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ABSOLUTE GRAVIMETRY ON THE AGULHAS NEGRAS CALIBRATION LINE

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ABSTRACT. The Agulhas Negras Gravity Calibration Line was established in the mid 1980s using LaCoste & Romberg gravimeters model "G" only. Five gravity stations were irregularly positioned along its 200 km length, spanning a total range of 627 mGal. The new absolute gravimeter Micro-g Solutions A-10 #011 of Observatório Nacional was taken to each calibration station and new measurements were made. The local vertical gravity gradient was also measured at each calibration station. This report shows their new gravity values and compares them with previously published values based solely on relative gravimetry. These new absolute values of local gravity should be taken as updated reference values in any calibration work along the Agulhas Negras Calibration Line.

Keywords: absolute gravimetry, gravity calibration line, vertical gravity gradient.

RESUMO. A Linha de Calibração Gravimétrica de Agulhas Negras foi estabelecida em meados dos anos 80 utilizando-se somente gravímetros relativos LaCoste & Romberg modelo "G". Cinco estações de calibração foram distribuídas irregularmente ao longo de seus aproximadamente 200 km de extensão e 627 mGal de amplitude. Utilizando o gravímetro absoluto Micro-g LaCoste A-10 #011, recentemente adquirido pelo Observatório Nacional, novas medições foram executadas nas estações de calibração, e o gradiente vertical local da gravidade foi medido em cada um desses sítios. Reportam-se aqui os novos valores absolutos de gravidade encontrados, que devem ser considerados como os atuais e mais precisos valores de referência a serem tomados em trabalhos de calibração. Uma comparação com os valores encontrados previamente, baseados somente em gravimetria relativa, também é apresentada.

Palavras-chave: gravimetria absoluta, linha de calibração gravimétrica, gradiente vertical da gravidade.

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INTRODUCTION

Gravity Calibration Lines have been in use for some time not only in Brazil but also in other regions worldwide, e.g. Wessells (1985), Wenzel (1996), Vieira et al. (2002) and Timmen et al. (2006). Calibration lines exploit the well-known fact that gravity varies with latitude as well as height.

The Agulhas Negras Gravity Calibration Line (ANGCL) was established in the mid 1980s as a tool to assess the operational capabilities of relative gravimeters used by either Brazilian academic institutions or the private sector. After some reconnaissance work, as early as 1982, teams of Observatório Nacional (ON) and Instituto de Astronomia, Geofísica e Ciências Atmosféricas (IAG-USP) started measuring relative gravity intervals between pairs of stations, beginning at the IGSN 71 station 40123A at ON, and ending at the ON benchmark at the Ibama Control Gate #03 of Itatiaia National Park. This calibration line is about 230 km in length, has a maximum elevation difference of 2 400 m, a maximum latitude difference of 31 arc minutes and a gravity range of 627 mGal (Fig. 1). Over the years, a large number of relative gravity observations were undertaken between five gravity stations irregularly distributed along this calibration line. The site provides a standard, high accuracy, short-range gravimeter calibration line in southeast Brazil. Government agencies as well as the private sector use this calibration line for the determination of gravimeter performance.

ABSOLUTE *VS.* RELATIVE GRAVIMETRY

Escobar et al. (1996) computed final gravity values for each station on the Agulhas Negras Calibration Line. Absolute gravity values and associated uncertainties derived from the adjustment of 728 gravity intervals measured with thirteen LaCoste & Romberg gravimeters from 1982 to 1994. The ANGCL was tied to the Brazilian Fundamental Gravity Network (BFGN) through stations 010176 Rio de Janeiro "A" (IGSN 40123A) and 016080 Rio de Janeiro "C", whose absolute gravity values were obtained as part of the adjustment of the entire BFGN (Escobar, 1987; Subiza Piña & de Sousa, 2001). Due to its poor logistics, station CAL 01 Angra dos Reis was occupied in 1982 only, and has been abandoned in favor of station 010176 in Rio de Janeiro since then. Nowadays, the Agulhas Negras Gravity Calibration Line is also tied to the absolute gravity stations IfE 142 (Torge et al., 1994) and to pier "B" at the Laboratory of Gravimetry of Observatório Nacional in Vassouras (RJ).

The recent acquisition of the absolute gravimeter Micro-g LaCoste A-10 #011 allowed new and independent measurements to be taken along the Agulhas Negras Gravity Calibration Line. This meter directly measures the vertical acceleration of gravity (Fig. 2). A test mass is dropped hundreds of times in vacuum, and its position is recorded with a polarization-stabilized He(Ne) laser interferometer (red light@633 nm), while the time standard is provided by a 10 GHz Rubidium atomic clock. Nominal specifications for this meter are (www.microglacoste.com/a10spec.htm): repeatability of 10μGal on a high quality pier and 10μGal accuracy, as compared to another A-10. Absolute gravity measurements are expressed directly in basic SI (*Système International*) units of length (meter) and time (second), thus avoiding the use of semi-empirical conversion tables, as needed for the relative spring gravimeters LC & R and the Scintrex "CG" series.

Absolute gravimetry was performed on the ANGCL from May 20 to July 07, 2006, when the acceleration due to gravity was measured with A-10 #011 at all five calibration stations. About four hours per station were usually needed to obtain GPS coordinates, to measure the local vertical gravity gradient (VGG), to set up the absolute gravimeter, to take the gravity measurement and to tear the meter down on measurement completion. Preliminary g values were computed on site using the simple spherical approximation of the VGG of 0.3086 mGal $\cdot$ m^{-1}. An Oregon Scientific Baro-Thermo-Hygrometer recorded the atmospheric pressure, the air temperature and the relative humidity at each calibration site when an absolute measurement took place. So far, only the local atmospheric pressure has been used in the actual computation of absolute gravity values.

LC & R model "G" meters were used in the determination of the local vertical gravity gradient at each calibration station. However, anthropogenic noise adversely affects these measurements in all calibration stations and the overall ensuing variability in precision reflects the degree of local noise. Post-processing in the lab involved the reexamination of all field data sets, the computation of actual VGGs and their use in the final computation of absolute gravity. Geophysical corrections to the absolute measurements included Earth tides, daily polar motion and the atmospheric pressure. A full set of absolute gravity measurements on each calibration station comprised six subsets of one hundred drops each, at a rate of one drop per second. The mean g value for each subset and its experimental standard deviation were computed, the final absolute g value being the weighted mean of all six subsets. The error budget of the absolute measurements includes type A and B evaluations of known error sources according to the GUM (2003). Prior to delivery to Observatório Nacional, the laser and clock of A-10 #011 were factory calibrated, with traceability given to primary standards certified by

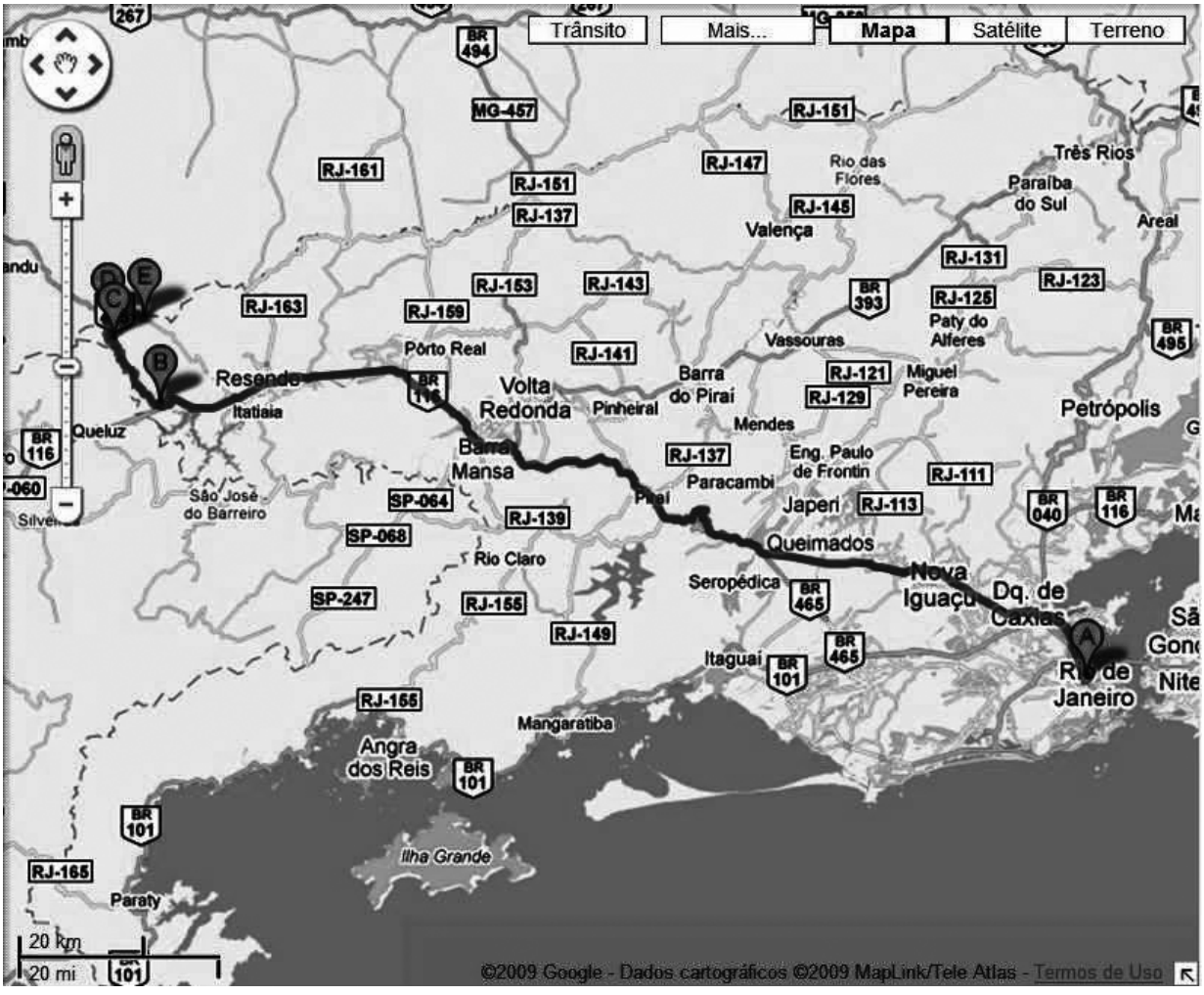

Figure 1 – Road map of the Agulhas Negras Gravity Calibration Line: **A** – Observatório Nacional in Rio de Janeiro, **B** – Engenheiro Passos, **C** – Fazenda Lapa, **D** – Marco Zero and **E** – Agulhas Negras. Source: Google Maps^{TM}.

the *Bureau International des Poids et Mesures* – BIPM. Appendix 1 shows the identification logs describing the five calibration stations as held in the Gravity Database of Observatório Nacional.

DISCUSSION

Absolute gravity values determined at each station of the Agulhas Negras Gravity Calibration Line are compared to those determined by Escobar et al. (1996) in Table 1. Points worth noticing are:

- Error estimates of gravity values in Escobar et al. (1996) are slightly underestimated, as they do not include the relative gravimeter systematic error component. According to the LC & R Instruction Manual (LaCoste & Romberg, 2004), the repeatability of readings taken with "G" meters is 0.01 mGal. Therefore, it is reasonable to estimate that a residual systematic error limit of 0.014 mGal is present in any measurement of gravity intervals using such meters. Assuming a Gaussian error distribution and a 95% confidence interval (Vuolo, 1996), a type B variance of half of this quantity, or 0.007^2 mGal^2, should be included in the final assessment of the standard uncertainty of gravity intervals derived from relative gravimetry only. The true uncertainties of adjusted gravity values in Escobar et al. (1996) should be about 0.004 mGal higher.
- Discrepancies are always negative, which may be interpreted as a small difference between the absolute datum of this study and that used at the time the calibration line was established. Similar datum differences have also been found elsewhere, e.g. Tracey (2006).

Table 1 – Newly determined absolute gravity values compared to those previously found on the Observatório Nacional – Agulhas Negras Gravity Calibration Line.

Calibration Station Site	Absolute gravity (mGal)		
	Present study	Escobar et al. (1996)	Discrepancy
IGSN 40123A Rio de Janeiro	978 789.852 ± 0.011	978 789.86 ± 0.014	–0.008 ± 0.015
CAL 02 Engenheiro Passos	978 601.078 ± 0.006	978 601.09 ± 0.012	–0.012 ± 0.013
CAL 03 Fazenda Lapa	978 419.483 ± 0.009	978 419.55 ± 0.013	–0.067 ± 0.016
CAL 04 Marco Zero	978 325.514 ± 0.008	978 325.58 ± 0.014	–0.066 ± 0.016
CAL 05 Posto Ibama #03	978 163.000 ± 0.008	978 163.10 ± 0.016	–0.100 ± 0.018

- Larger discrepancies towards the extreme station CAL 05 Agulhas Negras further indicate a datum difference, but also point out to an insufficiently accurate meter drift model used in the relative gravimetry data reduction of Escobar et al. (1996).

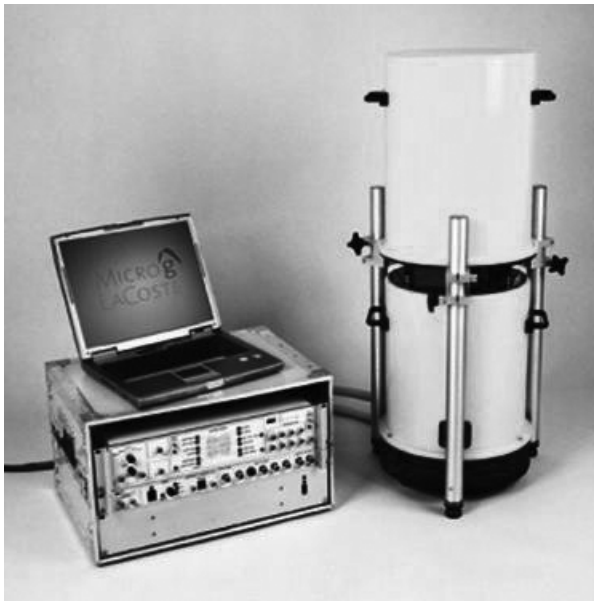

Figure 2 – Micro-g LaCoste absolute gravimeter A-10: repeatability and accuracy of 0.01 mGal on a quiet pier. High capacity battery for field operation not shown.

CONCLUSIONS

Gravity was measured with a free fall absolute gravimeter and observed values are now available to all stations pertaining to the Agulhas Negras Gravity Calibration Line. Given the largest error found of 0.01 mGal and the total gravity range of about 627 mGal, this calibration line is accurate to $1.6 \cdot 10^{-5}$ and allows for a better assessment of relative gravimeter performance. However, we think that the Agulhas Negras Gravity Calibration Line itself should be replaced by a better designed and properly monumented calibration line. New absolute gravity stations should be regularly positioned at about 50 mGal intervals along the whole line. Studies of periodic errors of LC & R gravimeters demand an even larger number of stations. Calibration sites must be of easier access and reasonably away from road traffic. Urgent repavement of the 14 km road between CAL 04 and CAL 05 stations needs to be done.

The Agulhas Negras Gravity Calibration Line yields about half of the total gravity range found in Brazil. As gravity diminishes with height, similar calibration lines should be established to the south and to the northeast parts of the country, e.g. the Serra Gaúcha in Rio Grande do Sul and Serra da Ibiapaba in Ceará.

APPENDIX

Absolute gravity stations records of the Agulhas Negras Gravity Calibration Line (in Portuguese).

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Laboratório de Gravimetria
Relatório de Estação Gravimétrica

Estação: Rio de Janeiro "A" (RJ) **Código:** 010176

Estação IGSN71 40123 "A". Gravímetro absoluto A-10 #011 sobre a placa gravimétrica do Interamerican Geodetic Survey, cravada no pilar SO da Sala 30 do Museu de Astronomia e Ciências Afins- MAST. Gradiente vertical da gravidade: -0,3161 ± 0,0072 mGal/m.

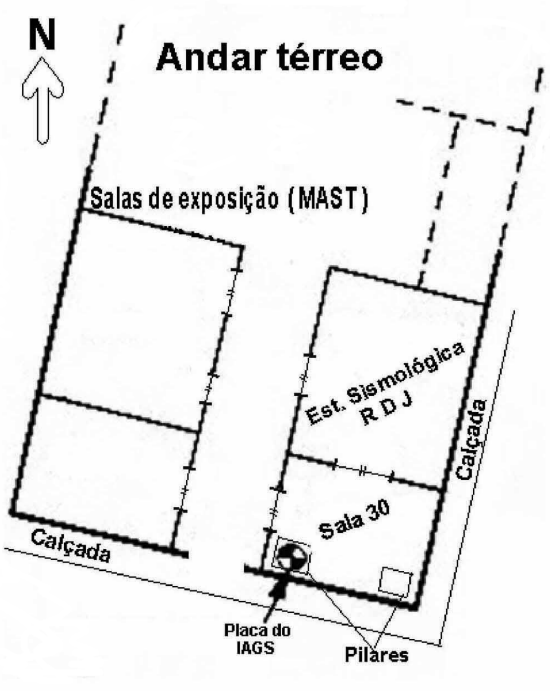
Situação em 27/08/2009: **PRESERVADO**

Coordenadas WGS84 / SIRGAS 2000

Latitude: 22° 53' 43,9" Sul
Longitude: 43° 13' 23,6" Oeste
Altitude Geométrica (m): 19
Altitude Ortométrica (m): 25

Gravimetria

Gravidade Ajustada (mGal): 978789,852 ± 0,011
Anomalia Ar-Livre (mGal): -16
Anomalia Bouguer (mGal): -19



Appendix 1

Laboratório de Gravimetria
Relatório de Estação Gravimétrica

Estação: Engenheiro Passos (RJ) **Código:** CAL 02

Gravímetro A-10 #011 sobre placa gravimétrica do ON, cravada na soleira da Capela de São Benedito, à direita de quem entra. Início da BR 354 para Caxambu (MG). Gradiente vertical local da gravidade: -0,2687 ± 0,0051 mGal/m.

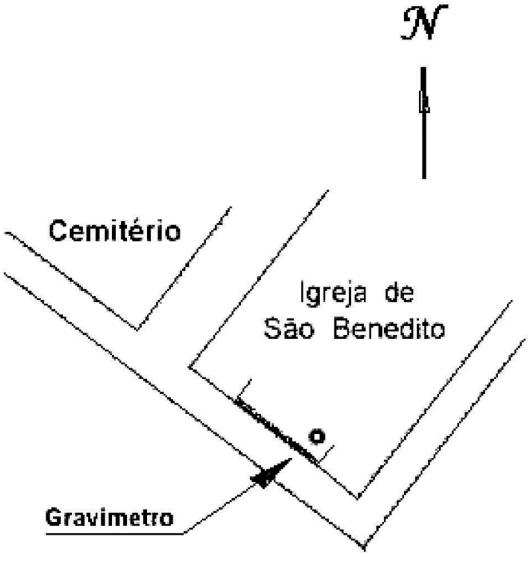
Situação em 07/04/2010: **PRESERVADO**

Coordenadas WGS84 / SIRGAS 2000

Latitude: 22º 29' 52,2" Sul
Longitude: 44º 40' 47,0" Oeste
Altitude Geométrica (m): 501
Altitude Ortométrica (m): 504

Gravimetria

Gravidade Ajustada (mGal): 978601,078 ± 0,006
Anomalia Ar-Livre (mGal): -32
Anomalia Bouguer (mGal): -88



Appendix 2

Laboratório de Gravimetria
Relatório de Estação Gravimétrica

Estação: Fazenda Lapa (RJ) **Código:** CAL 03

Gravímetro A-10 #011 sobre placa gravimétrica do ON cravada na soleira da Capela da Fazenda Lapa, à direita de quem entra, à margem direita da BR 354, sentido Caxambu. Gradiente vertical local da gravidade: -0,2834 ± 0,0051 mGal/m.

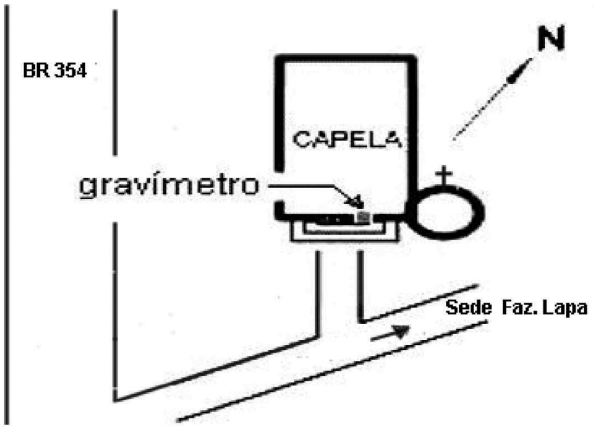
Situação em 07/04/2010: **PRESERVADO**

Coordenadas WGS84 / SIRGAS 2000

Latitude: 22º 24' 22,5" Sul
Longitude: 44º 45' 08,7" Oeste
Altitude Geométrica (m): 1232
Altitude Ortométrica (m): 1235

Gravimetria

Gravidade Ajustada (mGal): 978419,483 ± 0,009
Anomalia Ar-Livre (mGal): 18
Anomalia Bouguer (mGal): -120



Appendix 3

Laboratório de Gravimetria
Relatório de Estação Gravimétrica

Estação: Marco Zero (RJ) **Código:** CAL 04

Gravímetro A-10 #011 sobre placa de e. g. do ON, cravada em mureta próxima aos banheiros e bebedouro, à direita da BR 354, sentido Caxambu, na localidade de Garganta do Registro. Gradiente vertical local da gravidade: -0,2608 ± 0,0053 mGal/m.

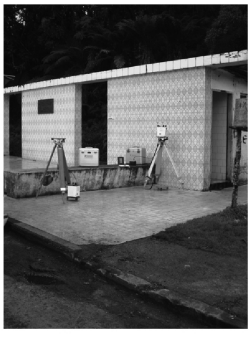
Situação em 07/04/2010: **PRESERVADO**

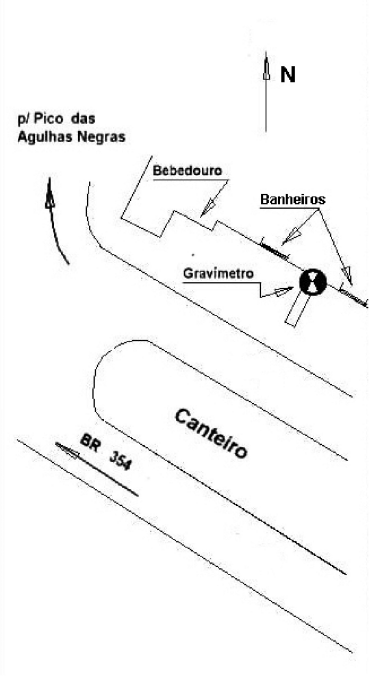
Coordenadas WGS84 / SIRGAS 2000

Latitude: 22º 22' 36,1" Sul
Longitude: 44º 45' 37,1" Oeste
Altitude Geométrica (m): 1672
Altitude Ortométrica (m): 1675

Gravimetria

Gravidade Ajustada (mGal): 978325,514 ± 0,008
Anomalia Ar-Livre (mGal): 62
Anomalia Bouguer (mGal): -126





Appendix 4

Laboratório de Gravimetria
Relatório de Estação Gravimétrica

Estação: Agulhas Negras (RJ) **Código:** CAL 05

Gravímetro A-10 #011 sobre placa de e. g. do ON, cravada na soleira da entrada lateral do Posto Ibama #03 do Parque Nacional de Itatiaia, à direita de quem entra. Gradiente vertical local da gravidade: -0,3066 ± 0,0052 mGal/m.

Situação em 07/04/2010: **PRESERVADO**

Coordenadas WGS84 / SIRGAS 2000

Latitude: 22º 22' 22,4" Sul

Longitude: 44º 42' 13,9" Oeste

Altitude Geométrica (m): 2452

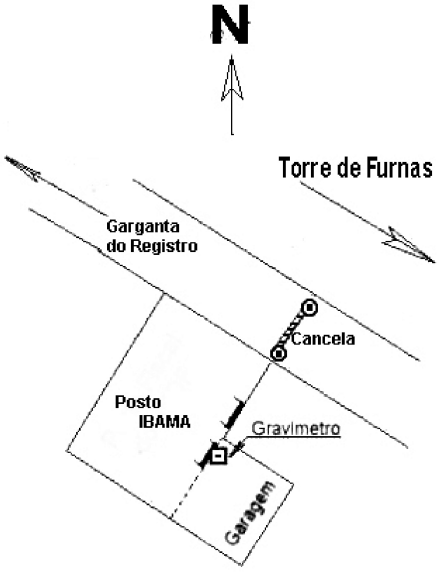
Altitude Ortométrica (m): 2455

Gravimetria

Gravidade Ajustada (mGal): 978163,000 ± 0,008

Anomalia Ar-Livre (mGal): 140

Anomalia Bouguer (mGal): -135



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