EPUSP
Escola Politécnica da Universidade de São Paulo

IBGE
Instituto Brasileiro de Geografia e Estatística

Present and Future of the gravity surveys and geoid model in South America

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SIRGAS

Ciudad de Concepción, Chile

29 y el 31 de octubrede 2012

Geoid (quasi-geoid) model in South America GEOID2010

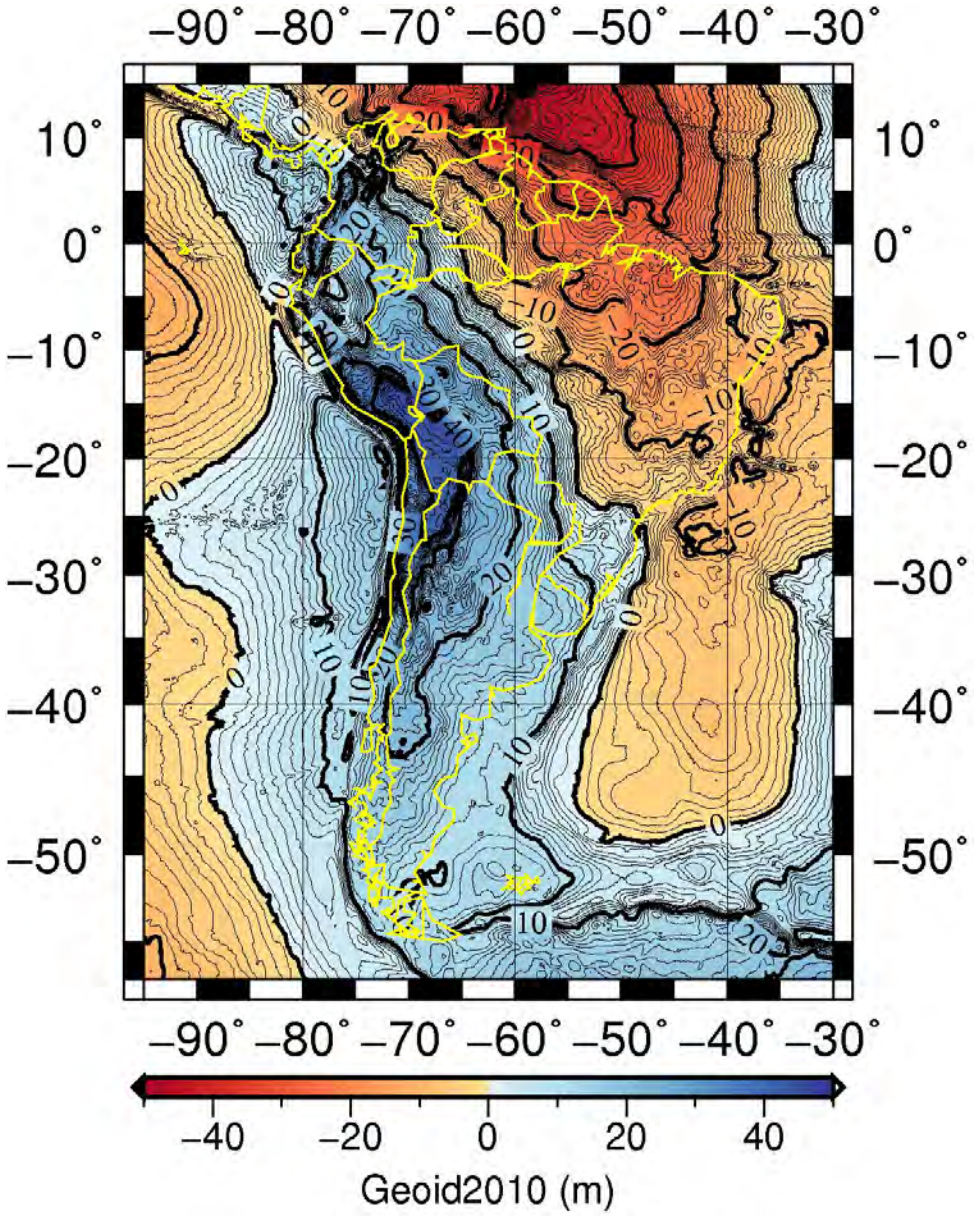
Limited by

15º N and 57º S in latitude

95º W and 30º W in longitude

5’ x 5’ geoid model

The model was based on EGM08 up to degree and order 150 as a reference field. The oceanic region was completed with the mean free-air gravity anomalies derived from a satellite altimetry model from the Danish National Space Center, called DNSC08. The complete Bouguer, Helmert gravity anomalies and primary indirect topographical effect have been derived through the Canadian package SHGEO. The short wavelength component was estimated via FFT with the modified Stokes kernel proposed by Featherstone.



GRAVITY DATA

Many activities going on by different organizations, universities and research institutes in South America.

It is important to mention:

- IBGE
- NGA
- GETECH
- BGI
- Civil and military institutions in different countries of South America.

Due to the important efforts undertaken by different organizations in the last few years to improve the gravity data coverage there are available at the moment approximately:

925878 point gravity data

in South and Central America.

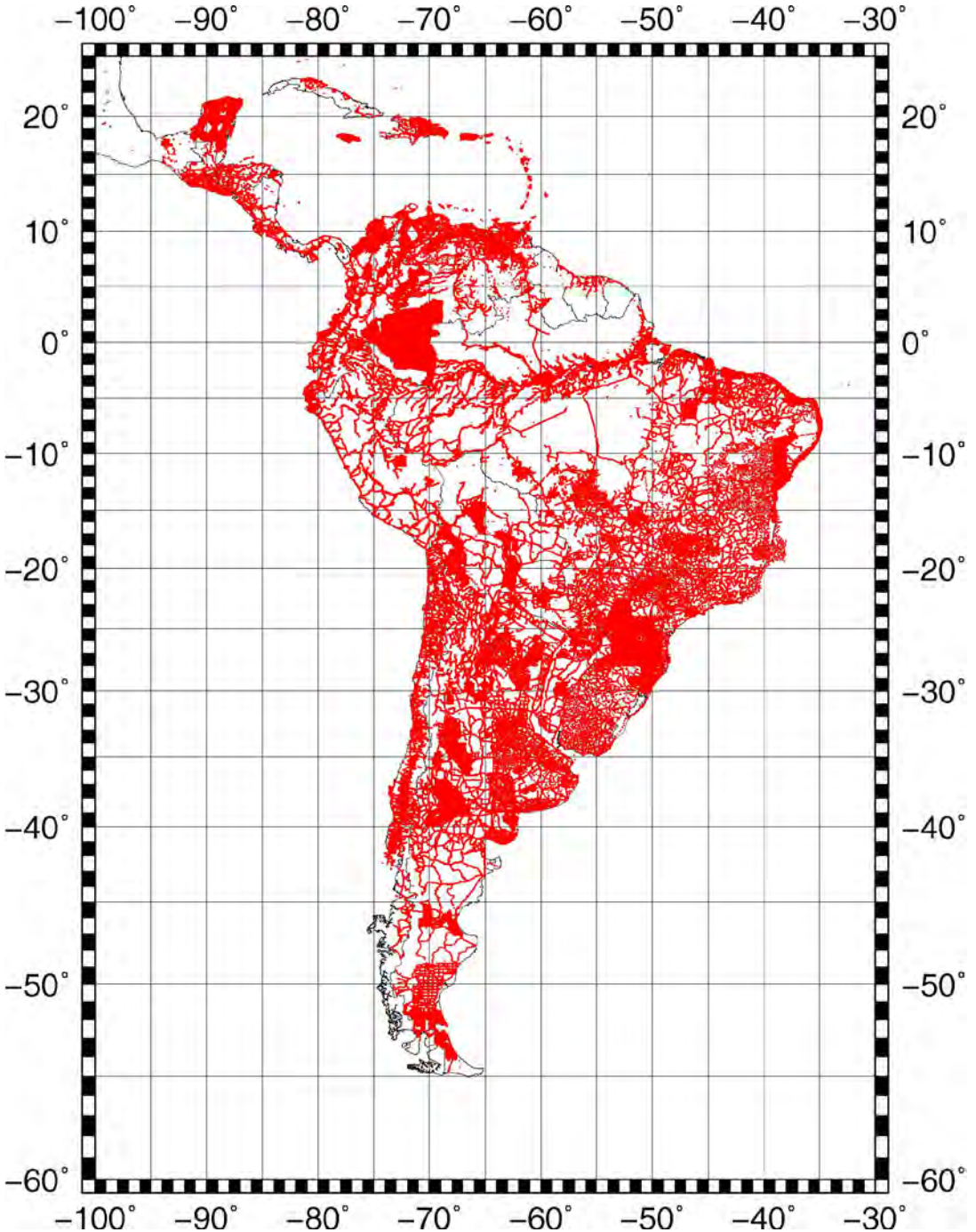
Geoid2010 is available in:
http://www.iges.polimi.it/pagine/db/America/Southamerica/db.SouthAm.asp

GRAVITY DATA DISTRIBUTION

925,878 point gravity data

MAPGEO2010

The Brazilian territory of the model GEOID2010 has been adopted as the official geoid model in Brazil since 2010 by **Brazilian Institute of Geography and Statistics (IBGE).**



RECENT EFFORT

ARGENTINA

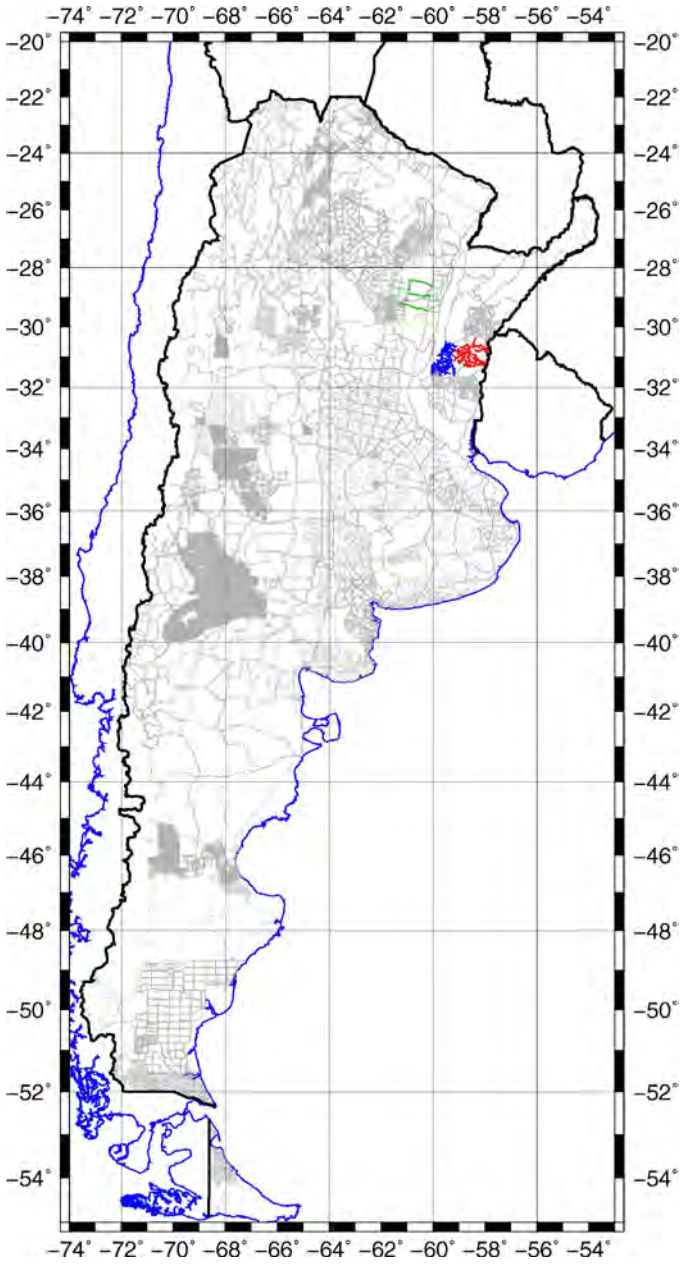
SAGS2011-2012

504 new gravity stations have been measured

The gravity observations have been undertaken with LaCoste & Romberg gravitymeters.

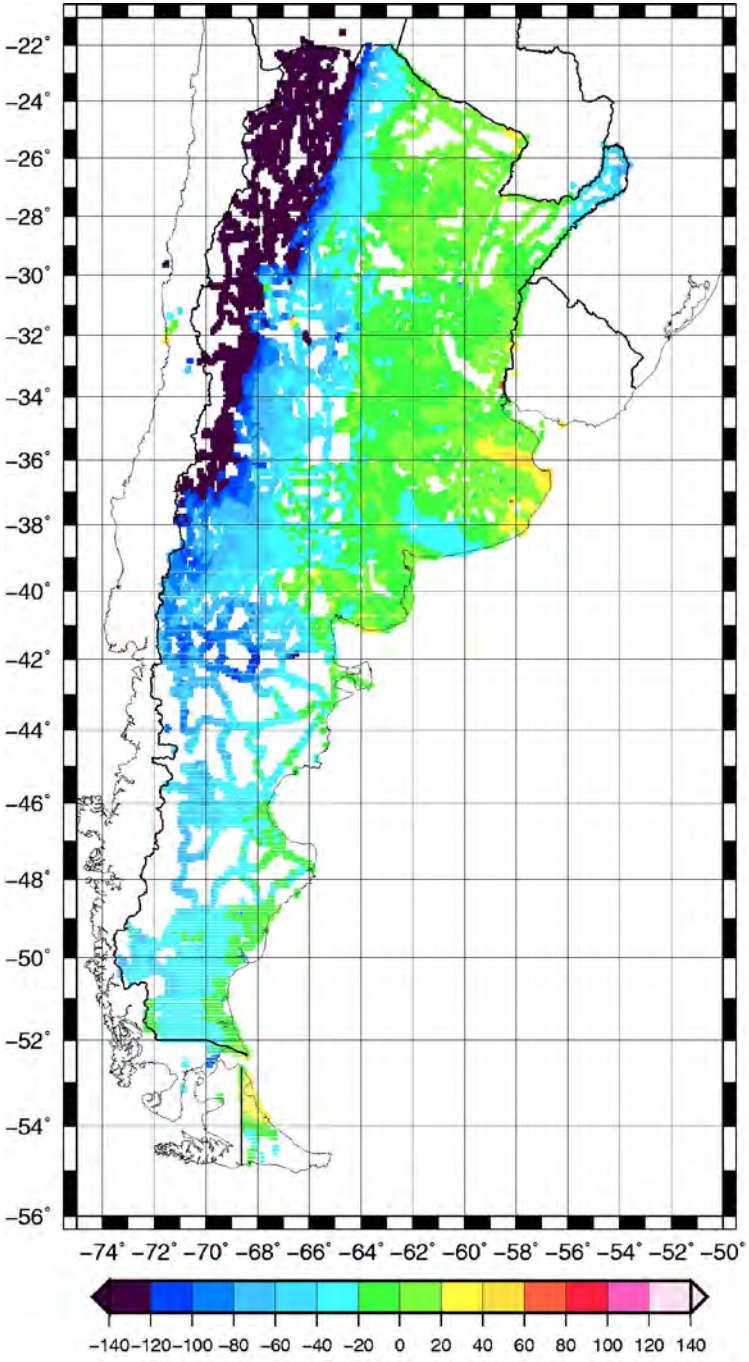
GPS double frequency receivers have been used to derive the geodetic coordinates of all stations.

The orthometric height was derived from geodetic height using EGM2008 restricted to degree and order 150.



Complete Bouguer Anomaly (mGal)

5’ grid resolution



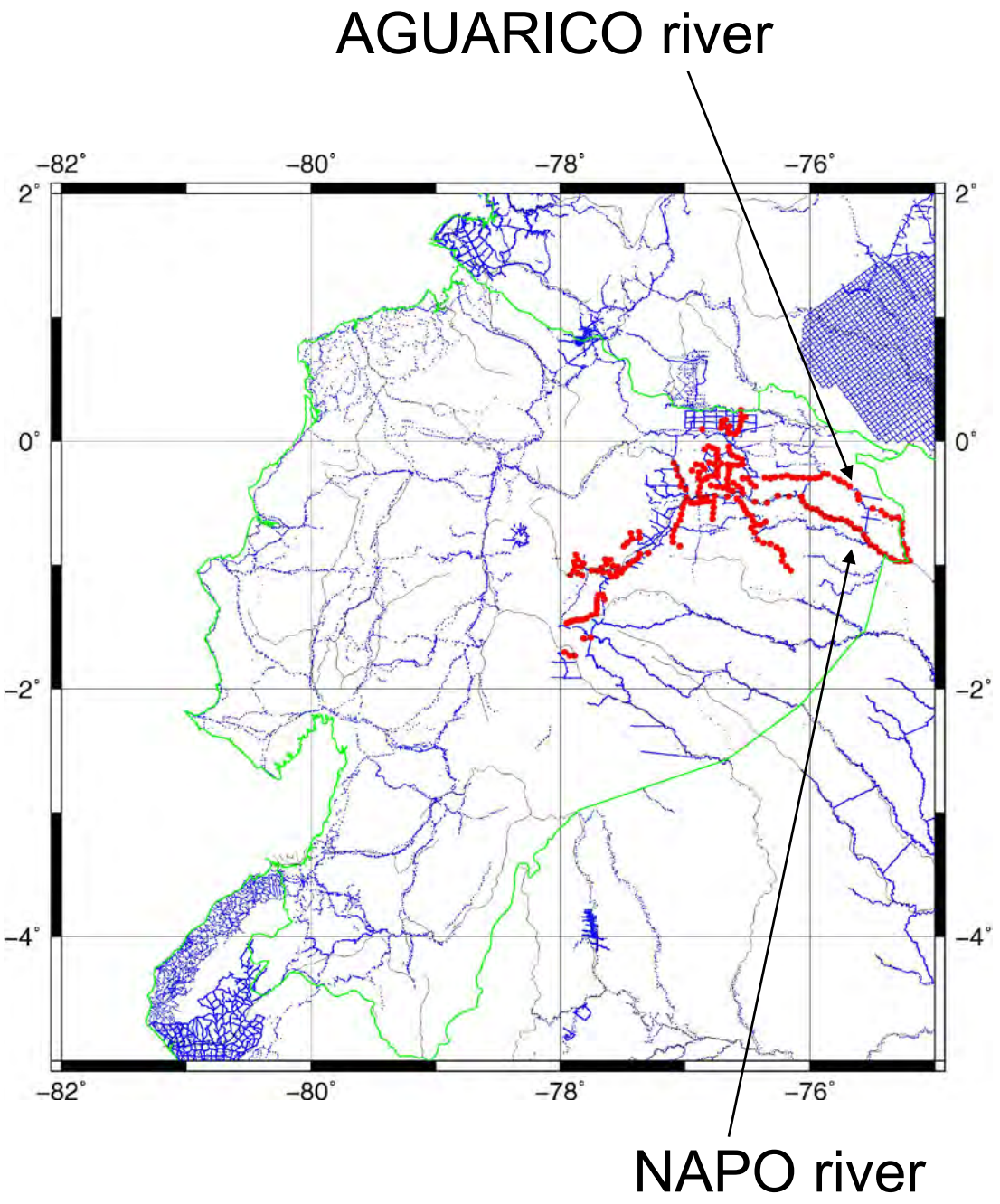
RECENT EFFORT

ECUADOR
SAGS2011-2012
(235 new points)

New gravity data were surveyed by IGM, IBGE and EPUSP in the period 2011 to 2012.

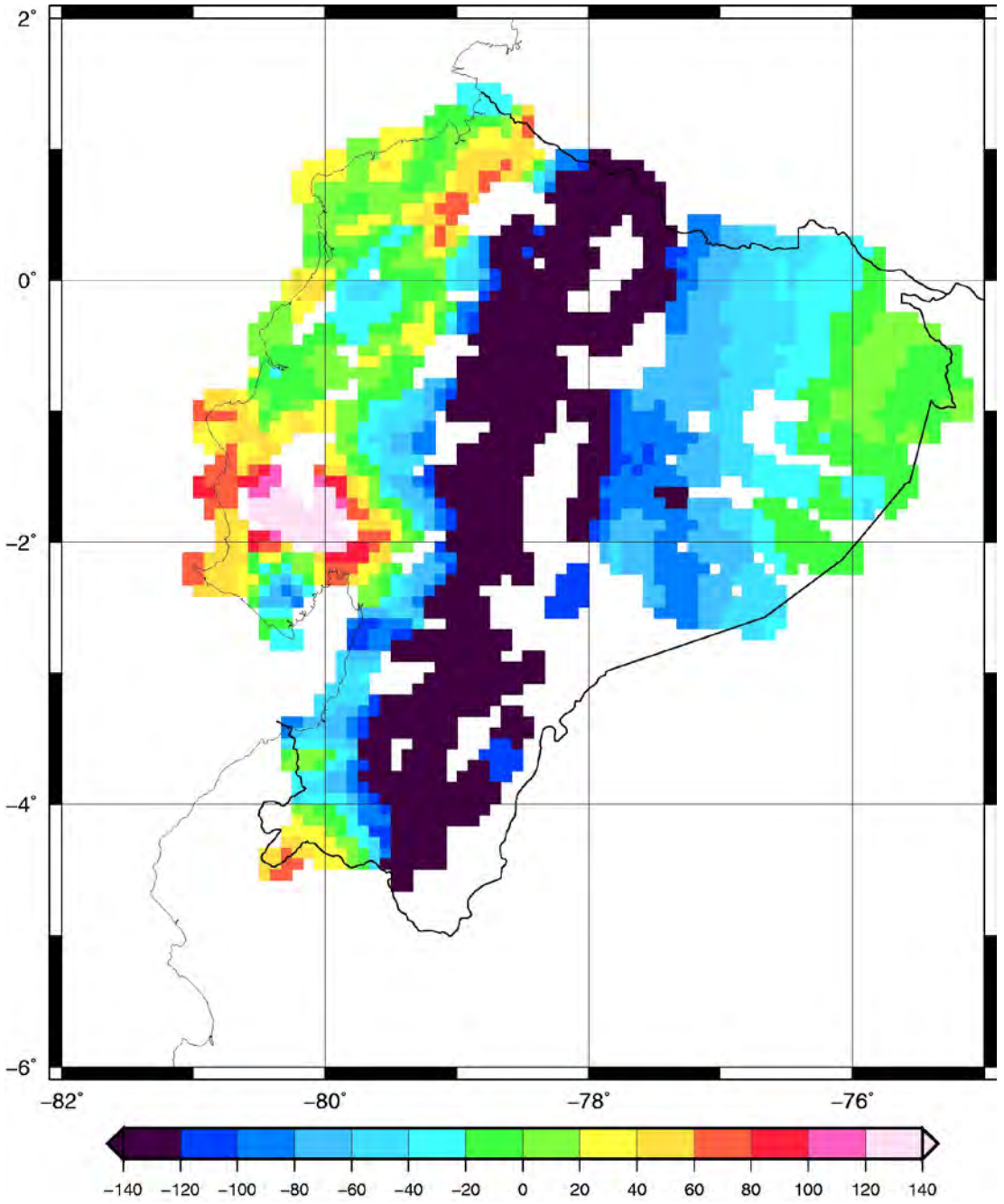
NAPO and AGUARICO rivers and some trials.

A sophisticated logistic was established to support the surveys along the wild rivers, Amazon. The gravity values of the densification surveys were connected to the FGN (Fundamental Gravity Network) of Ecuador.



Complete Bouguer Anomaly (mGal)

5’ grid resolution



The following photographs show the typical river survey conditions

Aguarico river

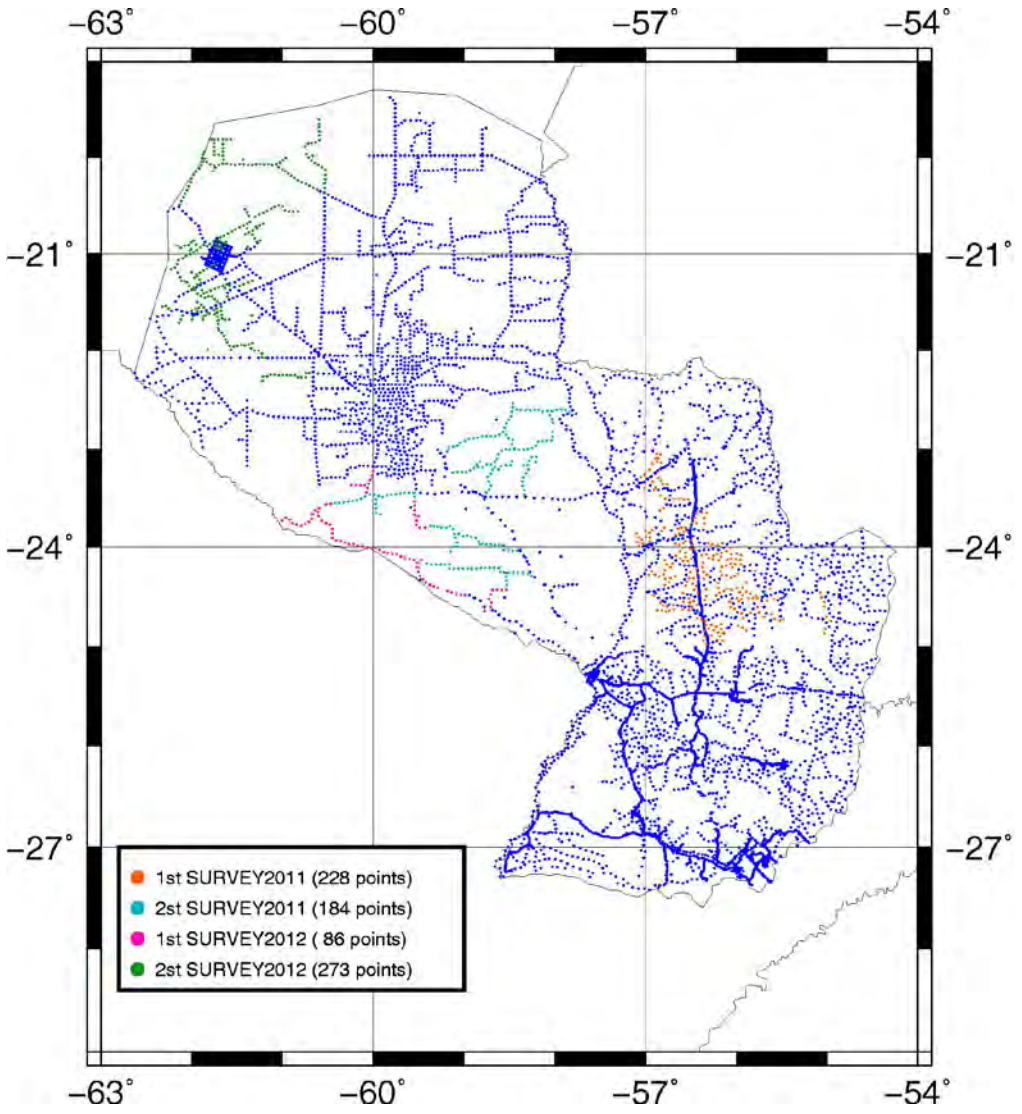
Napo river

RECENT EFFORT

PARAGUAY
SAGS2010-2011
SAGS2011-2012

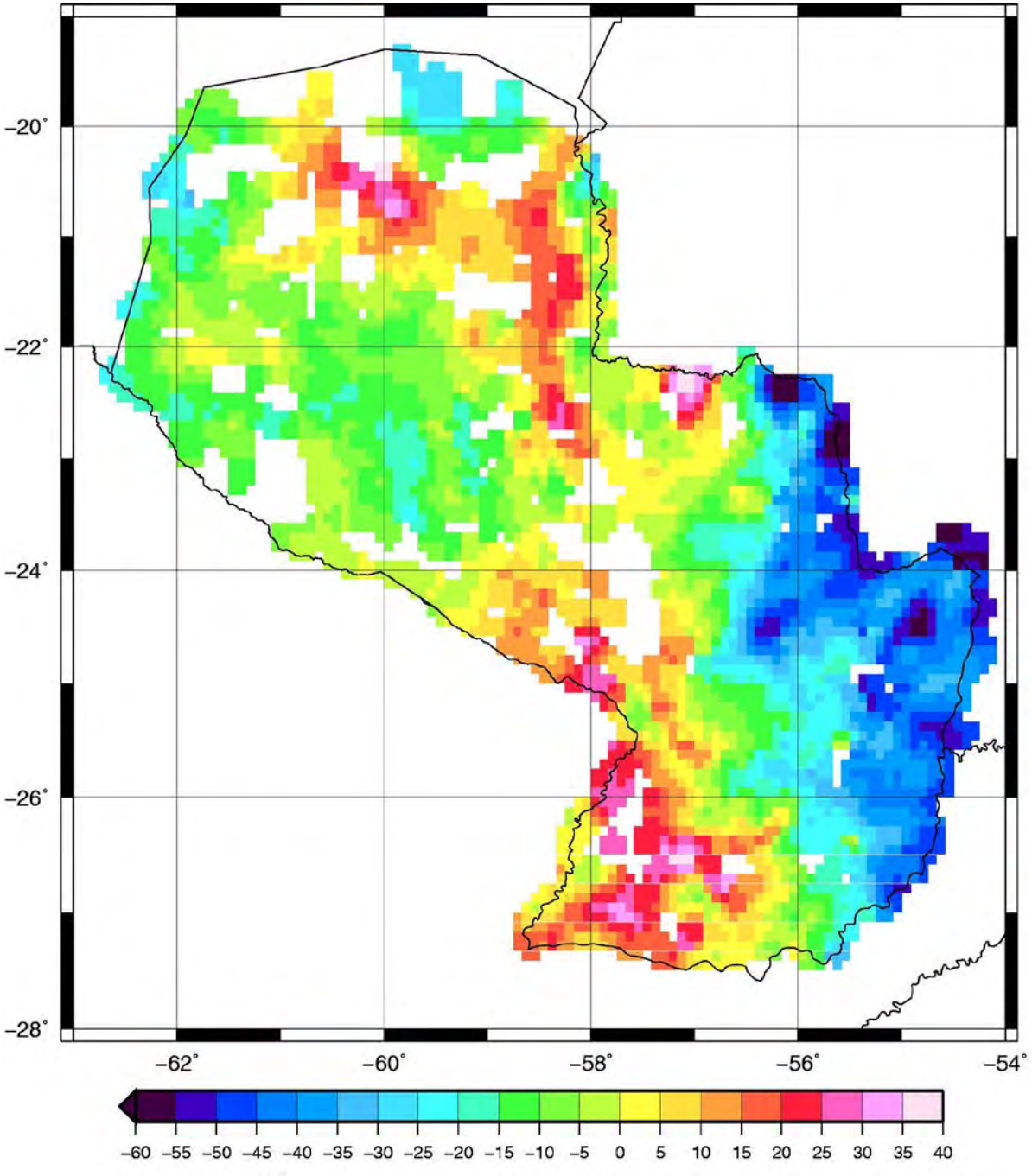
771 new gravity stations have been measured

The gravity observations have been carried out with LaCoste & Romberg gravitymeters. GPS double frequency receivers have been used to derive the geodetic coordinates of all stations. The orthometric height was derived from geodetic height using EGM2008 restricted to degree and order 150.



Complete Bouguer Anomaly (mGal)

5’ grid resolution



The following photographs show typical survey conditions

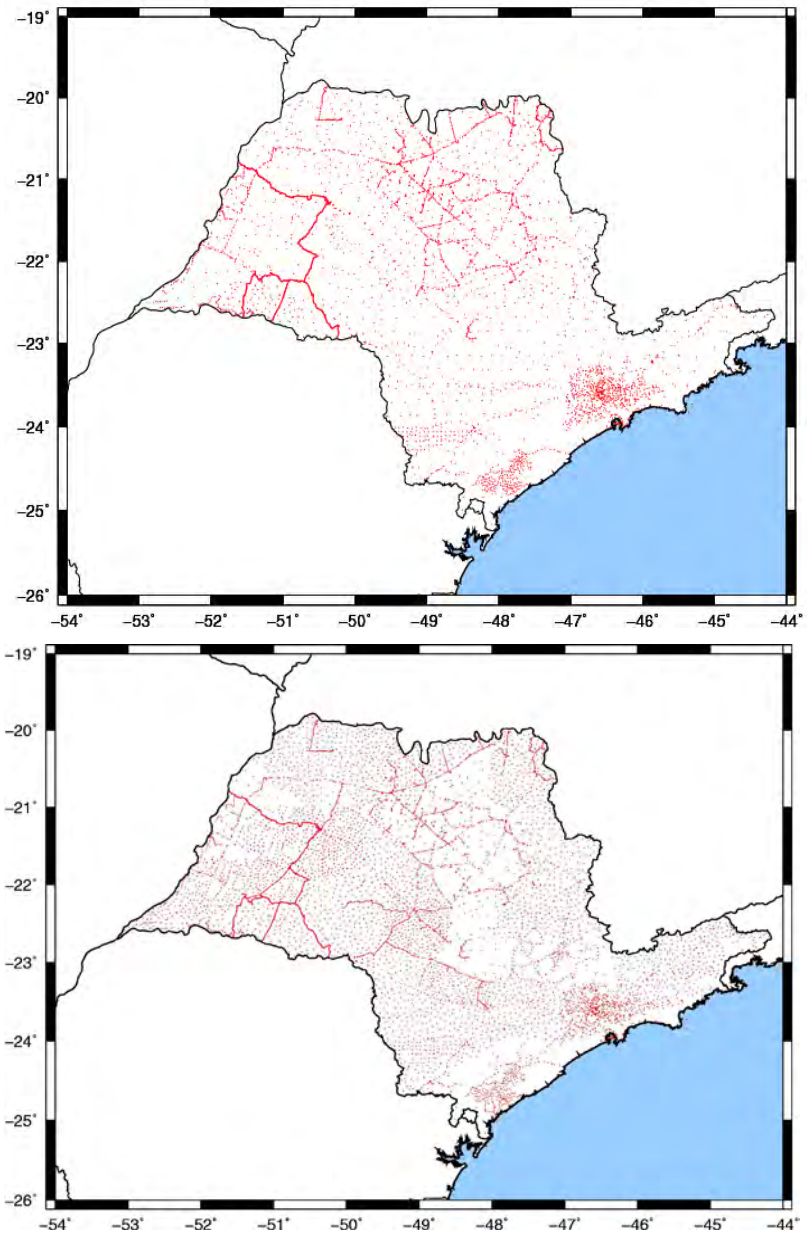
Gravity Data São Paulo State

Before Thematic Project

The land gravity data in the State of São Paulo was kindly provided by the National Observatory, the Brazilian Oil Company (PETROBRAS), the Brazilian Institute of Geography and Statistics (IBGE), the Institute of Astronomy, Geophysics and Atmospheric Science, and the Polytechnic School of the University of São Paulo (EPUSP). The total stations was 4,849 points.

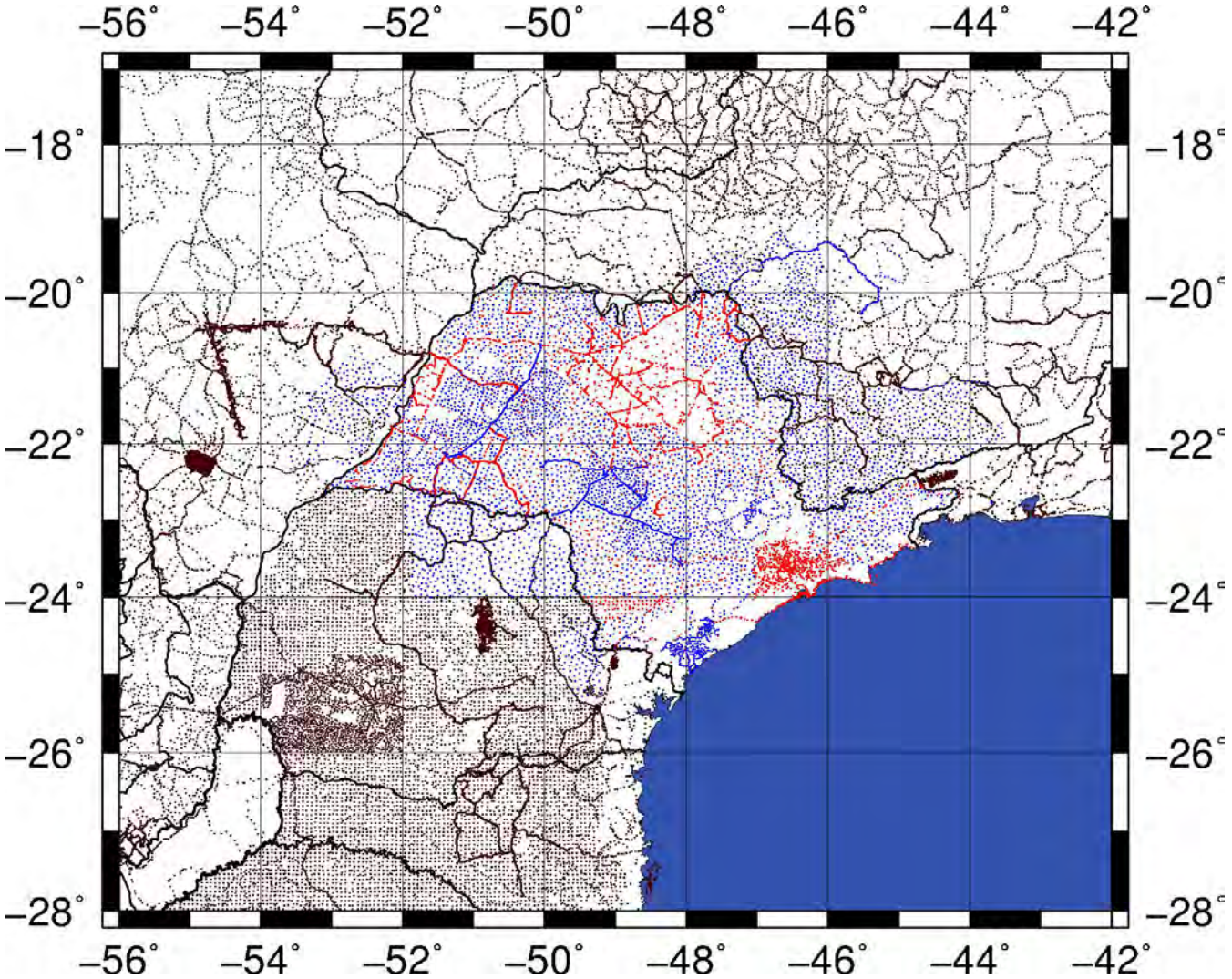
After Thematic Project

The total land gravity data used in this study within the borders of São Paulo is 9,788 points.



Current Scenario

- In red before thematic project
- In blue after it (THEMATIC PROJECT, IBGE and SAGS2011/2012)
- In brown old data out of the state of São Paulo



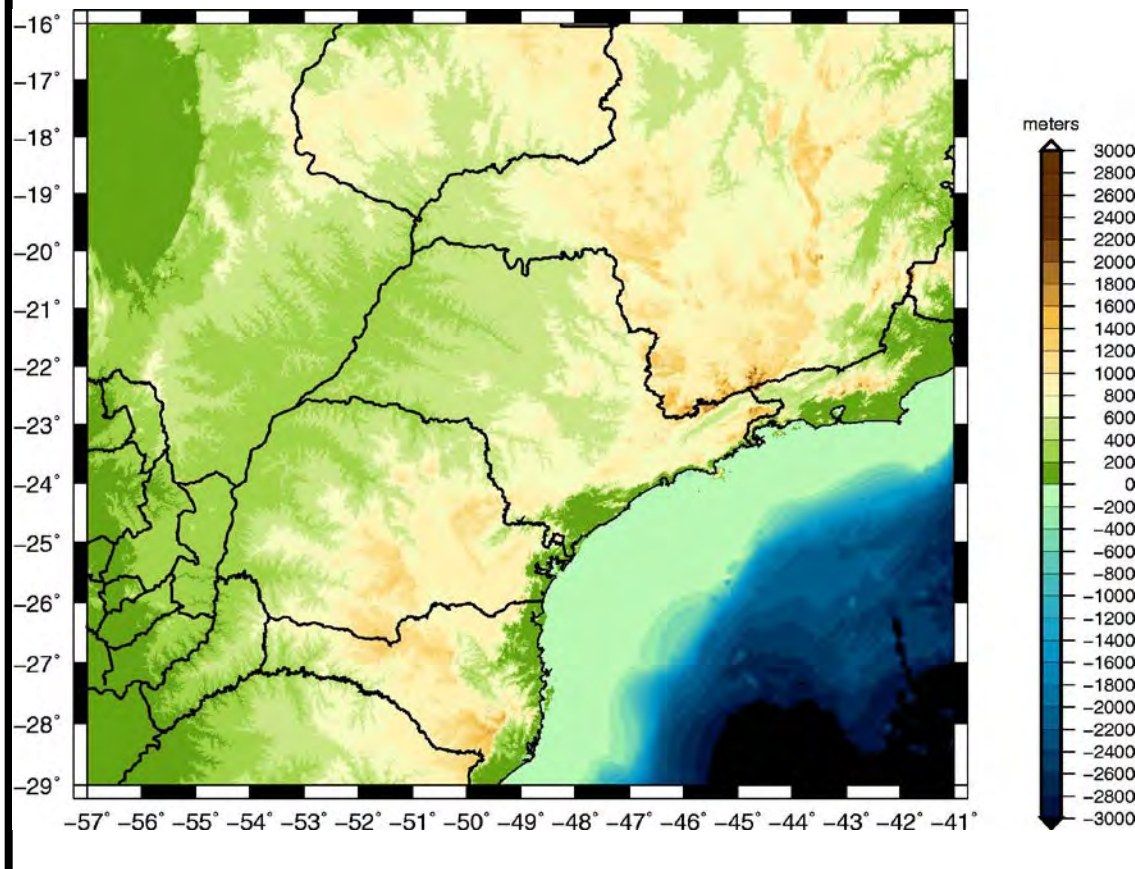
Particular efforts for the establishment:

Geoid model in the State of São Paulo (GEOIDSP)

- The software package SHGEO (Ellmann, 2005a; 2005b) solution of the Stokes boundary value problem employs a modified Stokes' formula in conjunction with the low-degree contribution of the Global Geopotential model.
- In the case of GEOIDSP, EGM2008 (Pavlis *et al.,* 2008) was used.
- For the modified Helmert's gravity anomaly, EGM2008 up to the degree and order 150 and 360 was used as a reference spheroid.
- The processing of the modified Stokes integral was carried out using FFT, according to the proposal of Featherstone et al. (1998). This modification applies the Meissl (1971) modification to the Vaníček and Kleusberg (1987) kernel.
- Numerical integration was computed by stokes_5min software developed by Prof. Dr. Denizar Blitzkow. The computation was carried out only at the GPS/levelling points.
- Least square collocation was used through GRAVSOFT programs COVFIT and EMPCOV (Forsberg and Tscherning, 2008) and the FASTCOL program (Bottoni and Barzaghi, 1993).
- The gravimetric surveys were validated with the program DIVA (BGI).

Digital Terrain Model and Bathymetric

SAM3s_v2 with a grid size of 3” x 3” (~90m x 90m). This model consists of SRTM3 (Farr *et al.,* 2007). EGM96 (Lemoine *et al.*, 1998) geoidal heights used in the SRTM3 was substituted by EIGEN-GL04C (Förste *et al.*, 2006); in order to derive the orthometric height. The gaps were substituted by digitising maps and DTM2002 (Saleh and Pavlis, 2002; Blitzkow *et al.*, 2007). Over the ocean the ETOPO2v2c was used.



Anomalies

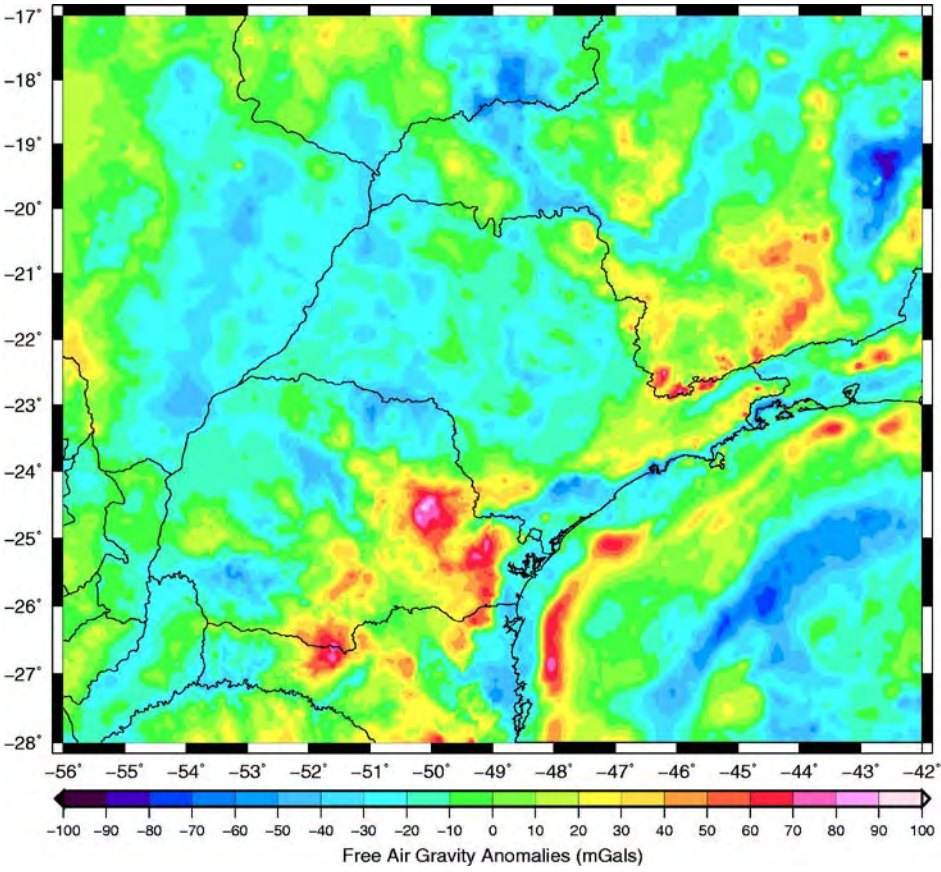
Free-air anomalies (FA)

Mean free-air gravity anomalies in a 5' grid were derived from the point gravity data. The free air gravity anomaly over the ocean were obtained from Danish National Space Center (DTU10) with resolution 1' x 1' (Andersen, 2010).

Helmert's gravity anomaly referred to the Earth's surface (HGES)

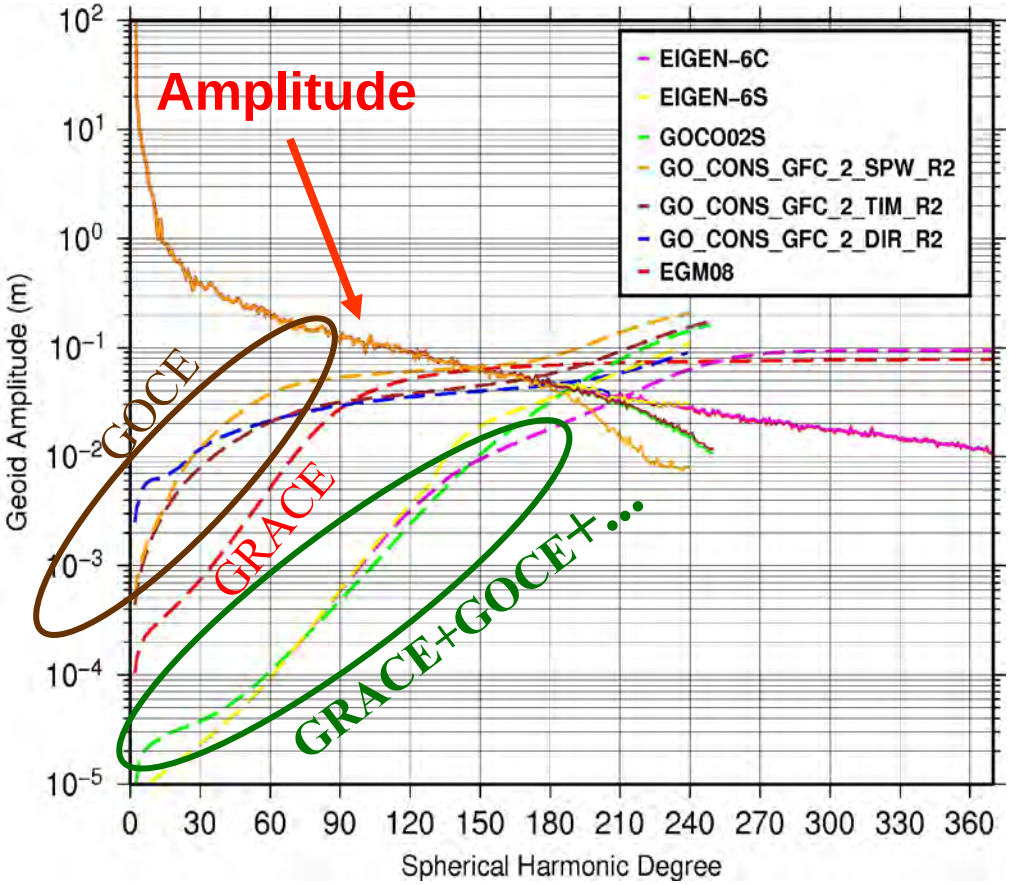
It was obtained by the sum of the free-air anomaly, the direct and secondary indirect topographic effects, the direct atmospheric effect and the geoid-quasi-geoid correction.

Free Air Gravity Anomalies



mGal	FA	HGES
Mean	-4.86	-4.91
Stdev	24.68	24.97
Máx.	134.29	134.11
Min.	-96.59	-97.93

The degree variance of the Geopotential Models



The amplitude (solid lines) and the commission error (dashed lines) for the seven models are represented in the figure at left hand side. These errors reflect the uncertainties of the spherical harmonic coefficients, which are due to errors in the observation that propagate in the geoid undulation. The Global Geopotential Models (GGMs) error for maximum degree is: 10 cm, 16 cm, 9 cm, 17 cm, 20.5 cm and 8 cm for EIGEN 6C, GOCO02S, DIR_R2, TIM_R2 and SPW_R2 and EGM2008, respectively. The EGM2008 commission error for degree 150 is 6 cm.

GPS data over Bench Marks

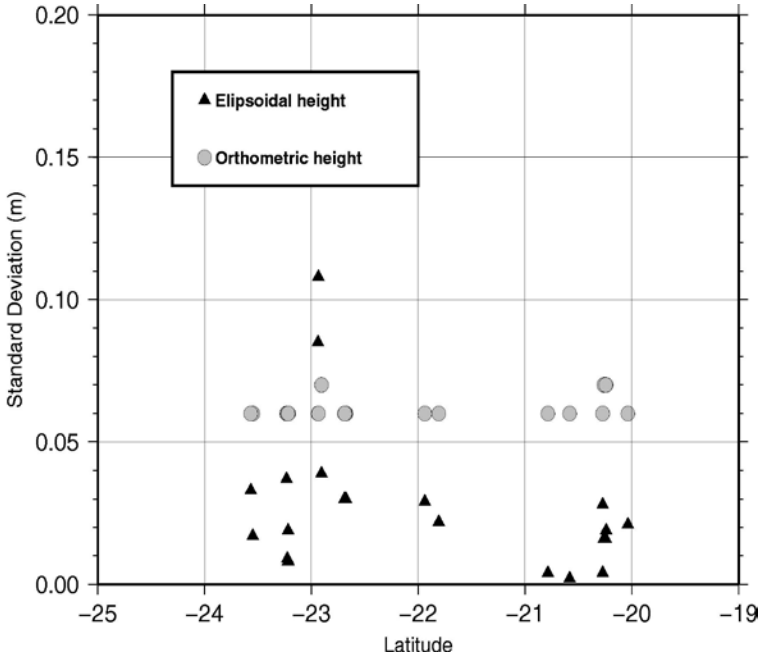
GPS observations carried out on benchmarks of the spirit leveling network in the State of São Paulo contributed for testing the gravimetric determination of the GEOIDSP (FFT, LSC and NI) as well as GGMs.

A total of 168 GPS/BM points are available in this area.

Attention to the following GGMs were addressed:

- **GO_CONS_GCF_2_DIR_R3** (n=m=240)
- **GO_CONS_GCF_2_TIM_R3** (n=m=250)
- **GO_CONS_GCF_2_SPW_R2** (n=m=240)
- **EIGEN-6C** (n=m=1420)
- **EIGEN-6S** (n=m= 240)
- **GOCO02S** (n=m=250)
- **GOCO01S** (n=m=224)
- **EGM2008** (n=m= 2160)
- **MAPGEO2010** (the official geoid model of Brazil. It was computed using EGM2008 for the long wavelength component of the geoid and the gravity anomaly (n=m=150) Blitzkow *et al.,* 2010).

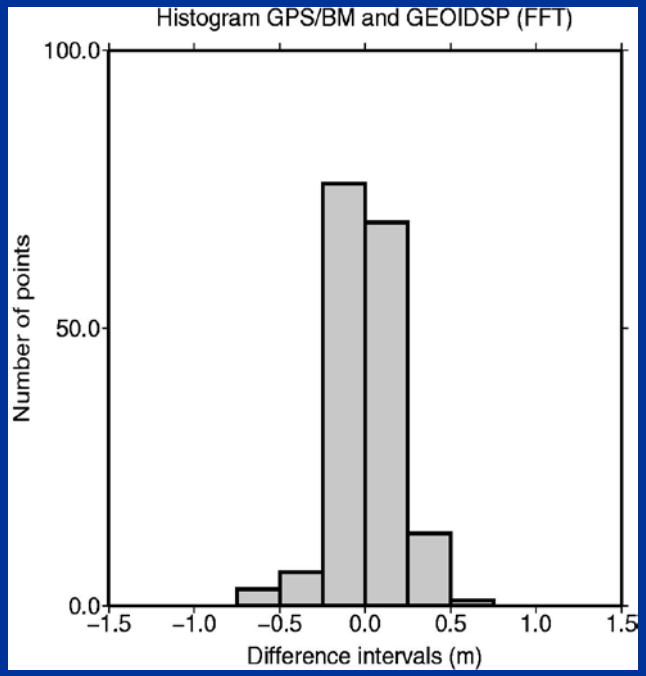
- 139 stations belong to the Laboratory of Geodesy and Topography of EPUSP.
- 29 stations were provided by the IBGE and they were adjusted recently.

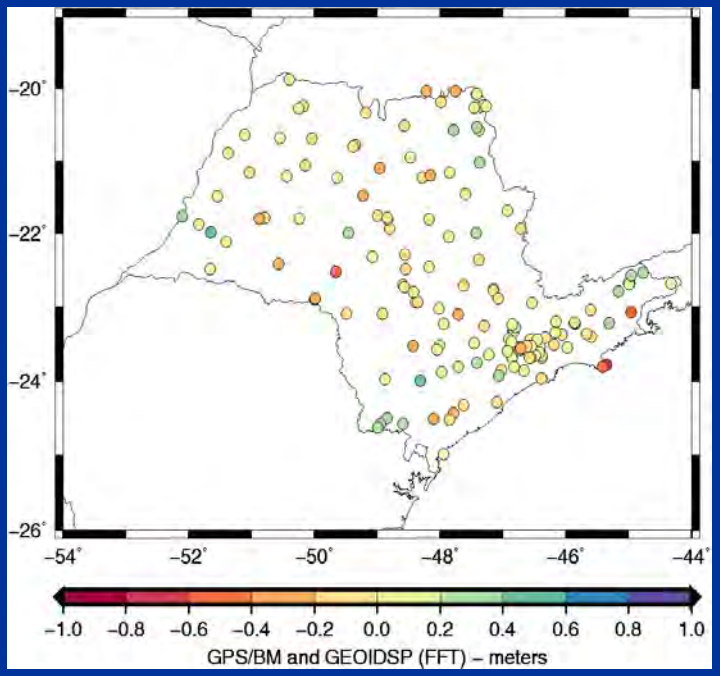


Standard deviation of the IBGE heights

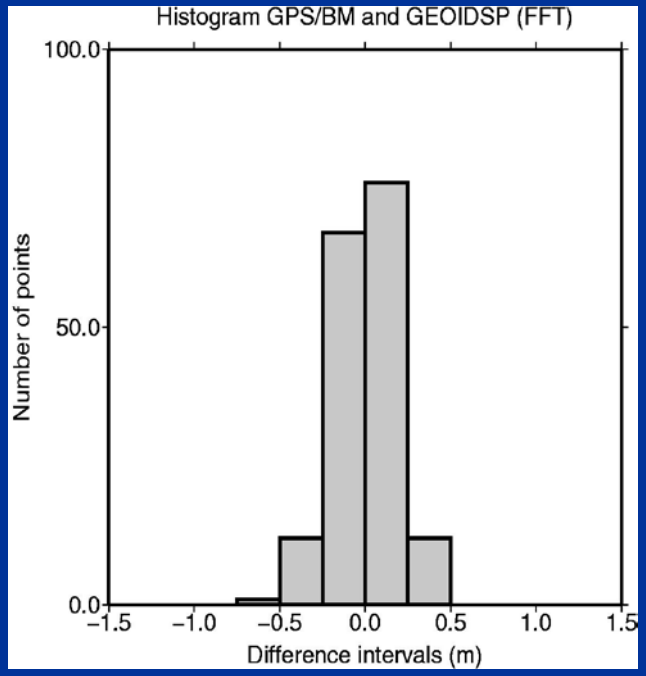
- GPS stations are referred to SIRGAS2000 (tide-free system).
- GPS/leveling points have decimeter precision.
- The GGMs are tide-free system and the zero-order term was considered in all cases (-0.41 m).

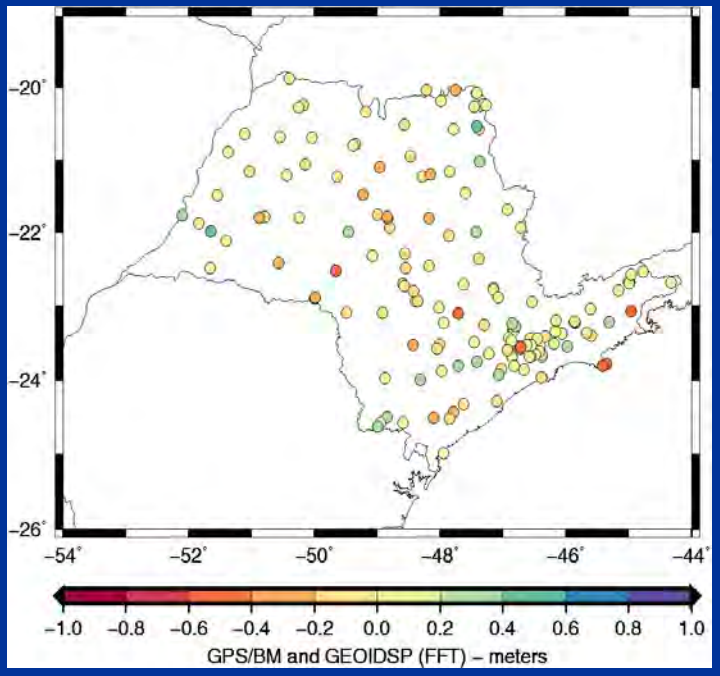
GEOIDSP EGM08 150 (FFT)



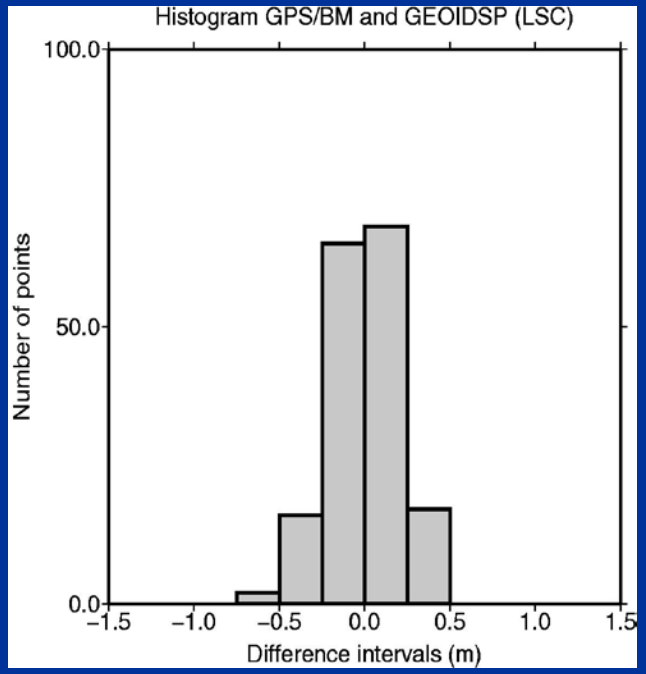


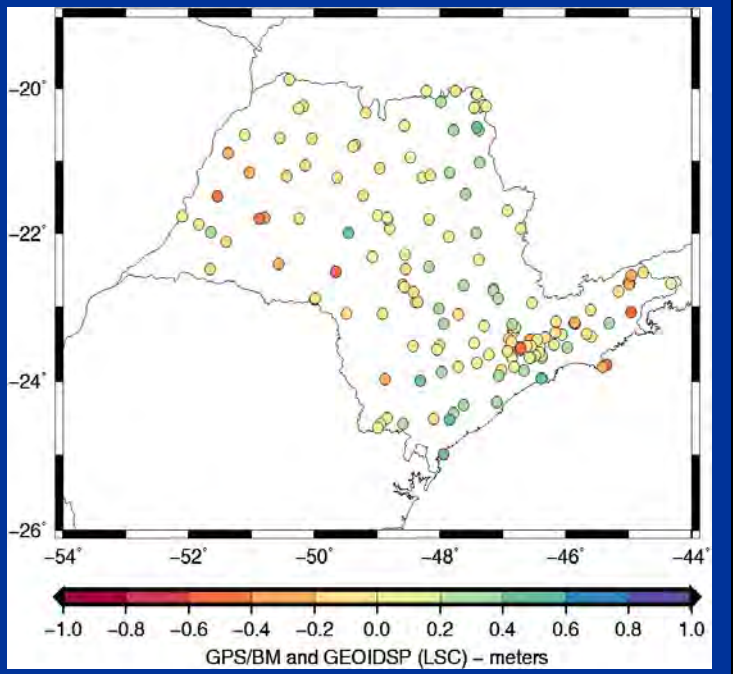
GEOIDSP EGM08 360 (FFT)



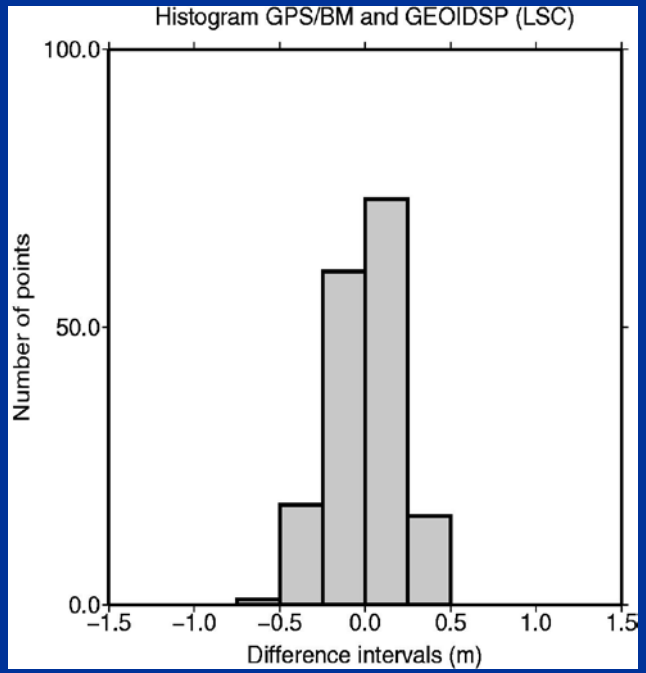


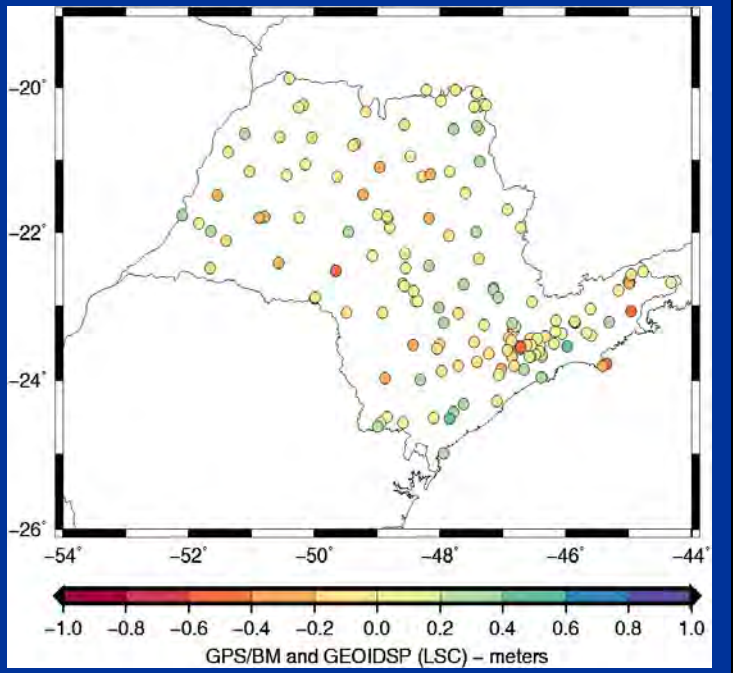
GEOIDSP EGM08 150 (LSC)



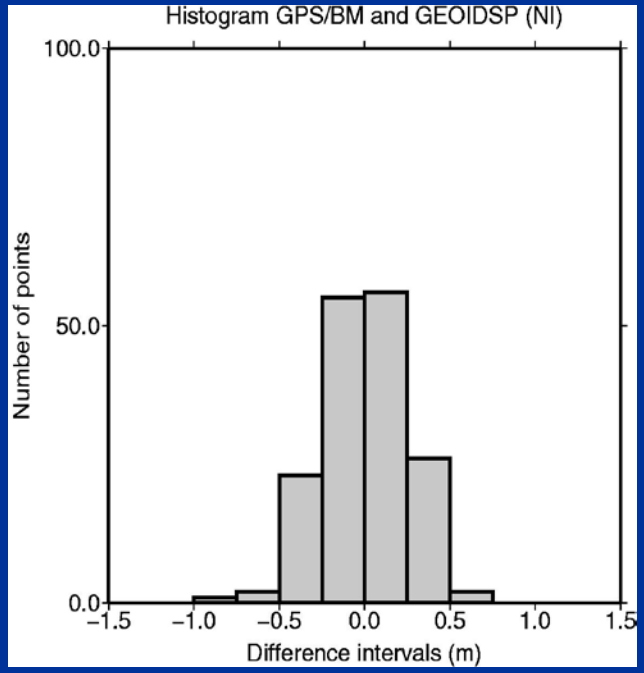


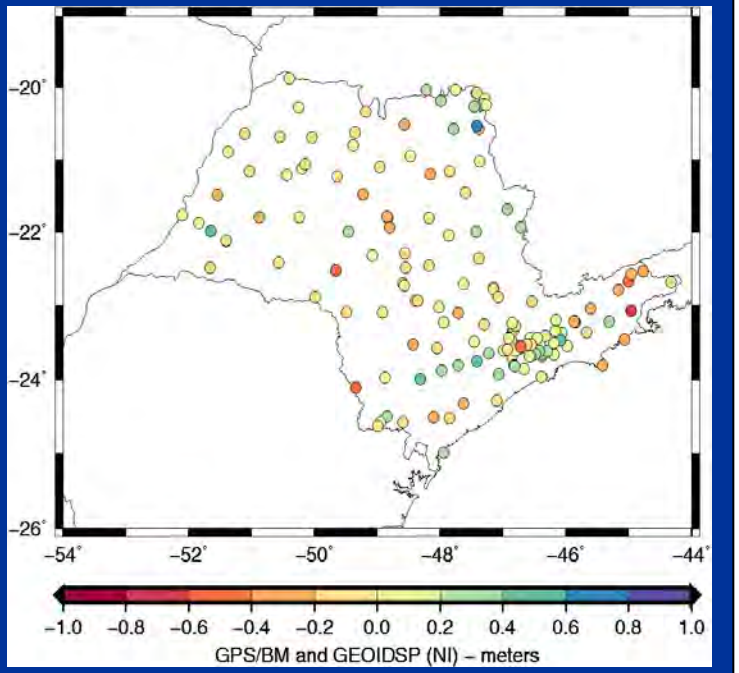
GEOIDSP EGM08 360 (LSC)





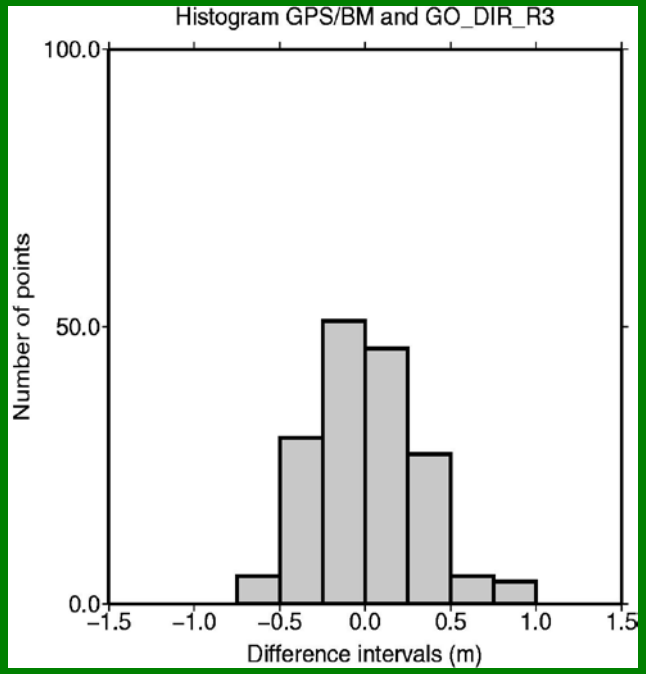
GEOIDSP EGM08 150 (NI)

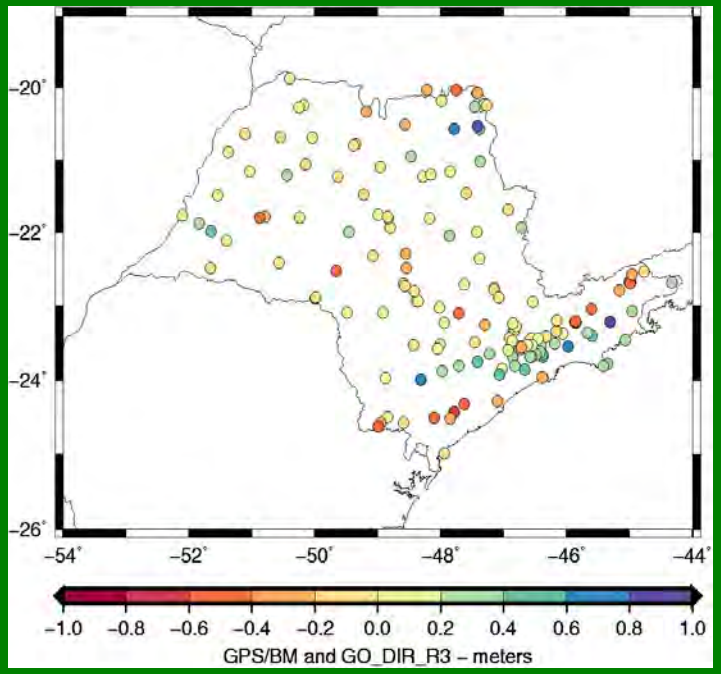




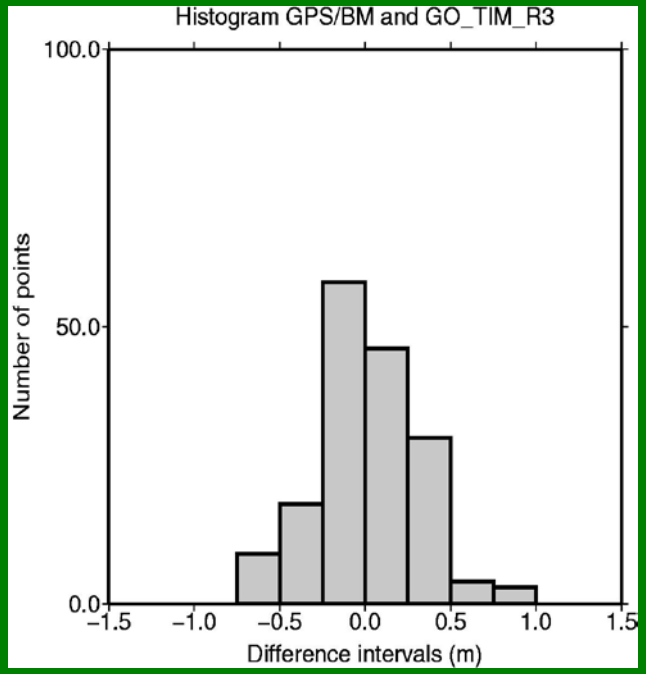
meters	Mean	Stand. Diff.	Kurtosis	Skewness	Max.	Min.
GEOIDSP 150 (FFT)	0.10	0.18	1.34	-0.36	0.51	-0.61
GEOIDSP 360 (FFT)	0.14	0.17	1.19	-0.41	0.49	-0.60
GEOIDSP 150 (LSC)	0.11	0.21	-0.10	-0.09	0.47	-0.53
GEOIDSP 360 (LSC)	0.15	0.19	0.12	-0.20	0.46	-0.58
GEOIDSP 150 (NI)	0.17	0.24	0.02	-0.08	0.69	-0.76

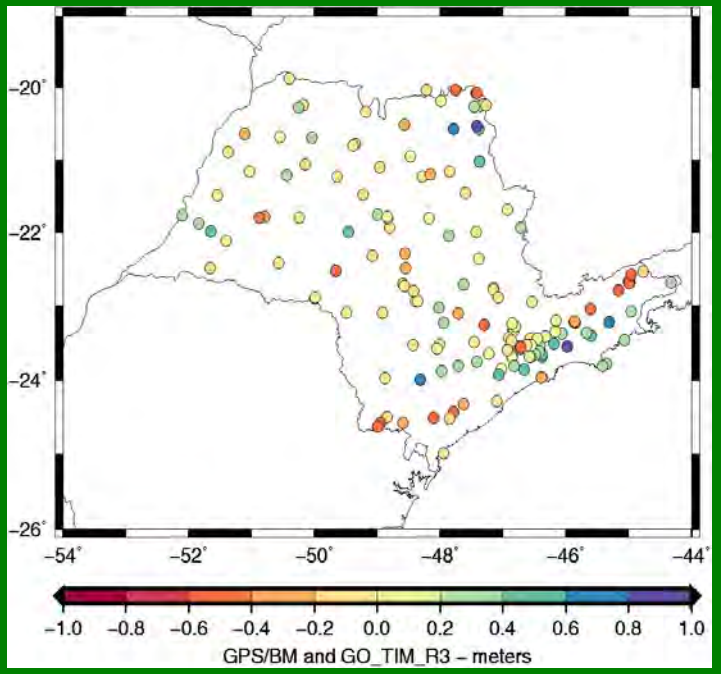
GO_DIR_R3



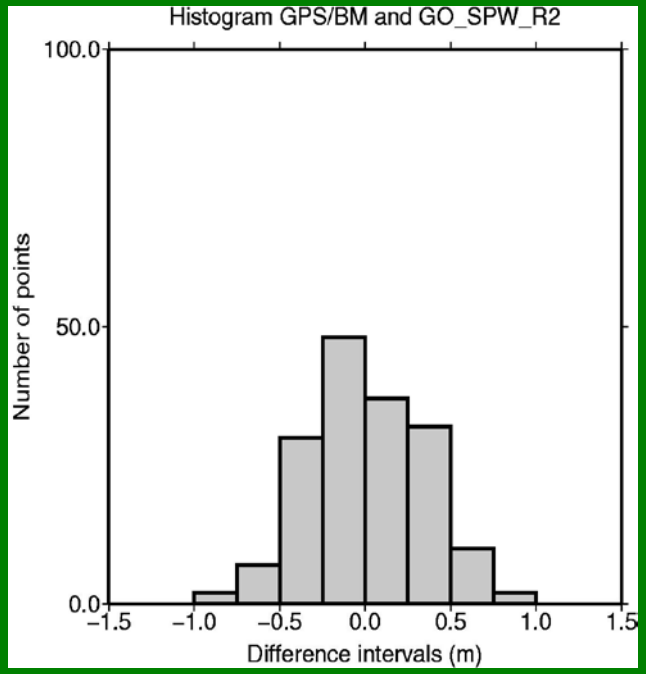


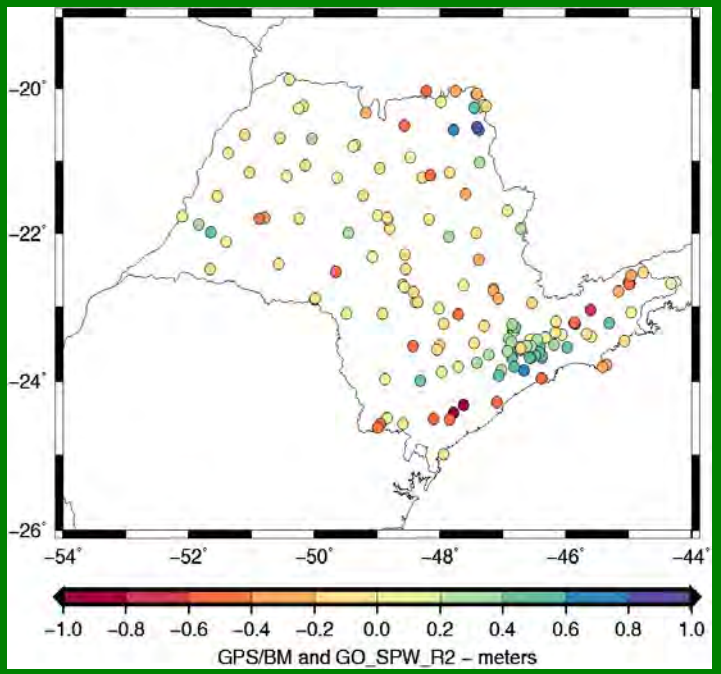
GO_TIM_R3



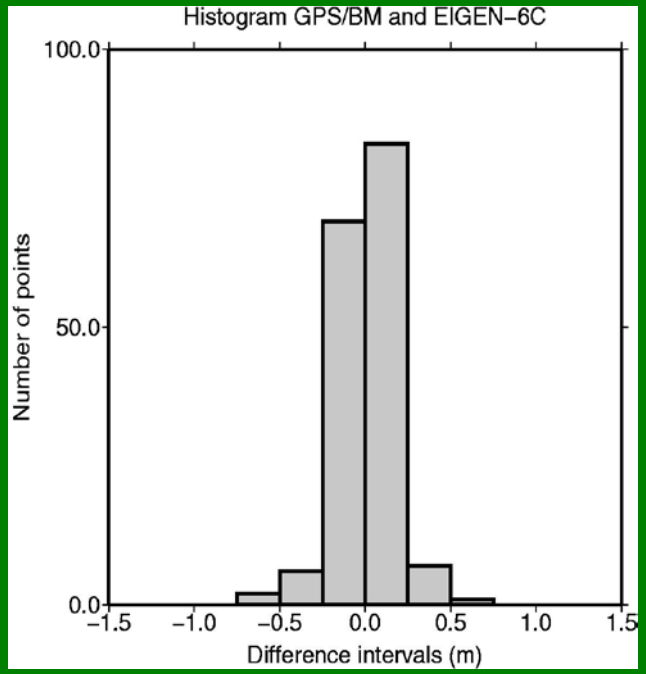


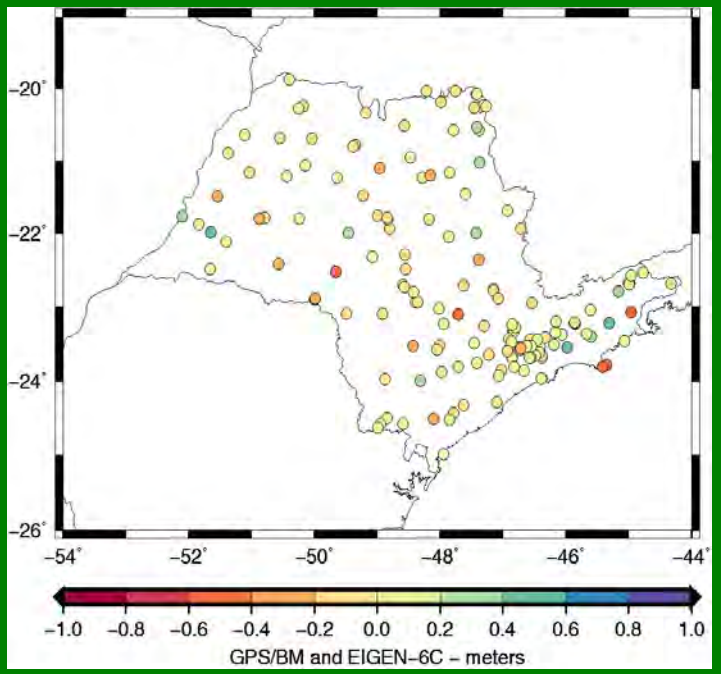
GO_SPW_R2



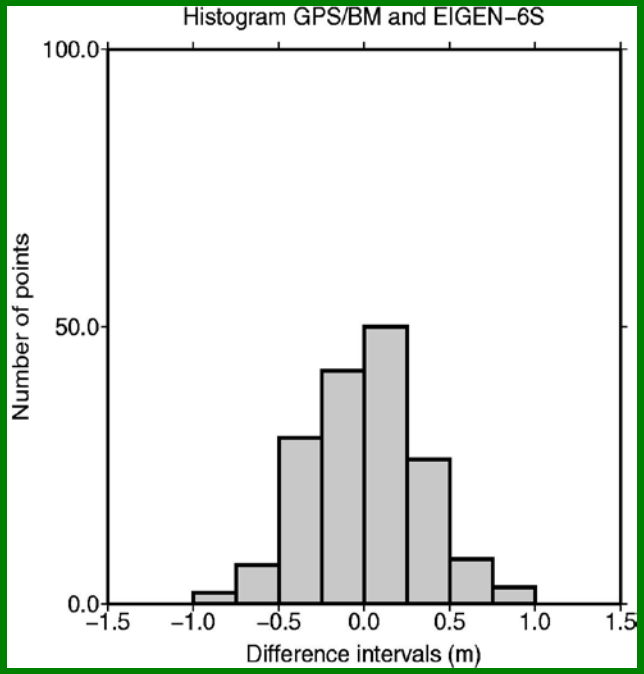


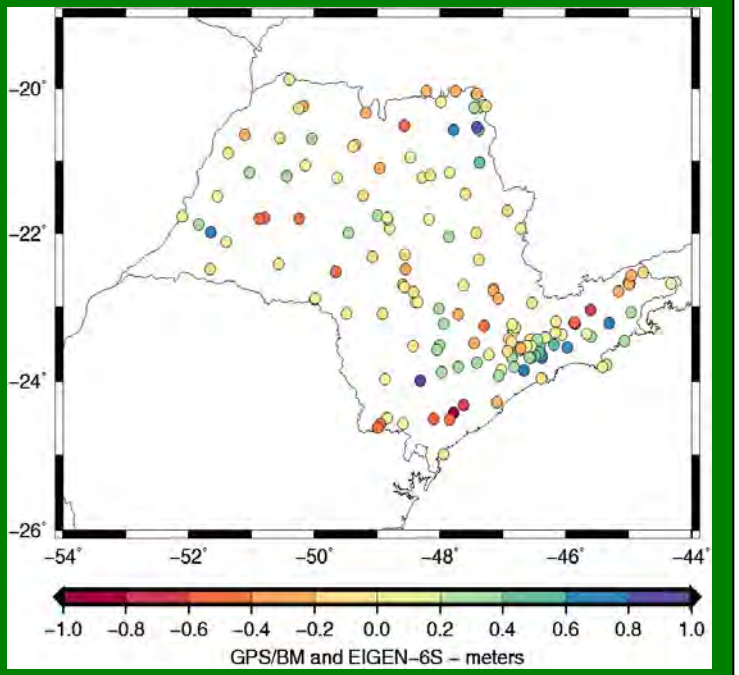
EIGEN-6C



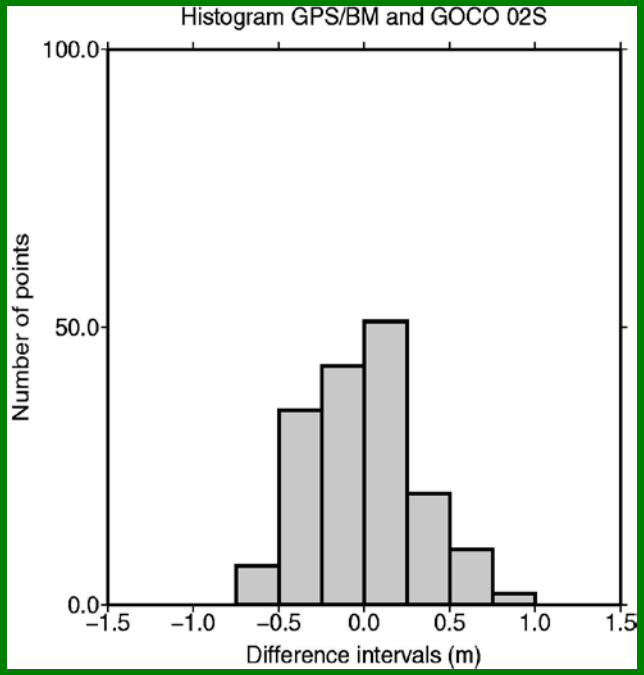


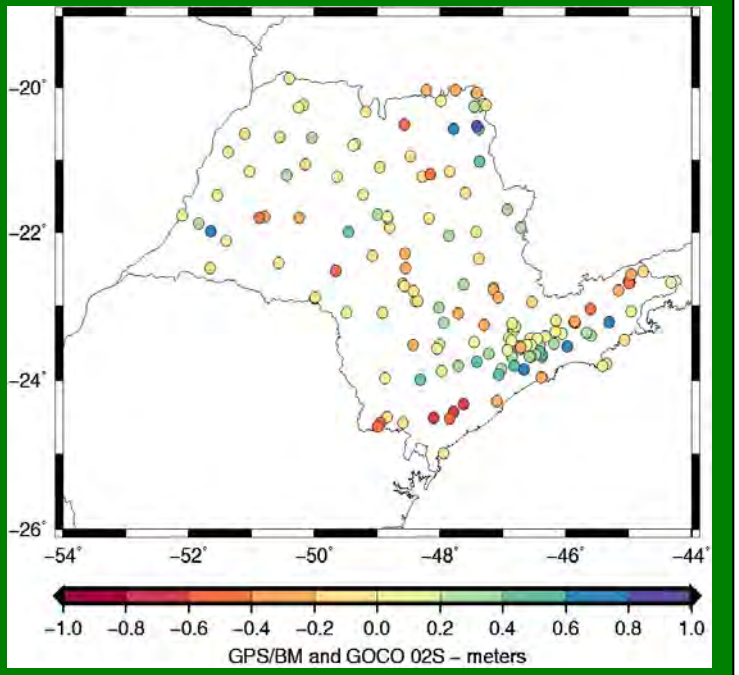
EIGEN-6S



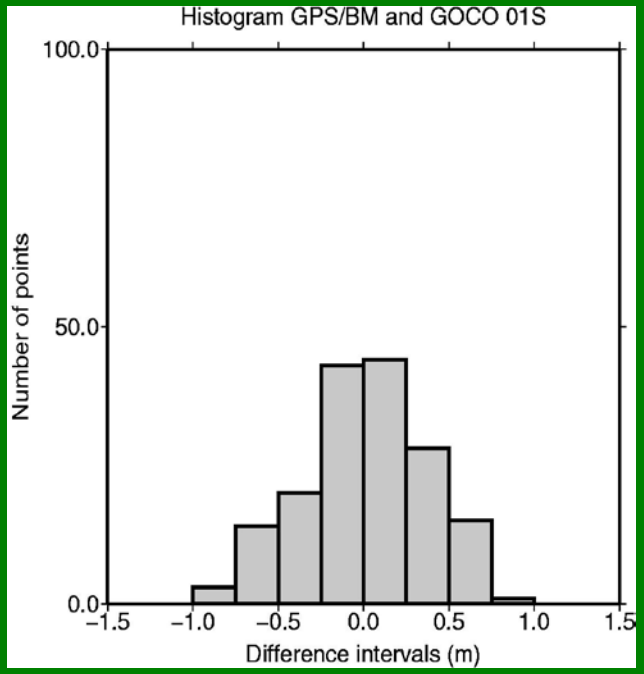


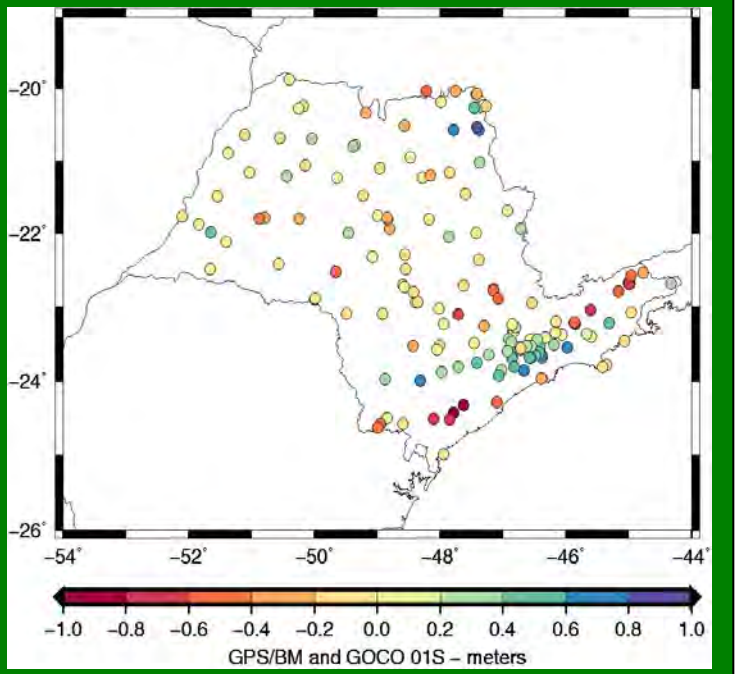
GOCO02S



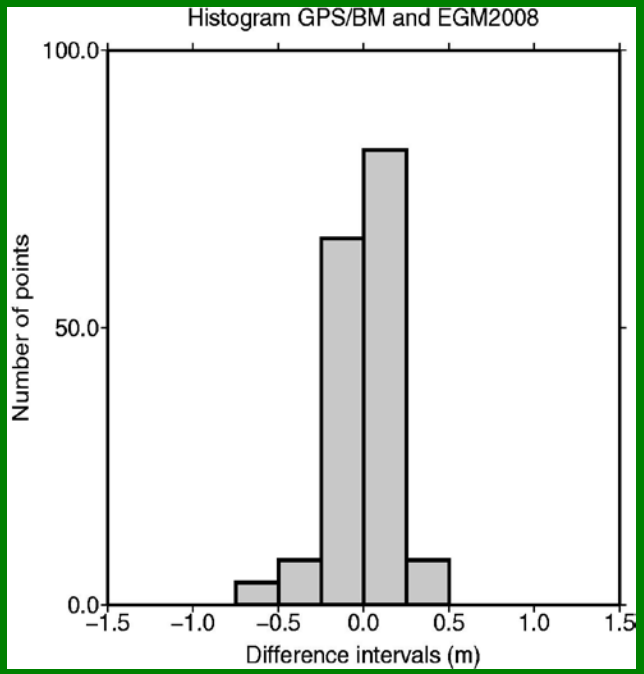


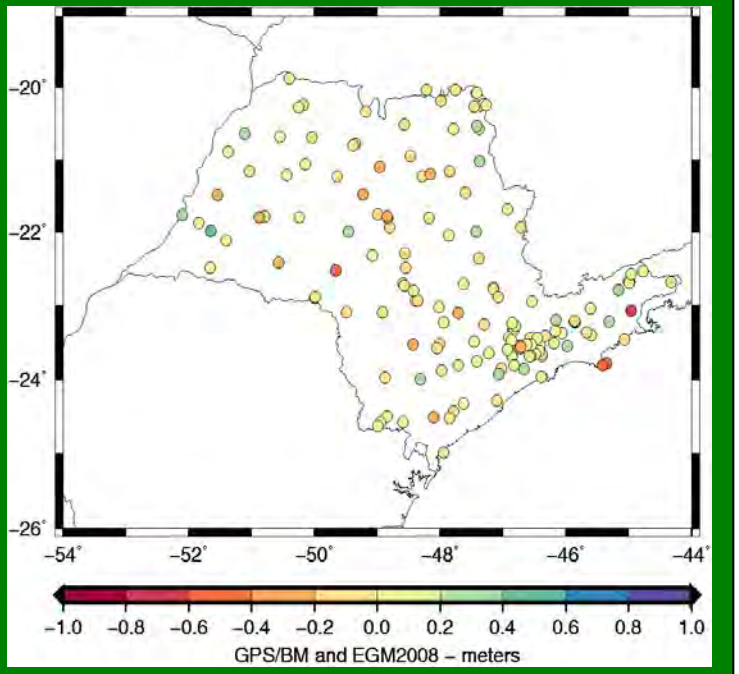
GOCO01S



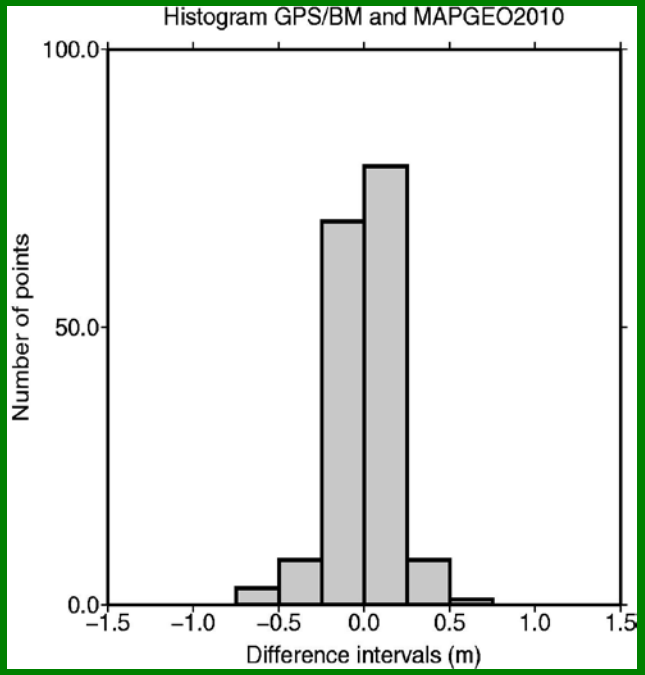


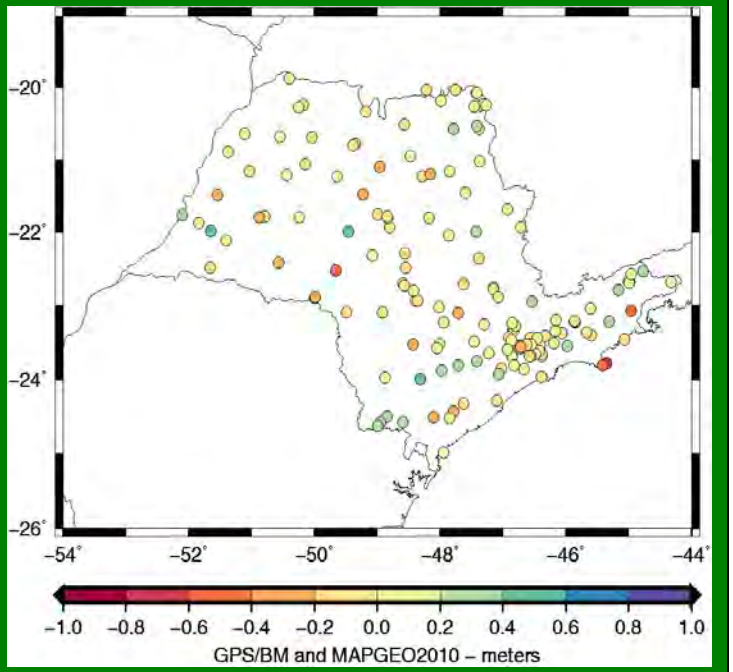
EGM2008





MAPGEO 2010





meters	Mean	Stand. Diff.	Kurtosis	Skewness	Max.	Min.
GO_DIR_R3	0.11	0.30	0.05	0.33	0.92	-0.61
GO_TIM_R3	0.10	0.30	-0.11	0.28	0.88	-0.57
GO_SPW_R2	0.19	0.34	-0.50	-0.00	0.96	-0.84
EIGEN-6C	0.17	0.16	1.90	-0.28	0.52	-0.56
EIGEN-6S	0.13	0.33	-0.07	0.14	0.92	-0.86
GOCO02S	0.15	0.31	-0.28	0.14	0.86	-0.74
GOCO01S	0.18	0.36	-0.40	-0.11	0.95	-0.95
EGM2008	0.18	0.17	2.59	-0.87	0.47	-0.70
MAPGEO2010	0.10	0.17	1.68	0.41	0.51	-0.61

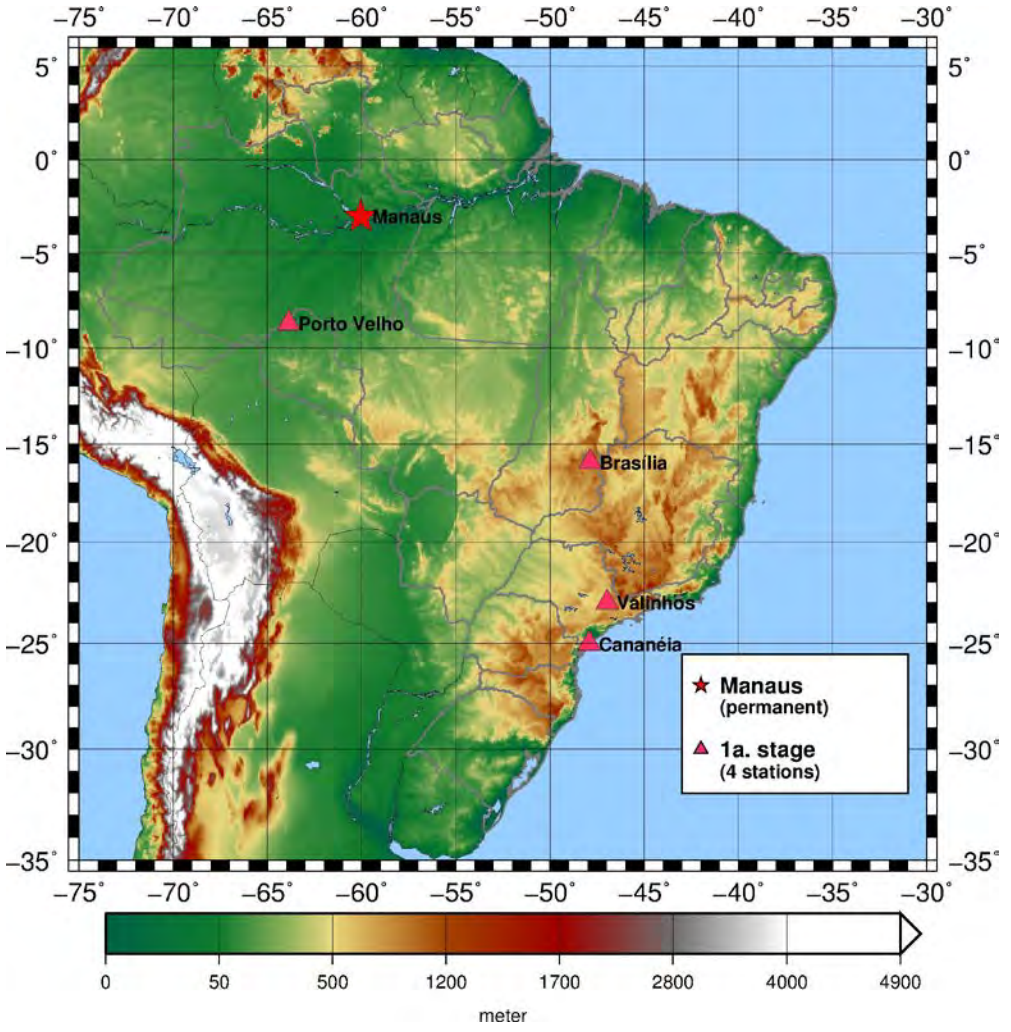
CONCLUSION
GEOIDSP

- The objective of the analysis was to verify the consistency between the quantities.
- The geoid in the State of São Paulo is a result of the Thematic Project efforts. This is a consequence of a hard work that involves some Brazilian institutions.
- The GEOIDSP model presented findings very similar, in terms of standard deviation, using FFT (150 and 360) and LSC (360) solutions.
- The high degree models (EIGEN-6C and EGM2008) presented results similar when compared with the GEOIDSP model.
- Also the official geoid model of Brazil is consistent with GPS/levelling in terms of 0,17 m.
- The low degree and order GGMs presented higher discrepancies in relation to the GPS/levelling in the mountain regions (coast area).

A new project in Brazil under the coordination of the LTG to establish an Earth tide model

The support:
1.ANP (Agência Nacional do Petróleo)
2.GEORADAR Levantamentos Geofísicos S.A.

Two Microg LaCoste gravitymeters are available for this purpose.
The project aims to establish 5 stations well distributed in Brazil, one of long term in Manaus (Amazon) and 4 others in a sequence of 6 months operation in different places. Initially, it will be a project for the next two years at least, with the possibility to extend for another 3 years.



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- GETECH, NGA and the Civil and Military organizations in South America (Argentina, Brazil, Chile, Colombia, Ecuador, Paraguay, Uruguay and Venezuela) for the spectacular efforts for cooperation.

Amazon (Negro River) – Gravimetric survey

Amazon - Gravimetric support

Amazon – Gravimetric survey

Pantanal (Mato Grosso do Sul State) – Gravimetric difficulties

Pantanal (Mato Grosso do Sul State) – Gravimetric survey

Chaco (Paraguay) – Gravimetric difficulties

Ecuador – Gravimetric survey

Thank you for your attention!

Pantanal (Mato Grosso do Sul State) – Gravimetric logistics