A new Moho depth model for Fennoscandia and surroundings

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Objectives

One important information of Earth's interior is the crustal/Moho depth (MD), which is widely mapped from seismic surveys. In this study, we aim at presenting a new MD model from satellite altimetry derived gravity and seismic data in Fennoscandia and its surroundings using the Vening Meinesz-Moritz (VMM) model based on isostatic theory. To that end, the refined Bouguer gravity disturbance (reduced for gravity of topography, density heterogeneities related to bathymetry, ice, sediments, and other crustal components by applying so-called stripping gravity corrections) is corrected for so-called non-isostatic effects (NIEs) of nuisance gravity signals from mass anomalies below the crust due to crustal thickening/thinning, thermal expansion of the mantle, Delayed Glacial Isostatic Adjustment (DGIA) and plate flexure. As Fennoscandia is a key area for GIA research, we particularly investigate the DGIA effect on the gravity disturbance and MD determination from gravity in this area. To do so, the DGIA effect is removed and restored from the NIEs prior to the application of the VMM formula.

1 . Methodology

Based on Sjöberg (2009) and (2013) the VMM inverse problem of isostasy is to determine the MD such that the isostatic compensating attraction $A_C(P)$ of the crustal mass totally compensates the Bouguer gravity disturbance on the Earth's surface, implying that the isostatic gravity disturbance $\delta g_I(P)$ vanishes for point *P* on the Earth's surface:

$$\delta g_I(P) = \delta g_B^R(P) + A_C(P) = 0.$$

Here $\delta g_B(P)$ is the Bouguer gravity disturbance corrected for the gravitational contributions of topography/bathymetry and density contrasts of the oceans, ice and sediments and also the NIEs (Bagherbandi et al. 2013). The VMM problem, based on formula above, can be formulated by the non-linear integral equation

$$R\iint_\sigma K(\psi,s)\,d\sigma = -\frac{1}{G\Delta\rho}\left[\delta g_B^R(P) + A_{C0}(P)\right],$$

where *K* is kernel function of the integral, *R* is the Mean Earth Radius, σ is is the unit sphere, ψ is the geocentric angle, *s* is the a simple function of the MD *T*, which is the unknown of the integral equation, *G* is Newton's gravitational constant, $\Delta\rho$ is the Moho density contrast, and A_{C_0} is the nominal compensation attraction with T_0 as the nominal MD.

2. Description of the data

We utilize the XGM2019e gravitational model (Zingerle et al. 2019) on a 1×1 arc-deg spherical grid with a spectral resolution complete to a spherical harmonic degree 180 to produce the free-air gravity disturbance along with the Earth2014 topography model and seismological models of CRUST1.0 and CRUST19. We then correct the gravity disturbances for the density variation of the oceans, ice sheets and sediment basins (i.e. stripping gravity corrections) according to Tenzer et al. (2015), the NIEs and also DGIA. As we already mentioned, this study emphasizes on investigating the DGIA effect on the gravity disturbance and Moho depth determination in Fennoscandia. To achieve this goal, we divide NIEs into NIE and NIE1, i.e. without and with special removal of the DGIA effect.

3. Numerical study

Table 1. Statistics of the free-air and refined Bouguer gravity disturbance estimated from XGM2019e model. STD is the standard deviation of the estimated quantities over the study area, $\delta g_{FA}^{XGM2019e}$ is free-air gravity disturbance, δg^{TBIS} is Bouguer gravity disturbance corrected for topography, bathymetry, ice thickness and sediment basins (i.e. stripping gravity corrections), δg^{NIE} is gravity disturbances corrected for NIEs, δg_R^{TBISN1} is the refined Bouguer gravity disturbance corrected for the stripping corrections structures and NIEs without removal of the DGIA effect, δg^{DGIA} is the DGIA effect on gravity, δg_B^{TBISN} is similar to δg_R^{TBISN1} but with the NIEs determined with application of the special correction for the DGIA effect.

Unit	Quantities	Max.	Mean	Min.	STD
mGal	$\delta g_{FA}^{XGM2019e}$	83.99	-0.56	-66.50	21.99
	δg^{TBIS}	577.181	492.81	231.61	71.26
	δg^{NIE}	-44.30	-193.50	-282.59	46.24
	δg_R^{TBISN1}	355.34	-26.57	-318.87	118.78
	δg^{DGIA}	4.82	-10.36	-19.36	5.34
	δg_R^{TBISN}	351.15	-16.20	-299.50	114.66

Table 2. Statistics of the MDs estimated from XGM2019e model. STD is the standard deviation of the estimated quantities over the study area, PHVMD19 is the (preliminary) MD, estimated from XGM2019e model, before applying the stripping gravity corrections and NIEs not including DGIA effect, HVMD19 is the final MD estimated from XGM2019e model, after applying the stripping gravity corrections, special DGIA effect and NIEs and DGIA is the remaining DGIA effect in PHVMD19, removed in HVMD19.

Unit	MD	Max.	Mean	Min.	STD
km	PHVMD19	58.14	41.08	10.11	10.87
	HVMD19	56.54	40.45	10.22	10.65
	DGIA	0.36	-0.69	-1.31	0.38

Table 3. Statistics of the differences between the PHVMD19/HVMD19 and MDs from the seismic model of CRUST1.0. STD is the standard deviation of the estimated quantities over the study area, RMS is Root Mean Square.

Unit	Difference	Max.	Mean	Min.	STD	RMS
km	PHVMD19 – CRUST1.0	11.80	1.39	-9.15	3.49	4.3
	HVMD19 – CRUST1.0	11.49	1.20	-9.04	3.43	3.6

4 . Analysis of the results

This section presents and interprets our (preliminary and final) MD results before and after the special correction for DGIA effect, named PHVMD19 and HVMD19, and it provides comparison with the CRUST1.0 model.

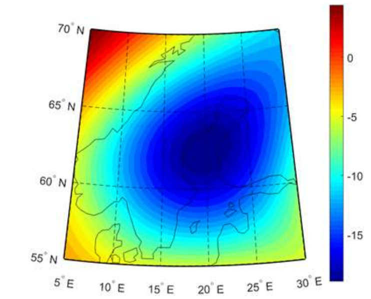

Figure 1. The DGIA effect on gravity with n_{max} = 23 (Unit: mGal).

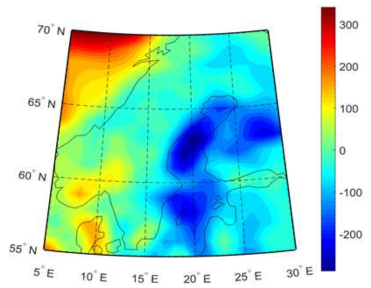

Figure 2. The estimated Refined Bouguer gravity disturbance after special correction for the DGIA effects. (Unit: mGal).

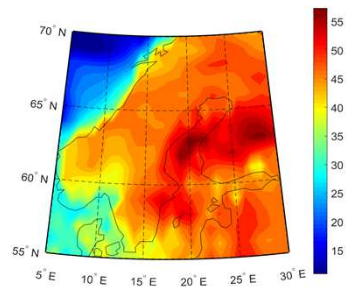

Figure 3. The estimated PHVMD19. (Unit: km)

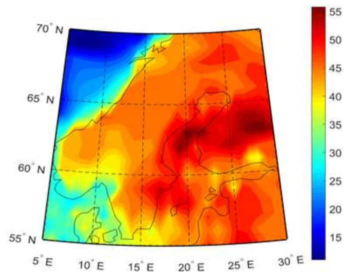

Figure 4. The estimated HVMD19. (Unit: km)

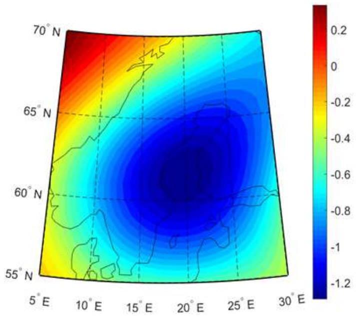

Figure 5. The remaining DGIA effect in PHVD19. (Unit: km).

Conclusion

We determined a new MD model for Fennoscandia using the VMM isostatic hypothesis from the refined Bouguer gravity disturbance and Earth2014 topographic data over 1°×1° blocks on land and ocean. To that end, the refined Bouguer gravity disturbance was primarily reduced for gravity of topography, density heterogeneities related to bathymetry, ice, sediments, and other crustal components using stripping gravity corrections, and it was further corrected for NIEs of nuisance gravity signals from mass anomalies below the crust due to crustal thickening/thinning, thermal expansion of the mantle, Delayed Glacial Isostatic Adjustment (DGIA) and plate flexure. As Fennoscandia is an important area for GIA investigation, we specifically studied the DGIA effects on gravity and MD to figure out if we can improve the stripping of the GIA related gravity signal from the observed gravity field by a specific correction prior to applying the general NIE. To fulfill this, we used the spectral HW 10-23 of the gravity field to calculate DGIA effect, as it yields the maximum correlation, of the order of 0.92, with the newest land uplift model NKG2016LU of the Nordic region. Also we validated the MDs estimated from the PHVMD19 and HVMD19 with the seismic based CRUST1.0 model, showing that the RMS difference of HVMD19/PHVMD19 and the seismic CRUST1.0 model is 3.6/4.3 km when the above strategy for removing the DGIA effect is/is not applied, respectively, and the mean value differences are 1.2/1.3 km, respectively. Hence, the specific correction for the DGIA effect slightly improves the agreement of the gravimetric-isostatic model and seismic model to about 10%.

Major references

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