Deltares
Enabling Delta Life

Modellering van getij op de Noordzee
vertikale referentie

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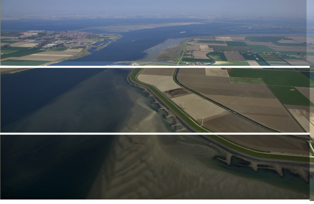
6 Feb 2014 NCG



Outline

- Introduction
  - Observations & harmonic analysis
  - Numerical models
  - Reference surfaces
- MDT and LAT
- More accurate model DCSMv6
- Challenges & future work

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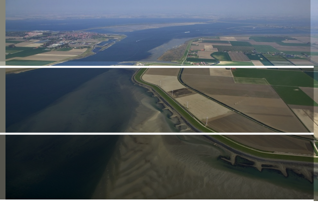
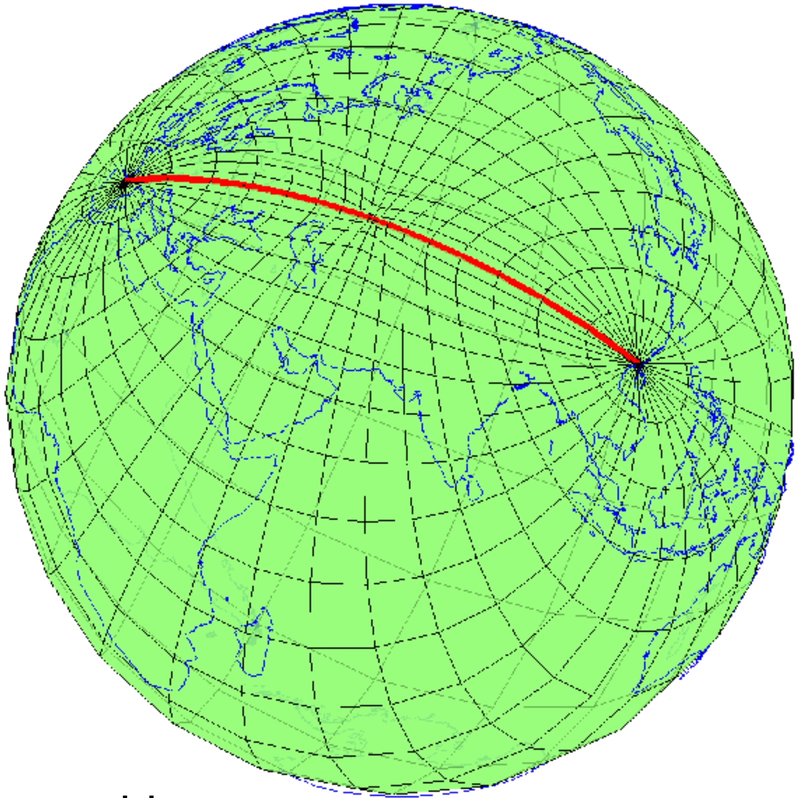
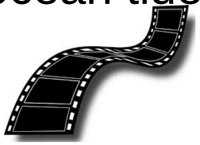
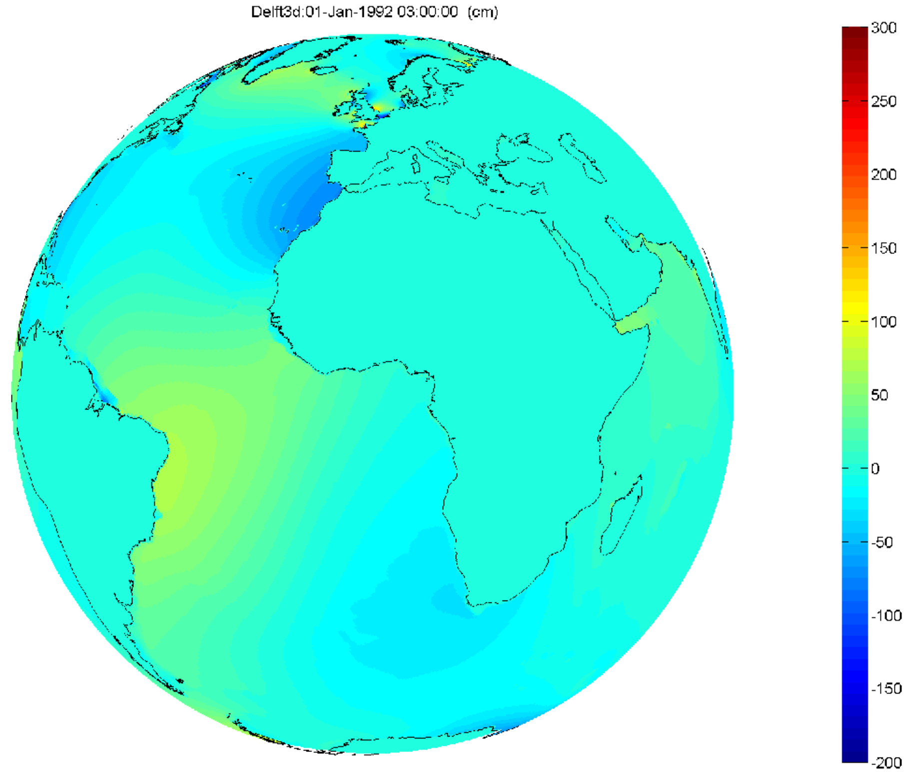


Global tide model



ocean tides





Student project.
Delft3d at http://oss.deltares.nl

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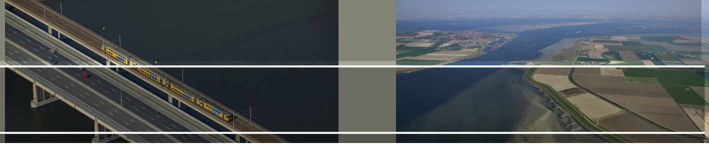
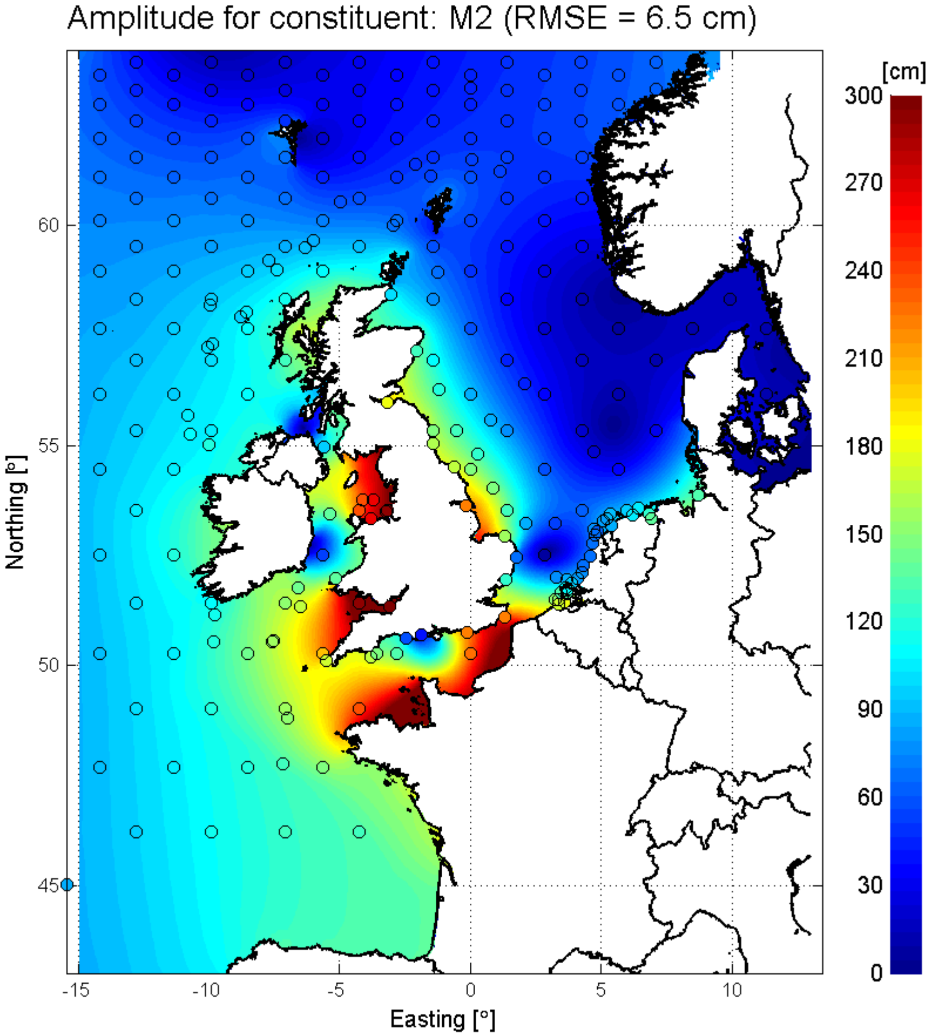
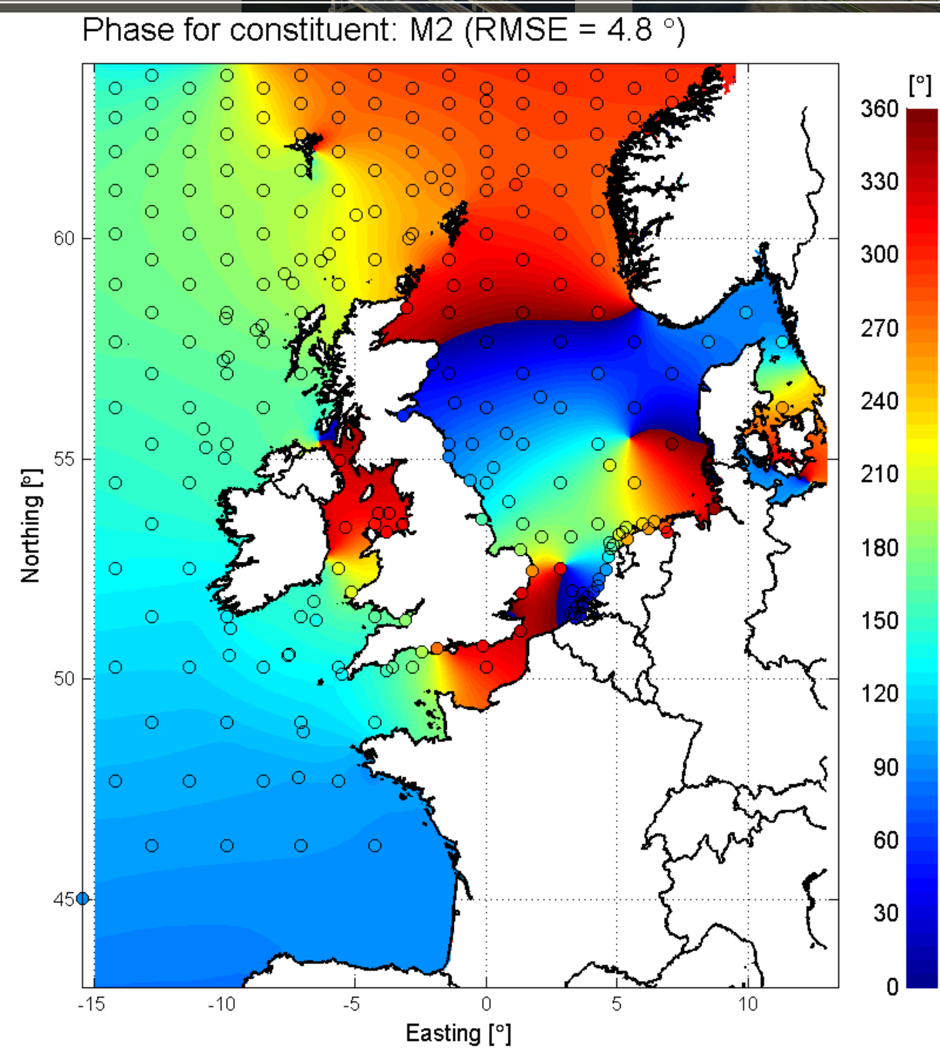
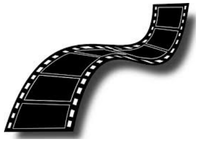
Tides in North Sea









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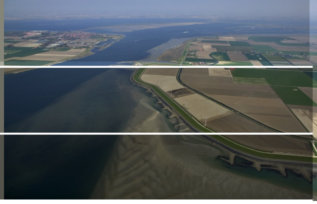
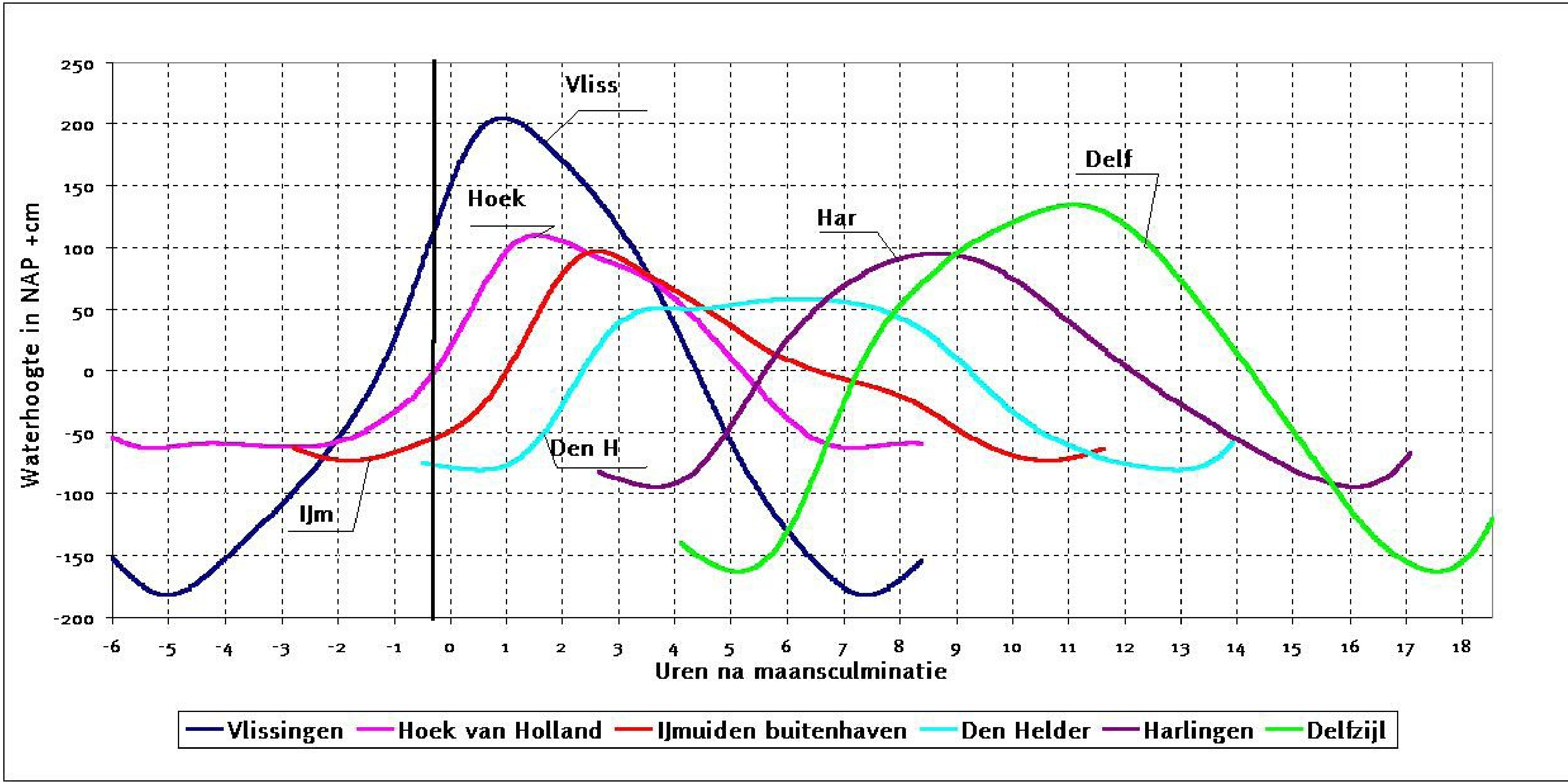
Tides along Dutch coast





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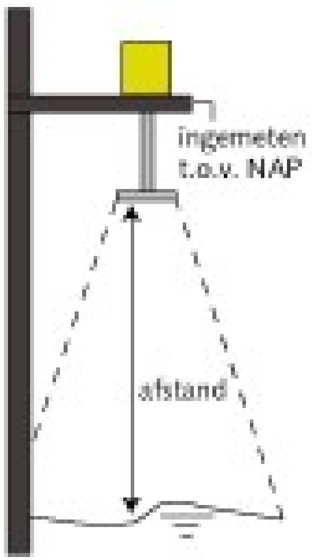
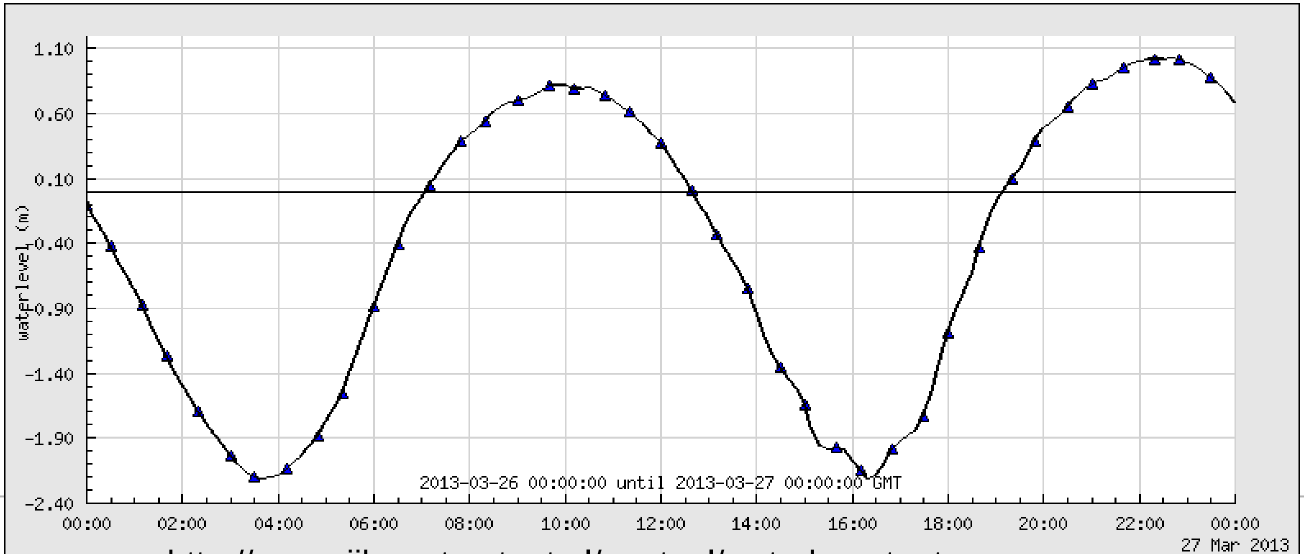
Radarnivometer





http://www.rijkswaterstaat.nl/geotool/waterhoogte_tov_nap.aspx

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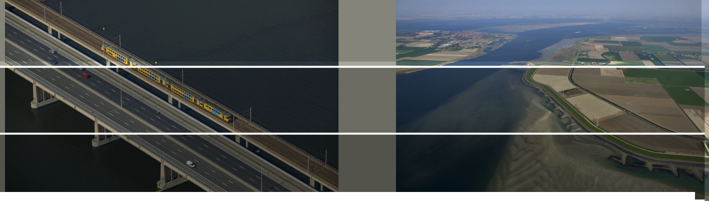
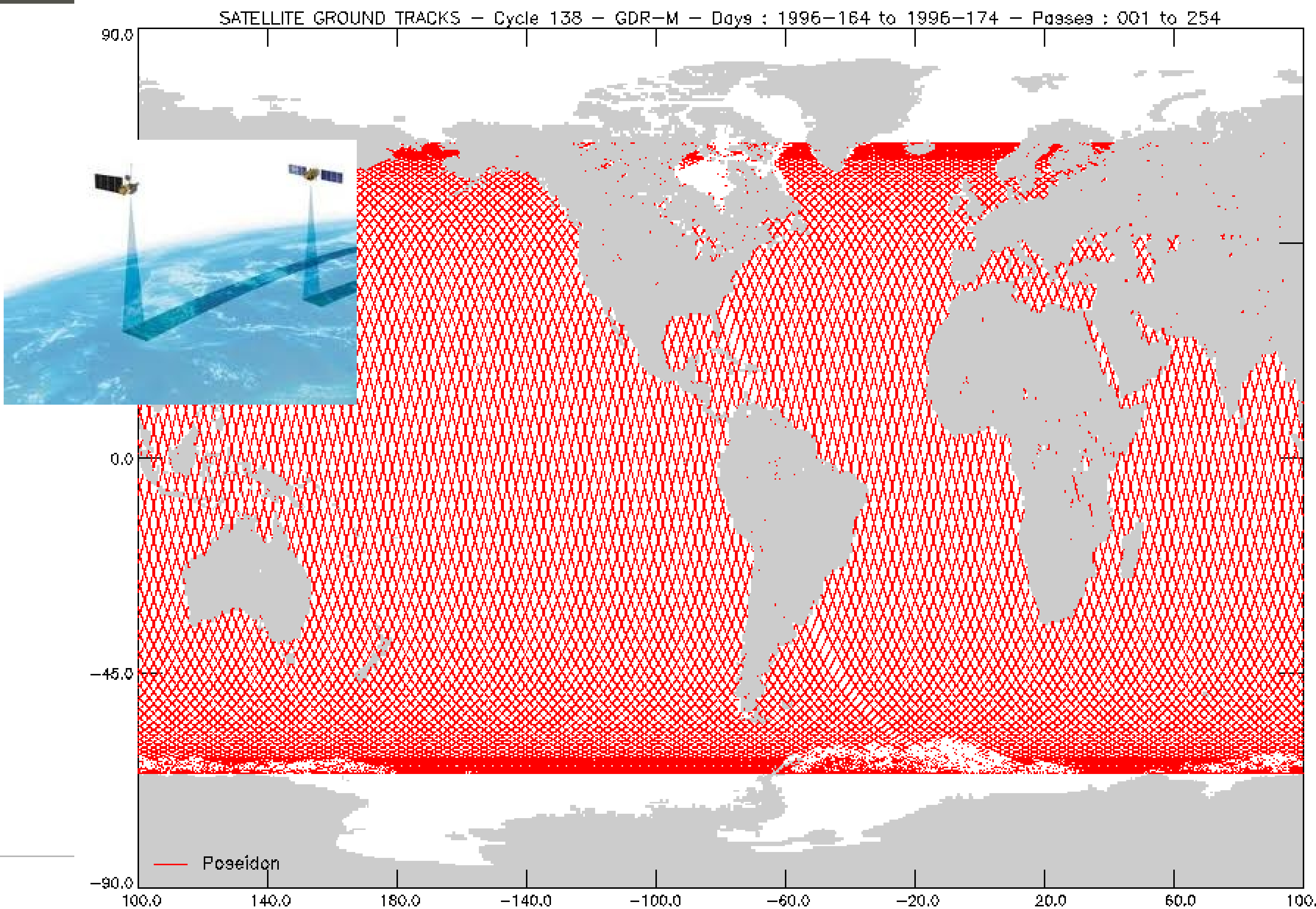
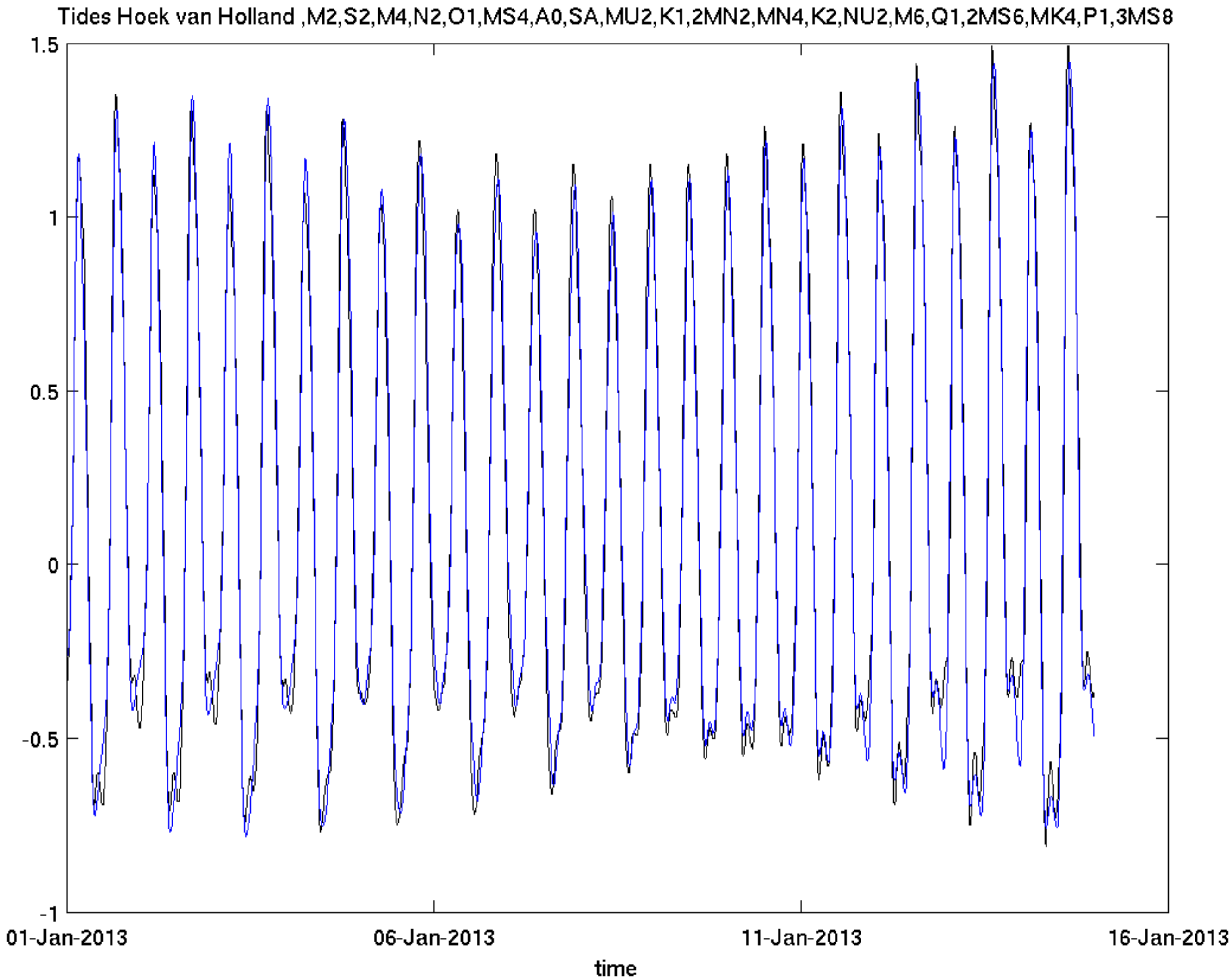
Altimeter observations





Harmonic analysis



20 constituents out of 95 in analysis

Needs at least 1 year of data

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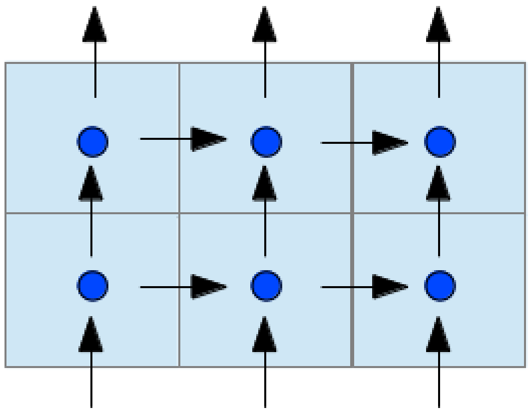
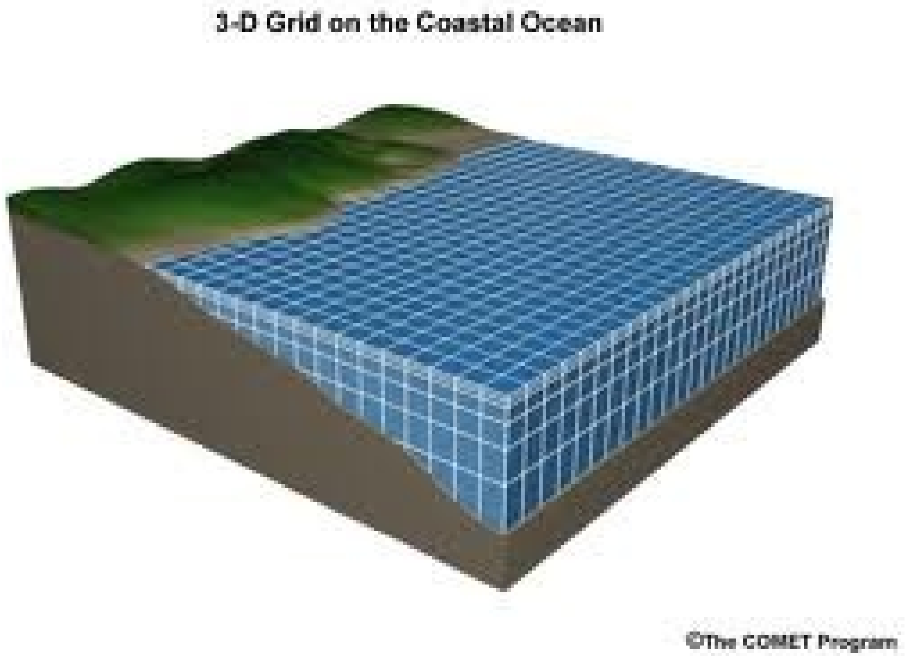
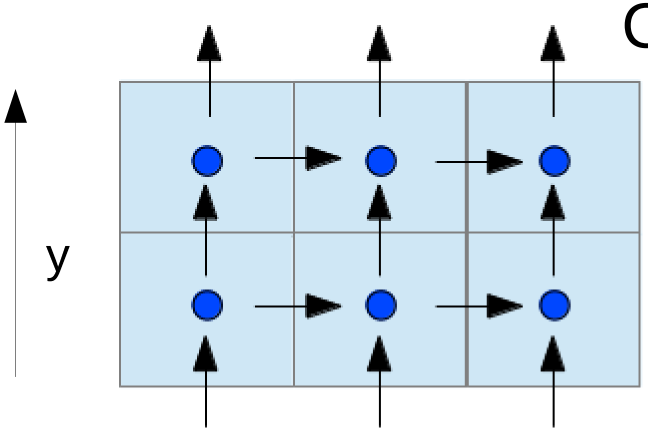
Numerical models

2D-Grid





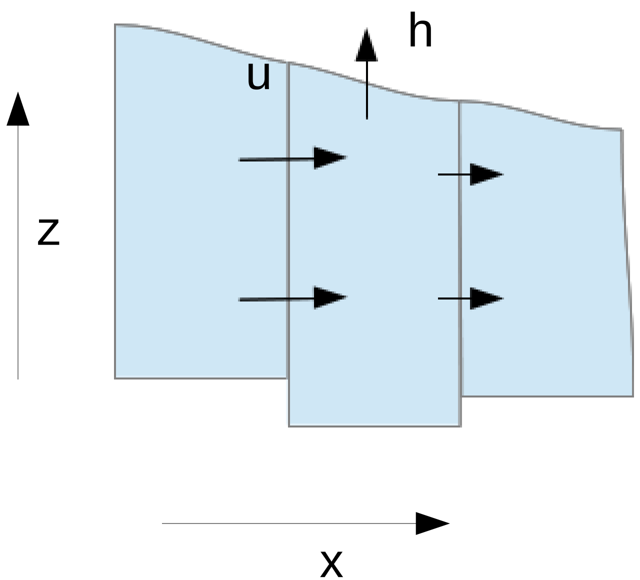
Shallow water model



Conservation of mass

Inflow | Level rise

$$\Delta t\, H\left(u(x) - u(x+\Delta x)\right)\Delta y = \Delta h\, \Delta x\, \Delta y$$



$$\frac{\Delta h}{\Delta t} + \frac{H\left(u(x+\Delta x) - u(x)\right)}{\Delta x} = 0$$

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

Note: non-linearity

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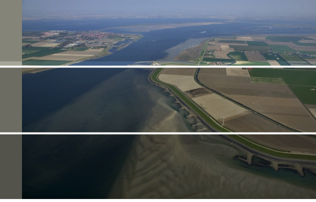
Shallow water model



Conservation of momentum in x-direction

$$\frac{\partial u}{\partial t} + g\frac{\partial h}{\partial x} - f v + \frac{c u}{H} + \frac{\partial \Phi'}{\partial x} = 0$$

$$M a = F$$

$$\frac{\partial u}{\partial t} = -g\frac{\partial h}{\partial x} + f v - \frac{c u}{H} - \frac{\partial \Phi'}{\partial x}$$

acceleration

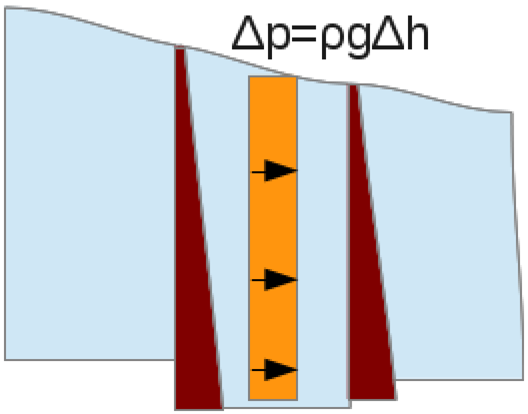
- Tidal potential
- Friction
- Coriolis 'force'
- Surface slope

Hydrostatic pressure

Surface slope

$$p = p_0 + \rho g (z - h)$$

$$F = \rho g H \left(h(x + \Delta x) - h(x) \right)$$



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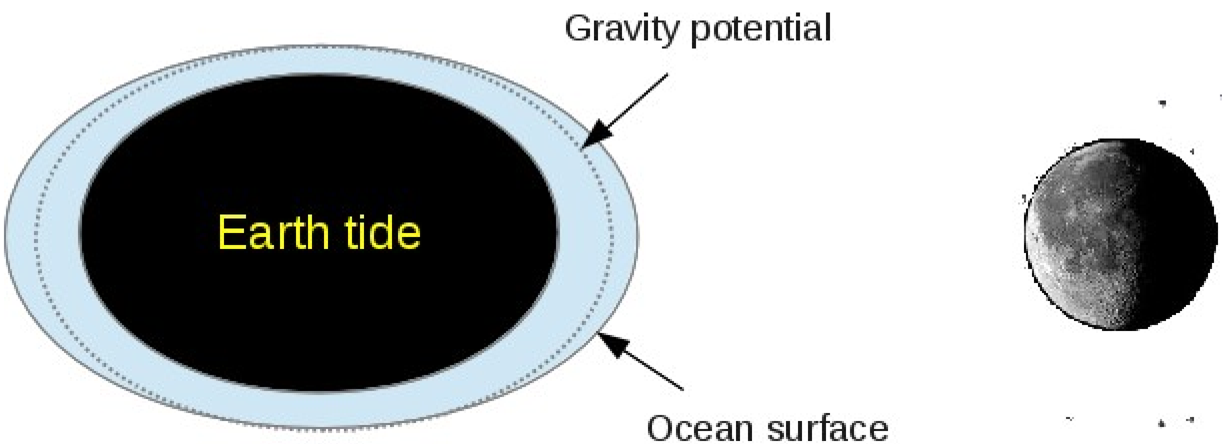
Tidal potential



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

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

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

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

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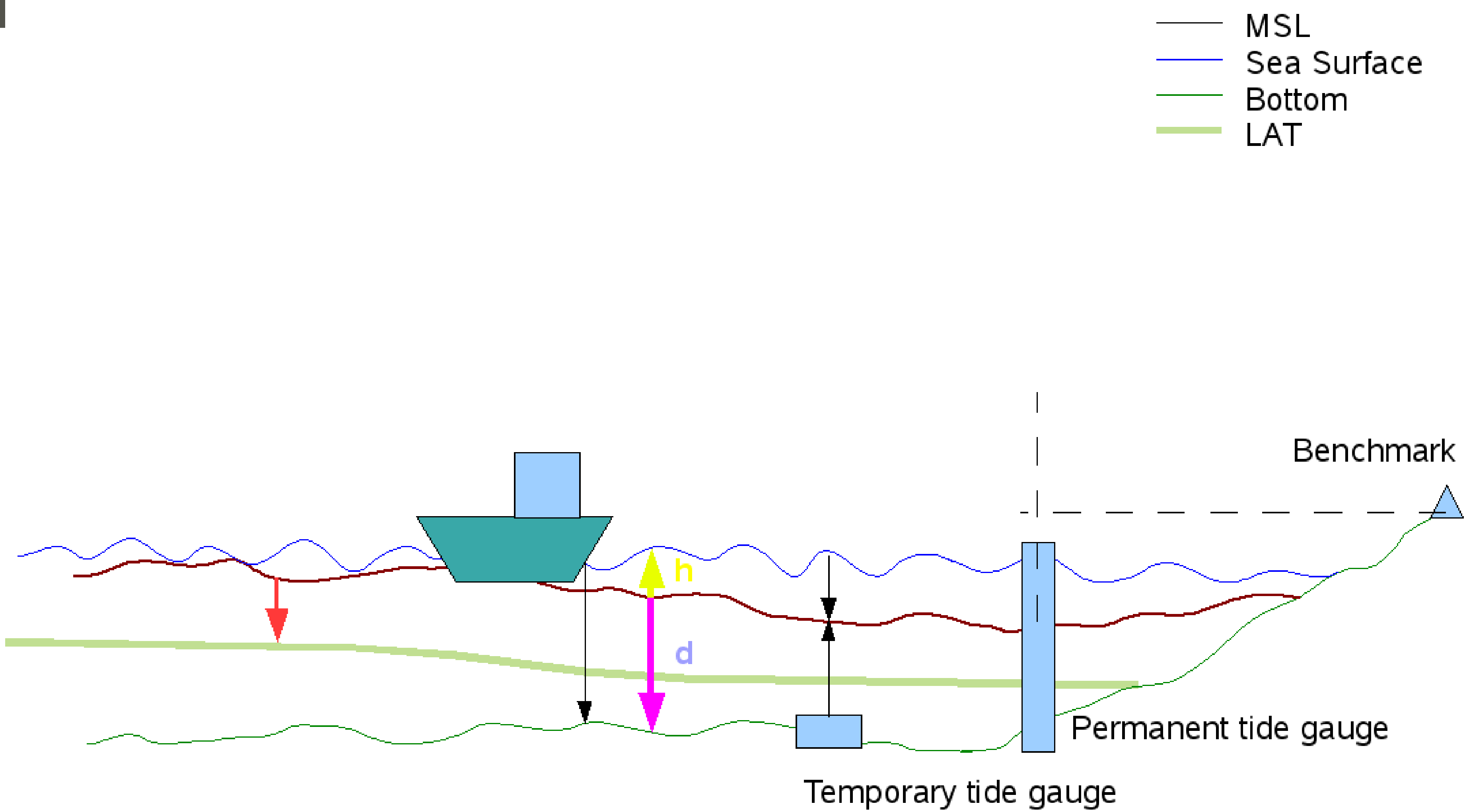
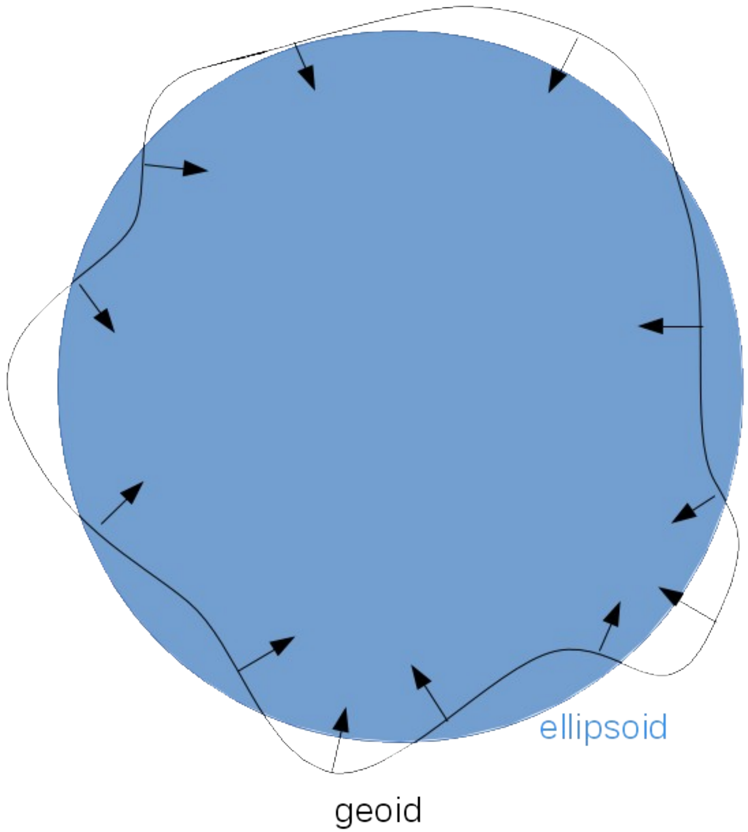
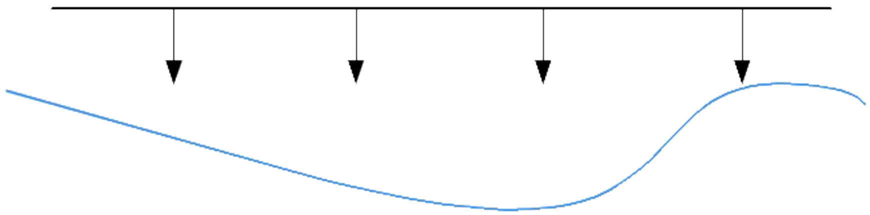


Source: citg.tudelft.nl

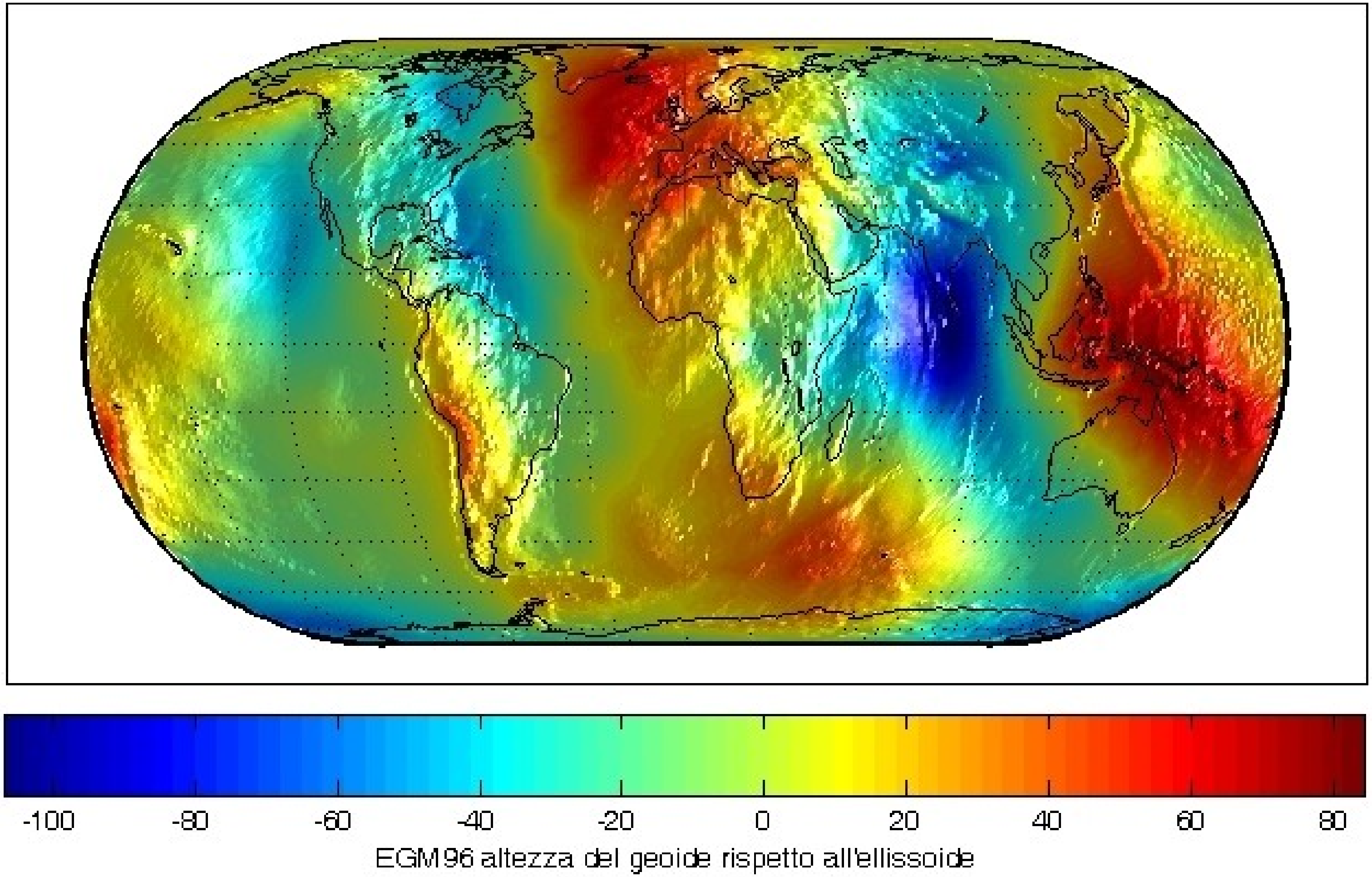
Geoid in numerical model





Gravity perpendicular to geoid

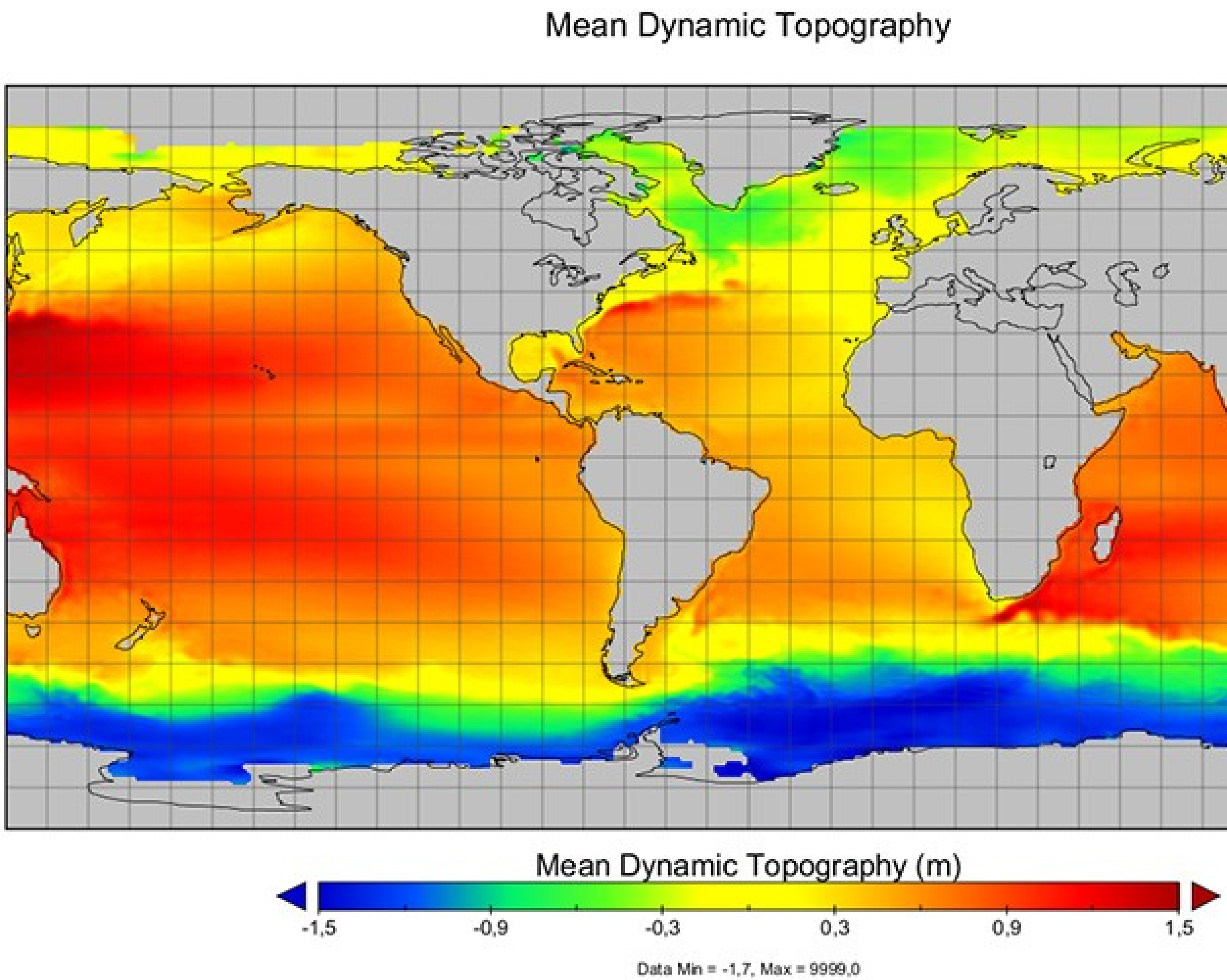
Geoid relative to ellipsoid



Source: cnes

Deltares

Mean dynamic topography



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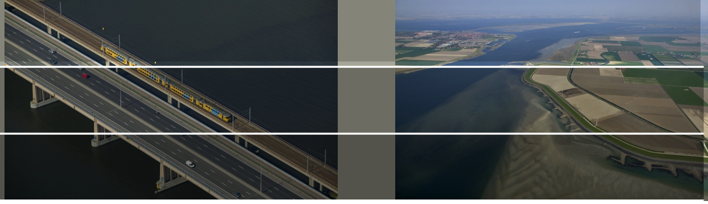
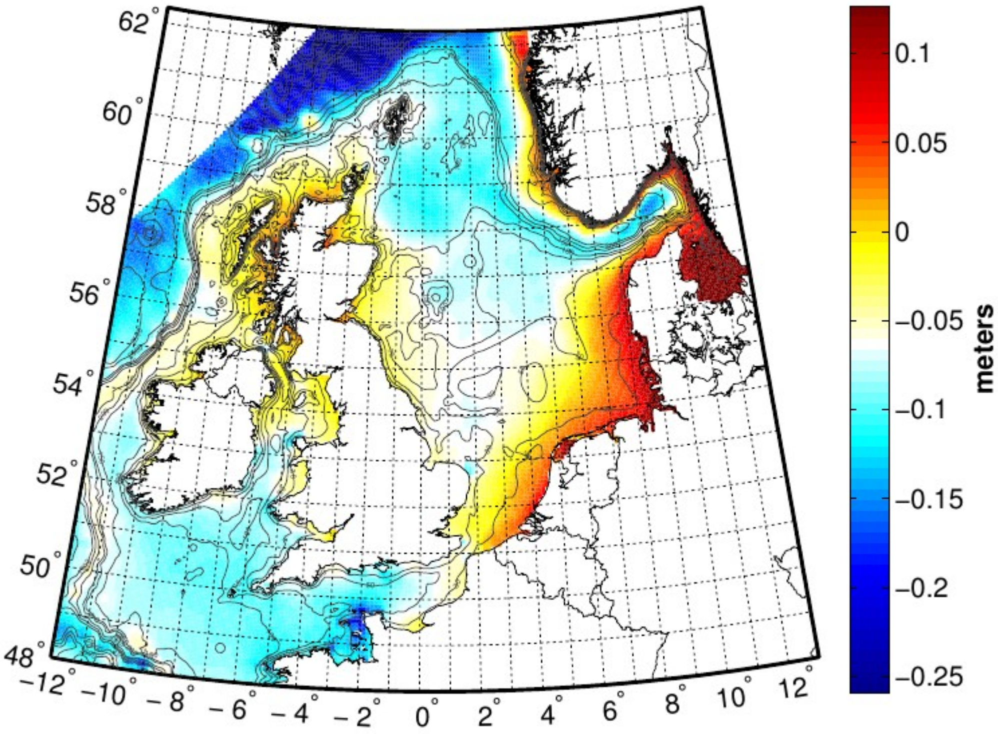
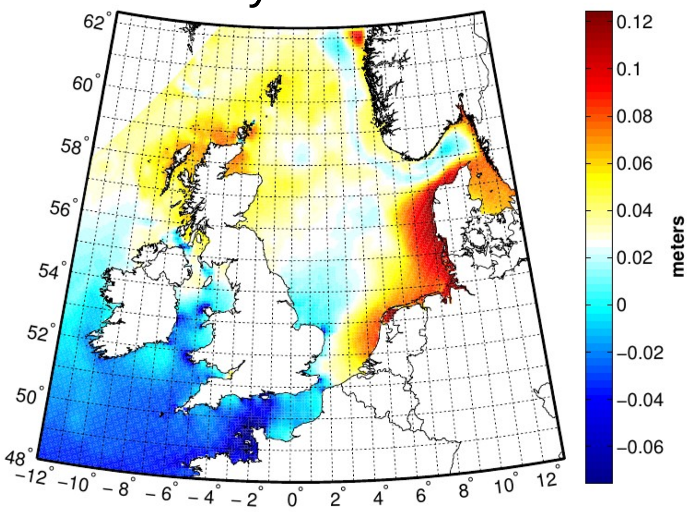


Mean dynamic topography

MDT wrt EGG08



Density contribution



Source: Slobbe et. al. 2012

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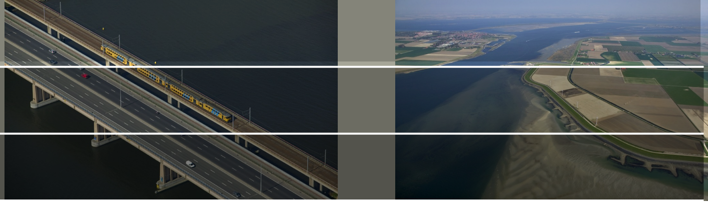
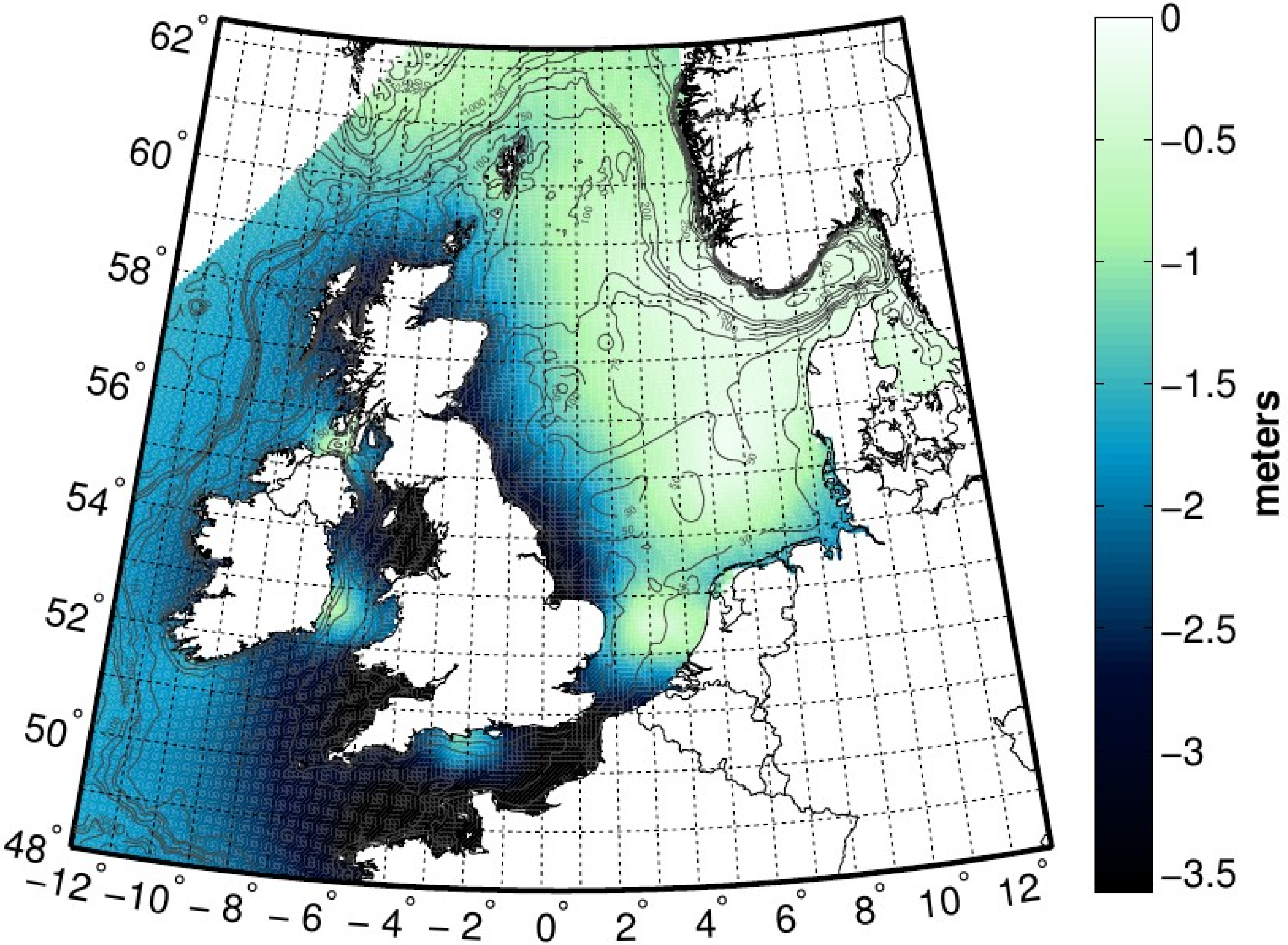
Lowest Astronomical Tide





Slobbe et. al. 2013

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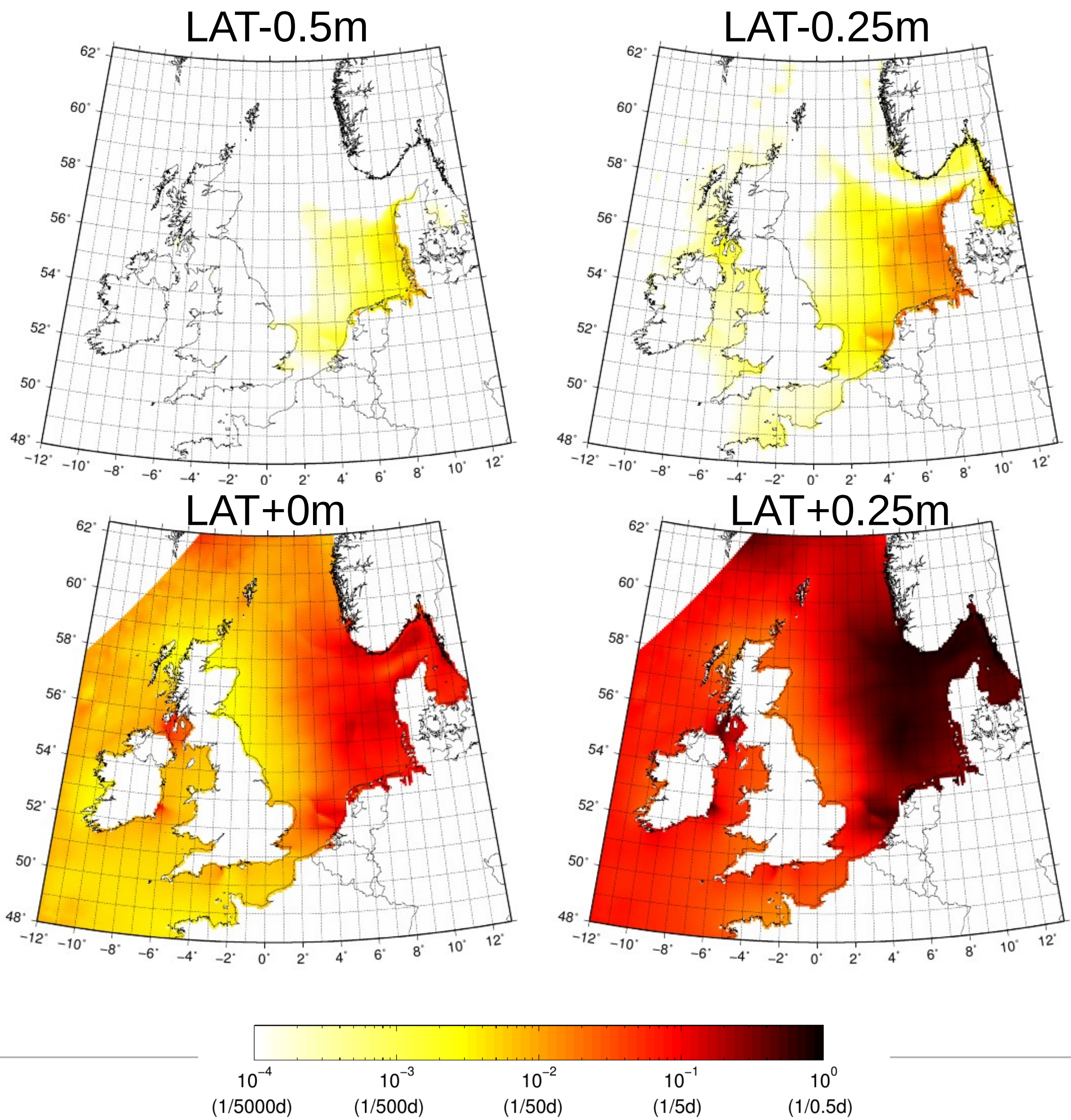
LAT exceedance frequency



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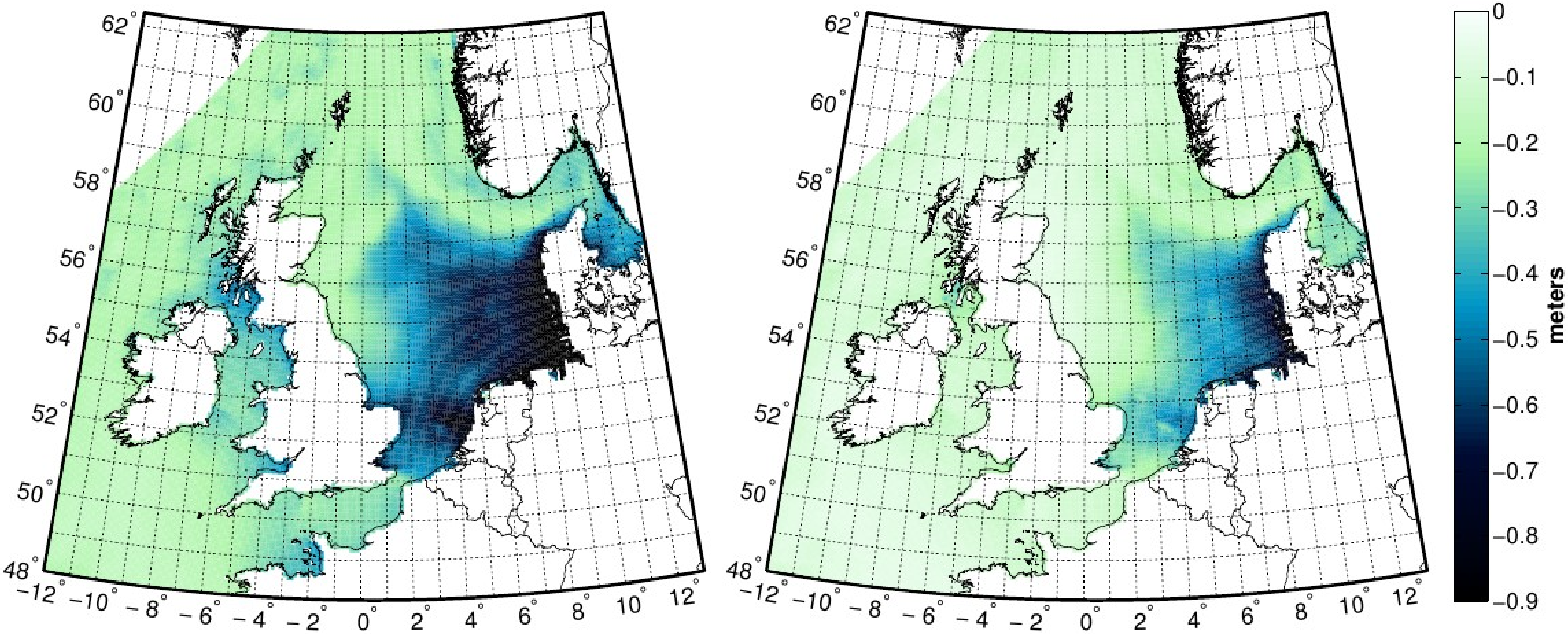
LAT exceedance frequency



(b) Once per 10 years

(c) Once per year

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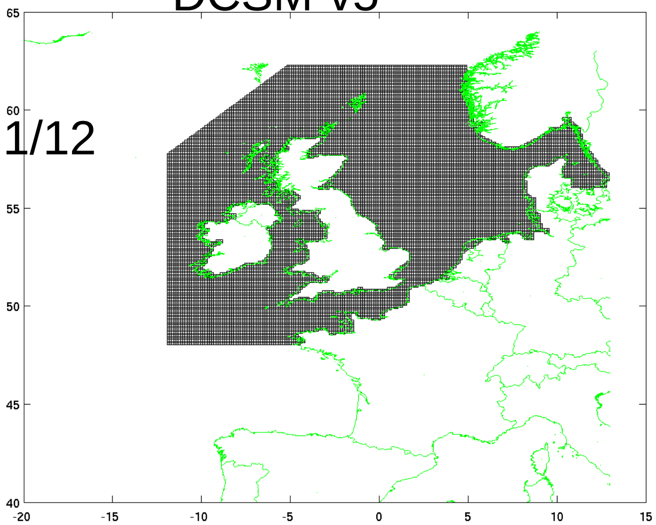
New surge & tide model – DCSMv6

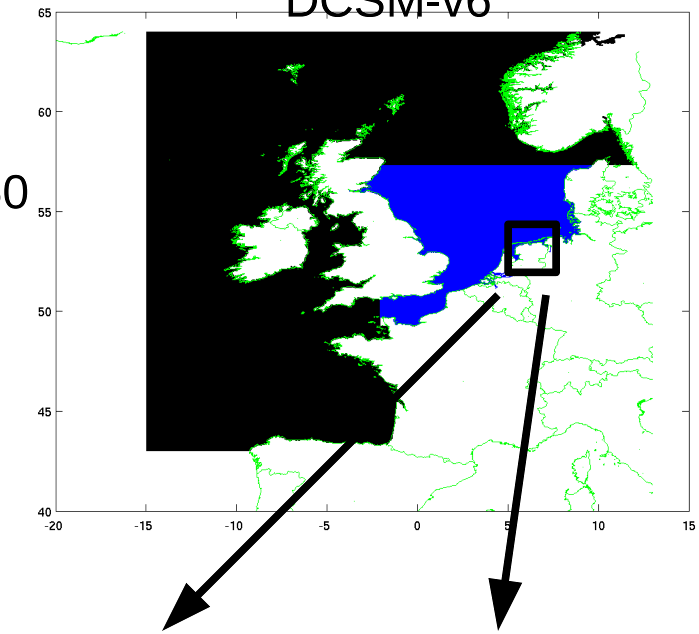
DCSM-v5

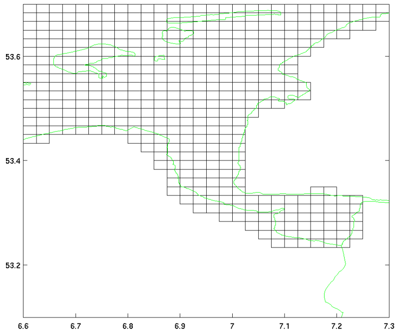
1/8 x 1/12



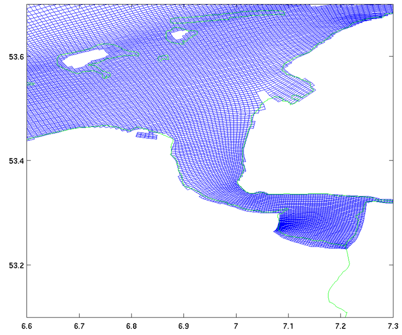
DCSM-v6

1/40 x 1/60





domain 1 detail



domain 2 detail

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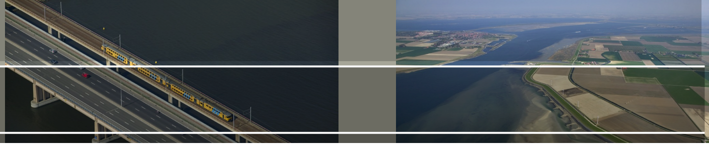
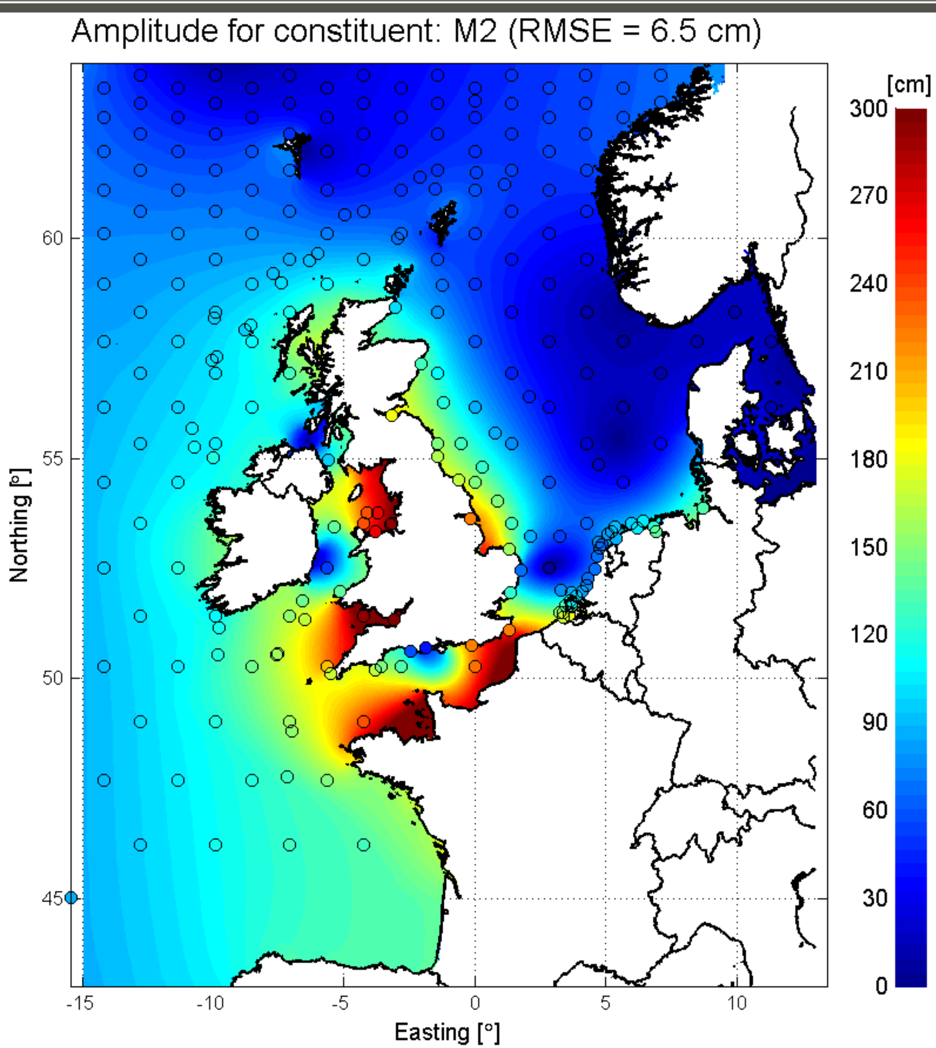
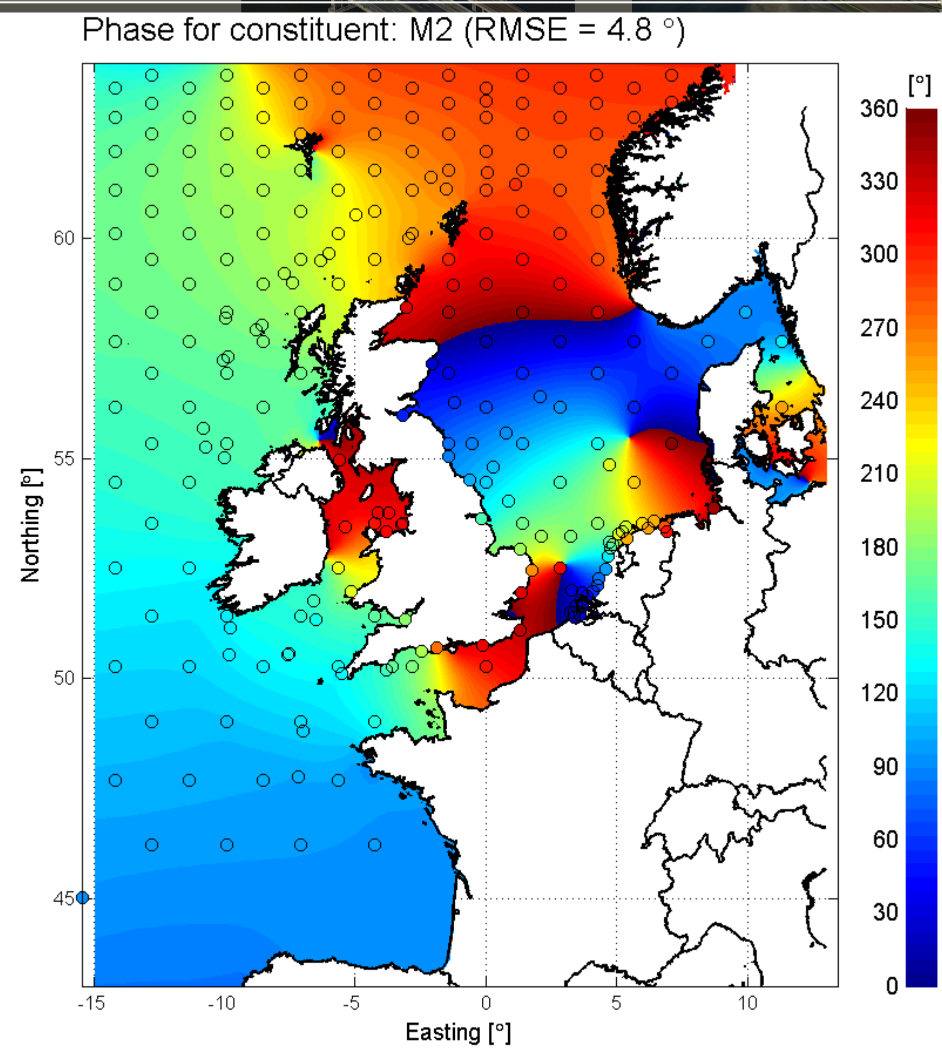
Calibration of tides







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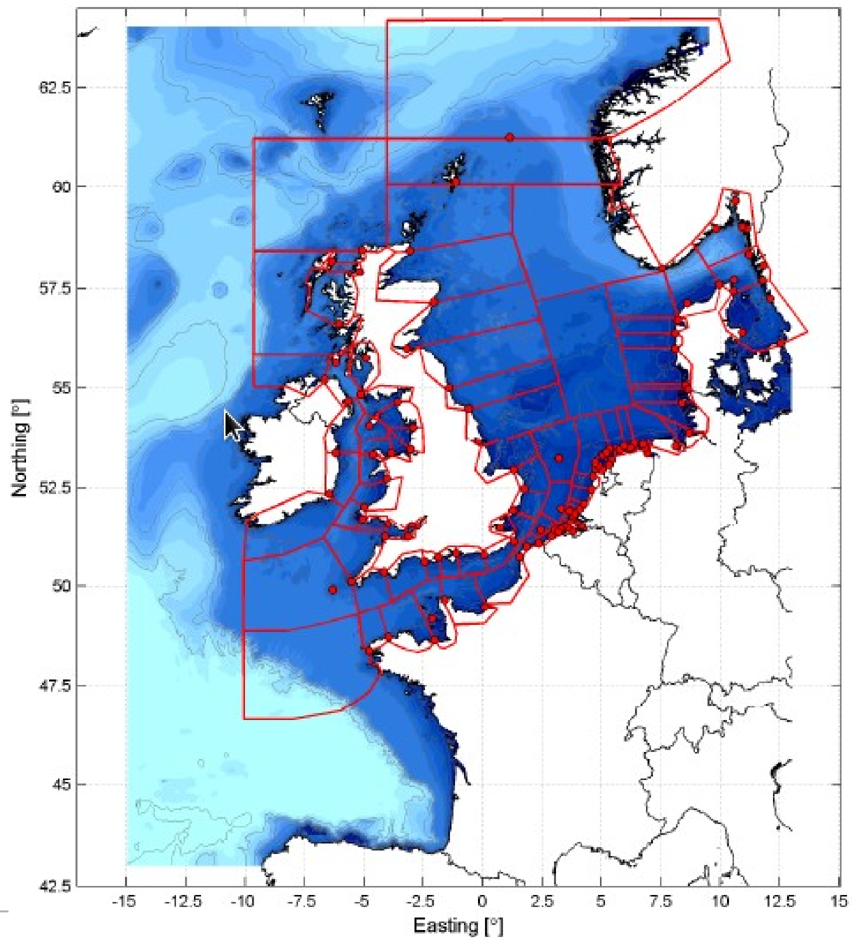
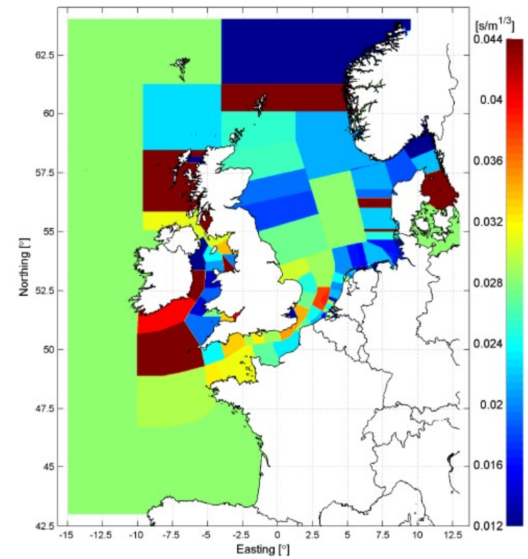
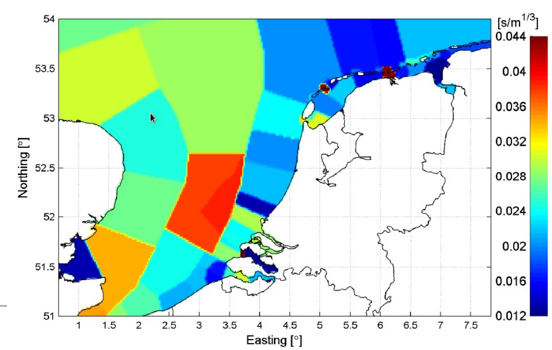
Calibration of tides

- More than 100 tide gages used
- Around 100 parameters for friction and 100 parameters for depth
- Efficient optimization methods with restarting and parallel computing







OpenDA
www.openda.org
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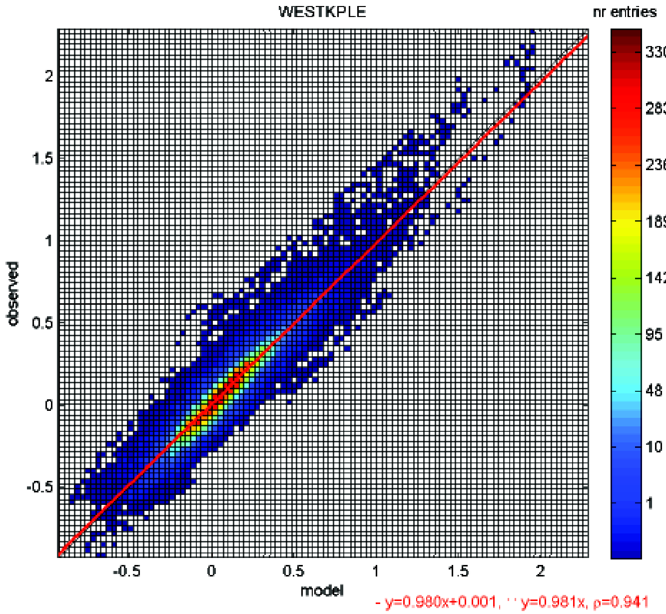
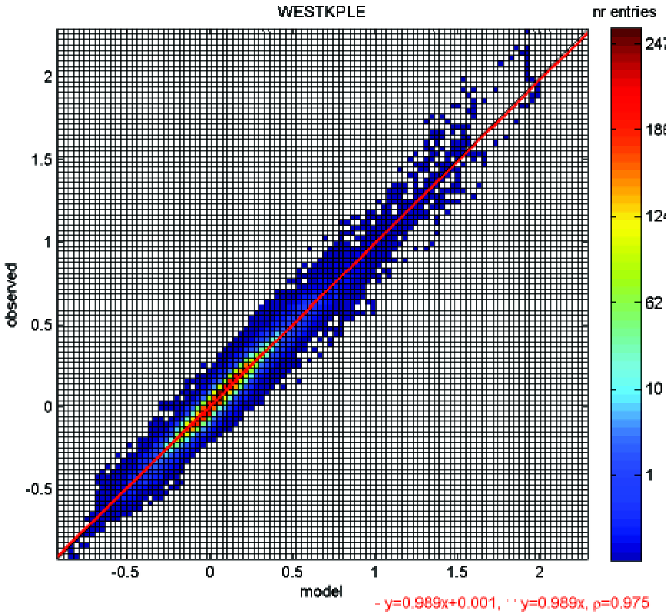
Results calibration DCSM-v6

	RMSE tides	RMSE surge	RMSE sea-level
Before calibration	6.6	9.7	11.7
After calibration	3.7	6.9	7.8



Surge before calibration



Surge after calibration

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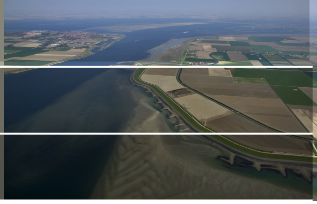
DCSM v5 and v6



Station	RMSE tide (cm)			RMSE surge (cm)			RMSE water level (cm)		
	DCSMv5	DCSMv6	(%)	DCSMv5	DCSMv6	(%)	DCSMv5	DCSMv6	(%)
CADZD	12.6	3.7	-71	10.8	7.0	-35	16.6	7.9	-52
WESTKPLE	10.4	3.2	-69	10.4	6.6	-37	14.7	7.3	-50
ROOMPBTN	14.2	3.0	-79	9.5	6.6	-31	17.1	7.2	-58
BROUWHVSGT08	8.3	3.3	-60	9.4	6.8	-28	12.6	7.6	-40
HARVT10	8.2	3.2	-61	9.5	7.0	-26	12.6	7.7	-39
HOEKVHLD	8.0	3.8	-53	9.1	6.8	-25	12.2	7.8	-36
SCHEVNGN	10.2	3.3	-68	8.6	7.0	-19	13.3	7.7	-42
IJMDBTHVN	7.5	3.7	-51	8.9	7.3	-18	11.7	8.1	-31
PETTZD	9.9	4.2	-58	8.8	7.2	-18	13.2	8.3	-37
K13APFM	8.2	3.0	-63	7.1	5.4	-24	10.8	6.2	-43
TERSLNZE	6.8	3.9	-43	8.2	7.2	-12	10.7	8.2	-23
WIERMGDN	7.7	4.4	-43	8.3	7.1	-14	11.4	8.4	-26
HUIBGT	8.6	4.2	-51	8.5	7.4	-13	12.1	8.5	-30
average	9.3	3.6	-61	9.0	6.9	-23	13.0	7.8	-40
RMS	9.5	3.7	-61	9.1	6.9	-24	13.1	7.8	-40

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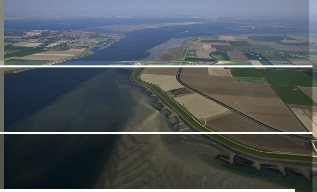
Effects of ZUNO domain & tidal correction



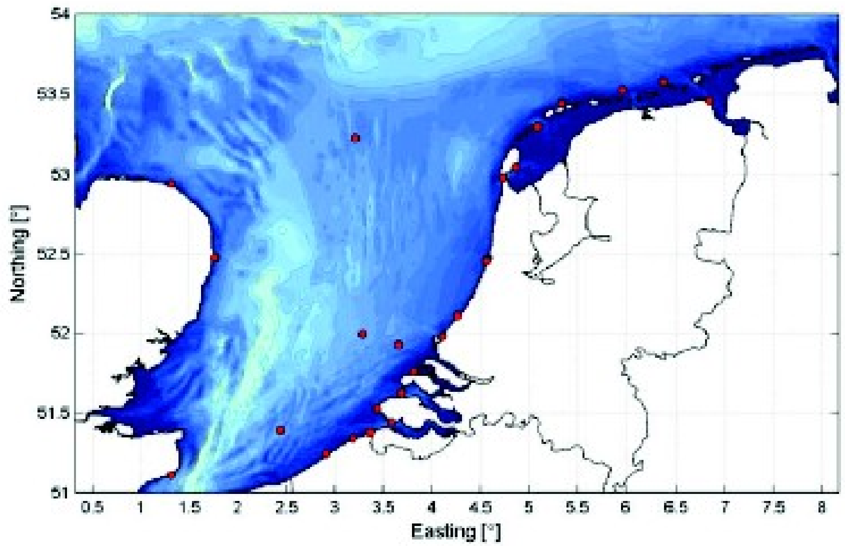
DSCMv6	RMSE tide	2007 RMSE	
datum		zonder	met
WICK	6.4	8.6	8.0
ABDN	4.9	7.6	8.9
NORTHSS	6.1	9.2	9.9
LOWST	3.8	7.8	8.3
SHEERNS	16.9	20.9	13.4
DOVR	7.9	10.1	10.5
CADZD	3.7	7.9	8.8
VLISSGN	4.1	8.7	9.2
HOEKVHLD	3.8	7.8	8.6
IJMDBTHVN	3.7	8.1	9.7
EURPFM	4.1	7.4	7.5
HUIBGT	4.2	8.5	10.3
HARLGN	7.0	11.3	12.3
DELFZL	11.9	17.8	14.6
gemiddelde	6.3	10.1	10.0
RMS	7.3	10.9	10.2

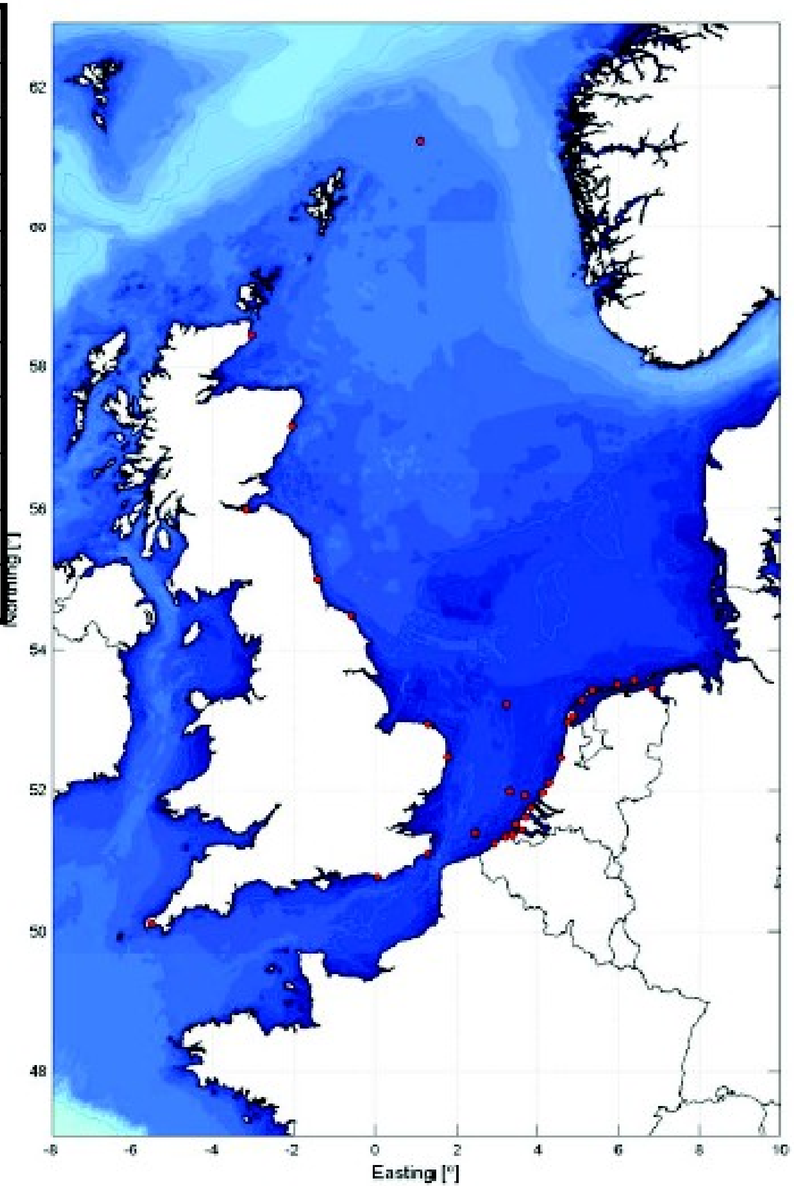
→

DCSMv6 +ZUNO	RMSE tide	2007 RMSE	
datum		zonder	met
WICK	5.8	8.6	9.3
ABDN	5.3	8.7	10.8
NORTHSS	5.3	9.6	12.1
LOWST	3.7	8.4	9.9
SHEERNS	7.4	12.8	14.0
DOVR	4.8	8.1	11.0
CADZD	3.2	8.2	10.1
VLISSGN	3.2	8.5	10.4
HOEKVHLD	3.4	7.7	9.5
IJMDBTHVN	3.3	8.1	10.3
EURPFM	2.9	7.1	8.5
HUIBGT	4.4	8.8	10.7
HARLGN	3.9	8.1	11.2
DELFZL	4.6	10.4	13.4
gemiddelde	4.4	8.8	10.8
RMS	4.5	8.9	10.9

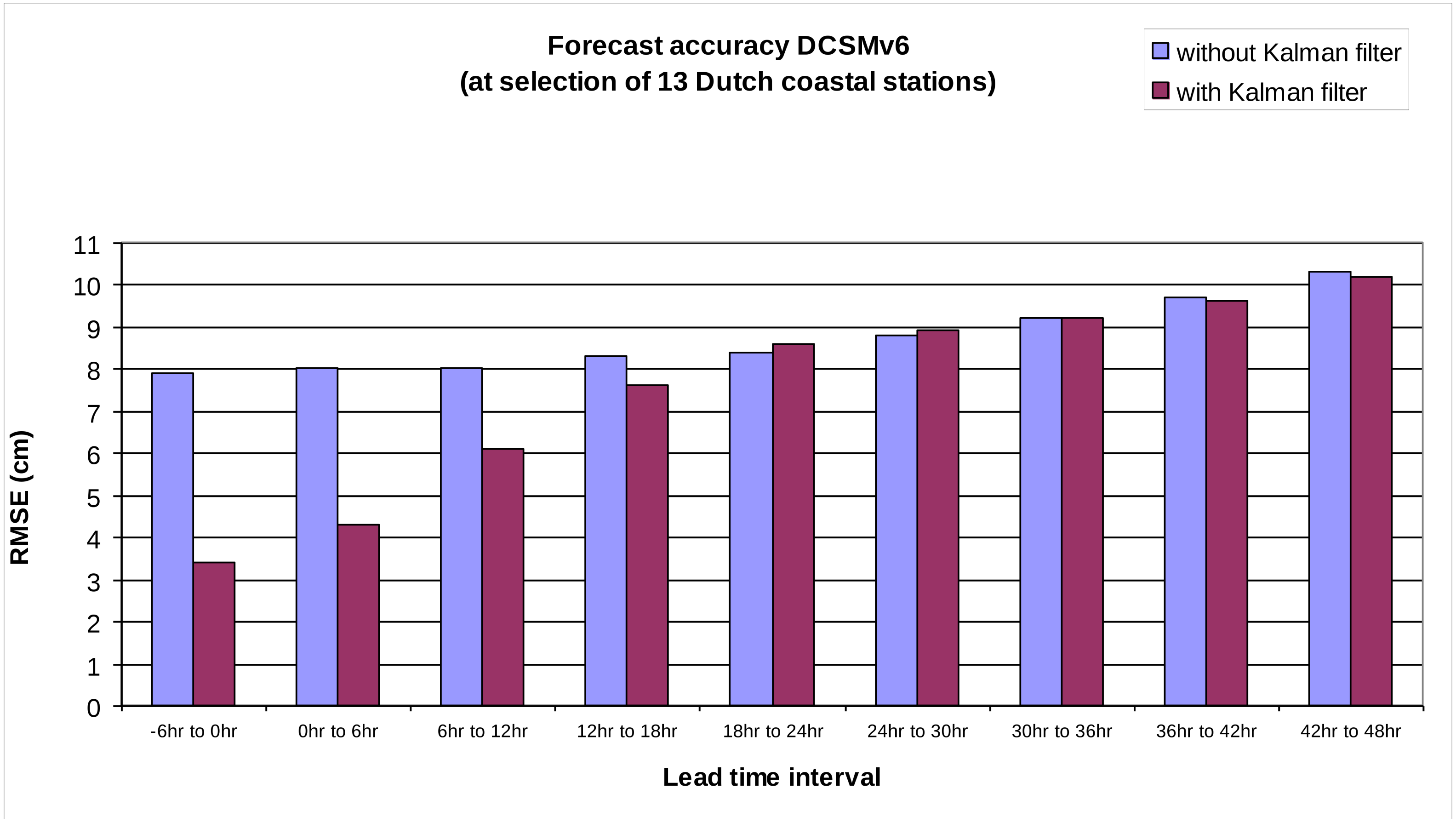
Kalman filter for DCSMv6

NORTHCMRT	CADZD	HUIBGT
WICK	WESTKPLE	NEWLN
ABDN	EURPFM	NEWHVN
LEITH	BROUWHVSGT08	DOVR
NORTHSS	LICHTELGRE	VLISSGN
WHITBY	HOEKVHLD	ROOMPBTN
CROMR	SCHEVNGN	DENHDR
LOWST	IJMDBTHVN	OUDSD
Oostende	K13APFM	VLIELHVN
Westhinder	TERSLNZE	EEMSHVN
Zeebrugge	WIERMGDN	





Accuracy of DCSMv6 with Kalman filter



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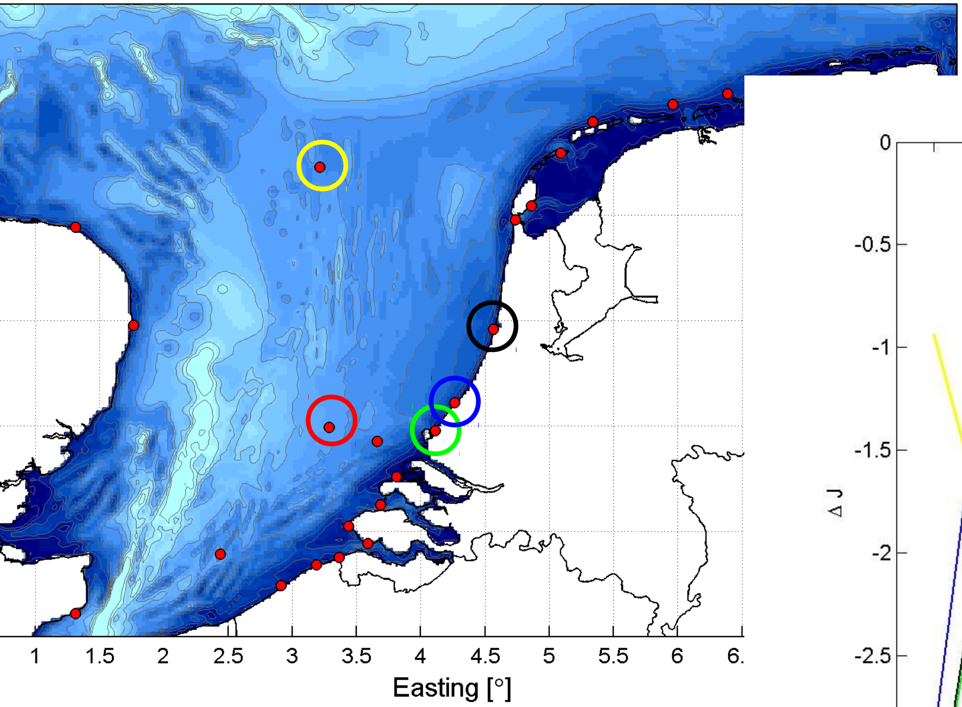
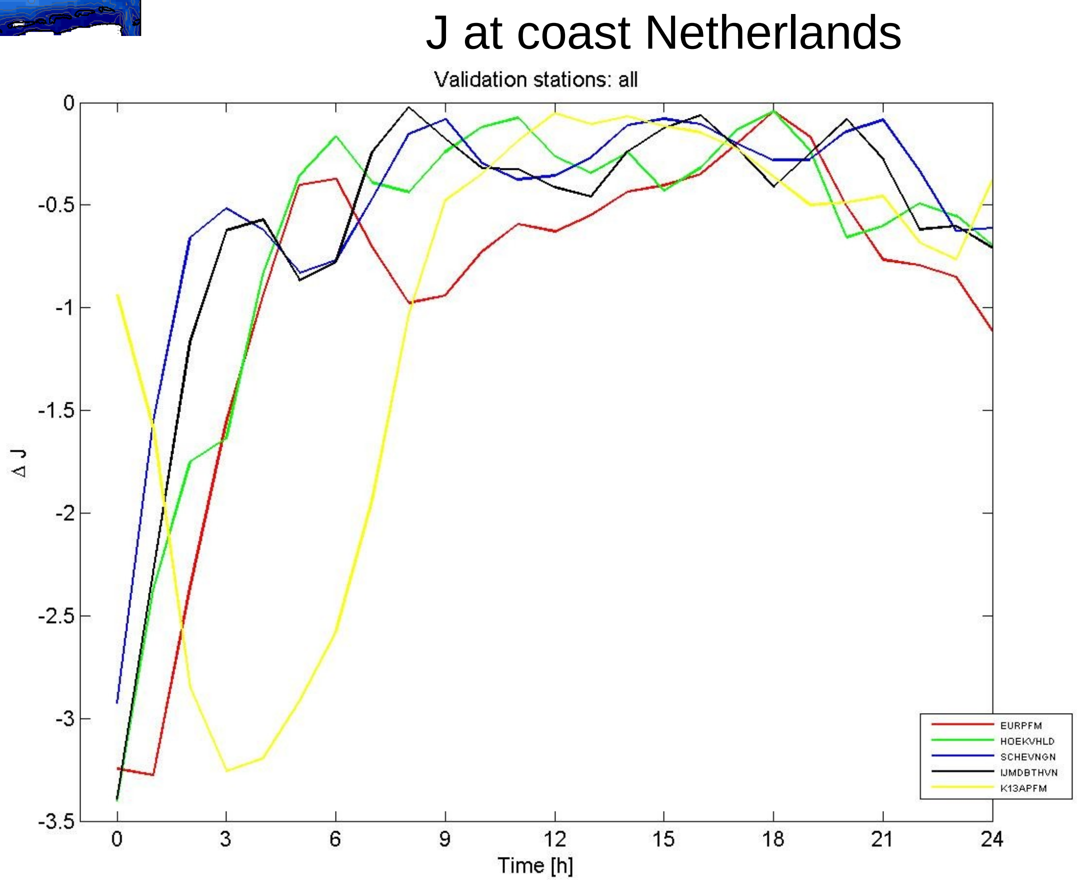
Impact of assimilation stations





Assimilating nearby stations gives immediate impact on the forecast accuracy.

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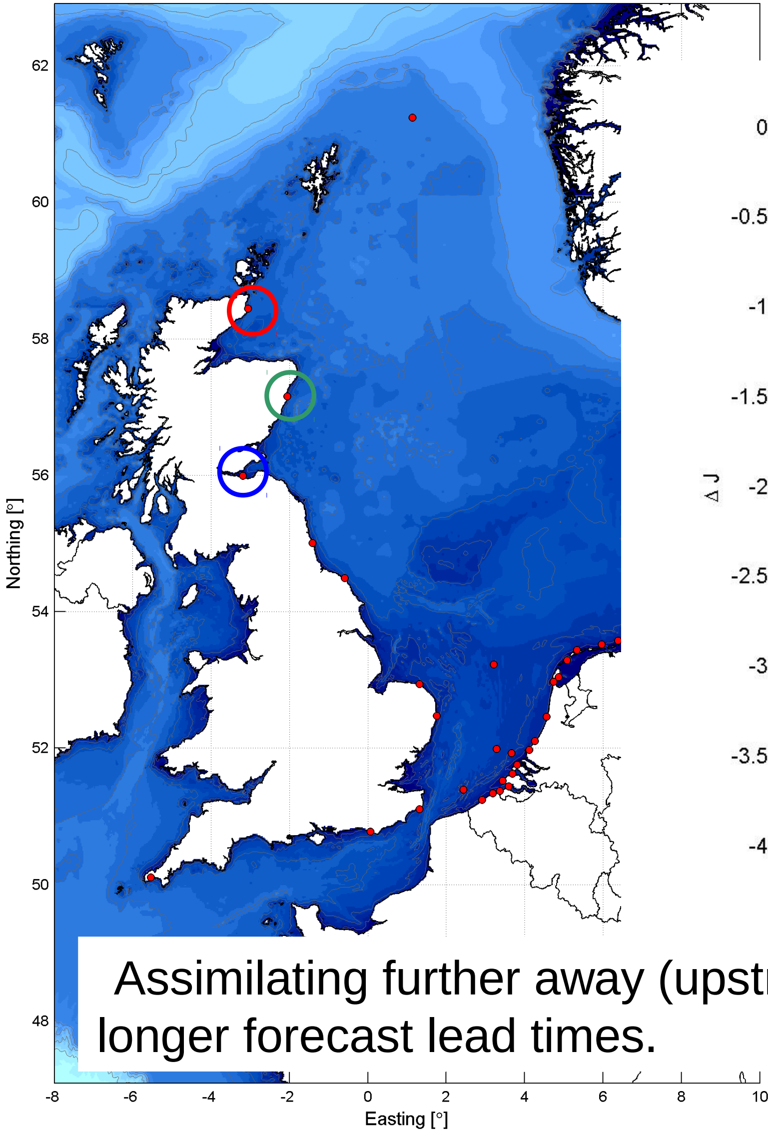
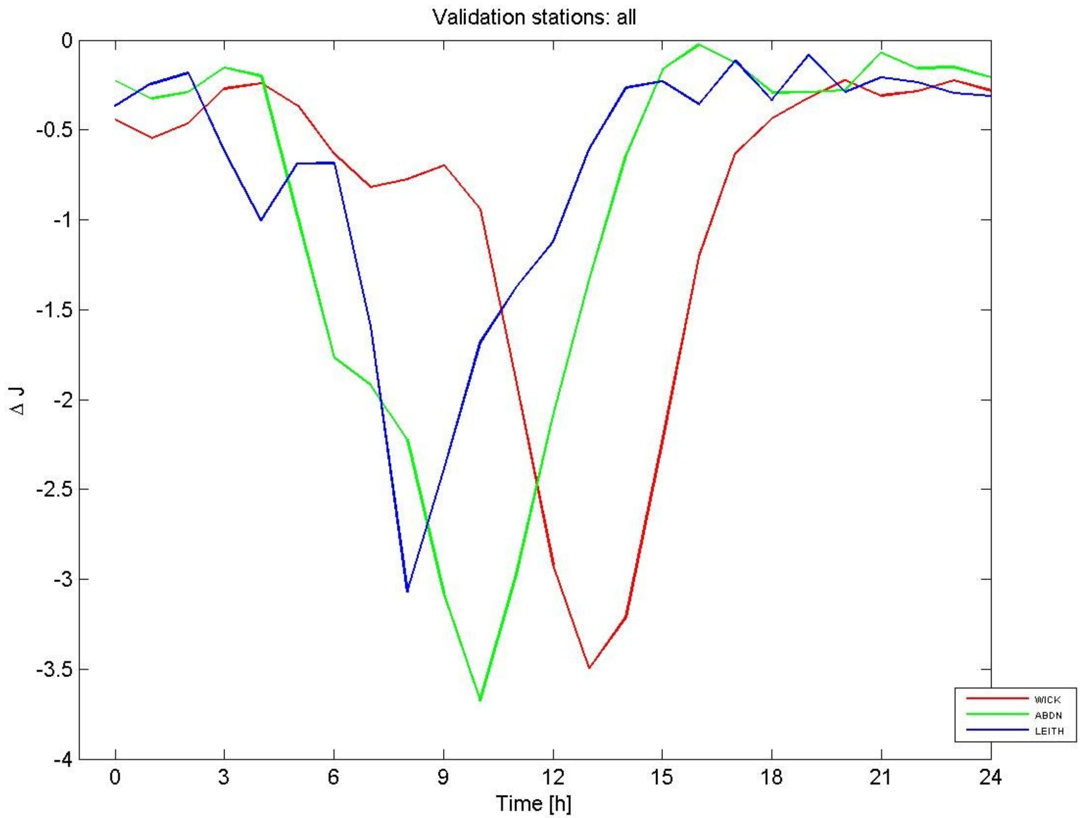
Impact of assimilation stations

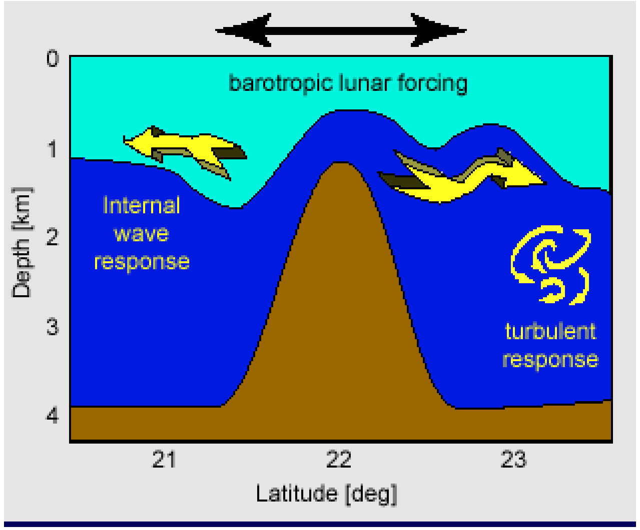




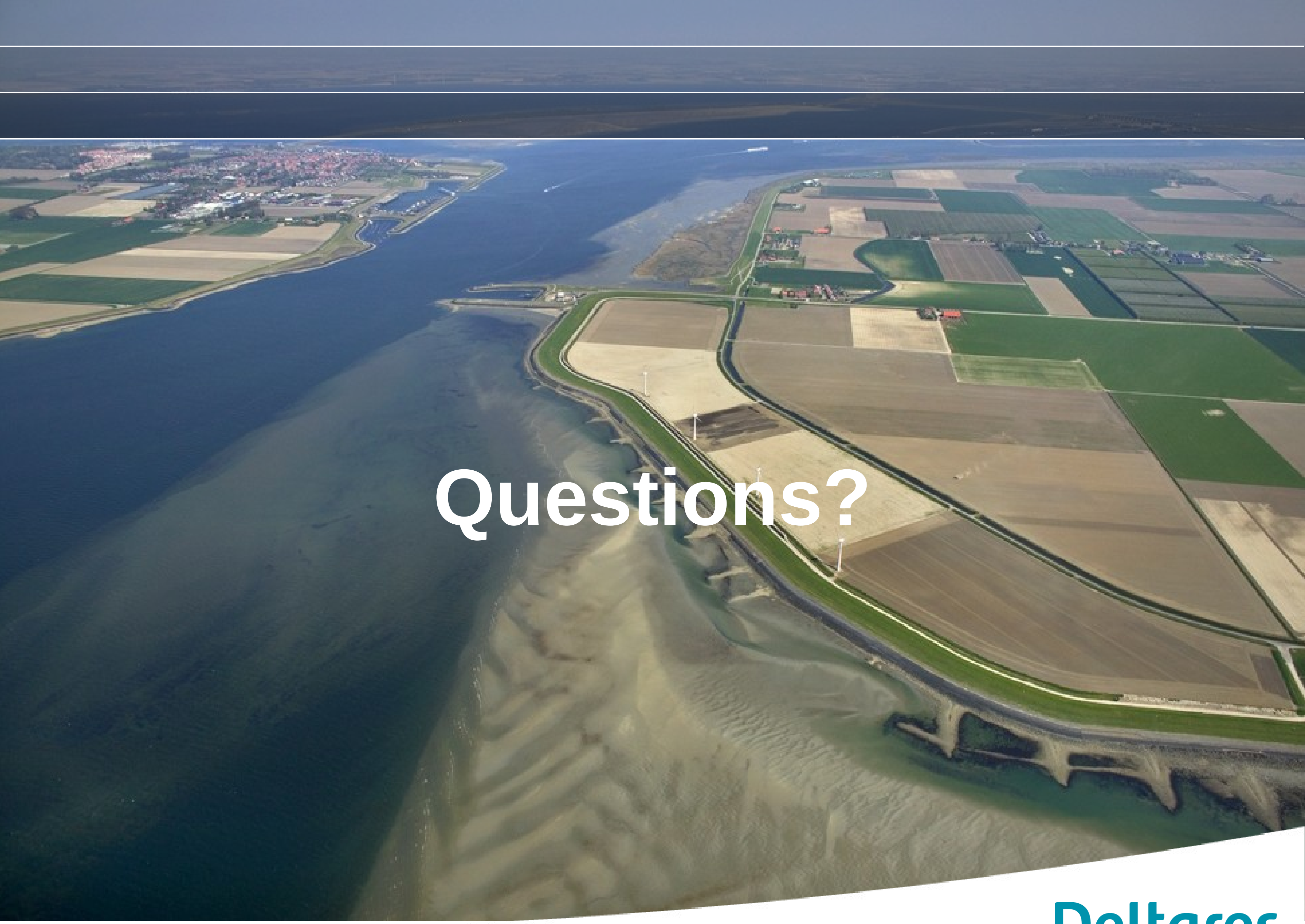
Assimilating further away (upstream) stations improves the accuracy of longer forecast lead times.

Challenges and future work

- Dissipation by internal tides
- Self Attraction and Loading
- Open boundary



Improved open boundaries & sensitivity



Questions?

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