Deltares

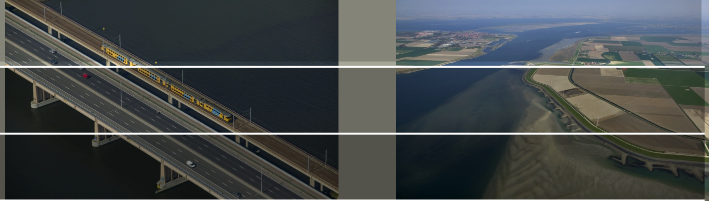
Enabling Delta Life

Global storm-surge model with Dflow Flexible Mesh

Martin Verlaan
Herman Kernkamp
Andrea Lalic

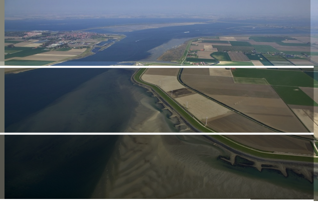
Jonsmod 12-14 May 2014

Outline



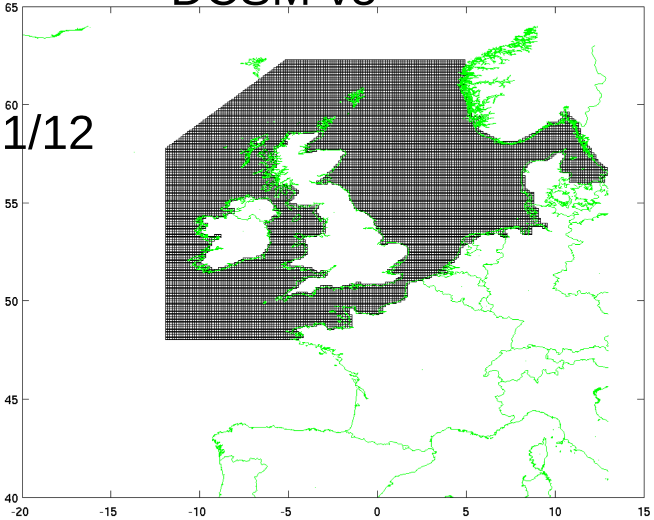
- Motivation
- Tidal forcing
- Grid development
- Internal tides
- Calibration
- Challenges

New storm-surge model – DCSMv6



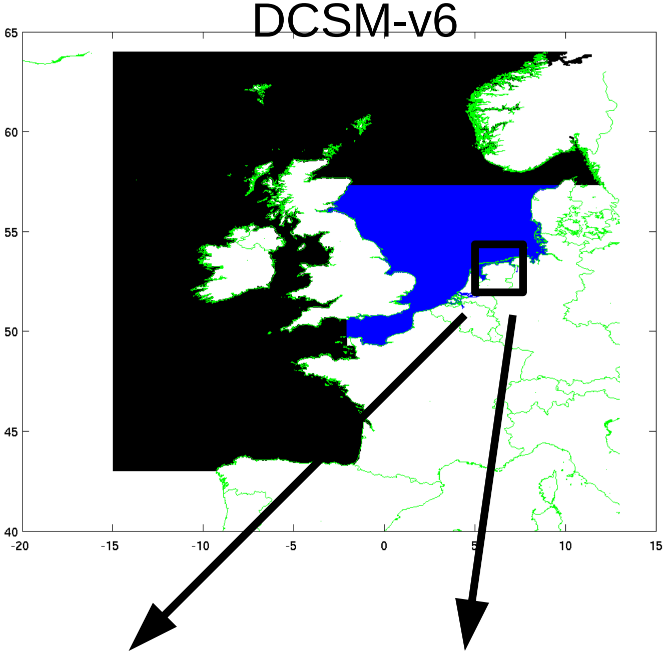
DCSM-v5

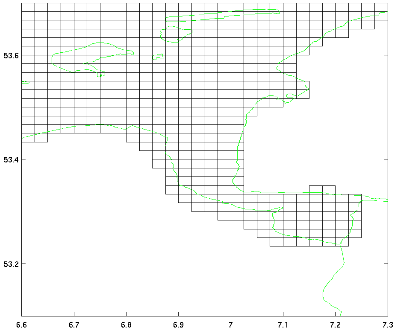
1/8 x 1/12



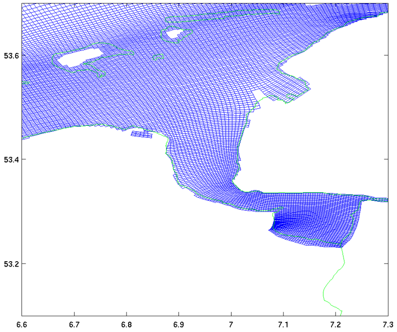
DCSM-v6

1/40 x 1/60





domain 1 detail



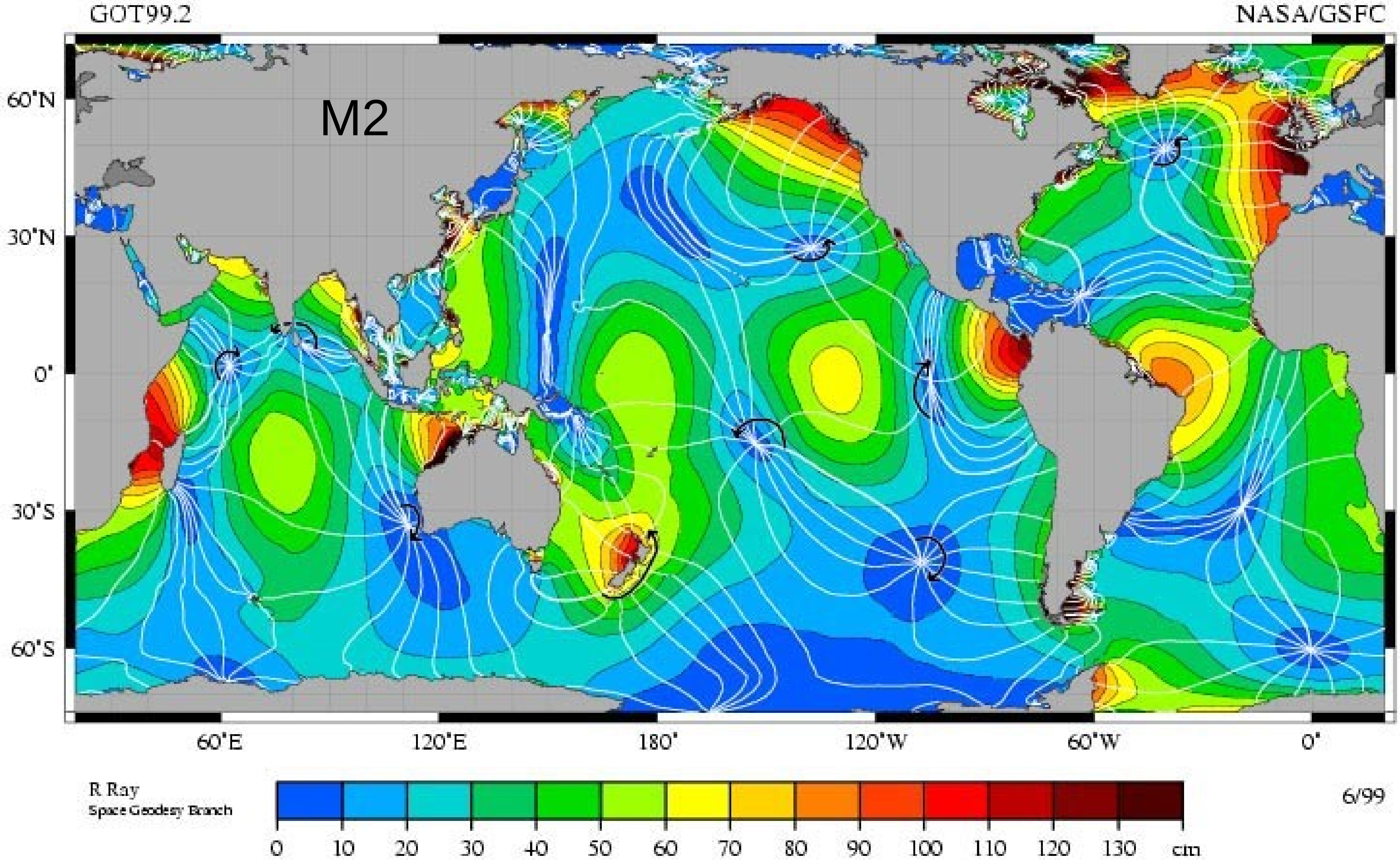
domain 2 detail

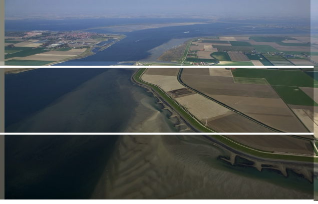
Questions:

- Boundary conditions?
  - tides
  - surge
  - steric contribution
- New physics needed with increasing scale?

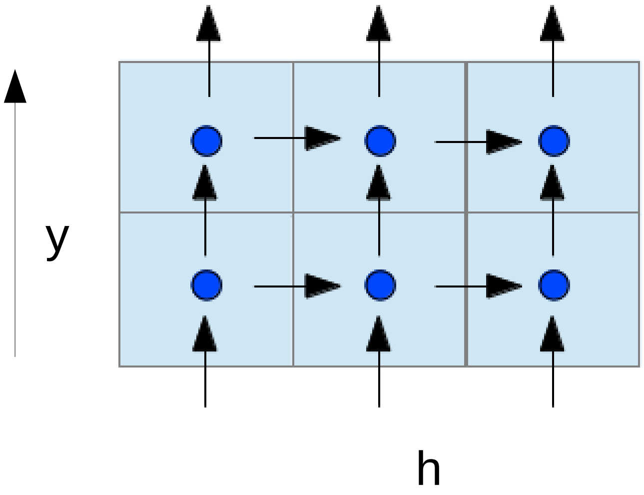
Deltares

Can we model tides/surge on a global scale?





Equations and tidal forcing



Conservation of mass

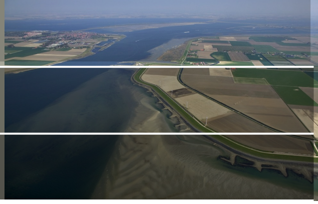
$$\frac{\partial h}{\partial t}+\frac{\partial H u}{\partial x}+\frac{\partial H v}{\partial y}=0$$

Conservation of momentum

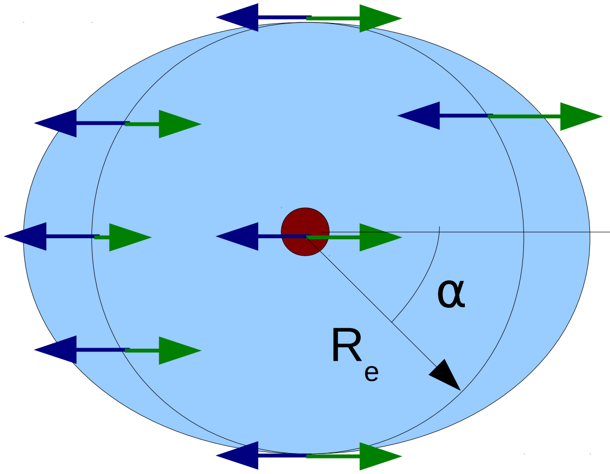
$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+g\frac{\partial h-\zeta}{\partial x}-f v+\frac{g u\sqrt{u^2+v^2}}{C^2 H}=0$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+g\frac{\partial h-\zeta}{\partial y}+f u+\frac{g v\sqrt{u^2+v^2}}{C^2 H}=0$$

ζ equilibrium tide

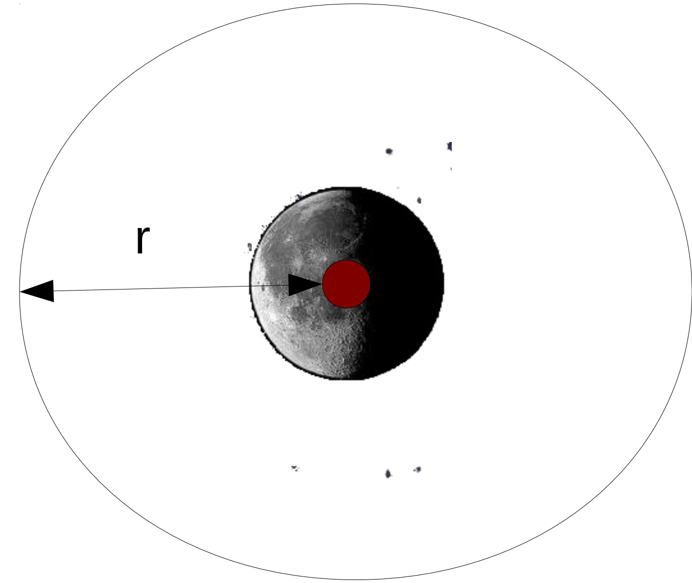


Tidal potential



$$F = -\nabla \Phi m$$

$$\Phi = \frac{-G M_m}{|r|}$$



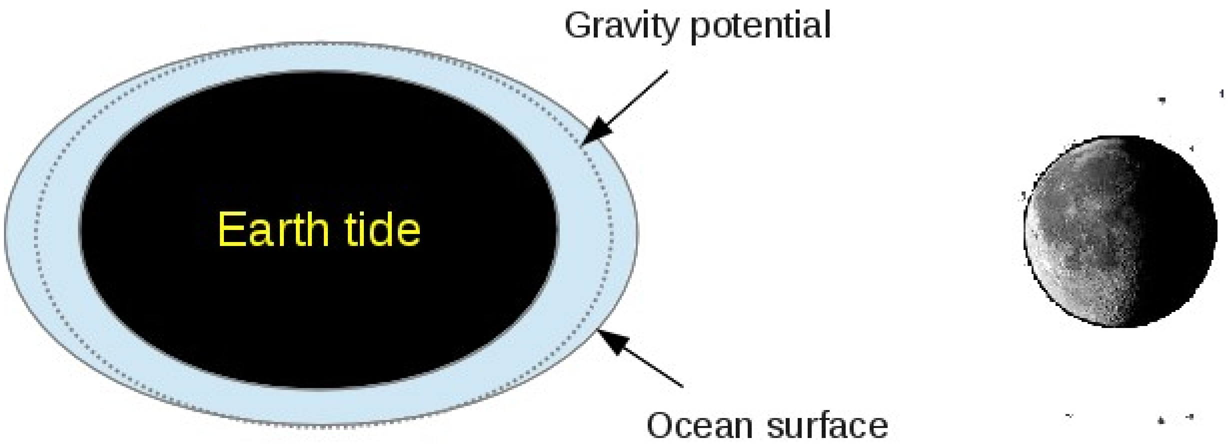
Moon $$\Phi_m' = \frac{G M_m R_e^2 (3/2 \cos\alpha^2 - 3/4)}{R^3}$$

Equilibrium tide

$$\zeta = \zeta_0 + \Phi'/g$$

Earth $$\Phi_e \approx \frac{G M_e}{R_e}(z - z_0) = g(z - z_0)$$

Tidal potential



$$\Phi = \frac{GM}{|x - x_m|}$$

$$F = -\nabla \Phi m$$

$$\Phi_{eff} = \Phi'(1 + k - h)$$

h=0.6 earth tide
k=0.3 change in earth's potential

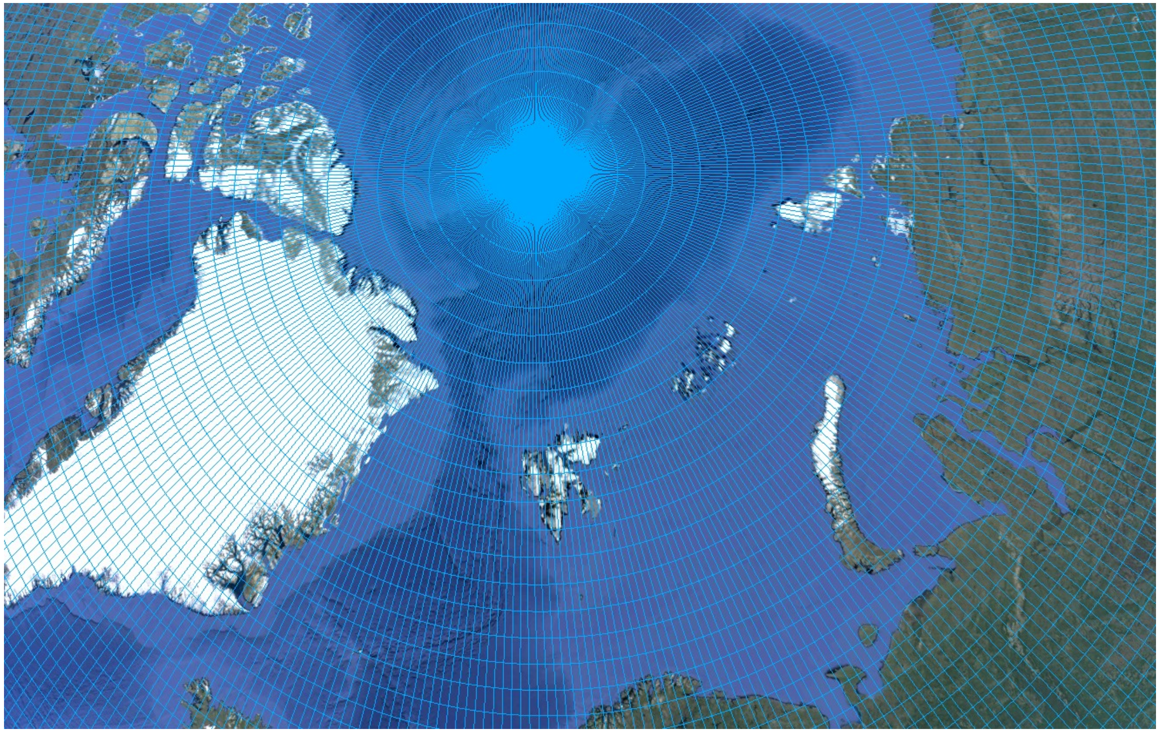
$$\zeta = \Phi_{eff} / g$$

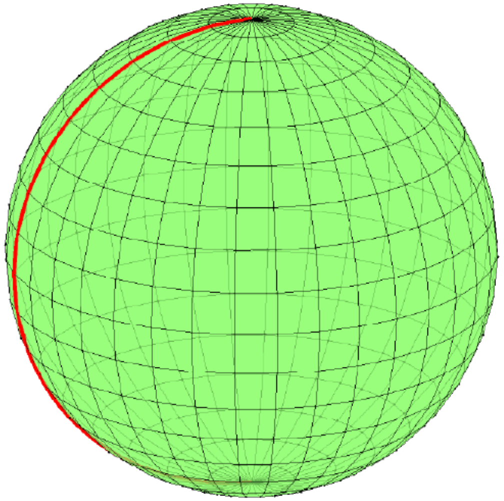
equilibrium tide

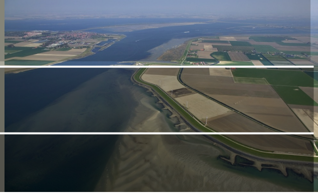
Grid development

Try regular lat-lon grid
In Delft3D?

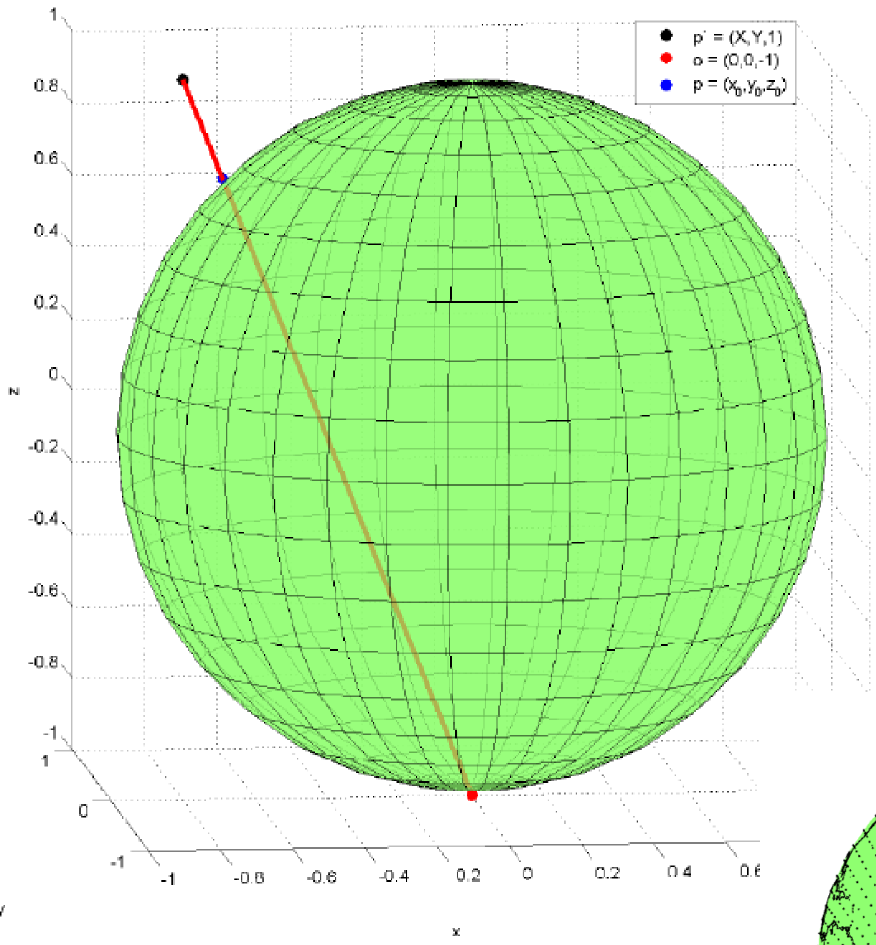
- singularity at north pole
- unnecesary refinement near poles
- no periodic boundaries in Delft3D

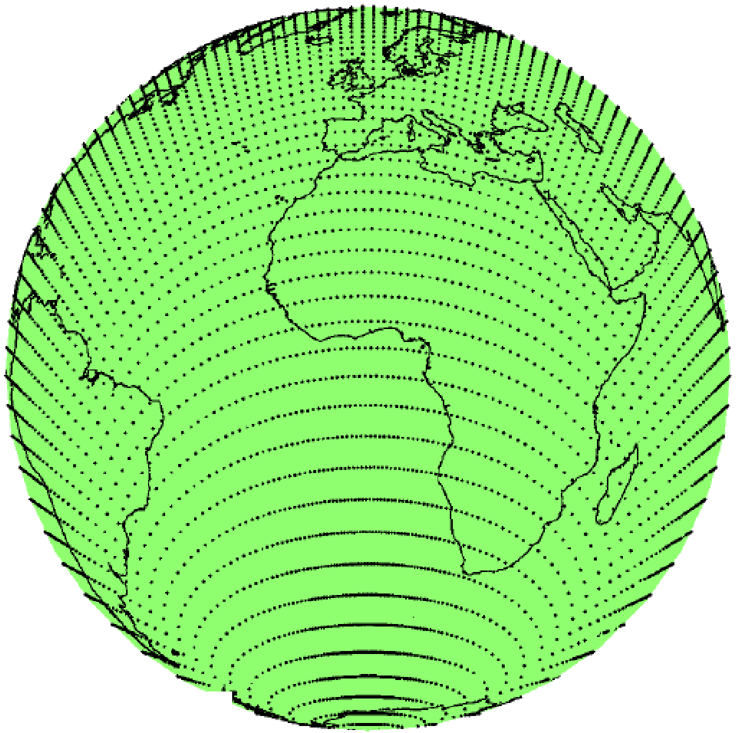


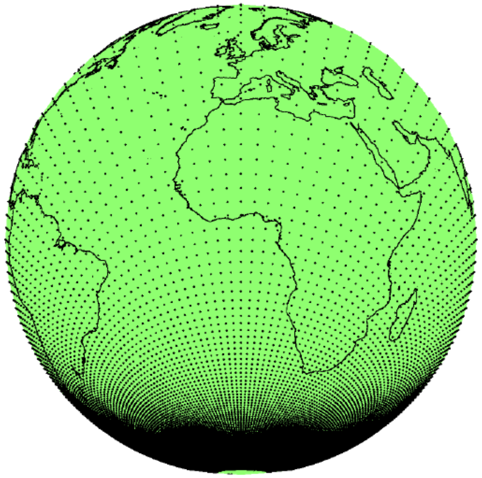




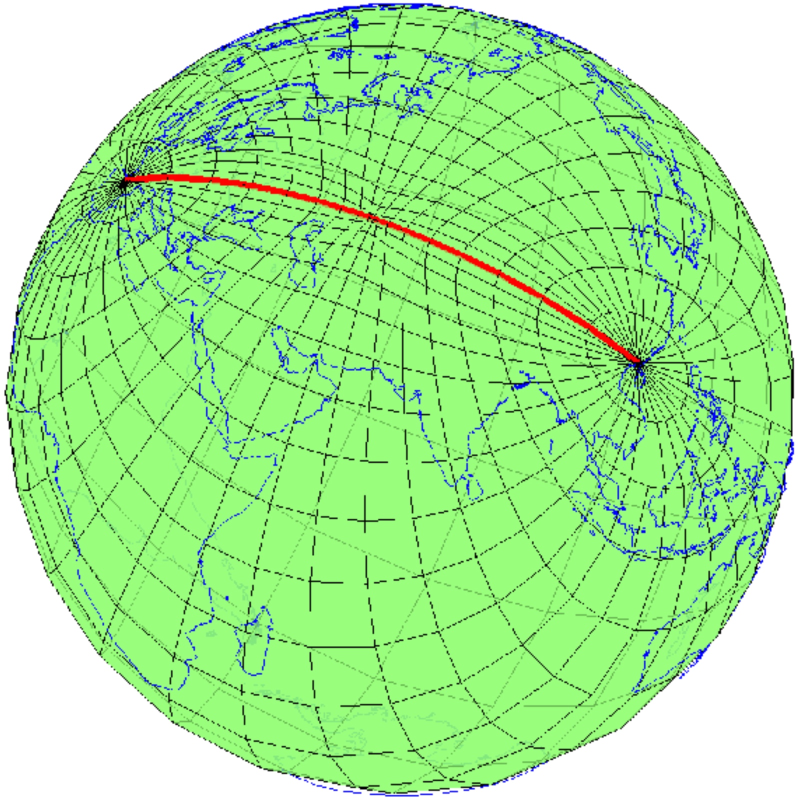
Stereographic projection

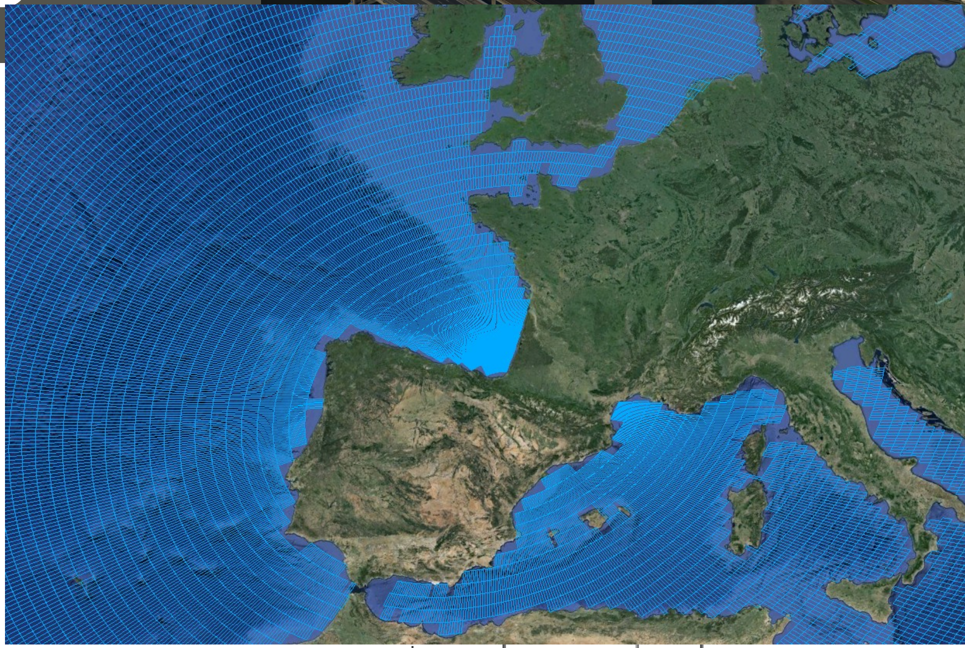


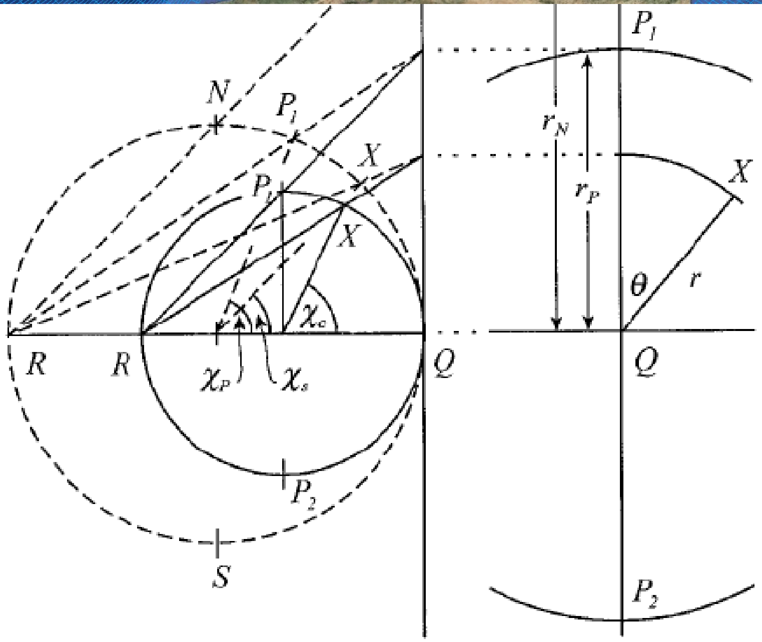




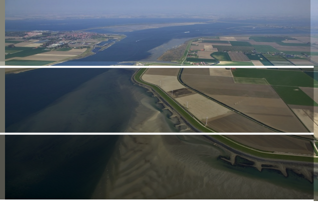
First attempt in Delft3D

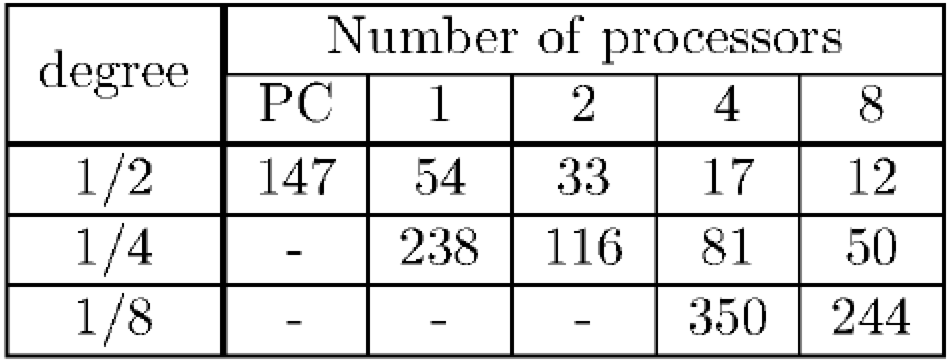






first results in Delft3D

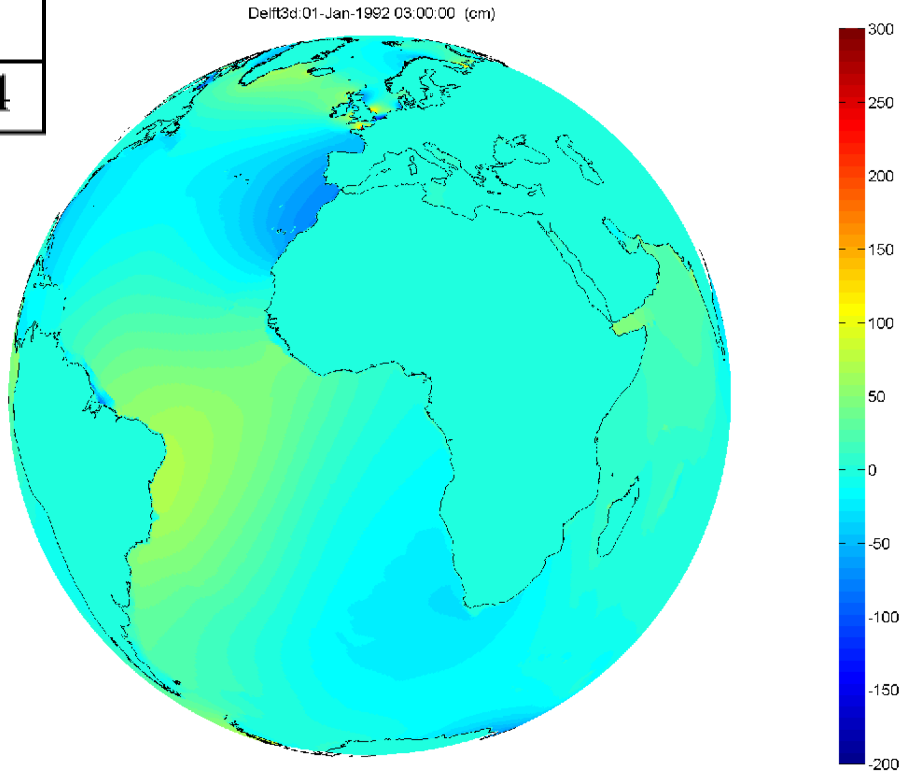




degree	Number of processors				
	PC	1	2	4	8
1/2	147	54	33	17	12
1/4	-	238	116	81	50
1/8	-	-	-	350	244

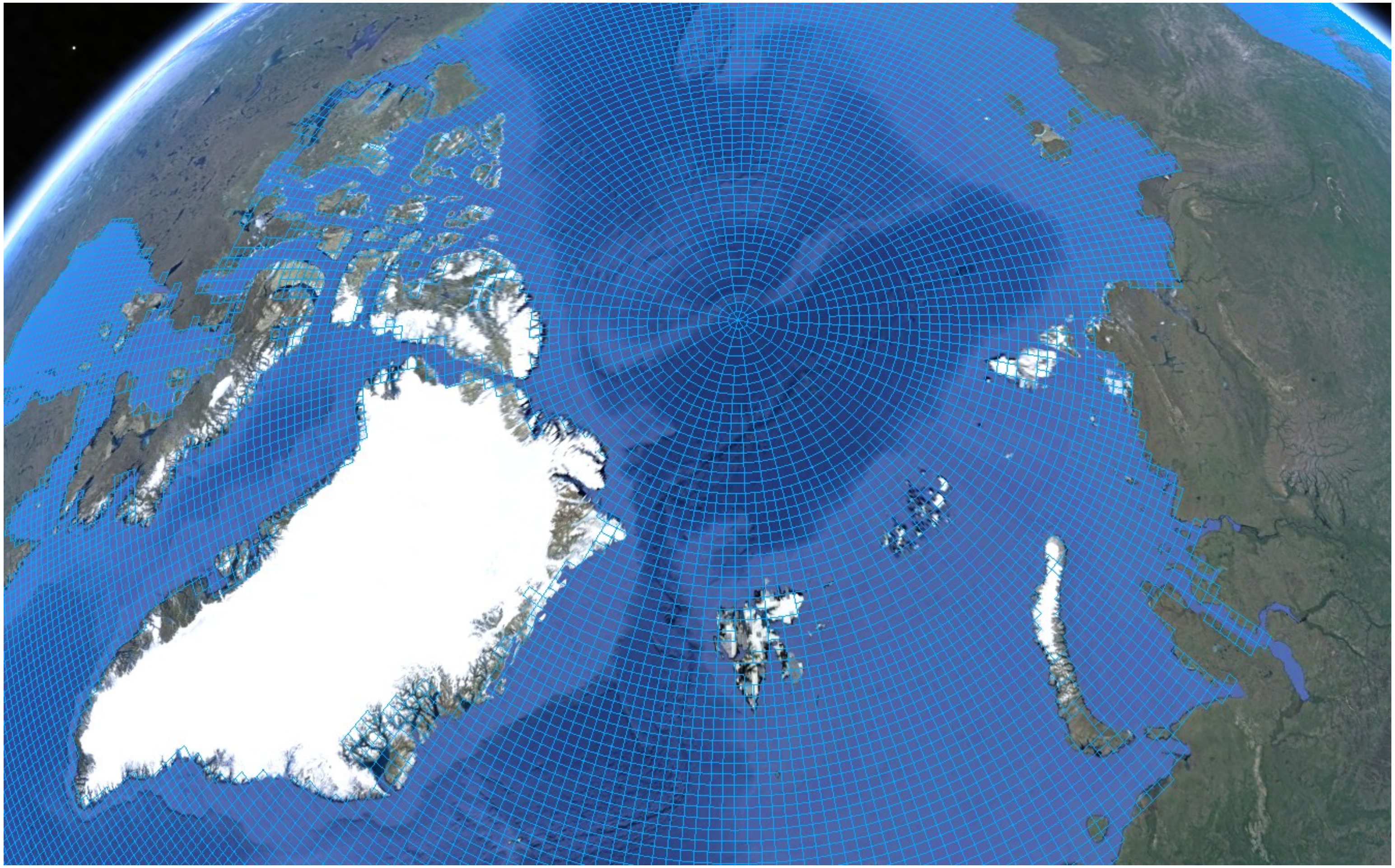
Minutes cpu/ 13day test simulation

Conclusion:
- much of the dissipation occurs on the continental shelves. This makes the model very sensitive to resolution.
- It would be very convenient to refine only the shelve areas.



Grid in Dflow-FM

Unstructured approach - step 1: grid thinning at high latitudes

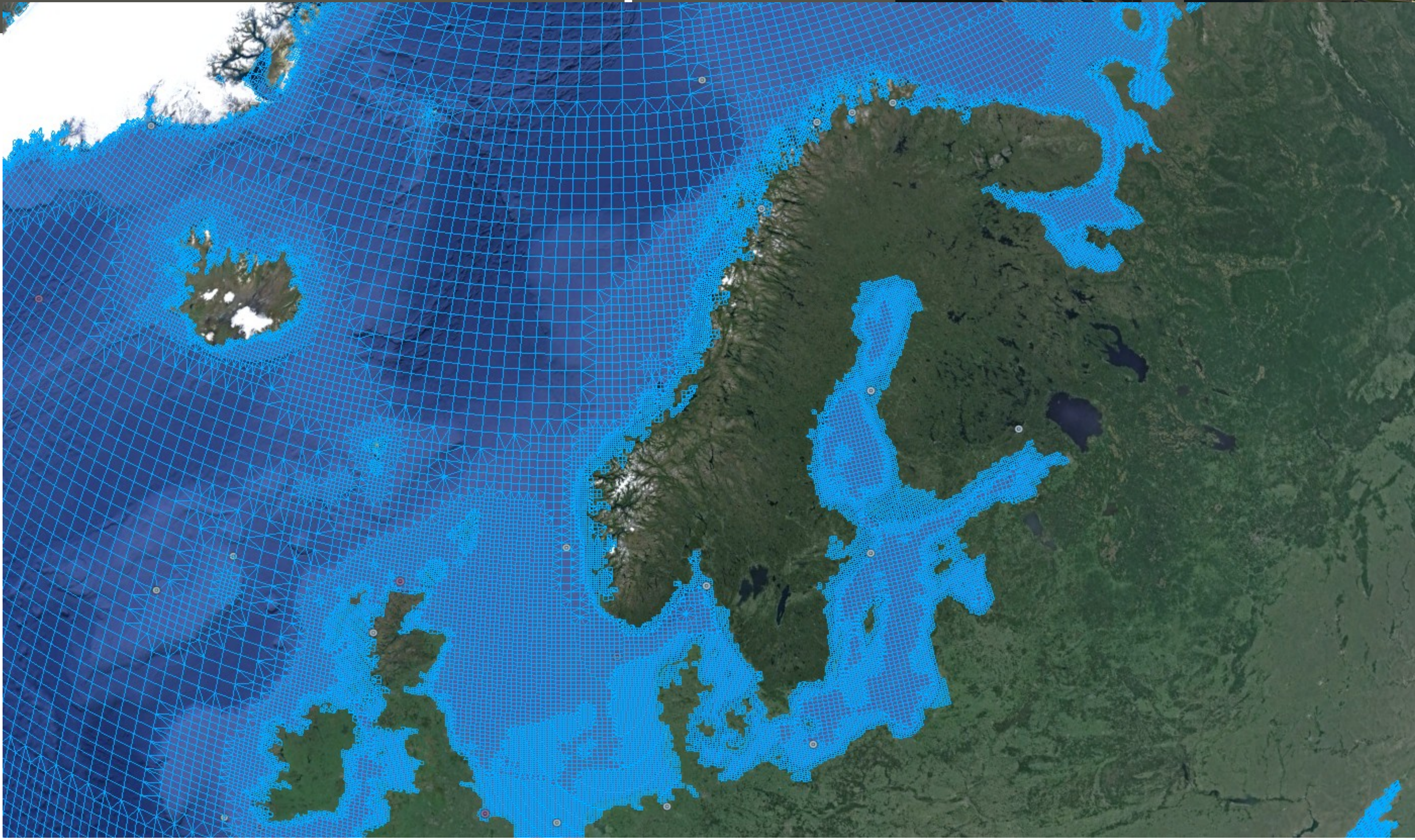


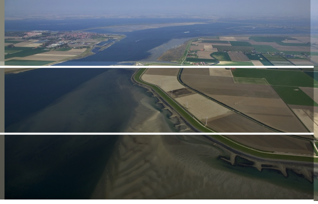
Grid in Dflow-FM

Unstructured approach - step 2: grid refinement in shallow areas

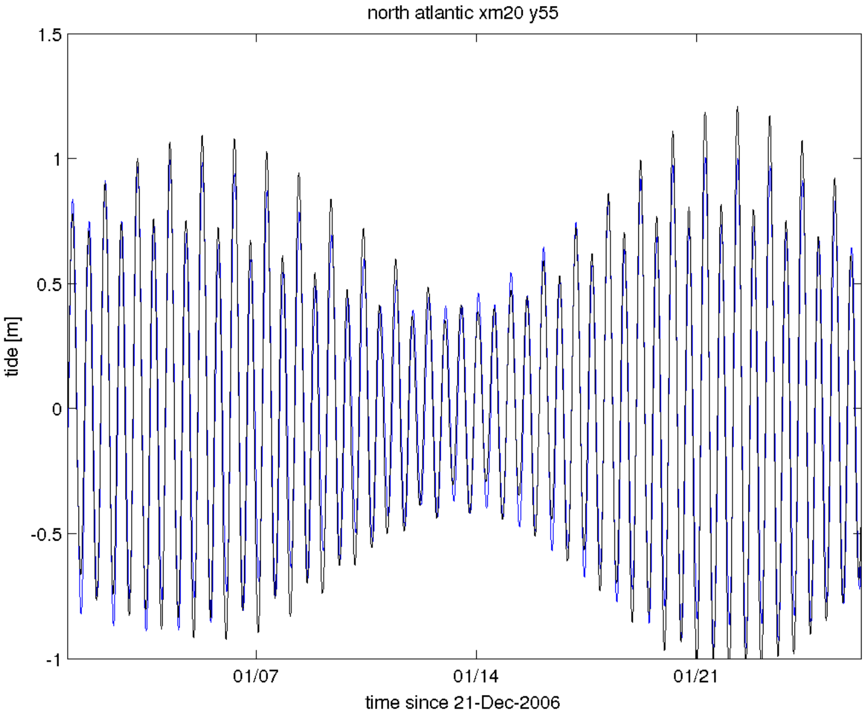
This Dflow-FM grid uses triangles and rectangles
for local grid refinement. Resolution is based on Courant number.

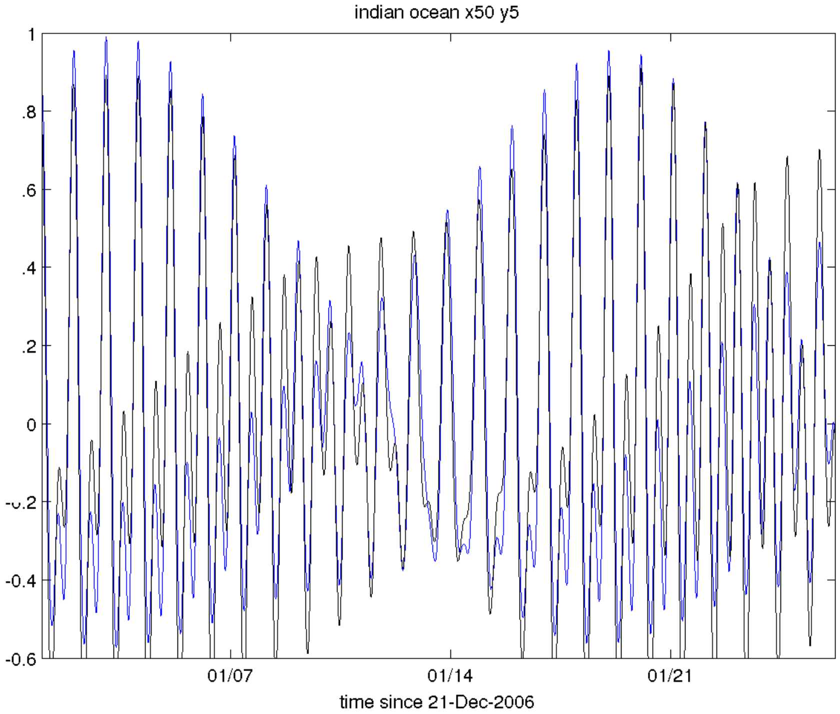
Grid Northern Europe





First results in Dflow-FM

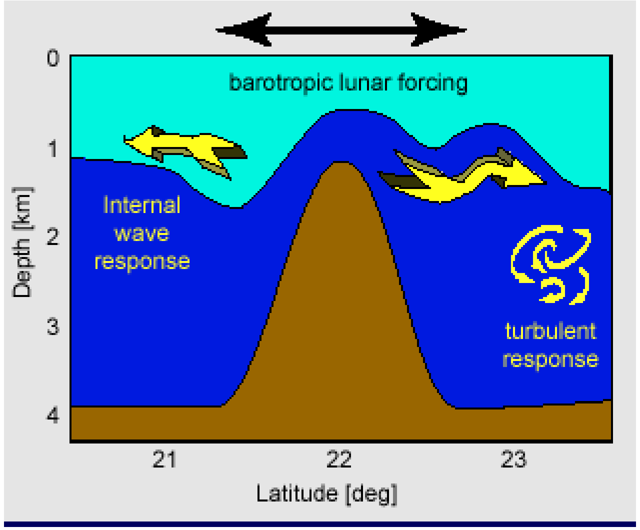




Necessary improvements

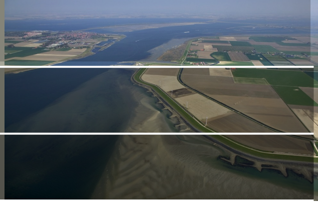
- Self attraction and loading
  - Tides modify the gravity potential as well
  - Computation is very time-consuming
  - Start wit simple approximation
- Internal tides
  - Tides create internal tide where there is stratification and steep bathymetry
  - This creates dissipation (roughly ¼ of total tidal dissipation on global scale)

$$f_x = \beta g \frac{\partial h}{\partial x}$$



$$\tau_x = \frac{-\alpha \kappa N d^2 \sqrt{\omega^2 - f^2}}{2\omega} u$$

$$N = \sqrt{\frac{-g}{\rho_0} \frac{\partial \rho}{\partial z}}$$



Internal tides & SAL term

Conservation of momentum

ζ

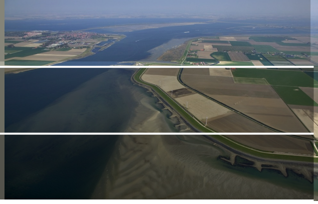
$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+g\frac{\partial h\boxed{-\zeta-\beta h}}{\partial x}-f\,v+\frac{g u\sqrt{u^2+v^2}}{C^2 H}+\boxed{\frac{\alpha\kappa N d^2\sqrt{\omega^2-f^2}}{2\omega H}}u=0$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+g\frac{\partial h\boxed{-\zeta-\beta h}}{\partial y}+f\,u+\frac{g v\sqrt{u^2+v^2}}{C^2 H}+\boxed{\frac{\alpha\kappa N d^2\sqrt{\omega^2-f^2}}{2\omega H}}v=0$$

1. tidal forcing
2. SAL
3. dissipation by internal tides

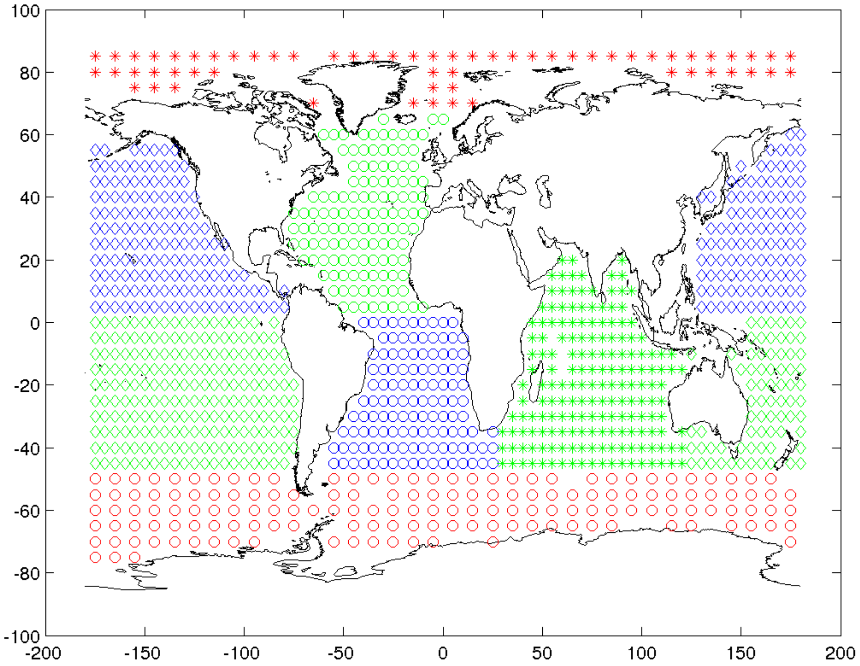
Conservation of mass

$$\frac{\partial h}{\partial t}+\frac{\partial H u}{\partial x}+\frac{\partial H v}{\partial y}=0$$



Accuracy before calibration

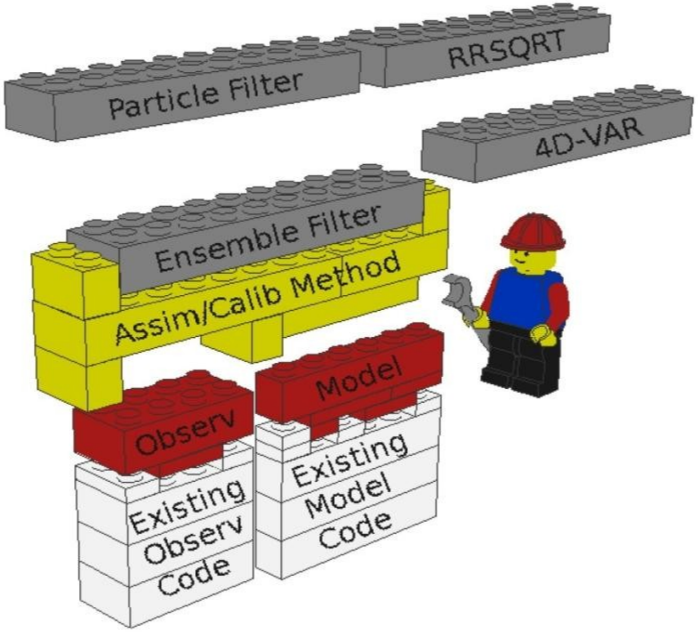
group	#stations	#values	std(res) [m]	relstd(res)	relrange	time-error [min]
arctic_ocean	61	222040	0.059	61.6%	88.0%	20.6
north_atlantic	124	451360	0.087	28.4%	98.7%	5.7
south_atlantic	121	440440	0.104	49.2%	123.9%	-15.1
indian_ocean	176	640640	0.135	43.9%	91.8%	-0.6
southern_ocean	153	556920	0.141	53.3%	113.8%	-5.7
north_pacific	247	899080	0.09	29.1%	97.0%	-6.6
south_pacific	274	997360	0.122	50.6%	98.2%	-0.5
total	**1156**	**4207840**	**0.111**	**43.4%**	**101.2%**	**-2.3**



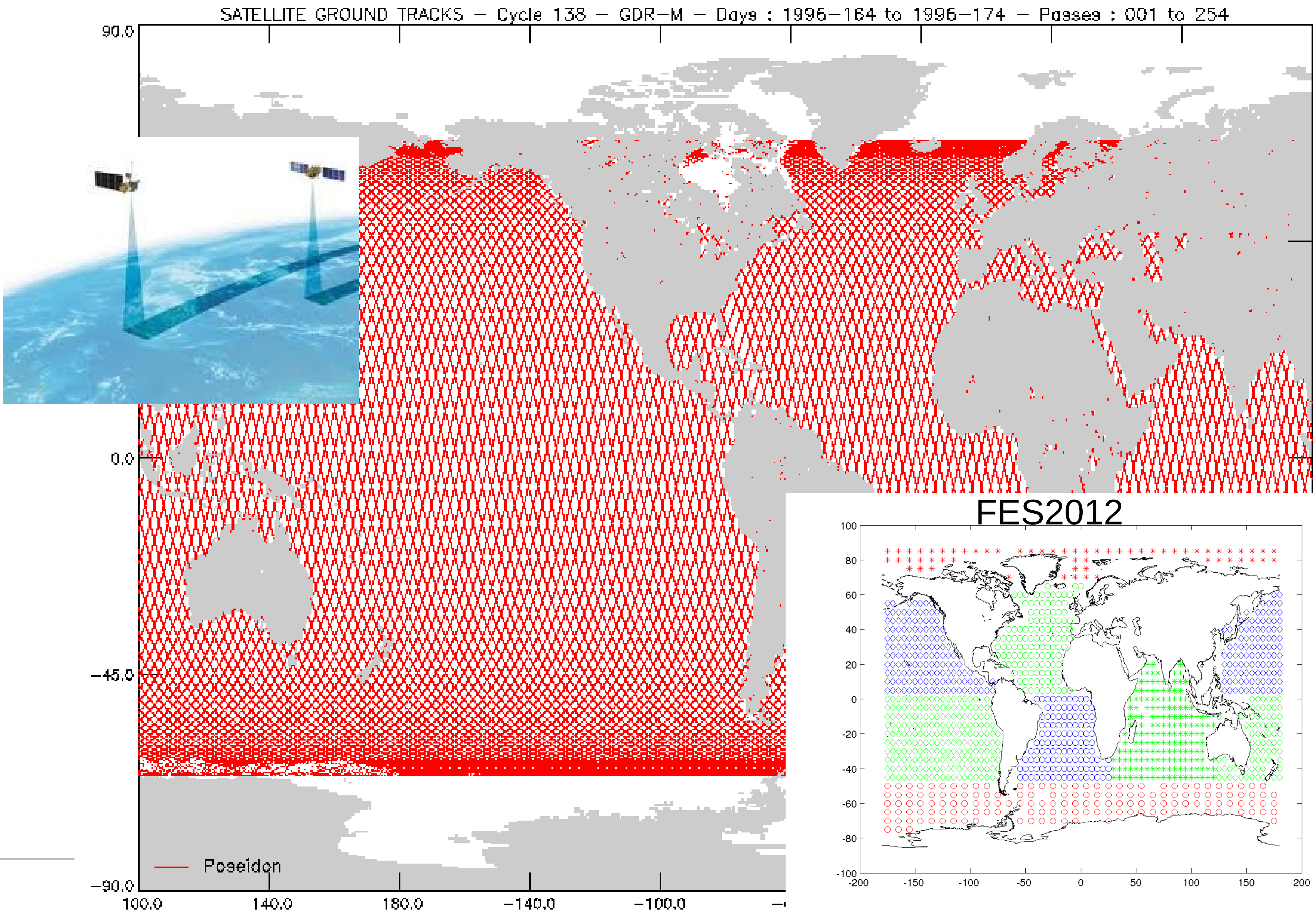
Comparison with FES2012 for January 2007

Calibration with OpenDA

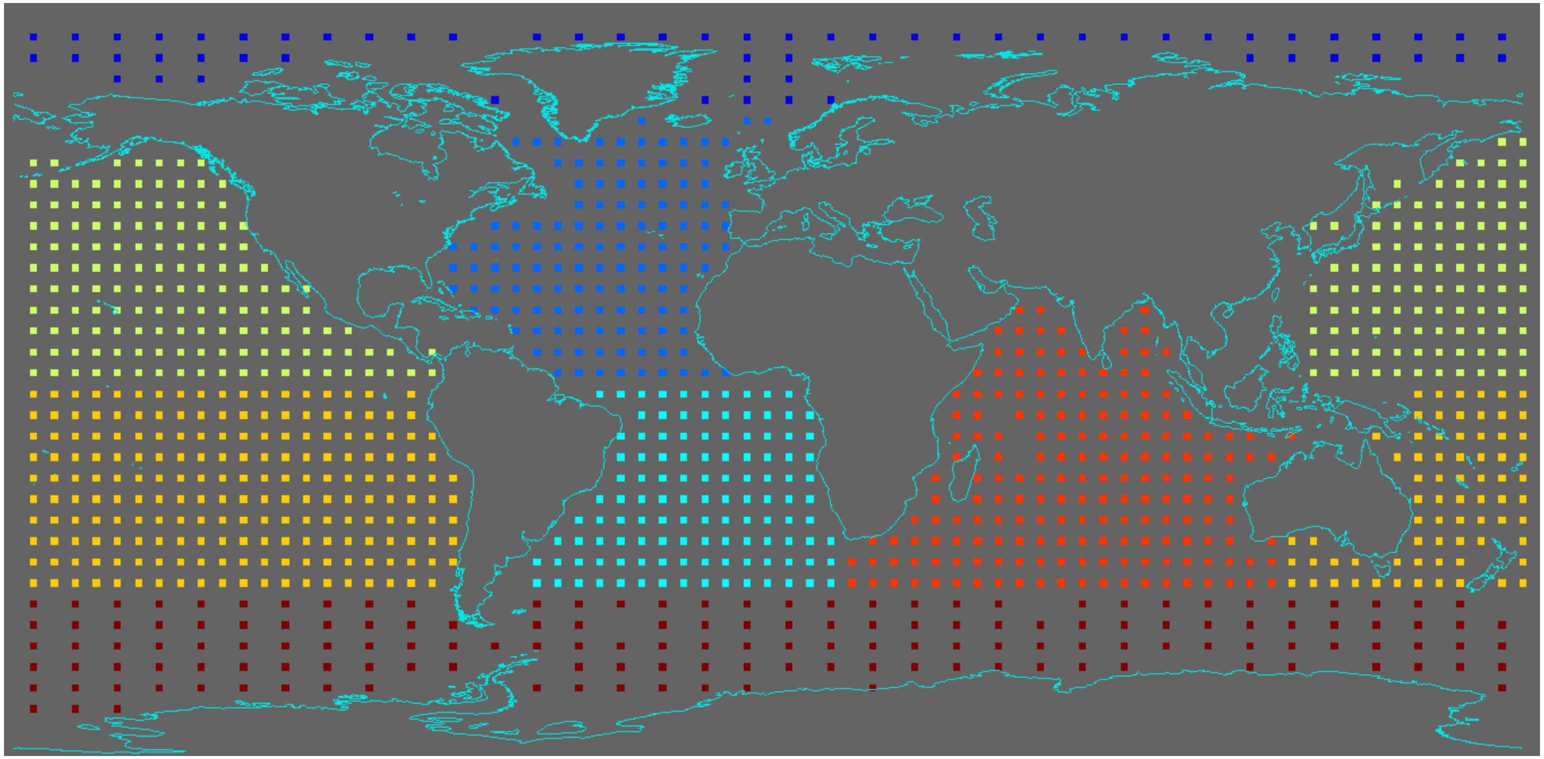
- OpenDA is generic toolbox for data-assimilation
- Open source (LGPL) see www.openda.org
- Contains calibration algorithms like:
  - Simplex
  - Conjugate-gradient
  - Powell
  - DUD
- Recently the coupling to DFLow-FM has been implemented



Altimeter observations

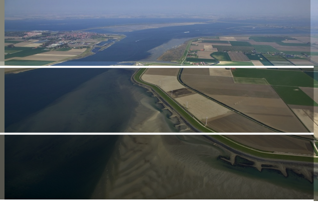


Model calibration



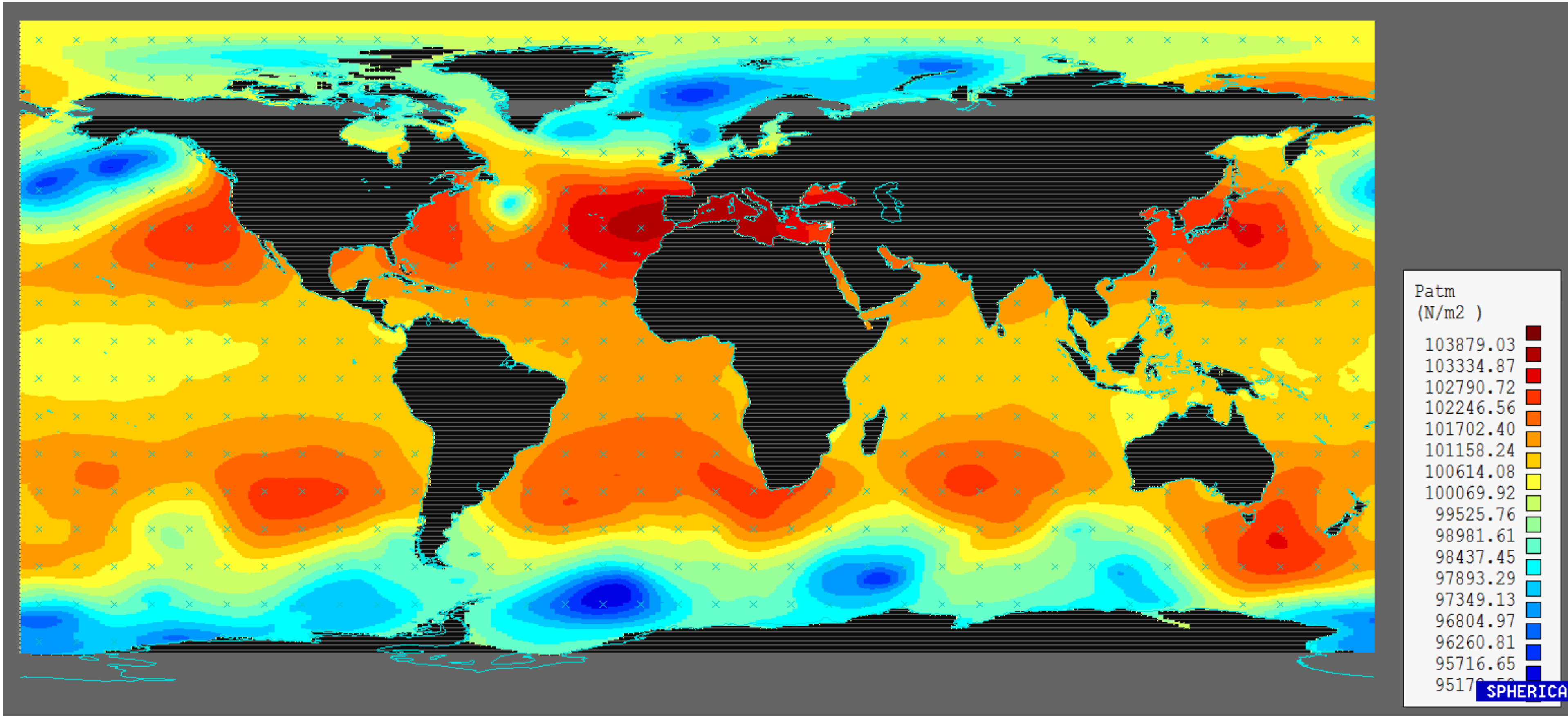
- parameter changes constant per selected area (as shown)
- linear parameter changes between areas
- use FES2012 as 'observations' for deep water (contains satellite altimeter)
- postpone calibration for coastal stations for 1st iteration

Next steps and challenges

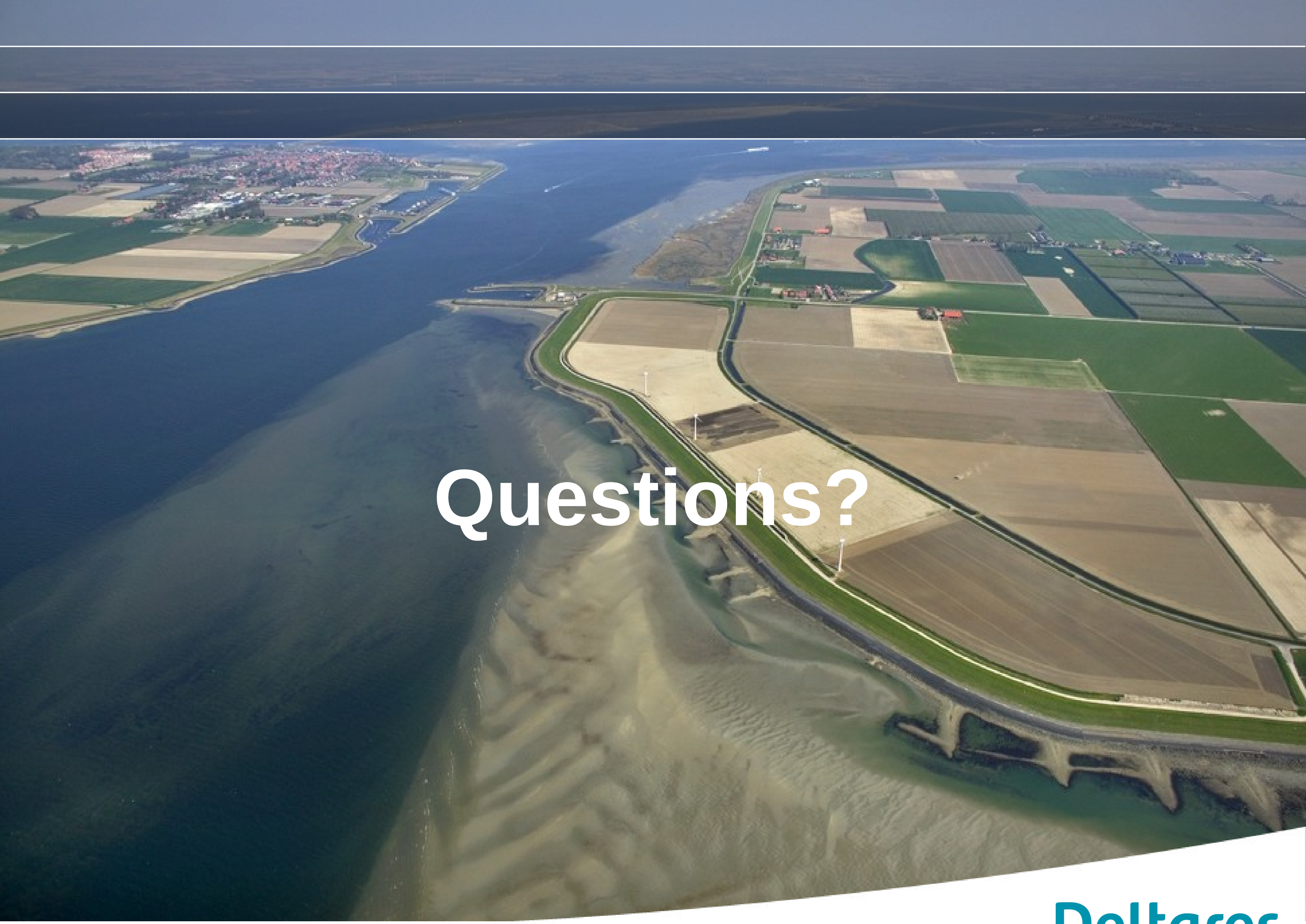


- Perform calibration
  - First for deep water with altimeter data
  - Next for coastal stations
- Implement improved SAL term
- Forcing with meteorological winds en air-pressure
  - Study impacts of climate change
  - Study inverse barometer assumption
  - Operational forecasting

Atmospheric forcing

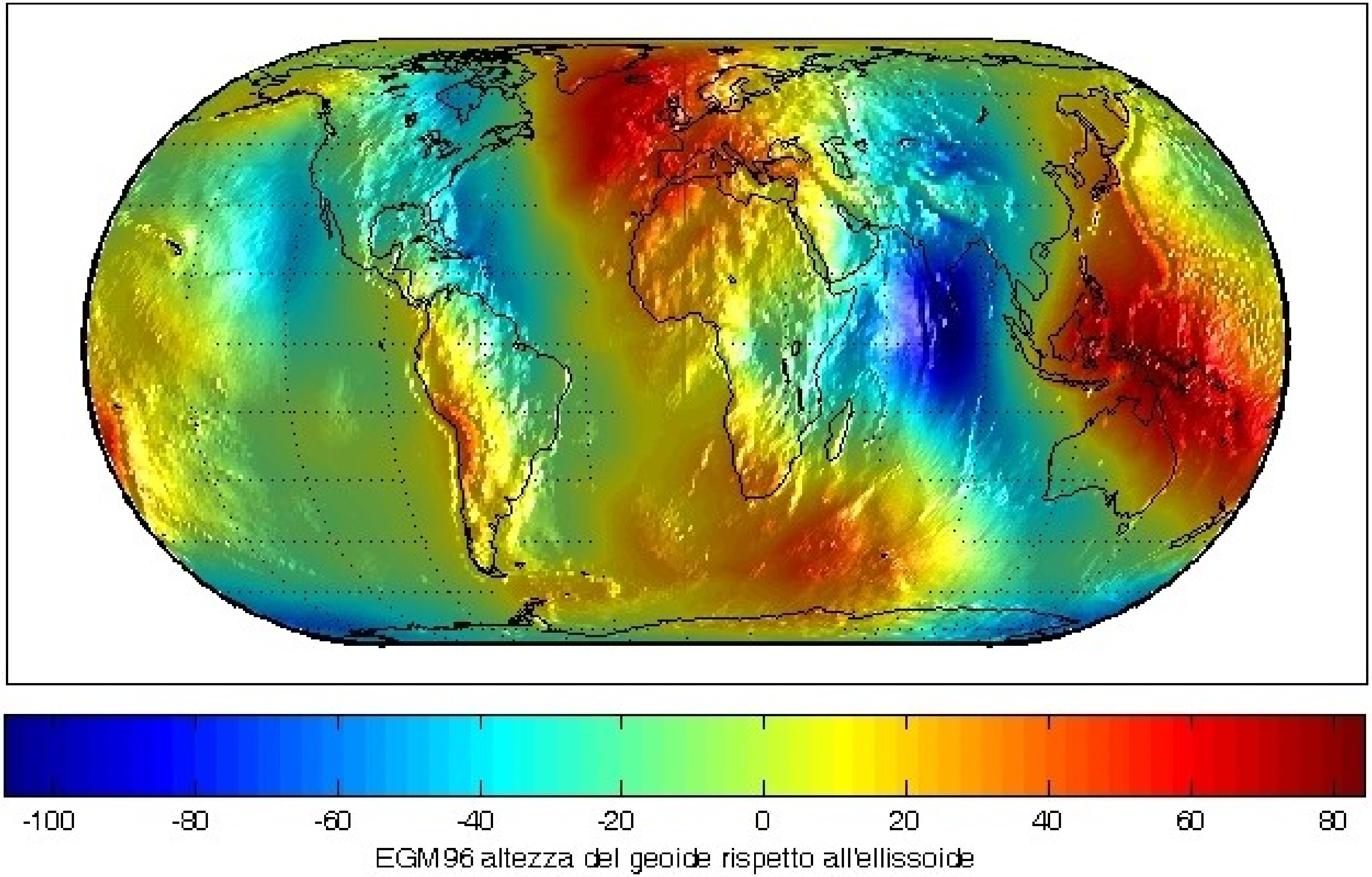


ERA-interim: P_{msl} Jan 1 2007 00:00h



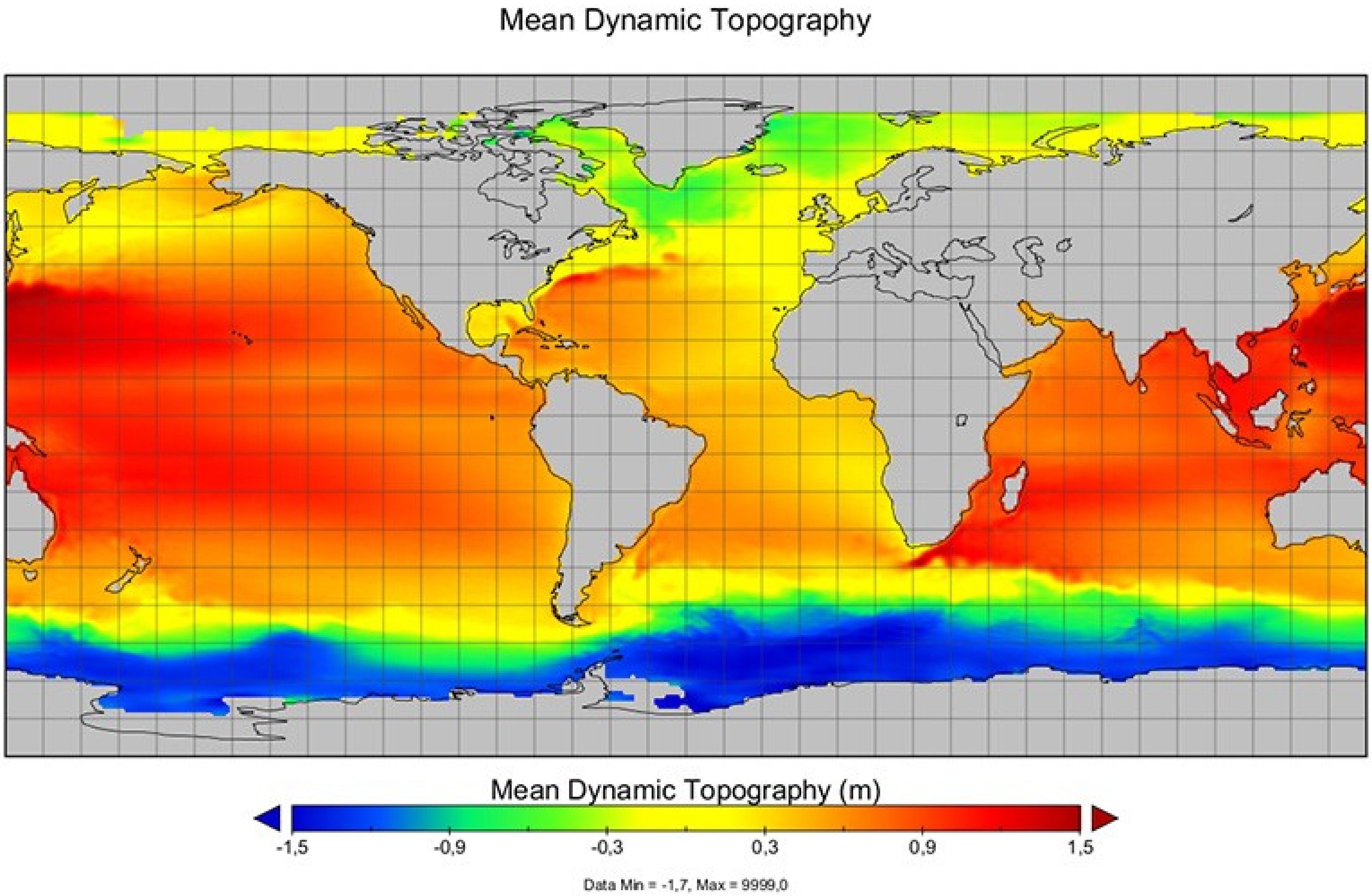
Questions?

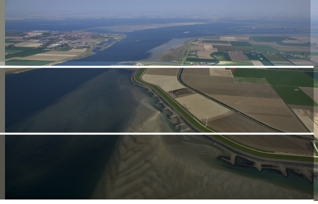
Geoid relative to ellipsoid



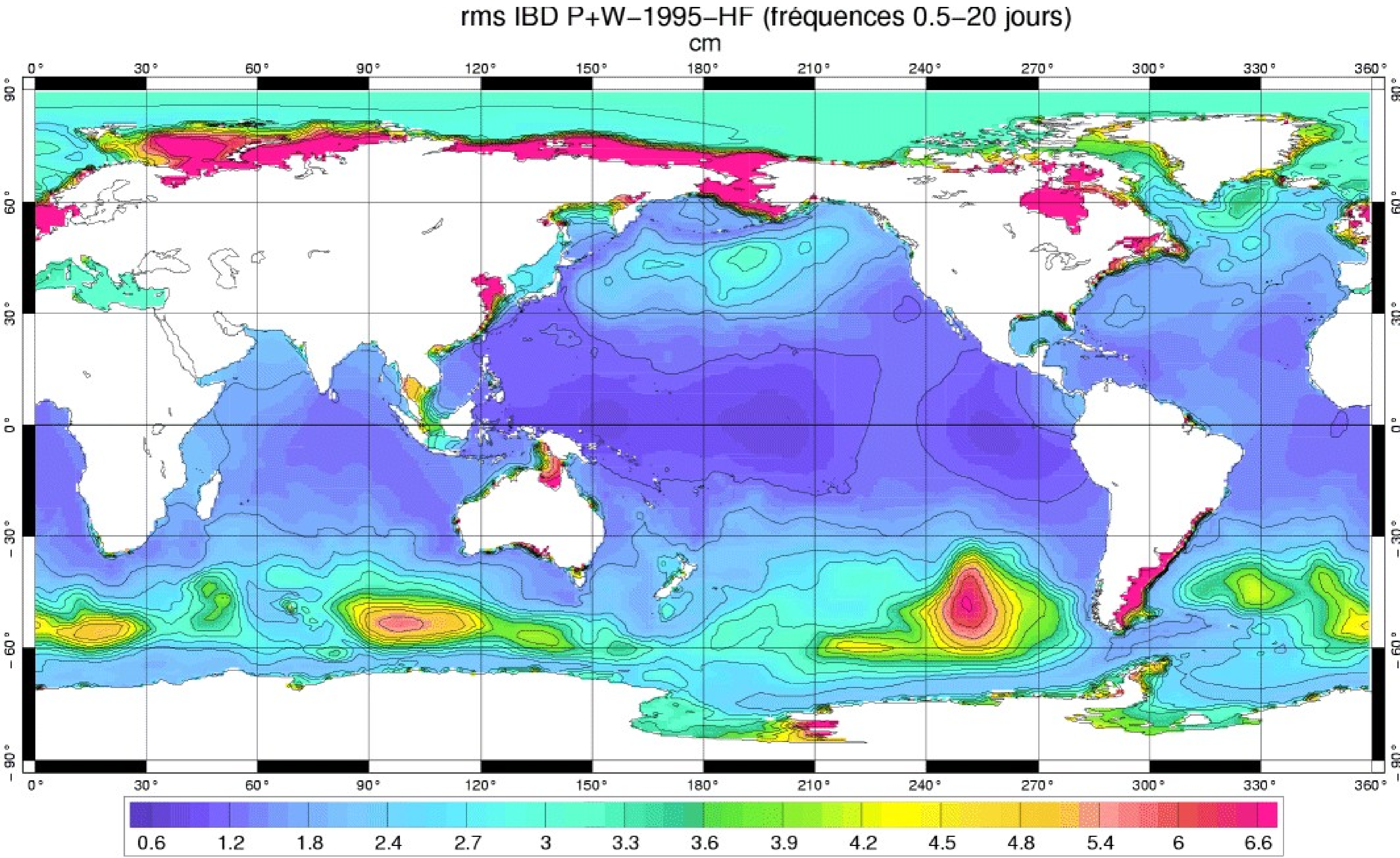
Source: cnes

Mean dynamic topography



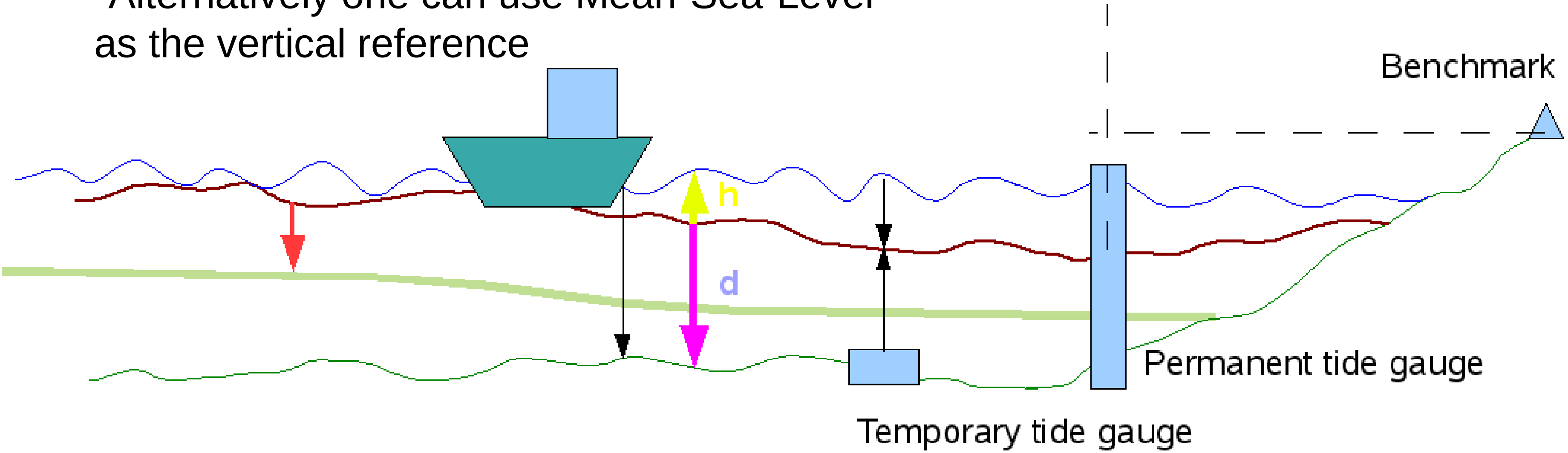


Surge – forced by wind and pressure



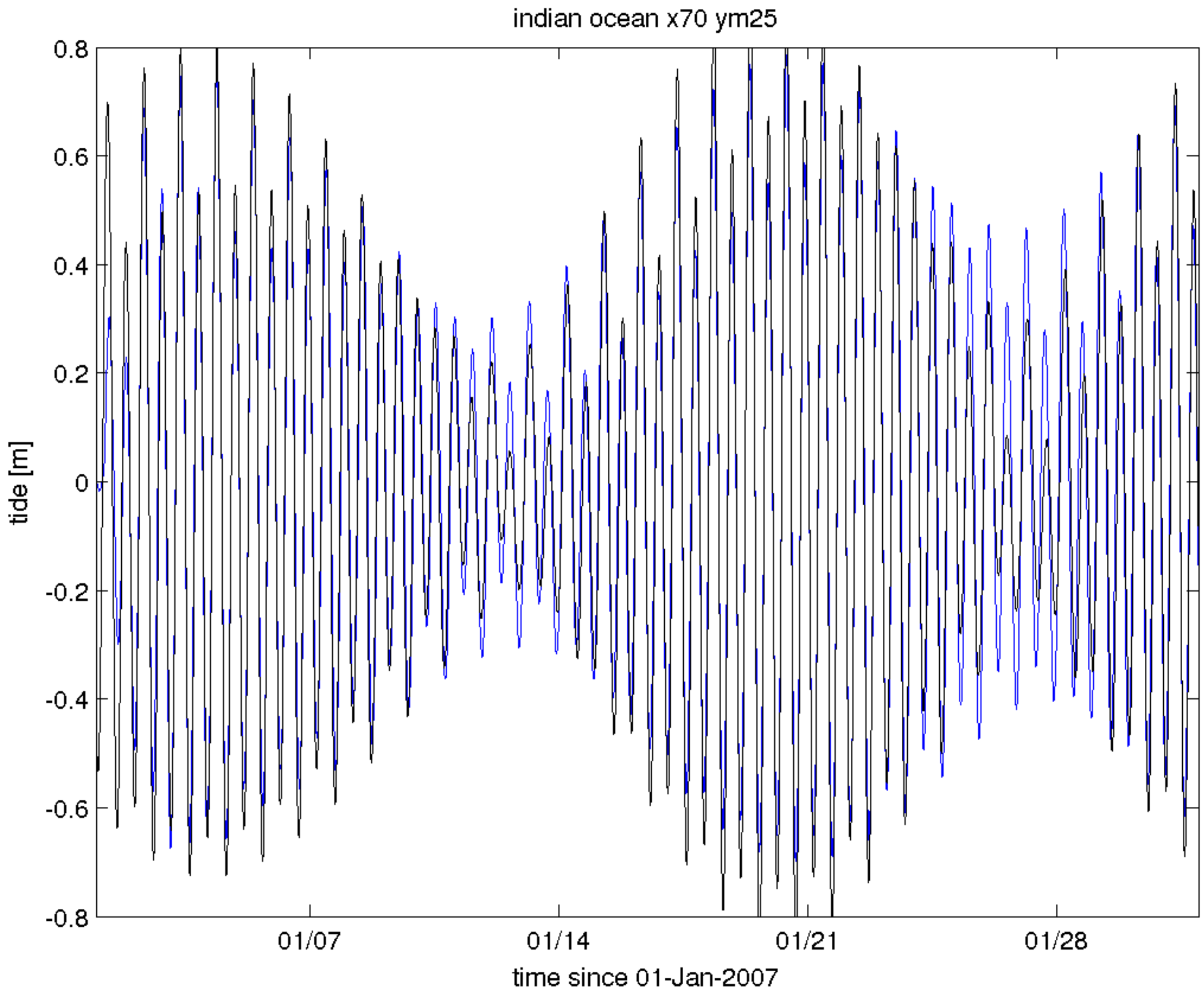
Sealevel =
Ellipsoid
+(Geoid-Ellipsoid)
+(MDT-Geoid)
+Tides
+Surge
(+interactions)

Alternatively one can use Mean-Sea-Level as the vertical reference

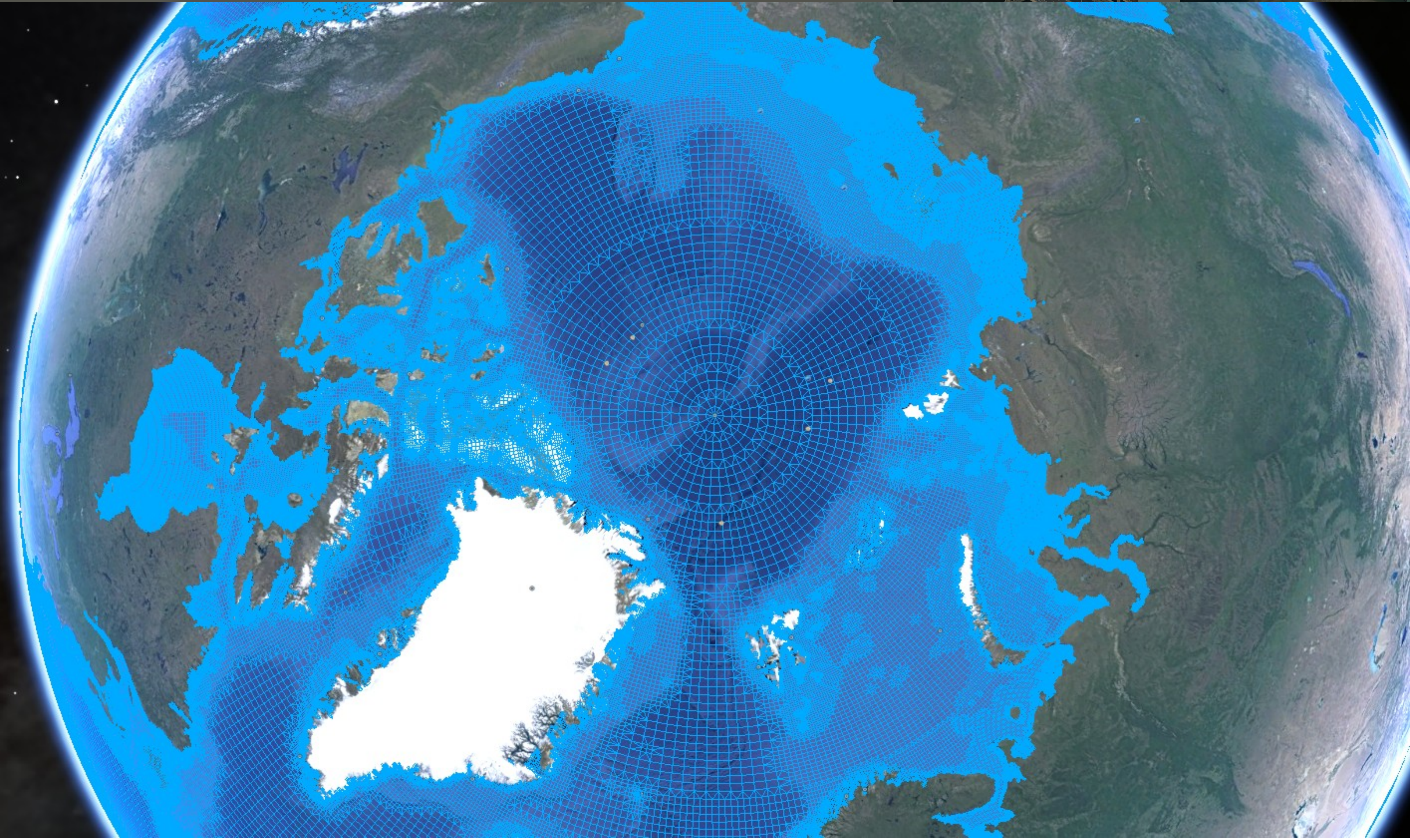


Source: citg.tudelft.nl

Sample time-series

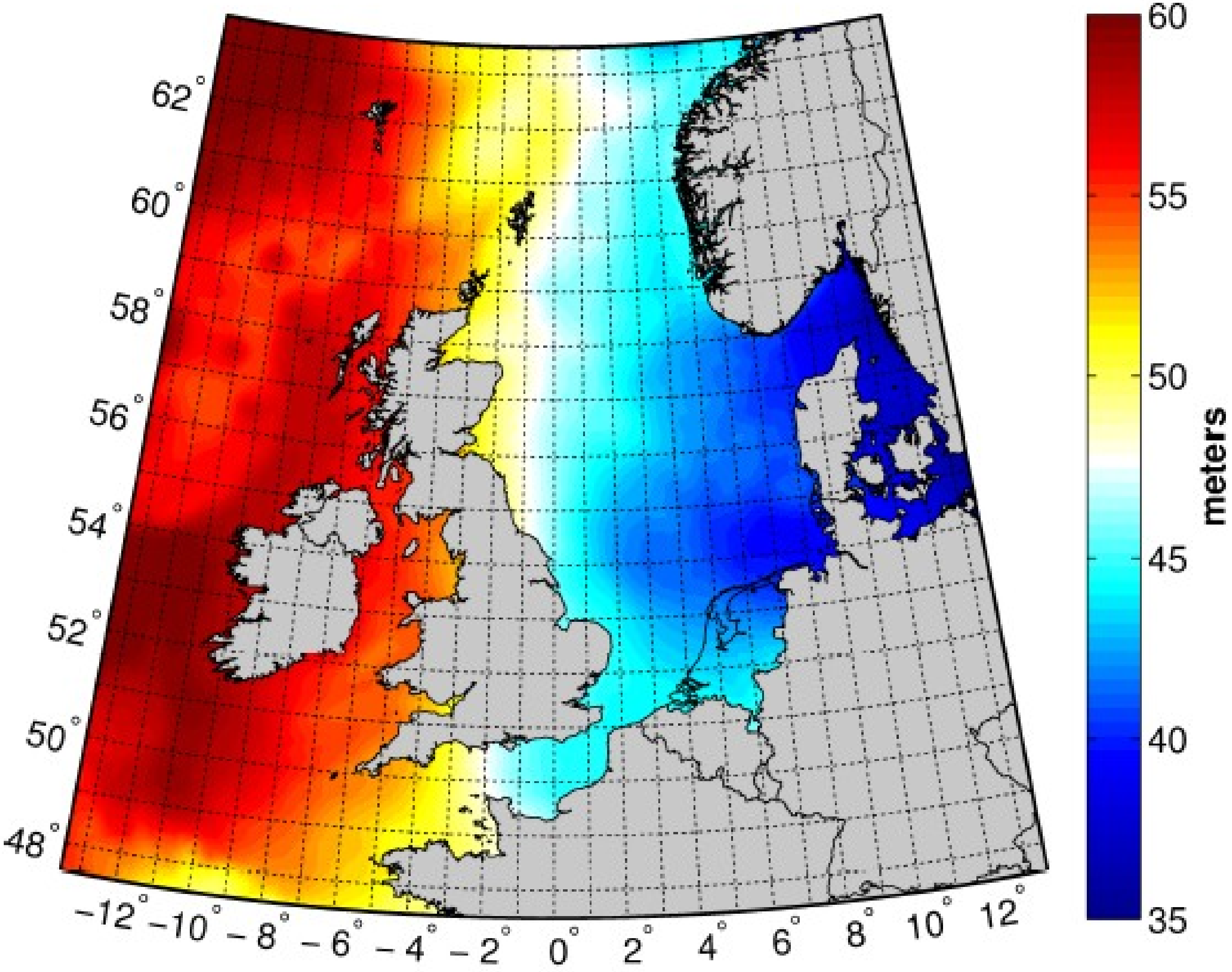


Grid Arctic

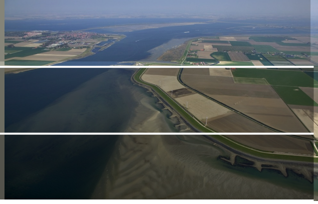


Grid North America

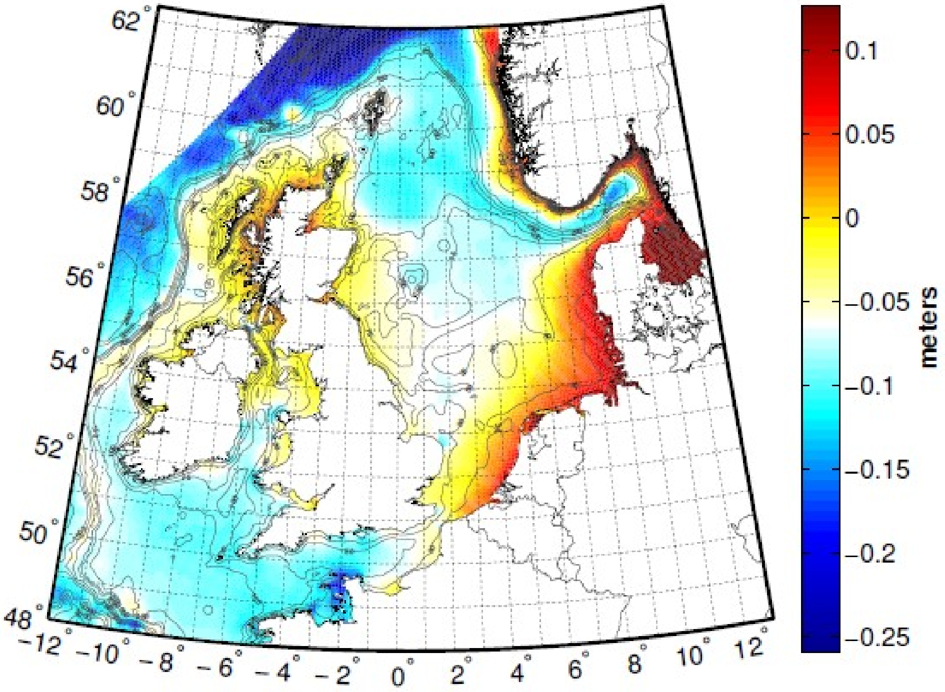
Absolute vertical referencing



NLGEO2013 Quasi-geoid relative to ellipsoid (Slobbe 2012,2013)



Absolute vertical referencing



Mean Dynamic Topography

Mean difference MDT between Model and Altimeter