EPUSP

Escola Politécnica da Universidade de São Paulo

IBGE

Instituto Brasileiro de Geografia e Estatística

Recent progress of the geoid in South America

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SIRGAS

42º Reunión del Consejo Directivo del Instituto Panamericano de Geografía e Historia (IPGH)
Lima, Perú

11 y 12 de noviembre de 2010

This presentation shows the progressive efforts for the establishment of:

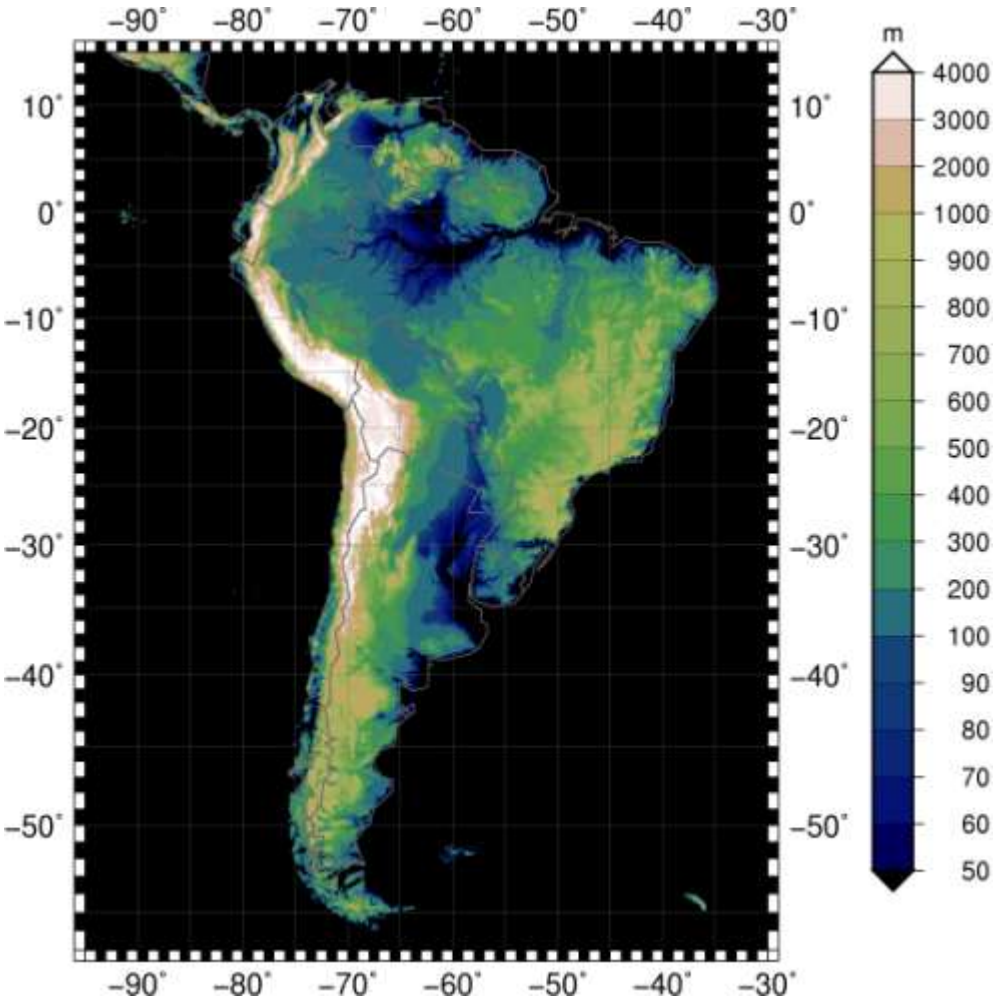
Geoid (quasi-geoid) model in South America

Version 2010

Limited by

15º N and 57º S in latitude

95º W and 30º W in longitude



The following data set was used for the geoid computation:

- **Free-air gravity anomalies** (925878 point gravity data);
- **Geopotential model** for computing the long wavelength component of the geoid and the gravity disturbance - EGM2008 (Pavlis, 2008);
- The best and accurate **DTM** for the computation of terrain correction and other topographic and atmospheric effects on geoid modeling (SAM3s_v2);
- **Satellite gravity model** for the ocean - DNSC08 (Andersen et al., 2008).

The package SHGEO developed by the University of New Brunswick - Canada (Ellmann, 2005a; 2005b) was used for the partial calculation combined with FFT (Featherstone et al., 1998) approach for the modified Stokes integral .

GRAVITY DATA

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

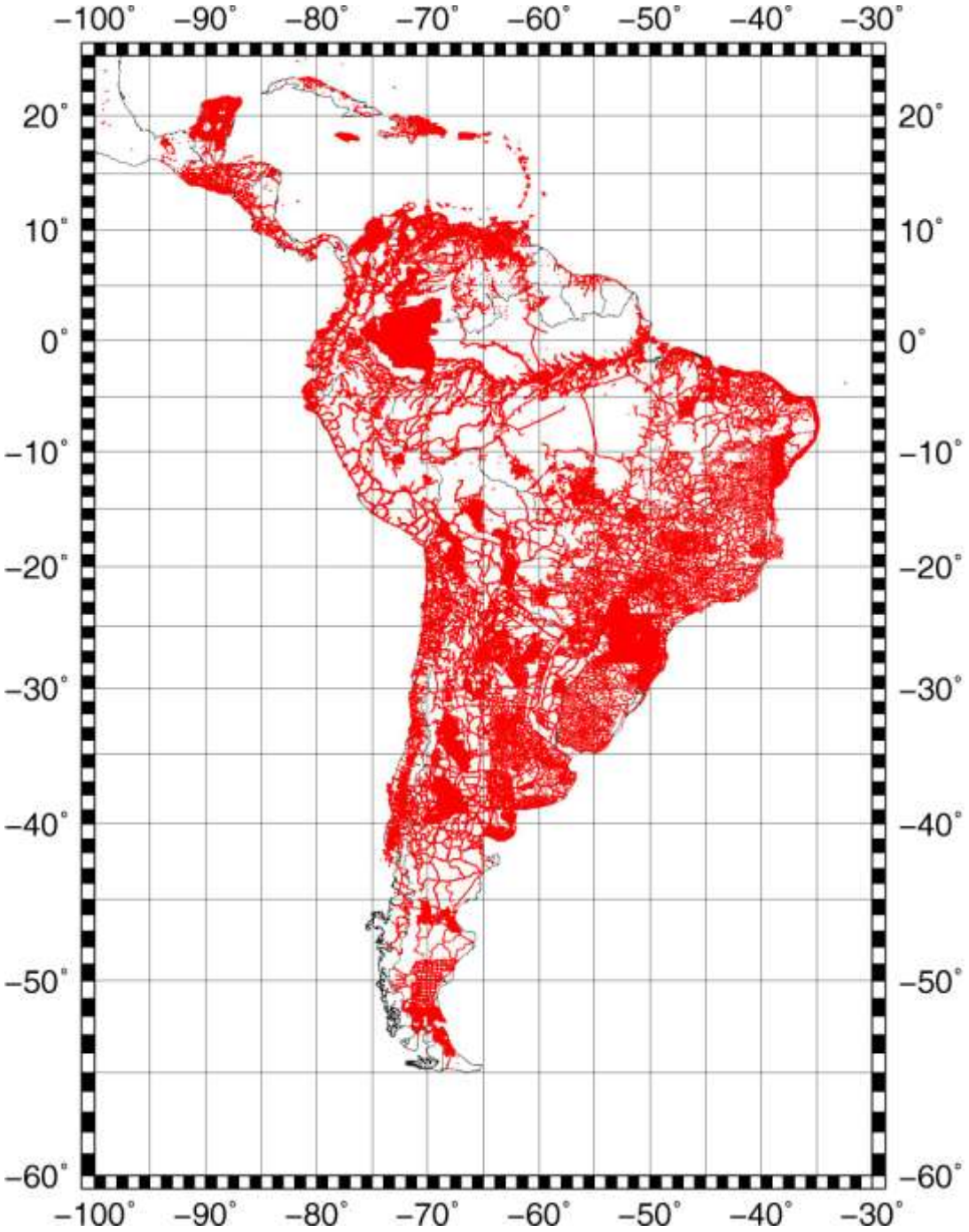
It is important to mention:

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

Due to the big 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.

GRAVITY DATA DISTRIBUTION



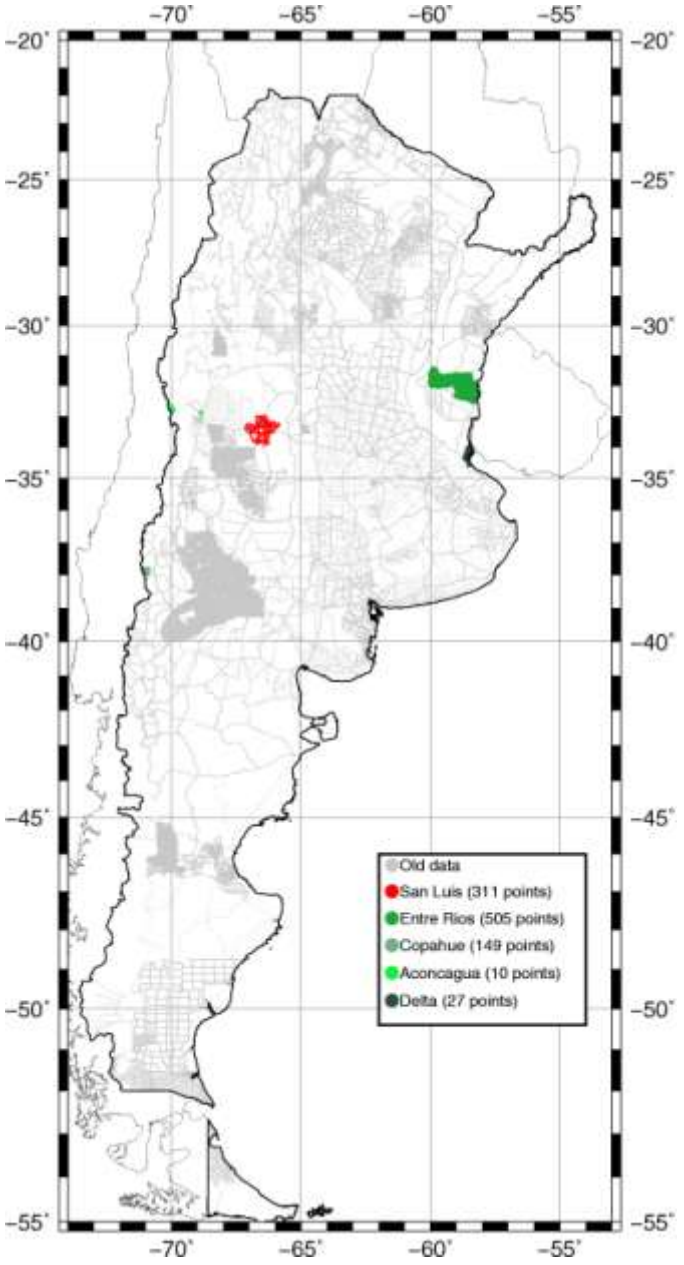
RECENT EFFORT

ARGENTINA
126012 GRAVITY DATA

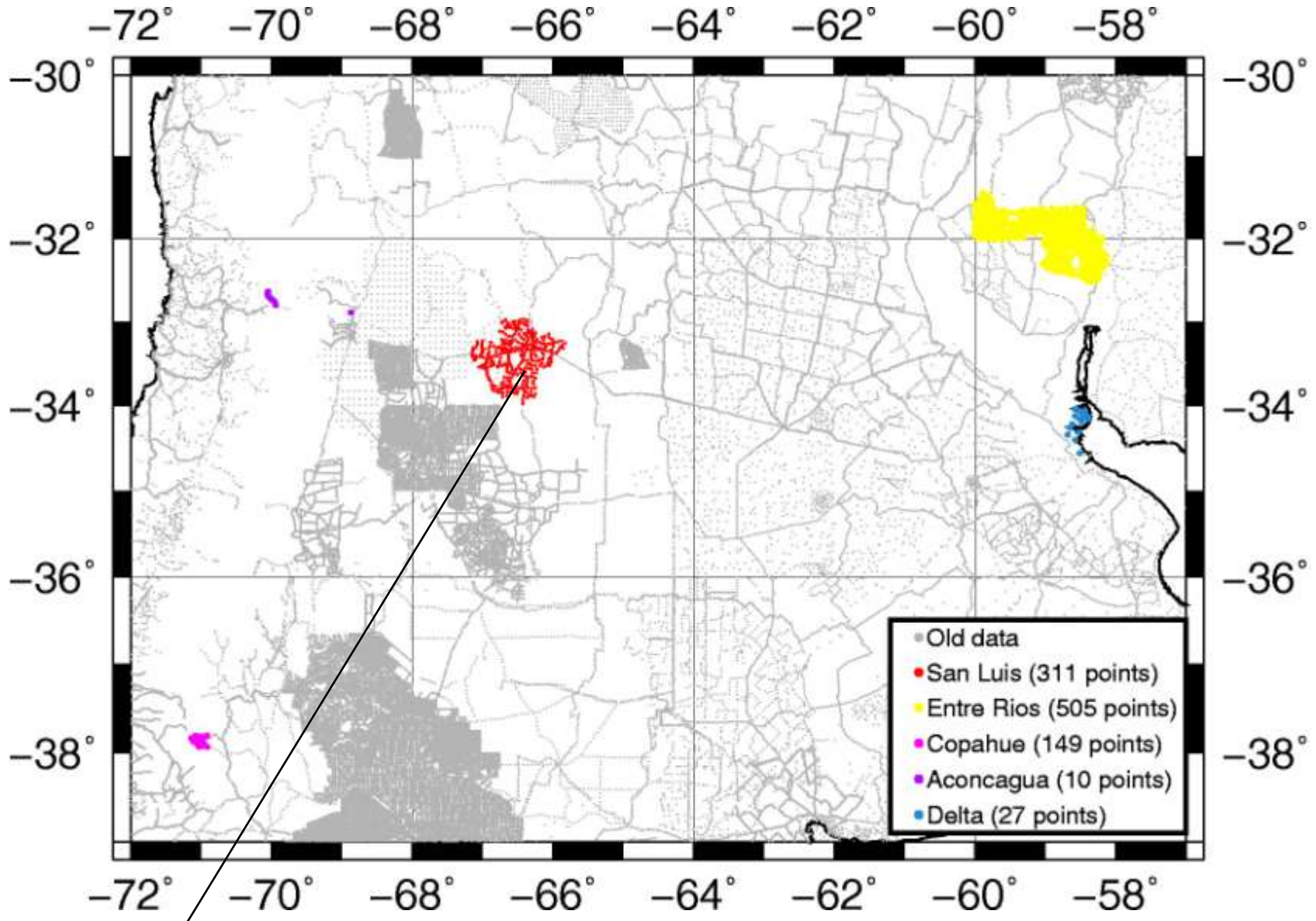
The land gravity data used in this study have been provided by:

- Instituto Geográfico Nacional (IGN – old IGM)
- Universities: Rosario, La Plata, Tucuman, San Juan and Berlin
- Oil companies: YPFA and Chevron
- International Gravimetric Bureau (BGI)
- National Geo-Spatial Intelligence Agency (NGA)

The complete gravity data base was validated and many inconsistencies solved for.



Campaighs in 2009/2010 – 1002 new stations



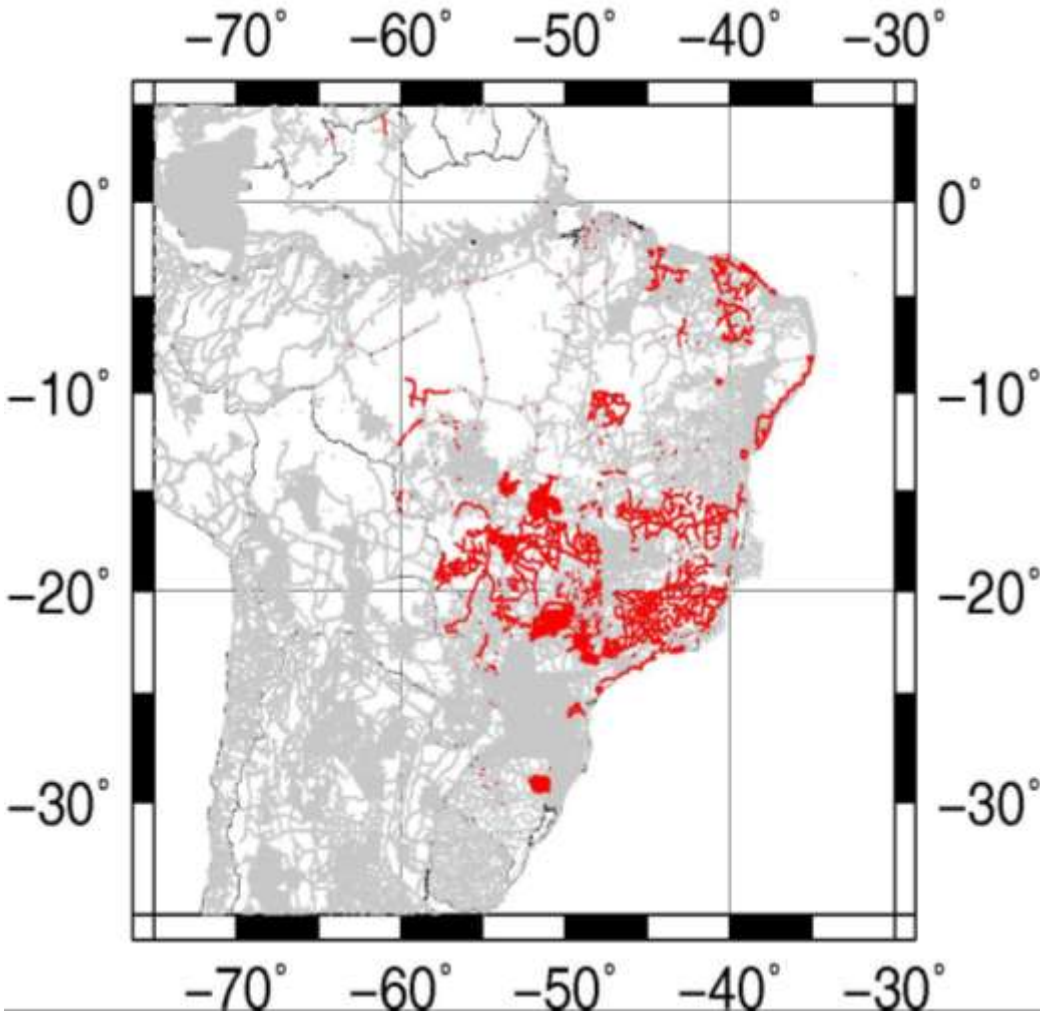
Used in geoid

RECENT EFFORT IN BRAZIL - 13057 GRAVITY DATA

- IBGE and EPUSP carried out gravity surveys with GNSS measurements for station positioning, in Center-West and South of Brazil (2103 stations).

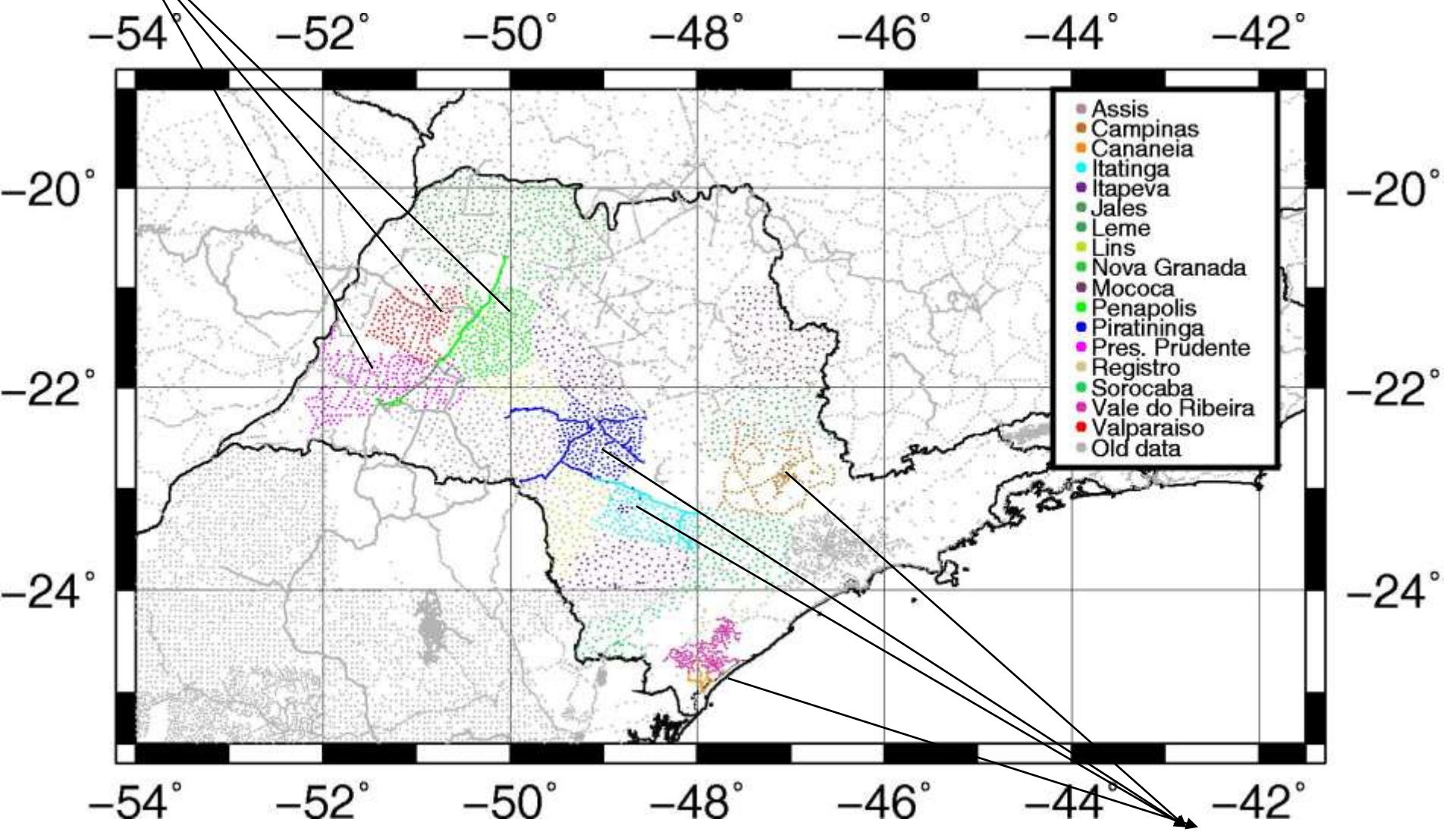
- IBGE also worked in Northeast, Southeast and Center-West parts of Brazil with a total of 9335 stations surveyed from 2004 to 2008.

- FAPESP (Foundation of the State of São Paulo) is supporting the Thematic Project, with the involvement of EPUSP/LTG (Laboratory of Surveying and Geodesy), FCT/UNESP (University of the State of São Paulo - Presidente Prudente campus), CPTEC (INPE), ESALQ (USP).
- Total of 1801 stations accomplished.



Used in geoid

Thematic Project has now 3,023 stations
17 campaigns – 7 used in geoid

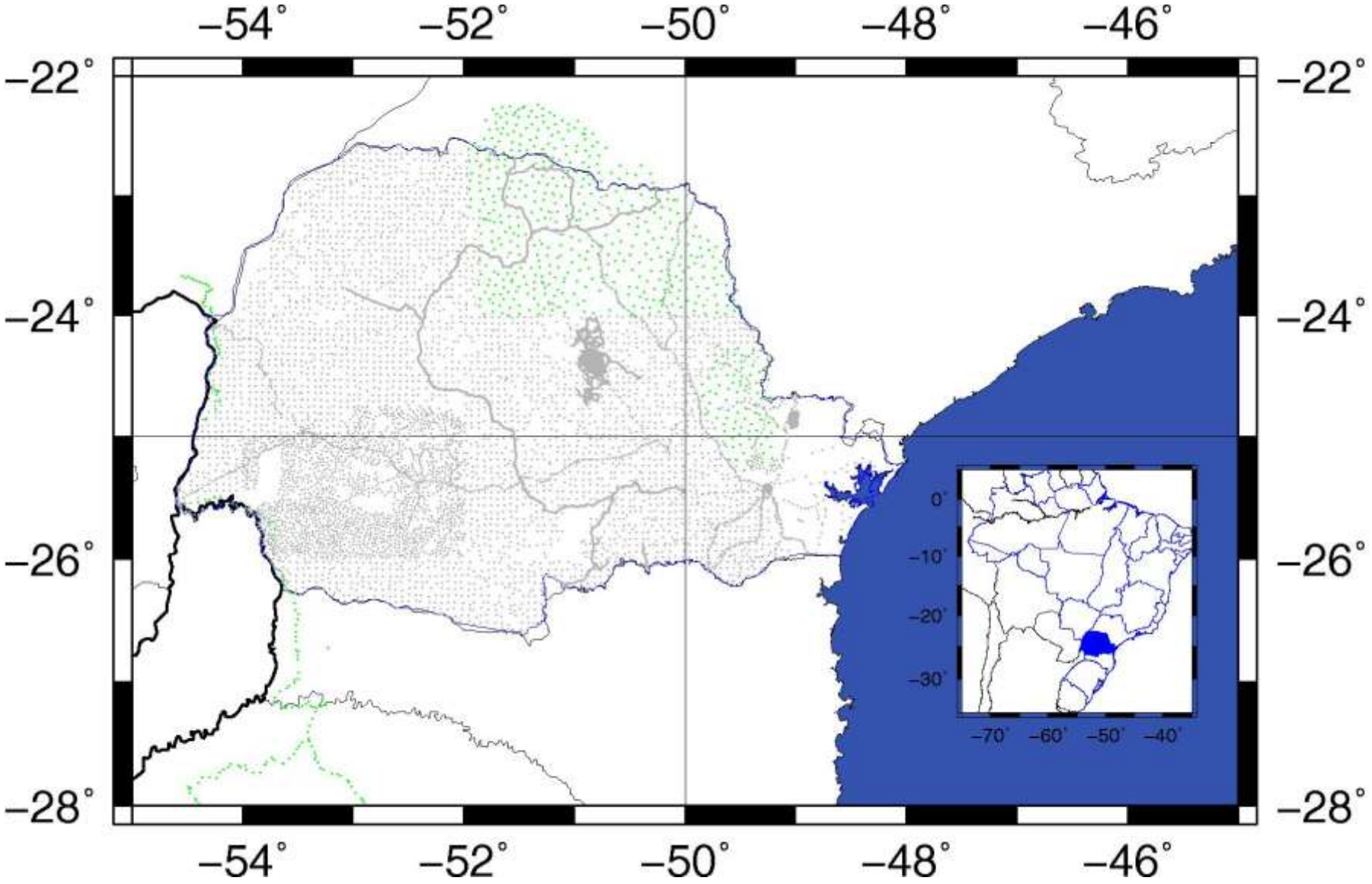


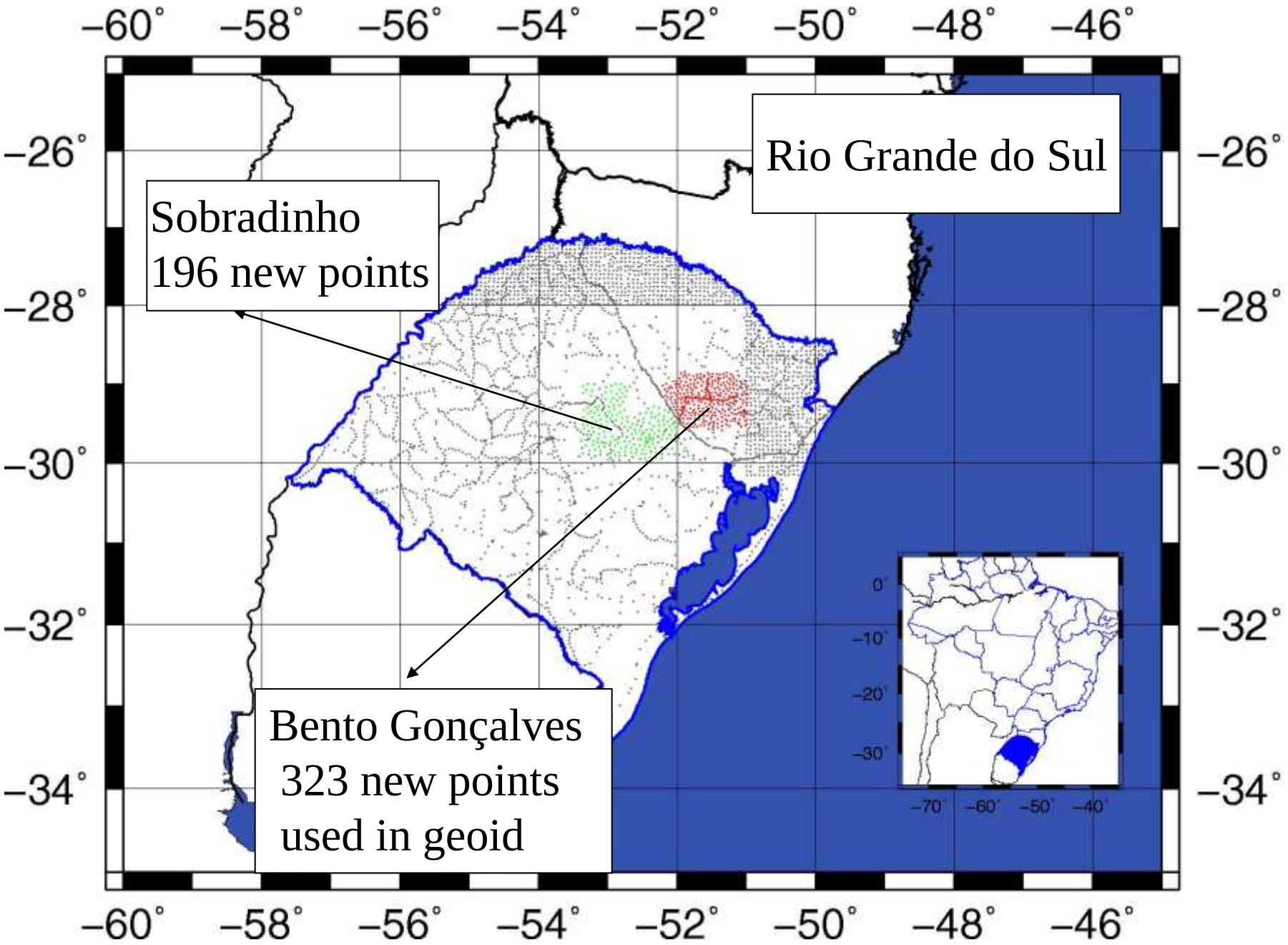
Used in geoid

Paraná State - IBGE campaigns

2004 up to 2008 – 836 new points in green (not used in geiod)

The correction and validation are finished this month



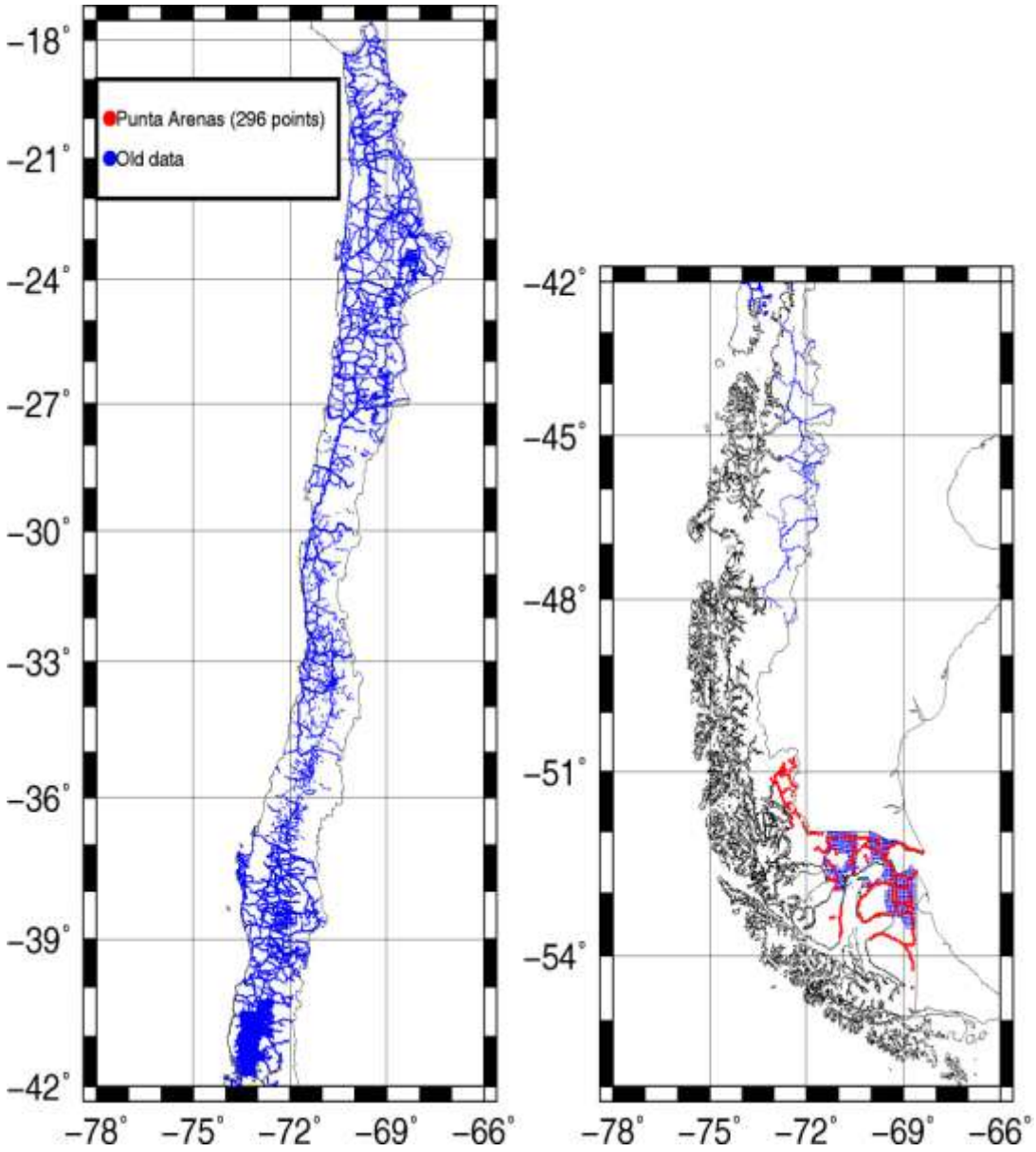

Rio Grande do Sul
Sobradinho
196 new points
Bento Gonçalves
323 new points
used in geoid
−60°
−58°
−56°
−54°
−52°
−50°
−48°
−46°
−26°
−28°
−30°
−32°
−34°
0°
−10°
−20°
−30°
−70°
−60°
−50°
−40°

RECENT EFFORT

CHILE
296 GRAVITY DATA

New gravity data were surveyed in Punta Arenas region in Southern Chile (296 points). This region is geodynamicaly very active and the gravitymeters have been subjected to instabilities during the measurements.

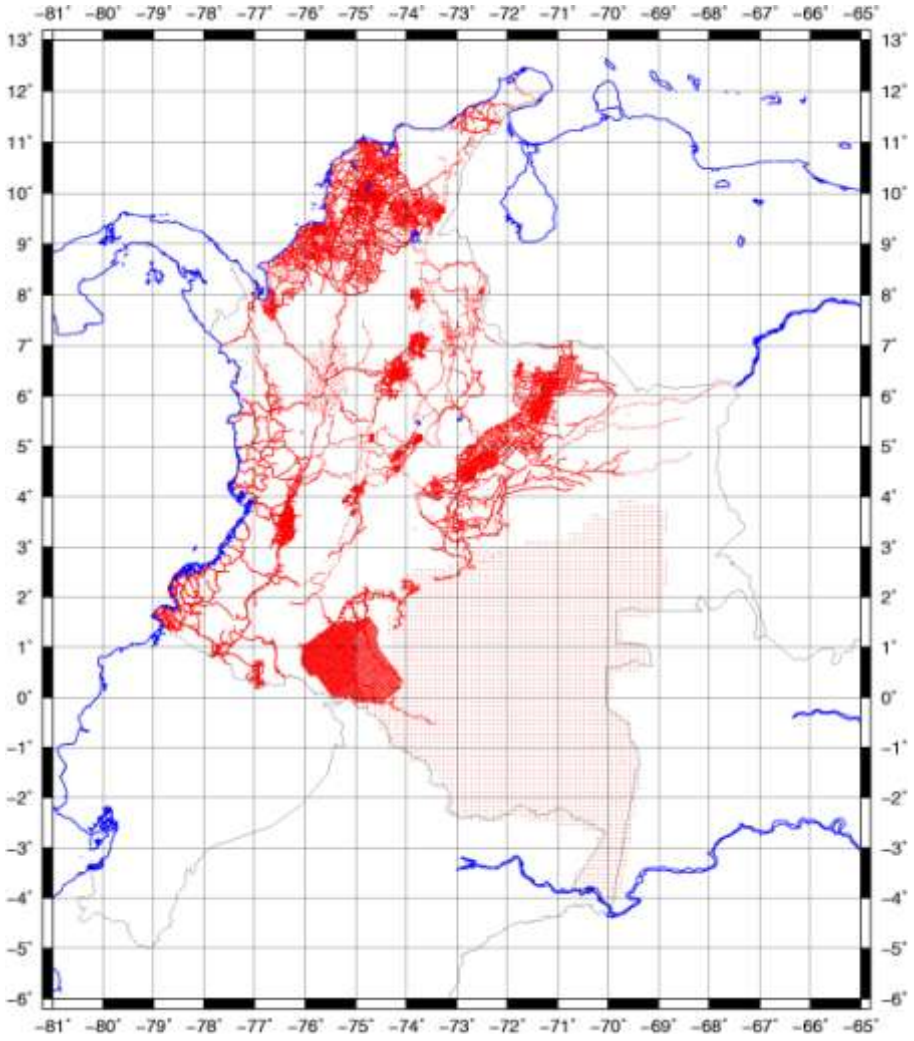
Due to the earthquake 2010 a new attention to the gravity data is necessary.



RECENT EFFORT

COLOMBIA
70800 GRAVITY DATA

At SIRGAS 2008 General Meeting, IAG CP2.5 (GGSA) and the IAG Sub-commission 1.3b (SIRGAS), through Working Group III (Vertical Datum) an agreement addressed the attention to the validation of the Colombian gravity data.

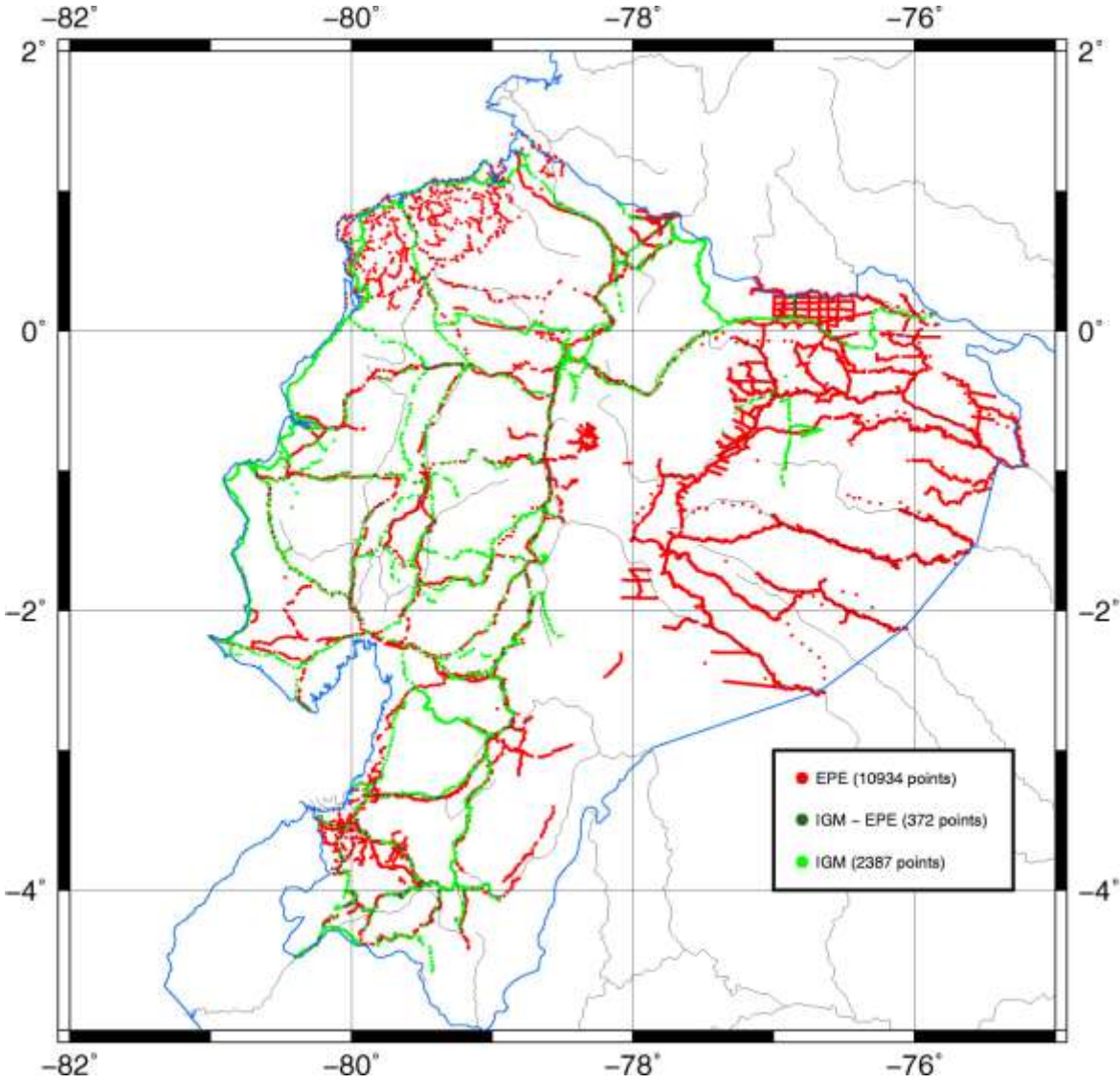


RECENT EFFORT

ECUADOR
2759 GRAVITY DATA

New gravity data were surveyed by IGM, IBGE and EPUSP in the period 2003 to 2009.

In general, the surveys were carried out on the BM. Old data exist on the rivers in the Amazon area; they will be subjected to a validation in 2011.

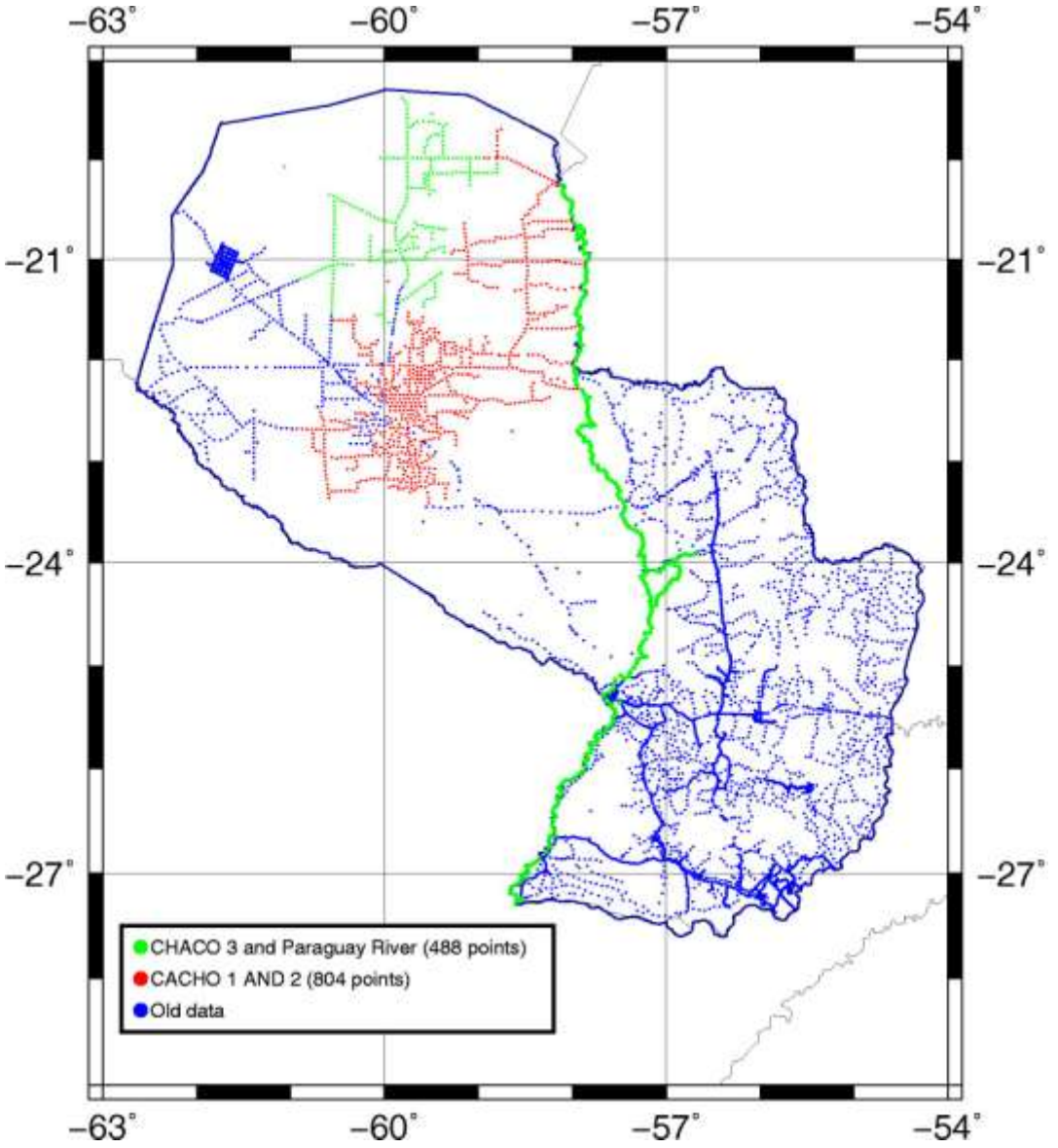


RECENT EFFORT

PARAGUAY
1292 GRAVITY DATA
(2008 up to 2010)

The efforts in Paraguay were concentrated in the Chaco area and Paraguay River, with a total of 1292 new stations surveyed.

This is a remote region with the requirement of special logistics.



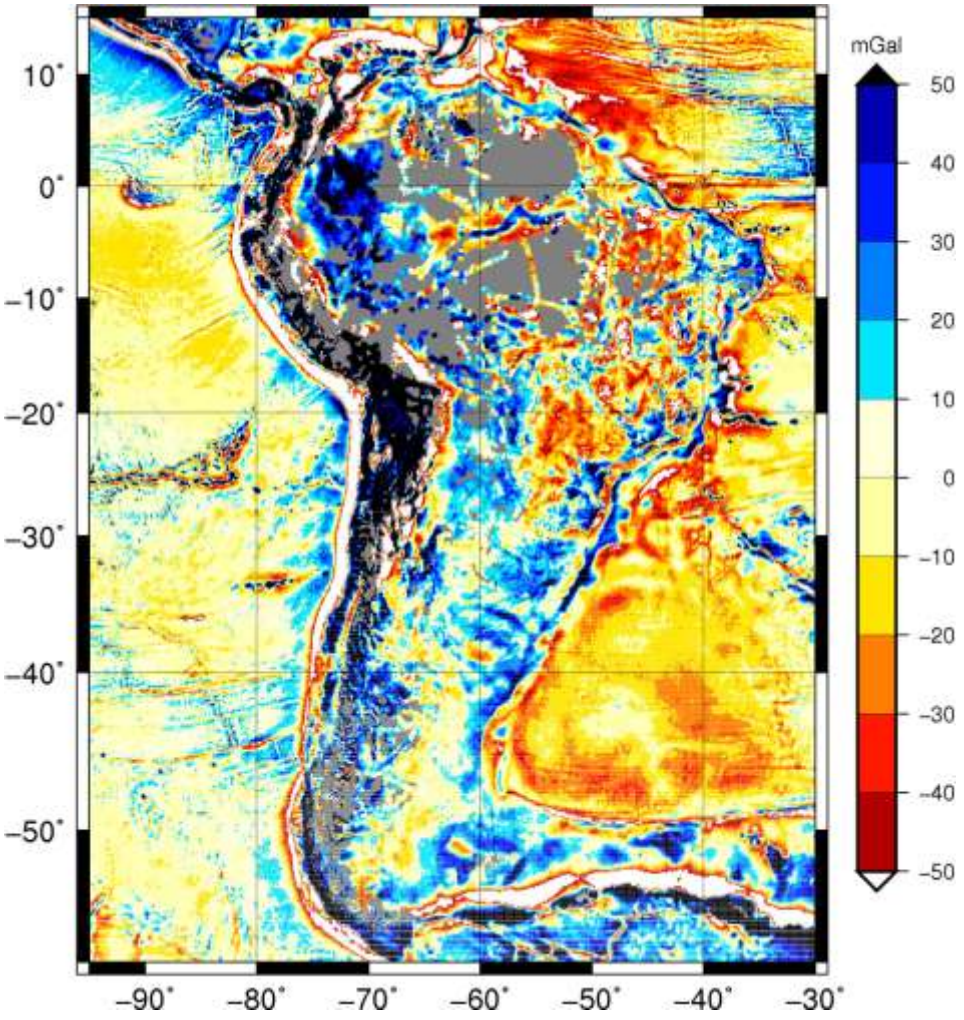
COMPLETE BOUGUER GRAVITY ANOMALY (BA)

BA was derived according to: Free Air gravity anomaly at measured points adding Bouguer Correction as function of height from gravity database and Terrain Correction (spherical approximation).

MEAN FREE-AIR GRAVITY ANOMALIES (FA)

FA in a 5’ grid over continent was derived from complete Bouguer Gravity Anomaly. FA over the ocean was obtained from DNSC08 (Andersen *et al.*, 2008)

MEAN FREE-AIR GRAVITY ANOMALIES (FA)



	MEAN	MAX	MIN
BA	-53.70	195.30	-455.31
FA	-0.71	486.37	-253.49

HELMERT GRAVITY ANOMALY REFERRED TO THE EARTH'S SURFACE (HGES)

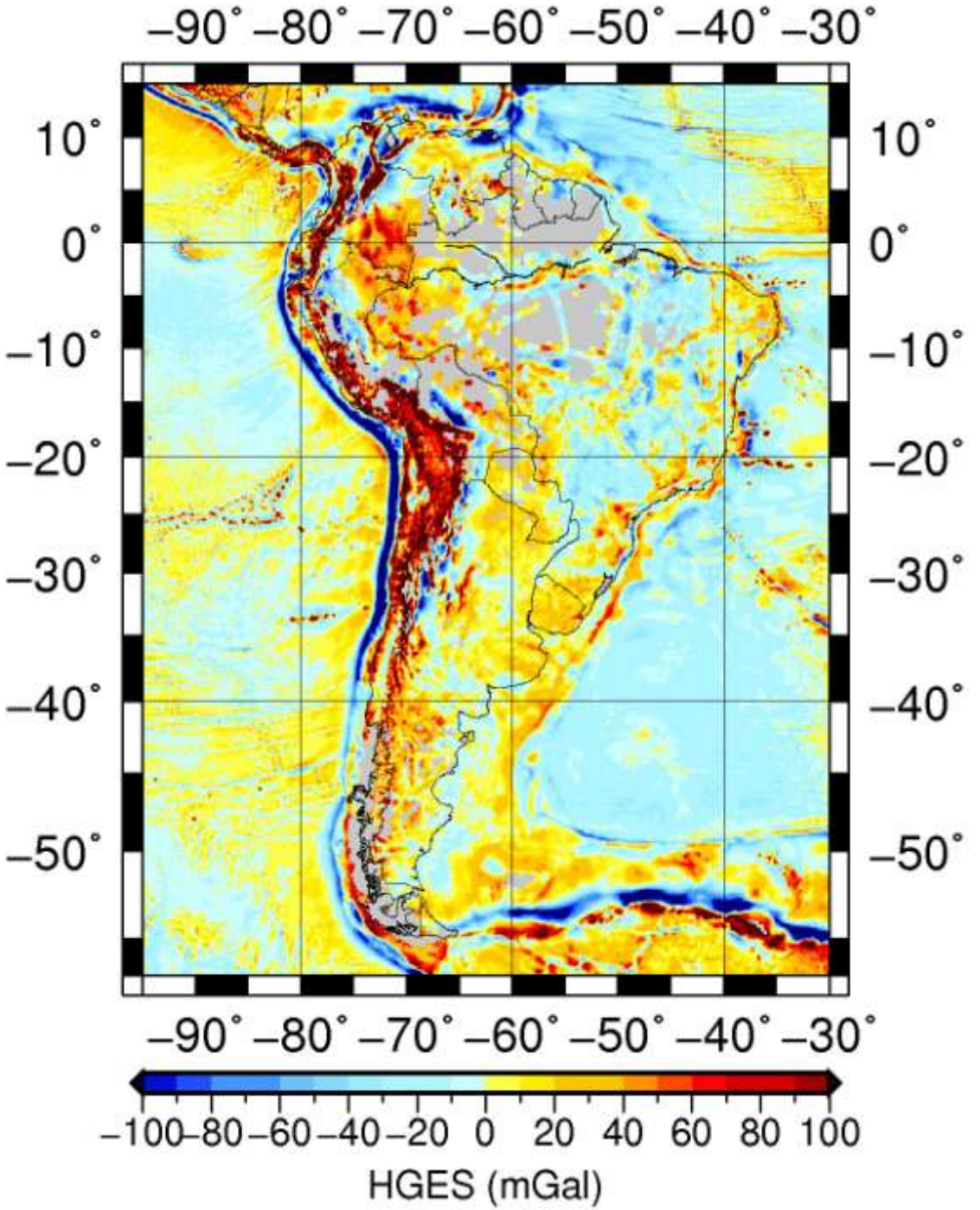
HGES (Vaníček *et al*., 1999) was obtained from the sum of:

- Mean Free-air gravity anomaly (FA);
- The Direct and Secondary Indirect Topographic Effects on the gravitational attraction (DTE and SITE);
- Direct Atmospheric Effect (DAE);
- Geoid-QuasiGeoid Correction to the fundamental formula of physical geodesy (GQGC).

	Mean mGal	Max mGal	Min mGal
FA	**-0.71**	**486.37**	**-253.49**
DTE	0.30	105.25	-87.34
SITE	-0.02	-0.004	-0.36
DAE	-0.82	-0.61	-0.84
GQGC	-0.01	0.06	-0.77
HGES	**-1.49**	**450.40**	**-363.29**

HELMERT GRAVITY ANOMALY REFERRED TO THE EARTH'S SURFACE (HGES)

mGal	Mean	Max	Min
FA	-0.71	486.37	-253.49
HGES	-1.49	450.40	-363.29



SOUTH AMERICA GEOID
(quasi-geoid)

Geoid2010 was obtained from the sum of:

- Geoid undulations from gravity anomaly (short wavelength);
- Reference spheroid (EGM2008 n=m=150 – long wavelength);
- Primary Indirect Topographic Effect (PITE);

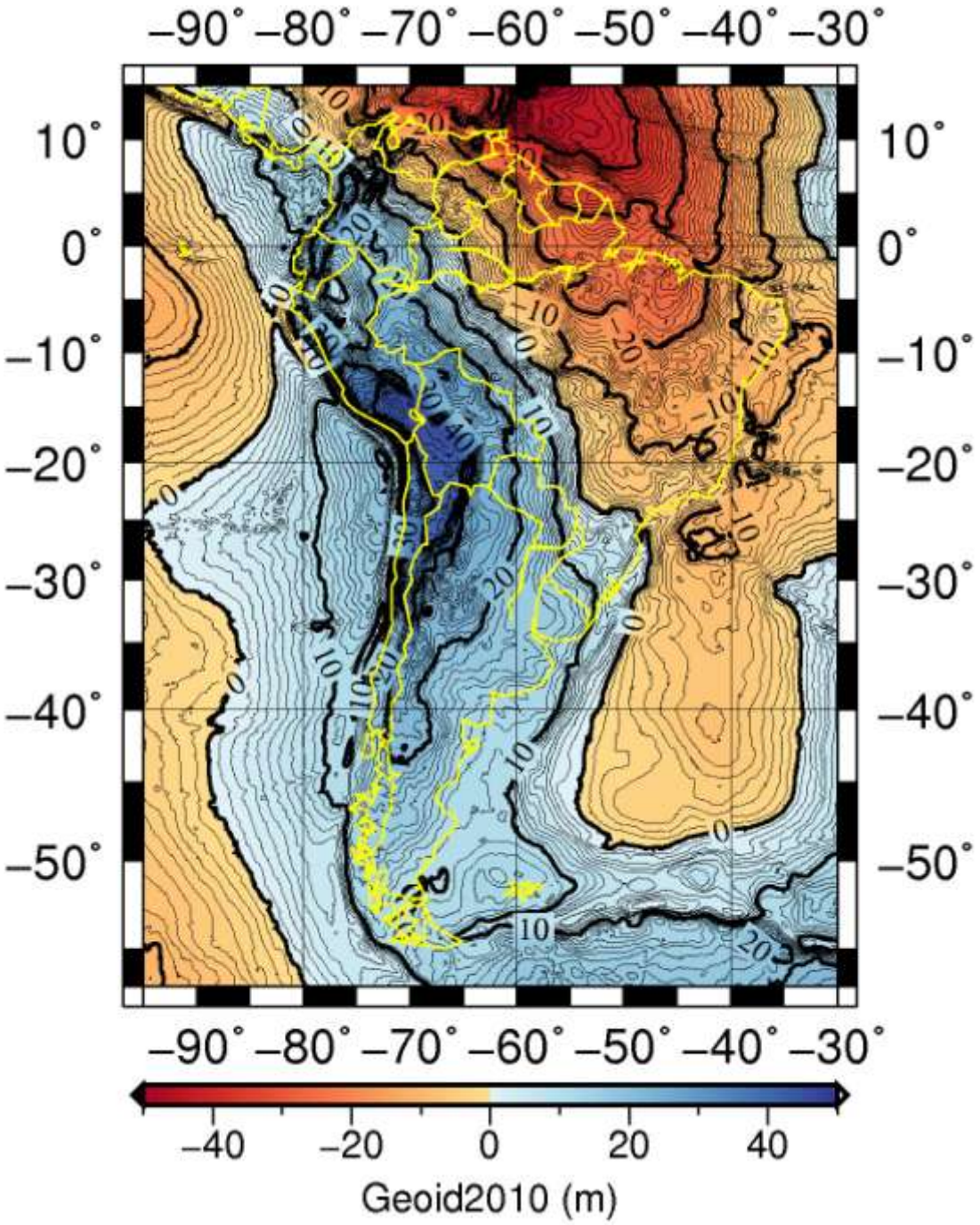
The processing of the modified Stokes integral used FFT through spheroidal Molodenskii-Meissl kernel modification (Featherstone et al, 1998).

	Mean (m)	Max (m)	Min (m)
PITE	-0.06	-0.01	-1.96
Geoid2010	0.44	48.46	-57.83

Geoid2010

SOUTH AMERICA GEOID

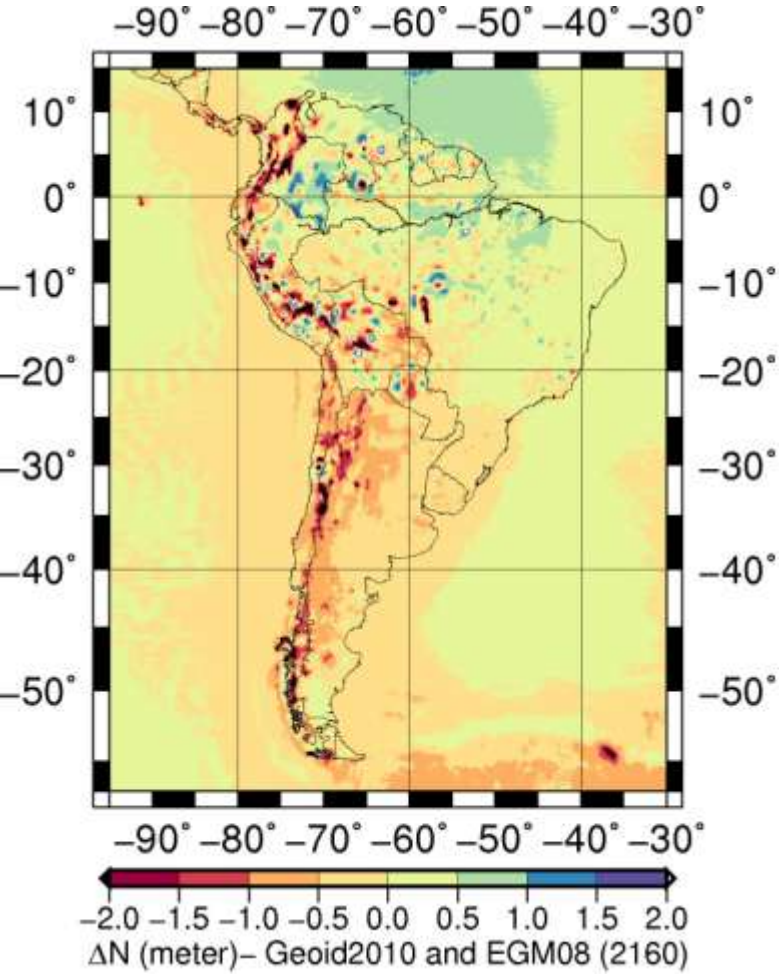
Mean meter	Max meter	Min meter
0.44	**48.46**	**-57.83**

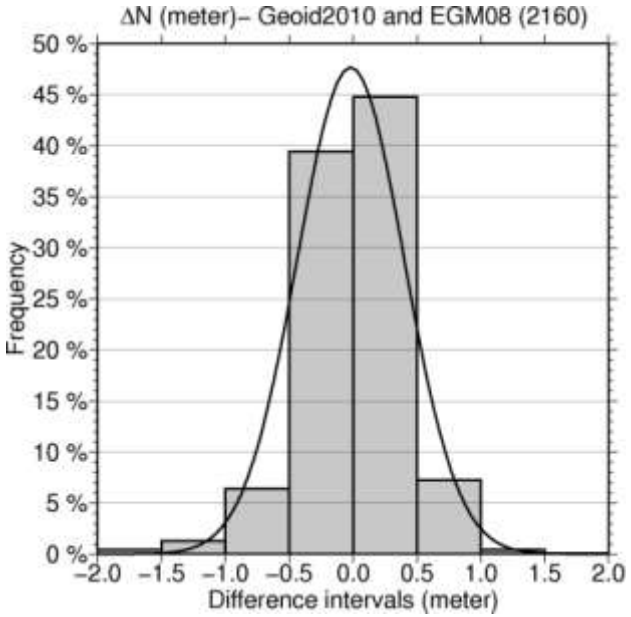


1st Geoid validation

GLOBAL GEOPOTENTIAL MODEL

The Geoid2010 was compared with height anomalies derived from EGM08 (n=m=2159) as a tide free model.





Mean	RMS Dif	Max.	Min.
-0.02	0.42	3.61	-10.51

meters

2nd Geoid validation

Geoid2010 → MAPGEO2010 (Brazil)

MAPGEO2010 was compared to:

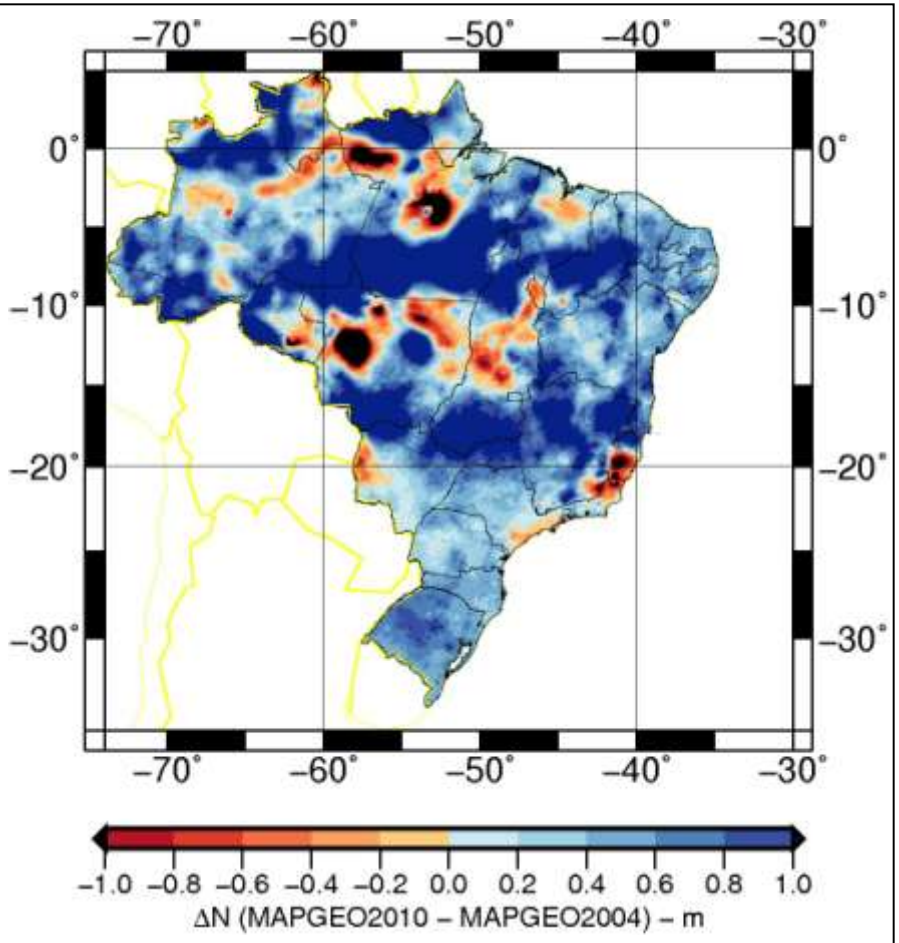
- Height anomaly derived from the Global Model EGM08 (n = m = 2159).

EGM08 is a free tidal model with a prescribed zero order term equal -0.41 m. This value was assigned for MAPGEO2010.

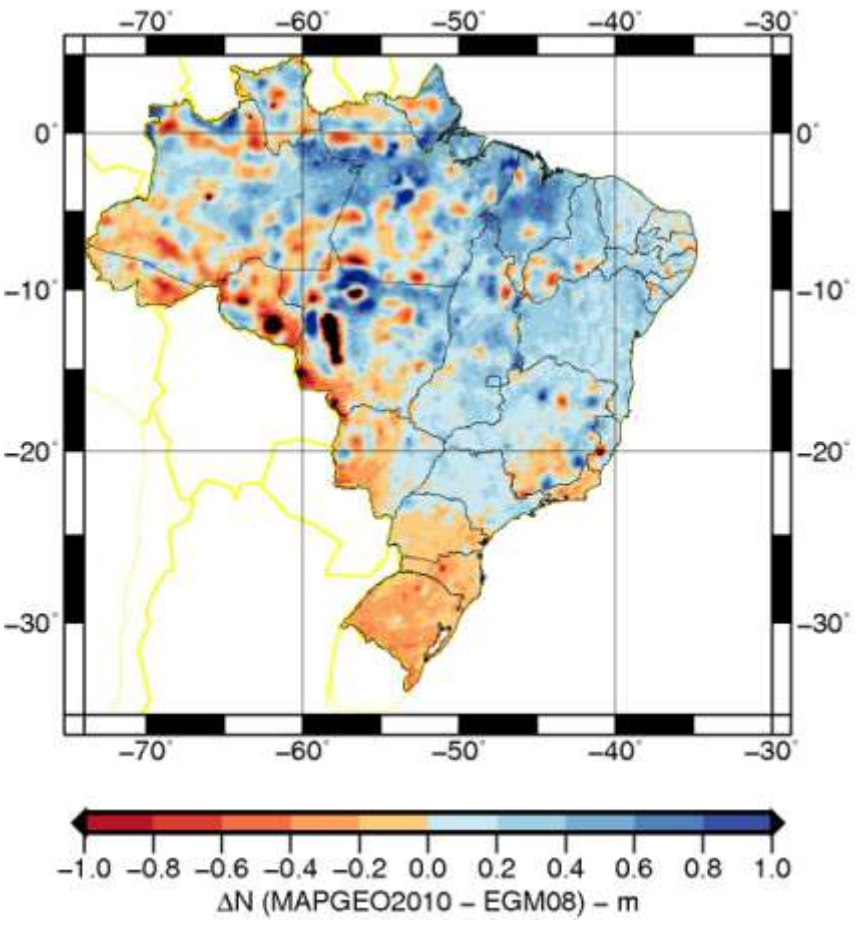
- MAPGEO2004 - previous official geoid model in Brazil since 2004; (Blitzkow and Lobianco, 2004; Blitzkow et al, 2004).

The zero order term in this case was -0.50 m.

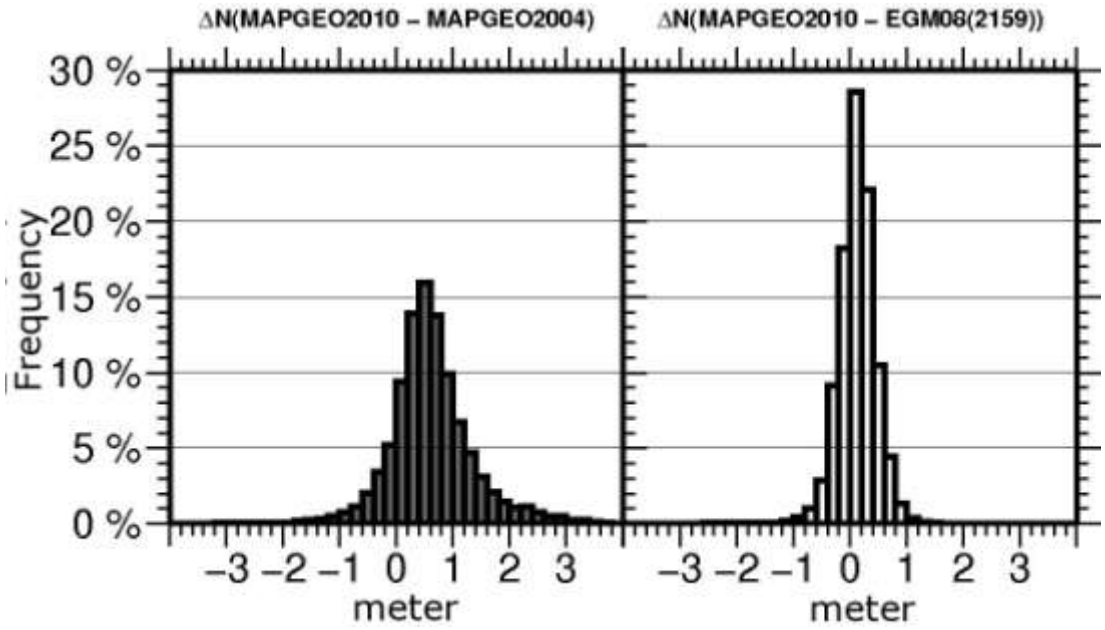
Geoid2010 in Brazil → MAPGEO2010



Discrepancies between MAPGEO2010 and MAPGEO2004 geoidal heights in Brazil.



Discrepancies between MAPGEO2010 geoidal heights and EGM08 height anomalies.



ΔN (meter)	**Mean**	**RMS Dif**	**Maximum Discrepancy positive**	**Maximum Discrepancy negative**
MAPGEO2010 - MAPGEO2004	0.61	.51	4.06	-3.55
MAPGEO2010 - EGM08 (2159)	.11	.12	3.10	-3.41

3rd Geoid validation

GPS DATA OVER BENCH MARKS IN SOUTH AMERICA

The Geoid2010 was compared with GPS observations carried out on benchmarks of the spirit levelling network in South America (Argentina, Brazil, Chile, Ecuador, Uruguay and Venezuela).

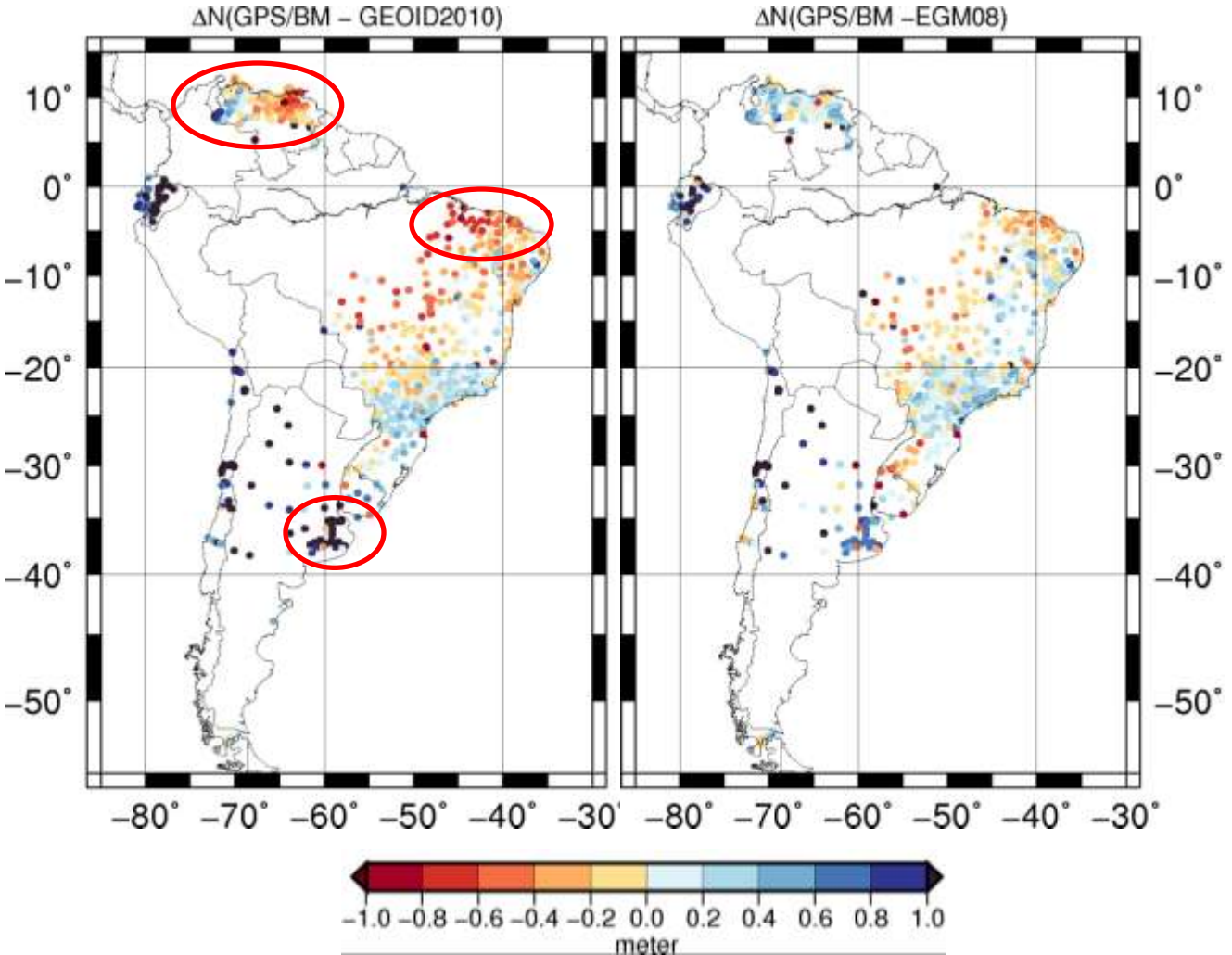
A total of 1304 GPS/BM points are available in this area.
They have been referred to SIRGAS2000

The zero-order term was considered in all cases (-0.41 m).

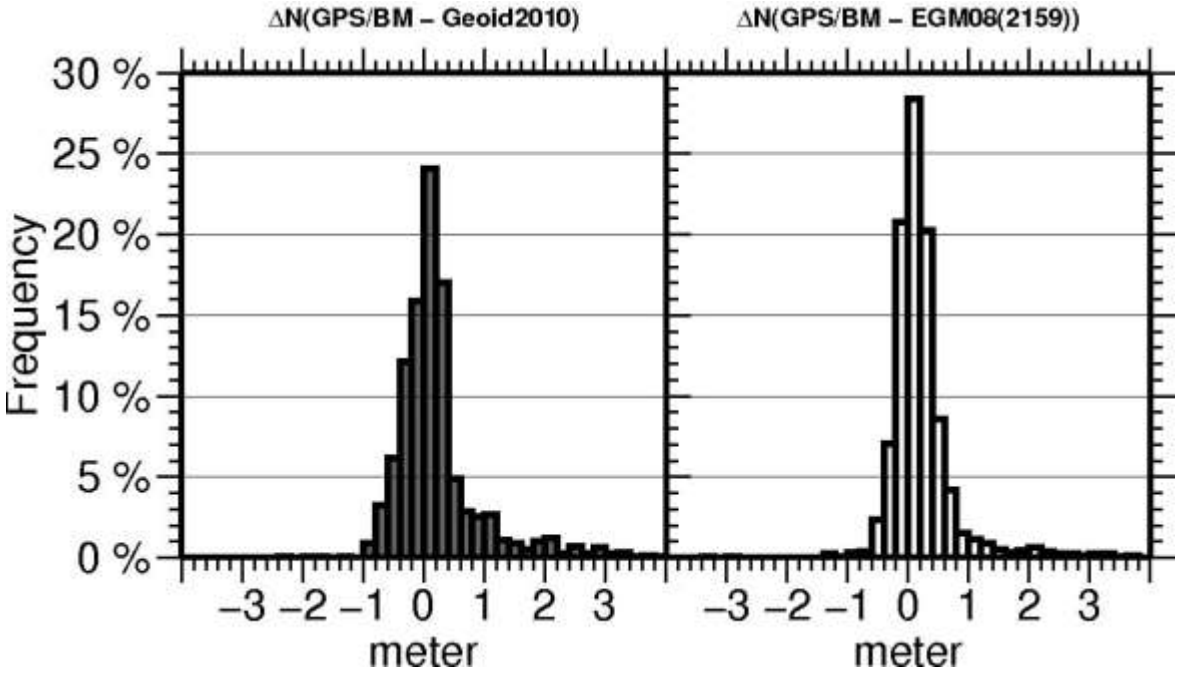
Discrepancies between GPS/BM geoidal heights and

Geoid2010
geoidal heights

EGM08 (2159)
height anomalies



Discrepancies among GPS/BM and Geoid2010 geoidal heights and EGM08 height anomalies



ΔN (meter)	Mean	RMS Dif	Max.	Min.
Geoid2010	0.21	0.72	3.87	-2.34
EGM08 (2160)	0.21	0.59	3.74	-3.22

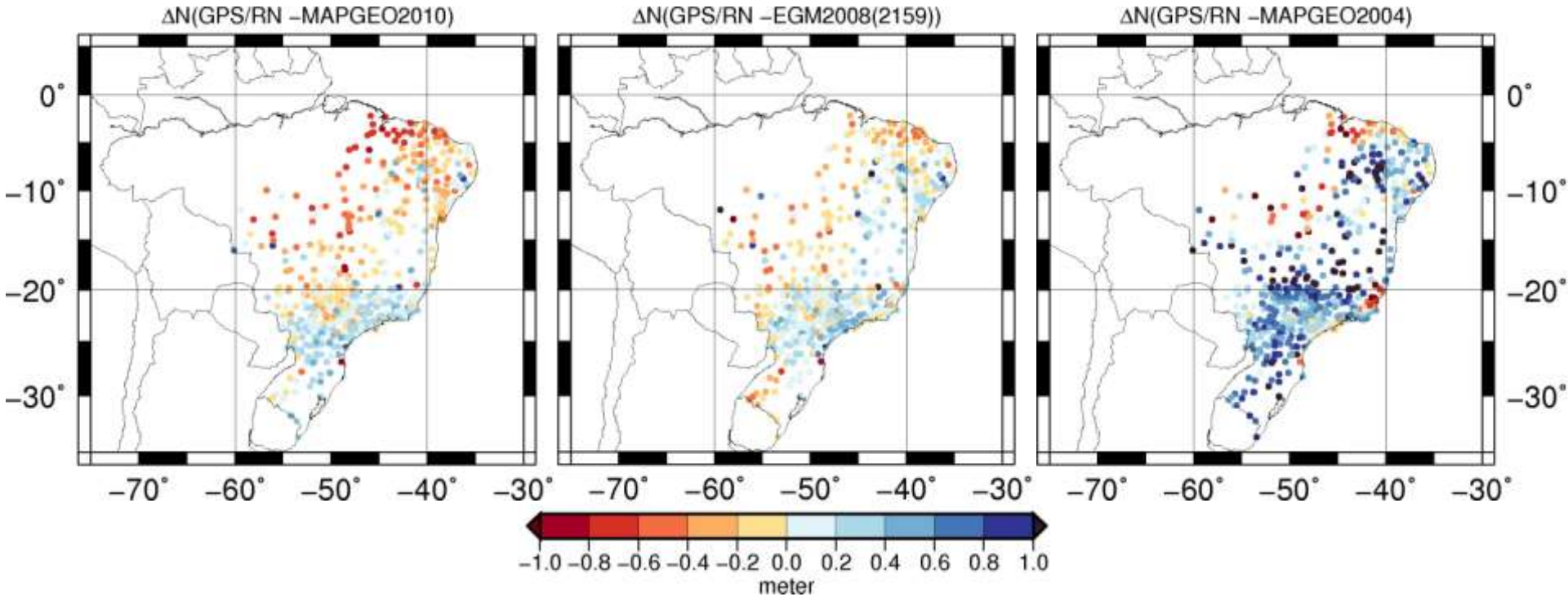
4th Geoid validation

GPS DATA OVER BENCH MARKS IN BRAZIL

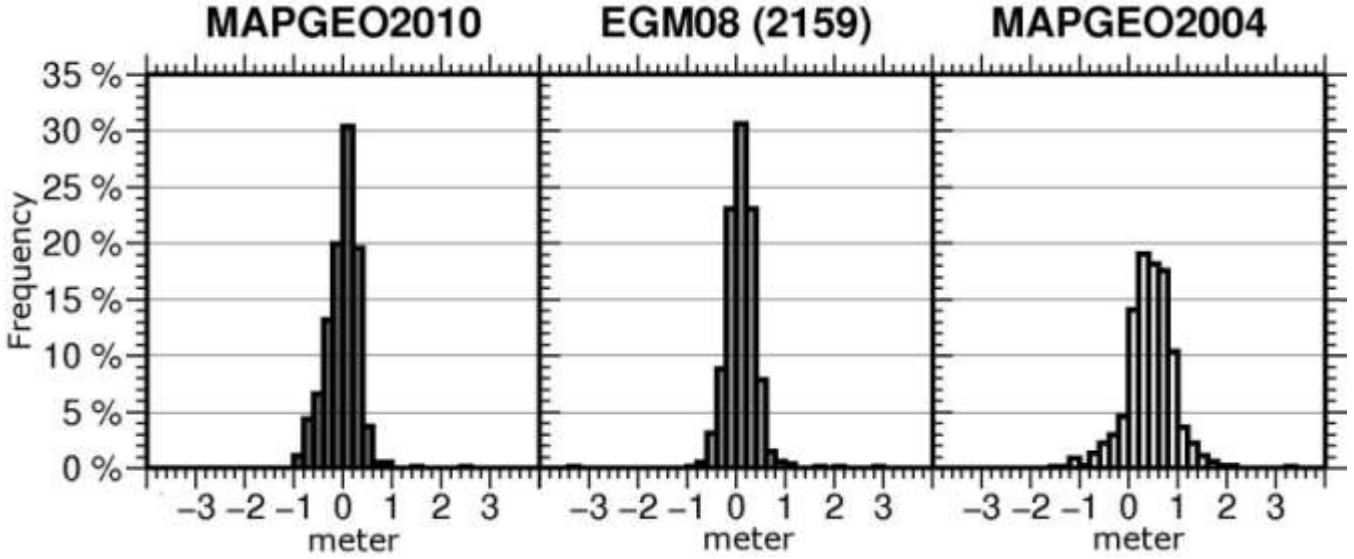
A total of 804 GPS/BM points are available in this area.
They have been delivered referred to SIRGAS2000

The zero-degree term of -0.41 m was considered in Geoid2010, EGM08 and -0.5 m in MAPGEO2004.

Discrepancies among GPS/BM, geoids and EGM08 in Brazil



Discrepancies among GPS/BM, geoids and EGM08 in Brazil

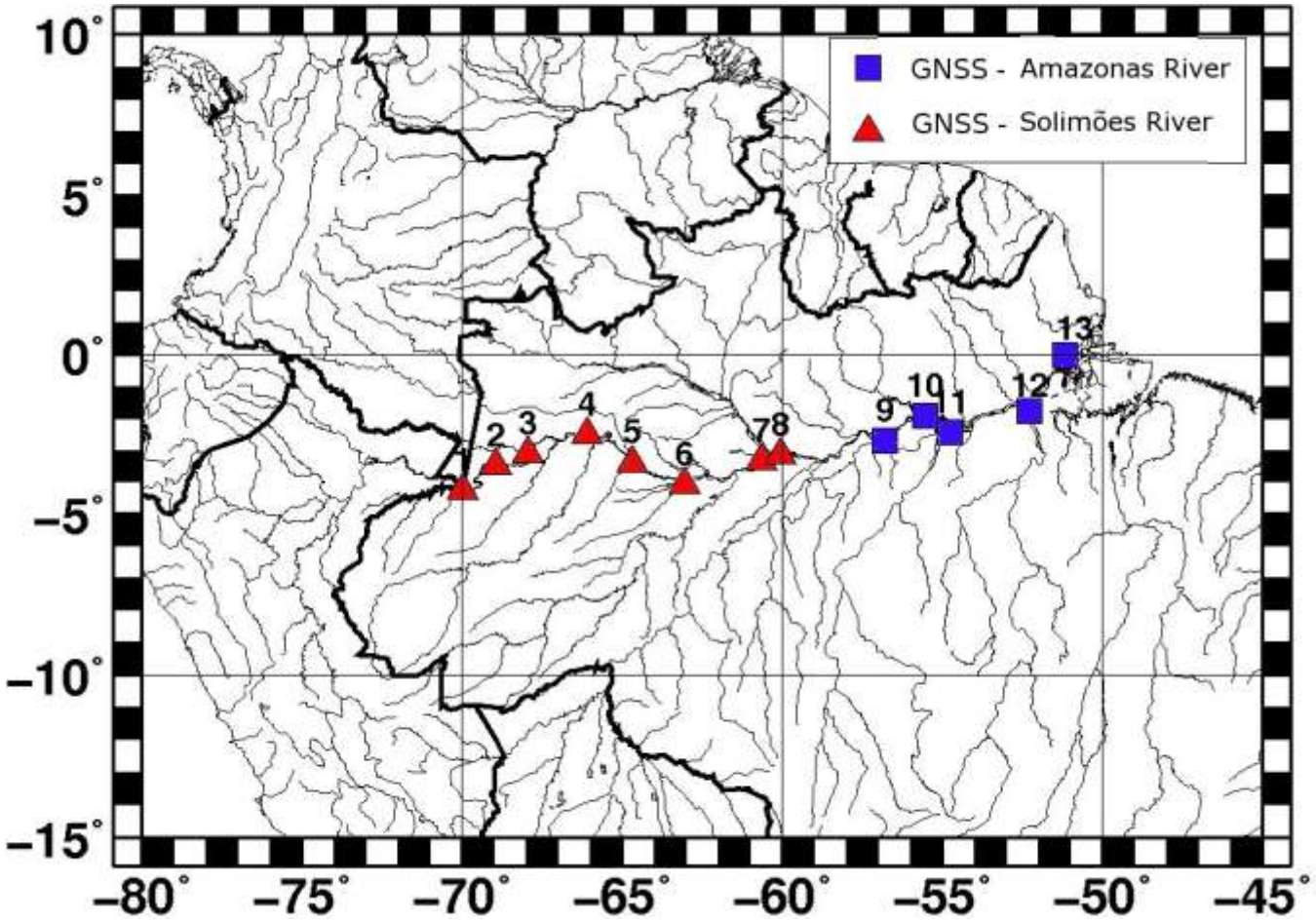


ΔN (meter)	**Mean (m)**	**RMS (m)**	Maximum Discrepancy positive (m)	Maximum Discrepancy negative (m)
GPS/BM - MAPGEO2010	- .	.	.	- .
GPS/BM - MAPGEO2004	.	.	.	- .
GPS/BM - EGM08 (2159)	.	.	.	- .

5th Geoid validation

Amazon is dominated by rivers and forest, therefore spirit levelling procedure is impossible for the establishment of a precise altimetric network. Moreover, this region is flat and the rivers have very small gradient. Campos (2004), supported by IBGE, established 13 GNSS checkpoints near limnimetrics stations located at Solimões and Amazonas rivers.

GNSS stations along Solimões and Amazonas rivers

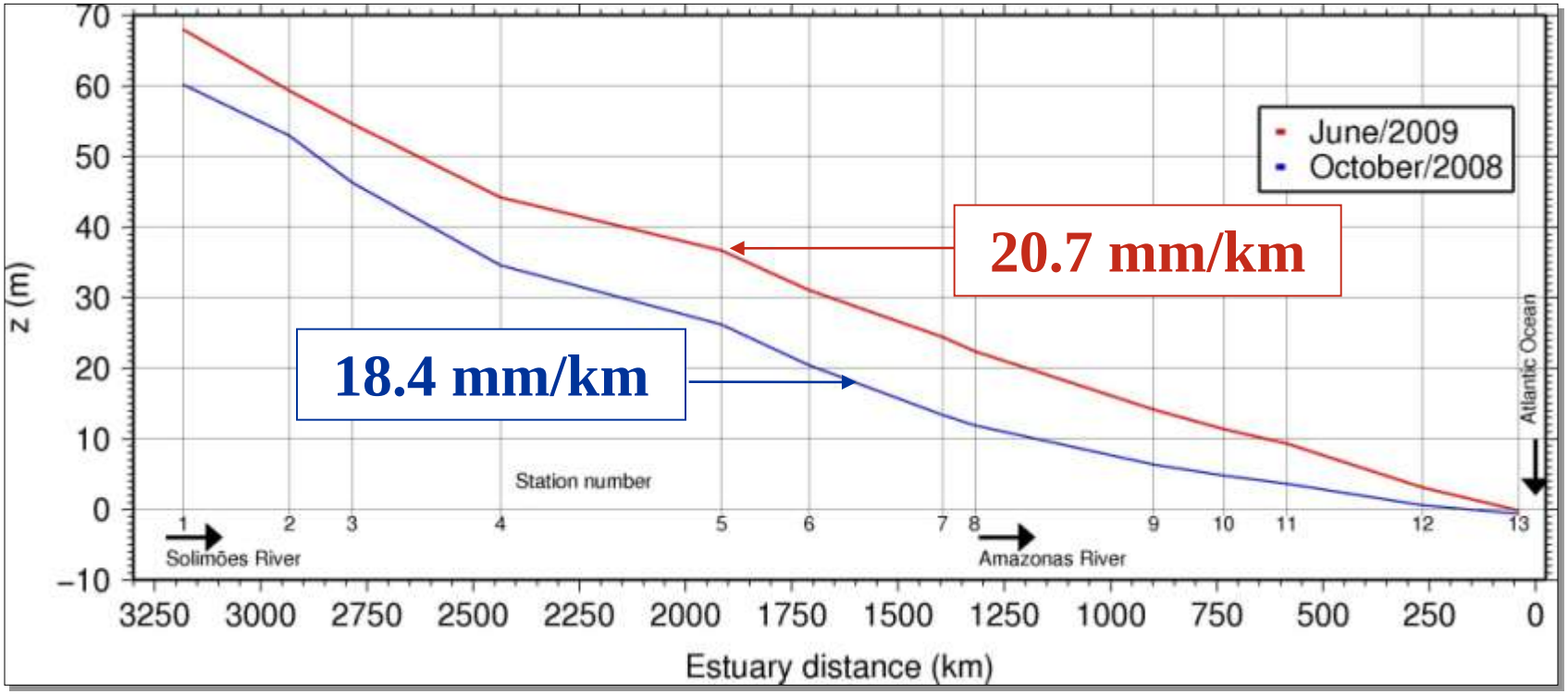


Stations:

1. Tabatinga;
2. São Paulo de Olivença;
3. Santo Antônio de Içá;
4. Fonte Boa;
5. C.Missões;
6. Itapeuá;
7. Manacapuru;
8. P.Trapiche 15 (Manaus);
9. Parintins;
10. Óbidos;
11. Santarém;
12. Porto de Moz;
13. Porto de Santana.

Height of water surface (*z*) versus distance from the estuary

The average gradient was computed for two periods, flood and ebb, were 20.7 and 18.4 mm/km, respectively. The model fits very well on the Solimões and Amazonas rivers gradient, so MAPGEO2010 is very reliable for the Amazon region. In fact, the rivers in Amazon have a good gravity coverage due to Petrobras surveys in the ~1950s.



CONCLUSION

- EGM08, with full order and degree, shows small differences with the mentioned geoid model in flat areas. The highest differences are in the Andes and regions without terrestrial gravity data.

- Despite of the efforts in the recent years of different organizations, universities and research institutes to fill in the areas without terrestrial gravity data, there are still large gaps.

- The geoidal heights associated with GPS/BM have their inaccuracies due to the error of the spirit levelling as well as of the GPS. Nevertheless, the comparison is very much useful to look after the consistency between the two heights. Maranhão state, in Brazil, shows the largest discrepancies with the GPS/BM points. This situation has to be investigated.

Acknowledgements

- The authors acknowledge Prof. Dr. Artur Ellmann (Tallinn University of Technology), Prof. Dr. Peter Vaníček and Prof. Dr. Marcelo Carvalho dos Santos (University of New Brunswick) for SHGEO package. The activity has been partially undertaken with the financial support of Government of Canada provided through the Canadian International Development Agency (CIDA).
- Foundation of the State of São Paulo (FAPESP) for supporting the Thematic Project;
- 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