XI Colóquio Brasileiro de Ciências Geodésicas

Universidade Federal do Paraná

Em direção ao estabelecimento do IHRF na América do Sul

Gabriel do N. Guimarães
Universidade Federal de Uberlândia
gabriel@ufu.br

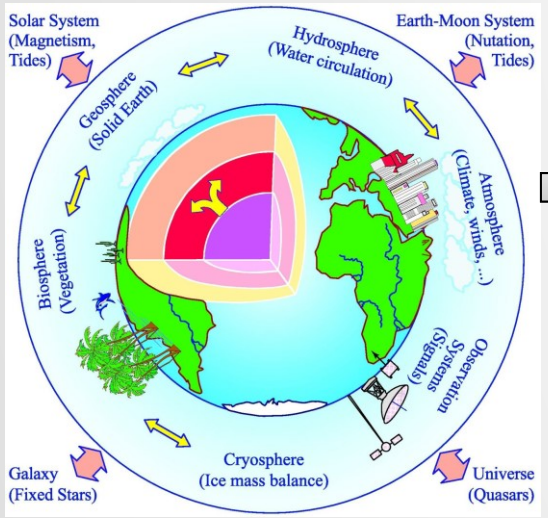
De 23 a 27 de Novembro de 2020
Universidade Federal do Paraná
Link do evento: www.cbcg.ufpr.br

Realização:
PÓS-GRADUAÇÃO EM CIÊNCIAS GEODÉSICAS

Apoio:
UFPR
SETOR DE CIÊNCIAS DA TERRA UFPR

Motivação

A geodinâmica do nosso planeta

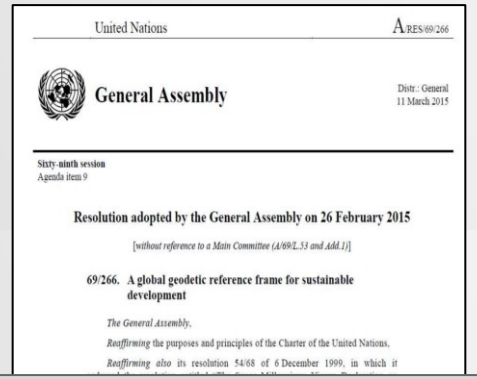


Sistema de Referência Geodésico Global

Global Geodetic Reference System (GGRS)
Global Geodetic Reference Frame (GGRF)

Medição e monitoramento contínuo, consistente e preciso

- ✓ Geometria da Terra
- ✓ Campo de Gravidade terrestre
- ✓ Orientação da Terra no espaço exterior



United Nations A/RES/69/266

General Assembly

Distr.: General 11 March 2015

Sixty-ninth session
Agenda item 9

Resolution adopted by the General Assembly on 26 February 2015

[without reference to a Main Committee (A/69/L.53 and Add.1)]

69/266. A global geodetic reference frame for sustainable development

The General Assembly,

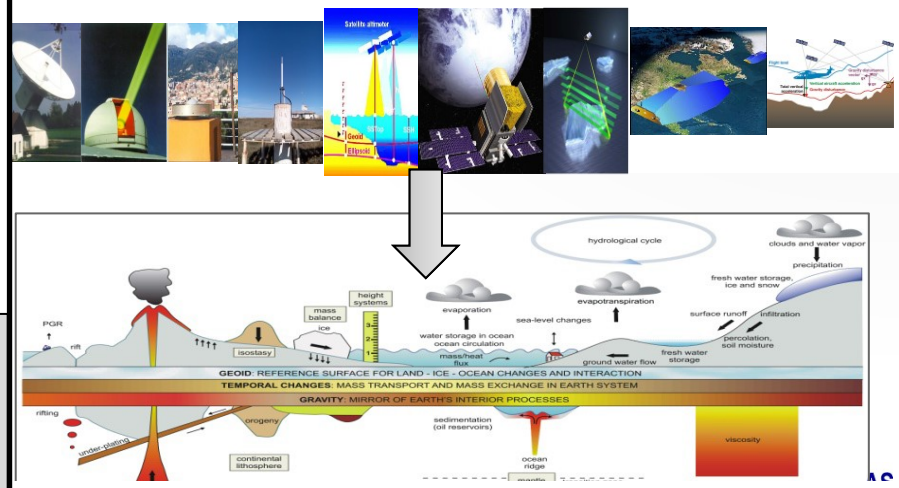
Reaffirming the purposes and principles of the Charter of the United Nations,

Reaffirming also its resolution 54/68 of 6 December 1999, in which it

Viabilidade Governamental: Resolução A/69/L.53 (02/2015) da ONU para uma "Infraestrutura de referência geodésica para o desenvolvimento sustentável"

IAG GGOS
Global Geodetic Observing System

Viabilidade científica e técnica: IAG *International Association of Geodesy*) e do seu Sistema Geodésico de Observação Global (GGOS)



te: H.-P. Plag& M. Pearlman (eds.), 2009. Global Geodetic Observing System, Springer, pp. 239.

Global Geodetic Reference System/Frame

International Terrestrial Reference System and Frame (ITRS/ITRF)

International Celestial Reference System and Frame (ICRS/ICRF)

Consolidado

International Height Reference System and Frame (IHRS/IHRF)

Em fase de implantação

International Gravity Reference System and Frame (IGRS/IGRF)

Em fase estudo

realizations: ITRF89, ITRF90, ITRF91, ITRF92, ITRF93, ITRF94, ITRF96, ITRF97, ITRF2000, ITRF2005, ITRF2008, ITRF2014

https://www.iers.org/IERS/EN/DataProducts/ITRF/itrf.html

International Height Reference System and Frame (IHRS/IHRF)

System (Sistema)

↓

Conceito e Definição

↓

- ✓ Teoria
- ✓ Convenções
- ✓ Constantes

Frame (Infraestrutura)

↓

Materialização e Realização

↓

- ✓ Prática (cálculo)
- ✓ Implantação e Manutenção

UFU

SIRGAS

International Height Reference System - IHRS

Conceito e Definição

- ✓ Coordenadas verticais são diferenças de potencial com respeito a um valor (W_0) convencional (que representa uma superfície de referência global):

$$C_P = W_0 - W(P) = -\Delta W(P) \qquad W_0 = const. = 62.636.853{,}4\ \mathrm{m^2\,s^{-2}}$$

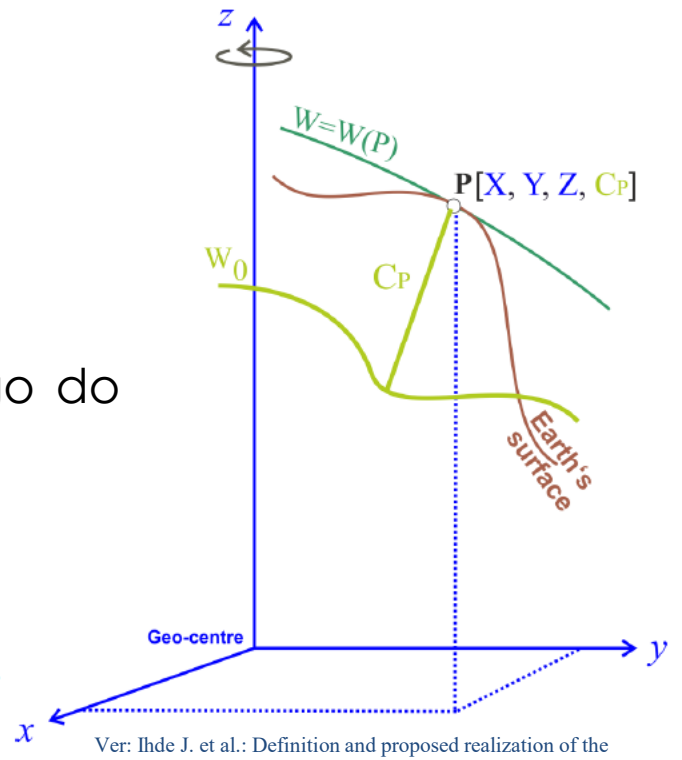
- ✓ A posição de P se define no ITRF

$$X_P\,(X_P, Y_P, Z_P) \Longrightarrow W(P) = W(X_P)$$

- ✓ A determinação de $X(P)$, $W(P)$ (ou $C(P)$) inclui as mudanças ao longo do tempo $\dot{X}(P)$, $\dot{W}(P)$ (ou $\dot{C}(P)$).
- ✓ Coordenadas no sistema *mean-tide*
- ✓ Unidades de medida: metro e segundo (*SI*)
- ✓ De acordo com os objetivos do GGOS, a precisão esperada de W é:

Posição $\approx \pm 3 \times 10^{-2}\ \mathrm{m^2\,s^{-2}}$ (~ 3 mm) Velocidade $\approx \pm 3 \times 10^{-3}\ \mathrm{m^2\,s^{-2}/a}$ (~ 0,3 mm/a)

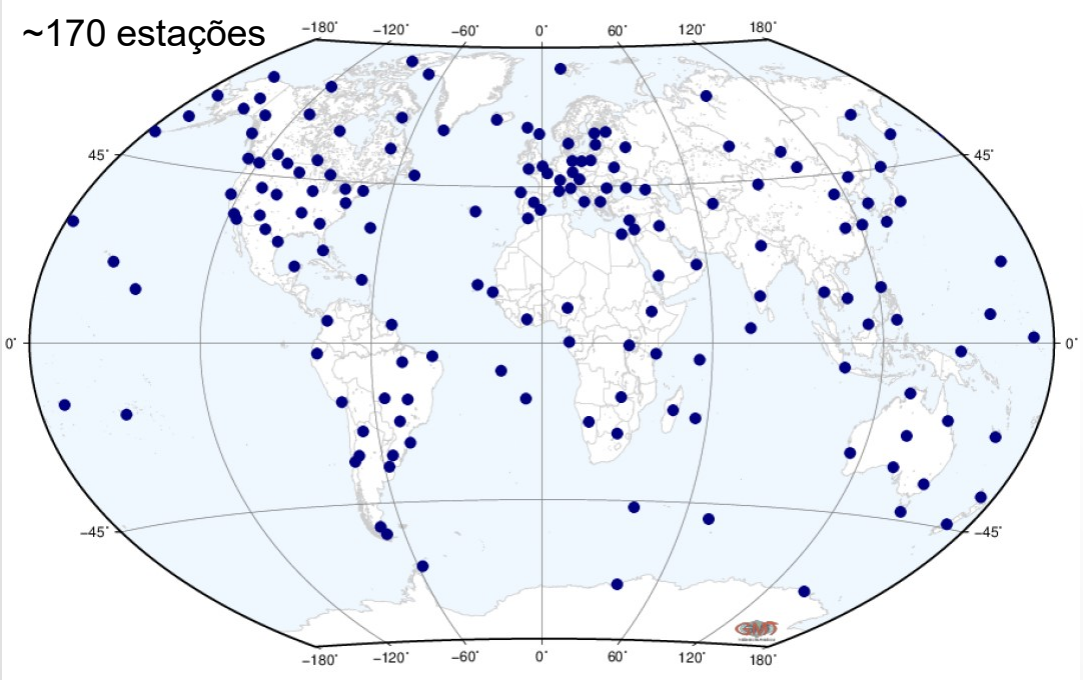
Hoje $\approx \pm 1 \times 10^{-1}\ \mathrm{m^2\,s^{-2}/a}$ (~ 1 cm)



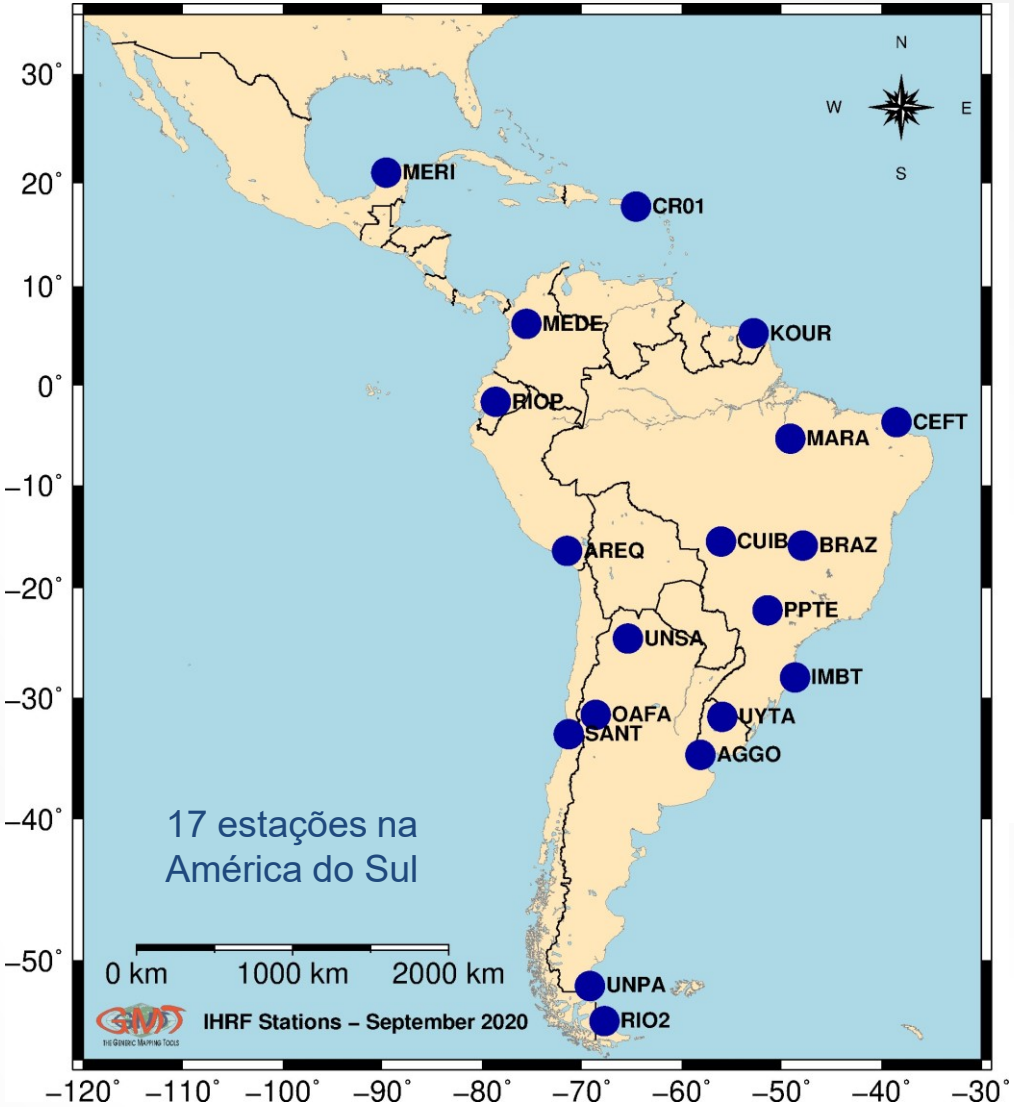
Ver: Ihde J. et al.: Definition and proposed realization of the International Height Reference System (IHRS). Surv Geophy 38(3), 549-570, 10.1007/s10712-017-9409-3, 2017
Sánchez L. et al.: A conventional value for the geoid reference potential W0, J Geod, 90(9): 815-835, 10.1007/s00190-016-0913-x, 2016.

International Height Reference Frame - IHRF

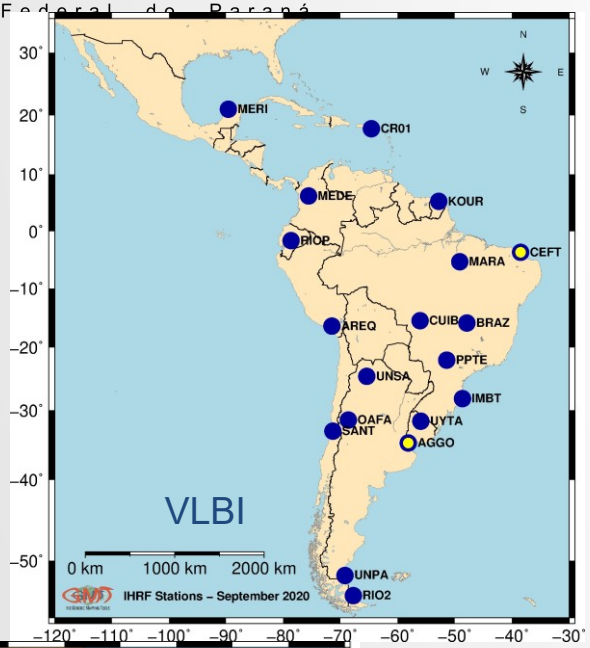
Materialização e Realização

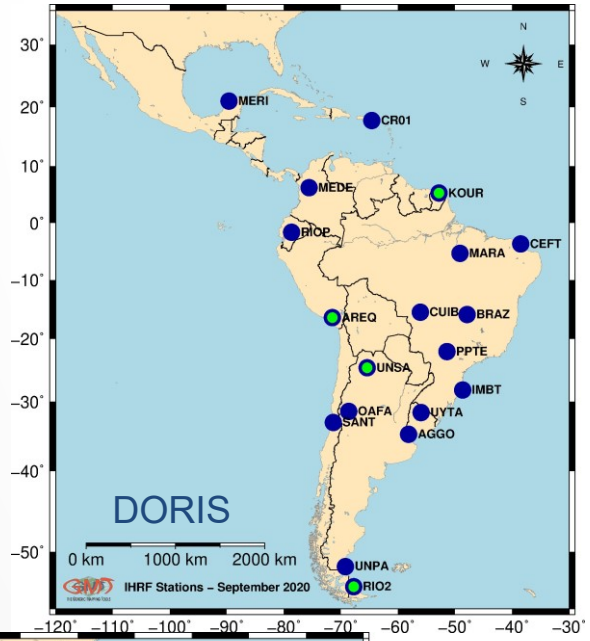


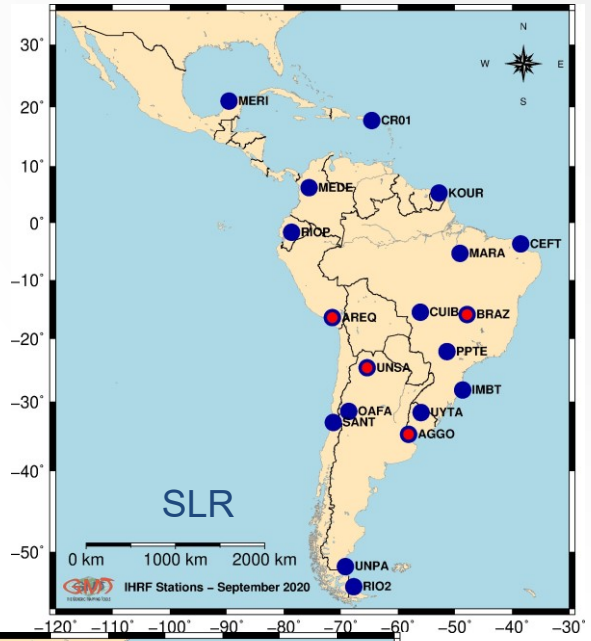
Sánchez, L.; Barzaghi, R.; Vergos, G. Infraestructura operacional para el Sistema Internacional de Alturas IHRS (International Height Reference System). Simposio SIRGAS2020, 2020-10-23. http://www.sirgas.org/fileadmin/docs/Boletines/Bol25/11_Sanchez_et_al_2020_Infraestructura_IHRF.pdf

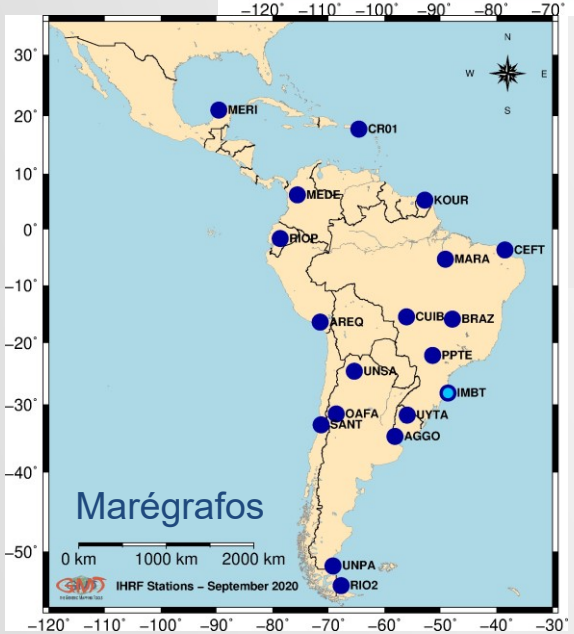


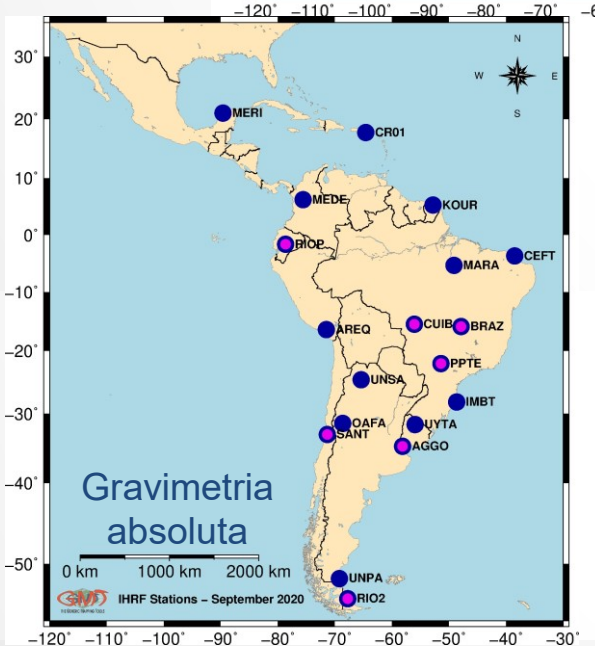
Diagnóstico das estações IHRF

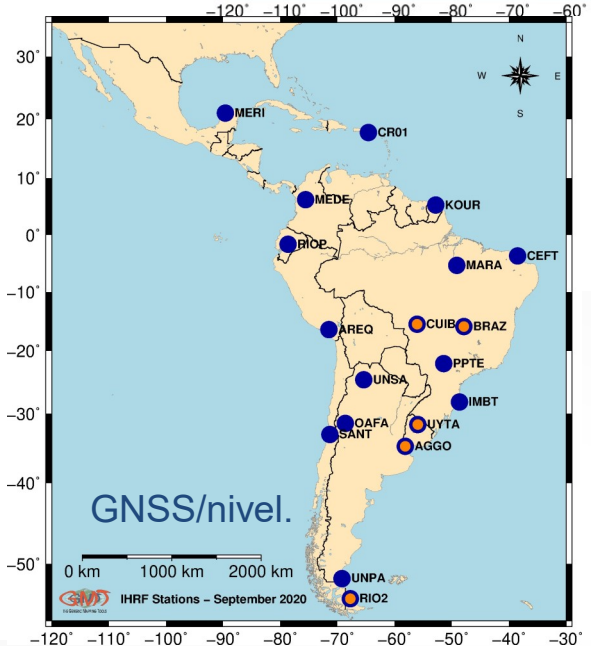






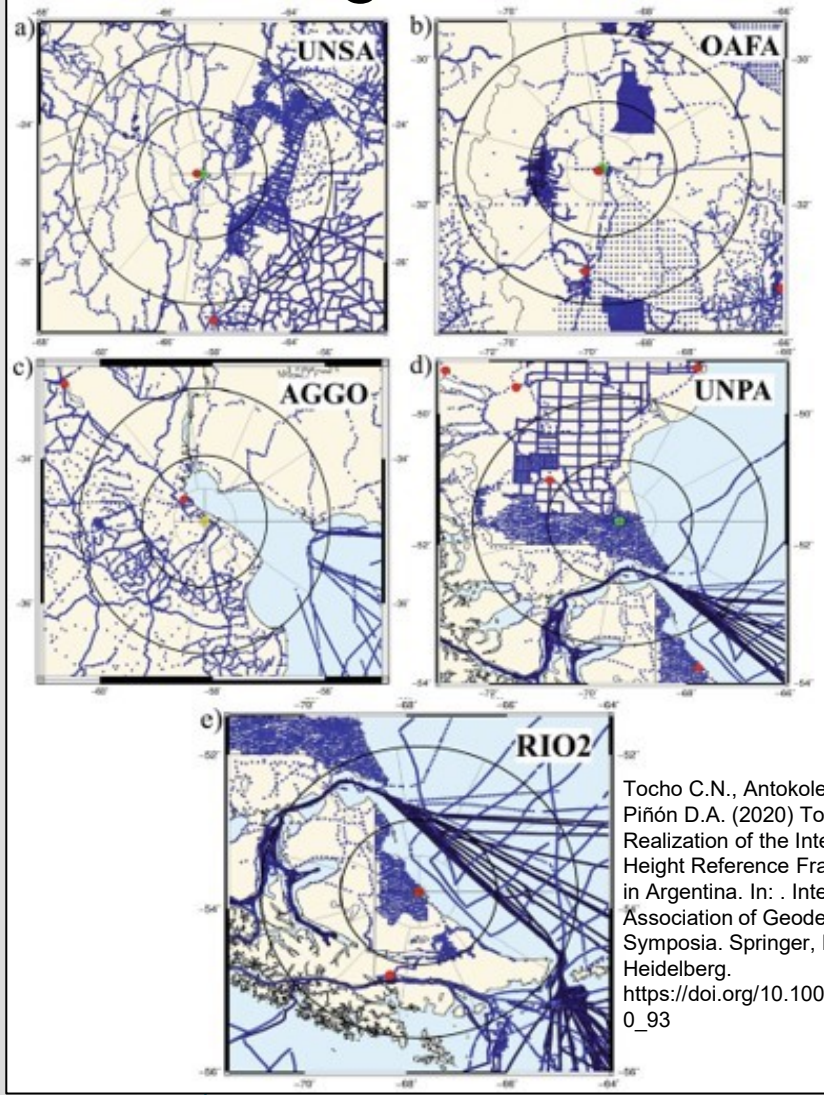






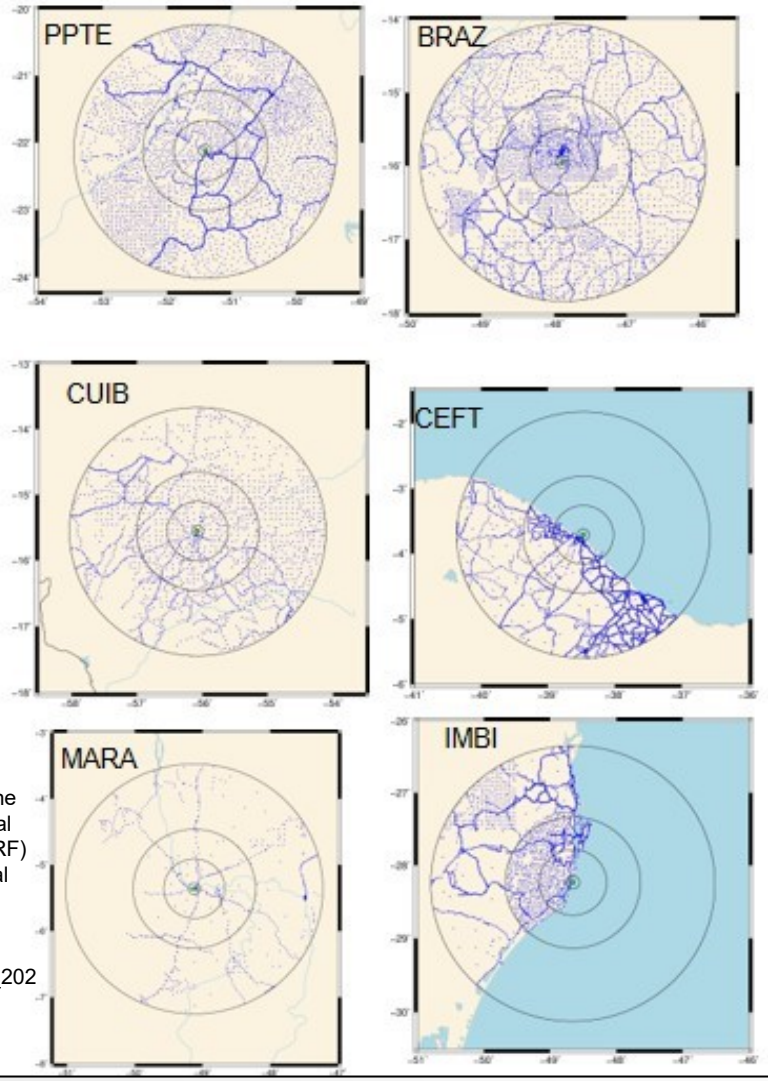
Diagnóstico das estações IHRF

Argentina

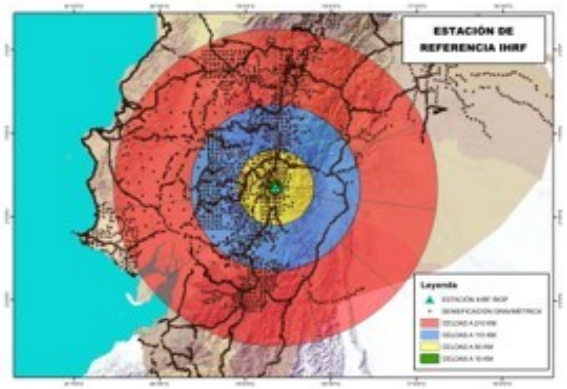


Tocho C.N., Antokoletz E.D., Piñón D.A. (2020) Towards the Realization of the International Height Reference Frame (IHRF) in Argentina. In: . International Association of Geodesy Symposia. Springer, Berlin, Heidelberg. https://doi.org/10.1007/1345_2020_93

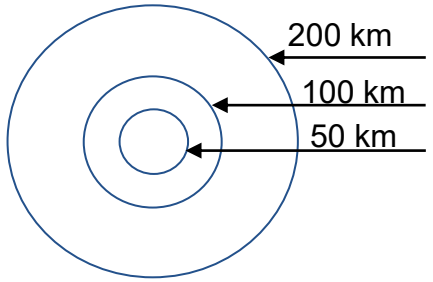
Brasil



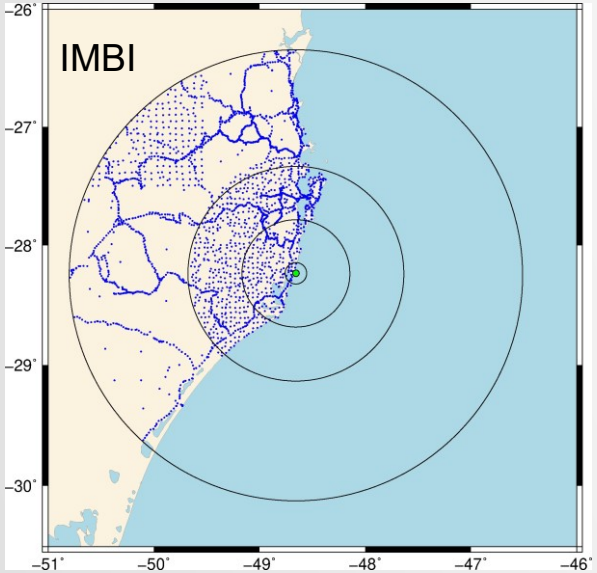
Equador

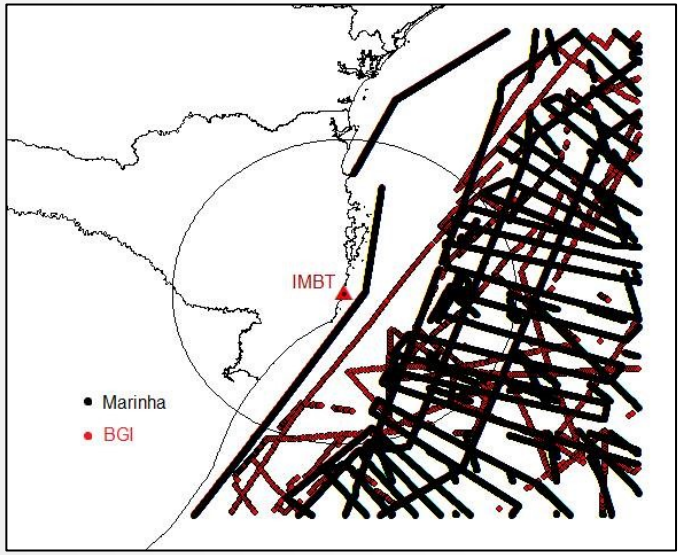


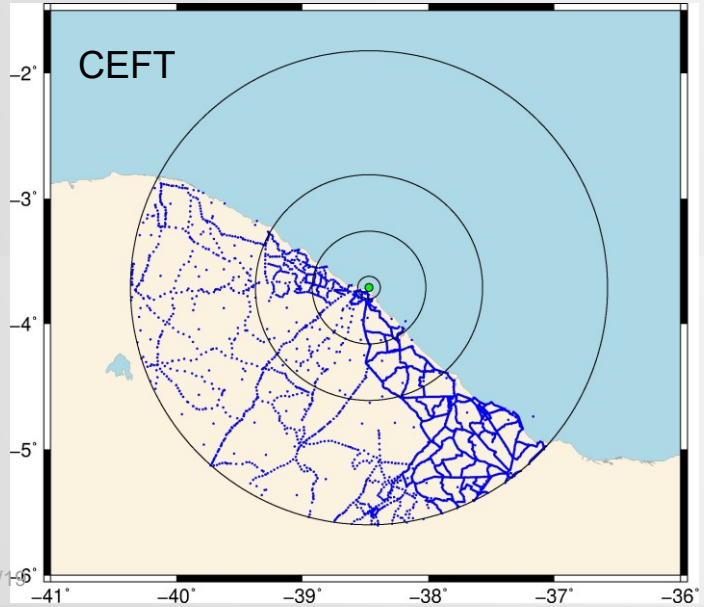
Mensagem pessoal de MAYO. IGEO. Edgar Parra do IGM/Equador

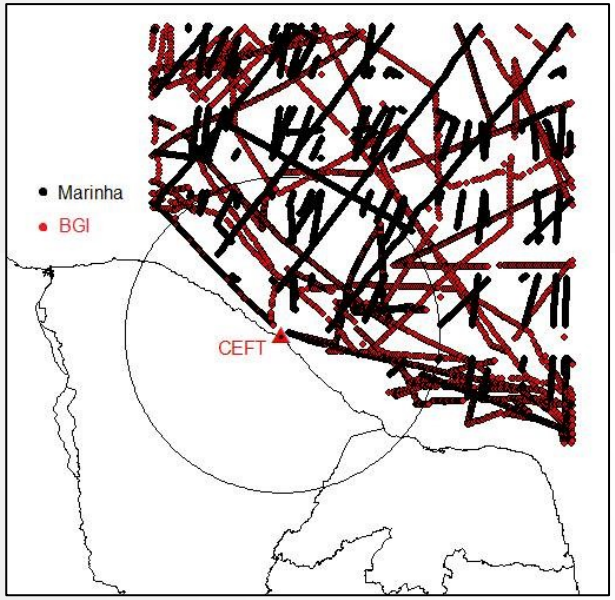


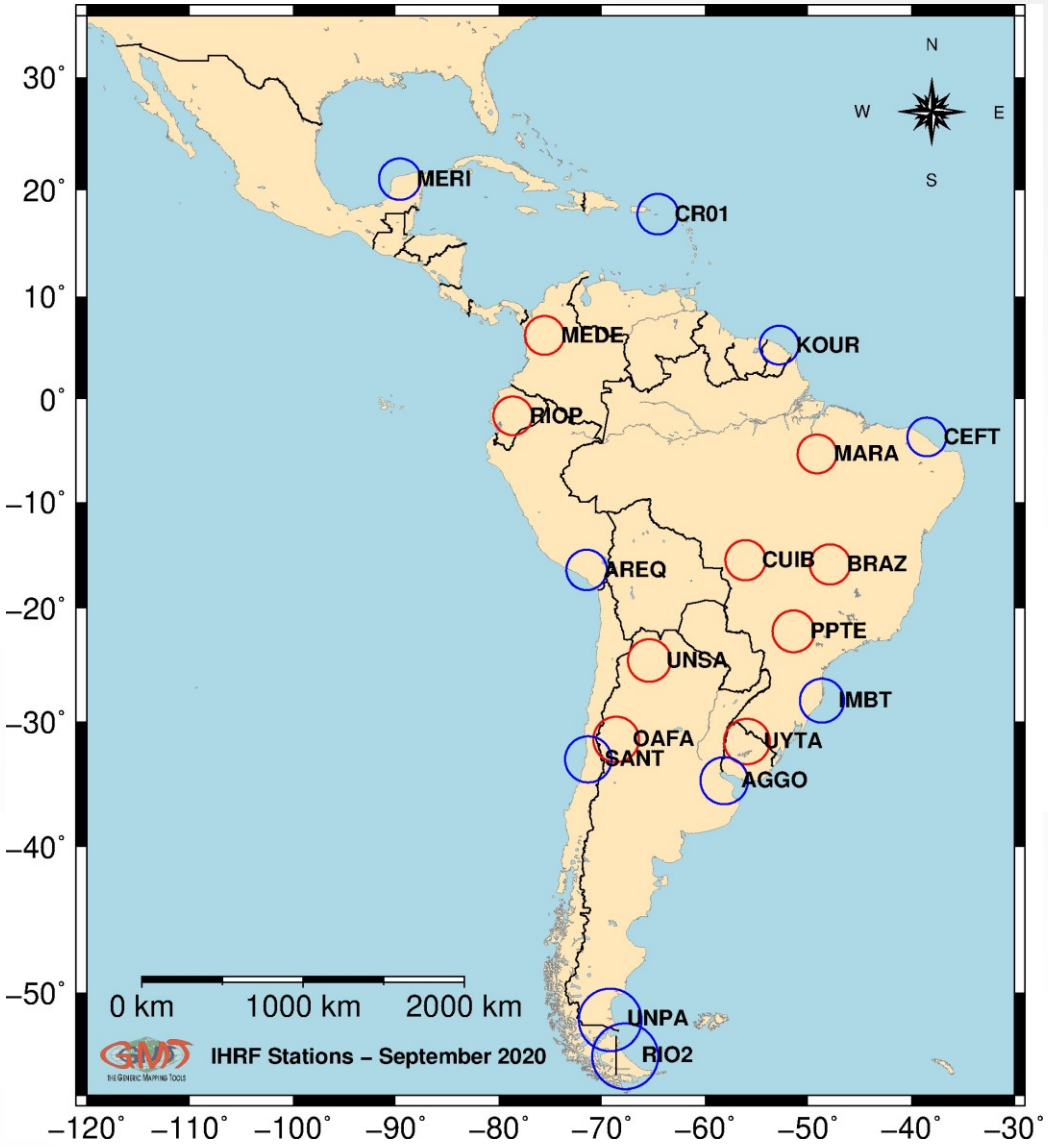
Diagnóstico das estações IHRF







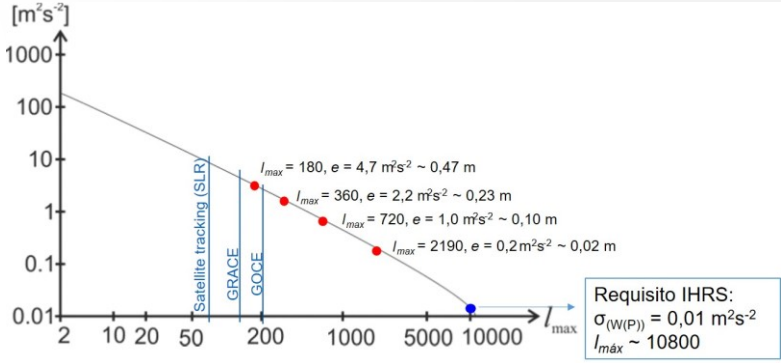


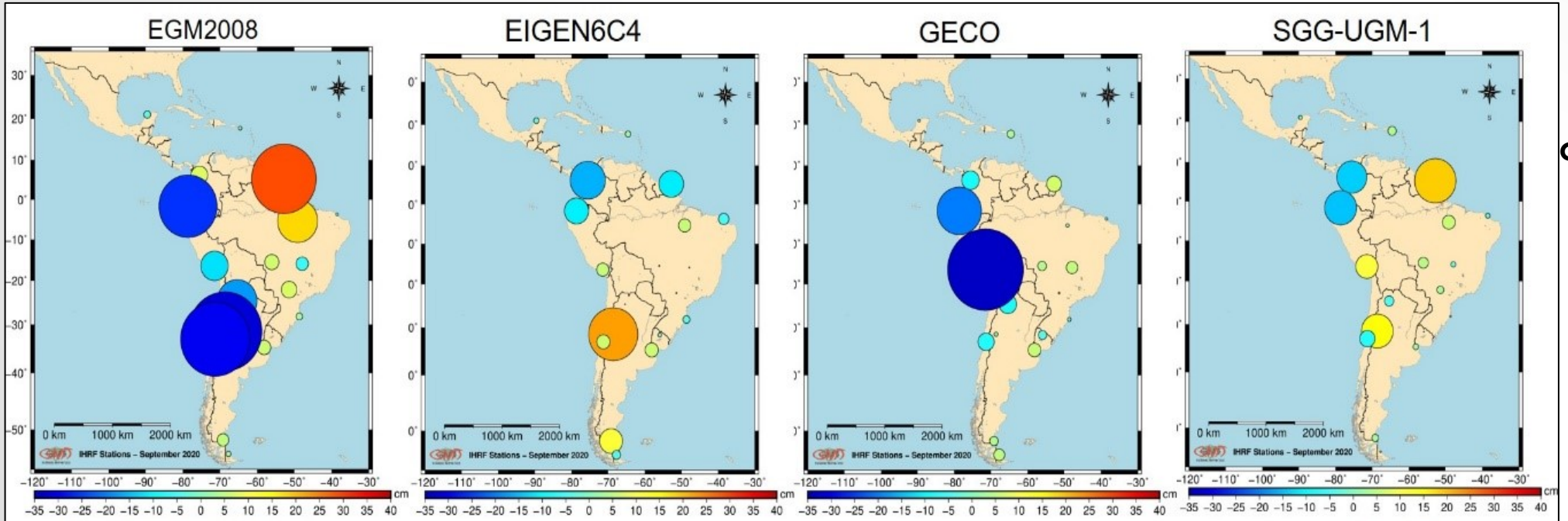


Possibilidades para determinar as coordenadas IHRF

1) Modelos Globais do Geopotencial de alta resolução

$$W(X,Y,Z) = \frac{GM}{r}\left[1 + \sum_{n=1}^{\infty}\left(\frac{a}{r}\right)^n \sum_{m=0}^{n}[C_{nm}cosm\lambda + S_{nm}senm\lambda]P_{nm(cos\theta)}\right] + \frac{1}{2}\omega^2 r^2 cos(90° - \theta)$$





EGM2008	EIGEN6C4	GECO	SGG-UGM-1
Valor medio: −2,33 cm,	Valor medio: 0,24 cm,	Valor medio: -2,60 cm,	Valor medio: 1,07 cm,
Std: ±15,85 cm,	Std: ±8,56 cm,	Std: ±10,13 cm,	Std: ±8,22 cm,
Min: −32,98 cm,	Min: −16,05 cm,	Min: −34,45 cm,	Min: −14,56 cm,
Max: 28,97 cm	Max: 22,44 cm	Max: 6,66 cm	Max: 18,78 cm

Comparação com o modelo XGM2019

Possibilidades para determinar as coordenadas IHRF

1) Modelos Globais do Geopotencial de alta resolução

Comparação do Modelo Geoidal GEOID2015 com os MGGs

Cálculo da anomalia de altura ζ nas 17 estações:

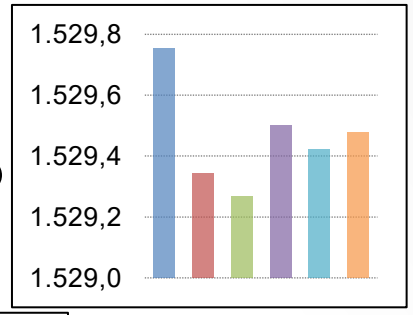
$$\zeta - N \cong -\frac{\Delta g_B}{\gamma} H^o$$

Δg_B → XGM2019 (n_{max} = 2190)

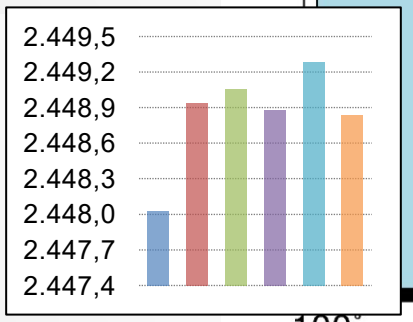
H^o → h - N, SRTM15+ V2.0

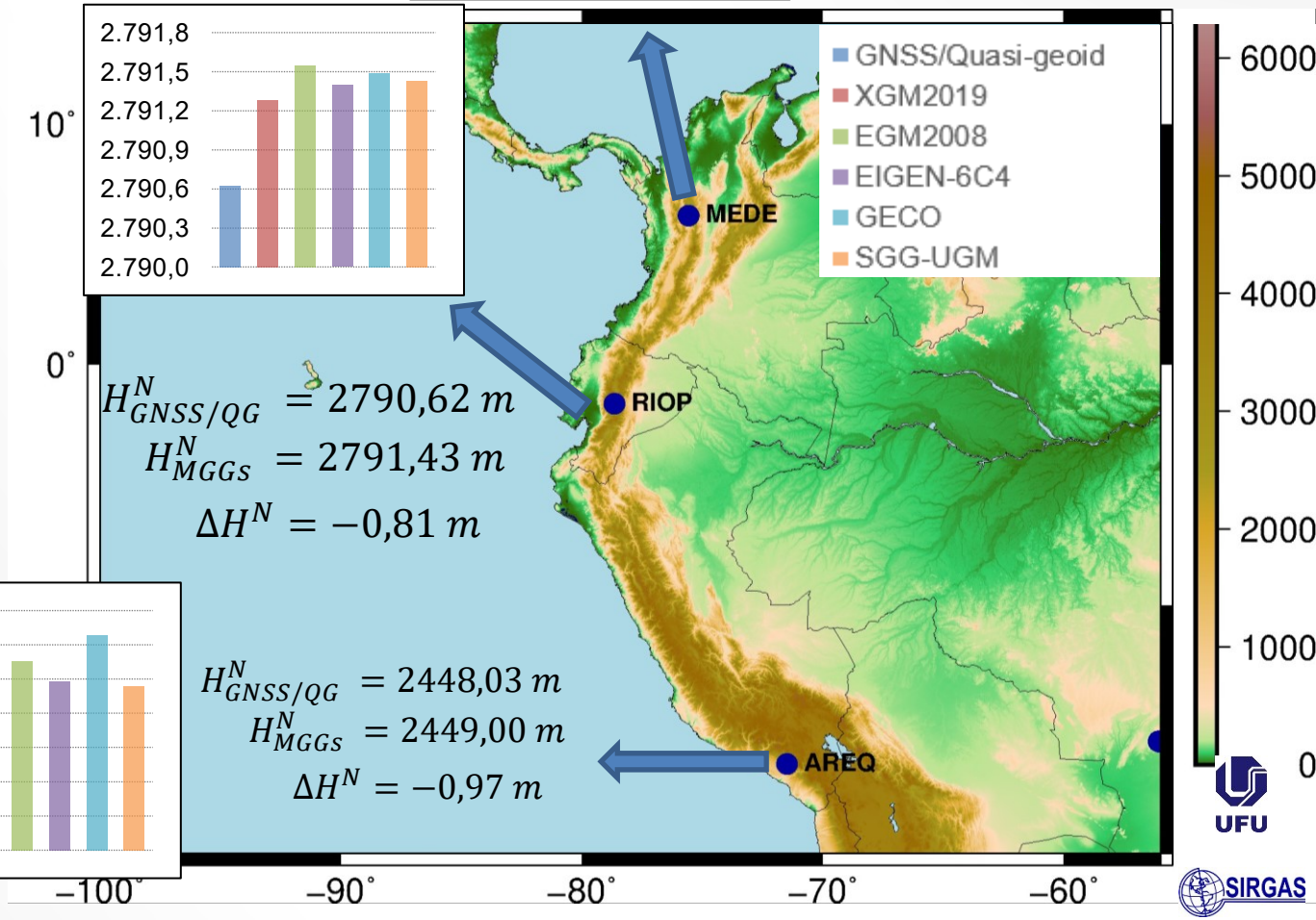
N → GEOID2015 América do Sul

- ✓ Sistema de Referência GRS-80
- ✓ Sistema de maré: *mean tide*
- ✓ *Zero degree term*: -0,93 m



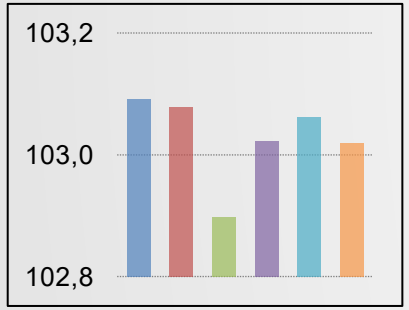
$H^N_{GNSS/QG} = 1529{,}75\ m$
$H^N_{MGGs} = 1529{,}40\ m$
$\Delta H^N = 0{,}35\ m$





$H^N_{GNSS/QG} = 2790{,}62\ m$
$H^N_{MGGs} = 2791{,}43\ m$
$\Delta H^N = -0{,}81\ m$

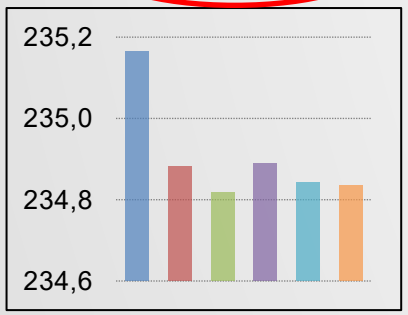
$H^N_{GNSS/QG} = 2448{,}03\ m$
$H^N_{MGGs} = 2449{,}00\ m$
$\Delta H^N = -0{,}97\ m$



$H^N_{GNSS/QG} = 103{,}09\ m$

$H^N_{MGGs} = 103{,}02\ m$

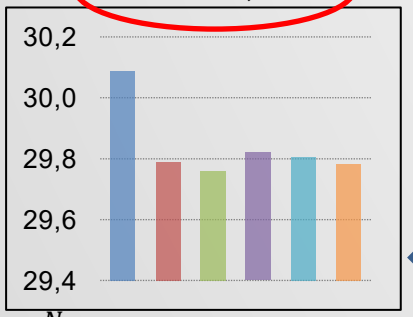
$\Delta H^N = 0{,}07\ m$



$H^N_{GNSS/QG} = 235{,}16\ m$

$H^N_{MGGs} = 234{,}85\ m$

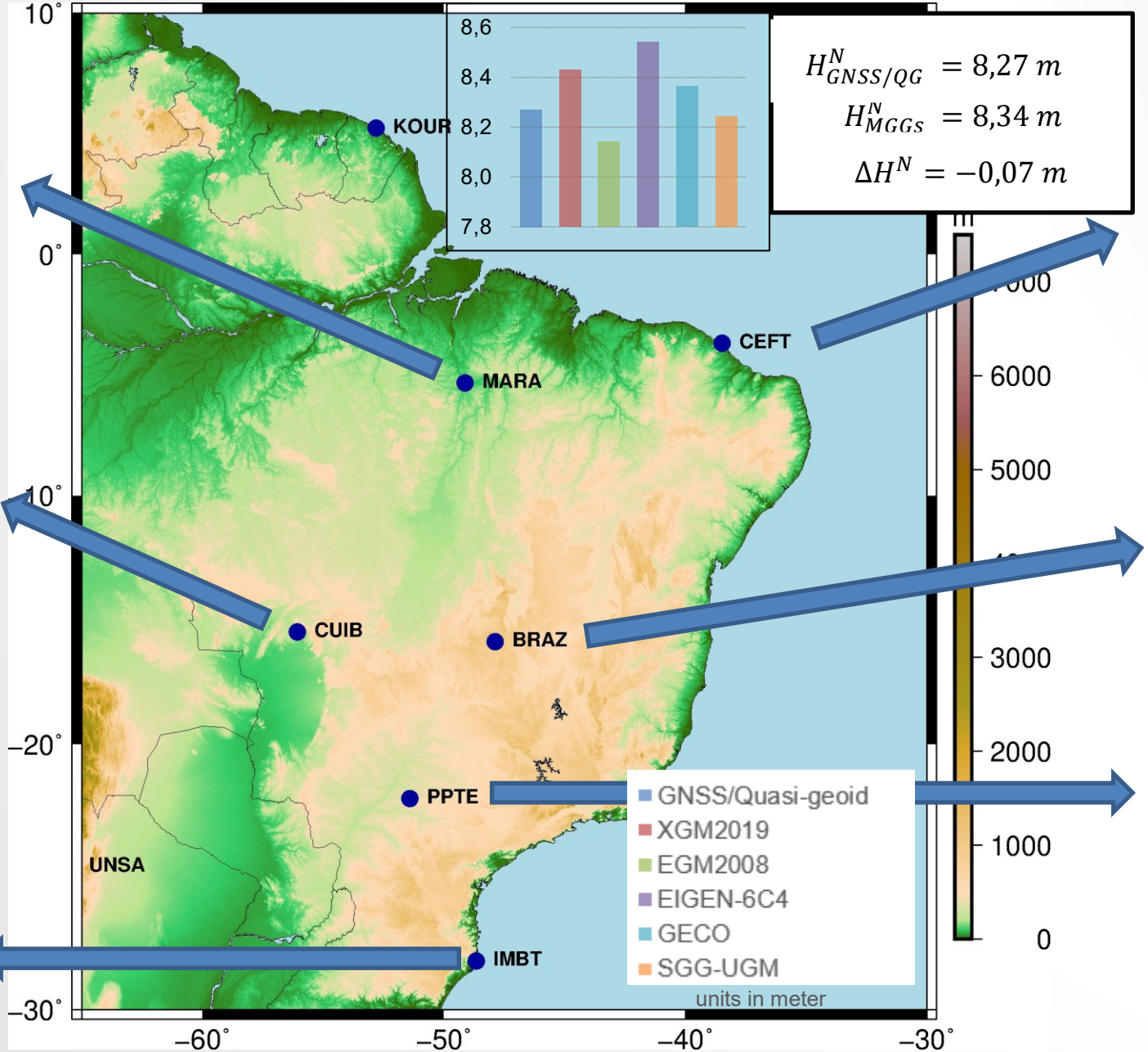
$\Delta H^N = 0{,}31\ m$

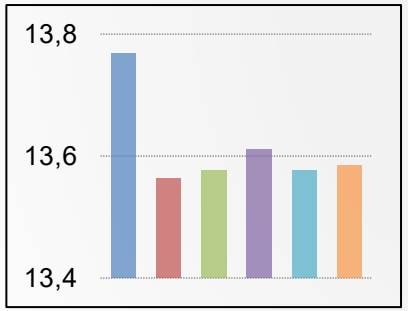


$H^N_{GNSS/QG} = 30{,}09\ m$

$H^N_{MGGs} = 29,79\ m$

$\Delta H^N = 0{,}70\ m$

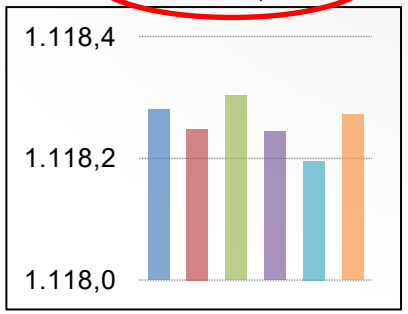




$H^N_{GNSS/QG} = 13{,}77\ m$

$H^N_{MGGs} = 13{,}58\ m$

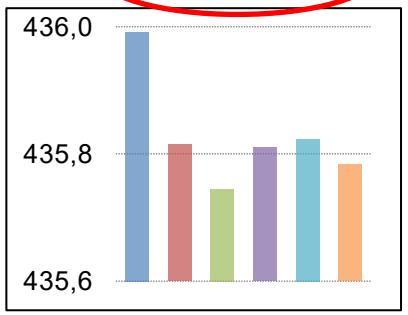
$\Delta H^N = 0{,}19\ m$



$H^N_{GNSS/QG} = 1118{,}28\ m$

$H^N_{MGGs} = 1118{,}25\ m$

$\Delta H^N = 0{,}03\ m$

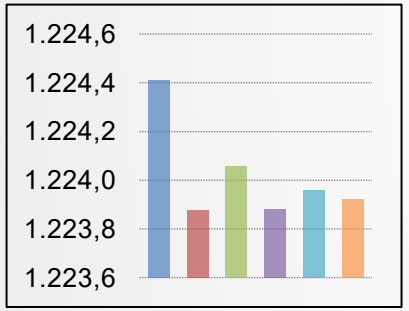


$H^N_{GNSS/QG} = 435{,}99\ m$

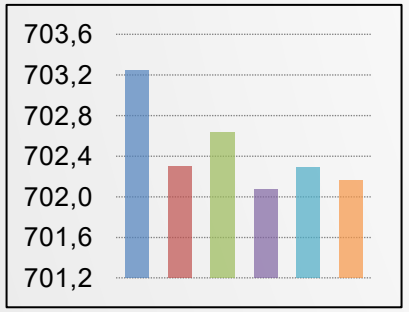
$H^N_{MGGs} = 435{,}80\ m$

$\Delta H^N = 0{,}19\ m$

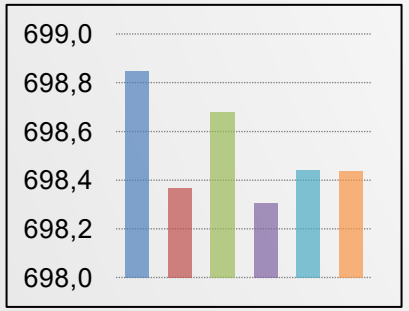
$H^N_{GNSS/QG} = 1224{,}41\ m$
$H^N_{MGGs} = 1223{,}94\ m$
$\Delta H^N = 0{,}47\ m$



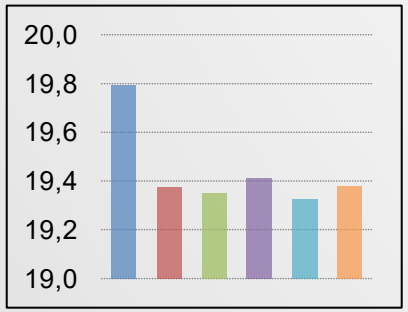
$H^N_{GNSS/QG} = 703{,}25\ m$
$H^N_{MGGs} = 702{,}29\ m$
$\Delta H^N = 0{,}96\ m$

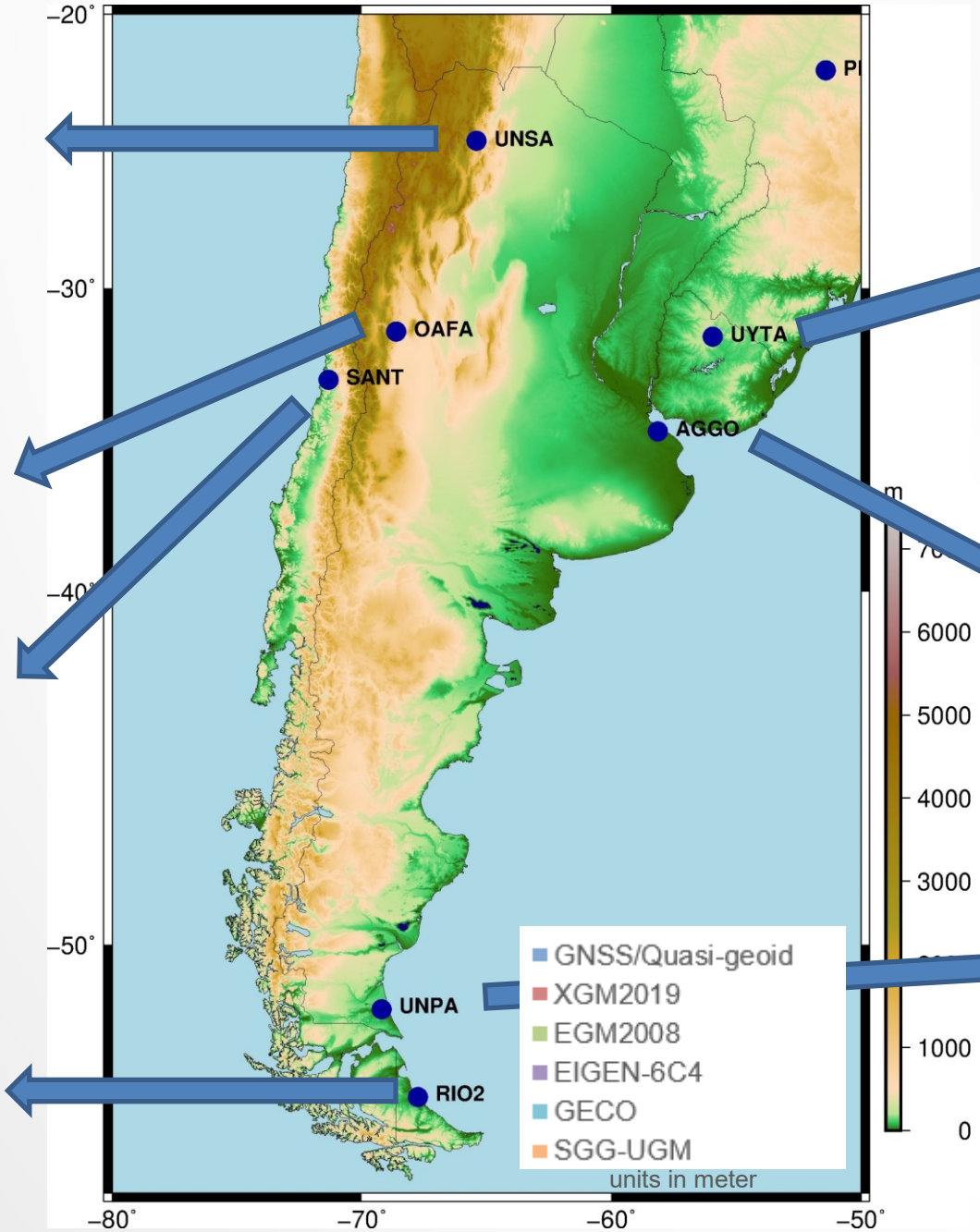


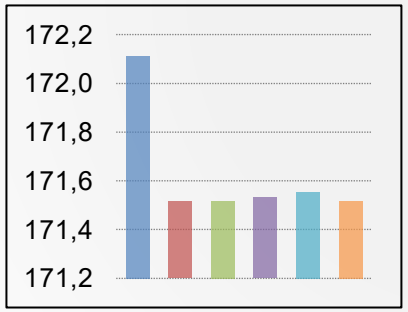
$H^N_{GNSS/QG} = 698{,}85\ m$
$H^N_{MGGs} = 698{,}45\ m$
$\Delta H^N = 0{,}40\ m$



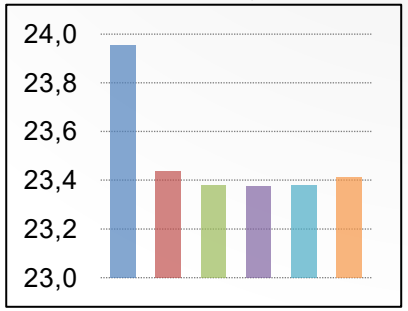
$H^N_{GNSS/QG} = 19{,}79\ m$
$H^N_{MGGs} = 19{,}37\ m$
$\Delta H^N = 0{,}43\ m$



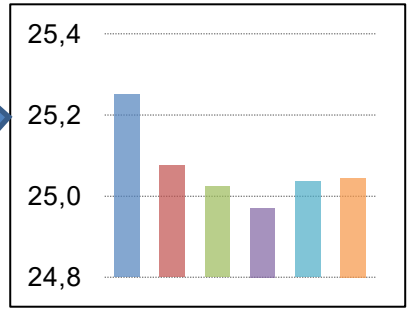




$H^N_{GNSS/QG} = 172{,}11\ m$
$H^N_{MGGs} = 171{,}53\ m$
$\Delta H^N = 0{,}58\ m$



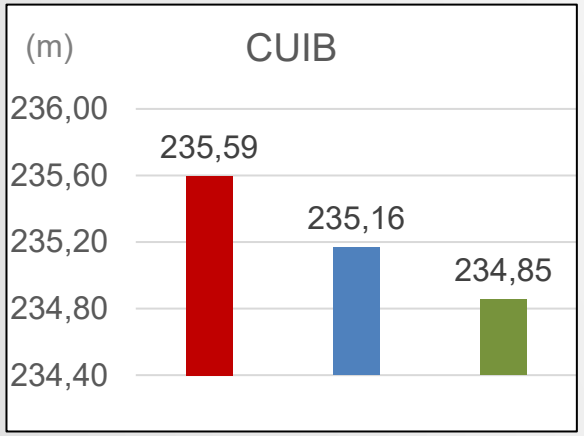
$H^N_{GNSS/QG} = 23{,}95\ m$
$H^N_{MGGs} = 23{,}40\ m$
$\Delta H^N = 0{,}56\ m$

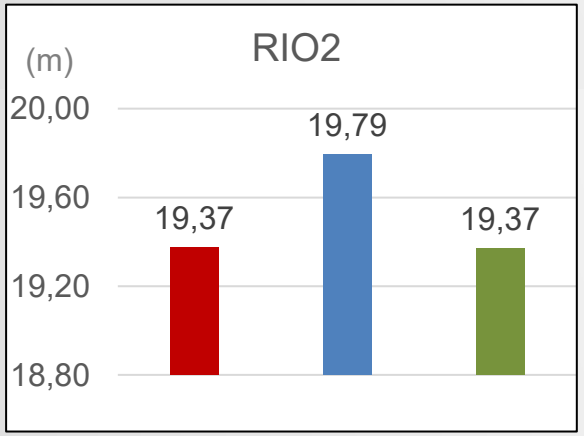


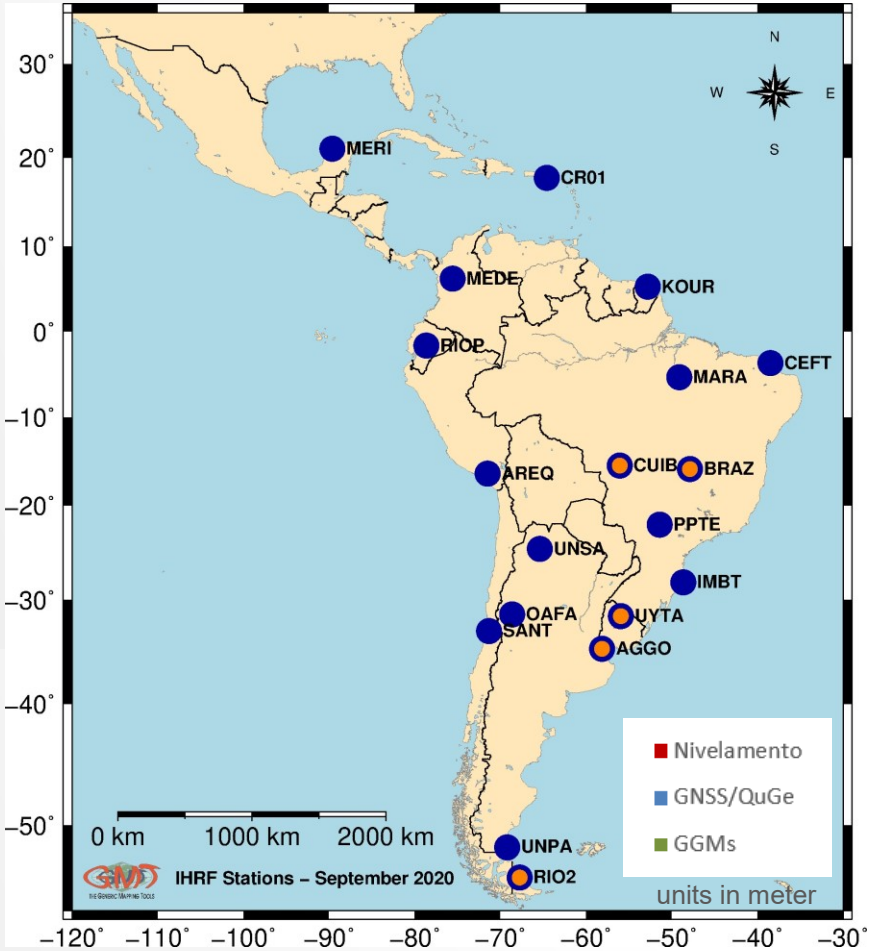
$H^N_{GNSS/QG} = 25{,}25\ m$
$H^N_{MGGs} = 25{,}03\ m$
$\Delta H^N = 0{,}22\ m$

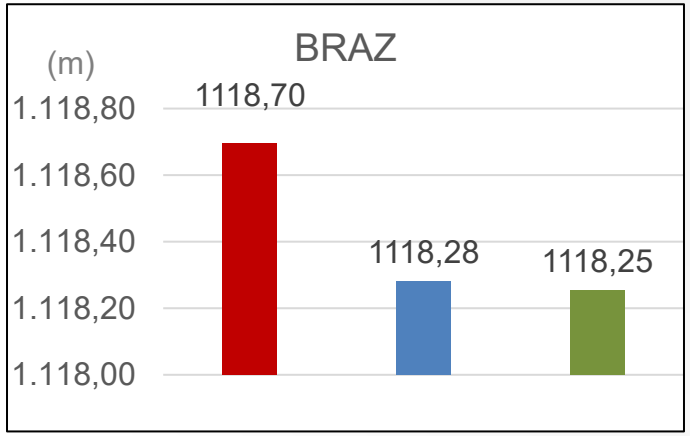
Possibilidades para determinar as coordenadas IHRF

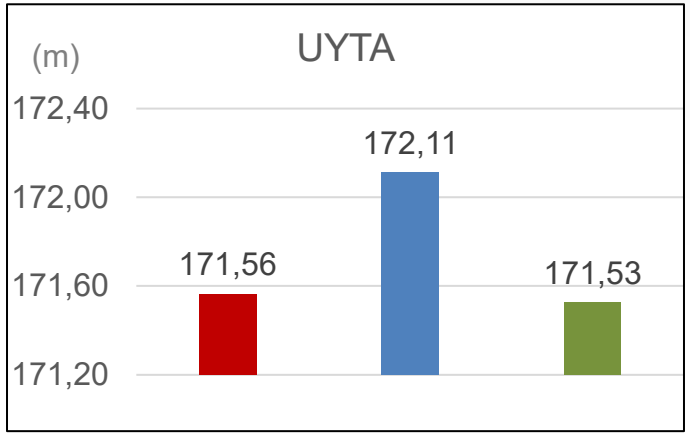
1) Modelos Globais do Geopotencial de alta resolução

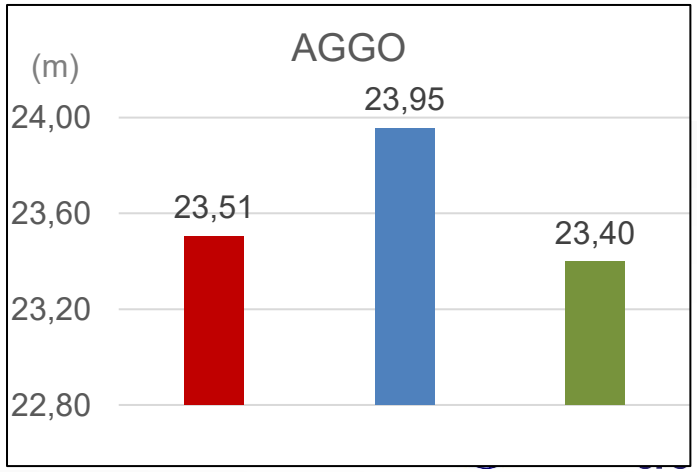












Possibilidades para determinar as coordenadas IHRF

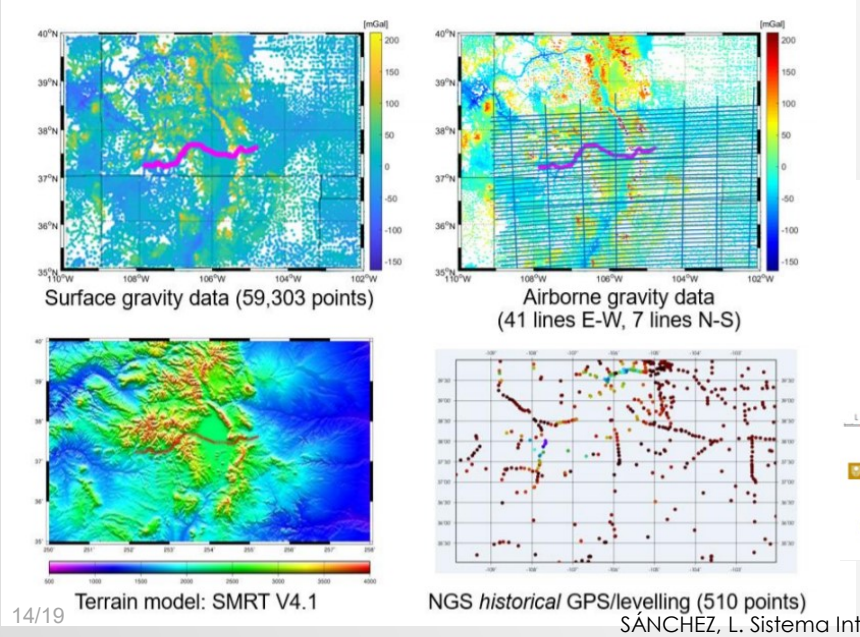
2) Cálculo regional do campo de gravidade (metodologia para determinar o geoide/quase-geoide)

$$W_P = U_P + T_P \Longrightarrow T_P = T_{P,satellite-only} + T_{P,residual} + T_{P,terrain}$$

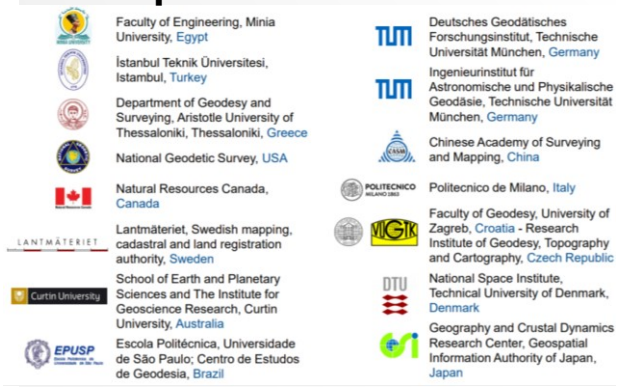
MGG — Gravimetria — MDT

Potencial Perturbador (m^2/s^2) GOCO n=m=200			
Estações	**Integral de Hotine**	**CMQ**	**Diferença**
BRAZ	-118,732	-116,847	-1,885
PPTE	-46,982	-45,744	-1,238
CUIB	24,516	25,757	-1,241
CEFT	-83,048	-82,544	-0,504
MARA	-225,772	-225,850	0,078
IMBT	21,331	17,327	4,004

GUIMARÃES, G.N.; BLITZKOW, D ; MATOS, A.C.O.C ; MENDONCA, L. R. . First Efforts for the IHRF Establishment in Brazil by Least Squares Collocation and Numerical Integration. In: 27th IUGG General Assembly, 2019, Montreal. 27th IUGG General Assembly Proceedings, 2019.



Experimento Colorado

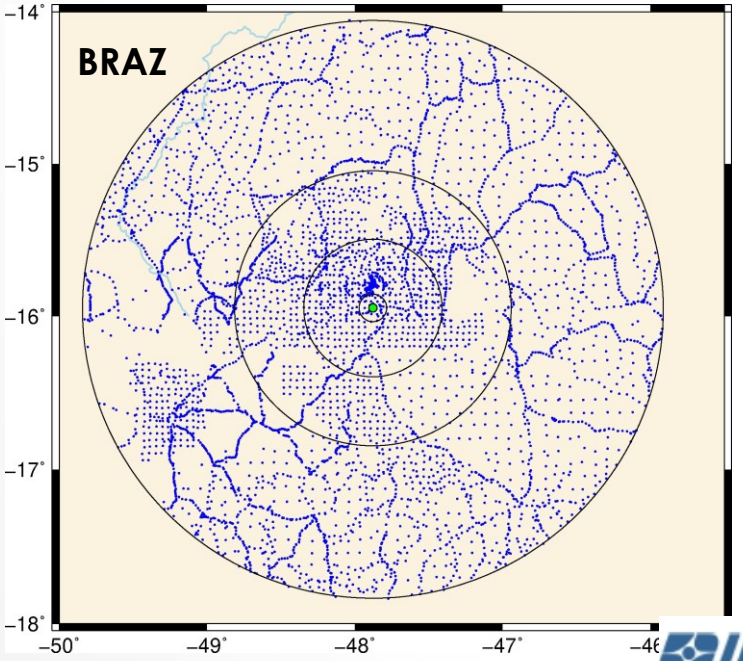


- ✓ **GGMs:** GOCO05s, XGM2016, XGM2018, xGEOID17B, EIGEN-6C4, EGM2008
- ✓ **MDTs**: SRTM V4.1, EARTH2014, COLH19M05, ERTM2160
- ✓ **Metodologias**:
  - Integração FFT e modificação na fórmula de Stokes (Wong-Gore).
  - Modificação por mínimos quadrados na fórmula de Stokes e correções adicionais
  - Colocação por mínimos quadrados
  - Estratégia Helmert-Stokes (H-S)
  - Integração de Hotine

Possibilidades para determinar as coordenadas IHRF

2) Cálculo regional do campo de gravidade (metodologia para determinar o geoide/quase-geoide)

- ✓ **MGG:** XGM2019 n=m=200
- ✓ **MDT**: SRTM15 plus
- ✓ **Metodologias**:
  - Colocação por mínimos quadrados (CMQ)
  - Integração de Hotine



http://www.ibge.gov.br/

CMQ

$$W_P = 62.625.913{,}73\ (\mathrm{m}^2/\mathrm{s}^2)$$

Hotine

$$W_P = 62.625.912{,}55\ (\mathrm{m}^2/\mathrm{s}^2)$$

$$Diferença = 1{,}18\ (\mathrm{m}^2/\mathrm{s}^2) \sim 12\ \mathrm{cm}$$

$$C_P = W_0 - W_P \qquad H_{fis} = \frac{C_P}{\bar{g}\ ou\ \gamma}$$

$$H_{CMQ} = 1118{,}299\ \mathrm{m}$$

$$H_{Hotine} = 1118{,}420\ \mathrm{m}$$

IBGE **Relatório de Estação Geodésica**

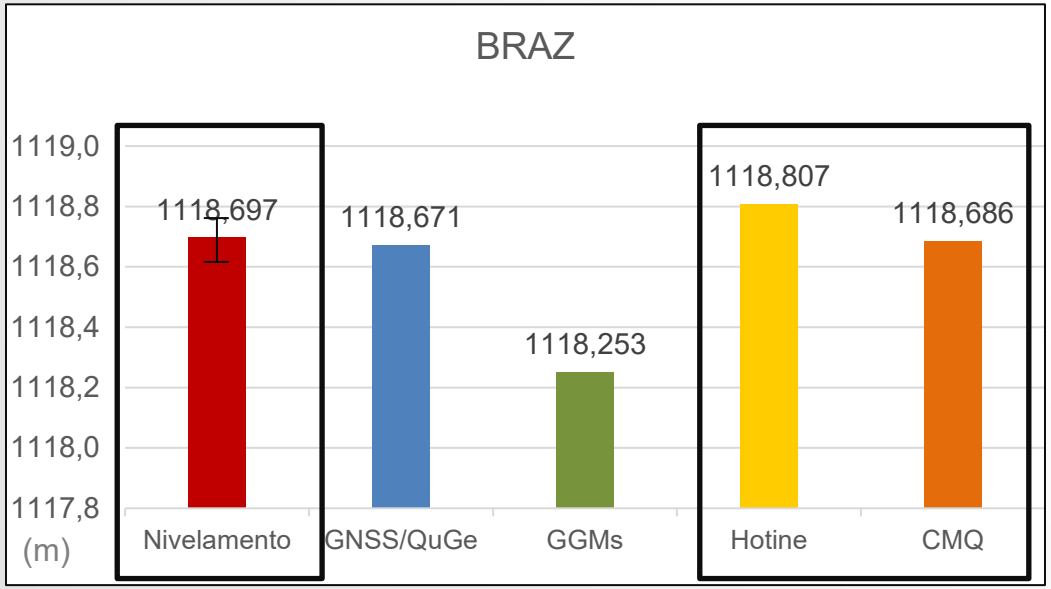
Estação :	91200	*Nome da Estação :*	91200
Município :	BRASÍLIA		
Última Visita:	12/07/2005	*Situação Marco Principal :*	BOM
Conexões :	RN : 2369V		

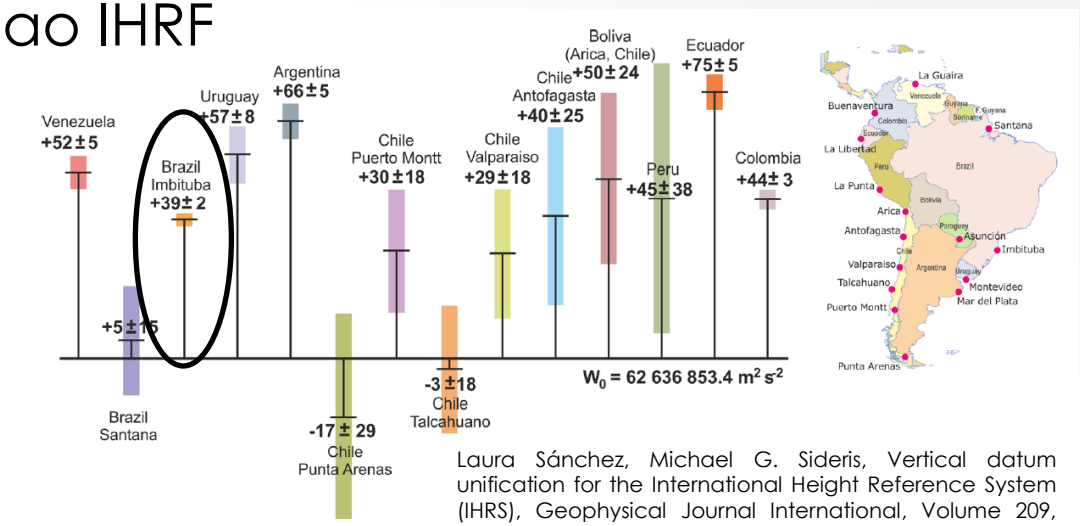
DADOS PLANIALTIMÉTRICOS		DADOS ALTIMÉTRICOS	
Latitude	15º 56' 50,91123" S	*Altitude Normal(m)*	1.118,6967
Longitude	47º 52' 40,32834" W	*Fonte*	Nivelamento Geométrico
Altitude Geométrica(m)	1.106,020	*Sigma Altitude(m)*	0,071
Fonte	GPS Geodésico	*Datum*	Imbituba
Origem	Ajustada	*Data Medição*	14/11/1994
Datum	SIRGAS2000	*Data Cálculo*	30/07/2018
Data Medição	15/05/2000	*Número Geopotencial (m²/s²)*	10.943,649
Data Cálculo	23/11/2004		
Sigma Latitude(m)	0,001		
Sigma Longitude(m)	0,001		
Sigma Altitude Geométrica(m)	0,001		
UTM(N)	8.234.747,340		
UTM(E)	191.901,219		
MC	-45		

Possibilidades para determinar as coordenadas IHRF

3) Conversão dos sistemas de altitudes existentes ao IHRF

$$W_P = \left(W_0^{local} + \delta W\right) - C_P; \qquad \delta W = W_0^{IHRF} - W_0^{local}$$





Laura Sánchez, Michael G. Sideris, Vertical datum unification for the International Height Reference System (IHRS), Geophysical Journal International, Volume 209, Issue 2, May 2017, Pages 570–586,

Considerações Finais

- ✓ Há países mais "adiantados" em relação a outros:
  - Altitudes expressas com base no número geopotencial
  - Densificação gravimétrica no entorno das estações IHRF e medição absoluta de gravidade
  - Conexão GNSS com nivelamento
  - Conexões internacionais
- ✓ Contínua capacitação para que aqueles países "atrasados" possam atender às demandas.

- ✓ Os valores de potencial (coordenadas IHRF) dependem:
  - Dados de entrada: MGGs, gravimetria (terrestre, marinha e aérea), modelos topográficos e a manipulação desses dados.
  - Métodos de cálculo.
  - Aproximações e modificações em certas regiões específicas.
- ✓ Padrões devem ser tomados e adotados com o objetivo de alcançar resultados que sejam compatíves e consistentes:
  - Elipsoide de referência
  - Sistema de marés
  - Constantes físicas e númericas

IUGG
IAG GGOS Global Geodetic Observing System
Bureau of Products and Standards

Considerações Finais

✓ Contínua divulgação e explanação para a comunidade geodésica (específica) e usuária (geral)

- O que é? Como funciona? O que altera após a adoção? E as altitudes vinculadas ao sistema "classico"? Qual altitude utilizar? Como converter?

SAD69 ⟹ SIRGAS2000

- Papel das Universidades, institutos geográficos e de pesquisas e organizações da área (SIRGAS e IAG)

Agradecimentos

- ✓ SIRGAS e ao Grupo de Trabalho III do SIRGAS – Datum vertical (Sônia M. A. Costa, Diego Piñon e Sílvio R. C. de Freitas)
- ✓ GGOS JWG: *Strategy for the realisation of the IHRS* (Laura Sánchez)
- ✓ Denizar Blitzkow e Ana Cristina O. C. de Matos

www.sirgas.org

Obrigado pela atenção!

gabriel@ufu.br