Insights into the Mexican Gravimetric Geoid (GGM05)

D. Avalos, M.C. Santos, P. Vanícek and A. Hernández

Abstract The precise geoid determination technique from the University of New Brunswick (UNB) was adopted in Mexico to compute the national geoid model GGM05. To generate it, the input data was treated carefully and the theoretical background is well established. However, the final assessment gives unsatisfactory biases at level of metres. Some preliminary results of the corresponding research expose the possible sources for those large errors. The reference geoidal heights are the main suspect. Hence, in order to obtain a reliable assessment for GGM05, the issue of building better references has to be addressed. New developments like recent vertical movements modeling, rigorous orthometric heights estimation and precise positioning shall be combined to help removing uncertainties from the reference data, resulting in a better understanding of the Mexican gravimetric geoid.

Keywords Geoid assessment · Orthometric height · Geoidal height

D. Avalos
Department of Geodesy and Geomatics Engineering, University of New Brunswick, 15 Dineen Drive, Fredericton, New Brunswick, Canada, E3B5A3

M.C. Santos
Department of Geodesy and Geomatics Engineering, University of New Brunswick, 15 Dineen Drive, Fredericton, New Brunswick, Canada, E3B5A3

P. Vanícek
Department of Geodesy and Geomatics Engineering, University of New Brunswick, 15 Dineen Drive, Fredericton, New Brunswick, Canada, E3B5A3

A. Hernández
INEGI, Dirección General Adjunta de Geomática, Av. Nacozari Sur 2301, Aguascalientes, Mexico, 20270

1 Introduction

The Mexican Gravimetric Geoid (GGM) is an ongoing effort from INEGI, the federal institution in Mexico responsible for the national geodetic control. After many years depending on foreign institutions and technicians to obtain the national geoid model, the Mexicans opted to learn the UNB Stokes-Helmert technique for precise geoid computation (Vaníček et al., 1999) to make it themselves. The mathematics of this technique is well established, leading the computation of geoidal heights with uncertainty of 1 cm.

Currently, the estimated accuracy of GGM05's geoidal heights is 36 cm rms (INEGI, 2007). This value results form a comparison against 1377 point values of geoidal height derived from GPS/BM references using the well known formula $N = h - H$, where N, h and H correspond to geoidal, geodetic and orthometric heights. Regional and systematic biases between GPS and BM observations have been detected, some reaching 2 m at the central part of the country, as indicated in Fig. 2. These differences are well beyond the reasonably expected since all height estimations were assumed to have centimetre accuracy. But some questions raised around the reference data because it is already aged. The levelling observations used were made, in average, 30 years before the GPS data were collected. This leads to a mandatory analysis of the computational process and the reference data used.

Preliminary results of the analysis are showing that time variation in heights is one of the main reasons for discrepancies between GGM05 and the reference data. Since heights are continuously changing due to geodynamical processes and the surveying data cannot be gathered in short periods of time, it is necessary to have geodetic tools to deal with time varying heights. Until now, the studies of recent vertical crustal movement on the Mexican territory have been devoted to small regions like city areas. These are not enough to explain long wavelength biases.

About the input data, there has been an effort to guarantee the use of a reliable dataset of gravity values and to assemble the first continuous digital elevation model with high resolution for national coverage.

2 The GGM05 Model

Digital elevation models of free air gravity anomaly, lateral density of topography and orthometric height are the main input in the Stokes-Helmert technique for geoidal height computation. From the beginning it was a challenge to obtain these models in the Mexican case, since the available data did not qualify in coverage and specifications. A strong campaign to accelerate gravity data collecting and building the homogeneous models of lateral density and orthometric heights with nationwide coverage was organized. Then the final input data set for GGM05 was released after discriminating outliers and suspicious values which could not be validated with the resources inside INEGI. The coverage, distribution, and general quality of gravity observations was greatly enhanced, but still not the ideal: there are at least one observation in every cell 2.5 min in latitude and longitude. Other data sources used to complete the input was the low frequencies of EIGEN2 geopotential model for reference spheroid, TOPEX-POSEIDON altimetry to derive free air gravity anomaly at the sea, and GRIM4 global topographic elevation model for computing for zone contributions to the gravity field.

GGM05 model has estimated geoidal heights ranging between −48 and +6 m. The resolution is 2.5 min in latitude and longitude and coverage from 86 to 119° west in longitude and 14 to 33° north in latitude, as illustrated in Fig. 1.

The computations to obtain GGM05 follow the UNB technique, Helmertizing the mean free air gravity anomalies to perform downward continuation to the cogeoid and evaluate the Stokes formula. Data processing was performed using SHGEO package version 2001 from the geodesy research group at UNB (Janak, 2001). The newest version of the software

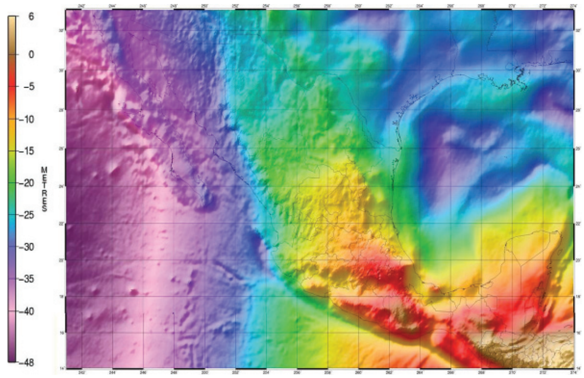

Fig. 1 Geoid Model GGM05 (courtesy INEGI, 2007)

was not available at that time, and one of the main enhancements is in the program to compute downward continuation of Helmert gravity anomalies.

Now GGM05 is offered as official national geoid model, but its characteristics are not fully investigated yet. The GPS/BM assessment of GGM05 brings the map of differences between geoidal heights at 1377 points on the Mexican area is presented in Fig. 2. Surprisingly the differences grow up to 2 m at some regions when it was expected to have few decimetres in the worse case.

Research is now taking place to find out the causes for such a high difference between the two sources in order to answer the next questions: where are the errors coming from?, is that difference a real error in GGM05 model?, if not, then what is the best feasible way to perform a reliable evaluation in the Mexican scenario?.

The first step to accomplish this research is gathering evidence which help discriminating error sources and its possible magnitude. Some preliminary results are exposed in Sect. 3 and they bring the issues to be faced in further stages. The second step is to design

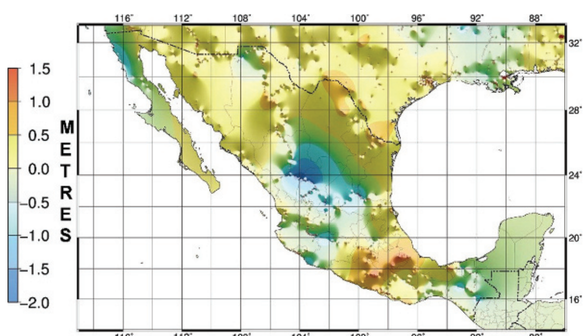

Fig. 2 Difference in geoidal height, GPS/BM – GGM05

an appropriate set of geodetic tools to assess geoidal heights in the present situation. We believe that it is feasible to apply recent developments and concepts to disadvantageous situations to obtain reliable and more accurate assessments.

3 On the Assessment of Geoidal Heights

The effort to investigate error sources began looking for geoidal height estimations independent from the GPS/BM. Previous geoid models with similar resolution and coverage, like MEX97, GEOID03 and EGM96 (all made by institutions in the United States of America), were compared to GGM05. In this case the results suggest that systematic errors may be affecting the GGM05 especially along the central part of the country, which coincides with the GPS/BM reference. The accuracy of these previous models is highly correlated since they use basically a common gravity data base. However, the quality of gravimetric data used for the Mexican territory was highly deteriorated (Lemoine et al., 1998), and the final accuracy of their geoidal heights over Mexico is difficult to ascertain (Smith, 2005).

We support the idea that GPS observations on benchmarks (GPS/BM) can be the best way to estimate geoidal heights, but there are many issues to consider in levelling and GPS techniques so that they become reliable reference at centimetre level. Observing the data used for GPS/BM it can be noticed that a significant difference in epoch for data collecting exists. The GPS measurements of geodetic heights were made between years 2001 and 2004, while levelling comes from the NAVD88 network, which is a Helmert approximation to orthometric height, observed between 1950 and 1980.

4 Time Variation of Height

For Mexicans it is a well known fact that height changes in time since it can be noticed visually at many places. As an example of the expected magnitude of recent vertical crustal movements, we quote the study about subsidence devoted to the urban area of Aguascalientes. Combining relevelled segments and GPS observations over years 2003–2004, the derived

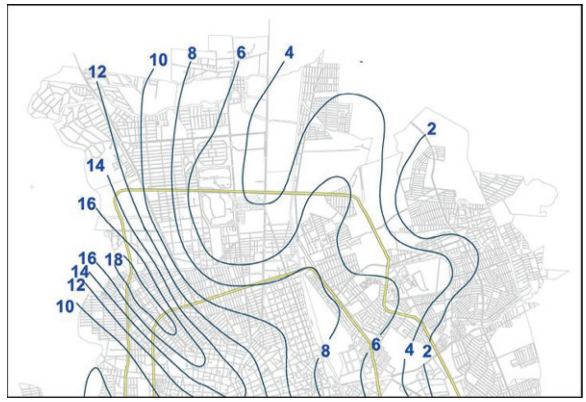

Fig. 3 Subsidence for Aguascalientes city. Units: cm/year (Courtesy R. Esquivel)

model of vertical velocities (Δh) show estimated geodetic heights decreasing from 2 to 18 cm per year (Esquivel et al., 2004). Figure 3 shows the contour lines of subsidence over Aguascalientes.

For an insight about the velocities in long wavelength we took advantage of a long relevelled segment across the central region in Mexico and passing over Aguascalientes. This line was originally observed during the 50's and the newest observation was made from 2001 to 2005. In order to compare height differences, the Helmert approximate orthometric height from NAVD88 was propagated from one benchmark taken arbitrarily. At the end of the line, benchmark QT136 was chosen as reference for its position is far from areas with known high dynamicity. Hence the height differences obtained are interpreted as mainly vertical movements relative to QT136. These differences are presented in Fig. 4, ranging from +45 to −130 cm.

Figure 4 illustrates the changes in shape of the profile sketched by Fig. 5. Some systematic trends can be noticed, which suggest that NAVD88 network is no longer compatible with recent observations. But there is a sudden change of sign in the height differences over the area of Aguascalientes.

On the side of geodetic height estimations from GPS, the methodology implemented L1 and L2 frequencies observations over periods of 3 h. Differential post processing, associated to reference stations in Mexico was performed then. However, no velocities on the reference stations were considered. This arise the question of probable systematic biases added to the geodetic heights.

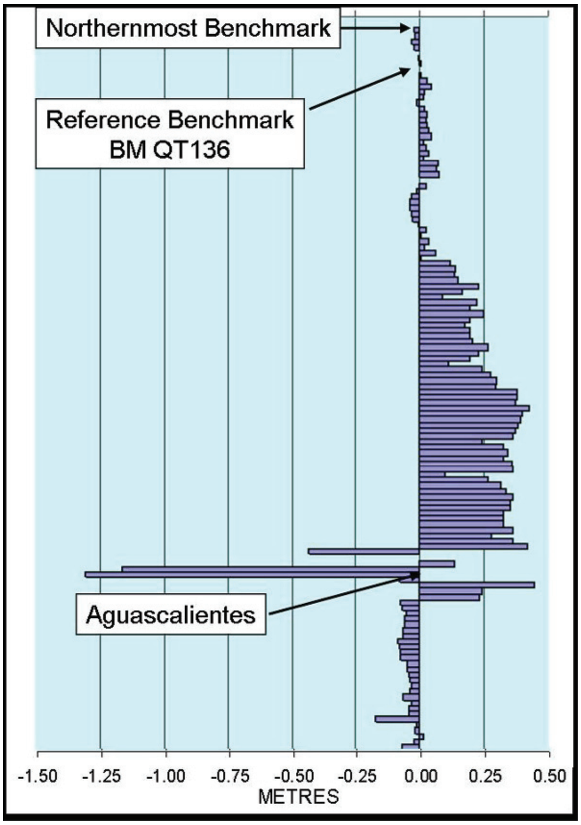

Fig. 4 Differences in the Helmert orthometric height, relative to BMQT136

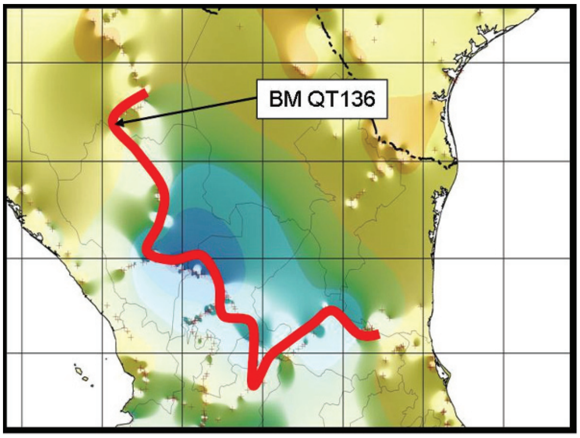

Fig. 5 Sketch of the relevelled segment

5 Conclusions and Future Work

The GGM05 model is a national vertical reference made from the best quality data ever used for geoid modeling in Mexico. Its theoretical background supports centimetre accuracy but the existing tools for the final assessment cannot guarantee similar level of uncertainty. It is important to know all of the characteristics of geoid models like GGM05, but the lack of precise orthometric height estimations prevents us from performing the GPS/BM combination to obtain the precise geodetic heights needed for the assessment.

Mexico seems to be a nice playground for the study of vertical movements due to its tectonic dynamicity. The new results give some evidence that vertical crustal movements should be regarded as one of the main factors of bias for old levelling. Hence, analysis is enforced to model and learn about the magnitude of recent vertical crustal movements. This implies the creation of a model of vertical crustal movements as detailed as possible, making use of relevelled lines, sea surface topography estimations, tide gauge and geological information. We believe that a reliable assessment of GGM05 at few centimetres level is possible after coupling the adequate geodetic tools.

Besides regarding the vertical dynamicity it can be implemented an approximation to rigorous orthometric heights (as proposed by Kingdon et al., 2005), taking advantage of by-products created during the GGM05 computations. On the side of GNSS processing, since the realistic accuracy of geodetic heights obtained might be easily biased by more than one centimetre, we shall address revision to the methodology to guarantee that error sources are treated as best as possible.

An alternative means of estimating absolute vertical crustal movements is GNSS data processing in Precise Point Positioning mode for reference stations. A time series over the last 10 years may provide useful information which could be incorporated as part of the model of vertical crustal movements. It should be kept in mind that an error of about 10% is introduced when geodetic height velocities are used to model orthometric heights (Vaníček, 1986). In order to determine the difference between geodetic and orthometric height velocities, knowledge on the geoidal height velocity would be also required.

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