Surface Gravity and Geoid Rates to constrain Postglacial Rebound Models in North-America

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INTRODUCTION

Surface data used to constrain postglacial rebound (PGR) models includes relative sea level data, GPS measurements, tide gauges and terrestrial gravity. The potential of gravity data has not been explored as thoroughly as other types of data. In this presentation we use rates of gravity change, and geoid rates from combined terrestrial gravity and GPS uplift data. The geoid rate pattern is smooth and can easily be extended. The gravity rate pattern can show more detail but likely includes non-PGR effects.

We investigate the variation of the geoid rate pattern and gravity rate pattern due to changing mantle viscosity based on simplifications of two models in the recent literature, and present a comparison with the data mentioned before. The results demonstrate the potential of currently available terrestrial data to discriminate between different viscosity profiles, and show the particular advantages of gravity and geoid rate data derived from terrestrial data.

PGR MODEL – Earth model

The postglacial rebound simulations use 6-layer Earth models that represent the major discontinuities in the Earth. Density and rigidity (see table 1) are obtained by volume-averaging from PREM. Love numbers are computed via the normal model method. The viscosity values used here, are shown in table 2 and fig. 1.

Layer	Depth [km]	Density [kg/m^3]	Rigidity [10^10 Pa]
Lithosphere	0	3192	6.0
UM1	115	3442	7.3
UM2	400	3882	11
LM1	670	4257	18
LM2	1171	5084	24
Core	2891	10925	0.0

Table 1: Elastic parameters of Earth model.

Layer	P	Pa1	Pa2	MF	MFa2
Lithosphere	inf	inf	inf	inf	inf
UM1	0.4	1	0.4	0.4	0.7
UM2	0.4	1	0.4	0.4	0.7
LM1	2	2	6	10	6
LM2	4	4	6	10	6
Core	0	0	0	0	0

Table 2: Viscosity values (x 10^{21} Pas) of Earth models used in the simulations. P approximates Peltier's VM2 (Peltier, 2004) model; MF approximates Mitrovica and Forte (2004);

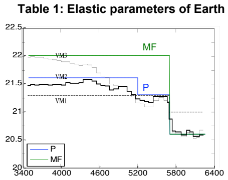

Figure 1: Log10 Viscosity values of Earth models P, MF and LK overlain by a plot of VM1-3 (Peltier 2004).

PGR MODEL – ice and sea level

The ICE-4G ice model (Peltier, 1994) is used; the method of Mitrovica and Peltier (1991) is used to solve the sea-level equation. The ocean function is time-dependent to consider ocean as land when it is covered with ice, but rotational feedback is not taken into account.

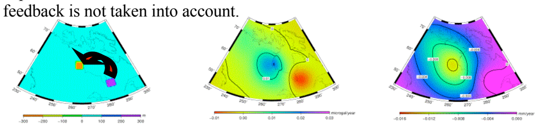

Fig. 1: The figure on the left shows the difference between ICE-4G and a modified ice model in which 300 m of ice height at last glacial maximum is shifted from one block to another. The height difference is spread out linearly over the glacial cycle. The effect on the gravity rate (middle) and geoid rate (right) is very small, showing that they are not sensitive to small changes in ice height.

GRAVITY RATES

Simulated free-air gravity anomalies are computed by the formulation in Mitrovica and Peltier (1989). The historical time rates of change of gravity are from the readjustment of the primary Canadian Gravity Standardization Network (**Pagiatakis and Salib, 2003**, hereafter **PS2003**). The pattern from g-dot shows features that are not related to PGR. Therefore, we chose to extract the general trend in data using an inverse multiquadrics approximation scheme. An orthogonal least-squares procedure that determines the location of inverse multiquadrics basis functions among all data points based on their statistical contribution to the data variance is applied. Figure 3 below shows the comparison between simulated and approximated gravity rate values. Note that the gravity rates have higher magnitude than the simulations and still show non-PGR effects.

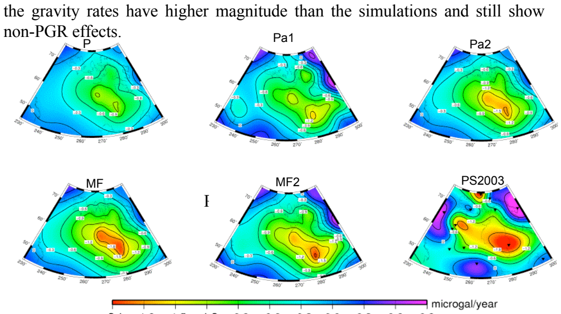

Figure 2: Gravity rate (microgal/year = 10^{-8} m/s^2) for the 5 different models and the Pagiatakis and Salib dataset at bottom right with triangles marking the locations of the sites used in the interpolation.

GRAVITY RATE COMPARISON

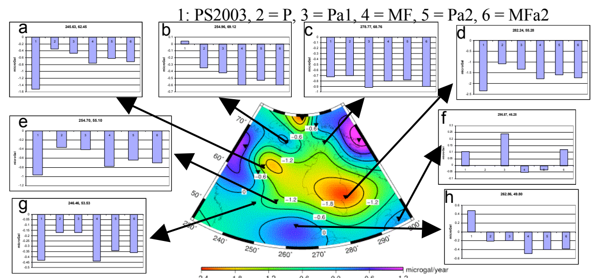

Figure 3: The bar plots show the PS2003 value and the model values in microgal/year. Good agreement can be seen in plot c, PS2003 gives larger values in a, d, e, g. In b and h, likely non-PGR effects cause the difference in sign.

P	Pa1	Pa2	MF	MFa2
7.98	6.81	5.64	4.83	4.96

Table 3: Chi-squared values between smoothed models and smoothed PS2003. It can be seen that MF and MFa2 give the best agreement.

GEOID RATES

The geoid rates are computed from surface gravity data and uplift velocities determined from gravity rates with gravity-to-height ratio of -0.18 microgal/mm (Lambert *et al*. 2006), by a least-squares procedure in which the trend is estimated using inverse multi-quadrics. To be consistent with the gravity rates, we have used the same stations as were used for the gravity rates.

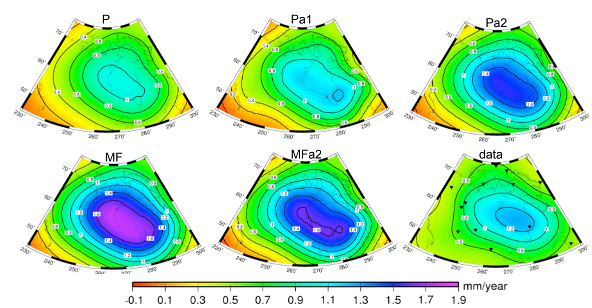

Figure 4: Geoid rate (mm/year) for the 5 different models and the combined GPS and gravity data (bottom right), with triangles marking the stations used.

Both increasing upper mantle viscosity (compare Pa1 to P and MFa2 to MF) and lower mantle viscosity (compare Pa2 to P) increases the geoid rate. Increasing upper mantle viscosity enhances the details in the pattern. Model Pa1 seems to agree best with the derived geoid rate. This is contrary to what was found for the gravity rates.

CONCLUSIONS AND OUTLOOK

It was shown that gravity rates and geoid rates are not sensitive to small changes in ice height (300 m at last glacial maximum spread out over the glacial cycle gives a difference of the order of 1 percent). The rates are more sensitive to change in mantle viscosity. The gravity rates have the advantage that they are the only data set that cover most of Canada. However, they contain other signals in addition to PGR. Geoid rates show less details but are less likely to be contaminated by other processes and can more easily be extrapolated to areas with few data.

The gravity rates from PS2003 are larger than the model predictions and sometimes even show different sign. Chi-square values show that the Mitrovica and Forte (2004) model agrees best with the PS2003 gravity rates (keeping in mind the simplifications in the modelling, such as neglect of rotational feedback). The magnitude of the geoid rate from the combination procedure is in between the model predictions. Visual inspection shows that the simplified VM2 model (Peltier, 2004) or one with slightly higher lower mantle viscosity agrees best with the constructed geoid rates. The different outcome of the geoid rates and gravity rates comparisons shows that more and different types of data should be used to infer a viscosity profile.

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