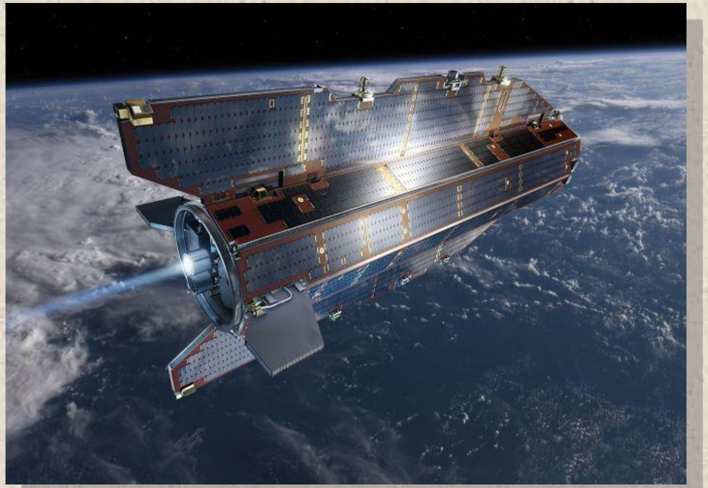
Realization of EVRS based on quasigeoid models and their validation using the GOCE-based gravity field models

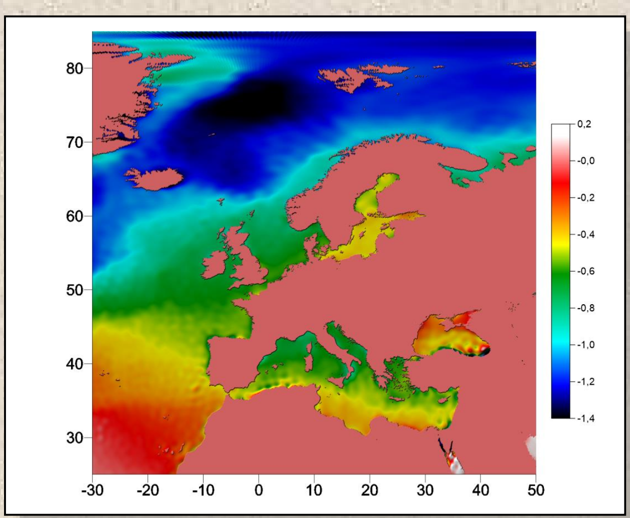
R. Čunderlík

cunderli@svf.stuba.sk

Department of Mathematics and Descriptive Geometry

Faculty of Civil Engineering
Slovak University of Technology
Bratislava
Slovakia





Realization of Vertical Reference Systems

Global approach

• ***globally homogenous approach based on precise gravity field modelling***

$$W_P = U_P(h^{GNSS}) + T_P$$

$$c_P = -(W_P - W_0)$$

satellite-only GGMs *(CHAMP, GRACE, GOCE)*

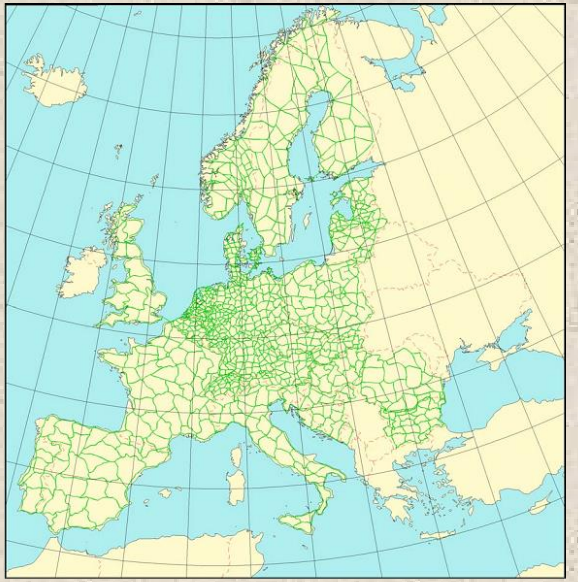
⇒ ***fully independent from LVDs***

⇒ ***low-frequency part obtained very precisely, however overall accuracy affected by the truncation error***

Continental approach *(e.g. EVRF2007)*

• ***regional approach based on spirit levelling and potential of the height reference surface W_{0i}***

$$c_P = c_{Pi} + W_0 - W_{0i} \Longrightarrow c_{Pi} = W_{0i} - W_P = \int_{0i}^{P} g\,dh$$



"Geometrical (geoidal) strategy"

selection of the global reference value W_0

↓

3D position of geoid W_0

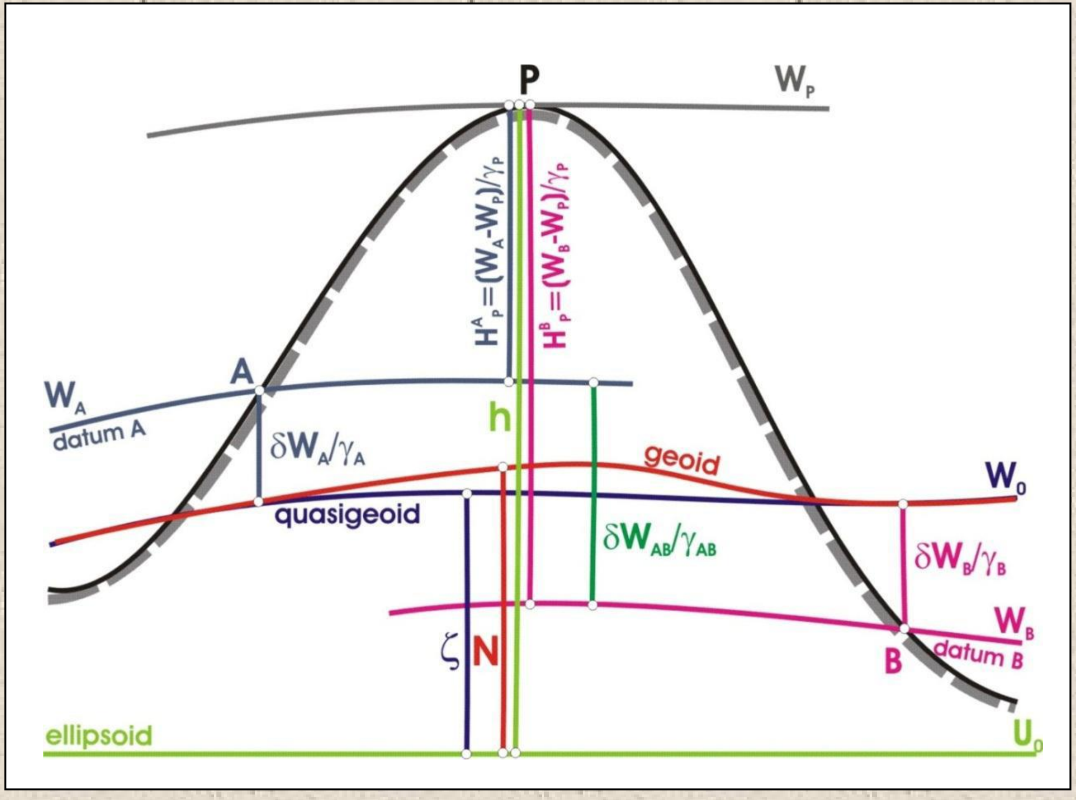
↓

Offsets of LVDs from global W_0

$$h^{GNSS} - H^{Orth} - N^{(W_0)} = \frac{\delta W}{\gamma}$$

zero degree term:

$$N_0 = -\frac{(W_0 - U_0)}{\bar{\gamma}}$$



Source: (Sanchez 2009)

“Potential (quasigeoidal) strategy”

Geopotential on the Earth’s surface

• *value without its 3D position*

$$W_P = U_P(h_{GNSS}) + T_P$$

$$c_P = -(W_P - W_0)$$

Assumptions:

• *to know precise 3D position of the Earth’s surface*
- *lands: 3D positioning by GNSS*
- *oceans: altimetry*

• *determined on the Earth’s surface*
• *independent from LVDs offsets*

⇒ ***directly from precise GGMs*** ***(e.g. EGM-2008, EIGEN-6C4)***

⇒ ***solving geodetic BVPs*** ***on the Earth’s surface:***

- **Molodensky problem**
  (globally inconsistent gravity anomalies)
- **fixed gravimetric BVP**
  (globally consistent gravity disturbances)

(Remark: Quasigeoid is not an equipotential surface, however ζ_P corresponds to T_P on the Earth’s surface)

Objective of this study

Global approach

• ***based on*** ***precise gravity field modelling***

$$W_P = U_P(h^{GNSS}) + T_P$$

$$c_P = -(W_P - W_0)$$

GOCE-based satellite-only GGMs

⇒ ***low-frequency part obtained very precisely:***
"accuracy of 1 to 2 cm and a spatial resolution of about 100 km" (GOCE goal)

⇒ ***affected significantly by stripping noise due to omission errors***

⇓

necessary to model the high-frequency part

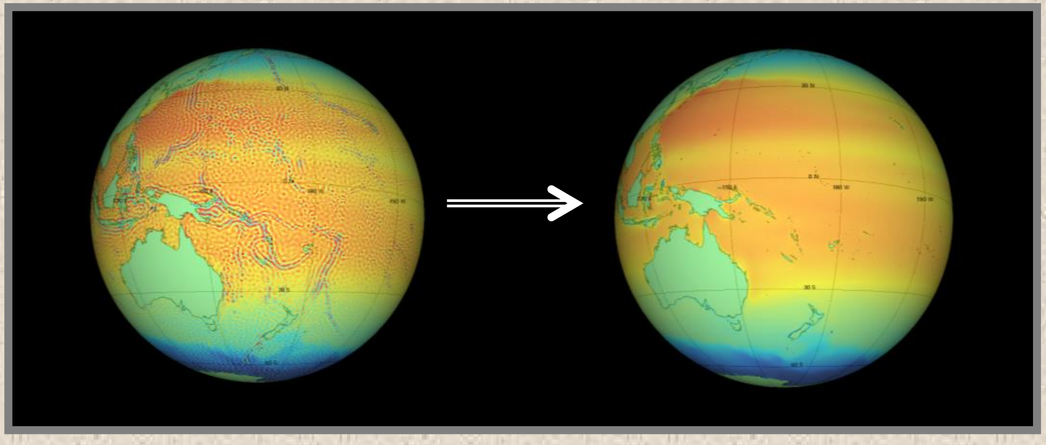
(combined GGMs, national (quasi)geoid models)

Objectives

• ***to filter the geopotential:***
  - ⇒ ***on the DTU13_MSS model generated from the GOCE-based GGMs***
  - ⇒ ***on the geoid surface obtained from a transformation of quasigeoid models***

• ***local realization:***
  - ⇒ ***combination of GNSS 3D positioning and local quasigeoid models to determine physical heights within a levelling lines***

Nonlinear diffusion filtering on a closed surface



Linear heat equation on a (closed) surface:

$$\frac{\partial u(X,t)}{\partial t} = \Delta_S u(X,t)$$

$$\frac{\partial u}{\partial t} = \nabla_S . (\nabla_S u)$$

Δ_S ***- the Laplace-Beltrami operator***

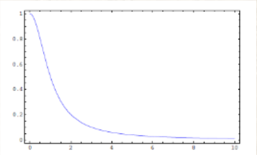
Regularized surface PM model ***- nonlinear parabolic PDE***

$$\frac{\partial u}{\partial t} = \nabla_S \cdot (g(|\nabla_S u^\sigma|) \nabla_S u)$$

∇_S ***- surface gradient***

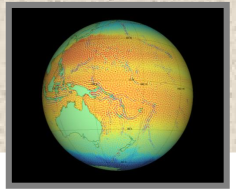
Edge detector

$$g(v) = \frac{1}{1 + H \left| \nabla_S u^\sigma \right|^2}$$

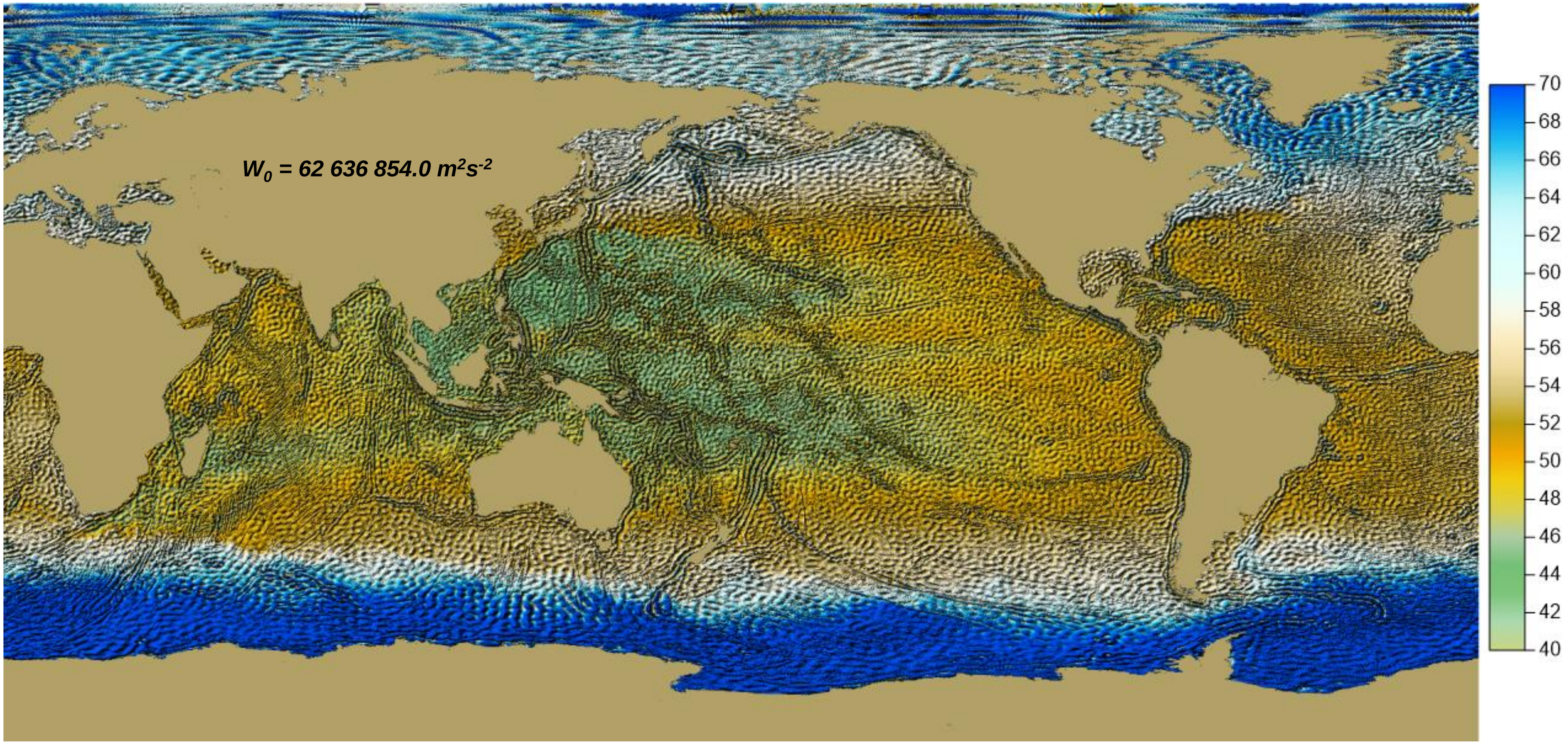


<u>More details</u>: Čunderlík R, Mikula K, Tunega M (2013) Nonlinear diffusion filtering of data on the Earth's surface. Journal of Geodesy, Vol. 87(2), pp. 143–160

Geopotential from GOCE-DIR5 on DTU13_MSS

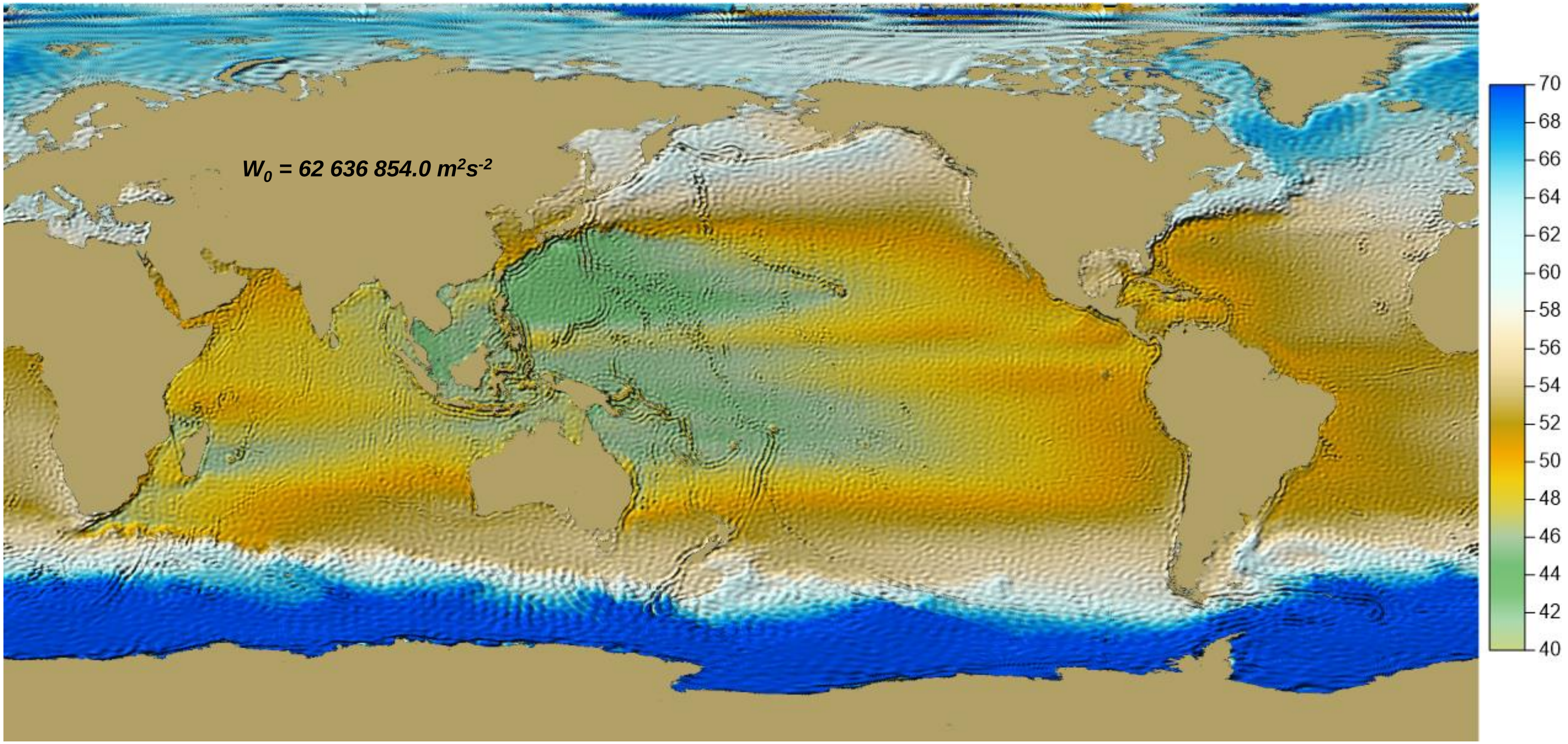


GO_CONS_GCF_2_DIR_R5 *(SH up to d/o 300)*



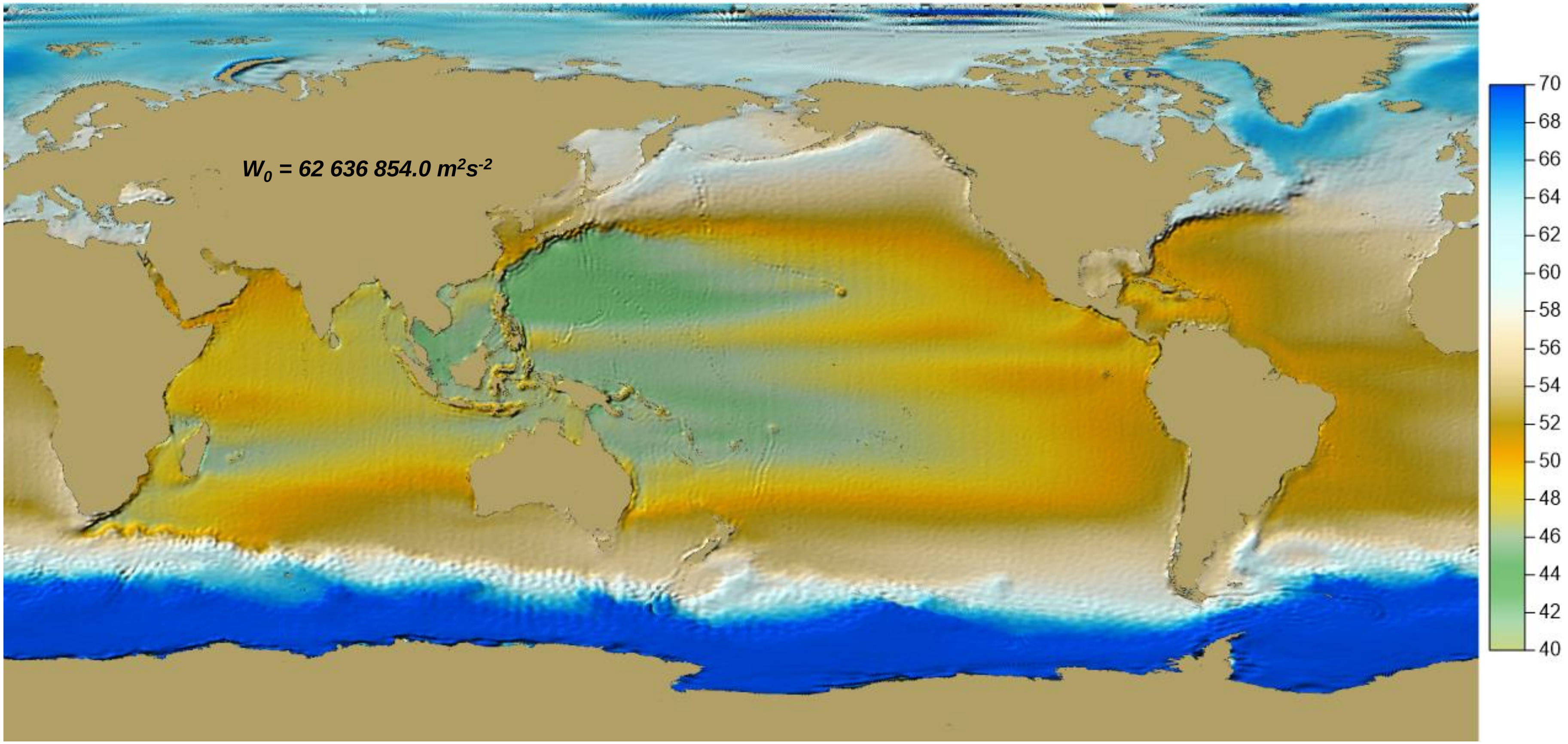
Geopotential from GOCE-DIR5 on DTU13_MSS

2 iterations



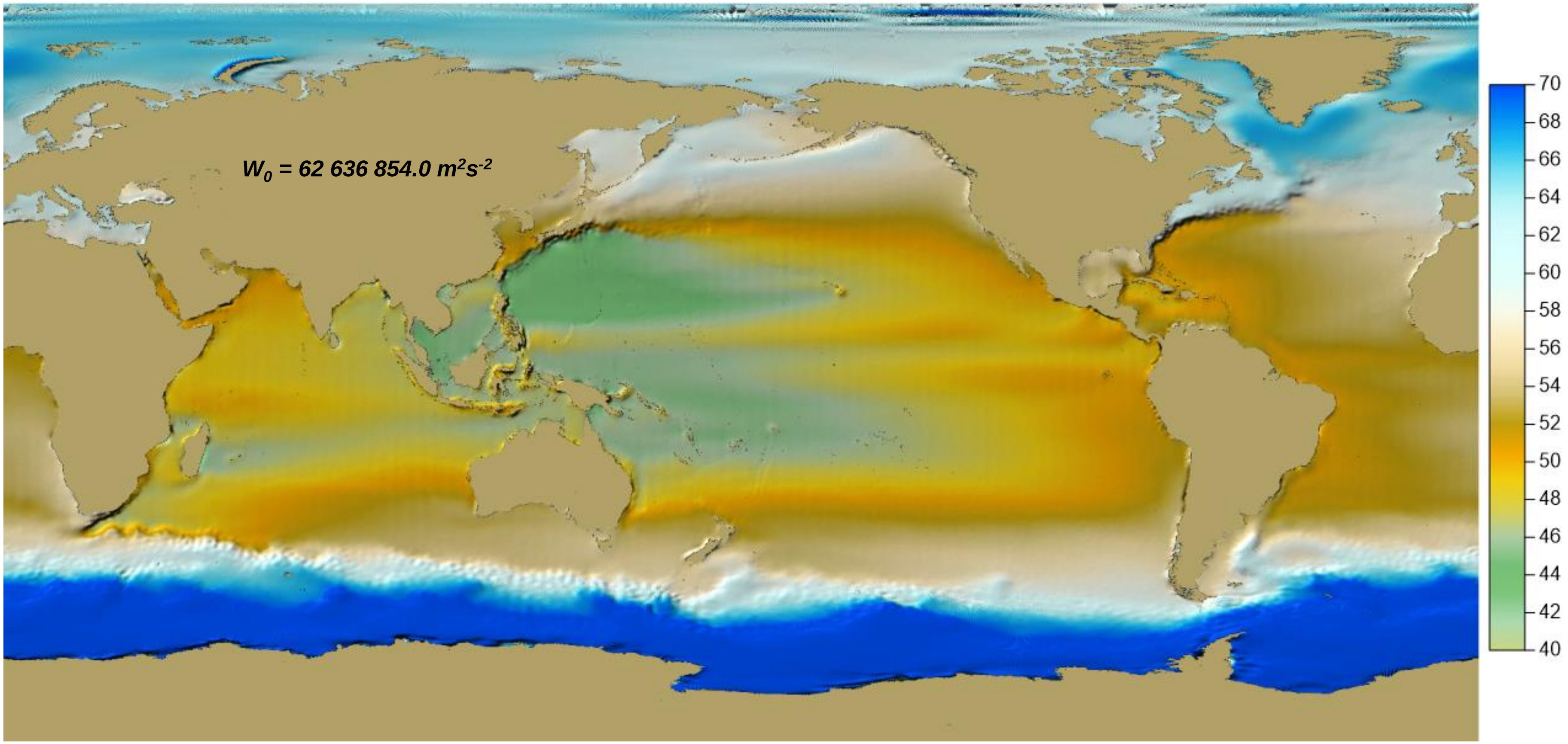
Geopotential from GOCE-DIR5 on DTU13_MSS

4 iterations



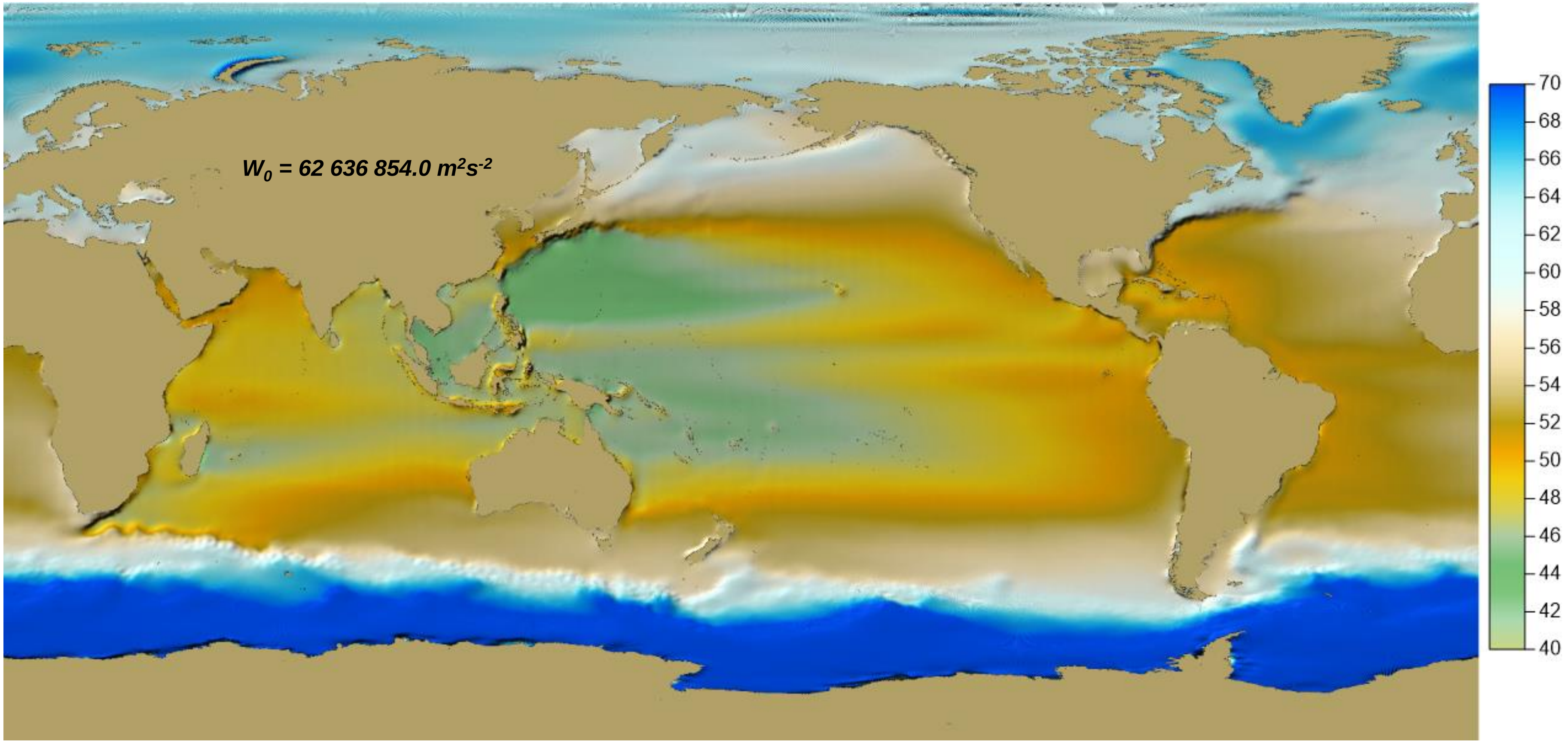
Geopotential from GOCE-DIR5 on DTU13_MSS

6 iterations



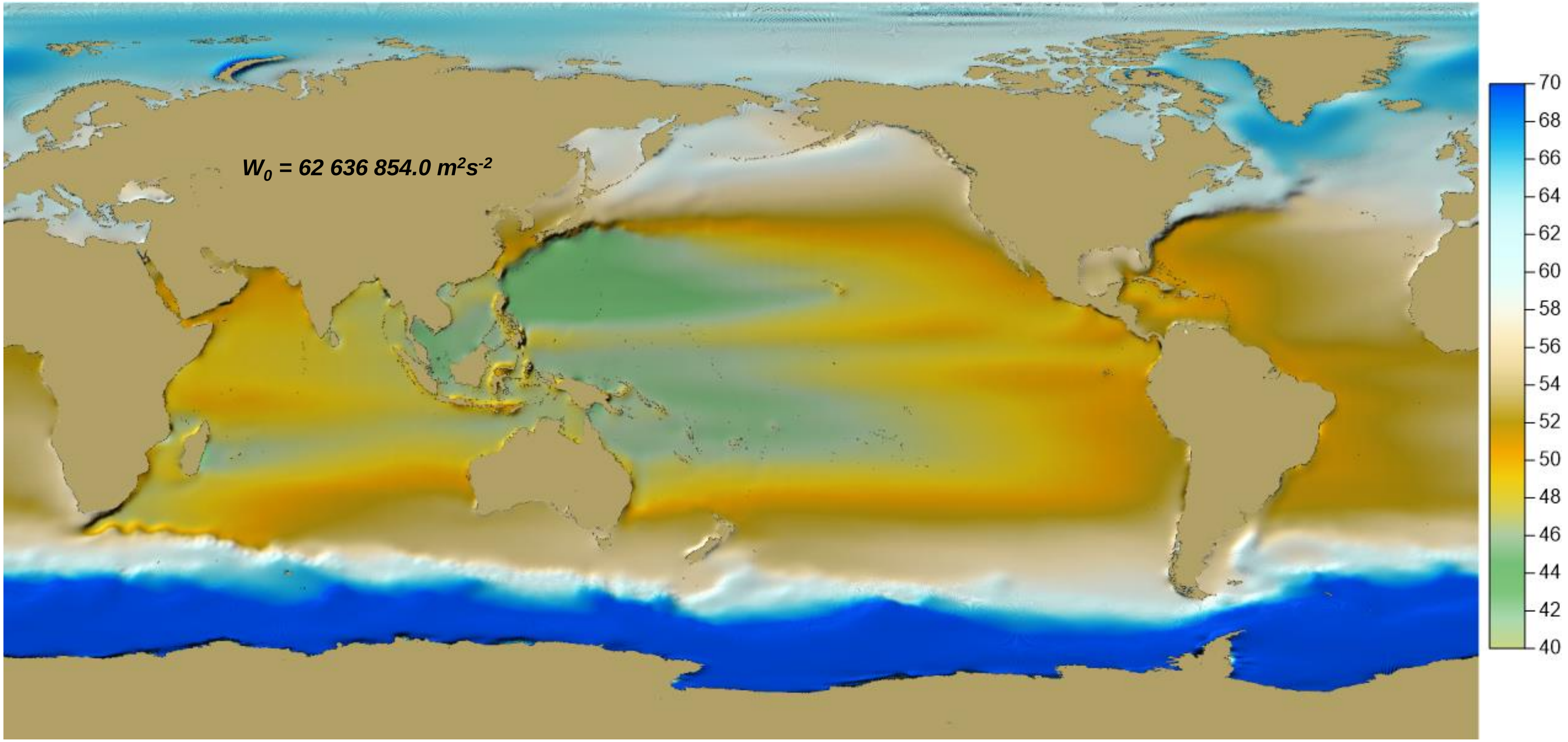
Geopotential from GOCE-DIR5 on DTU13_MSS

8 iterations

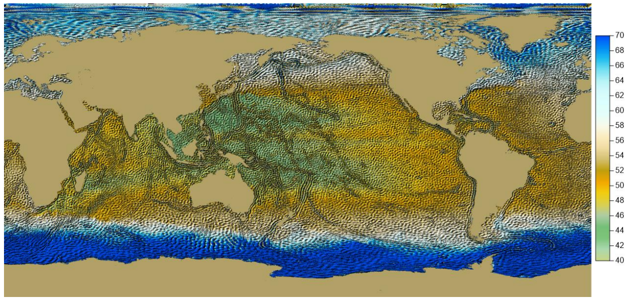


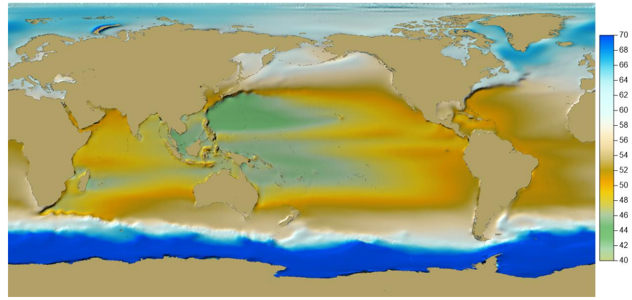
Geopotential from GOCE-DIR5 on DTU13_MSS

10 iterations

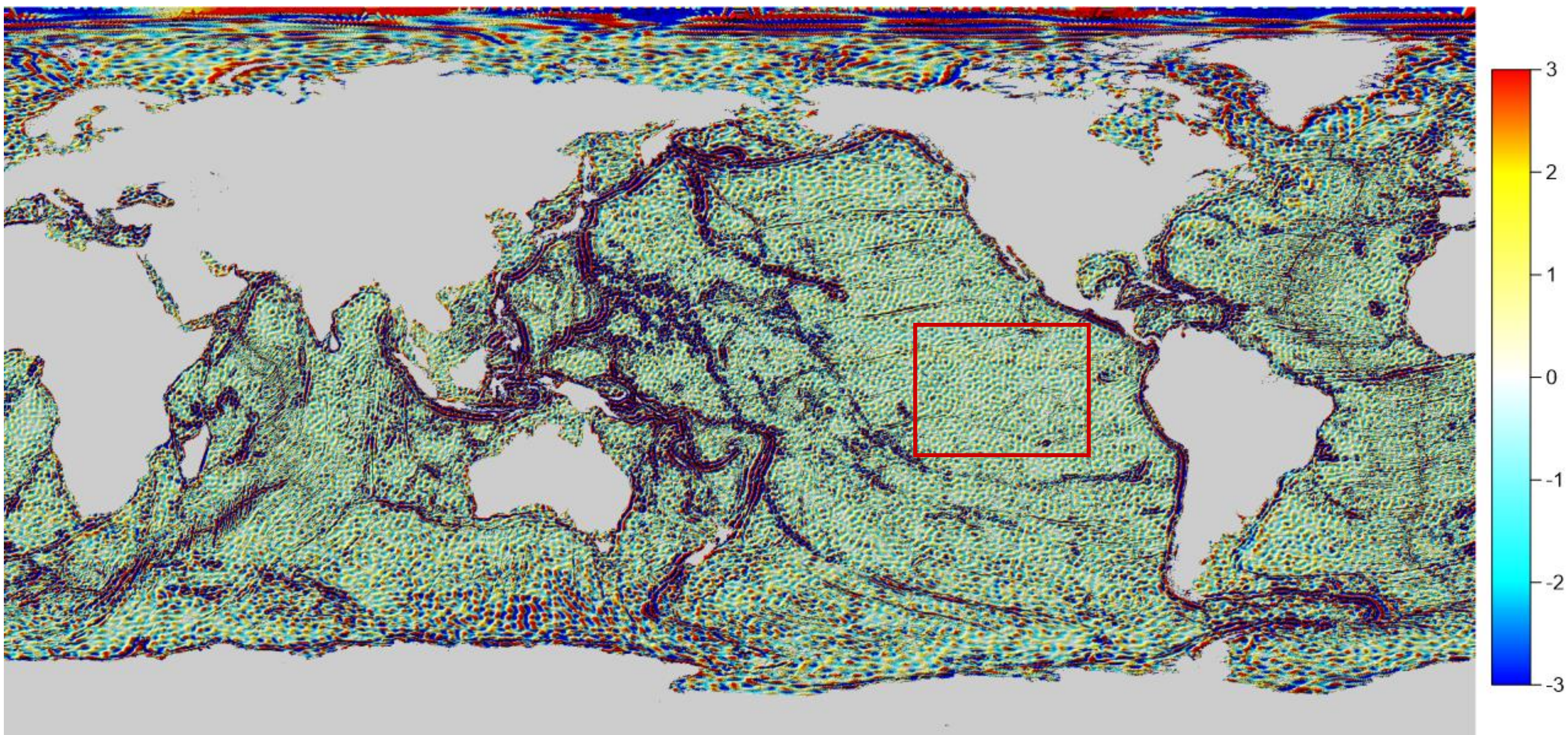


Stripping noise due to omission errors



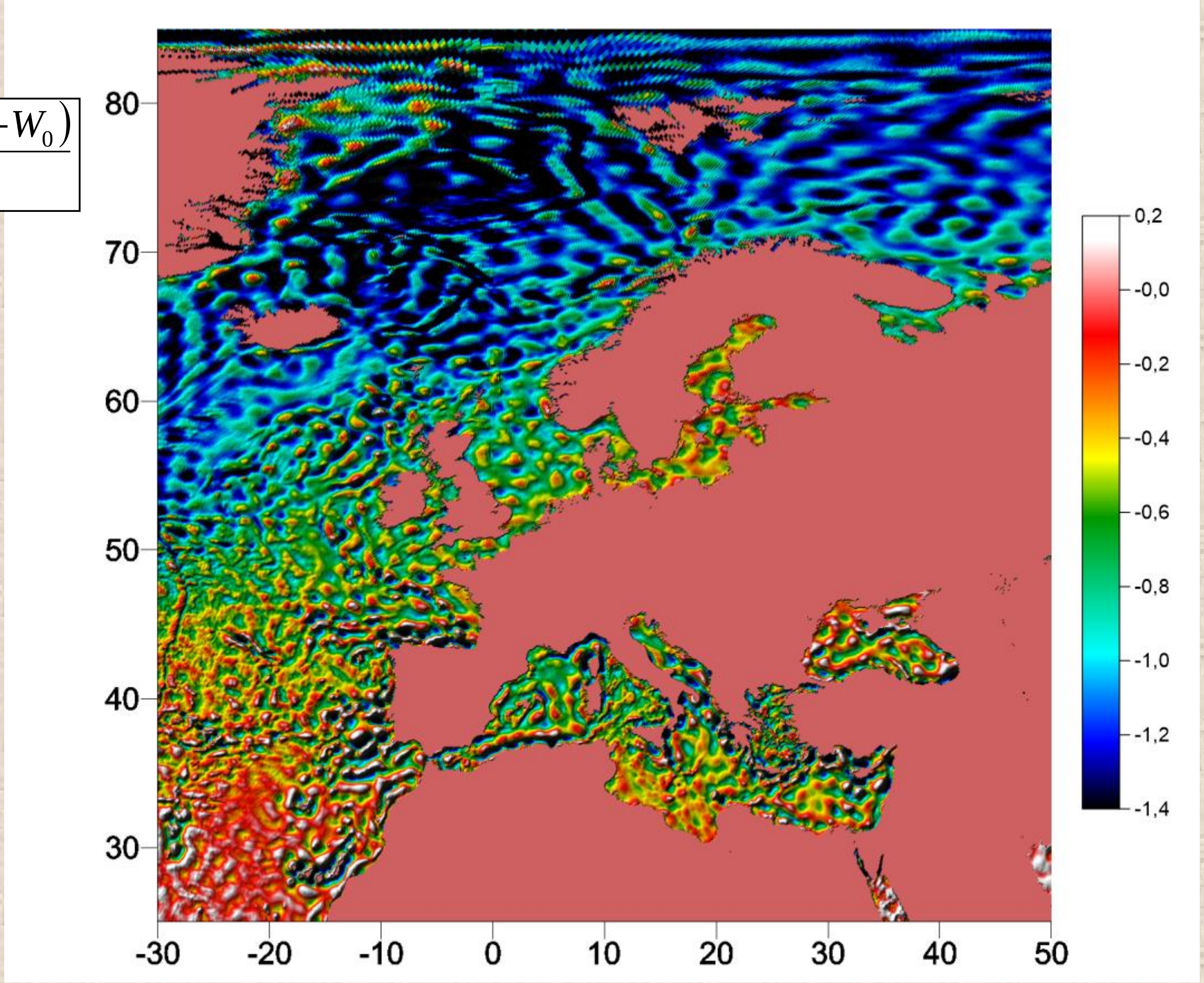


Statistics	TOTAL	Pacific
Mean [m^2s^{-2}]	0.019	-0.004
STD [m^2s^{-2}]	2.687	1.201



MDT from GOCE-DIR5 on DTU13_MSS in Europe

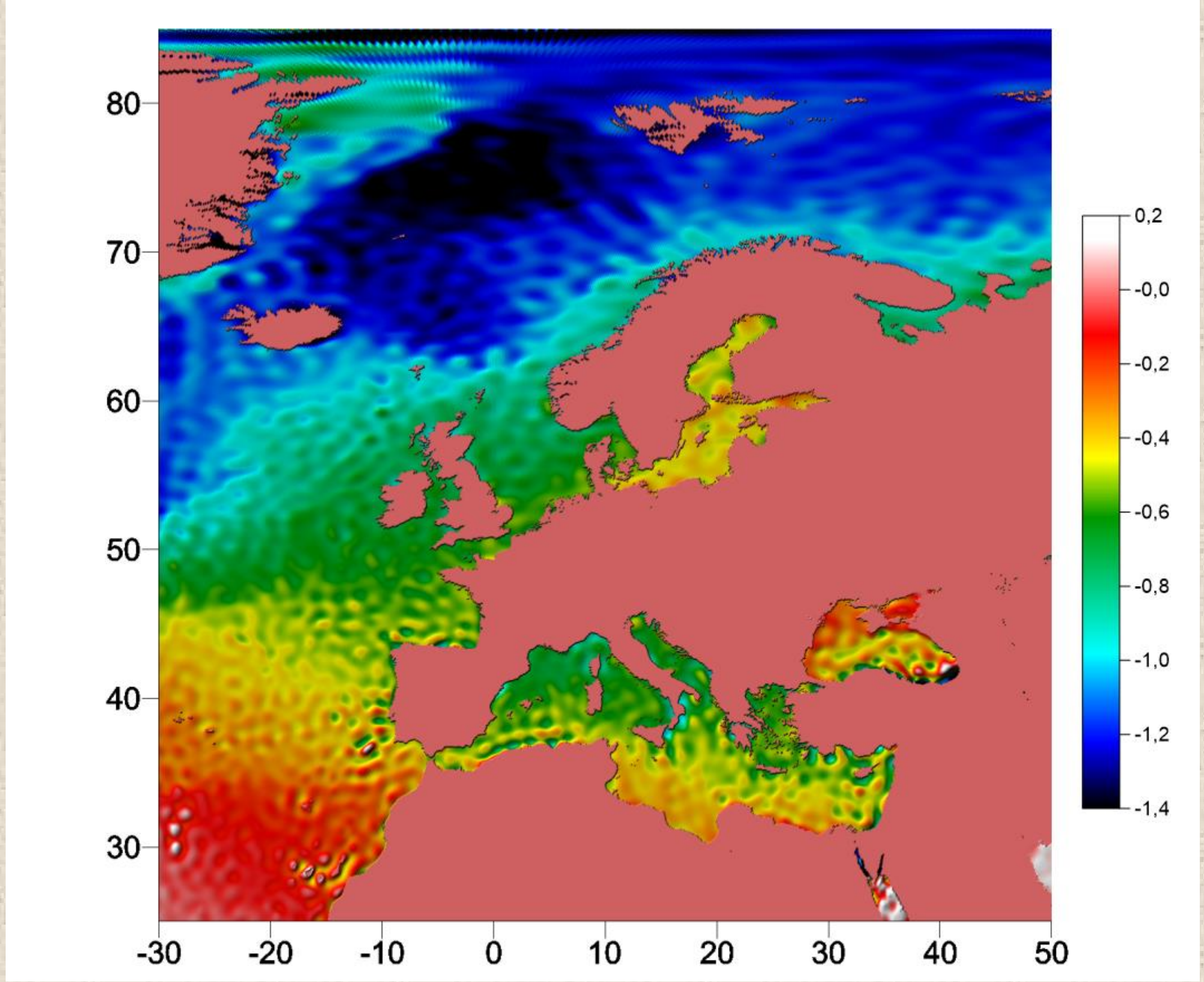
$$h_i^{MDT} = \frac{-\left(W_i - W_0\right)}{\gamma_i}$$



GO_CONS_GCF_2_DIR_R5

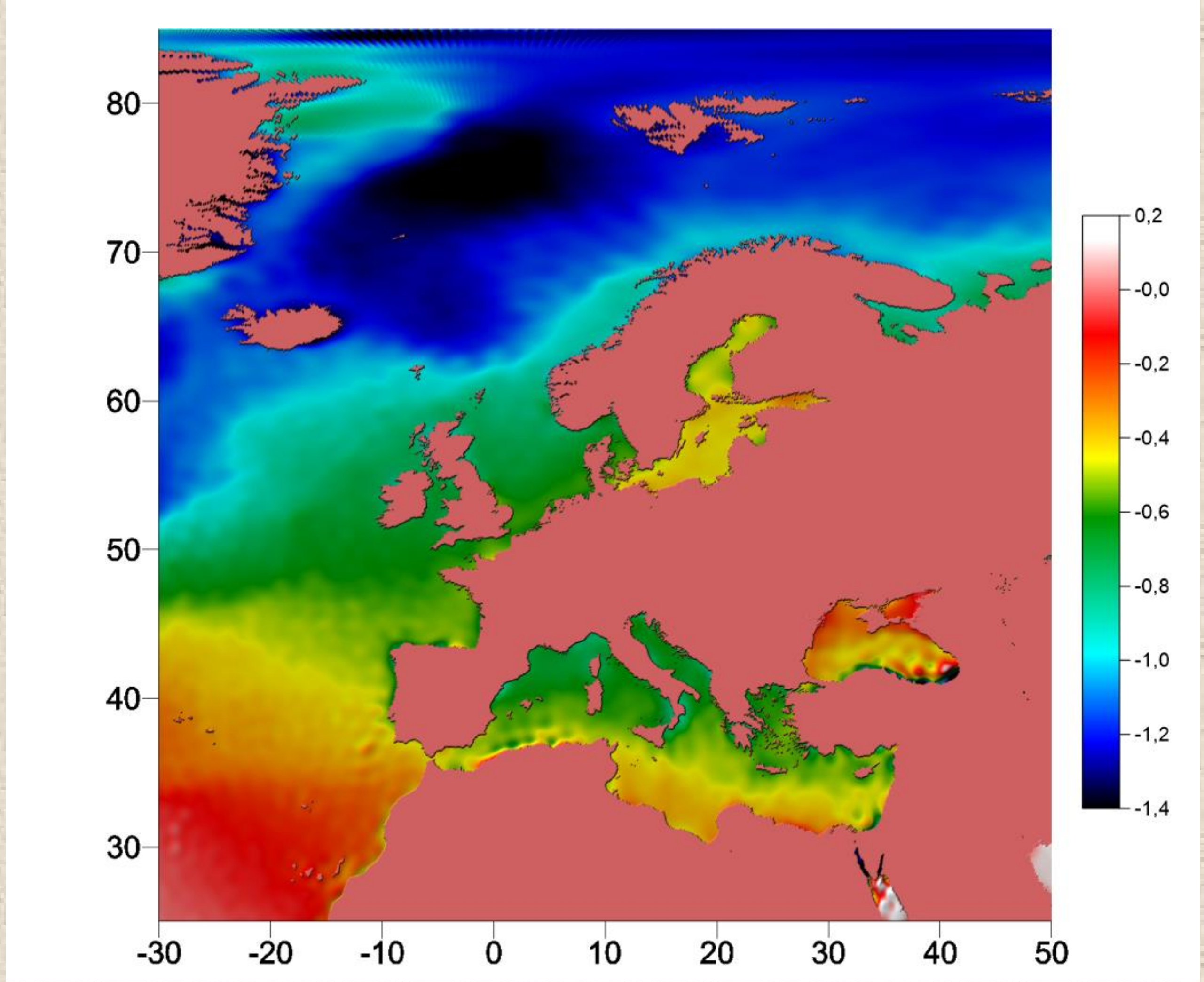
(SH up to d/o 300)

MDT from GOCE-DIR5 on DTU13_MSS in Europe



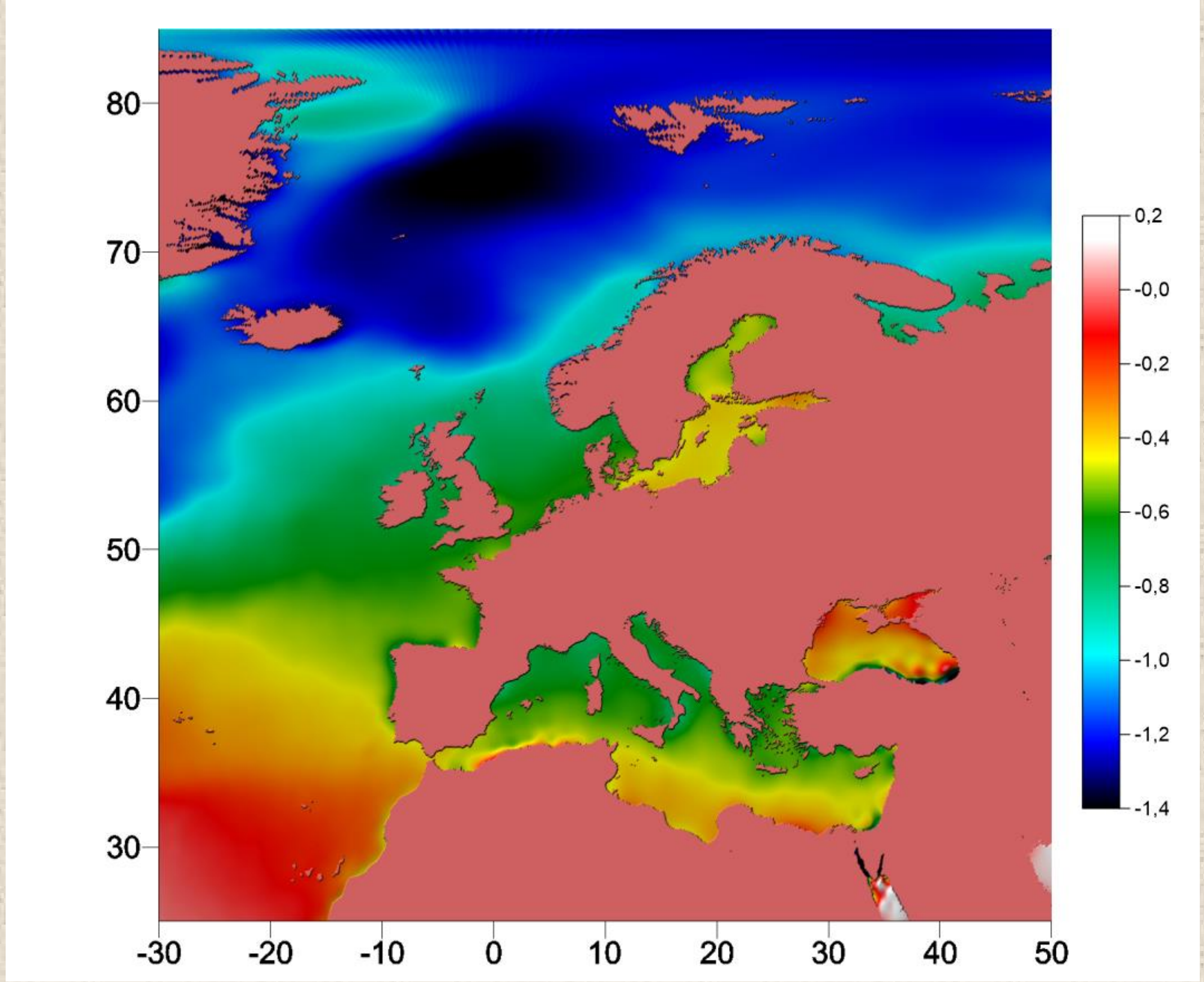
2 iterations

MDT from GOCE-DIR5 on DTU13_MSS in Europe



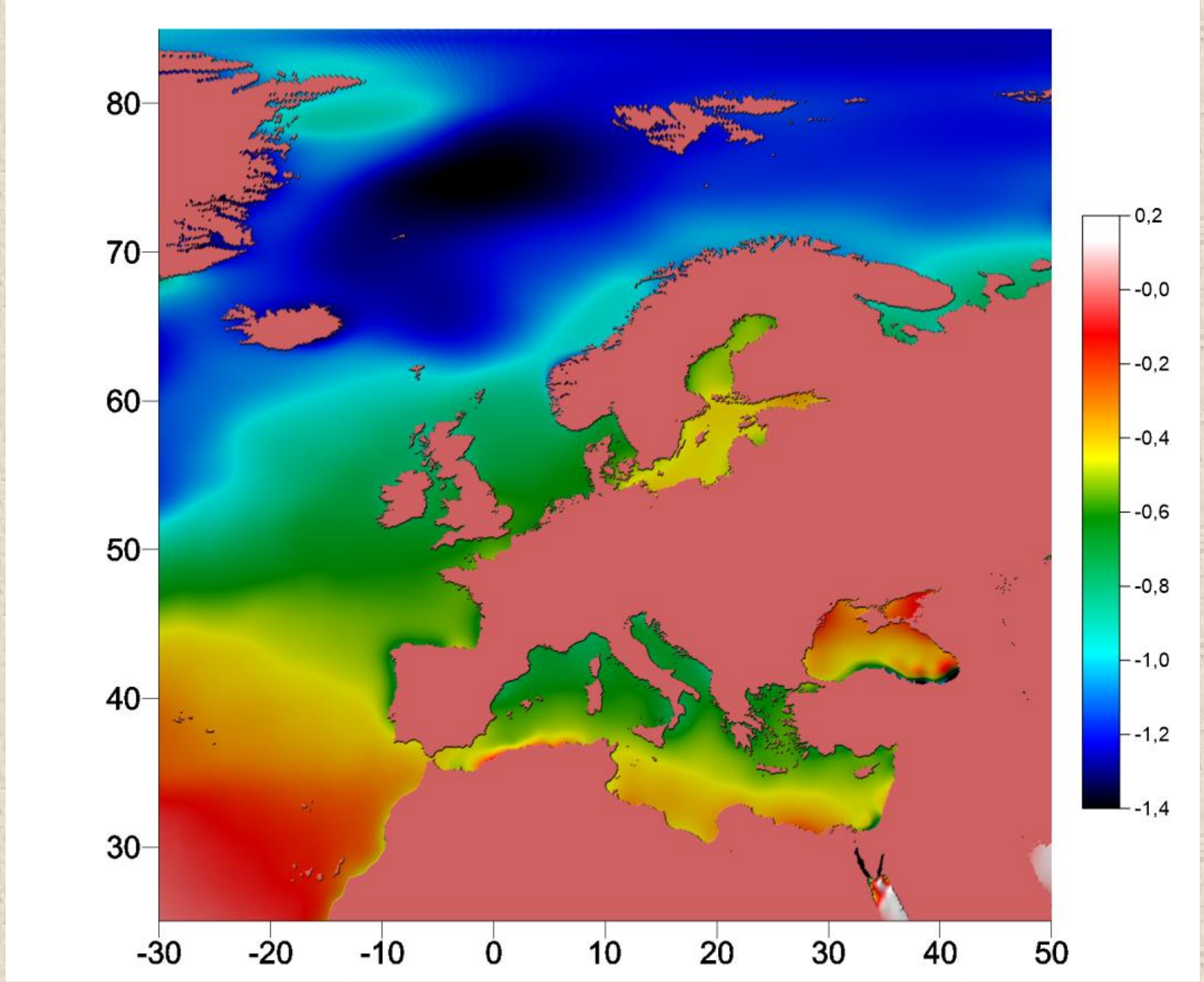
4 iterations

MDT from GOCE-DIR5 on DTU13_MSS in Europe



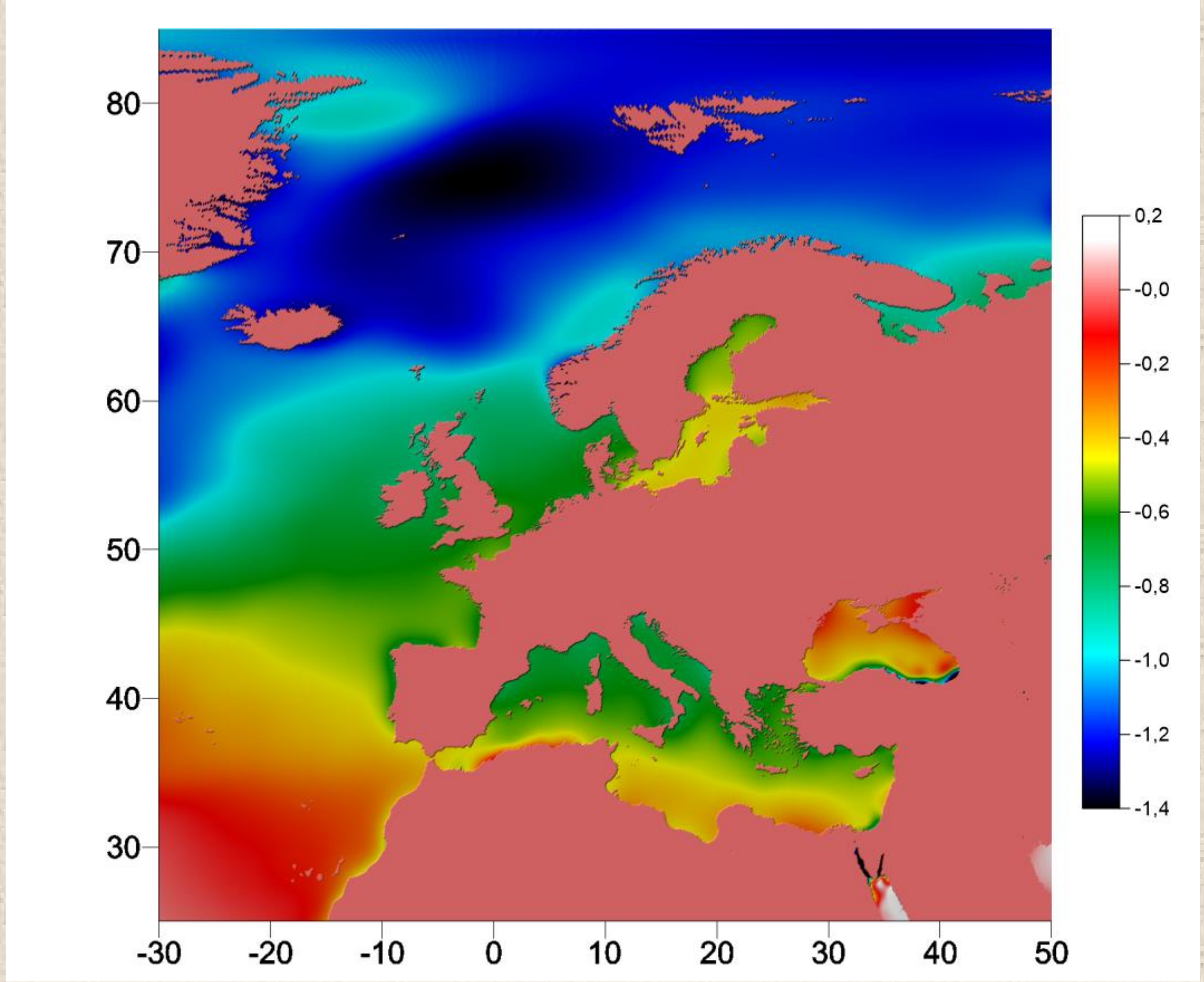
6 iterations

MDT from GOCE-DIR5 on DTU13_MSS in Europe



8 iterations

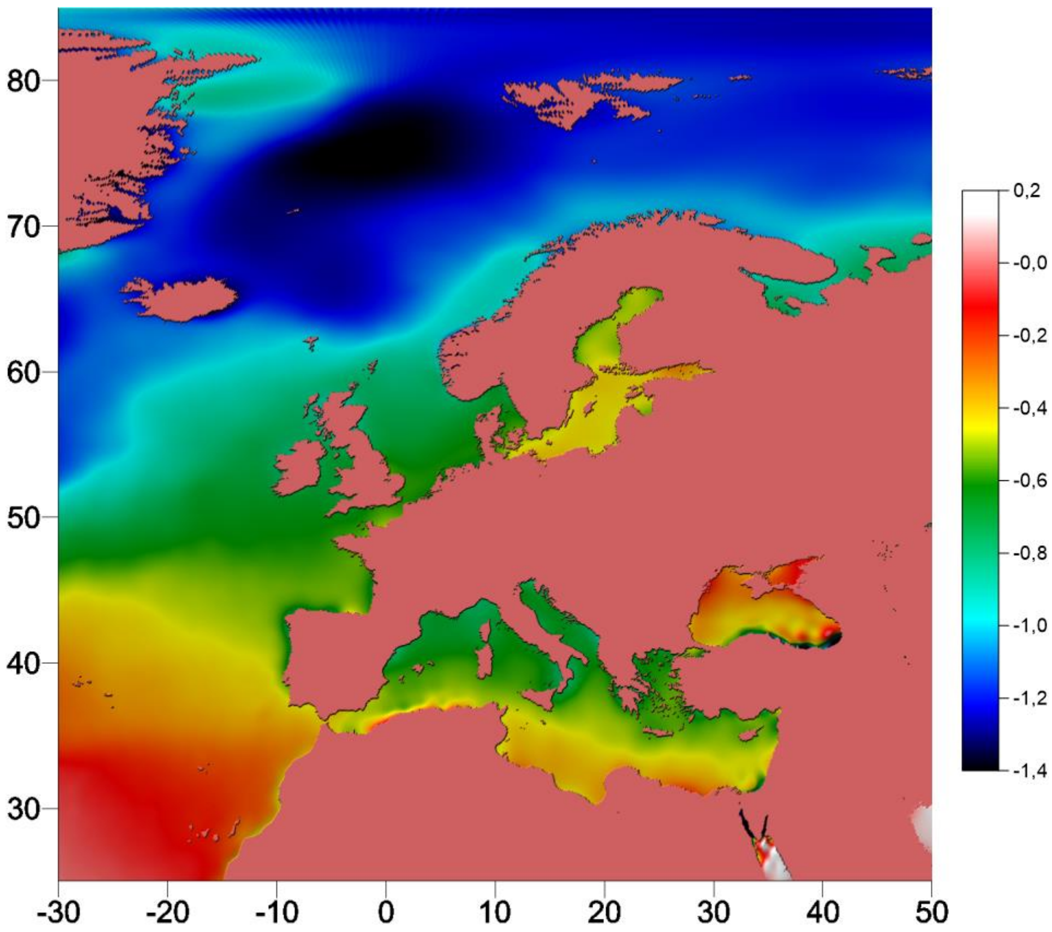
MDT from GOCE-DIR5 on DTU13_MSS in Europe



10 iterations

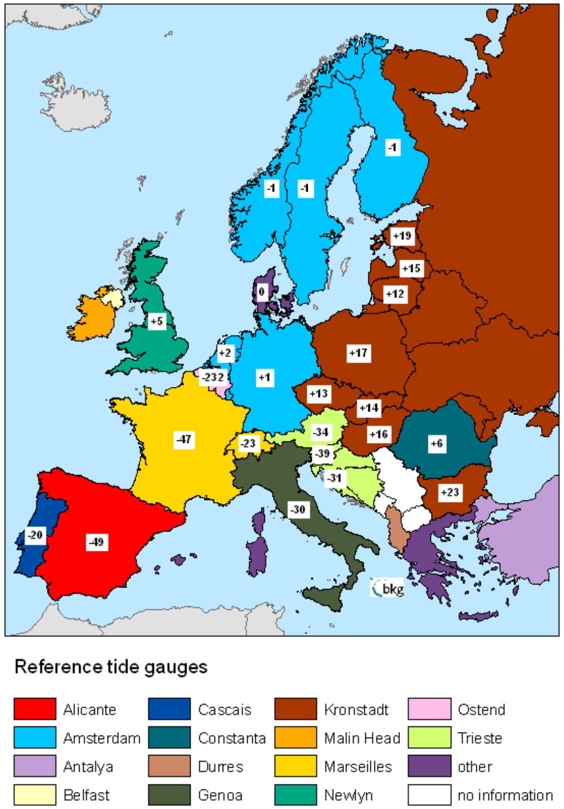
Filtered satelite-only MDT and tide gauges

Satellite-only MDT

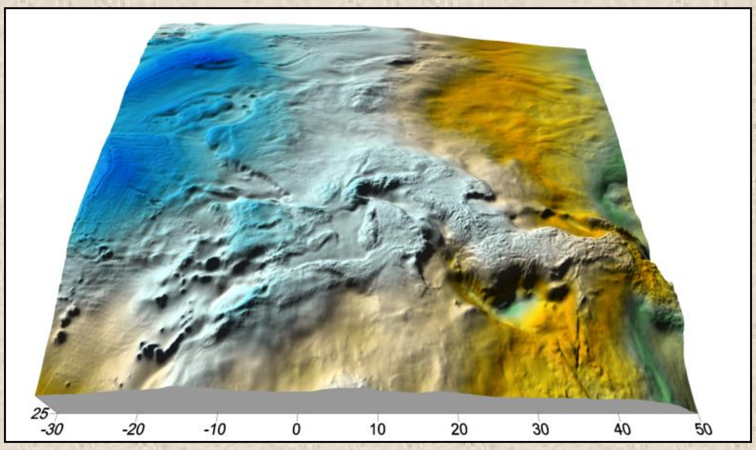


Relations between European national height reference systems and EVRF2007

(source: http://www.bkg.bund.de)



Validation of quasigeoid models by GOCE-DIR5



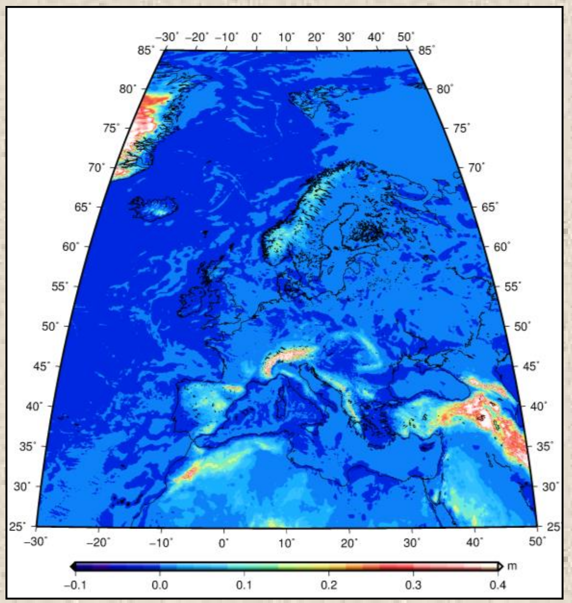
Quasigeoid models

combined GGMs

⇒ **EGM-2008** (SH up to d/o 2190)
⇒ **EIGEN-6C4stat** (SH up to d/o 2190)

continental quasigeoid models - gravimteric

⇒ **EGG-2008** (European Gravimetric Quasigeoid)



3D position of the equipotential surface

- *transformation from quasigeoid to geoid*

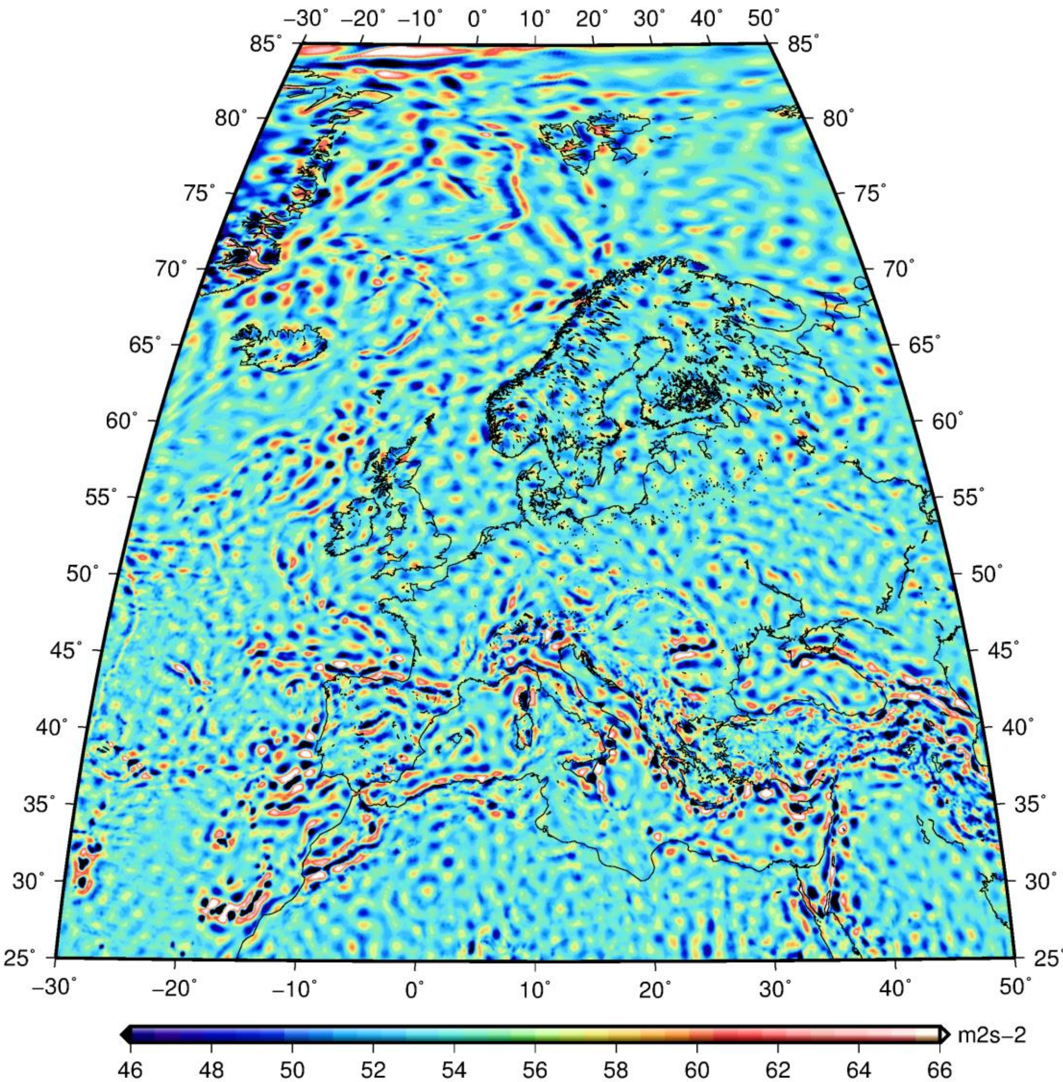
correction:

$$corr = N - \zeta = \frac{\Delta g_{BA}}{\bar{\gamma}} H$$

… approximate relation !!!

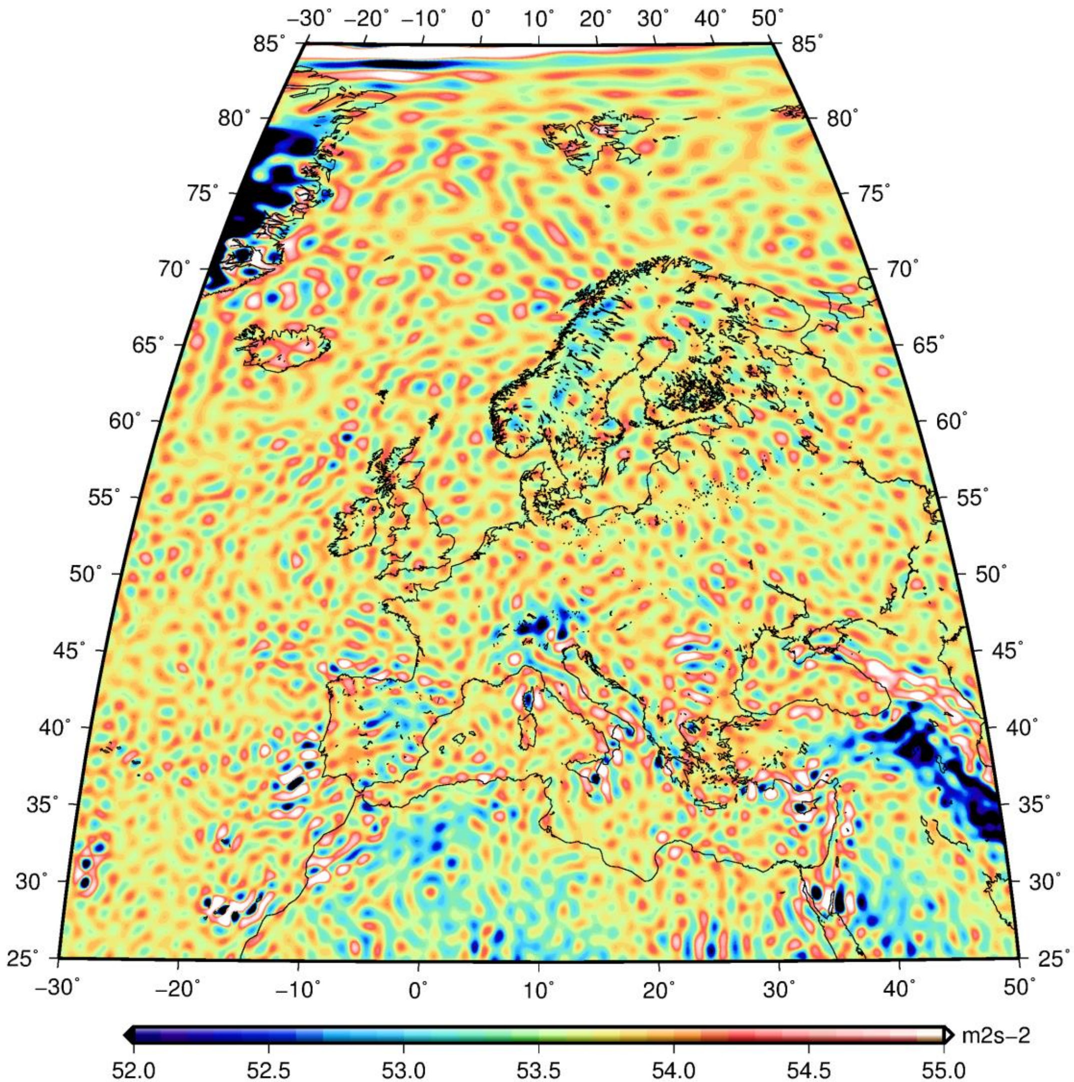
(zero degree term: N_0 = -0,21 m)

GOCE-DIR5 on EIGEN-6C4



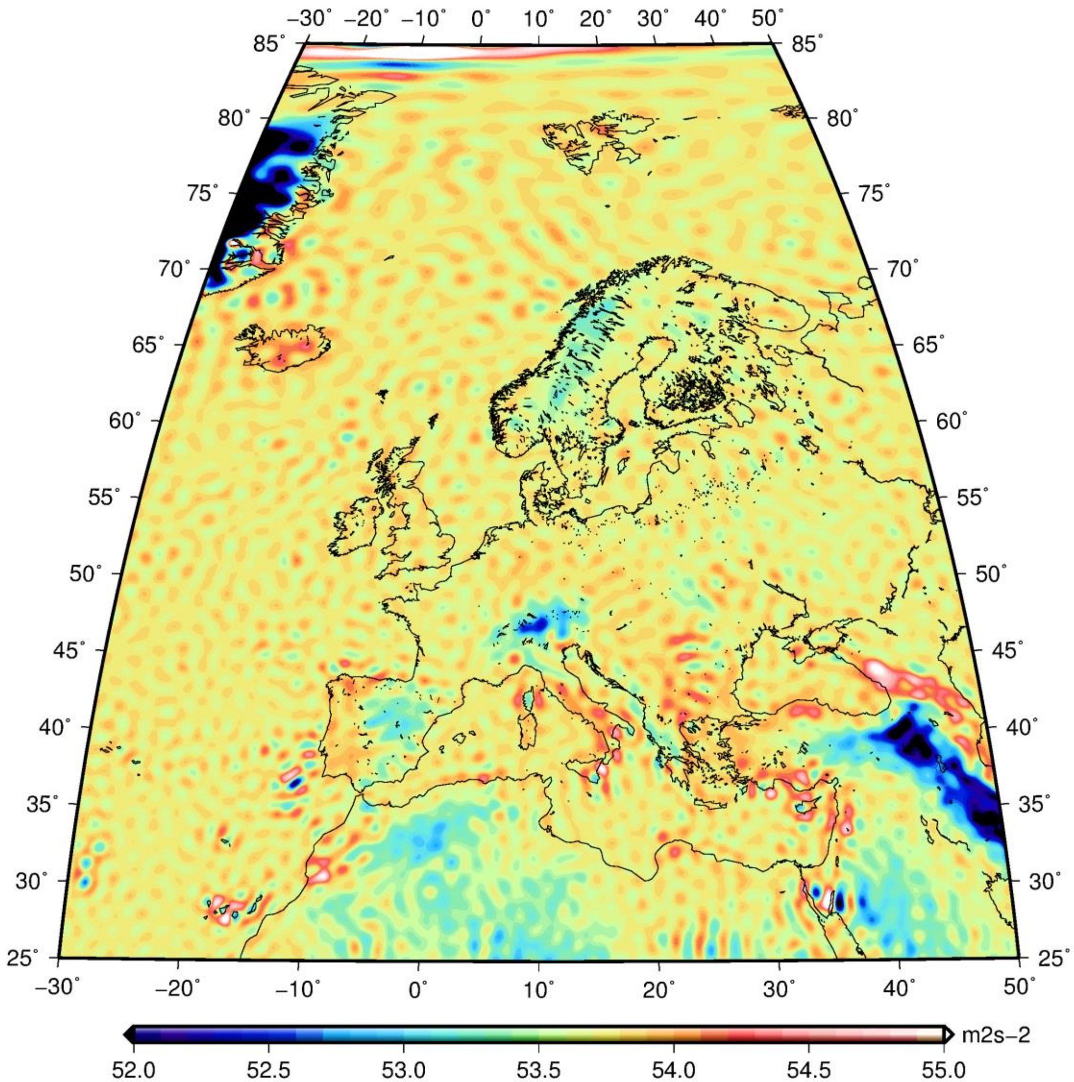
Initial data

GOCE-DIR5 on EIGEN-6C4



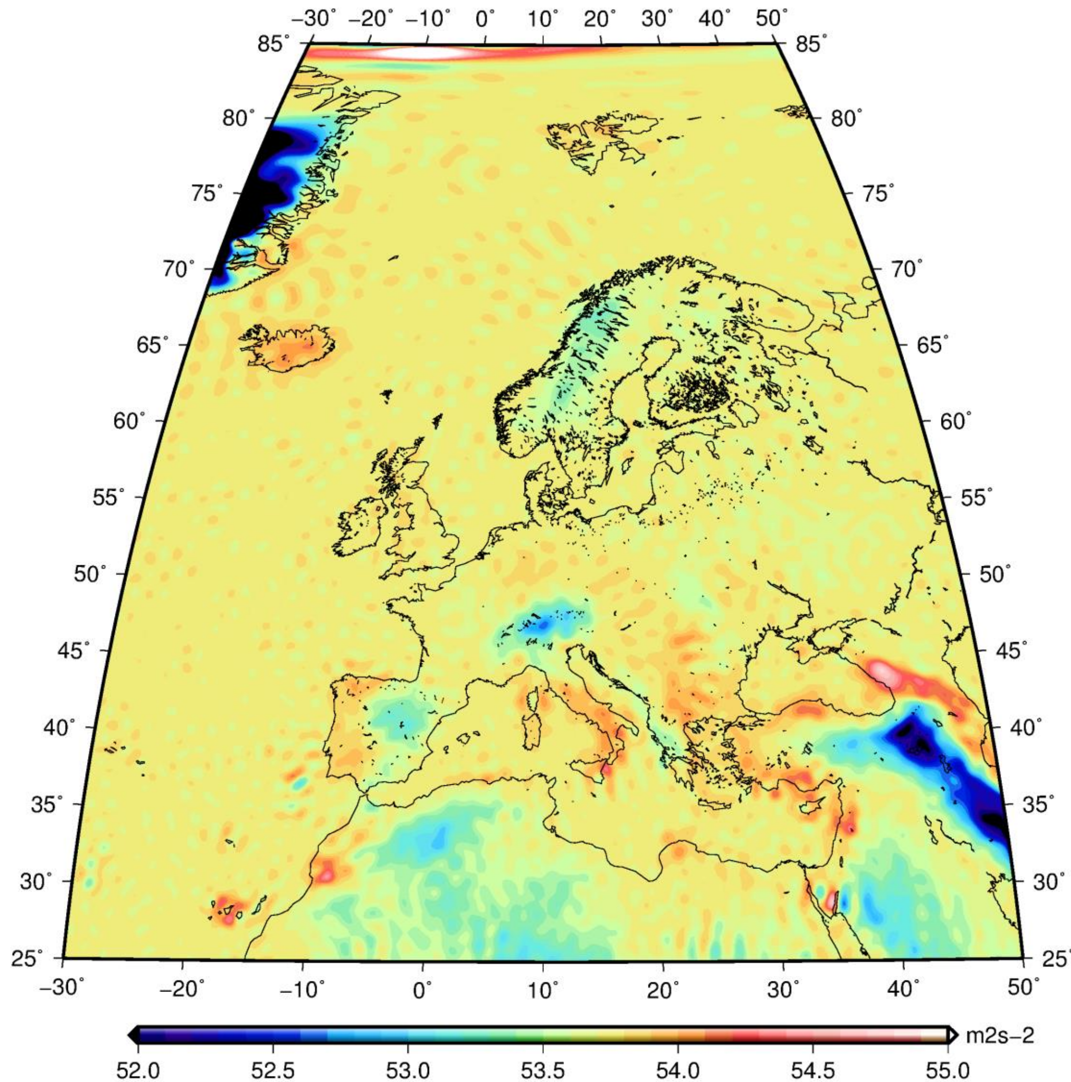
2 iterations

GOCE-DIR5 on EIGEN-6C4



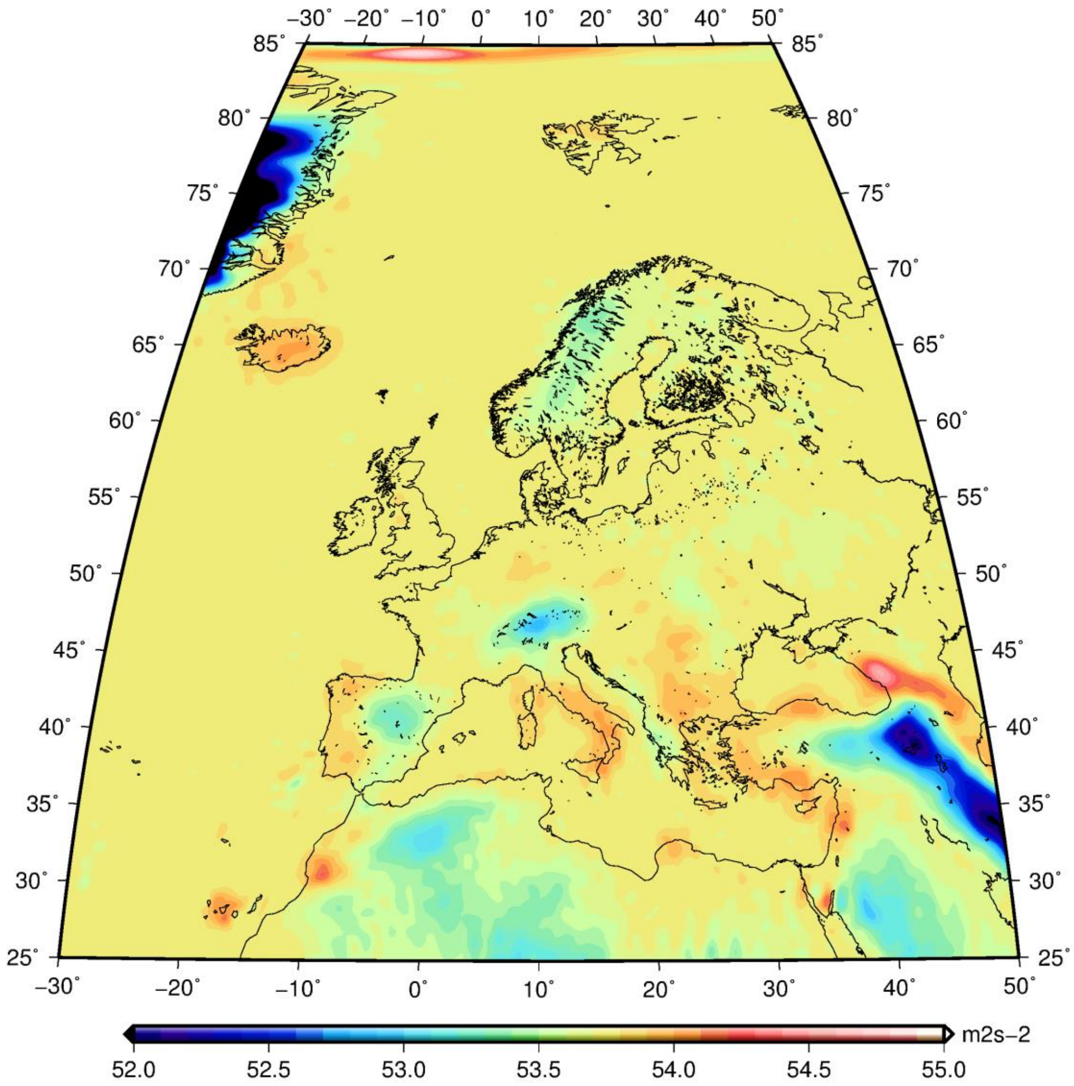
3 iterations

GOCE-DIR5 on EIGEN-6C4



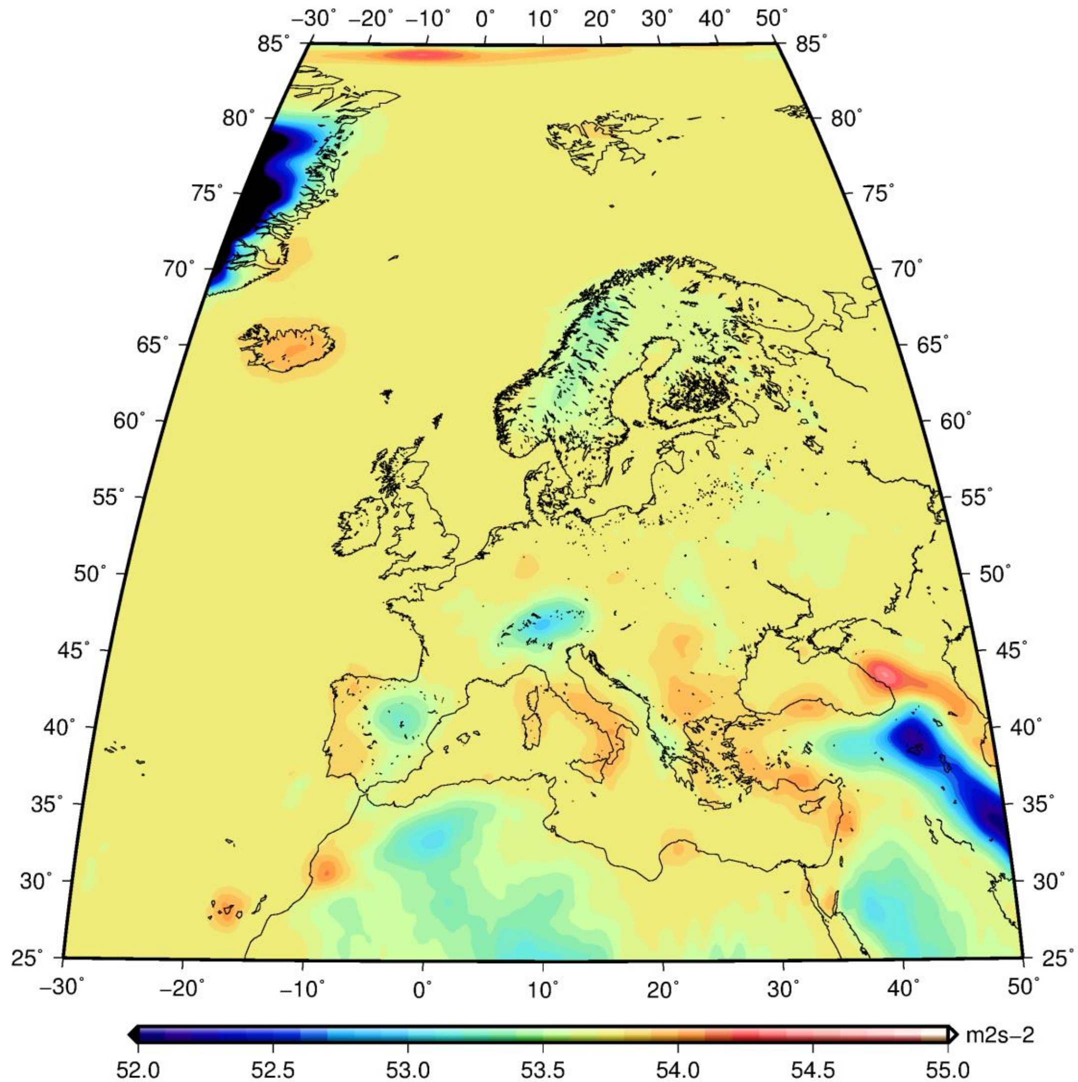
4 iterations

GOCE-DIR5 on EIGEN-6C4



5 iterations

GOCE-DIR5 on EIGEN-6C4

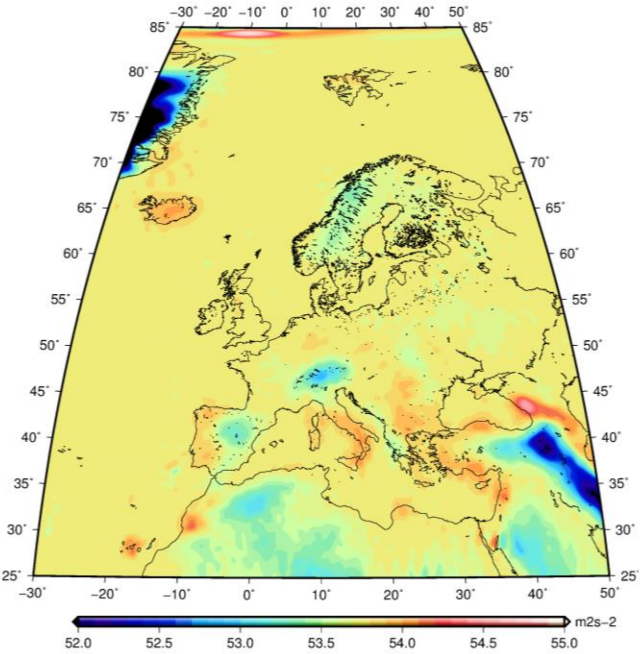


6 iterations

Filtered W from GOCE-DIR5 on geoid models

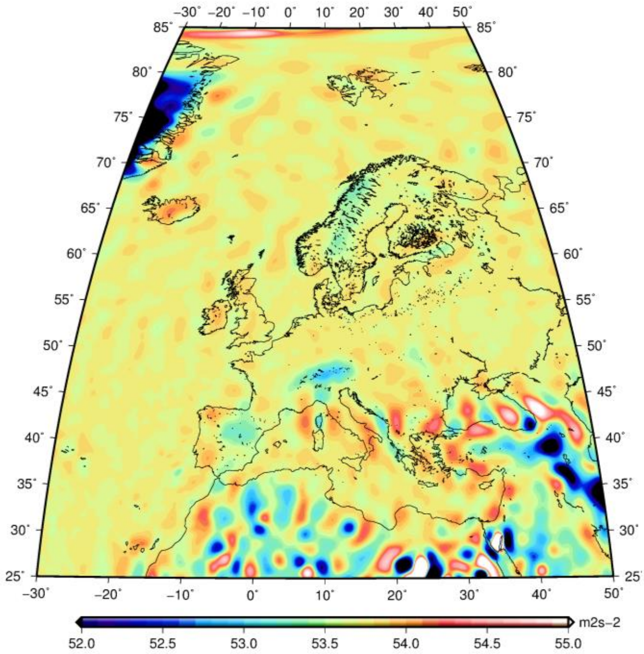
EIGEN-6C4

(SH up to d/o 2190)



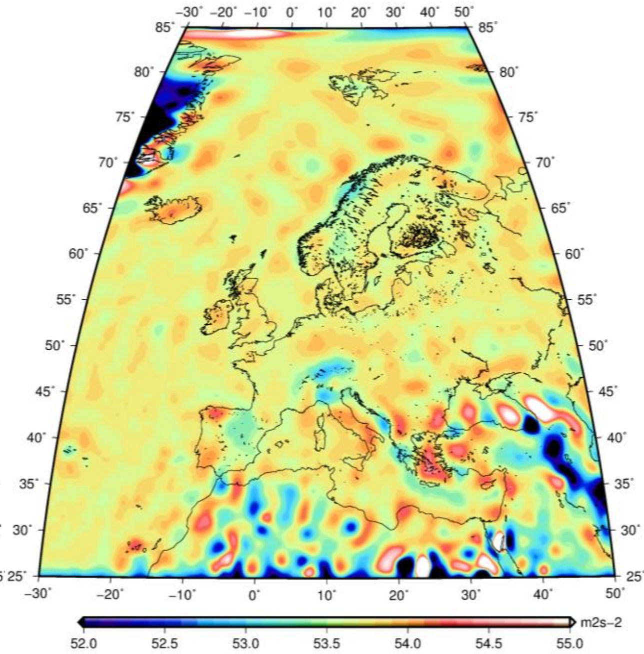
EGM-2008

(SH up to d/o 2190)



EGG2008

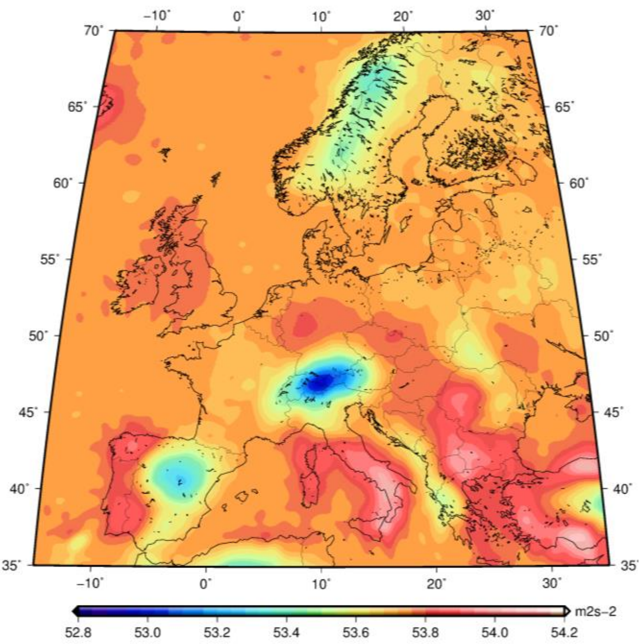
(European Gravimetric Quasigeoid)



Filtered W from GOCE-DIR5 on geoid models

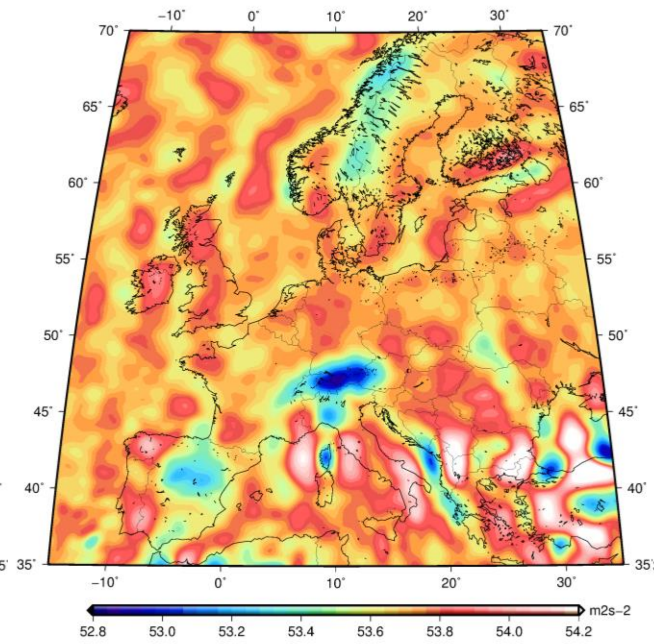
EIGEN-6C4

(SH up to d/o 2190)



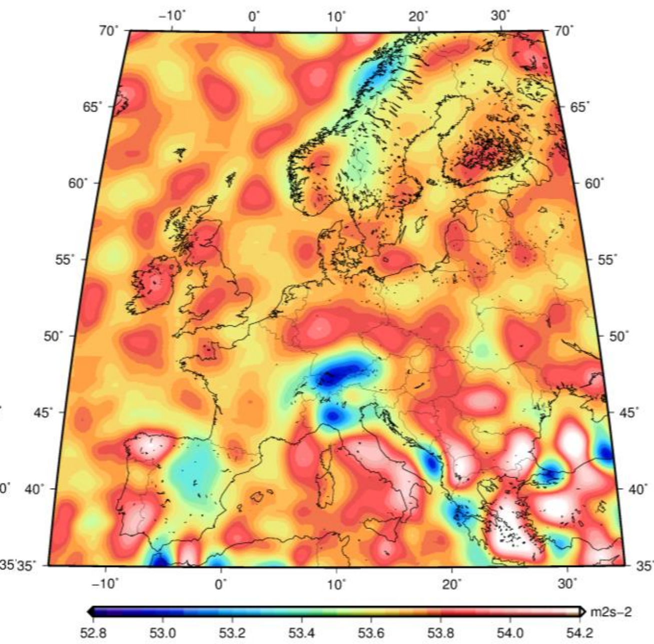
EGM-2008

(SH up to d/o 2190)

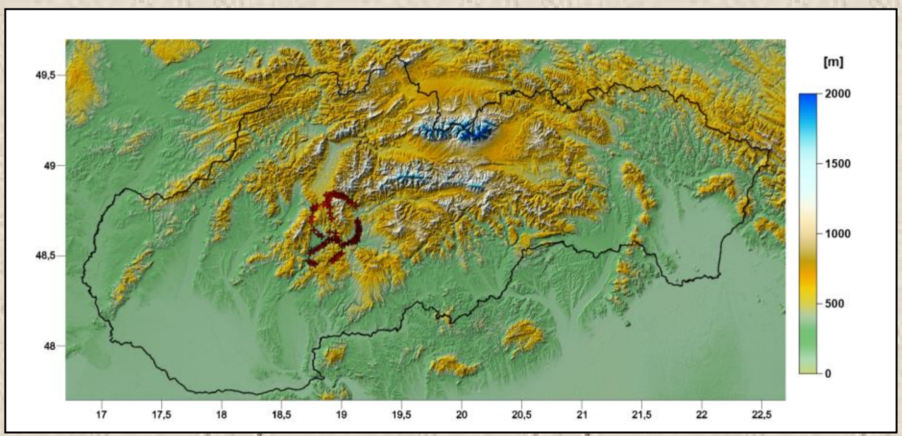


EGG2008

(European Gravimetric Quasigeoid)

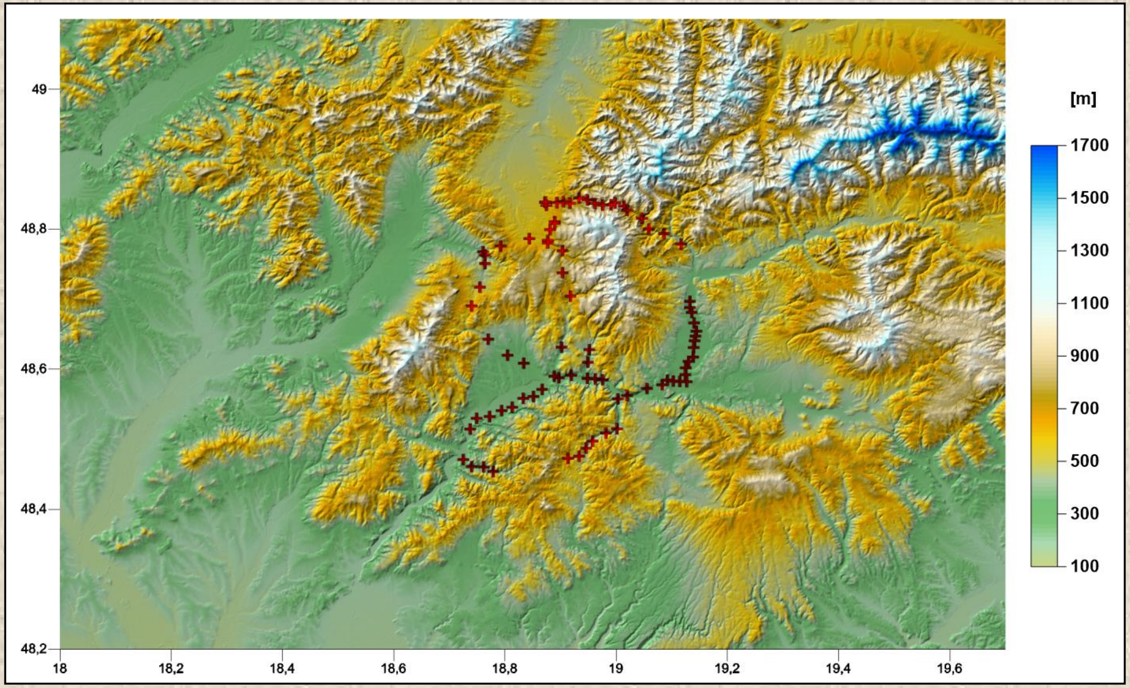


Local realization in central Slovakia

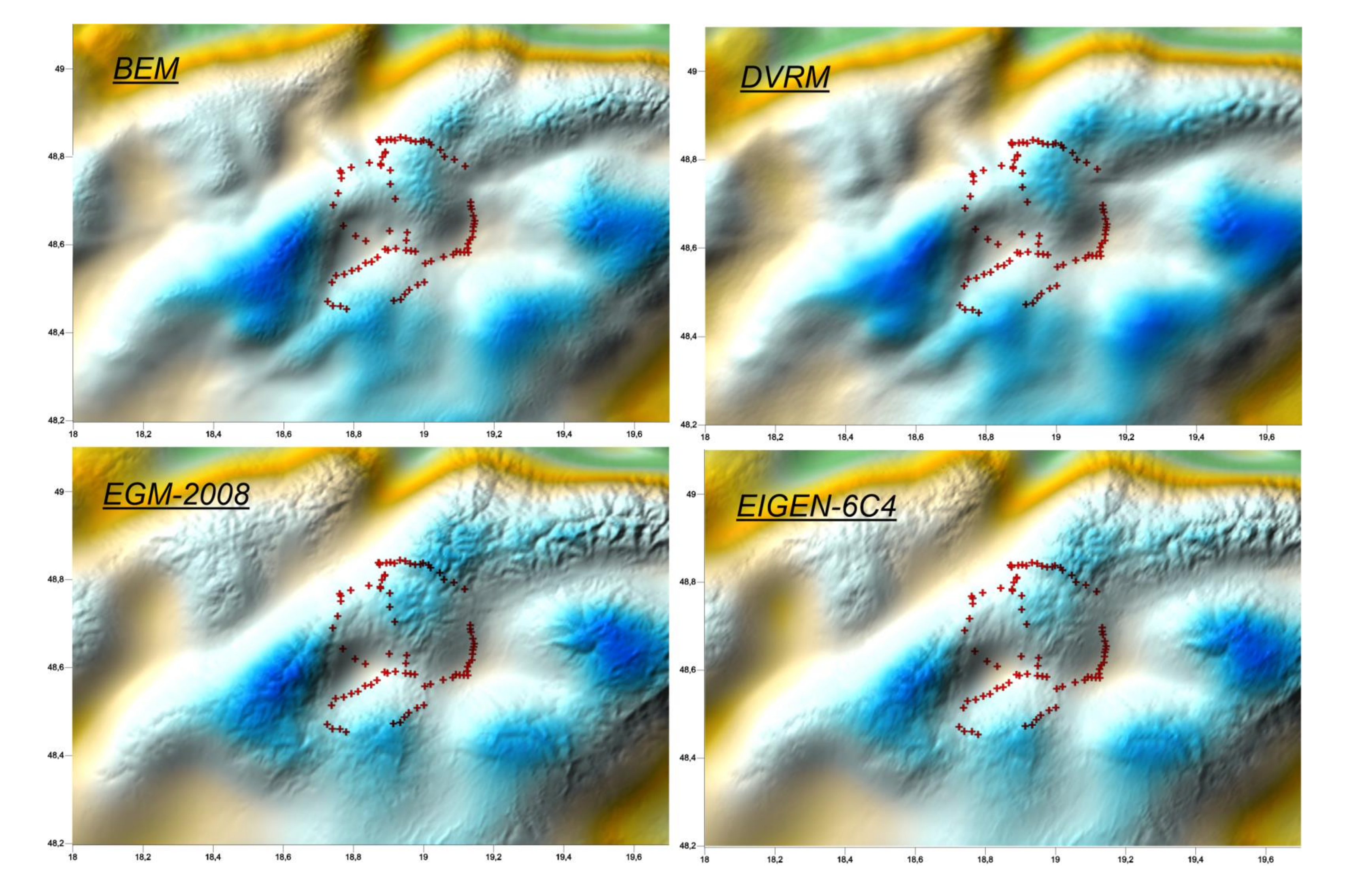


$$H_P = \frac{-(W_P - W_0)}{\bar{\gamma}_P} = \frac{-[U_P(h^{GNSS}) + T_P - W_0]}{\bar{\gamma}_P}$$

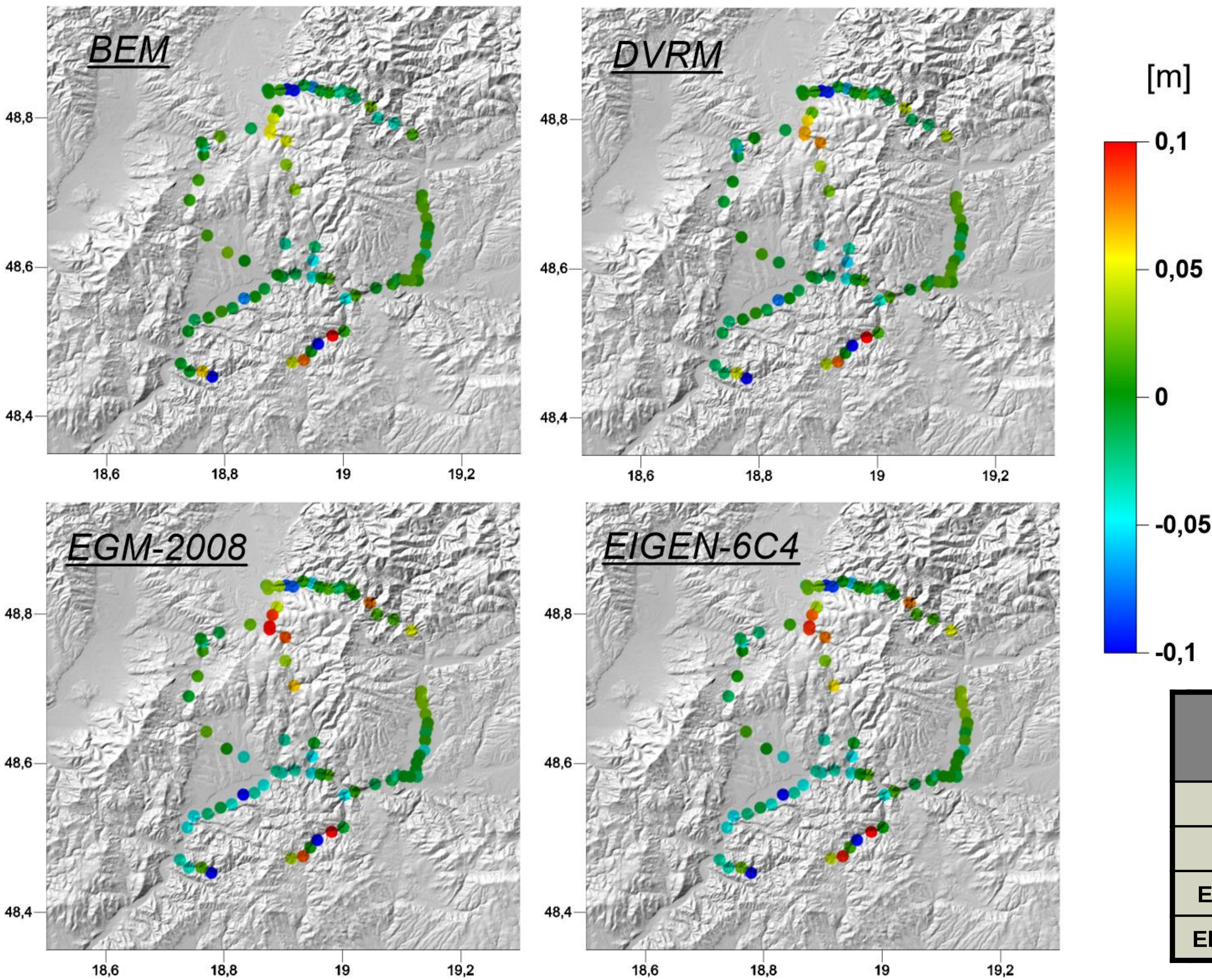
• along levelling lines (the 1st and 2nd order) close to the reference levelling benchmark "Pitelova" (reference point of EVRF2007)



Tested quasigeoid models



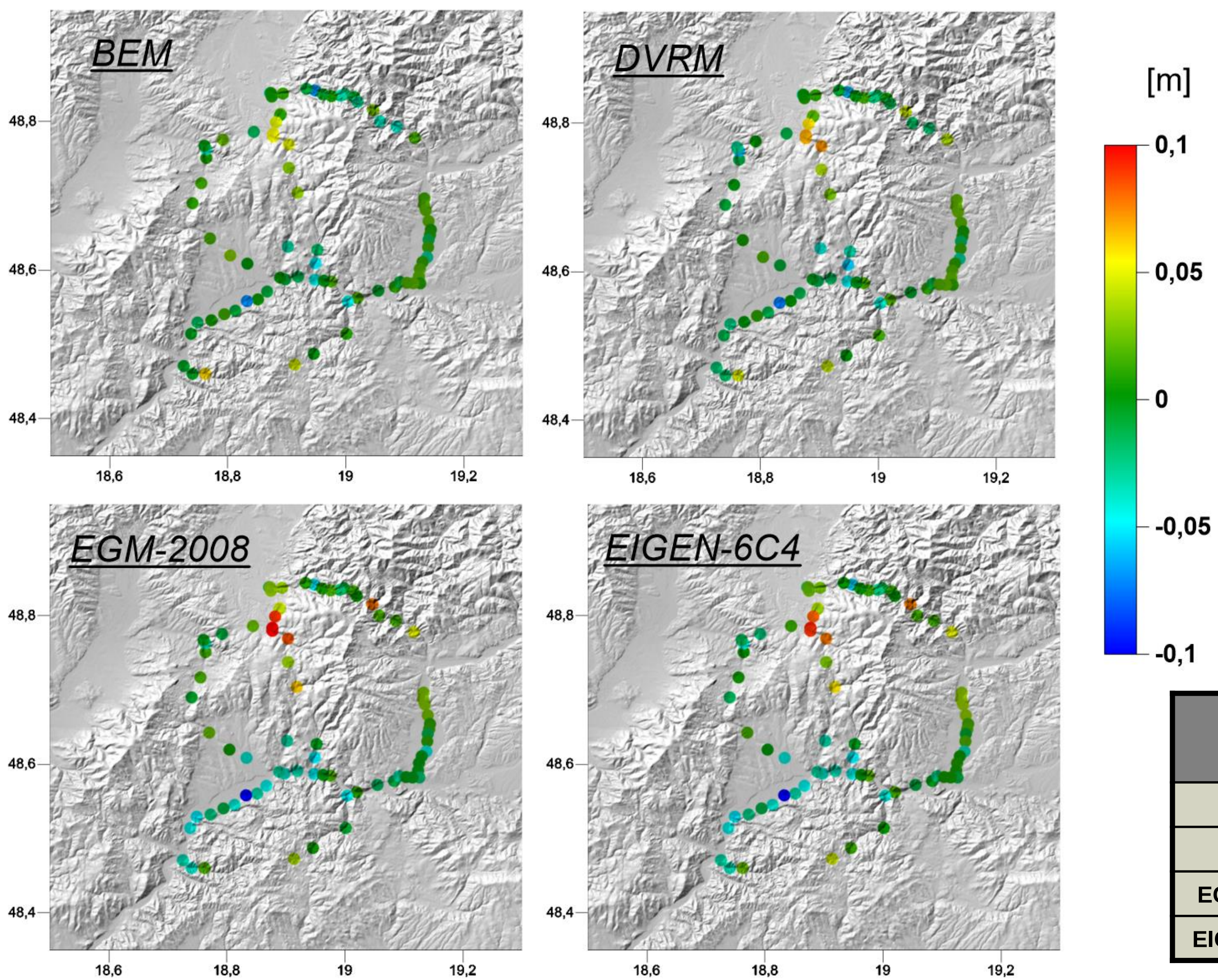
GNSS-Levelling test



82 points:
(1 removed)

Model	Range [cm]	STD [cm]
BEM	20.3	3.7
DVRM	21.4	3.9
EGM-2008	27.3	4.6
EIGEN-6C4	25.8	4.5

GNSS-Levelling test



77 points:
(6 removed)

Model	Range	STD
	[cm]	[cm]
BEM	13.2	2.7
DVRM	14.8	3.0
EGM-2008	21.2	3.9
EIGEN-6C4	20.3	3.7

Conclusions

Realization of EVRS

⇒ based on gravity field modelling is till limited due to a demand for precise quasigeoid models with a real "cm-level" accuracy

⇒ low-frequency part obtained form the GRACE\GOCE-based satellite-only GGMs provides an essential basis

⇒ however it is practically inevitable to model high-frequency part:

- combined GGMs (EGM2008, EIGEN6C4stat) still need improvements
- precise national (quasi)geoid models based on reliable terrestrial gravimetric measurements are very welcome (fixed gravimetric BVP!!!)

⇒ our validation of candidates for "the European (quasi)geoid" using GOCE-DIR5 and nonlinear diffusion filtering shows:

- some systematic tendencies up to several cm
- in high mountains (e.g. Alpes) it can be problem of inaccurate corrections ($\zeta \Rightarrow N$)
- reducing of stripping noise of the satellite-only MDT provides its better relationship to the 3D positions of the geoid models in coastal areas


Thank you