GOCESeaComb

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

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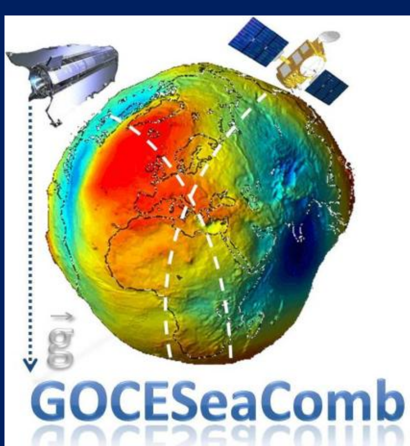
Newsletter Issue 4/28.02.2013

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.

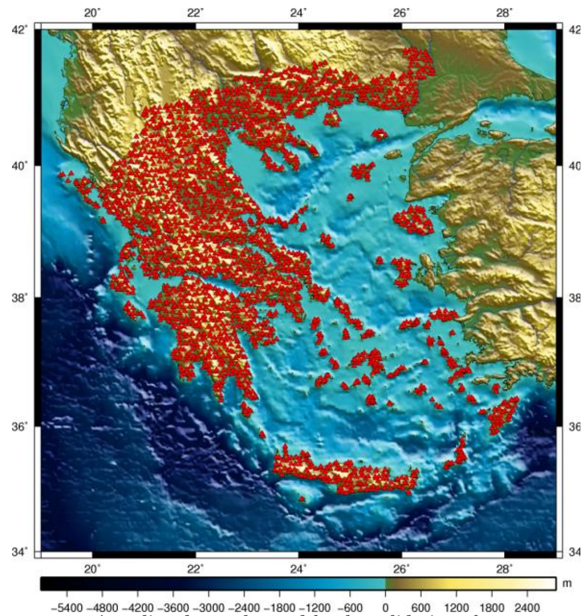
Contract: C4000106380

Duration: July 2012 – July 2014



The GOCESeaComb Project Logo

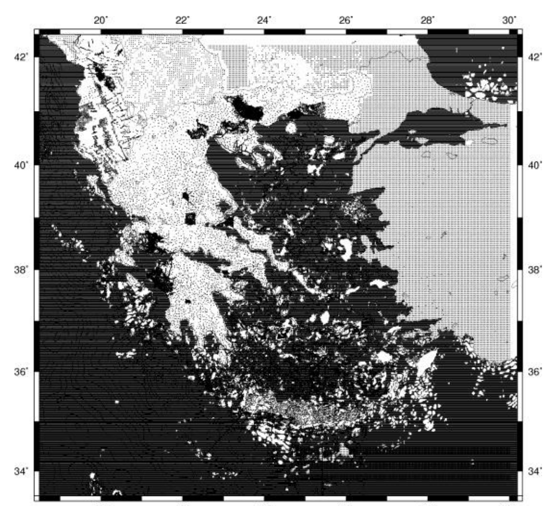
GOCESeaComb methodologies for GOCE validation



GPS/Leveling data to be used for the validation of GOCE observables, geoid models, etc.

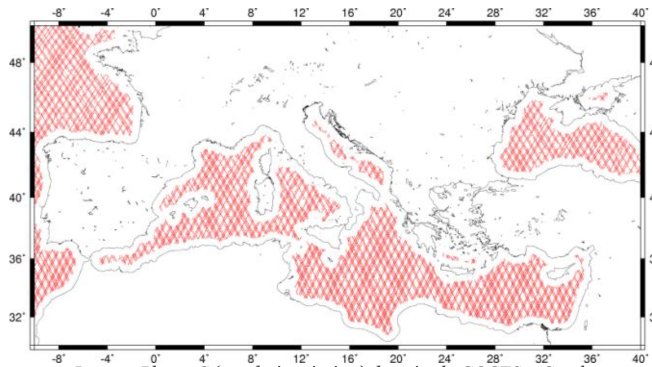
During the period of this newsletter and since the last newsletter in December 2012, all project activities are going according to schedule. During the last period, the needed terrestrial and satellite data for the project implementation have been collected and archived to the project server. Moreover, the methodologies for GOCE validation, data combination, DOT and SLA determination and covariance modeling have been outlined.

GPS/Leveling BMs



Gravity data to be used for the validation of GOCE observables, geoid models, etc.

Within this frame, the local data refer to GPS/Leveling observations at collocated BMs. These cover Greece entirely, both the mainland and the islands. The orthometric heights come from the Hellenic Geographic Military Service (both spirit and trigonometric leveling), while the ellipsoidal ones from the Hellenic Positioning System (HEPOS) project. The GPS/Leveling observations have been unified in terms of the tidal model used (all referred to the tide-free system) and the ellipsoid (all referred to GRS80). Moreover, blunder detection and removal has been carried out with a simple 3rms test.



Jason-1 Phase-C (geodetic mission) data in theGOCESeaComb area.

Models	n_{max}	***Data***
EGM2008	2190	S(GRACE), G, A
EIGEN-51C	359	S(GRACE, CHAMP), G, A
EIGEN-6C	1420	S(GOCE, GRACE, LAGEOS), G, A
GOCO01S	224	S(GOCE, GRACE)
GOCO02S	250	S(GOCE, GRACE, CHAMP, SLR)
GOCO03S	250	S(GOCE, GRACE, CHAMP, SLR)
ITG-GRACE2010S	180	S(GRACE)
GIF48A	360	S(GRACE), G, A
DIR_R1	240	S(GOCE + background model EIGEN-51C)
DIR_R2	240	S(GOCE+ background model ITG-GRACE2010S)
DIR_R3	240	S(GOCE, GRACE, LAGEOS)
TIM_R1	224	S(GOCE)
TIM_R2	250	S(GOCE)
TIM_R3	250	S(GOCE)
SPW_R1	210	S(GOCE)
SPW_R2	240	S(GOCE)
DGM-1S	250	S(GRACE, GOCE)

Gravity data

The gravity data consist of ~200k free-air gravity anomalies over land and marine areas unified in terms of the reference ellipsoid, tide system used and gravity reference system. This database refers to irregularly distributed point gravity data over Greece, with a mean accuracy of 5 mGal generated at an earlier stage by the research team. All data have undergone a blunder detection and removal test with least-squares collocation. For the GOCE GGM validation, geoid estimation, SLA monitoring and DOT determination, and as far as the local gravity data are concerned, a 3 arcsec DTBM (Digital Terrain and Bathymetry Model) has been generated for the area under study to provide the high-frequency content of the gravity field spectrum.

Satellite altimetry data

As far as satellite altimetry data are concerned, the missions of Jason-1, Jason-2, ERS-1, ERS-2 and ENVISAT will be used. All mission data have been collected in the form of SLAs referenced to EGM2008, with unified geophysical and instrumental corrections applied. Especially for Jason-1 the latest Phase C (geodetic mission) SSHs will be incorporated as well for as long as the mission remains operational. For Jason-2, data collection will be a work in progress since the satellite is operational, so that all new cycles will be collected as they become available.

Satellite gravimetry data

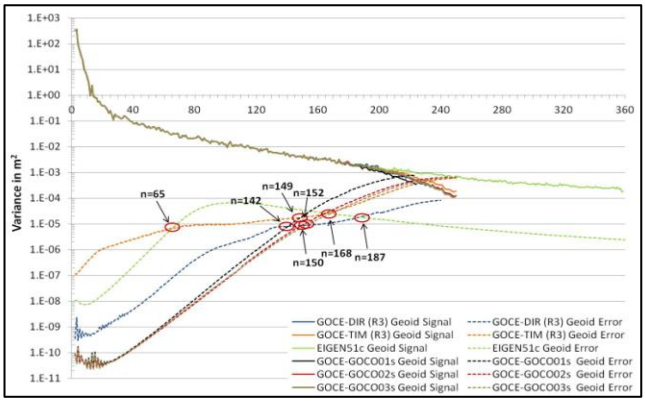
As far as satellite gravity are concerned, all the latest GOCE, GOCE/GRACE and combined GGMs have been collected (see insert on the left for a list of the models collected). The GGMs have been unified in terms of the tide system they refer to (the TF system was used), reference ellipsoid (GRS80 used throughout), while the zero-degree harmonic term (N_o) of the GGM contribution has been determined for all models relative to the latest IERS conventions. In all cases, W_o was set to its IAG-nominal value of 62636856.0 m^2/s^2 and a mean Earth radius (R) of 6371008.7714 m was used. Moreover, GOCE gradiometric observations have been collected in the form of Level 2 data (SST_NOM_2), i.e., processed second order derivatives (gravity gradients) of the gravity potential in a local North-East-Up Earth Fixed Reference Frame. GOCE gradiometric observations mentioned earlier are tagged only with their GPS time of acquisition and refer to the GRF. Therefore, a transformation from GRF to IRF and from IRF to EFRF is needed, with all detailed information provided in the SST_PSO_2 product. The GOCE gradiometric observations need to be transformed from the given GRF to IRF, then from IRF to EFRF and finally from EFRF to LNOEF, so that they can be combined with other data (altimetry, local gravity and GPS/Leveling, GGMs, topography/bathymetry, etc.) and be presented in a more meaningful from the GRF earth-based reference system.

GOCESeaComb METHODOLOGIES FOR GOCE VALIDATION

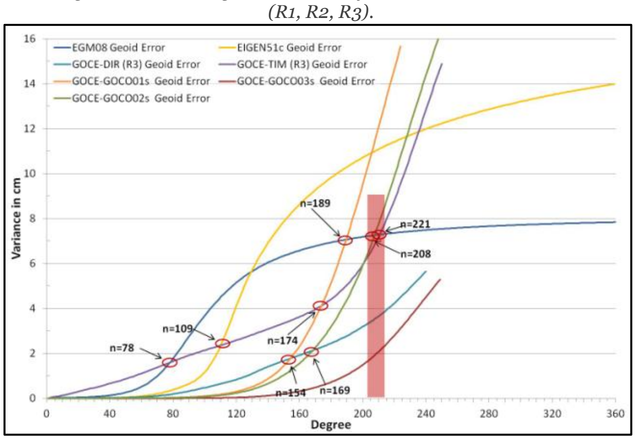
GOCE data validation will be performed following three main approaches. The first one refers to the evaluation of the GOCE/GRACE based GGMs signal and error in the form of the provided degree and error variances. The second refers to an external evaluation of the GGMs against the local gravity and GPS/Leveling 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. The validation refers firstly to the external calibration/validation of GOCE data against terrestrial gravity data available by the research team both for continental areas (mainland Greece) and marine regions. As far as GOCE data are concerned, the Level 2 data of the satellite will be used in the form of GOCE-only global geopotential models (GGMs). In a first step, we will use anomaly differences between coefficients from CHAMP-only, GRACE-only and GOCE-only GGMs with the coefficients provided by EGM2008 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. 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. Therefore, the scaled, relative to sphere of radius *R*, signal and error degree variances will be computed as follows, for geoid heights:

$$\sigma_n^2 = \left(\frac{GM}{\gamma a}\right)^2 \left(\frac{a^2}{R^2}\right)^{n+1} \sum_{m=o}^{n} \left(\delta\bar{C}_{nm}^{*2} + \delta\bar{S}_{nm}^2\right),$$

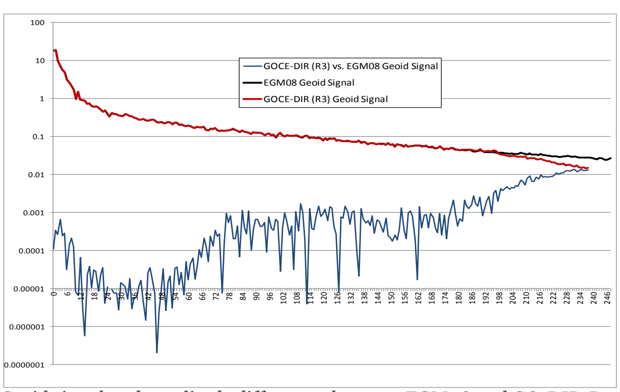
$$\varepsilon_{\sigma_n}^2 = \left(\frac{GM}{\gamma a}\right)^2 \left(\frac{a^2}{R^2}\right)^{n+1} \sum_{m=o}^{n} \left(\varepsilon_{\delta\bar{C}_{nm}^*}^2 + \varepsilon_{\delta\bar{S}_{nm}}^2\right).$$



Geoid degree and error degree variances of the TIM, DIR and GOCO models (R1, R2, R3).



Cumulative geoid signal and error of the TIM, DIR and GOCO models (R1, R2, R3).



Geoid signal and amplitude differences between EGM08 and GO-DIR-R3.

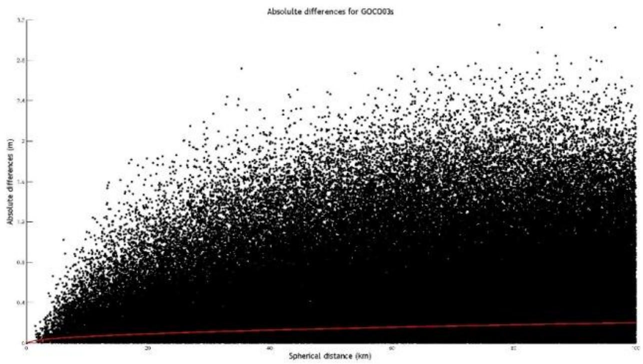
An example is shown in the figure on the left panel (top) where the geoid signal and error are depicted for various GOCE, GOCE/GRACE and combined GGMs. The figure on the middle panel presents the cumulative geoid error for the respective GGMs.

The second approach will focus on the determination of the 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. It is noticed that the basic idea behind this methodology is that the GOCE-only model should bridge the gap between CHAMP-only GGMs (which model with high accuracy the low degrees), GRACE-only GGMs (which model with high accuracy the medium up to degree 60 harmonics) and the local data, since GOCE is promising a 1-cm geoid accuracy to degree and order 200. Therefore, the previous analysis will signal whether GOCE-only GGMs can boost the abovementioned accuracy in the representation of the Earth's gravity field. Following the same mathematical frame as in the degree and error degree variances we can form the geoid height and anomaly degree and error degree differences, relative to a combined GGM, as:

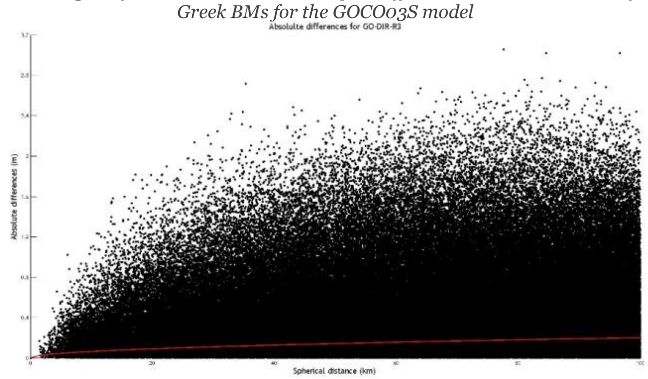
$$\delta\sigma_n^2 = \sigma_n^{2\,(i)} - \sigma_n^{2(EGMo8)} \left(\frac{GM}{\gamma a}\right)^2 \left(\frac{a^2}{R^2}\right)^{n+1} \sum_{m=o}^{n} \left[\left(\delta\bar{C}_{nm}^{*2} + \delta\bar{S}_{nm}^2\right)^{(i)} - \left(\delta\bar{C}_{nm}^{*2} + \delta\bar{S}_{nm}^2\right)^{(EGMo8)}\right],$$

$$\delta\varepsilon_{\sigma_n}^2 = \varepsilon_n^{2\,(i)} - \varepsilon_n^{2(EGMo8)} = \left(\frac{GM}{\gamma a}\right)^2 \left(\frac{a^2}{R^2}\right)^{n+1} \sum_{m=o}^{n} \left[\left(\varepsilon_{\delta\bar{C}_{nm}^*}^2 + \varepsilon_{\delta\bar{S}_{nm}}^2\right)^{(i)} - \left(\varepsilon_{\delta\bar{C}_{nm}^*}^2 + \varepsilon_{\delta\bar{S}_{nm}}^2\right)^{(EGMo8)}\right].$$

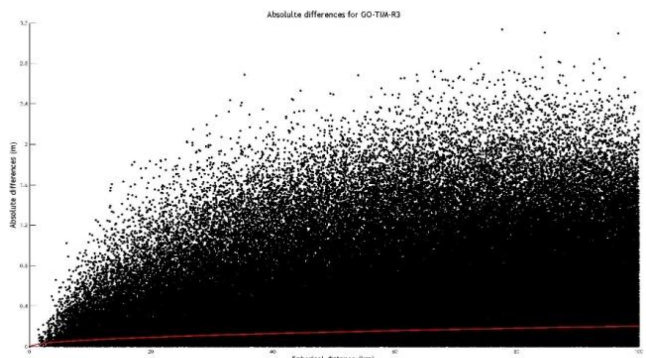
An example of the evaluation of the amplitude differences is shown in lower figure on the left panel, where the geoid signal differences of GO-DIR-R3 is evaluated relative to EGM08. The final part of the spectral evaluation of the GOCE, GOCE/GRACE and combined GGMs will be in terms of their signal and error PSD per frequency with a synchronous evaluation w.r.t to Kaula's rule for the decay of the geoid spectrum and omission error. The geoid signal PSD $\Phi_N\left(f_N\right)$ can be evaluated as:



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.



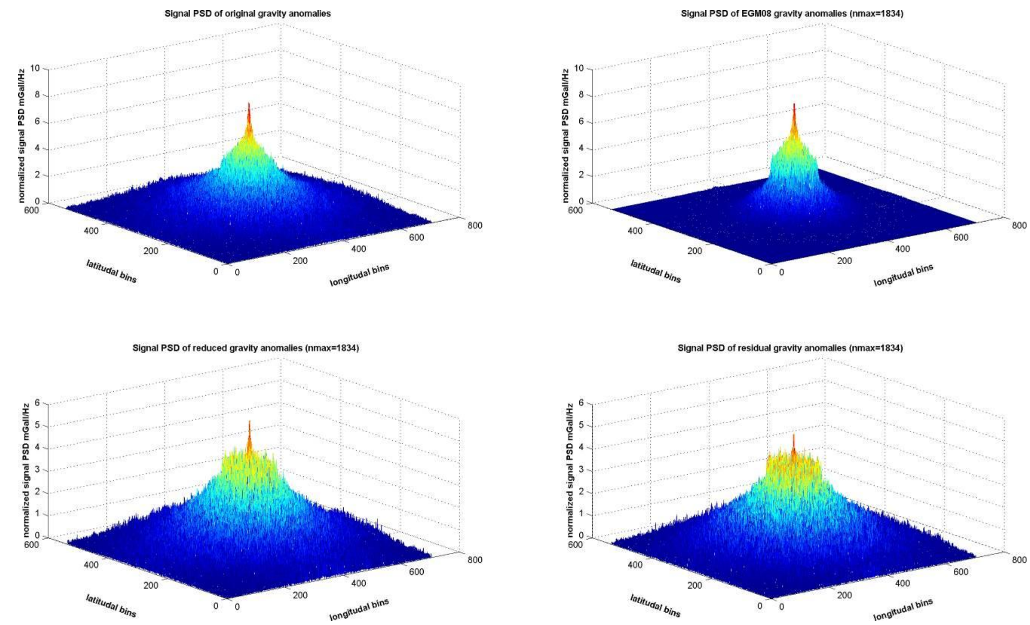
Scatter plots of absolute orthometric heights differences over the network of BMs for the GO-TIM-R3 model.

$$\Phi_N\left(f_N\right) = \frac{2\pi R^2}{n}\left(\sigma_N^2\right)_n .$$

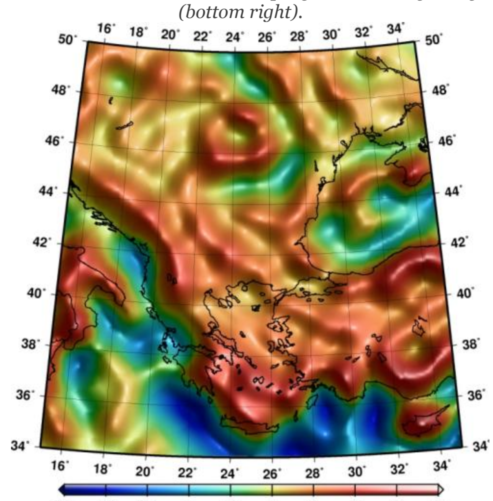
The second validation methodology refers to an external evaluation of the GGMs against the local gravity and GPS/Leveling data for various degrees of GGM expansion. In this process we will evaluate both absolute as well as relative differences of the GPS/Leveling geoid heights and GGM geoid heights in 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 the figures in the right panel, where absolute 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 the Figure below, where the signal PSDs for the original, reduced to EGM08 (n_{max}=1834) and RTM reduced gravity data are depicted.

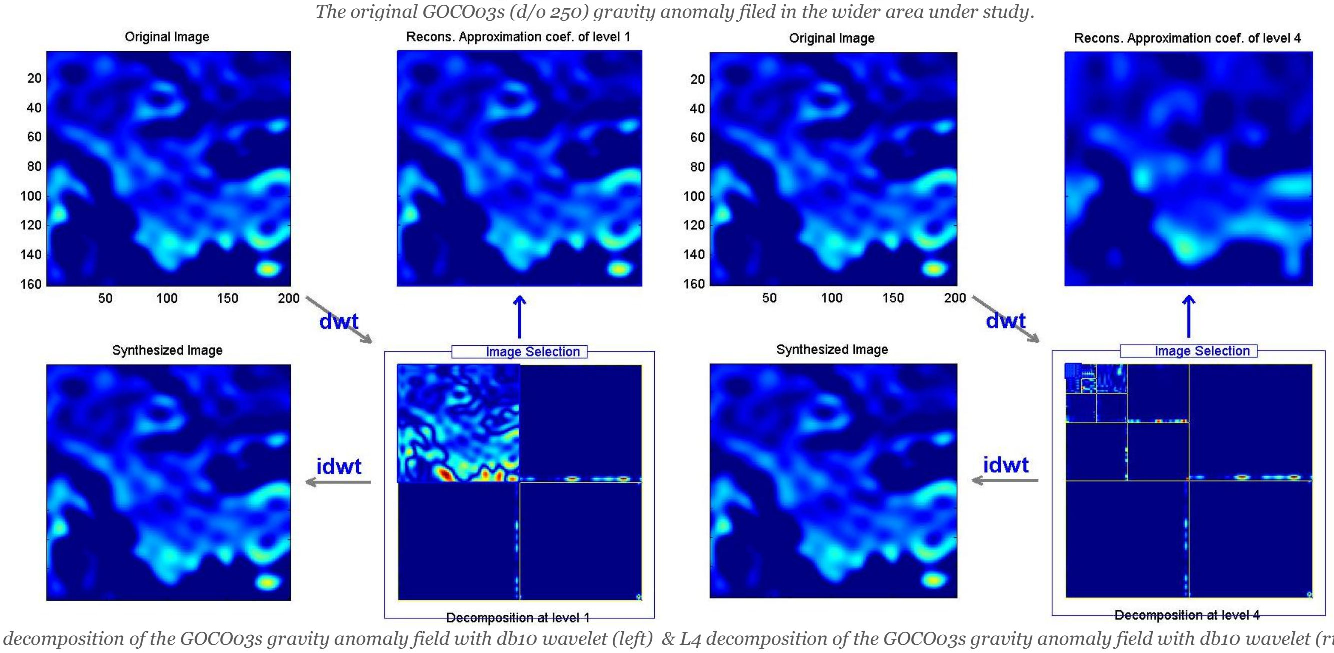
Finally, the idea behind the multi-resolution analysis (MRA) with wavelets is that the two-dimensional wavelet transform can give wavelet coefficients at different spatial scales L_i, while these scales are connected and directly related to the signal frequencies, i.e., harmonic degrees of expansion. 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 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 10^{th} moment (derivative) of the field will be zero. The analysis is presented for various decomposition levels ranging from L1, L4 and L5. 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.



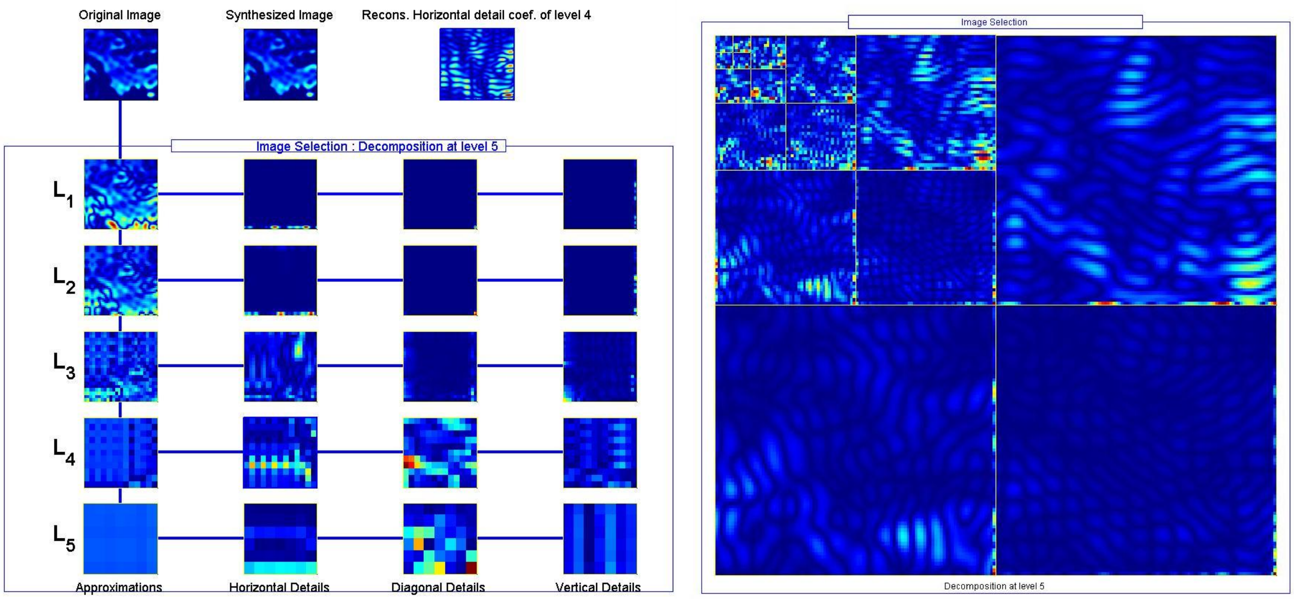
Signal PSDs for the original gravity data (top left), EGM08 (n_{max}=1834) contribution (top right), reduced gravity (bottom left) and residual field after the RTM reduction (bottom right).



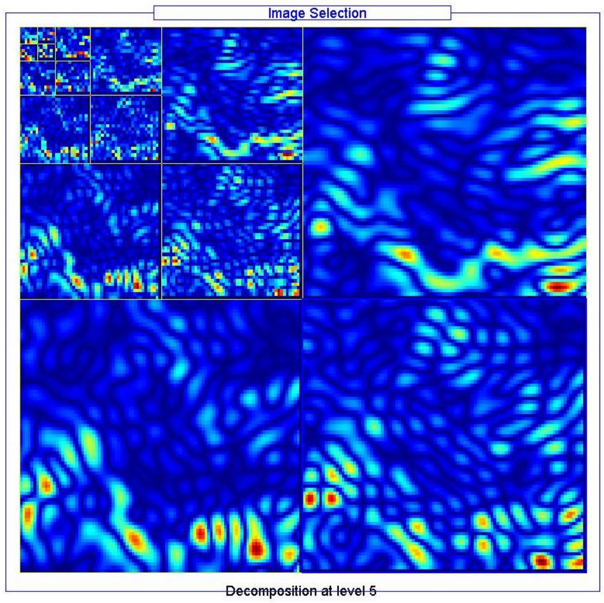
The original GOCO03s (d/o 250) gravity anomaly filed in the wider area under study.



L1 decomposition of the GOCO03s gravity anomaly field with db10 wavelet (left) & L4 decomposition of the GOCO03s gravity anomaly field with db10 wavelet (right)



L5 decomposition of the GOCO03s gravity anomaly field with db10 wavelet, approximation and detail coefficients for each level are shown & L5 decomposition of the GOCO03s gravity anomaly field with coiflet wavelet, approximation and detail coefficients for each level are shown.



L5 decomposition of the GOCO03s gravity anomaly field with haar wavelet, approximation and detail coefficients for each level are shown.

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