SIRGAS2018 GEOCENTRIC REFERENCE SYSTEM FOR THE AMERICAS

Aguascalientes, Mexico

Preliminary tests on BVRN new representation through Normal Heights based on GGMs and discrete GNSS observations

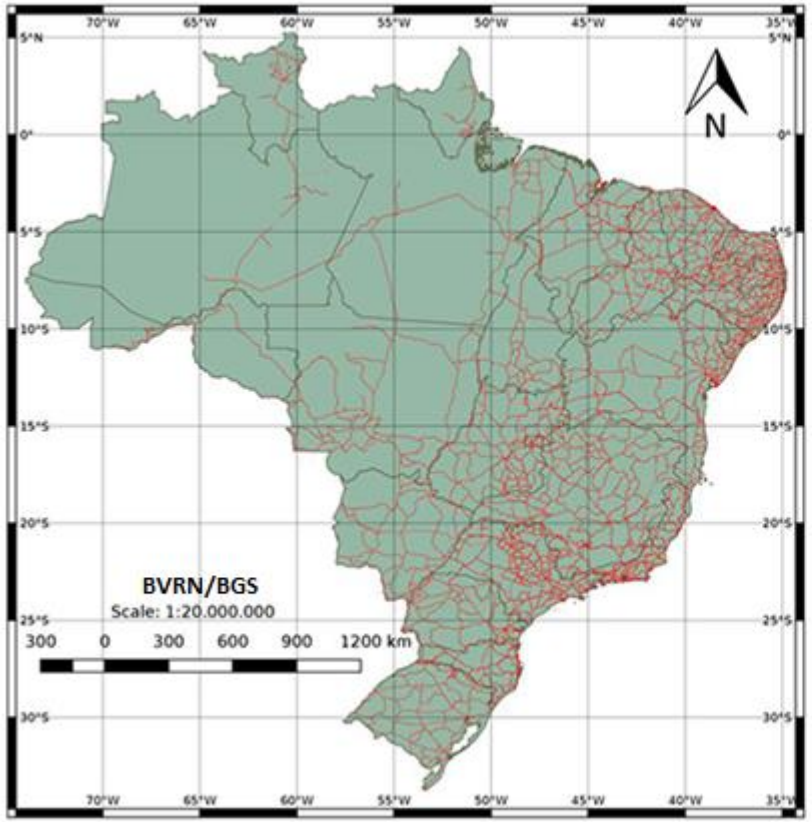
E. ***Nicacio*** *&* *R.* ***Dalazoana*** *&* *S. R. C.* ***De Freitas***

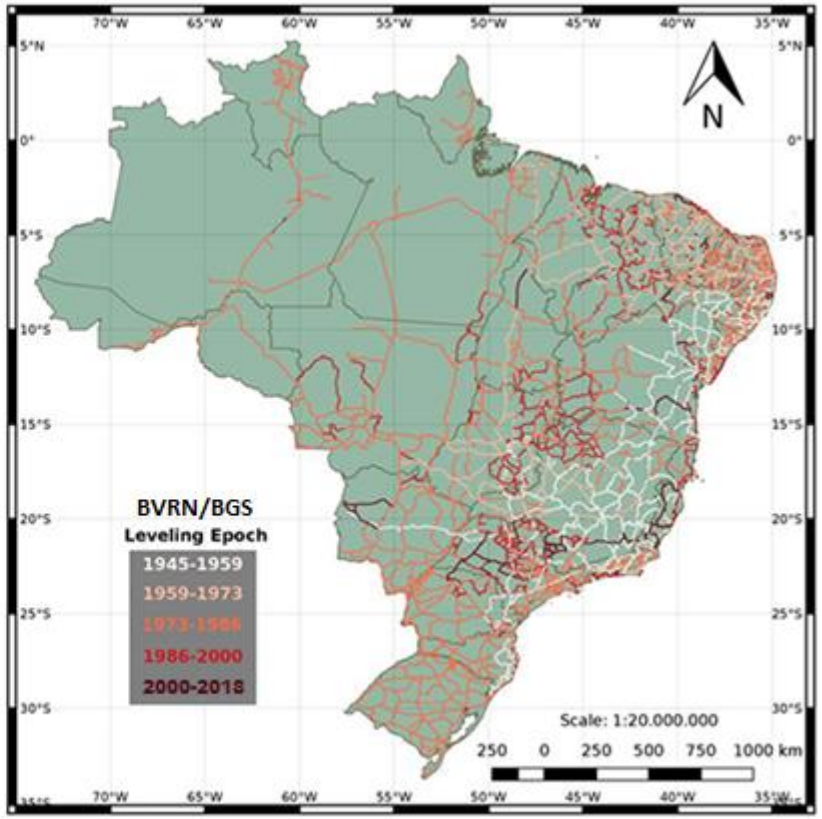
Aguascalientes, Mexico – November 11th, 2018

Introduction

- Brazilian Vertical Reference Network (BVRN)
  - One of the networks that integrate the Brazilian Geodetic System (BGS) and under responsibility of Brazilian Institute of Geography and Statistics (IBGE);

- Currently: ~ 70,000 benchmarks
- 2 reference tide gauges: DVB-I (Imbituba-SC) and DVB-S (Santana-AP);

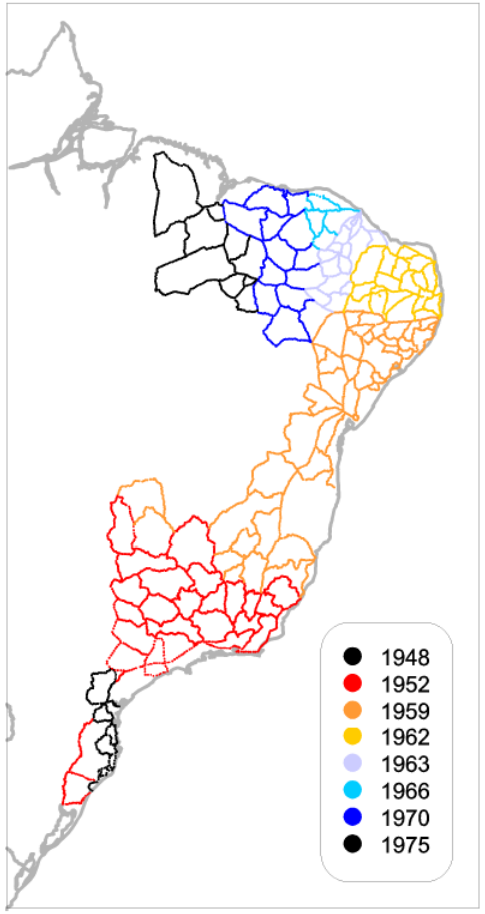




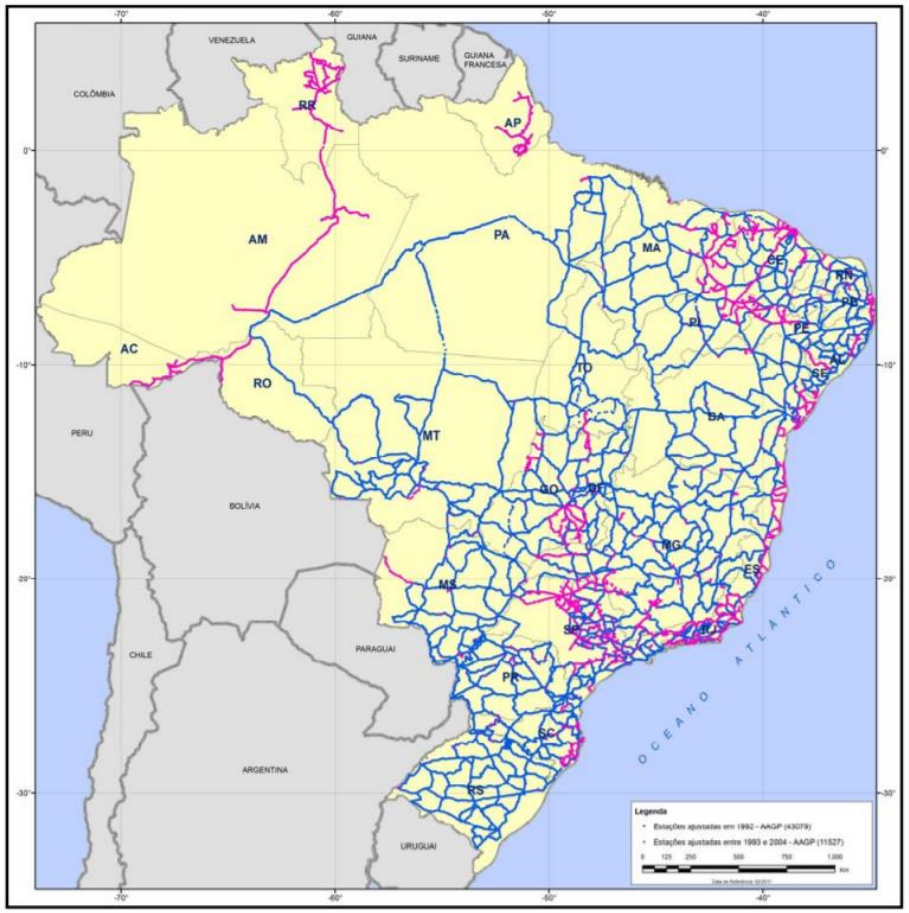
Source: Nicacio e Dalazoana (2018) and IBGE (2018).

Introduction

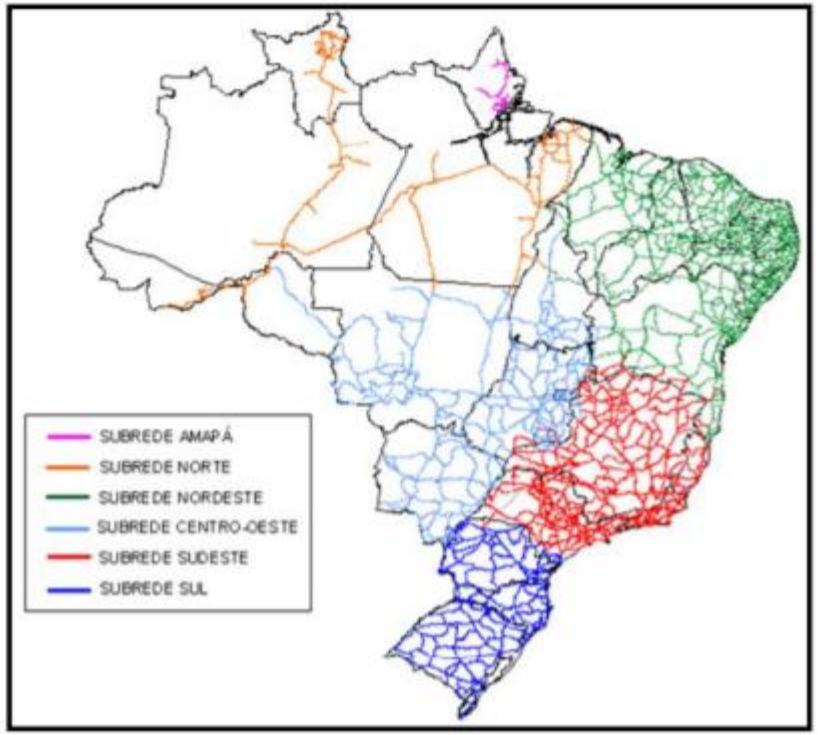
- BVRN historical evolution milestones



Previous BVRN adjustments (1948-1975)



Preliminary Global Altimetric Adjustment [AAGP] (1992-2004)



Global BVRN adjusment (2005-2011)

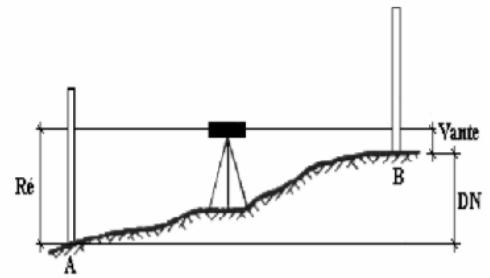
- GHOST software – NRCan
- Helmert's blocking division – subnetworks
- Normal-orthometric correction

$$\delta H^{NOrt} \approx -2\,\alpha_1\,H_m\,\Delta\varphi\,sen(2\varphi_m)\,[1+(\alpha_1-2\alpha_2/\alpha_1)\,cos(2\varphi_m)]$$

Source: Luz (2007), IBGE (2011), Nicacio (2017) and IBGE (2018).

Introduction

- BVRN current adjustment (released in July 30th, 2018)
  - Adjustment in terms of geopotential numbers; altimetric information in form of normal heights



$$+ g_{obs/interp} = \Delta C$$

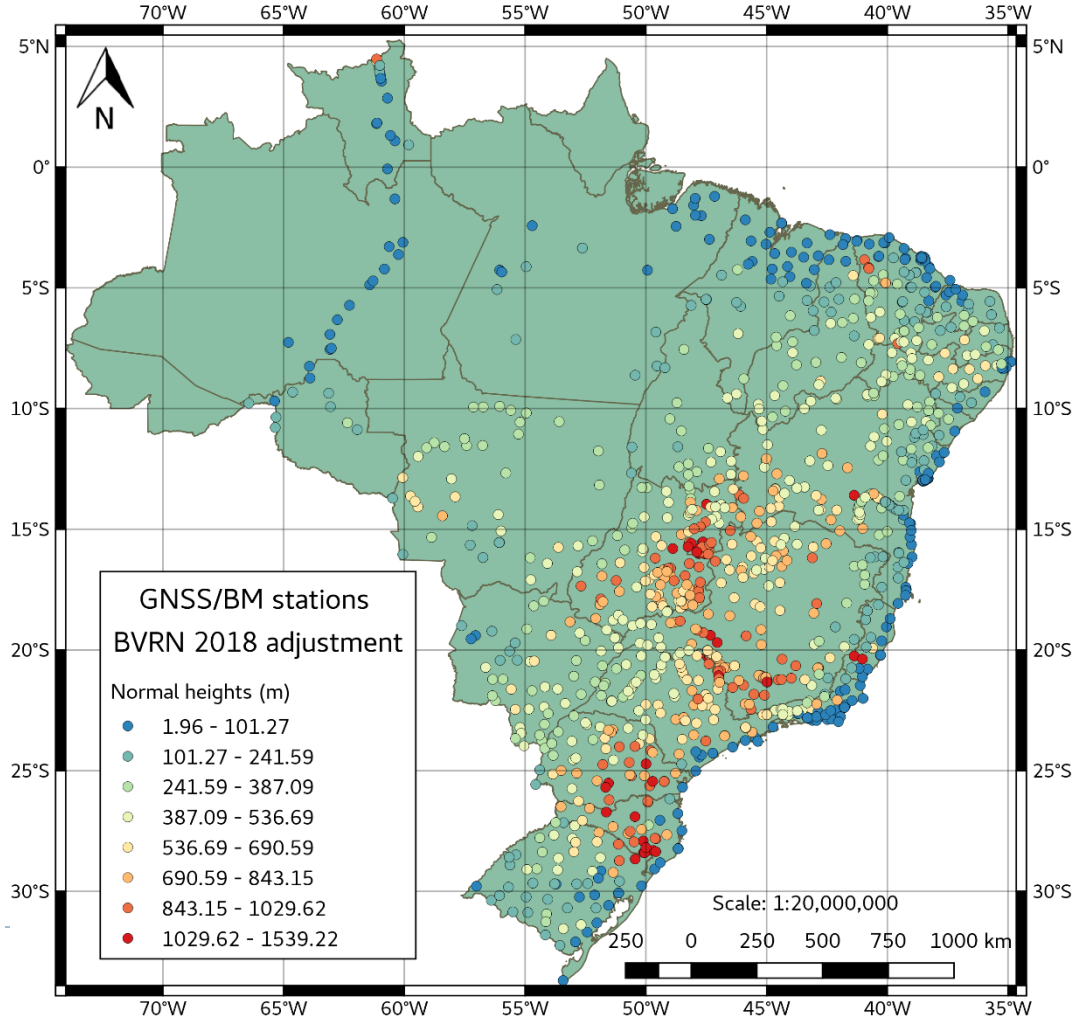
$$\Delta C_{AB} = C_B - C_A = -(W_A - W_B) \cong g^{AB}_{obs/interp} \cdot \Delta \mathrm{H}^{AB}_{obs}$$

$$\Delta C \rightarrow X = N^{-1}U \rightarrow C_{adj}$$

$$H^N = C_{adj}/\bar{\gamma}$$

$$\bar{\gamma} = \gamma_0 \left[1 - \frac{2}{a}(1 + f + m - 2f\,sen^2\varphi)H^N + 3\left(\frac{H^N}{a}\right)^2\right]$$

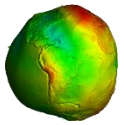
$$\gamma_0 = \frac{a\,\gamma_e \cos^2\varphi + b\,\gamma_p\,\mathrm{sen}^2\,\varphi}{\sqrt{a^2\cos^2\varphi + b^2\,\mathrm{sen}^2\,\varphi}}\;;\; m = \frac{\omega^2 a^2 b}{GM}$$



Nicacio & Dalazoana & De Freitas

Source: adapted from Nicacio et al. (2017), Luz et al. (2017) and IBGE (2018).

Introduction



- Preliminary tests on BVRN normal heights main objectives

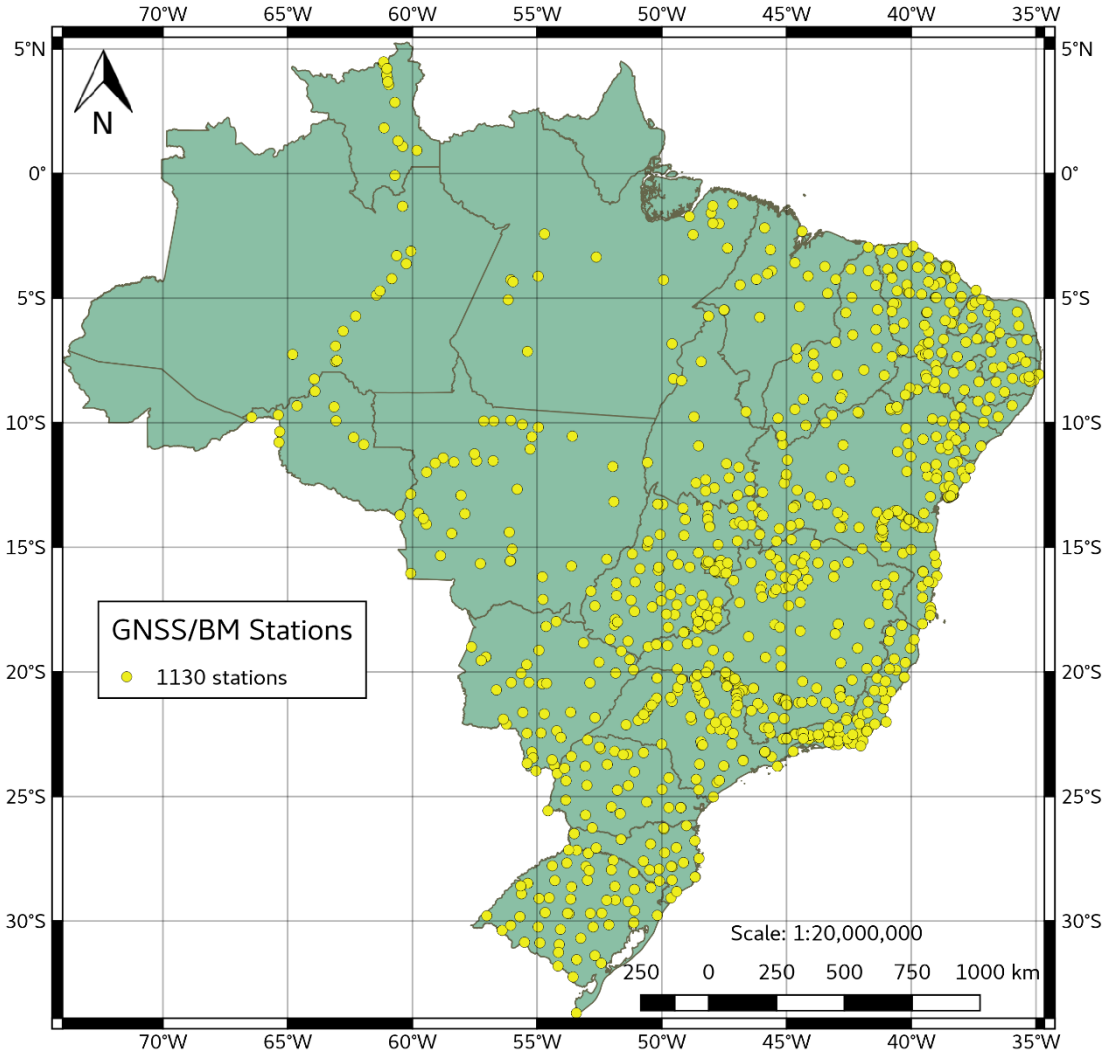
1. Perform comparisons of height anomalies provided from GNSS/BM information (h and H^N data available) with results calculated from GGMs with proven highlighted performance in previous studies/adjustment all along the study area;

2. Identify possible gains/losses with new representation of BVRN benchmarks in terms of normal heights;

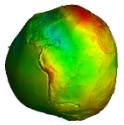
3. Provide IBGE with relevant inconsistencies observed during preliminary tests, in order to enable futher investigation.

Study area

- Brazilian territory;
- 1162 stations of BVRN with connection with IBGE's SAT-GPS network – GNSS/BM stations
  - 1130 GNSS/BM stations - *stable* stations and linked to DVB-I
  - 32 under further investigation or linked to DVB-S
  - Shapefile format [IBGE's BDG] – easier handling;
  - Carry information of both elipsoidal [h] and normal heights [H^N];
  - Non-uniform distribution of stations acceptable for these preliminary tests.



GGMs employed

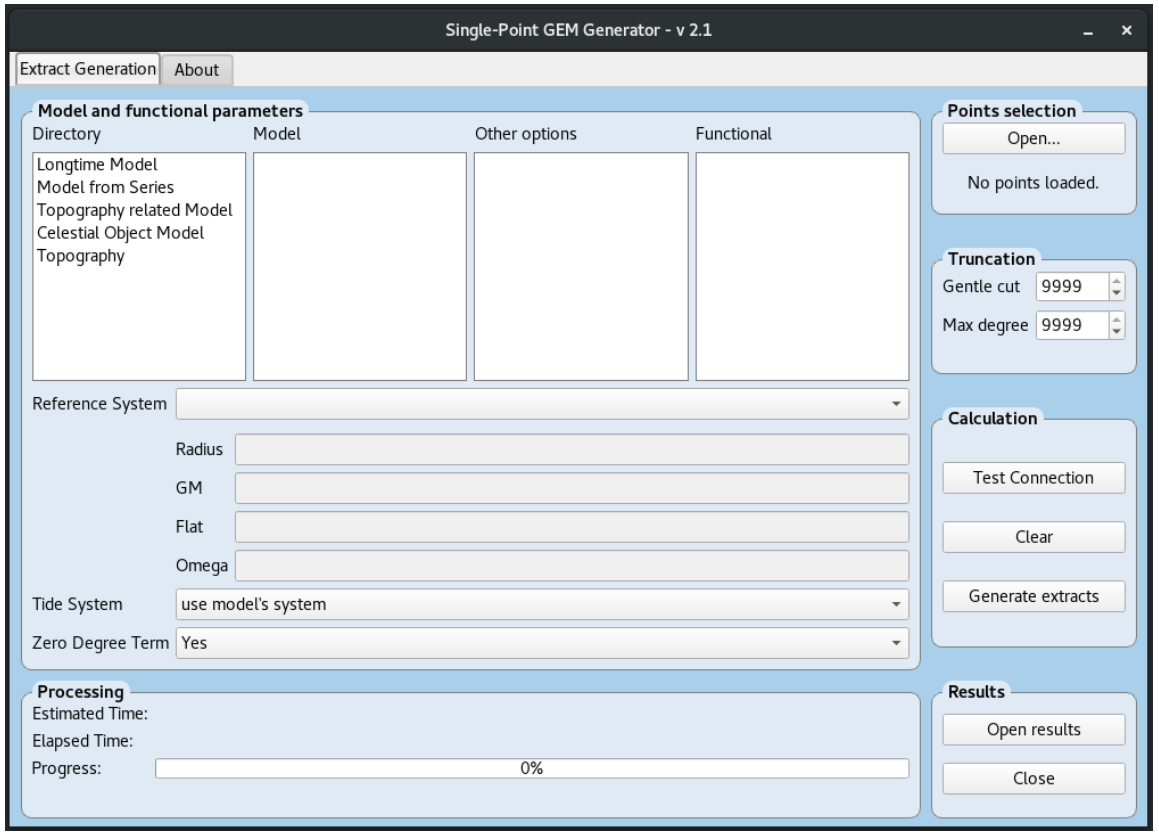


- Selection
  - Main combined GGMs since EGM2008;
  - Proven to be highlights on metric geopotential functionals representation on the study area;
  - Single geopotential functional: height anomaly.

GGM	Harmonic Degree		
EGM2008	2190	-	720
EIGEN-6C4	2190	-	720
SGG-UGM-1	-	2159	720
GOCO05C	-	-	720
XGM2016	-	-	719

- Acquisition
  - SPGG v2.1 [pointwise approach]

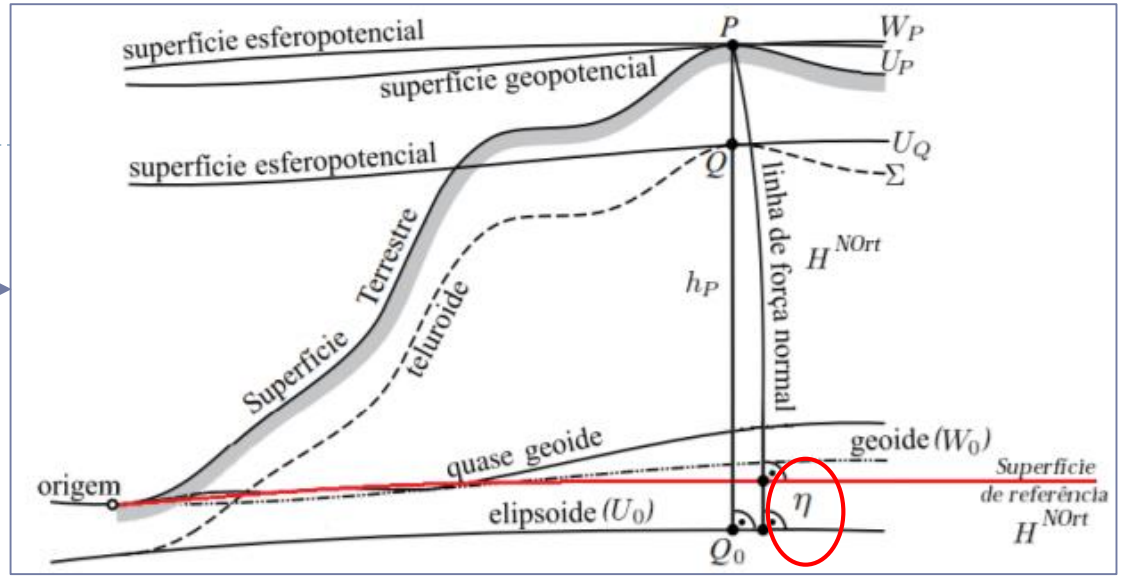
(See: https://euriconicacio.github.io/spgg/help/)

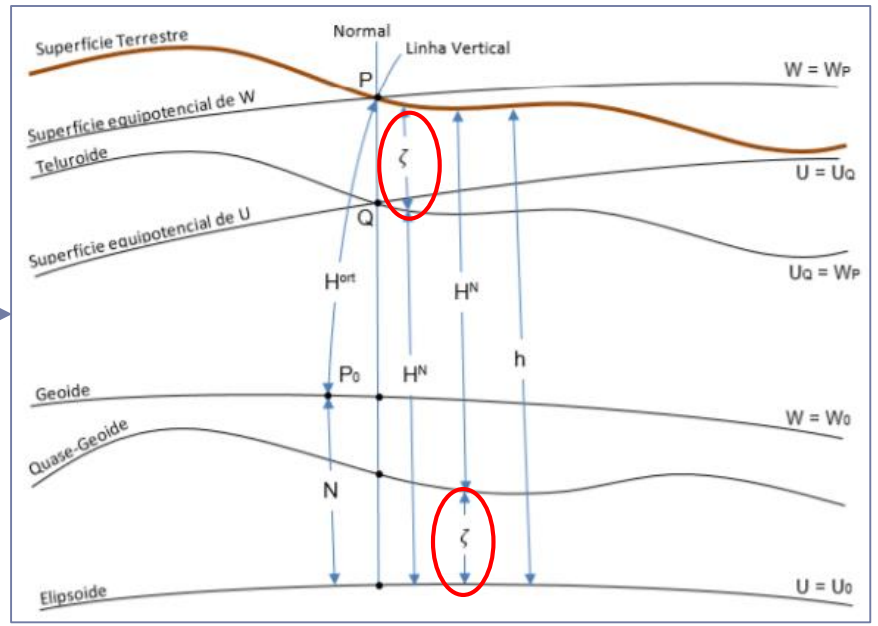


Source: Nicacio (2016), Nicacio et al. (2018) and Nicacio e Dalazoana (2017a).

Height anomalies modelling

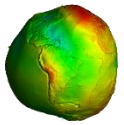
- Previous BVRN adjusment: normal-orthometric heights [H^{NOrt}]
  - Existence of normal-geoid height (η) concept: $h \cong H^{NOrt} + \eta$
  - Normal-geoid heights (η) could be better modelled by height anomalies (ζ) or geoid heights (N), depending on the study área;
- Current BVRN adjusment: normal heights [H^N]
  - Relation between elipsoidal heights (h) and normal heights (H^N) given by height anomalies (ζ): $h \cong H^N + \zeta$





Source: adapted from Ferreira et al. (2011), Nicacio et al. (2017) and Nicacio (2017).

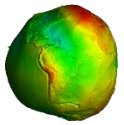
Height anomalies modelling – relative approach



- Featherstone (2001), Sánchez (2016), and Nicacio and Dalazoana (2018):
  - In order to mitigate aditive errors inherent to the processing approach and to the obtaintion method of the GGMs, use of relative approach instead of the absolute one;
  - Absolute approach: $h \cong H^N + \zeta$
  - Relative approach: $\Delta h = \Delta H^N + \Delta\zeta \implies \boxed{\zeta_P = \zeta_0 + h_P - h_0 - H_P^N + \mathrm{H}_0^{\mathrm{N}}}$
  - Prior results confirm this is the most advisable alternative these days, specially under the aspect of vertical reference systems consecution.
- Permanent tide systems compatibilization [Ekman (1989), Mäkinen and Ihde (2006) and Tenzer et al. (2011)]:

$$h_{mean-tide} = h_{tide-free} - \left\{(1 + k - h)\left[-0.198 \times \left(\frac{3}{2} sen^2\phi - \frac{1}{2}\right)\right]\right\}$$

Evaluation criteria

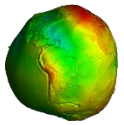


- Optimal configuration (OC) – model with minimum mean difference for the whole set of points

$$\begin{cases} [\zeta_P]_{EGM2008} \\ [\zeta_P]_{EIGEN-6C4} \\ [\zeta_P]_{SGG-UGM-1} \\ [\zeta_P]_{GOCO05C} \\ [\zeta_P]_{XGM2016} \end{cases} \Longrightarrow min\ \theta_P = \left| \left| \zeta_P^{ref} \right| - \left| \zeta_P^{calc} \right| \right|$$

- Global evaluation (Brazil) and comparison with results for previous BVRN BMs representation [Nicacio et al. (2018) and Nicacio and Dalazoana (2017)].

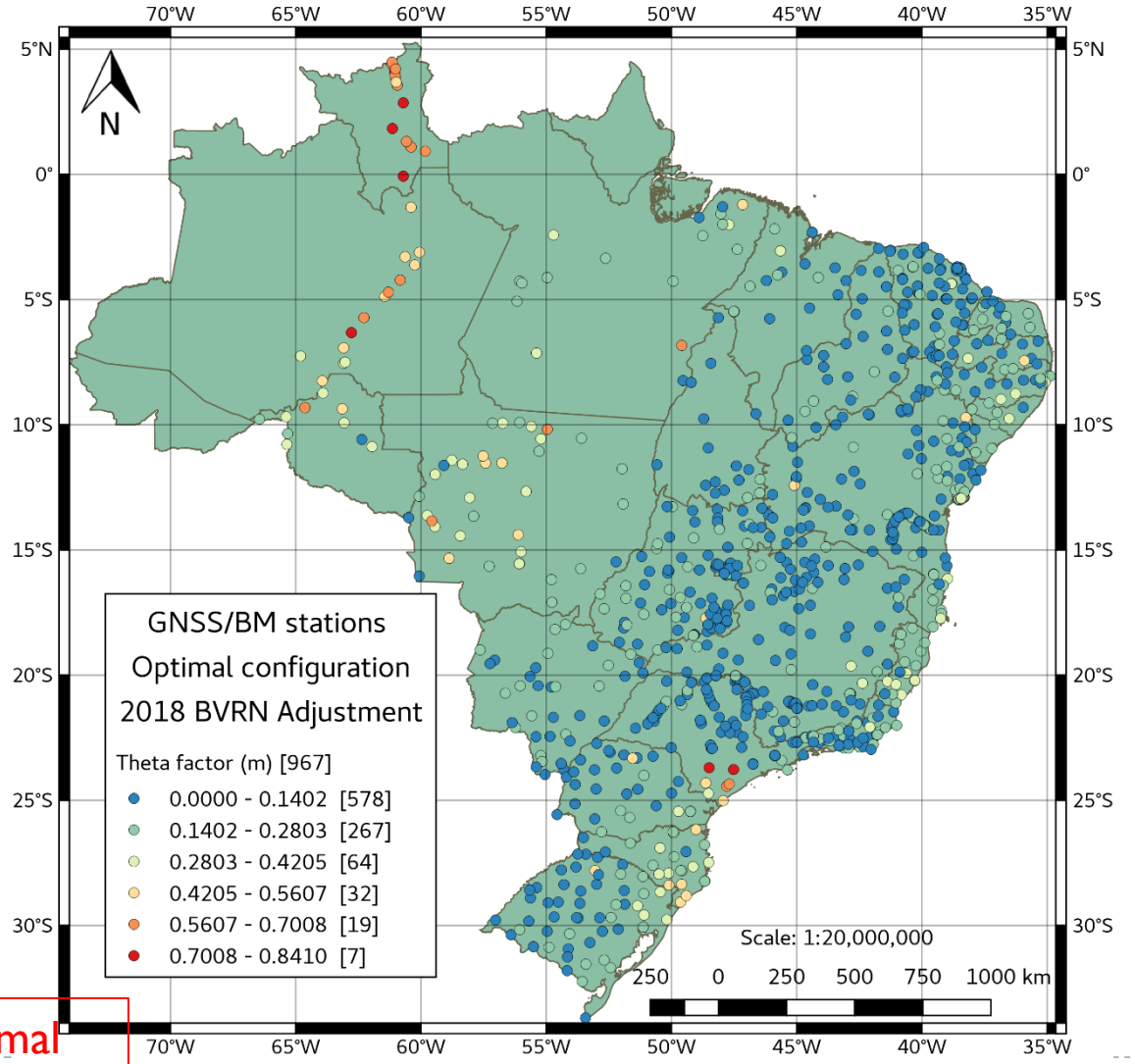
Results and discussions



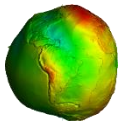
2018 Adjustment	GGM	DIF	DEGREE/ORDER		
			2190	2159	720/719
	EGM2008	MIN	0,0000	-	0,0000
		MEAN	**0,1568**	**-**	**0,1618**
		MAX	1,2202	-	1,2252
		RMS	0,1652	-	0,1668
	EIGEN-6C4	MIN	0,0000	-	0,0000
		MEAN	**0,1461**	**-**	**0,1565**
		MAX	0,9097	-	1,0437
		RMS	0,1429	-	0,1546
	SGG-UGM-1	MIN	-	0,0000	0,0000
		MEAN	-	**0,1458**	**0,1531**
		MAX	-	0,8938	0,9416
		RMS	-	0,1430	0,1480
	GOCO05C	MIN	-	-	0,0000
		MEAN	**-**	**-**	**0,1420**
		MAX	-	-	0,8598
		RMS	-	-	0,1332
	XGM2016	MIN	-	-	0,0000
		MEAN	**-**	**-**	**0,1386**
		MAX	-	-	0,8410
		RMS	-	-	0,1332

Differences statistics, in meters, between GNSS/BM solutions and GGM height anomalies modelling for current BVRN adjustment.

Optimal configuration



Results and discussions



2011 Adjustment

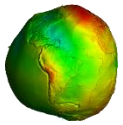
GGM	DIF	DEGREE/ORDER AND FUNCTIONAL			
		2190		720	
		Geoid	Height Anom	Geoid	Height Anom
EGM2008	MIN	0,0000	0,0000	0,0000	0,0000
	MEAN	**0,1741**	**0,1712**	**0,1807**	**0,1773**
	MAX	2,9766	2,9651	2,9292	2,9107
	RMS	0,2399	0,2354	0,2385	0,2337
EIGEN-6C4	MIN	0,0000	0,0000	0,0000	0,0000
	MEAN	**0,1548**	**0,1521**	**0,1631**	**0,1612**
	MAX	1,1824	1,1463	1,1595	1,1208
	RMS	0,1637	0,1613	0,1665	0,1632
GOCO05C	MIN	-	-	0,0000	0,0000
	MEAN	**-**	**-**	**0,1528**	**0,1489**
	MAX	-	-	1,1345	1,1166
	RMS	-	-	0,1554	0,1504
XGM2016	MIN	-	-	0,0000	0,0000
	MEAN	**-**	**-**	**0,1496**	**0,1461**
	MAX	-	-	0,9738	0,9696
	RMS	-	-	0,1518	0,1480

2018 Adjustment

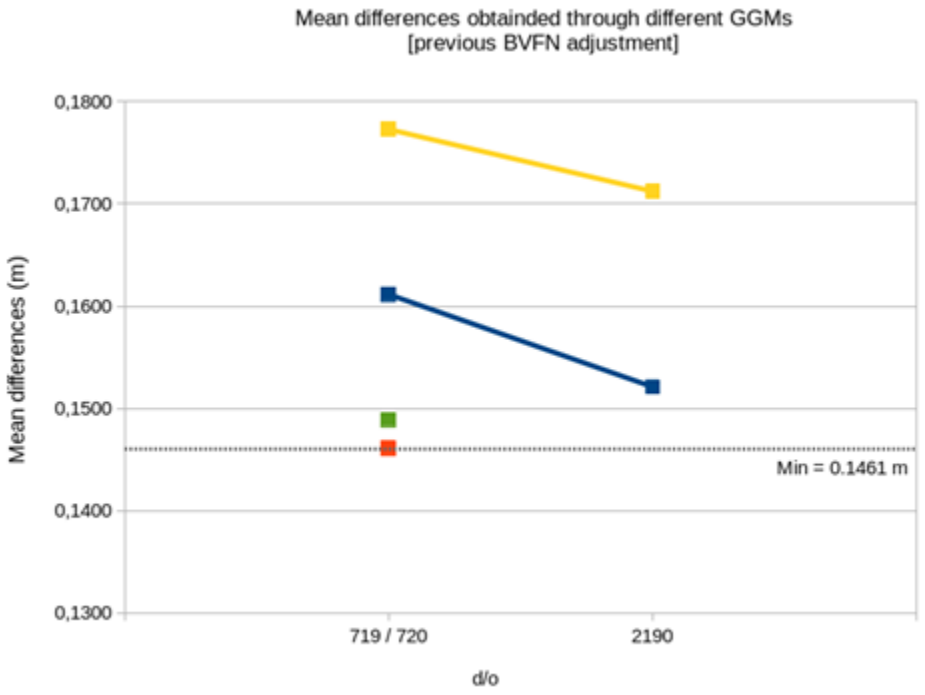
GGM	DIF	DEGREE/ORDER		
		2190	2159	720/719
EGM2008	MIN	0,0000	-	0,0000
	MEAN	**0,1568**	**-**	**0,1618**
	MAX	1,2202	-	1,2252
	RMS	0,1652	-	0,1668
EIGEN-6C4	MIN	0,0000	-	0,0000
	MEAN	**0,1461**	**-**	**0,1565**
	MAX	0,9097	-	1,0437
	RMS	0,1429	-	0,1546
SGG-UGM-1	MIN	-	0,0000	0,0000
	MEAN	-	**0,1458**	**0,1531**
	MAX	-	0,8938	0,9416
	RMS	-	0,1430	0,1480
GOCO05C	MIN	-	-	0,0000
	MEAN	**-**	**-**	**0,1420**
	MAX	-	-	0,8598
	RMS	-	-	0,1332
XGM2016	MIN	-	-	0,0000
	MEAN	**-**	**-**	**0,1386**
	MAX	-	-	0,8410
	RMS	-	-	0,1332

Optimal configuration

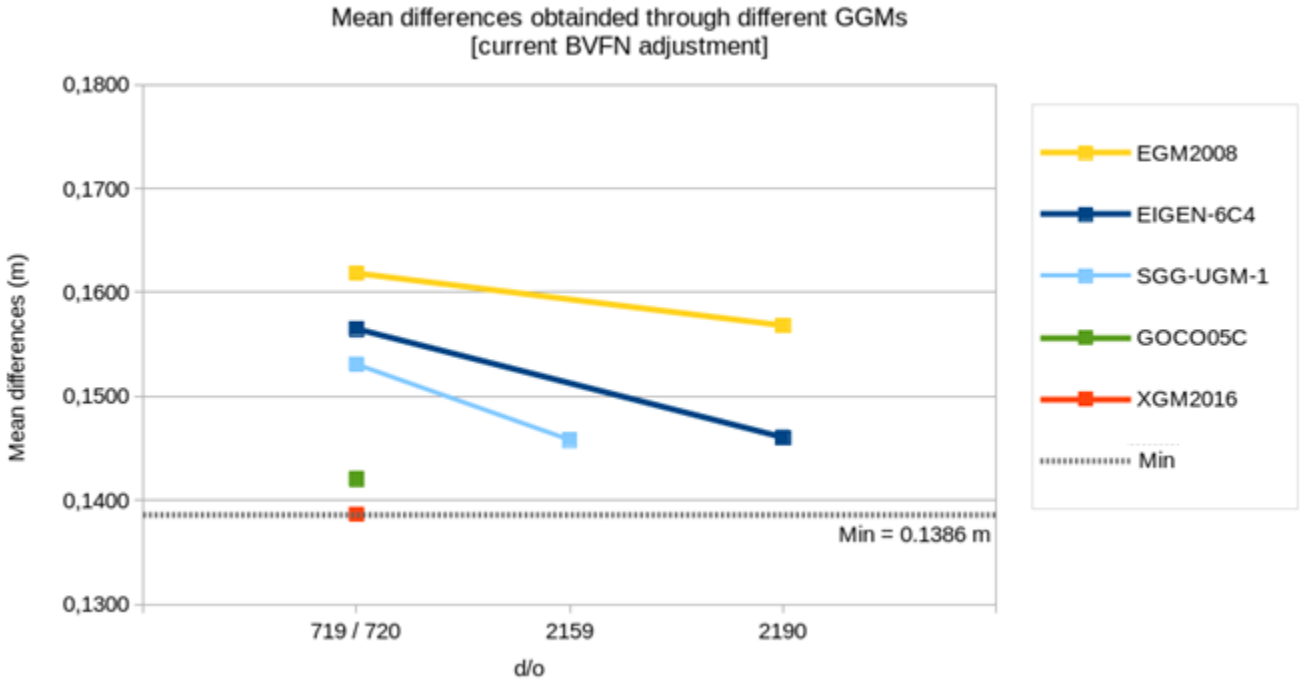
Results and discussions



Previous BVRN adjustment

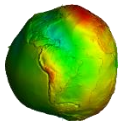


Current BVRN adjustment



- To sum up, results obtained with the GGMs tested presented significant gains in accuracy from previous to current BVRN adjustments.
- Optimal configuration kept (GGM XGM2016, height anomaly functional, d/o 719), with a $\sim 1\ cm$ gain in representation accuracy.

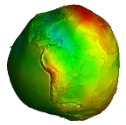
Conclusions and outlook



- Usage of the relative approach for handling GGMs is recommended;
- Relevant increase in the accuracy of altimetric representation with the adoption of normal heights, mainly when comparing mean discrepancies obtained from optimal configurations in each benchmark, for each height representation – both normal-orthometric and normal heights;
- Despite some point-wise and local inconsistencies, which are already under further investigation, the mean positive results are justified by a closer alignment to physical meaning when using normal heights;
- Furthermore, it must be emphasized the efforts made by IBGE in order to provide large scale products for the community with outstanding quality, clearly aiming at an advance towards a national alignment with the state-of-art, definitions and recommendations of the International Association of Geodesy (IAG);
- Validity for GNSS/levelling tests on Brazilian territory is still remarkable;
- Results limited to input information accuracy [h and H^N].

References

Acknowledgments



- Brazilian Army – DCT / DSG;
- PPGCG/UFPR;
- Co-authors:
  - Prof.ª Dr.ª Regiane Dalazoana (UFPR); and
  - Prof. Dr. Silvio Rogério Correia de Freitas (SIRGAS GT-III & UFPR);
- IBGE team responsible for current BVRN adjustment, led by Dr. Roberto Luz.
- Local organizing Committee, SIRGAS 2018 Symposium.

¡Muchas gracias!

Cap QEM/Cart MSc Eurico Nicacio [euriconicaciojr@gmail.com]

Prof.ª Dr.ª Regiane Dalazoana [regiane@ufpr.br]

Prof. Dr. Silvio de Freitas [sfreitas@ufpr.br]