A global correlation of the step-wise consolidated crust-stripped gravity field quantities with the topography, bathymetry, and the CRUST 2.0 Moho boundary

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Abstract: We investigate globally the correlation of the step-wise consolidated crust-stripped gravity field quantities with the topography, bathymetry, and the Moho boundary. Global correlations are quantified in terms of Pearson's correlation coefficient. The elevation and bathymetry data from the ETOPO5 are used to estimate the correlation of the gravity field quantities with the topography and bathymetry. The 2×2 arc-deg discrete data of the Moho depth from the global crustal model CRUST 2.0 are used to estimate the correlation of the gravity field quantities with the Moho boundary. The results reveal that the topographically corrected gravity field quantities have the highest absolute correlation with the topography. The negative correlation of the topographically corrected gravity disturbances with the topography over the continents reaches –0.97. The ocean, ice and sediment density contrasts stripped and topographically corrected gravity field quantities have the highest correlation with the bathymetry (ocean bottom relief). The correlation of the ocean, ice and sediment density contrasts stripped and topographically corrected gravity disturbances over the oceans reaches 0.93. The consolidated crust-stripped gravity field quantities have the highest absolute correlation with the Moho boundary. In particular, the global correlation of the consolidated crust-stripped gravity disturbances with the Moho boundary is found to be –0.92. Among all the investigated gravity field quantities, the consolidated crust-stripped gravity disturbances are thus the best suited for a refinement of the Moho density interface by means of the gravimetric modeling or inversion.

Key words: bathymetry, correlation, crust, gravity field, Moho interface, topography

1. Introduction

In *Tenzer et al. (2009b)*, we have compiled the global maps of the gravity disturbances step-wise corrected for the effect of topography and stripped of the effects of the major known density contrasts within the earth's crust based on the CRUST 2.0 global crustal model and the global geopotential model EGM08 *(Pavlis et al., 2008a; 2008b)* complete to degree 180 of spherical harmonics. The density contrasts include the ocean, ice, sediments and crystalline crust, and were taken relative to an adopted value of the reference crustal density of 2670 kg/m^3. The subsequent application of the topographic and model crust density contrasts stripping corrections to the observed gravity disturbances results in the consolidated crust-stripped gravity disturbances.

The topographically corrected gravity disturbances showed a presence of the isostatic compensation in the mountainous regions. The bathymetrically stripped and topographically corrected gravity disturbances (BT gravity disturbances) revealed the main structures of the ocean floor relief and the global pattern of the lithospheric plates predominantly due to a diverse-from-continental and varying density and thickness of the oceanic lithospheric plates. The ice and sediment stripped BT gravity disturbances were obtained by applying the ice and sediment stripping corrections to the BT gravity disturbances. The application of the ice stripping correction changed the BT gravity disturbances over the regions with the largest thickness of the polar ice sheet of Greenland and Antarctica. The application of the sediment stripping correction primarily changed the BT gravity disturbances over the regions with the largest sediment thickness at continental shelves and in the Caspian Sea region. The application of the consolidated crust stripping correction to the ice and sediment stripped BT gravity disturbances results in the consolidated crust-stripped gravity disturbances. The strongest signal in such a gravity disturbance is due to the density contrast of the Moho interface relative to the mantle. Another substantial contribution to the gravity signal is attributed to the global upper mantle morphology and density composition (reflecting global past and present tectonics with respective thermal and stress fields, and the tendency toward isostatic balance), and from the sub-lithospheric (deeper mantle) density heterogeneities (reflecting the lithosphere-mantle interactions and the mantle convection). Large errors are, however, expected due to the deviations of the CRUST 2.0 model density from the real earth's crustal density heterogeneities and the Moho-relief uncertainties. The complementary studies of the step-wise topography corrected and crust density contrasts stripped gravity field quantities (gravity anomalies and geoid) can be found in *Tenzer et al. (2008b; 2009a)*.

In this study we investigate the correlation of the step-wise topographically corrected and crust density contrasts stripped gravity field quantities with the topography, bathymetry, and the Moho boundary. The correlations are investigated globally for the gravity disturbances, gravity anomalies and disturbing potentials computed at the 1×1 arc-deg grid of points at the earth's surface. Pearson's correlation coefficient is used to quantify these correlations. The 5×5 arc-min global elevation and bathymetry data from the ETOPO5 (provided by the NOAA's National Geophysical Data Centre) are used to generate the Global Elevation and Bathymetry Model coefficients. These coefficients with a spectral resolution complete to degree and order 180 are used to estimate the global correlations of the gravity field quantities with the topography and bathymetry (Sections 2 and 3). The maximum heights and depths of the spectral topography and bathymetry complete to degree and order 180 reach about 6 km; see Fig. 1. The 2×2 arc-deg discrete data of the Moho depths from the global crustal model CRUST 2.0 are used to estimate the global correlation of the gravity field quantities with the Moho boundary (Section 4). The CRUST 2.0 model *(Bassin et al., 2000)* is an upgrade of the CRUST 5.1 model *(Mooney et al., 1998)*. The deepest Moho boundary is beneath the mountainous regions of Himalayas, Tibet, and Andes, where depths reach 70–75 km; see Fig. 2.

2. Correlation of gravity field quantities with the topography

The relation between the step-wise topographically corrected and crust density contrasts stripped gravity disturbances evaluated at the earth's surface and the corresponding elevations of the computation points is shown in Fig. 3. As can be seen from Fig. 3a, there is no significant systematic trend between the observed gravity disturbances and the elevation. We estimated that the correlation of the observed gravity disturbances with the topography is 0.19 over the continents (cf., Table 1). A significant linear trend of

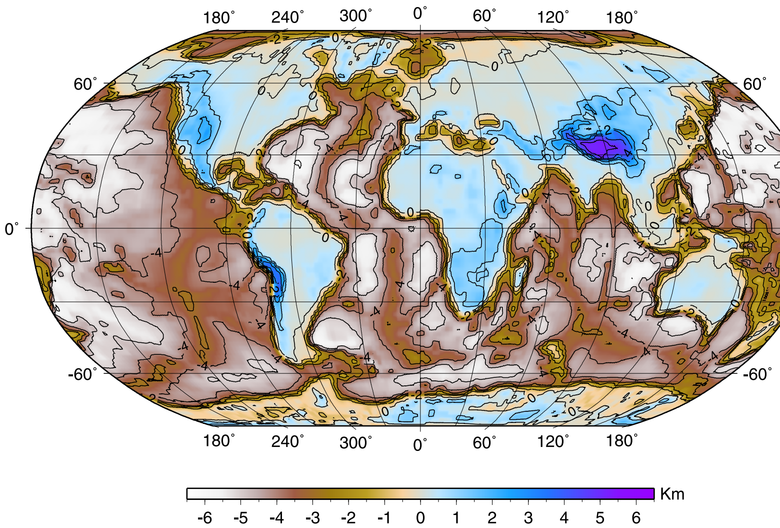

Fig. 1. The global topography and bathymetry; the 1 × 1 arc-deg mean topographic heights and ocean depths obtained from the coefficients of the global elevation and bathymetric models complete to degree and order 180.

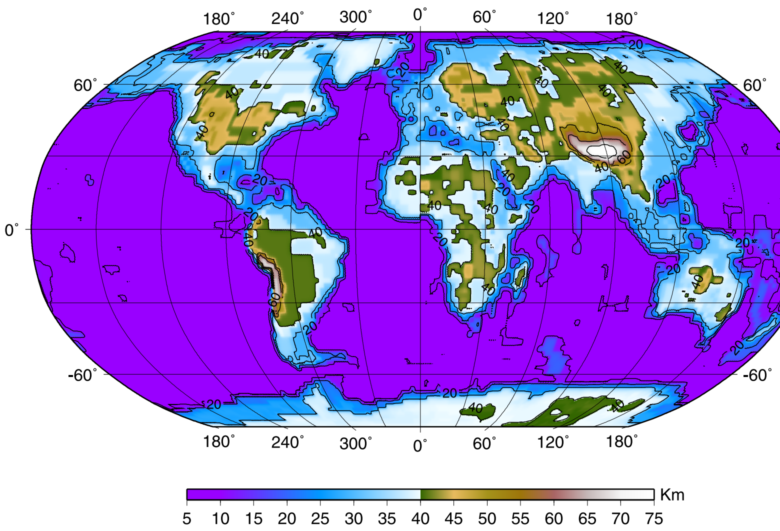

Fig. 2. The depth of the Moho boundary; 2 × 2 arc-deg discrete data from the global crustal model CRUST 2.0.

Table 1. Pearson's correlation of the step-wise consolidated crust-stripped gravity field quantities with the topography over the continents

Type	Gravity disturbances	Gravity anomalies	Disturbing potential
Earth's	0.19	0.26	-0.11
Topographically corrected	-0.97	-0.95	-0.79
BT	-0.96	-0.86	-0.16
Ice and sediment stripped BT	-0.77	-0.75	-0.05
Consolidated crust-stripped (relative to 2670 kg/m^3)	-0.66	-0.73	0.27

the topographically corrected gravity disturbances and of the BT gravity disturbances with the elevation is seen in Figs. 3b and 3c. In both cases, the dispersion of gravity disturbances taken relative to the same elevations is mostly within 200 mGal, except over the oceans and the regions with the low elevations, where this dispersion reaches about 400 mGal and about 600 mGal for the topographically corrected gravity disturbances and for the BT gravity disturbances respectively. Over the continents, the topographically corrected gravity disturbances have among all the investigated types of gravity disturbances the highest negative correlation with the topography of –0.97 (cf., Table 1). This large negative correlation is mainly due to a presence of the isostatic compensation in the mountainous regions. The BT gravity disturbances have almost the same correlation with the topography over the continents of –0.96. This is due to the fact that the application of the bathymetric stripping correction to the topographically corrected gravity disturbances does not change the high-frequency part of the gravity signal over the continents except for the coastal regions; compare Figs. 3b and 3c. The application of the ice and sediment stripping corrections to the BT gravity disturbances significantly decreased the absolute correlation with the topography to –0.77. Compared to the BT gravity disturbances over the continental regions, the dispersion of the ice and sediment stripped BT gravity disturbances taken relative to the same elevations increased to about 400 mGal (cf., Fig. 3d). The reason is that the application of the ice stripping correction to the BT gravity disturbances substantially decreased a large negative contribution of the topographical correction. Consequently, it increased the dispersion (taken relative to the same elevations) of gravity disturbances over the areas with the polar ice sheet in Antarctica and Greenland. Analogically, the application of the sediment stripping correction increased the dispersion of gravity disturbances over the continental regions with the large sediment deposits due to the fact that the density of the soft and hard sediment components is lower than the adopted average topographical/crustal density. The application of the consolidated crust stripping correction further decreased the absolute correlation of the consolidated crust-stripped gravity disturbances to –0.66 (cf., Table 1).

The correlation of the step-wise consolidated crust-stripped gravity field quantities (i.e., gravity disturbances, gravity anomalies, and disturbing potential) with the topography over the continents is summarized in Table 1. Since the observed gravity anomalies differ globally from the observed gravity disturbances within ± 21 mGal (cf. e.g., *Hackney and Featherstone, 2003*), the correlation of the observed gravity disturbances and gravity anomalies with the topography is similar (the correlation difference is 0.07). When the topographic and crust density contrasts stripping corrections are applied to the gravity anomalies, the complete corrections consist not only of subtracting the direct effects, but also of adding the secondary indirect effects (cf., *Vajda et al., 2007; 2008*); the global secondary indirect effects were evaluated and shown in *Tenzer et al. (2008a)*. Nevertheless, the correlation of the step-wise consolidated crust-stripped gravity disturbances and of the corresponding gravity anomalies with the topography is very similar (cf., Table 1). The largest correlation difference of 0.1 is found between the BT gravity disturbances and the BT gravity anomalies. Compared to the gravity disturbances and gravity anomalies, the correlation of the step-wise consolidated crust-stripped disturbing potentials with the topography differs significantly. The topographically corrected disturbing potential has the highest negative correlation with the topography of –0.79 over the continents. The correlation of the ice and sediment stripped BT disturbing potential and of the consolidated crust-stripped disturbing potential is only –0.05 and 0.27 respectively. A relatively high negative correlation of the topographically corrected disturbing potential with the topography, still much lower than the corresponding correlation of the topographically corrected gravity disturbances/anomalies, is due to the fact that the topography-generated gravitational potential is correlated with the regional topography rather than with the local topography and especially with the elevations

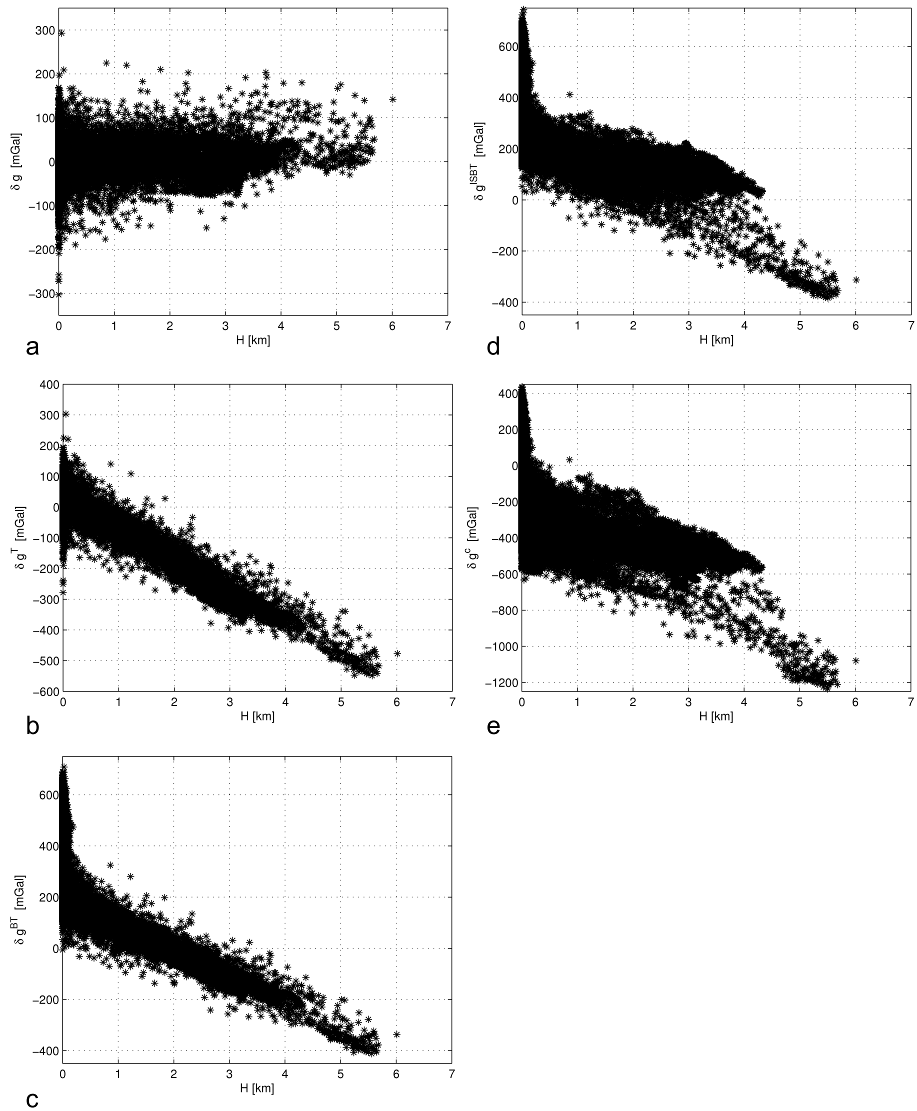

Fig. 3. The relation between the topography (elevations above the sea level H) and various types of the step-wise corrected gravity disturbances: (**a**) – observed δg, (**b**) – topographically corrected δg^{T}, (**c**) – bathymetrically stripped and topographically corrected δg^{BT}, (**d**) – ice, sediment and bathymetrically stripped and topographically corrected δg^{ISBT}, and (**e**) – consolidated crust-stripped δg^{C}.

of the computation points. On the other hand, a large long-wavelength contribution of the bathymetric stripping correction to the disturbing potential significantly decreased the absolute correlation of the BT disturbing potential with the topography over the continents.

3. Correlation of gravity field quantities with the bathymetry

The relation between the step-wise topographically corrected and crust density contrasts stripped gravity disturbances evaluated at the earth's surface and the ocean floor depths is shown in Fig. 4. The observed gravity disturbances are practically uncorrelated with the bathymetry (see Fig. 4a); over the oceans their correlation is only –0.09 (cf., Table 2). The dispersion of the gravity disturbances evaluated at the ocean surface is mostly within the range of about 200 mGal. As can be seen in Fig. 4b, the application of the topographical correction to the observed gravity disturbances at the ocean surface significantly changed this dispersion to about 500 mGal over the shelf seas (especially close to the onshore mountainous regions). The correlation of the topographically corrected gravity disturbances with the bathymetry over the oceans became positive and slightly increased to 0.29. The application of the bathymetric stripping correction to the topographically corrected gravity disturbances revealed a linear trend between the BT gravity disturbances and the ocean floor depths. The magnitude of the BT gravity disturbances increases over the deep oceans. Compared to the topographically corrected gravity disturbances, the dispersion of the BT gravity disturbances taken relative to the same ocean floor depths remained almost unchanged. The correlation of the BT gravity disturbances with the bathymetry over the oceans increased significantly to 0.9. The application of the ice and sediment stripping corrections to the BT gravity disturbances does not change the predominantly linear trend of the BT gravity disturbances with the ocean floor depths, but significantly decreased the dispersion of the ice and sediment stripped BT gravity disturbances (taken relative to the same ocean depths) over the shelf seas to less than 300 mGal (cf., Fig. 4d). As a consequence, the correlation of the ice and sediment stripped BT gravity disturbances with the bathymetry over the oceans slightly increased to 0.93. The linear systematic trend and the dispersion (taken relative to the same ocean depths) of the gravity disturbances

Table 2. Pearson's correlation of the step-wise consolidated crust-stripped gravity field quantities with the bathymetry over the oceans

Type	Gravity disturbances	Gravity anomalies	Disturbing potential
Earth's	-0.09	-0.11	-0.02
Topographically corrected	0.29	0.06	0.54
BT	0.90	0.67	0.68
Ice and sediment stripped BT	0.93	0.62	0.65
Consolidated crust-stripped (relative to 2670 kg/m^3)	0.90	0.33	0.55

remained almost unchanged after applying the final stripping correction due to the consolidated crust. Similarly the correlation of the consolidated crust-stripped gravity disturbances with the bathymetry over the oceans decreased only slightly to 0.90.

The correlation of the step-wise consolidated crust-stripped gravity field quantities with the bathymetry over the oceans is summarized in Table 2. The observed gravity anomalies have a slightly higher absolute correlation with the bathymetry over the oceans than the observed gravity disturbances. The correlation of the step-wise topographically corrected and crust density contrasts stripped gravity anomalies with the bathymetry over the oceans is however much lower compared to the correlation of the corresponding gravity disturbances. The highest correlation difference of 0.56 is between the consolidated crust-stripped gravity disturbances and the corresponding gravity anomalies. The correlation of the BT disturbing potential and of the ice and sediment stripped BT disturbing potential with bathymetry over the oceans is very similar to the correlation of the corresponding gravity anomalies.

The global correlation of the step-wise consolidated crust-stripped gravity field quantities computed at the earth's surface with the topography and bathymetry is summarized in Table 3. The global absolute correlation of the observed gravity field quantities with the topography and bathymetry is small (less than 0.15). The BT gravity disturbances and the ice and sediment stripped BT gravity disturbances have the highest negative global correlation with the topography and bathymetry of –0.93 and –0.96, respectively.

4. Correlation of gravity field quantities with the Moho boundary

The relation between the step-wise topographically corrected and crust density contrasts stripped gravity disturbances evaluated at the earth's surface and the depths of the Moho boundary (bellow the reference ellipsoid) from the CRUST 2.0 model is shown in Fig. 5. The subsequent application of the topographical and crust density contrasts stripping corrections to the observed gravity disturbances increased the correlation of gravity disturbances with the Moho boundary. This is also confirmed by the correlation coefficients given in Table 4. Despite the observed gravity disturbances are practically uncorrected globally with the Moho boundary (cf., Table 4), there is apparently a presence of the systematic trend in the mountainous regions beneath which the Moho depths reach more than 50–55 km. The corresponding dispersion of the gravity disturbances taken relative to the same Moho depths is mostly within 300 mGal. After applying the topographical correction to the observed gravity disturbances, the correlation with the Moho boundary increased in absolute sense significantly to –0.52 (cf., Table 4). This can also be seen in Fig. 5b, showing a presence of the systematic tendency of decreasing the magnitude of the topographically corrected gravity disturbances with the increasing Moho depths beneath the continental regions. The application of the bathymetric stripping correction further revealed the systematic trend between the offshore BT gravity disturbances and the Moho boundary beneath the oceans. The correlation of

Table 3. The global Pearson's correlation of the step-wise consolidated crust-stripped gravity field quantities with the topography and bathymetry

Type	Gravity disturbances	Gravity anomalies	Disturbing potential
Earth's	0.10	0.14	-0.01
Topographically corrected	-0.49	-0.34	-0.50
BT	-0.93	-0.75	-0.74
Ice and sediment stripped BT	-0.96	-0.76	-0.71
Consolidated crust-stripped (relative to 2670 kg/m^3)	-0.94	-0.38	-0.66

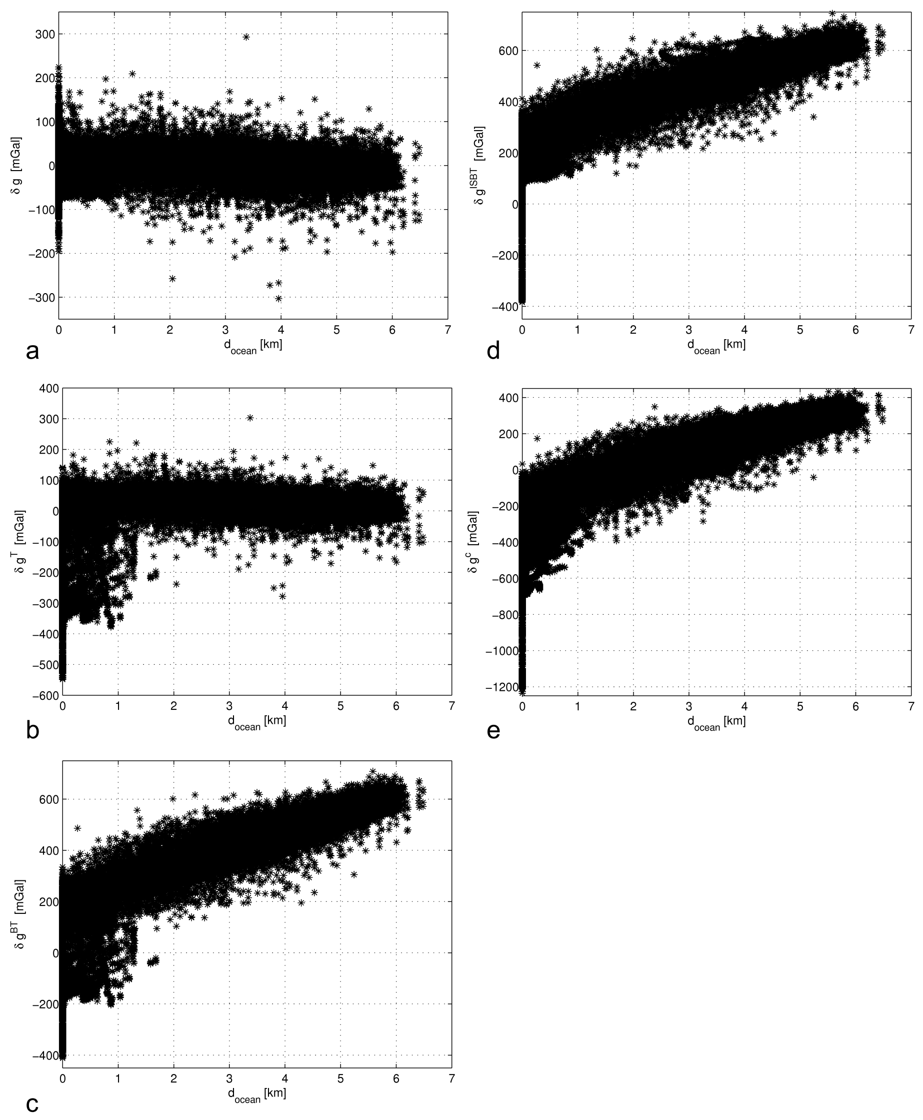

Fig. 4. The relation between the bathymetry (ocean bottom depths d_{ocean}) and various types of the step-wise corrected gravity disturbances: (**a**) – observed δg, (**b**) – topographically corrected δg^{T}, (**c**) – bathymetrically stripped and topographically corrected δg^{BT}, (**d**) – ice, sediment and bathymetrically stripped and topographically corrected δg^{ISBT}, and (**e**) – consolidated crust-stripped δg^{C}.

Table 4. Pearson's correlation of the step-wise consolidated crust-stripped gravity field quantities with the Moho boundary (i.e., the depths of the crust-mantle density interface from the CRUST 2.0 model bellow the reference ellipsoid)

Type	Gravity disturbances	Gravity anomalies	Disturbing potential
Earth's	-0.01	0.02	-0.09
Topographically corrected	-0.52	-0.38	-0.62
BT	-0.87	-0.68	-0.76
Ice and sediment stripped BT	-0.89	-0.68	-0.75
Consolidated crust-stripped (relative to 2670 kg/m^3)	-0.92	-0.34	-0.72

the BT gravity disturbances with the Moho boundary increased in absolute sense to –0.87. Finally, the application of the ice, sediment and consolidated crust stripping corrections increased in absolute sense the global correlation of the consolidated crust-stripped gravity disturbances with the Moho boundary up to –0.92 (cf., Table 4). Over the oceanic lithospheric plates the correlation of the consolidated crust-stripped gravity disturbances with the Moho boundary is –0.84, while over the continental lithospheric plates it decreases in absolute sense to –0.55.

The global correlation of the step-wise consolidated crust-stripped gravity field quantities with the Moho boundary is summarized in Table 4. Similarly to the observed gravity disturbances, the observed gravity anomalies and disturbing potential are not correlated with the Moho relief more likely due to the isostatic balance of the earth's lithosphere. The application of the topographic and bathymetric stripping corrections significantly increased the absolute correlation of the gravity field quantities with the Moho boundary. The same however does not hold for the application of the ice, sediment and consolidated crust density contrasts stripping corrections to the gravity anomalies and disturbing potential. After applying these stripping corrections, the correlation of the disturbing potential slightly decreased in absolute sense from –0.76 (for the BT disturbing potential) down to –0.72 (for the consolidated crust-stripped disturbing potential). The correlation of the gravity anomalies decreased in absolute sense significantly from –0.76 (for the BT gravity anomalies) down to –0.34 (for the consolidated crust-stripped gravity anomalies).

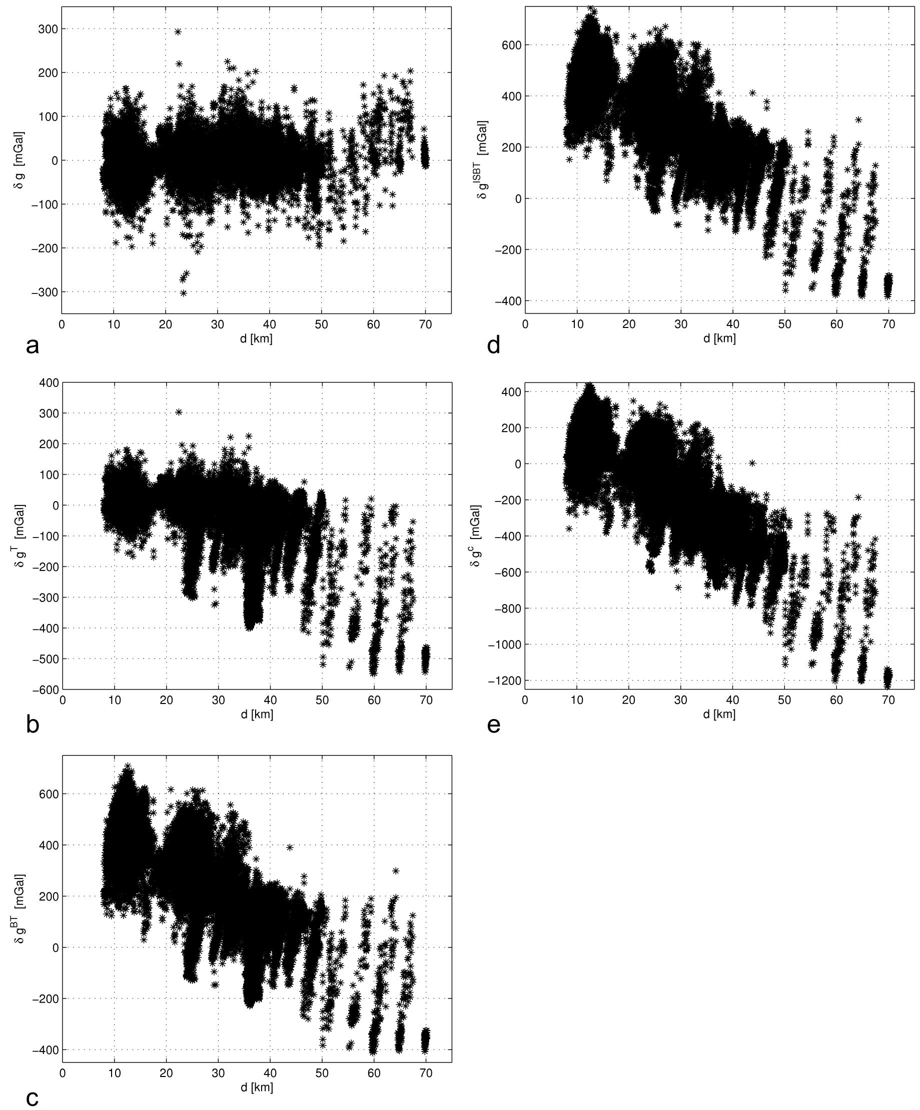

Fig. 5. The relation between the Moho boundary (depths of the crust-mantle density interface d from the CRUST 2.0 model) and various types of the step-wise corrected gravity disturbances: (**a**) – observed δg, (**b**) – topographically corrected δg^{T}, (**c**) – bathymetrically stripped and topographically corrected δg^{BT}, (**d**) – ice, sediment and bathymetrically stripped and topographically corrected δg^{ISBT}, and (**e**) – consolidated crust-stripped δg^{C}.

The correlation of the step-wise topographically corrected and crust density contrasts stripped gravity field quantities with the thickness of the earth's crust (i.e., from the Moho boundary up to the earth's surface) is given in Table 5. The differences between the correlations of the gravity field quantities with the Moho depths (bellow the reference ellipsoid) and with the entire thickness of the earth's crust are less than 0.05; compare Tables 4 and 5.

Table 5. Pearson's correlation of the step-wise consolidated crust-stripped gravity field quantities with the total thickness of the earth's crust (taken from the Moho boundary up to the earth's surface)

Type	Gravity disturbances	Gravity anomalies	Disturbing potential
Earth's	-0.01	0.03	-0.10
Topographically corrected	-0.56	-0.43	-0.65
BT	-0.89	-0.71	-0.76
Ice and sediment stripped BT	-0.90	-0.70	-0.75
Consolidated crust-stripped (relative to 2670 kg/m^3)	-0.93	-0.37	-0.71

5. Summary and conclusions

We have investigated globally the correlation of the step-wise topographically corrected and crust density contrasts stripped gravity disturbances, gravity anomalies, and disturbing potentials with the topography, bathymetry, and the Moho boundary. The topographically corrected gravity disturbances evaluated at the earth's surface have the highest negative correlation of -0.97 with the topography over the continents. Over the oceans, the highest correlation of 0.93 with the bathymetry (ocean bottom depths) is attributed to the ice and sediment stripped BT gravity disturbances evaluated at the earth's surface. The consolidated crust-stripped gravity disturbances evaluated at the earth's surface have the highest negative global correlation of –0.92 with Moho boundary from the CRUST 2.0 model. Realizing that the global data from the seismic topography are implicitly incorporated in the CRUST 2.0 model, we expect that the consolidated crust-stripped gravity disturbances are best suited gravity data type for a global refinement of the Moho density by means of the purely gravimetric modeling or inversion.

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