Basic agreements for the computation of station potential values as IHRS coordinates within empirical experiments based on data provided by the IAG JWG 2.2.2 (the 1 cm geoid experiment)

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Preamble

During the business meeting of the JWG 0.1.2[1] held at IAG-IASPEI 2017 (Kobe, Japan), J. Ågren[2] and J. Huang[3] proposed to establish a strong interaction with the JWG 2.2.2 (the 1 cm geoid experiment). Aim of JWG 2.2.2 is the computation and comparison of geoid undulations using the same input data and the own methodologies/software of colleagues involved in the geoid computation. The comparison of the results should highlight the differences caused by disparities in the computation methodologies. In this frame, it was decided to extend the "geoid experiment" to the computation of station potential values as IHRS coordinates. With this proposal, Y.M. Wang agreed to provide terrestrial gravity data, airborne gravity, and digital terrain model for an area of about 700 km^2 in Colorado, USA. With these data, the different groups working on the determination of IHRF coordinates should compute potential values for some *virtual* geodetic stations located in that region. Afterwards, the results obtained individually should be compared with the Geoid Slope Validation Survey 2017 (GSVS17). In the same meeting, it was also agreed to standardise as much as possible the data processing to get as similar and compatible results as possible with the different methods. However, the definition of a "standard or unified" processing procedure/strategy is not suitable, because regions with different characteristics apply particular approaches. Therefore, at this first stage, we agreed to outline a set of basic (minimum) requirements to initiate the experiments for the computation of the potential values. The choice of the processing method is up to the gravity field modeller. This document presents a first attempt to identify that set of basic requirements.

Objective

The goal of this experiment is to assess the repeatability of potential values as IHRS coordinates using different computation approaches. Based on the comparison of the results, a set of standards should be identified to get as similar and compatible results as possible.

Basics

- The determination of station potential values $W(P)$ as IHRS coordinates is straightforward if the disturbing potential $T(P)$ is known: $W(P)=U(P)+T(P)$.
- Since the disturbing potential should be estimated with high-precision, it is proposed to compute (a) the long wavelength component (about d/o $\leq$ 200 … 250) using a satellite-only global gravity model (GGM) and (b) the short wavelength component (d/o > 200 … 250) by the combination of terrestrial (airborne, marine and land) gravity data and detailed terrain models.
- The GGM should be based at least on the combination of SLR (satellite laser ranging), GRACE and GOCE data, due to the improvement offered by these data to the long wavelengths of the Earth's gravity field modelling.
- The potential values realising the IHRS coordinates must be determined at the reference stations; i.e., at the Earth's surface and not at the geoid. Therefore, a scalar free Geodetic Boundary Value Problem (GBVP) based on the telluroid as the approximation to the boundary surface should be used (i.e. Molodensky approach). This in addition prevents from uncertainties caused by disparities

[1] GGOS JWG: Strategy for the Realization of the IHRS, chair L. Sánchez.
[2] Chair of IAG SC 2.2: Methodology for geoid and physical height systems.
[3] Chair ICCT JSG 0.15: Regional geoid/quasi-geoid modelling - Theoretical framework for the sub-centimetre accuracy.

between the hypotheses introduced to compute gravity anomalies at the geoid. Depending on the available observations to determine the geometry of the Earth's surface, a fixed GBVP may be also applied.

- According to the IHRS definition, the station coordinates have to be given in the mean tide system. In our meeting in Kobe, we agreed to perform the computations in zero-tide system and afterwards, to transfer the coordinates to mean-tide system at the very end, using simplified formulas. This keeps the computations consistent with the gravity/geoid work in zero-tide without introducing an awful amount of new transformations and corrections.
- However, as the gravity data and geometric coordinates provided by NGS/NOAA are in tide-free system, we should use the tide-free system for these first computations. If everything is consistent, this should not influence the comparison of results.
- For these first experiments, we assume the Earth's gravity field to be stationary; i.e., time changes are disregarded so far.

Standards

General constants (numerical values needed for the solution of several equations)

- Constant of gravitation (G) 6.674 28 × 10−11 $m^3kg^{-1}s^{-2}$
- Geocentric gravitational constant (GM) 3.986 004 415 × 10^{14} m^3s^{-2} (including the Mass of the Earth's Atmosphere)
- Nominal mean angular velocity of the Earth (ω) 7.292 115 × 10^{-5} rad s^{-1}
- Conventional reference potential value (W_0) 62 636 853.4 m^2s^{-2}
- Average density of topographic masses (ρ) 2670 kg m^{-3}

Reference ellipsoid (to be used for the computation of gravity anomalies, disturbing potential, ellipsoidal coordinates, etc.):

- GRS80 – please use the parameters published in *Moritz H.: Geodetic Reference System 1980, J Geod 74: 128-133, doi: 10.1007/s001900050278, 2000*. Previous publications contain some typos in the normal gravity formulae. A free available copy of the paper can be found at https://link.springer.com/content/pdf/10.1007%2Fs001900050278.pdf

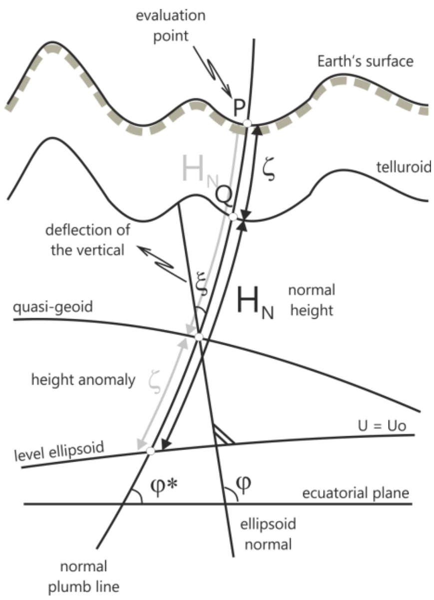
Global Gravity Model (GGM): Although we prefer the use of a satellite-only GGM, we also open the possibility of using a combined GGM (combined means including terrestrial gravity data)

- Satellite-only GGM: GOCO05s, d/o=280 (Mayer-Gürr et al., 2015), available at http://icgem.gfz-potsdam.de/tom_longtime.
- Combined GGM: XGM2016, d/o=719 (Pail et al. 2017), available at http://icgem.gfz-potsdam.de/tom_longtime.
- Experimental global gravity model xGEOID17A/PGM2017 (d/o=2160, these models will be made available by NGS/NOAA at a later stage)
- One-degree coefficients (C_1=C_{11}=S_{11}=0) are assumed to be zero to align the Earth's centre of masses with the origin of the geometric coordinate system (ITRS/ITRF).
- The zero-term T_0 has to include the difference between Earth's and ellipsoid's reference potential and GM constant:

  $$T_0 = \Delta GM - \Delta W_0 ;\ \Delta W_0 = W_0 - U_0 ;\ \Delta GM = \left(GM - GM_{GRS80}\right)/R$$

Gravity anomalies

- According to Molodensky, the generalised gravity anomaly at a point P on the Earth's surface with geodetic latitude φ, longitude λ and physical height H is the difference between the *real* gravity g at P minus the ellipsoid's normal gravity γ at a point Q with the same latitude φ and longitude λ and having an ellipsoidal height equal to H: $\Delta g = g_P - \gamma_Q$. Strictly speaking, H has to be the normal height H_N.



- No atmospheric reduction has been applied on the given terrestrial gravity nor on the GRAV-D airborne data. Therefore, it should be taken care of in the computation.

<u>Expected results</u>

Please provide a brief description of the computation method and constants you used. Please provide also the following values at the nodes of a 1'x1'-grid:

- Potential value: W=U+T

- Height anomaly: $\zeta = T/\gamma$

- Geoid undulations (for comparison with the NGS/NOAA databank):

$$N - \zeta = \frac{\bar{g} - \bar{\gamma}}{\bar{\gamma}} H^O = H^N - H^O$$

H^O and H^N are the orthometric and normal height, respectively.
$\bar{g}$ mean real gravity value along the plumb line between Earth's surface and geoid.
$\bar{\gamma}$ mean normal gravity value along the normal plumb line between ellipsoid and telluroid (or between Earth's surface and quasi-geoid).
$\bar{g} - \bar{\gamma}$ shall be approximated by $\Delta g - 2\pi G \rho H^O$ in order to be compatible with the Helmert orthometric heights of NGS/NOAA. Here Δg is the surface gravity anomaly, *G* is Newton's gravitational constant and ρ = 2670 kg m^{-3} is the average (constant) density of the topographic masses.

To compare interpolation results, we also kindly ask you to provide potential values, height anomalies and geoid undulations at the GPS/levelling points (called GSVS17 marks) provided by NGS.