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# A modern gravimetric methodology applied to the study of the Bolivian Andes

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## SUMMARY

In this work we show that gravity anomalies and disturbing earth potential can be used together to consistently study crustal structures. An example on Bolivian Andean chain supports this proposal. In the first part of the paper, topography is used as input data, while in the second part, geoid undulations are the data used. With a modern digital terrain model as input signal, and assuming perfect isostatic balance in Airy's system for the zone (general assumed tendency), we have evaluated free-air anomalies, Bouguer anomalies and geoid undulations in the study area. Then, using EGM96's geoid in Bolivia (real data), we have filtered long and intermediate wavelengths using a sparse Fourier transform method, obtaining residual geoid values, which showed a tendency to isostatic balance when compared with isostatic geoid values from our predictive assumed model.

With residual geoid values from EGM96 model, we have evaluated free-air and Bouguer anomalies using two methods: equivalent sources and planar Stokes' formulae. Compared with those from the assumed comparison model, Bouguer anomalies certify the balance already found, while free-air anomalies although less consistent, remark the separation between positive and negative values areas. Results also agree with observed free-air and Bouguer anomalies charts for the zone. So, we show that geological structures can be studied by means of geoid undulations and topography values without using observed gravity anomalies.

## INTRODUCTION

It is well known that the Central Andes present duplicated crustal thickness and isostatic balance (Isacks, 1988; Introcaso *et al*, 2000; Abriata & Introcaso, 1990; Miranda & Introcaso, 2000a). Isostatic balance is usually analysed using isostatic anomalies evaluated in different systems (Airy, Pratt, flexural, etc). In this work we compare geoid undulations charts, and also anomalies charts obtained from geoid undulations (either than from gravimeters).

The methodology used here is based on comparing geoid undulations originated by our predictive model (isostatically balanced model in Airy's hypothesis, using a digital elevation model), with geoid undulations obtained from a filtered global geoid's model. Comparison between them reveals that Bolivia is in general isostatically balanced in Airy's system.

Gravity charts (free-air and Bouguer anomalies) obtained from both models (real and predictive), are also compared.

## STUDY AREA, THEORETICAL MODEL AND GEOID UNDULATIONS

The present work was performed on Bolivia's territory, on an area that extends from 14° to 22° South latitudes, and from 69° to 62° West longitudes. This area contains all Bolivian Andes (which reach 6000m altitude) and part of flat terrain at the east of the country (Figure 1). Geophysical previous works (Abriata & Introcaso, 1990; Isacks, 1988; Miranda & Introcaso, 2000a, etc.) reveal that Central Andes show isostatic balance in Airy's system. This previous result encouraged us to adopt this zone in order to prove the methodology used here.

Present work has a recent antecedent by Introcaso & Introcaso (2004), where a cortical analysis from geoid undulations was made on a section of Bolivian Andes placed at 22°S. Earlier, Miranda & Introcaso (2000b) have analyzed geoid values in an East-West section of Bolivian Andes placed at 20°S. In both works just profiles of geoid undulations were studied, without extracting anomalies from them.

A theoretical model of the studied area is built, assuming perfect isostatic balance in Airy's hypothesis. We have considered the digital elevation model GLOBE (GLOBE Task Team, 1999) with a resolution of 30"x30" as input signal. We have considered (Intocaso *et al*, 2000) topographic density as $\rho_t = 2.67\, g/cm^3$ , normal crustal thickness as $T_n = 33km$ , and contrast density between lower crust and upper mantle as $\Delta\rho = -0.4\, g/cm^3$ .

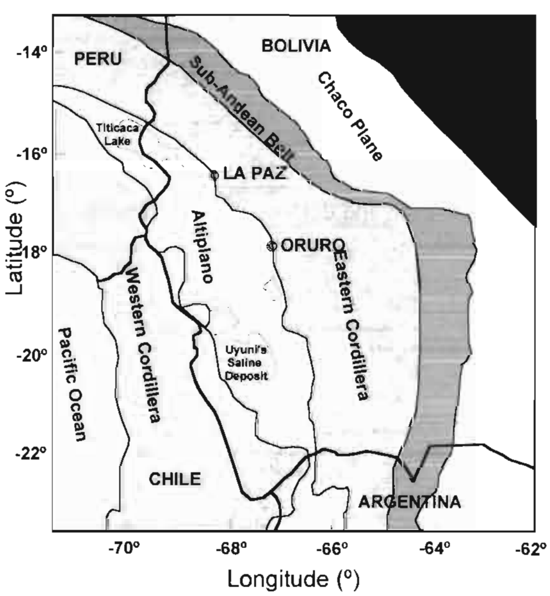


Figure 1 – Bolivian Andes map

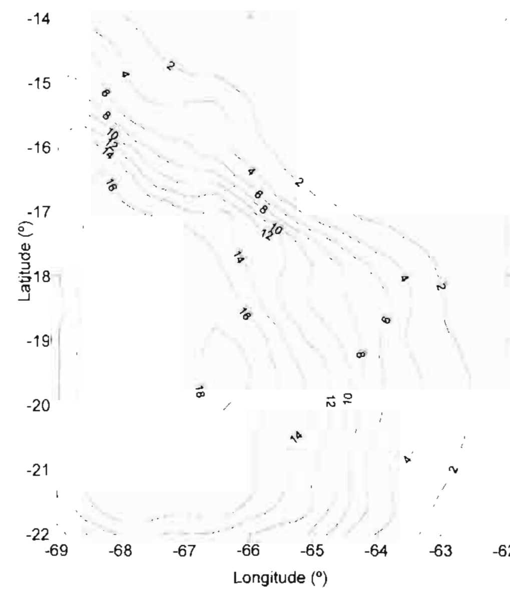


Figure 2 – Geoid undulations curves (m) in Bolivia from an isostatic balanced model.

Gravity attractions of visible topographic masses and hidden compensating masses were exactly calculated approximating both structures with several right parallelepipeds (Nagy, 1966). From this model, free-air anomalies were calculated adding both attractions, while hidden masses attractions (placed below geoid) were directly interpreted as Bouguer anomalies. In a similar way, both masses' gravity potentials were obtained (Guspí, 1999) and from that total anomalous potential, geoid undulations were built using the well known Bruns' expression (Figure 2).

Real geoid undulations were obtained using the global geopotential model EGM96 (Lemoine *et al*, 1998). EGM96's geoid undulations consider the whole planet masses, involving different kinds of wavelengths that must be separated. To appreciate the different contributions and isolate Andean effect, a wider EGM96 geoid undulations chart was calculated, including the study area, where the Andes' contribution to global undulations is clear. Qualitatively, this has been already pointed out by Froideveaux & Isacks (1984) and by Introcaso, Cornaglia & Pacino (2000). We have filtered geoid undulations using a sparse Fourier transform method (Guspí & Introcaso, 2000). In Figure 3 we show an E-W profile at 18°S, where the regional and residual geoid undulations obtained from this filtering technique result perfectly represented. Figure 4a shows a global geoid undulations chart from EGM96 and Figure 4b shows residual geoid undulations obtained after filtering, in the study area.

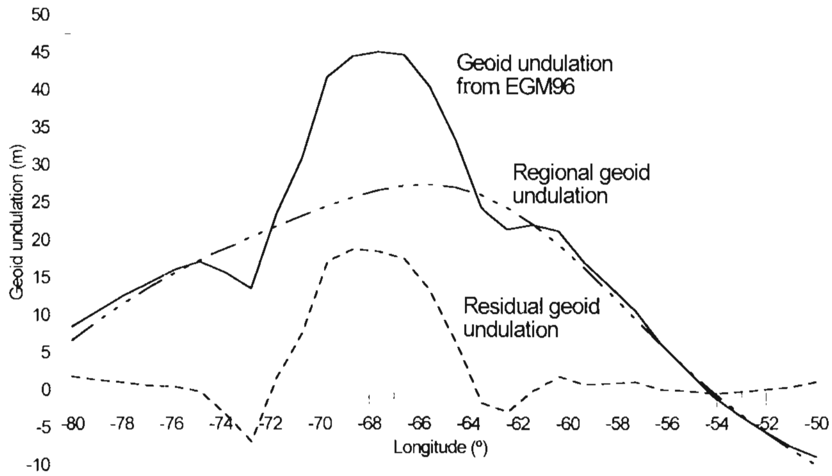


Figure 3 – Profile at 18°S showing EGM96 (solid line), regional (dash and dot line) and residual (dashed line) geoid undulations (m).

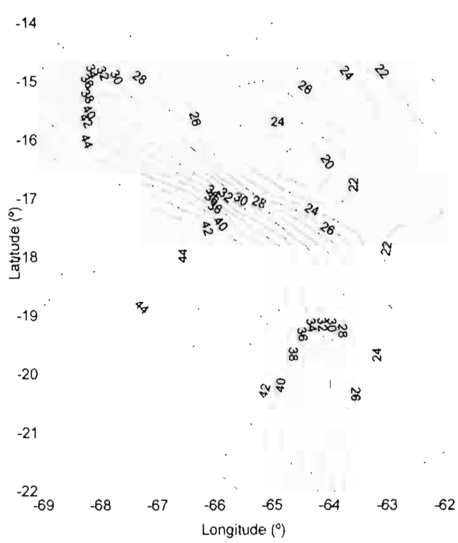


Figure 4 (a) - Global geoid undulations in Bolivia from EGM96.

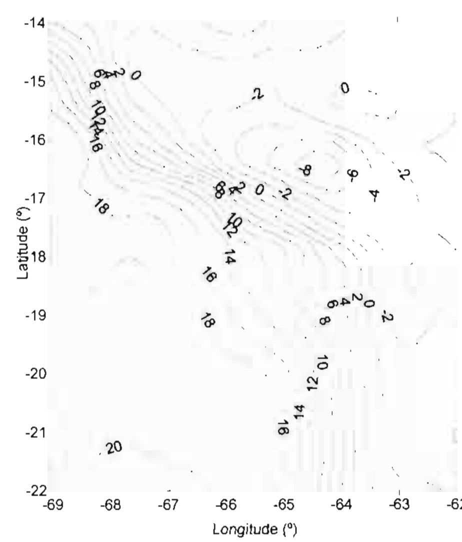


Figure 4 (b) - Residual geoid undulations obtained by filtering global chart in (a).

Using residual geoid undulations as input, two free-air anomalies charts were also built applying two different methods: equivalent sources technique (Guspí *et al*, 2004) and the well known planar Stokes' formulae, finding they well agree, as expected. Bouguer anomalies charts were constructed from these free-air anomalies charts using classical Bouguer's correction.

A comparison between geoid undulations from the theoretical isostatic model (Figure 2) and residual geoid undulations from filtered EGM96 model (Figure 4b), show qualitative and quantitative consistence, except on an area placed around -64°W,-16°S. In order to validate our study, we have also compared free-air and Bouguer anomalies charts from the isostatic model with those derived from filtered EGM96's geoid, finding well agreement between them.

## CONCLUSION

Crustal and isostatic studies are usually made by comparing observed gravity anomalies with those obtained from perfectly balanced models.

A great amount of geoid undulations charts exists today. They are built from deflections of the vertical, differences between ellipsoidal and orthometric levels h-H, deformations of satellite orbits combined with others techniques, but they all allow us to make isostatic studies. In the preset study, geoid undulations obtained from EGM96 model. have been compared with those obtained from a perfectly balanced Airy's model. Consistence between results points out a tendency to isostatic balance (Airy's system). Comparison between free-air and Bouguer anomalies charts derived from EGM96's geoid and those obtained from the perfectly balanced Airy's model, agrees in general terms with the isostatic balance previously found and confirms that methodology used here is adequate to make isostatic studies without using observed gravity anomalies.

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