Recent gravity field modelling studies and future plans at GFZ

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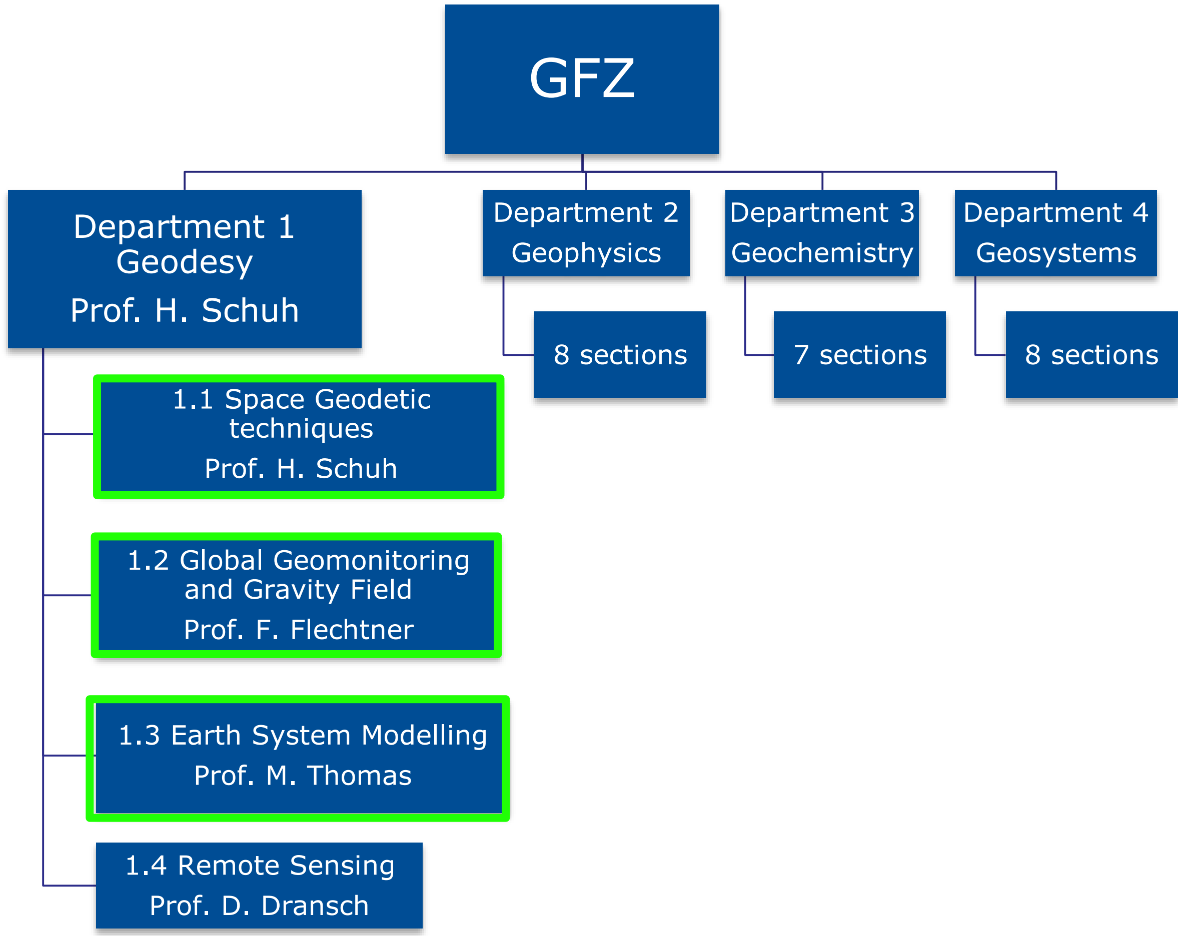
Institute and Topics

Global Geomonitoring and Gravity Field

Main Topics

- Development, Operation and Analysis of Gravity Field Satellite Missions
- Terrestrial and Airborne Gravimetry
- Earth System Parameters and Orbit Dynamics
- Geodetic Hazard Monitoring



Section and Topics

Services

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INFORMATION SYSTEM AND DATA CENTER
Global Earth Science Data

ICGEM

IGETS

GravIS
Gravity Information Service

Gravity field modelling in GFZ

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The constituents of g and measurements

Spatial gravity variations | Temporal gravity variations

$g = 9.80\,724\,673\ldots\ \mathrm{m/s^2}$

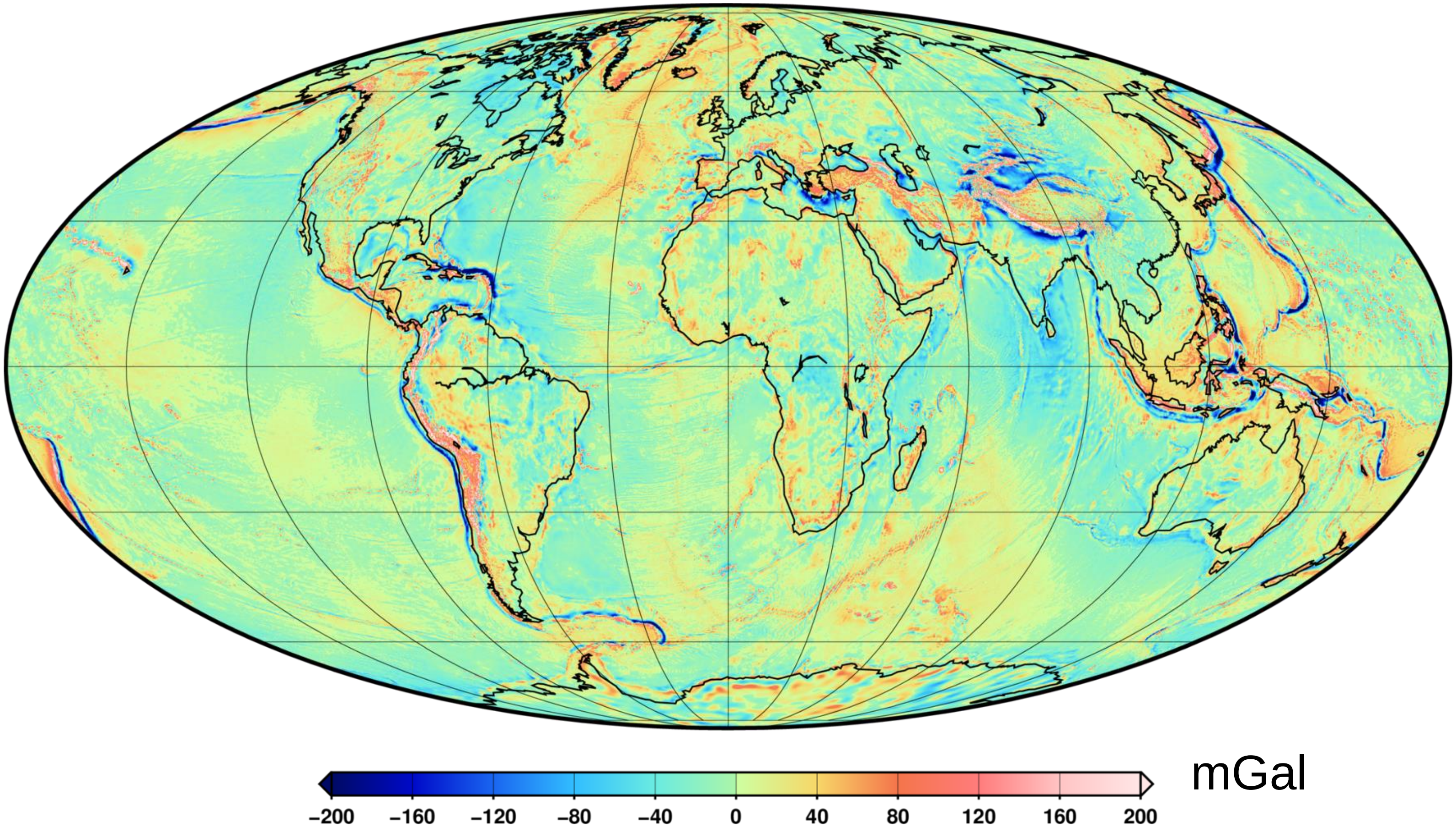
- Earth flattening and rotation
- Mountains and ocean trenches
- Internal mass distribution
- Large reservoirs
- Solid Earth and ocean tides
- Atmospheric mass redistribution, hydrology
- Polar motion

Spring gravimeter (Scintrex)

Superconducting gravimeter (GWR)

Absolute gravimeter (Micro g LaCoste)

Gravity anomalies from high-resolution combined model



Gravity field modelling in GFZ

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Gravity field modelling in GFZ

Global Gravity Field Modelling

- Static gravity field
  - Satellite-only gravity field modelling (e.g. DIR-R6)
  - High resolution static global gravity field models (e.g. EIGEN-6C4)
- Temporal gravity field (e.g. GRACE/GRACE-FO monthly solutions)
- Topographic gravity field (forward modelling)

Terrestrial and airborne Gravimetry

- Mobile Gravimetry
- Superconducting Gravimetry

- Terrestrial gravity
  - Airborne and shipborne gravimetry (e.g. GEOHALO, FAMOS Project)
  - Superconducting gravity (e.g. Southerland, Zugspitze)

FAMOS

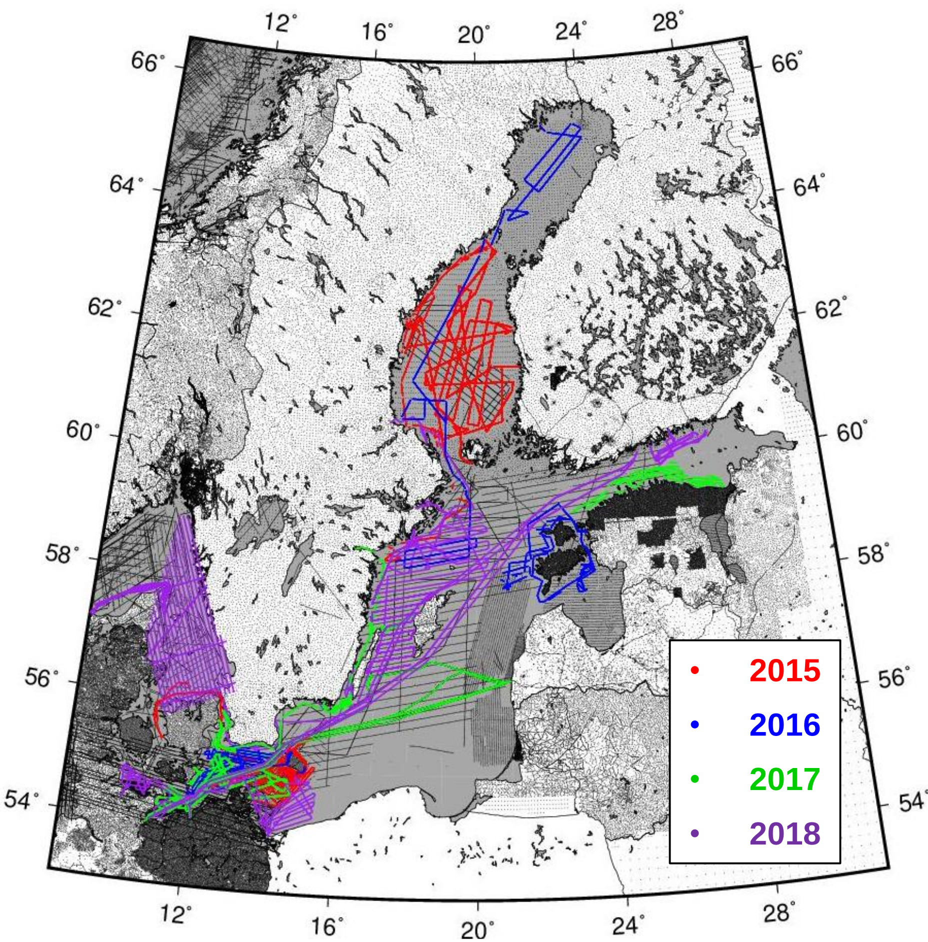
(Finalising Survey for the Baltic Motorways of the Sea)

Contribute to future satellite navigation and hydrographic surveying with GNSS based methods by improving the marine geodetic infrastructure.

Shipborne gravity measurements support the development of a 5cm accuracy geoid model to be used as the common unified chart datum in the Baltic Sea.

International cooperation among 7 countries, administrated by Swedish Maritime Administration.

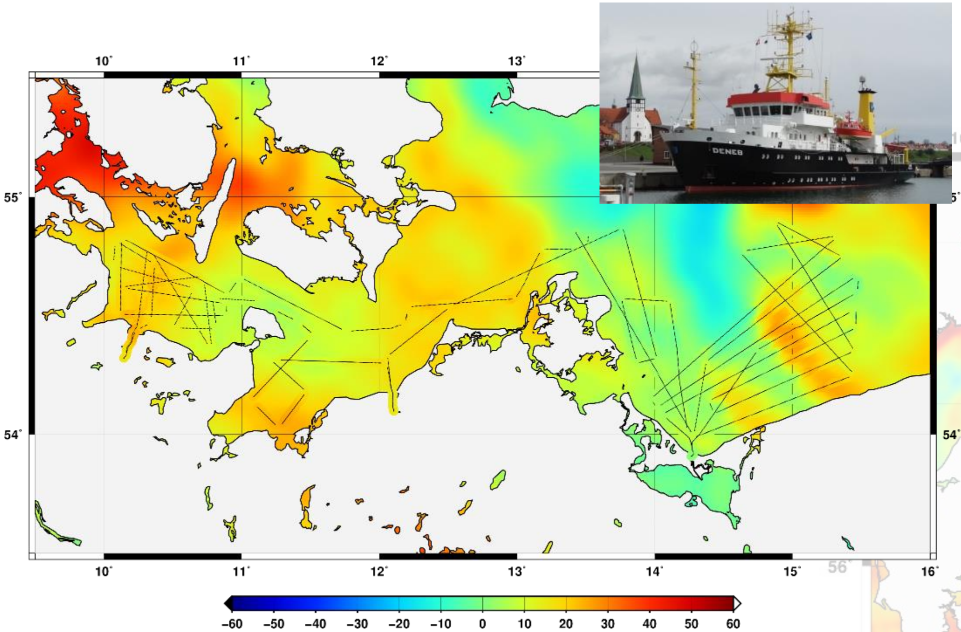
Close cooperation German Federal Agency for Cartography and Geodesy and Maritime and Hydrographic Agency



Agren J. (2016)

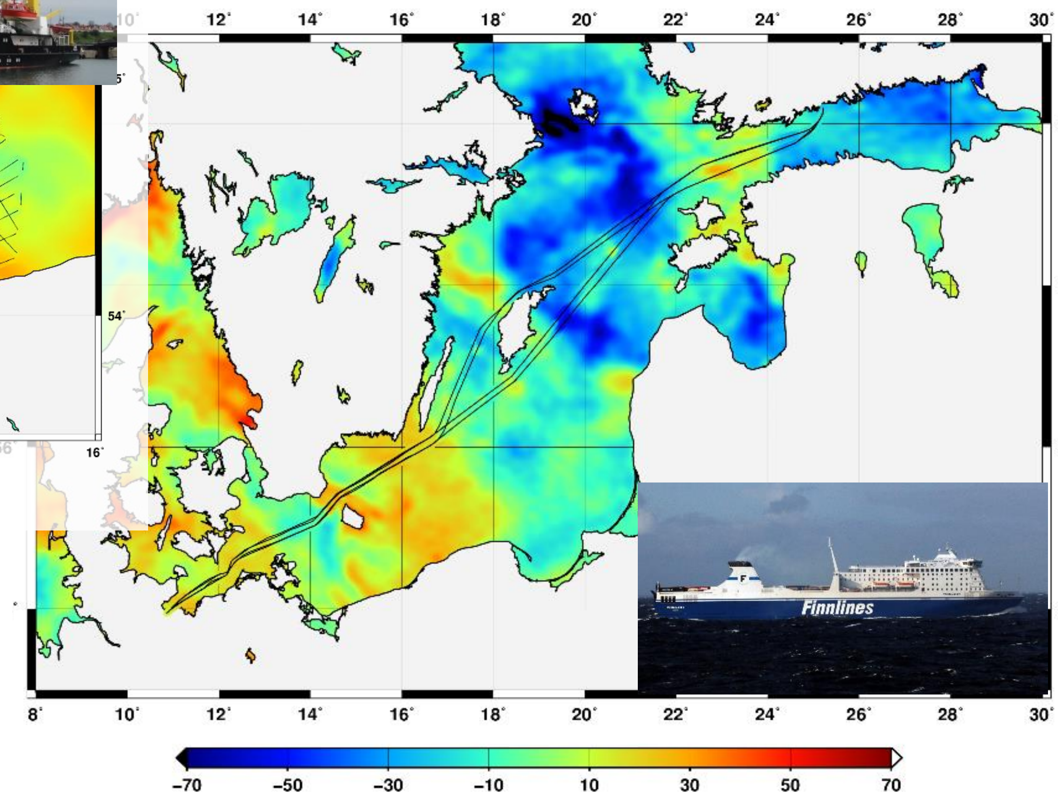
Deneb2018 (BKG & BSH)

Dedicated campaign



Finnlady2018 (Finnlines)

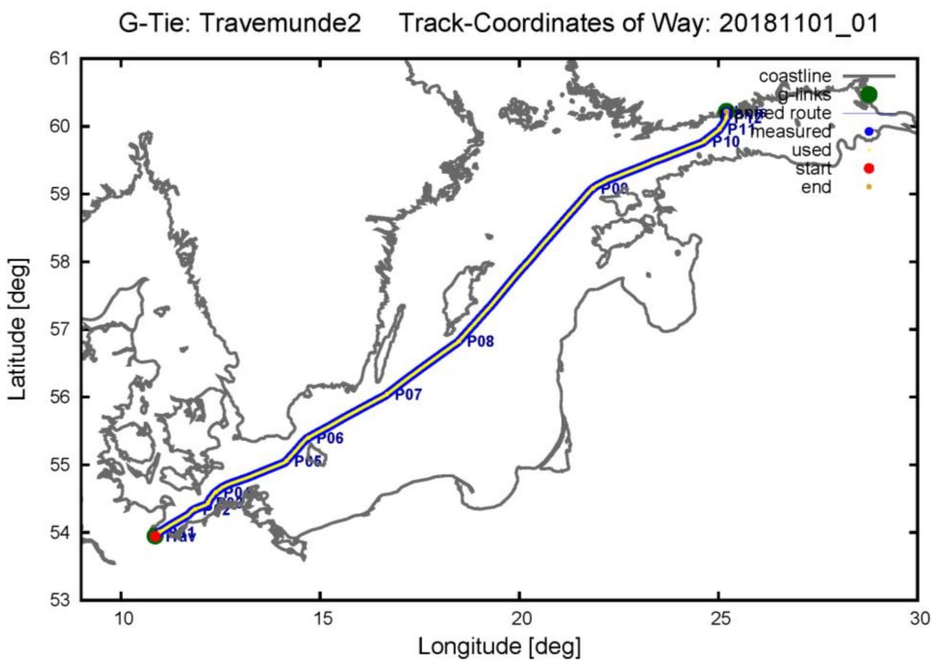
Piggy-back measurements

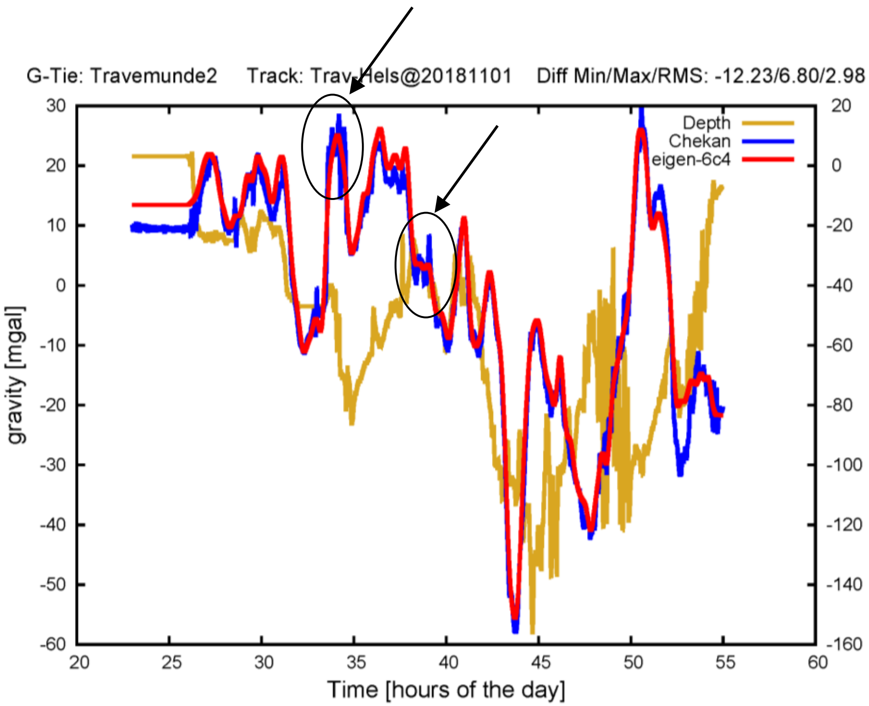


- Quick check gravity disturbances (mGal) computed on the ship
- Background is EIGEN-6C4 gravity disturbances

BKG: Federal Agency for Cartography and Geodesy
BSH: Federal Maritime and Hydrographic agency

Differences/ contribution to EIGEN-6C4





Sutherland

National Research Foundation

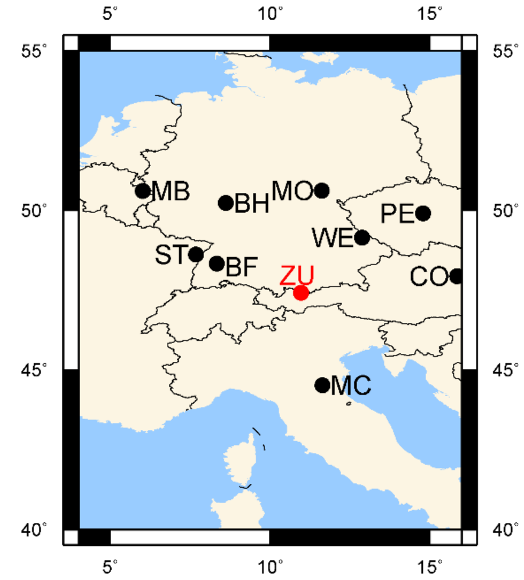
SAAO South African Astronomical Observatory

- First geodynamic observatory in Africa running since 2000, jointly operated by various GFZ sections, support from SAAO
- Improvement of the efficiency of the global network, analysis of global geophysical effects on one of the most stable stations worldwide
- Permanent operation and quality assessment, regular maintenance, analysis and provision to IGETS, long-term analysis of water storage variations

Voigt C.

Zugspitze

Umwelt Forschungsstation Schneefernerhaus



- First geodynamic observatory in the Alps running since 2018
- Operated by GFZ's Section 1.2 and 1.1 and supported by UFS

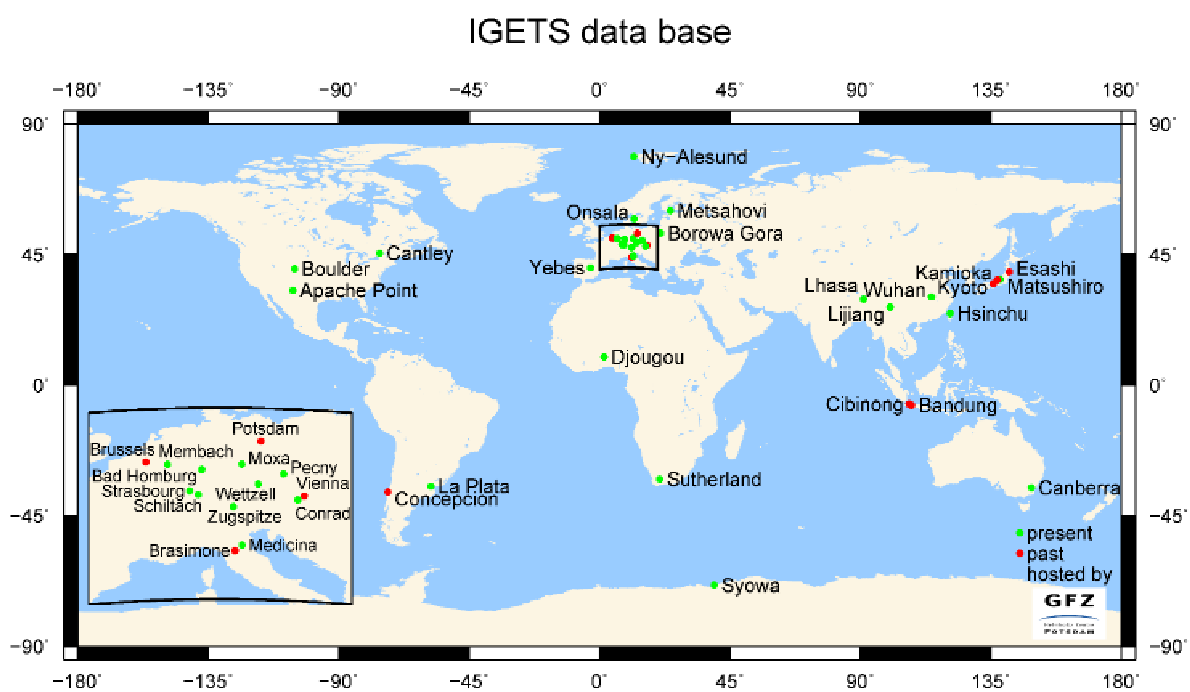
- Continuous long-term monitoring for hydrology (snow, permafrost, glaciers, GRACE-FO)
- Data provision to IGETS
- Understanding climate change signal
- ZU SG observations reduced by local hydrology show large-scale hydrological variations to be compared with GRACE-FO

Voigt C.

IGETS Database

International Geodynamics and Earth Tide Service (IGETS)

- Monitoring temporal gravity field variations via long-term records of ground gravimeters and other sensors
- Operation of the IGETS database



http://isdc.gfz-potsdam.de/igets-data-base/

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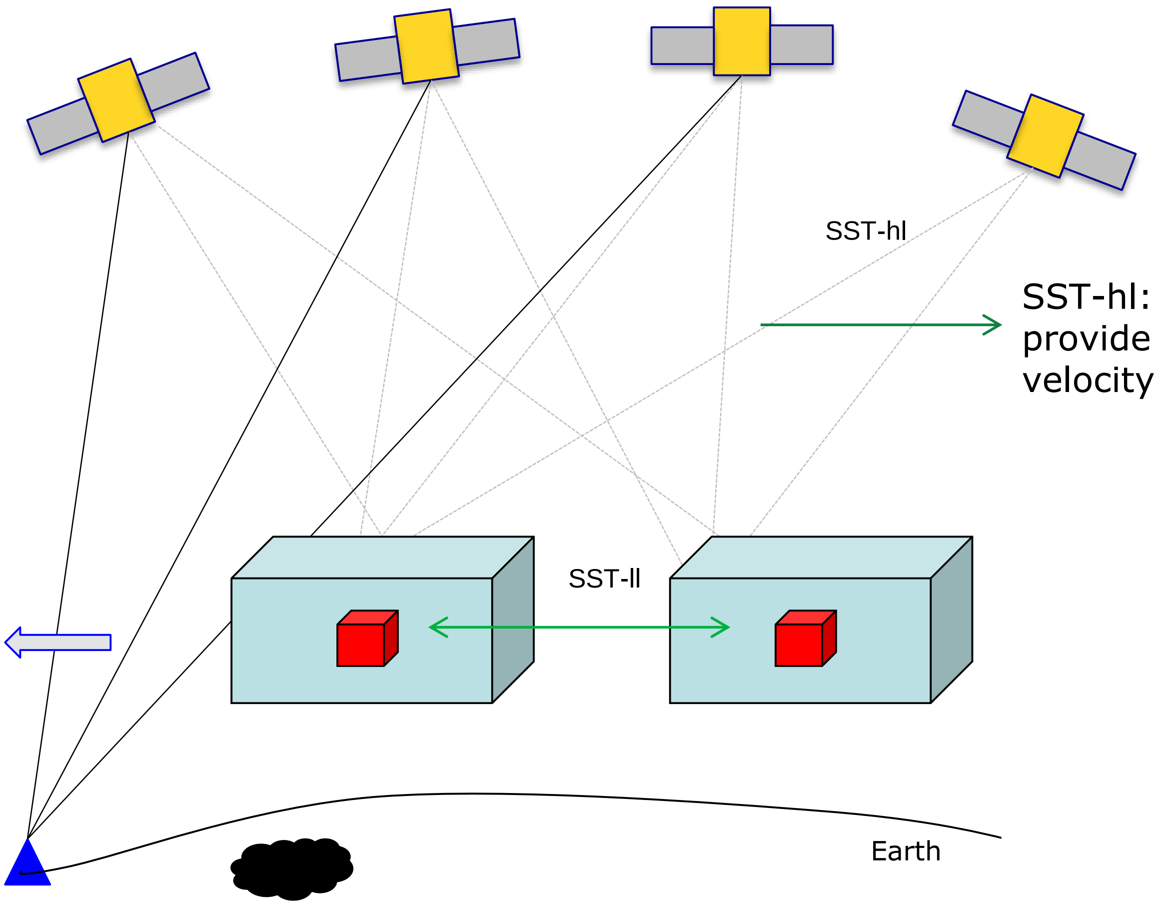
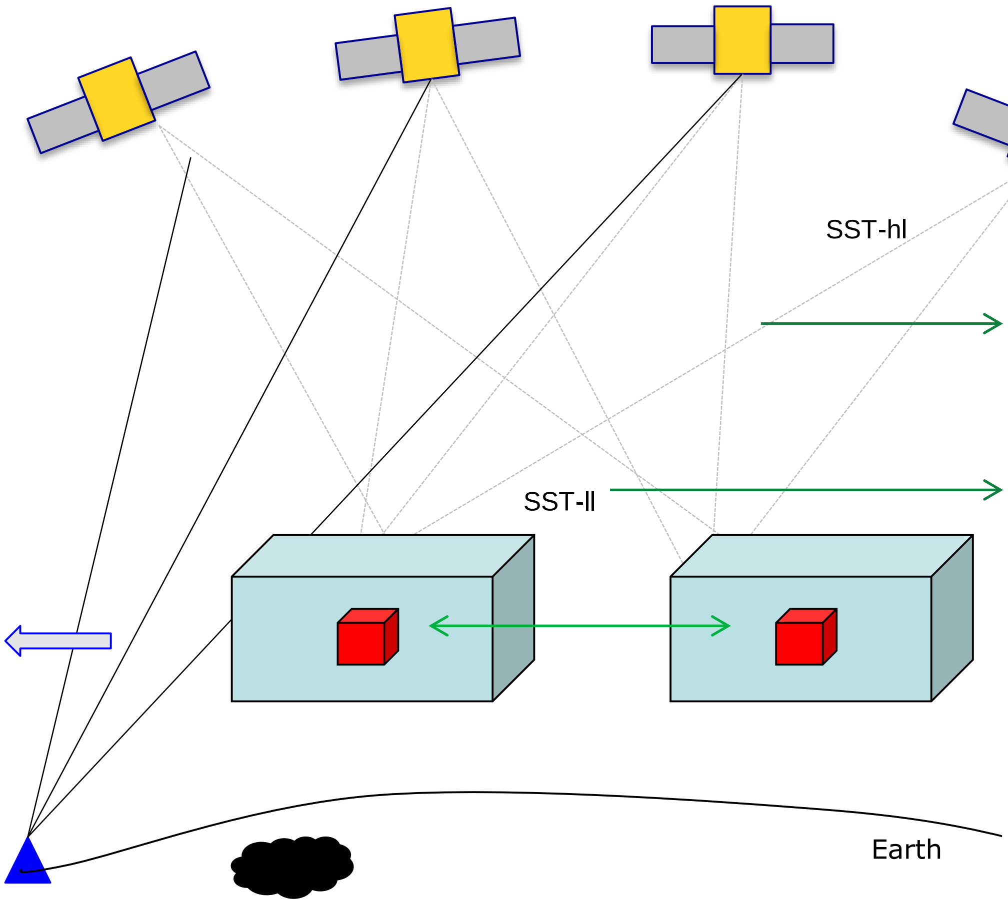
Satellite to satellite tracking



SST-hl: The high-orbiting satellites (e.g. GPS) provide highly accurate 3D position information, velocity and acceleration of the LEO

Satellite to satellite tracking



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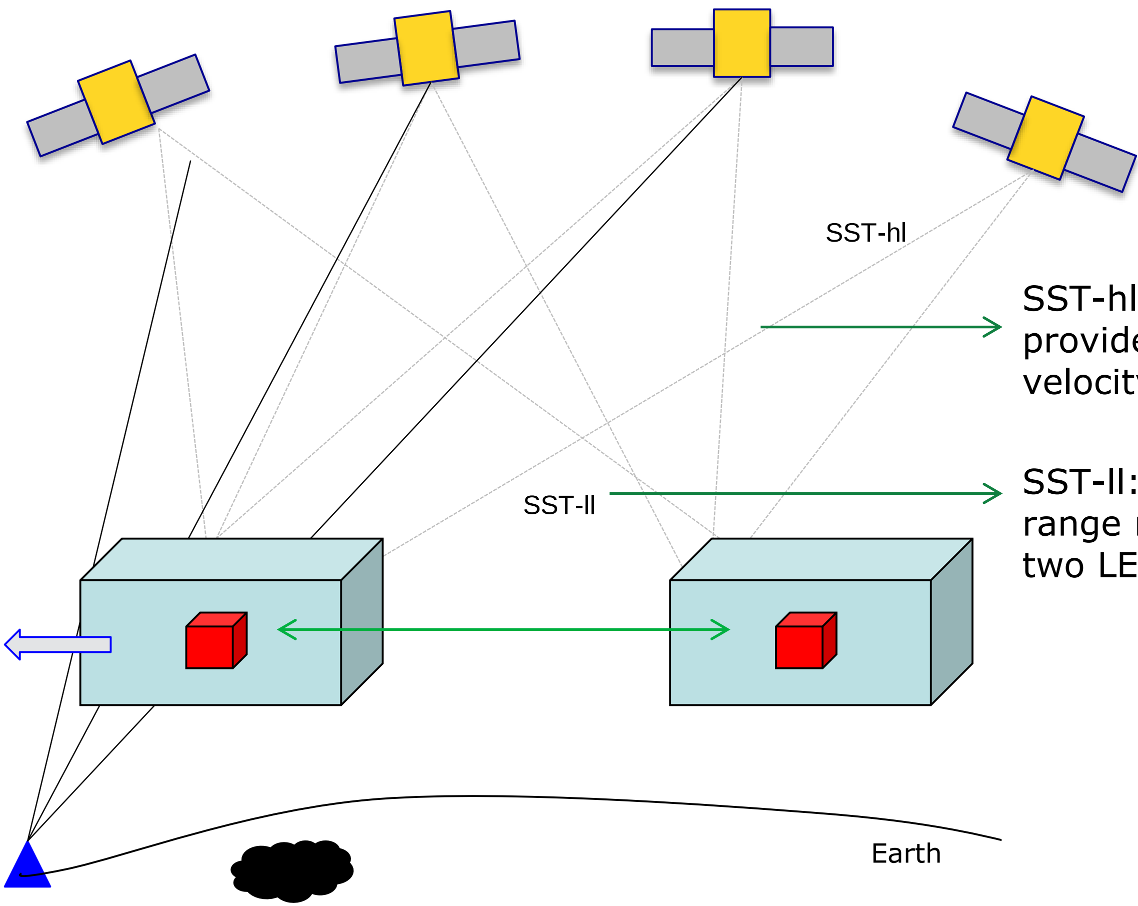
SST-ll: Line-of-sight measurement of the range, range rate or acceleration difference between two LEO satellites

Satellite to satellite tracking



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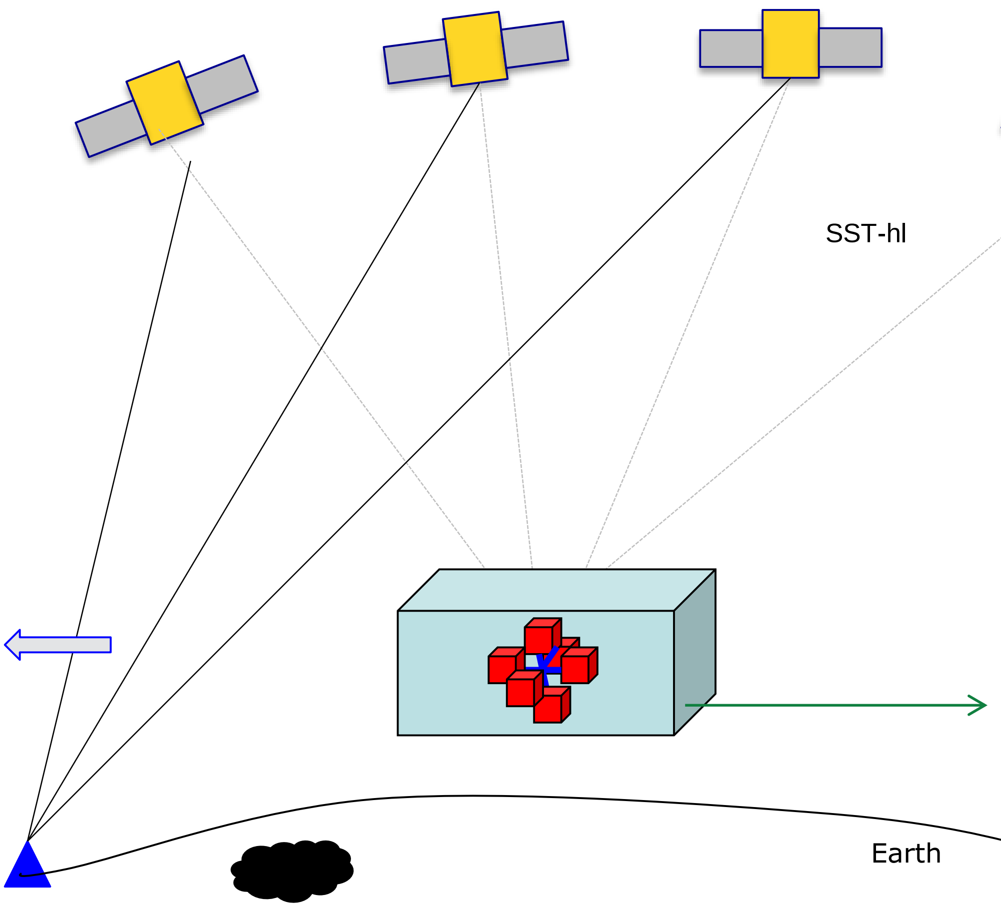
Satellite Gravity Gradiometry



SST-hl: The high-orbiting satellites (e.g. GPS) provide highly accurate 3D position information, velocity and acceleration of the LEO

SST-ll: Line-of-sight measurement of the range, range rate or acceleration difference between two LEO satellites

SGG - Satellite Gravity Gradiometry: Gravity acceleration measurements observed in 3D over the short baselines

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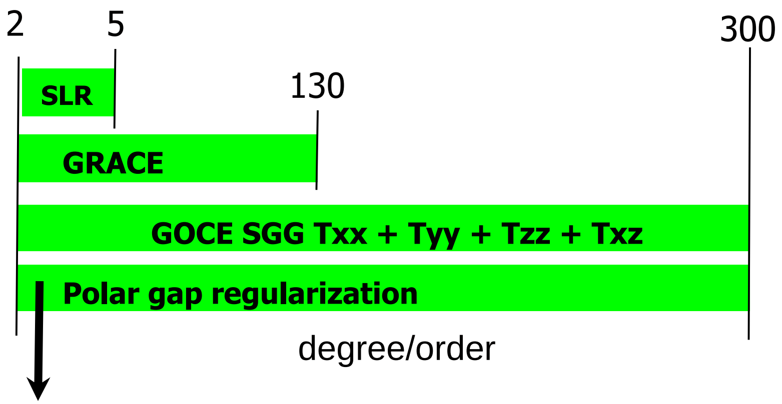
Configuration of the latest satellite-only model

Combination scheme of the normal equations for GOCE-DIR-R6



Application of external gravity field information over the polar gaps:
GRACE/SLR to d/o 130 + zero coefficients to d/o 300

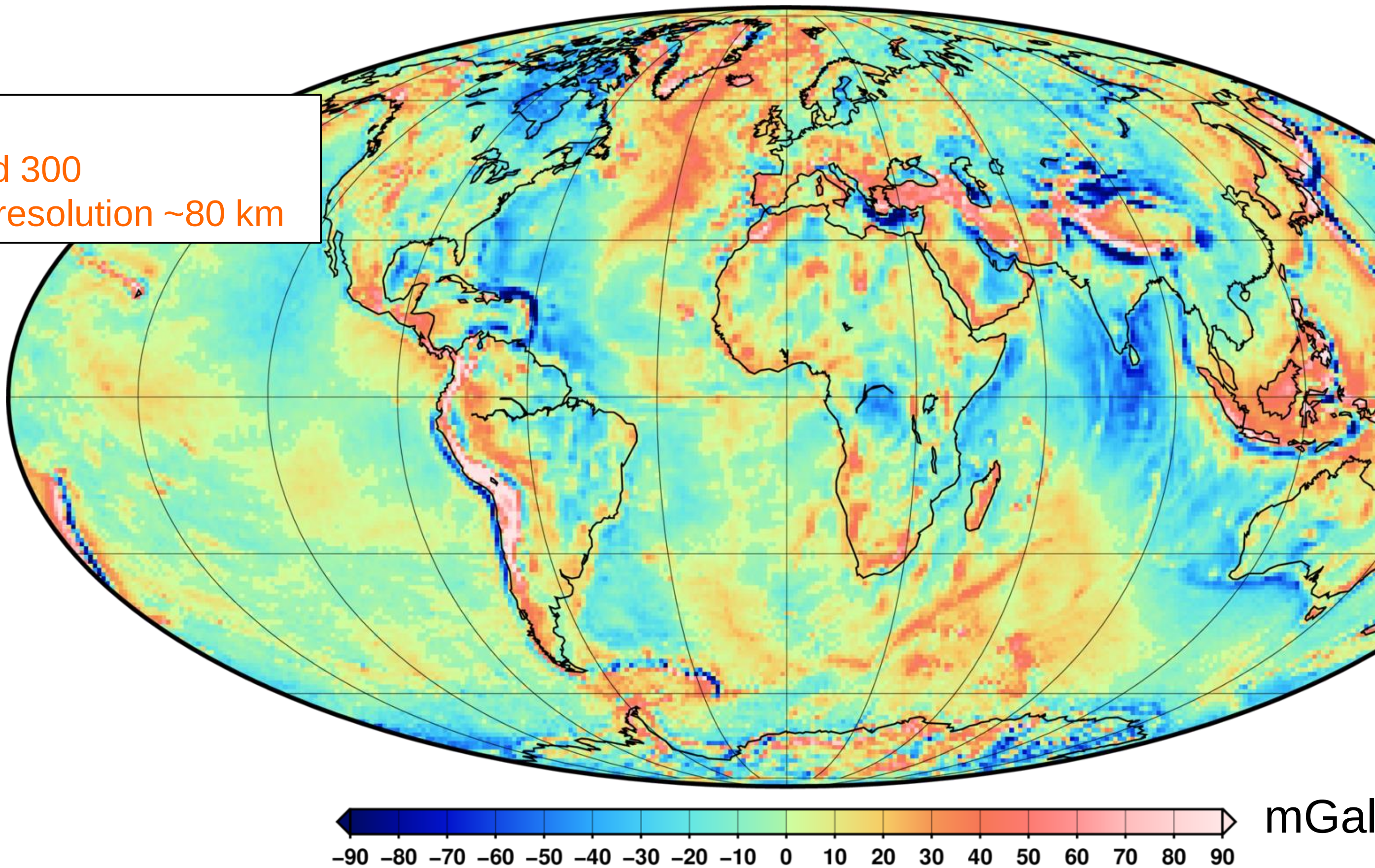
Algorithm: **Spherical cap regularization** (Metzler & Pail 2005)

Long + Medium wavelength components of the gravity field

Förste et al. (2019)

GFZ's DIR-R6 Satellite-only model ESA GOCE Project

DIR-R6
Max shd 300
Spatial resolution ~80 km



Förste et al. (2019)

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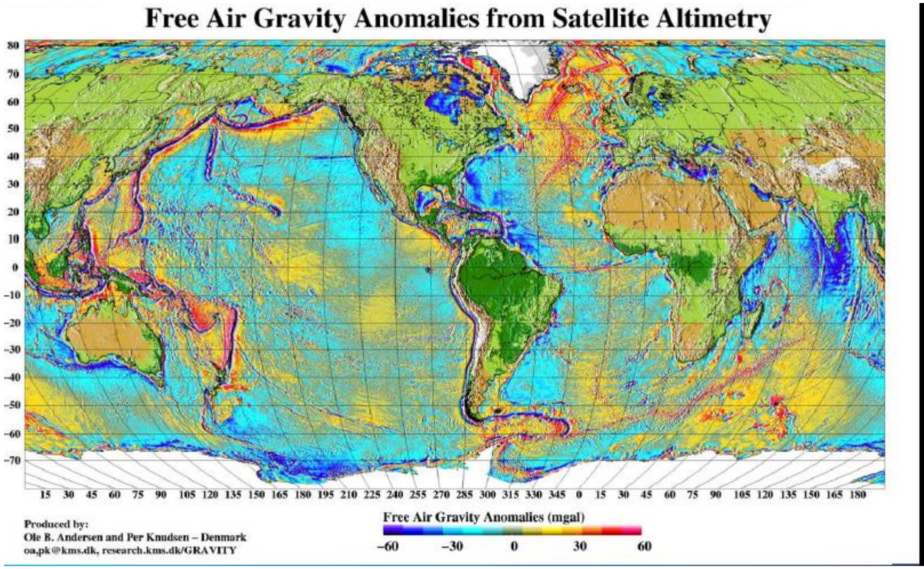
Satellite only + Land + Marine + Airborne +?

Satellite altimetry derived gravity field functionals over the ocean

Surface gravity data which include land, marine, and airborne gravity measurements

Gravity forward modelling based on digital elevation and density models



Anderson, O.

Satellite only + Land + Marine + Airborne +?

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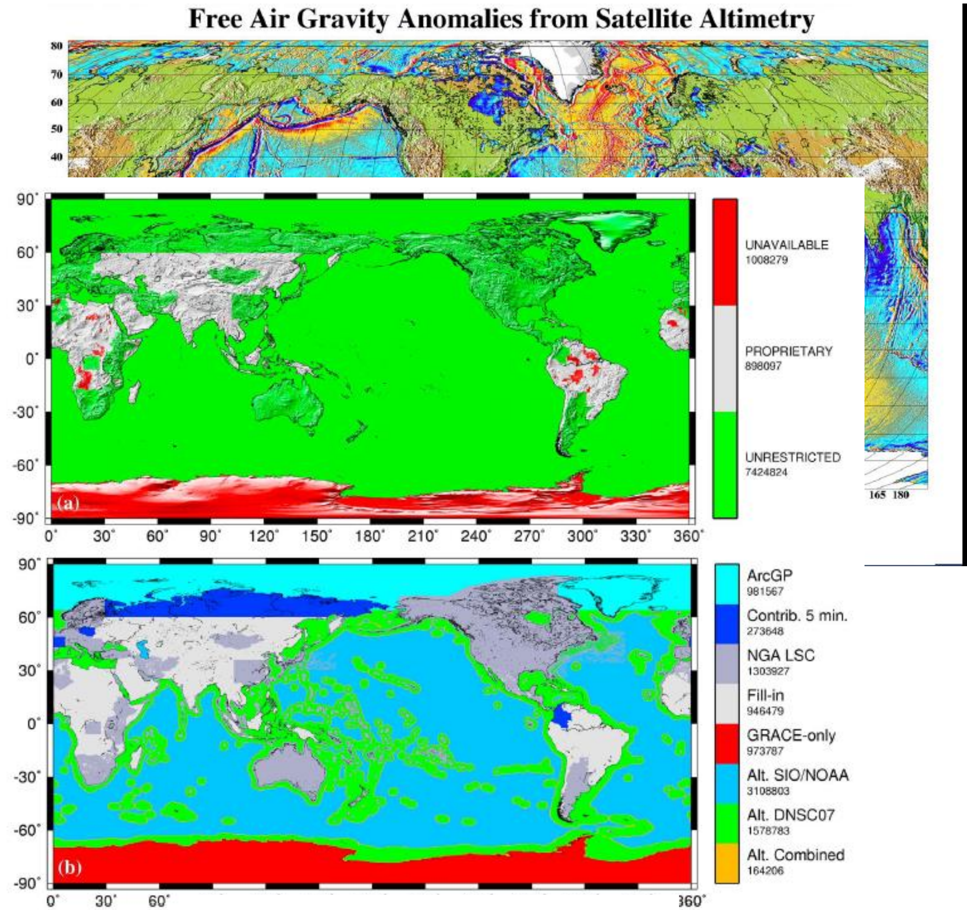

Pavlis et al. (2012)

Satellite only + Land + Marine + Airborne +?

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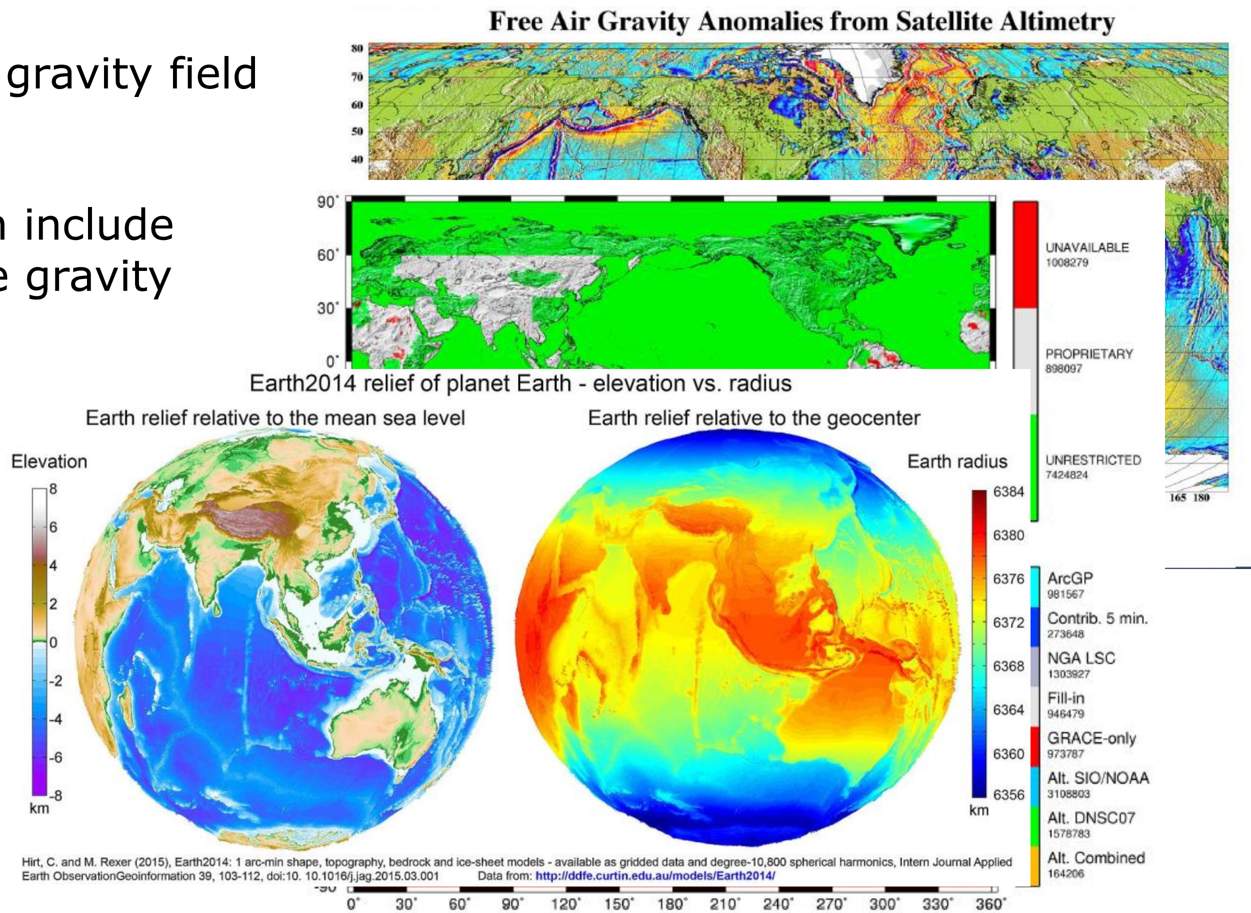


Hirt and Rexer (2015)

Configuration of the latest high resolution combined model

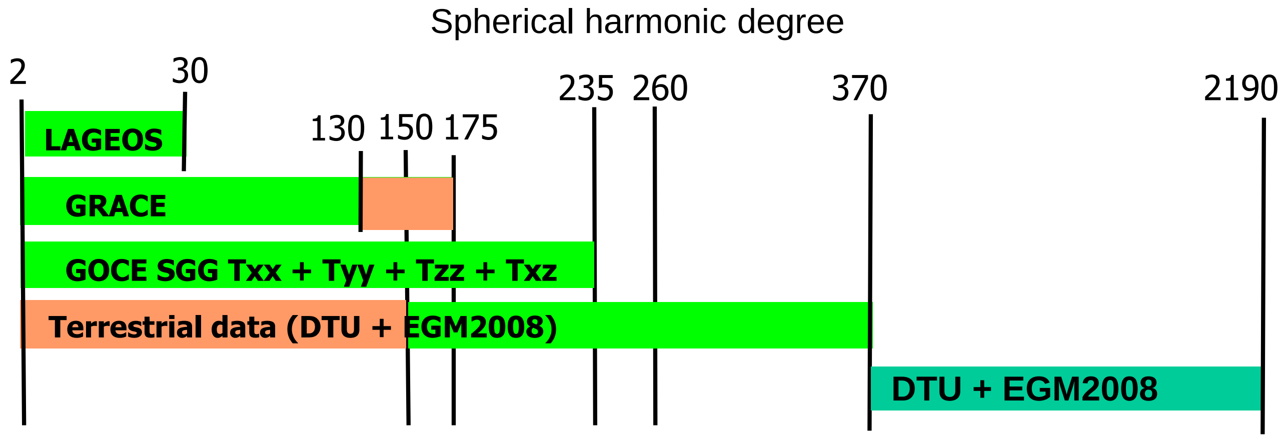
Combination scheme of the normal equations for EIGEN-6C4

Accumulation of a matrix up to d/o 370:

contribution to the solution EIGEN-6C4:

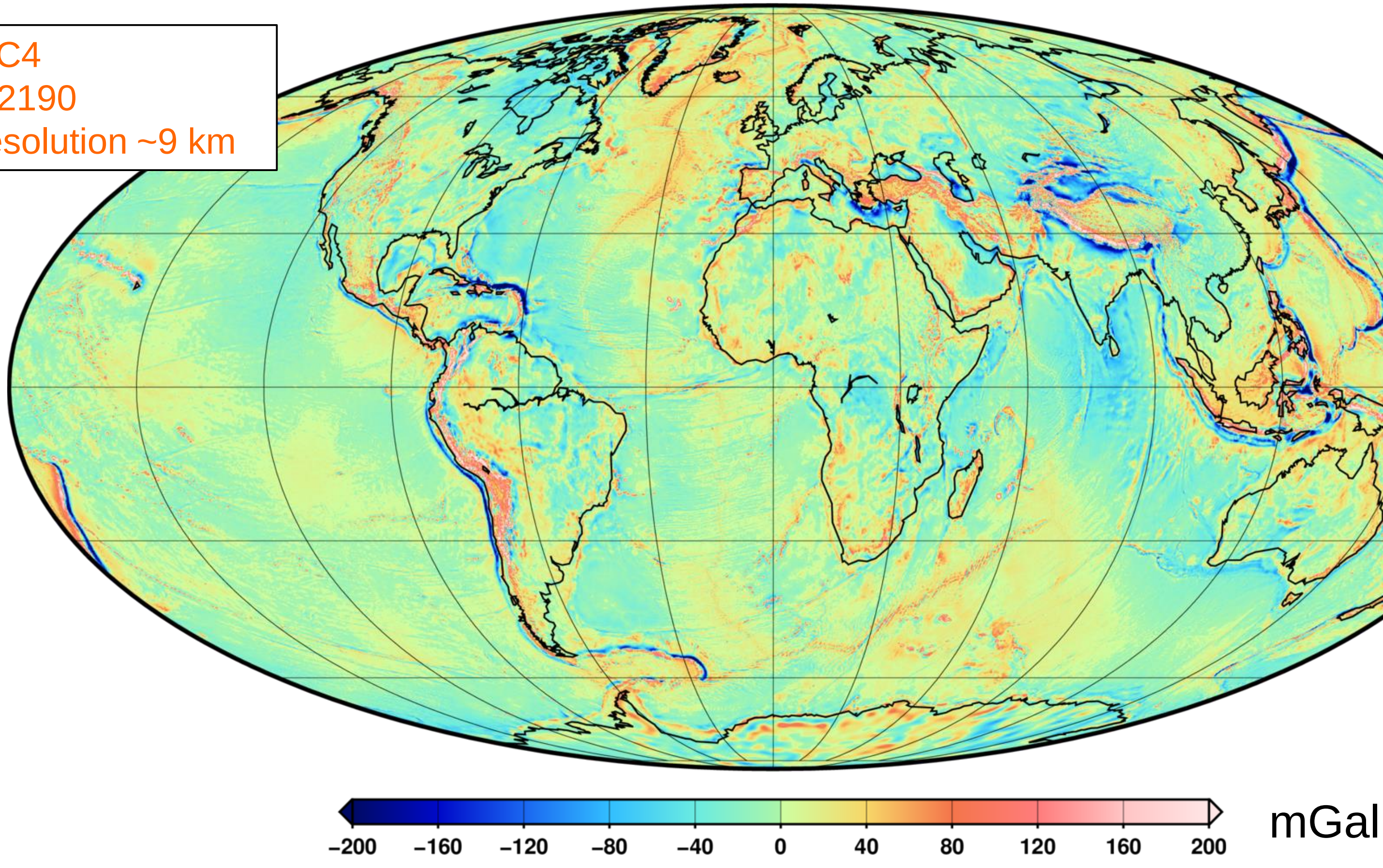
eliminated beforehand:

Separate solution (GRGS):



EIGEN-6C4

EIGEN-6C4
Max shd 2190
Spatial resolution ~9 km



Förste et al. (2014)

History: EIGEN-6C, EIGEN-6C2, EIGEN-6C3stat, EIGEN-6C4 and EIGEN-X

Dedicated Gravity missions

+

Global grid

+

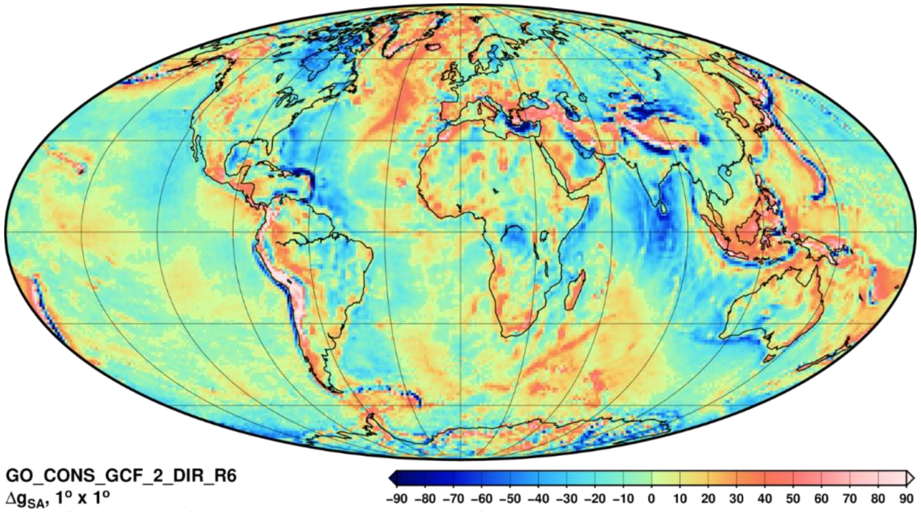
Forward model

	EIGEN-6C (2011)	EIGEN-6C2 (2012)	EIGEN-6C3stat (2013)	EIGEN-6C4 (2014)	EIGEN-X (?)
Max d/o	1420	1949	1949	2190	3660?
LAGEOS	GRGS 2003 - 2009	GRGS 1985 - 2010	GRGS 1985 - 2010	GRGS 1985 - 2010	GFZ LAGEOS + others
GRACE	GRGS RL02 2003 - 2009	GRGS RL02 2003 - 2010	GRGS RL02 (deg. 2 – 100) 2003 – 2011 GFZ RL05 (deg. 55 – 180) 2003 - 2012	GRGS RL03 10 years 2003 – 2012	GFZ RL06 GRACE & GRACE-FO 2003-2019?
Max d/o GRACE	130	130	180	130	130?
GOCE	200 days T_{xx} T_{yy} T_{zz}	350 days T_{xx} T_{yy} T_{zz}	nominal orbit altitude: 837 days T_{xx} T_{yy} T_{zz} T_{xz} + lower orbit phases: 225 days T_{xx} T_{yy} T_{zz}	nominal orbit altitude: 837 days T_{xx} T_{yy} T_{zz} T_{xz} + lower orbit phases: 422 days T_{xx} T_{yy} T_{zz} T_{xz}	Reprocessed GOCE SGG
Max d/o GOCE	210	210	235	235	235?
Terrestrial data	DTU Global gravity anomalies	DTU Global gravity anomalies and ocean grid + EGM2008 geoid grid	DTU Global gravity anomalies and ocean grid + EGM2008 geoid grid	DTU Global gravity Anomalies and ocean geoid + EGM2008 geoid grid	DTU Global gravity anomalies and ocean geoid (version?) + EGM2020 geoid grid + Forward model

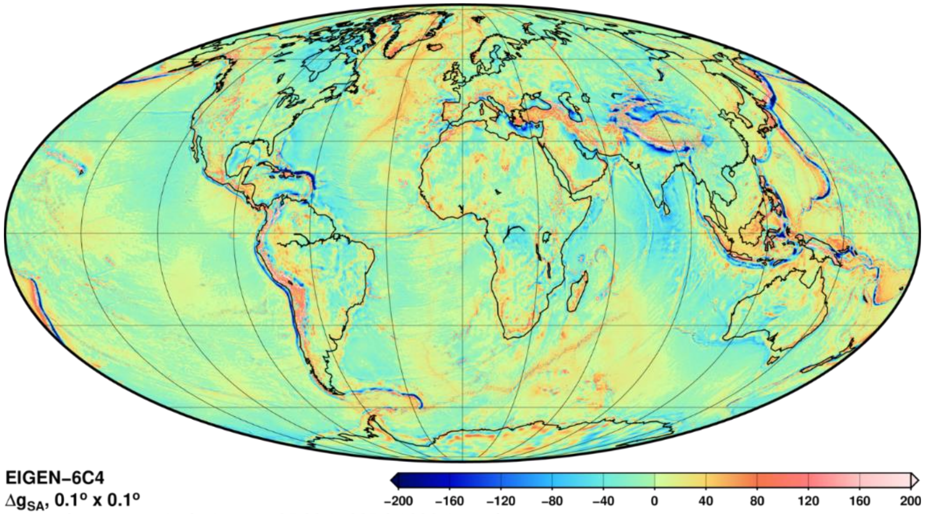
EIGEN = "European Improved Gravity model of the Earth by New techniques"

Satellite-only vs high-resolution combined global gravity field model

DIR-R6 Spatial resolution ~80 km

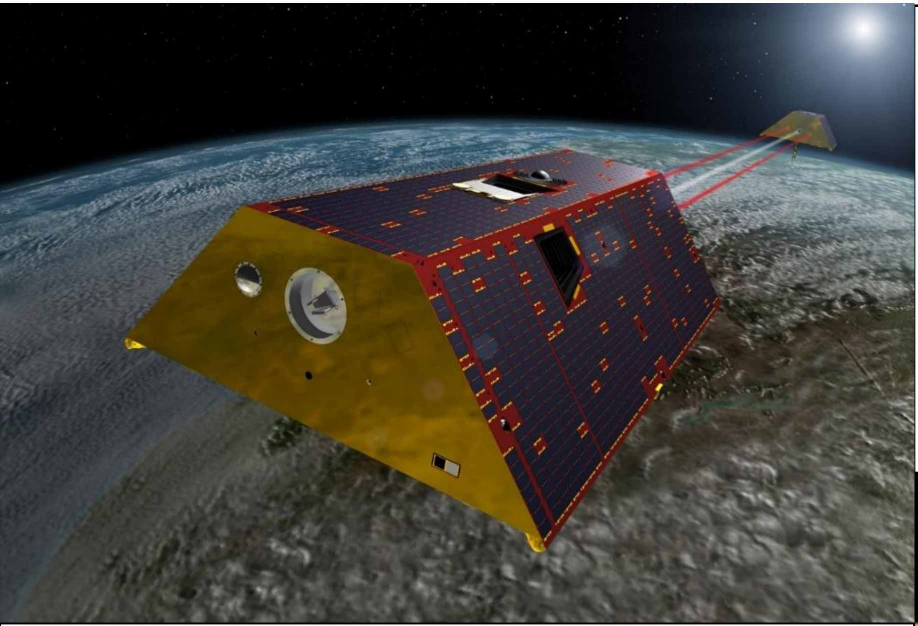


EIGEN-6C4 Spatial resolution ~9km



Next: A higher spatial resolution (~5km) global combined model?

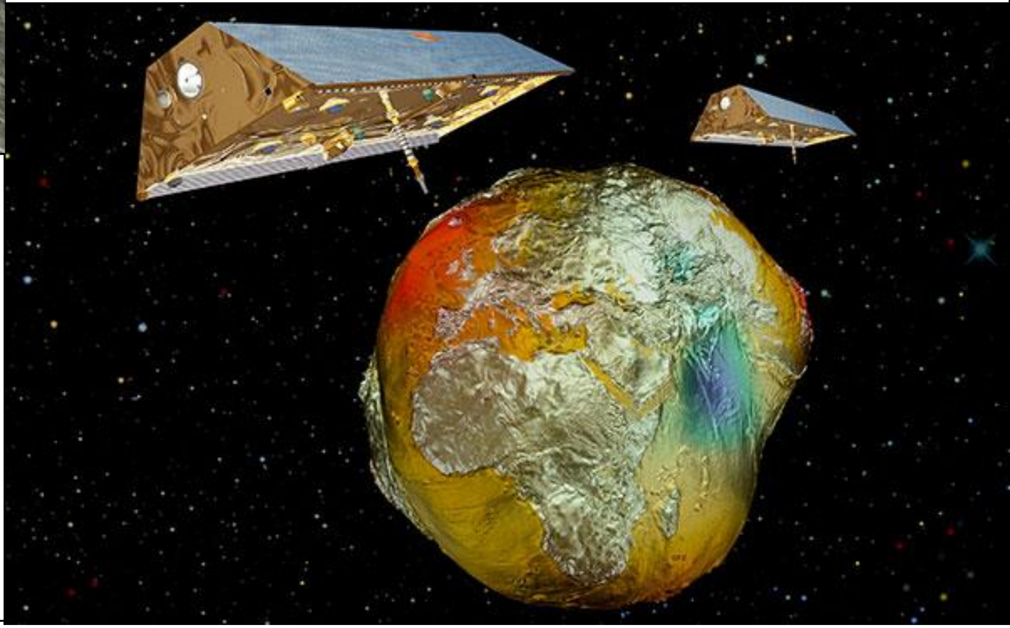
Gravity Field Satellite Mission



GRACE

Launch March 2002, end Oct. 2017
Initial alt. ~500km, two satellites ~220 km apart, exceeded its 5-year design lifespan

Accomplished: Continuous monitoring of the mass distributions of the Earth's gravity field and their variations and interactions between the Earth's surface and atmosphere



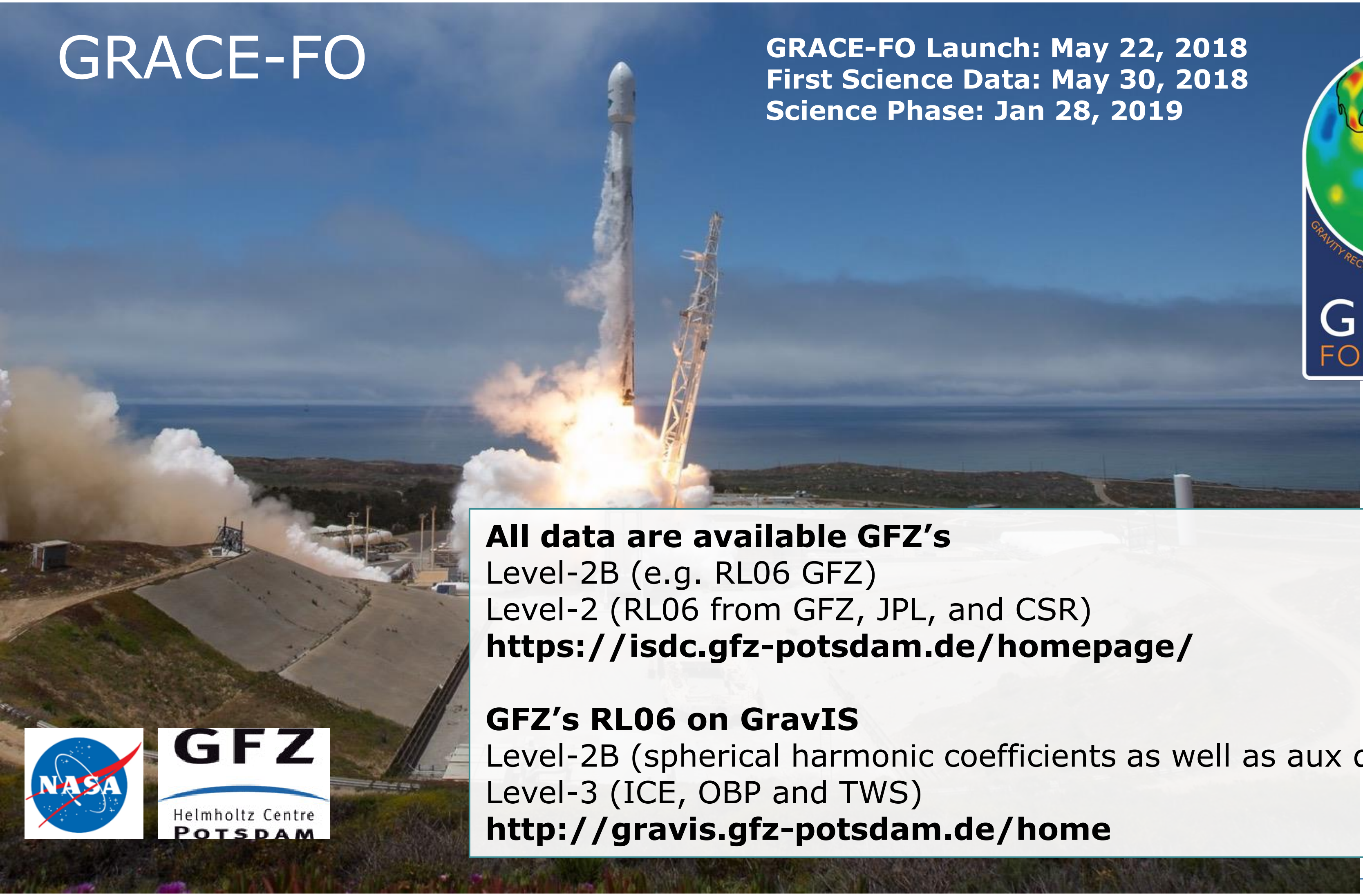
GRACE-FO

Launch 22 May, 2018
NASA-GFZ joint project

Aim Continuity of the GRACE observations eith increased accuracy, technology demonstrator,

benefit to society

GRACE-FO Launch & Data Availability



GRACE-FO

GRACE-FO Launch: May 22, 2018
First Science Data: May 30, 2018
Science Phase: Jan 28, 2019

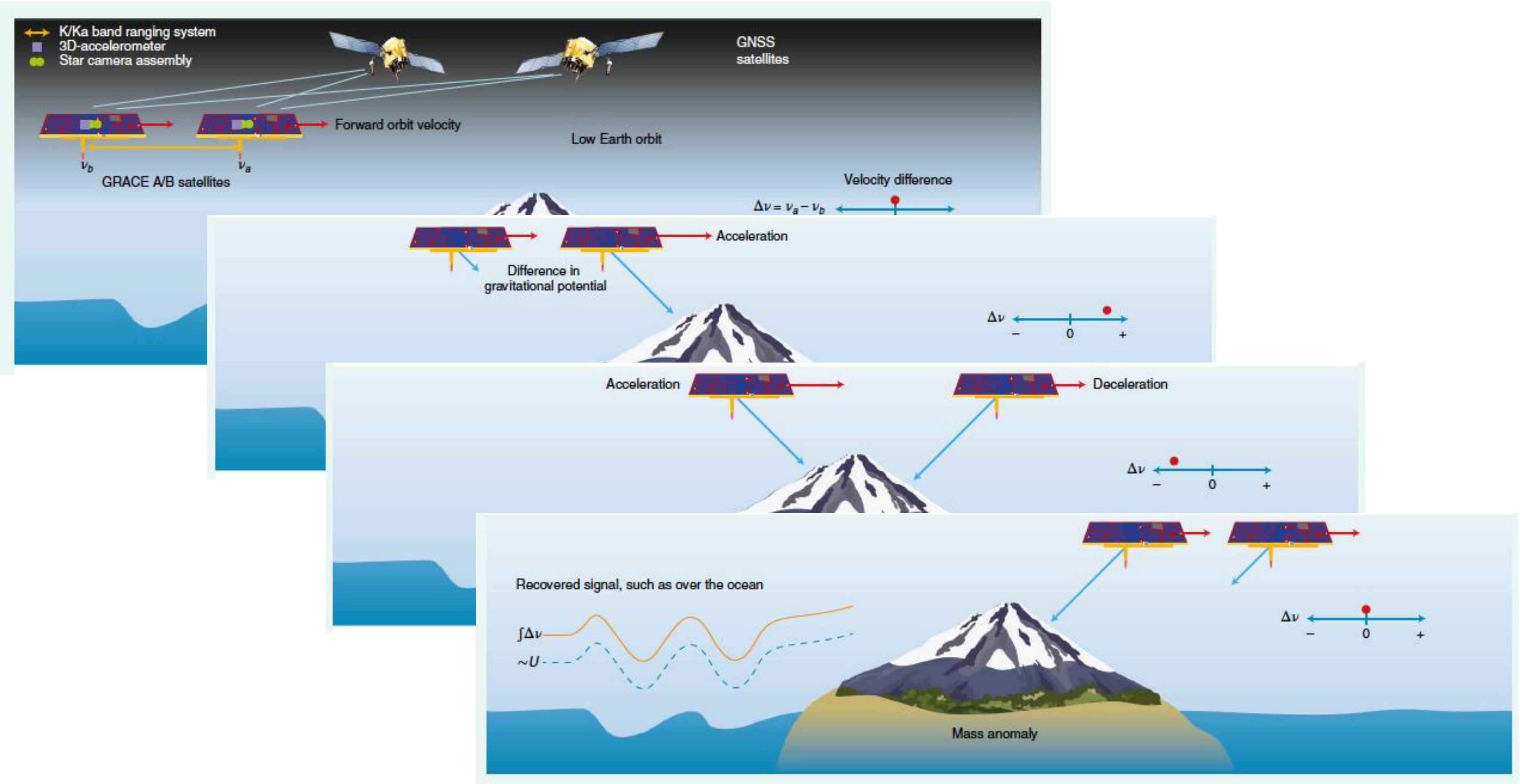
GRACE FOLLOW-ON
GRAVITY RECOVERY AND CLIMATE EXPERIMENT
NASA JPL GFZ

All data are available GFZ's
Level-2B (e.g. RL06 GFZ)
Level-2 (RL06 from GFZ, JPL, and CSR)
https://isdc.gfz-potsdam.de/homepage/

GFZ's RL06 on GravIS
Level-2B (spherical harmonic coefficients as well as aux data)
Level-3 (ICE, OBP and TWS)
http://gravis.gfz-potsdam.de/home

NASA
GFZ Helmholtz Centre Potsdam

GRACE Measurement Principle

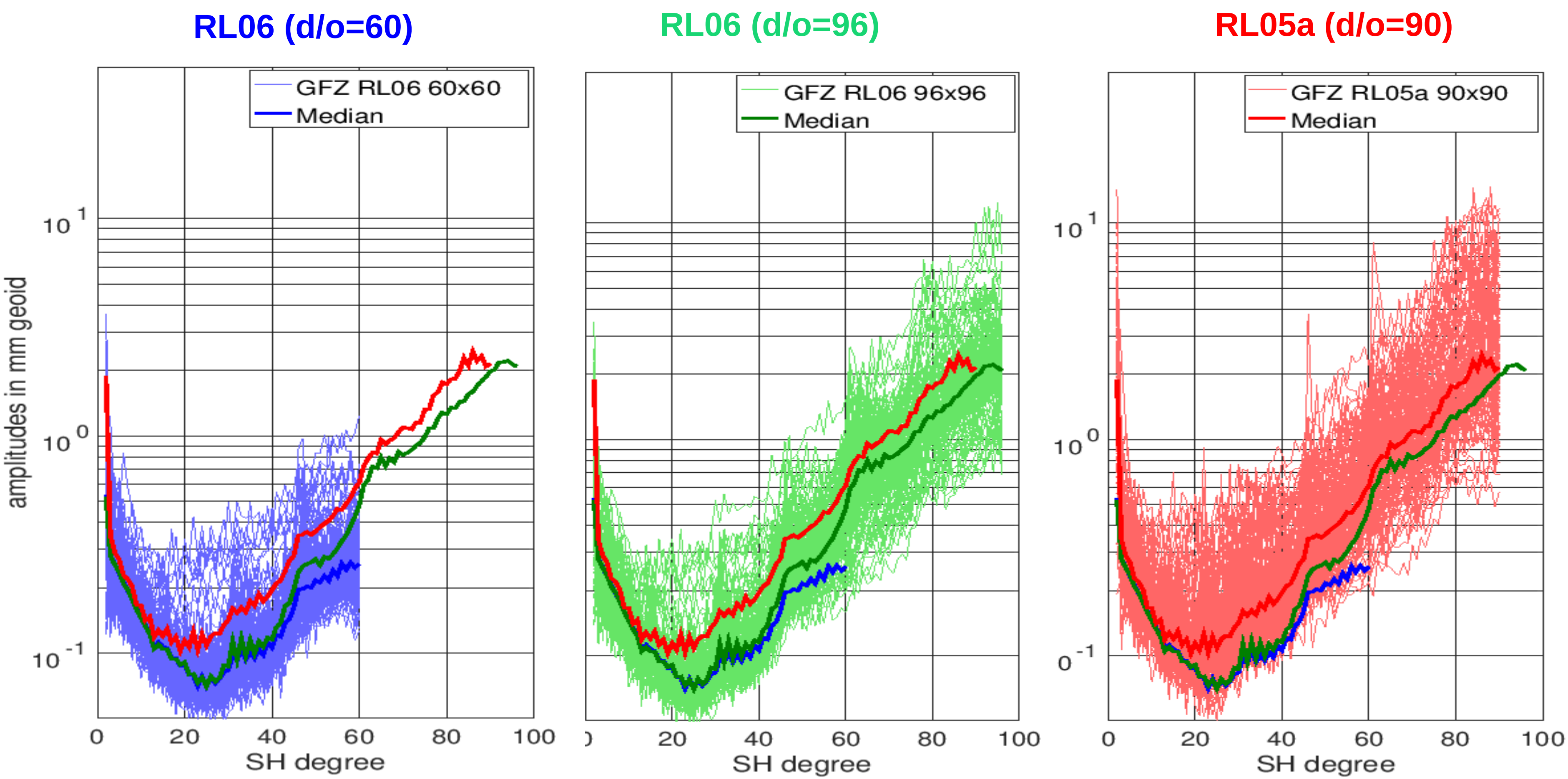


Tapley, D., Watkins M, Flechtner F. et al. "Contributions of GRACE to understanding climate change." *Nature Climate Change* (2019): 1.

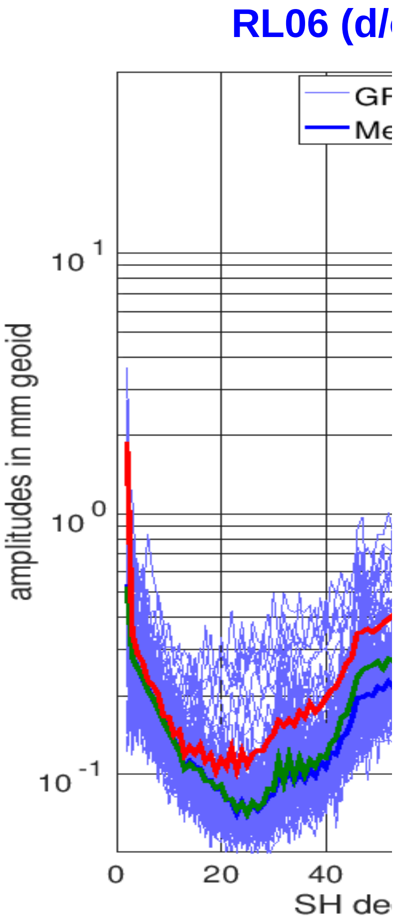
Continuous Improvement
New Releases

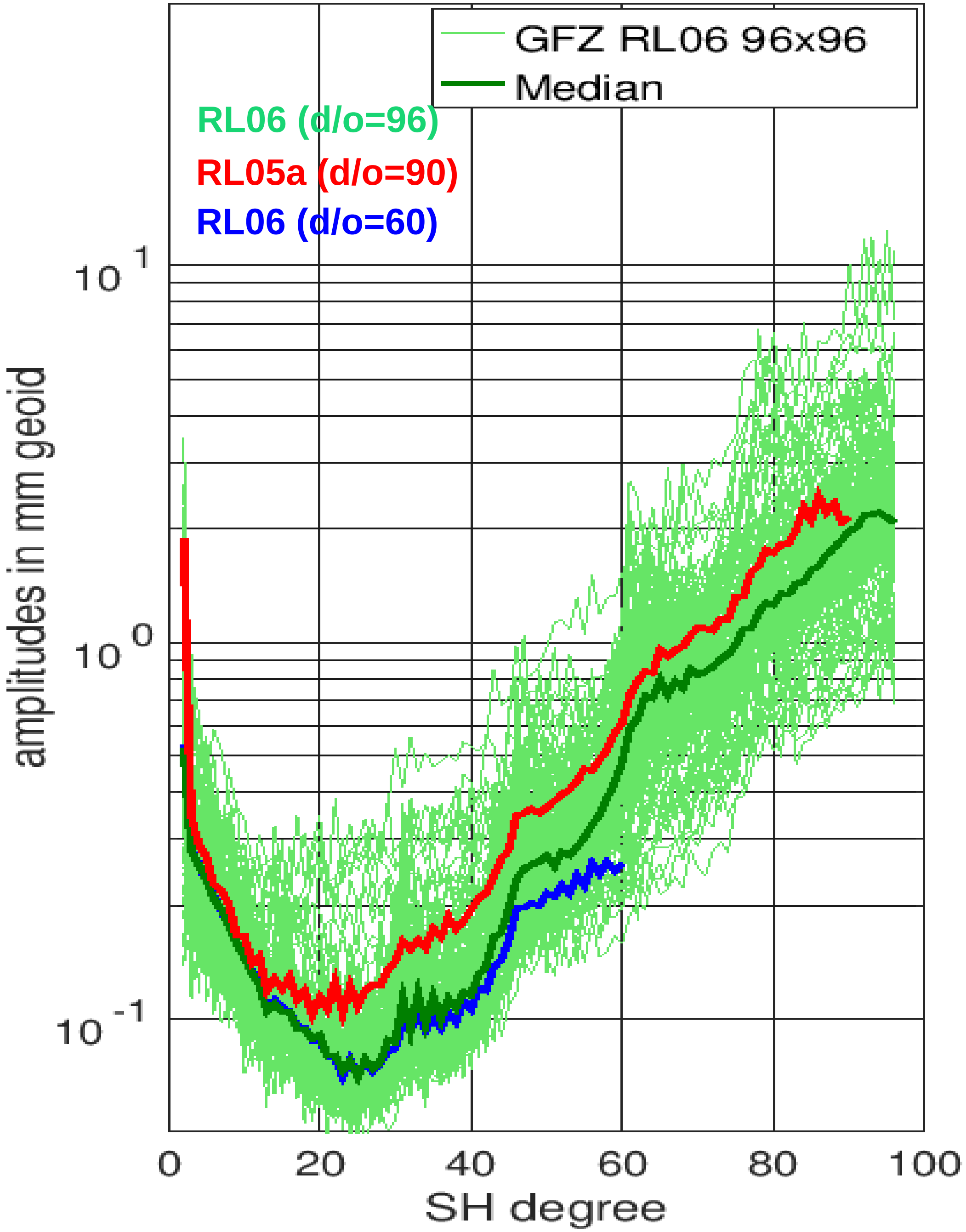
RL05 vs RL06

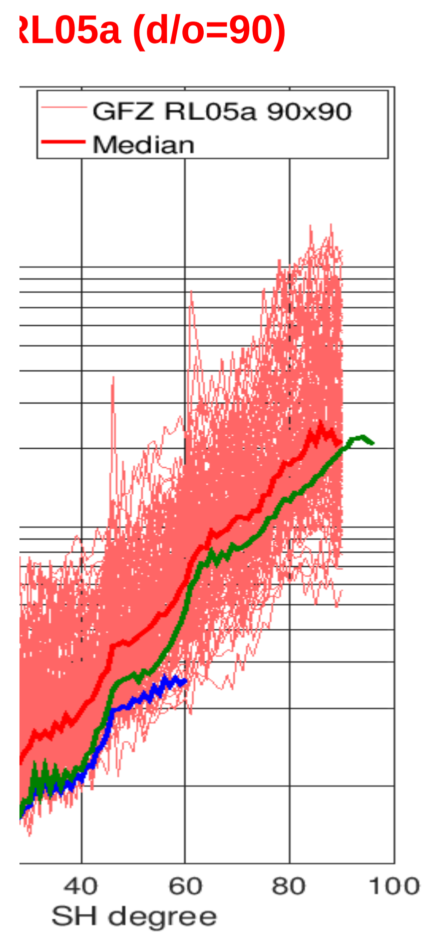
Differences to Climatology Model
2002 - 2017



Dahle et al. (2019)

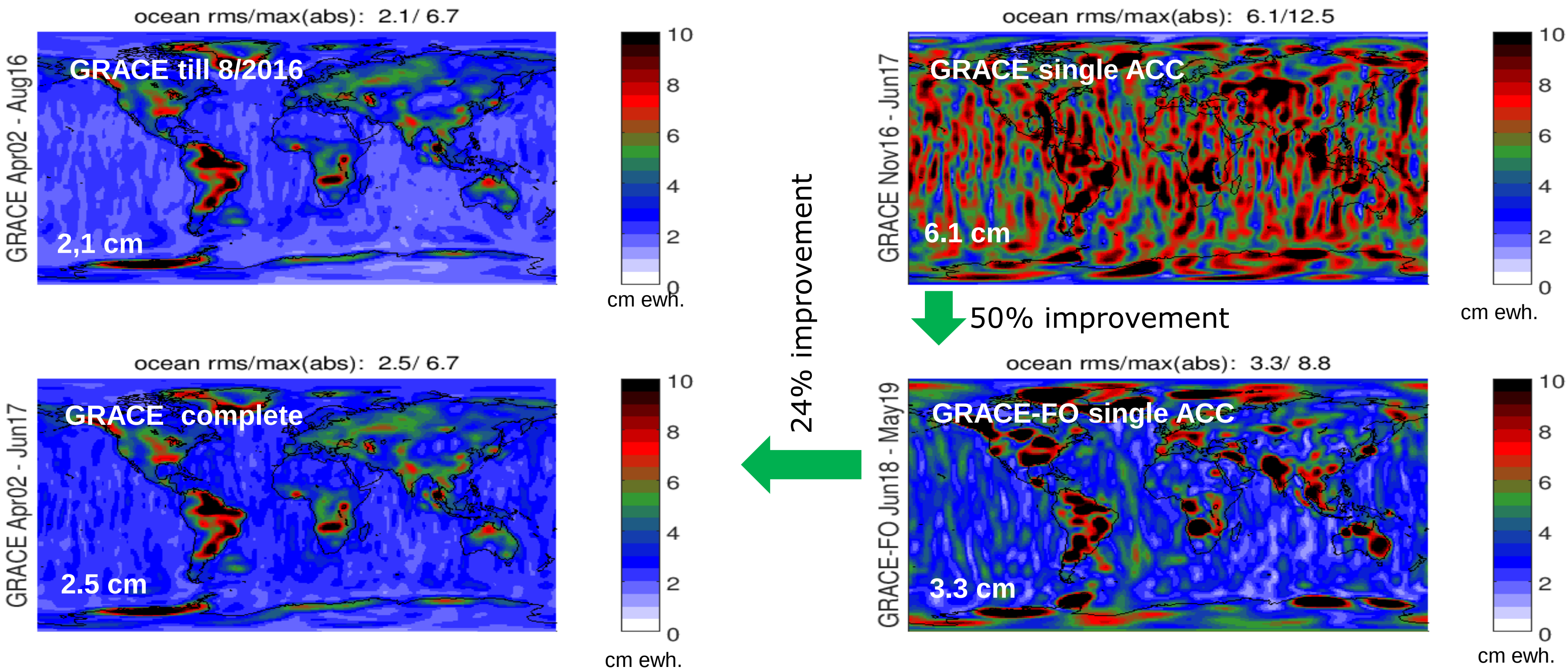






Dahle et al. (2019)

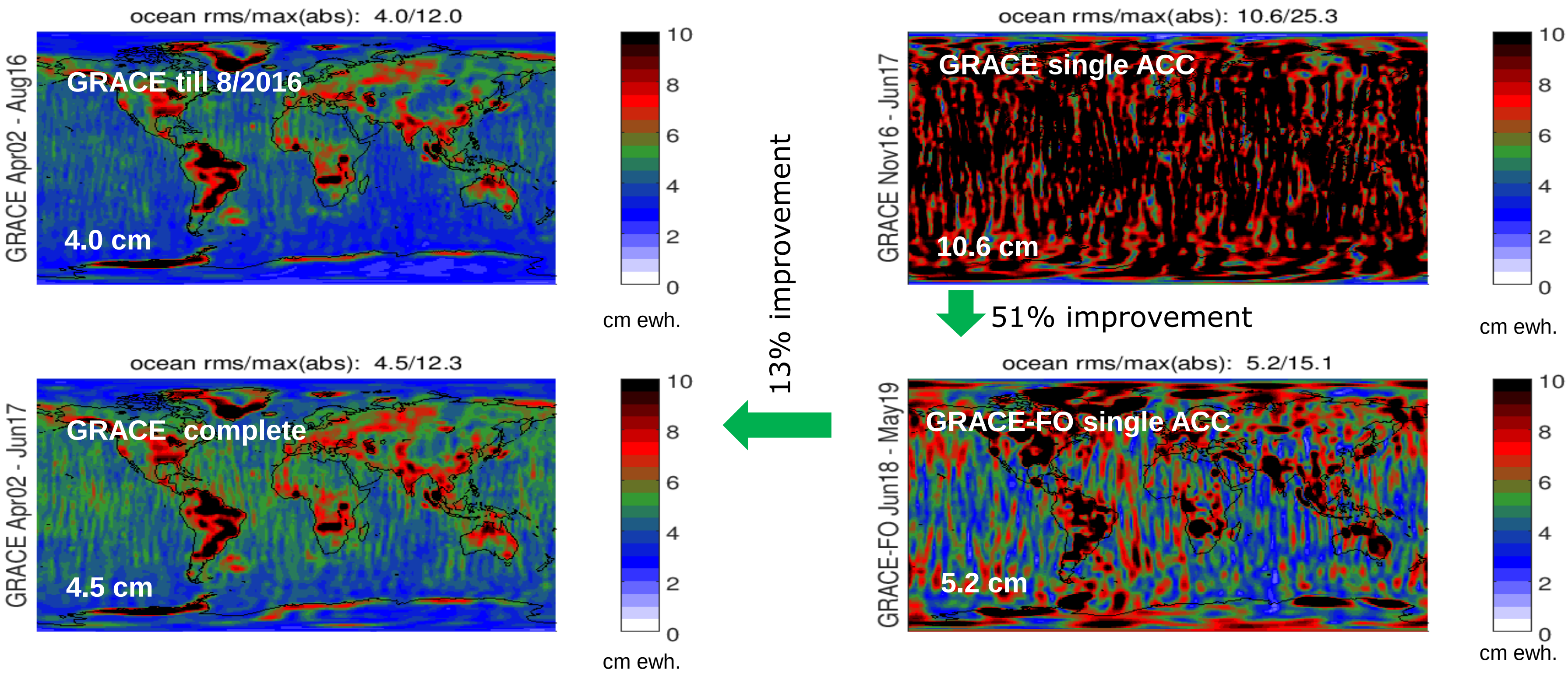
RMS of Residual Signal, RL06 d/o=96, DDK3 filtered



Dahle et al. (2019)

Filtering makes a difference and need to be studied based on the region as well as application of interest

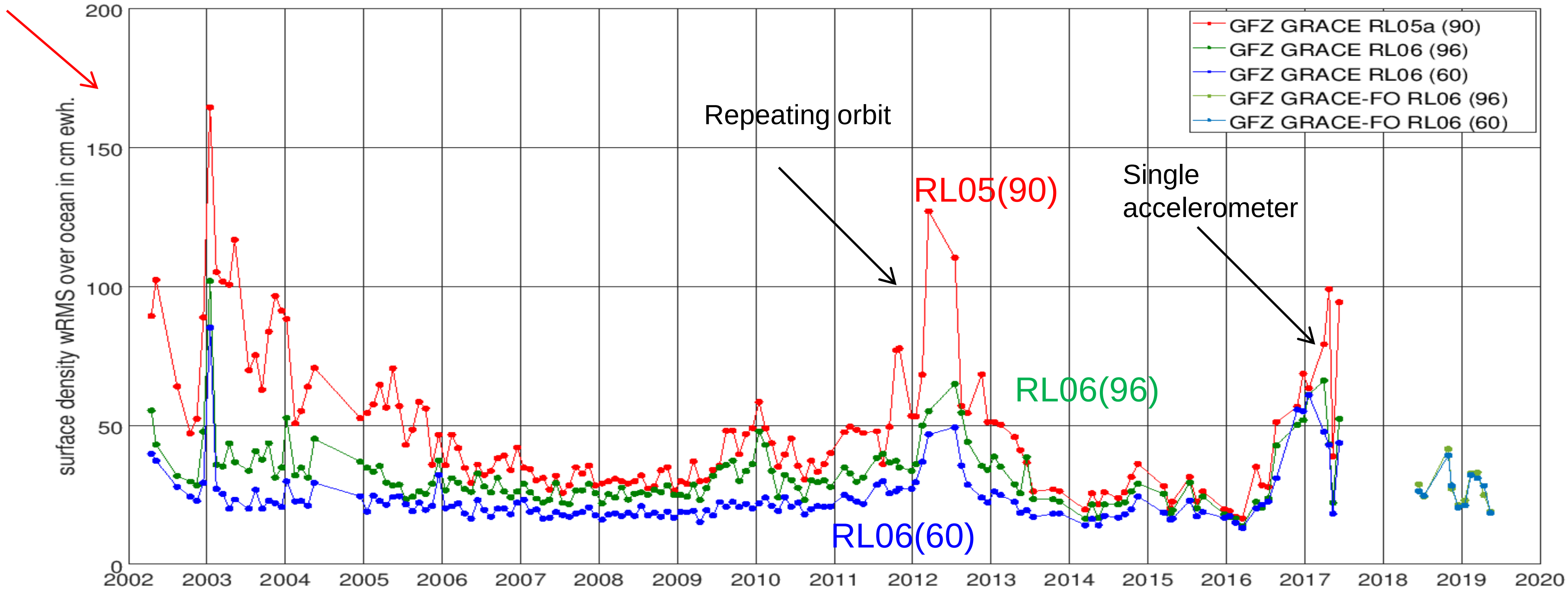
RMS of Residual Signal, RL06 d/o=96, DDK5 filtered



Dahle et al. (2019)

Ocean wRMS, unfiltered (l_{max} = 60)

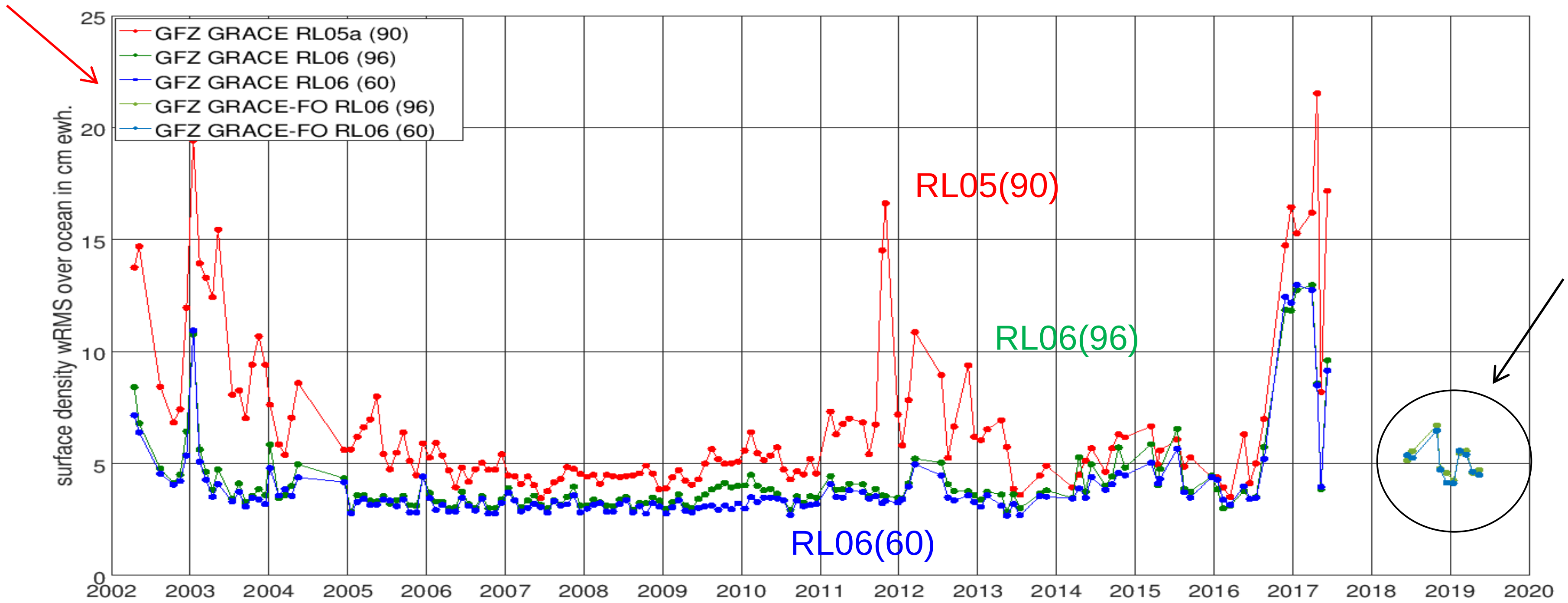
Residuals wrt to climatology model



Dahle et al. (2019)

Ocean wRMS, DDK5 filtered

Residuals wrt to median value

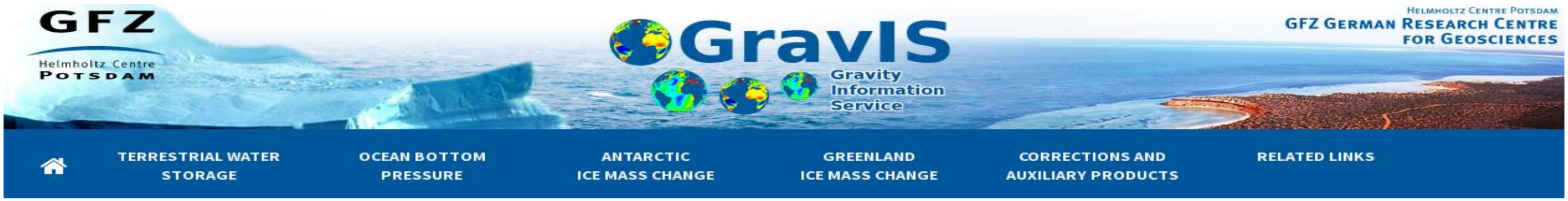


Dahle et al. (2019)

How to transform satellite raw data to applications?

GRACE / GRACE-FO
Level-1 data to Level-2, Level-3

GFZ Gravity Information Service (GravIS)



New Level-3 portal in collaboration with TU Dresden and AWI

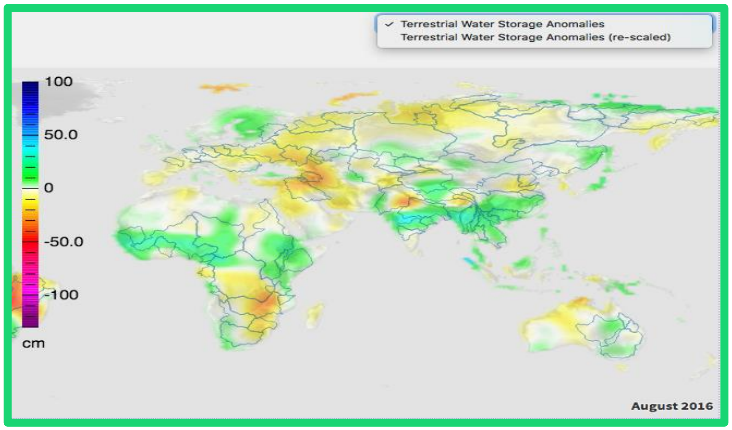
- At GravIS, user-friendly mass anomaly products (Level-3) based on most recent GFZ GRACE/GRACE-FO release of monthly gravity field solutions (Level-2)
  - can be visualized interactively,
  - are described in detail, and
  - are available for download at ISDC.

- Level-3 products comprise dedicated globally gridded mass anomalies as well as basin average time series for
  - terrestrial water storage over non-glaciated regions,
  - bottom pressure variations in the oceans and
  - ice mass changes in Antarctica and Greenland.

http://gravis.gfz-potsdam.de/

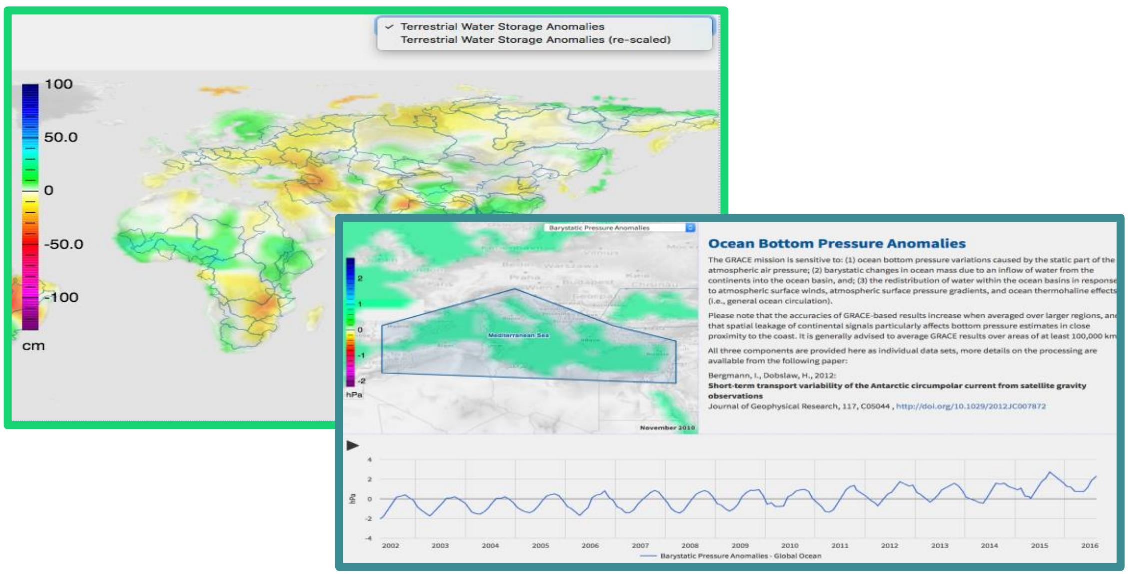
TECHNISCHE UNIVERSITÄT DRESDEN

GFZ Gravity Information Service (GravIS)



online with GFZ RL06

GFZ Gravity Information Service (GravIS)



online with GFZ RL06

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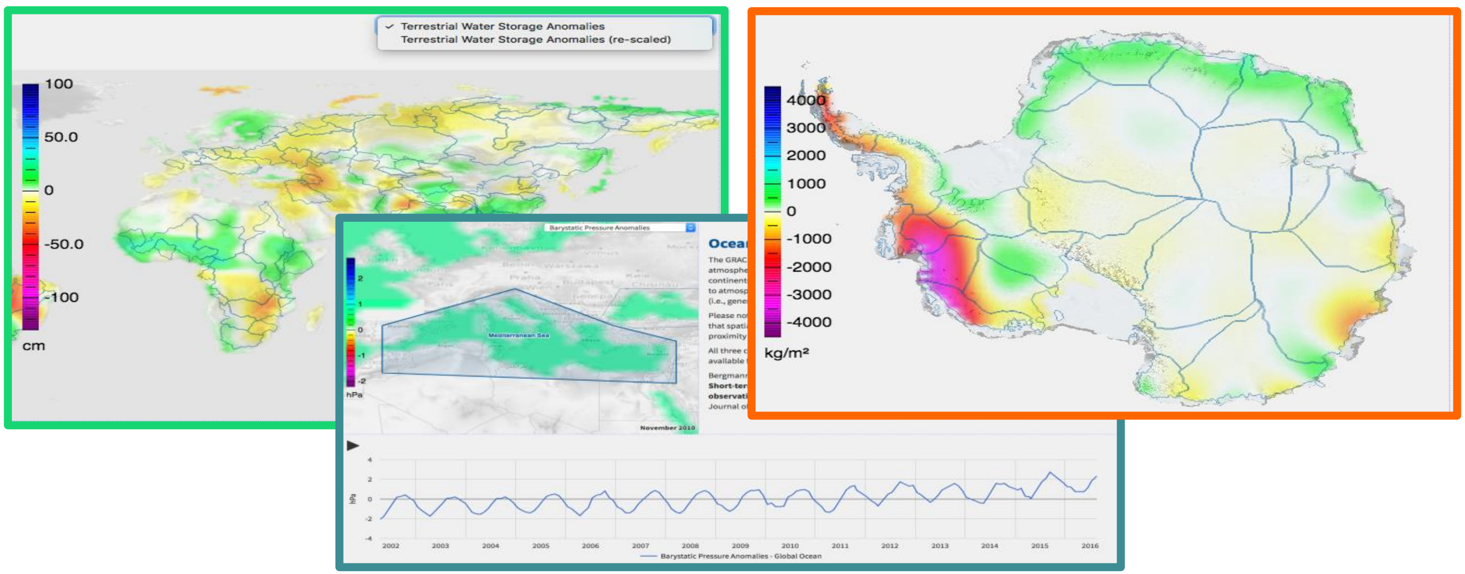

online with GFZ RL06

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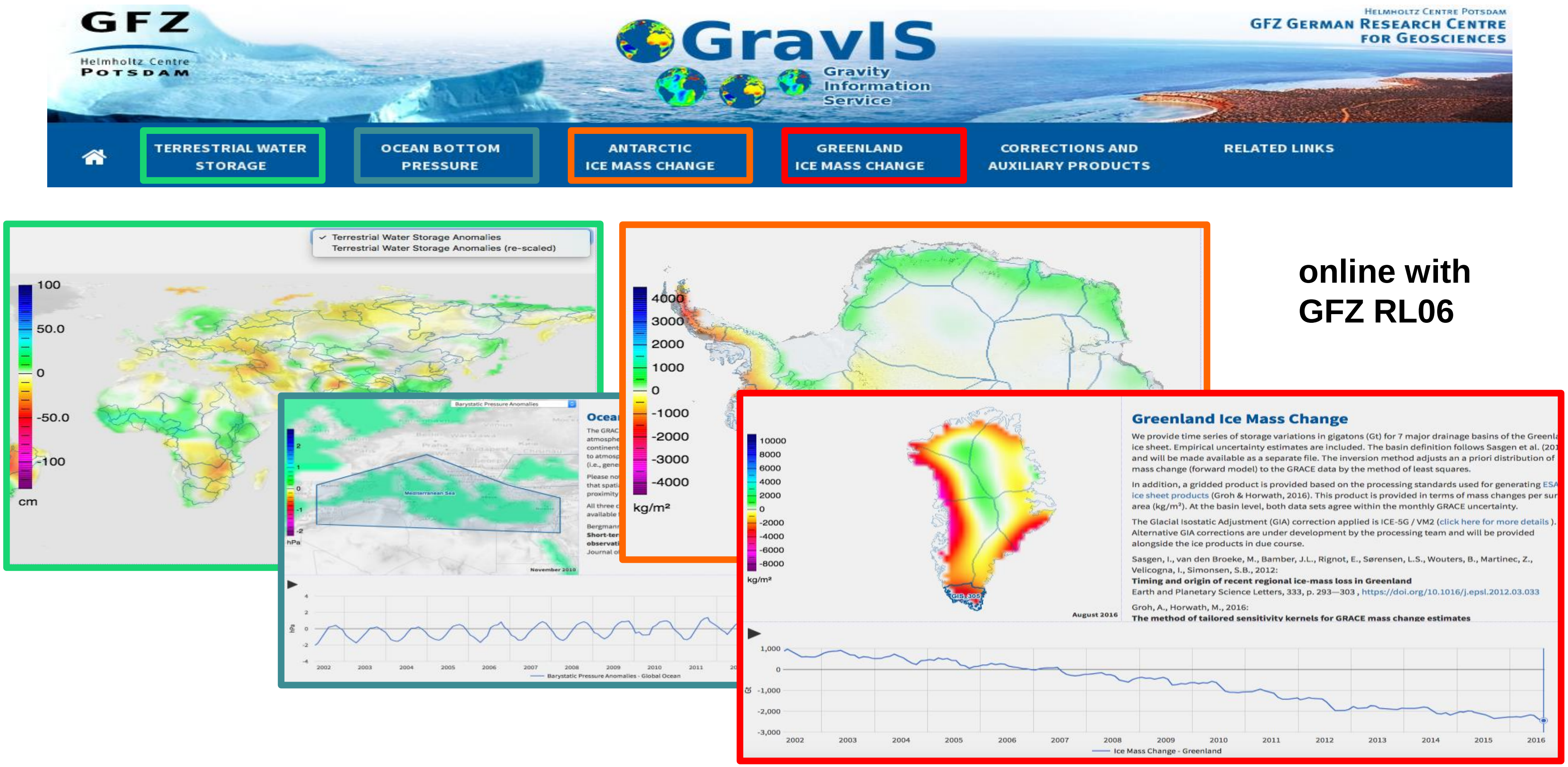

online with GFZ RL06

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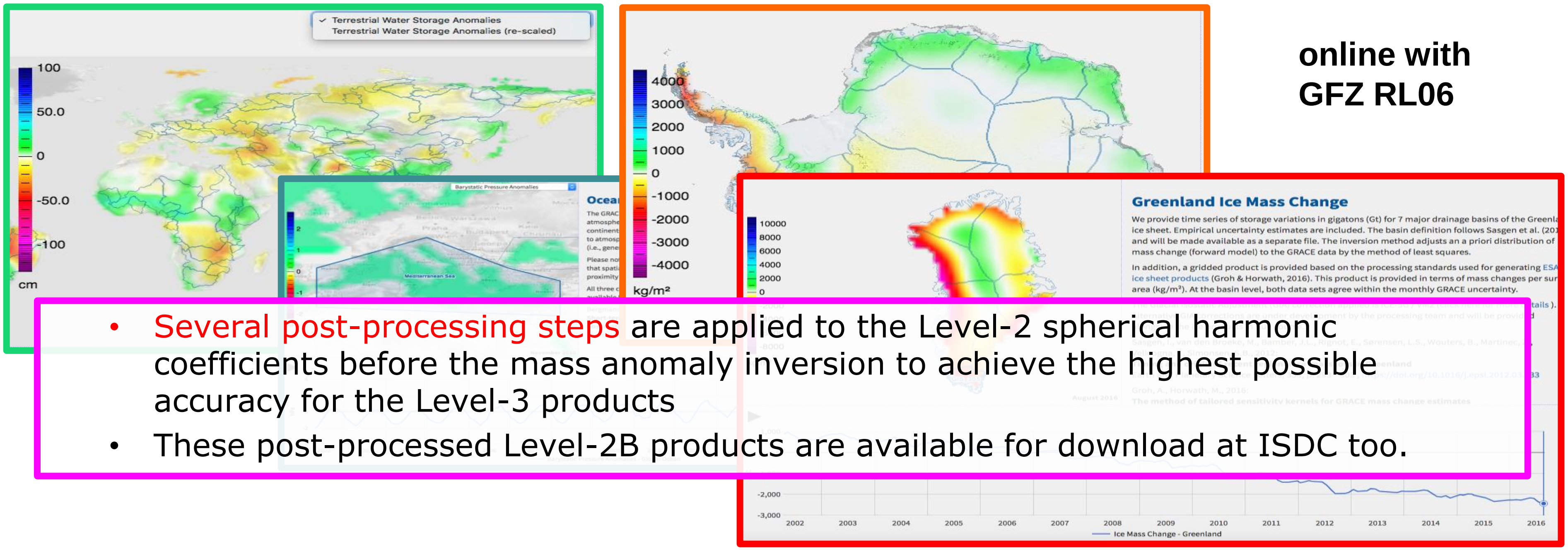


online with GFZ RL06

- Several post-processing steps are applied to the Level-2 spherical harmonic coefficients before the mass anomaly inversion to achieve the highest possible accuracy for the Level-3 products
- These post-processed Level-2B products are available for download at ISDC too.

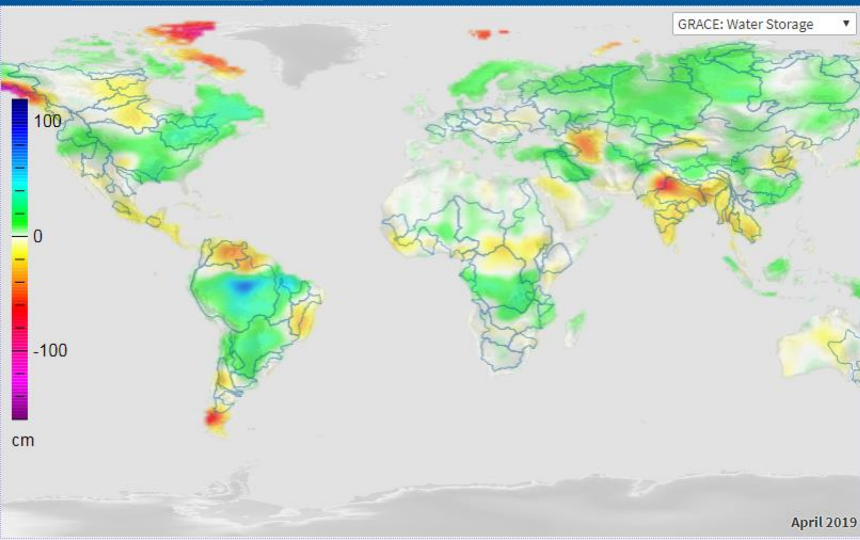
GFZ Gravity Information Service (GravIS)

GFZ Helmholtz Centre Potsdam

GravIS Gravity Information Service

Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences

TERRESTRIAL WATER STORAGE | OCEAN BOTTOM PRESSURE | ANTARCTIC ICE-MASS CHANGE | GREENLAND ICE-MASS CHANGE | CORRECTIONS AND AUXILIARY PRODUCTS | RELATED LINKS



Terrestrial Water Storage Anomalies

Terrestrial Water Storage (TWS) variability as observed by GRACE/GRACE-FO is an integrated signal from a number of different processes. The following individual components are available:

GRACE: Water Storage
Water mass anomalies expressed in terms of equivalent water height from all water storage compartments including snow, surface water, soil moisture, and deep groundwater.

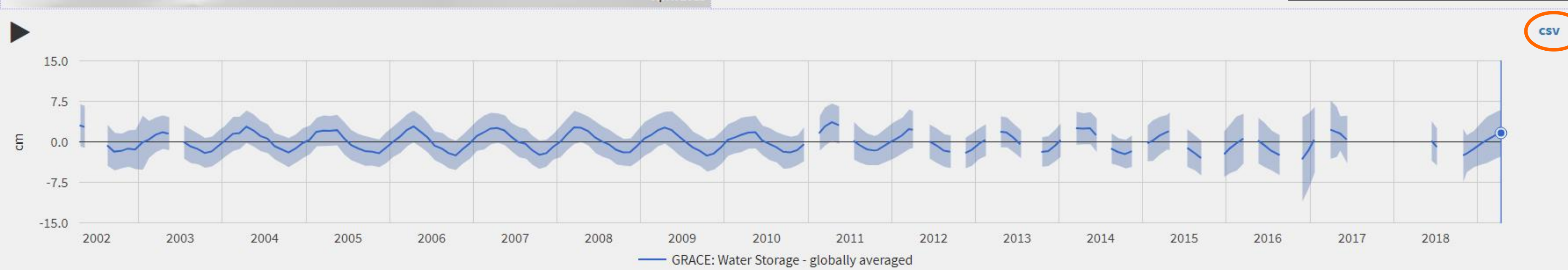
Errors: Water Storage
Time-variable component of the uncertainty estimate for the GRACE-based water storage variability.

Model: Atmospheric Mass
Atmospheric mass variability as represented in the non-tidal de-aliasing model AOD1B expressed in terms of equivalent water height.

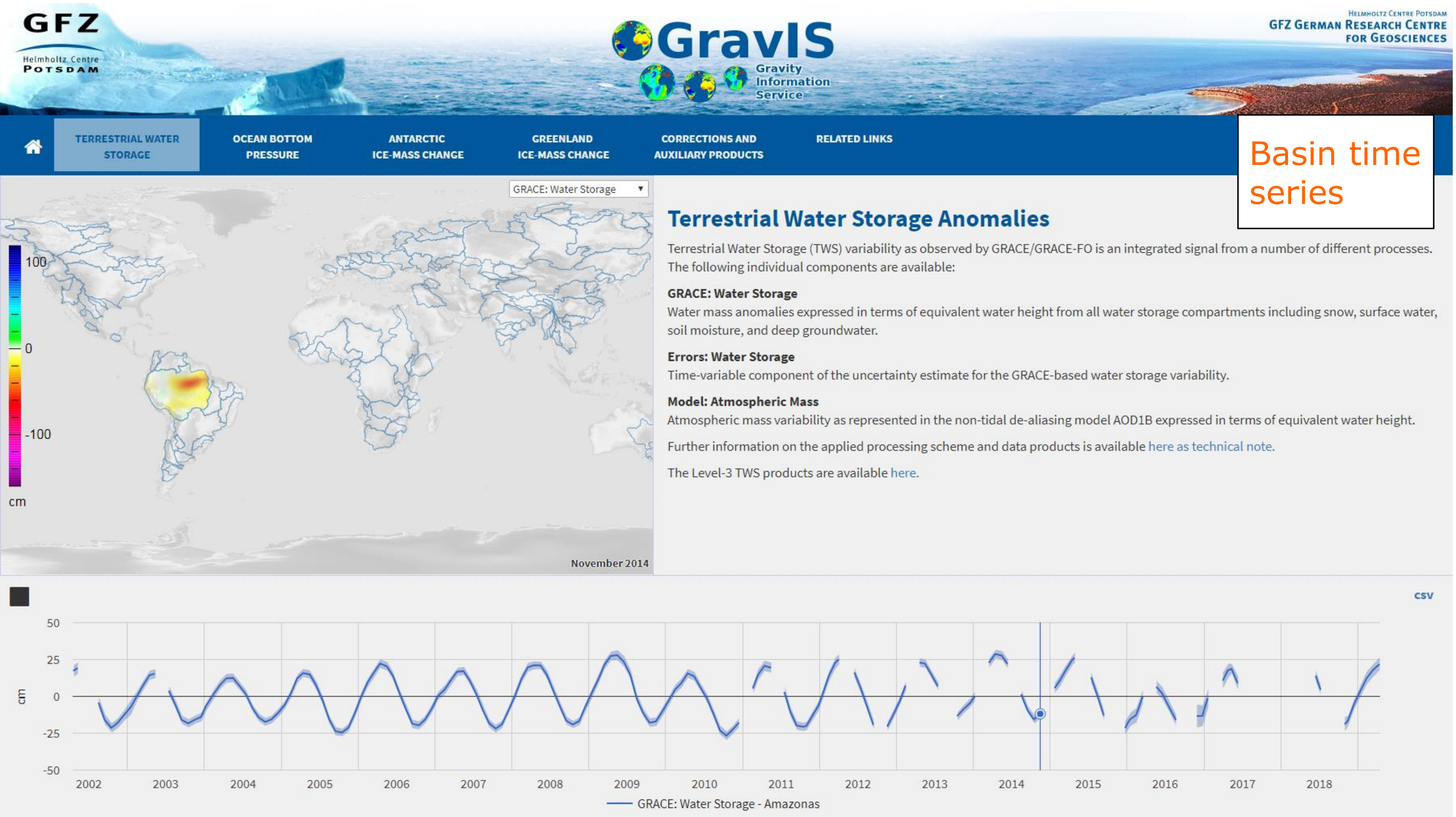
Further information on the applied processing scheme and data products is available here as technical note.

The Level-3 TWS products are available here.

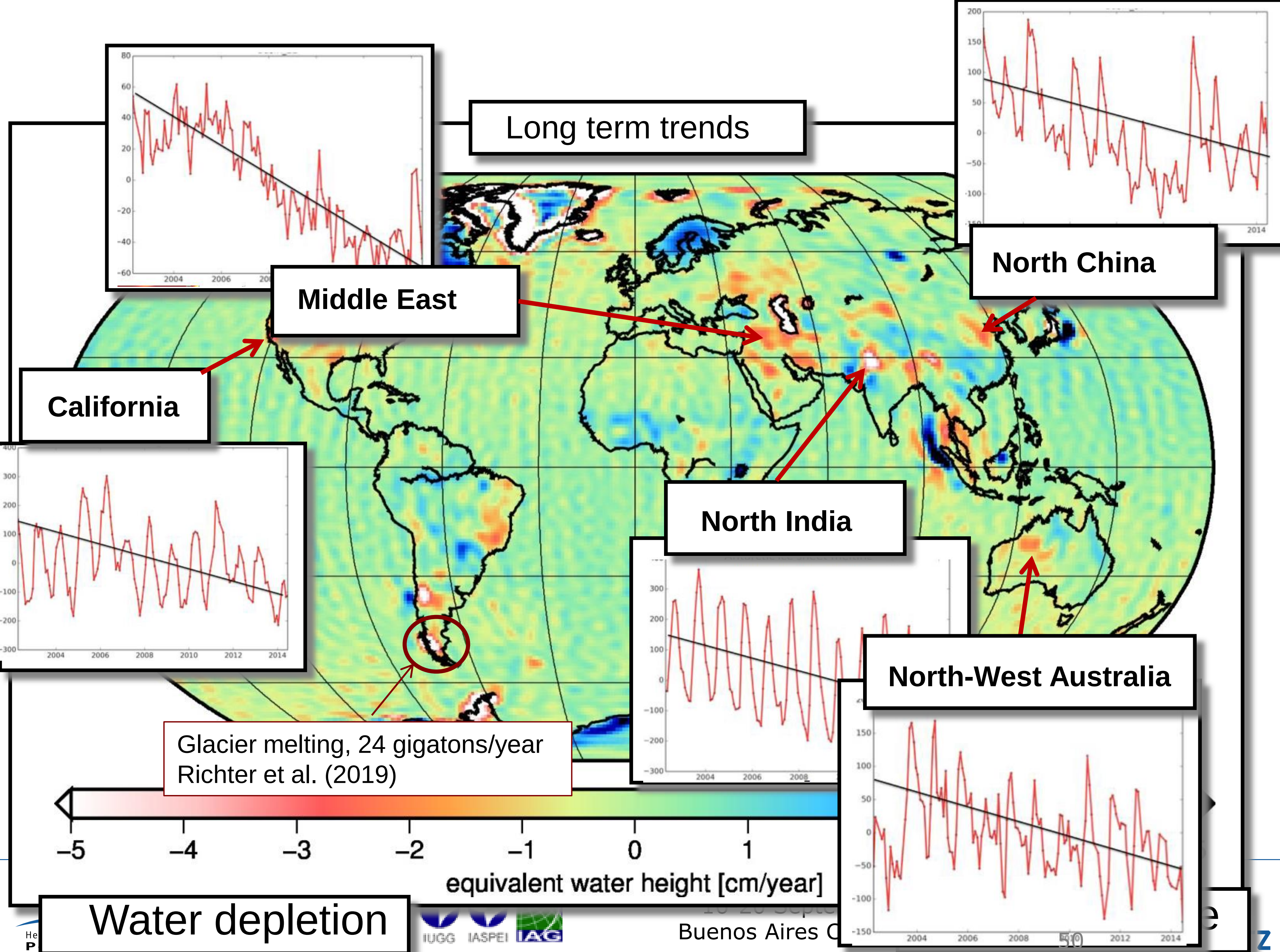
Downloadable Level-3



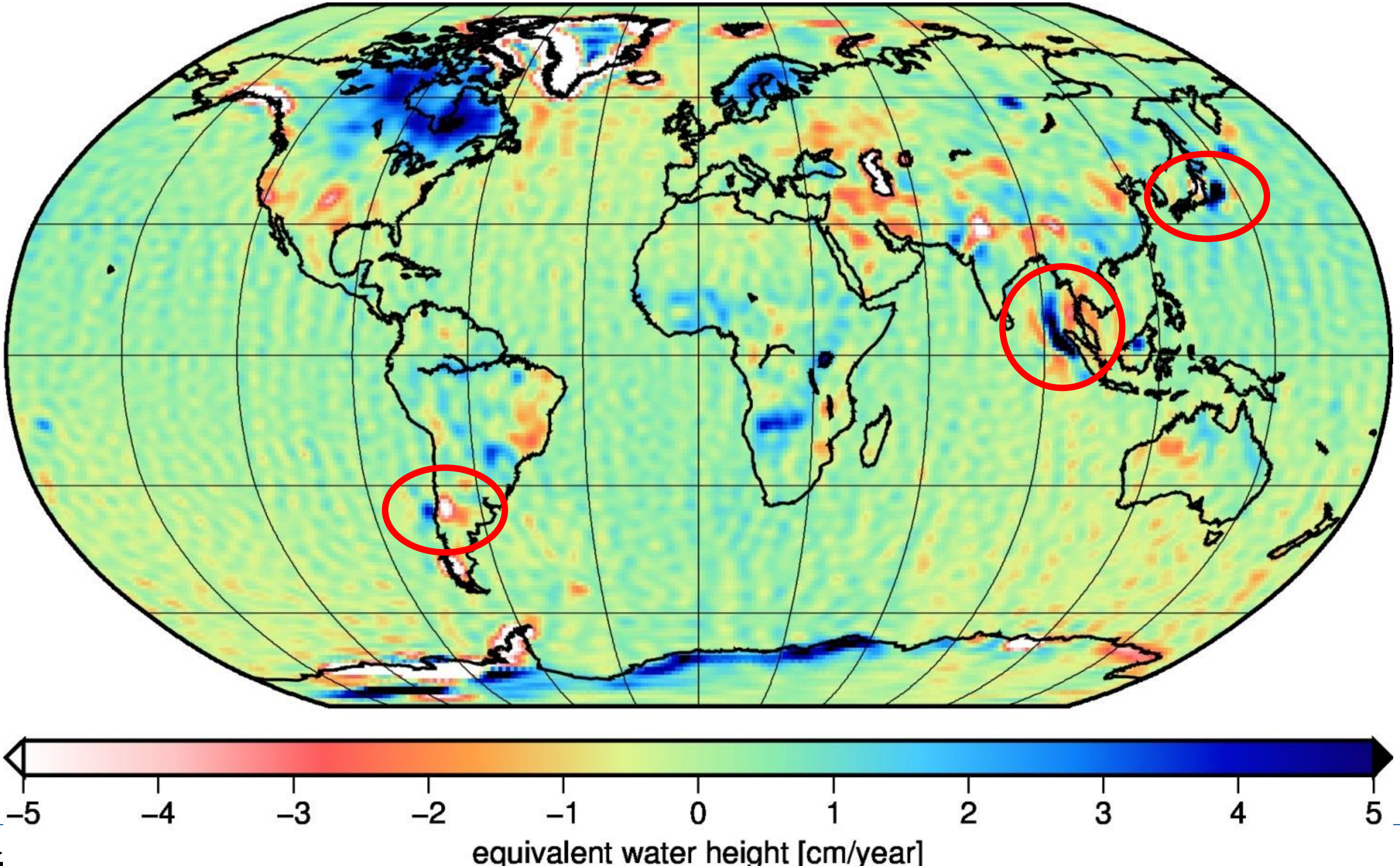
GFZ Gravity Information Service (GravIS)



Basin time series

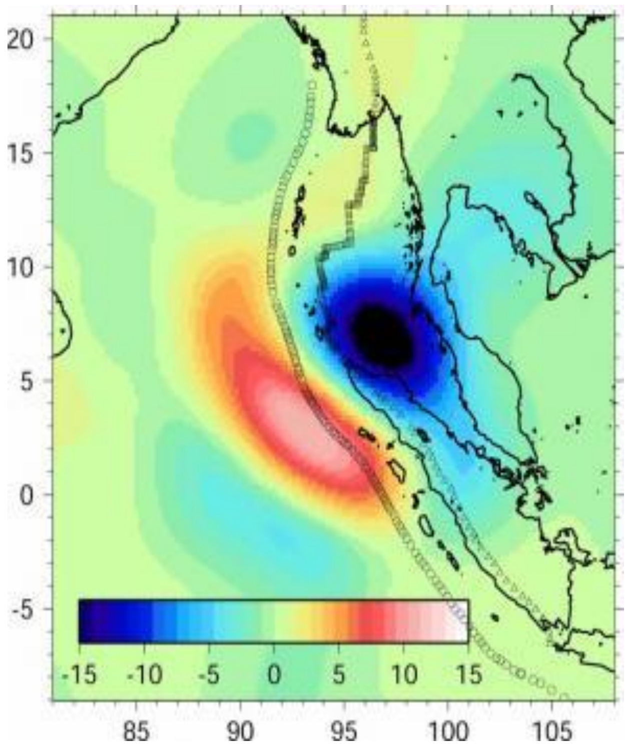

Long term trends
Middle East
North China
California
North India
North-West Australia
Glacier melting, 24 gigatons/year
Richter et al. (2019)
−5
−4
−3
−2
−1
0
1
equivalent water height [cm/year]
Water depletion
IUGG
IASPEI
IAG
Buenos Aires C

Earthquakes from Satellite Gravimetry

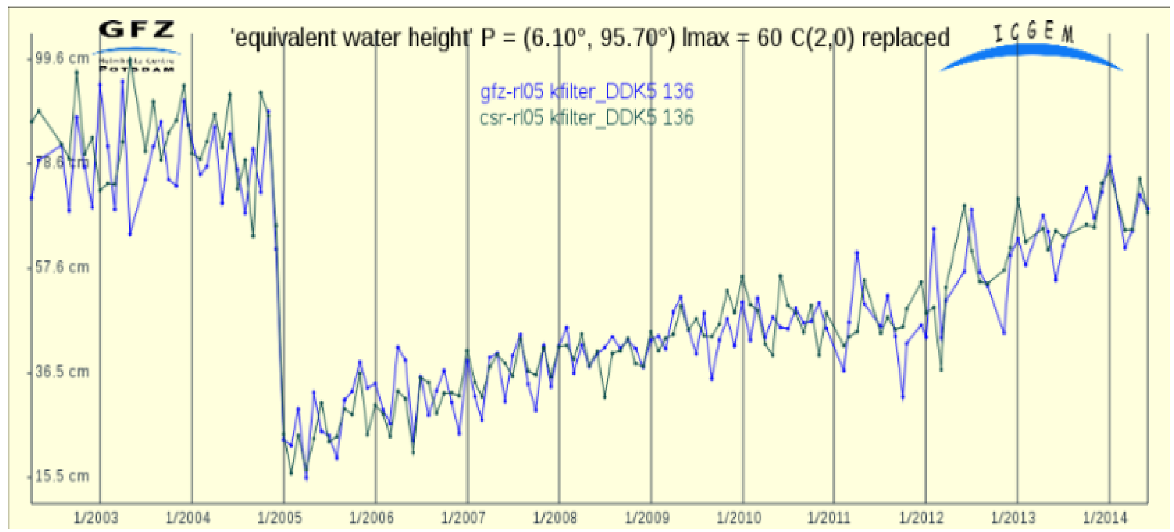


Earthquakes from Satellite Gravimetry

Tectonics: Co- and Post-Seismic Deformations



GFZ's G3 Browser on ICGEM



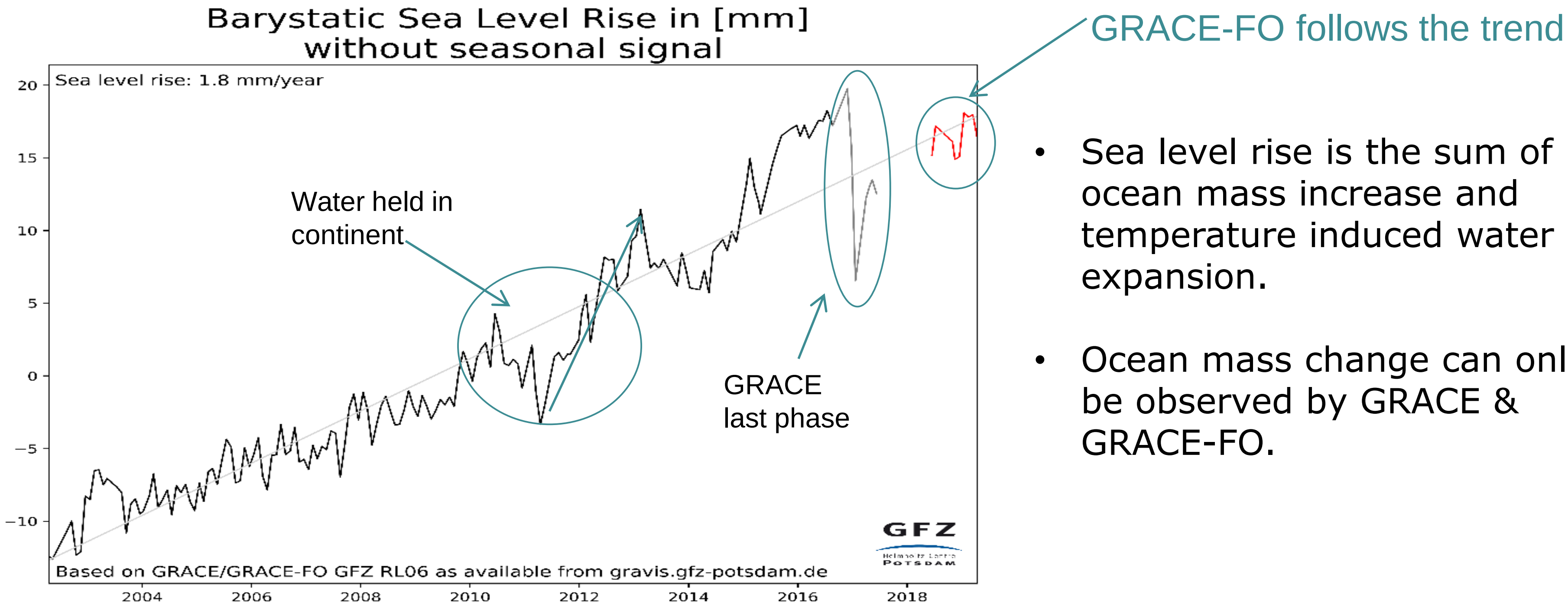
Han et al. (2006)

−5 −4 −3 −2 −1 0 1 2 3 4 5

equivalent water height [cm/year]

Continuity between GRACE and GRACE-FO

Global Sea Level Rise



- Sea level rise is the sum of ocean mass increase and temperature induced water expansion.
- Ocean mass change can only be observed by GRACE & GRACE-FO.

Flechtner et al. (2019)

Global Gravity Field Modelling

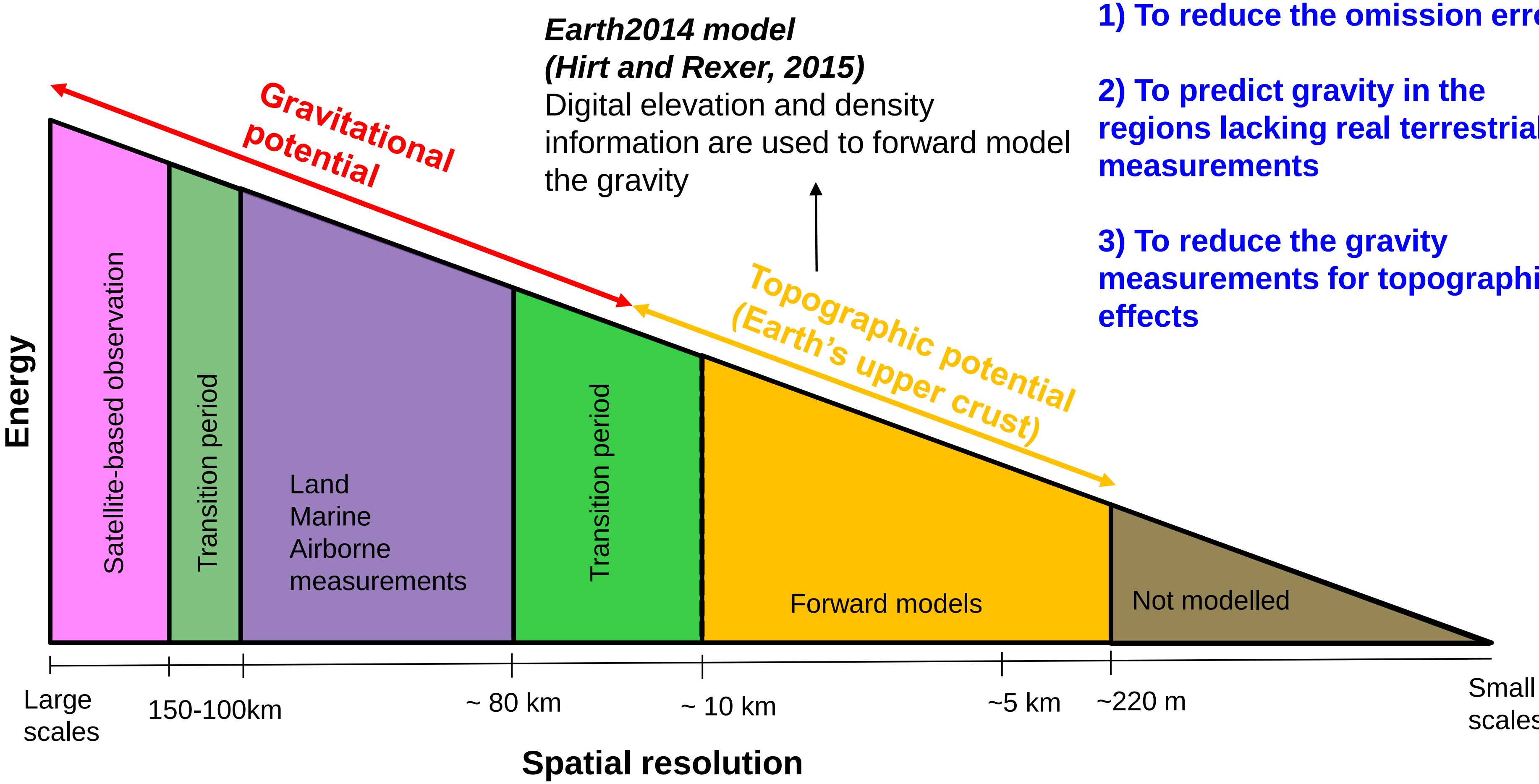
- Static gravity field
  - Satellite-only gravity field modelling (e.g. DIR-R6)
  - High resolution static global gravity field models (e.g. EIGEN-6C4, EIGEN-X)
- Temporal gravity field (e.g. Grace/GRACE-FO monthly solutions)
- Topographic gravity field (forward modelling)

High-resolution Global Gravity Field Modelling
Towards EIGEN-X Series

1) To reduce the omission error

2) To predict gravity in the regions lacking real terrestrial measurements

3) To reduce the gravity measurements for topographical effects

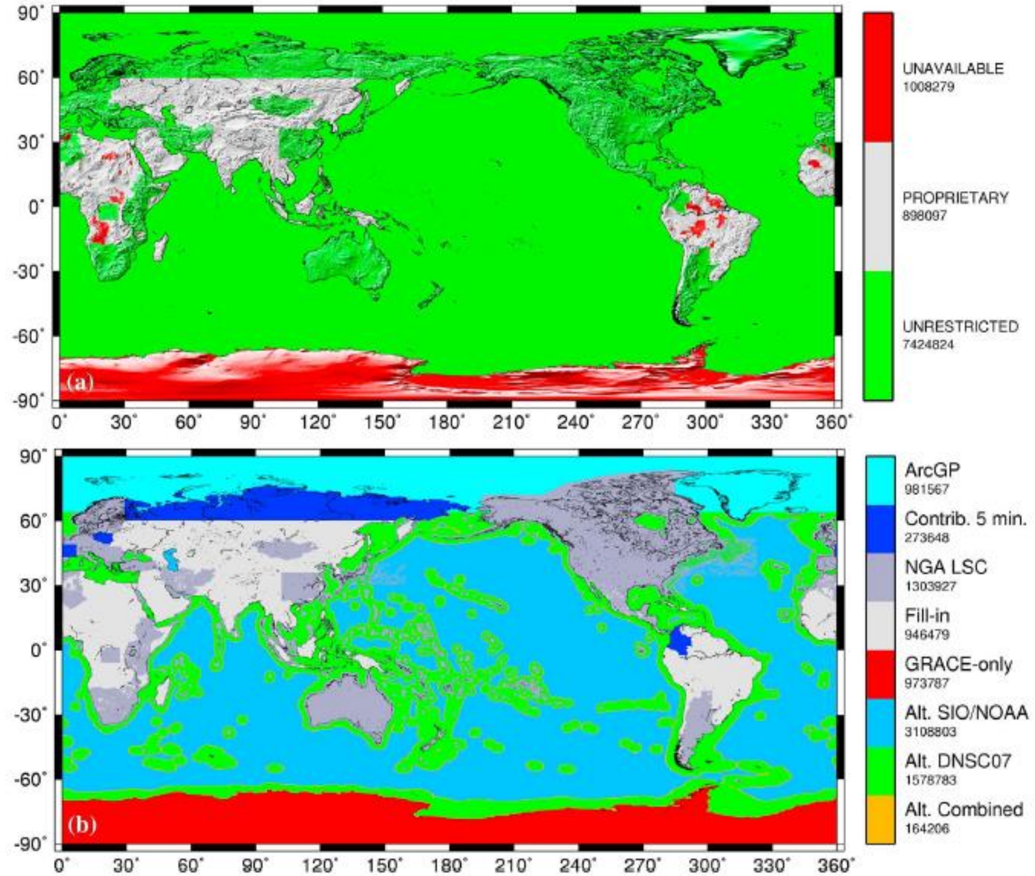


Contribution from the topography wrt EIGEN-6C4

EIGEN-6C4 uses EGM2008 grid

Antarctica is based on GRACE-only observation
(no terrestrial data contribution)

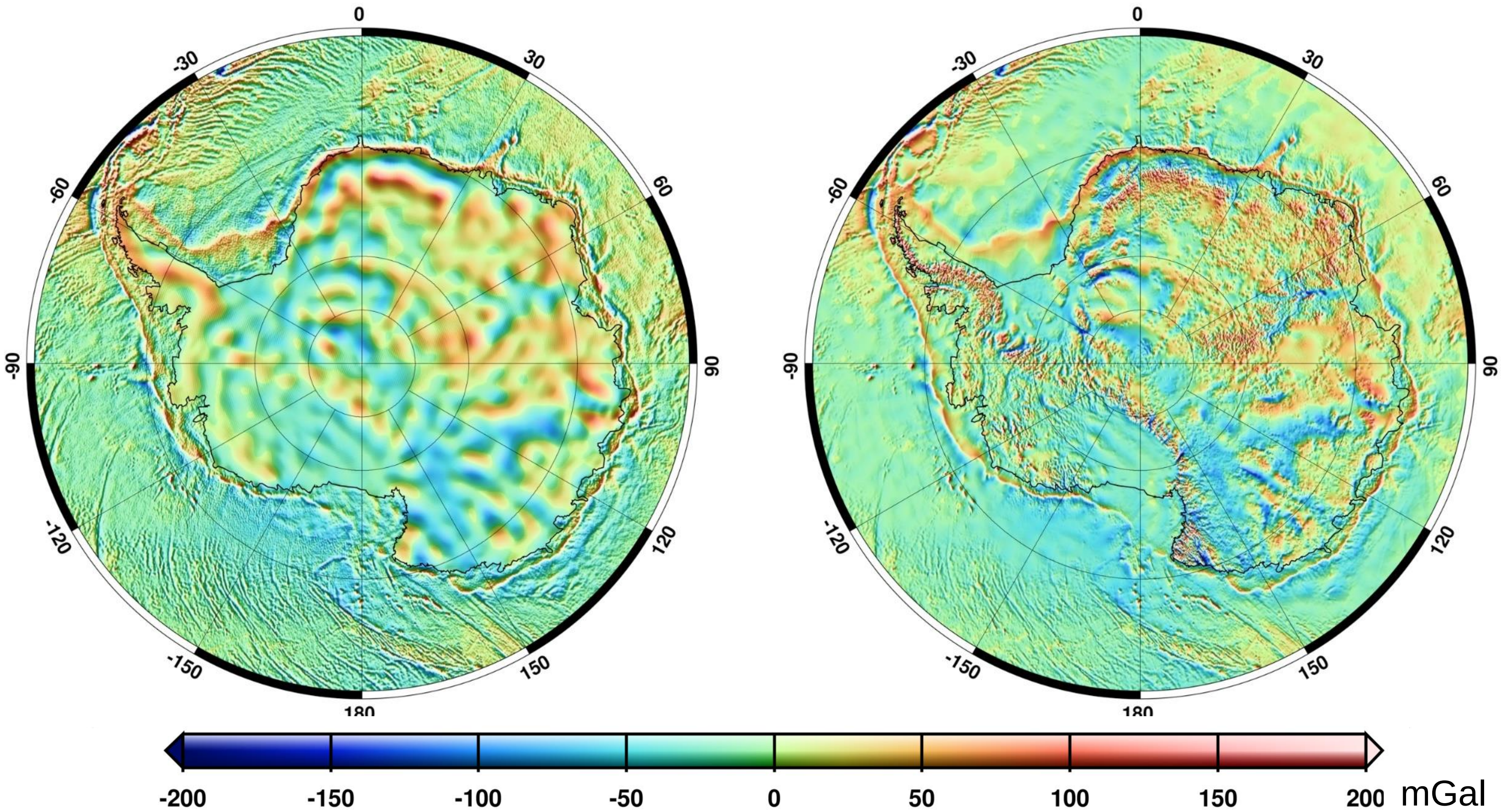
Topography augmented model
vs
EIGEN-6C4 only



Pavlis et al. (2012)

EIGEN-6C4

EIGEN-6C4 + Forward model
(EIGEN-X)



Ince et al. 2019 in preparation

Summary

- We have an operational **GRACE successor** in space
- **Mobile gravimetry** is still active and we are open to collaborative projects (next one is North Sea, 2020)
- First **topographic gravity field model** developed at GFZ will be released soon
- **Evaluation of EGM2020** (PGM17) and its preliminary models are ongoing
- Continuation of high resolution global gravity field modelling (**EIGEN-x**) –release after EGM2020!
- Continuation to support **IAG Services**

Thank you
for your attention!

References

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