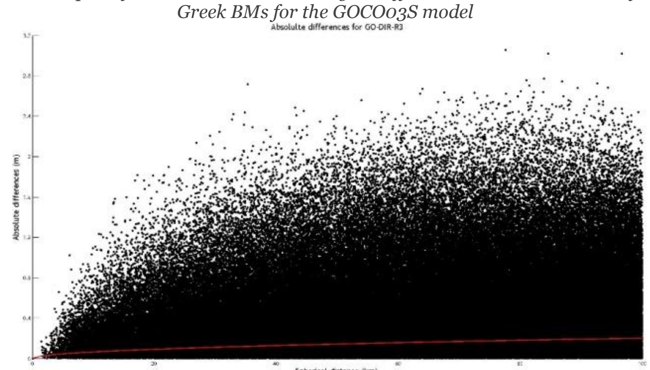
The final part of this spectral evaluation of the GOCE/GRACE GGMs is performed by determining differences between coefficients from CHAMP-only, GRACE-only and GOCE-only GGMs with the coefficients provided by EGM008 as reference. The same will be performed for anomaly degree variances and geoid signal and error variances for the same models, so that the corresponding RMS anomaly and geoid heights differences per degree will be computed. 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.

The second validation methodology refers to an external evaluation of the GGMs against the local gravity and GPS/Leveling data for various degrees of GGM expansion. In this process we will evaluate 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 an analysis is shown in Figures 2, where absolute and relative geoid height differences are plotted as a function of the baseline length.

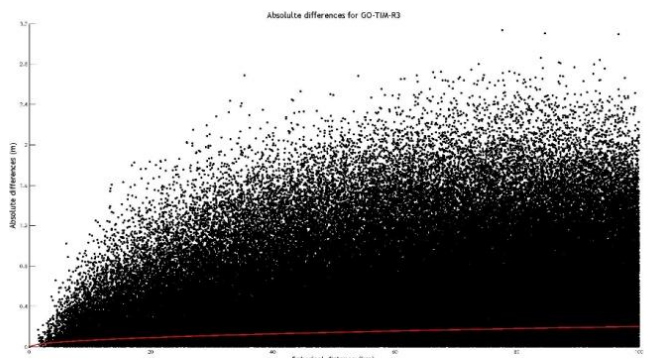
The third methodology will be based on spectral methods and consists of two parts, one based on FFT and another on wavelets. Within the FFT concept, an estimation of the anomaly degree variances from the power spectral density (PSD) of the differences between the GGMs from each satellite and EGM08, as well as the local (terrestrial and marine) gravity data will be performed. This will follow 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 will be 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 this approach is presented in Figure 4 below, where the signal PSDs for the original, reduced to EGM08 (n_{max}=1834) and RTM reduced gravity data are depicted.



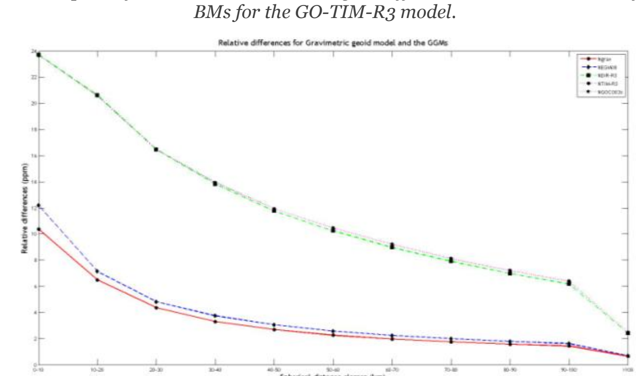
Scatter plot of absolute orthometric heights differences over the network of Greek BMs for the GOCO03S model



Scatter plots of absolute orthometric heights differences over the network of BMs for the GO-DIR-R3 model.

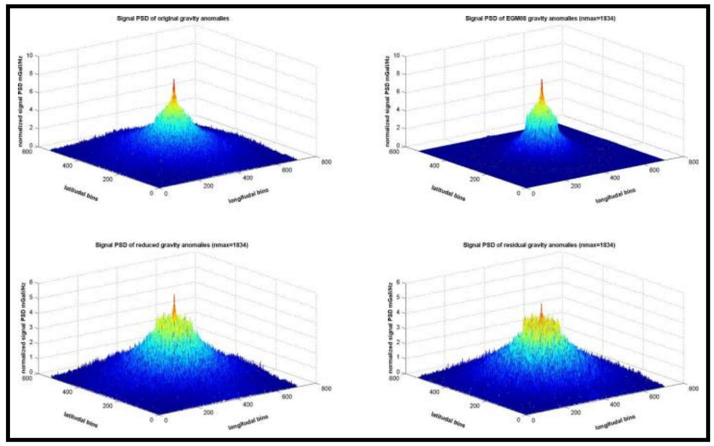


Scatter plots of absolute orthometric heights differences over the network of BMs for the GO-TIM-R3 model.



Relative geoid heights differences over the network of BMs for the EGM08, DIR-R3, TIM-R3, GOCO03S and local models.

Figure 3: *External validation of GOCE/GRACE GGMs.*



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

Figure 4: *FFT-based evaluation of the GOCE/GRACE GGMs.*

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, various wavelets will be tested in order to conclude on the one that gives the best analysis of the input data, but given that the selection of the wavelet is not the main point of interest in this project, we will limit the investigation to orthogonal ones like the coiflet, Daubechies wavelet and Haar wavelet. An example is presented in Figure 5 below, where the gravity anomaly field from the GOCO03S model is 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 L10 decomposition level. It is interesting to notice the MRA aspects offered by WLs be increasing level of analysis, given the representation of the approximation and detail coefficients. The same analysis has been performed with the coiflet wavelet for L5 and the haar wavelet for L5, where the unique noise exaggeration/suppression properties depend on their vanishing moments.

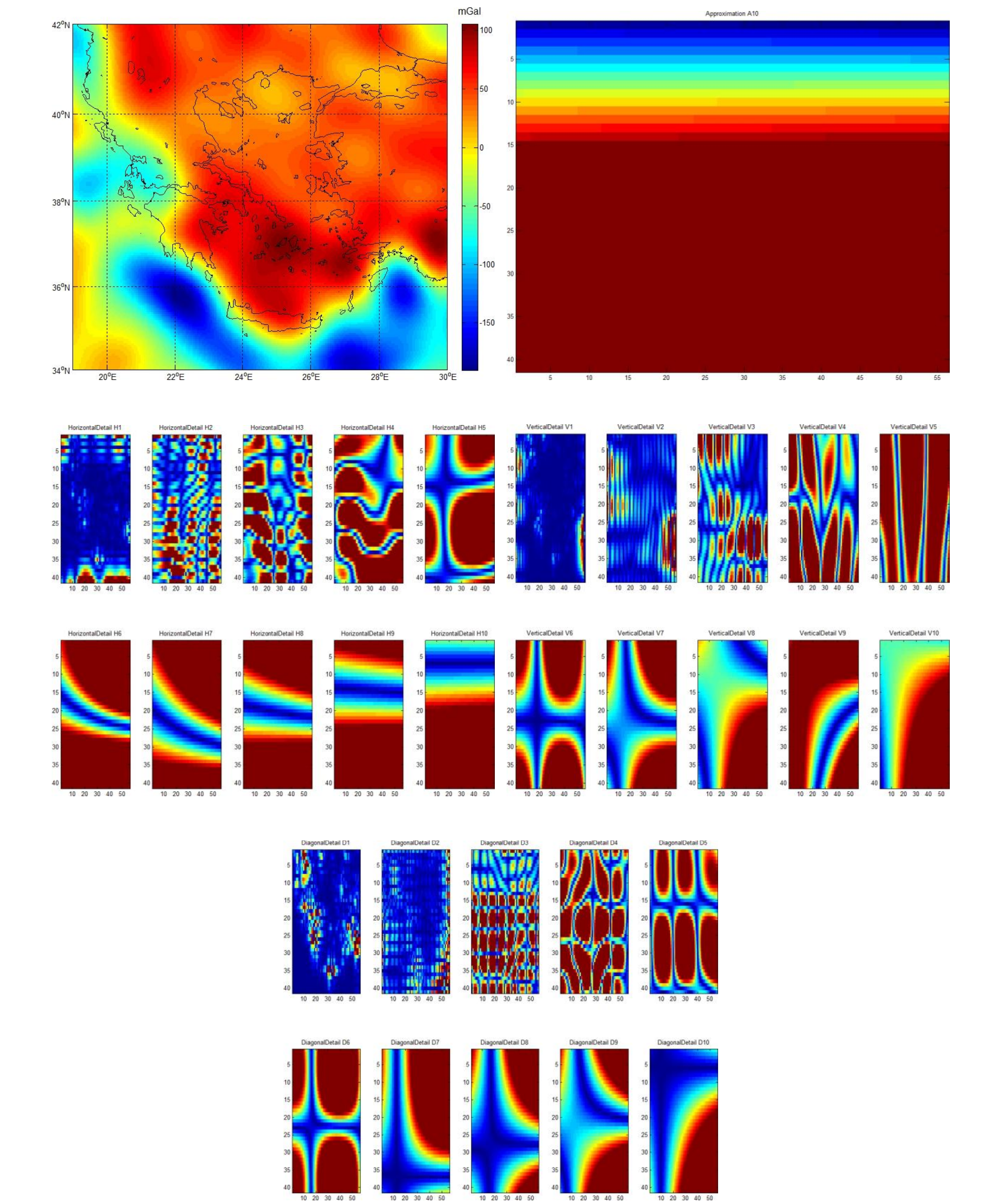


Figure 5: *L10 decomposition of the GOCO03s gravity anomaly field with db10 wavelet. Original field (top left), approximation coefficients (top right), horizontal coefficients (middle left), vertical coefficients (middle right) and diagonal coefficients (bottom) for each level are shown.*

This field MPA approach will be used in order to compare the various GGMs and the information that they contain at each level of decomposition. An example is shown in Figure 6 for gravity anomalies derived from the GOCO03S and EIGEN6C2 GGMs (n_{max}=250 and n_{max} =1949, respectively) where the former provides information up to spatial scales of ~80 km and the latter up to ~10 km. Consequently, the signals have been analyzed with Daubechies 10 (db10) wavelet up to L6 for the GOCO03S field and L10 for the EIGEN6C2 one. Given their spectral content, the corresponding spatial scales for GOCO03S that the WL coefficients represent are at 80-160 km (L1), 160-320 km (L2), 320-640 km (L3), 640-1280 (L4), 1280-2560 (L5) and 2560-5120km (L6). Correspondingly, for EIGEN6C2 the WL coefficients represent spatial scales of 10-20 km (L1), 20-40 km (L2), 40-80 km (L3), 80-160 (L4), 160-320 km (L5), 320-640 km (L6), 640-1280 (L7), 1280-2560 (L8) and 2560-5120km (L9). Therefore, in a practical sense GOCO03S for L1 corresponds to L4 for EIGEN6C2, so that the former can be, a) filled-in with EIGEN6C2 coefficients to increase its resolution, b) filtered to remove the purely modeled by GOCE high-frequencies in L1 and be substituted with the EIGEN6C2 L4 which comes from local data, etc. Within this concept, the GGMs will be evaluated to construct a WL-based combined model, which will then be evaluated against the local data to assess the possible improvement.

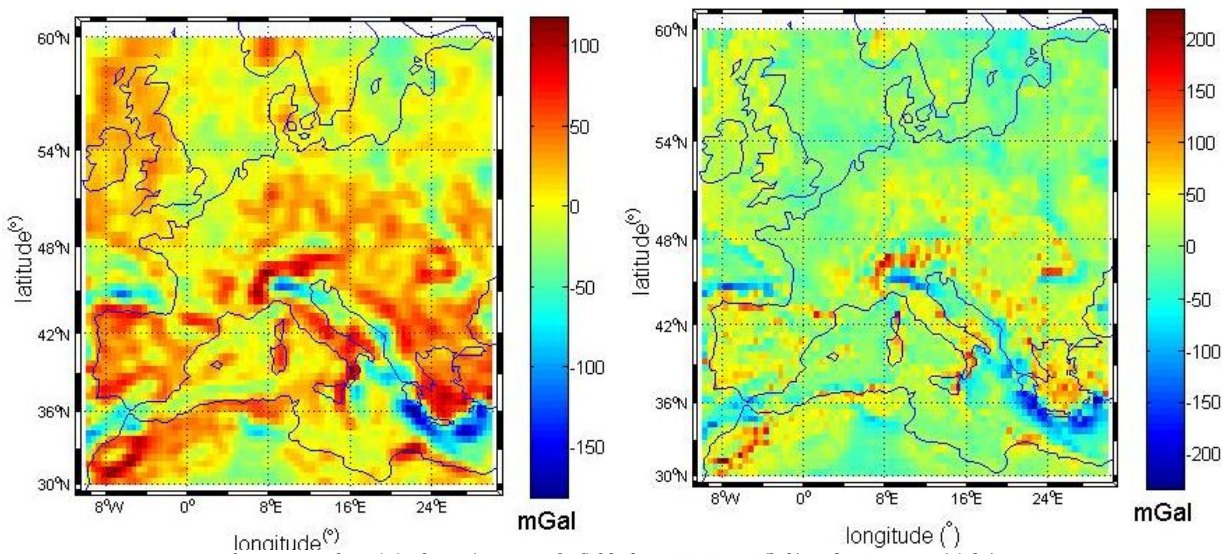


Figure 6a: *The original gravity anomaly fields from GOCO03S (left) and EIGEN6C2 (right).*

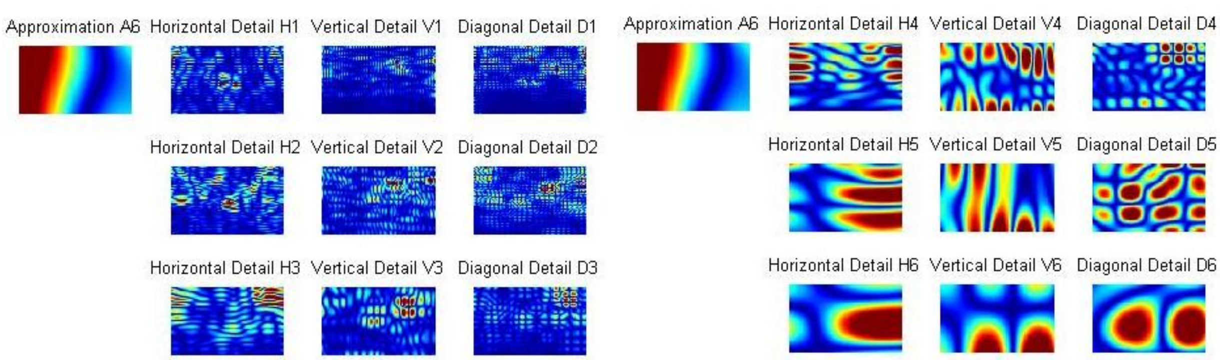


Figure 6b: *L1, L2 and L3 coefficients (left) and L4, L5 and L6 coefficients (right) for the GOCO03S GGM.*

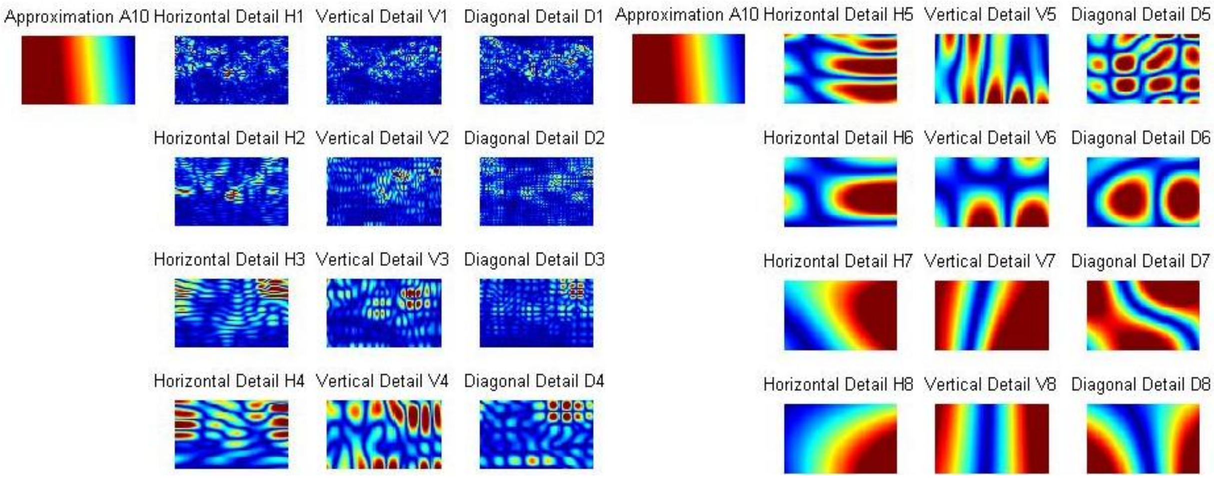


Figure 6c: *L1, L2, L3 and L4 coefficients (left) and L5, L6, L7 and L8 coefficients (right) for the EIGEN6C2GGM.*

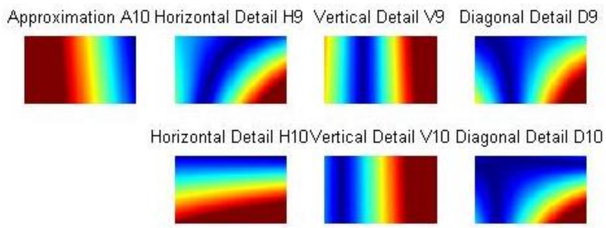


Figure 6d: *L9 and L10 coefficients for the EIGEN6C2GGM.*

Figure 6: *MRA for various levels of decomposition for gravity anomalies over Europe from the GOCO03S and EIGEN6C2 GGMs.*

Contact Us

GeoGrav - AUTh
Department of Geodesy and Surveying, Aristotle University of Thessaloniki
University Campus, University Box 440, GR-54124
Thessaloniki, Greece
T: ++302310996125 | **F**: ++302310995948
tziavos@topo.auth.gr & vergos@topo.auth.gr
http://olimpia.topo.auth.gr/GOCESeaComb/