Geoid and quasi-geoid models for South America

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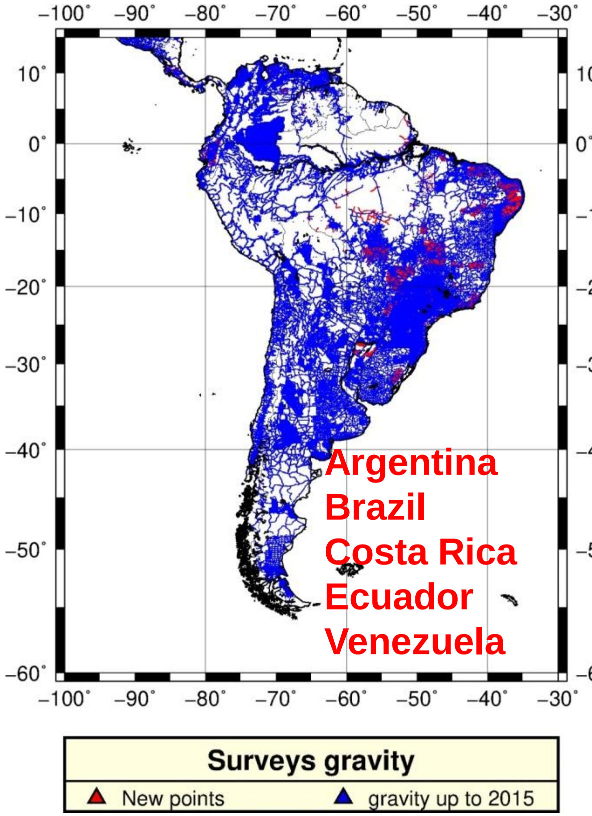
GRAVITY DATA COLLECTION

Activities going on by different organizations, universities and geographic institutes in South America.

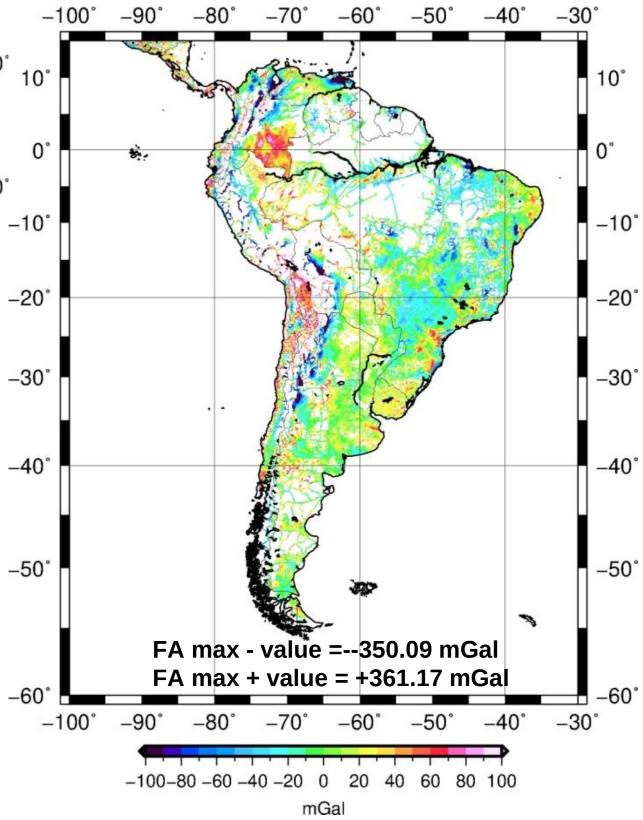
In the last 6 years, the collaborating institutions were:

- ❖ UNR - ARGENTINA
- ❖ IBGE (CGED) - BRAZIL
- ❖ EPUSP, UFU and CENEGEO - BRAZIL
- ❖ Costa Rica University – COSTA RICA
- ❖ IGM - ECUADOR
- ❖ IGVSB - VENEZUELA



In the last 26 years 959,404 terrestrial gravity points were measured.

Punctual free air anomaly (mGal)



GRAVITY DATA DISTRIBUTION

❖Gravimeters: **LaCoste&Romberg** and/or **CG5 gravity meters**;

❖**GPS double frequency**;

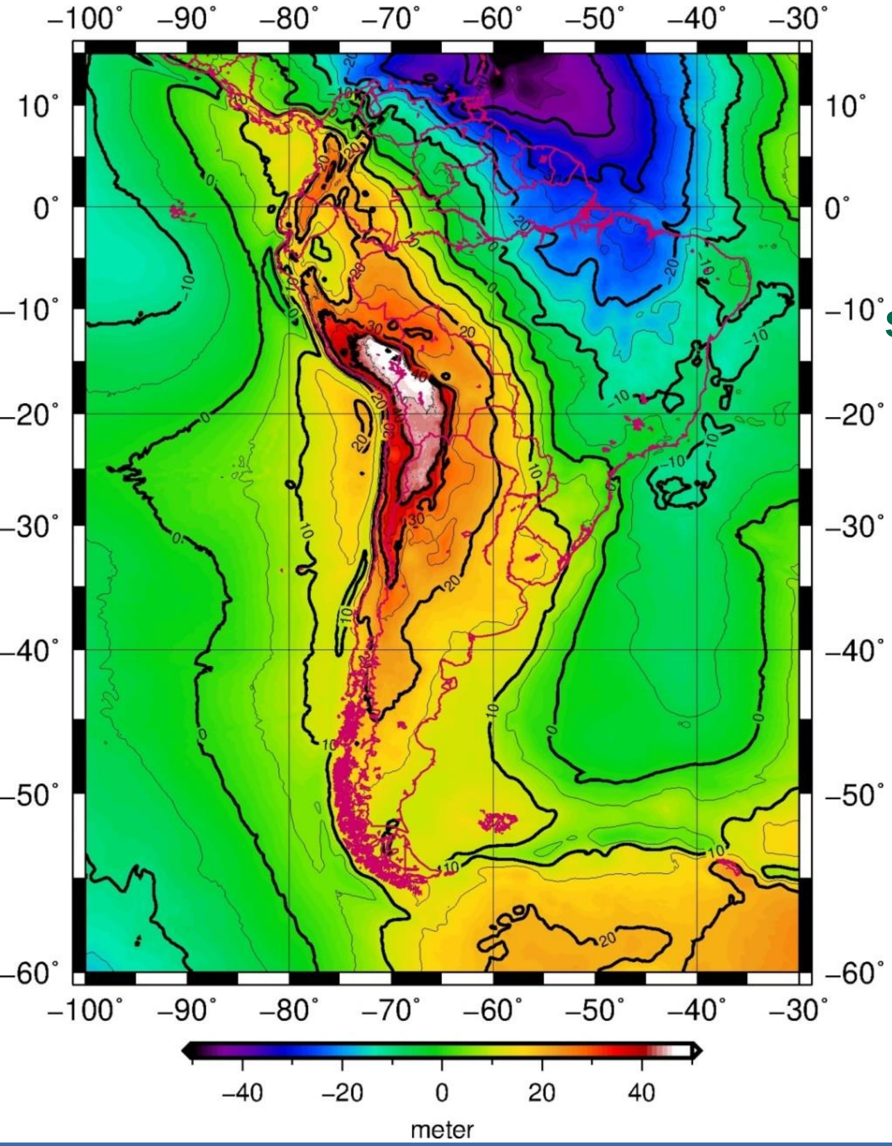
❖The **"orthometric height"** for the recent surveys was derived from geodetic height using **XGM2019e** restricted to **degree and order 2190**.

Geoid model in South America - GEOID2021

- The mainland, free air anomaly grid was computed by gravity points and the **regions without gravimetric information** were completed with the **XGM2019e gravity anomaly (2190).**
- The **oceanic area** was completed with the mean free-air gravity anomalies derived from **a satellite altimetry model** from the Danish National Space Center, **DTU17**.
- The **DTE, SITE, DAE, geoid-quasigeoid correction, PITE and PIAE** have been derived through the Canadian package **SHGEO** (**DEM -> SRTMv3**).
- The model was based on **XGM2019e (n=m=200)** as a reference field.
- The **short wavelength component** was estimated via **FFT** with the modified Stokes kernel proposed by Vaníček and Kleusberg (1987).

VANÍČEK, P.; KLEUSBERG, A. (1987). The Canadian geoid-Stokesian approach. Manuscripta Geodaetica, 12(2), pp. 86-98.

Geoid model in South America GEOID2021



- 5’ x 5’ grid
- 15º N and 60º S in latitude
- 100º W and 30º W in longitude
- Max. positive value = 50.77 m and Max. negative value = -58.74 m

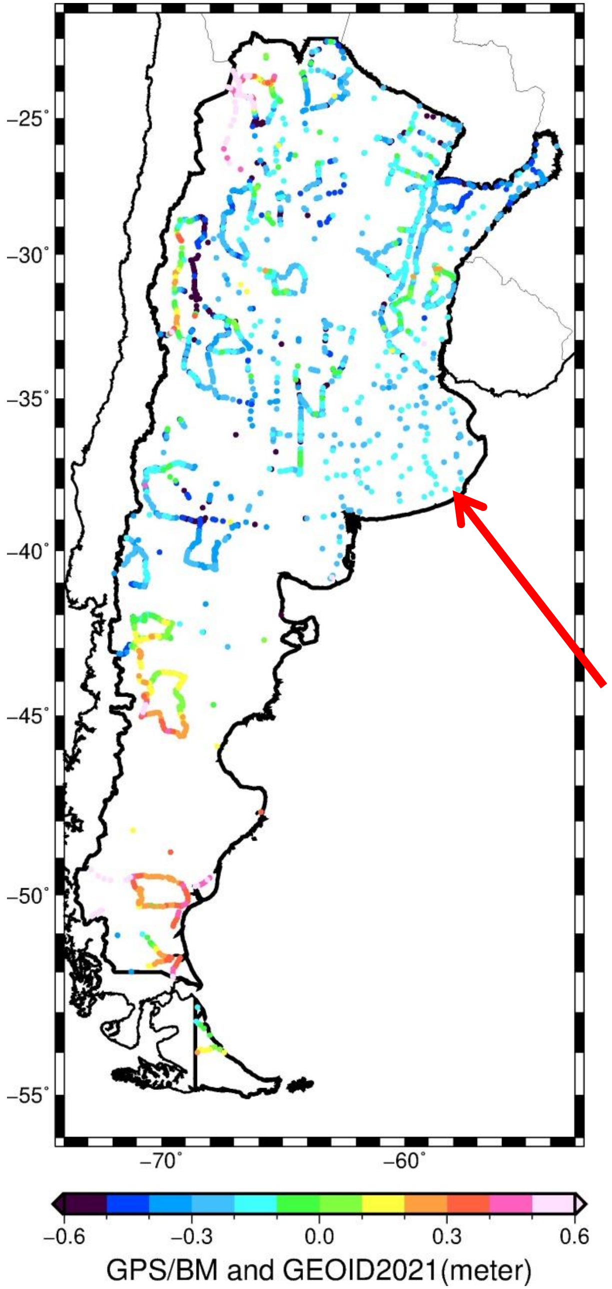
Summary of absolute analysis: geoid heights RMS difference among GPS/BM and GEOID2021 and GGMs (max degree) for each country in meters. Zero tide – zero degree term

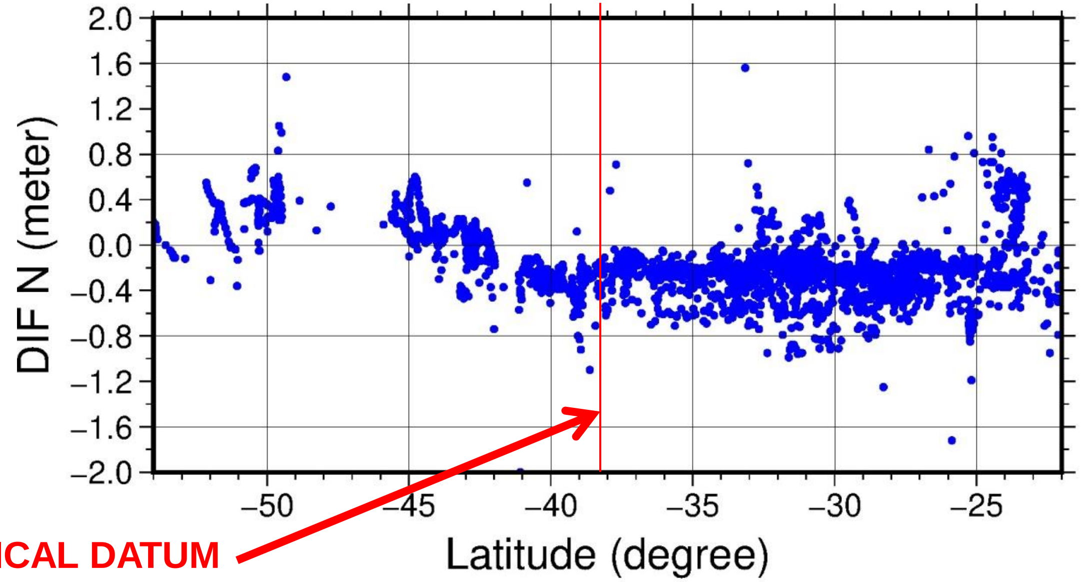
METER RMSE	EGM2008 (2190)	EIGEN6C4 (2190)	XGM2019e (2190)	SGG-UGM-2 (2190)	GEOID2021
Argentina* (2,931 points)	0.34	0.33	0.33	0.33	0.34
Chile** (176 points)	0.62	0.72	0.56	0.68	0.43
Colombia** (464 points)	0.45	0.42	0.42	0.41	0.56
Ecuador** (703 points)	0.80	0.78	0.75	0.78	0.92
Venezuela** (190 points)	0.53	0.53	0.54	0.53	0.44

* H orthometric height (methodology proposed by Mader (1954)) ** H normal-orthometric height

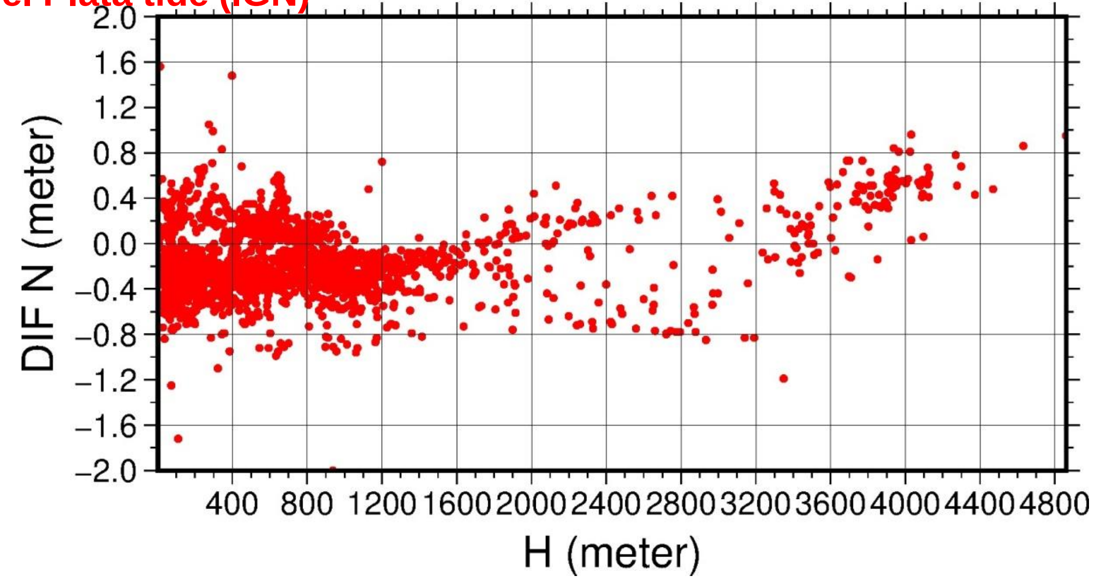
Mader, K. (1954). Die orthometrische Schwerekorrektion des Prazisions-Nivellements in den Hohen Tuaern. Wien, Osterreichischer Verein fur Vermessungswesen, 1954., 1.

Argentina –Absolute analysis

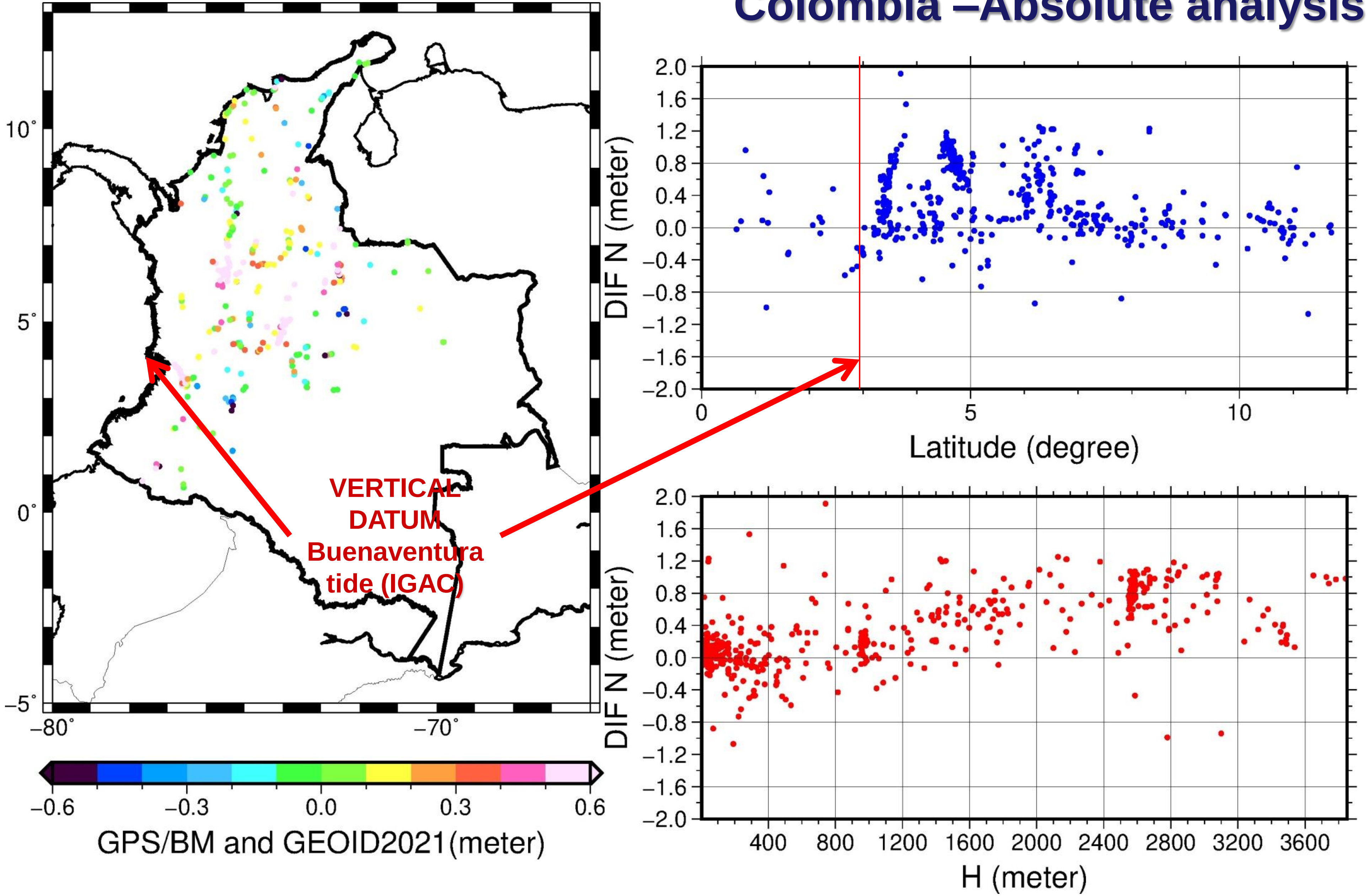




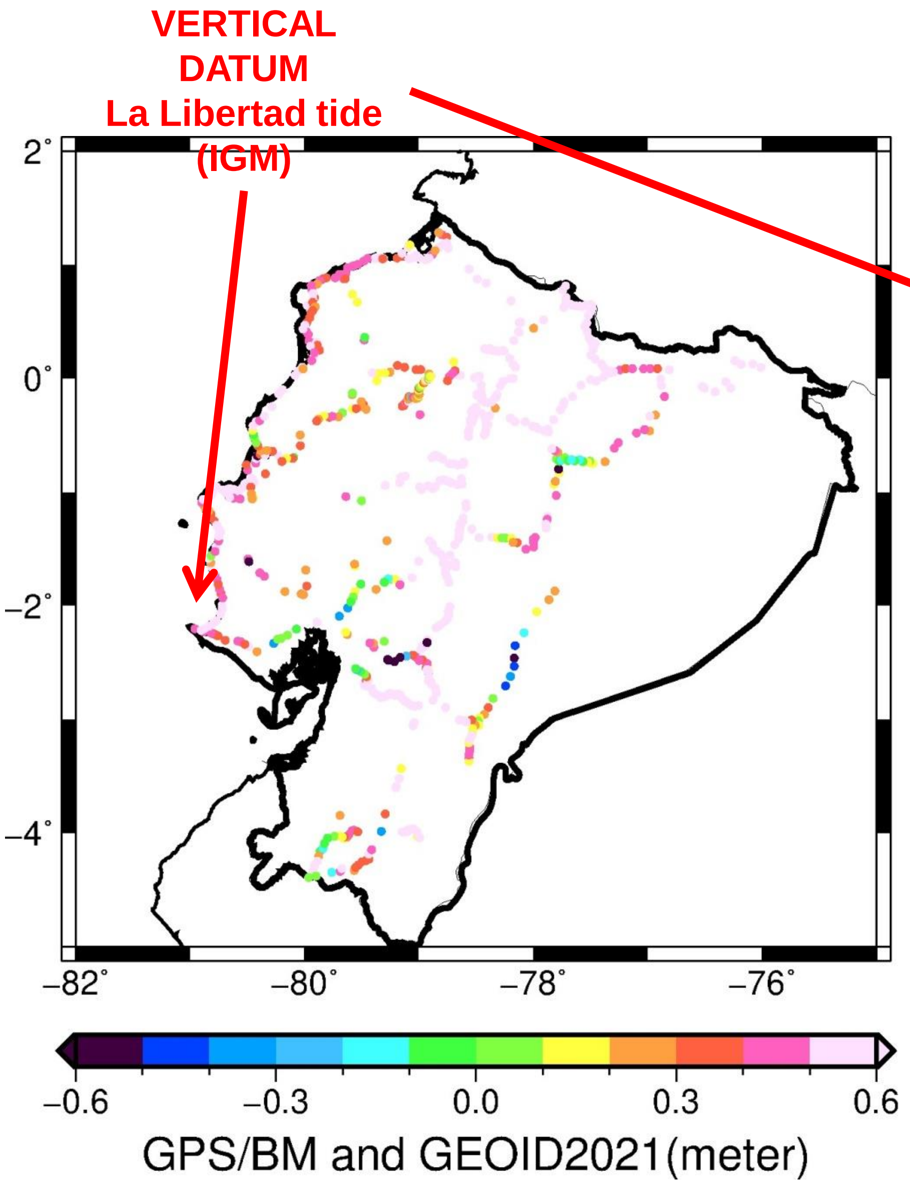
VERTICAL DATUM
Mar Del Plata tide (IGN)

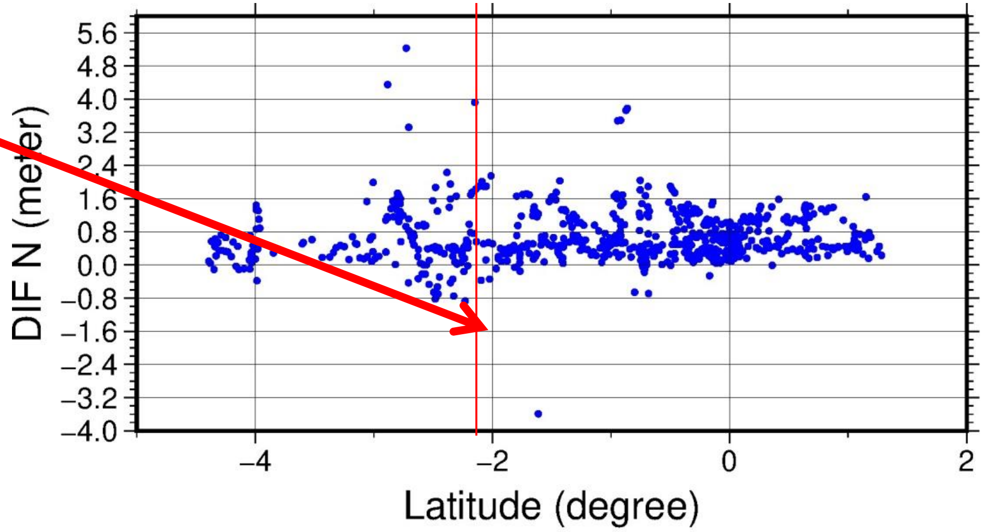


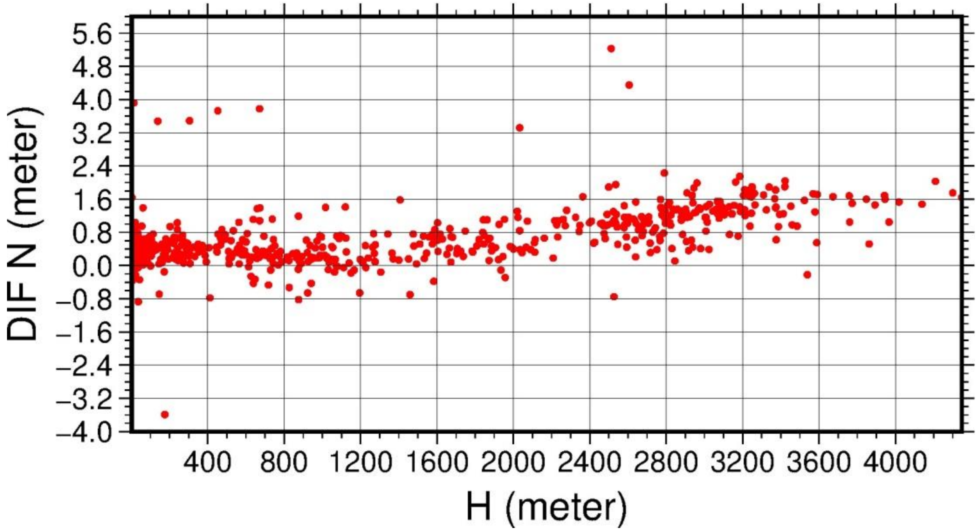
Colombia –Absolute analysis



Ecuador –Absolute analysis

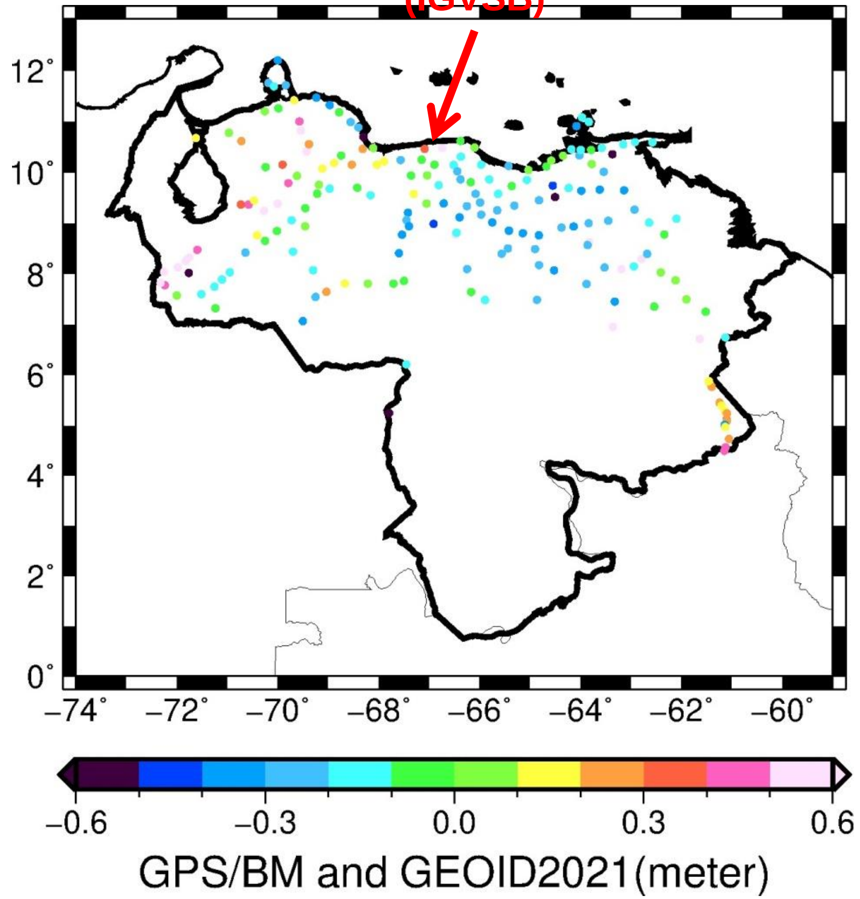


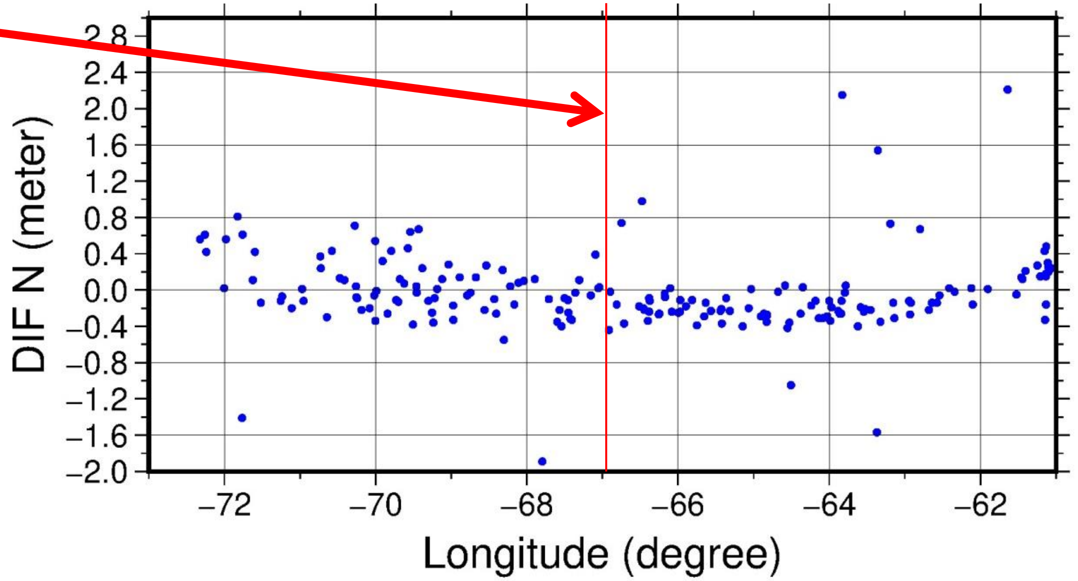


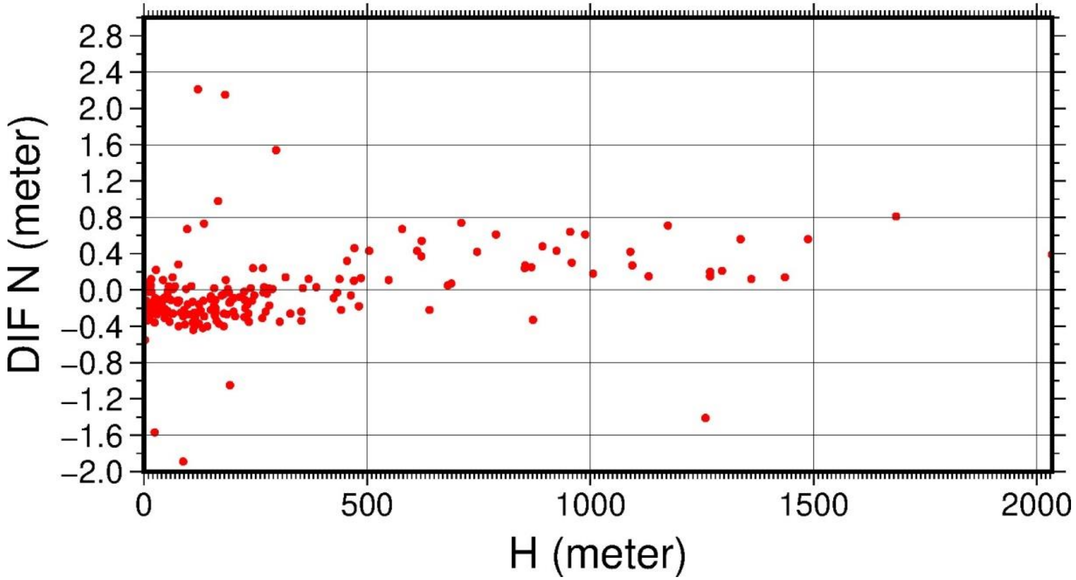


Venezuela –Absolute analysis

VERTICAL DATUM
La Guaira tide
(IGVSB)







Summary of relative analysis of the GPS/BM points with GEOID2021 and GGMs (max degree) for each country in cm/km.

Zero tide – zero degree term

STANDARD ERROR

cm/km	EGM2008 (2190)	EIGEN6C4 (2190)	XGM2019e (2190)	SGG-UGM-2 (2190)	GEOID2021
Argentina* (1157pairs)	0.90	0.88	0.90	0.88	0.96
Chile** (62 pairs)	1.65	1.61	1.47	1.61	1.98
Colombia** (128 pairs)	1.11	1.11	1.04	1.09	1.26
Ecuador** (283 pairs)	3.12	3.13	3.10	3.12	2.97
Venezuela** (67 pairs)	1.48	1.48	1.52	1.49	1.58

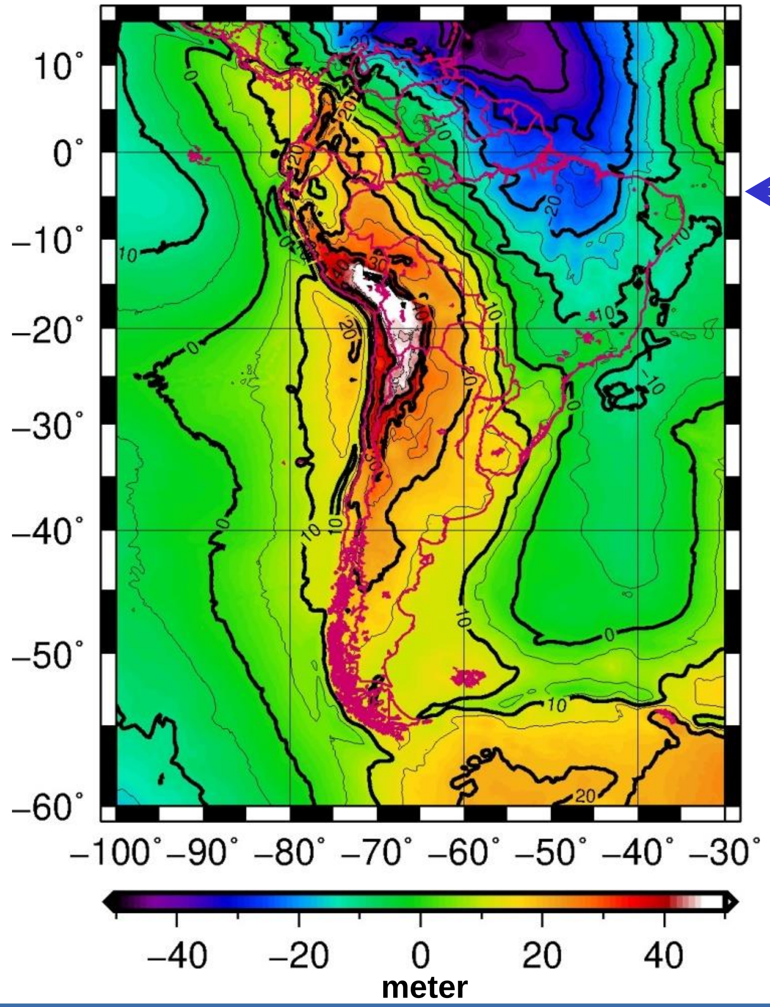
* H orthometric height

** H normal-orthometric height

Quasi-geoid model in South America - QGEOID2021

$$\zeta = N - \frac{\Delta g_B H}{\gamma}$$

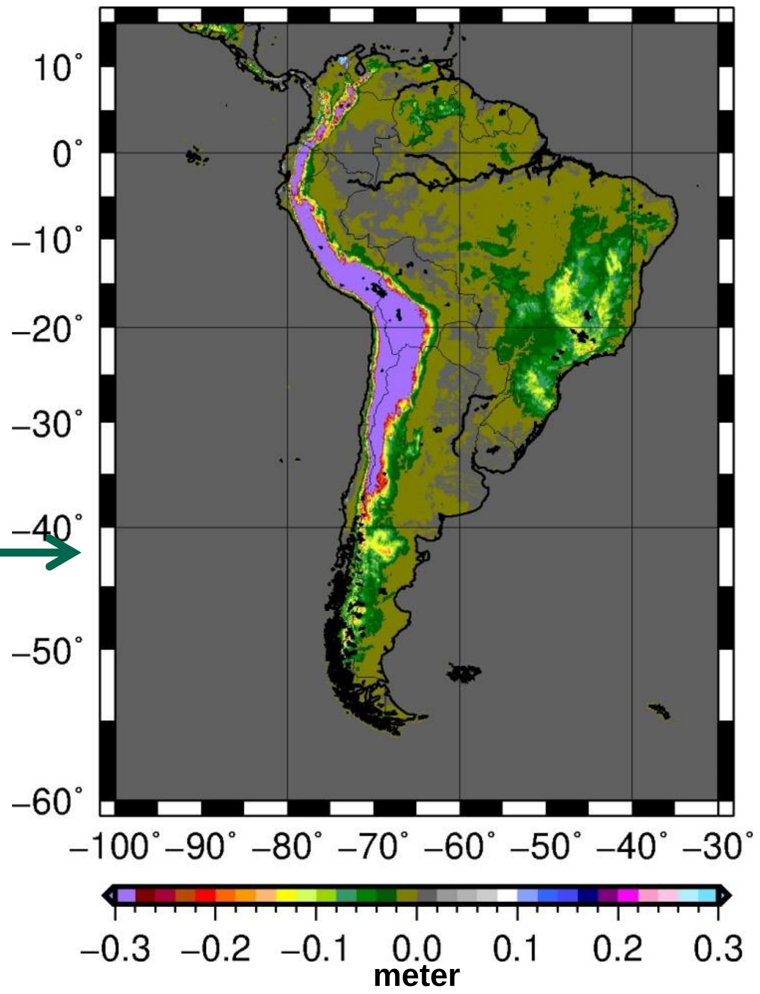
GRAVSOFT: N2ZETA



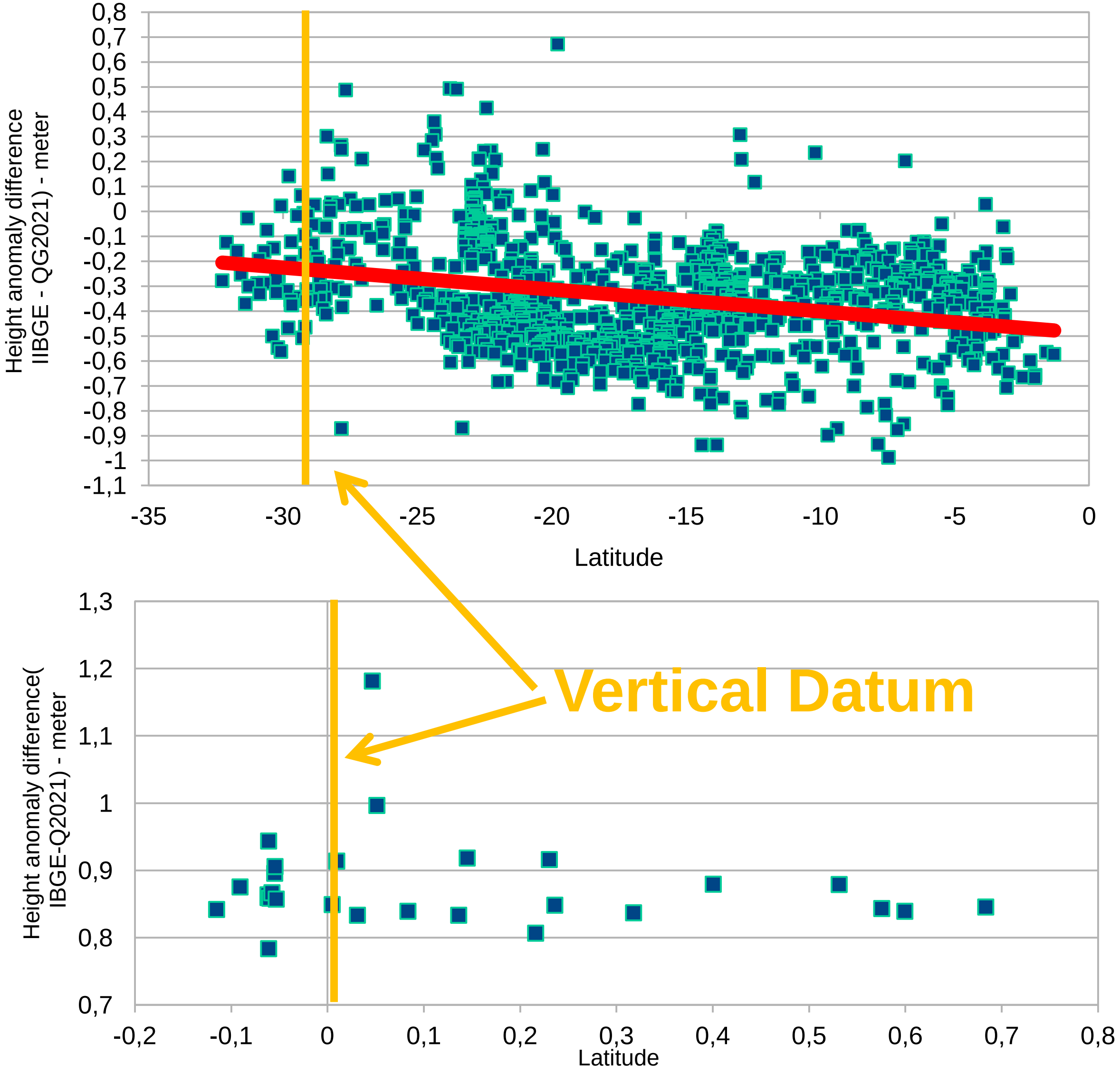
Meter
Max. + = 53.05 m
Max. - = -58.74 m

Meter
Max. + = 1.83 m
Max. - = -2.79 m

$N - \zeta$



Quasi-geoid model in South America - QGEOID2021



Height anomaly difference (meter)

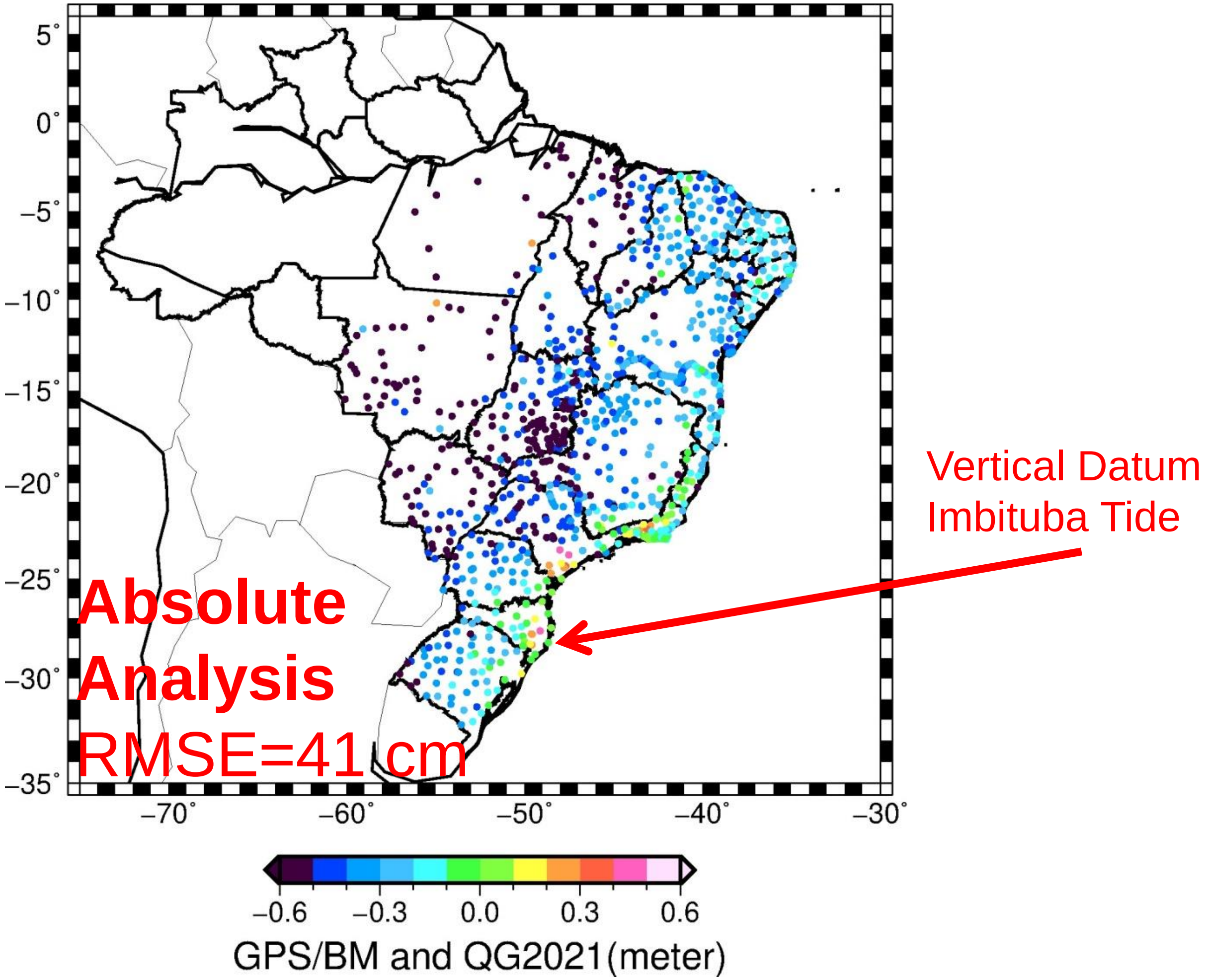
IMBITUBA TIDE	HA(IBGE-QG2021)
Mean	-0.35
Standard deviation	0.21
RMSE	0.41
Max. Positive value	0.67
Max. Negative value	-0.99

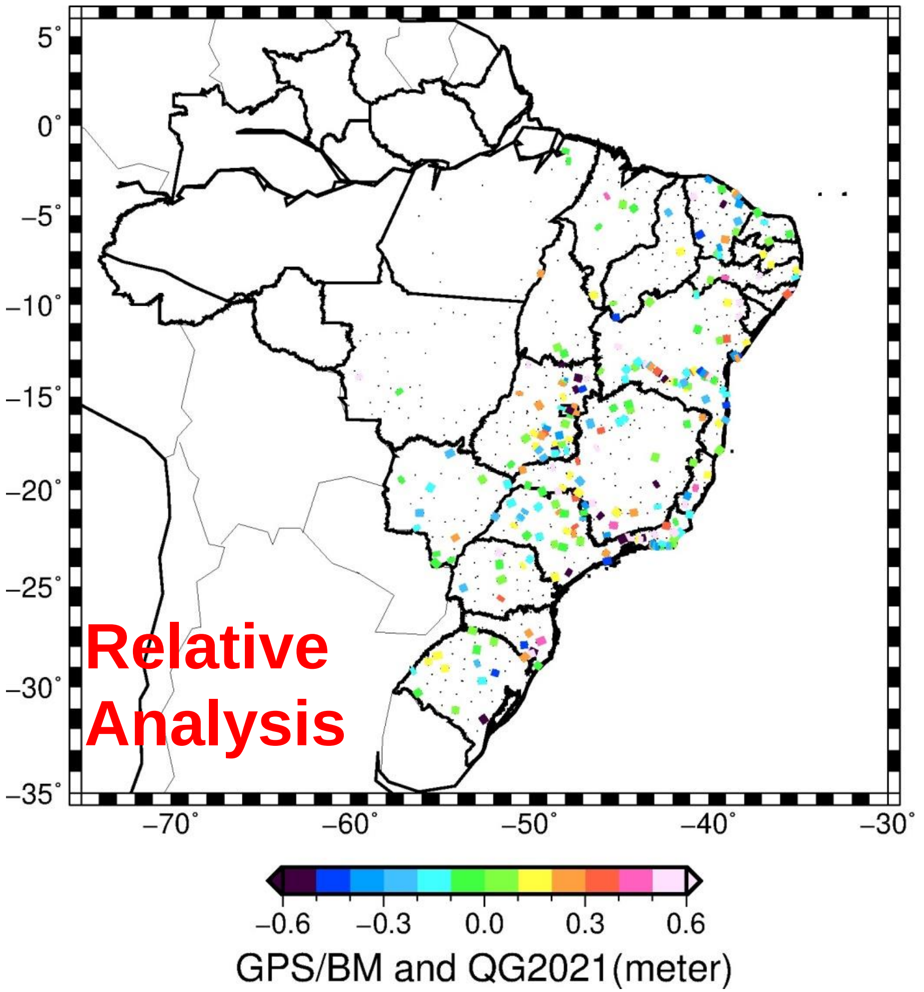
Height anomaly difference (meter)

SANTANA TIDE	HA(IBGE-QG2021)
Mean	0.88
Standard deviation	0.07
RMSE	0.88
Max. Positive value	1.18
Max. Negative value	0.78

Height anomaly difference (GPS/BM IBGE-QGEOID2021)

285 independent pairs standard error = 0.53 cm/km





1,108 GPS /BM located in Brazil

Statistical analysis of height anomaly GPS/BM between QGEOID2021 and GGMs in Brazil
IMBITUBA TIDE
1,108 points (absolute) – 285 pairs (relative)
Zero tide – zero degree term

Absolute analysis (meter)	EGM2008 (2190)	EIGEN6C4 (2190)	XGM2019e (2190)	SGG-UGM-2 (2190)	QGEOID2021
Mean	-0.61	-0.60	-0.60	-0.59	-0.35
σ diff	0.26	0.21	0.17	0.20	0.21
RMS diff	0.66	0.63	0.62	0.63	0.41
Max. Positive value	1.77	0.39	0.48	0.39	0.67
Max. Negative value	-3.61	-2.48	-1.52	-2.62	-0.99
Relative analysis standard error (cm/km)	0.56	0.54	0.50	0.54	0.53

CONCLUSION – GEOID2021/QGEOID2021

- 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 geoid heights associated with GPS/BM have their **inaccuracy 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**.

- **The vertical datum is not the same for different countries**. For example, the vertical datum discrepancy between Brazil and Argentina is higher than 20 cm, and Brazil and Ecuador is higher than 80 cm (Sánchez and Brunini, 2009; Sánchez, 2005). The height difference of each country was not corrected for the discrepancies.

SÁNCHEZ L., BRUNINI C. (2009) Achievements and Challenges of SIRGAS.. https://doi.org/10.1007/978-3-642-00860-3_25
SÁNCHEZ, L. SIRGAS-GTIII: Datum Vertical Reporte 2005. Reunión SIRGAS 2005 Caracas, noviembre17 y 18 de 2005.

FUTURE

1. To use differents DEMs, such as:
- Advanced Land Observing Satellite Digital Elevation Model (ALOS - PALSAR DEM; Dataset: © JAXA/METI ALOS PALSAR)
- Multi-Error-Removed Improved-Terrain DEM (MERIT; YAMAZAKI et al., 2017);
- South America Model (SAM3s_v2; BLITZKOW & MATOS, 2009).
- Copernicus DEM 2021

2. To use differents GGMs derived from GRACE, GOCE and GRACE-FO ,such as:
- EIGEN6C4 (FÖRSTE et al, 2014);
- SGG-UGM-2 (LIANG et al., 2020)
- future EGM2020 (BARNE et al., 2015).

3. To use aerogravimetry data in Brazil, belonging to *Agência Nacional de Petróleo* (ANP).

4. To compute quasi-geoid model for South America with the GRAVSOFT software package (FORSBERG & TSCHERNING, 2014).

BARNES, D.; FACTOR, J.K.; HOLMES, S.A.; INGALLS, S.; PRESICCI, M.R.; BEALE, J.; FECHER, T. (2015). Earth Gravitational Model 2020, American Geophysical Union, Fall Meeting 2015, abstract id. G34A-03.
BLITZKOW, D.; MATOS, A.C.O.C. (2009). EGM2008 and PGM2007A evaluation for South America Newton's Bulletin, v. 4, p. 79-89. Disponível em: https://www.isgeoid.polimi.it/Newton/Newton_4/Report_A3_SAmerica.pdf.
FORSBERG, R.; TCHERNING, C. (2014). An overview manual for the GRAVSOFT geodetic gravity feld modelling programs, 3th edn, DTU Space. https://ftp.space.dtu.dk/pub/RF/gravsoft_manual2014.pdf
FÖRSTE, C.; BRUINSMA, S.L.; ABRIKOSOV, O.; LEMOINE, J.-M.; SCHALLER, T.; G ¨OTZE, H.-J.; EBBING, J.; MARTY, J.C.; FLECHTNER, F.; BALMINO, G.; BIANCALE, R (2014).. DOI: 10.5880/icgem.2015.1.
LIANG, W.; LI,J.; XU, X.; ZHANG, S.; ZHAO, Y. (2020). DOI: 10.1016/j.eng.2020.05.008.
YAMAZAKI, D.; IKESHIMA, D.; TAWATARI, R.; YAMAGUCHI, T.; O'LOUGHLIN, F.; NEAL, J.C.; SAMPSON, C.C.; KANAE S.; BATES, P.D. (2017). : DOI: 10.1002/2017GL072874.
ZINGERLE, P.; PAIL, R.; GRUBER, T.; OIKONOMIDOU, X. (2020). DOI: 10.1007/s00190-020-01398-0.

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We look forward to feedback from everyone who can test the geoid and quasi-geoid models so that we can improve the computation.

Muchas gracias.