Signal and Error Assessment of GOCE-based High Resolution Gravity Field Models

Thomas Gruber & Martin Willberg
Institute of Astronomical and Physical Geodesy
Technical University of Munich

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Outline

High Resolution (HR) Models

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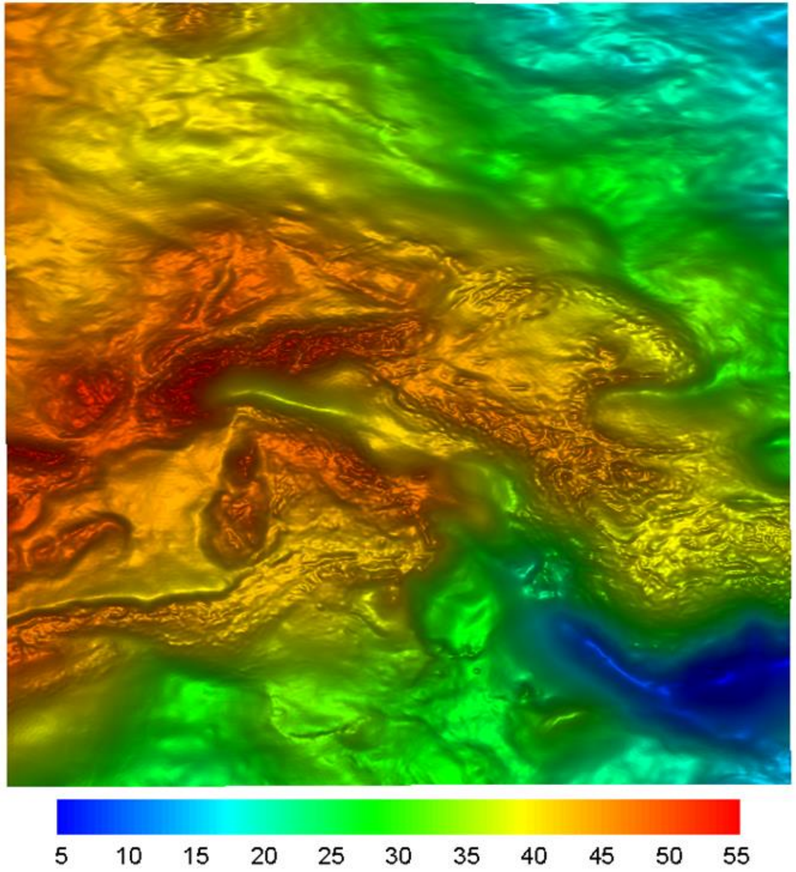
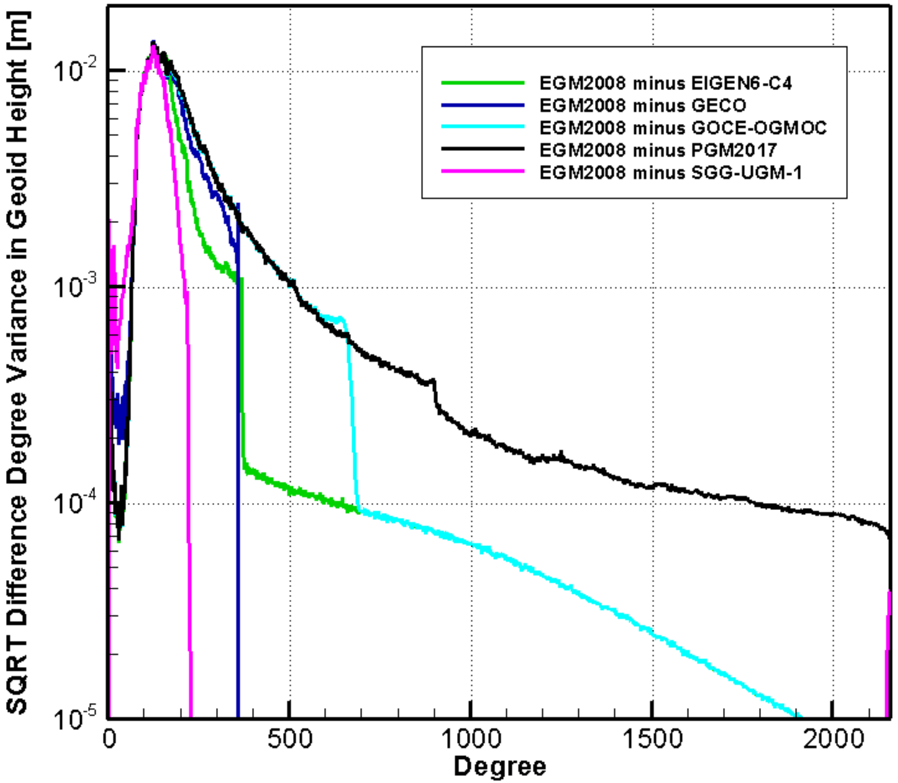
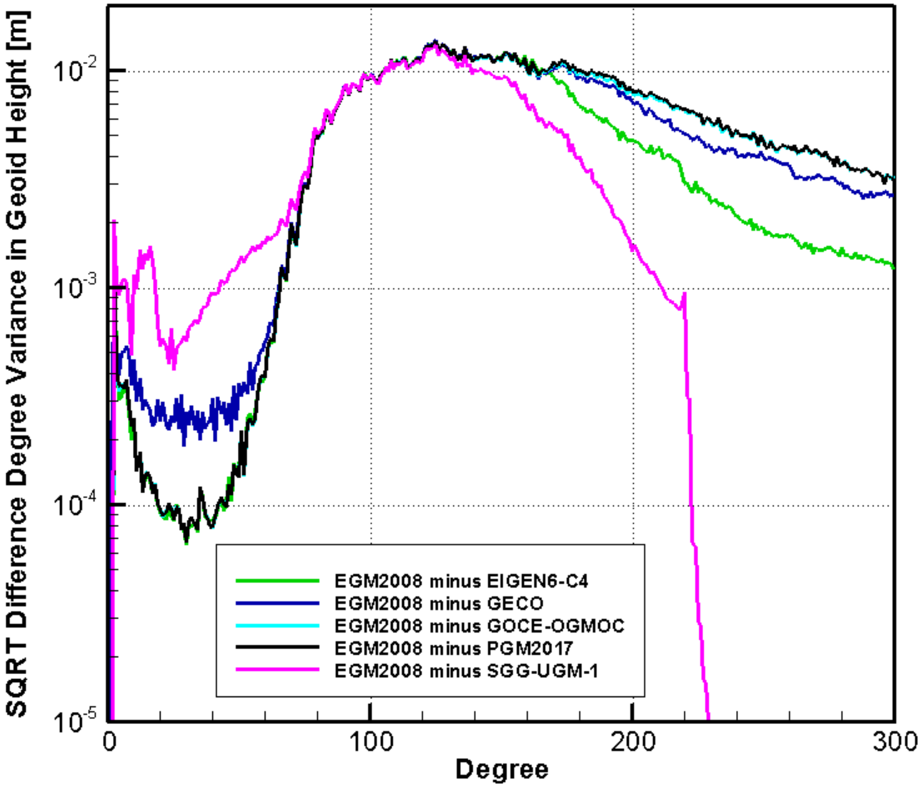


HR Models Overview

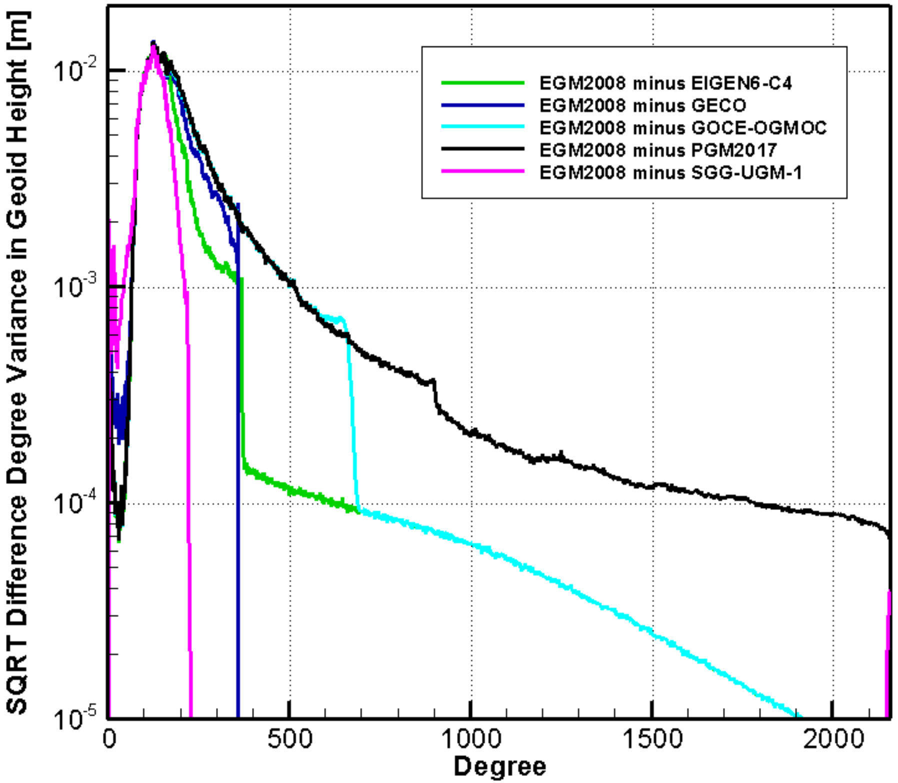
Model	Resolution	Satellite Data	Surface Data	Technique	Originator
EGM2008	2159 (ell.) 2190 (sph.)	GRACE ITG-GRACE03S	DNSC07 Altimetry SS v18.1 Altimetry NGA08 Land	d/o 359 full d/o 2159 BD	NGA, Pavlis et al, 2012
EIGEN6-C4	2190 (sph.)	GRACE-GRGS (10y) GOCE-DIR5 LAGEOS	DTU10 Altimetry EGM2008 Land	d/o 370 full d/o 2190 BD	GFZ/CNES Förste et al, 2014
GECO	2190 (sph.)	GOCE-TIM5	EGM2008 Land EGM2008 Ocean	Geoid spectral combination	POLIMI Gilardoni et al, 2016
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
SGG-UGM-1	2159 (sph.)	GOCE	EGM2008 Land EGM2008 Ocean	d/o 220 full d/o 2159 BD	WHU Liang, 2018
PGM2017	2159 (ell.) 2190 (sph.)	GOCO05S	NGA (5‘)	?	NGA, 2017

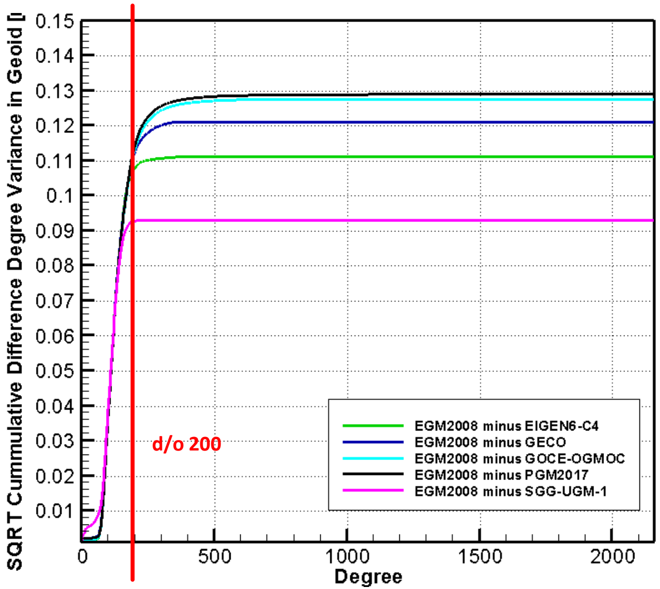
HR Models Signal Characteristics





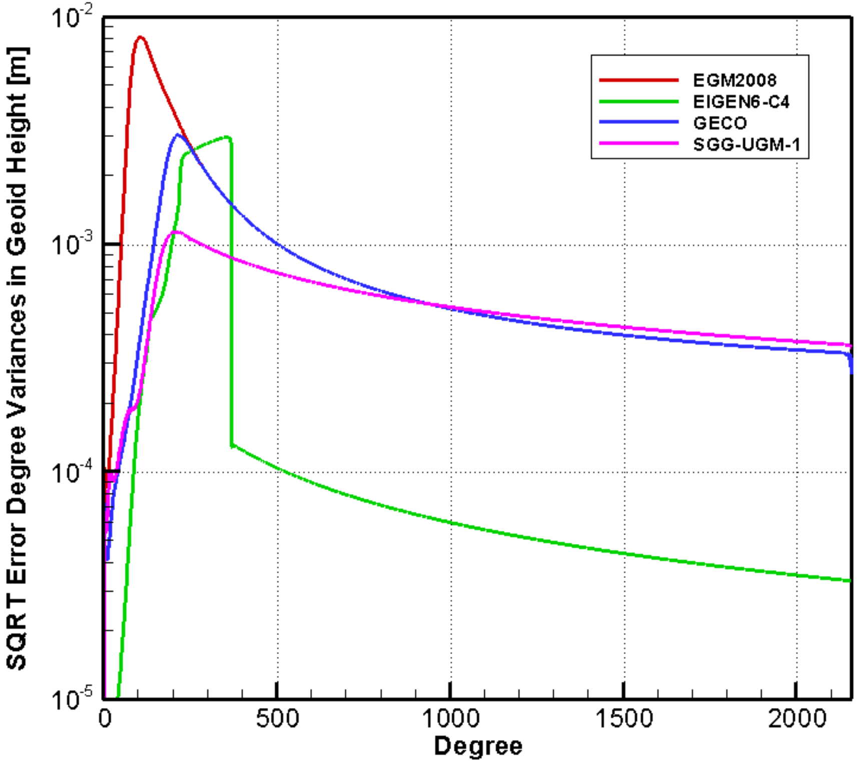
HR Models Signal Characteristics

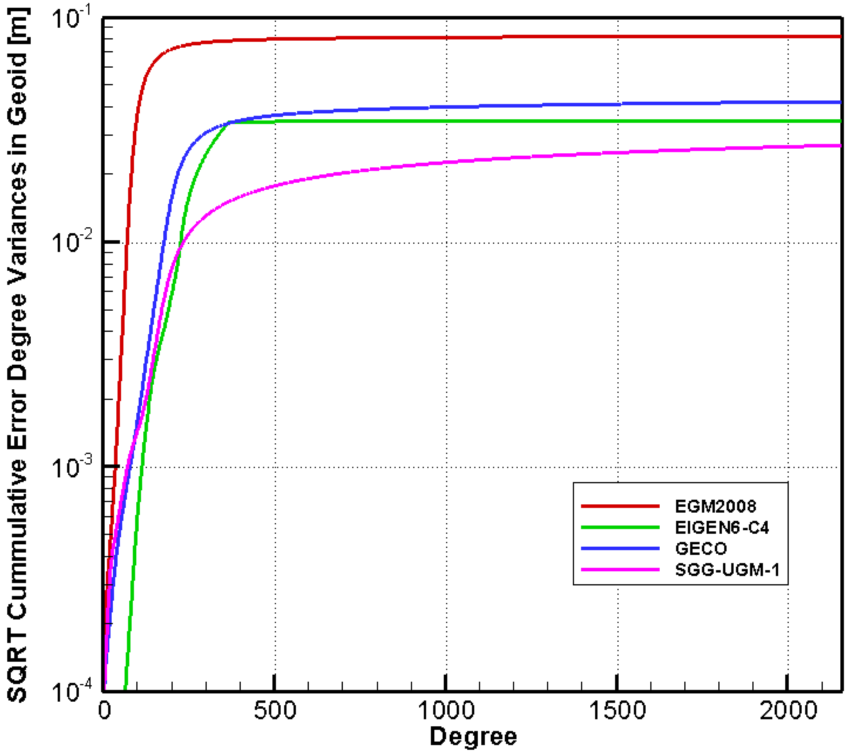




- Signal differences to EGM2008 exhibit the impact of new information in the HR-models.
- In global average most impact from adding GOCE data (up to d/o 200), less impact from new surface data (above d/o 200).

HR Models Error Characteristics

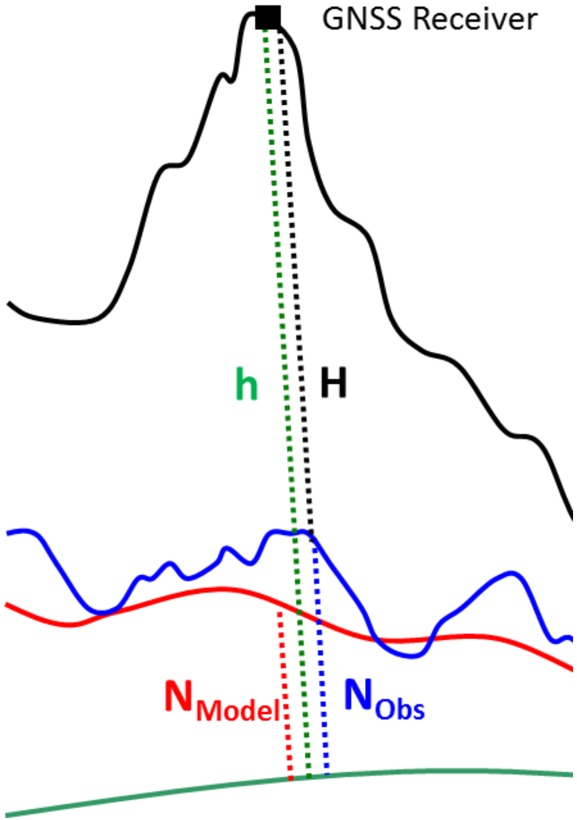




- Error degree variances not very meaningful.

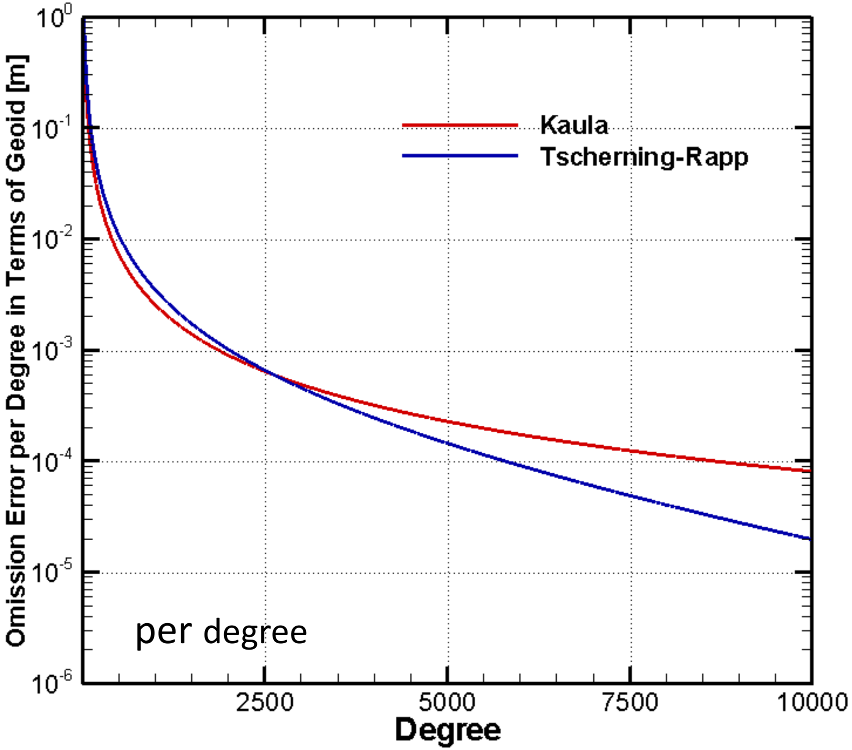
Error Assessment by GNSS-Levelling

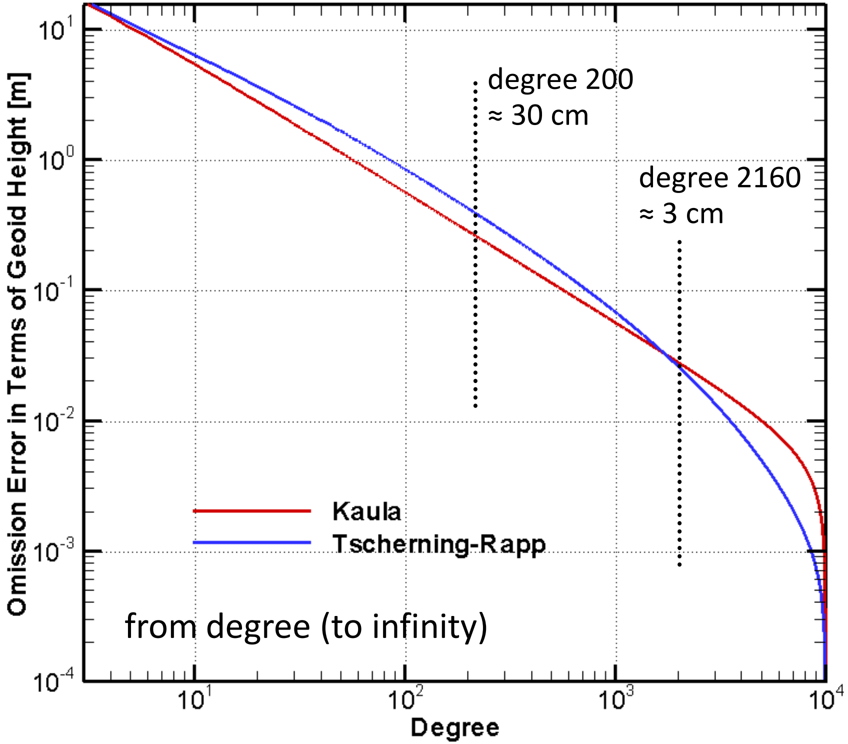
- Compute height anomaly at GNSS-levelling station from global model up to degree and order N.
- Estimate omitted signal from existing HR-model from degree N+1 to 2160 (2190).
- Estimated omitted signal above 2160 from topographic gravity field model. (ERTM2160, Hirt et al, 2014)
- If necessary, convert 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)
- Compute differences of geoid slope differences and analyse them wrt. distances, height differences, directions (angle)



Error Assessment by GNSS-Levelling

Omission Error Estimate from Gravity Field Model





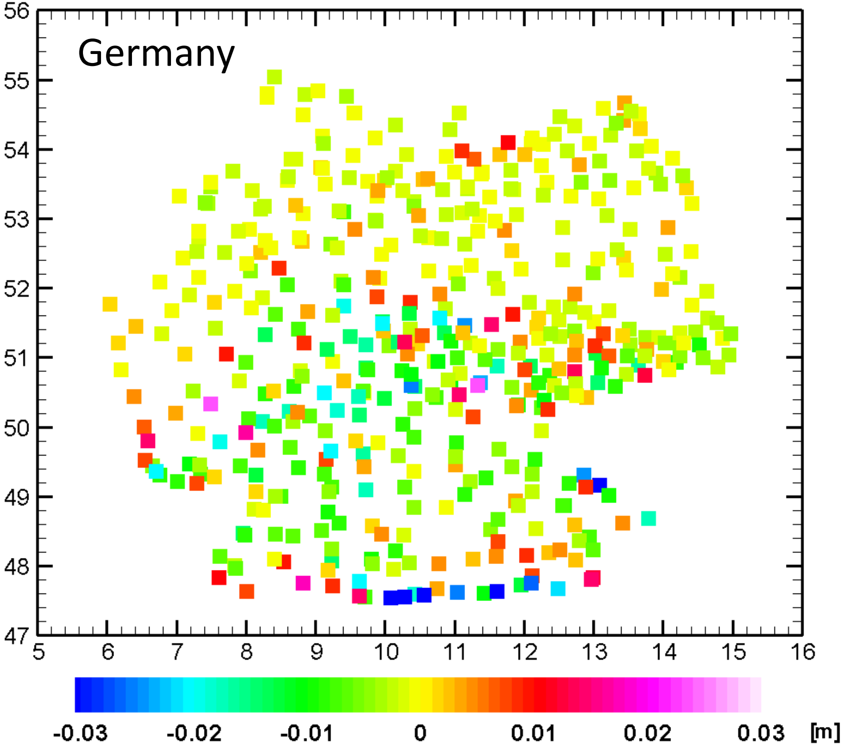
GNSS-Levelling Results

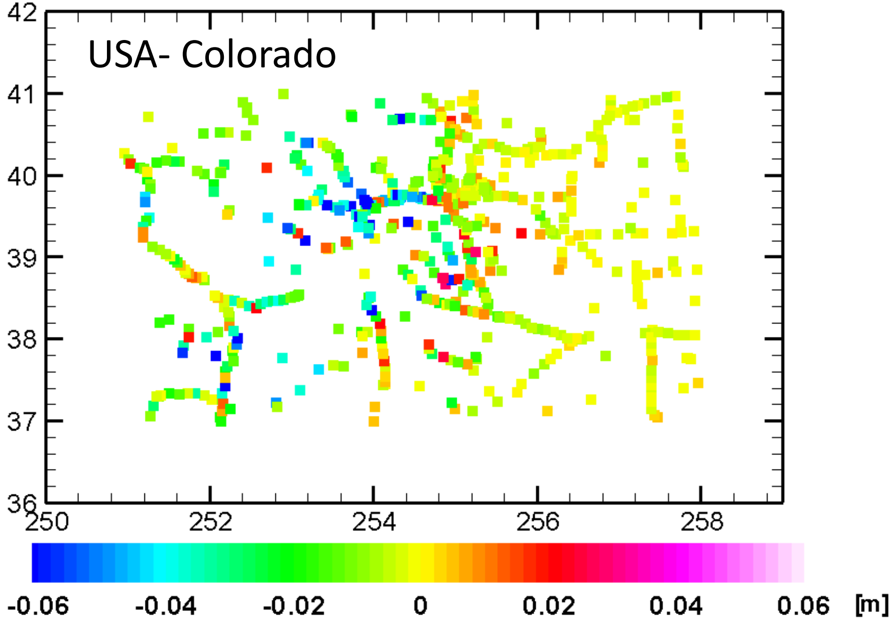
GNSS-Levelling Data Sets

Region	No. Points	Reference
Australia	197	Geoscience Australia, 2003
Brazil	683	Brazilian Institute of Geography and Statistics - IBGE, Directorate of Geosciences - DGC, Coordination of Geodesy – CGED, 2012
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 Topographic Gravity Field Model (ERTM2160)

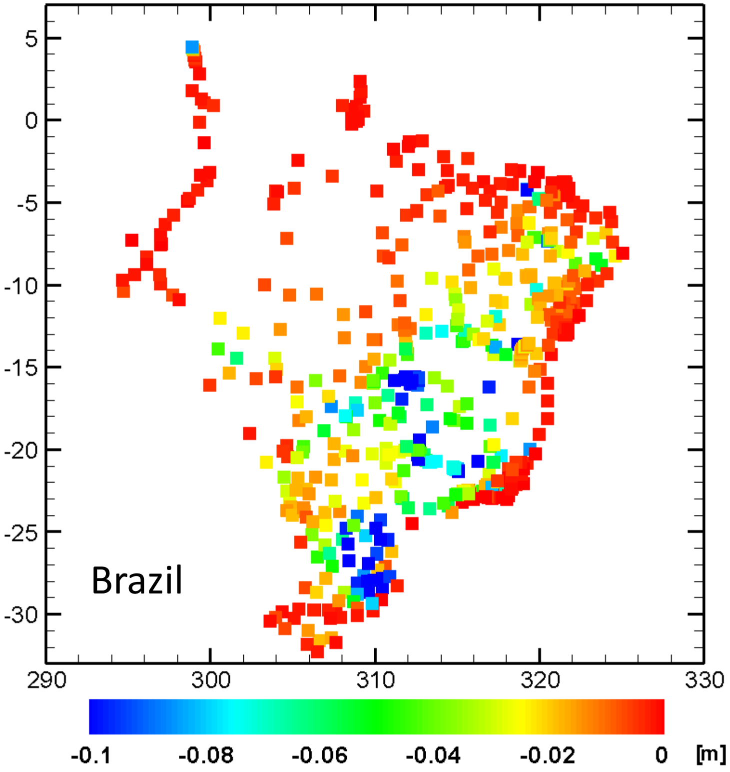


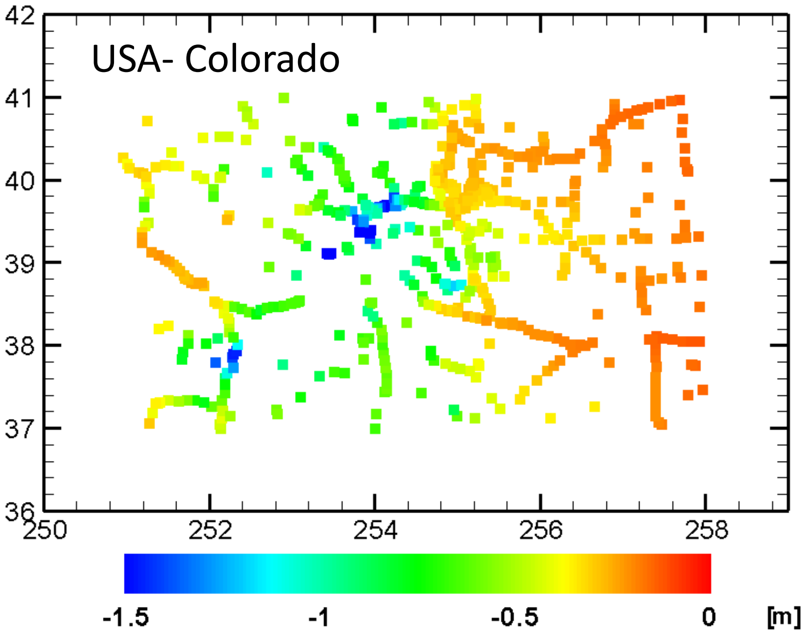


- up to ±10-20 cm in mountaineous areas

Error Assessment by GNSS-Levelling

Conversion Height Anomalies to Geoid Undulations

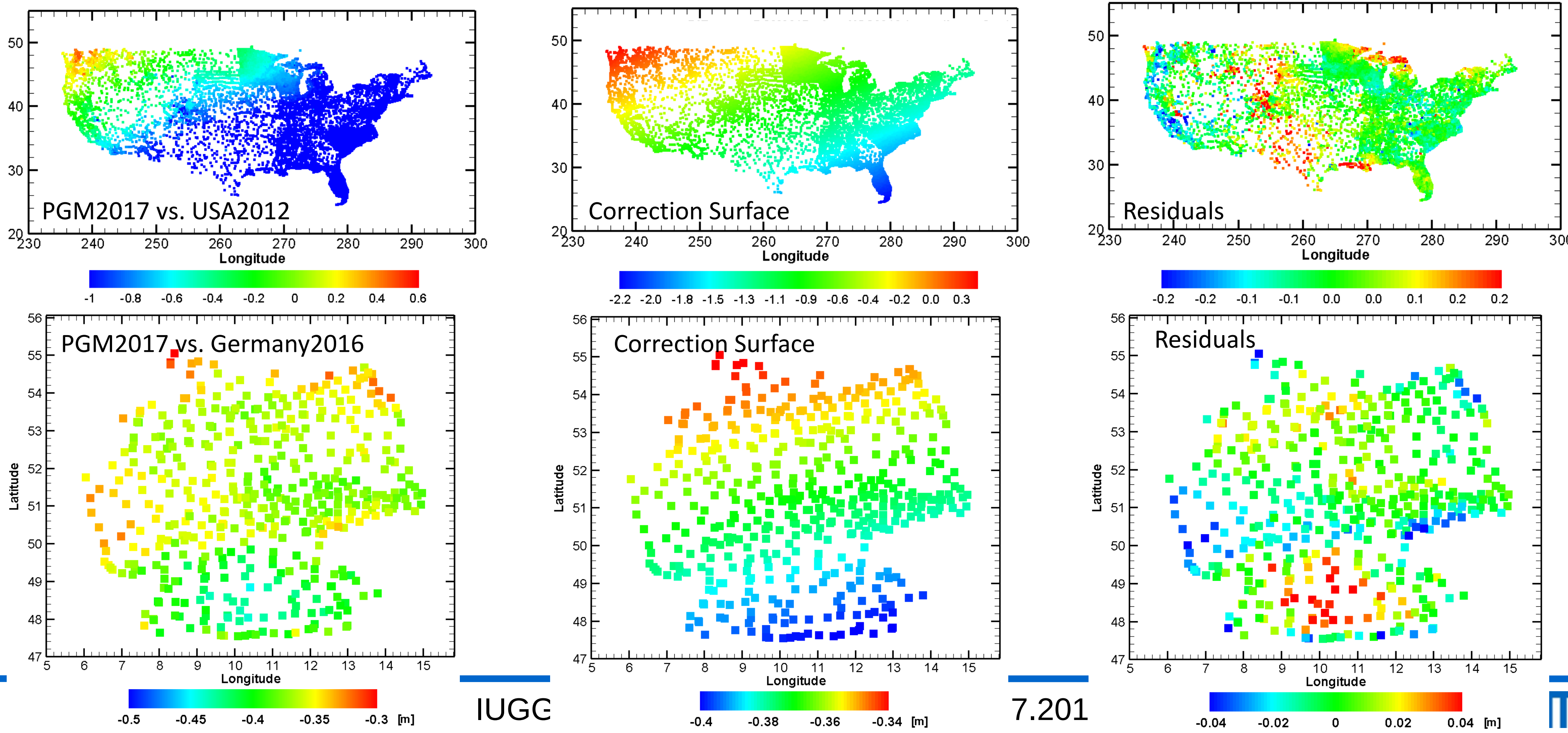




- up to ±1-2 m in mountaineous areas

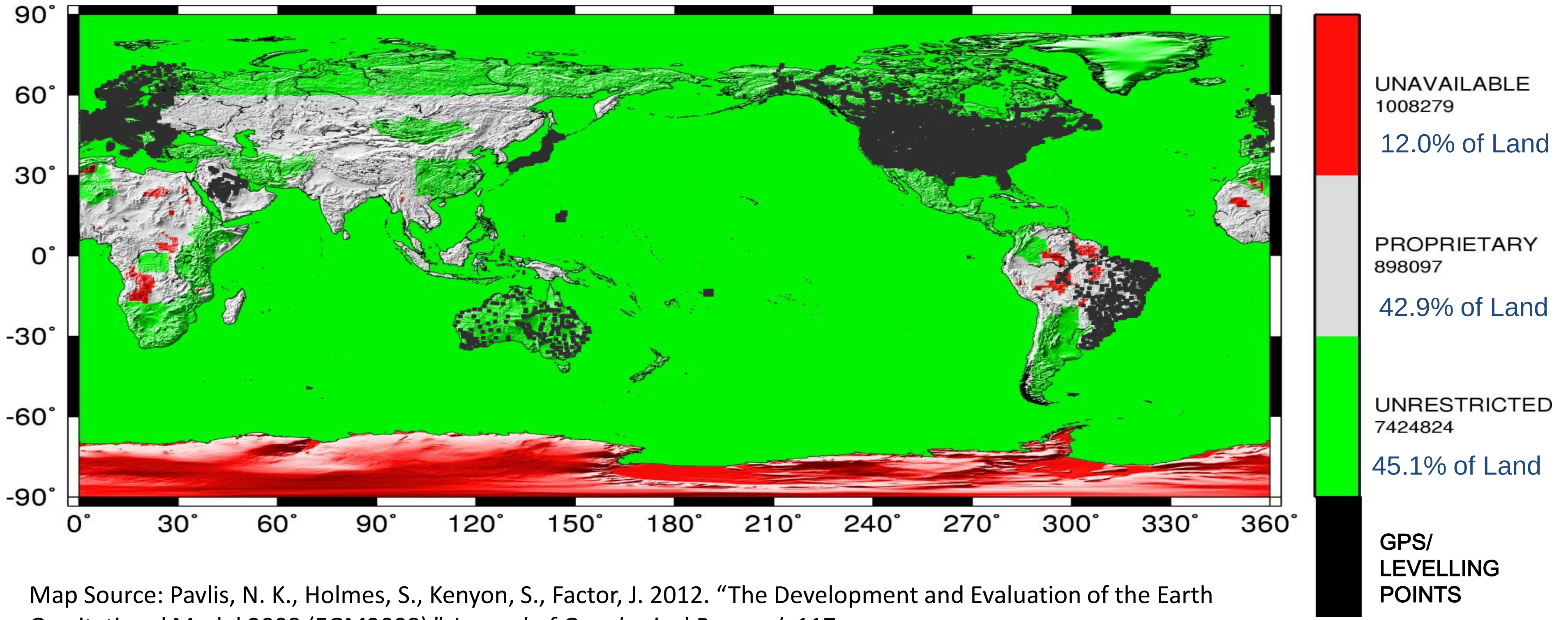
Error Assessment by GNSS-Levelling

Correction Surface (for PGM2017 d/o 2190)



GNSS-Levelling Results

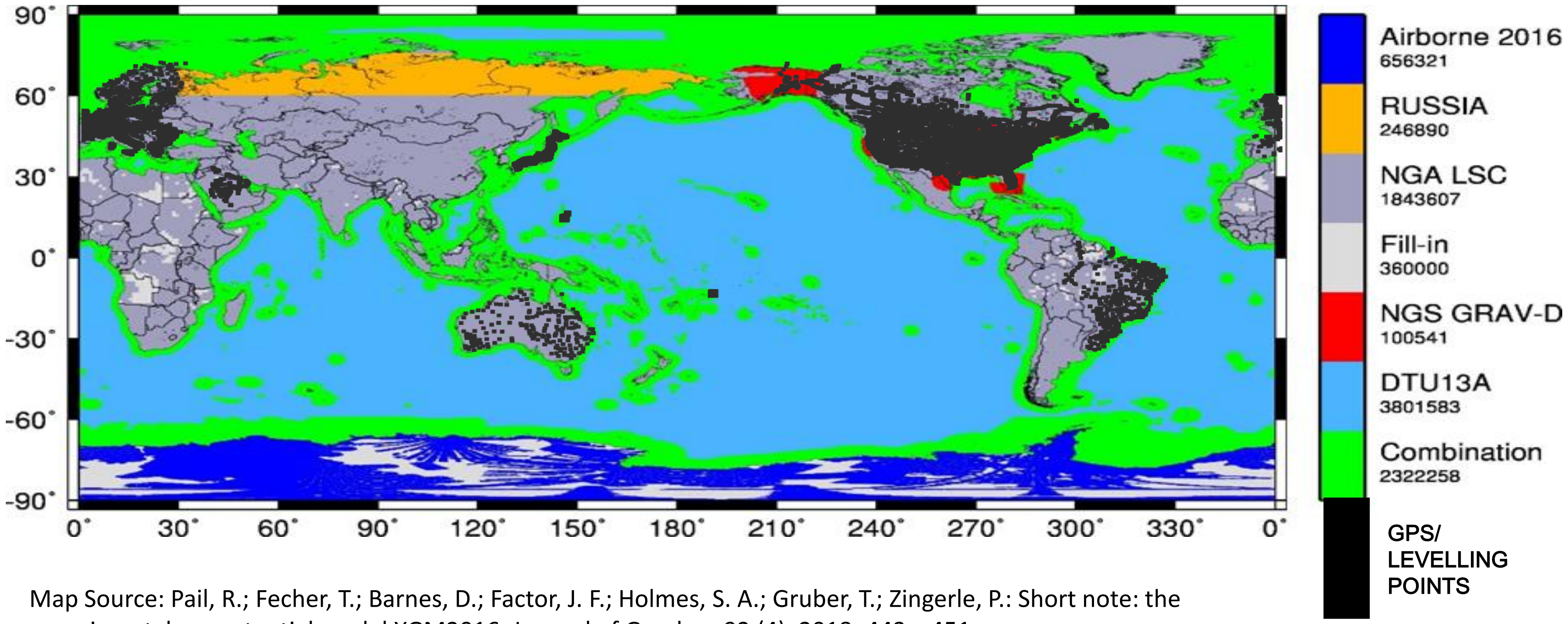
EGM2008 Data Coverage & Coverage of GNSS-Levelling Data



Map Source: Pavlis, N. K., Holmes, S., Kenyon, S., Factor, J. 2012. “The Development and Evaluation of the Earth Gravitational Model 2008 (EGM2008).” *Journal of Geophysical Research* 117

GNSS-Levelling Results

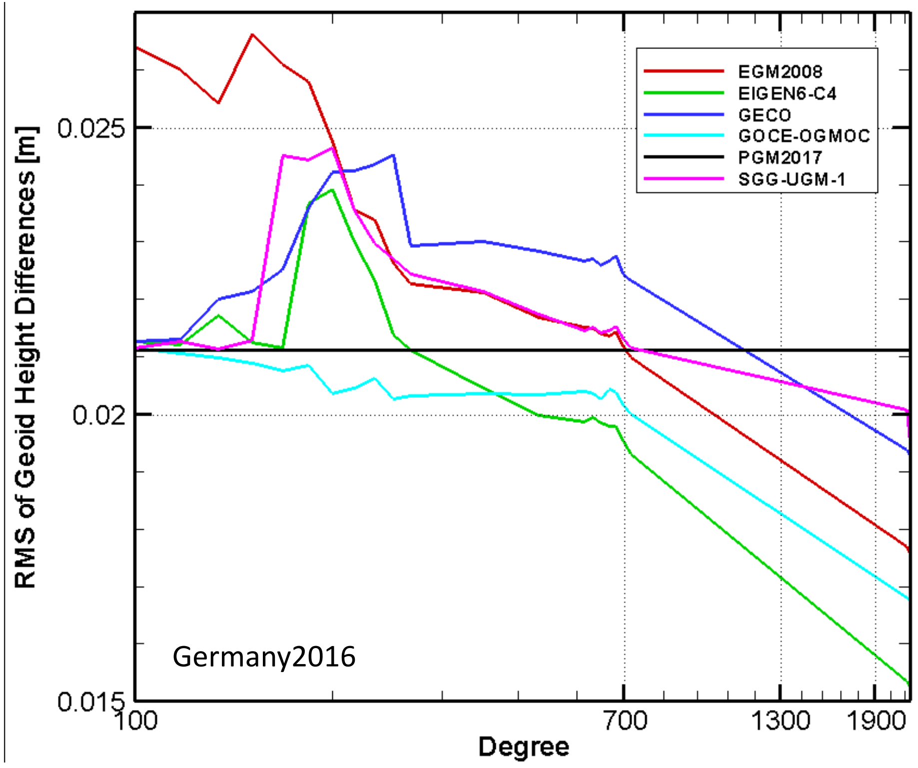
XGM2016 (GOCE-OGMOC) Data Coverage & Coverage of GNSS-Levelling Data

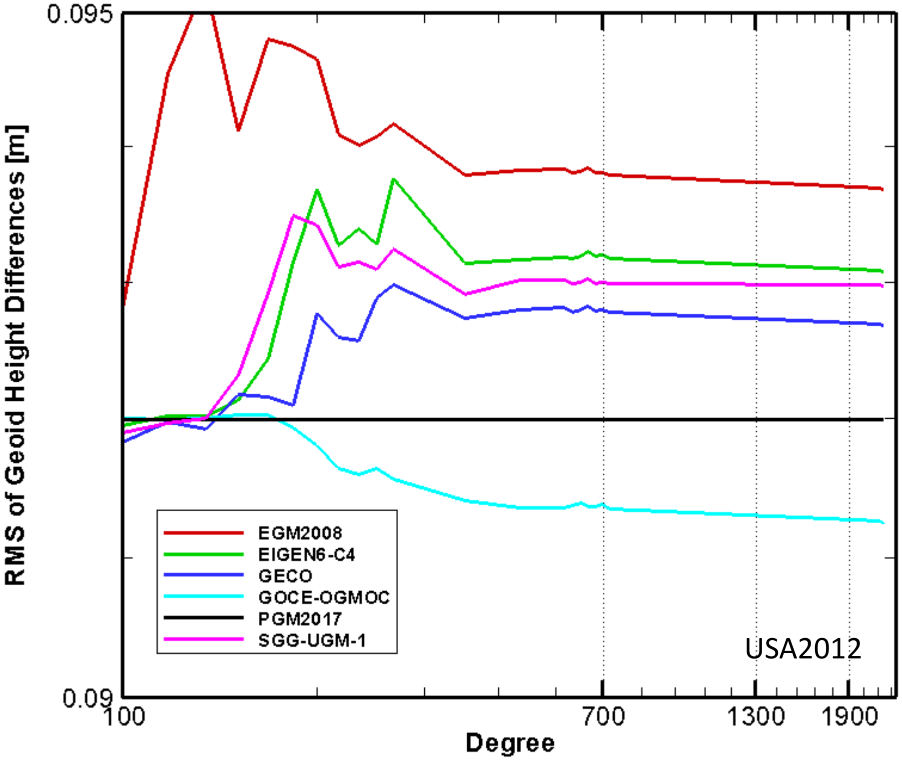


Map Source: Pail, R.; Fecher, T.; Barnes, D.; Factor, J. F.; Holmes, S. A.; Gruber, T.; Zingerle, P.: Short note: the experimental geopotential model XGM2016. Journal of Geodesy 92 (4), 2018, 443—451

GNSS-Levelling Results

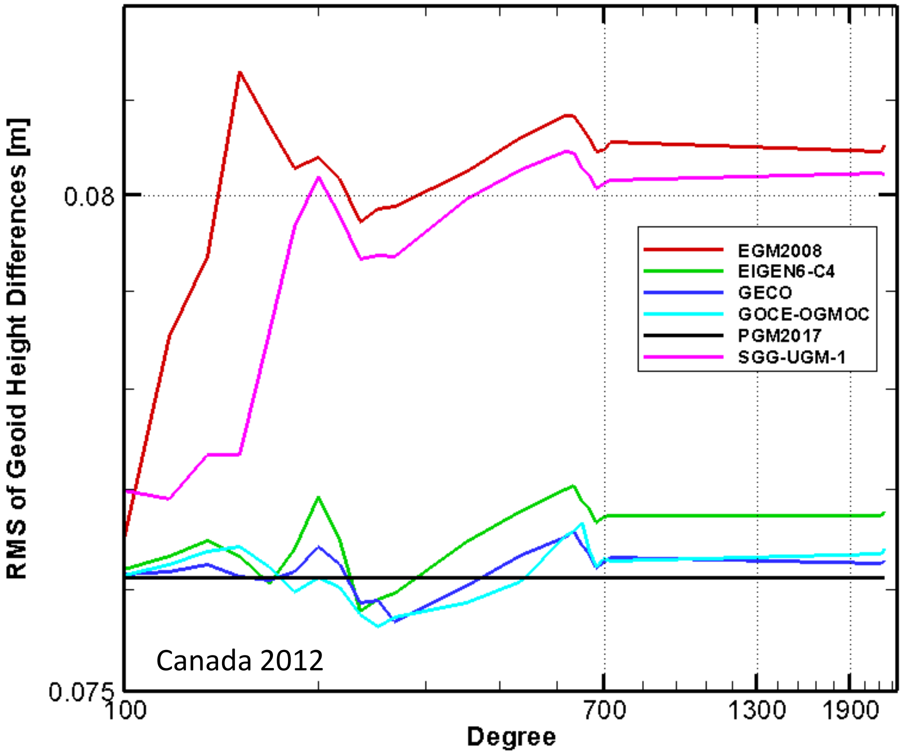
RMS of Geoid Differences per Data Set for Different Model Resolutions

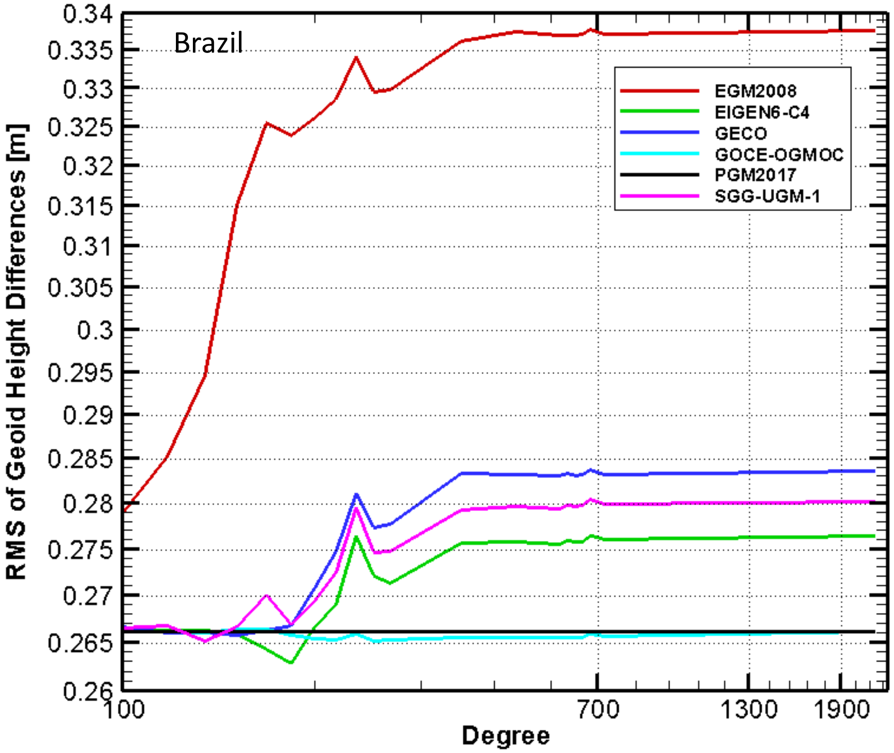




GNSS-Levelling Results

RMS of Geoid Differences per Data Set for Different Model Resolutions





GNSS-Levelling Results

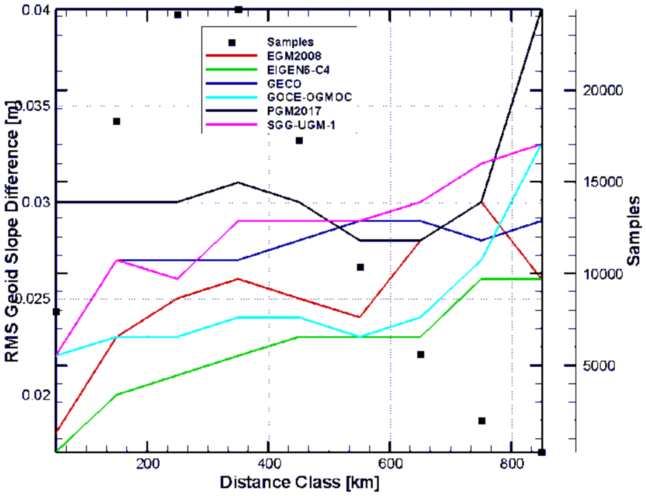
Overview Height Differences

GNSS-levelling Dataset	EGM2008	EIGEN6-C4	GECO	GOCE-OGMOC	SGG-UGM-1	PGM2017
G01 (AUS)	17.9	17.5	17.9	17.6	17.8	17.6
G02 (BR)	33.7	27.6	28.3	26.6	28.0	26.6
G03 (CDN)	8.6	8.2	8.3	8.1	8.4	8.2
G04 (CDN)	8.1	7.7	7.6	7.6	8.0	7.6
G05 (A)	3.0	1.7	2.2	2.1	2.1	2.8
G05 (EST)	4.7	3.8	4.4	2.2	4.4	2.2
G05 (FIN)	6.9	5.0	5.9	4.8	6.1	4.7
G05 (F)	9.1	8.9	9.3	9.1	9.0	9.1
G05 (NL)	1.7	2.0	2.1	1.9	1.4	1.6
G06 (D)	2.0	2.1	2.4	2.4	2.4	2.7
G07 (D)	1.8	1.5	1.9	1.7	2.0	2.1
G08 (GB)	4.2	3.7	4.3	3.7	4.2	3.6
G09 (GR)	13.9	12.4	13.4	13.0	13.1	13.1
G10 (J)	7.4	6.5	6.8	6.3	6.3	6.3
G11 (MEX)	30.1	29.9	29.2	28.3	29.2	28.6
G12 (KSA)	51.6	50.2	50.1	48.5	50.0	48.8
G13 (USA)	9.4	9.3	9.3	9.1	9.3	9.2
G13 (AL)	25.7	25.4	25.1	25.3	25.2	23.9
G13 (CA)	8.3	8.2	8.3	8.1	7.9	8.3
G13 (CO)	23.5	23.4	23.4	23.1	23.0	24.0
G13 (FL)	4.5	5.0	4.1	3.6	4.0	3.7
G13 (MN)	3.4	3.7	3.7	3.5	3.7	3.5
G13 (NC)	7.5	7.9	7.7	7.5	7.6	7.6
G13 (SC)	4.7	4.8	4.7	4.5	4.6	4.7

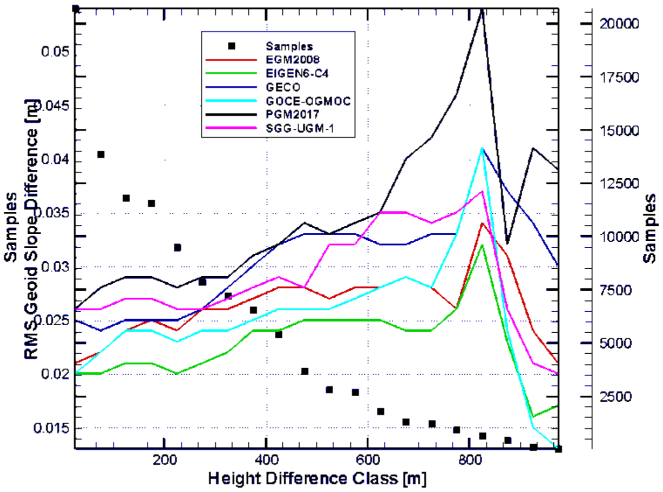
GNSS-Levelling Results

Geoid Slope Differences – Germany2016

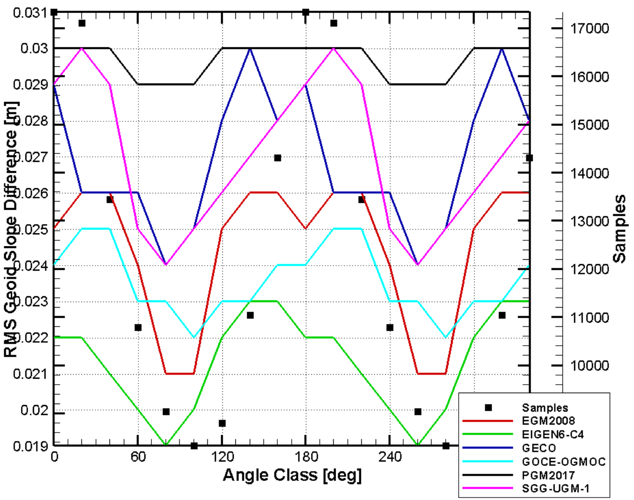
RMS Geoid Slope Differences per Distance Class



RMS Geoid Slope Differences per Height Difference Class



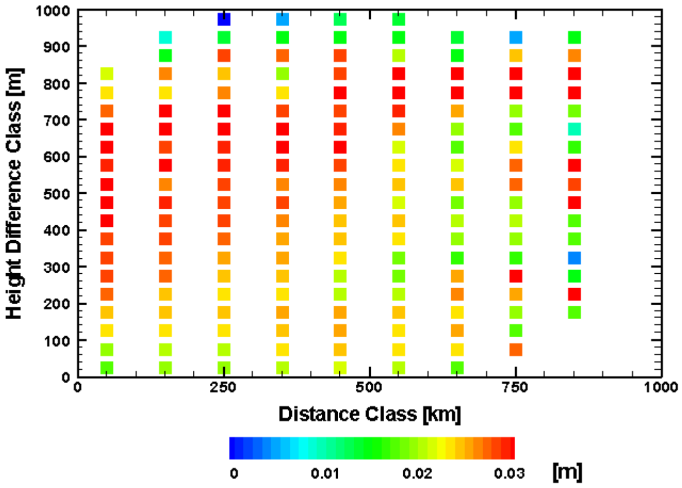
RMS Geoid Slope Differences per Orientation Class



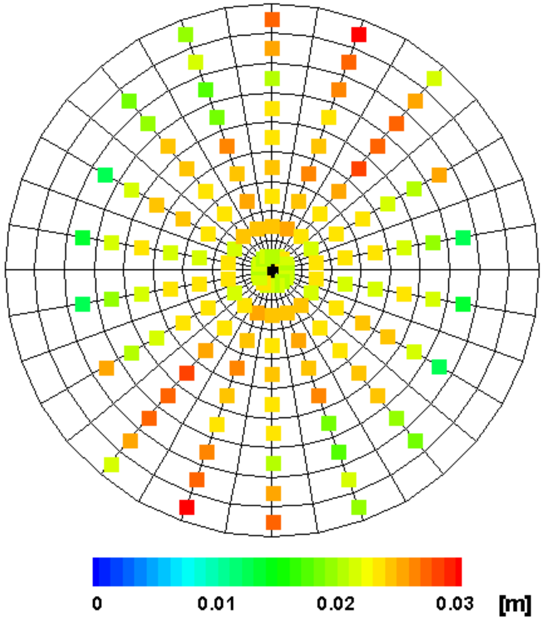
GNSS-Levelling Results

Geoid Slope Differences for GOCE-OGMOC Model – Germany2016

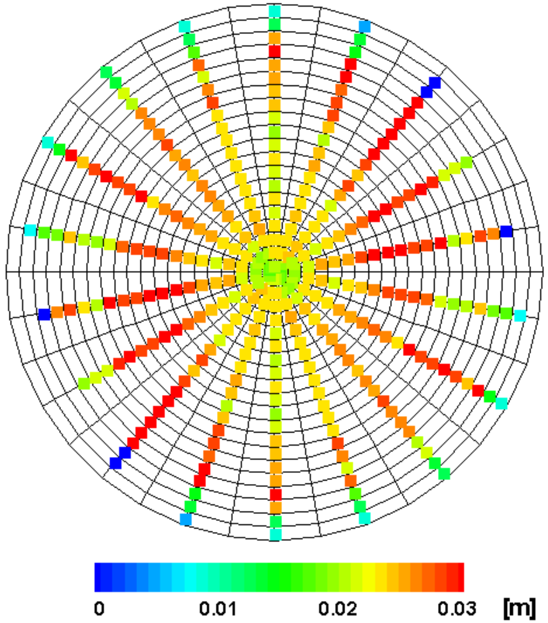
RMS Geoid Slope Differences per Distance/Height Difference Class Combination



RMS Geoid Slope Differences per Distance/Orientation Class Combination



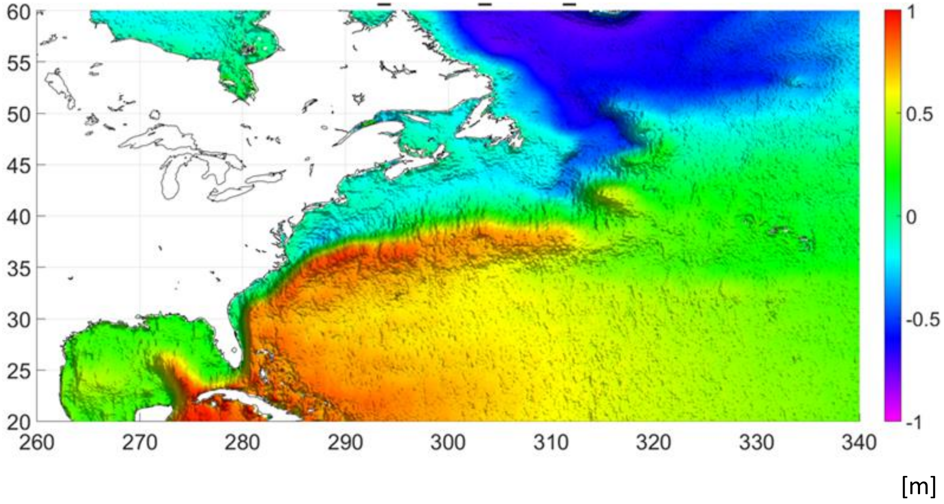
RMS Geoid Slope Differences per Height Difference/Orientation Class Combination



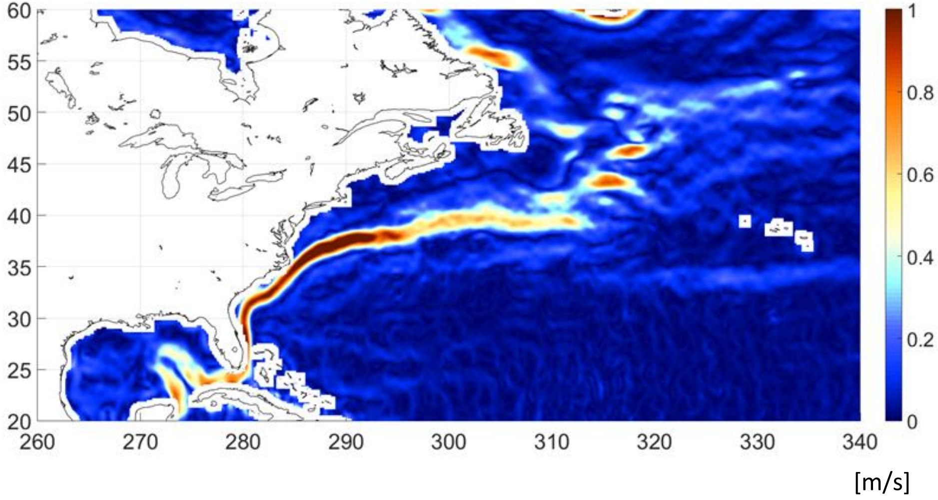
Achievements - Oceans

Mean Dynamic Topography from GOCE-OGMOC Geoid

MDT North Atlantic



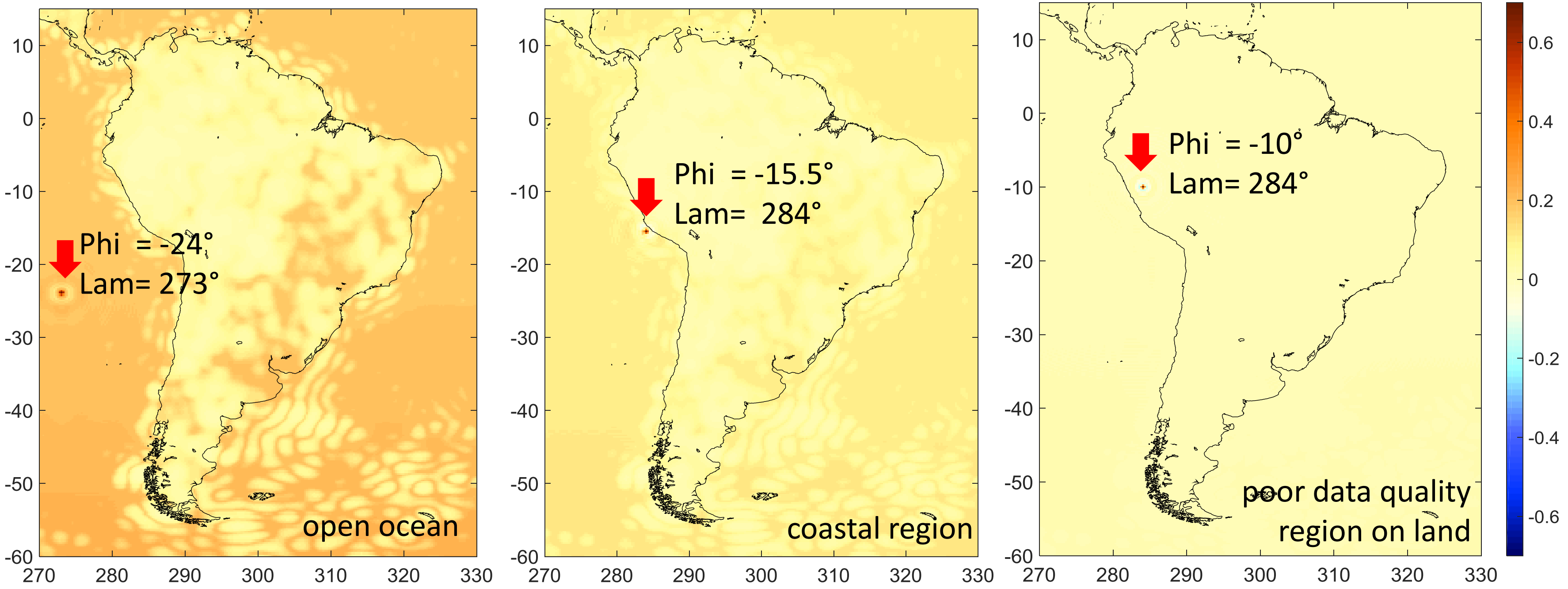
Geostrophic Velocities North Atlantic



The mean dynamic topography is computed by subtracting the GOCE-OGMOC ocean geoid from the DTU15 mean sea surface (spatial resolution 5’x5’). From the MDT geostrophic current velocities are computed.

Achievements - Oceans

Geoid in Coastal Regions – Correlation Analysis GOCE-OGMOC (d/o 719)

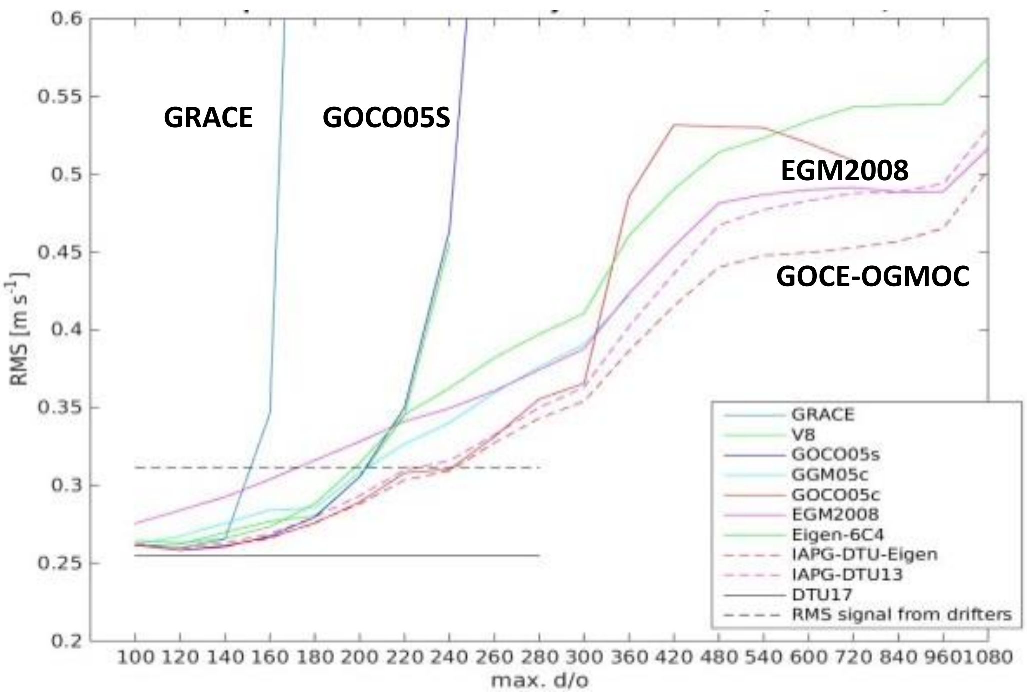


Point in the open ocean is highly correlated with all other points of high accuracy. Correlations for the point in coastal region are much smaller. Point on land in a poor data quality region is mainly uncorrelated.

Achievements - Oceans

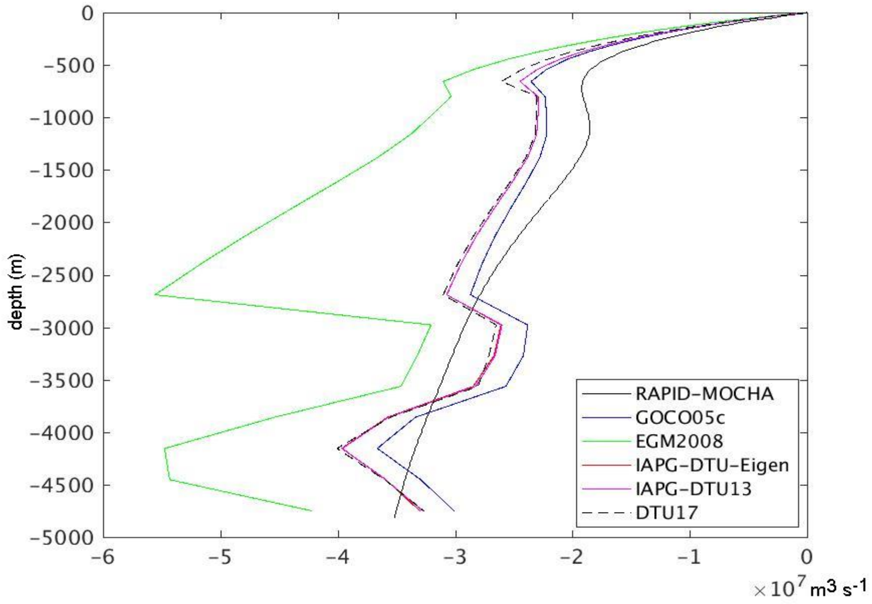
MDT in Coastal Regions

Comparison to Drifter Velocities Near Coastal Areas (d < 50 km)



Achievements - Ocean

Ocean Volume and Heat Transports in the North Atlantic at 26°N



Meridional overturning circulation from combination of EN4 reanalysis (subsurface ocean temperature and salinity data) and geodetic MDTs.

Model	Mass Transport (10^6 m^3 s^{-1})	Eddy-Heat Transport (10^{15}W)
GOCO05c	-30.1	0.042
EGM2008	-42.2	0.550
IAPG-DTU-Eigen	-33.0	0.061 **GOCE-OGMOC**
IAPG-DTU13	-32.7	0.067
DTU17	-32.6	0.163
RAPID	-36	0.08

- Higher transports in the upper ocean than from RAPID
- Probably large errors in EN4 T, S below 2000m depth due to sparse data
- Total transport close to expectations

Courtesy: Frank Siegismund, TUM

Conclusions

High Resolution Models – Signals & Errors

- In global average most improvement wrt. EGM2008 from GOCE data (70%-80% up to d/o 200).
- Some improvement from better surface data (20%-30% up to full resolution).

GNSS-Levelling Height Comparisons

- Planar correction surface shall be applied – Reduction of systematic levelling errors. Higher order surfaces possible, but are they reasonable?
- Very difficult to distinguish between errors caused by levelling, GNSS, global model and corrections.
- Detailed analysis for each regional GNSS-levelling data set required. For available GNSS-Levelling datasets the GOCE-OGMOC and PGM2017 models in most cases perform best.
- Geoid slope comparisons for distances, height differences and directions confirm results.

Achievements over Oceans

- Improved estimate of ocean mass and heat transport by better ocean geoid.
- Consistent global geoid as height reference surface enables height system unification.
- Improved look to the Earth‘s interior

Reference: Ms. No. JGS-D-18-00023: 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, 2019

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- Australia: Geoscience Australia, 2003
- Brazil: Brazilian Institute of Geography and Statistics - IBGE, Directorate of Geosciences - DGC, Coordination of Geodesy – CGED, 2012
- 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