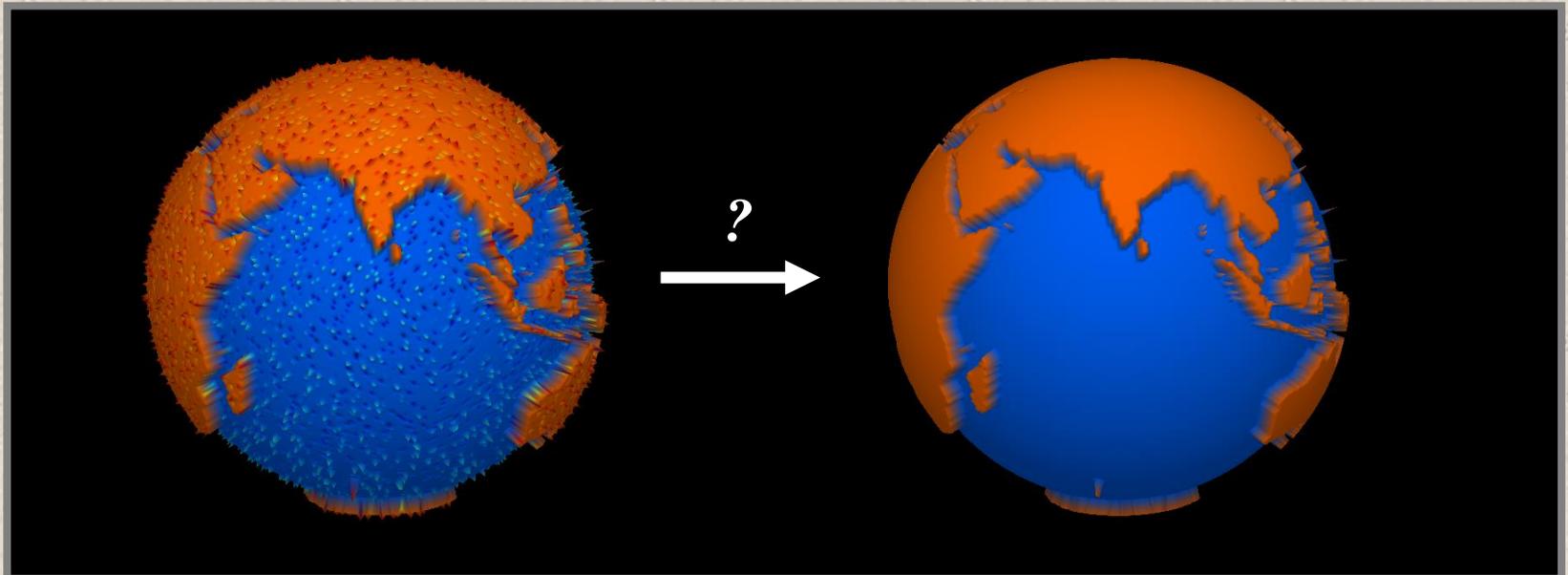


Filtrácia dát na povrchu Zeme a na orbitách družicových misií

Róbert Čunderlík, Karol Mikula

cunderli@svf.stuba.sk

mikula@math.sk



Obsah

- **Motivácia**
- **Difúzna filtrácia na uzavretých plochách**
(napr. na guli, elipsoide alebo na zemskom povrchu)
- **Testovací príklad**
- **Filtrovanie priamych meraní družicovej misie GOCE**
- **Filtrovanie dynamickej topografie oceánov**



Motivácia

- množstvo družicových misií monitorujúcich našu planétu
⇒ merania sú ovplyvnené šumom

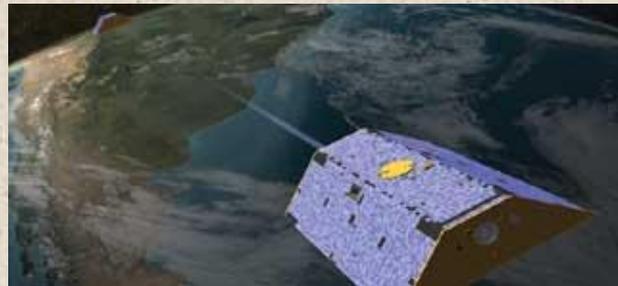
Dôvody: - prechod signálu atmosférou (troposférou a ionosférou)
- nepresnosť polohy a orientácie družicovej misie
- chyby samotného meracieho zariadenia

Tiažové pole zeme a jeho časové variácie

CHAMP (2000-2010)



GRACE (2002-now)



GOCE (2009-2013)



Družicová altimetria – variácia hladiny oceánov

- **Seasat** (1978), **Geosat** (1985), **TOPEX-Poseidon** (1992-2006)
- **ERS-2**, **Jason-1**, **ENVISAT**, **Jason-2**, ...



Motivácia

Vplyv oceánov na klímu

Vplyv filtrácie dát na interpretáciu výsledkov

The Oceans' Role in Climate

Jason-1 Measuring Ocean Surface Topography From Space



The Jason-1 satellite, an international mission with France, extends ocean topography measurements into the 21st century. Jason-1 continues the quest to better understand our planet through long-term monitoring of Earth's oceans.

CLIMATE RESEARCH

OFFSHORE INDUSTRIES

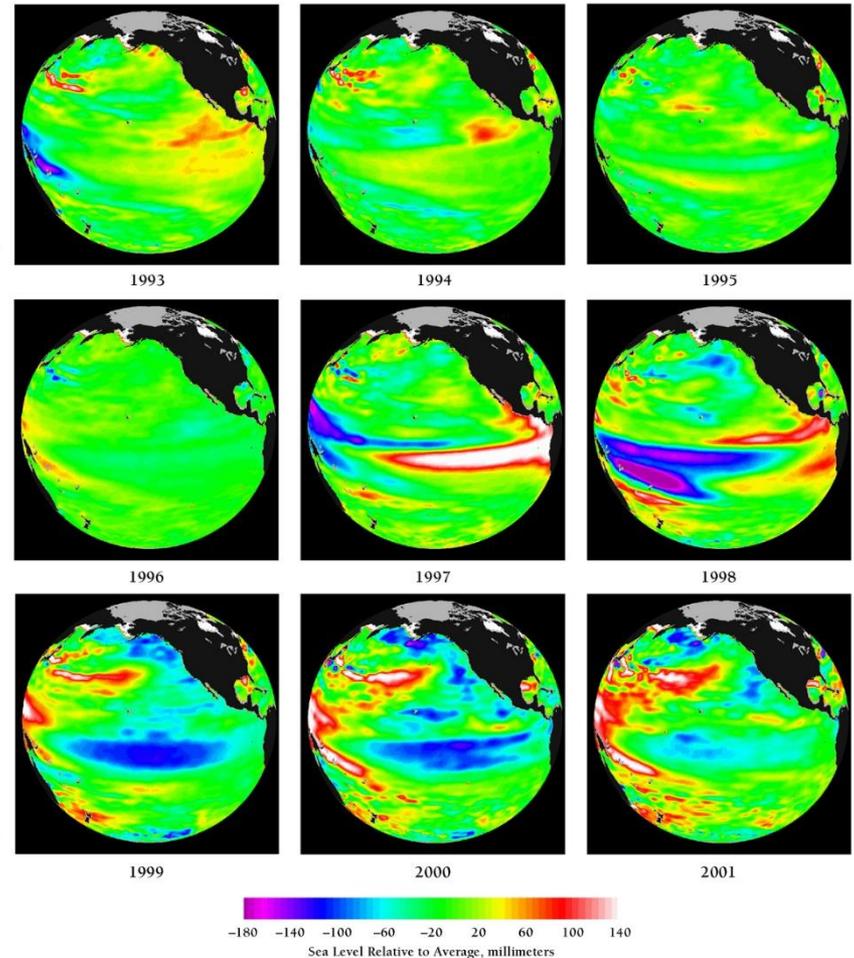
MARINE MAMMAL RESEARCH

SHIP ROUTING

TOPEX/Poseidon revolutionized our knowledge of ocean circulation and its effects on global climate change. This satellite provided measurements that led to early predictions of the great El Niño 1997-98, which caused extreme disruptions to weather patterns worldwide.

Jason-1 will build on TOPEX/Poseidon's monitoring of the Earth's oceans, continuing the goal of building long-term data sets of Earth's ocean surface topography.

<http://sealevel.jpl.nasa.gov>



Difúzna filtrácia dát na uzavretých plochách

- filtrovanie šumu v dátach sa dá realizovať aj pomocou riešenia tzv. rovnice vedenia tepla
⇒ často sa používa v spracovaní obrazu (image processing)

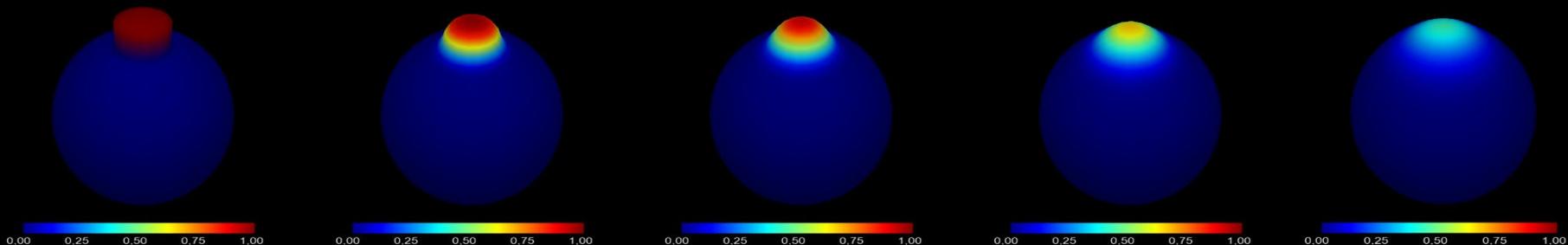
Rovnica vedenia tepla na ploche

$$\frac{\partial u(x,t)}{\partial t} - \Delta_S u(x,t) = 0$$

Δ_S - the Laplace–Beltrami operator (druhé derivácie)
 $u(x,t)$ – skalárna funkcia daná na ploche

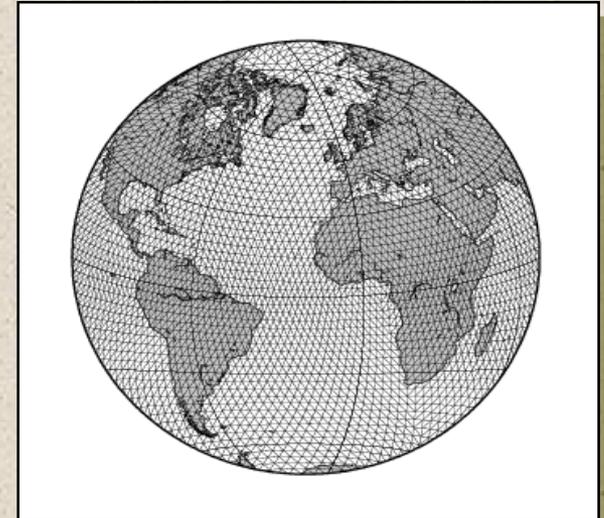
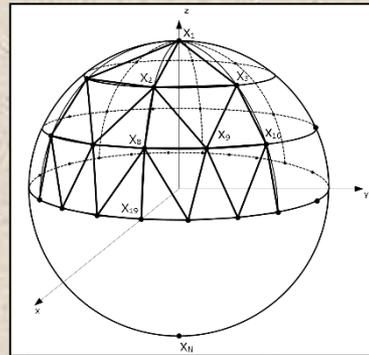
- vstupné zašumené dáta ako počiatočná podmienka:

$$u(x,0) = u_o(x)$$



Numerické riešenie metódou konečných objemov

Triangulácia uzavretej plochy

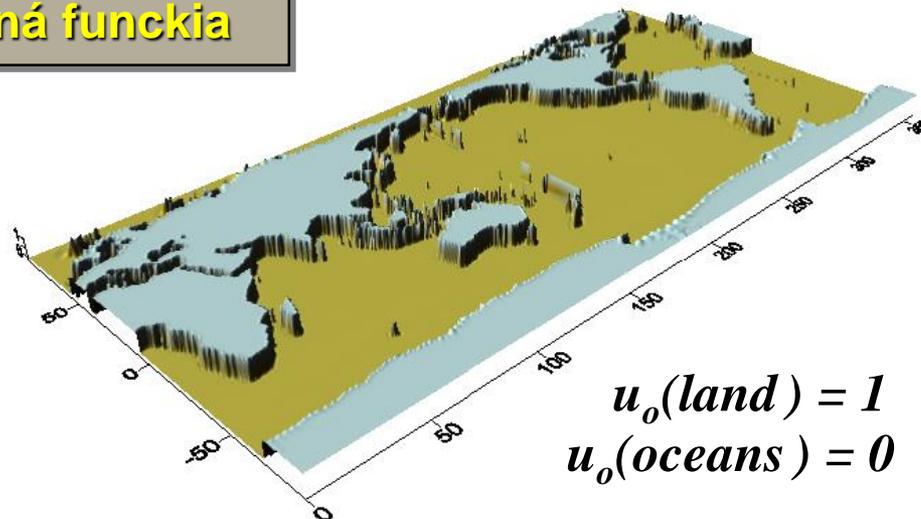
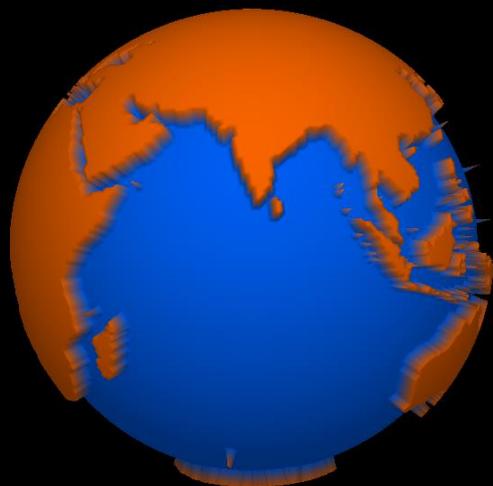


Riešenie systému lineárnych rovníc

- lineárna difúzia \Rightarrow riešenia rovnice vedenia tepla (zhladzuje aj dôležité prvky)
- nelineárna difúzia \Rightarrow riešenia modifikovanej rovnice vedenia tepla (umožňuje zachovávať dôležité prvky)

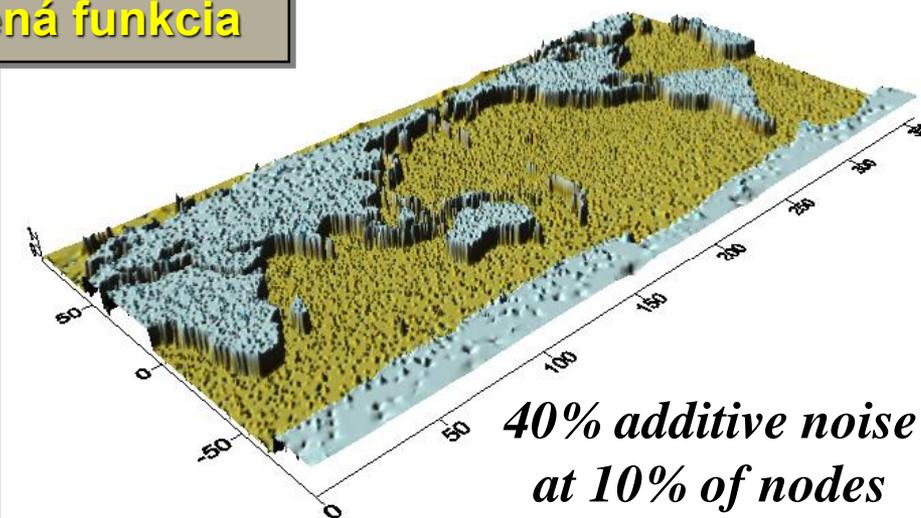
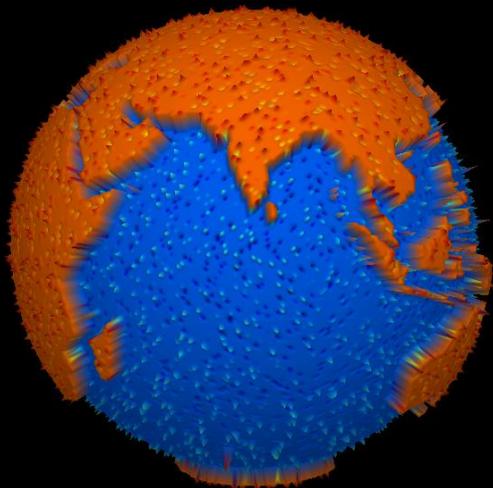
Testovací príklad

Pôvodná funkcia



$$u_o(\text{land}) = 1$$
$$u_o(\text{oceans}) = 0$$

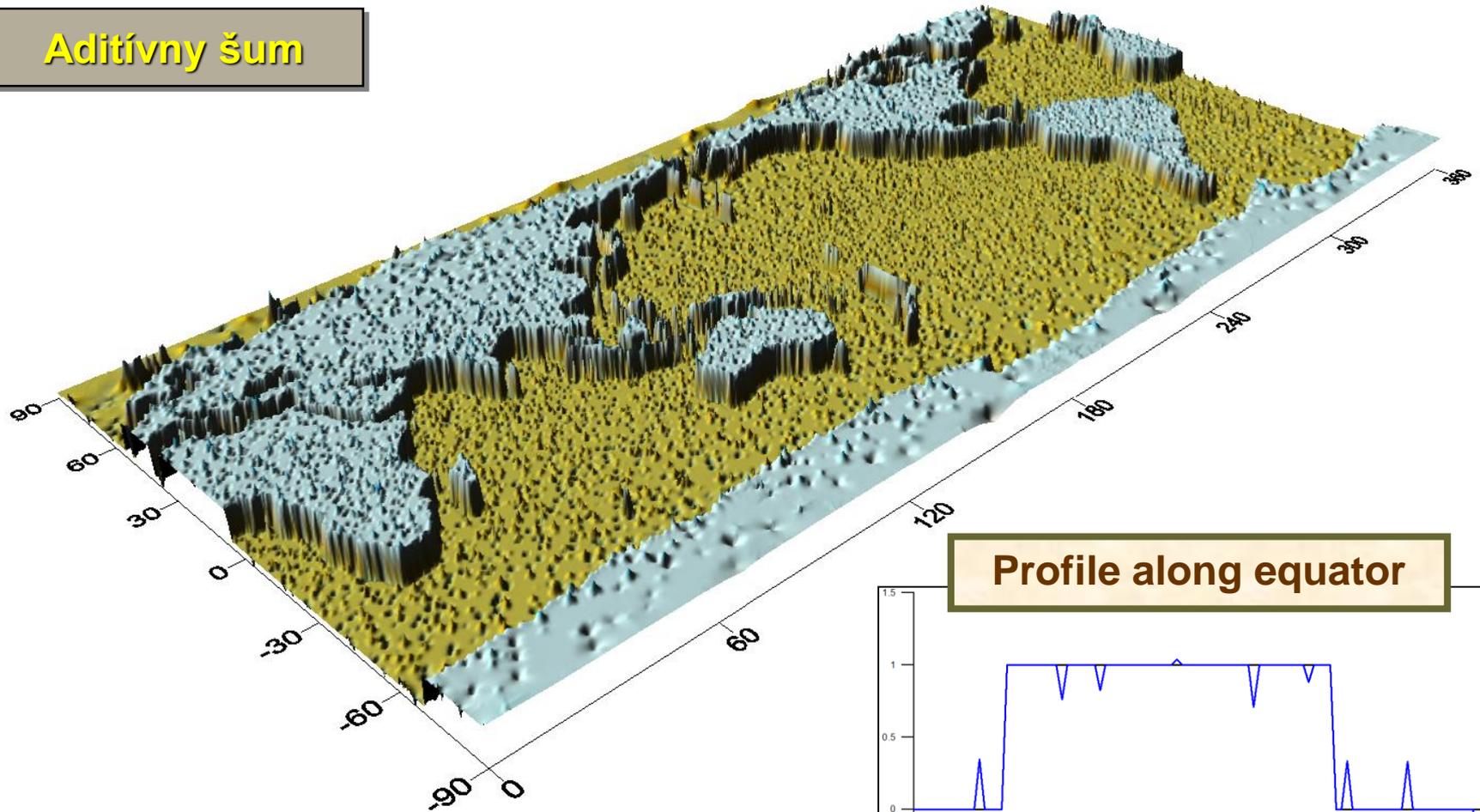
Zašumená funkcia



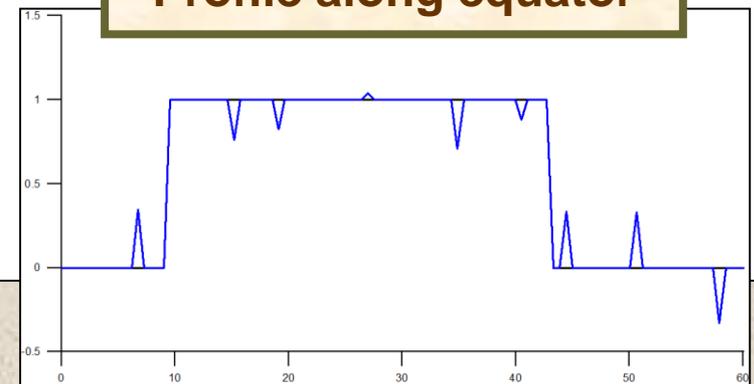
40% additive noise
at 10% of nodes

Lineárna difúzia – vstupné dáta

Aditívny šum

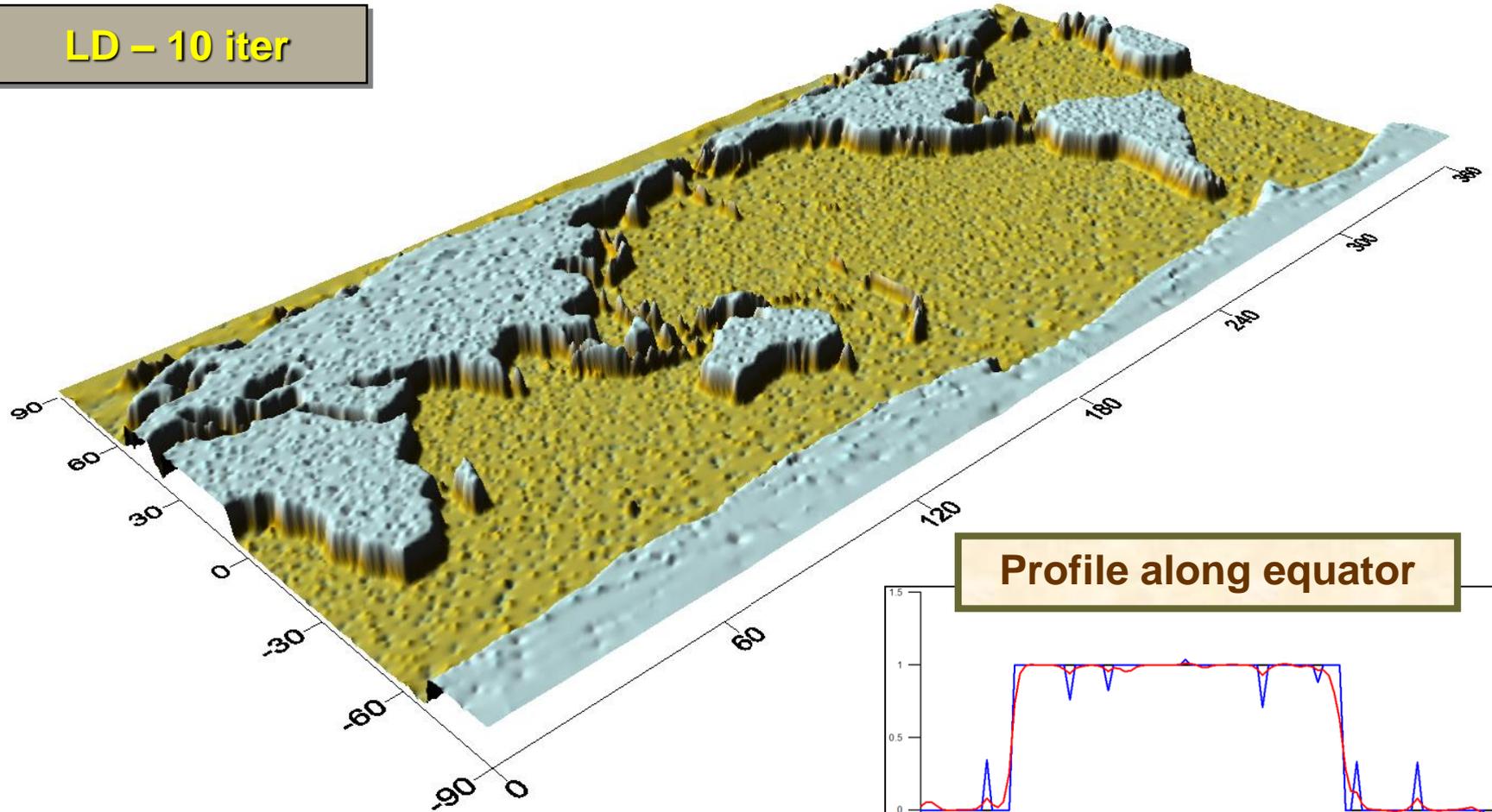


Profile along equator

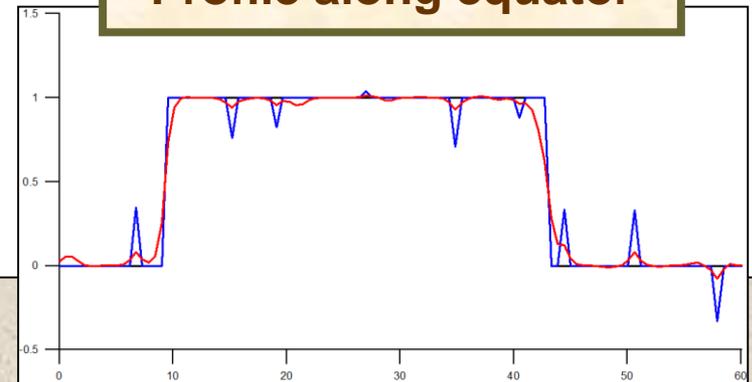


Linear diffusion – 10 iterations

LD – 10 iter

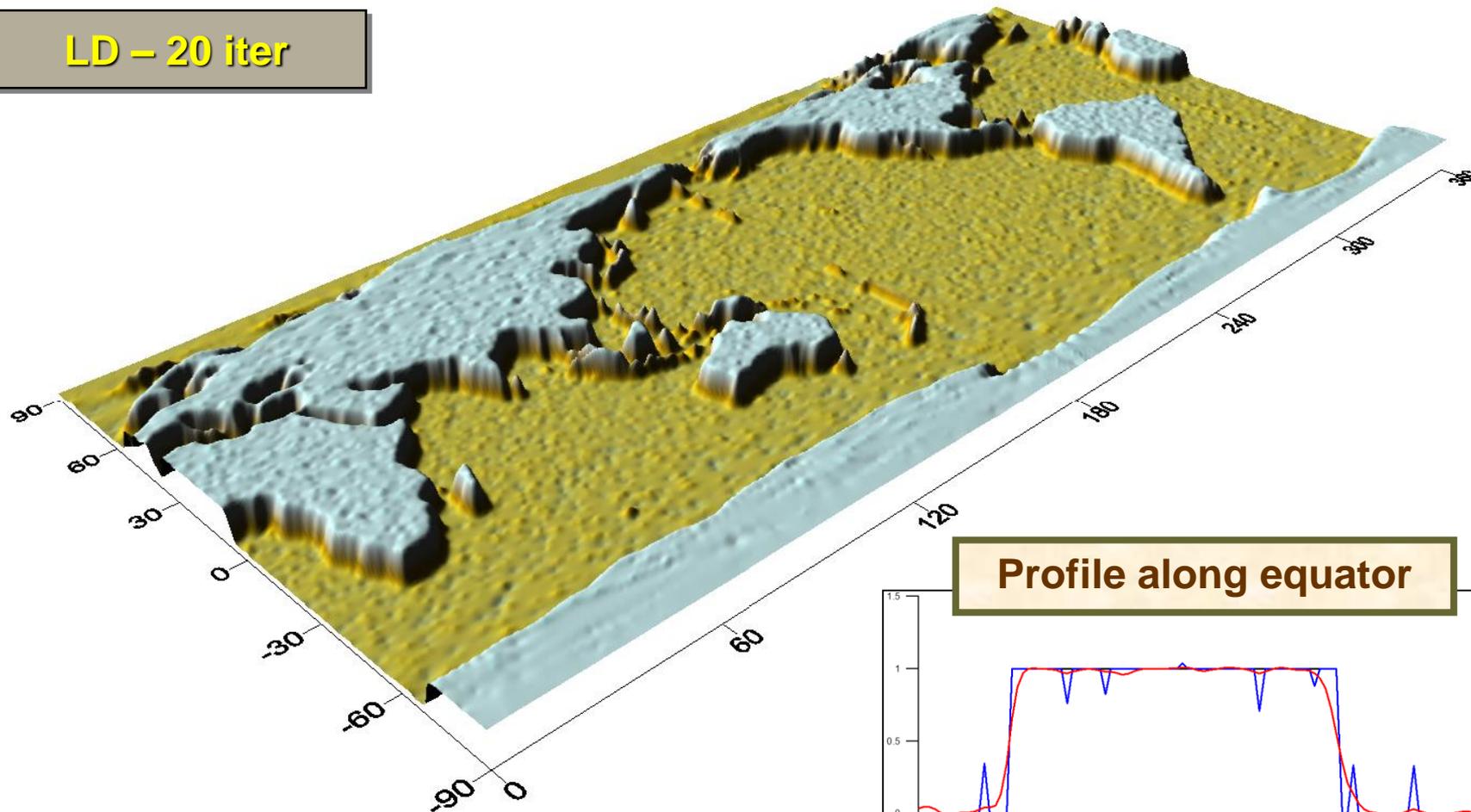


Profile along equator

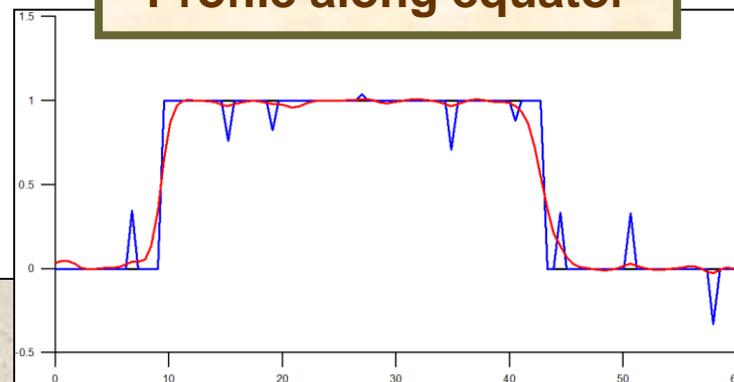


Linear diffusion – 20 iterations

LD – 20 iter

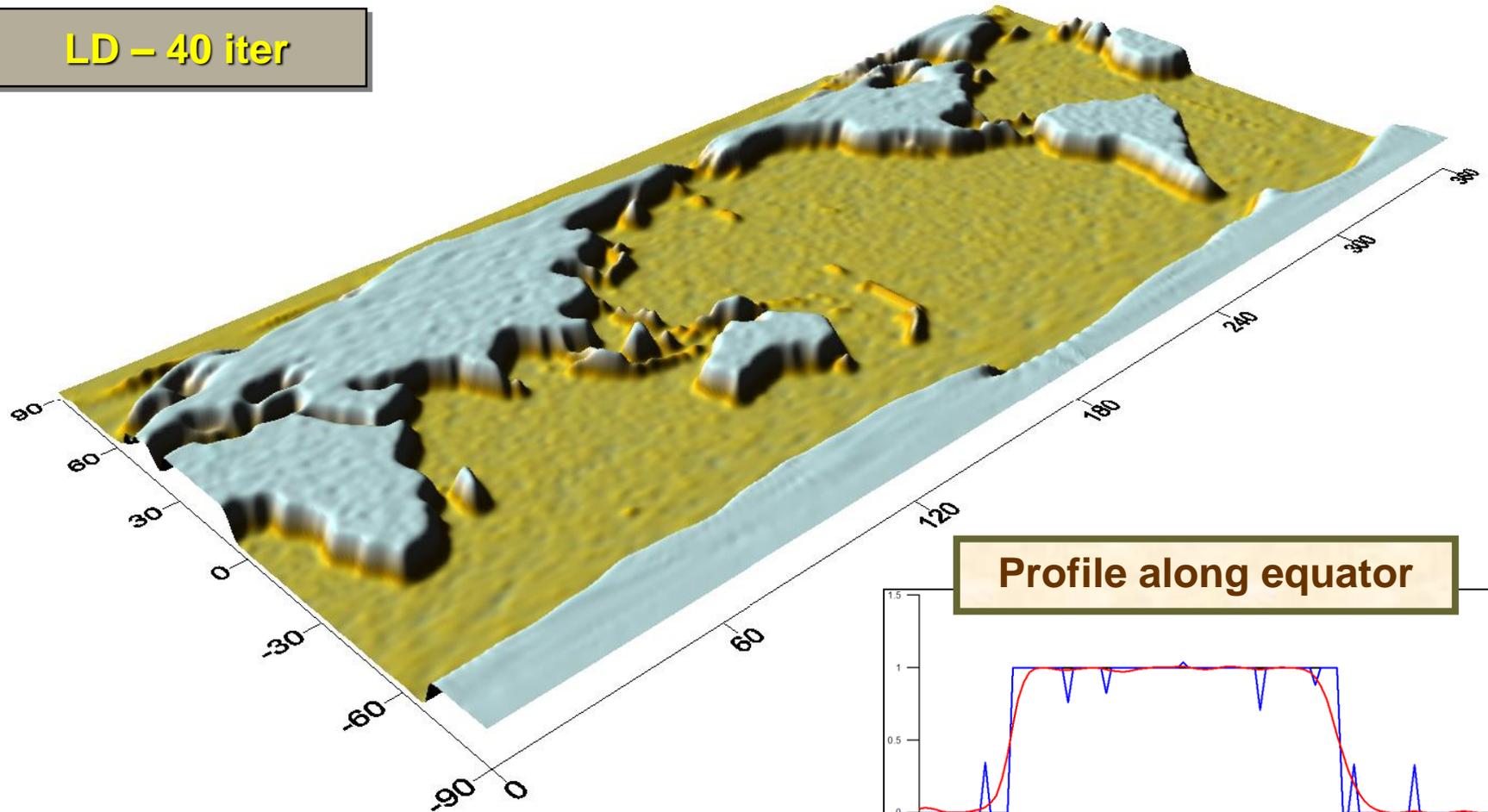


Profile along equator

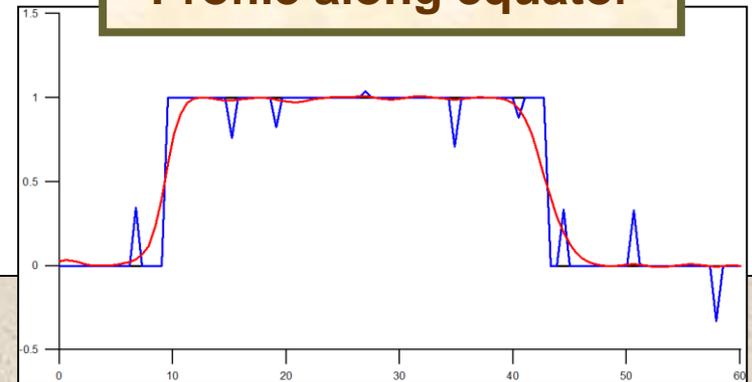


Linear diffusion – 40 iterations

LD – 40 iter

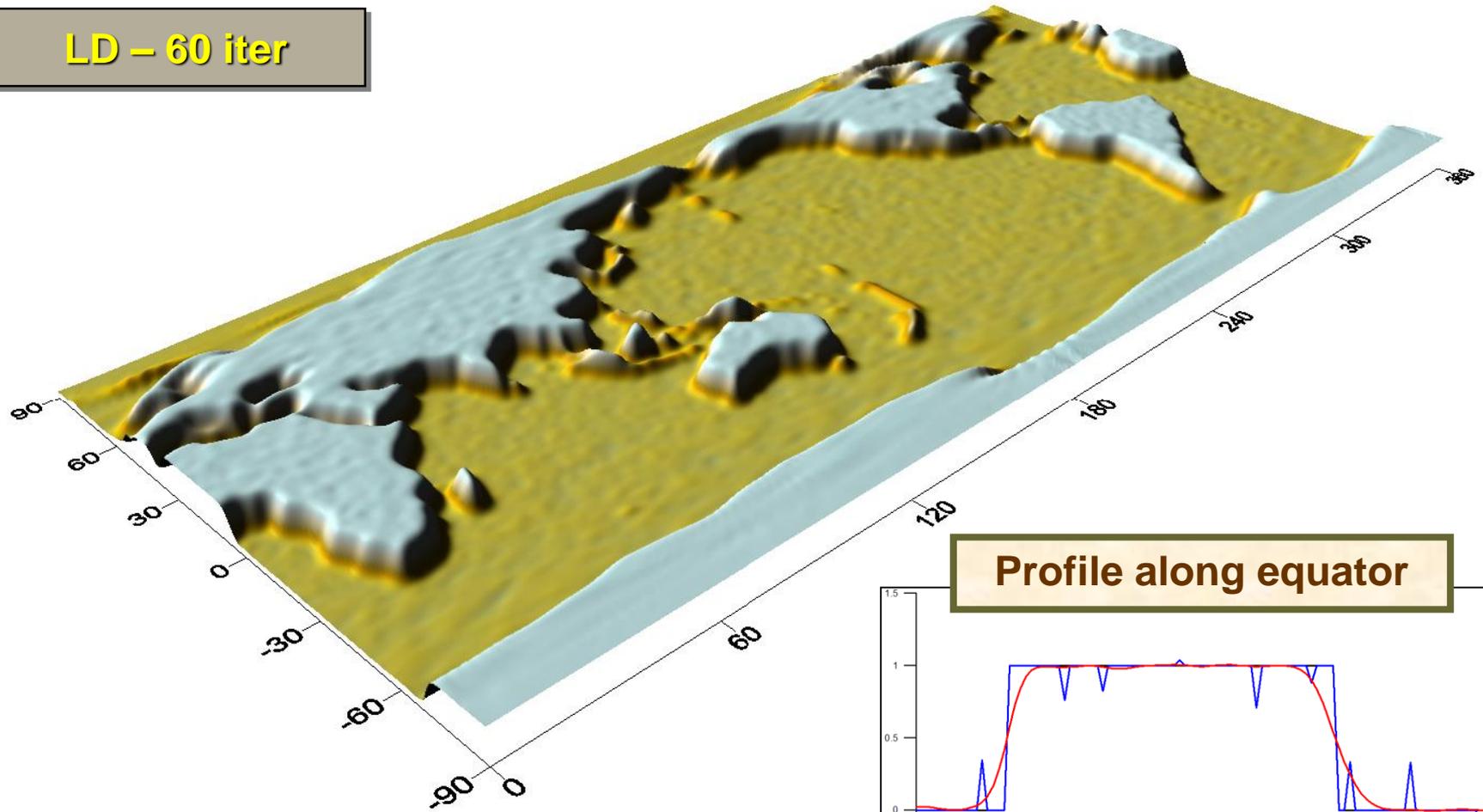


Profile along equator

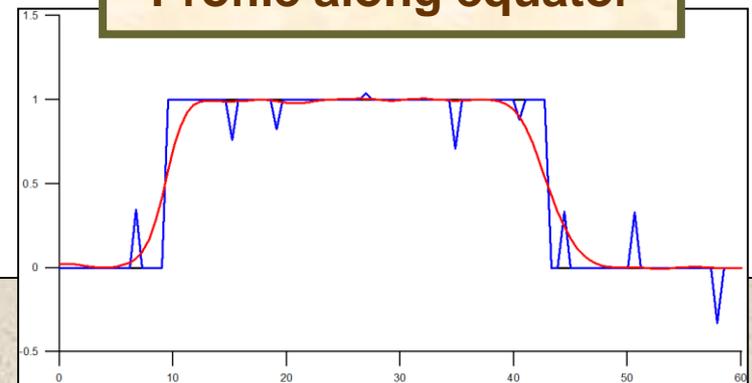


Linear diffusion – 60 iterations

LD – 60 iter

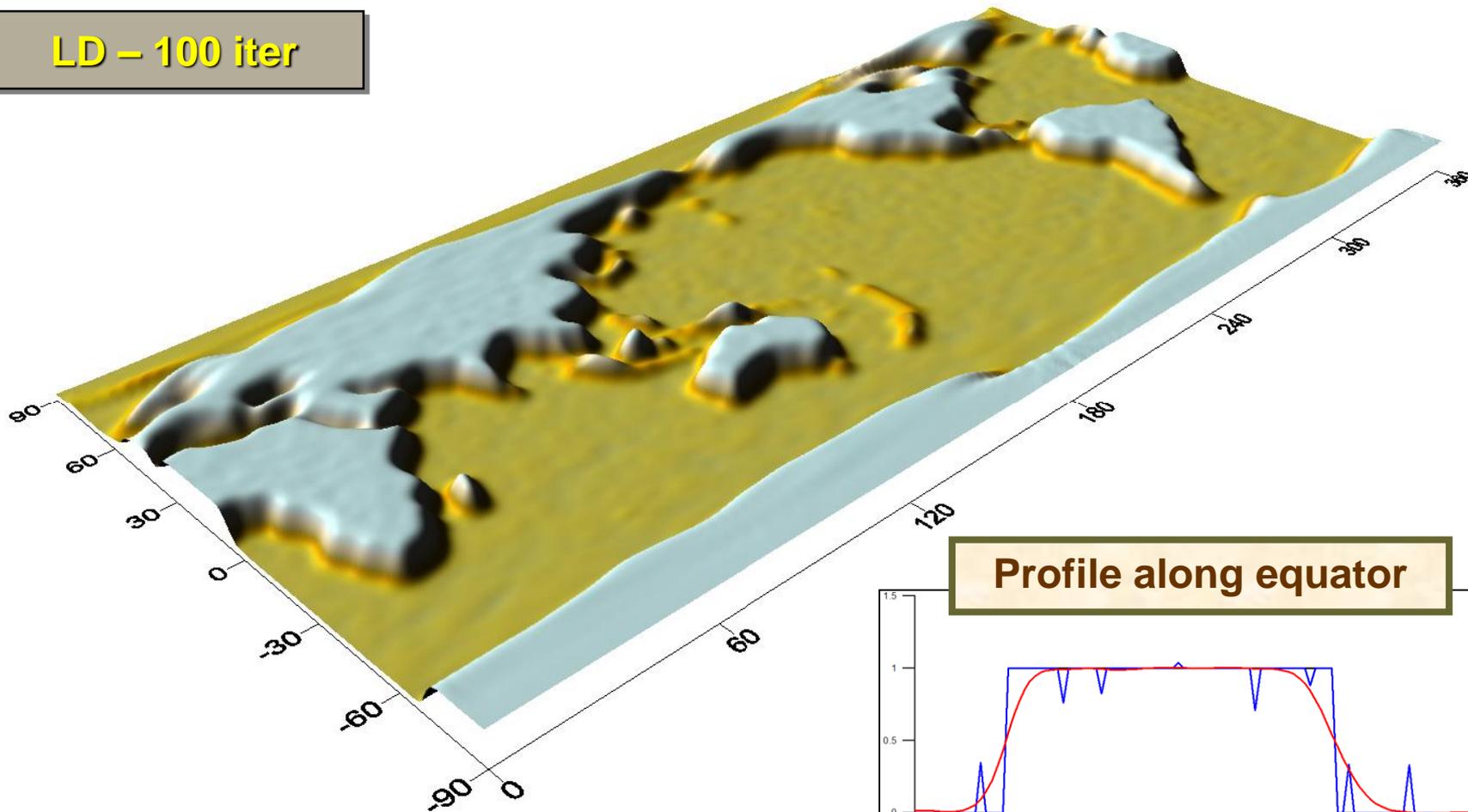


Profile along equator

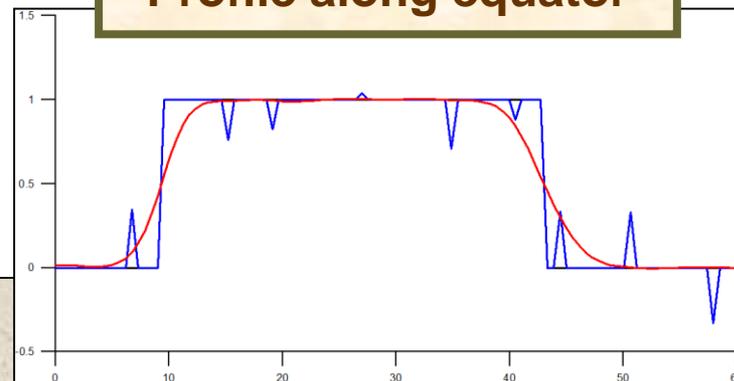


Linear diffusion – 100 iterations

LD – 100 iter



Profile along equator

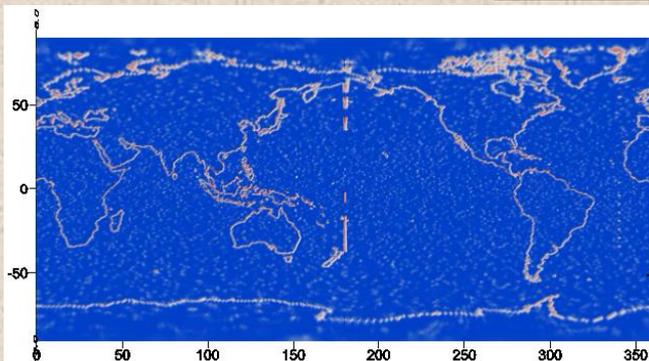


Nelinárna difúzia – hranový detektor

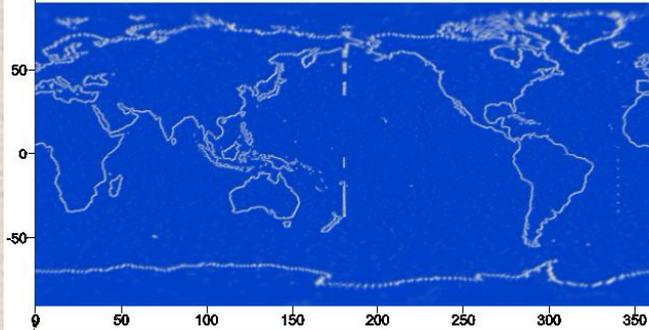
Hranový detektor

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

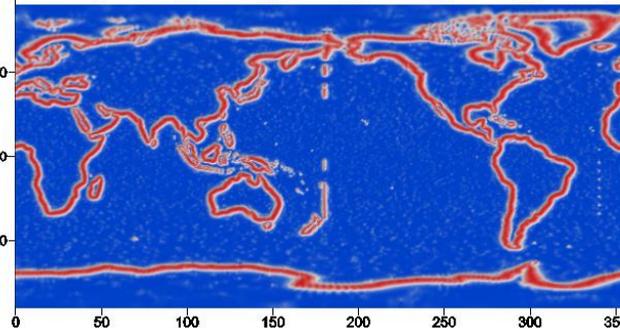
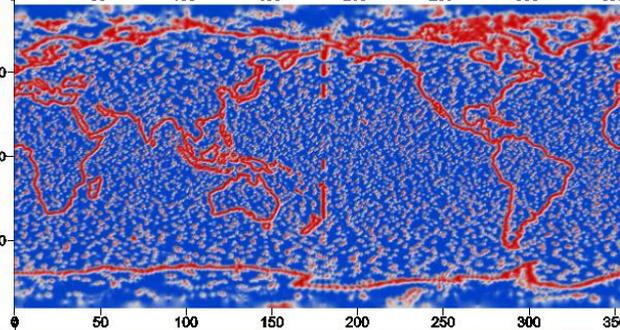
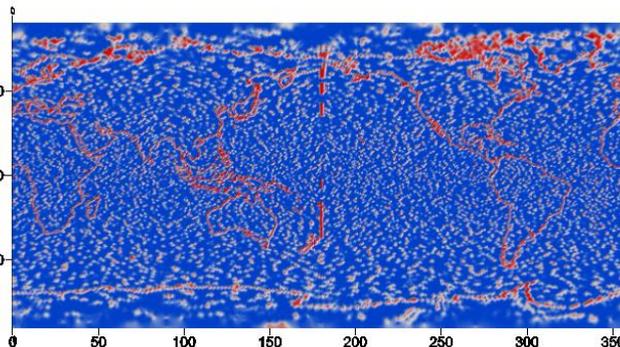
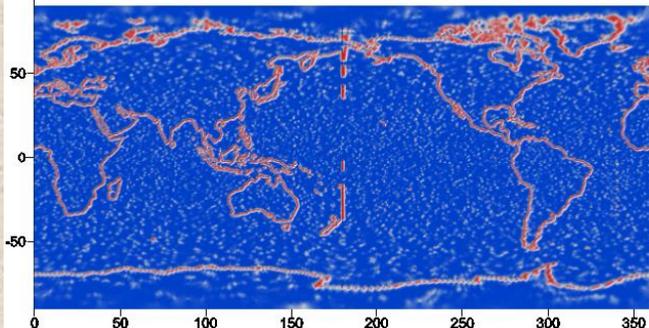
$\sigma = \tau$
 $H = 10^{10}$



$\sigma = 10\tau$
 $H = 10^{10}$



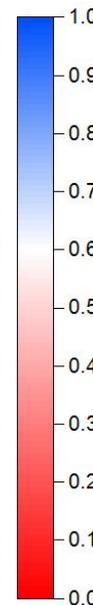
$\sigma = 10\tau$
 $H = 10^{11}$



$\sigma = \tau$
 $H = 10^{11}$

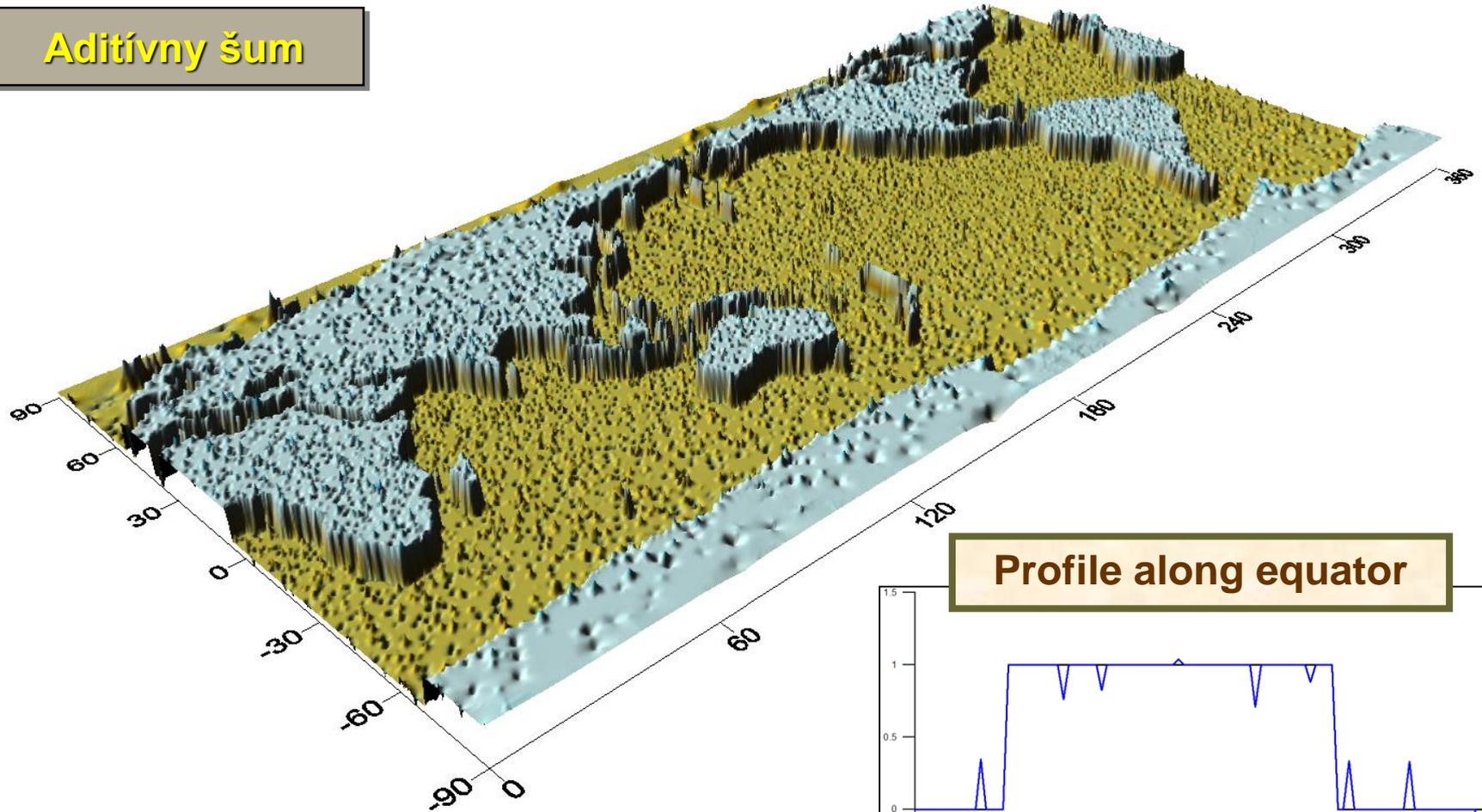
$\sigma = 10\tau$
 $H = 10^{12}$

$\sigma = 100\tau$
 $H = 10^{12}$

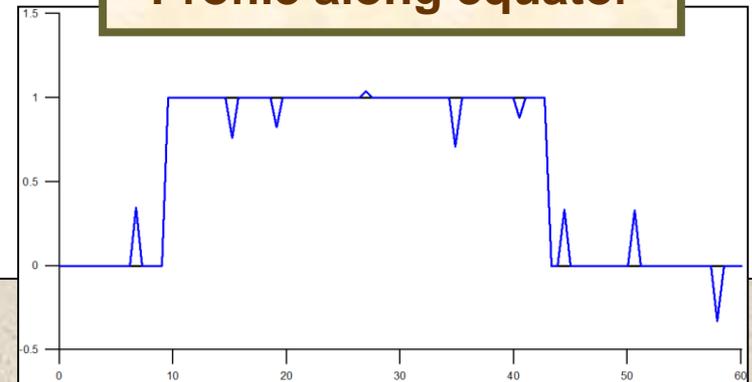


Nelineárna difúzia – vstupné dáta

Aditívny šum

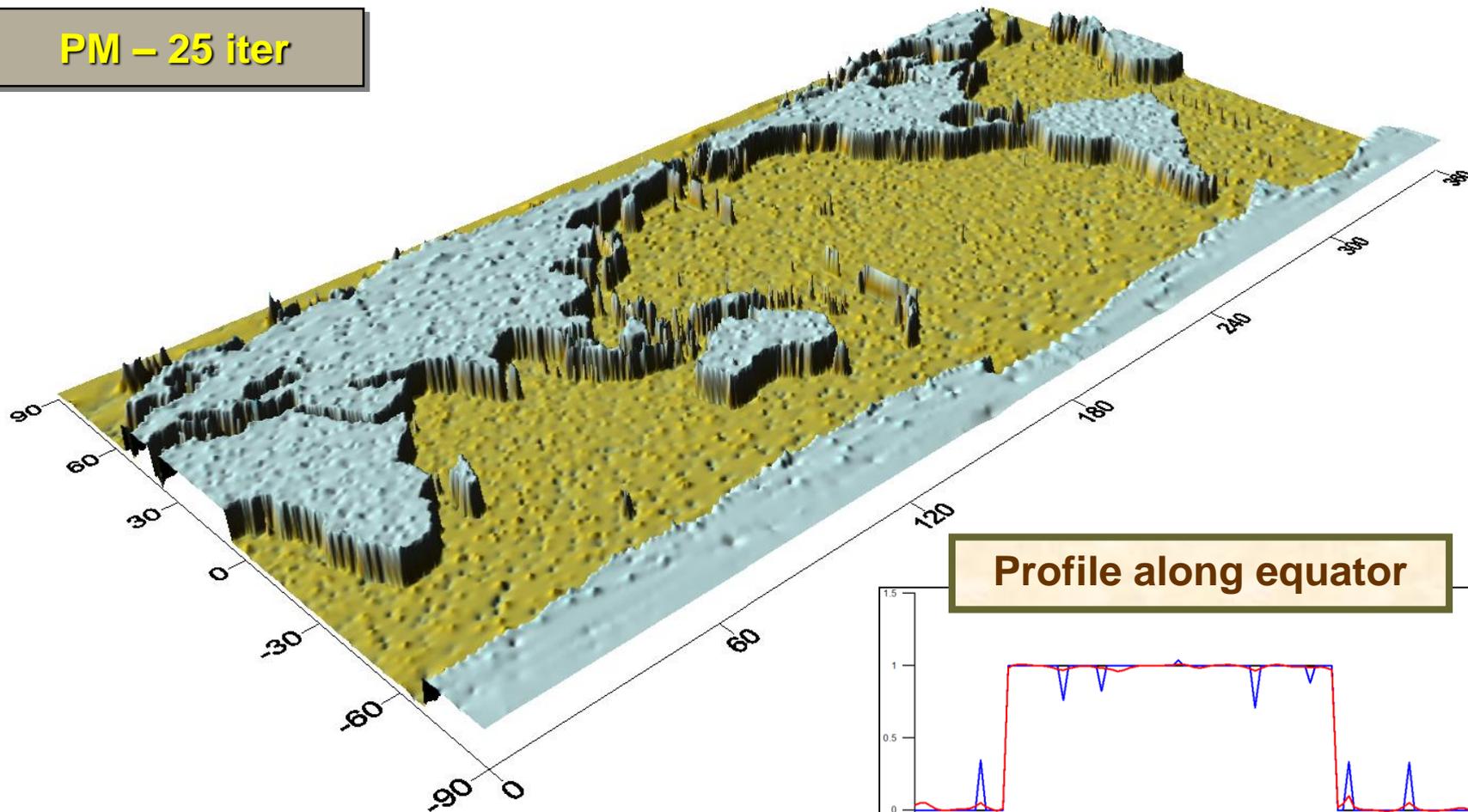


Profile along equator

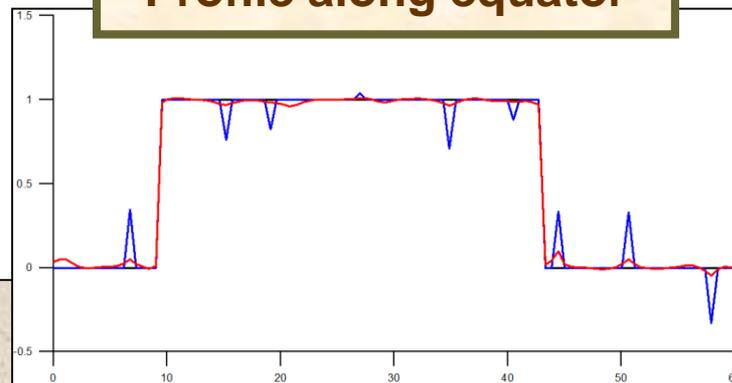


Nonlinear diffusion – 25 iterations

PM – 25 iter

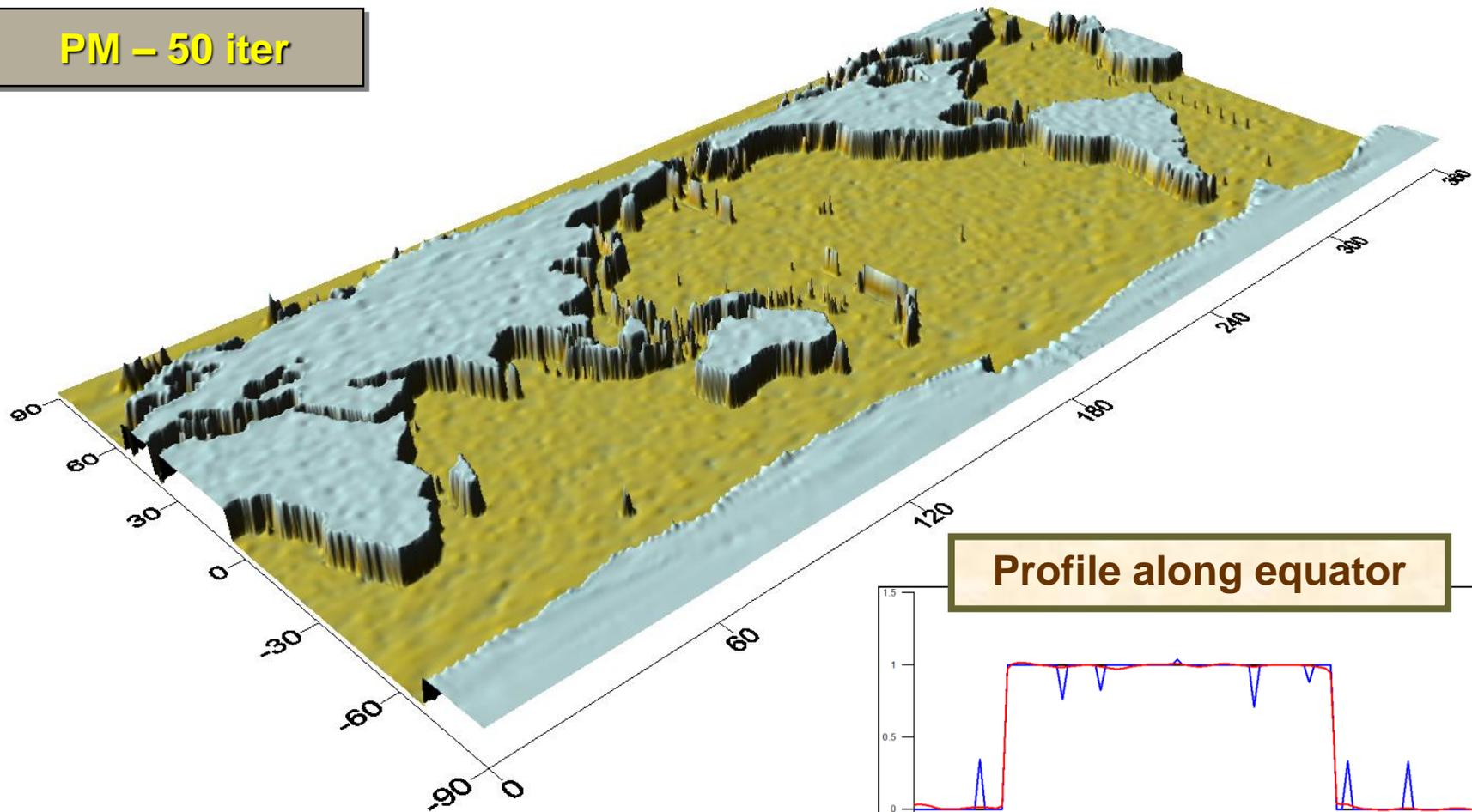


Profile along equator

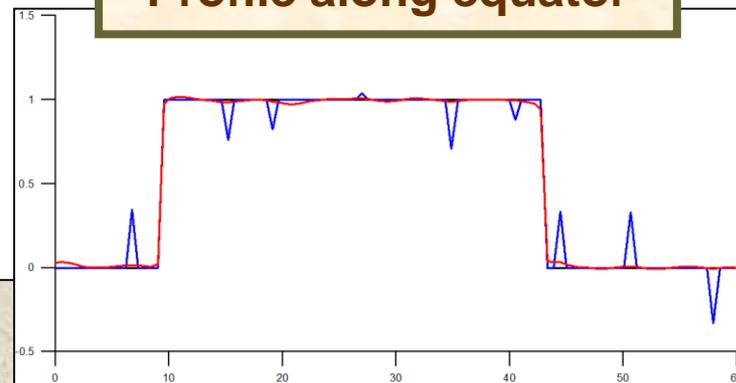


Nonlinear diffusion – 50 iterations

PM – 50 iter

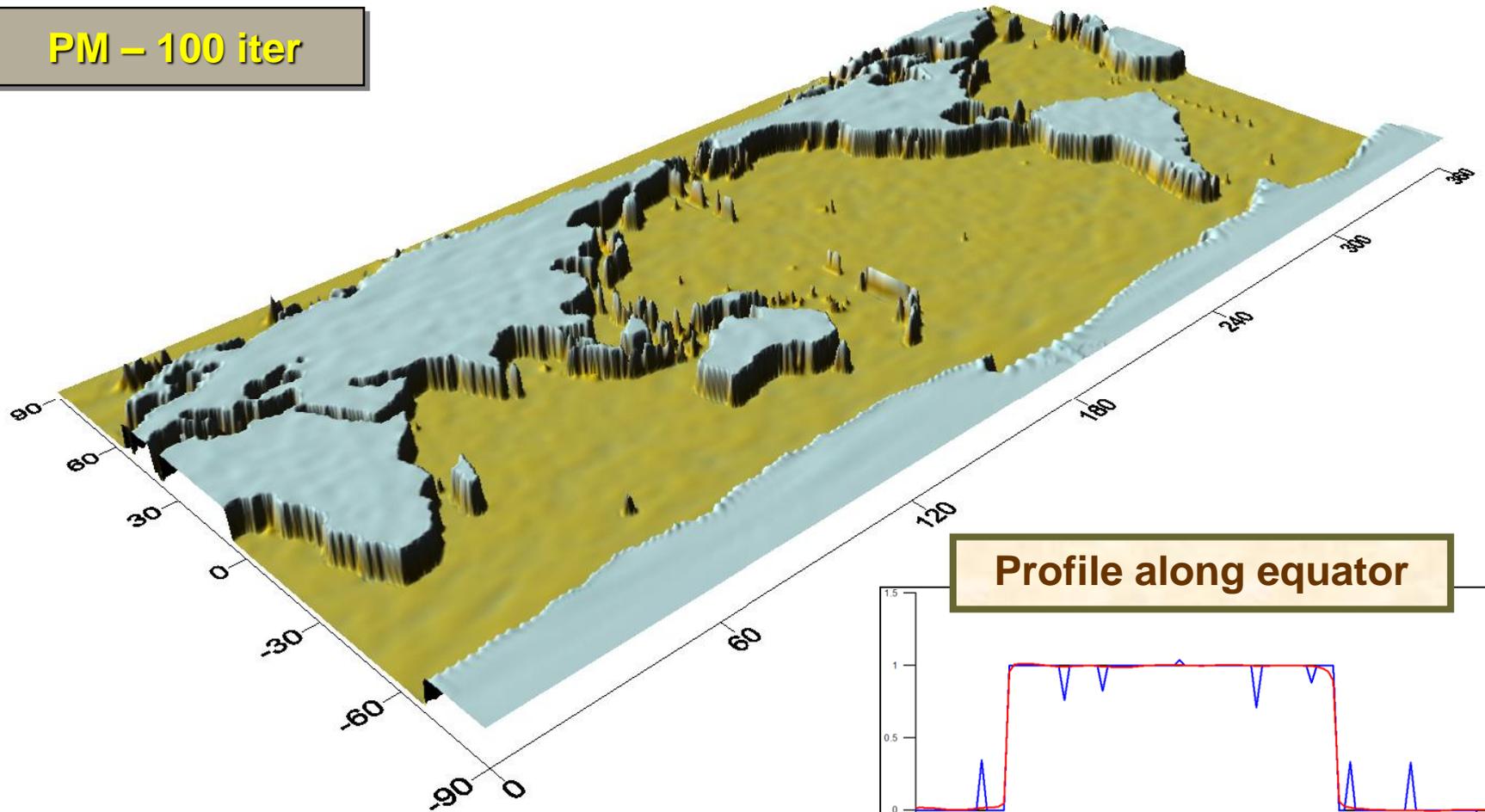


Profile along equator

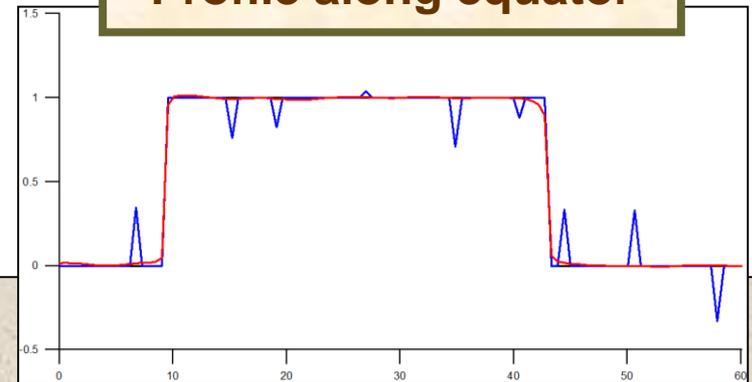


Nonlinear diffusion – 100 iterations

PM – 100 iter

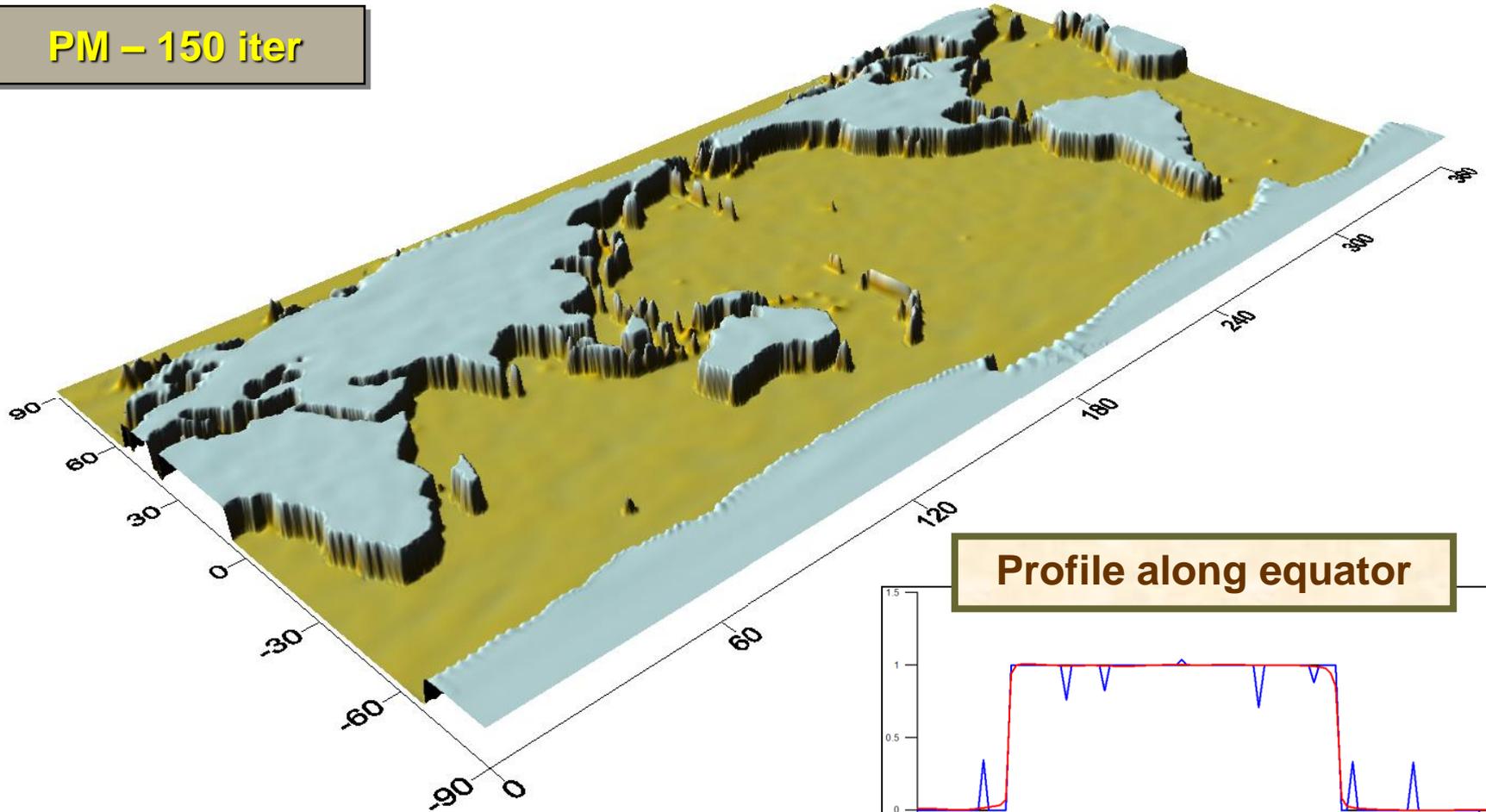


Profile along equator

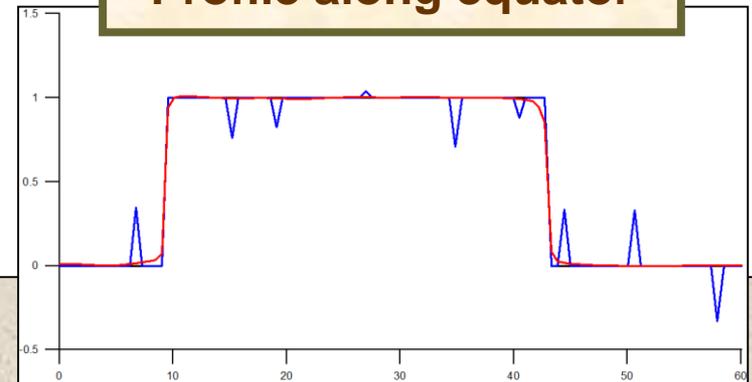


Nonlinear diffusion – 150 iterations

PM – 150 iter

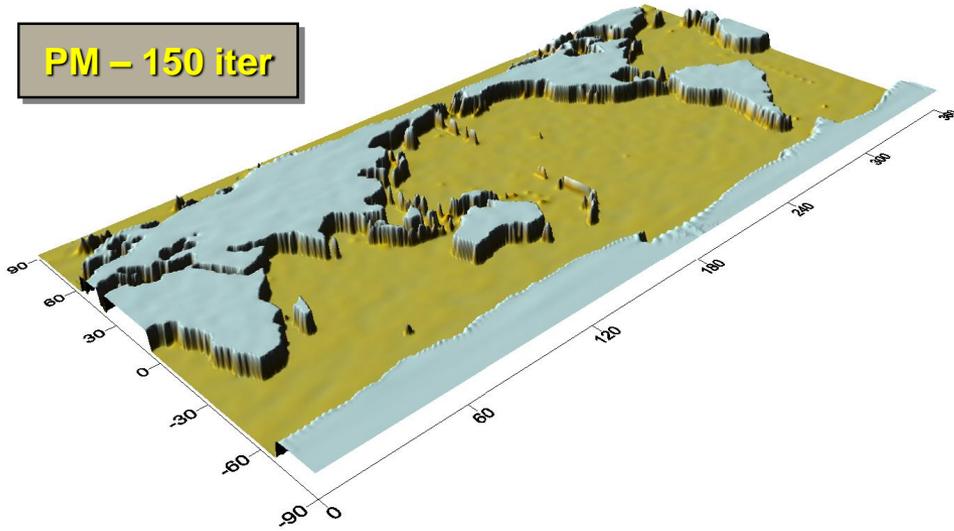


Profile along equator

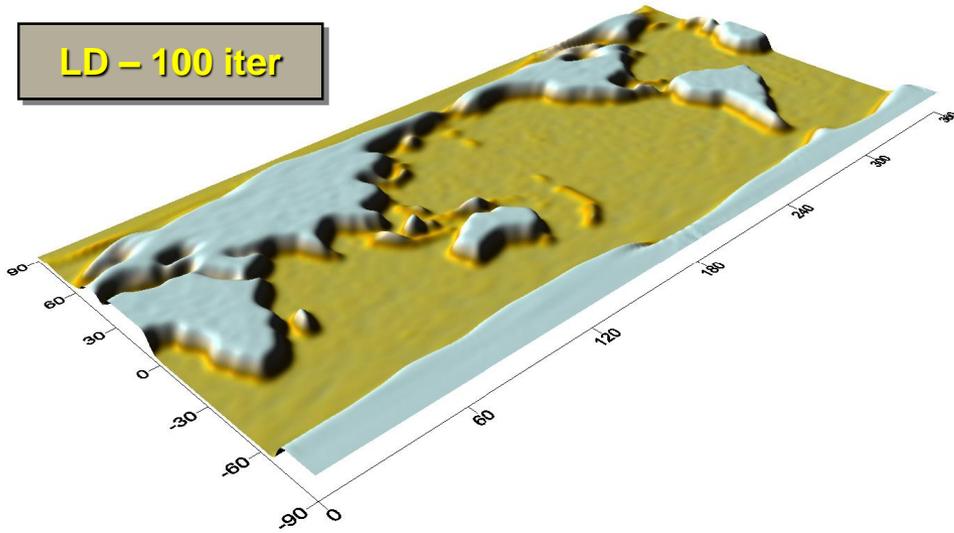


Porovnanie: lineárna ↔ nelineárna difúzia

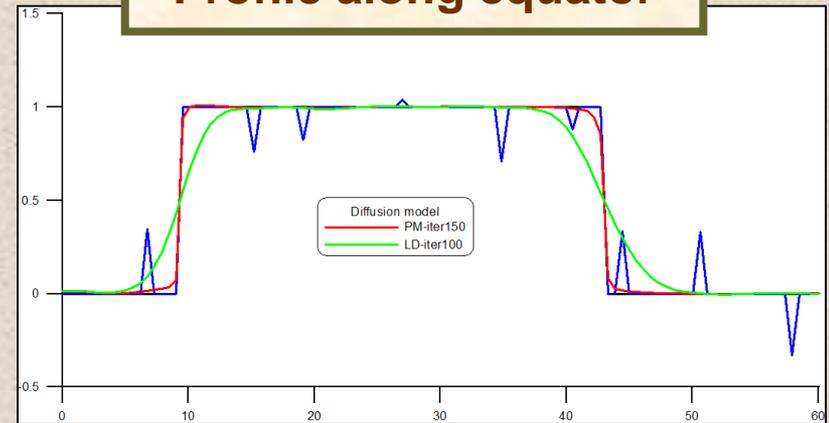
PM – 150 iter



LD – 100 iter

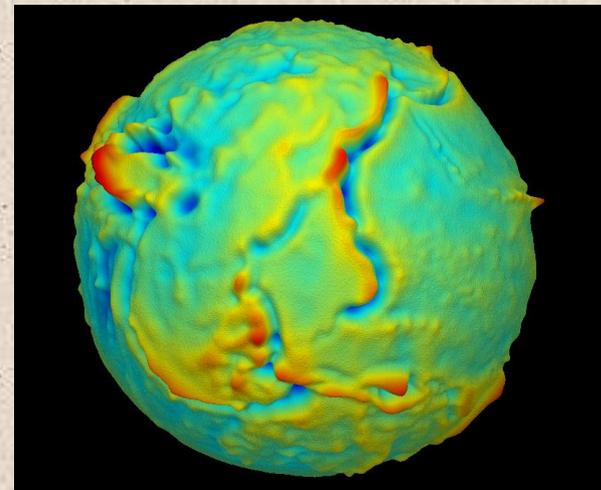


Profile along equator

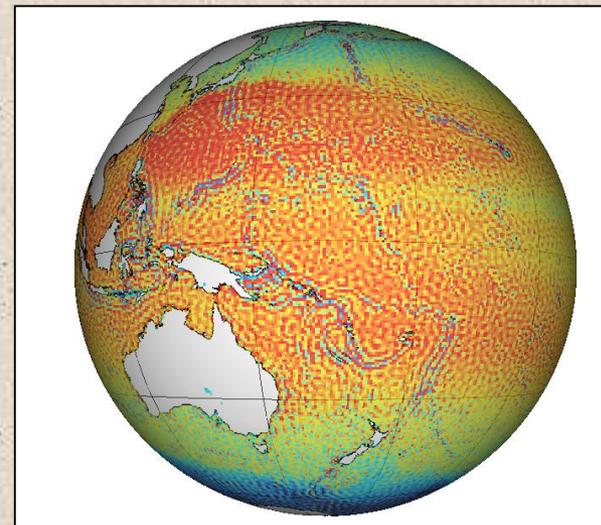


Filtrácia geodetických veličín

- Filtrovanie priamych meraní družicovej misie GOCE

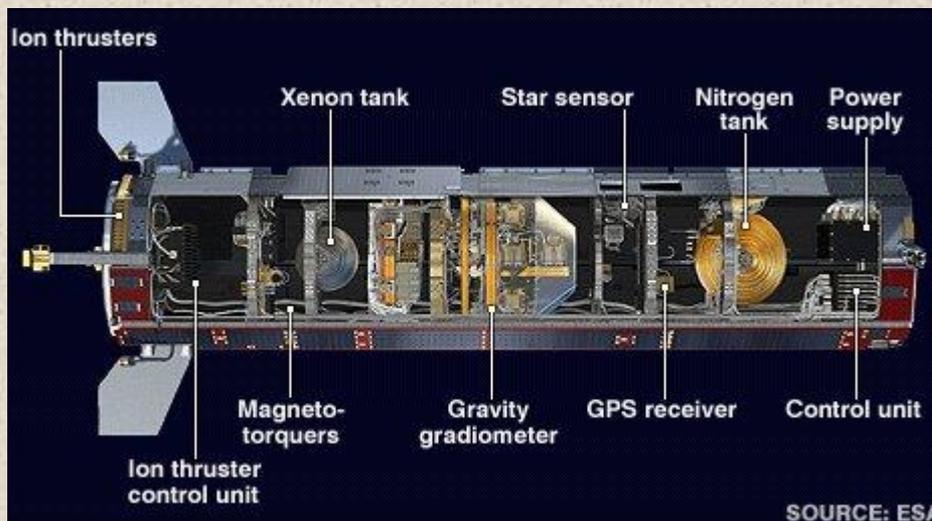


- Filtrovanie strednej hladiny mora a dynamickej topografie oceánov



Družicová misia GOCE

Gravity Field and Steady-State Ocean Circulation Explorer

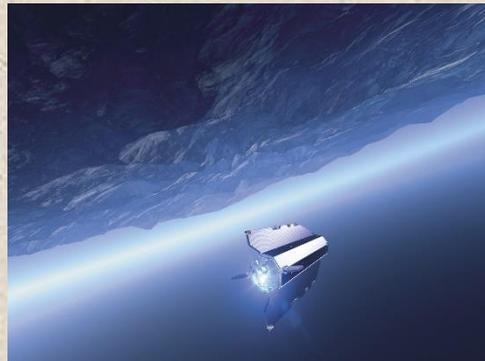


$$\text{grad}(\text{grad}V) = \text{grad}(\vec{g}) =$$

$$= \begin{bmatrix} V_{xx} & V_{xy} & V_{xz} \\ & V_{yy} & V_{yz} \\ & & V_{zz} \end{bmatrix}$$

Vypustenie družice

(17 marec 2009)

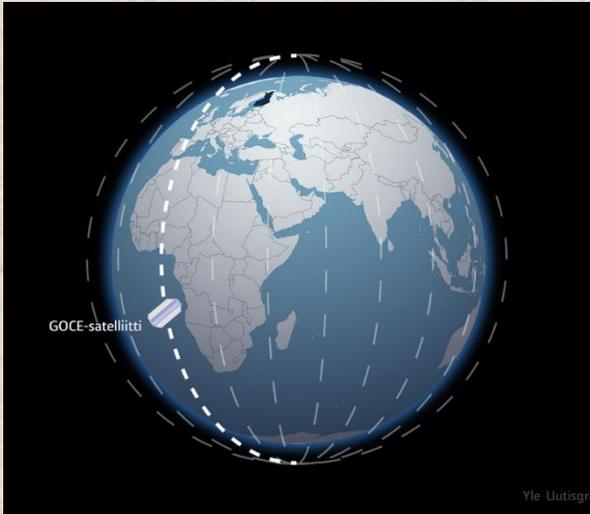


Koniec misie

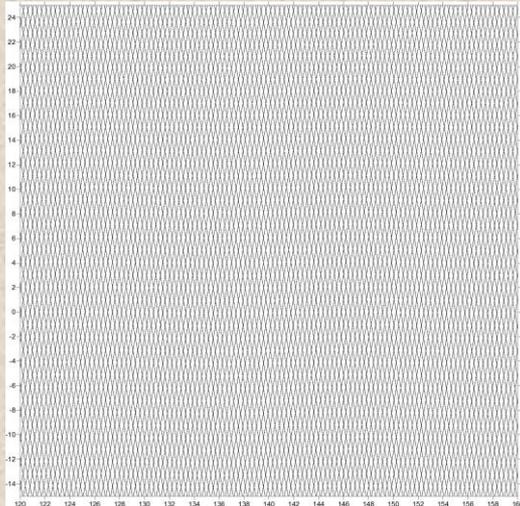
(11 november 2013)



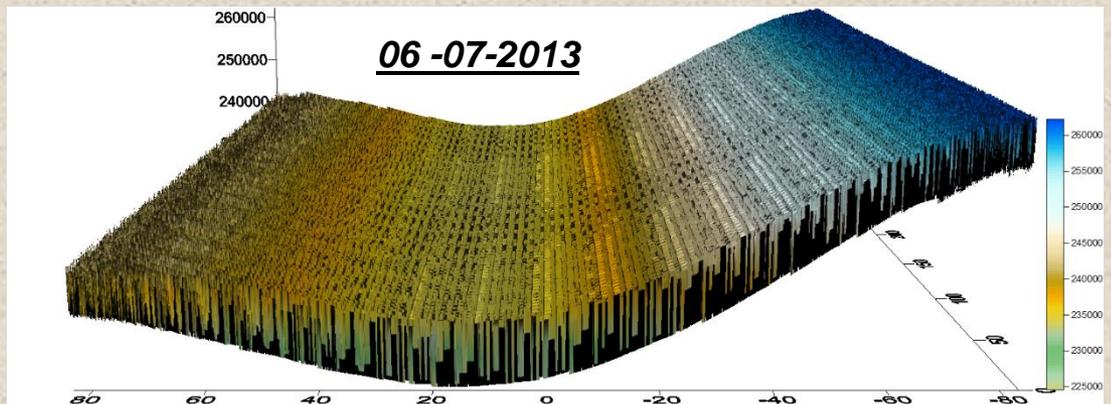
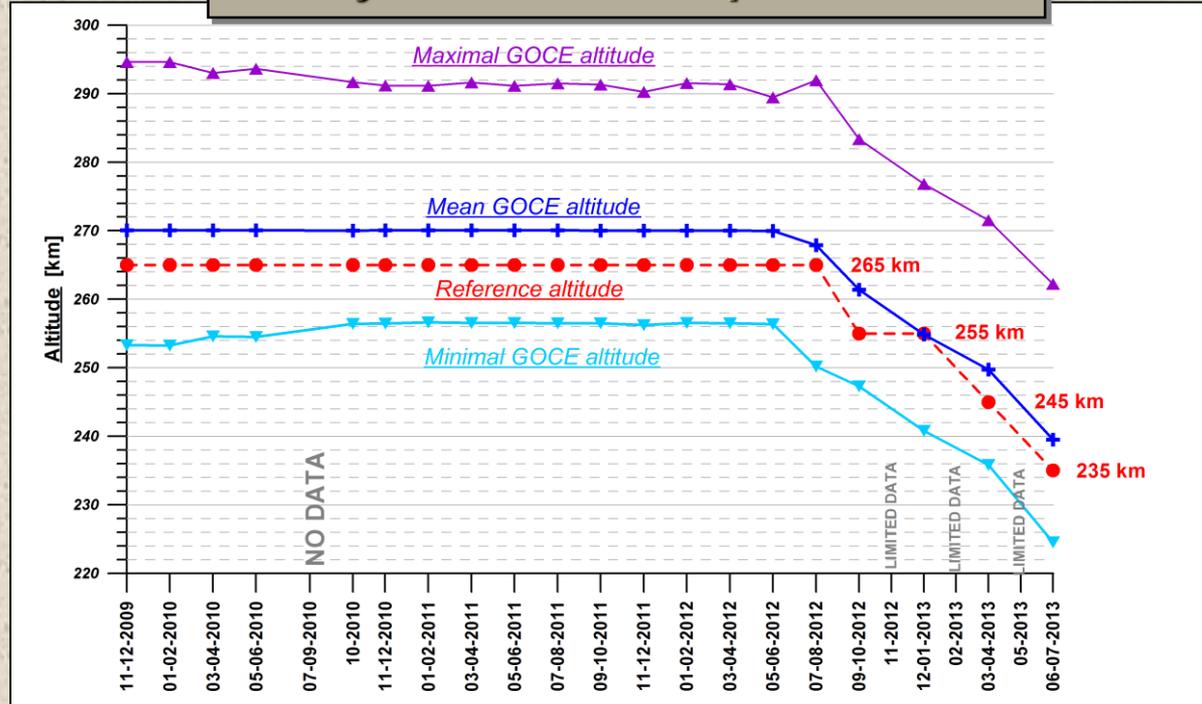
Orbity družicovej misie GOCE



Hustota meraní
(61 dní)



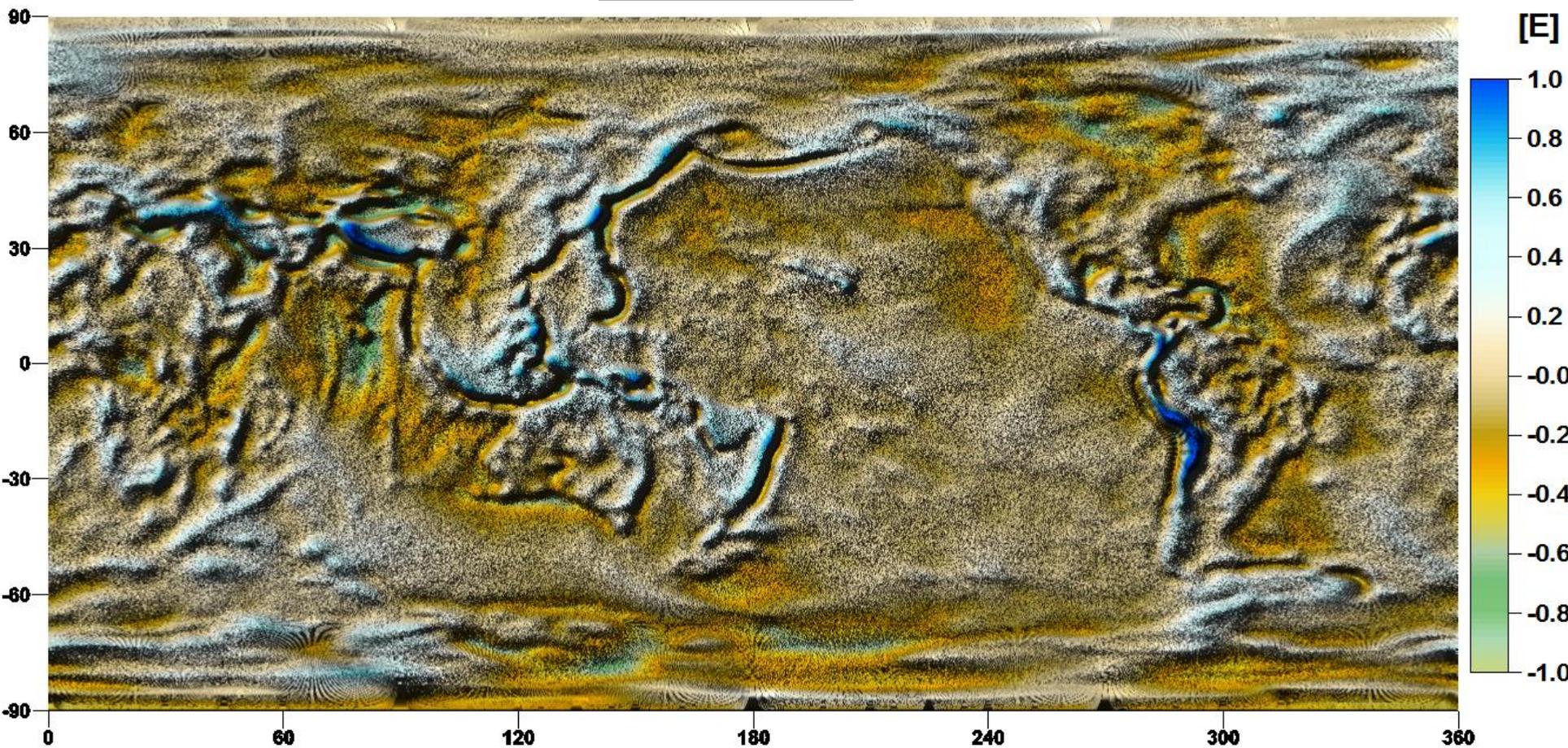
Výška letu nad elipsoidom



Priame merania GOCE

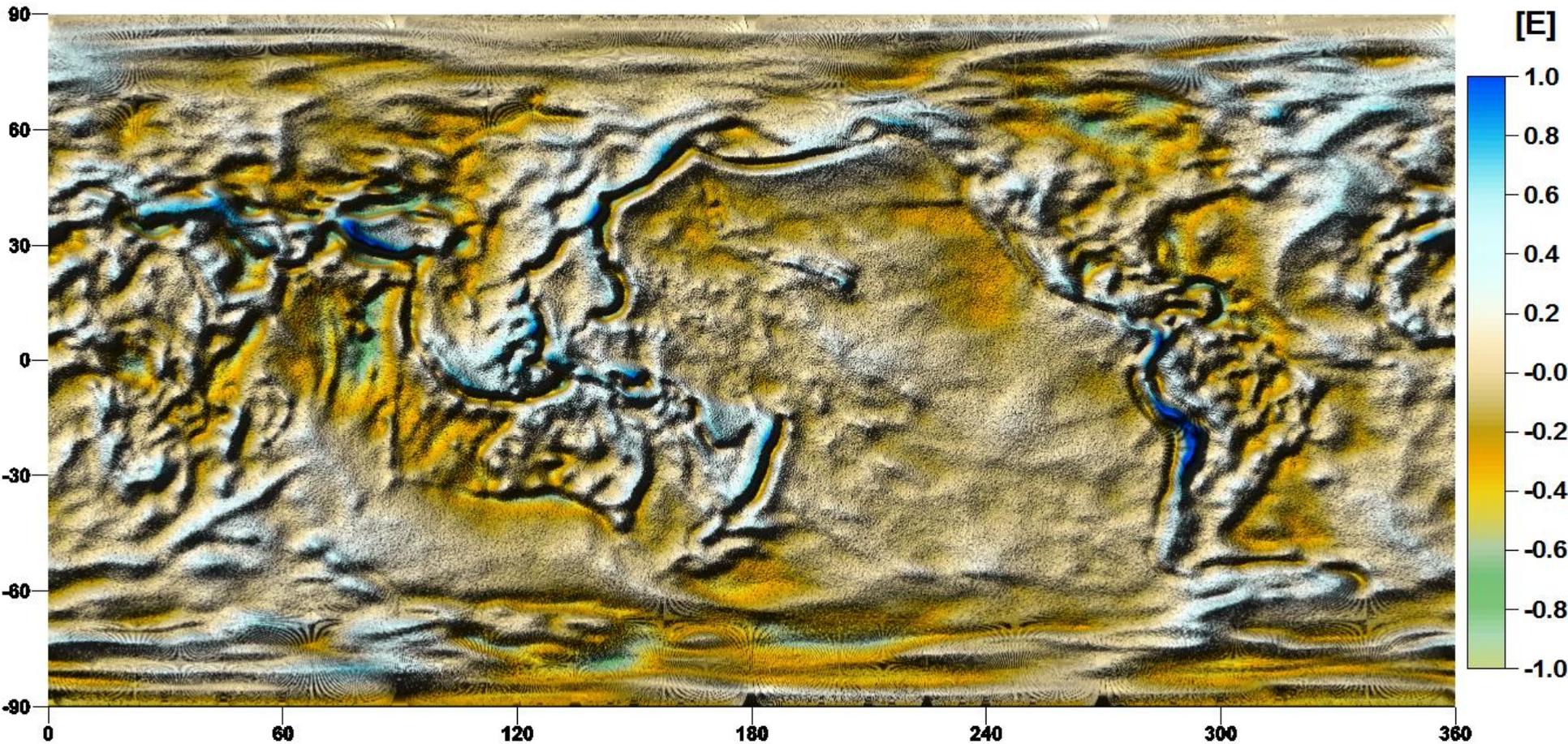
T_{zz} komponent tiažového tenzora

$$T_{zz} = V_{zz} - U_{zz}$$



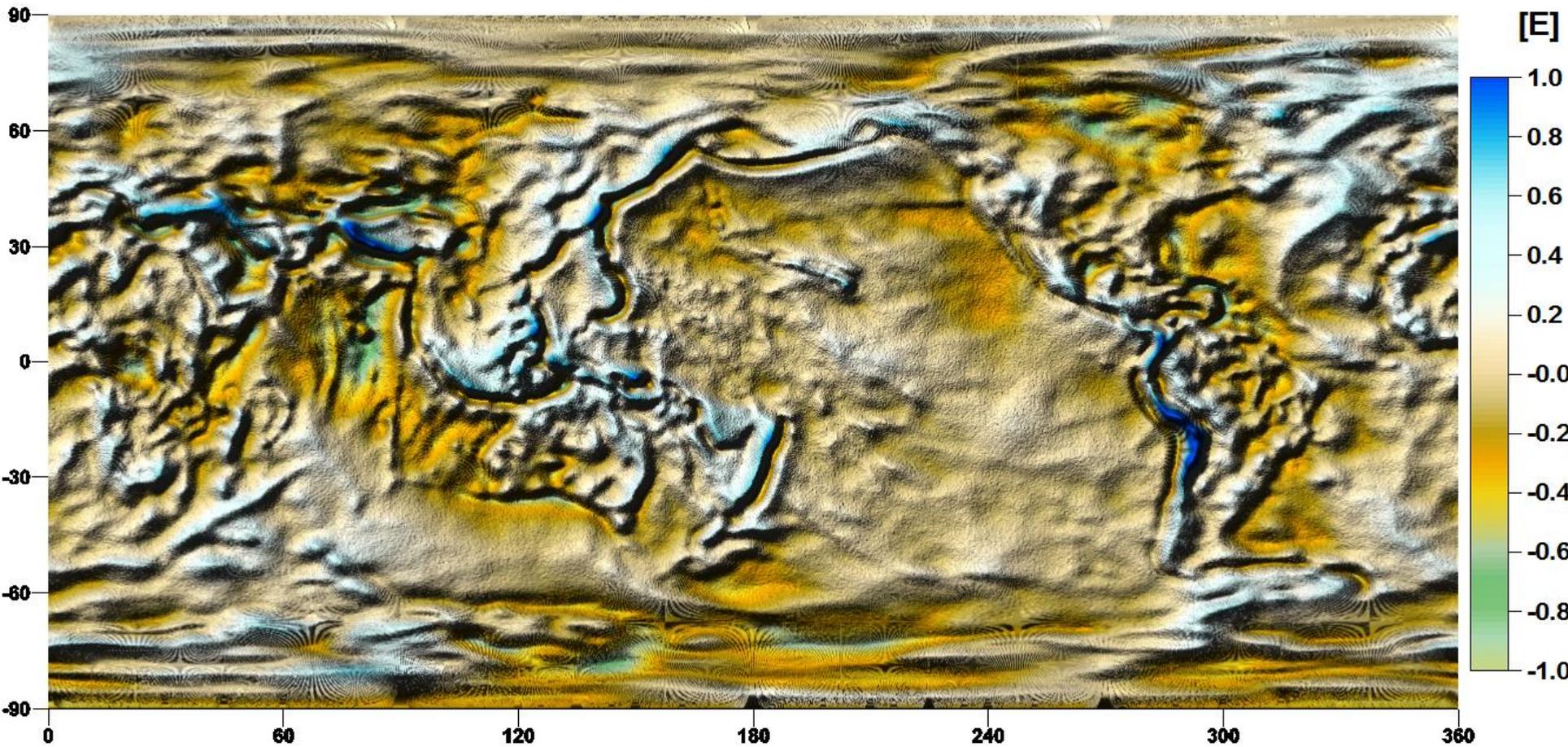
Nonlinear diffusion

10 iterations



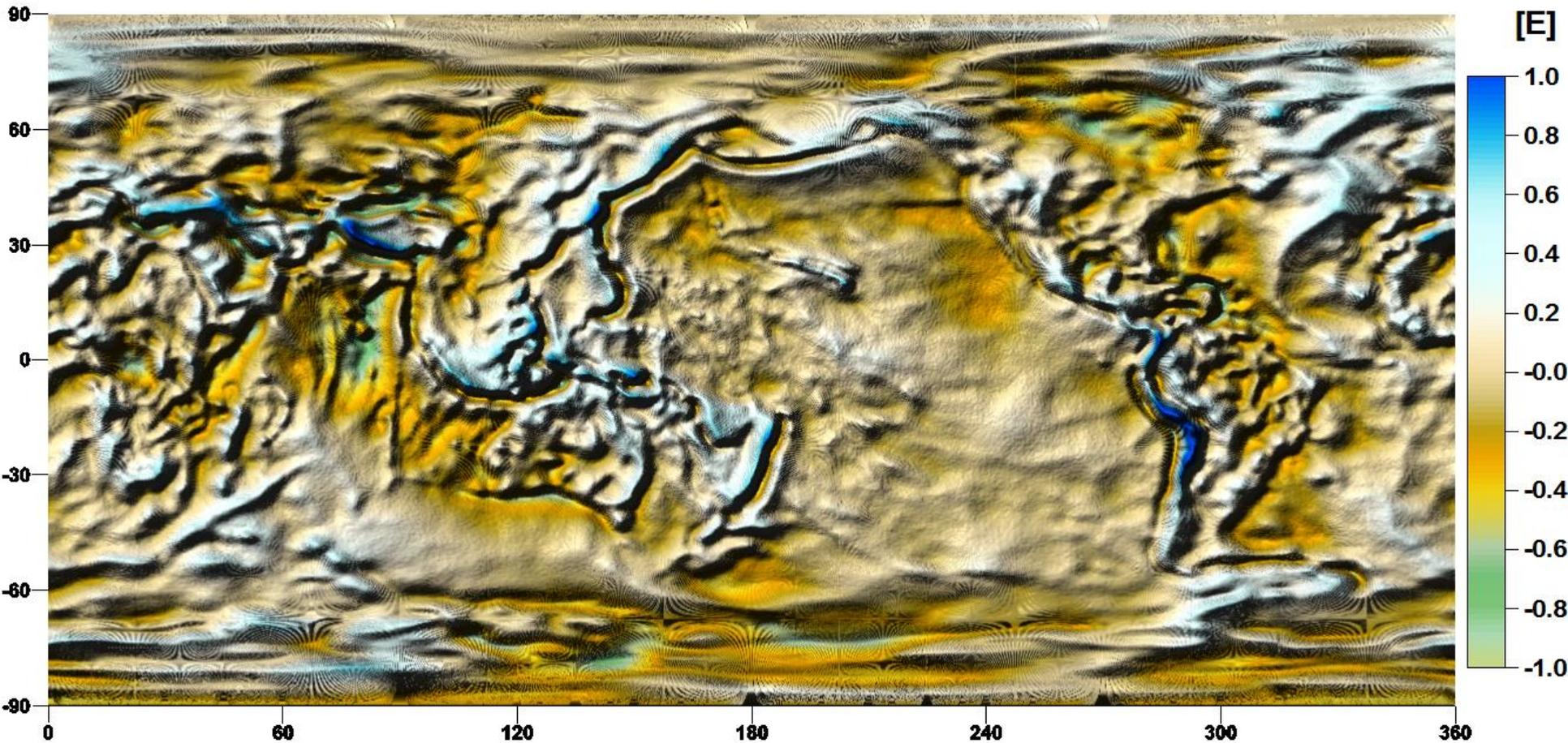
Nonlinear diffusion

20 iterations



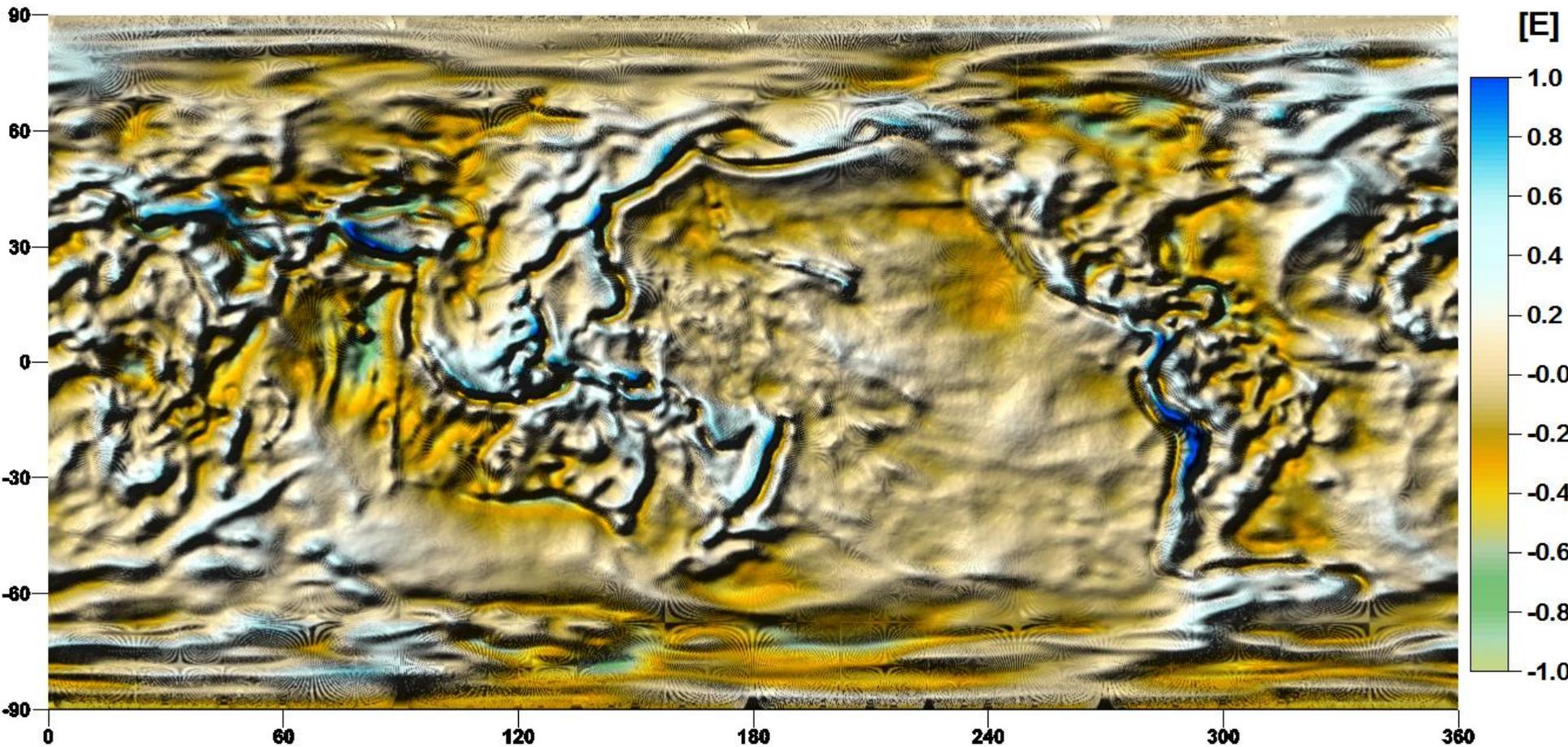
Nonlinear diffusion

50 iterations



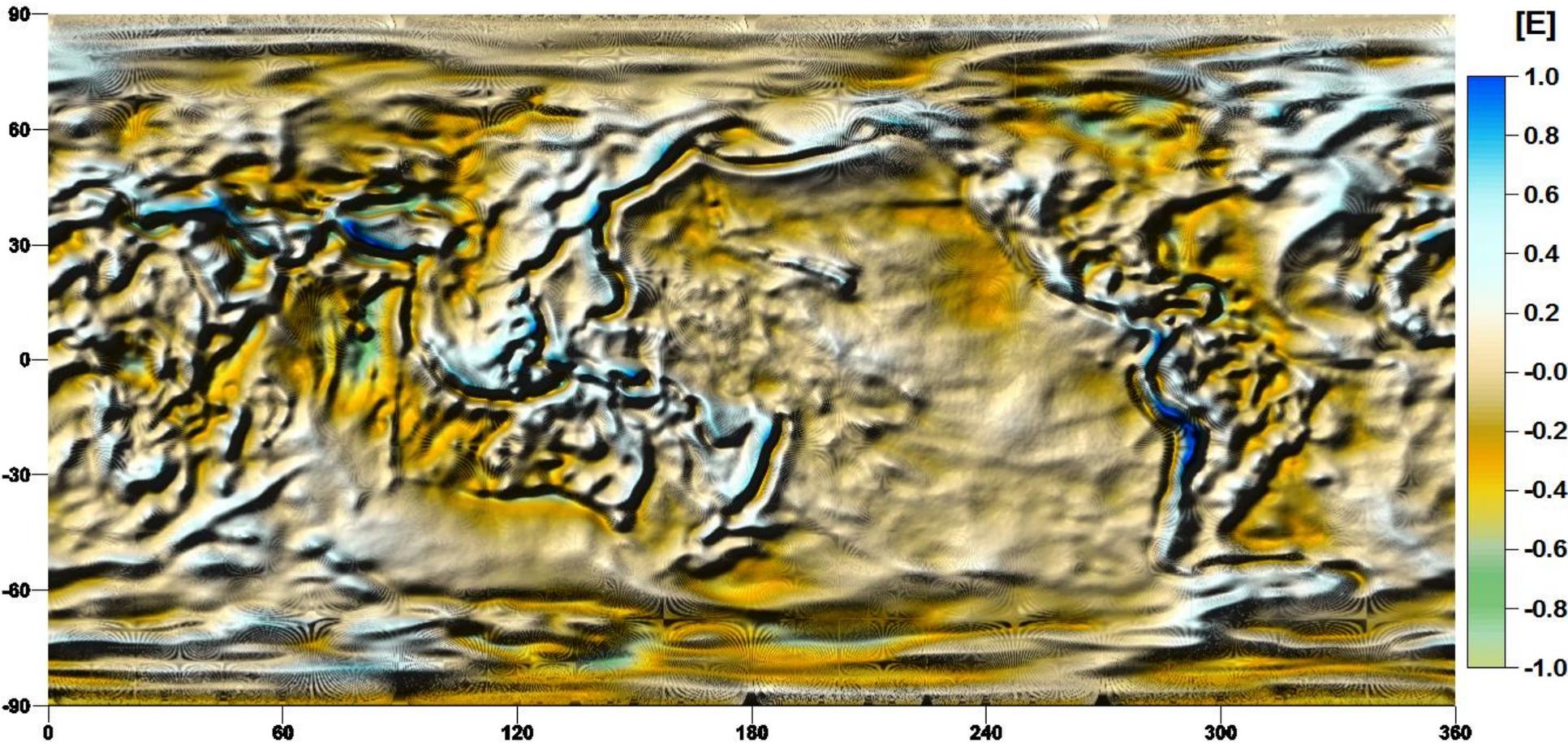
Nonlinear diffusion

100 iterations



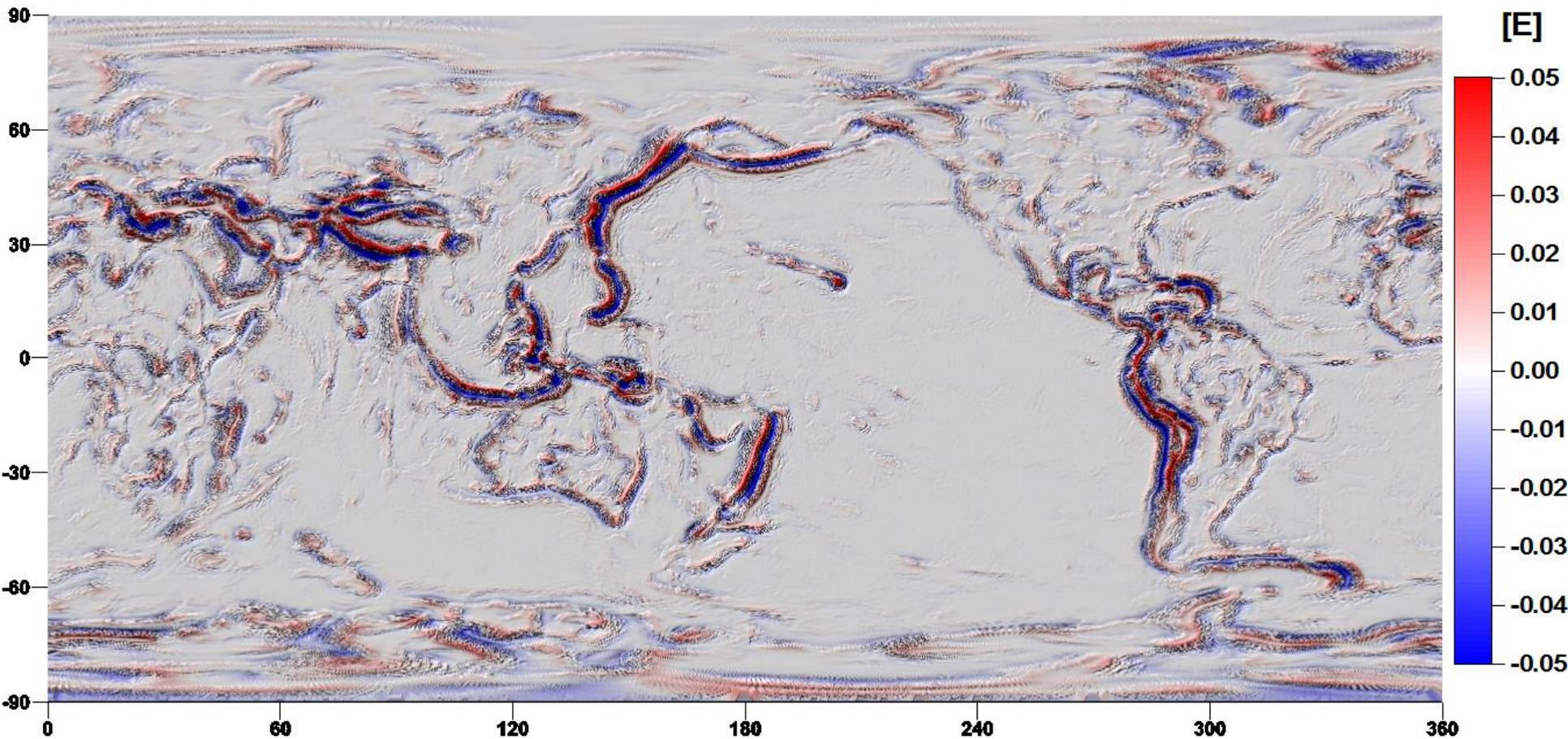
Linear diffusion

100 iterations



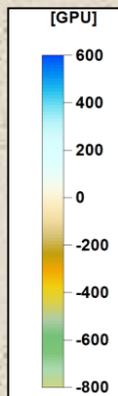
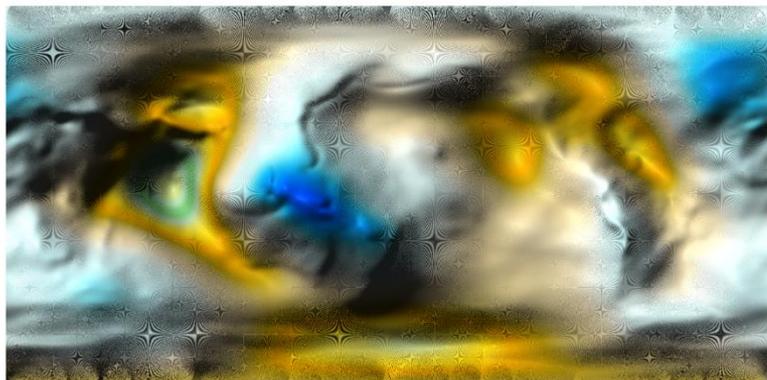
Nelineárna – lineárna difúzia

100 iterations

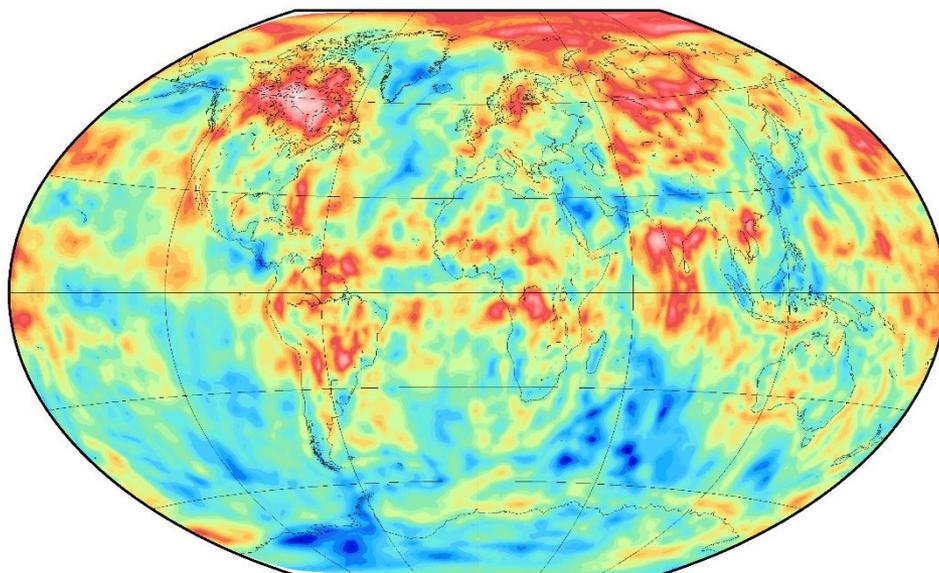
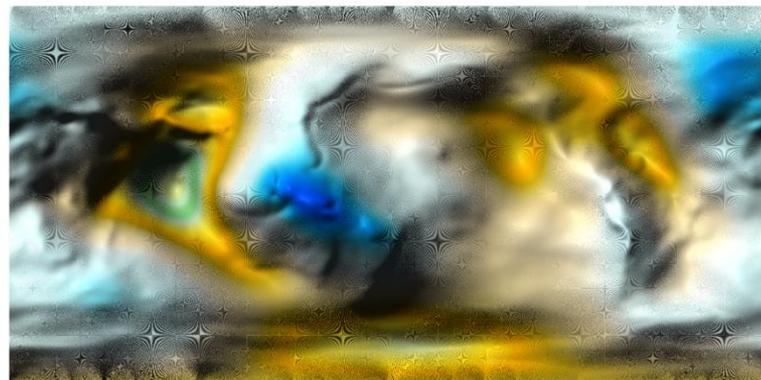


Model tiažového poľa z filtrovaných dát

MFS



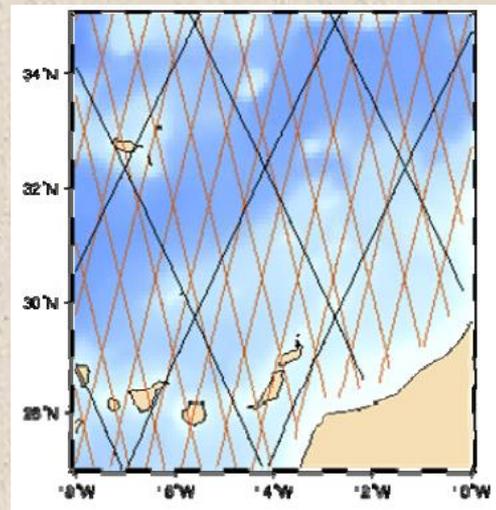
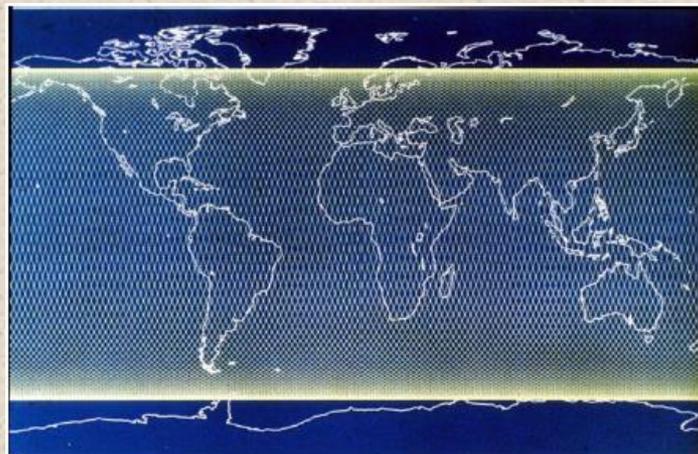
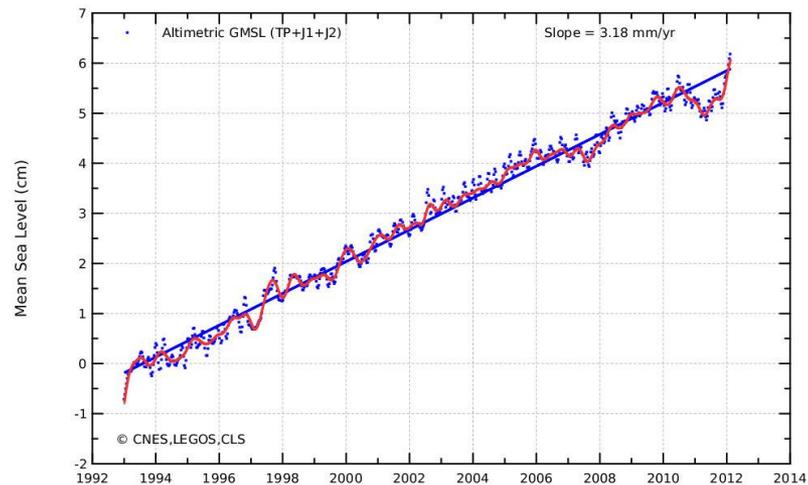
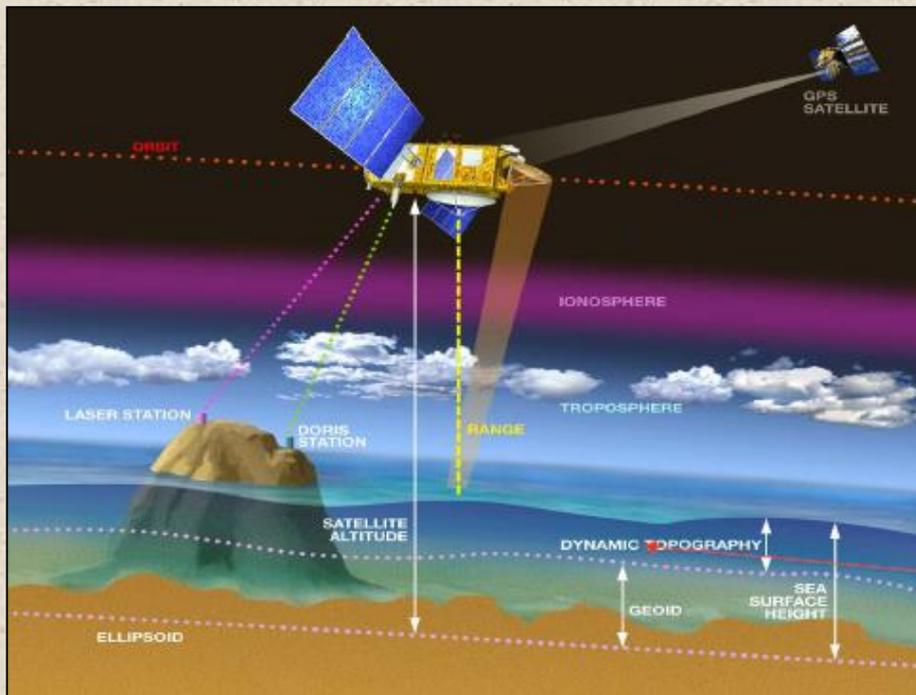
GOCO03S



STATISTICS

Nodes	5 760 002
Mean	-0.004 m²s⁻²
Max	0.268 m ² s ⁻²
MIN	-0.231 m ² s ⁻²
St. Dev.	0.069 m²s⁻²

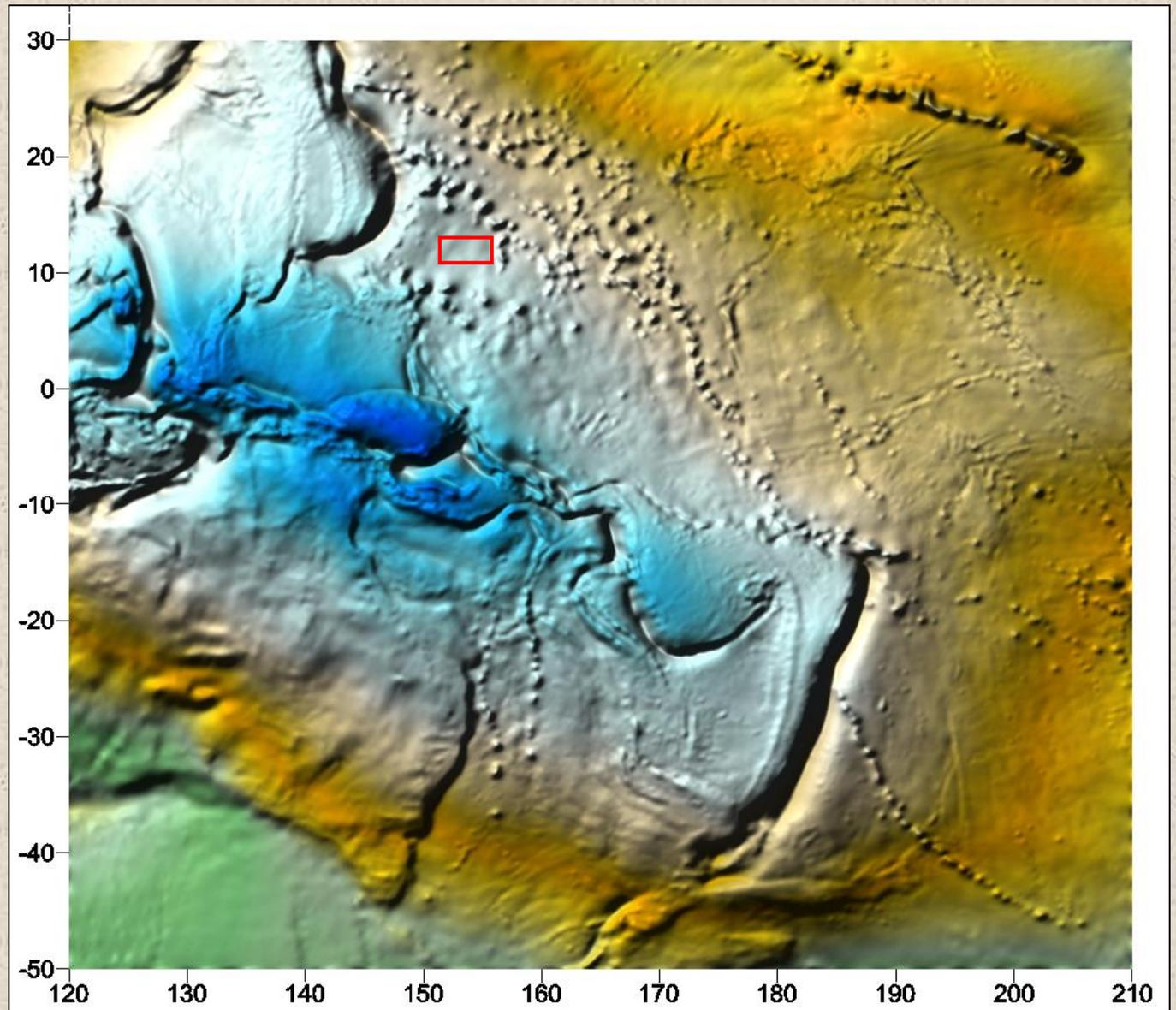
Družicová altimetria



Družicová altimetria

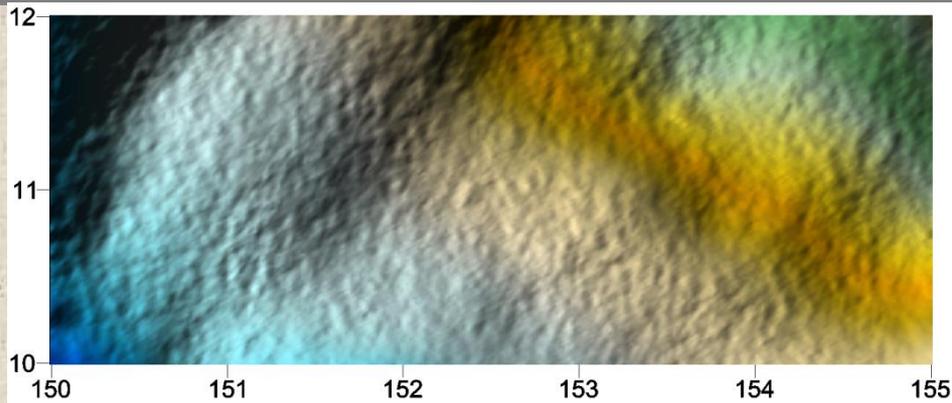


Stredná
hladina mora

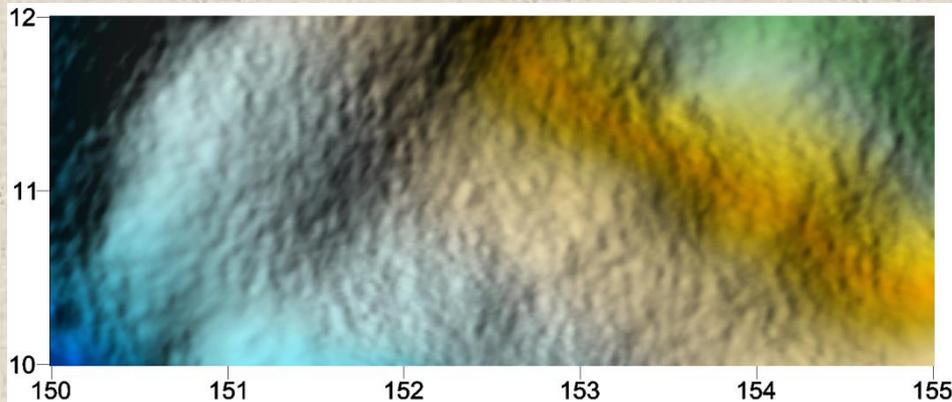


Filtrácia strednej hladiny mora

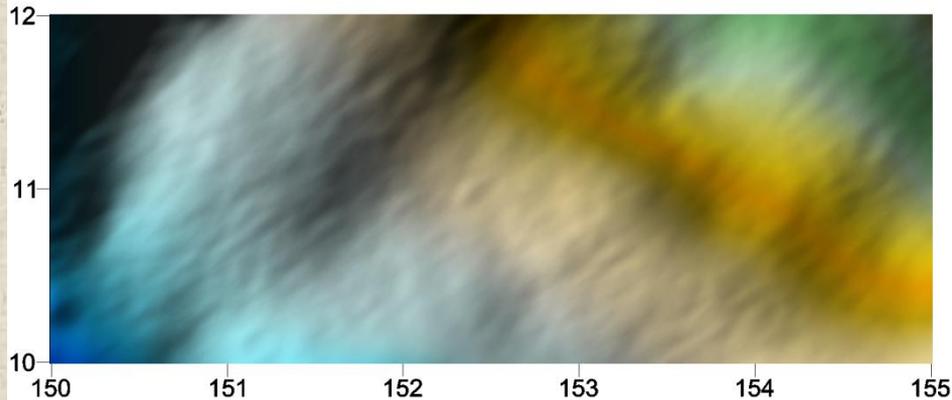
**Model strednej
hladiny mora
DTU13
(1"x 1")**



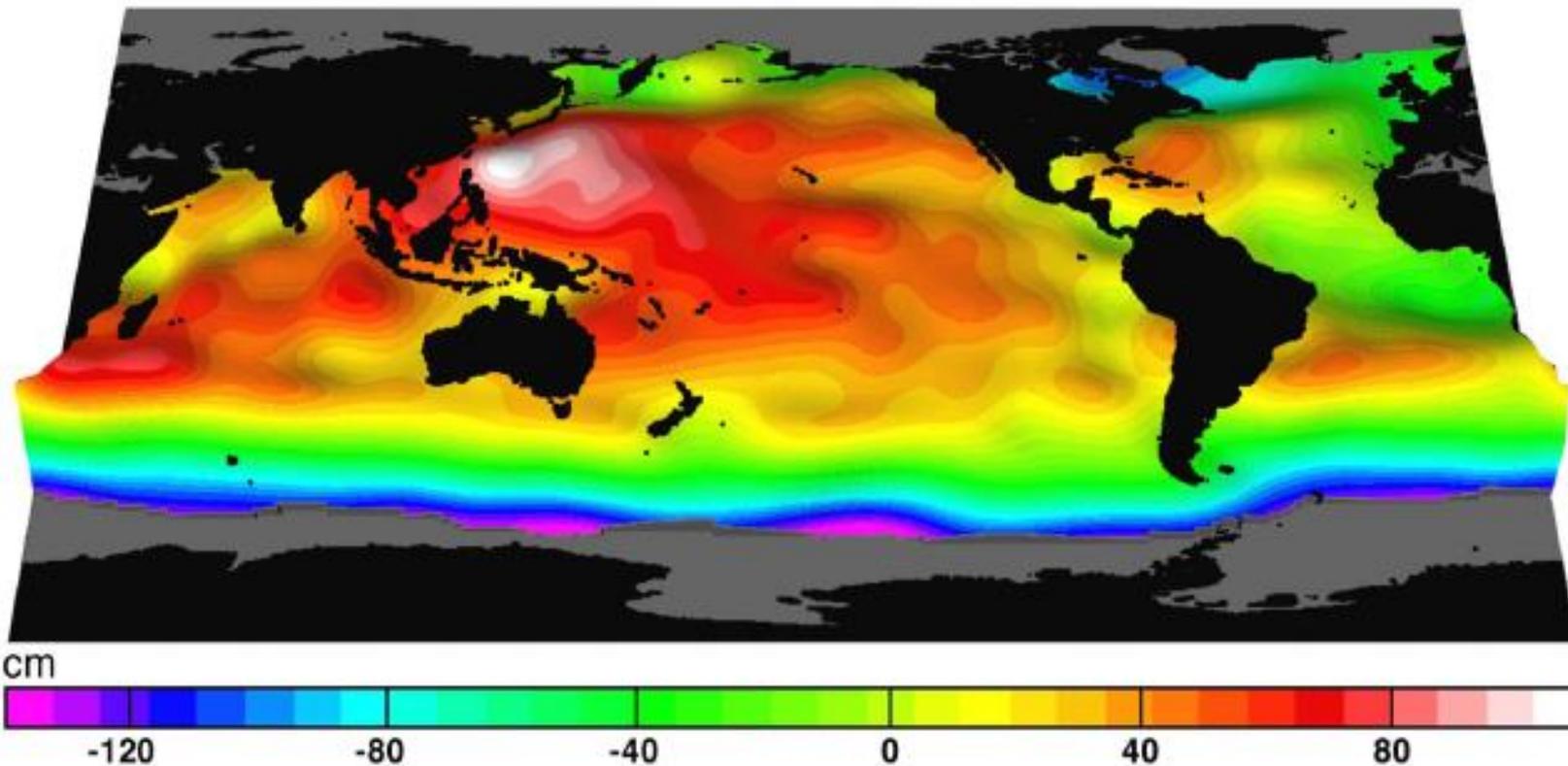
**2 kroky
nelineárnej
filtrácie**



**2 kroky
lineárnej
filtrácie**



Dynamická topografia oceánov



Dynamická topografia oceánov

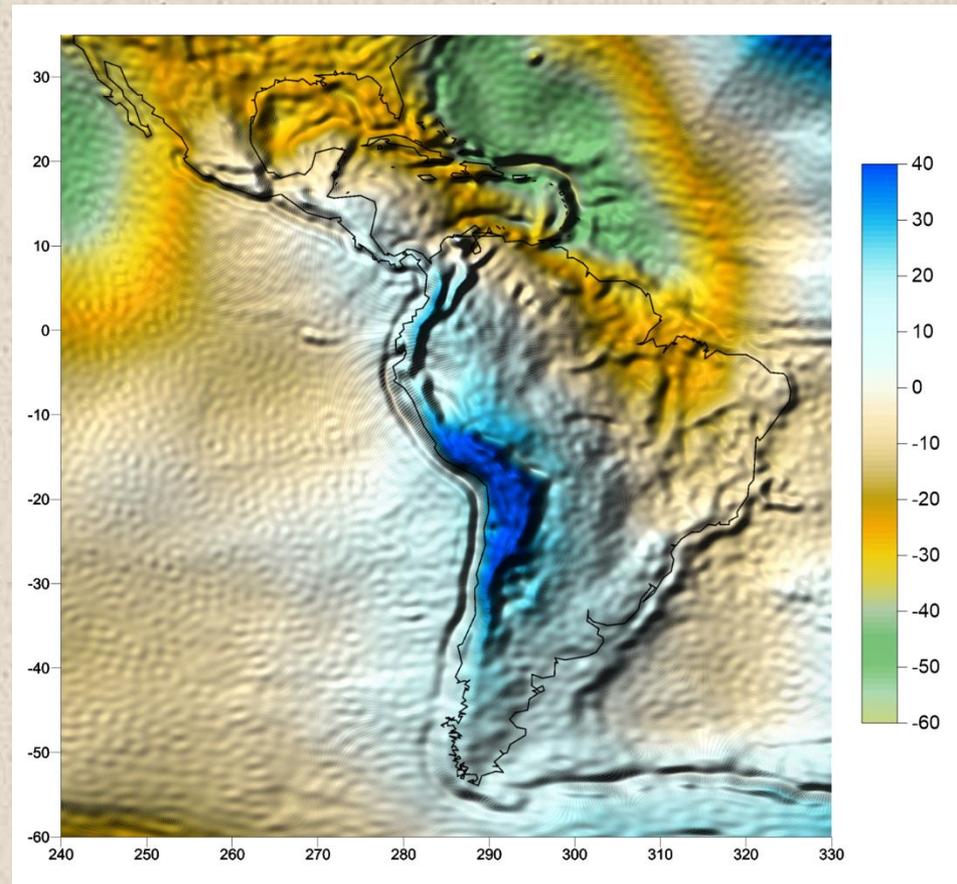
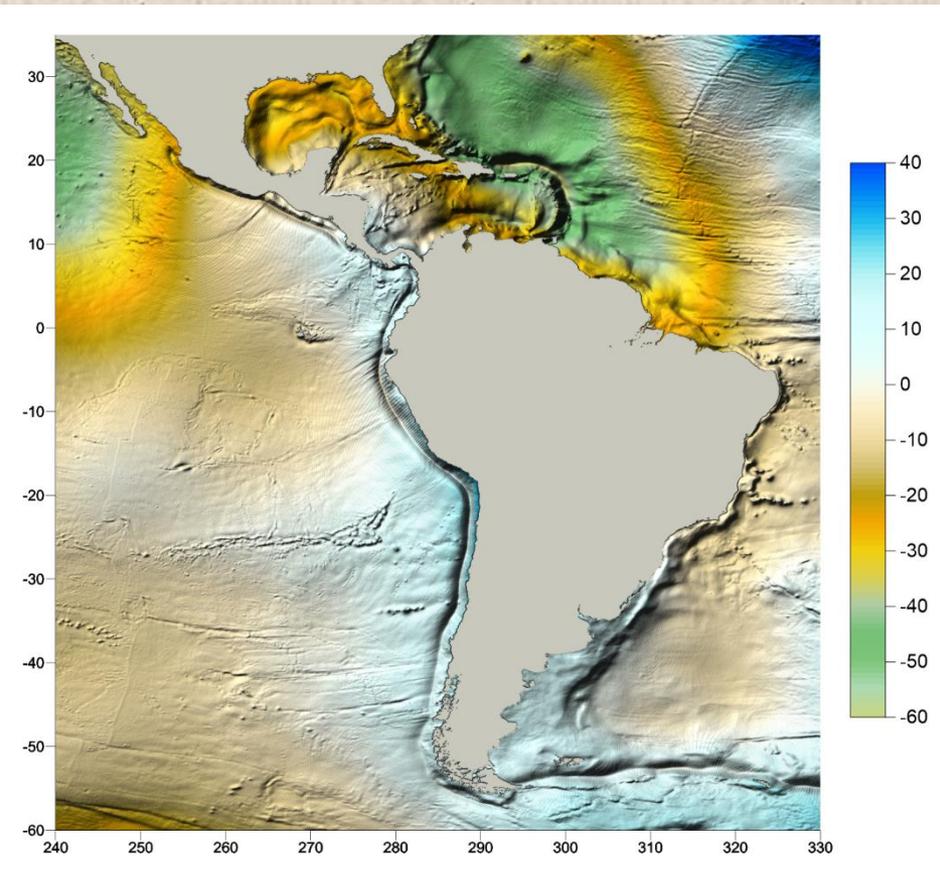
Družicová altimetry:

DTU13_MSS

Globálny geopotenciálny model:

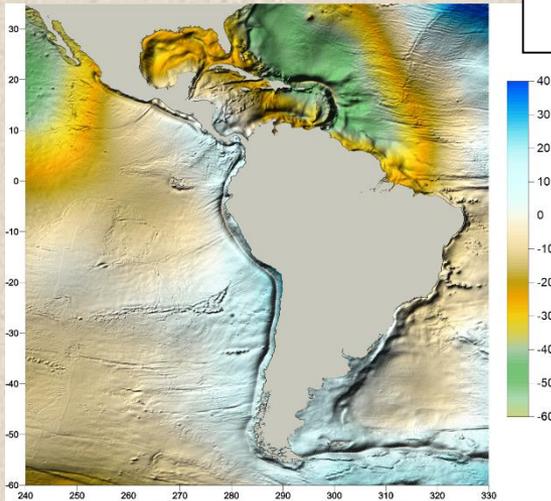
GO_CONS_GCF_2_DIR_R5

(SH do rádu 300)

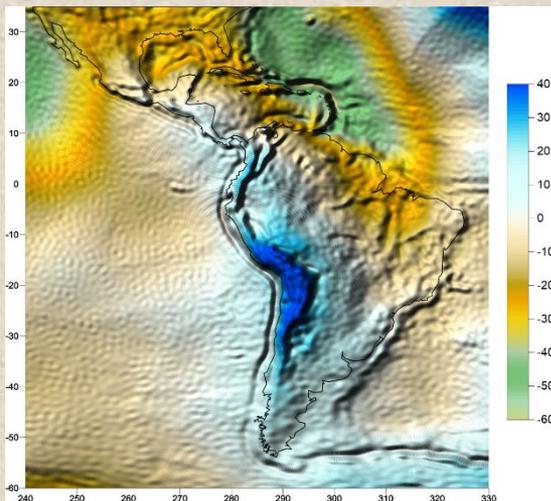


Dynamická topografia oceánov

DTU13_MSS



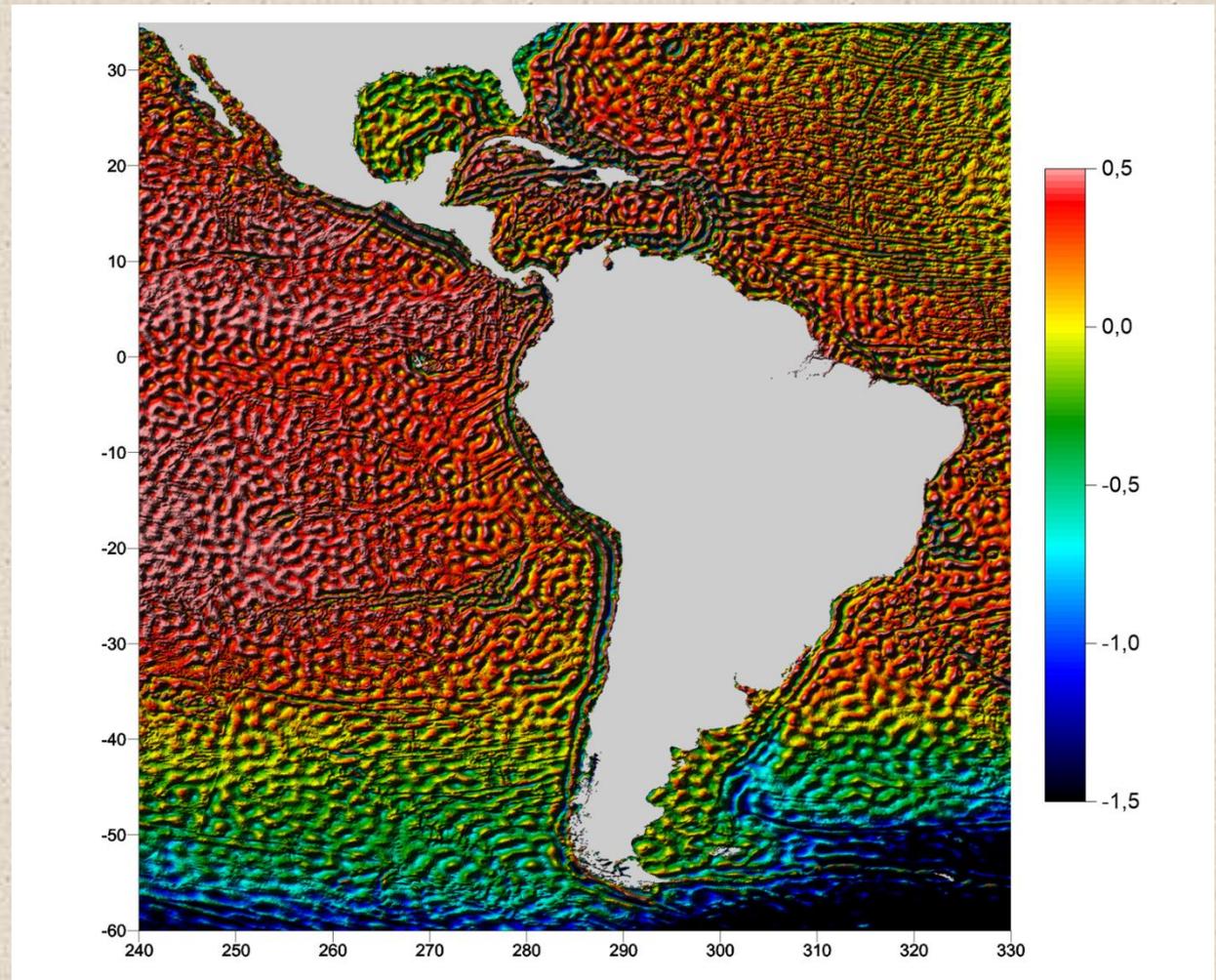
GO_CONS_GCF_2_DIR_R5



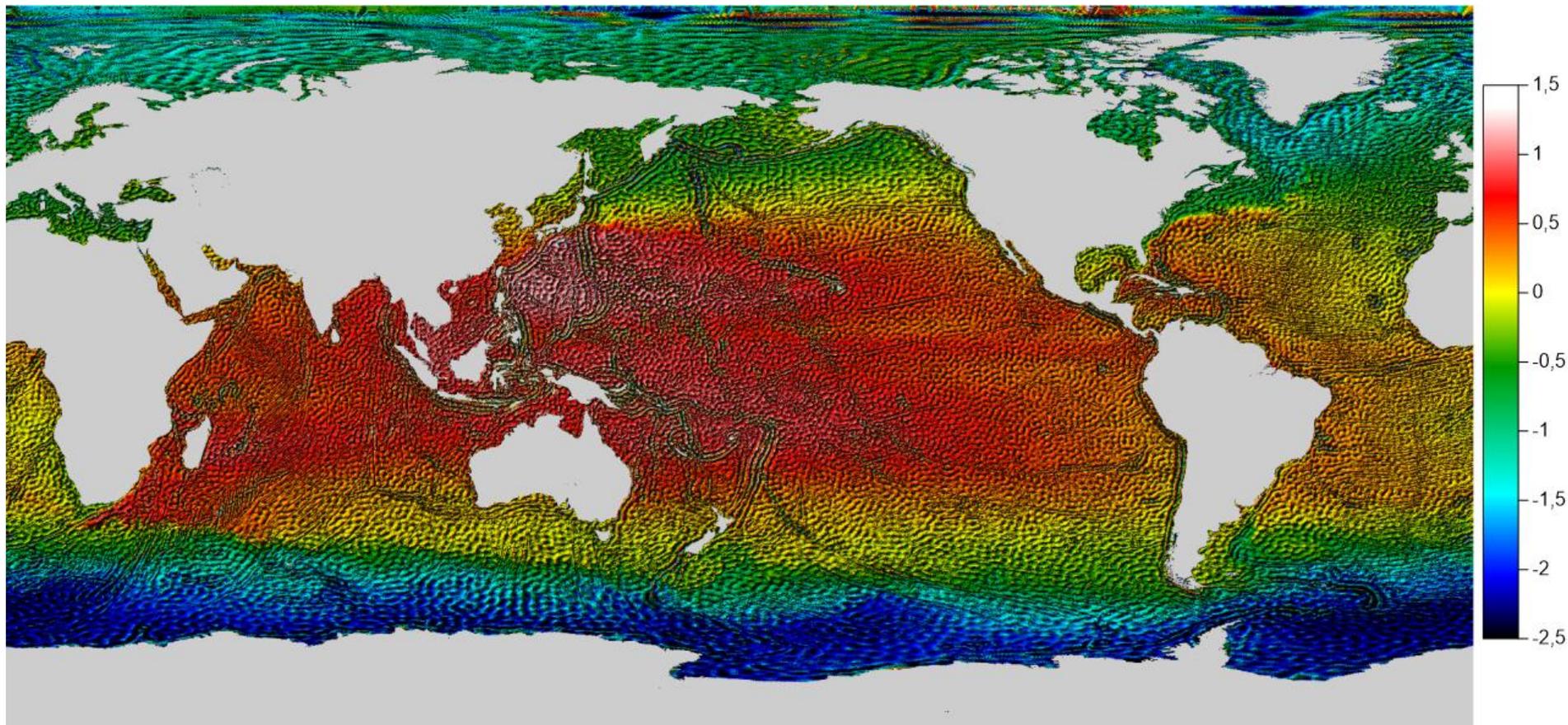
“geodetický prístup”

$$\text{SDTO} = \text{SHM} - \text{geoid}$$

SDTO – stredná dynamická topografia oceánov
SHM – stredná hladina morí



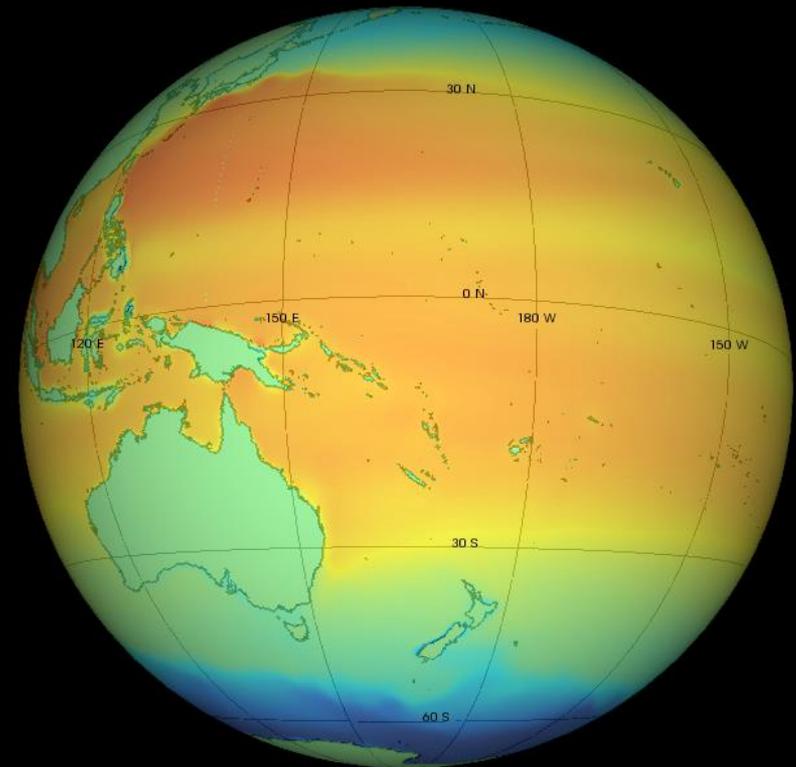
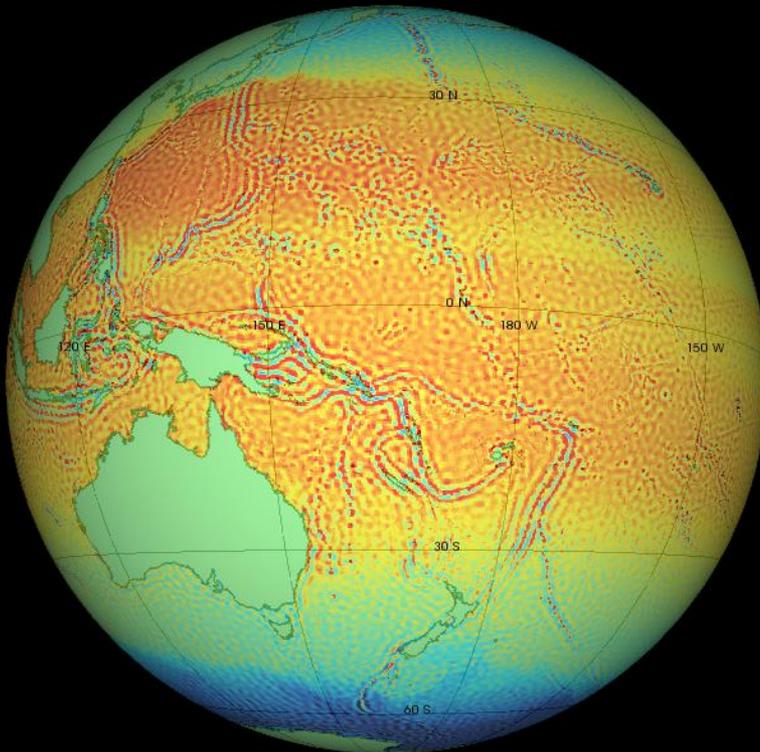
Dynamická topografia oceánov



Dynamická topografia oceánov

Družicová altimetry + GOCE

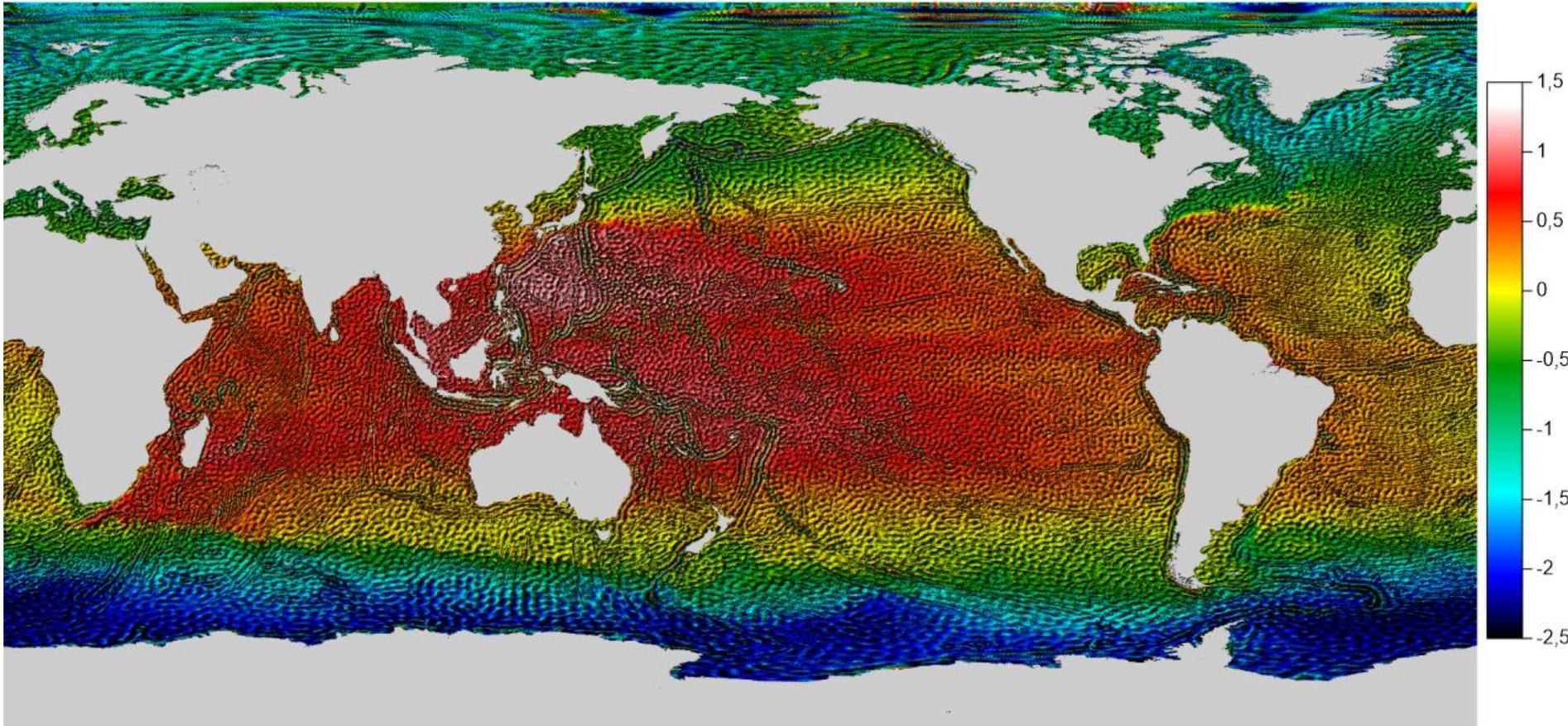
Po filtrovaní



Dynamická topografia oceánov

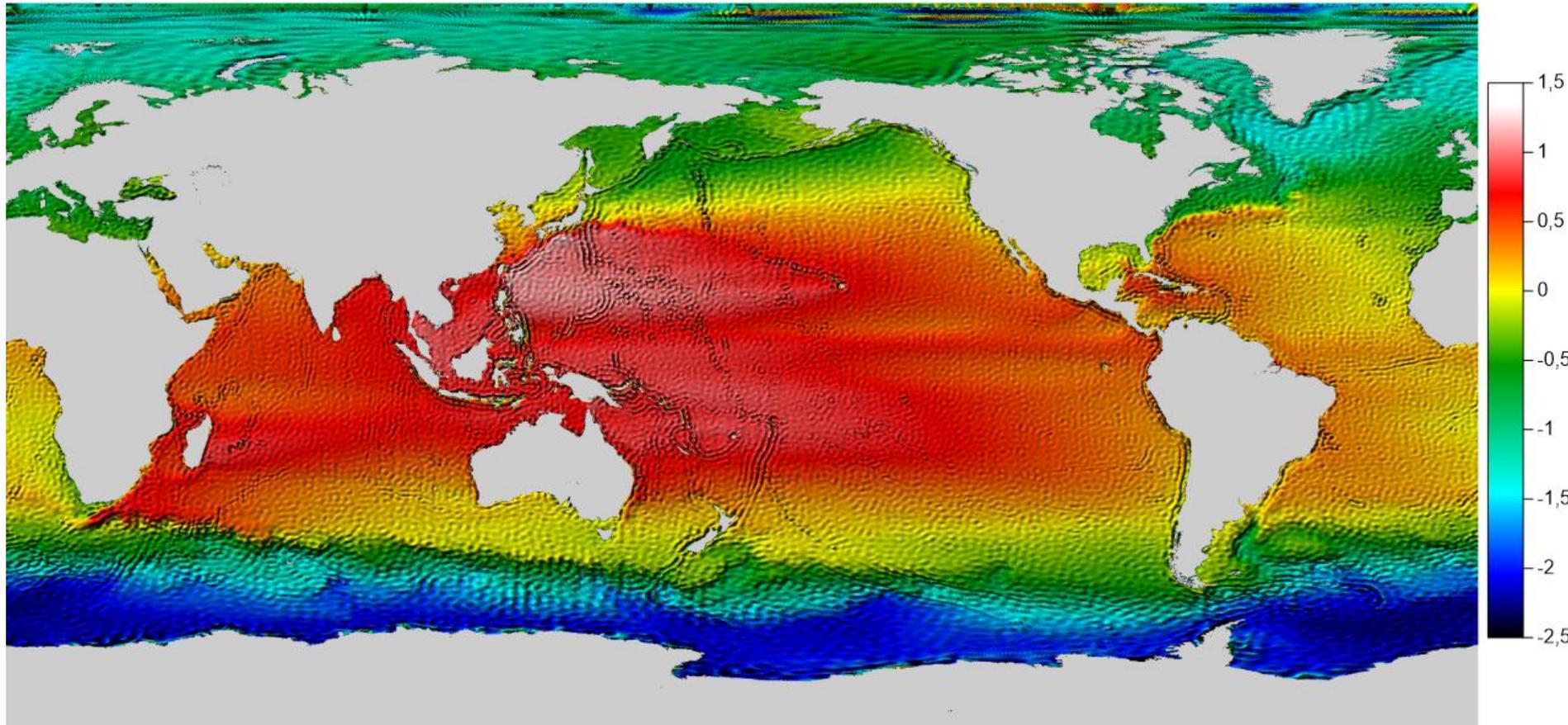
Initial data

DTU13_MSS - GOCE_DIR5
(SH up to 300)



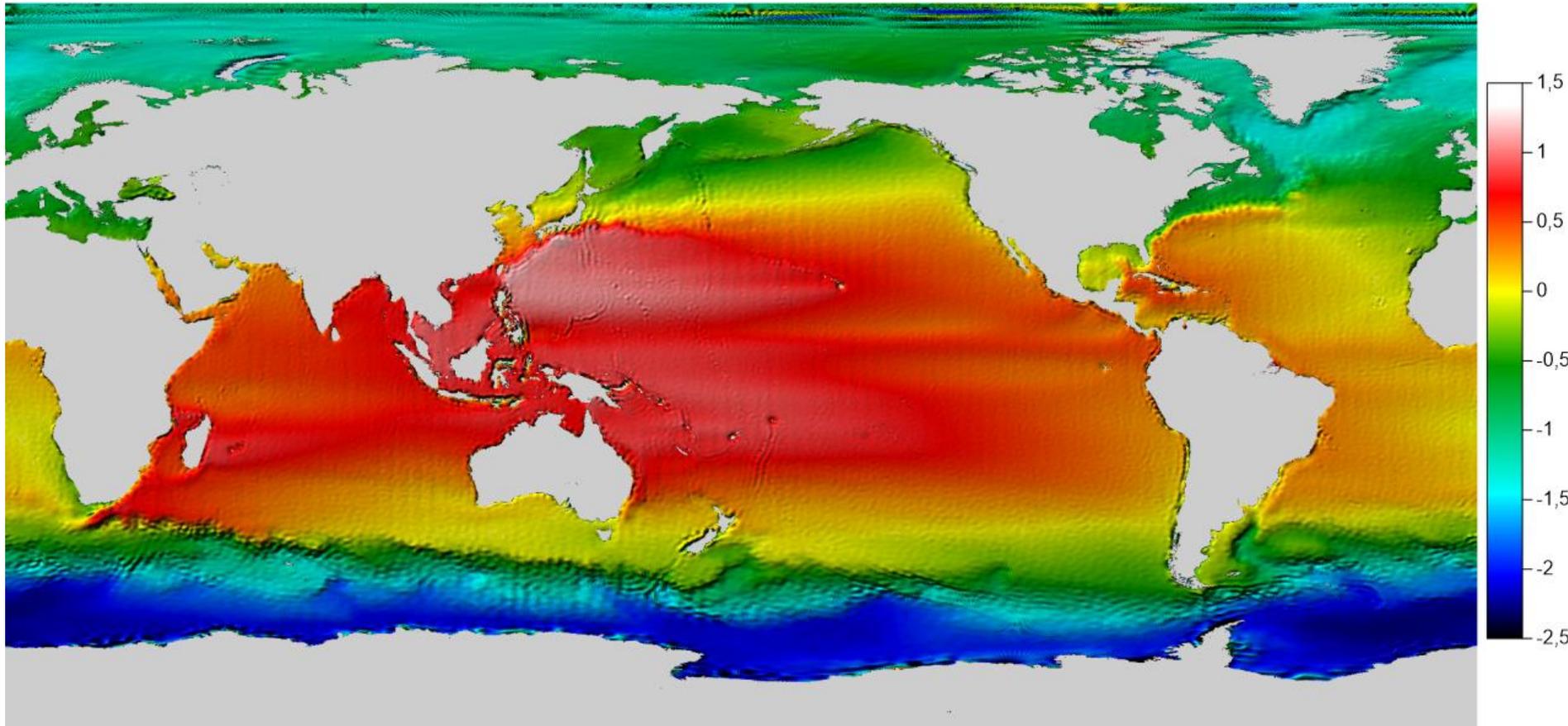
Nelineárna filtrácia

2 iterations



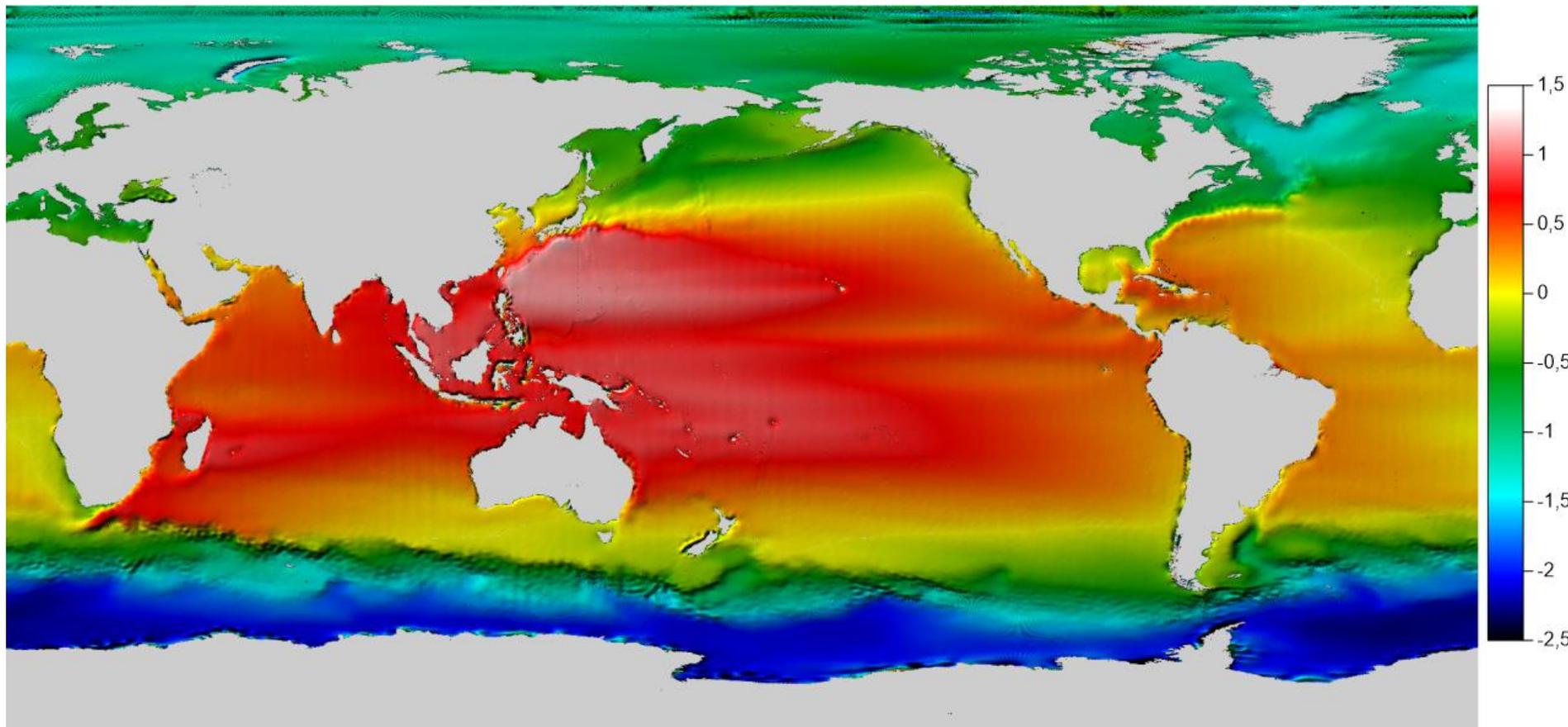
Nelineárna filtrácia

4 iterations



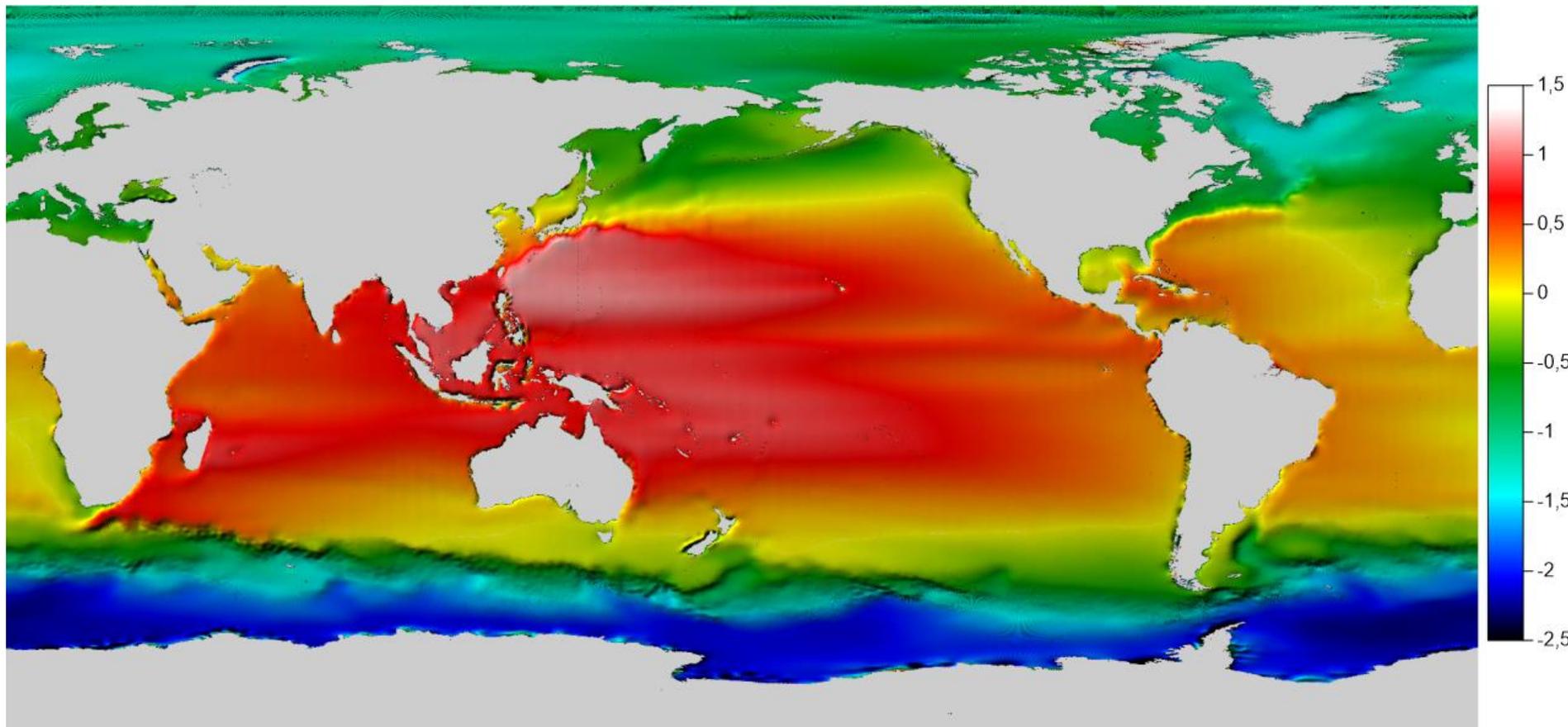
Nelineárna filtrácia

6 iterations



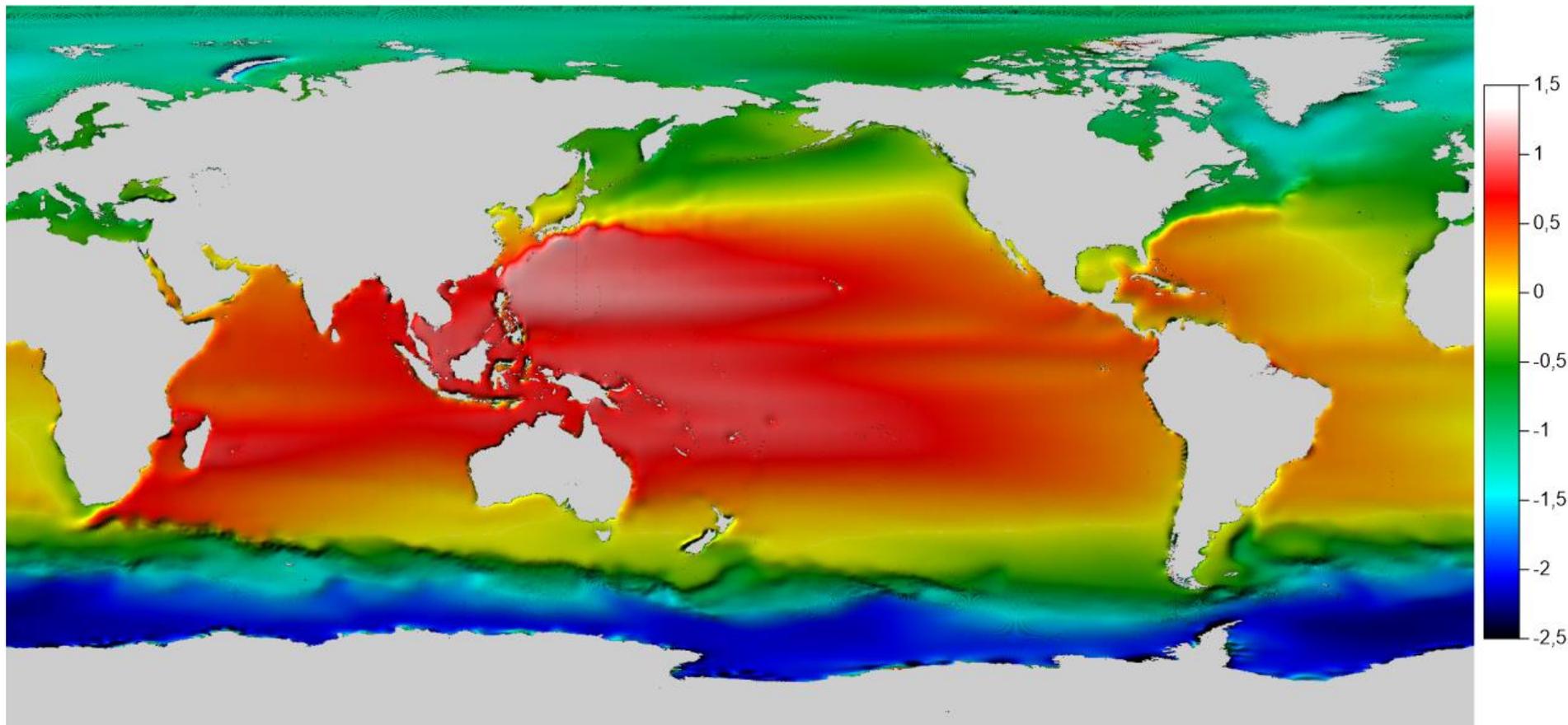
Nelineárna filtrácia

8 iterations



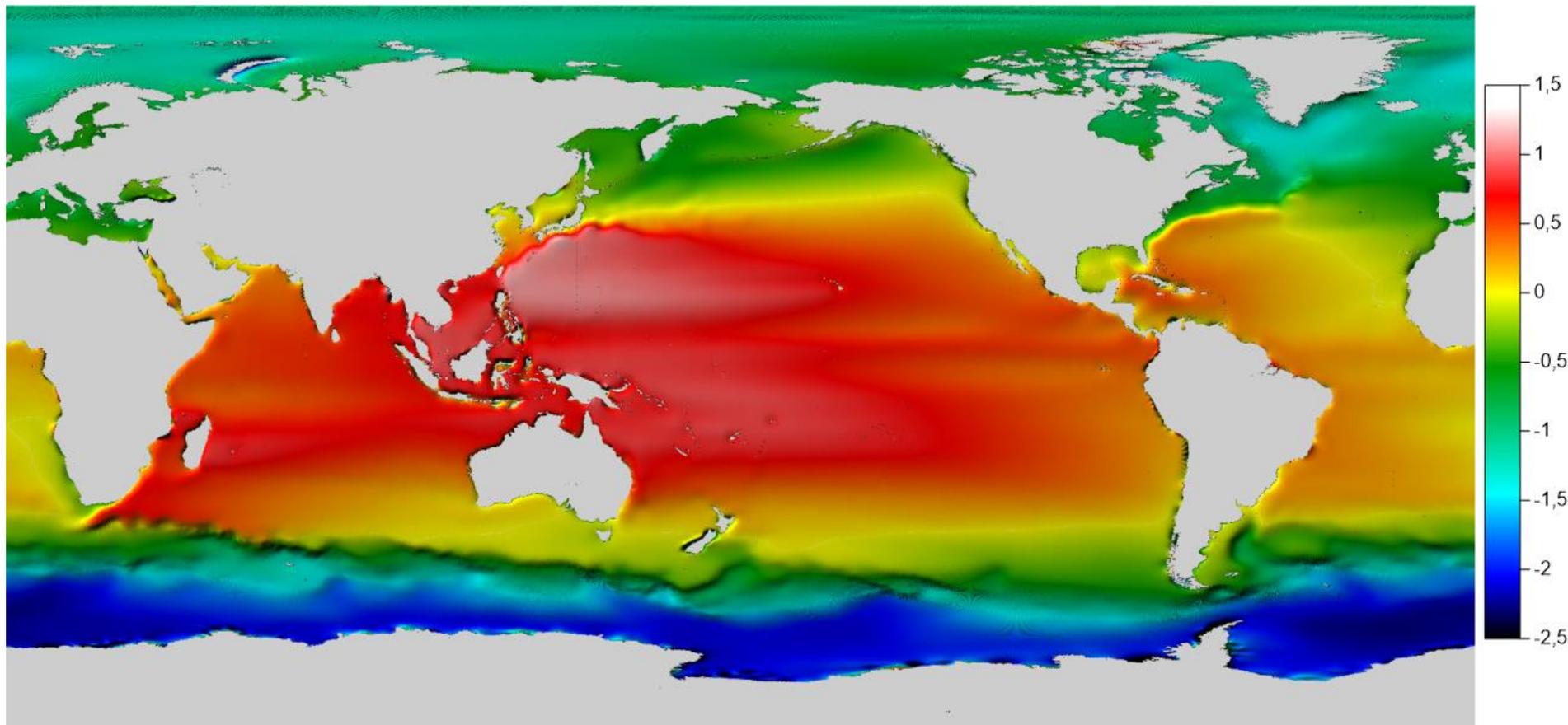
Nelineárna filtrácia

10 iterations



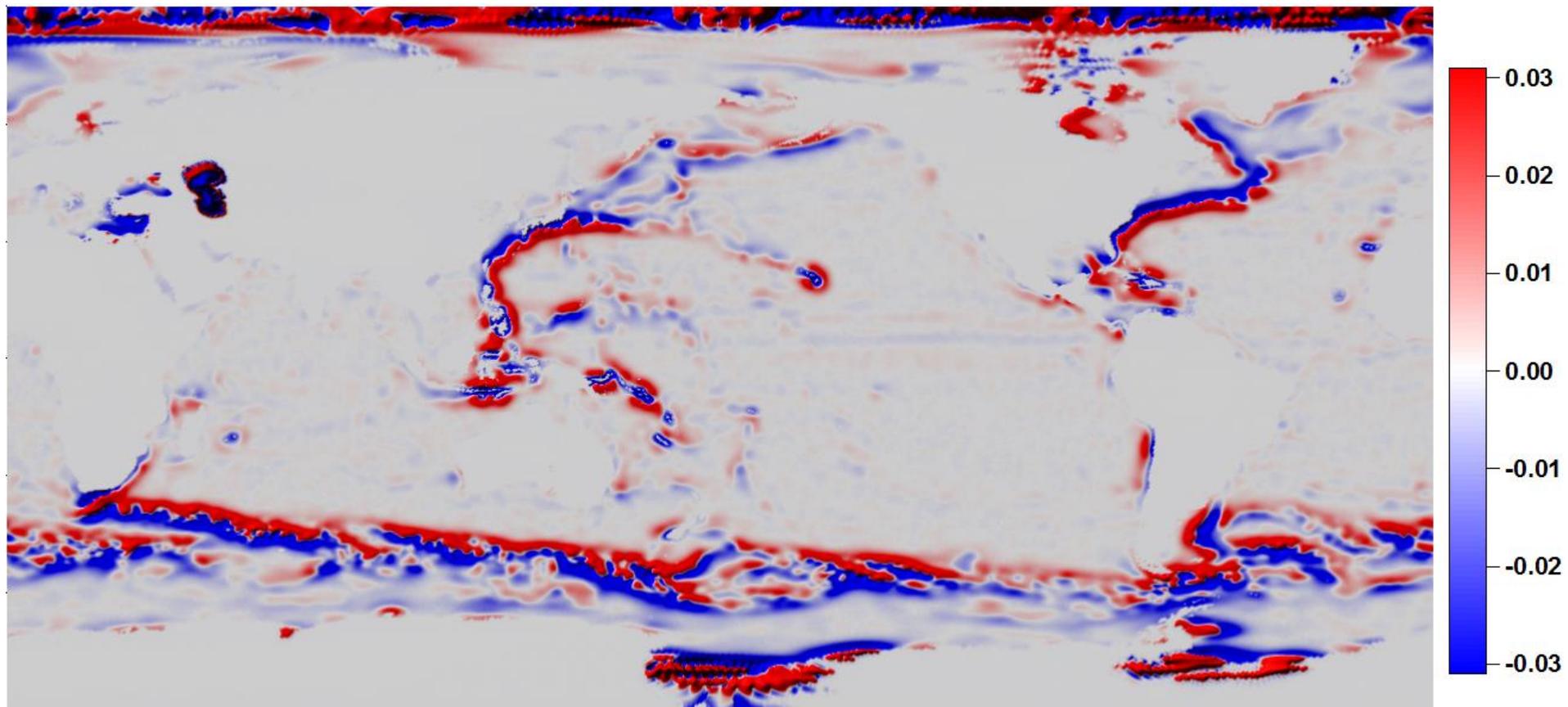
Nelineárna filtrácia

12 iterations

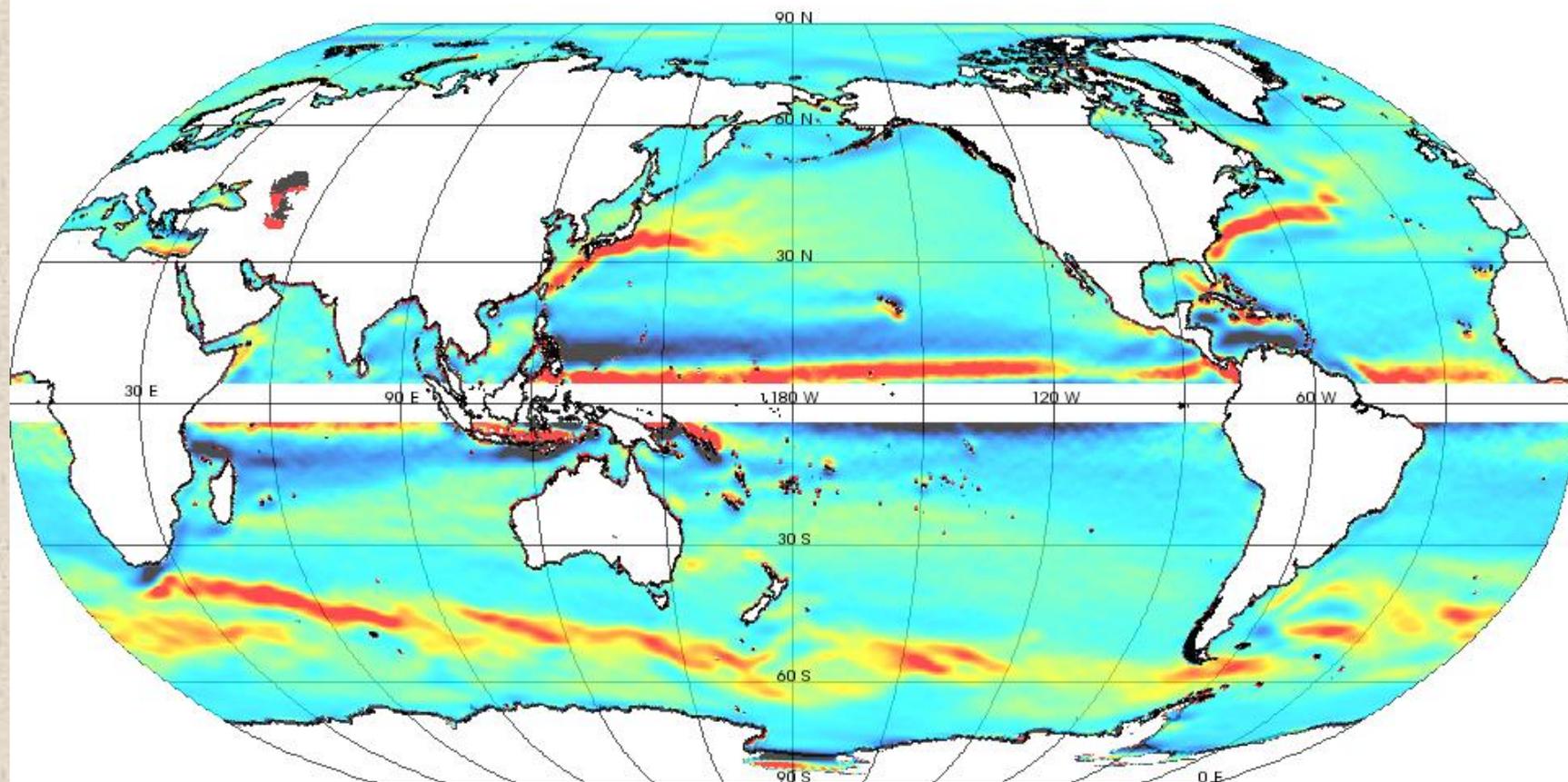


Nelineárna - lineárna difúzia

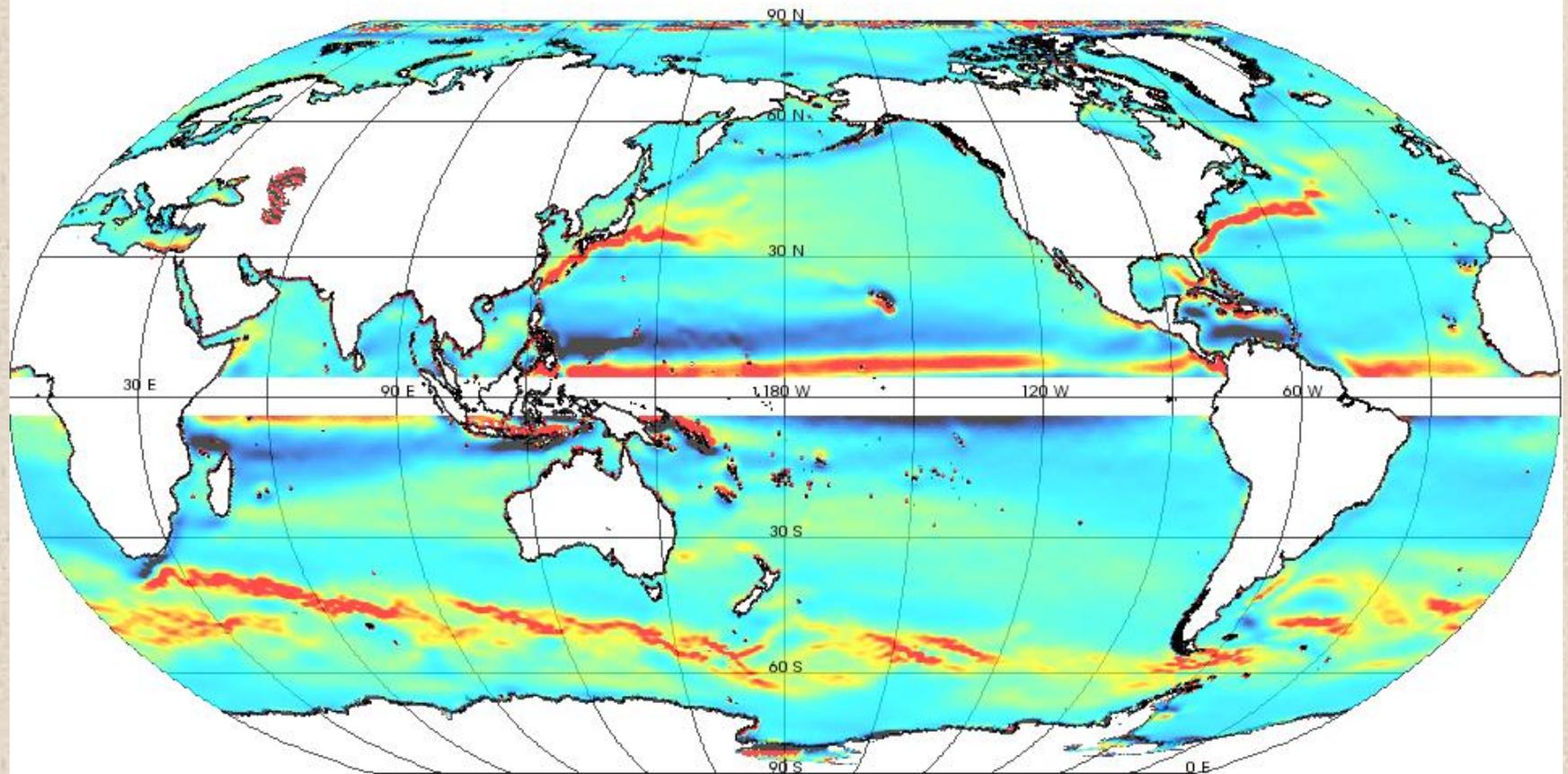
8 iterations



Geostrofické rýchlosti – lineárna difúzia

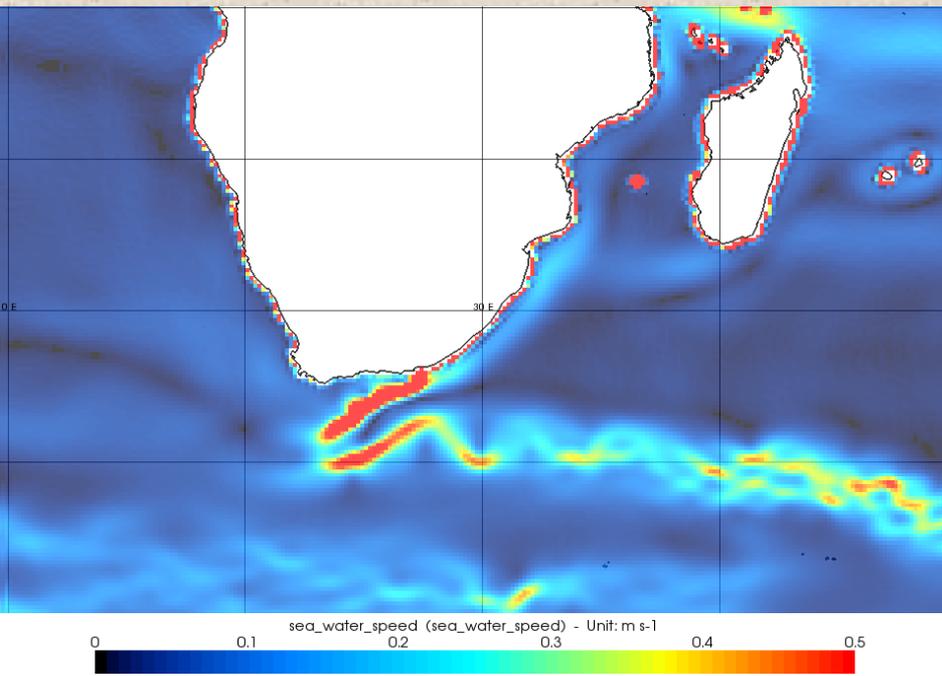


Geostrofické rýchlosti – nelineárna difúzia

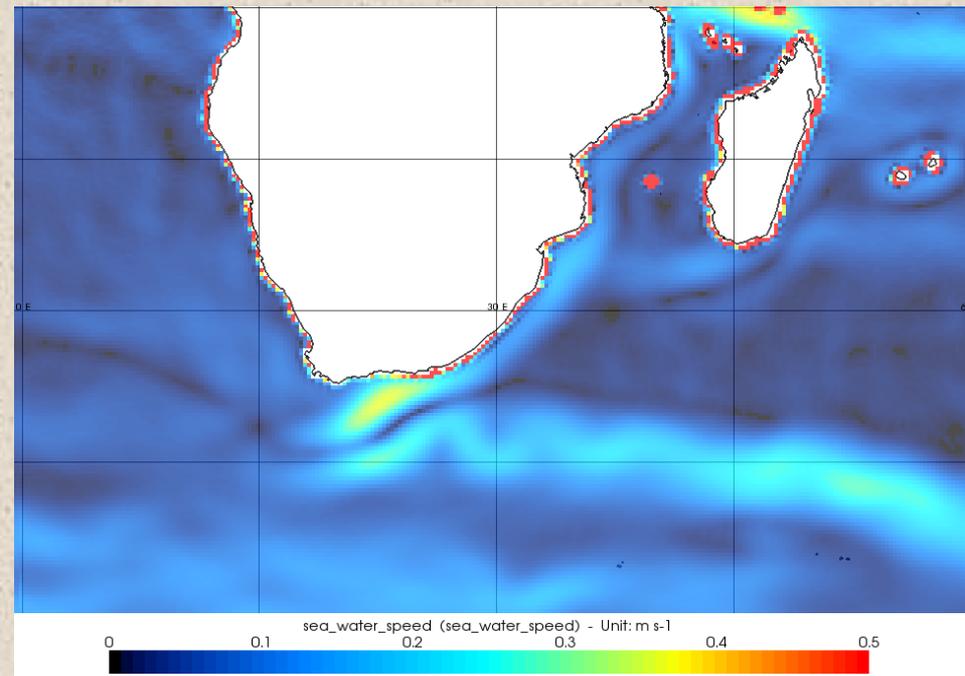


Geostrofické rýchlosti prúdov

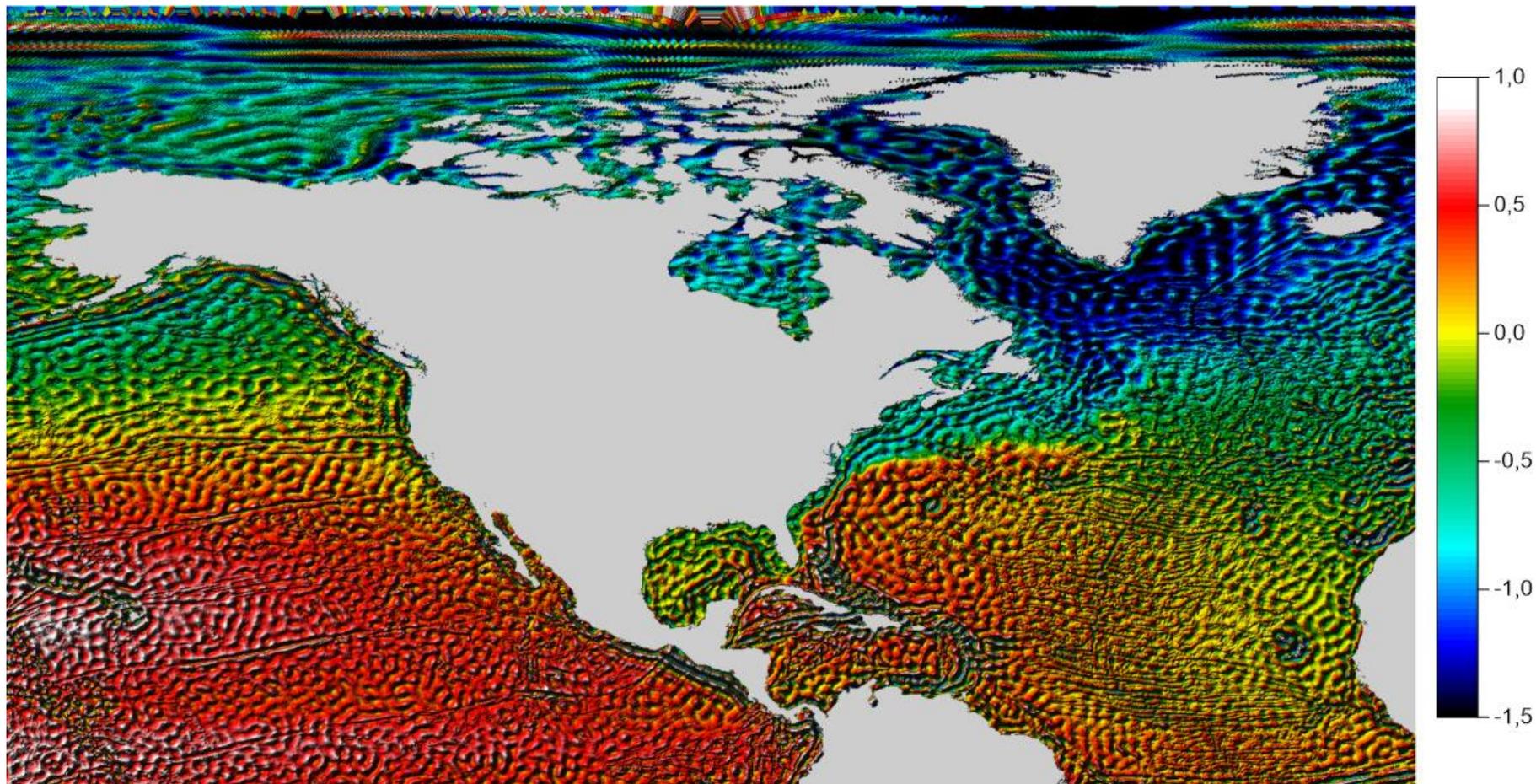
Nelineárna difúzia



Lineárna difúzia



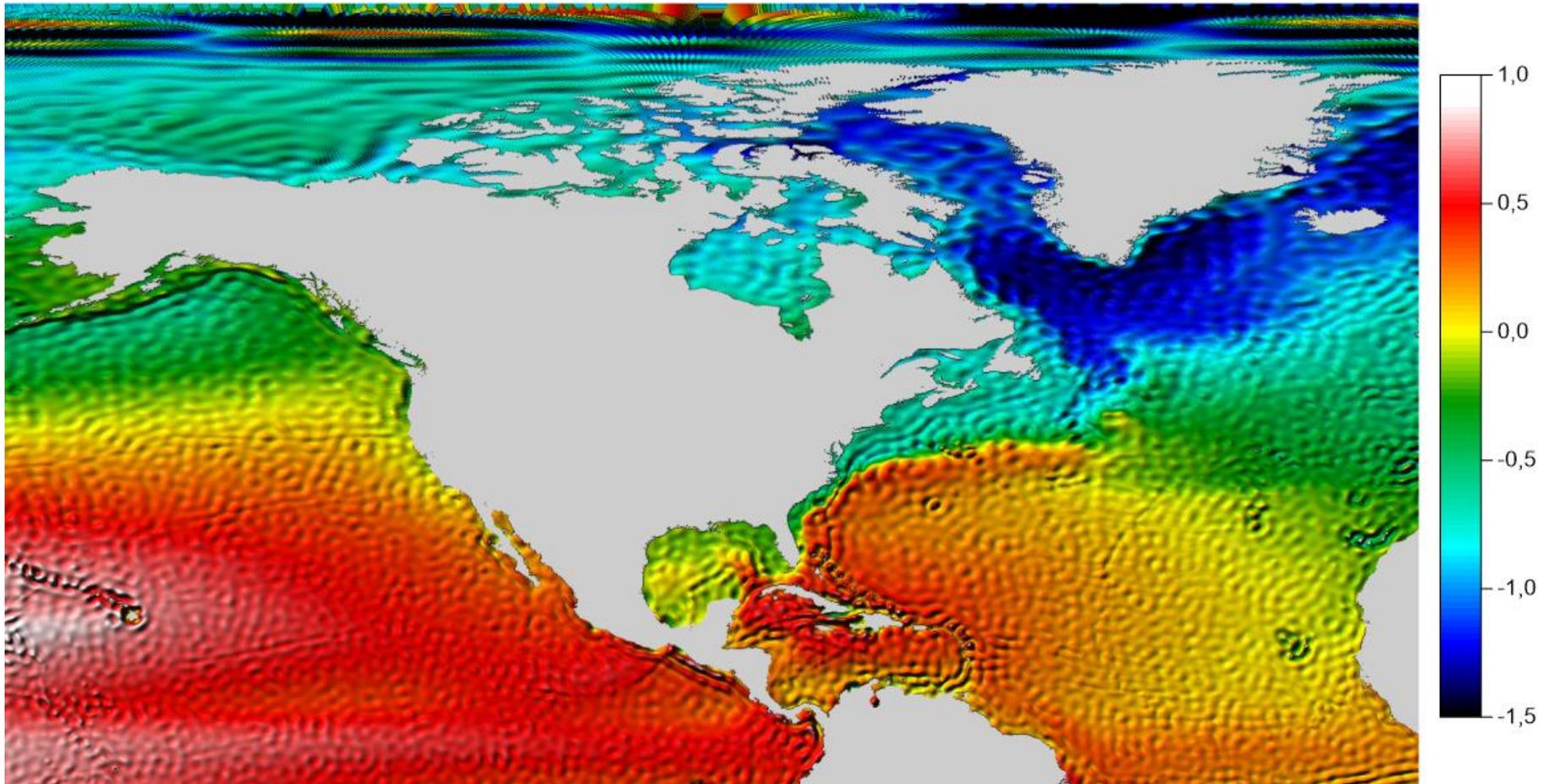
Filtrácia dynamickej topografie oceánov



GO_CONS_GCF_2_DIR_R5

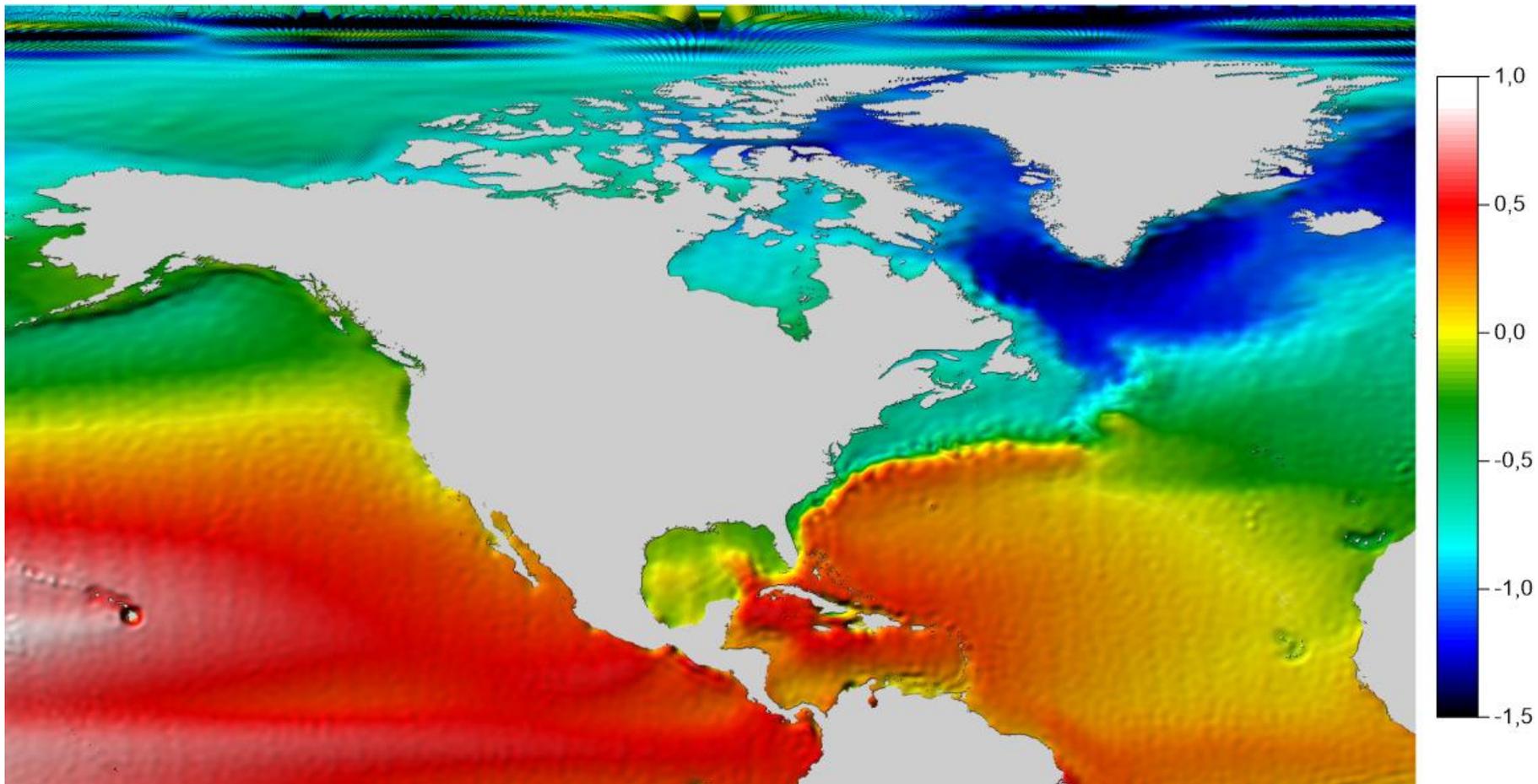
(SH up to d/o 300)

Filtrácia dynamickej topografie oceánov



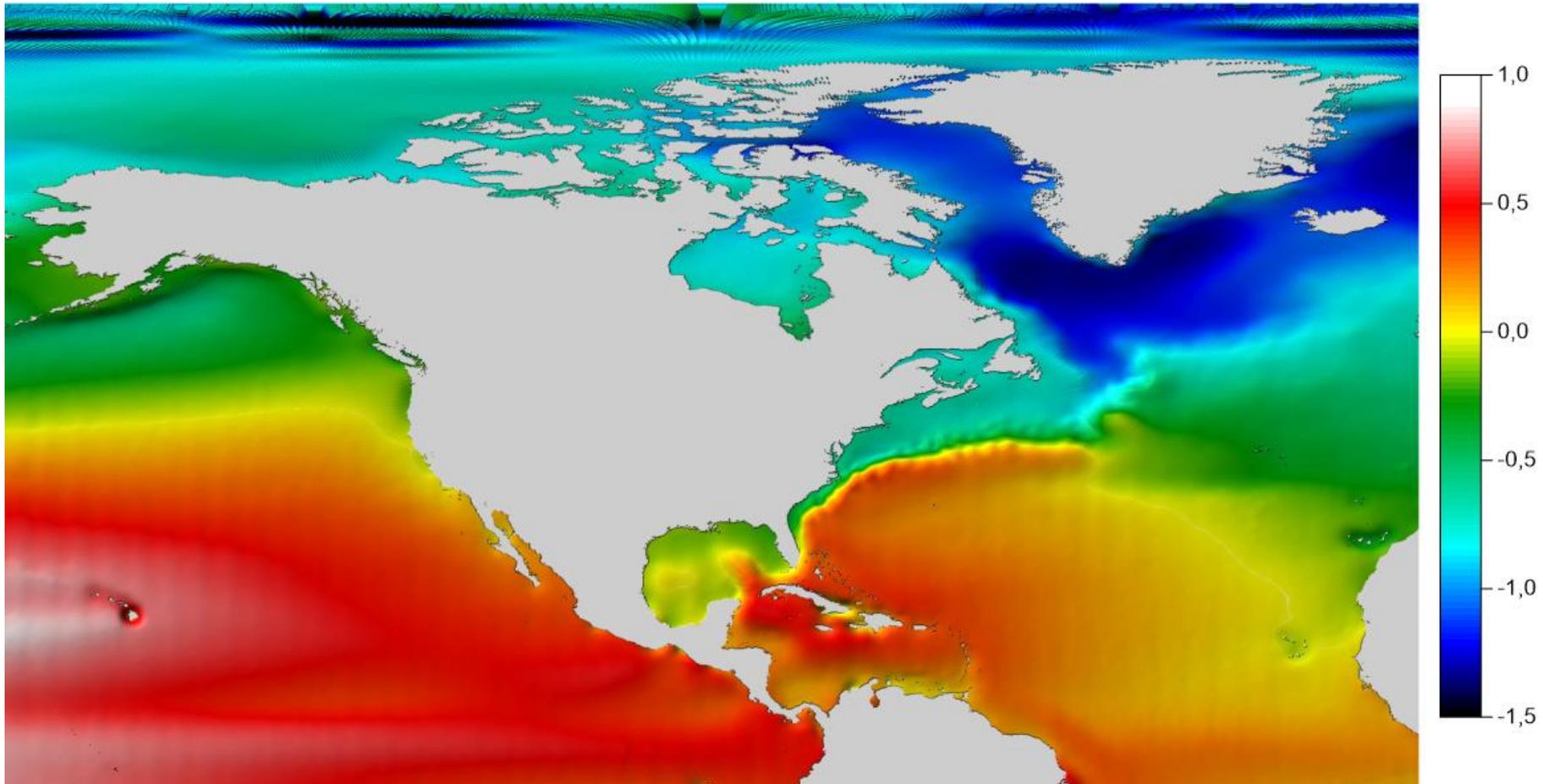
2 iterations

Filtrácia dynamickej topografie oceánov



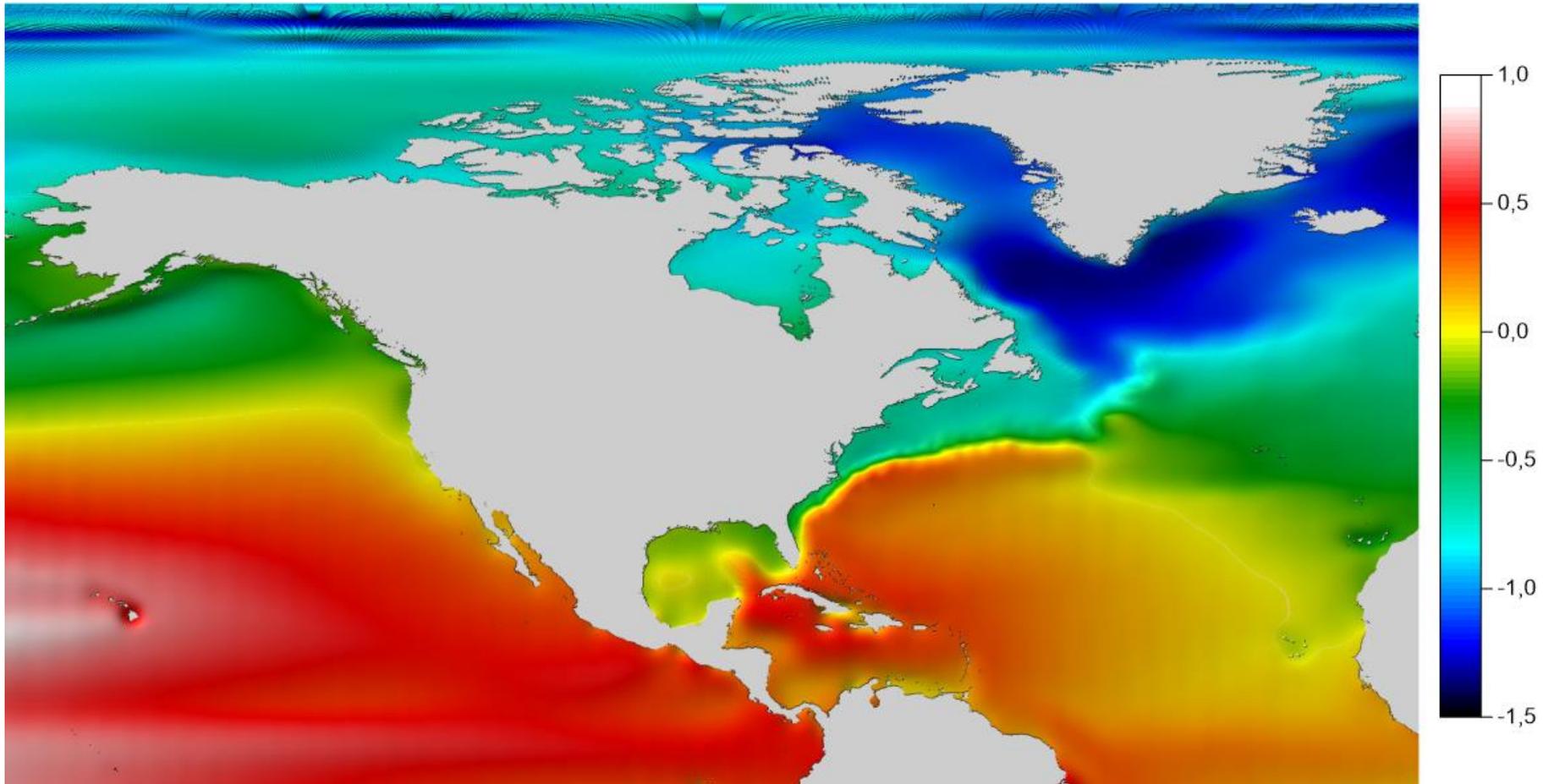
4 iterations

Filtrácia dynamickej topografie oceánov



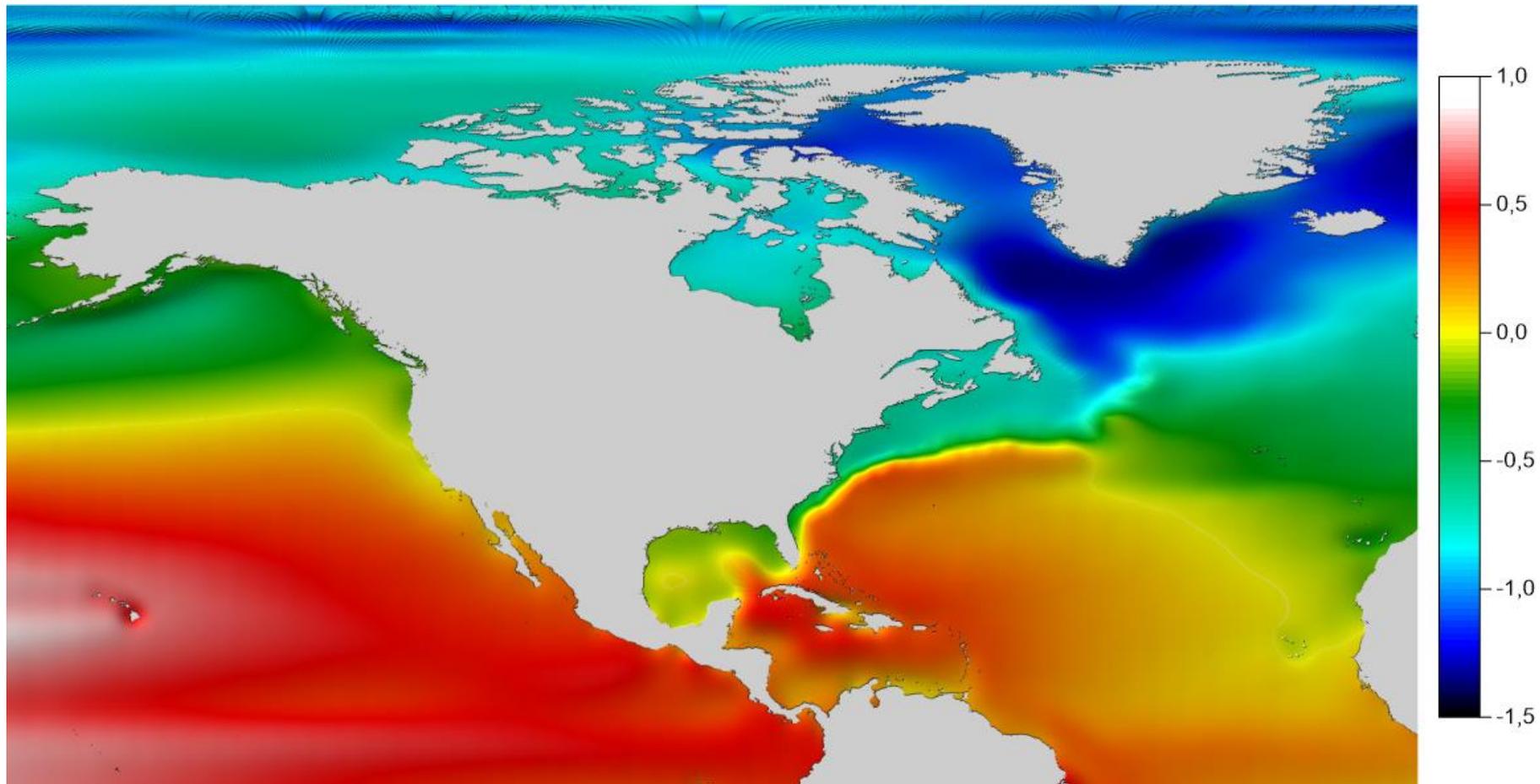
6 iterations

Filtrácia dynamickej topografie oceánov



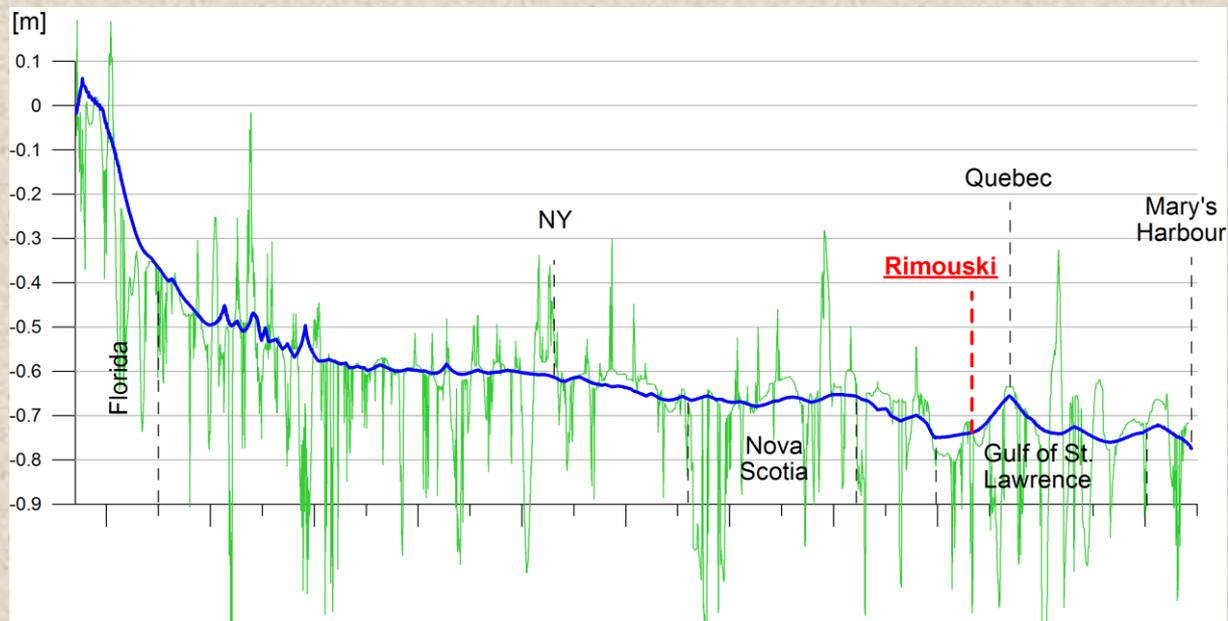
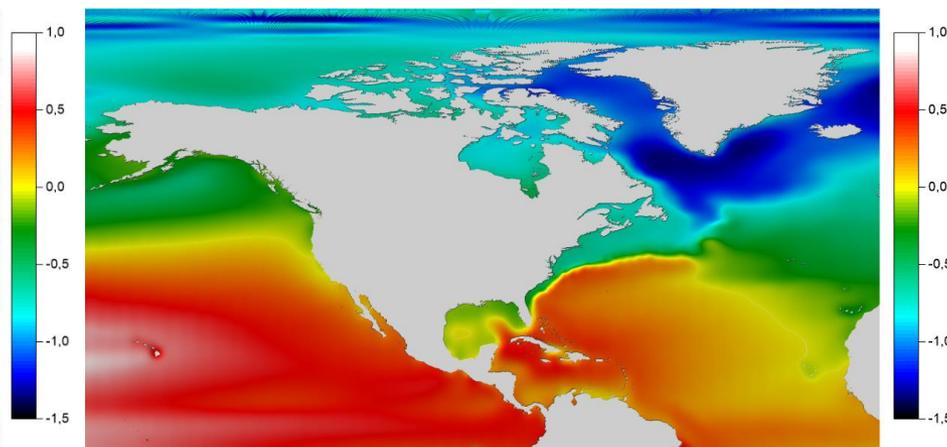
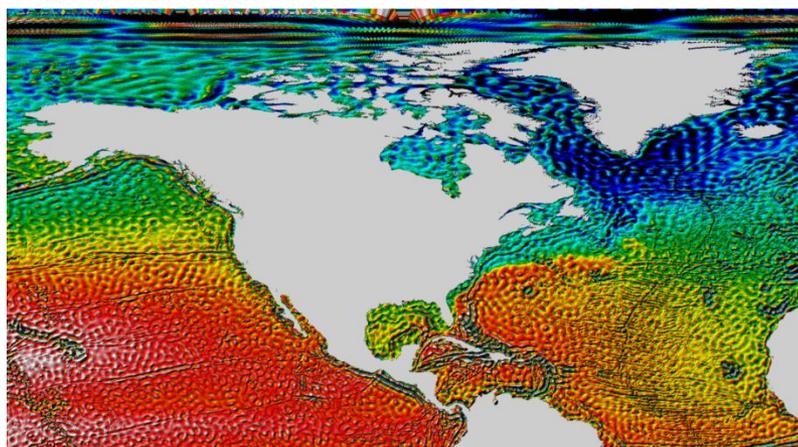
8 iterations

Filtrácia dynamickej topografie oceánov

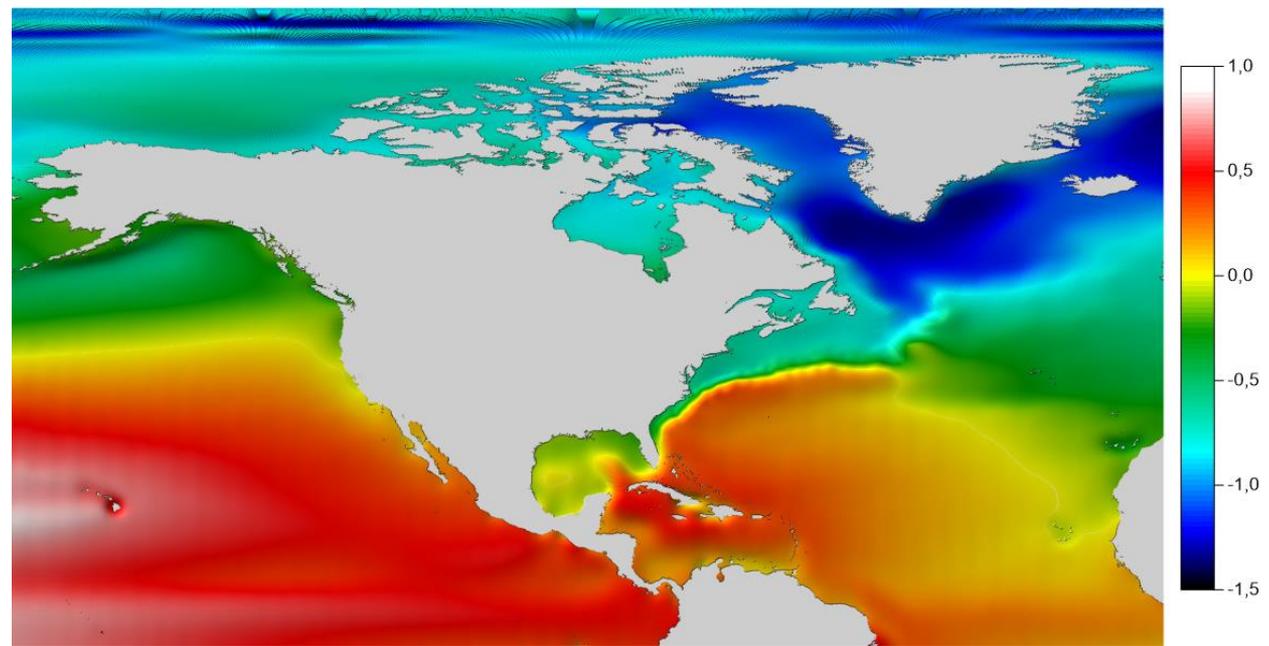


10 iterations

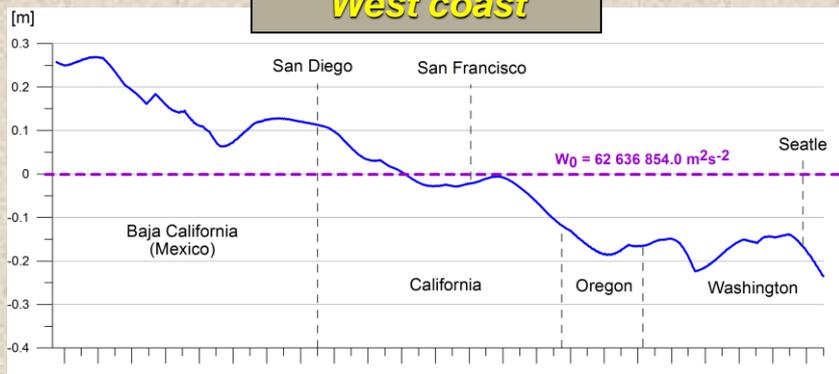
Interpolované hodnoty pozdíž pobřeží (Sev.Am.)



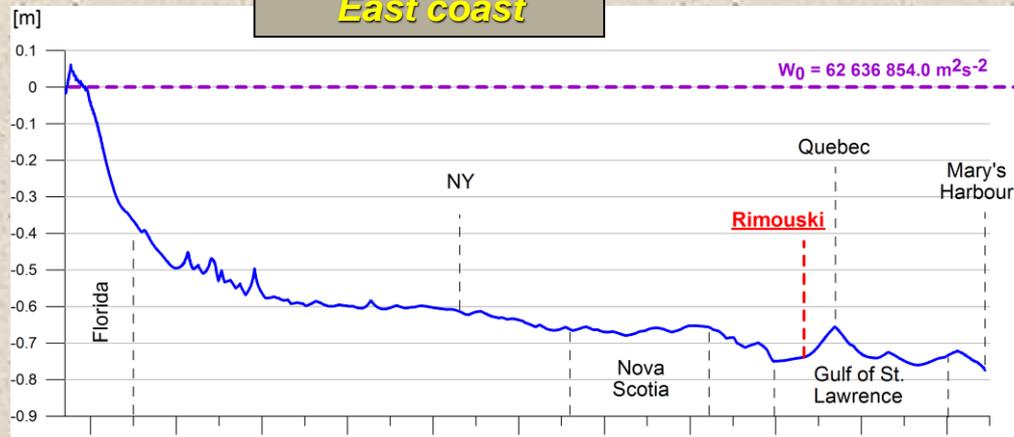
Interpolované hodnoty pozdíž pobřeží (Sev.Am.)



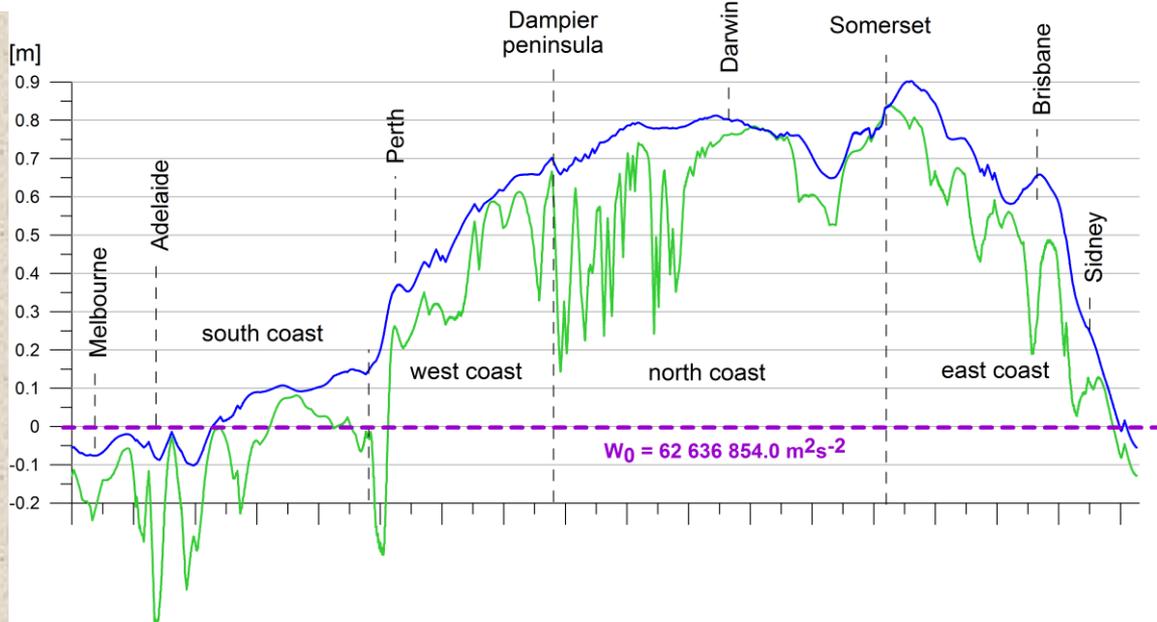
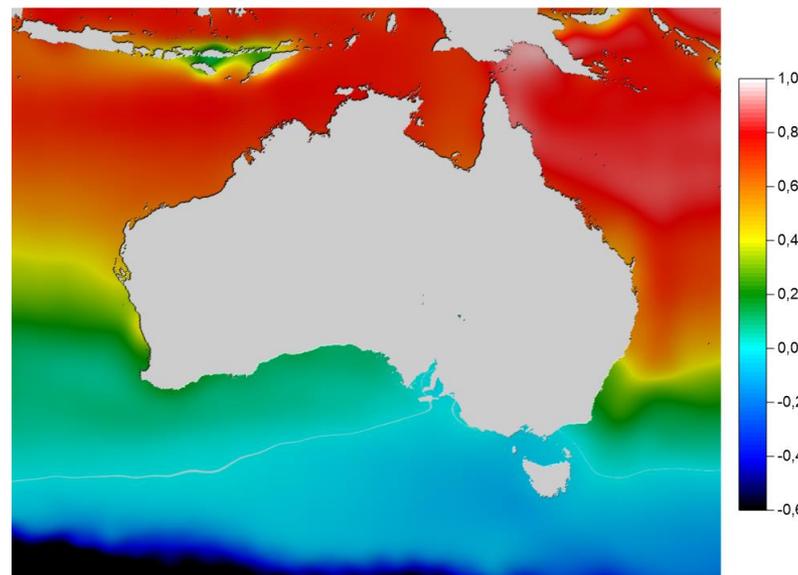
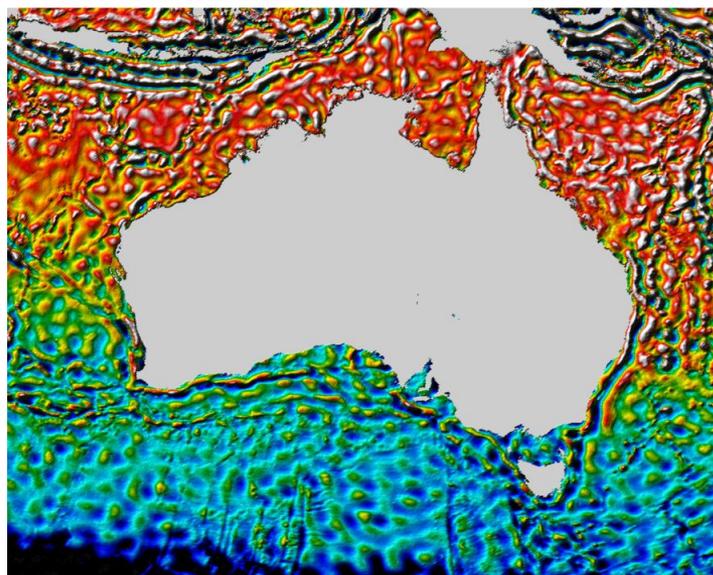
West coast



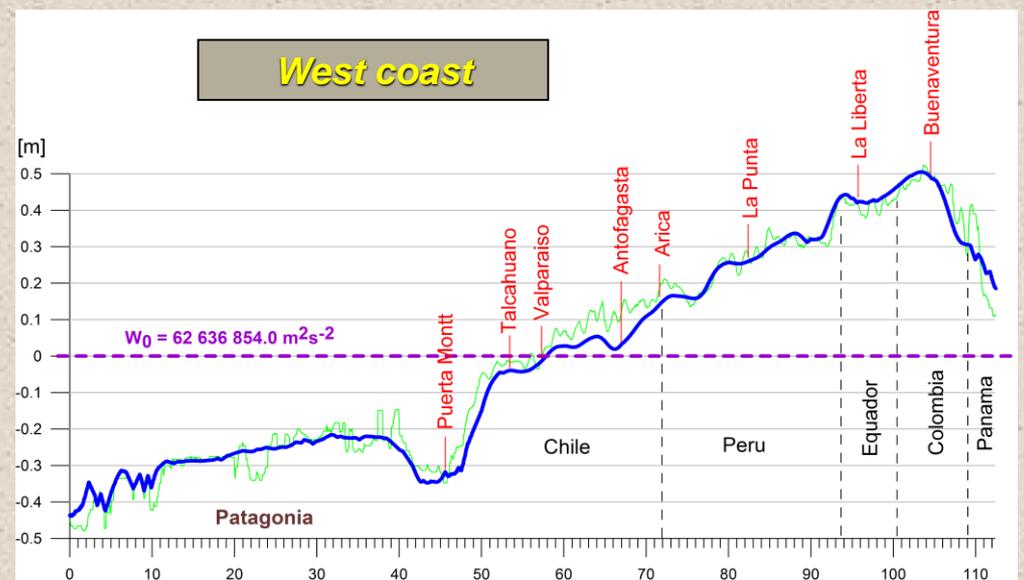
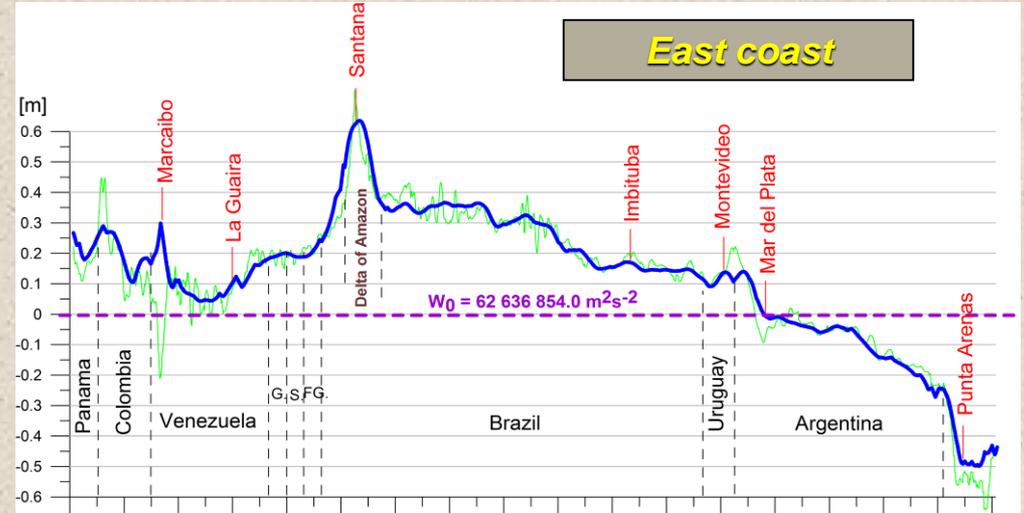
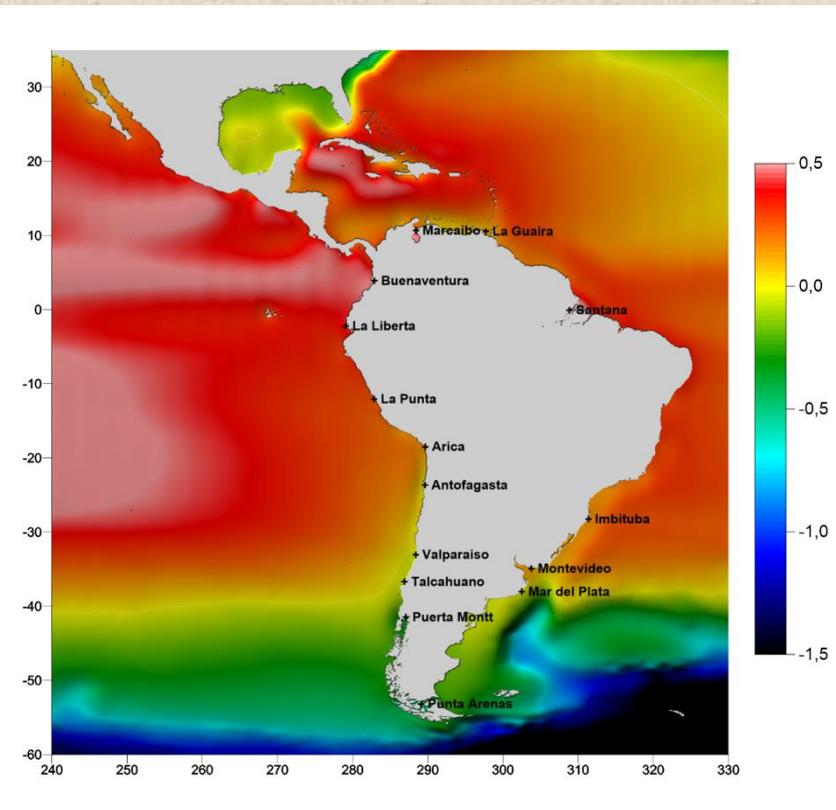
East coast



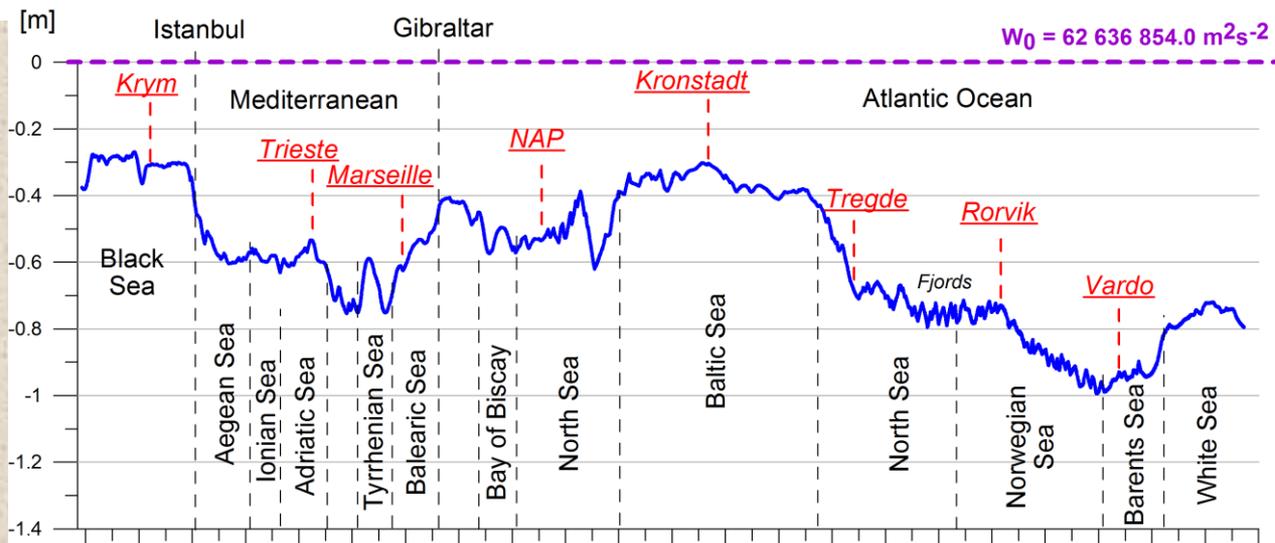
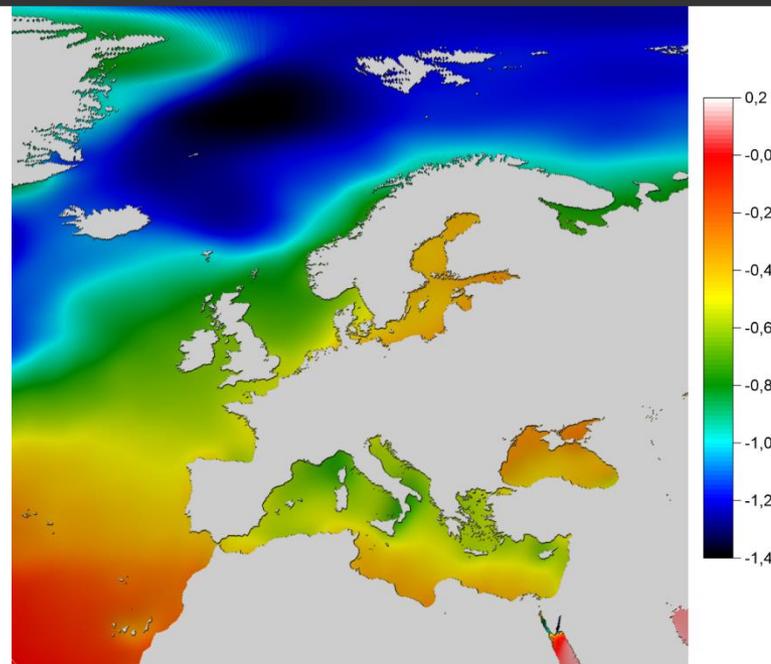
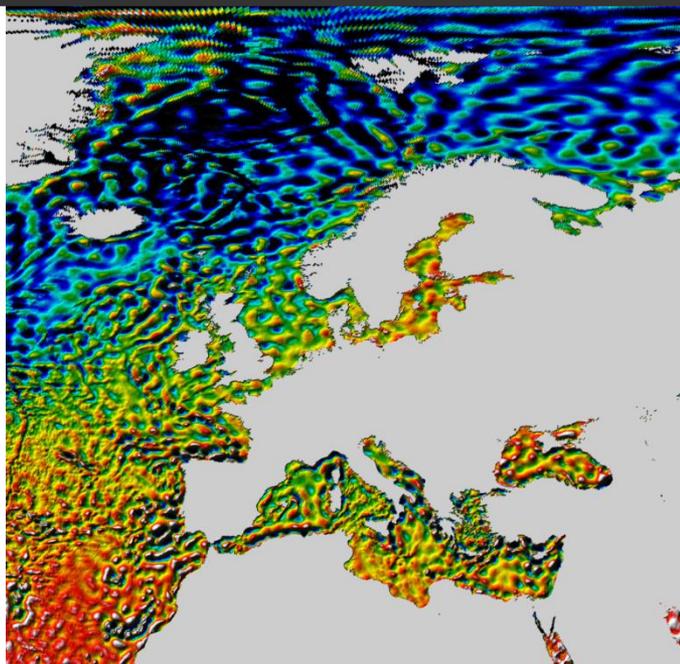
Interpolované hodnoty pozdíž pobřeží (Austrálie)



Interpolované hodnoty pozdíž pobřeží (Juž.Am.)

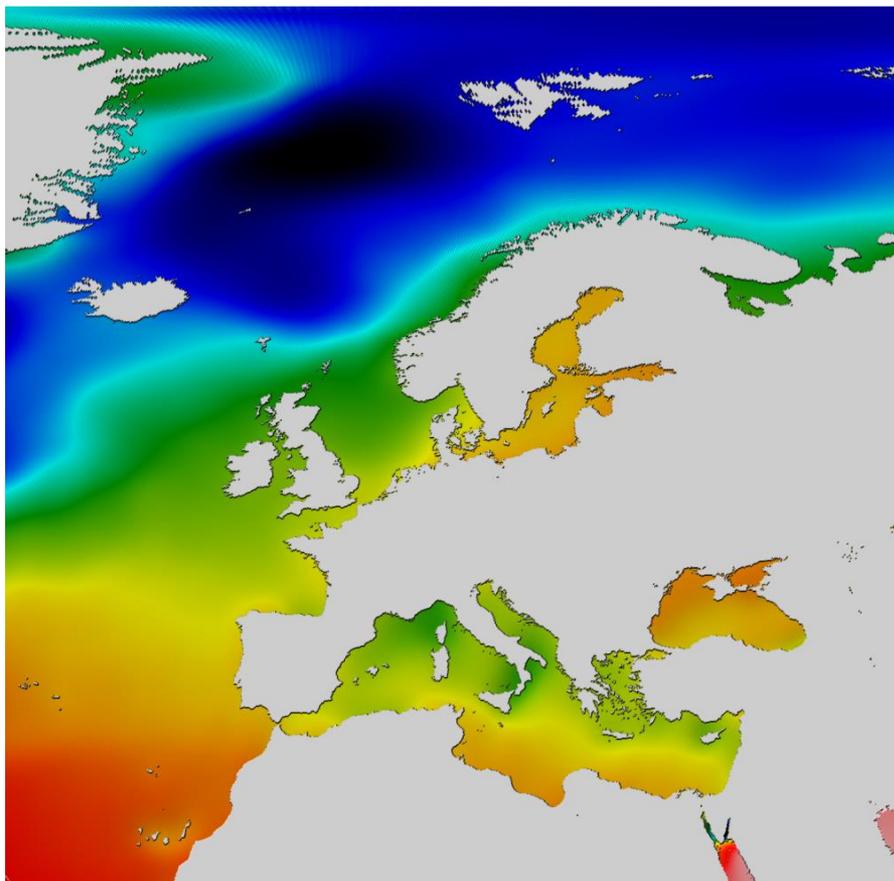


Interpolované hodnoty pozdíž pobřeží (Európa)



Porovnanie s výškovými systémami v Európe

Satellite-only MDT



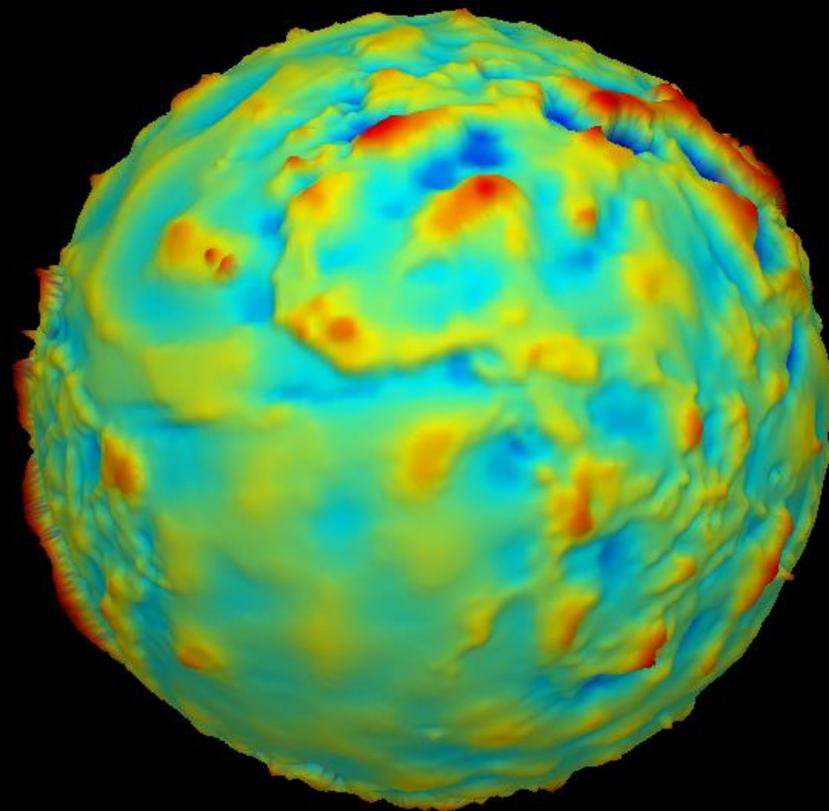
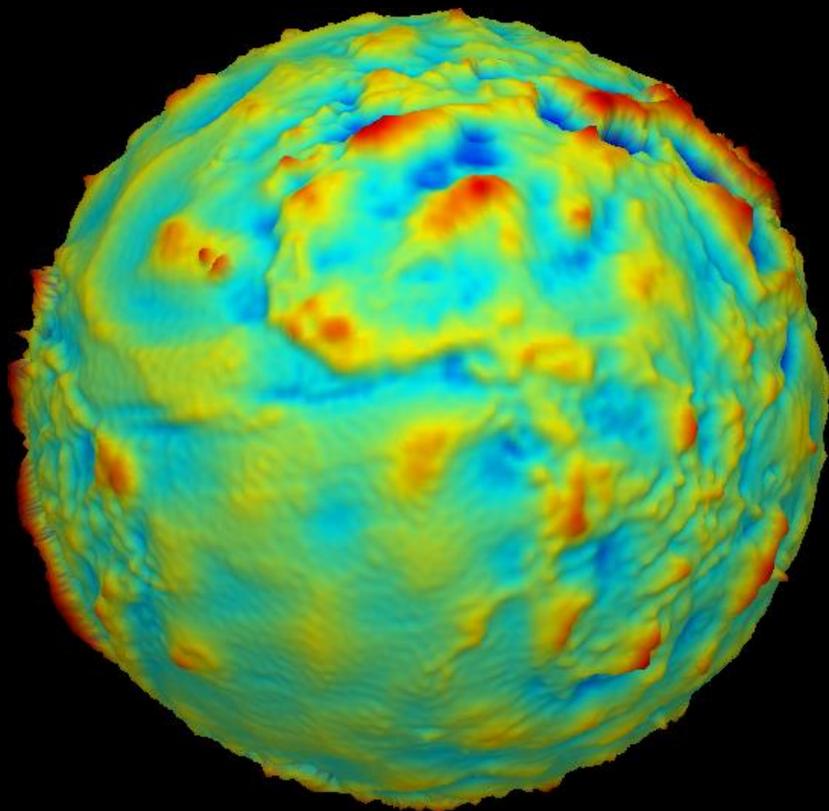
Relations between European national height reference systems and EVRF2007

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



Reference tide gauges

Alicante	Cascais	Kronstadt	Ostend
Amsterdam	Constanta	Malin Head	Trieste
Antalya	Dures	Marseilles	other
Belfast	Genoa	Newlyn	no information



Vd'aka za pozornost'