Paper review for EGUsphere

Title: Improving the Gravity Anomaly Map of French-Belgian Hainaut using Multi-Scale Fusion of New Gravity Acquisition and Legacy Data in an Adaptive and Open-Source Gravimetric Processing Workflow.

Authors: Q. Campeol, Dupont N and Kaufmann O.

Result of the review: worthy of publishing, but **substantial revision** is needed

General comments: As a lecturer of Physical Geodesy for many years, active participant in numerous international gravimetric surveys, manager of large regional gravity database that includes data from different countries and as active user of gravity data for both geodetic and geophysical purposes, I'm truly puzzled by this contribution. Many modeling problems mentioned in the paper look familiar, however the way that these problems are addressed is often non-standard. In other words, the data processing elements (the corrections) that you mention in the paper are completely understandable-, important- and worth addressing, but the way you address them does not always follow what is "the common practice" among the practitioners.

To my opinion the paper suffers, technically, from "too much irrelevant information" that blur the content. For example, in your writing it is not necessary to refer to pre-computer age graphical methods of terrain correction and to Hammer zones (as if it was an option). You should focus on what you did in practice to correct the gravitational effect of the near and far terrain. To my opinion, and because of this, the main message of what you did with MoreGeo data drowns in all kinds of irrelevant detail. Also, the prism formula for the gravitational potential of Nagy et al., 2000, 2002 (which you didn't use) is also irrelevant. Terrain corrections, Bouguer anomalies (both simple and refined) are part of standard corrections in Physical Geodesy and in gravity surveys and must not be explained "from scratch".

My experience from many years of international gravity projects is that different countries have slightly different approaches to how to design and conduct a gravity survey. In this context I'm also aware of different approaches across different disciplines of geosciences - between geodesy and geophysics/geology. When we include gravity data to a gravity database, we sometimes face a problem that the data collected for the purpose of geology/geophysics are not always properly tied to a well-defined absolute system. In your paper you claim a connection to the world system (GRS80 ellipsoid and WGS84 datum through your RTK positioning). However, GRS80 is more than the geometrical aspect. As geodesist there are two things in your paper that bother me concerning your explanations of the MoreGeo project processing: (1) Where are the absolute gravity references/ties of your measurements? (2) Why is the normal gravity model (GRS80) not mentioned explicitly? This is important and probably hidden in your Eq. (26) where you quote (Moritz 1980). A standard definition of free-air gravity anomalies is by using a normal gravity model (currently GRS80). In your contribution it is (probably) what you call, the latitude correction. By definition, a gravity anomaly means a difference between the true gravity value (measured by the relative gravimeter; g_measured in your Eq. 28) and a normal gravity value γ of the normal gravity model. Thus, a true gravity field is treated as anomaly with respect to the (normal) model field. This aspect is not explicit in your writing.

Also, I'm completely amazed by your way of treating the collected gravity data. You seem to correct directly the gravity readings until you obtain the anomalies. On the positive side, the survey results that you obtain and show on Figure 12 (green dots) look fine to me. The problem with this figure is the numbers. Your y-axis on Fig 9, Fig. 11 and Fig. 12 is not (as you claim) "g

[mgal]" but the reduced gravity readings (?). "g" is reserved for absolute gravity and 6-digit numbers (when in mGals) starting with "9". I do not know any place on Earth where the Bouguer gravity anomaly is 4300 mGals as it is on most of your figures!

Another thing that truly amazes me is the idea of modeling the relative gravimeter drift over large time span to ensure (as I understand it) that the drift corrected gravity readings yield the same value at points that the survey measured more than once (possibly at entirely different times). The drift model refers to the specific time (the start time of the first period) and the corrected readings express what the gravimeter would measure at all points of the profile if the gravimeter drift was zero. However, at the level of accuracy that you aim for (sub 10 microgals) there can be environmental changes that can occur around the stations between the two times so that the local reading is affected (e.g. hydrology). For modelling the long term gravimeter drift the paper that you are inspired by a paper on drift of a superconducting gravimeter which is a stationary instrument measuring over large time span and affected by the same gravitational pull of the Earth for this location. For such instrument it makes sense to consider a drift model over long time, but not necessarily for a relative gravimeter like CG-6.

You have completely different setup for the relative gravimeters and a microgravity survey that you conduct. If I was to plan such a microgravity survey, I would have included reference points with absolute gravity values and (if possible) visit on the way other points with known and well-established absolute gravity values. I realize that you measure 40 points a day which makes it logistically difficult. But this is about independent validation of your drift model. In this setup, the drift would be determined daily and would for a given day of measurements approximately be linear. After all, there is a drift self-calibration option a CG6. One could almost do daily such drift calibration test overnight. Consequently, you can determine CG6 drift daily and compare it to the one obtained from the absolute stations. In fact, you do not even need an absolute station in the field to get a drift estimate. You just need a base point that you start from and end at the same day. On the positive side, you seem to get something reasonable with the long time span drift function.

A different (but serious) technical issue with the paper is the notation and your very loose use of different concepts. Equations (21), (22) and (23) make no sense. Please, look them up in (Heiskanen and Moritz, 1967) that you quote. Bouguer gravity anomaly, free-air gravity anomaly, gravity disturbances have precise meaning. They need to be defined first. Use consistent symbols. In Eq. (25) you write rho for density and ρ in prism formulas just below. I'm also in doubt about your loose terminology regarding heights. Ellipsoidal heights are usually denoted h while normal- and orthometric heights are denoted H^* and H respectively. It seems you only use ellipsoidal heights, but I don't know. You also get the free-air reduction wrong. Yes, I do realize that there is a minor latitude effect as stated in your Eq. (24). Your normal gravity γ as a function of ellipsoidal height is for all terrestrial points approximated as Taylor series in powers of h truncated at degree 2. When you differentiate wrt. h to get $\frac{\partial \gamma}{\partial h}$ you should get a 1 order polynomial. Free-air reduction F uses $-\frac{\partial g}{\partial H} H \approx -\frac{\partial \gamma}{\partial h} H$ so that $F = 0.3086 \cdot H$ (mGal) when H is in meters. Unfortunately, in (Heiskanen and Moritz, 1967) there is a notational inconsistency in Eq. (3-17) where they write: $F = 0.3086 \cdot h$, but what they mean by h in this equation is the orthometric height (height over geoid). This inconsistency is corrected in (Hofmann-Wellenhof and Moritz, 2006), eq. (3-26). Bottom line, it is $F \equiv -\frac{\partial \gamma}{\partial h} H$ and not $F \equiv -\frac{\partial \gamma}{\partial h} h$ which corresponds to your eq.(24), The base level of the Bouguer plate or Bouguer spherical shell is geoid/quasi-geoid and not the ellipsoid! Referring to your Eq. (24) it is only the first part of the equation that is used as a standard and for H as a station height not h . Other examples of strange notation in the paper are Eq. (7), (8) and (9) denoting (I guess) confidence intervals(?) of student distribution. Where is LHS (left-hand-side) of the equation? What does it mean?

What to do?

Let me be clear, I encourage you to correct the paper. I find the results and this kind of cross border reconciliation of gravity data important and relevant. Unfortunately, if I do not understand in full what you did with GeoMore data, the question of merging these results with legacy data is at this stage irrelevant. As it is now, I'm not entirely sure if you and I even agree on what is free-air gravity anomaly, Bouguer gravity anomaly (simple, refined), terrain correction, topographic correction ... etc. Your paper in its current state is, to put it mildly, not helpful. So, before you and I can engage in any meaningful discussion about the content, these things must be corrected. Reduce the paper considerably, use appendices for details, use strict and standard definitions, use systematic and uniform standard mathematical notation, be explicit about the heights that you use at each step (ellipsoidal, orthometric, normal), relate the introduced concepts to global models (GRS80 normal gravity model). If you still insist on formulating your processing steps as corrections relate them to the above standard definition of concepts. Use the absolute gravity ties explicitly. Be very careful about your figures, the numbers that you show and how you label your y-axis.

Concerning the last part of the paper, the consistency with the legacy gravity data, there are important topics to discuss (e.g. reconciling different conventions of reducing the data sets, truncated station location coordinates, map projection issues, different conventions regarding topographic mass density assumptions ... etc). But we cannot engage in this kind of discussion before the paper is corrected.

Good luck with it!