



SIRGAS

Sistema de Referencia Geocéntrico
para las Américas

2019

Rio de Janeiro,
Brasil

30 years of absolute gravity measurements in South America

30 anos de medições absolutas de gravidade na América do Sul

30 años de mediciones de gravedad absoluta en América del Sur



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Carlos Alberto Côrrea e Castro Júnior ⁽⁴⁾
Mariana Eiko Borba Inoue ⁽¹⁾



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⁽³⁾ Universidade de São Paulo, Brazil

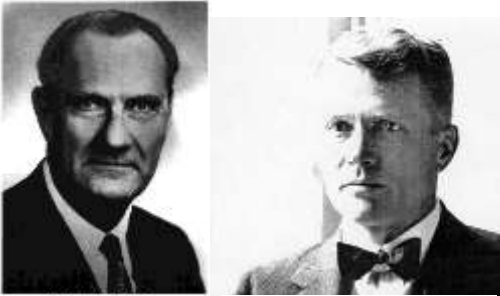
⁽⁴⁾ Instituto Brasileiro de Geografia e Estatística, Brazil

Outline

- Timeline
- Absolute measurements 80's and 90's
- Absolute measurements 2000s
- Absolute measurements 2010 – today
- Next Steps and Remarks

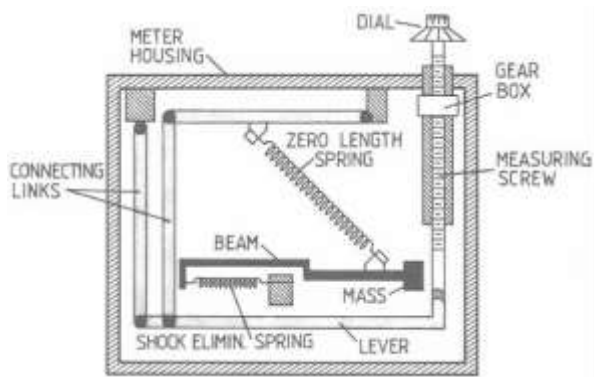


Timeline



Lucien LaCoste Arnold Romberg

1934



Timeline

1934

1948



Worden Gravimeter

Timeline



Sputnik 1

1957

1934

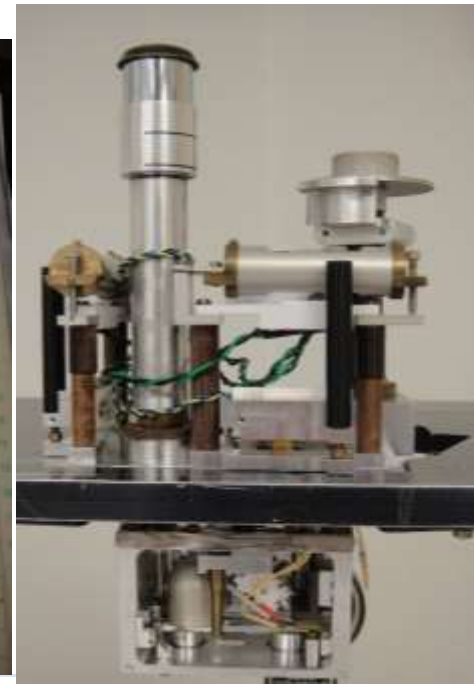
1948

1958

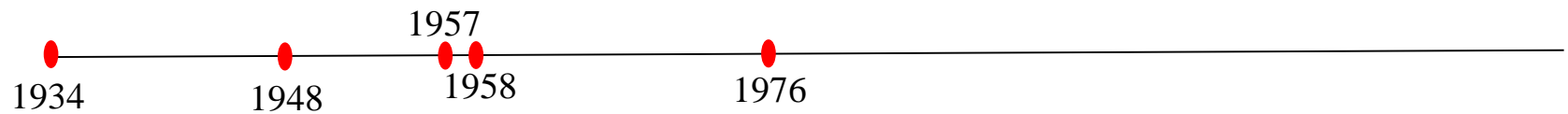
A photograph of a handwritten data table on graph paper. The table has several columns and rows of numbers and text. The text is written in cursive and includes the words "Gravimetric measurements" and "L&R G1 model".

Station	Height	Latitude	Longitude	Time	Gravimetric	Notes
1	27.00	19° 12'	72° 00'	1958	9.800	1-2-59
2	23.00	19° 12'	72° 00'	1958	9.800	1-2-59
3	24.00	19° 12'	72° 00'	1958	9.800	1-2-59
4	24.00	19° 12'	72° 00'	1958	9.800	1-2-59
5	24.00	19° 12'	72° 00'	1958	9.800	1-2-59
6	24.00	19° 12'	72° 00'	1958	9.800	1-2-59
7	24.00	19° 12'	72° 00'	1958	9.800	1-2-59
8	24.00	19° 12'	72° 00'	1958	9.800	1-2-59
9	24.00	19° 12'	72° 00'	1958	9.800	1-2-59
10	24.00	19° 12'	72° 00'	1958	9.800	1-2-59
11	24.00	19° 12'	72° 00'	1958	9.800	1-2-59
12	24.00	19° 12'	72° 00'	1958	9.800	1-2-59
13	24.00	19° 12'	72° 00'	1958	9.800	1-2-59
14	24.00	19° 12'	72° 00'	1958	9.800	1-2-59
15	24.00	19° 12'	72° 00'	1958	9.800	1-2-59
16	24.00	19° 12'	72° 00'	1958	9.800	1-2-59
17	24.00	19° 12'	72° 00'	1958	9.800	1-2-59
18	24.00	19° 12'	72° 00'	1958	9.800	1-2-59
19	24.00	19° 12'	72° 00'	1958	9.800	1-2-59
20	24.00	19° 12'	72° 00'	1958	9.800	1-2-59
21	24.00	19° 12'	72° 00'	1958	9.800	1-2-59
22	24.00	19° 12'	72° 00'	1958	9.800	1-2-59
23	24.00	19° 12'	72° 00'	1958	9.800	1-2-59
24	24.00	19° 12'	72° 00'	1958	9.800	1-2-59
25	24.00	19° 12'	72° 00'	1958	9.800	1-2-59
26	24.00	19° 12'	72° 00'	1958	9.800	1-2-59
27	24.00	19° 12'	72° 00'	1958	9.800	1-2-59
28	24.00	19° 12'	72° 00'	1958	9.800	1-2-59
29	24.00	19° 12'	72° 00'	1958	9.800	1-2-59
30	24.00	19° 12'	72° 00'	1958	9.800	1-2-59

1st gravimeter L&R G1 model

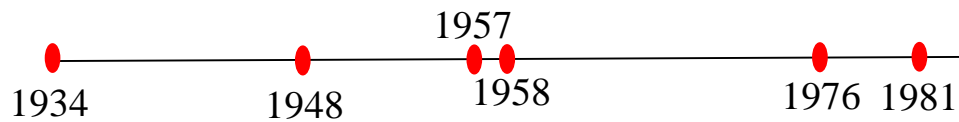


Timeline




LASer GEODynamic Satellite (LAGEOS)

Timeline

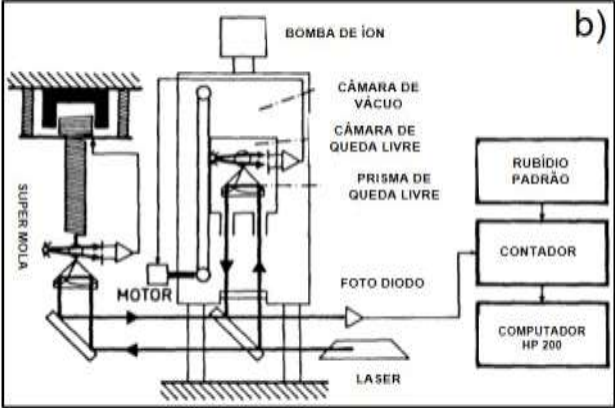


a)



b)

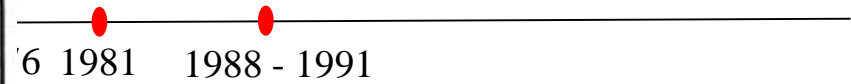
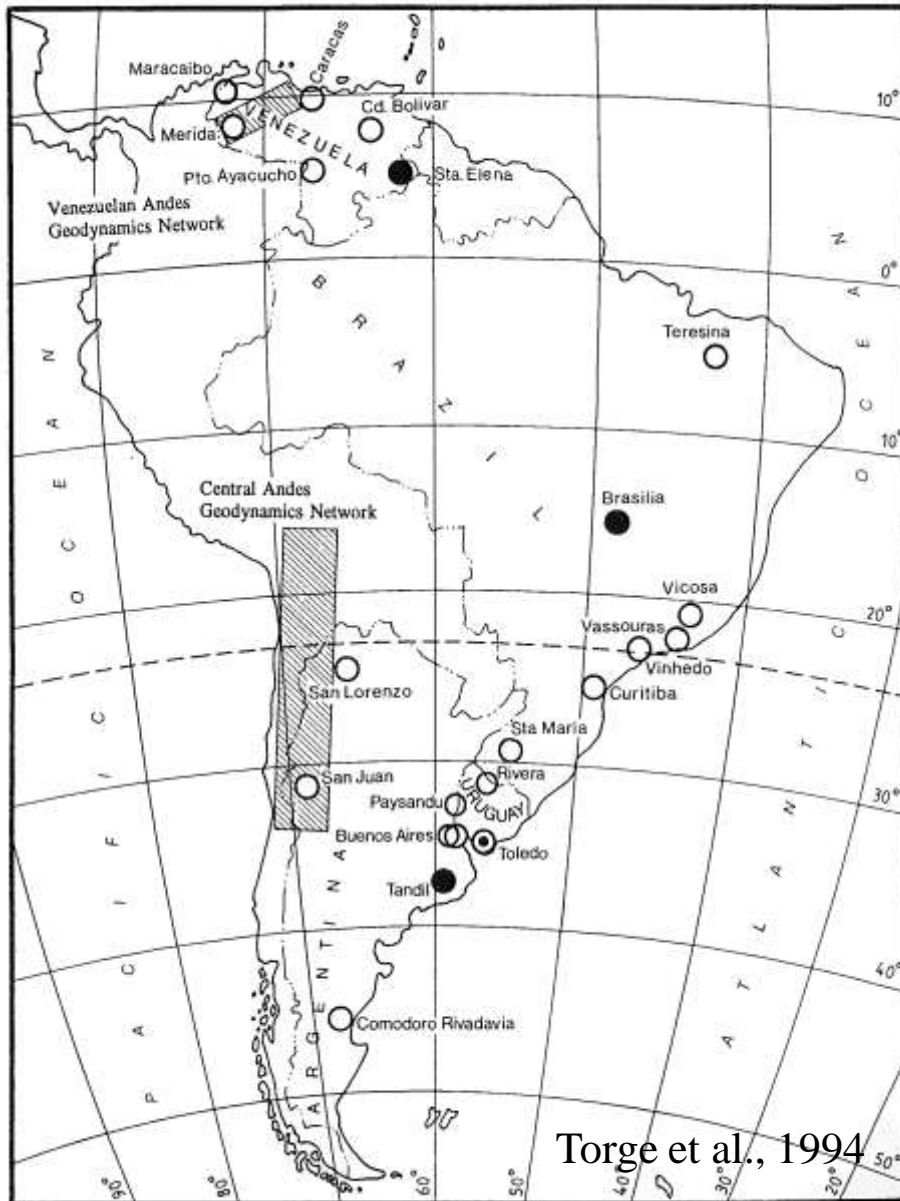
Jilag gravimeter



BOMBA DE IÓN
CÂMARA DE VÁCUO
CÂMARA DE QUEDA LIVRE
PRISMA DE QUEDA LIVRE
RUBÍDIO PADRÃO
CONTADOR
COMPUTADOR HP 200
SUPERMOLA
MOTOR
FOTO DIODO
LASER

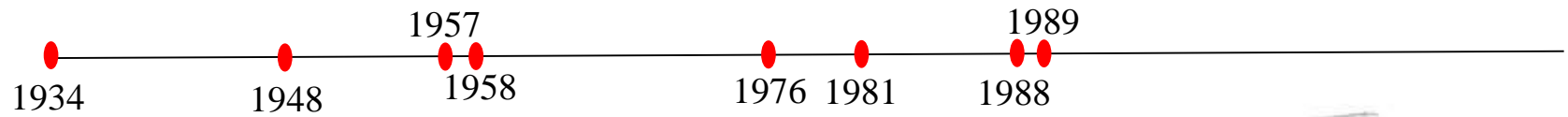
a) Timmen et al., (2008)
b) Adaptado de Torge et al., (1987).

Timeline

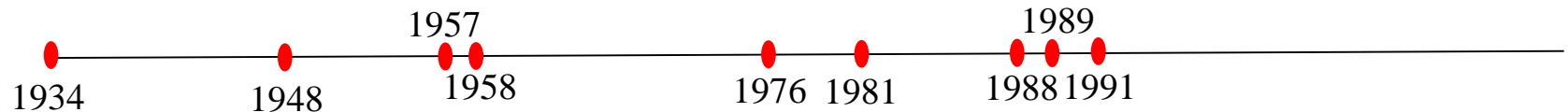


The IFE Absolute Gravity Program
“South America”
1988 - 1991

Timeline



Timeline



ZLS Corporation

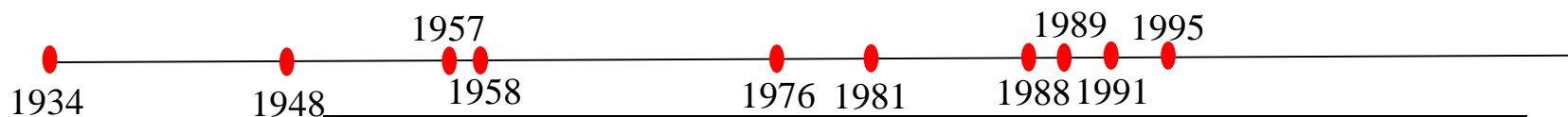


30 years of absolute gravity measurements in South America


Burris - ZLS



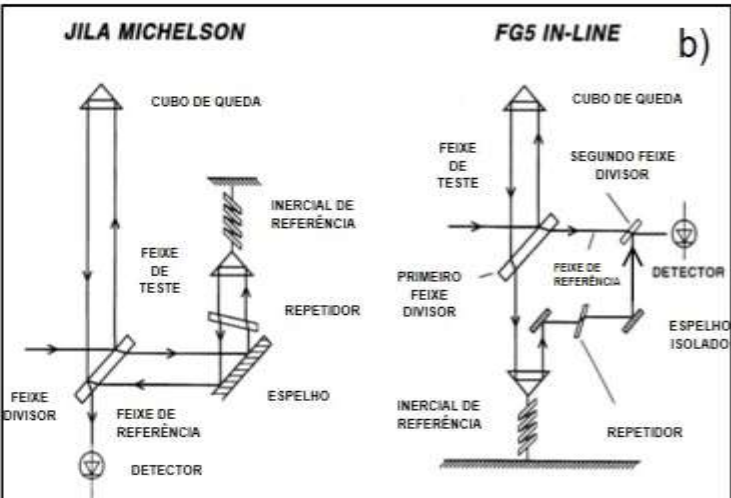
Timeline



FG-5 gravimeter



a)

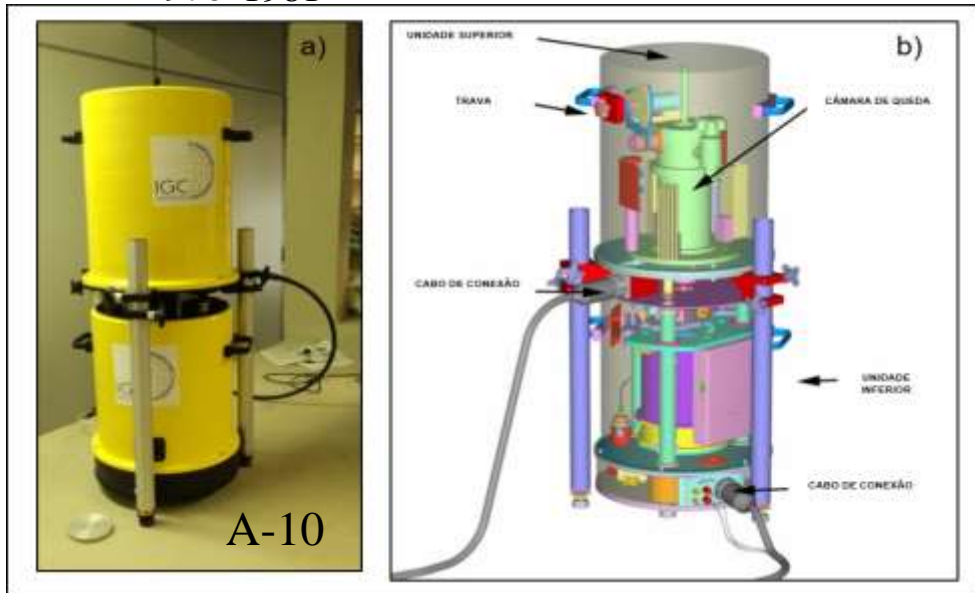
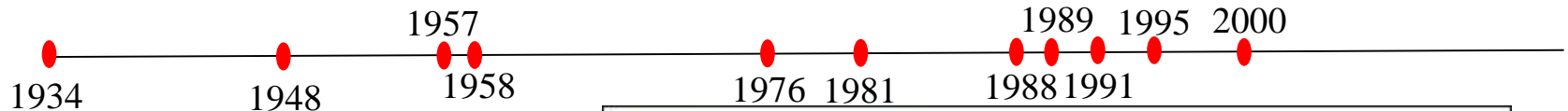
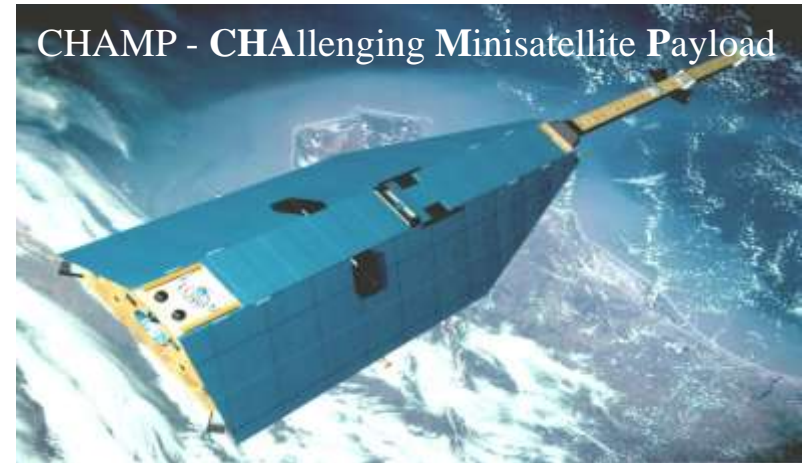


b)

a) Microg Lacoste (2019)

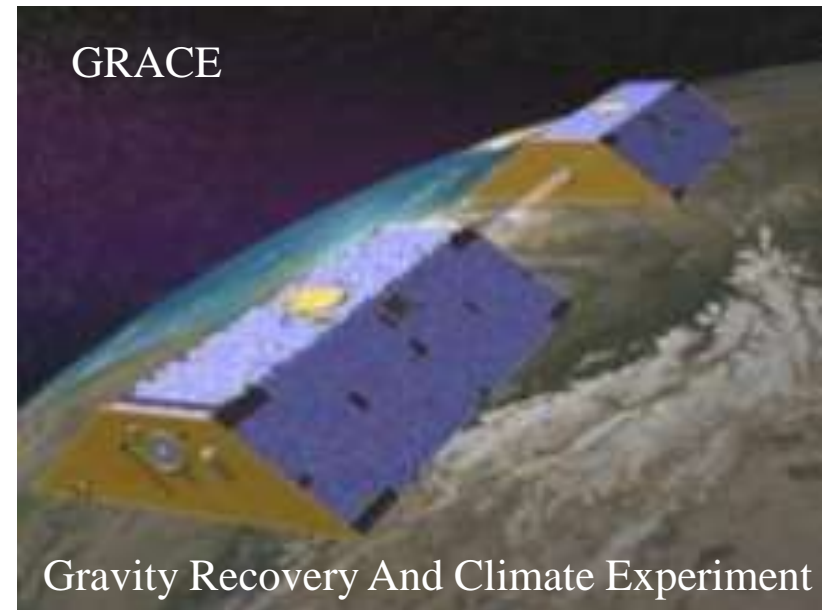
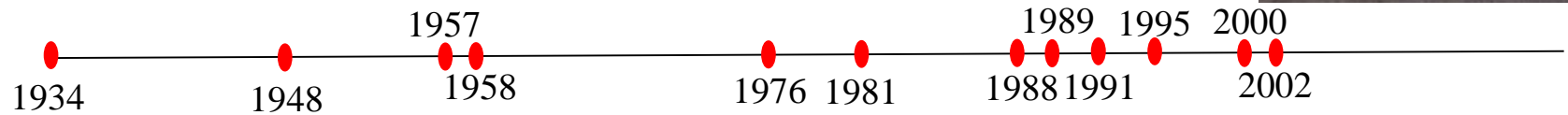
b) Adaptado de Niebauer et al., (2005).

Timeline

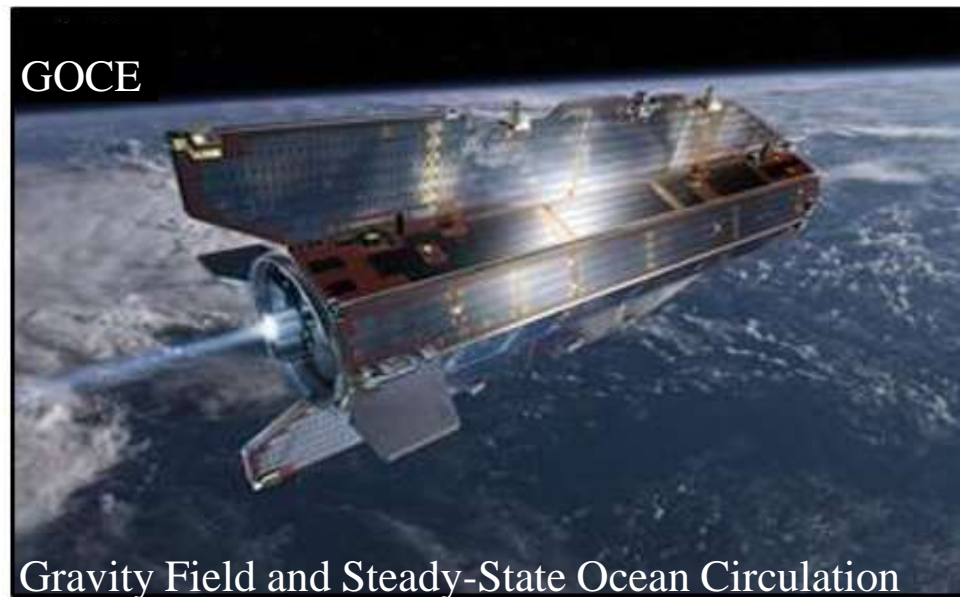
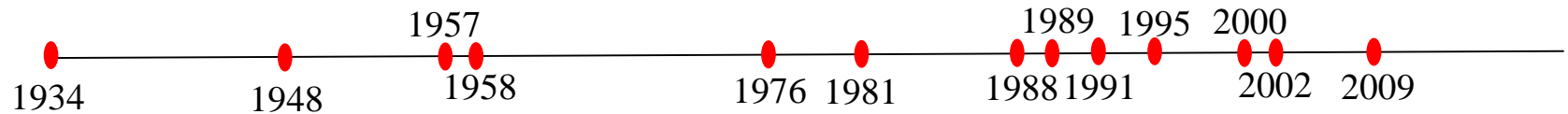


b) Adaptado de Micro-g LaCoste (2008).

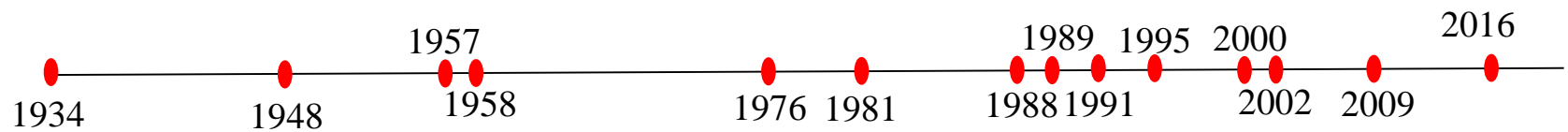
Timeline



Timeline



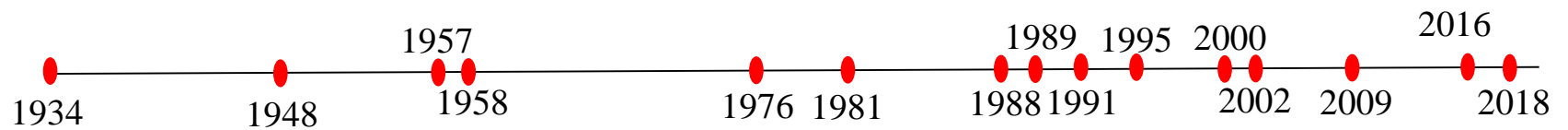
Timeline



CG-6



Timeline

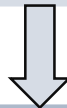


30 years of absolute gravity measurements in South America

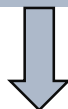
Measurements in the 80-90's

The IFE Absolute Gravity Program

Institut für Erdmessung (IFE) – Universität Hannover



Deutsche Forschungsgemeinschaft (DFG)
and
Instituto Panamericano de Geografía y Historia (IPGH)



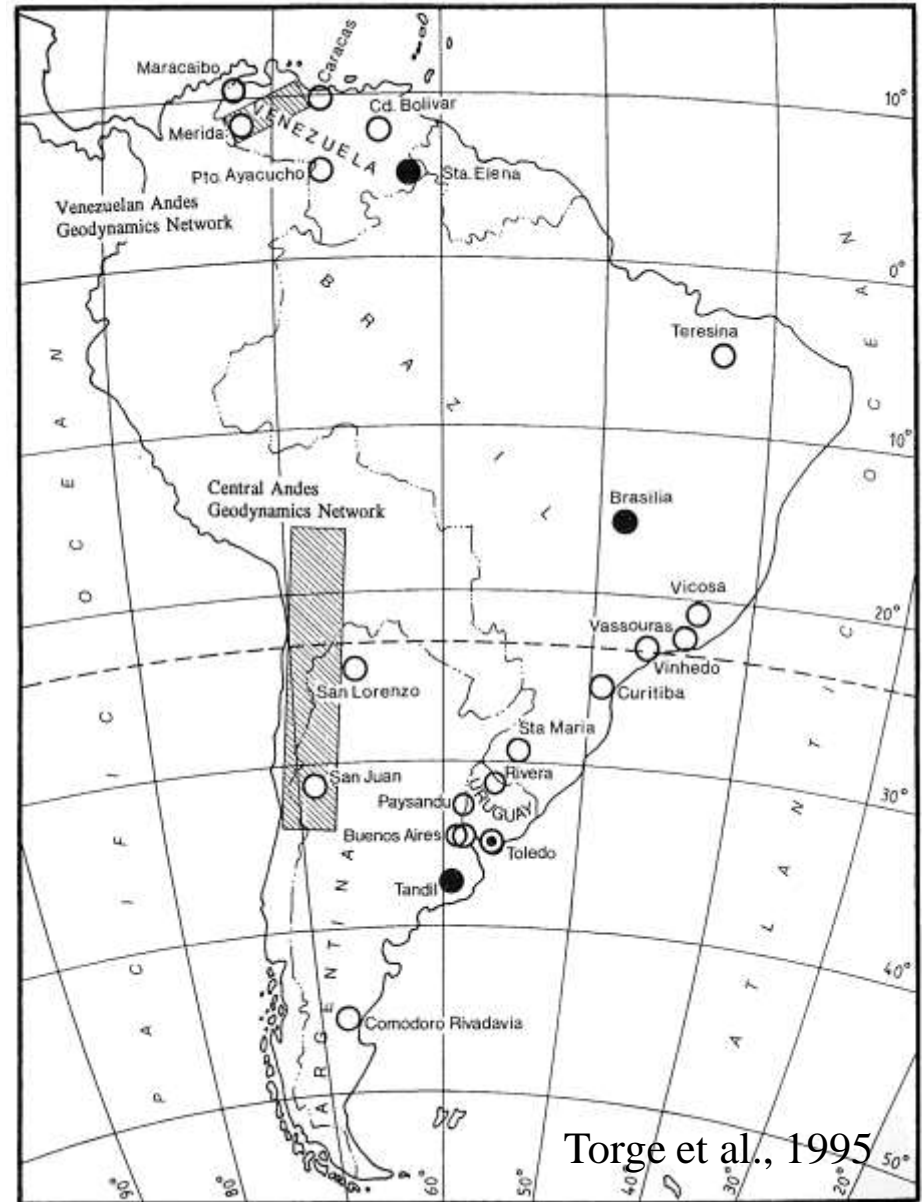
- Escuela de Ingeniería Geodesia, La Universidad del Zulia, Maracaibo, Venezuela
- Dirección de Cartografía Nacional, Caracas, Venezuela
- Dirección de Geología, Ministerio de Energía y Minas, Caracas, Venezuela
- Curso de Pós-Graduação em Ciências Geodésicas, Universidade Federal do Paraná, Curitiba, Brasil
- Servicio Geográfico Militar, Montevideo, Uruguay
- Instituto de Geodesia, Facultad de Ingeniería, Universidad de Buenos Aires, Argentina
- Instituto Geográfico Militar, Buenos Aires, Argentina

TORGE, W. TIMMEN, L. RÖDER, R. H. SCHNÜLL, M. Large Scale Absolute Gravity Control in South America, JILAG-3 Campaigns 1988–1991 Gravity and geoid (pp. 46-55): Springer. 1995.

Measurements in the 80-90's

Argentina: 6 stations
Brazil: 7 stations
Venezuela: 6 stations
Uruguay: 3 stations

Brasília, Tandil and Santa Elena stations are part of the International Absolute Gravity Base Station Network (IAGBN).



Measurements in the 80-90's

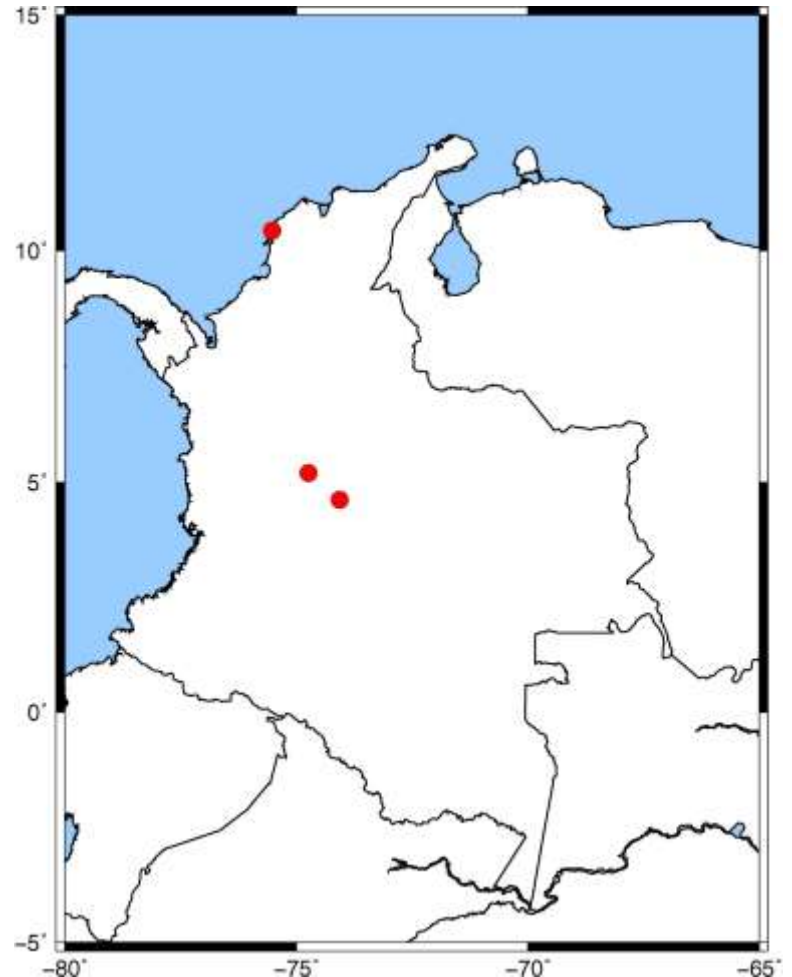
Colombia 1995

Institution: Defense Mapping Agency (DMA) and

Instituto Geográfico Agustín Codazzi

Equipment: FG-5

3 stations (Bogota, Honda and Cartagena)



2000s measurements

Argentina 2006

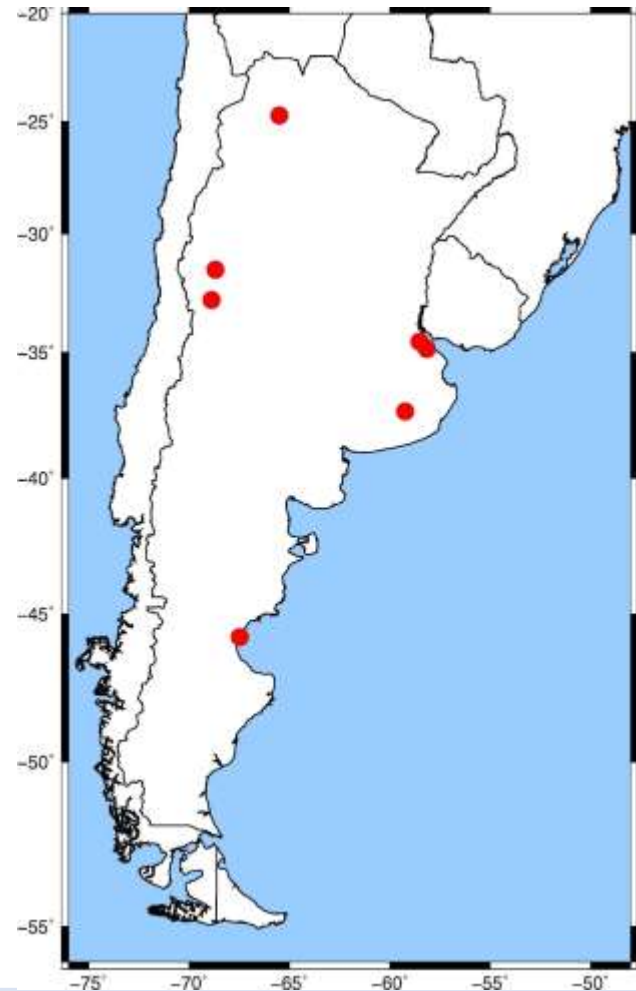
Institution: Institut de Recherche pour le Développement (IRD)

Equipment: A-10 014

2 stations

Argentina 2008

In 2008 the *Bureau Gravimétrique International* (BGI) recalculated the values measured between 1988 e 1991.



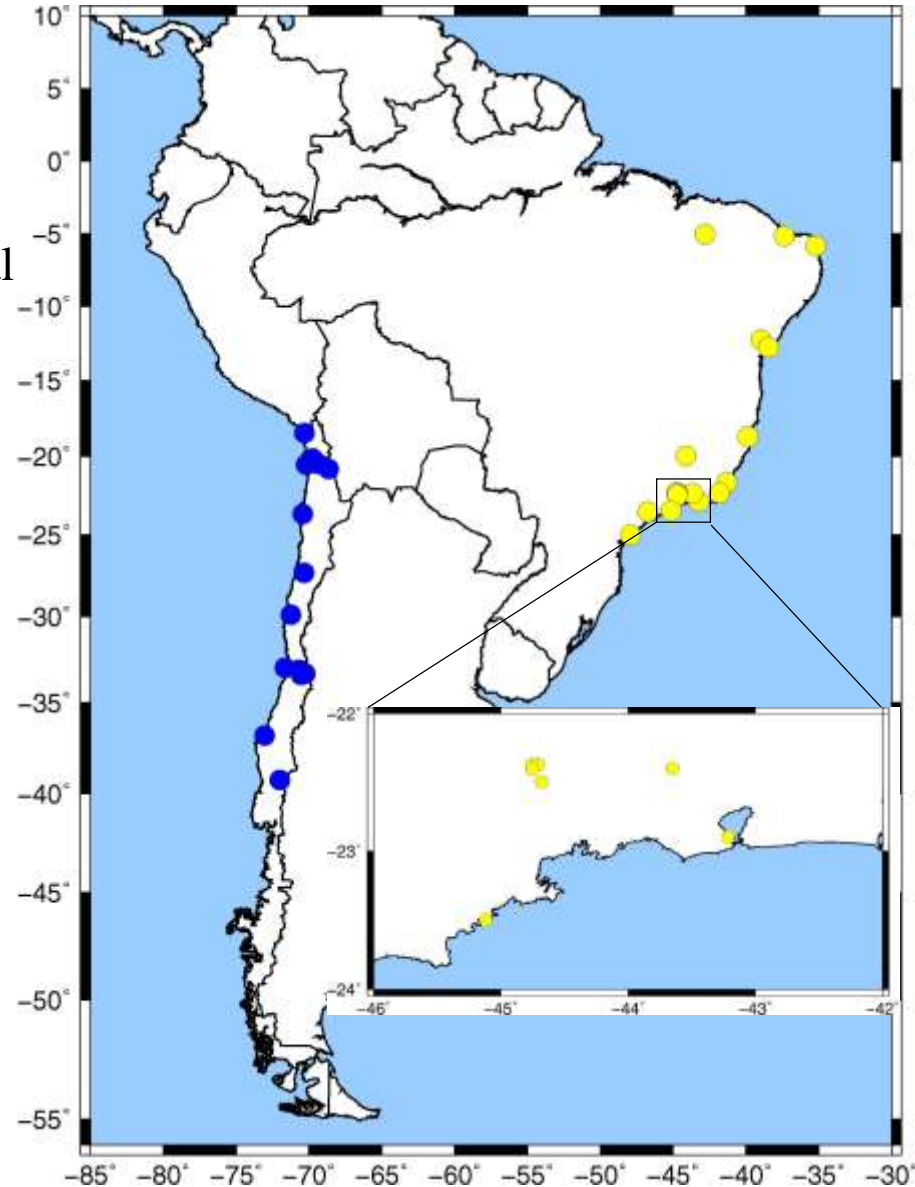
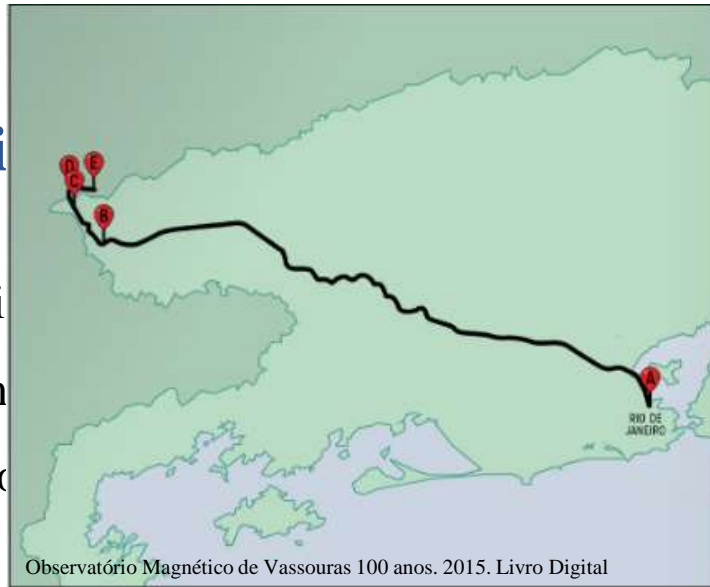
2000s measurements

Chile 2005 - 2007

Institution: Bureau Gravimétrique International
(BGI)

Equipment: FG-5 206

16 stations



Brazil

Instituti

Equipm

20 stati

Measurements 2010 - Today

Peru 2010

Institution: Institut de Recherche pour le Développement (IRD)

Equipment: FG-5 206

5 stations

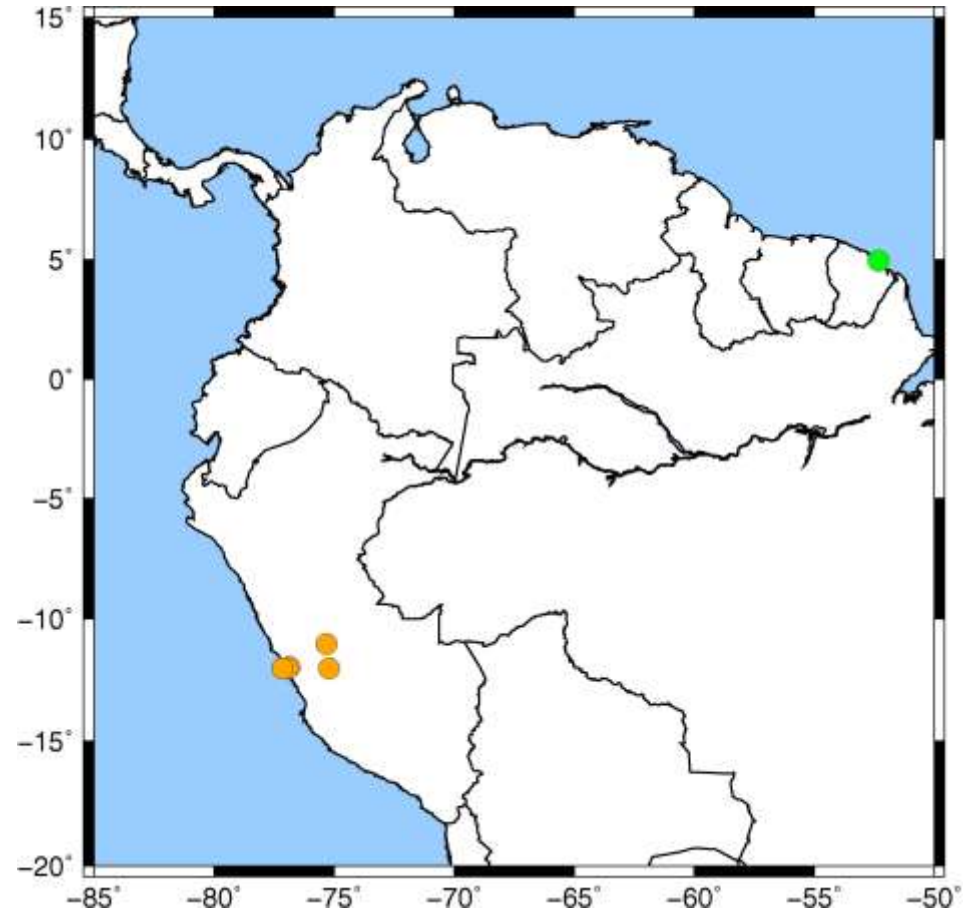
French Guiana 2010

Institution: Bureau Gravimétrique

International (BGI)

Equipment: A-10 014

1 station



Measurements 2010 - Today

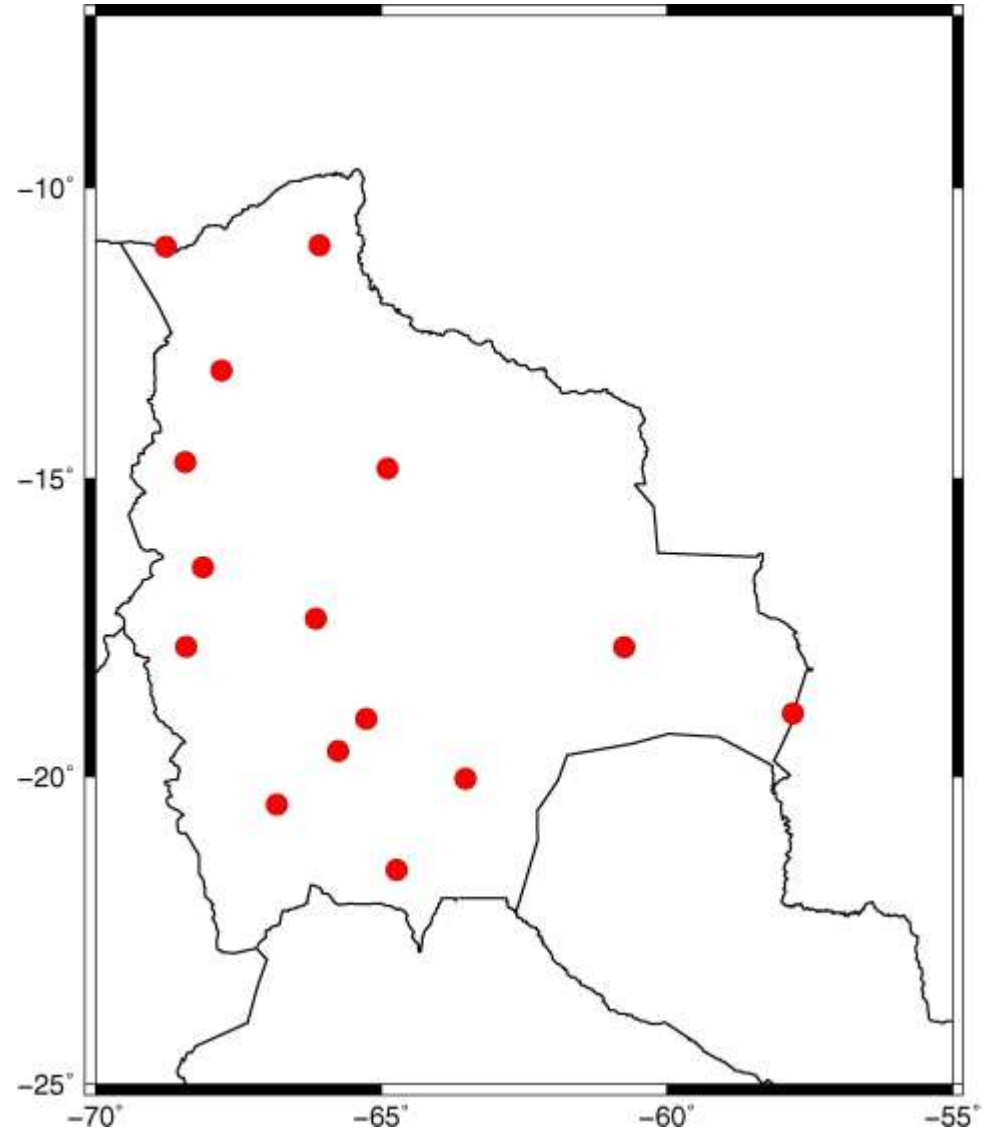
Bolivia 2010

Institution: Ohio State University

Equipment: A10 019

12 stations

3 stations reoccupied (established in 1997 by NIMA using FG-5)



Measurements 2010 - Today

Absolute Gravity Network in South America (RGAAS)

The establishment of the fundamental gravity stations with the absolute gravimeter A-10 in South America is being conducted under the coordination of:

✓ EPUSP/LTG (Escola Politécnica da USP/Laboratório de Topografia e Geodesia);



✓ CENEGEO (Centro de Estudos de Geodesia).



and with support of:

✓ IGC (Instituto Geográfico e Cartográfico do Estado de São Paulo);



Measurements 2010 - Today

Absolute Gravity Network in South America (RGAAS)

Other institutions involved:

Argentina: Instituto Geográfico Nacional (IGN)

Universidad Nacional de Rosario (UNR)

Universidad Nacional de La Plata

Universidad Nacional de San Juan

Brazil: Instituto Brasileiro de Geografia e Estatística

Universidade Federal de Uberlândia

Costa Rica: Universidad de Costa Rica

Ecuador: Instituto Geográfico Militar (IGM)

France : Bureau Gravimétrique International (BGI)

Institut de Recherche pour le Développement (IRD)



Absolute Gravity Network in South America (RGAAS)

Other institutions involved:

Uruguay: Instituto Geografico Militar



Venezuela: Instituto Geográfico de Venezuela Simon Bolivar (IGVSB)

Petroleos de Venezuela SA (PDVSA)

Universidad Central de Venezuela (UCV)



Measurements 2010 - Today

The A-10 n° 032

- ✓ 10 sets of measurements are made, on average, each with 120 falls of 1 second;
- ✓ The process is controlled by a computer that corrects the luni-solar attraction, the effect of rotation of the Earth, the ocean load and the barometric pressure, providing a final “g” value;
- ✓ The final value of absolute gravity is an adjustment of all observations in the different sets, after corrections.
- ✓ Subsequently, the value is reduced to the ground with local gradient obtained with a relative gravimeter.

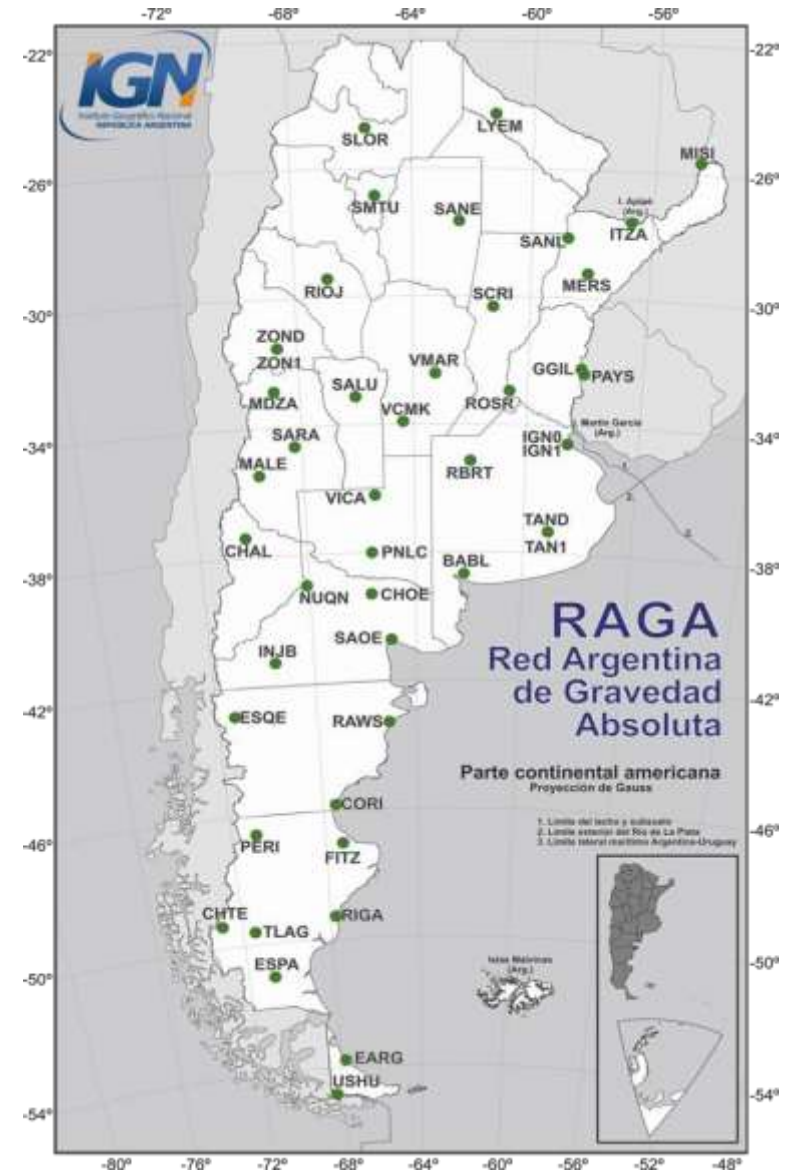


Measurements 2010 - Today

Argentina 2014 - 2016

The Absolute Gravity Network of Argentina (RAGA) was established in three different campaigns.

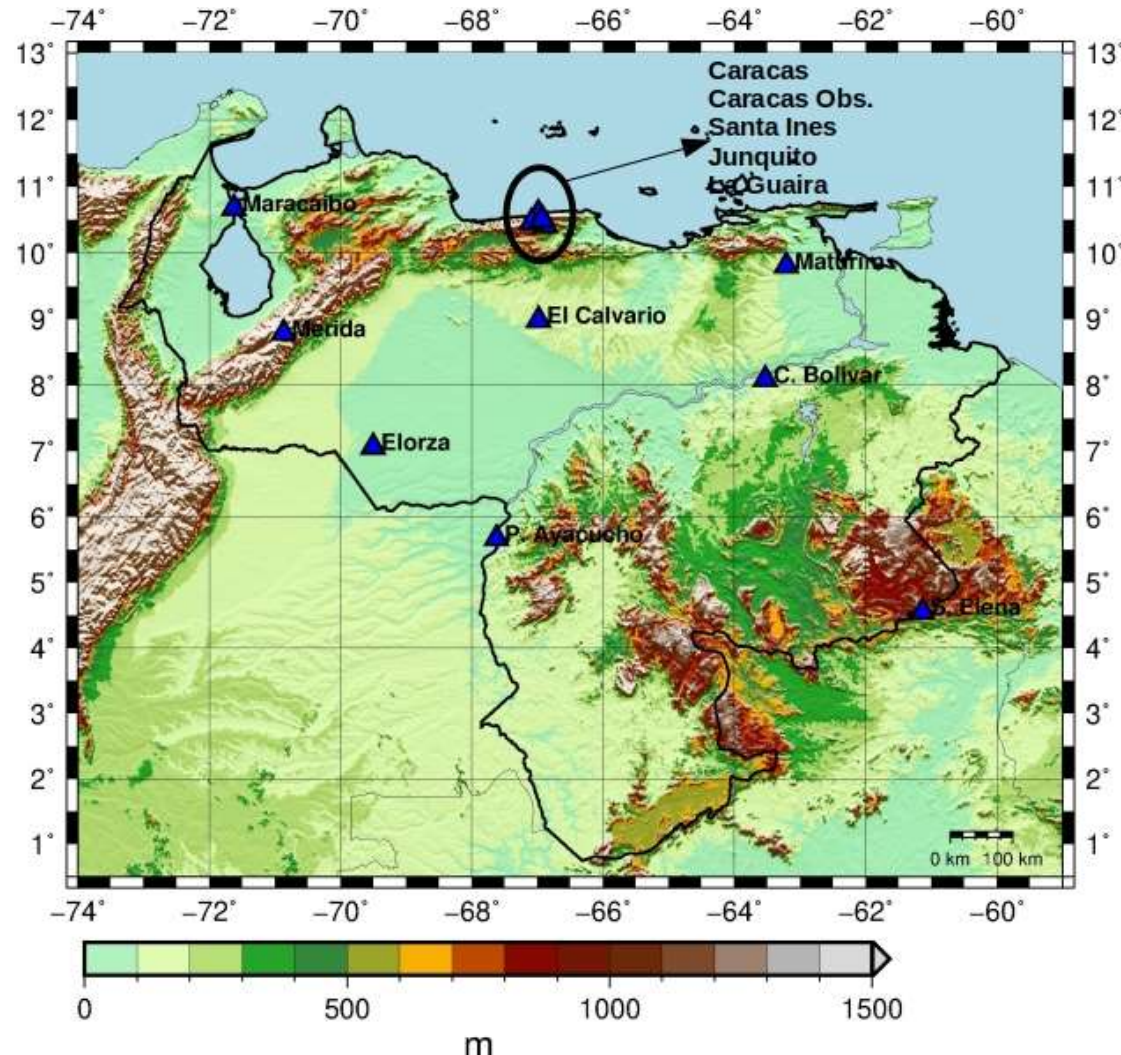
A total of **35 stations** were observed, three of which were also subject to measurements by the IRD, which allowed a comparison. The network standard deviation is ± 0.02 mgal.



Measurements 2010 - Today

Venezuela 2016

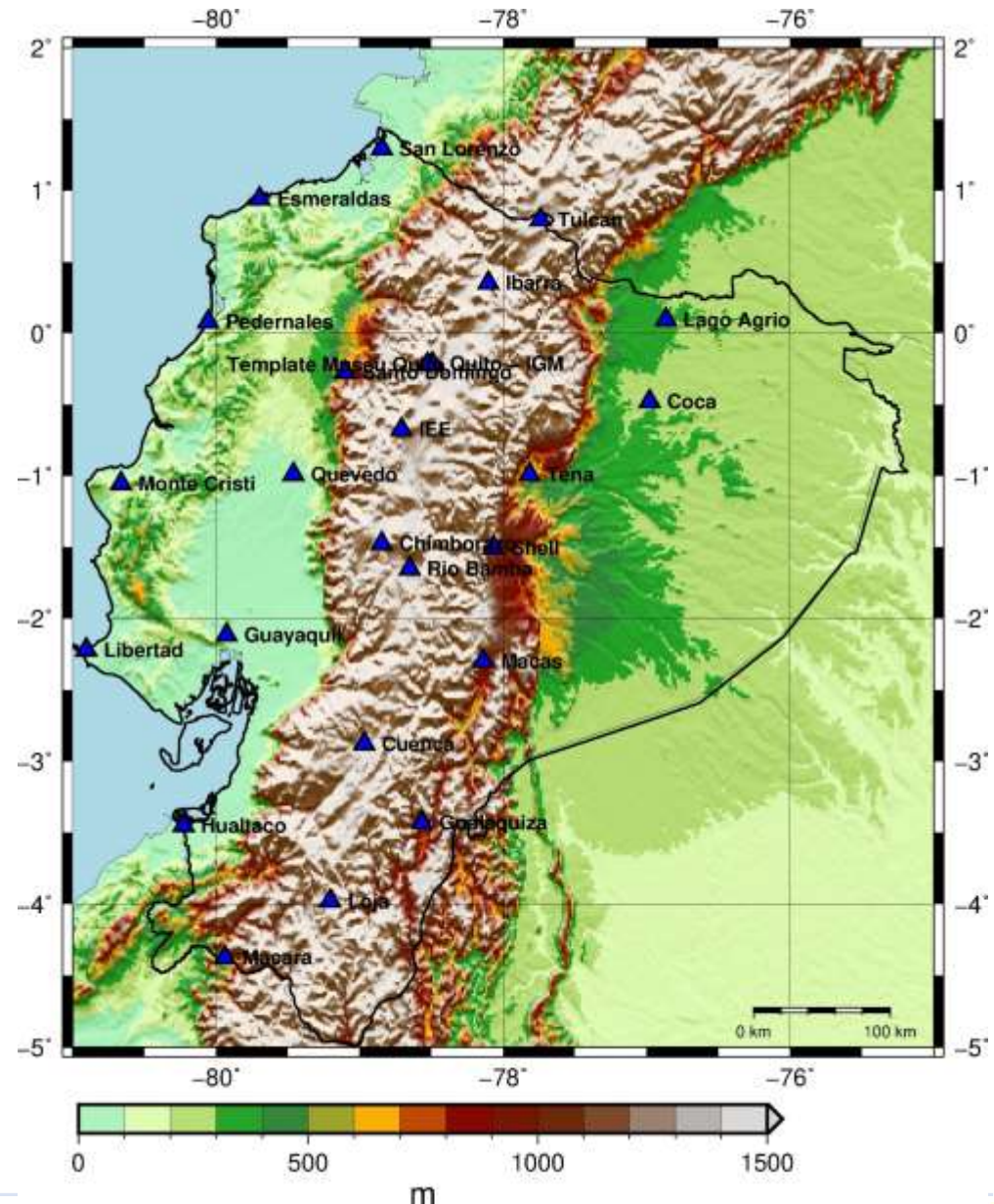
13 stations were established (4 reoccupations), selected within the possibilities of the country, by the Instituto Geográfico de Venezuela Simón Bolívar IGVSb. The main problem of the country is forest area.



Measurements 2010 - Today

Ecuador 2016

25 stations were established homogeneously, but with the restrictions of the Amazon region.

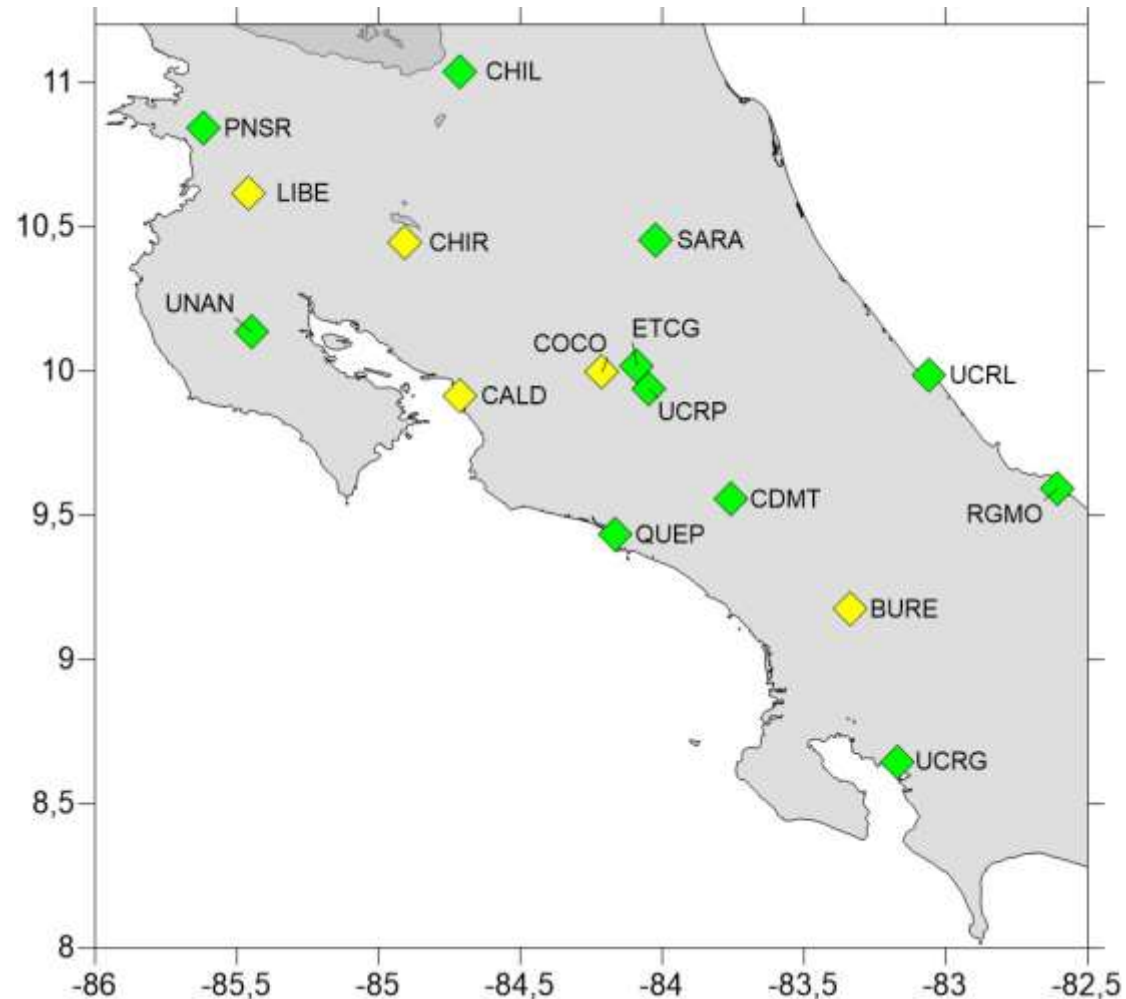


Measurements 2010 - Today

Costa Rica 2019

16 stations were established ,
5 of wich were reobservations
(yellow).

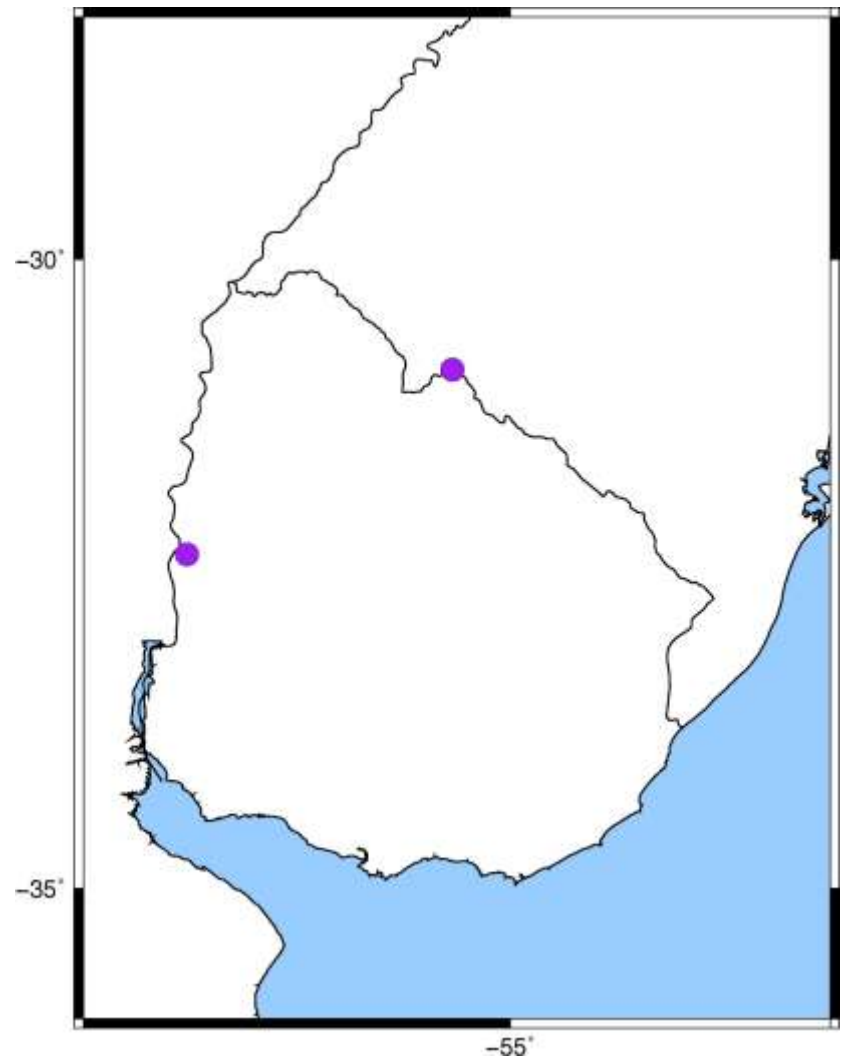
The planning was made by the
Universidade de Costa Rica
(UCR)



Measurements 2010 - Today

Uruguay

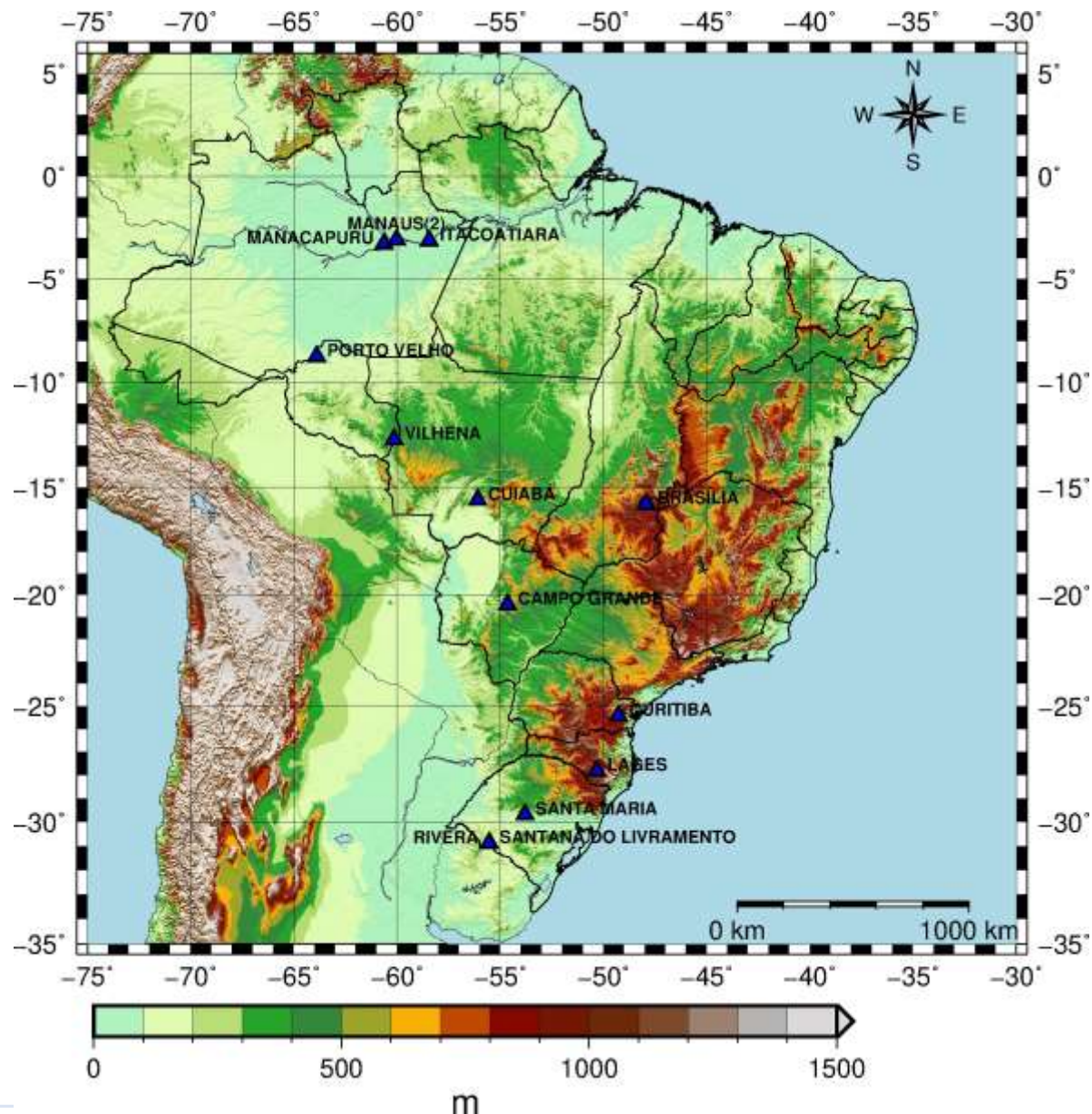
Rivera and Paysandu stations were reoccupied. First measurements were conducted between 1988 – 1991.



Measurements 2010 - Today

Brazil

In Brazil, **16 stations** were established along a profile that extends from Manaus to Santana do Livramento.



Measurements 2010 - Today

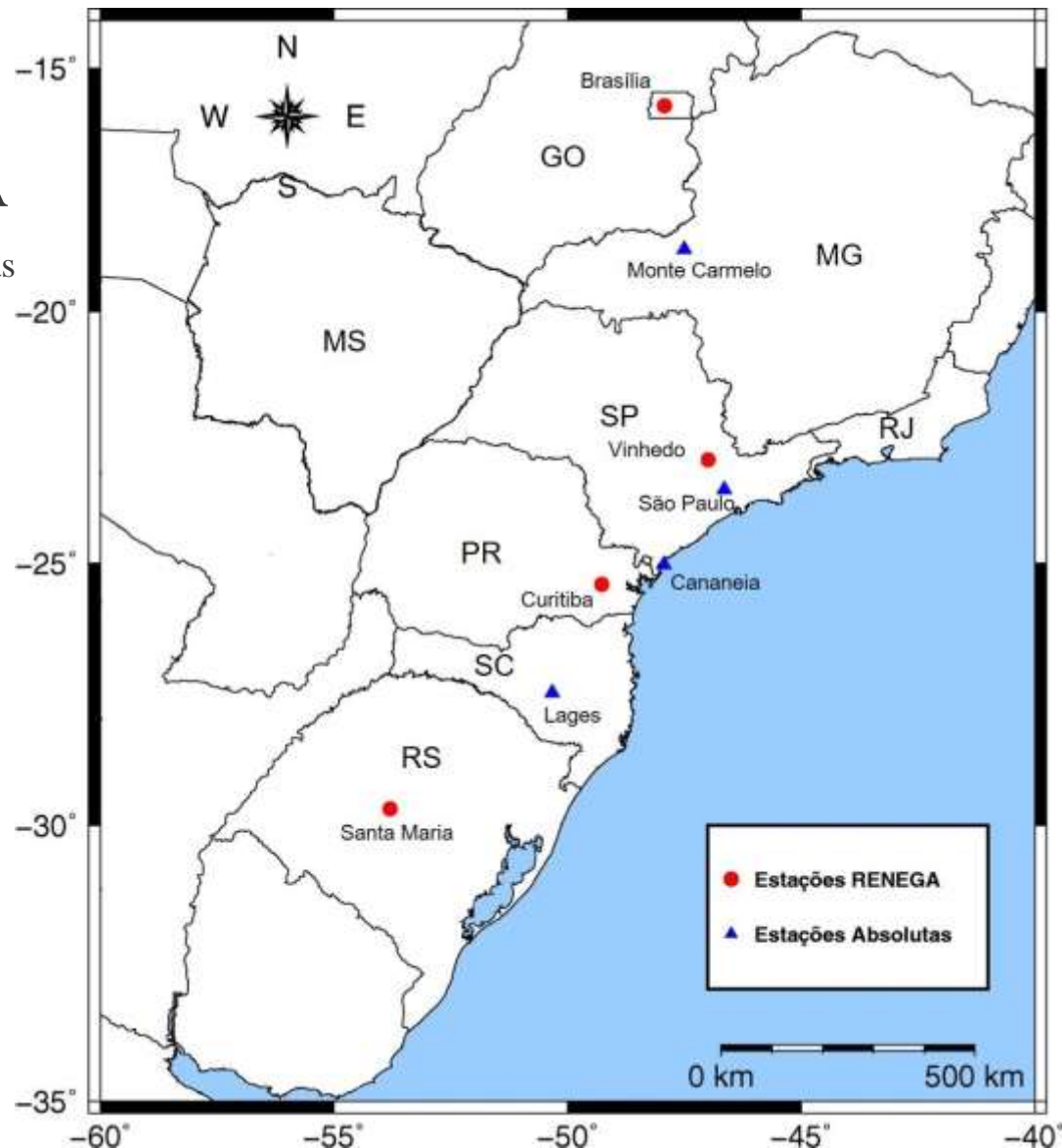
Brazil

(Re)observations in RENEGA

Rede Nacional de Estações Gravimétricas Absolutas

Station	g value (mGal)
Brasília (IBGE)	978079.072
Monte Carmelo	978293.411
Vinhedo (RENEGA)	978563.644
São Paulo	978641.820
Cananeia	978934.232
Curitiba	978760.387
Lages	978890.777
Santa Maria (RENEGA)	979261.568

$\sigma = \pm 0.011$ mGal



Measurements 2010 - Today

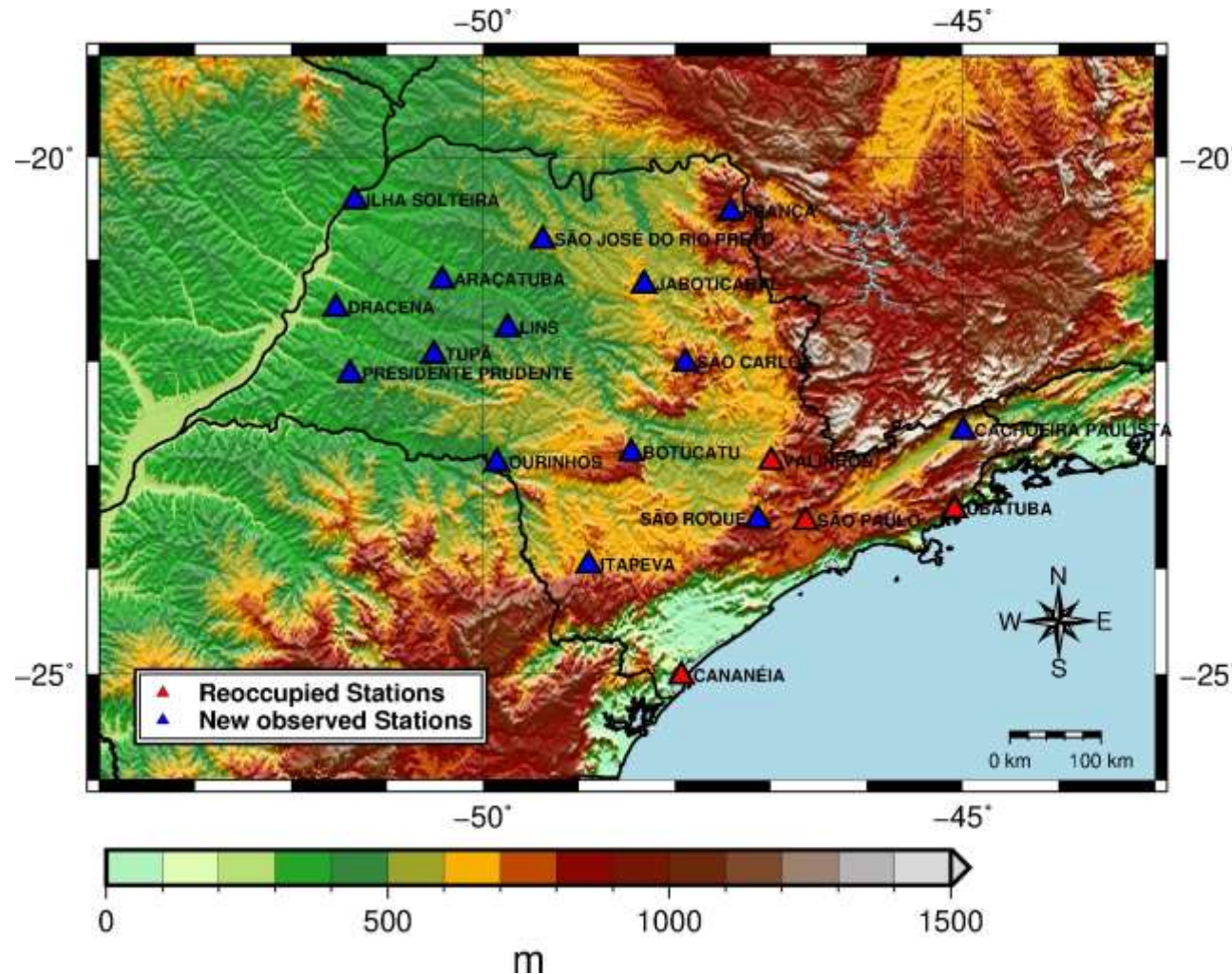
Gravimeter calibration in RENEGA



Measurements 2010 - Today

Brazil – State of São Paulo 2013 - 2016

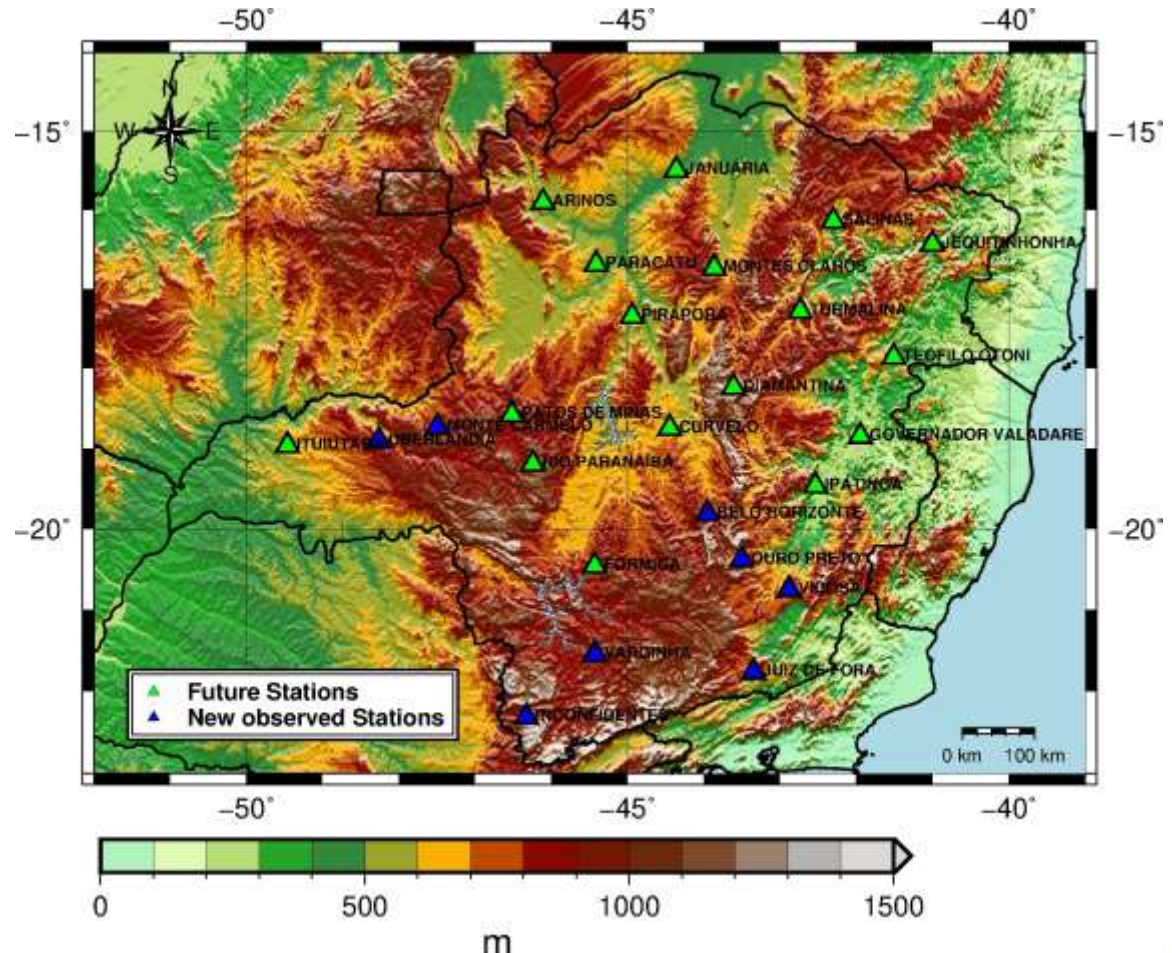
In the State of São Paulo, **19 stations** were established, **15 new** and **4 reoccupations**. These were measured by the Observatório Nacional, allowing a comparison.



Measurements 2010 - Today

Brazil – State of Minas Gerais 2017 - 2020

In Minas Gerais field work is in the final phase. The project aims **25 stations**, most of them located inside the universities and institutions.



Projeto Universal FAPEMIG – Processo: CRA - APQ-01547-17

Projeto Universal CNPq – Processo: 420555/2016-1



Comparisons of Absolute Measurements

BRAZIL

Equipament	Station	Year	Gravity (μGal)	Difference (μGal)
JILAG 4	Brasília	1992	978079100	28
A-10 032		2016	978079072 \pm 11	
JILAG 3	Santa Maria	1989	979261636	68
A-10 032		2017	979261568 \pm 11	
JILAG 3	Valinhos	1989	978563778	34
A-10 032		2013	978563744 \pm 11	

ECUADOR

Equipament	Station	Year	Gravity (μGal)	Difference (μGal)
A-10 (NGA)	Quevedo	2008	977980217	-152
A-10 032		2014	977980369 \pm 11	
A-10 (NGA)	Quito	2008	977245637	51
A-10 032		2017	977245586 \pm 11	

Comparisons of Absolute Measurements

VENEZUELA

Equipament	Station	Year	Gravity (μGal)	Difference (μGal)
JILAG3	Pto. Ayacucho	1988	978043866	45
A10/32		2016	978043821	
JILAG 3	Mérida	1988	977352210	36
A10/32		2016	977352174	
JILAG 3	Cd. Bolivar	1988	978115349	67
A10/32		2016	978115282	
JILAG 3	St.Elena	1988	977822084	112
A10/32		2016	977821972	

URUGUAY

Equipament	Station	Year	Gravity (μGal)	Difference (μGal)
JILAG 3	Paysandu	1991	979523526	3
A-10 032		2014	979523523 \pm 11	
JILAG 3	Rivera	1991	979344377	5
A-10 032		2017	979344372 \pm 11	

Comparisons of Absolute Measurements

ARGENTINA				
Equipament	Station	Year	Gravity (μGal)	Difference/ μGal
A10 014	Mendoza	2014	979199568	-7
A10 032		2014	979199575	
A10 014	Neuquén	2014	979965802	27
A10 032		2014	979965784	9
A10 032		2016	979965775	
A10 014	Malargüe	2014	979325665	-10
A10 032		2016	979325675	
A10 014	San Rafael	2014	979495714	75
A10 032		2016	979495639	
JILAG3	San Juan	1989	979141649	-58
A10 014		2014	979141732	25
A10 032		2014	979141729	22
A10 032		2016	979141707	

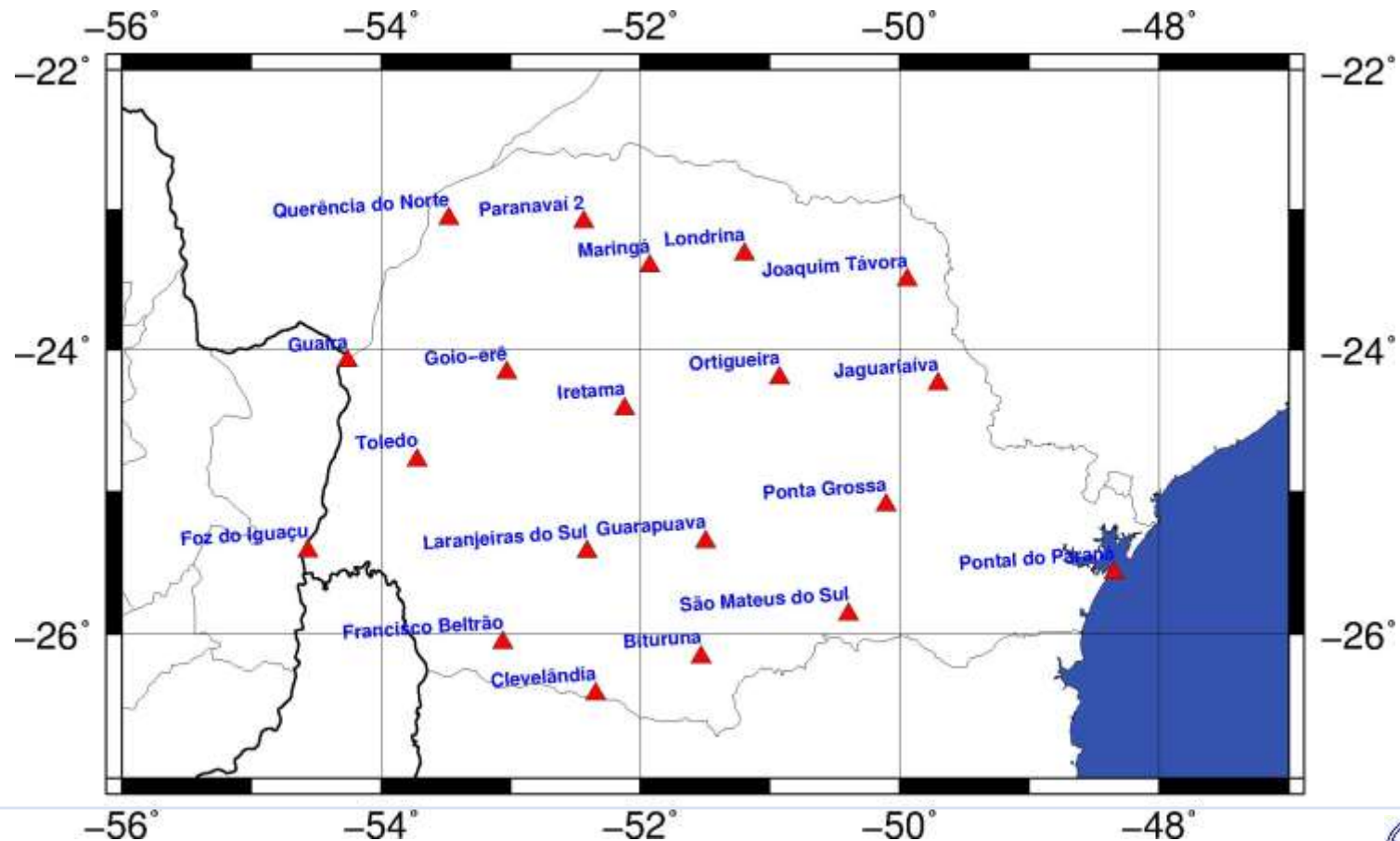
Comparisons of Absolute Measurements

ARGENTINA				
Equipament	Station	Year	Gravity (μGal)	Difference/ μGal
JILAG 3	San	1989	978409410	-15
A10/32	Lorenzo	2014	978409425	
A10/32	Iguazú	2014	978905515	30
A10/32		2016	978905485	
JILAG 3	Comodoro	1991	980663757	-25
A10/32	Rivadavia	2014	980663782	
A10/32	Tres Lagos	2014	980959941	3
A10/32		2016	980959938	

Next Steps

Brazil – State of Paraná

20 stations are being planned with the support of the Instituto de Terras, Cartografia e Geologia do Paraná (ITCG).

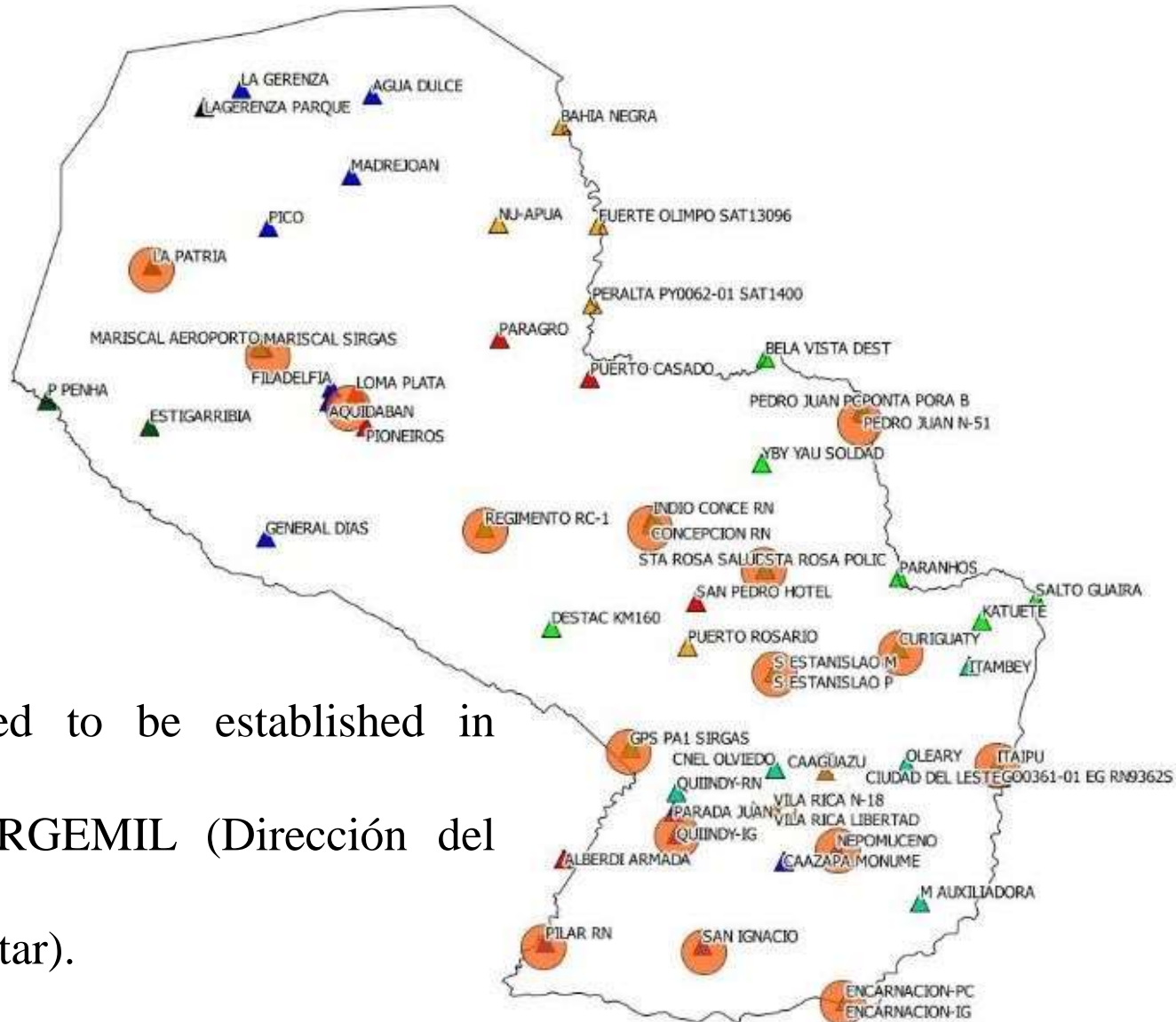


30 years of absolute gravity measurements in South America

Next Steps

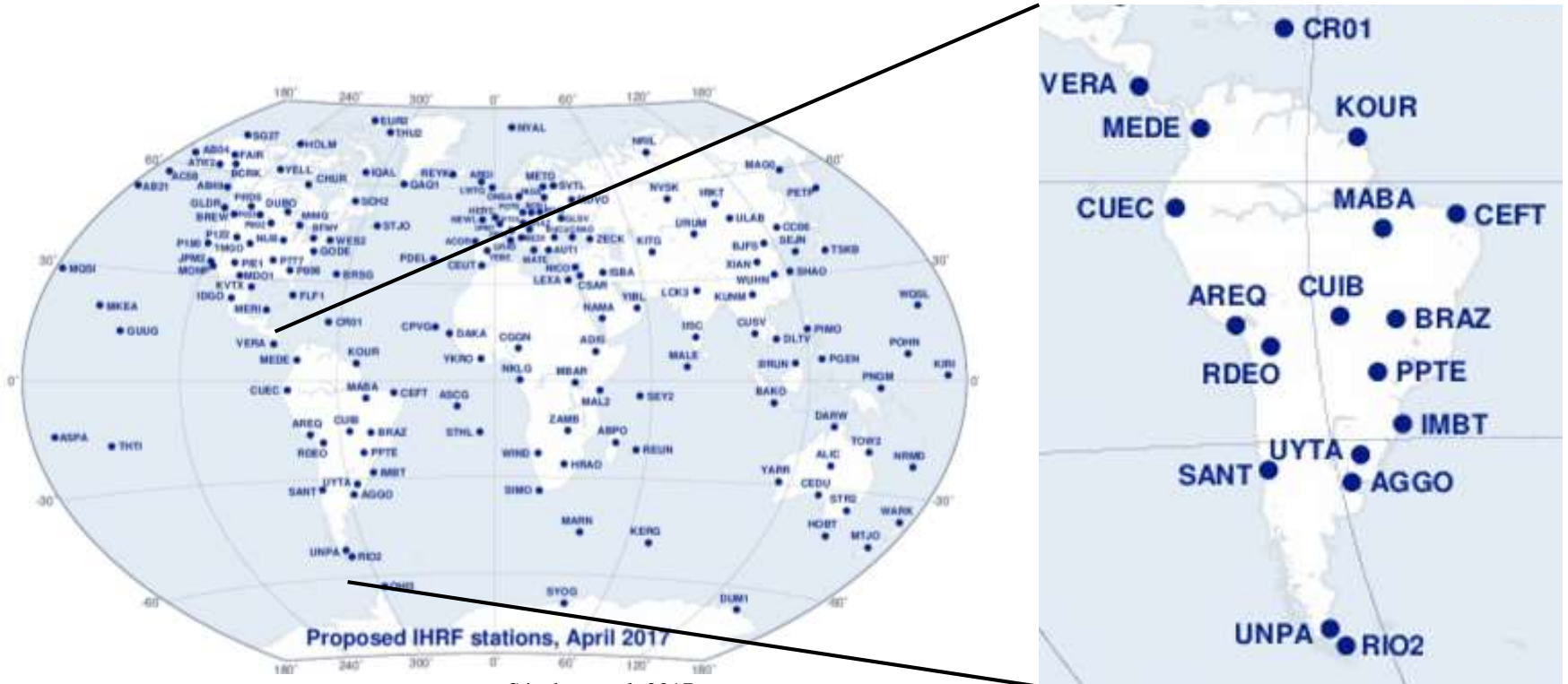
Paraguay

16 stations are planned to be established in conjunction with DISERGEMIL (Dirección del Servicio Geográfico Militar).



Next Steps

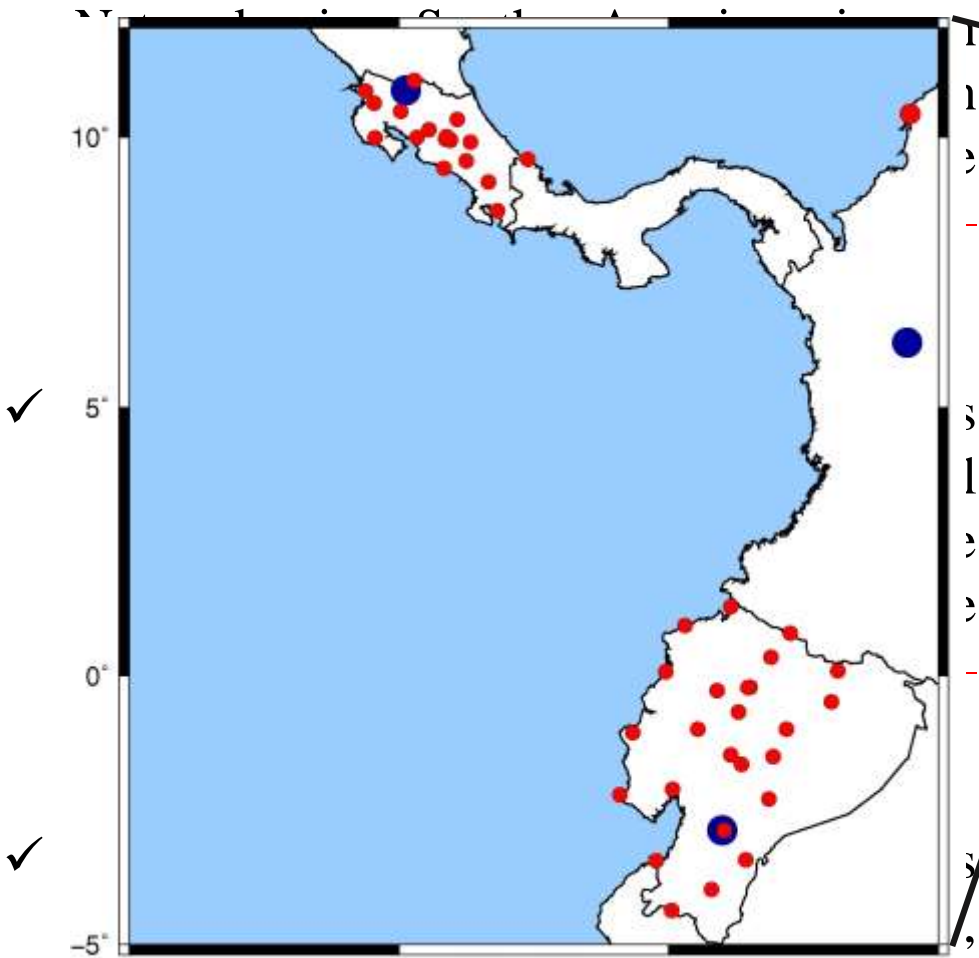
IHRF stations measurements



Sánchez et al. 2017

Remarks

✓ Establishing an Absolute Gravity



site and setup uncertainties, software corrections applied among other factors.

