High Resolution Gravity Field Models as Global Reference Surface for Heights

Thomas Gruber, Philipp Zingerle, Roland Pail,
Xanthi Oikonomidou
Institute of Astronomical and Physical Geodesy
Technical University of Munich

SIRGAS 2019, Rio de Janeiro, 12.11.2019

Outline

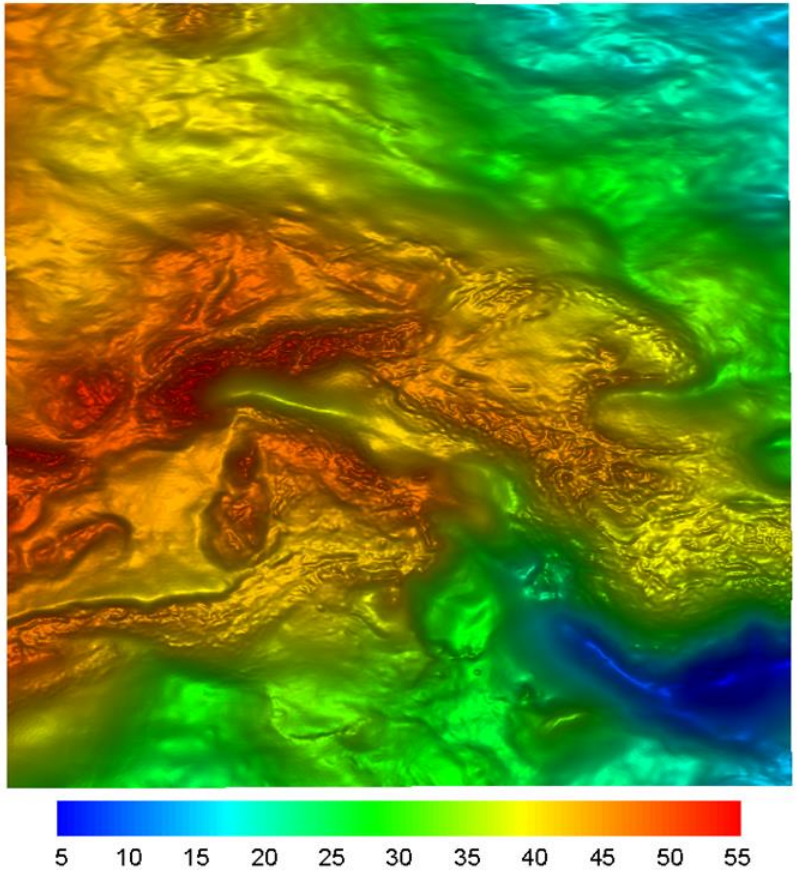
High Resolution (HR) Models

- Models Overview
- The new XGM2019e Model
- Signal & Error Characteristics

Quality Assessment

- GNSS-Levelling as a Tool
- GNSS-Levelling Results

Summary & Conclusions

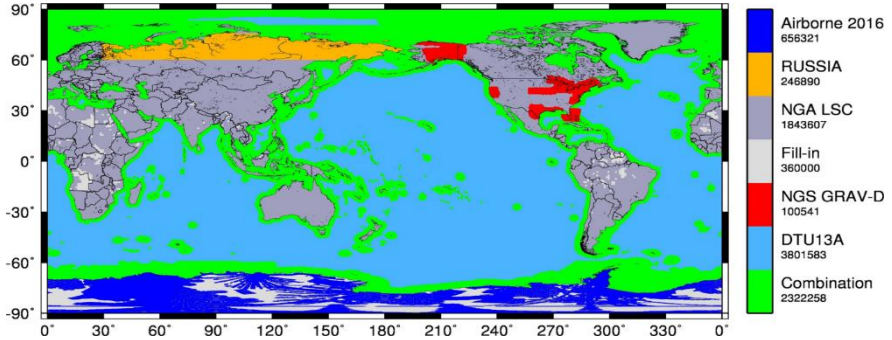


HR Models Overview

Model	Resolution	Satellite Data	Surface Data	Technique	Originator
EGM2008	2159 (ell.) 2190 (sph.)	GRACE ITG-GRACE03S	DNSC07 Altimetry SS v18.1 Altimetry NGA08 Land	d/o 359 full d/o 2159 BD	NGA, Pavlis et al, 2012
EIGEN6-C4	2190 (sph.)	GRACE-GRGS (10y) GOCE-DIR5 LAGEOS	DTU10 Altimetry EGM2008 Land	d/o 370 full d/o 2190 BD	GFZ/CNES Förste et al, 2014
GOCE-OGMOC	2190 (sph.)	GOCO05S	DTU13 Altimetry NGA16 Land (15’)	XGM2016 (d/o 719 full) EIGEN6-C4 (720-2190)	IAPG-TUM Gruber et al, 2018
PGM2017	2159 (ell.) 2190 (sph.)	GOCO05S	NGA (5‘)	-	NGA, 2017
XGM2019e XGM2019e_2159 XGM2019	5399 (ell.) 5540 (sph.) 2159 (ell.) 2190 (sph.) 719 (ell.) 760 (sph.)	GOCO06S	DTU13 Altimetry NGA16 Land (15’) Topogr. Gravity EARTH2014	d/o 719 full d/o 5399 BD	IAPG-TUM Zingerle et al, 2019 DOI: 10.5880/ICGEM.2019.007

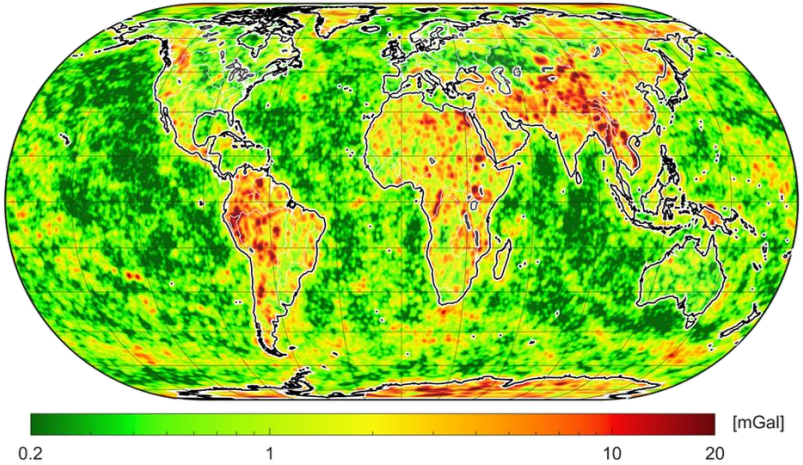
XGM2019e Model

Data Coverage

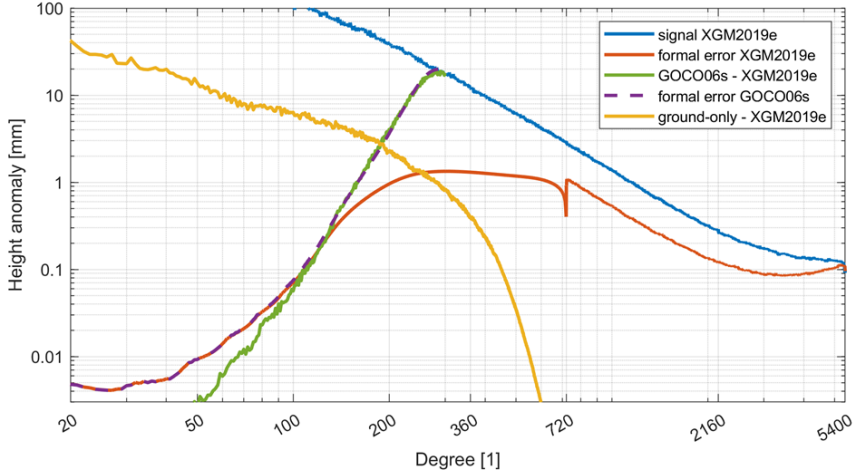


- Full normal equations up to d/o 719 (ell.) from NGA 15‘ land/ocean data and GOCO06S.
- Block-Diagonal normal equations up to d/o 5399 (ell.) from DTU13 altimetric gravity over oceans and topographic gravity over land

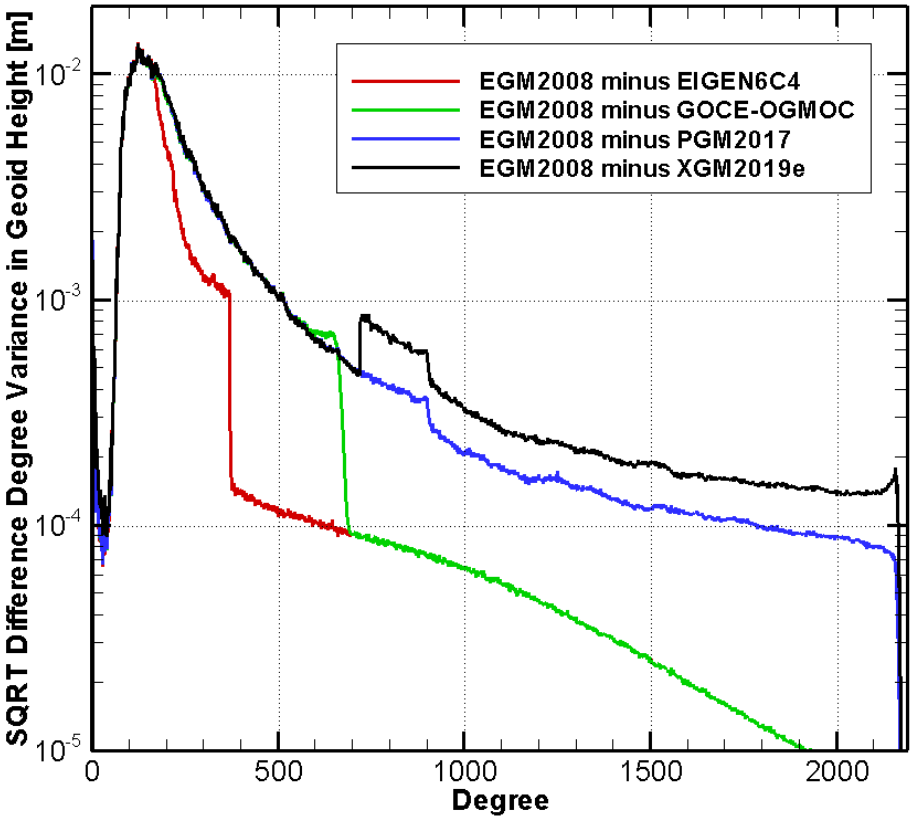
Weighting Scheme

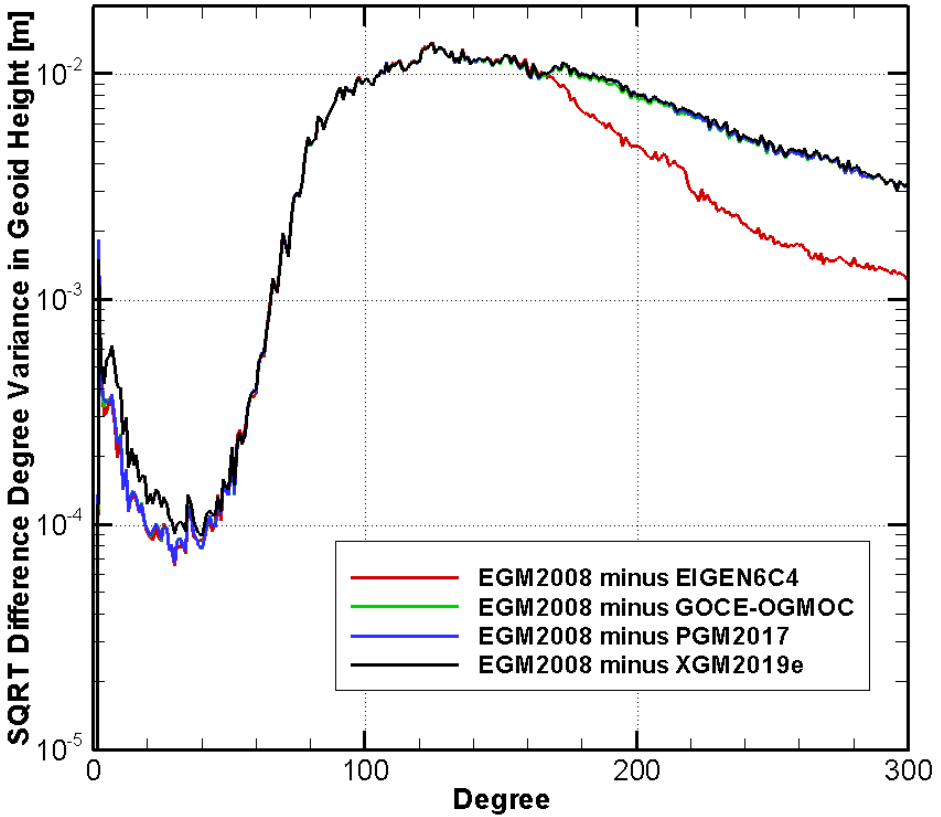


Signal and Error Degree Variances (SQRT)



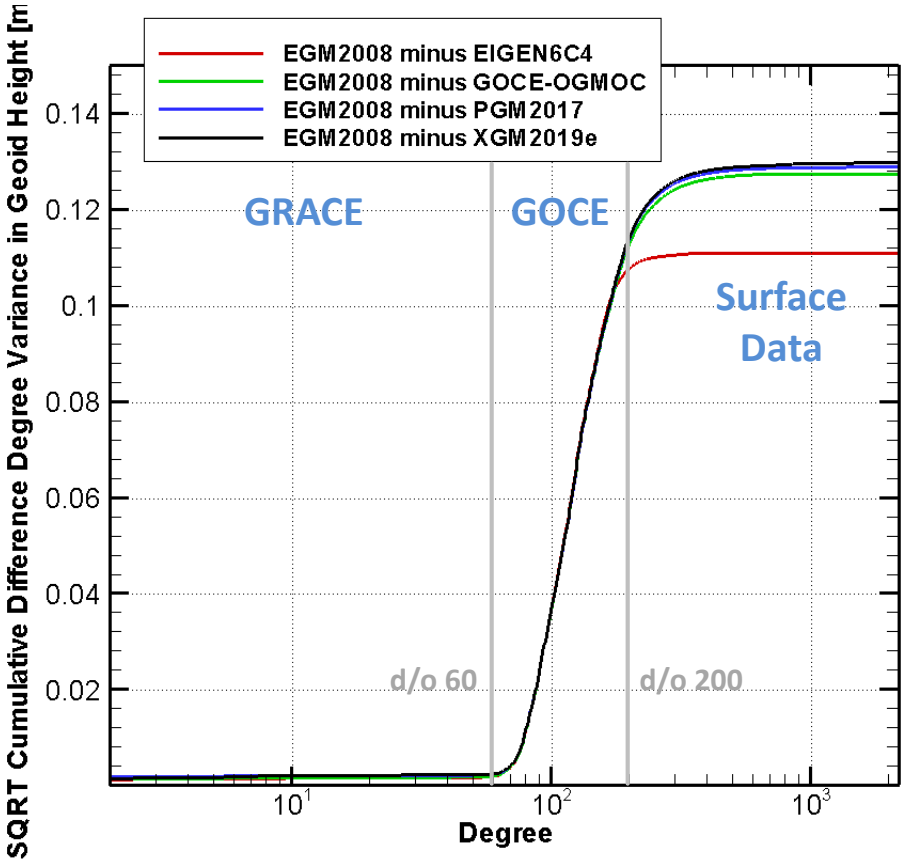
HR Models Signal Characteristics



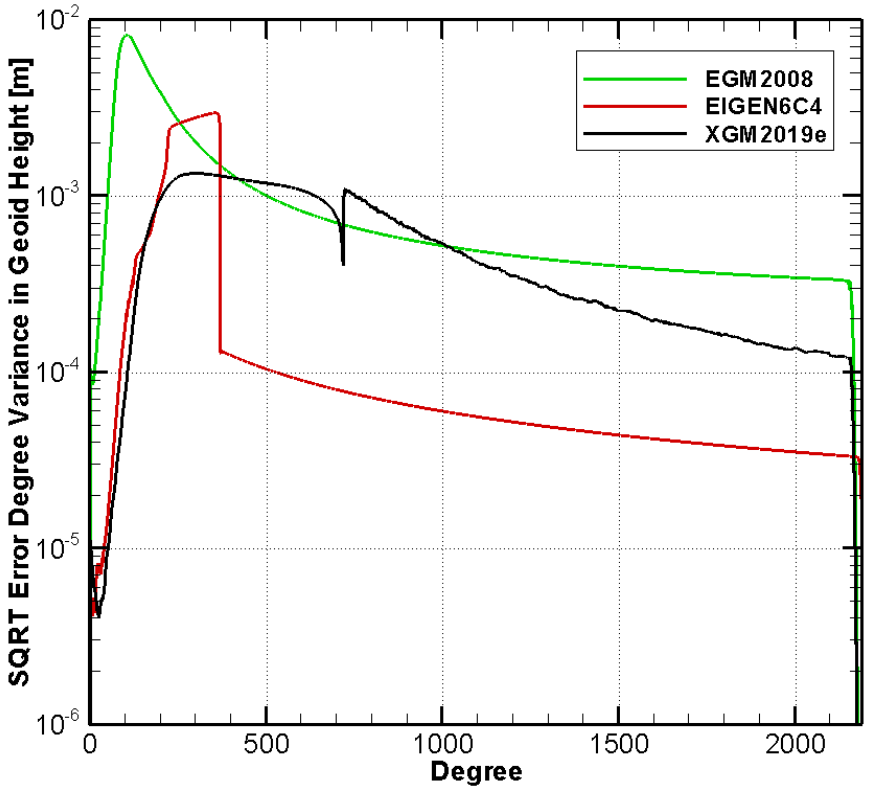


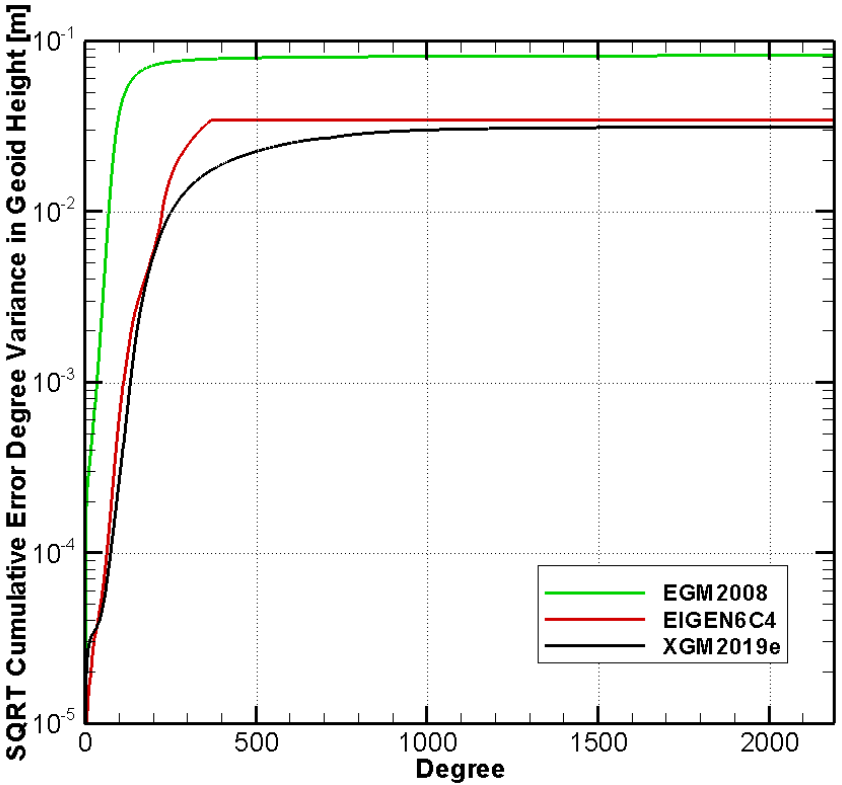
HR Models Signal Characteristics

- Signal differences to EGM2008 exhibit the impact of new information in the high resolution gravity field models.
- Up to d/o 60 hardly any difference, indicating that all models are similar in this range and dominated by GRACE.
- Between d/o 60 and 200 In global average most impact from adding GOCE data (about 80% of total impact).
- Above d/o 200 impact from new surface data visible (20% of total impact)



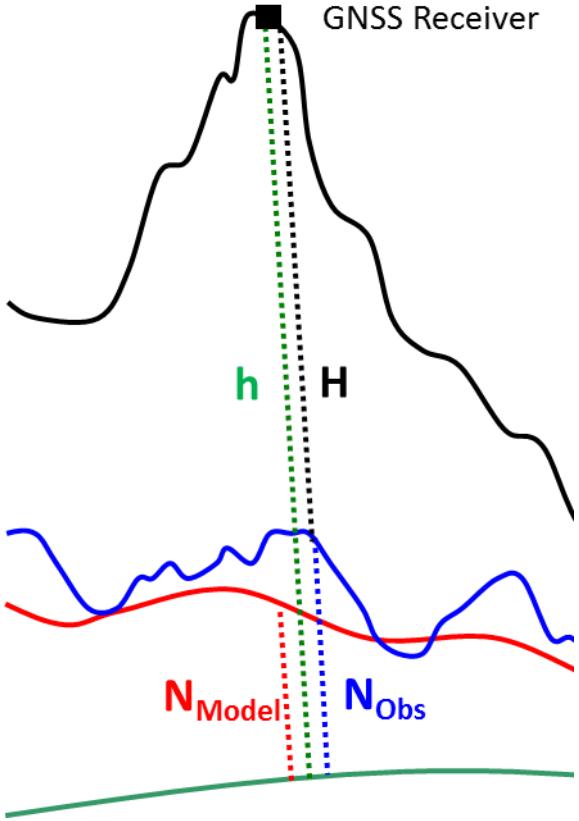
HR Models Error Characteristics





Error Assessment by GNSS-Levelling

- Compute height anomaly at GNSS-levelling station from global model up to degree and order N.
- Estimate omitted signal from existing HR-model from degree N+1 to 2160 (2190) (EIGEN6C4 was used in this study).
- Estimated omitted signal above 2160 from topographic gravity field model. (ERTM2160, Hirt et al, 2014)
- If necessary, convert from height anomalies to geoid undulations (Rapp, 1997).
- Compare with geoid height / height anomaly at GNSS-levelling station computed from h-H
- Systematic differences between model and observed geoid heights are possible (definition of local height systems).
- Apply correction surface (planar fit to differences)
- Analyse corrected geoid height differences

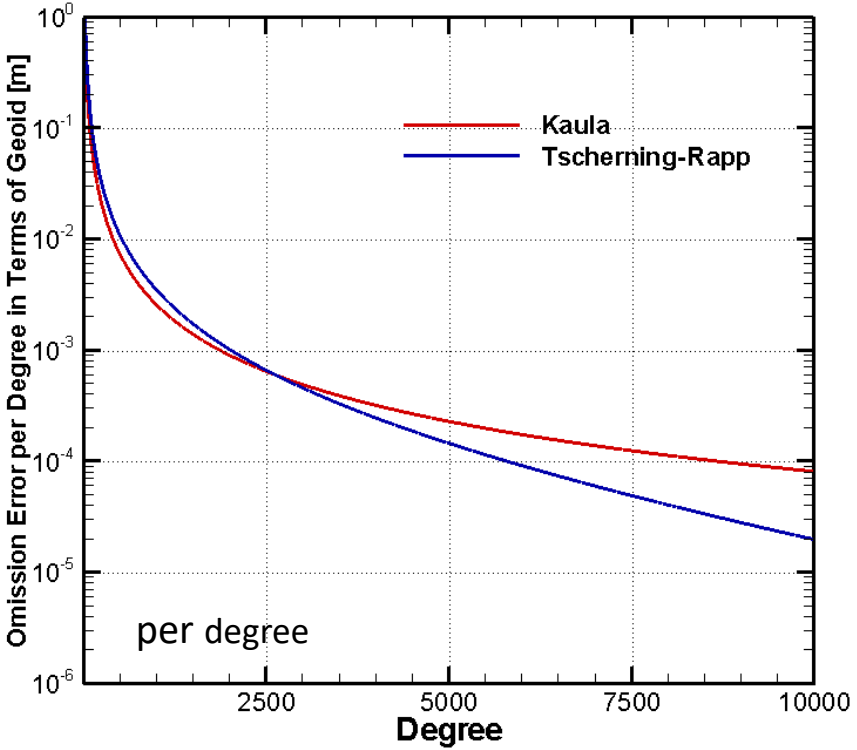


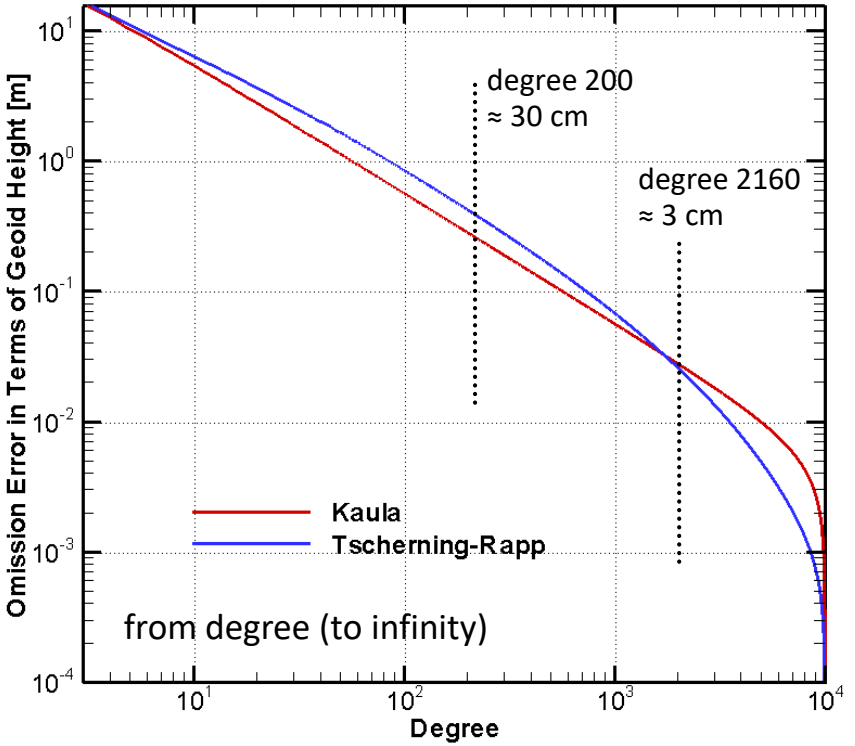
GNSS-Levelling Data Sets

Region	No. Points	Reference
Australia	197	Geoscience Australia, 2003
Brazil	683 1287	Brazilian Institute of Geography and Statistics - IBGE, 2012 Brazilian Institute of Geography and Statistics - IBGE, 2019
Canada 2012 Canada 2007	579 2576	National Resources of Canada (NRCan), via US National Geodetic Survey (NGS), 2012 National Resources of Canada (NRCan), 2007
Europe Various Countries, EUREF EUVN	1233	Bundesamt für Kartographie und Geodäsie, Frankfurt/Main, 2007
Germany 2007 (DHHN92) Germany 2016 (DHHN16)	675 470	Bundesamt für Kartographie und Geodäsie, Frankfurt/Main, 2003 © GeoBasis-DE / Geobasis NRW, 2018
Great Britain	177	UK Ordnance Survey, 2011
Greece Mainland	1542	Aristotle University of Thessaloniki, 2016
Japan	837	Japanese Geographical Survey Institute, 2003
Mexico	744	Instituto Nacional de Estadística y Geografía (México) via US National Geodetic Survey, 2012
Saudi Arabia	382	King Abdulaziz City for Science and Technology KACST, 2012
USA	24872	National Geodetic Survey, 2012

Error Assessment by GNSS-Levelling

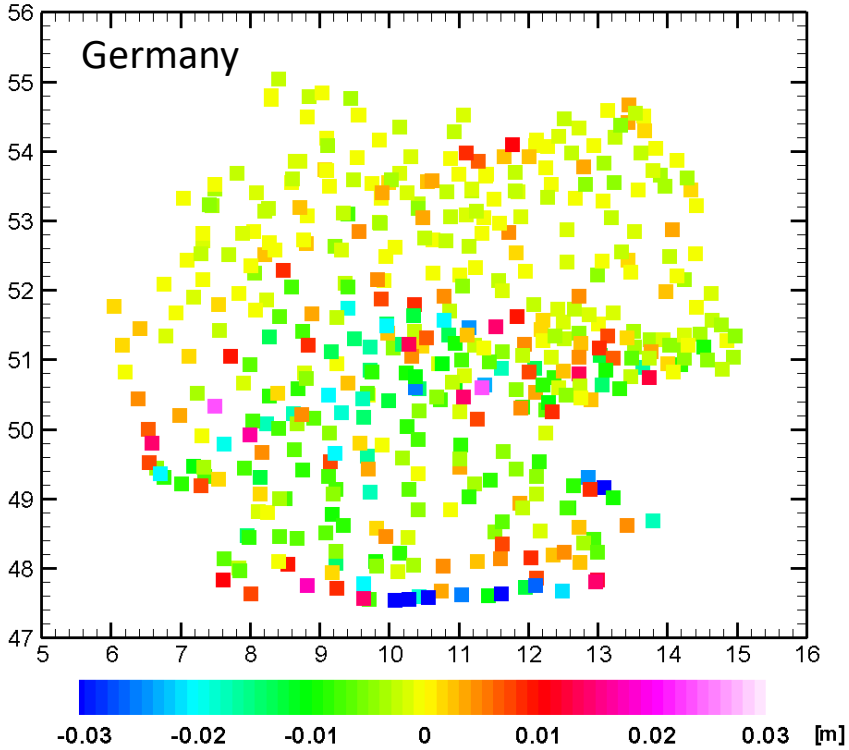
Omission Error Estimate from Degree Variance Models

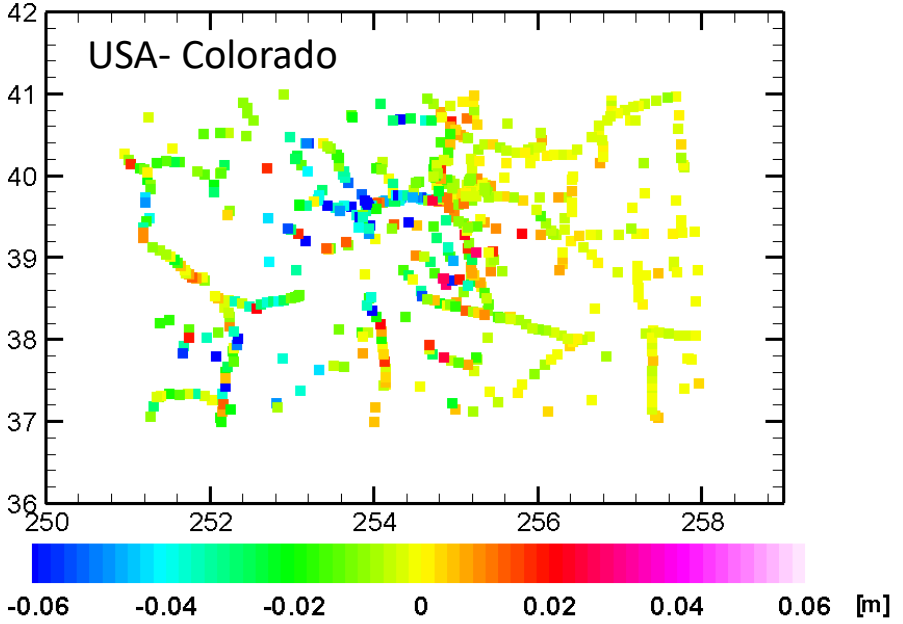




Error Assessment by GNSS-Levelling

Omission Error Estimate from Topographic Gravity Field Model (ERTM2160)

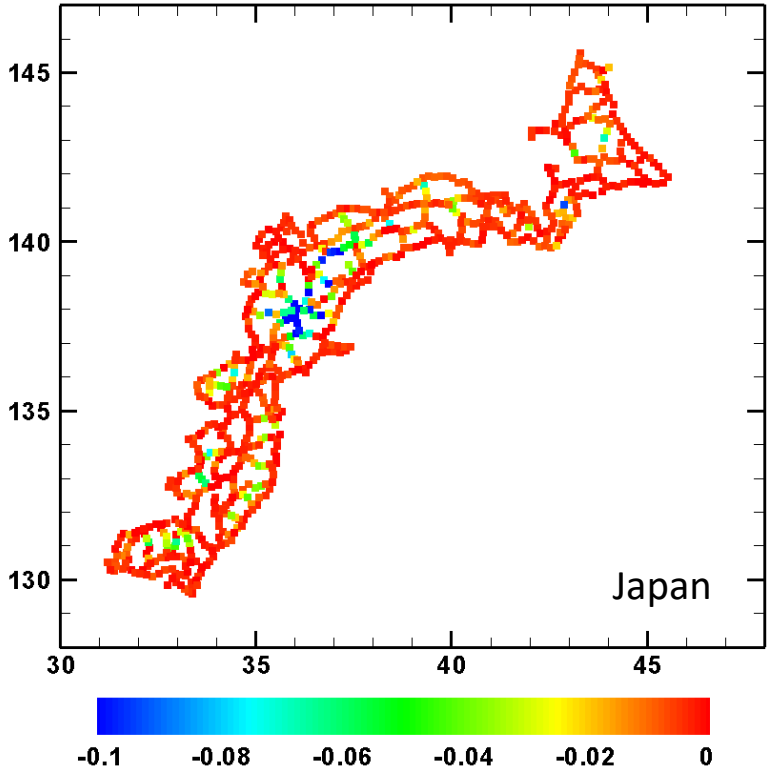


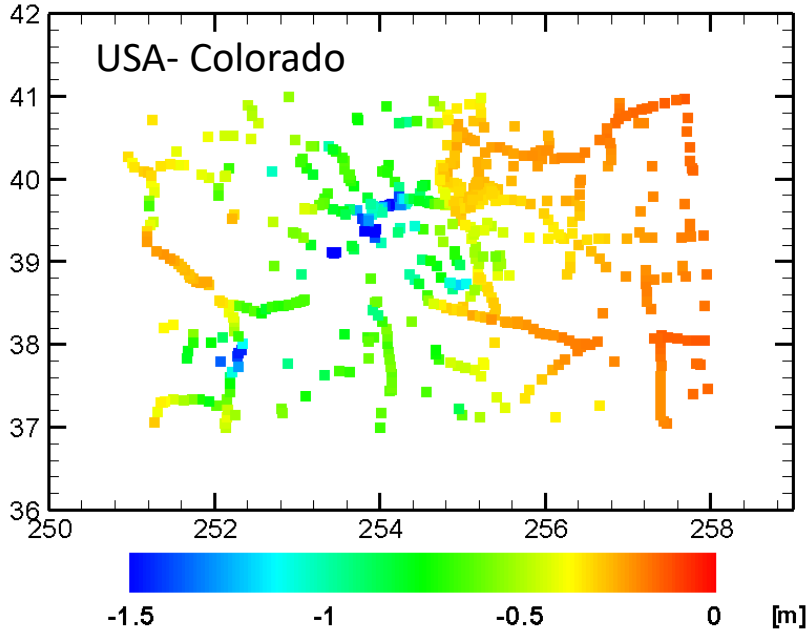


- up to ±10-20 cm in mountaineous areas

Error Assessment by GNSS-Levelling

Conversion Height Anomalies to Geoid Undulations (if needed)



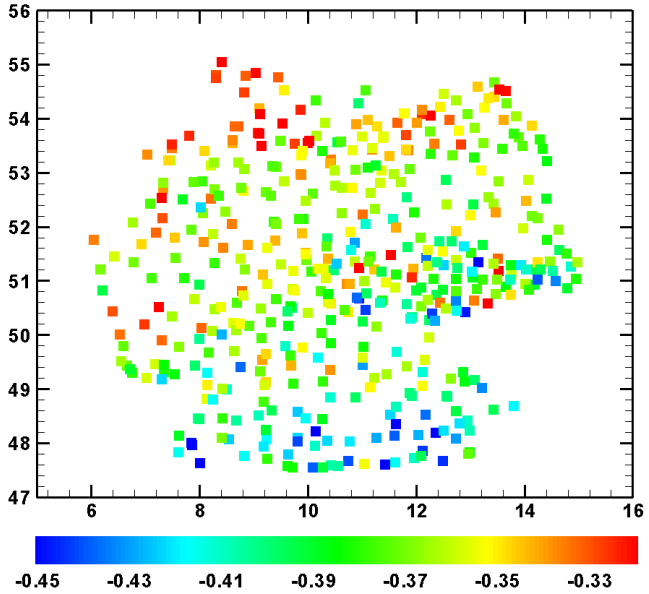


up to ±1-2 m in larger mountaineous areas

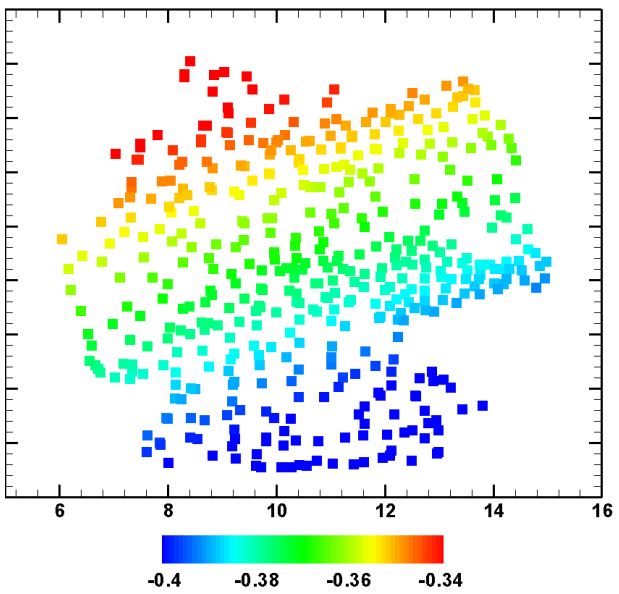
Error Assessment by GNSS-Levelling

Correction Surface (for XGM2019e d/o 2190)

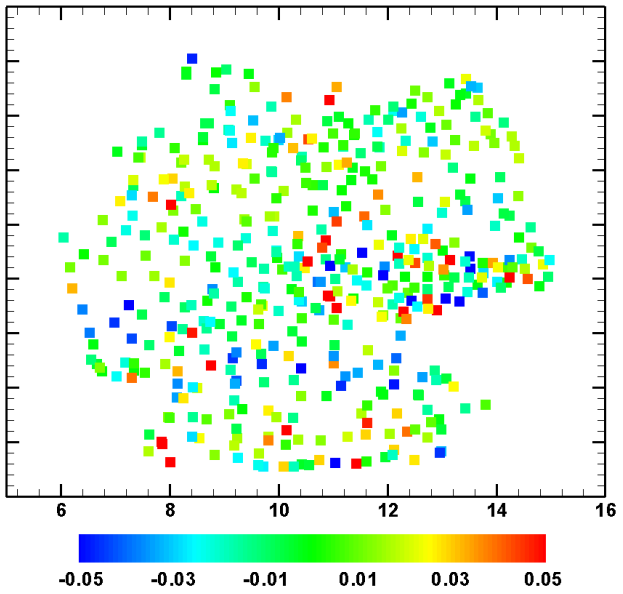
XGM2019e vs. Germany2016



Correction Surface

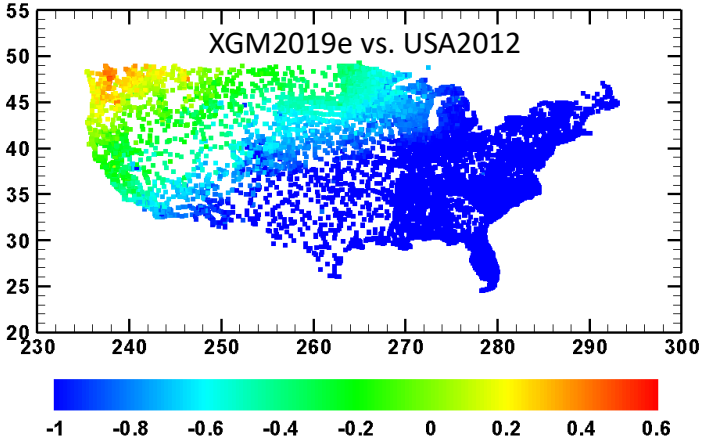


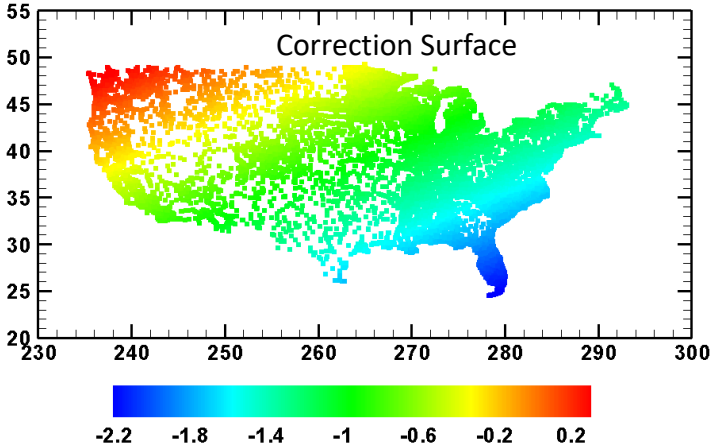
Residuals

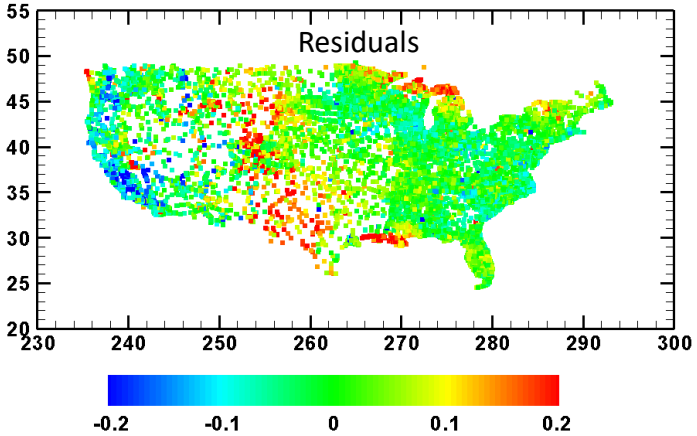


Error Assessment by GNSS-Levelling

Correction Surface (for XGM2019e d/o 2190)



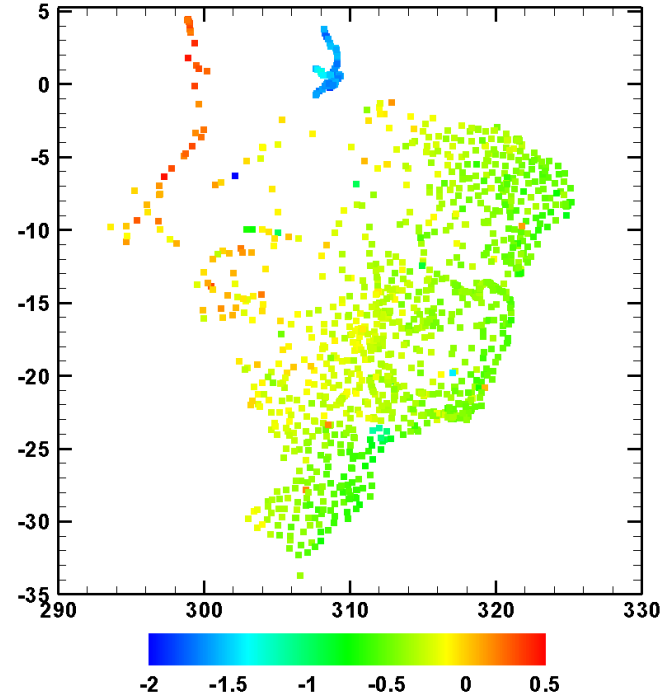




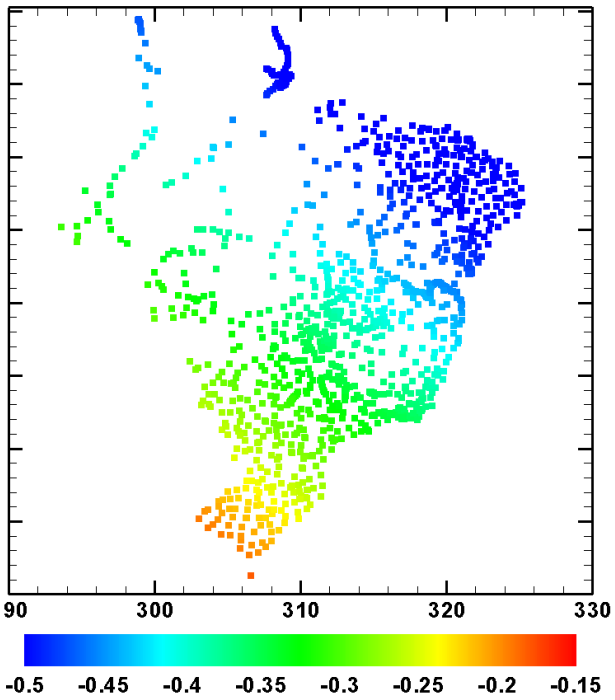
Error Assessment by GNSS-Levelling

Correction Surface (for XGM2019e d/o 2190)

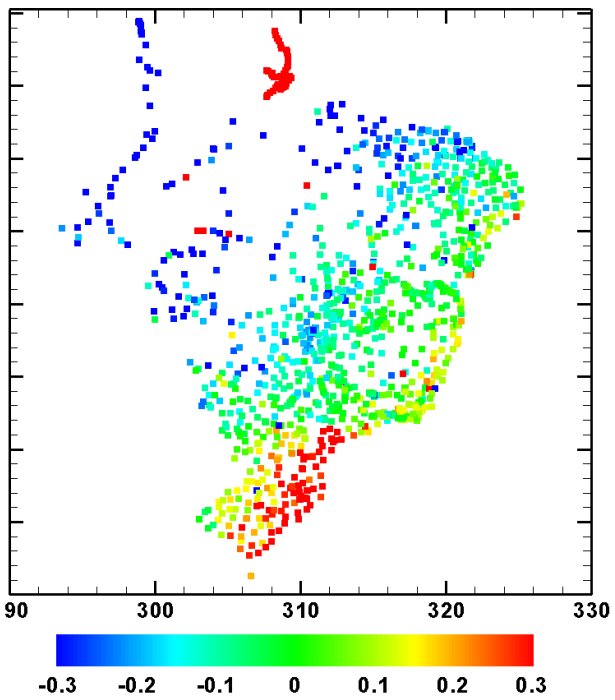
XGM2019e vs. Brazil2019



Correction Surface



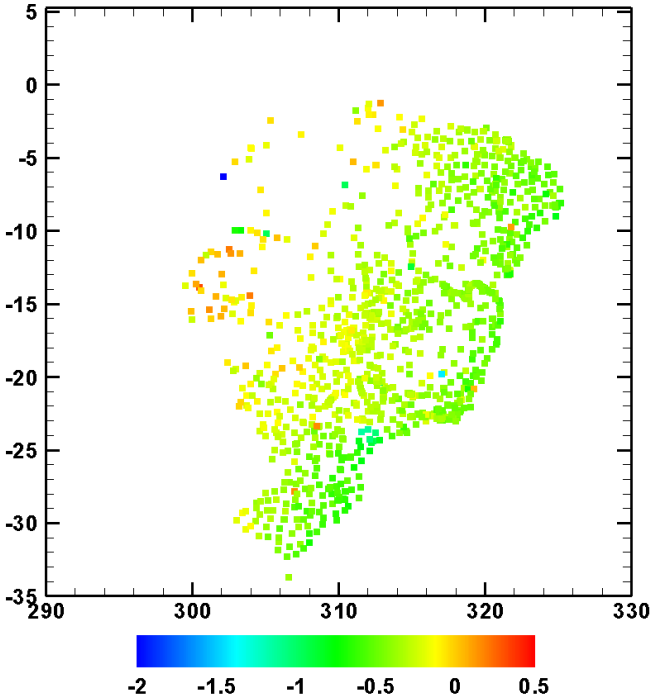
Residuals



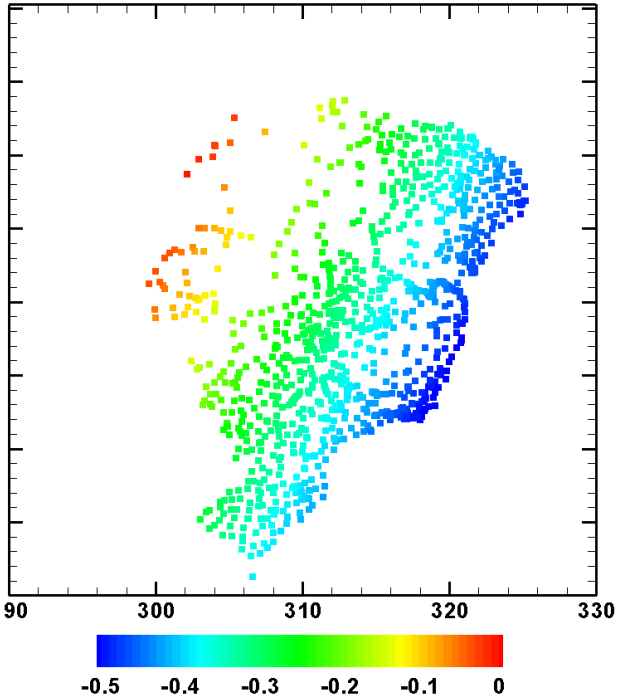
Error Assessment by GNSS-Levelling

Correction Surface (for XGM2019e d/o 2190)

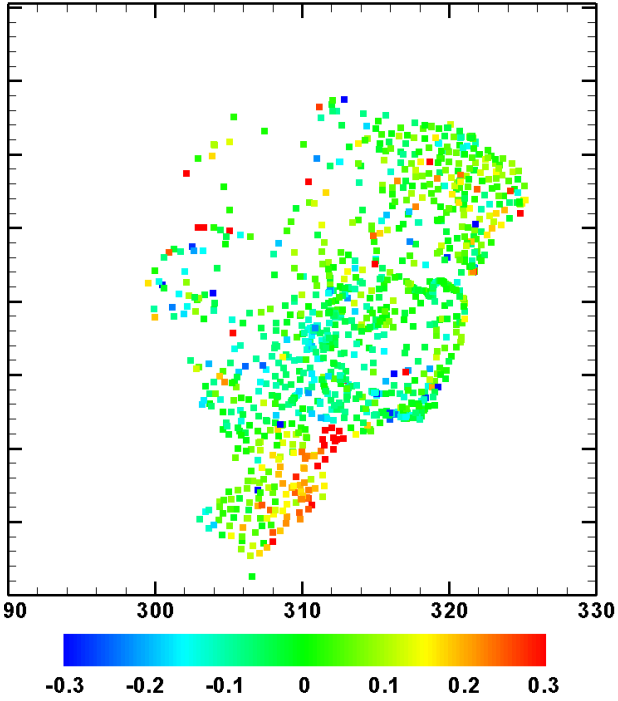
XGM2019e vs. Brazil2019 (subset not including data from Amapa, Amazonas, Rondonia, Roraima)



Correction Surface



Residuals



GNSS-Levelling Results

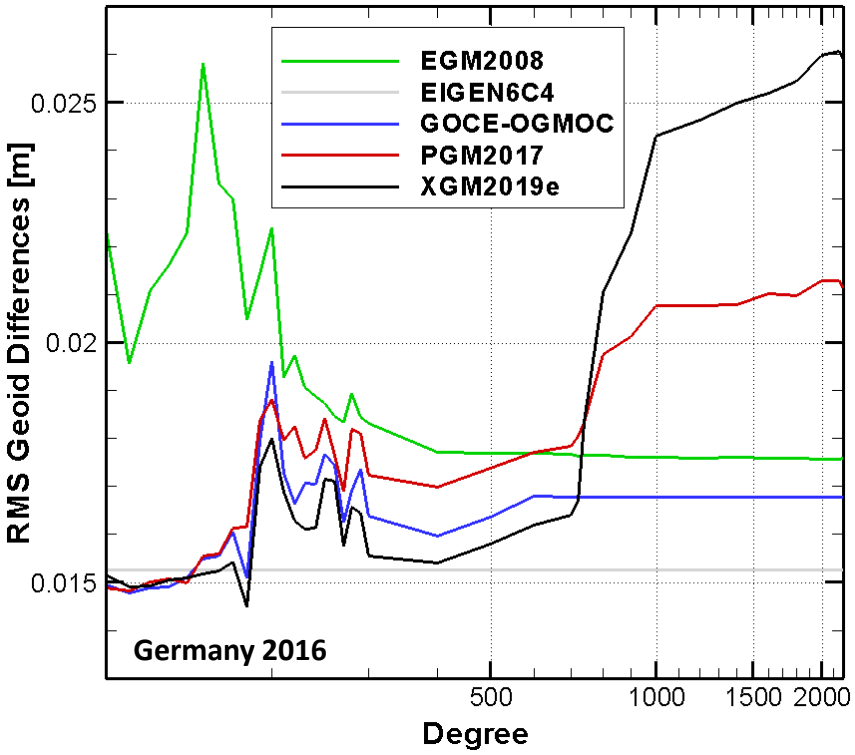
Overview Height Differences (d/o 2190)

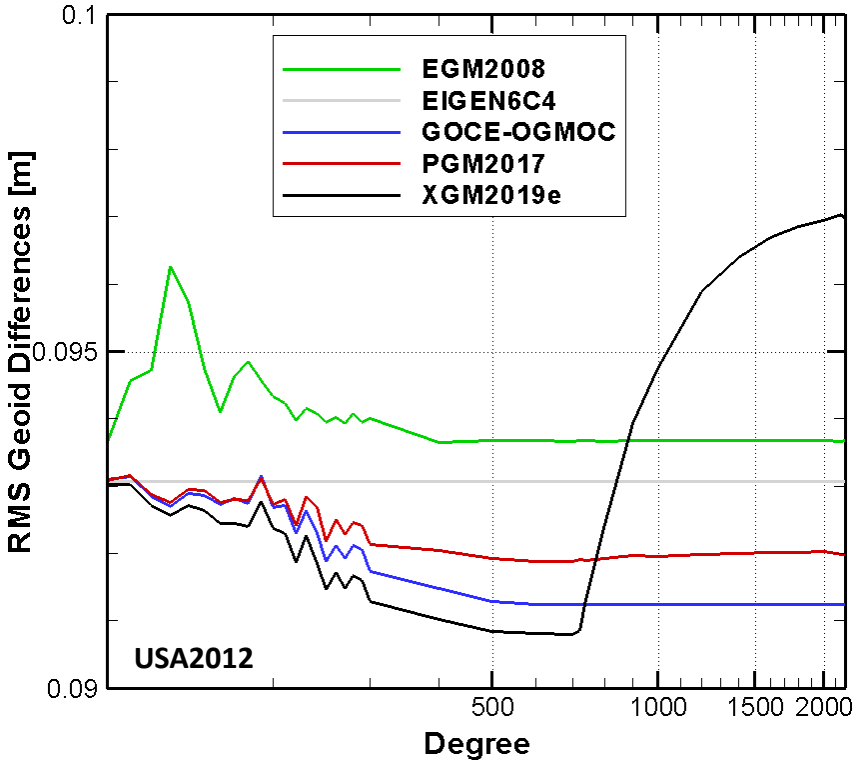
GNSS-levelling Dataset	No.	EGM2008	EIGEN6-C4	GOCE- OGMOC	PGM2017	XGM2019e
Alaska	109	25.7	25.4	25.3	23.9	25.3
Australia	197	17.9	17.5	17.6	17.6	17.6
Brazil 2012	683	33.7	27.6	26.6	26.6	26.2
Brazil 2019 (complete)	1287	40.0	35.2	33.9	33.7	33.5
Brazil 2019 (subset)	1180	27.0	21.0	18.4	18.4	18.5
Canada	579	8.1	7.7	7.6	7.6	7.9
Germany 2016	470	1.8	1.5	1.7	2.1	2.6
Greece	1542	13.9	12.4	13.0	13.1	13.7
Japan	837	7.4	6.5	6.3	6.3	7.8
Mexico	744	30.1	29.9	28.3	28.6	28.7
Puerto Rico	29	2.7	3.1	2.8	3.2	6.0
UK	177	4.2	3.7	3.7	3.6	4.6
USA	24872	9.4	9.3	9.1	9.2	9.7

RMS around mean after subtracting correction surface (all points) [cm]

GNSS-Levelling Results

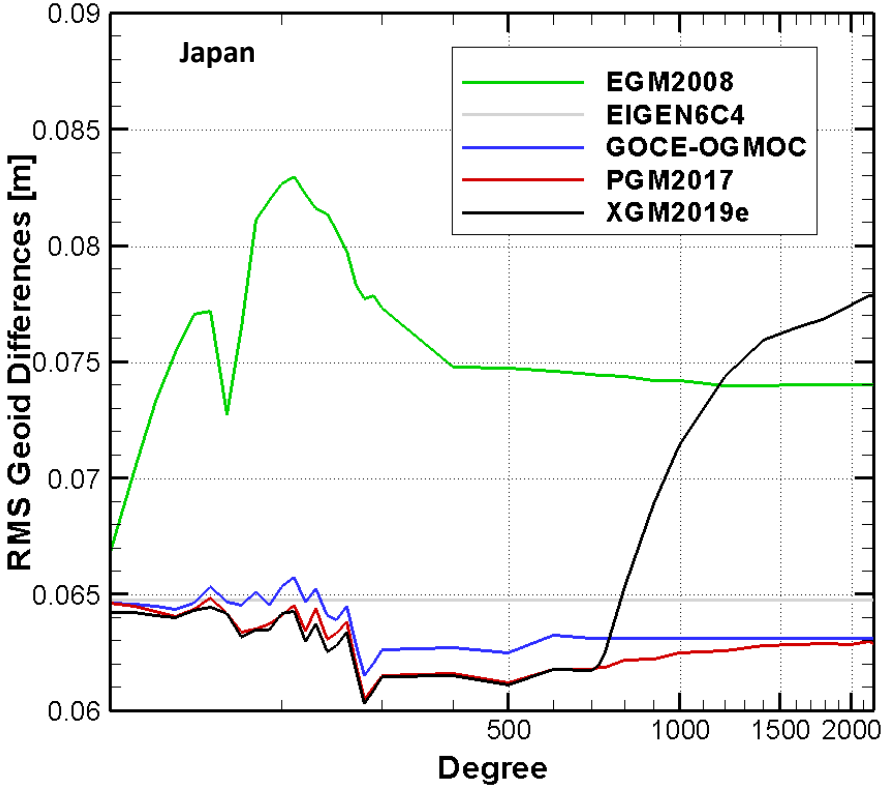
RMS of Geoid Differences per Data Set for Different Model Resolutions

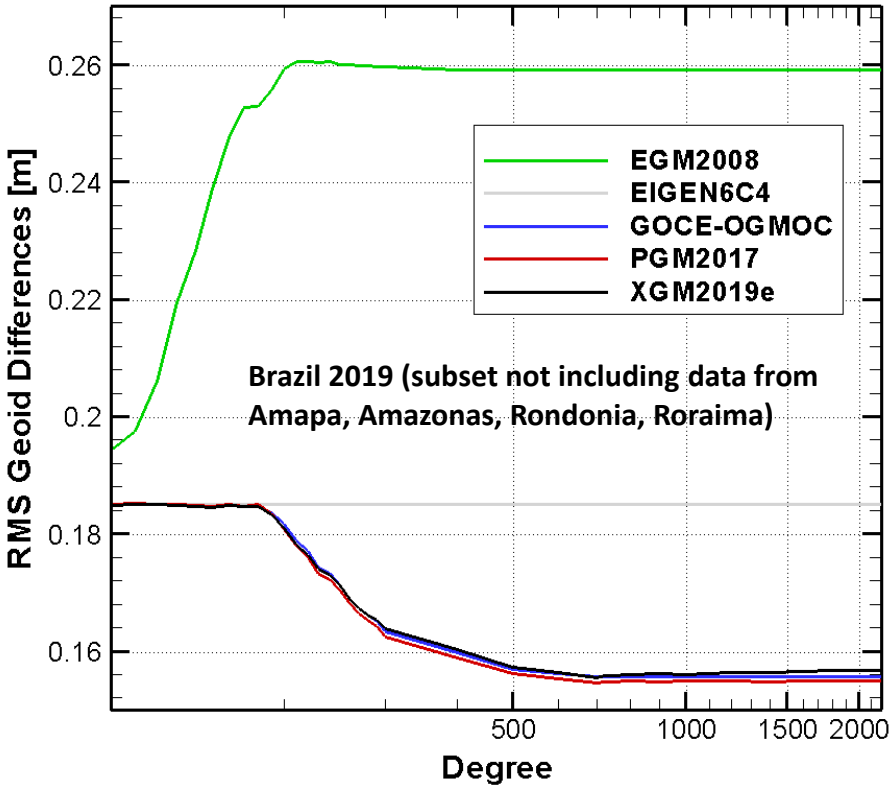




GNSS-Levelling Results

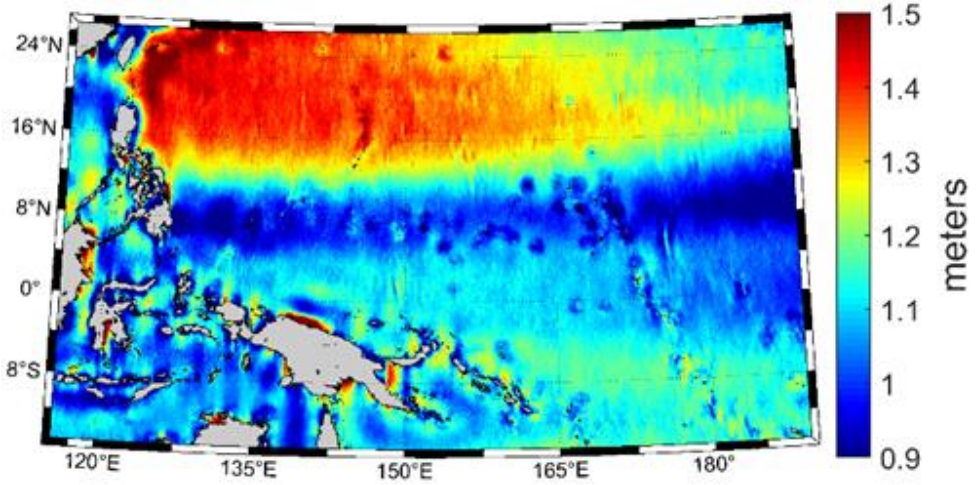
RMS of Geoid Differences per Data Set for Different Model Resolutions



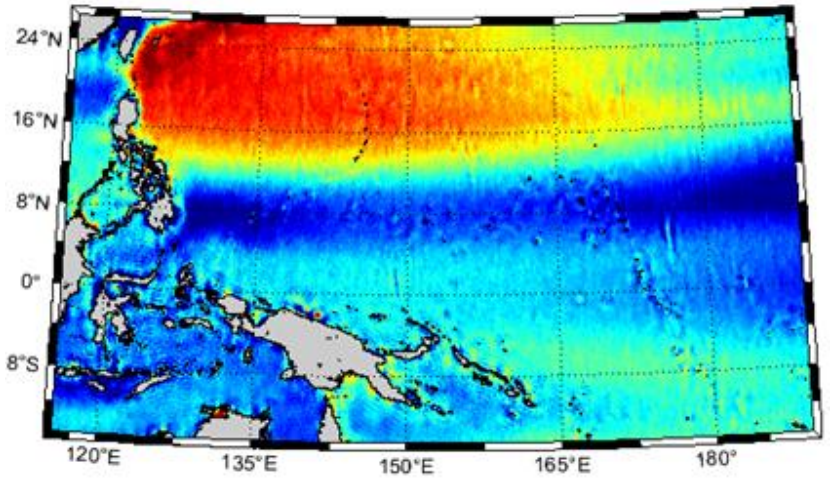


Ocean Mean Dynamic Topography (MDT)

MDT from CNES/CLS2015 MSS minus EGM2008



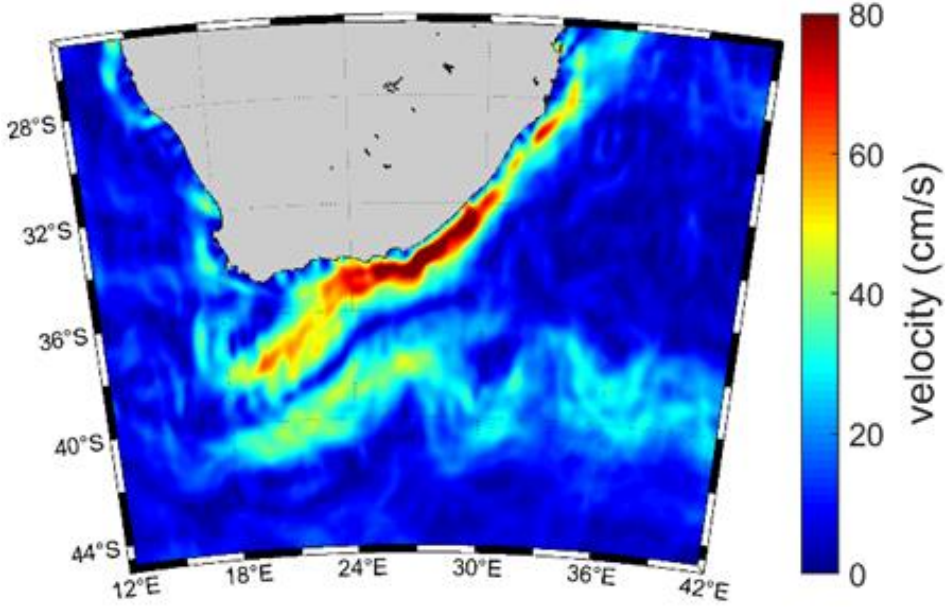
MDT from CNES/CLS2015 MSS minus XGM2019e



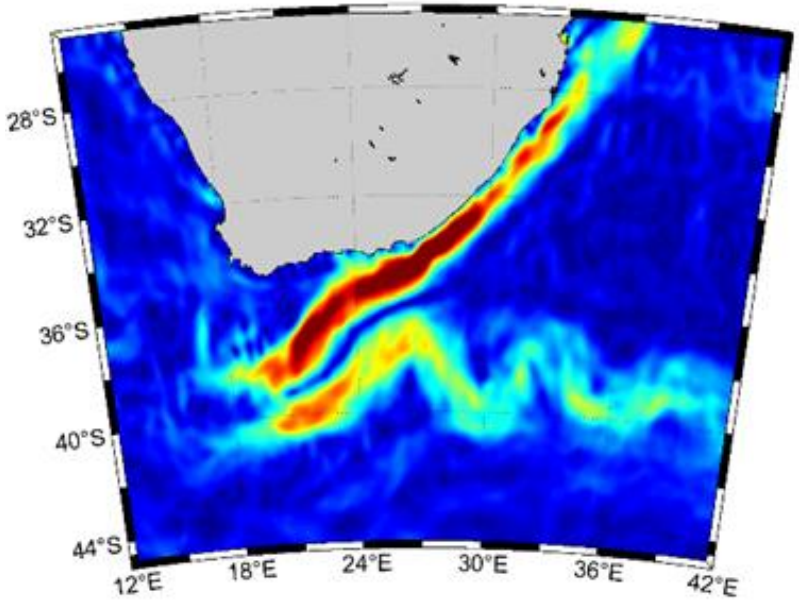
The mean dynamic topography is computed by subtracting the unfiltered ocean geoid model from the unfiltered CNES/CLS 2015 mean sea surface.

Ocean Mean Dynamic Topography (MDT)

Geostrophic velocities from CNES/CLS2015 MSS minus EGM2008



Geostrophic velocities from CNES/CLS2015 MSS minus XGM2019e



From the MDT geostrophic current velocities are computed by horizontal derivatives. Both MDT's are filtered identically before differentiation.

Summary & Conclusions

High Resolution Models

- A new ultra high resolution model up to degree and order 5540 has been computed – XGM2019e is completely independent from any a-priori high resolution model.
- In global average most improvement wrt. EGM2008 from GOCE data (70%-80% up to d/o 200) and some improvement from better surface data (20%-30% up to full resolution).

HR Model Performance

- Very difficult to distinguish between errors caused by levelling, GNSS, global model and corrections. For a high quality GNSS-leveling data set (e.g. Germany) differences between 1.5 and 2.5 cm can be reached.
- XGM2019e performance over continents degraded for degrees above 719 due to modelling the signal purely from a topography model. But, degradation only at a level of a few cm due to missing observed gravity data.

HR Model as Height Reference Surface

- Depending on the roughness of surface topography, global models deliver an equipotential surface as global height reference at a level of 1 to 10 cm in terms of accuracy.
- For areas with less good gravity infrastructure such global models represent the best choice.

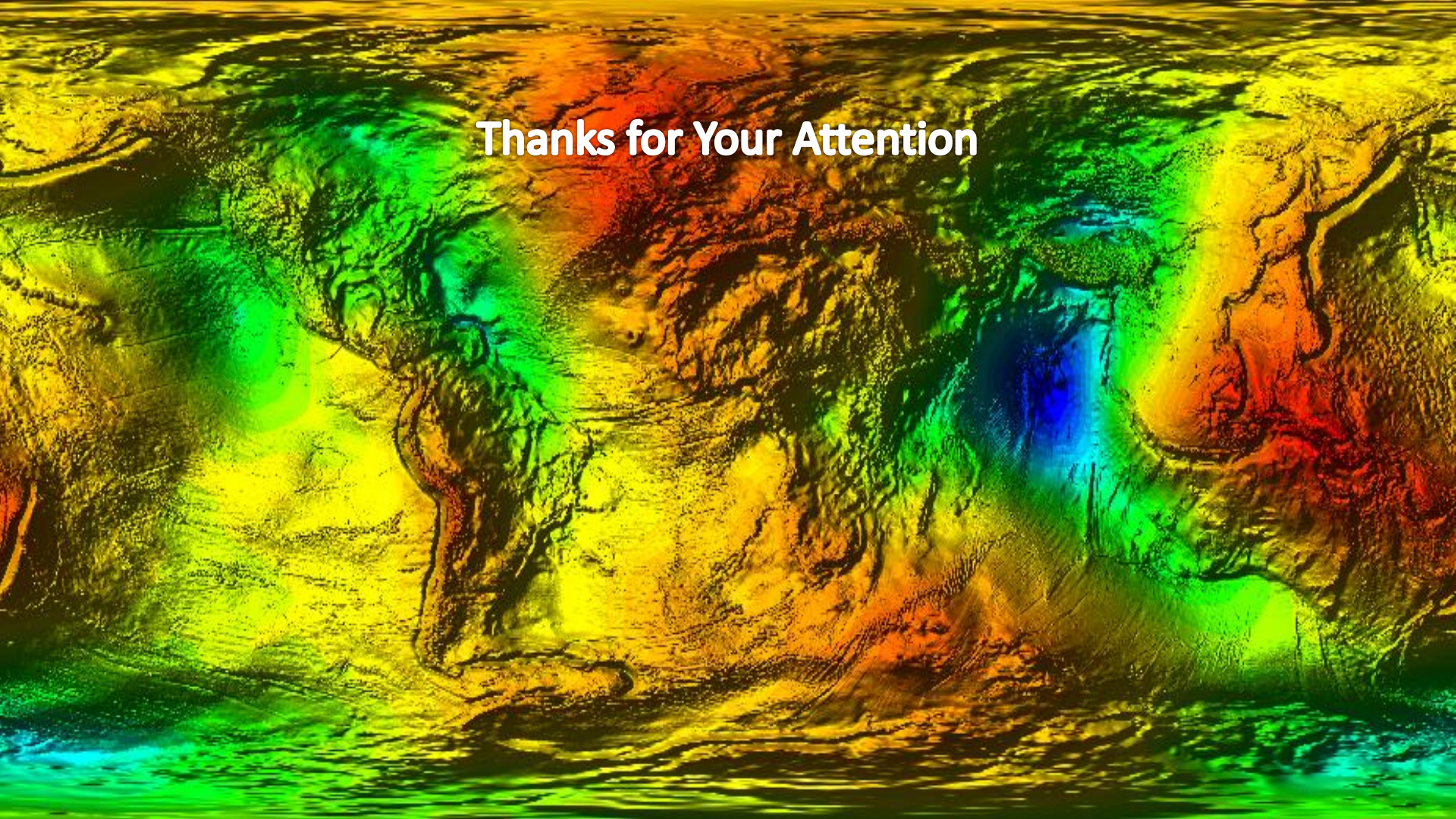
References & Acknowledgement

References:

- Thomas Gruber and Martin Willberg: Signal and Error Assessment of GOCE-based High Resolution Gravity Field Models; accepted for publication by Journal of Geodetic Science, Ms. No. JGS-D-18-00023, 2019
- Zingerle, Philipp; Pail, Roland; Gruber, Thomas; Oikonomidou, Xanthi (2019): The experimental gravity field model XGM2019e. GFZ Data Services. http://doi.org/10.5880/ICGEM.2019.007

GNSS-Levelling Data have been provided by:

- Australia: Geoscience Australia, 2003
- Brazil: Brazilian Institute of Geography and Statistics - IBGE, Directorate of Geosciences - DGC, Coordination of Geodesy – CGED, 2012, 2019
- Canada: National Resources of Canada (NRCan), via National Geodetic Survey, 2012
- Europe Various Countries, EUREF EUVN: Bundesamt für Kartographie und Geodäsie, Frankfurt/Main, 2007
- Germany: Bundesamt für Kartographie und Geodäsie, Frankfurt/Main, 2007
- Great Britain: UK Ordnance Survey, 2011
- Greece: Aristotle University of Thessaloniki, 2016
- Japan: Japanese Geographical Survey Institute, 2003
- Mexico: via US National Geodetic Survey, 2012
- Saudi Arabia: King Abdulaziz City for Science and Technology KACST, 2012
- USA: National Geodetic Survey, 2012


Thanks for Your Attention

GNSS-Levelling Results Brazil

Overview Height Differences (d/o 2190)

GNSS-levelling Dataset	No.	EGM2008	EIGEN6-C4	GOCE- OGMOC	PGM2017	XGM2019e
Brazil 2019 (complete)	1287	40.0	35.2	33.9	33.7	33.5
Brazil 2019 (subset)*	1180	27.0	21.0	18.4	18.4	18.5
Alagoas	6	15.6	8.7	13.6	12.6	11.5
Amapa	65	19.9	11.8	11.7	11.9	10.5
Amazonas	16	28.1	20.9	12.9	15.4	13.3
Bahia	176	14.3	15.3	14.3	14.8	15.2
Ceara	82	7.9	9.2	8.5	8.6	8.4
Distrito Federal	26	8.6	5.8	7.0	6.0	5.8
Espirito Santo	17	31.1	18.3	19.5	19.6	19.9
Goias	107	18.0	13.3	9.0	8.6	8.9
Maranhao	40	13.9	12.8	9.1	9.6	9.4
Mato Grosso do Sul	54	12.9	11.3	9.2	8.8	9.5
Mato Grosso	56	76.4	38.2	20.9	21.6	21.8
Minas Gerais	155	21.8	17.3	15.1	15.1	15.5
Para	24	62.1	47.6	46.8	46.2	46.0

*excluding GPS-levelling points from from Amapa, Amazonas, Rondonia, Roraima

RMS around mean after subtracting correction surface (all points) [cm]

GNSS-Levelling Results Brazil

Overview Height Differences (d/o 2190)

GNSS-levelling Dataset	No.	EGM2008	EIGEN6-C4	GOCE- OGMOC	PGM2017	XGM2019e
Brazil 2019 (complete)	1287	40.0	35.2	33.9	33.7	33.5
Brazil 2019 (subset)*	1180	27.0	21.0	18.4	18.4	18.5
Paraiba	12	22.9	12.8	9.4	9.3	9.2
Parana	53	16.6	15.2	14.9	15.3	15.0
Pernambuco	29	25.8	17.0	11.3	10.5	10.4
Piaui	44	15.5	9.9	10.2	10.5	10.4
Rio Grande do Norte	16	9.3	5.5	4.6	3.8	4.3
Rio Grande do Sul	66	16.1	15.4	15.3	15.6	15.3
Rio de Janeiro	59	20.4	18.4	10.3	10.2	9.4
Rondonia	10	31.4	22.3	14.7	14.9	14.9
Roraima	16	24.5	10.8	8.2	9.4	9.1
Santa Caterina	32	10.5	9.1	10.1	9.5	9.3
Sao Paulo	102	22.2	22.4	21.2	21.1	21.1
Sergipe	4	19.5	4.7	4.6	7.6	7.4
Tocantins	20	22.8	14.7	8.4	8.0	7.8

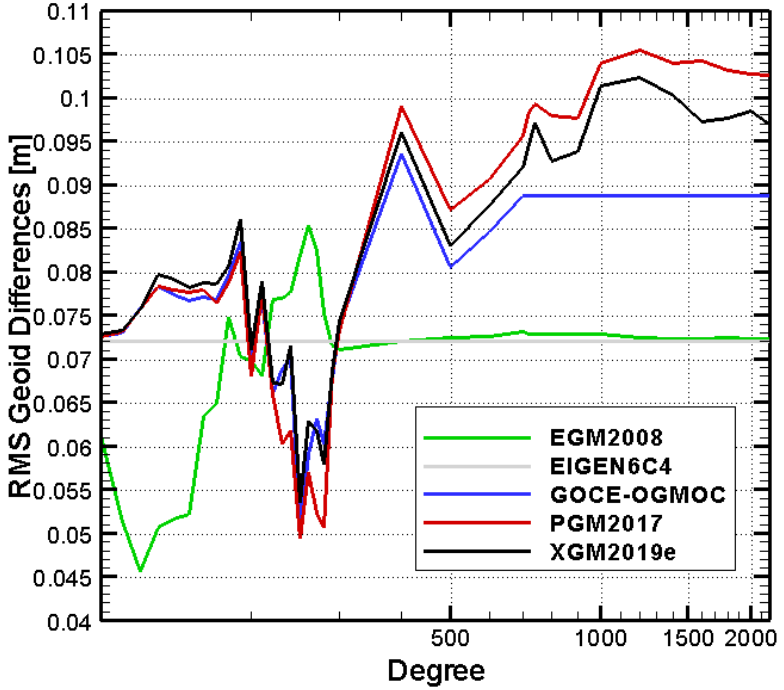
*exluding GPS-levelling points from from Amapa, Amazonas, Rondonia, Roraima

RMS around mean after subtracting correction surface (all points) [cm]

GNSS-Levelling Results Brazil

RMS of Geoid Differences per Data Set for Different Model Resolutions

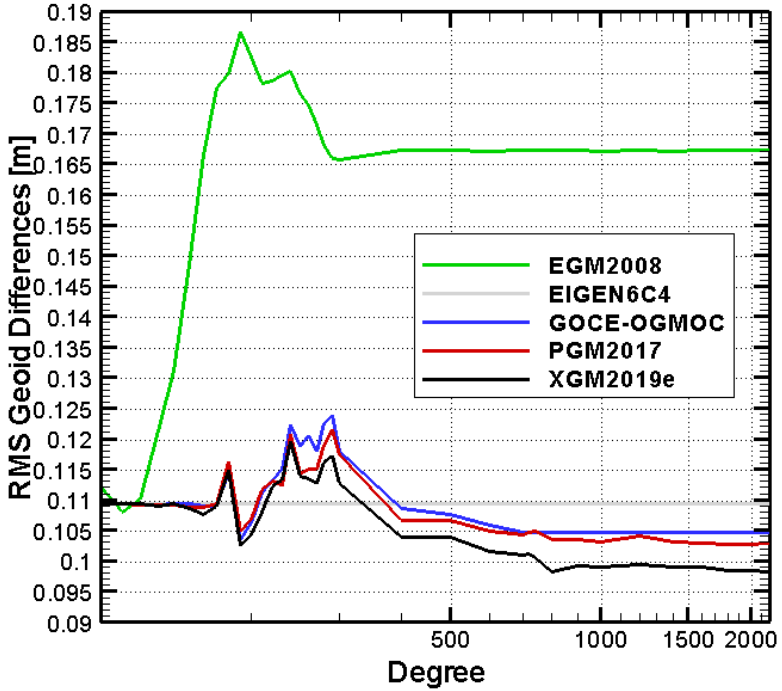
Alagoas (6 Points)



GNSS-Levelling Results Brazil

RMS of Geoid Differences per Data Set for Different Model Resolutions

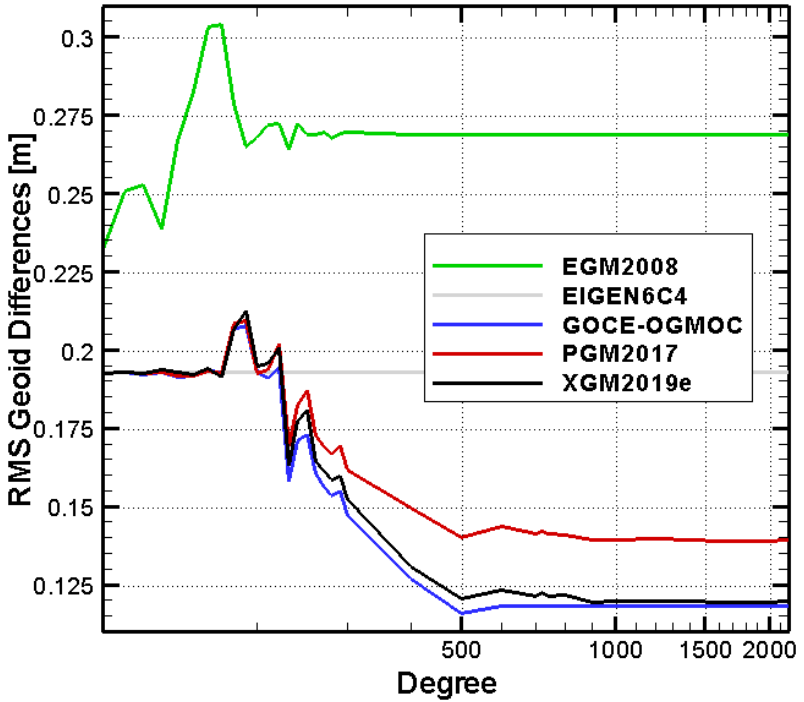
Amapa (65 Points)



GNSS-Levelling Results Brazil

RMS of Geoid Differences per Data Set for Different Model Resolutions

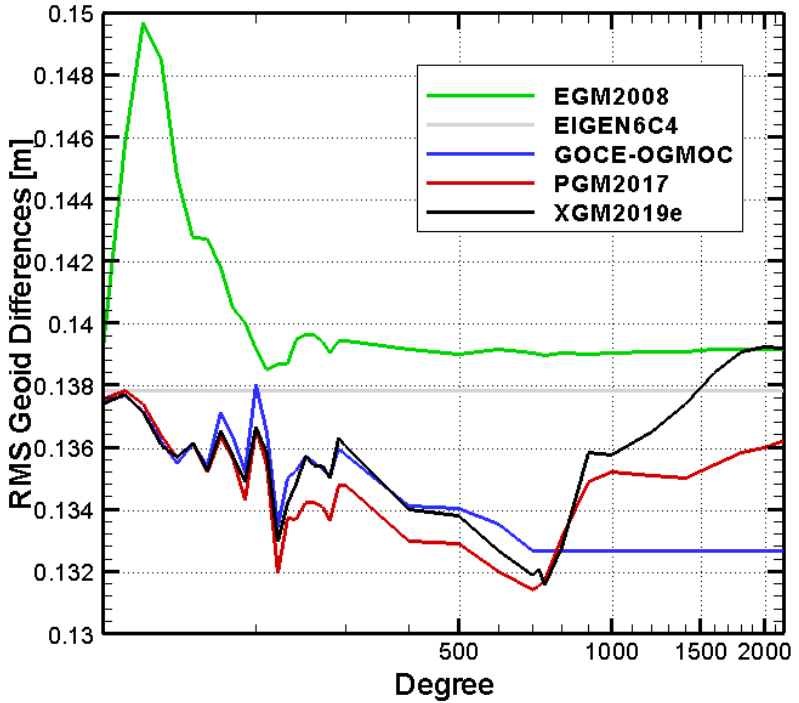
Amazonas (16 Points)



GNSS-Levelling Results Brazil

RMS of Geoid Differences per Data Set for Different Model Resolutions

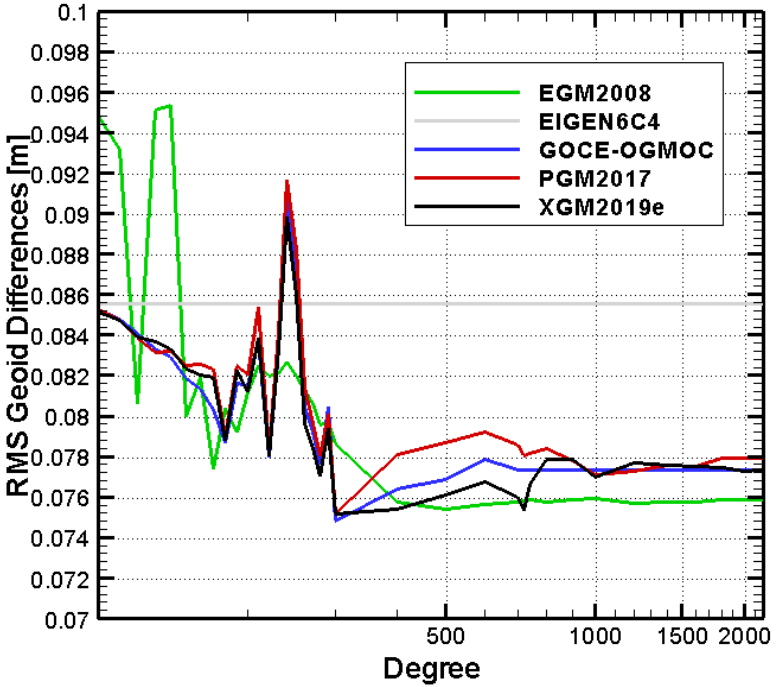
Bahia (176 Points)



GNSS-Levelling Results Brazil

RMS of Geoid Differences per Data Set for Different Model Resolutions

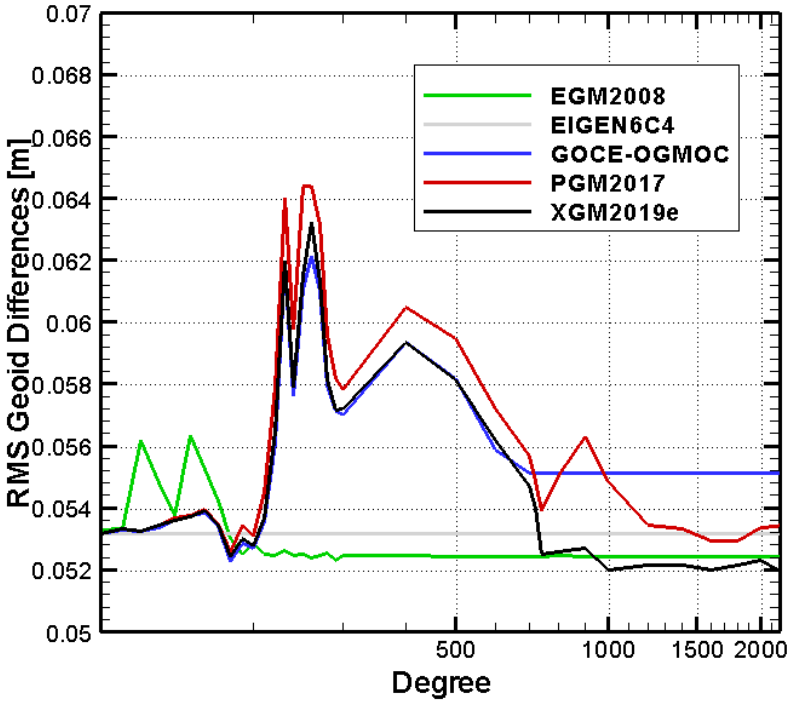
Ceara (82 Points)



GNSS-Levelling Results Brazil

RMS of Geoid Differences per Data Set for Different Model Resolutions

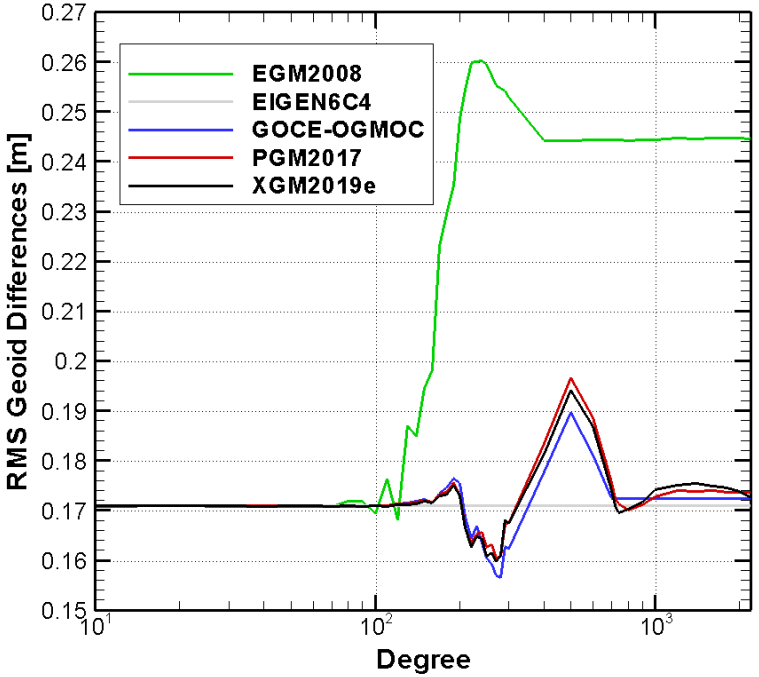
Distrito Federal (26 Points)



GNSS-Levelling Results Brazil

RMS of Geoid Differences per Data Set for Different Model Resolutions

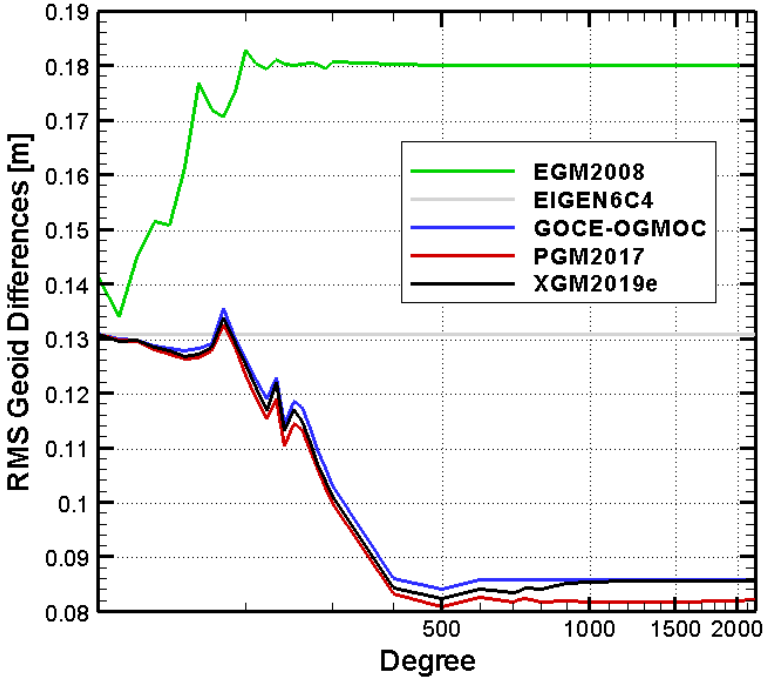
Espirito Santo (17 Points)



GNSS-Levelling Results Brazil

RMS of Geoid Differences per Data Set for Different Model Resolutions

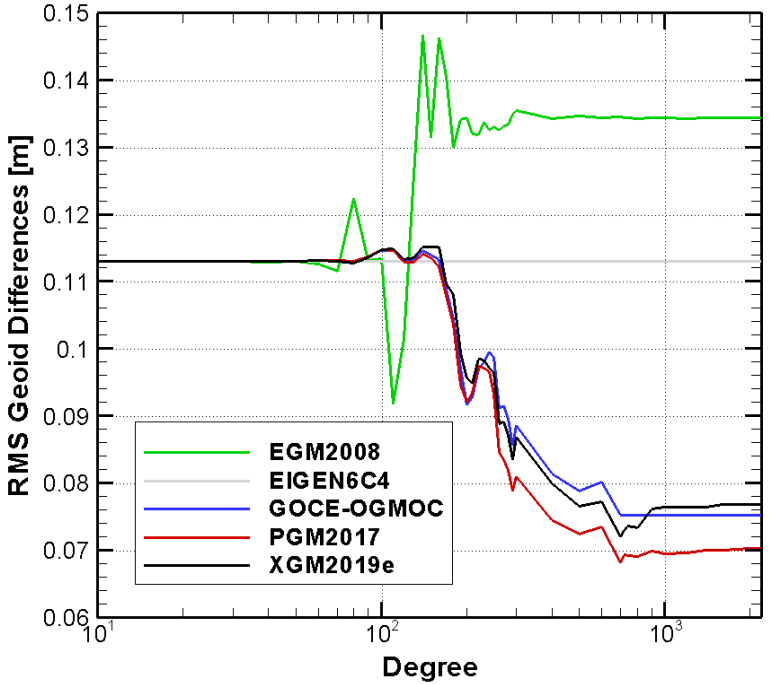
Goias (107 Points)



GNSS-Levelling Results Brazil

RMS of Geoid Differences per Data Set for Different Model Resolutions

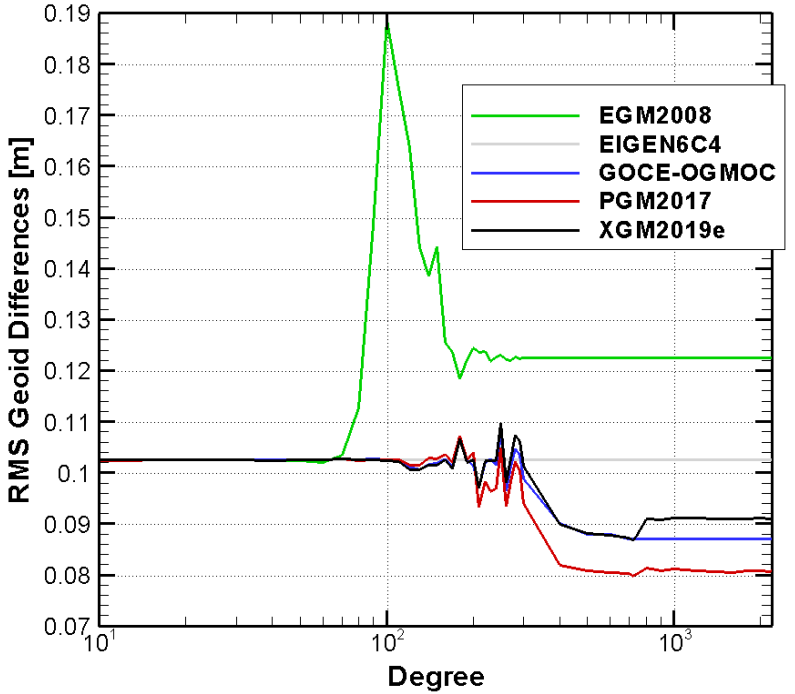
Maranhao (40 Points)



GNSS-Levelling Results Brazil

RMS of Geoid Differences per Data Set for Different Model Resolutions

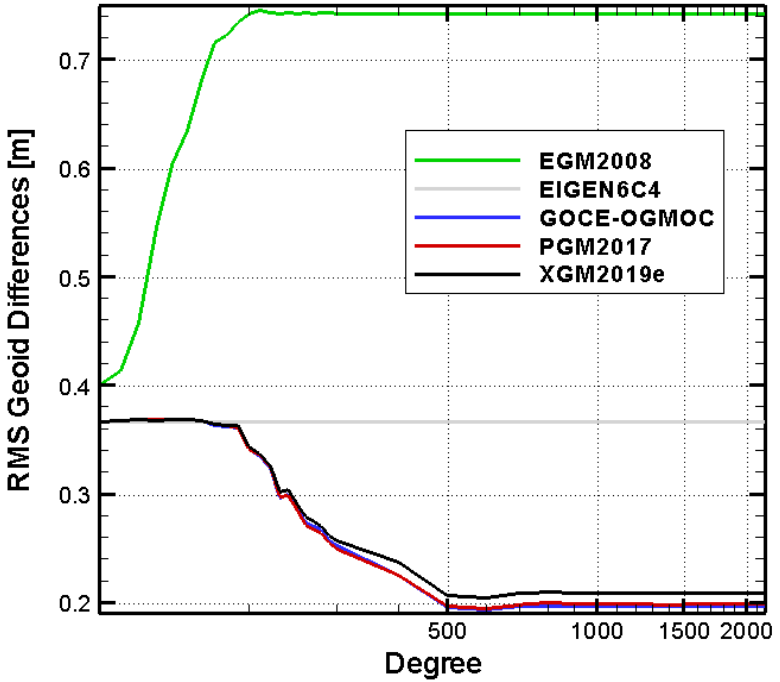
Mato Grosso do Sul (54 Points)



GNSS-Levelling Results Brazil

RMS of Geoid Differences per Data Set for Different Model Resolutions

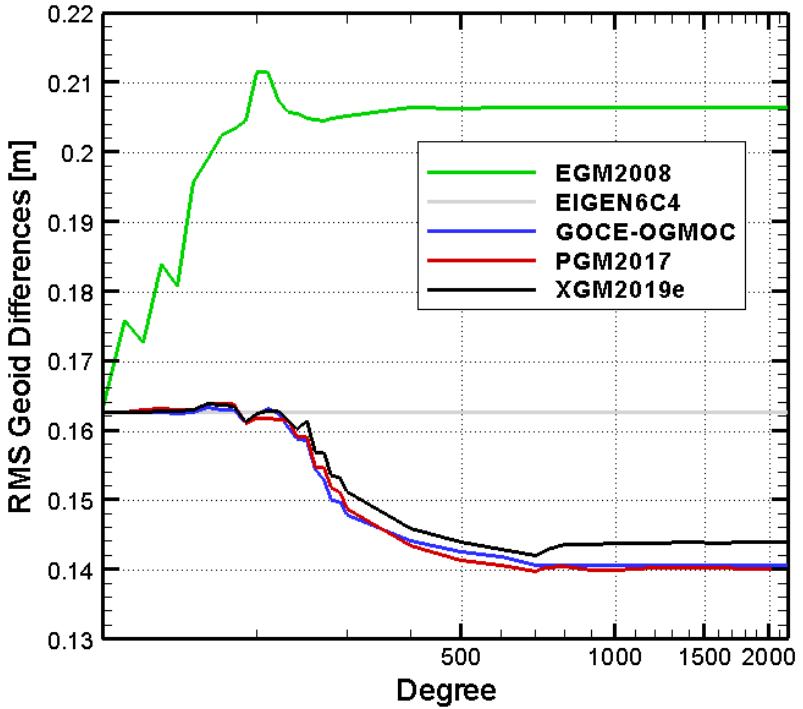
Mato Grosso (56 Points)



GNSS-Levelling Results Brazil

RMS of Geoid Differences per Data Set for Different Model Resolutions

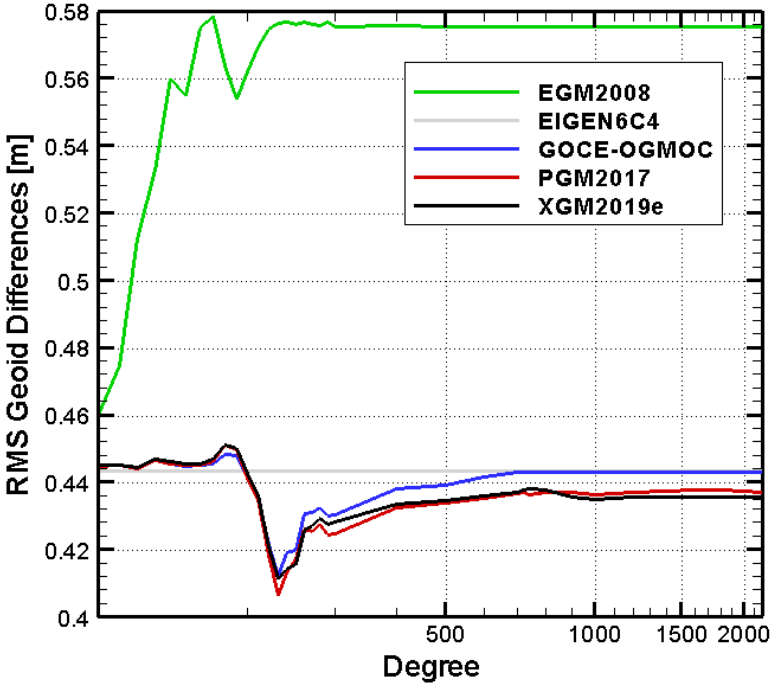
Minas Gerais (155 Points)



GNSS-Levelling Results Brazil

RMS of Geoid Differences per Data Set for Different Model Resolutions

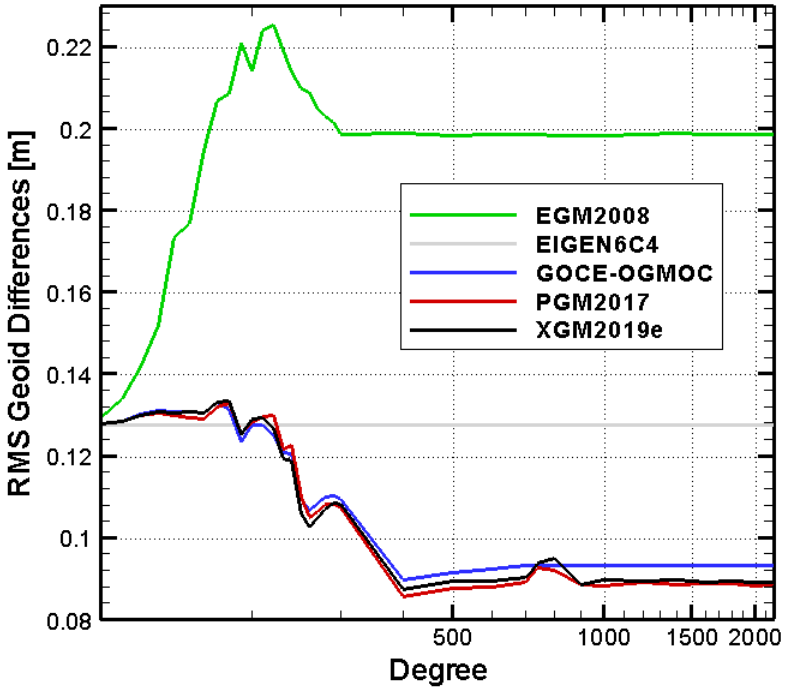
Para (24 Points)



GNSS-Levelling Results Brazil

RMS of Geoid Differences per Data Set for Different Model Resolutions

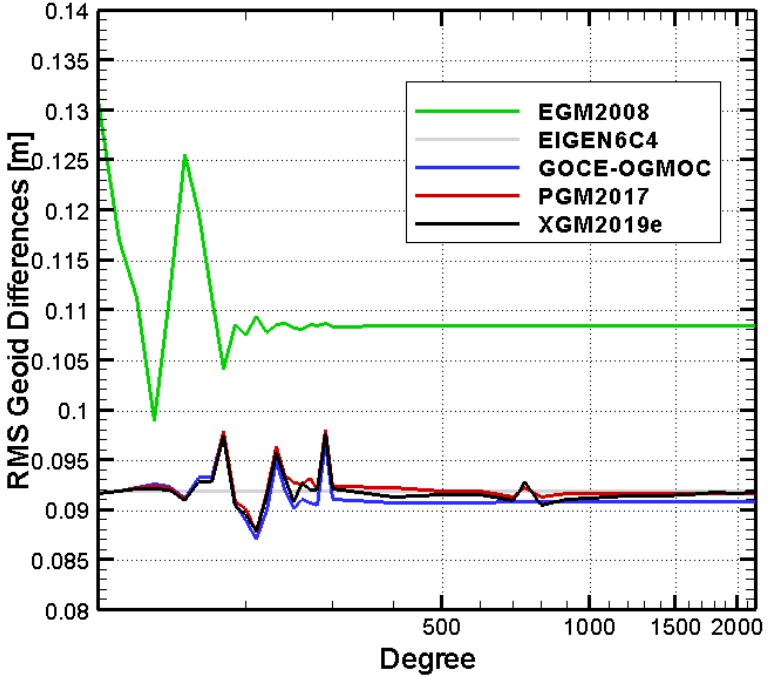
Paraiba (12 Points)



GNSS-Levelling Results Brazil

RMS of Geoid Differences per Data Set for Different Model Resolutions

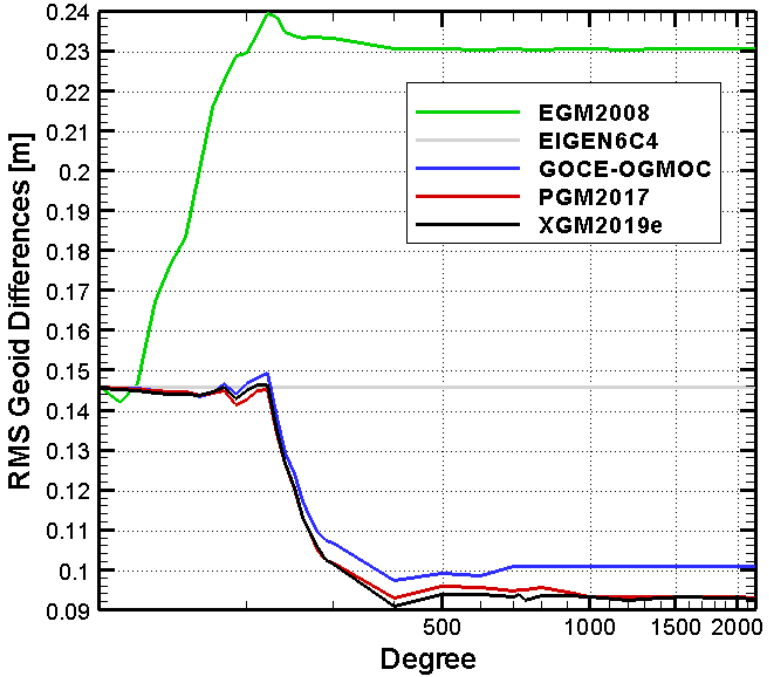
Parana (53 Points)



GNSS-Levelling Results Brazil

RMS of Geoid Differences per Data Set for Different Model Resolutions

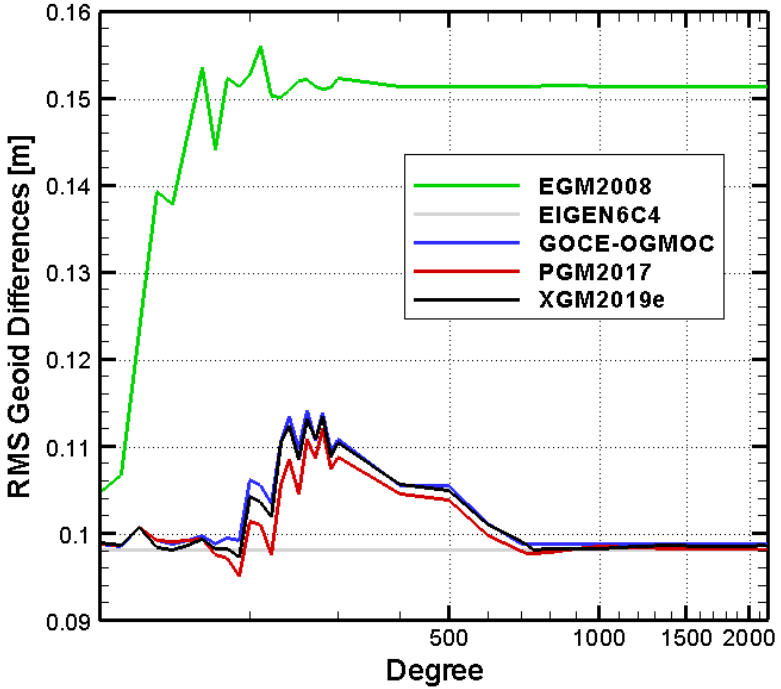
Pernambuco (29 Points)



GNSS-Levelling Results Brazil

RMS of Geoid Differences per Data Set for Different Model Resolutions

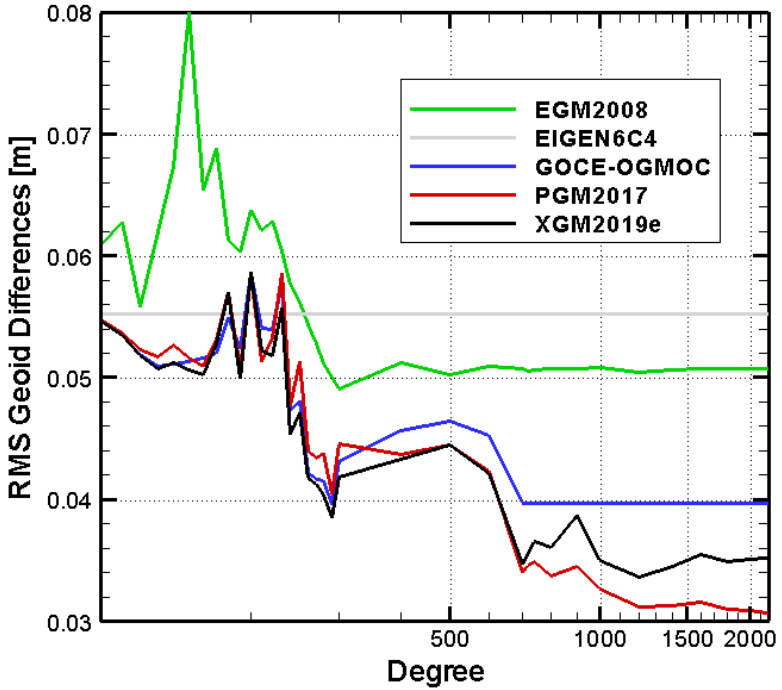
Piaui (44 Points)



GNSS-Levelling Results Brazil

RMS of Geoid Differences per Data Set for Different Model Resolutions

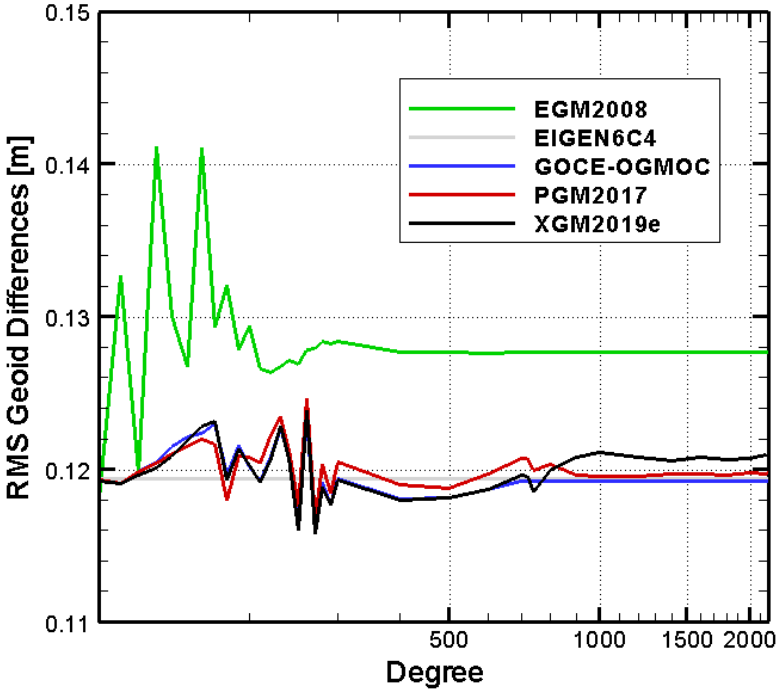
Rio Grande do Norte (16 Points)



GNSS-Levelling Results Brazil

RMS of Geoid Differences per Data Set for Different Model Resolutions

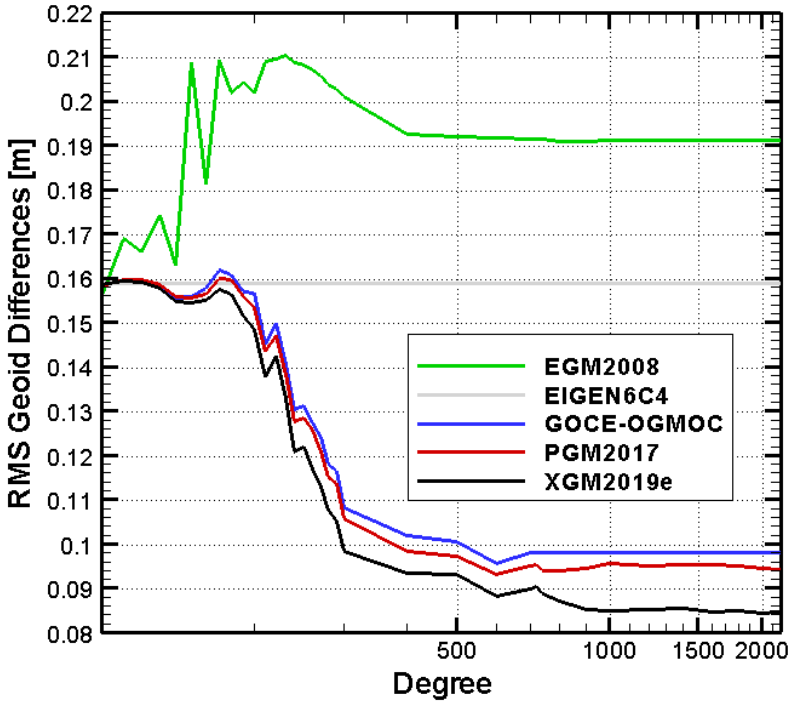
Rio Grande do Sul (66 Points)



GNSS-Levelling Results Brazil

RMS of Geoid Differences per Data Set for Different Model Resolutions

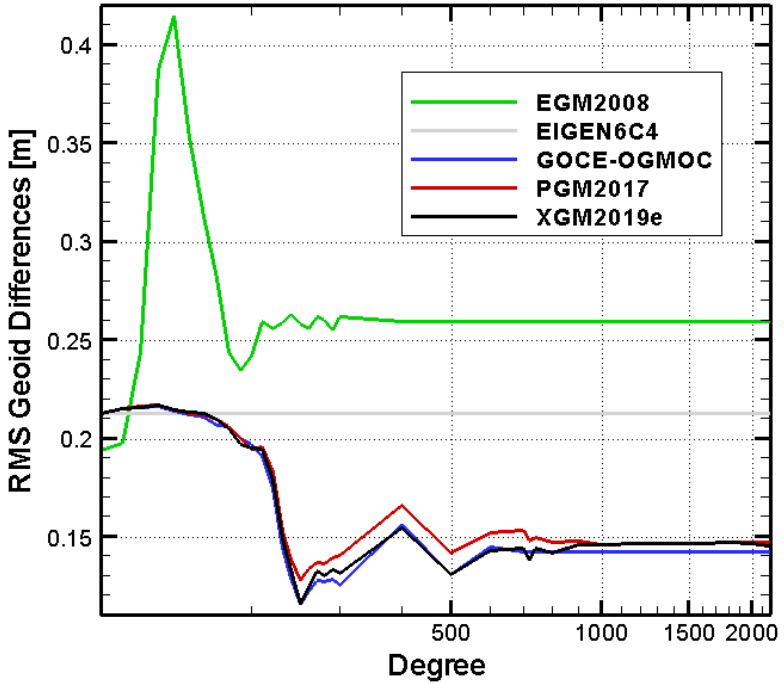
Rio de Janeiro (59 Points)



GNSS-Levelling Results Brazil

RMS of Geoid Differences per Data Set for Different Model Resolutions

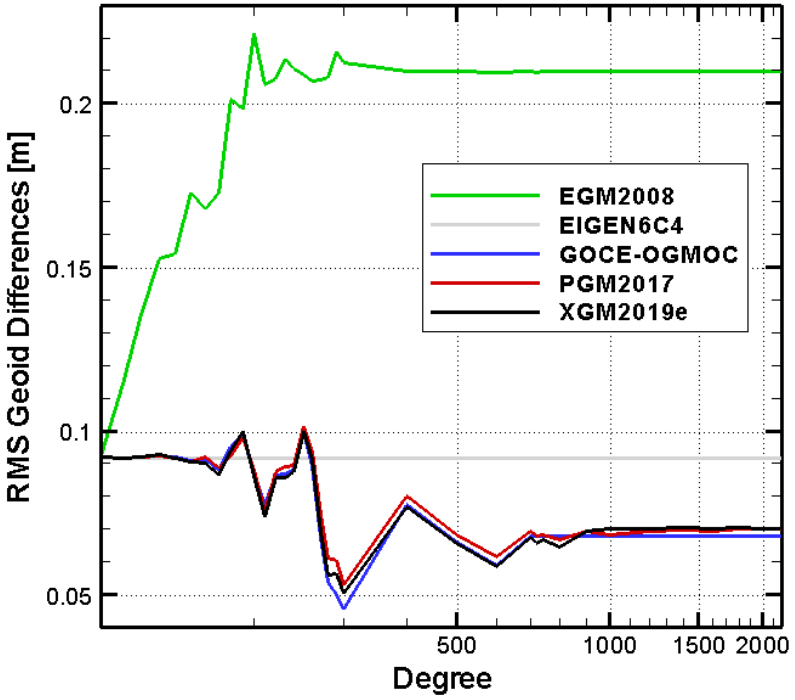
Rondonia (10 Points)



GNSS-Levelling Results Brazil

RMS of Geoid Differences per Data Set for Different Model Resolutions

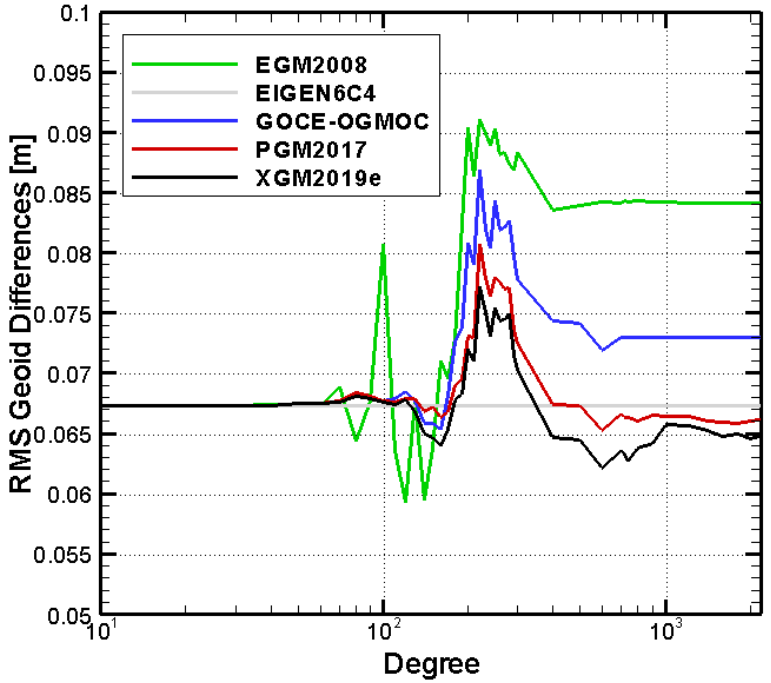
Roraima (16 Points)



GNSS-Levelling Results Brazil

RMS of Geoid Differences per Data Set for Different Model Resolutions

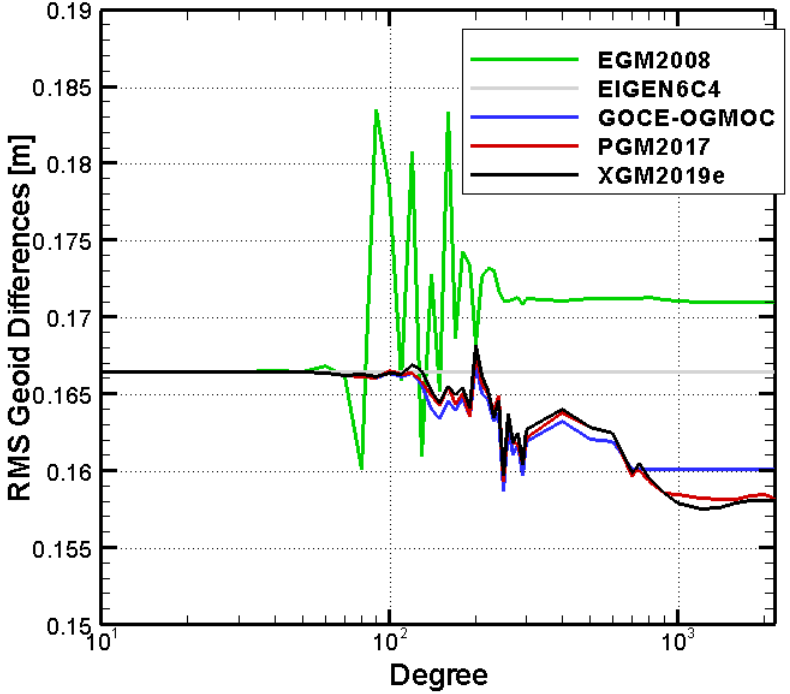
Santa Caterina (32 Points)



GNSS-Levelling Results Brazil

RMS of Geoid Differences per Data Set for Different Model Resolutions

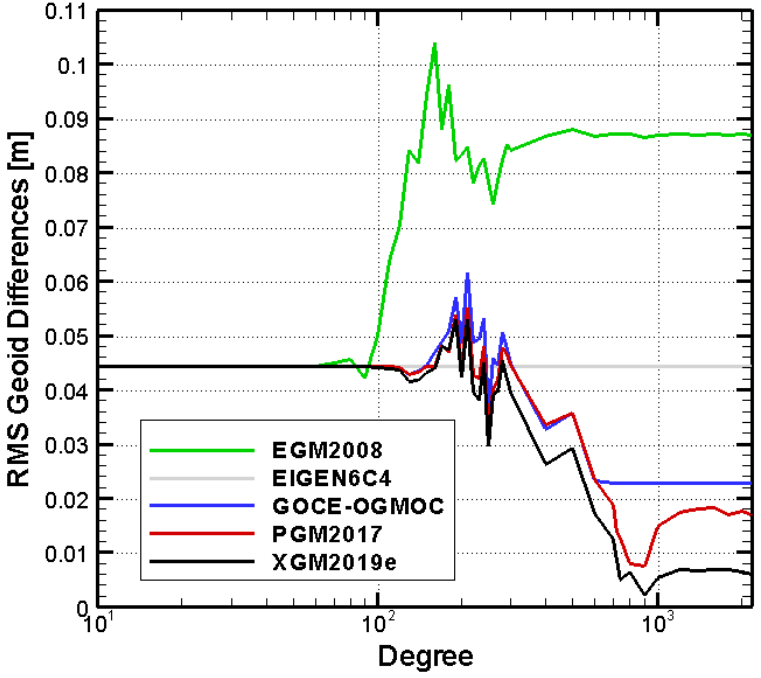
Sao Paulo (102 Points)



GNSS-Levelling Results Brazil

RMS of Geoid Differences per Data Set for Different Model Resolutions

Sergipe (4 Points)



GNSS-Levelling Results Brazil

RMS of Geoid Differences per Data Set for Different Model Resolutions

Tocantins (20 Points)