IHRS experiment Colorado

Results with the AUSGeoid2020 computation approach

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1. Introduction

This document outlines the method used at Curtin University, Perth, Australia, on the International Height Reference System (IHRS) experiment. We applied, as much as possible, the approach used in the computation of the Australian geoid model AUSGeoid2020 to the Colorado test data set. This approach is explained in detail in Featherstone et al. (2018). However, due to differences in terrain, data, and product requirements, some changes to the AUSGeoid2020 approach were required. Further work to validate the computations is currently ongoing or planned for the near future, but the latest results are presented here.

The following data sources were used in this experiment:

- 3″ Digital Elevation Model: *Colorado_dem_33_42_248_260.grd*
- Terrestrial gravity data: *Colorado_gravity_data.dat*
- Airborne gravity data: *GRAVD_ms05_median_debiased_1hz.txt*
- Global Gravity Model (GGM): *Cnm_refB_v050317a_s2-2190zt_4*
- GSVS coordinates: *gsvs17_IGS08_2017p4.xlsx*
- GNSS-levelling data: *Colorado_GPSBM_v2.2_08Feb18.txt* (used for validation only)

2. Gravity data

The surface gravity and airborne gravity observations were first transformed into Molodensky-type free-air anomalies. Somigliana-Pizzetti normal gravity was computed rigorously using GRS80 reference ellipsoid parameters (Moritz 2000). For the surface gravity data, the ellipsoidal height of the telluroid was approximated by the orthometric height of the gravity observation. For the airborne gravity data, the altitude of normal gravity was computed by subtracting GGM height anomalies from the provided ellipsoidal heights.

The 3″ × 3″ DEM over Colorado was used to compute planar terrain corrections over the test area using two different algorithms: 1) the algorithm used in AUSGeoid2020 (McCubbine et al. 2017), and 2) a more recently derived algorithm (Goyal et al. 2019). The differences in the final geoid model due to these different terrain corrections reach a maximum of 38 mm. The second method was selected.

Airborne gravity data were downward continued to the topography using 3D Least Squares Collocation with planar logarithmic covariance function (Forsberg 1987, McCubbine et al. 2018). The downward continuation requires further fine-tuning, which is currently ongoing work. Bouguer anomalies were used for gridding of the data to a 1′ × 1′ grid using the tensioned spline routine in Generic Mapping Tools (GMT) (Wessel et al. 2013). The gridded Bouguer anomalies were converted into Faye anomalies, which are used for quasigeoid computation.

3. Global Gravity Model

The GGM *Cnm_refB_v050317a_s2-2190zt_4* (herein called RefB) is in zero-tide, but had to be converted to tide-free to meet the IHRS experiment's basic requirements (Sánchez et al. 2018). A tide correction ($\Delta C_{20} = 0.4173576 \cdot 10^{-8}$) was determined from the published tide-free and zero-tide models of EGM2008 and applied to RefB.

As per the AUSGeoid2020 computation scheme, height anomalies and ellipsoidal gravity anomalies from the GGM up to d/o 2190 are computed at 1' × 1' resolution at the surface of the topography. In the computation of AUSGeoid2020 this was done using the isGrafLab software (Bucha and Janák 2014) for efficiency, but since the Colorado test area is smaller, the harmonic_synth software (Holmes and Pavlis, 2008) was used instead in scattered point mode. While harmonic_synth is computationally slower, it can compute ellipsoidal gravity anomalies in one step, avoiding the more complicated procedure described in Featherstone et al. (2018, section 2.3.2). In the spherical harmonic synthesis of both height anomalies and gravity anomalies, the GRS80 reference field parameters (Moritz 2000) were used.

4. Quasi-geoid computation

The GGM gravity anomalies were subtracted from the gridded Faye anomalies to obtain residual gravity anomalies, which were subsequently high-pass filtered. 1D-FFT modified Stokes integration was applied on the residual gravity anomalies. The kernel used is the FEO-kernel (Featherstone et al. 1998) with modification degree $M = 40$ and an integration cap radius of 0.5 degrees. In the restore step, the residual height anomalies were added to the GGM height anomalies.

A zero-degree geoid term was estimated to take into account 1) the difference between the geocentric gravitational constant selected for the project ($GM = 3.986004415 \cdot 10^{14}\ \mathrm{m^3 s^{-2}}$; Sánchez et al. 2018) and defined in the GRS80 reference ellipsoid ($GM_0 = 3.986005 \cdot 10^{14}\ \mathrm{m^3 s^{-2}}$; Moritz 2000), and 2) the difference between the conventional reference potential value used in this project ($W_0 = 62636853.4\ \mathrm{m^2 s^{-2}}$; Sánchez et al. 2018) and the reference potential at the surface of the GRS80 ellipsoid ($U_0 = 62636860.850\ \mathrm{m^2 s^{-2}}$; Moritz 2000). A mean Earth radius was used for the computation area to obtain a constant zero-degree term:

$$\zeta_0 = -0.1785\ \mathrm{m}$$

This zero-degree geoid term was added to the restored height anomalies, resulting in the final height anomalies.

5. Geoid model and potential values

As AUSGeoid2020 is a quasigeoid model, the computation of the geoid model and potential values outlined below are not part of the AUSGeoid2020 computation approach. In adherence to the basic requirements (Sánchez et al. 2018), the geoid-quasigeoid correction was approximated using the following simple equation (Heiskanen and Moritz 1967, Eqs. 8-102 - 8-103)

$$N - \zeta = \frac{\Delta g_B \cdot H}{\gamma}$$

The geoid-quasigeoid corrections reach a maximum of 1.426 m. These corrections were subtracted from the final height anomaly grid to obtain the final geoid model. This model is herein called Curtin Colorado Geoid, version 3 (CCGv3).

To create a grid of potential values, the magnitude of normal gravity γ and normal potential U were computed rigorously at the topography. The generalised Bruns's formula (Heiskanen and Moritz 1967, Eq. 2-178) was used to compute the disturbing potential. Finally, the gravity potential W at the topography was computed by adding the normal potential U at the topography to the disturbing potential T.

Finally, height anomaly and geoid grid values were bi-cubically interpolated to the locations of 223 reference marks along the Geoid Slope Validation Survey 2017 (GSVS17). Gravity potential values on the GSVS17 reference marks were also generated. However, to avoid large interpolation errors of more than 1000 m^2s^{-2}, these were not directly interpolated from the gravity potential grid. Instead, the GRS80 normal potential was computed rigorously at the ellipsoidal heights of the GSVS17 reference marks. The disturbing potential was bi-cubically interpolated to the reference marks from the grid, and then added to the normal potential values.

The final results are stored in six files, shown in Table 1. All files are in ASCII format and contain three columns: longitude, latitude, and the values of the quantity in question. Height anomalies and geoid heights are in metres, and gravity potential values in m^2s^{-2}. The regular grids use centre-cell registration.

Quantity	Spatial resolution	File name
Height anomaly	1′ × 1′ grid	height_anomaly_Colorado_grid_v3.llf
Geoid height	1′ × 1′ grid	geoid_Colorado_grid_v3.llf
Gravity potential	1′ × 1′ grid	gravity_potential_Colorado_grid_v3.llf
Height anomaly	223 GSVS17 marks	height_anomaly_Colorado_GSVS_v3.llf
Geoid height	223 GSVS17 marks	geoid_Colorado_GSVS_v3.llf
Gravity potential	223 GSVS17 marks	gravity_potential_Colorado_GSVS_v3.llf

Table 1: Overview of results

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