OpenDA

Deltares
Enabling Delta Life

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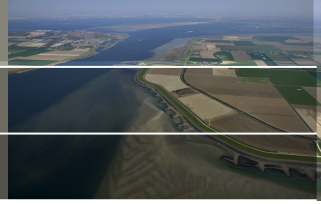
# OpenDA application to operational forecasting of storm-surges and waves

**Martin Verlaan**

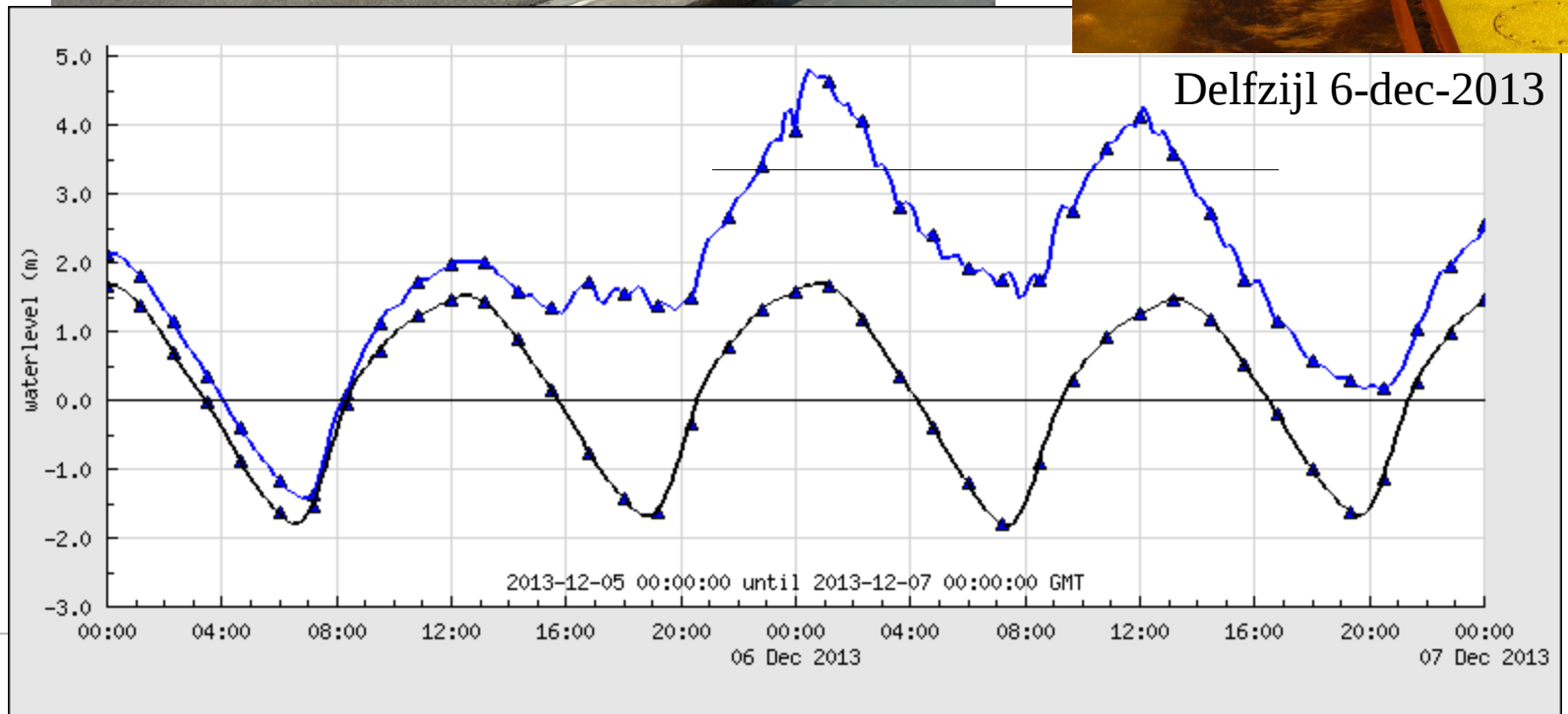
**Martin.Verlaan@deltares.nl**

# Outline



- Operational forecasting of storm-surge and waves
- Modelling and observations of storm-surges
- Calibration of tides
- Kalman filtering for storm surges
- Wave model
- Kalman filtering for waves
- What is next?

# Storm surges



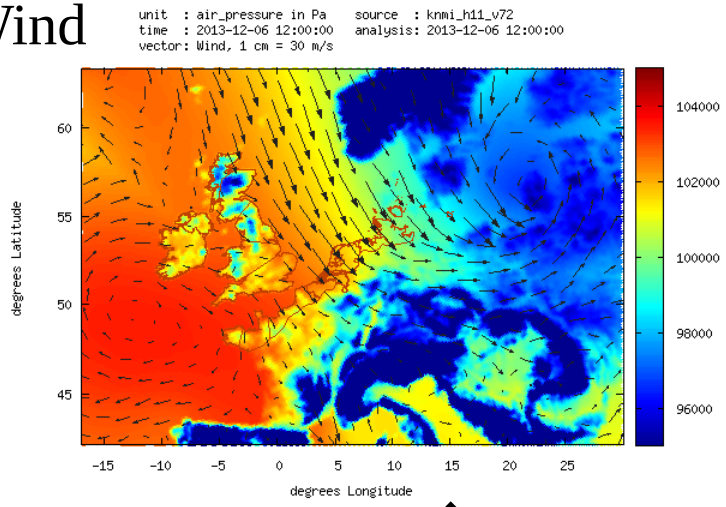
# Waves



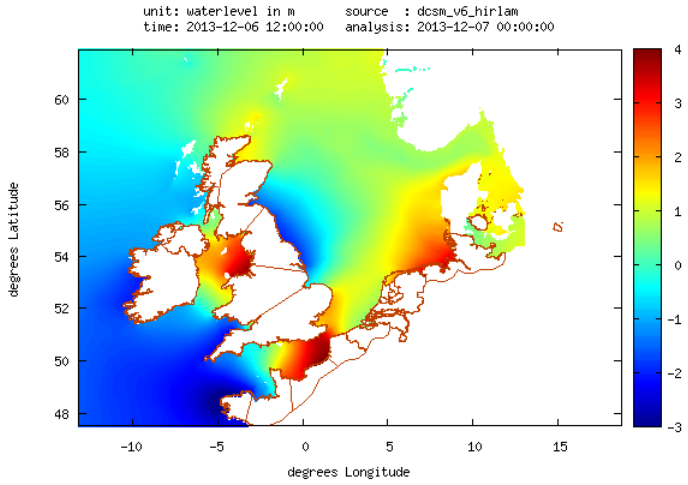
Floodmark

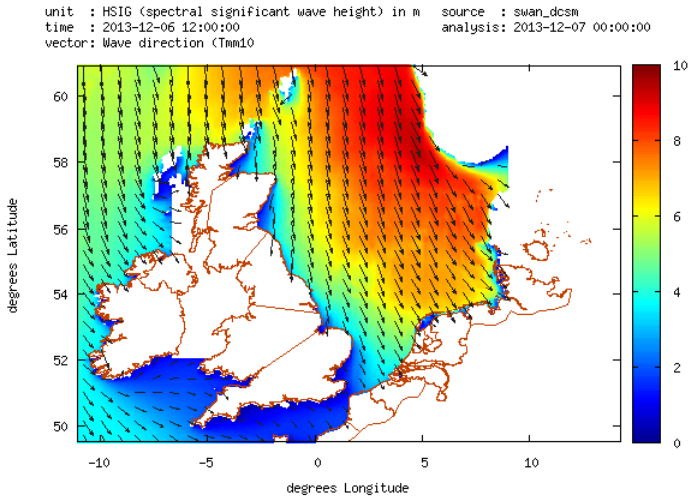
# Storm impact

Wind




Surge



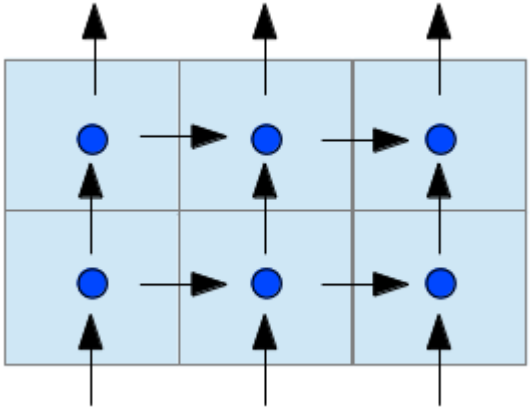



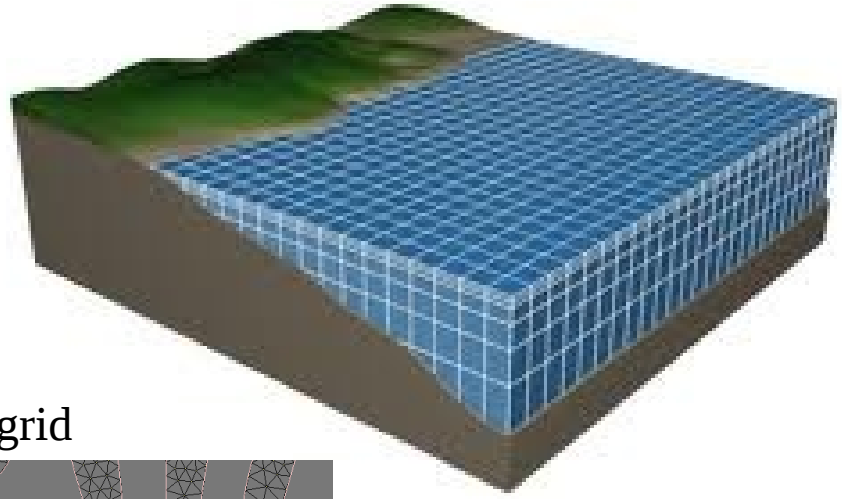

Waveheight

Dec 6 2012 12:00h

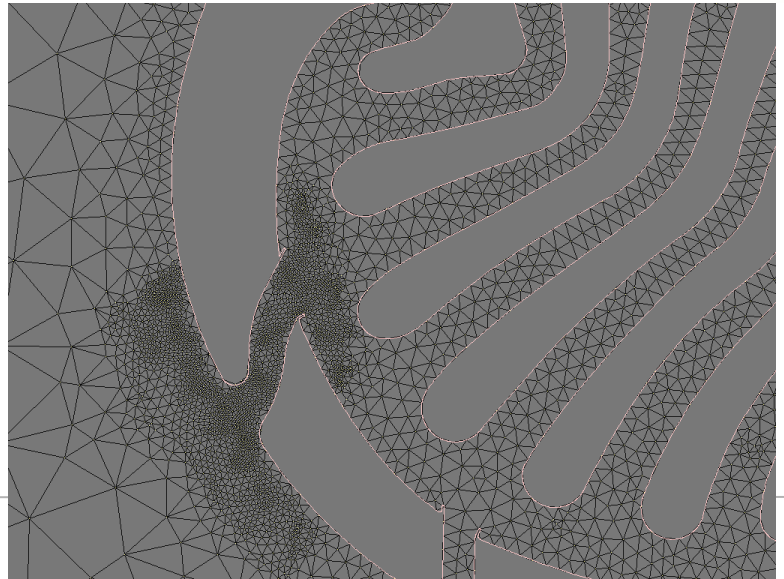
# Numerical grids

2D-staggered C-Grid

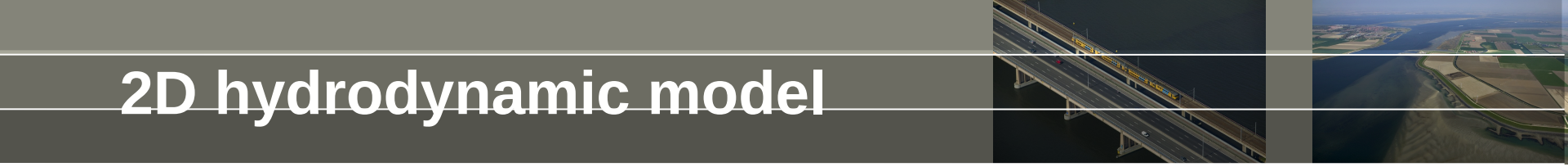




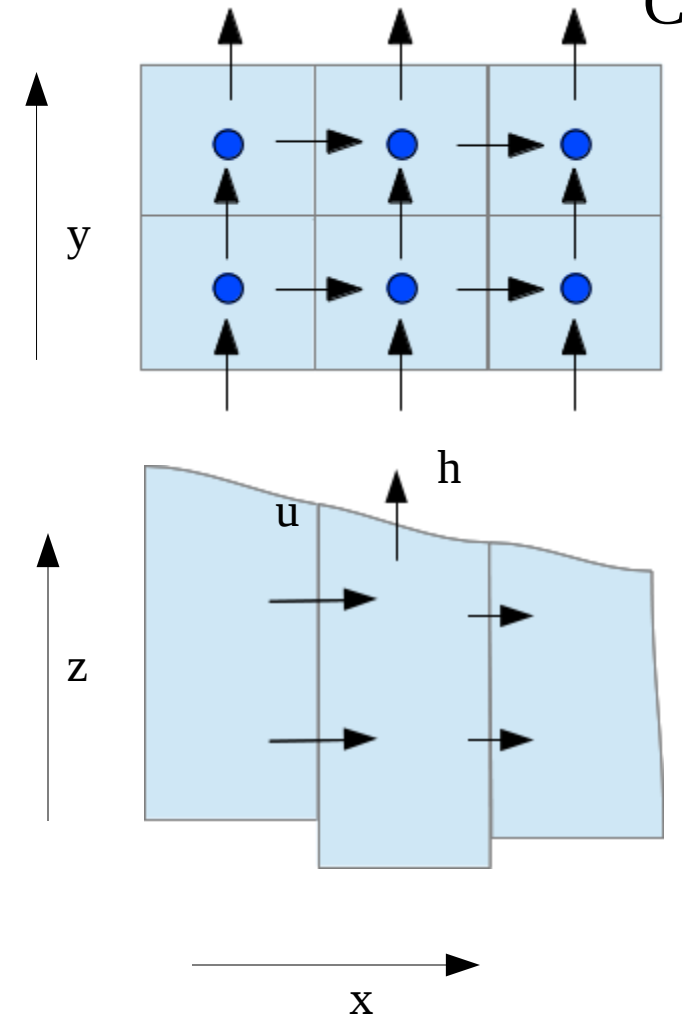

Unstructured grid



# 2D hydrodynamic model



## Conservation of mass




Inflow Level rise

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

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

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

# 2D hydrodynamic model

Conservation of momentum in x-direction

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

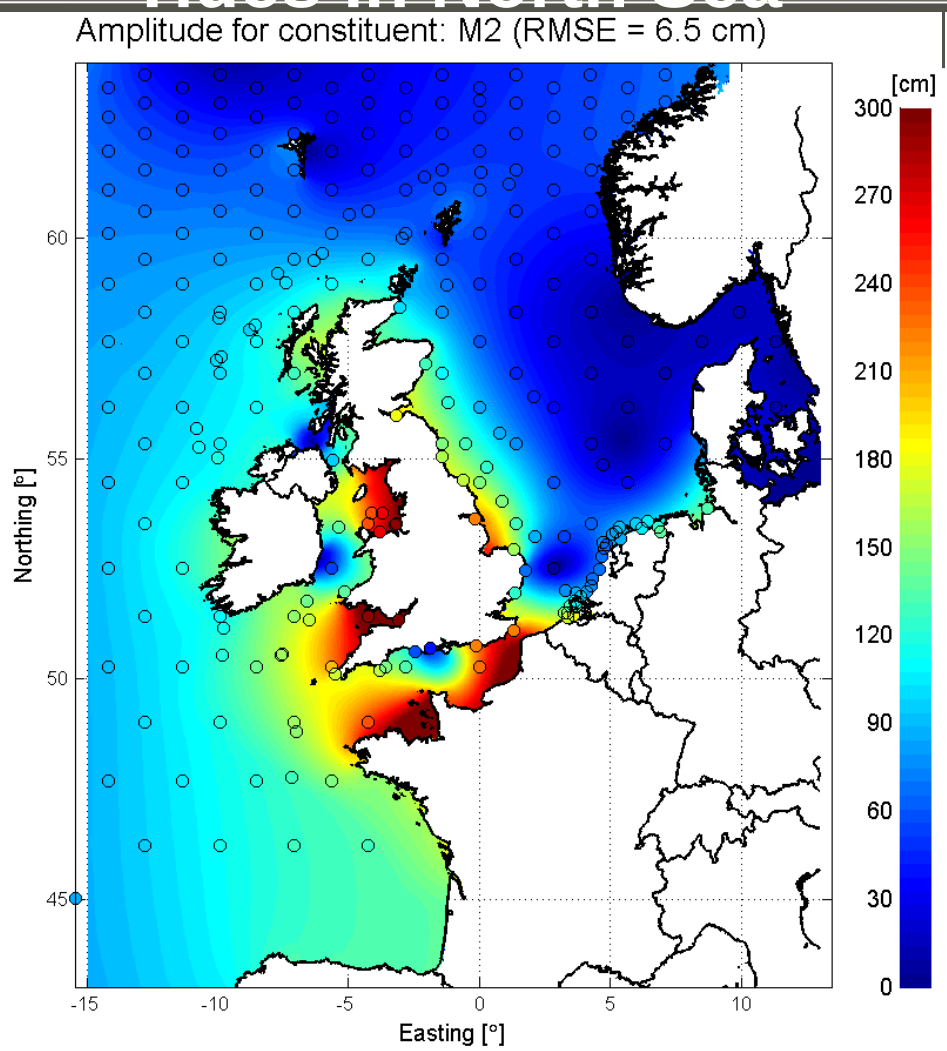
$$M a = F$$

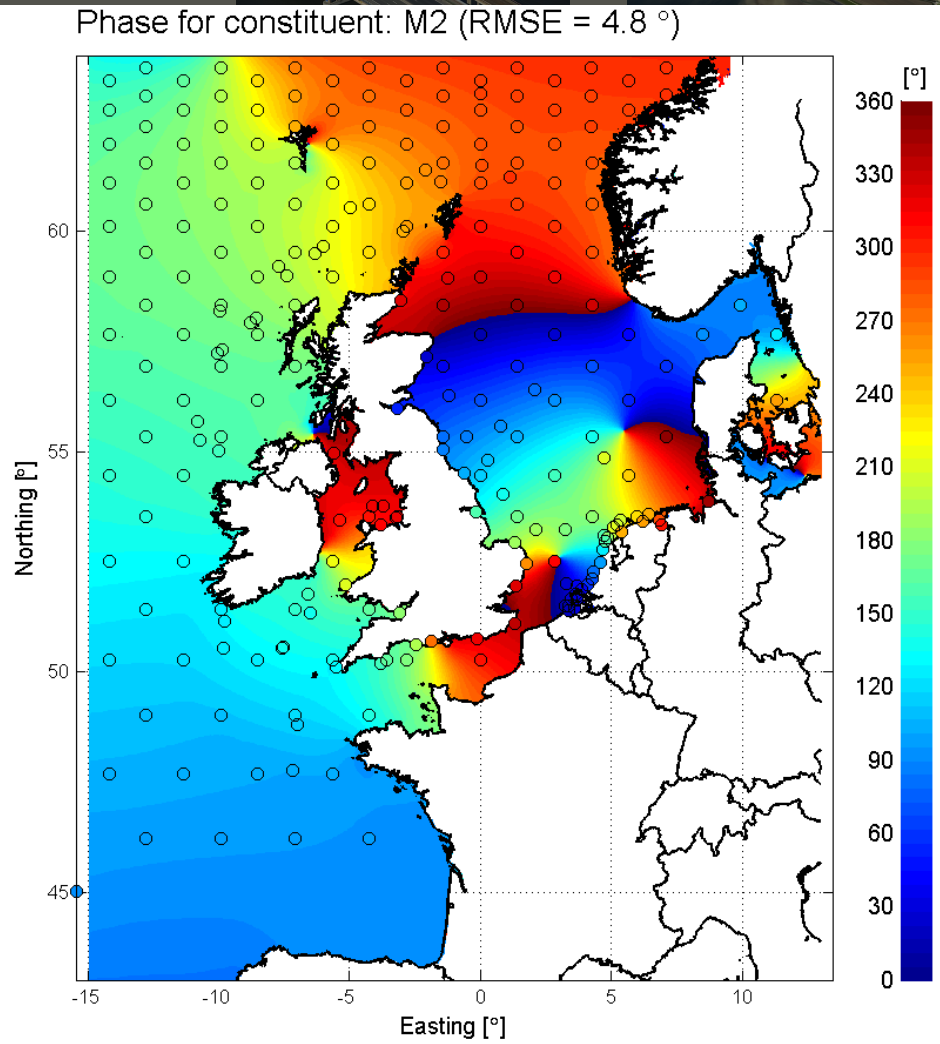
$$\frac{\partial u}{\partial t} = -g\frac{\partial h}{\partial x} + f v - \frac{c u}{H} - \frac{\partial \Phi'}{\partial x}$$

acceleration

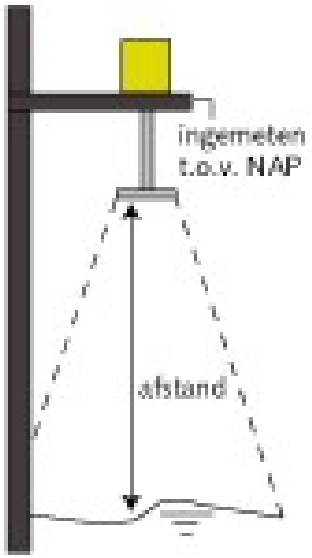
- Tidal potential
- Friction
- Coriolis 'force'
- Surface slope

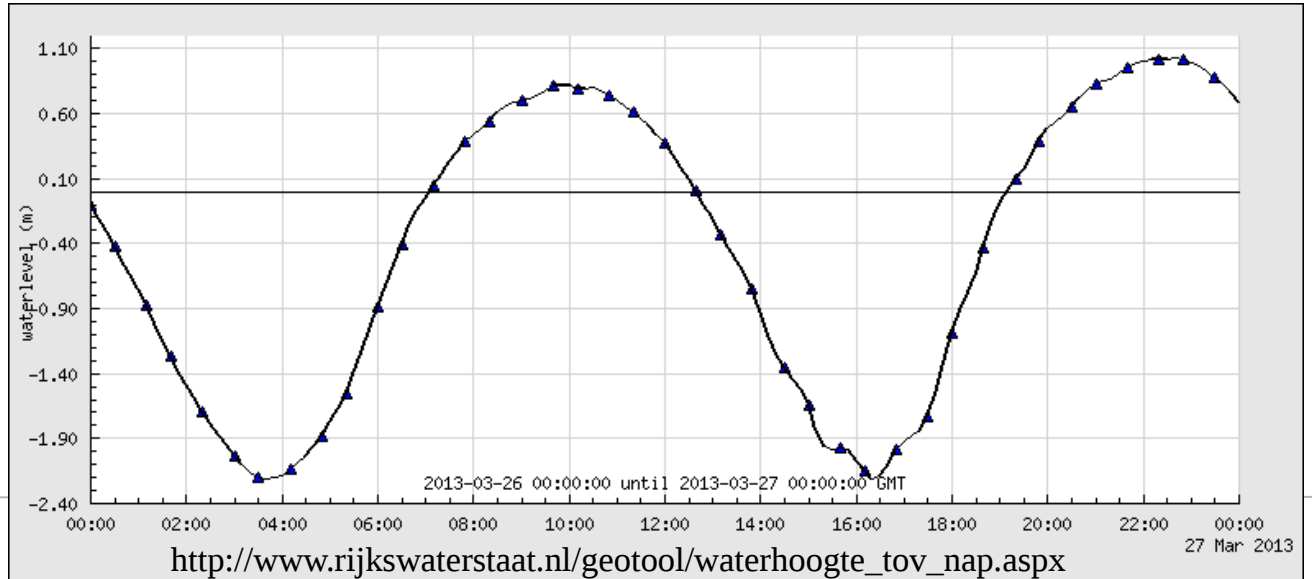
# Tides in North Sea



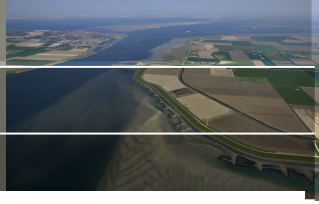

# Tide gauges



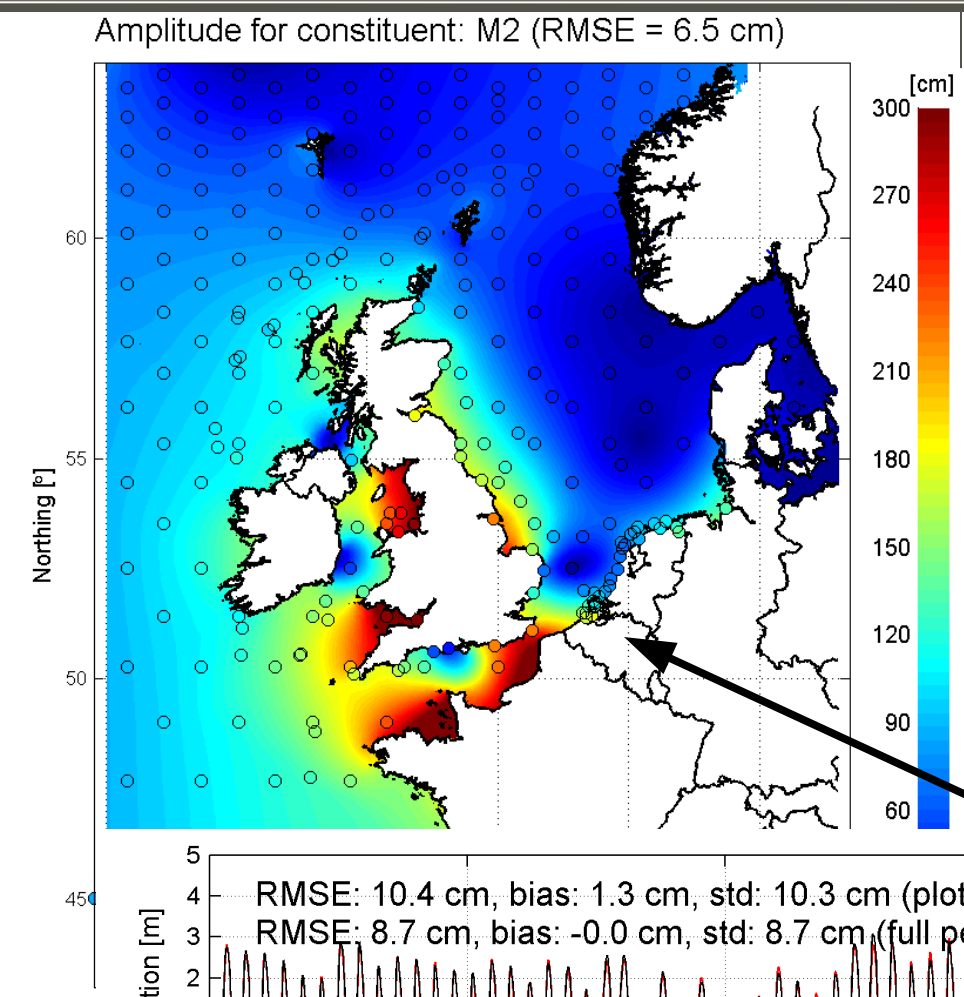



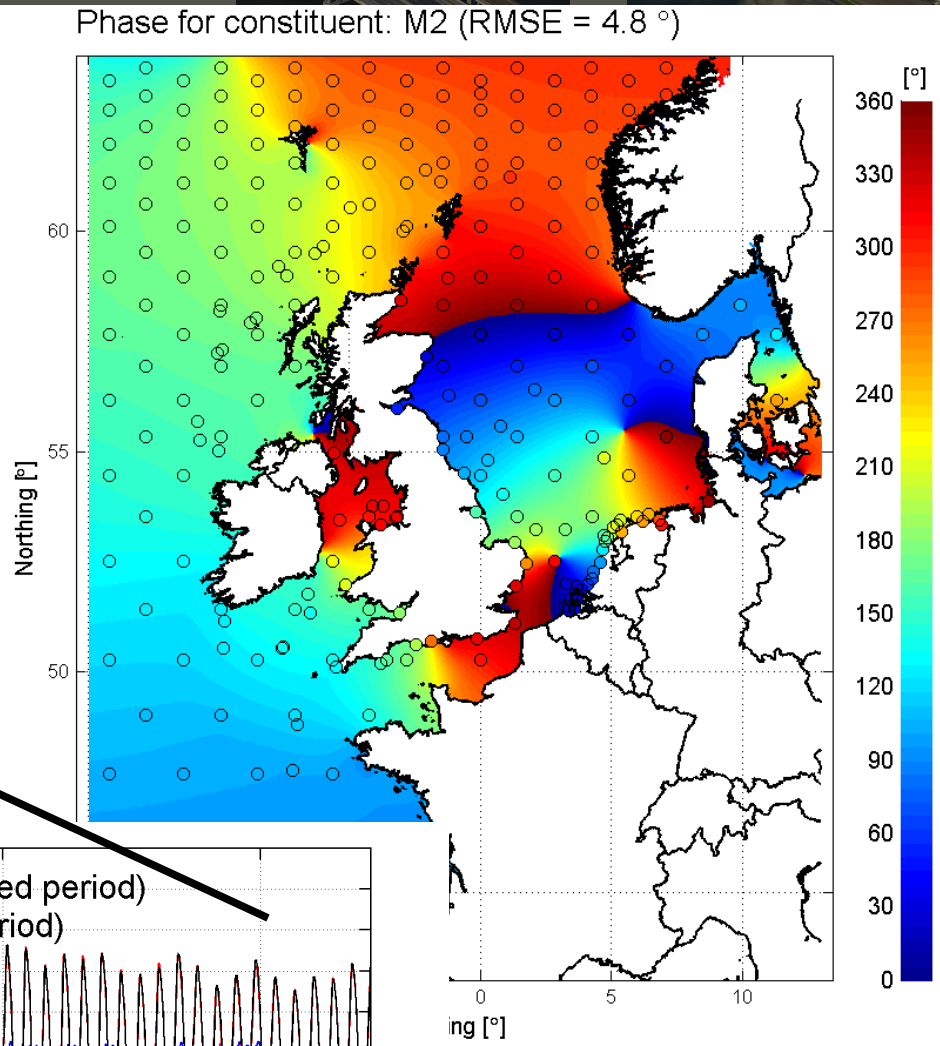

http://www.rijkswaterstaat.nl/geotool/waterhoogte_tov_nap.aspx

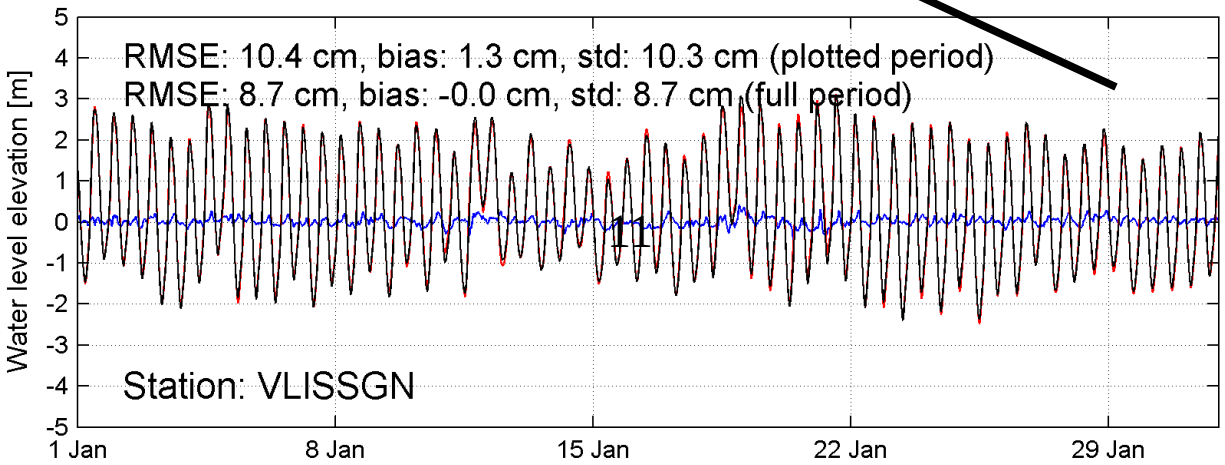
# Altimeter observations



# Calibration of tides

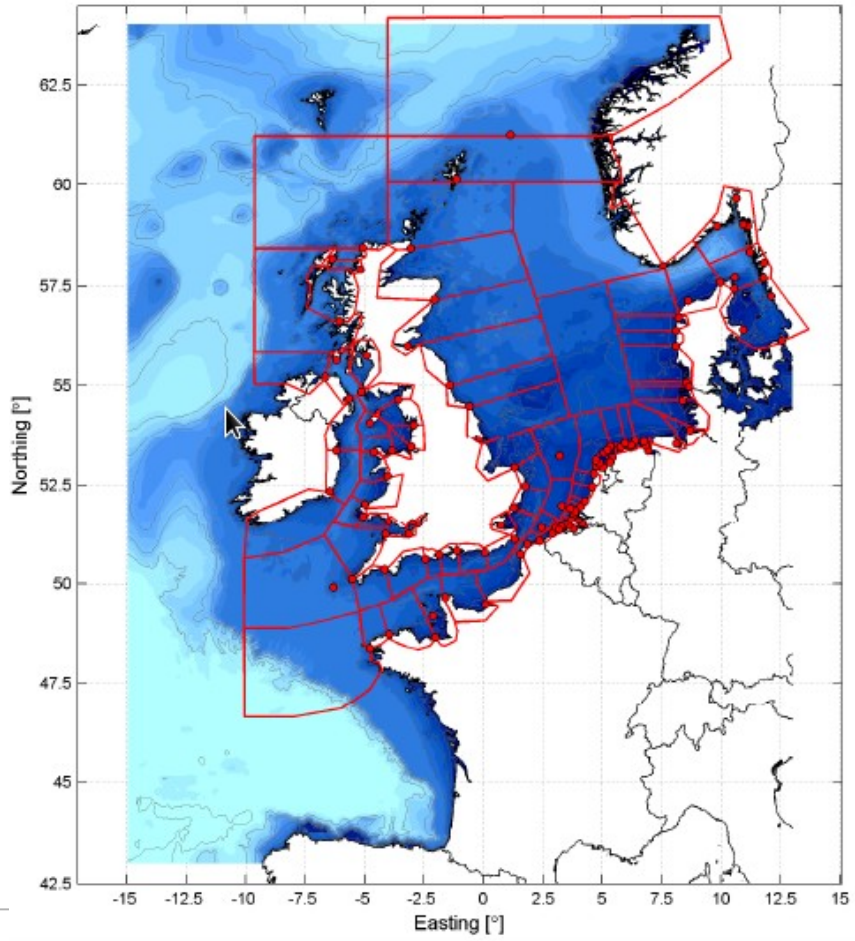


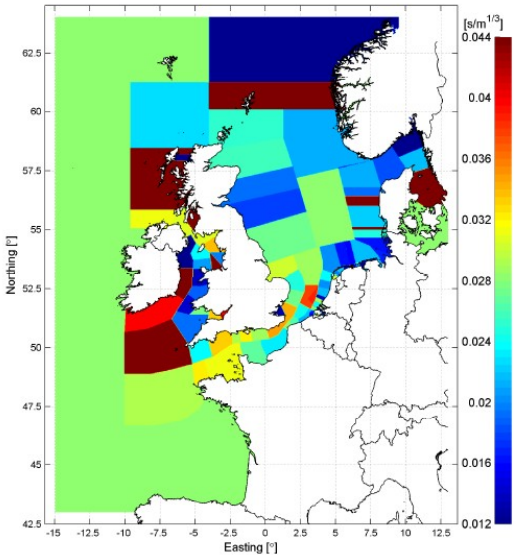



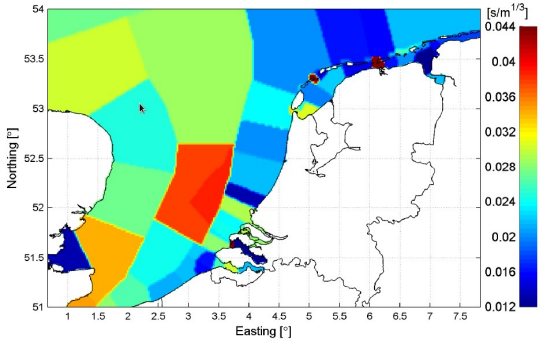



# Calibration of tides

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

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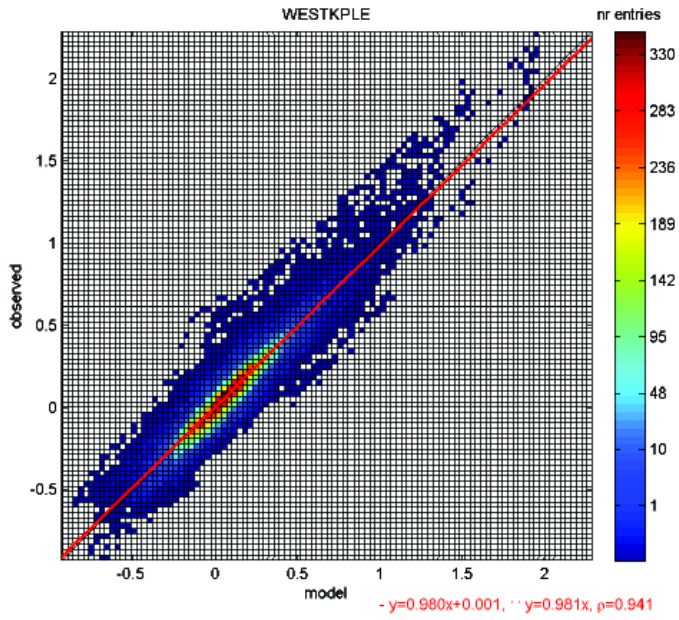
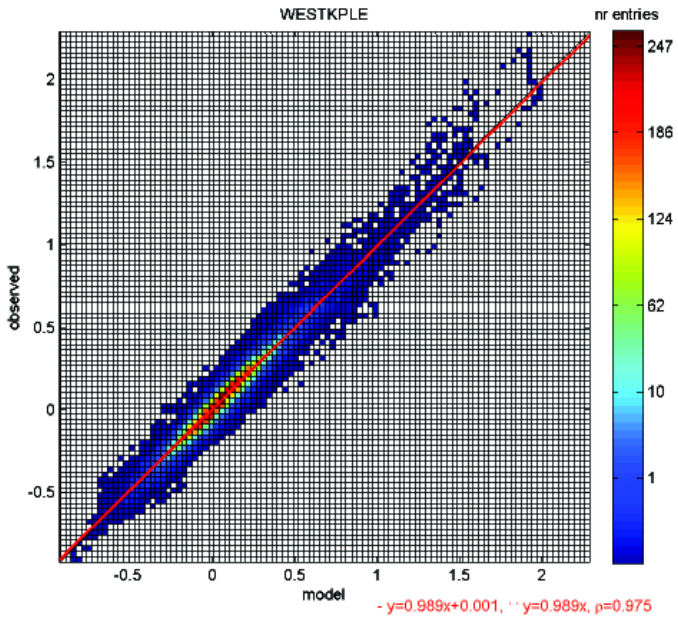
# Results calibration DCSM-v6

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

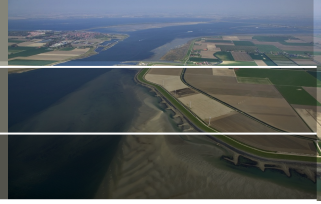



Surge before calibration

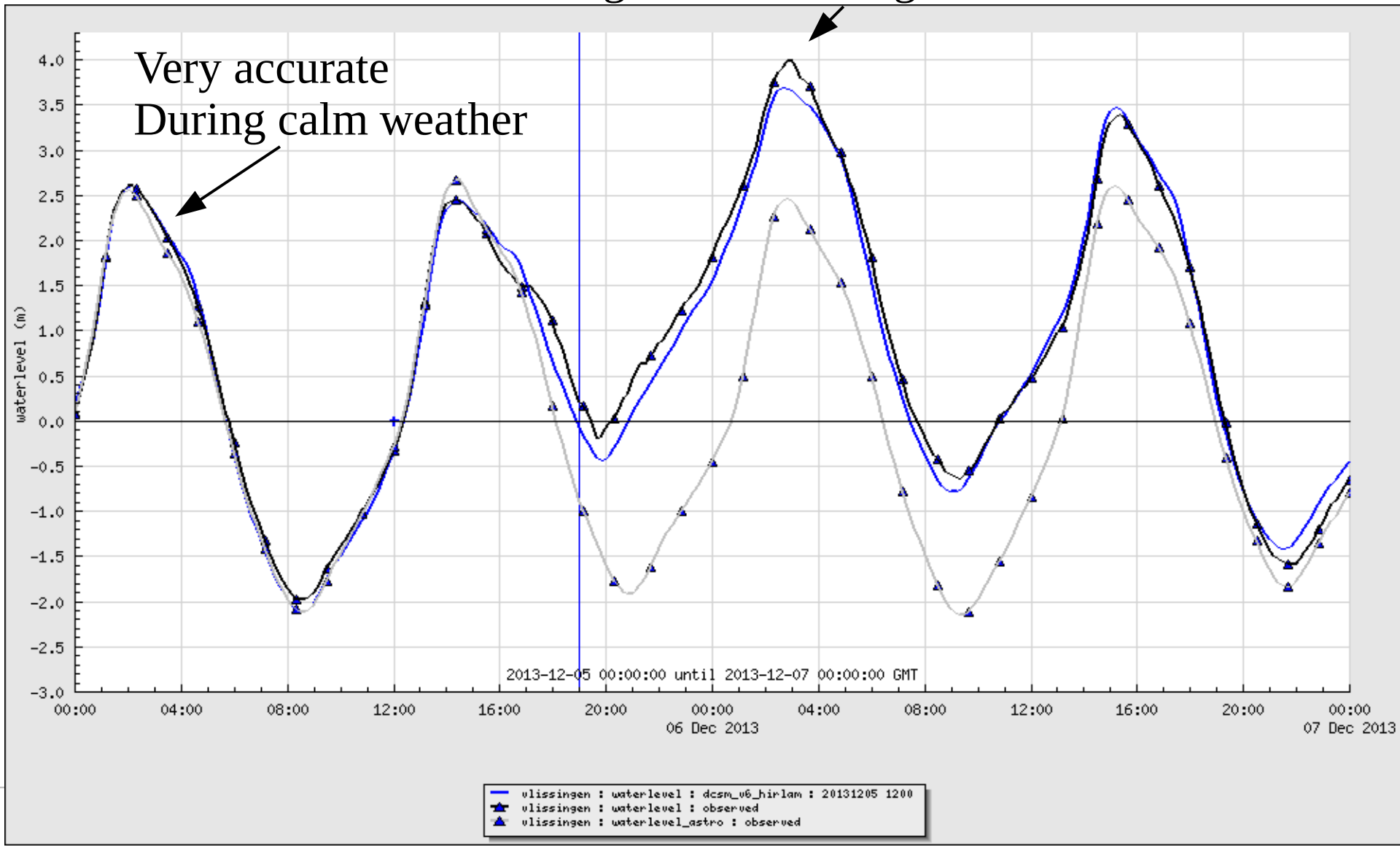



Surge after calibration

# Real-time data-assimilation



Larger errors during severe storms

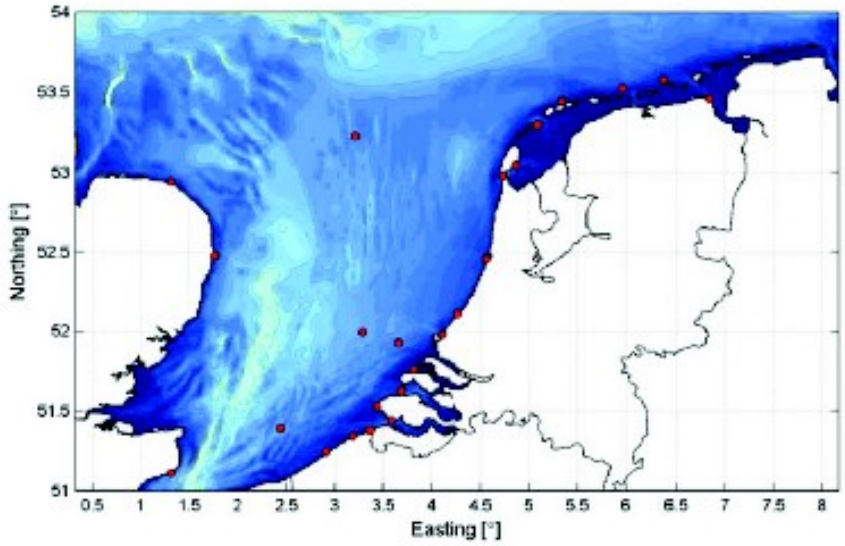


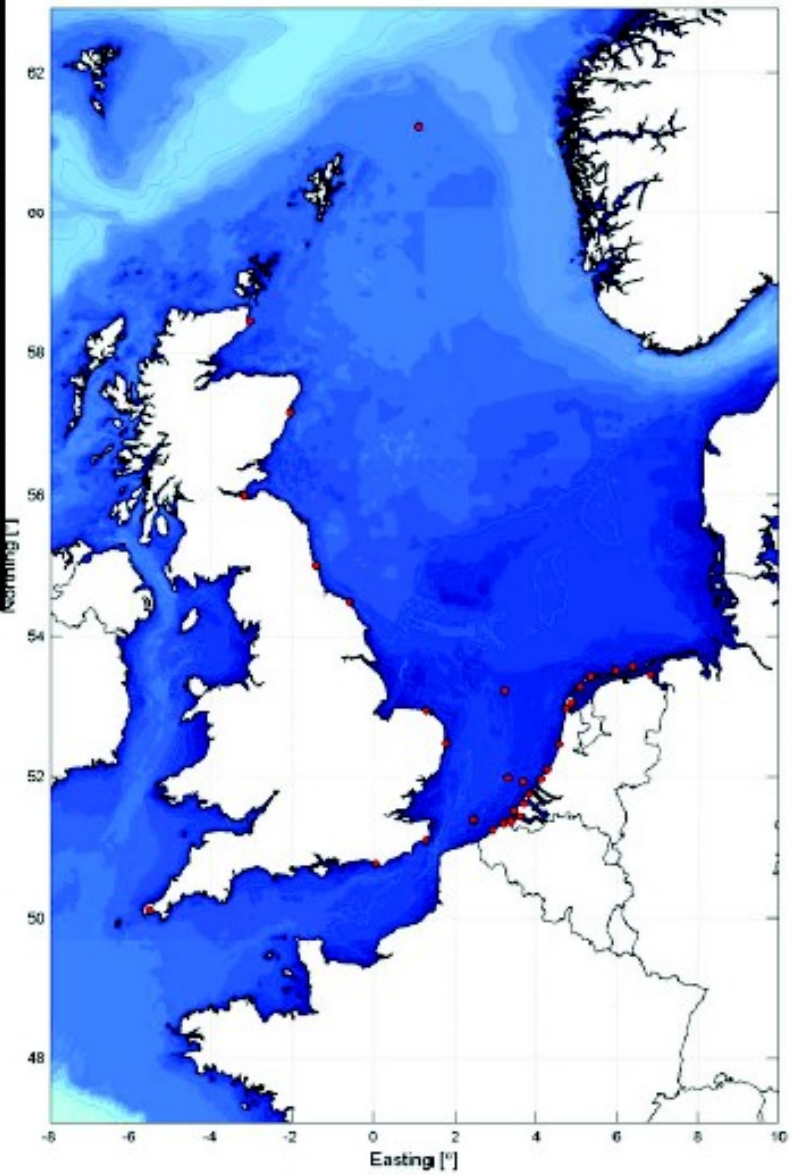
# Kalman filter for storm-surge model

- Compute Kalman gain with EnKF
  - > 100 members
  - > Near linear storm-surge model
  - > Stochastic forcing from wind-stress and boundaries
  - > Spurious correlations:
    - – Schur product
  - > Temporal averaging (Sorensen & Madsen 2004)
- Use steady-state Kalman gain for operational computations
  - > Very efficient

# Selection of assimilation locations

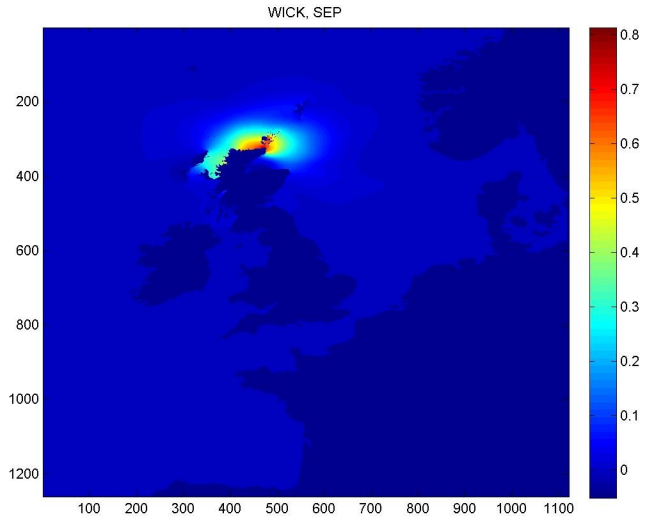
| | | |
|---|---|---|
| NORTHCMRT | CADZD | HUIBGT |
| WICK | WESTKPLE | NEWLN |
| ABDN | EURPFM | NEWHVN |
| LEITH | BROUWHVSGT08 | DOVR |
| NORTHSS | LICHTELGRE | VLISSGN |
| WHITBY | HOEKVHLD | ROOMPBTN |
| CROMR | SCHEVNGN | DENHDR |
| LOWST | IJMDBTHVN | OUDSD |
| Oostende | K13APFM | VLIELHVN |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

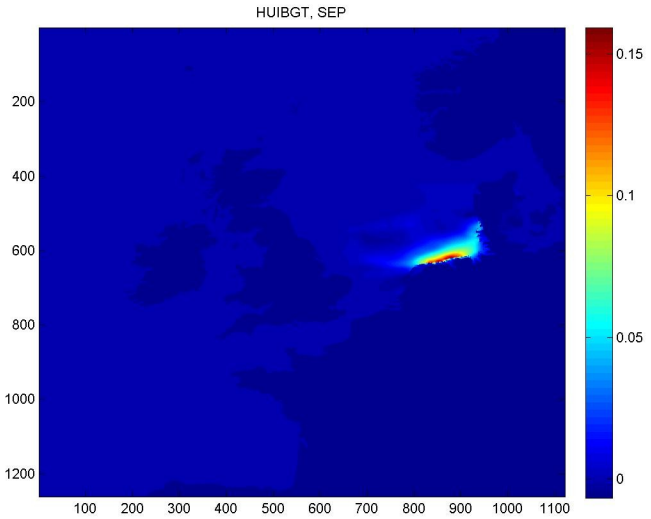


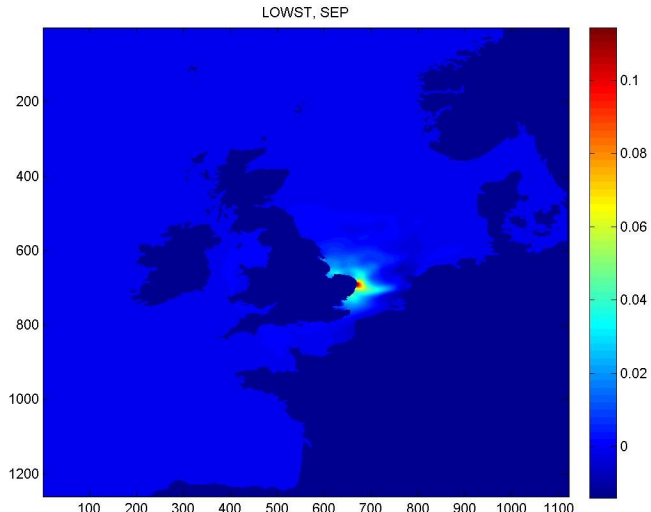



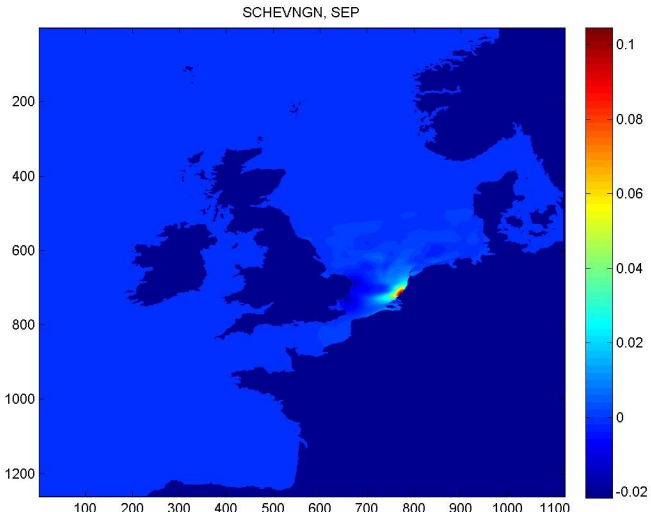
# Ensemble Kalman filter

Examples of Kalman gain (DCSMv6, 100 members with localization)



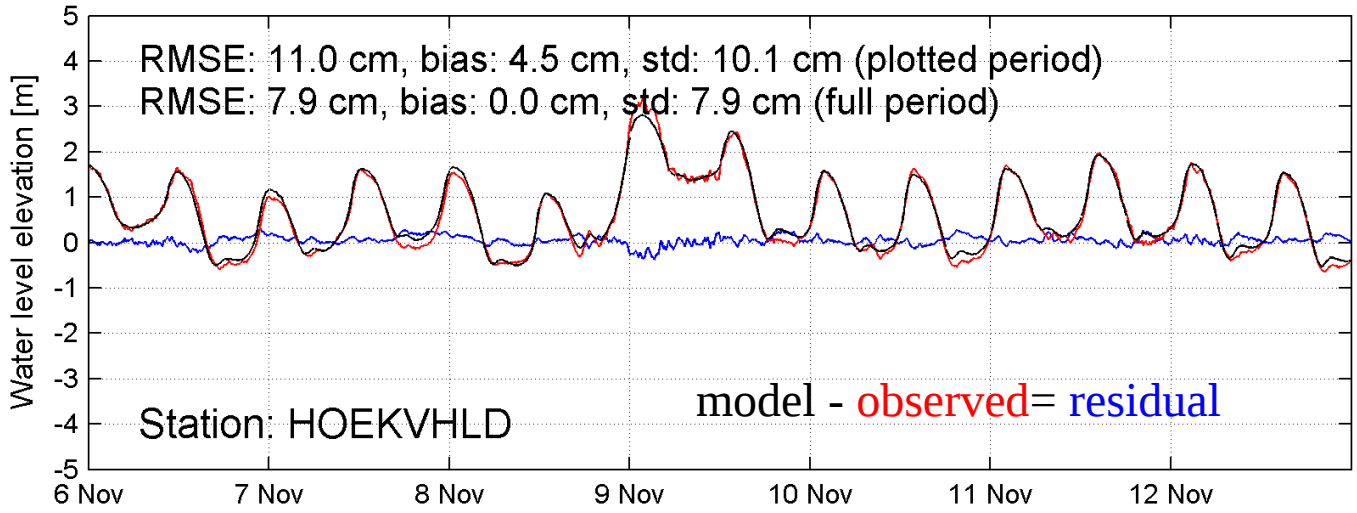



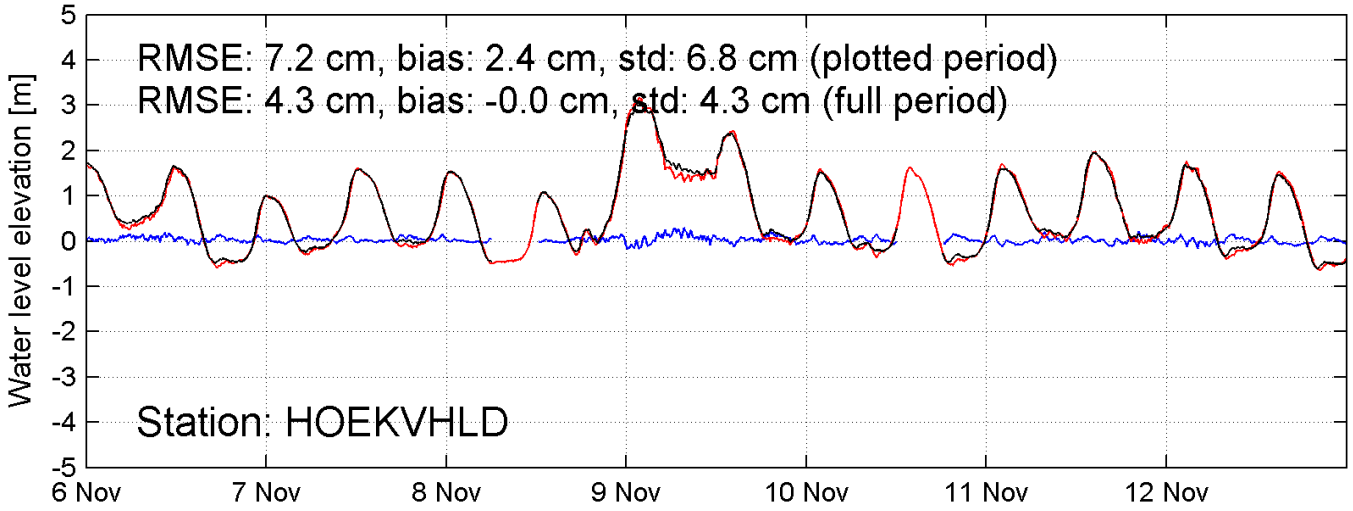



# Results ( -6 – 0 h )

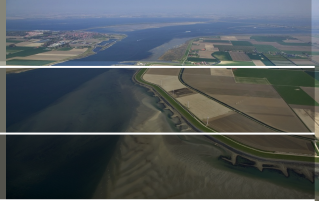
DCSMv6:

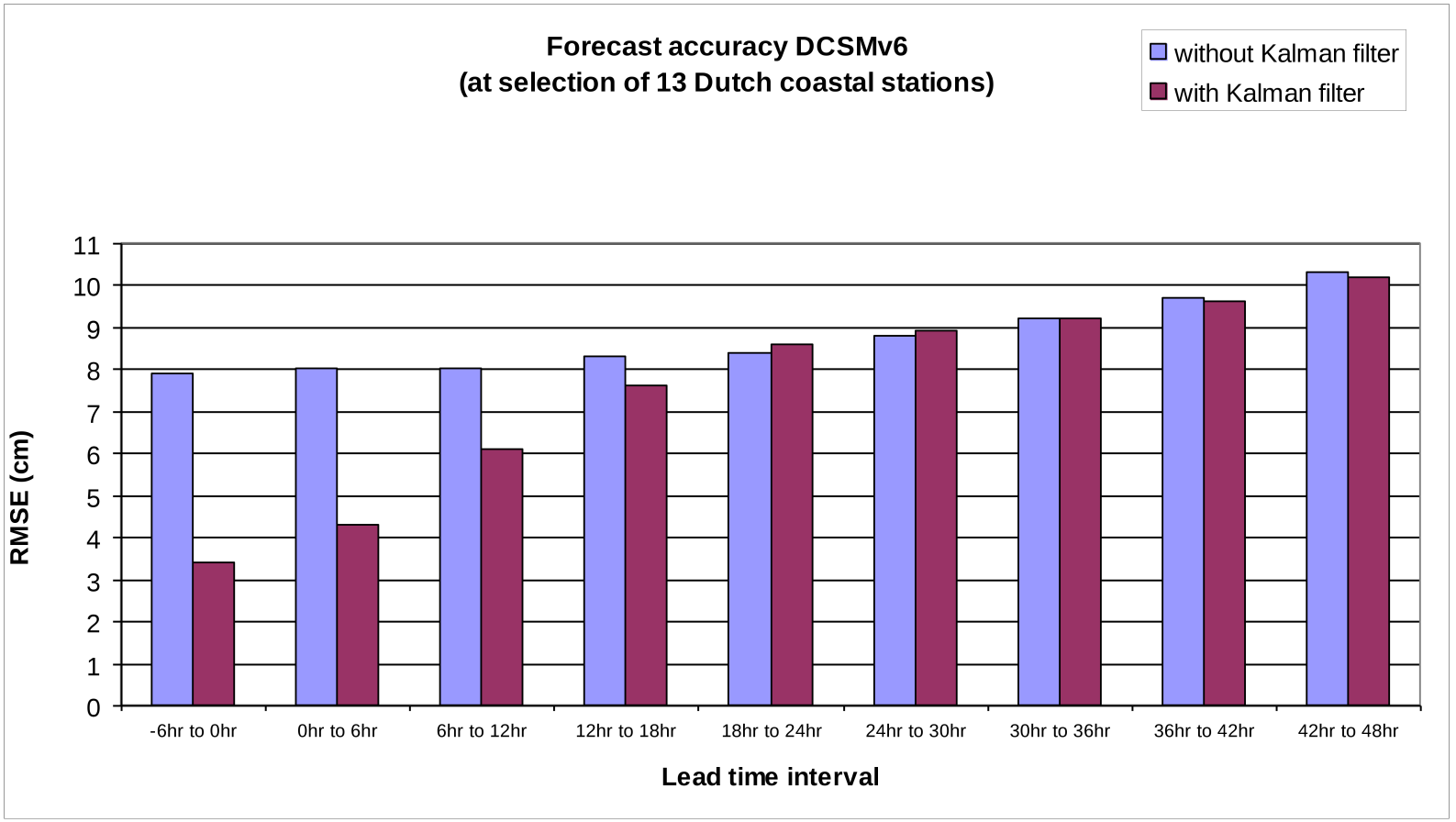



DCSMv6+KF:

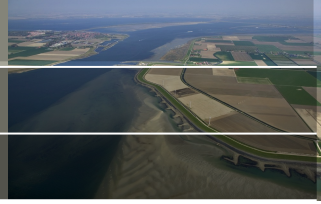


# Results

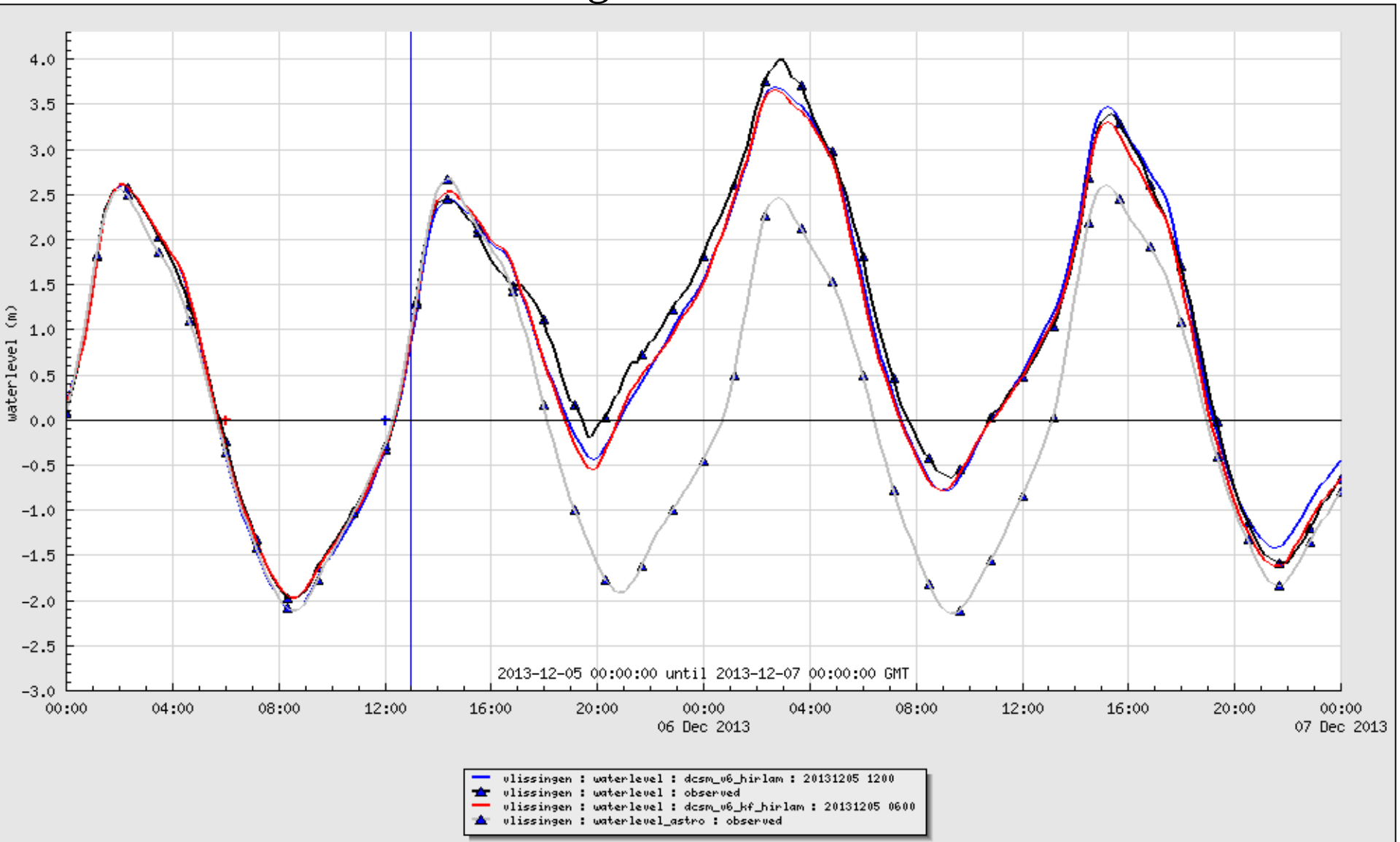



Forecast accuracy DCSMv6
(at selection of 13 Dutch coastal stations)
without Kalman filter
with Kalman filter
RMSE (cm)
0
1
2
3
4
5
6
7
8
9
10
11
-6hr to 0hr
0hr to 6hr
6hr to 12hr
12hr to 18hr
18hr to 24hr
24hr to 30hr
30hr to 36hr
36hr to 42hr
42hr to 48hr
Lead time interval

# Impact during a storm

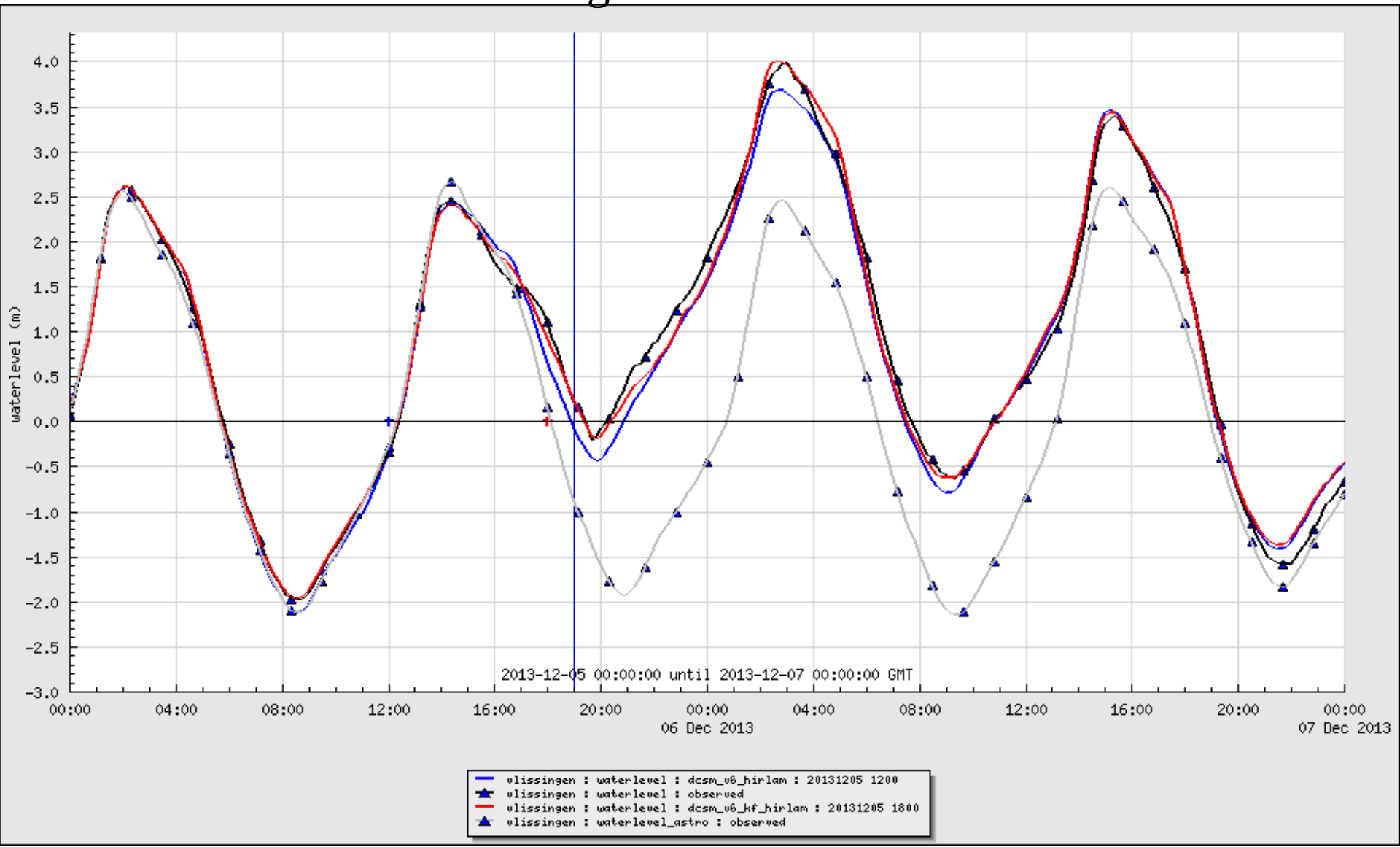


Forecast for Vlissingen at Dec 5 13h



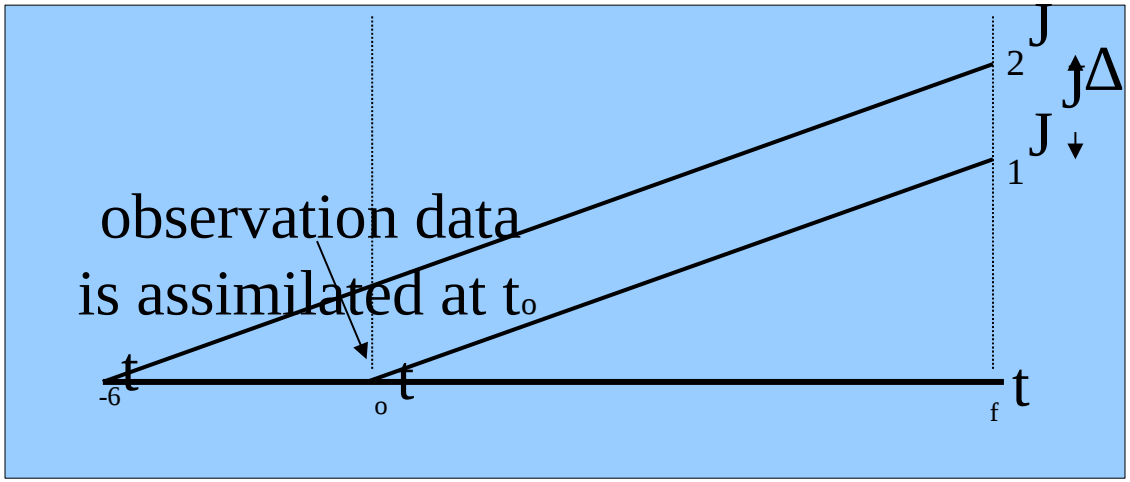
# Impact during a storm

Forecast for Vlissingen at Dec 5 19h



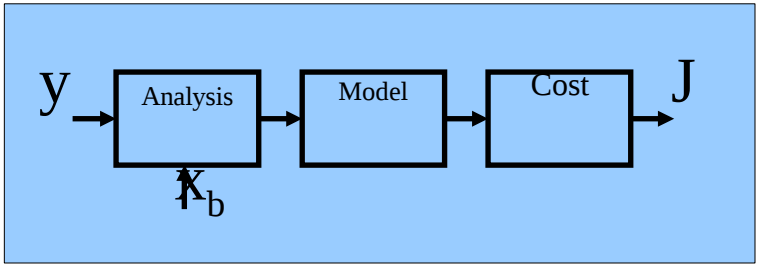
# Observation sensitivity

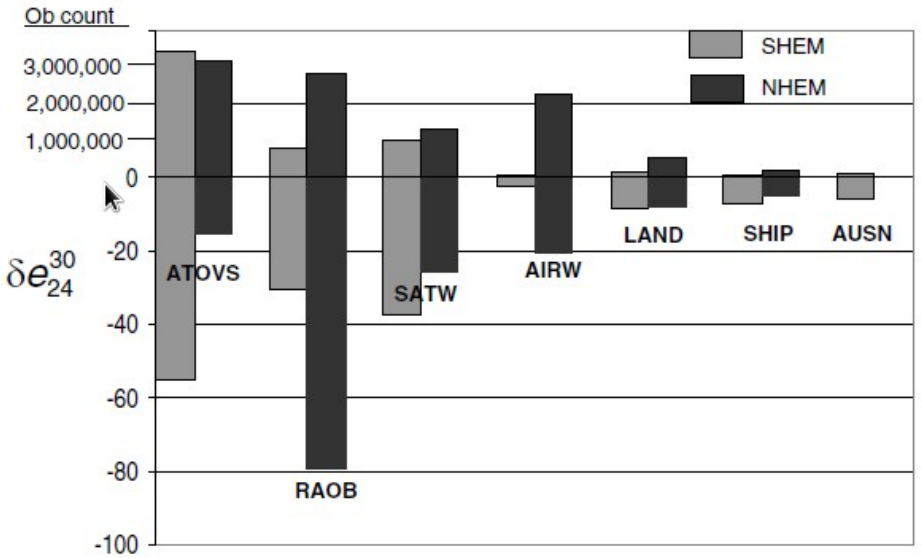
- Langland and Baker (2004), Errico(2007), Gelaro et. al. (2007)



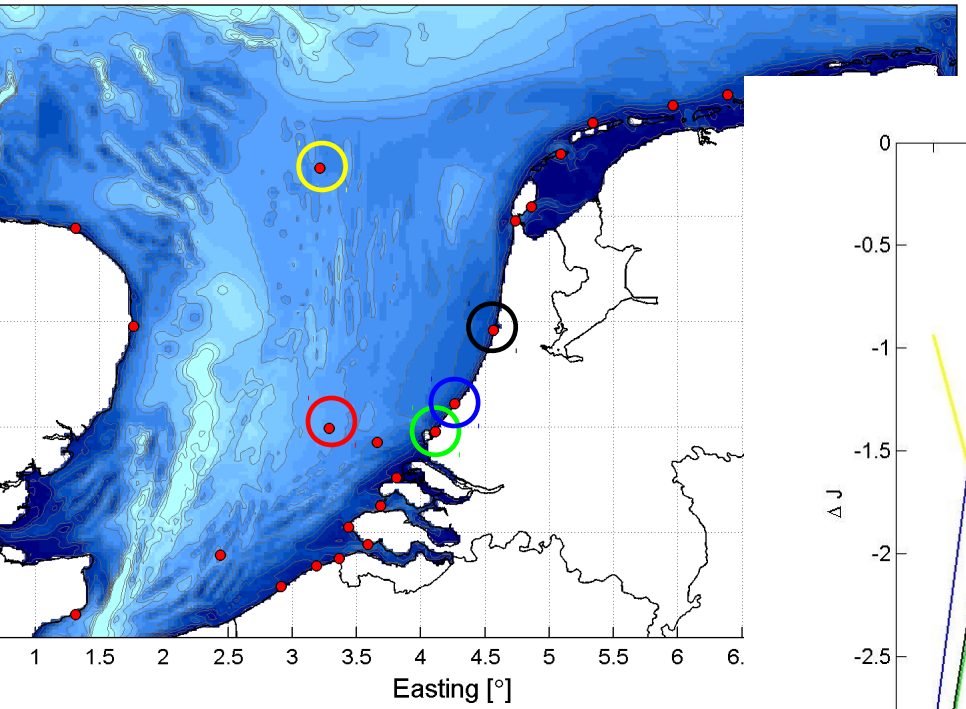

Common $J=(x^f-x^a)'C(x^f-x^a)$
We use:

$$J = \left( y - Hx^f \right)' R^{-1} \left( y - Hx^f \right)$$

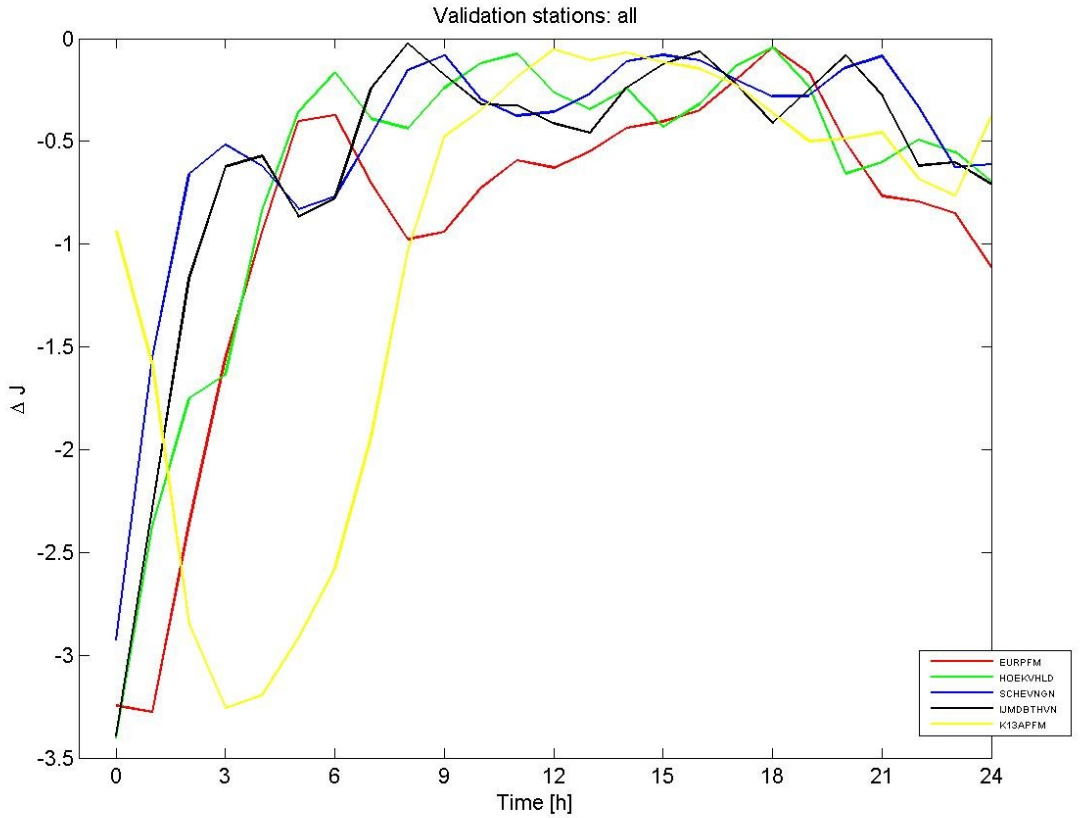


# Selection of assimilation stations

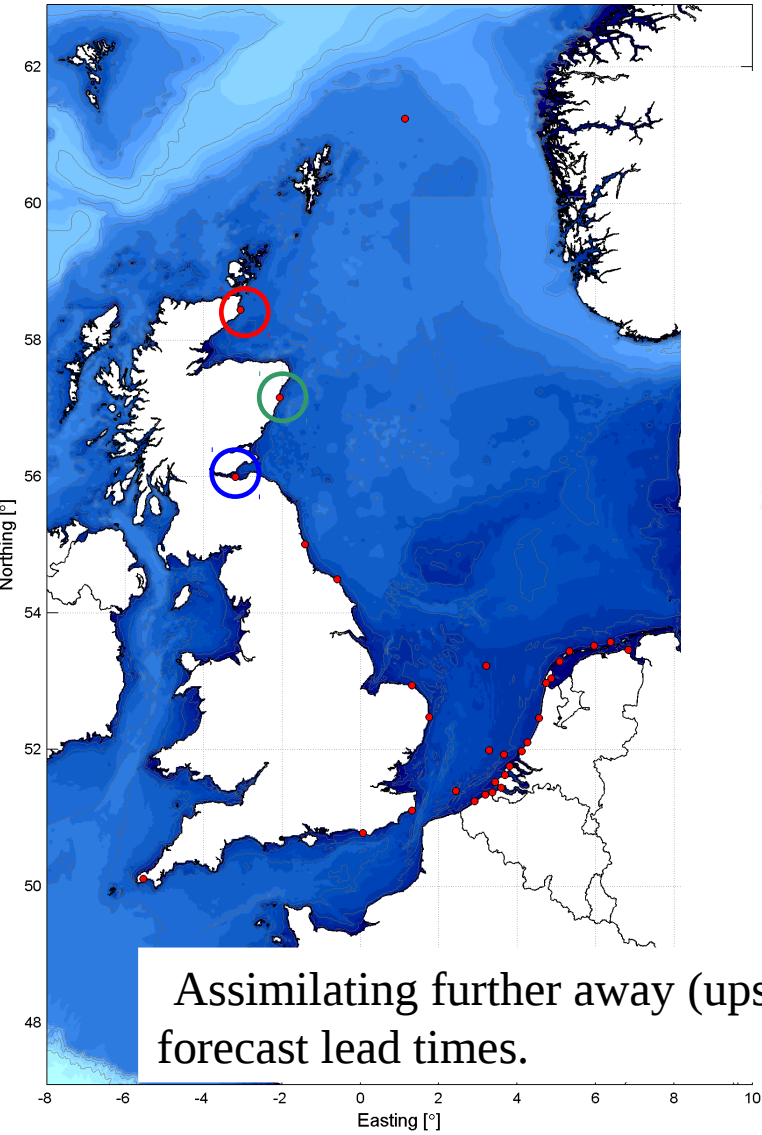


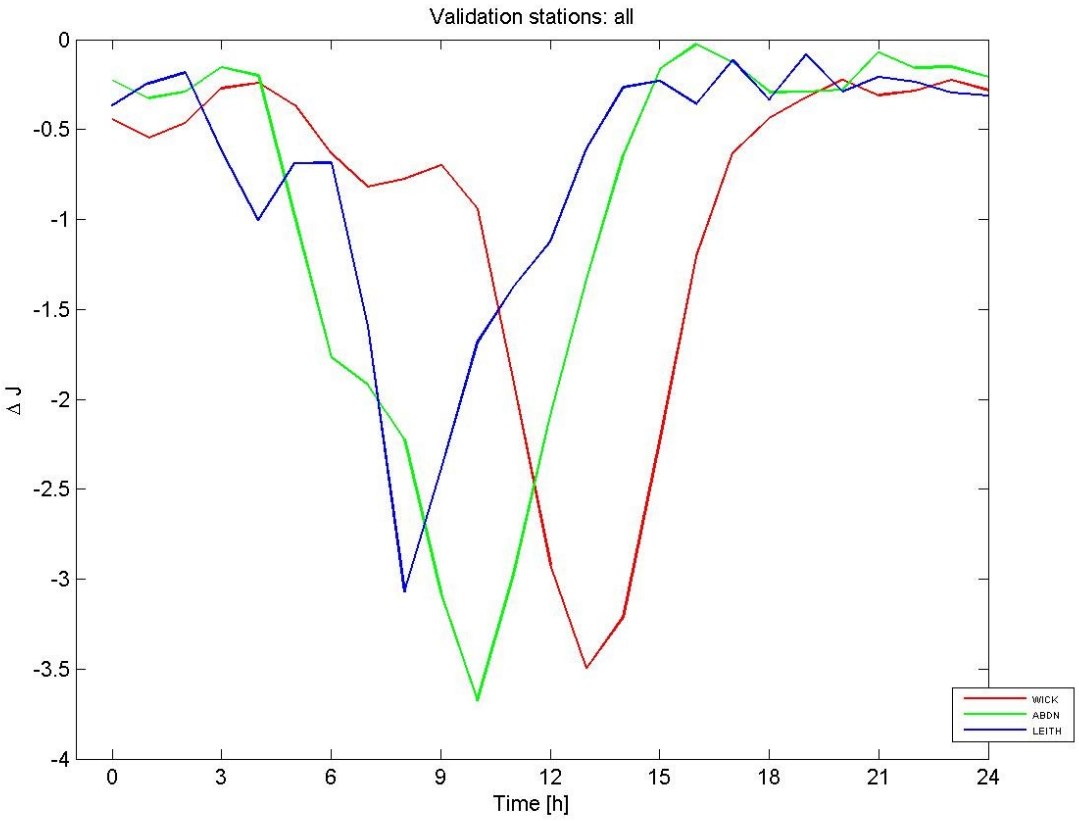

J at coast Netherlands




Assimilating nearby stations g

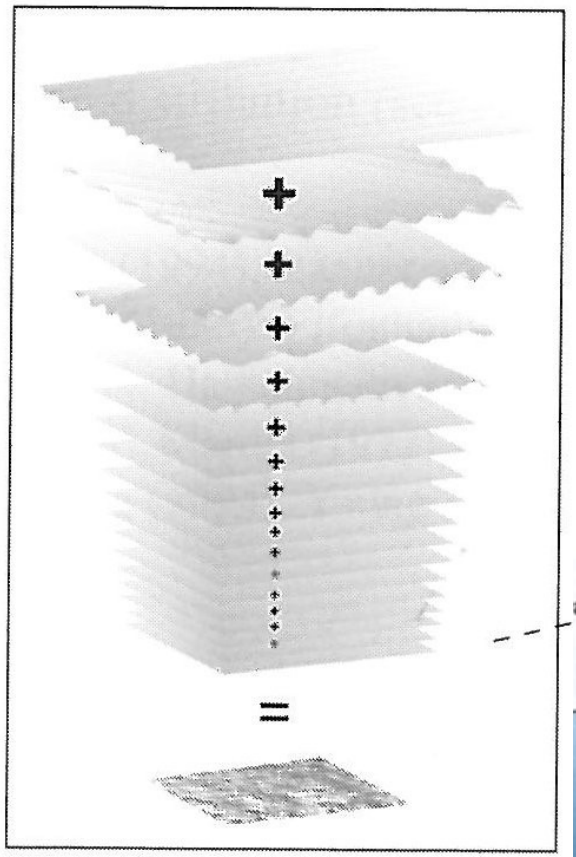
# Selection of assimilation stations



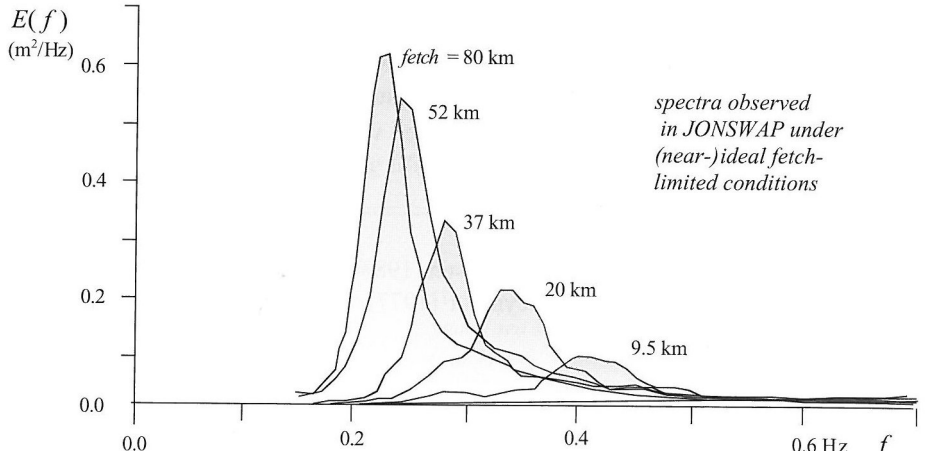



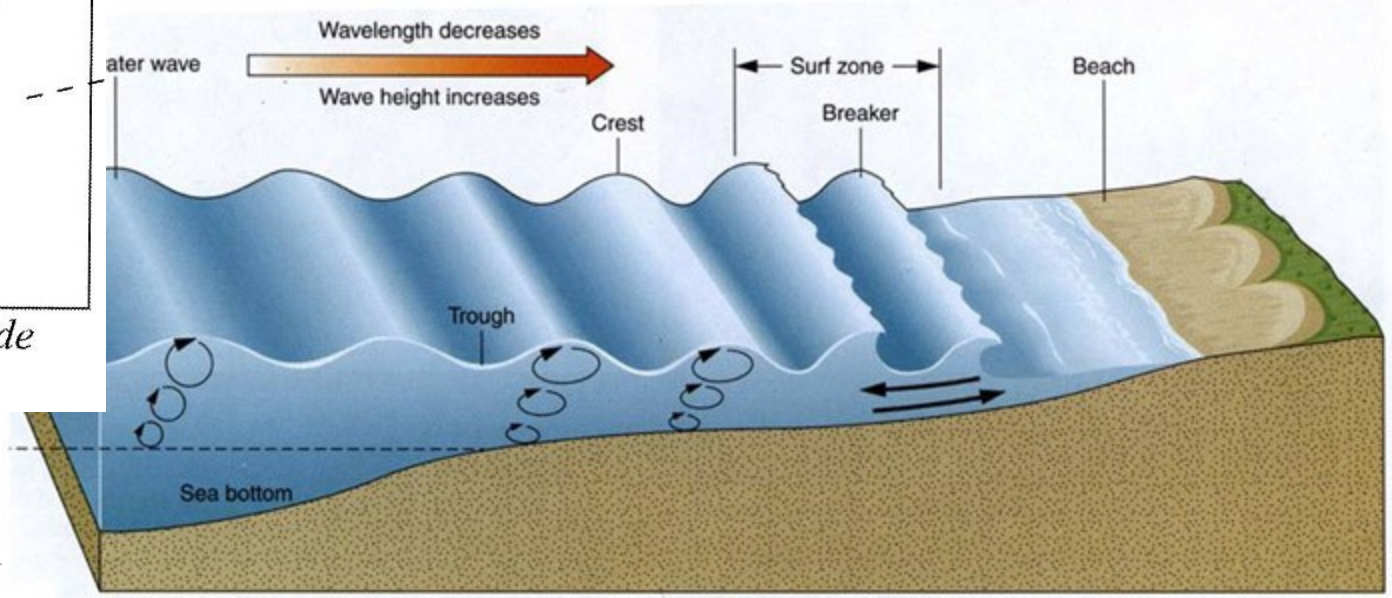

Assimilating further away (upstream) stations improves the accuracy of longer forecast lead times.

# Simulating Waves Near-shore SWAN



*random-phase/amplitude model*

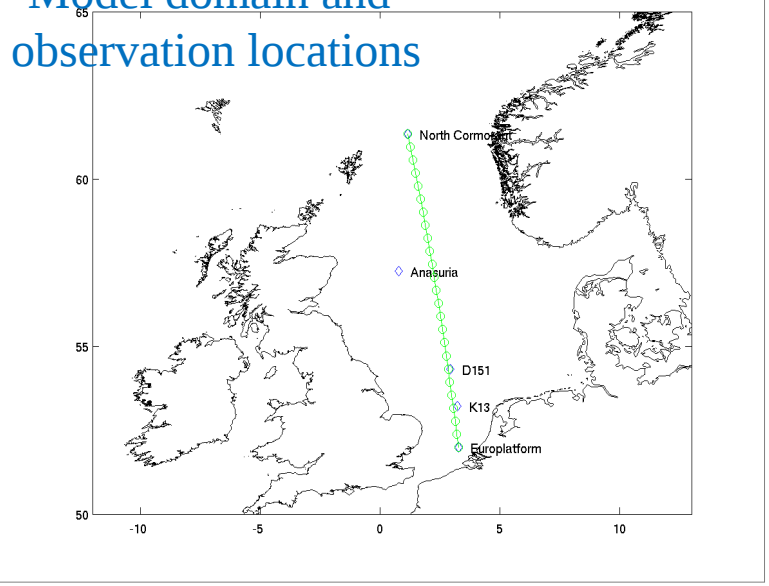


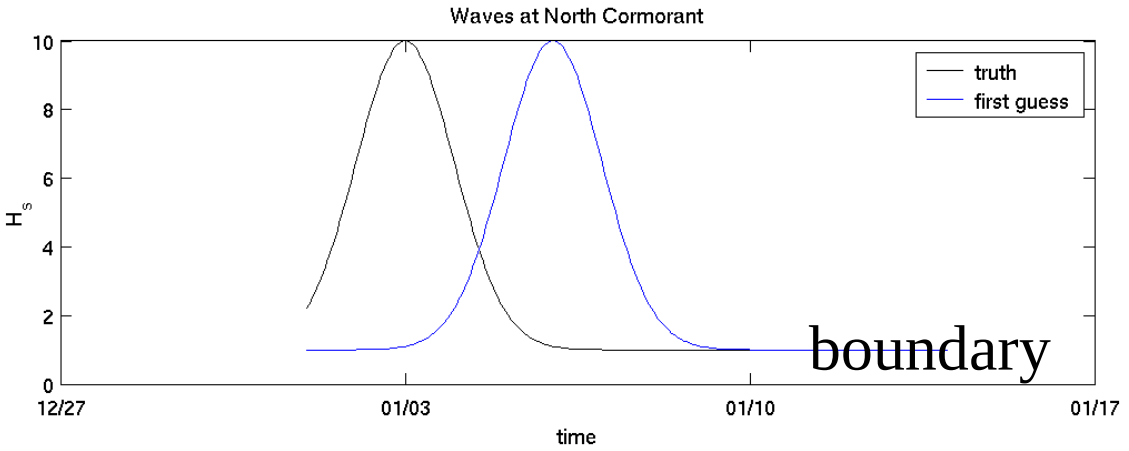

(Plummer et al., 2001)

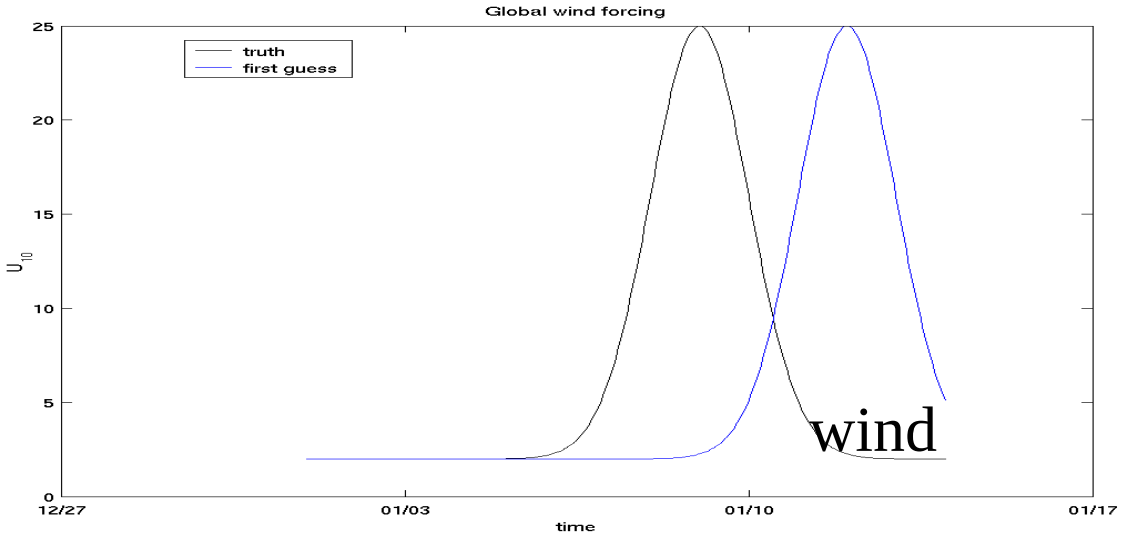
# EnKF for SWAN wave model

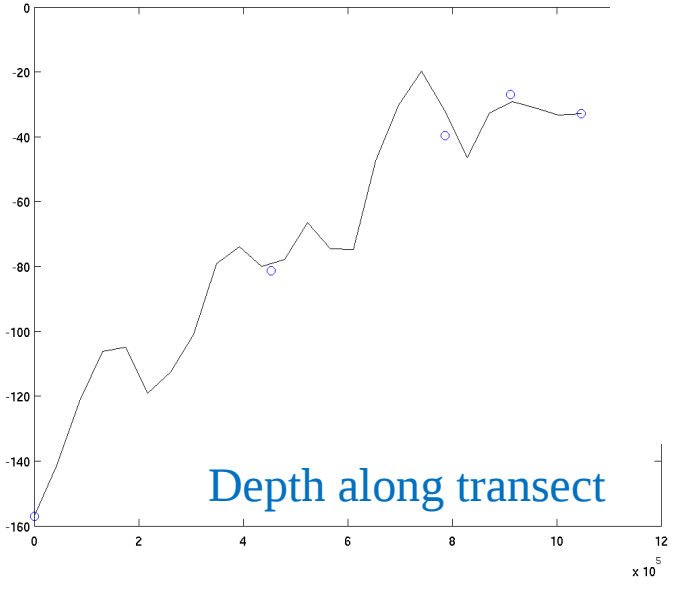
## Model domain and observation locations




## Twin experiment 1D

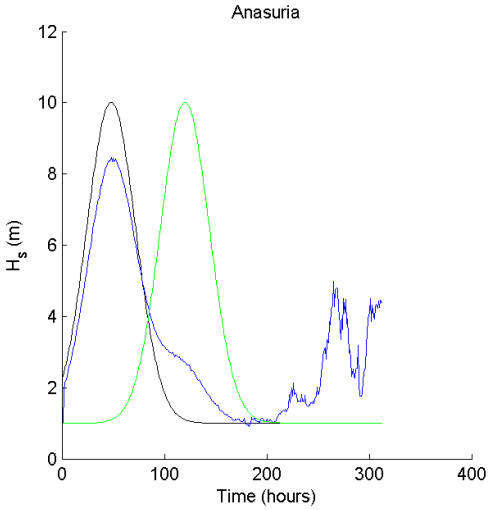


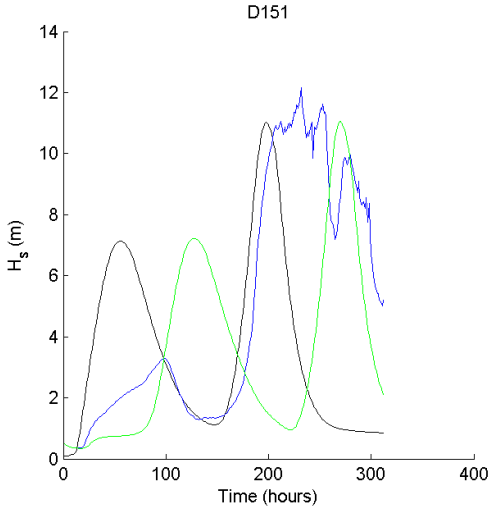



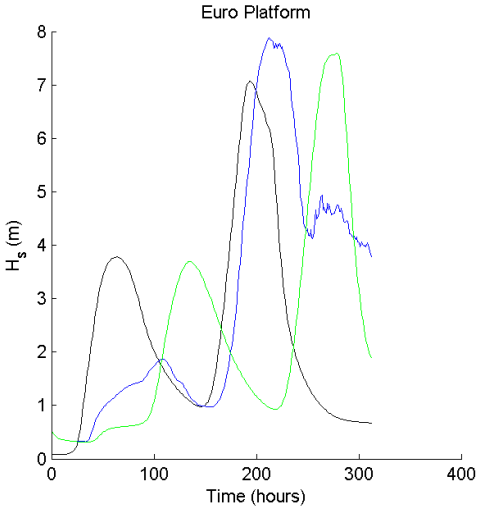



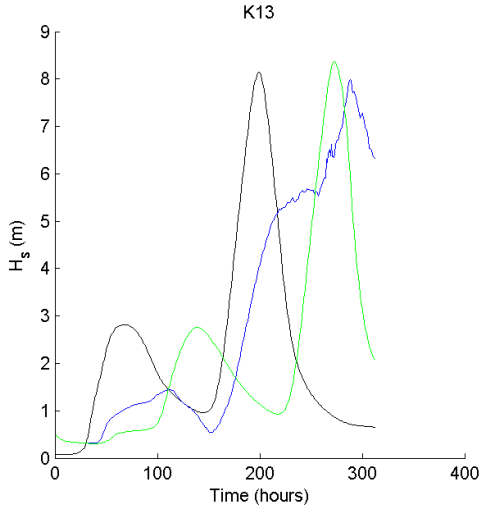
# EnKF for SWAN wave model

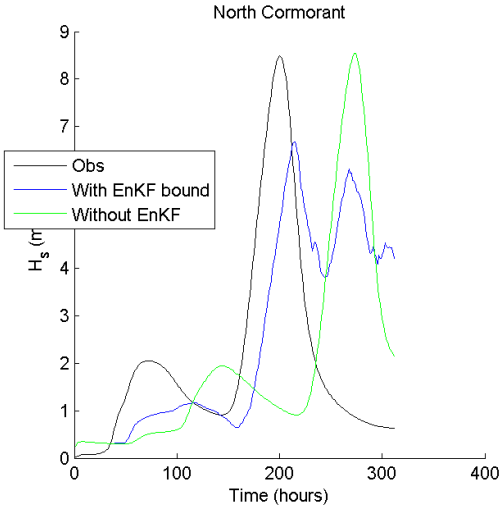
## Twin experiment 1D



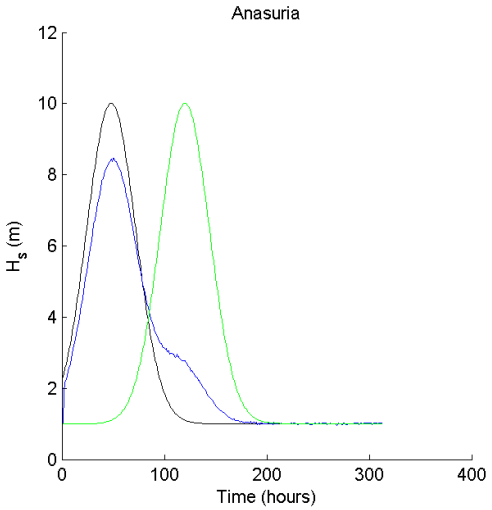



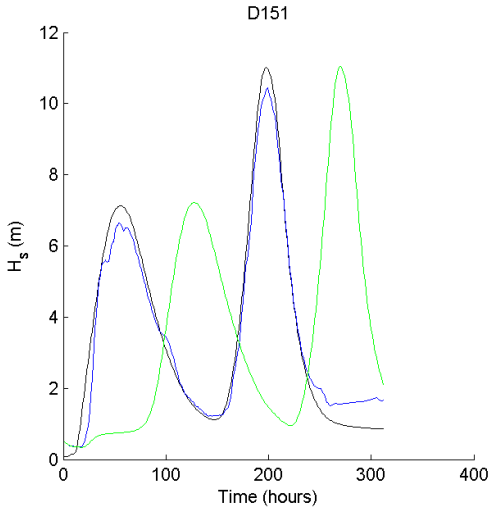

Assimilation of Hs at the 4 buoy locations

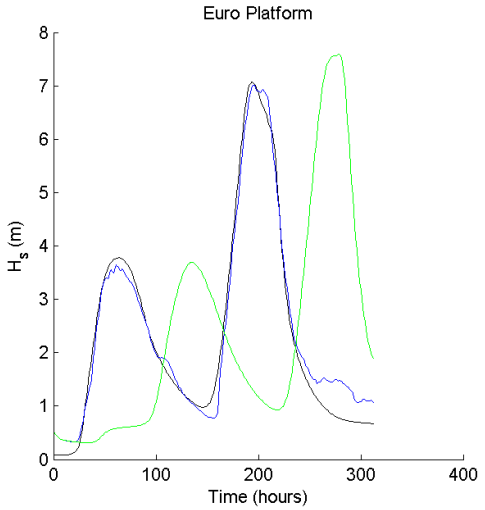
Adjustment of boundary wave conditions and of the 2D spectra at each computational grid location

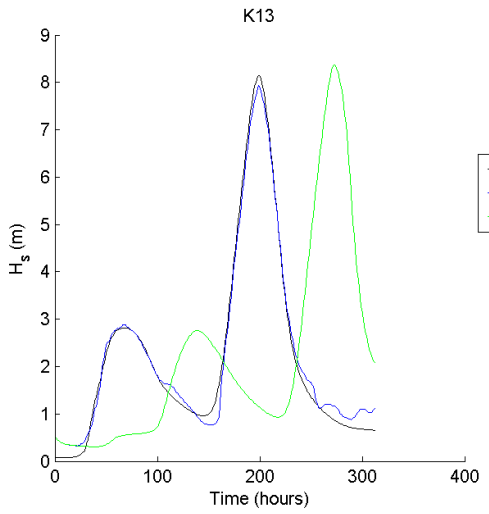
# EnKF for SWAN wave model

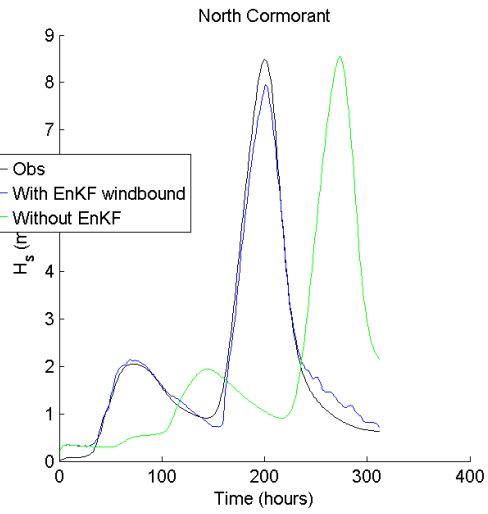
## Twin experiment 1D



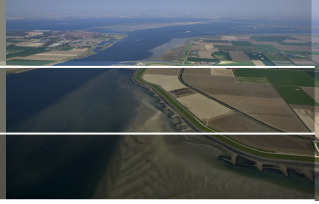




Assimilation of Hs at the 4 buoy locations

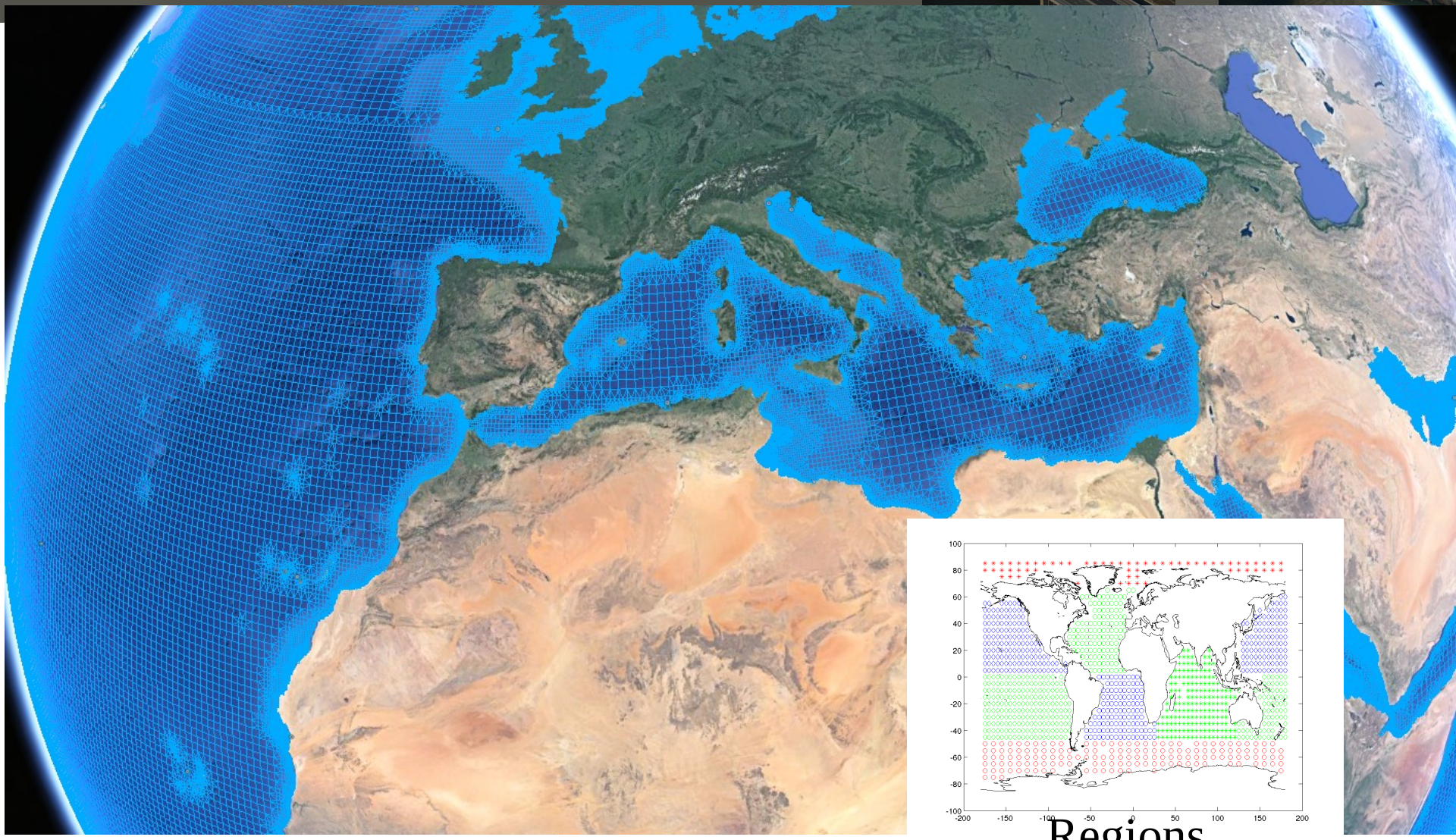
Adjustment of boundary wave conditions and wind input and of the 2D spectra at each computational grid location

# Challenges



- Improve robustness of DUD algorithm (eg with constraints)
- Design good parallel calibration algorithms
- Parallel computing for analysis in EnKF
- Application to unstructured grid models
- Strengthen variational methods in OpenDA

# Global Tide model






Regions

This Dflow-FM grid uses triangles and rectangles for local grid refinement

OpenDA

Deltares

Enabling Delta Life

www.openda.org

The end