Implementation of EnKF in a high resolution spectral wave model

- with application in the Southern North Sea

14TH INTERNATIONAL ENKF WORKSHOP IN VOSS
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Agenda

- Motivation and ideas
- Spectral wave modeling (MIKE 21 SW)
- DA in MIKE FM
- Implementation DA in MIKE 21 SW
- Case study: Dutch Coast
- Closing remarks and future work

Motivation

- Accurate prediction of wave conditions
  - Design of offshore and coastal structures (hindcast)
  - Operations at sea (forecast)

- SW + EnKF = better wave models

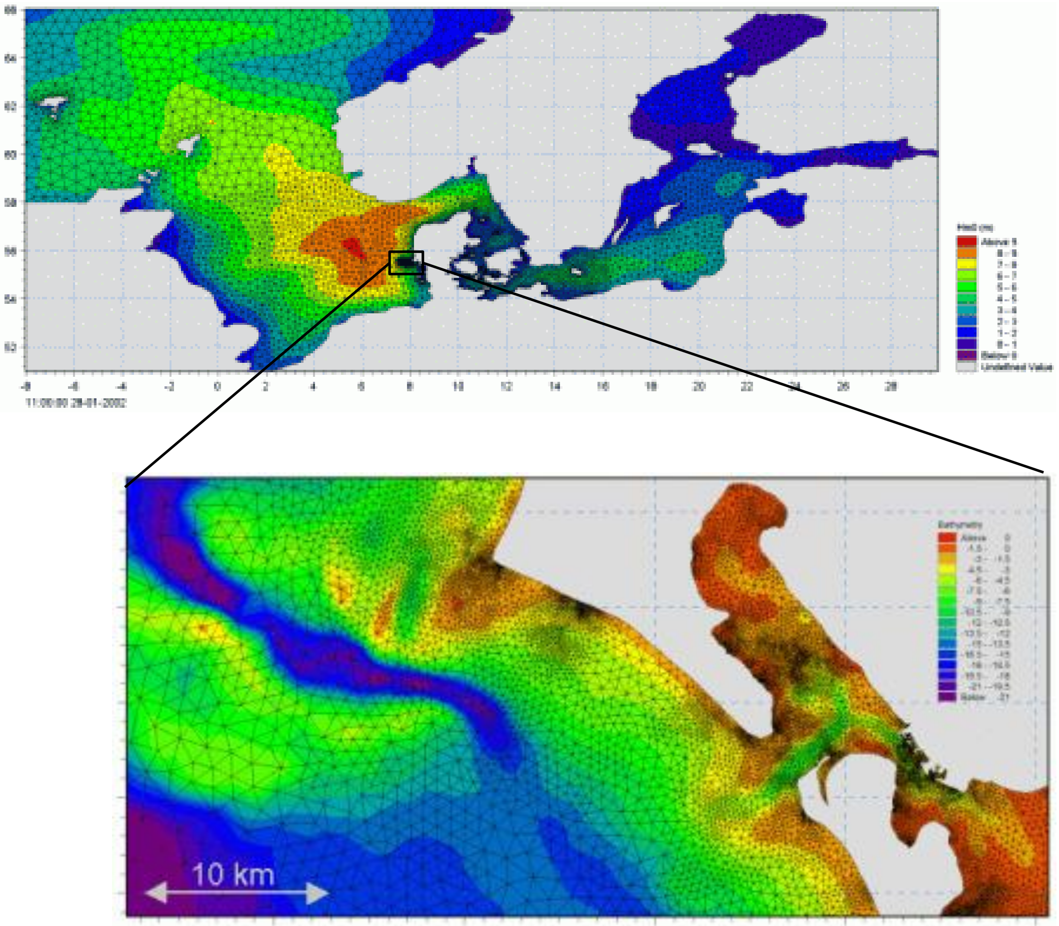
- Is EnKF necessary? – or is it enough to use static error covariance?
- Can we reduce model complexity and rely on data and EnKF instead?

Spectral wave modelling

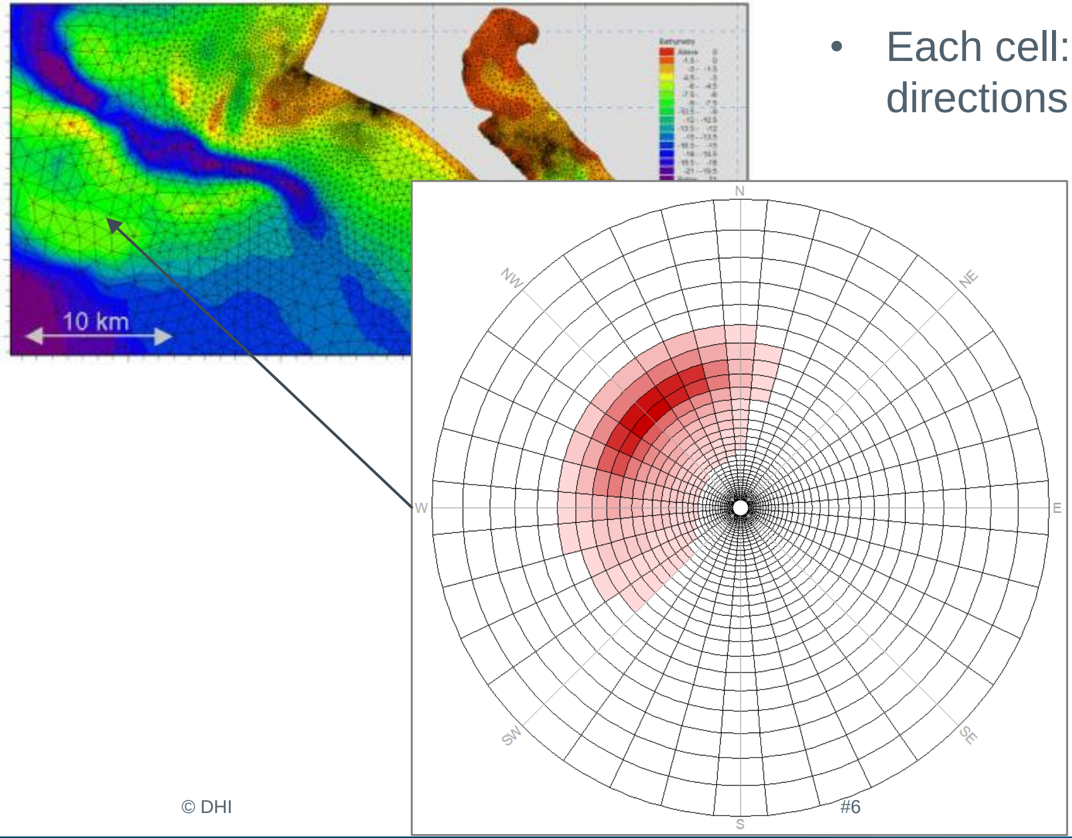
MIKE 21 SW

- 3rd generation spectral wind-wave model
- Unstructured mesh
- Finite volume
- Wave growth, decay and transformation

$$\frac{\partial N}{\partial t} + \nabla \cdot (\vec{v}N) = \frac{S}{\sigma}$$



MIKE 21 SW – discretization and variables



- Each cell: Energy density with e.g. 16 directions and 25 frequencies

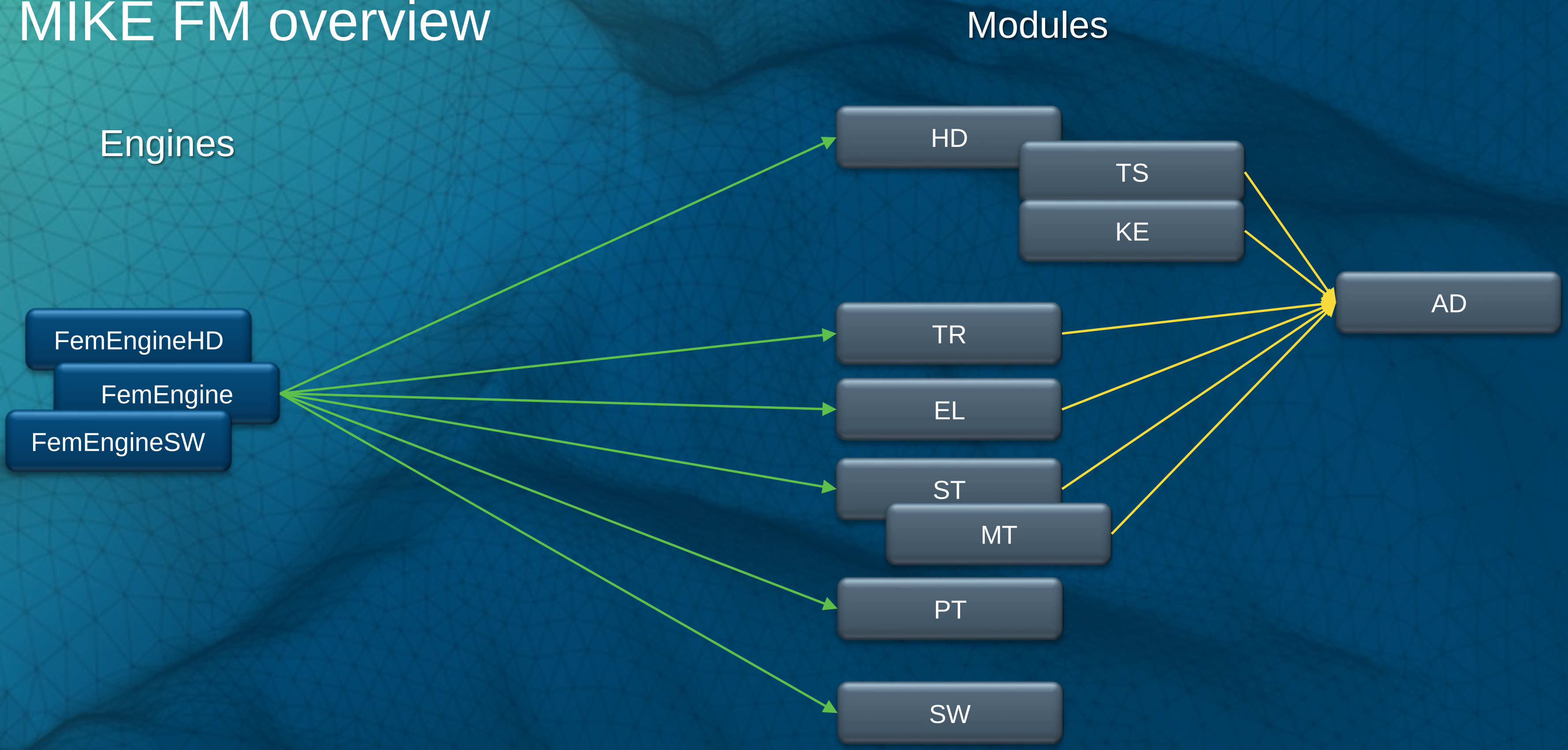
MIKE 21 SW - Source terms

$$S = S_{wind} + S_{nl} + S_{ds} + S_{bot} + S_{surf}$$

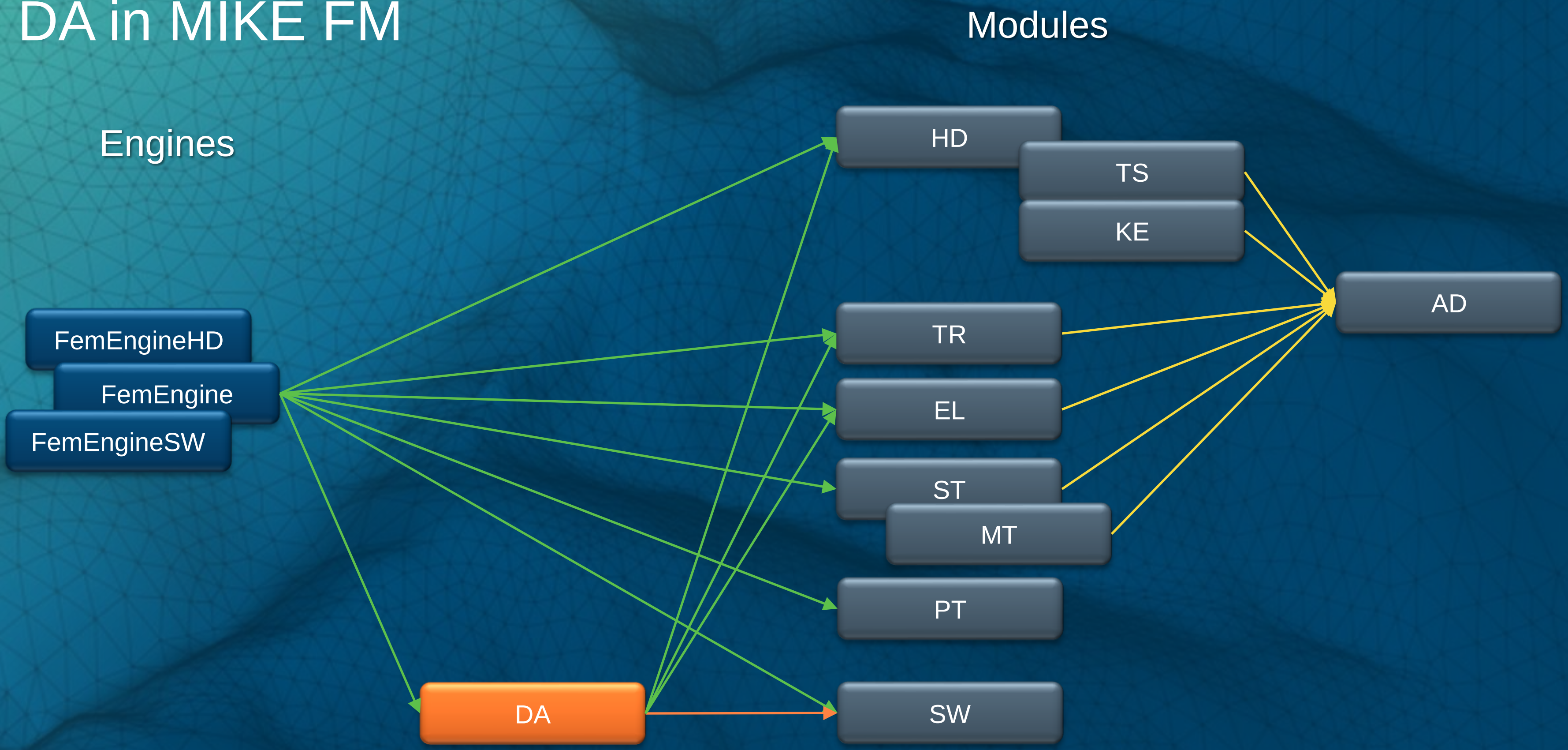
- Wind generation ($wind$)
- Non-linear energy transfer (nl)
- Dissipation by white capping (ds)
- Dissipation due to bottom friction (bot)
- Surf zone dissipation/wave breaking ($surf$)

MIKE FM

MIKE FM overview



DA in MIKE FM

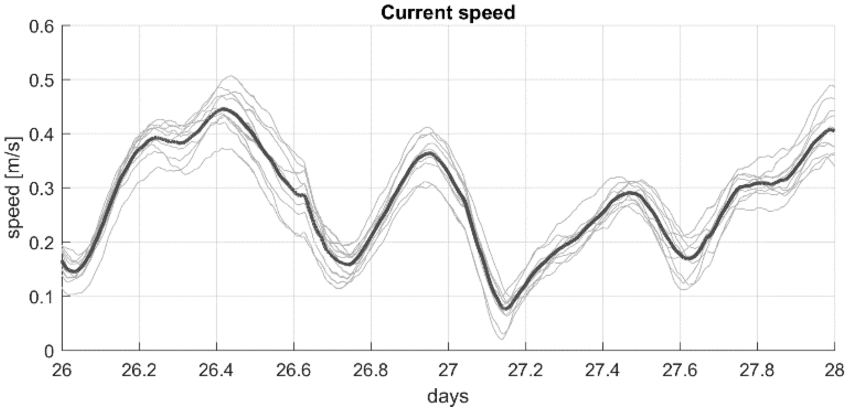

Modules
Engines
HD
TS
KE
AD
TR
EL
ST
MT
PT
SW
FemEngineHD
FemEngine
FemEngineSW
DA

Ensemble models

- Ensemble consisting of m *members*

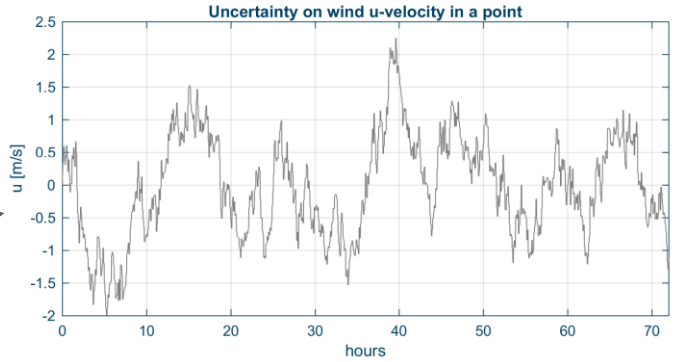
How to introduce variability in model?

- Add small “errors” (=pertubations) to…
  - Initial conditions
  - Forcings
  - Parameters

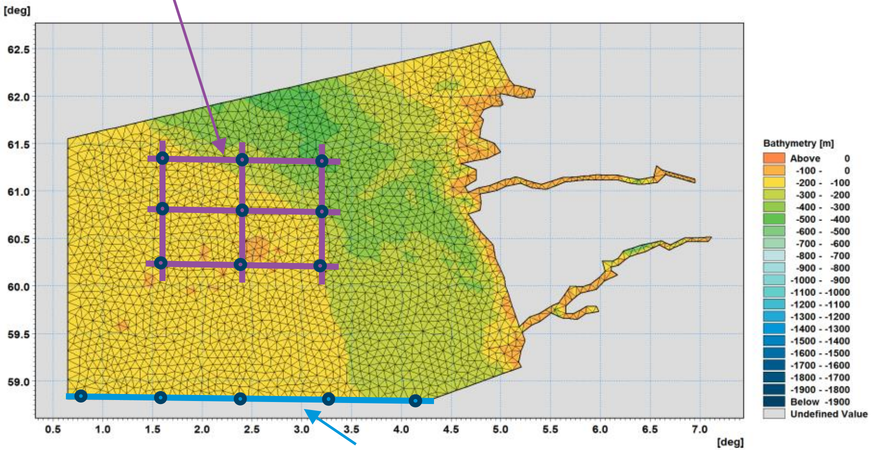


Uncertainty modelling in MIKE FM

- Amplitude (e.g. wind st.dev 1m/s)
- Time scales, AR(1)
- Spatial scales
  - Discretization (coarse)
  - Covariance Q (e.g. 300 km)
- Vector ϵ



Discretized wind uncertainty (part)



Discretized boundary uncertainty

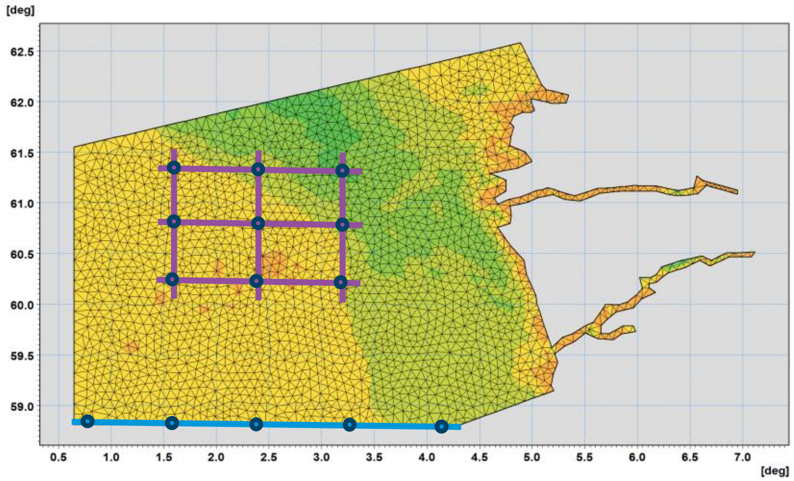
State representation in MIKE 21/3 FM

- Model variables according to selected modules
  - State variables x_{model} =(wl, u, v, …)

- Model errors
  - Types: open bc, wind-u, wind-v, …
  - Discretized on a grid: ϵ

- Augmented state

$$x_{state} = \begin{bmatrix} x_{model} \\ \epsilon \end{bmatrix}$$



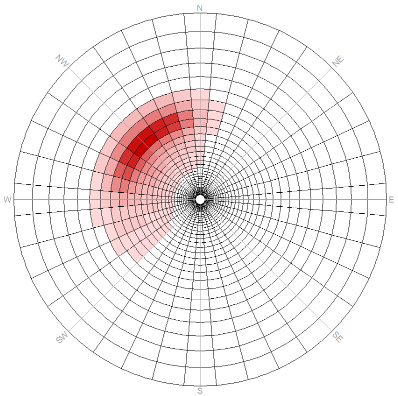
DA scheme

- ESRF (no perturbation of measurements)
  - Serial-ESRF (”Potter scheme”)
  - ETKF
- R-factor for inflation

Data assimilation for MIKE 21 SW

State representation

- Action density!
- And… variables that we would like to assimilate
  - Hm0, Tp
- Model errors



Creating the MIKE 21 SW ensemble

- Forcings
  - Wind
  - Windspeed

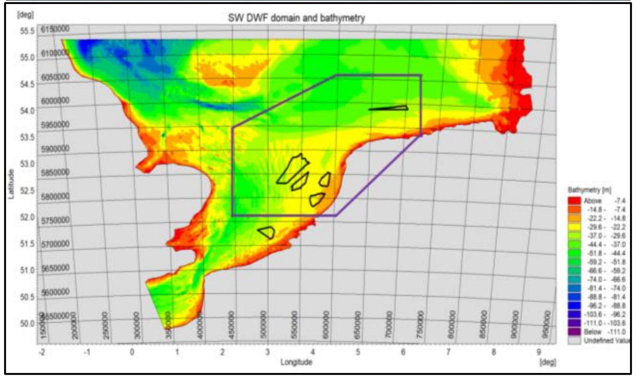
- Parameters
  - Whitecapping CDIS
  - Bottom friction (Nikuradse roughness)

- Boundary conditions (later)

Case study

Case Study: Dutch Coast Metocean Desk Study

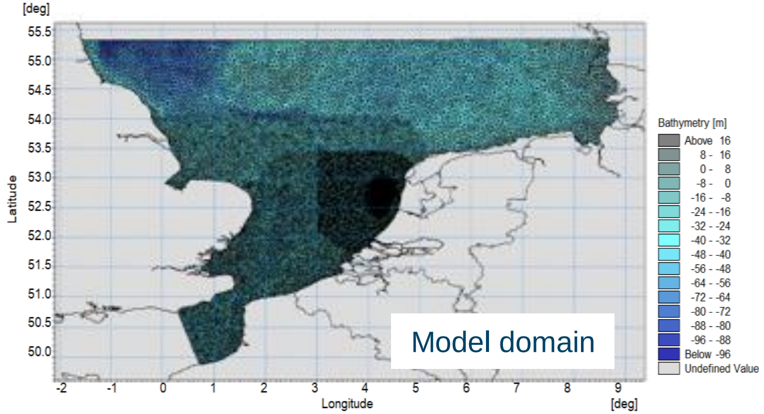
- Project within DHI from 09.2018-01.2019
- Provide meteorological and oceanographic (metocean) conditions for the Dutch Coast wind Farm zone
- Based on numerical modelling over 39 years

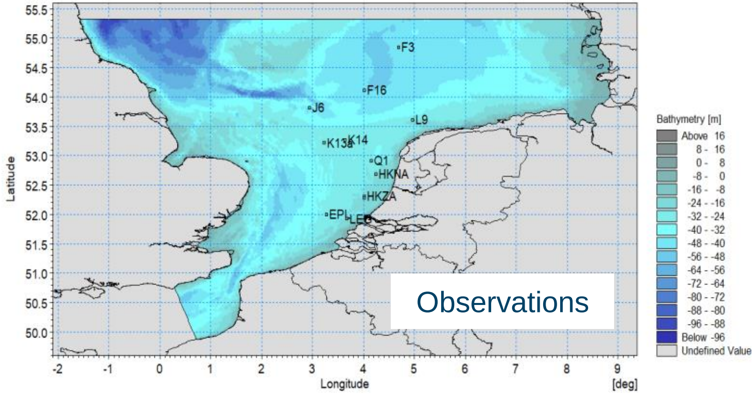


Case Study: MIKE 21 SW settings

- Coarse-resolution edition of existing SW model setup
- Default calibration
- CFSR wind
- Boundary conditions from well-calibrated regional model

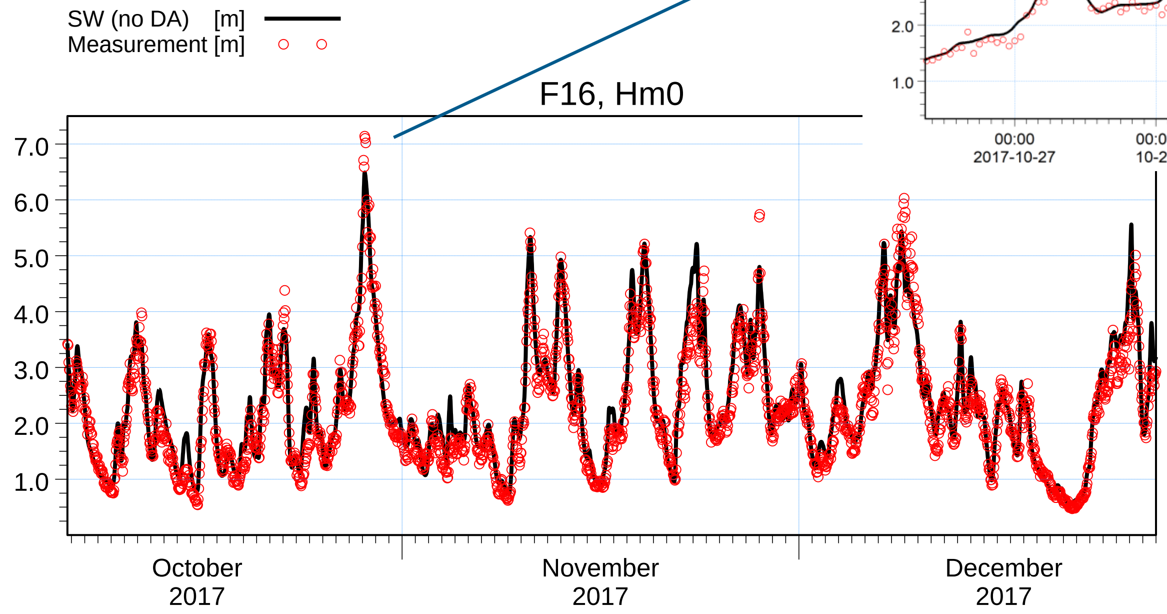
- **Study period** October-December 2017
  - Including a severe NW storm October 29

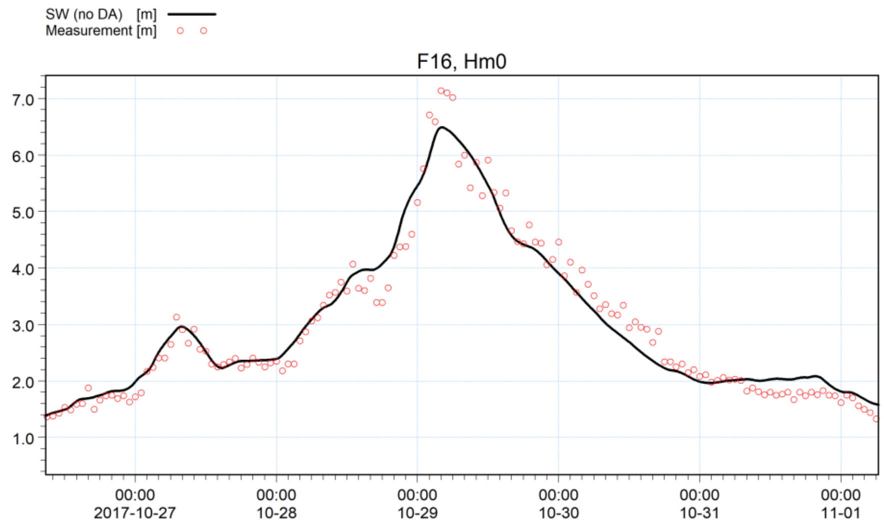


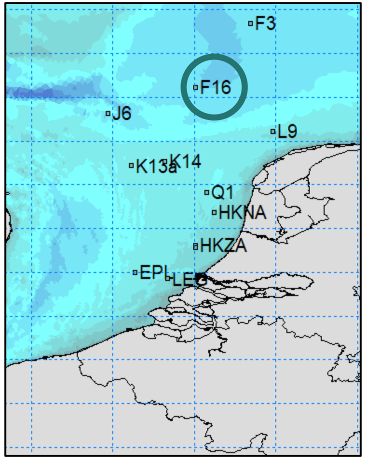


Base model is already good!

But with some room for improvement…



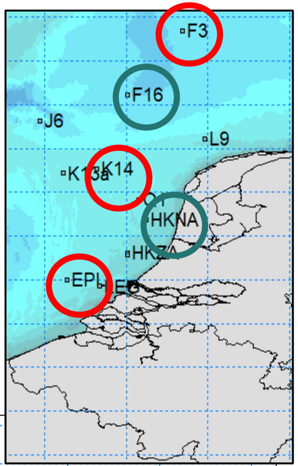


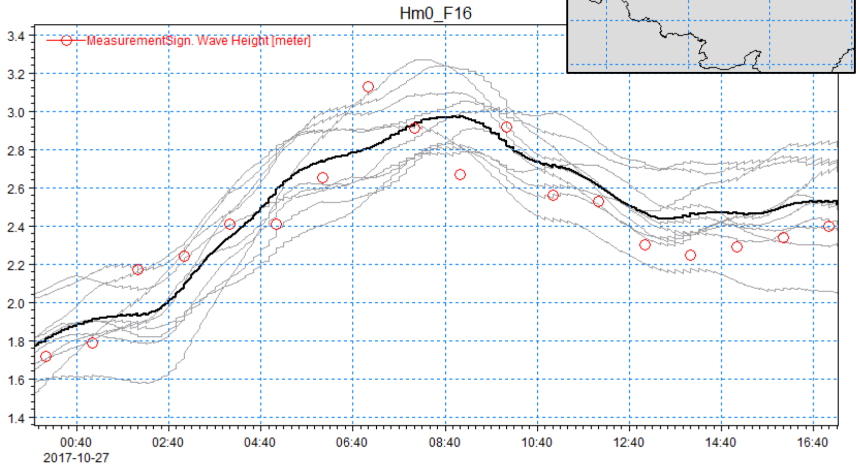


Case Study: DA settings

DA reference model

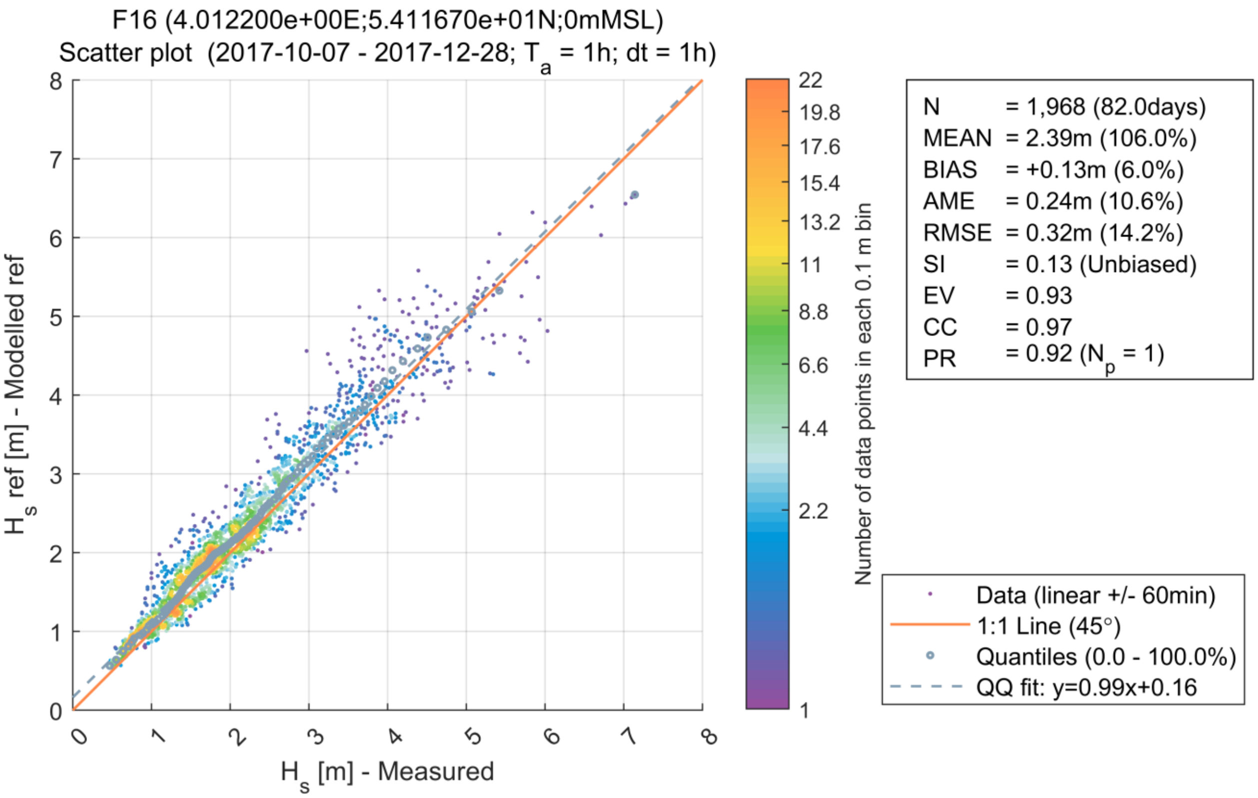
- Ensemble size: 10
- Perturbation of wind forcing:
  - 1.5m/s additive error on 80km grid
  - Horizontal correlation: 500km
  - AR(1) half-time: 3 hours
- Serial ESRF (potter scheme)
- Assimilation stations (Hm0): 3
- Assimilation every 10 minutes
- Observation uncertainty: st.dev=0.7m
- R-factor: 3
- No localization



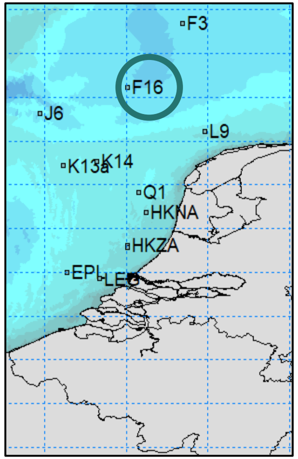


Let’s check Hm0 at the F16 station

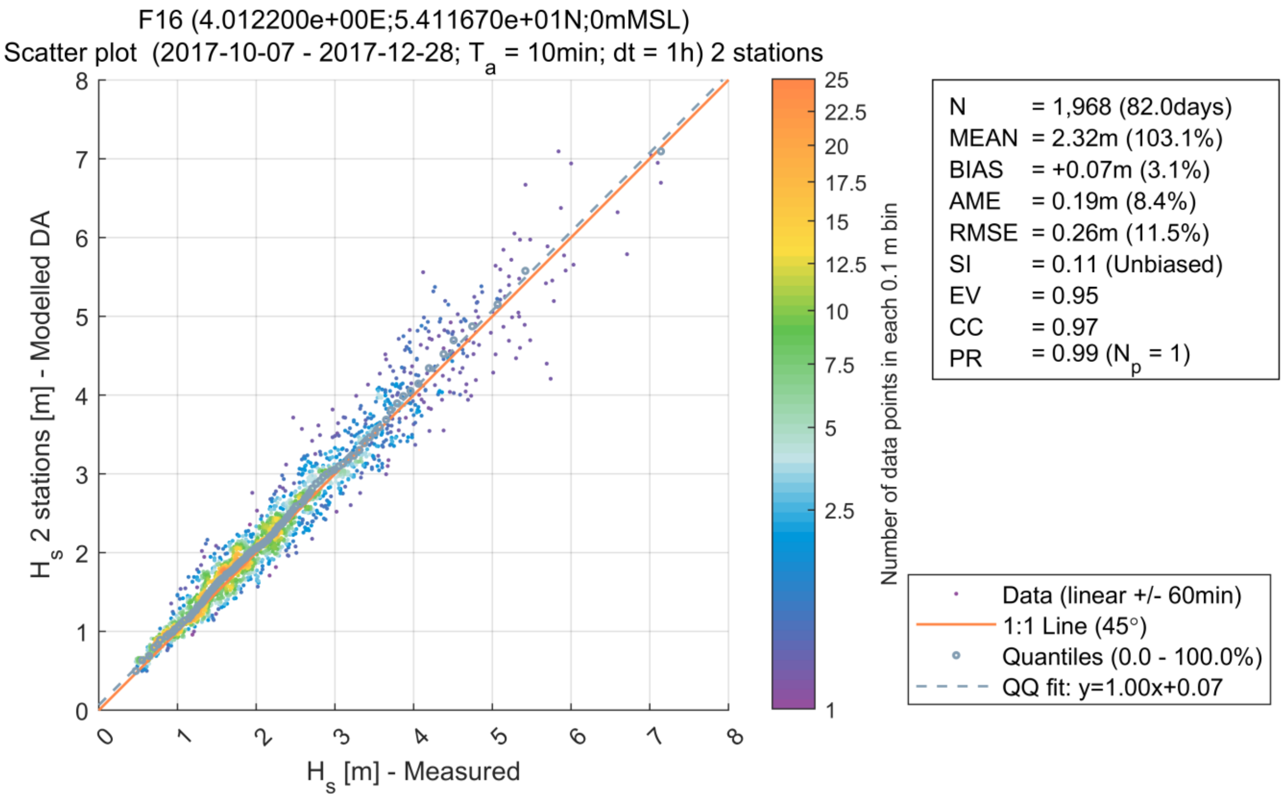
Station F16 – no DA

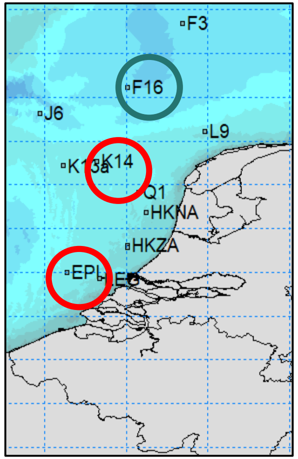


N	= 1,968 (82.0days)	
MEAN	= 2.39m (106.0%)	
BIAS	= +0.13m (6.0%)	
AME	= 0.24m (10.6%)	
RMSE	= 0.32m (14.2%)	
SI	= 0.13 (Unbiased)	
EV	= 0.93	
CC	= 0.97	
PR	= 0.92 (N_p = 1)	

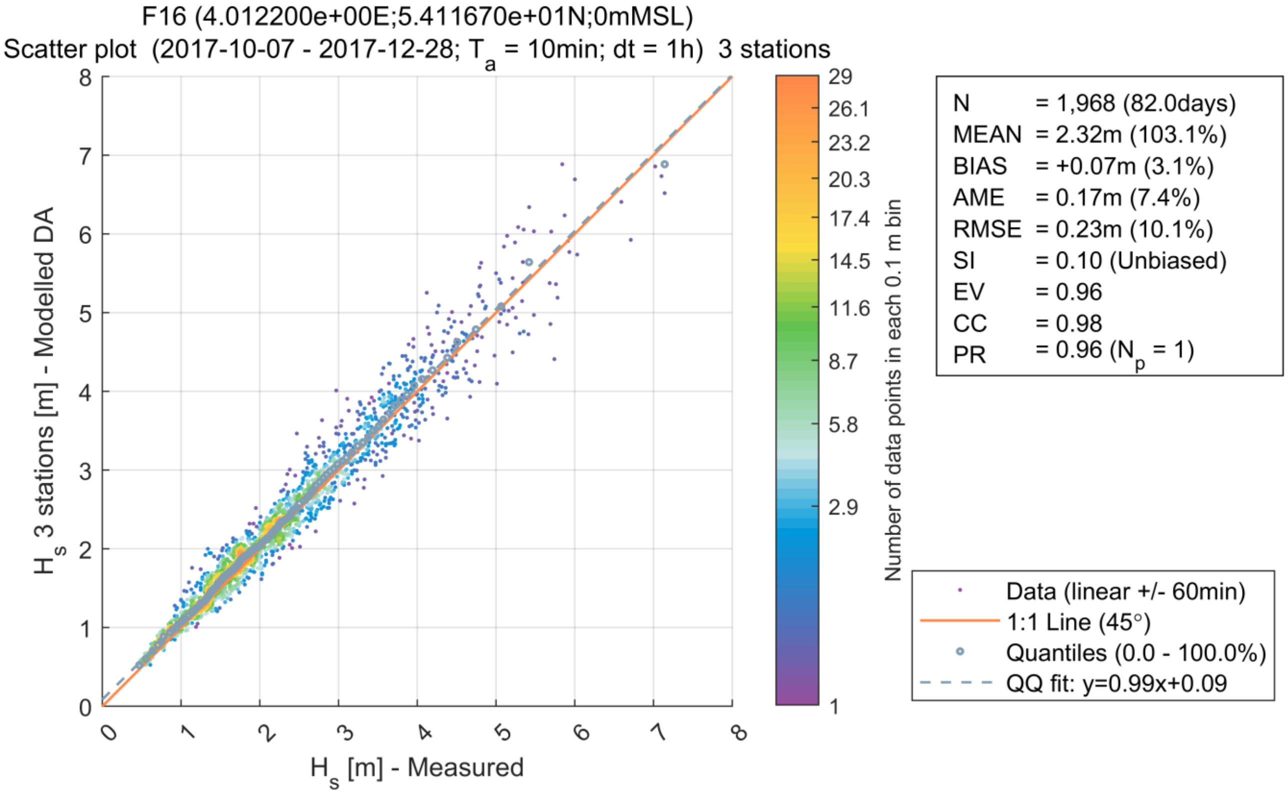


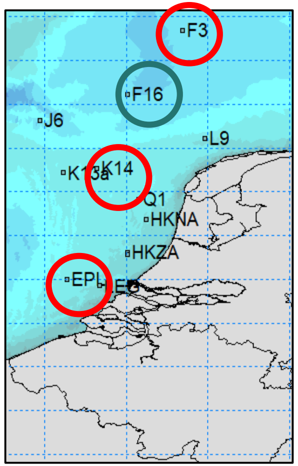
Station F16 – DA with 2 stations



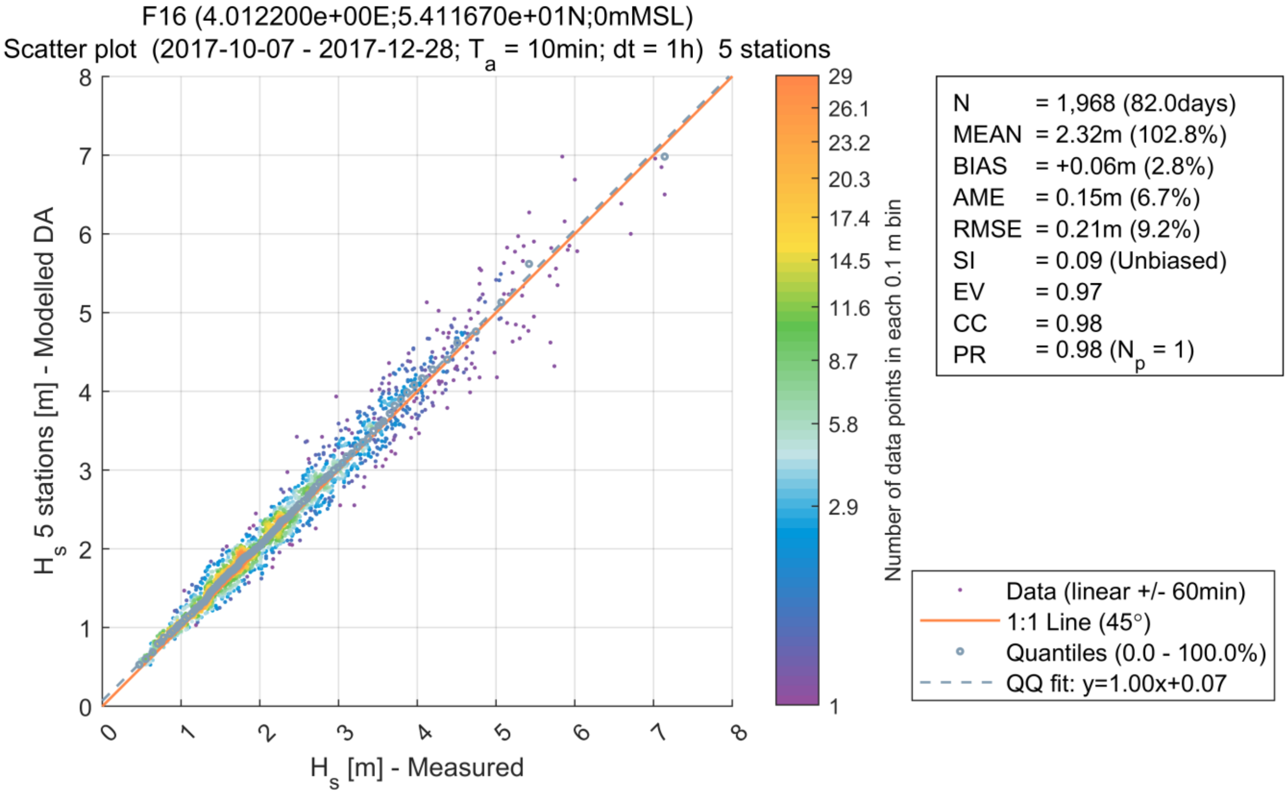


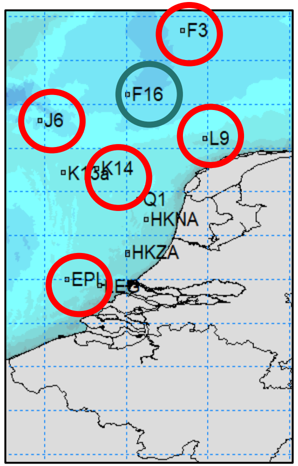
Station F16 – DA with 3 stations





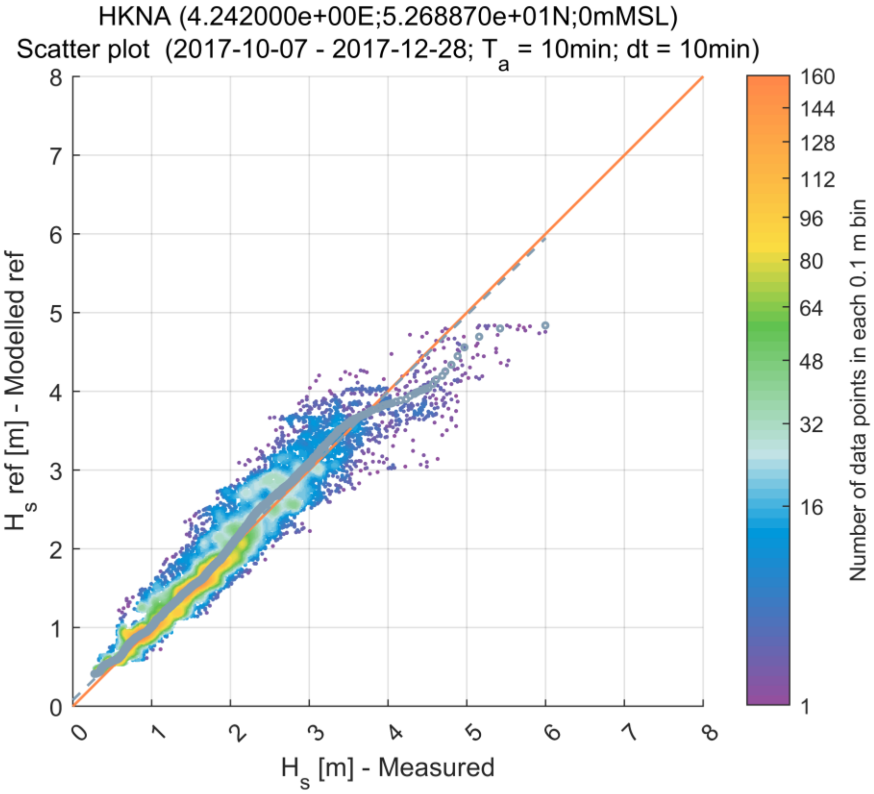
Station F16 – DA with 5 stations





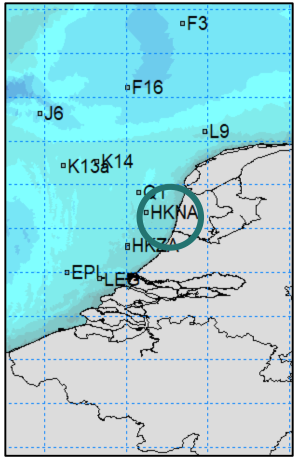
Let’s check another station…

Station HKNA – no DA

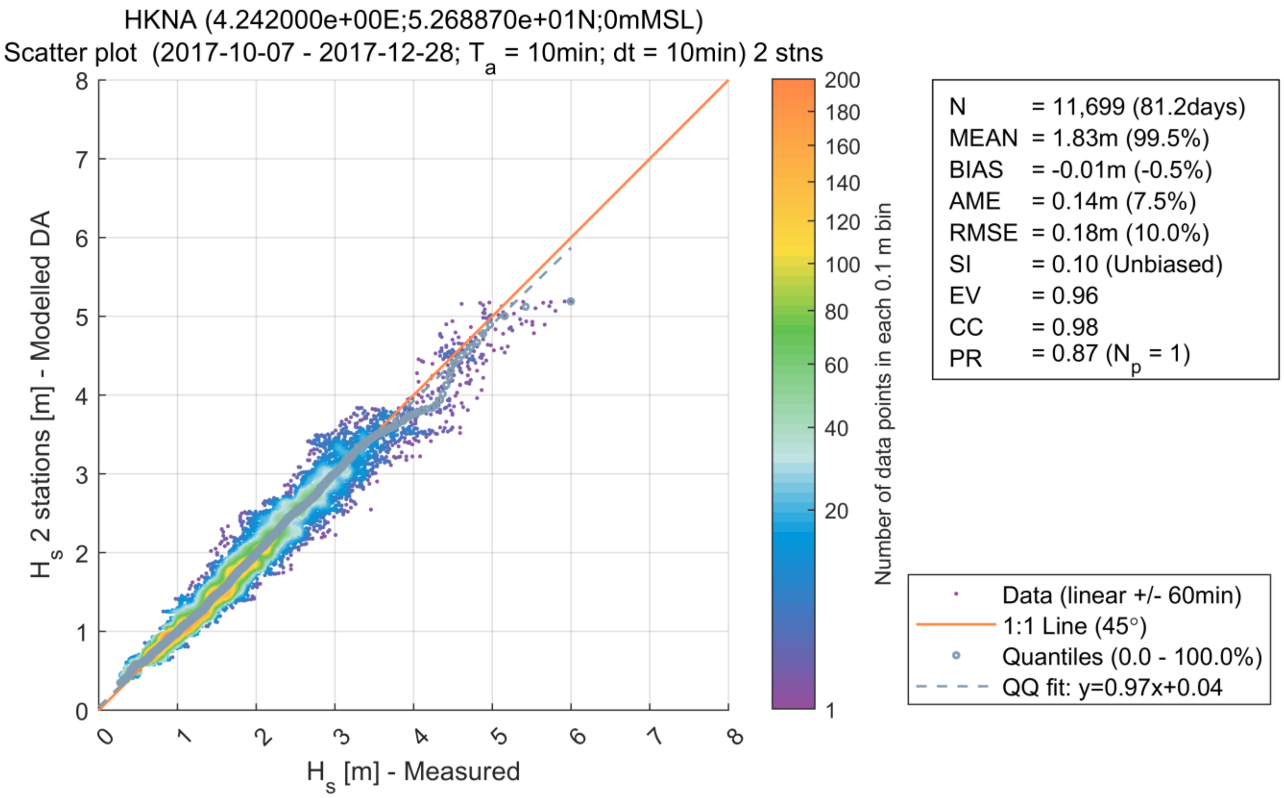


N	= 11,699 (81.2days)
MEAN	= 1.87m (102.2%)
BIAS	= +0.04m (2.2%)
AME	= 0.20m (10.8%)
RMSE	= 0.27m (14.7%)
SI	= 0.15 (Unbiased)
EV	= 0.91
CC	= 0.96
PR	= 0.81 (N_p = 1)

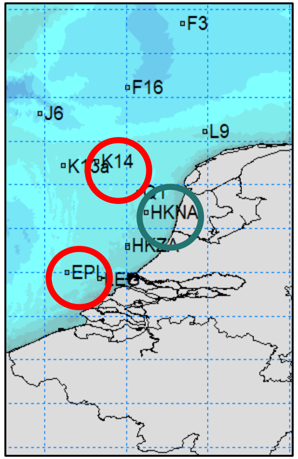
Data (linear +/- 60min)
1:1 Line (45°)
Quantiles (0.0 - 100.0%)
QQ fit: y=0.98x+0.08



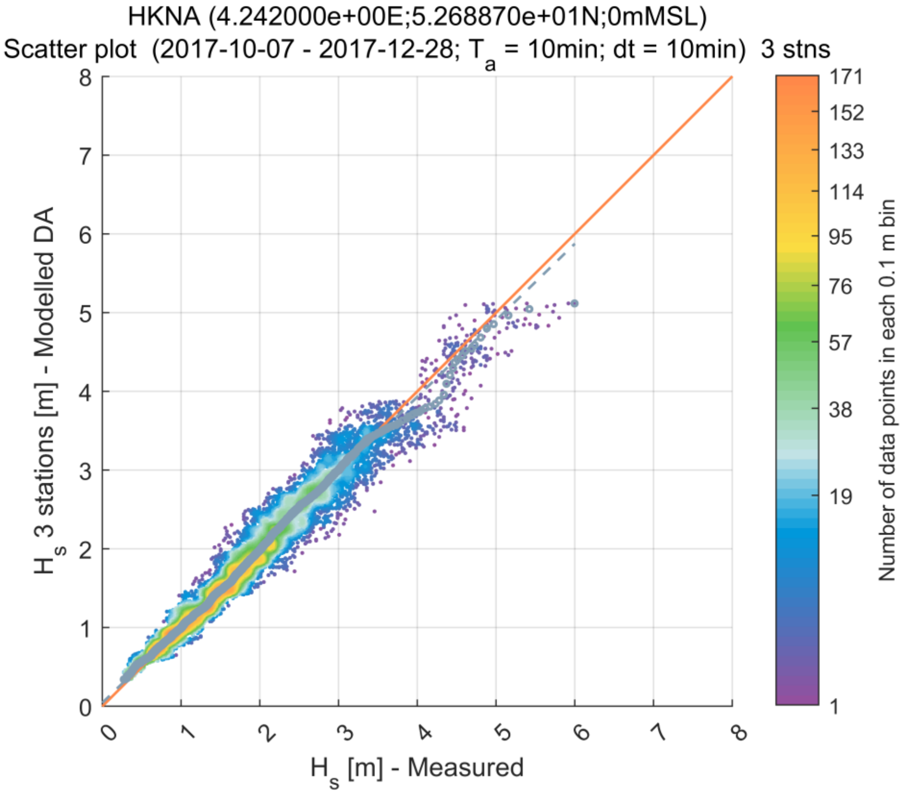
Station HKNA – DA with 2 stations



N = 11,699 (81.2days)
MEAN = 1.83m (99.5%)
BIAS = -0.01m (-0.5%)
AME = 0.14m (7.5%)
RMSE = 0.18m (10.0%)
SI = 0.10 (Unbiased)
EV = 0.96
CC = 0.98
PR = 0.87 (N_p = 1)

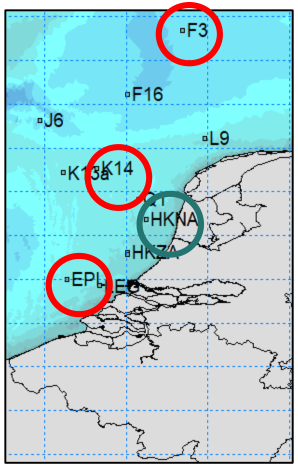


Station HKNA – DA with 3 stations

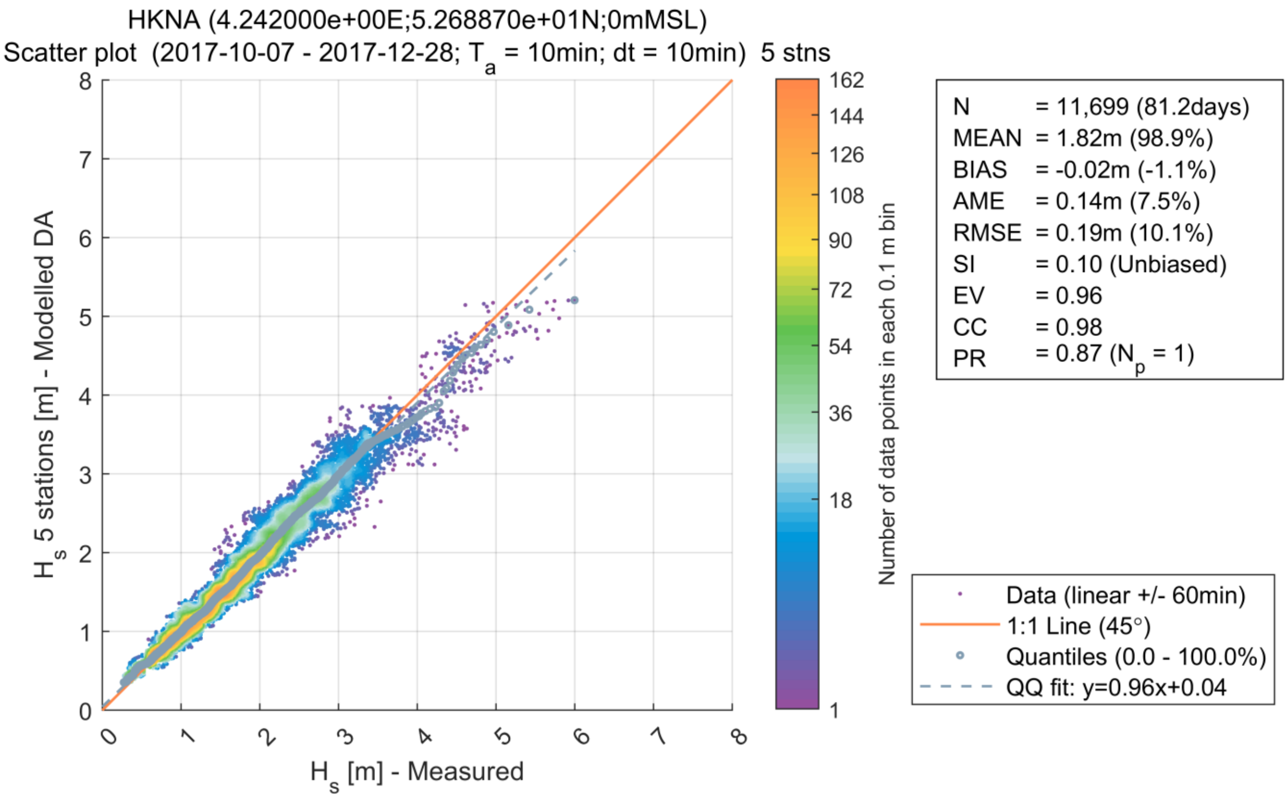


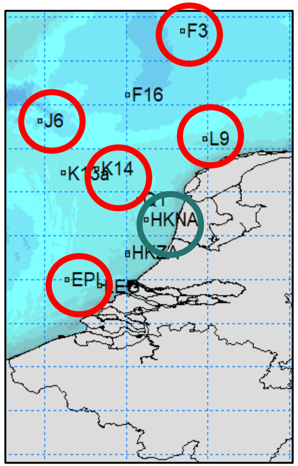
N = 11,699 (81.2days)
MEAN = 1.83m (99.6%)
BIAS = -0.01m (-0.4%)
AME = 0.14m (7.7%)
RMSE = 0.19m (10.4%)
SI = 0.10 (Unbiased)
EV = 0.96
CC = 0.98
PR = 0.85 (N_p = 1)

Data (linear +/- 60min)
1:1 Line (45°)
Quantiles (0.0 - 100.0%)
QQ fit: y=0.97x+0.04



Station HKNA – DA with 5 stations

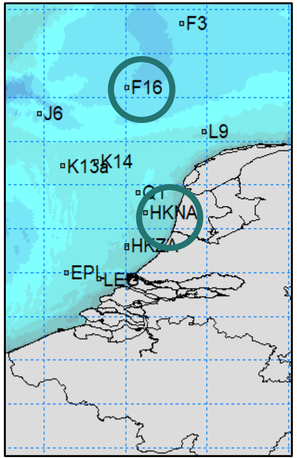




How about other DA parameters

Improvement in Hm0 RMSE

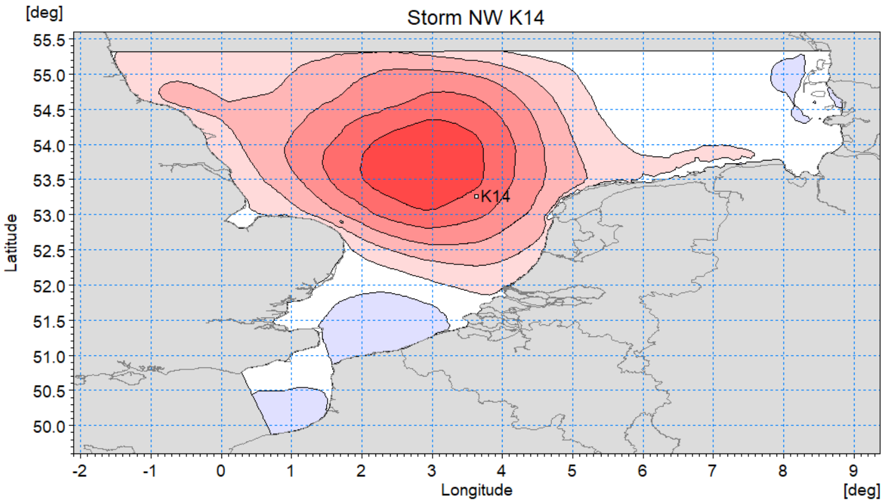
	F16	HKNA
DA Reference (10mem, 3stn, additive 3hour wind)	30.6%	30.0%

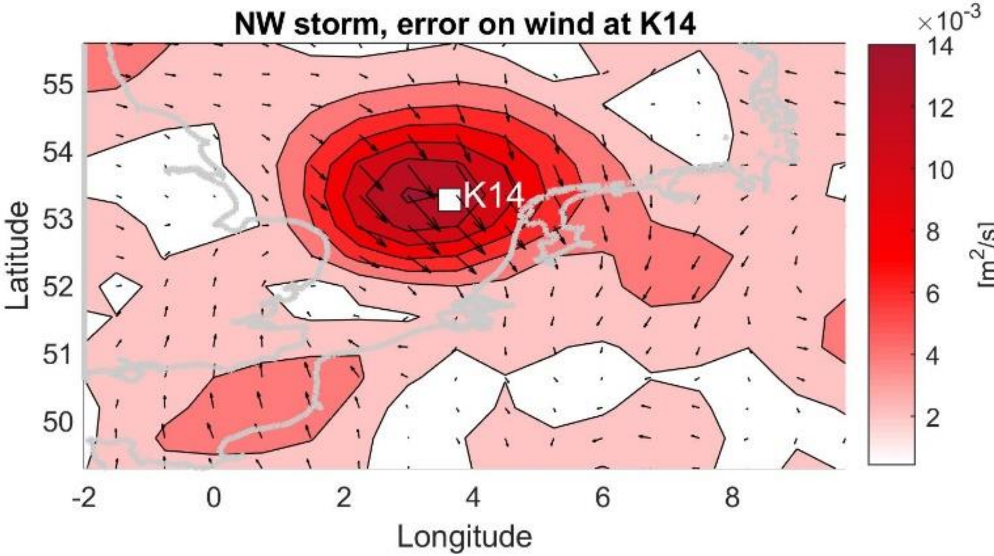


Error covariance

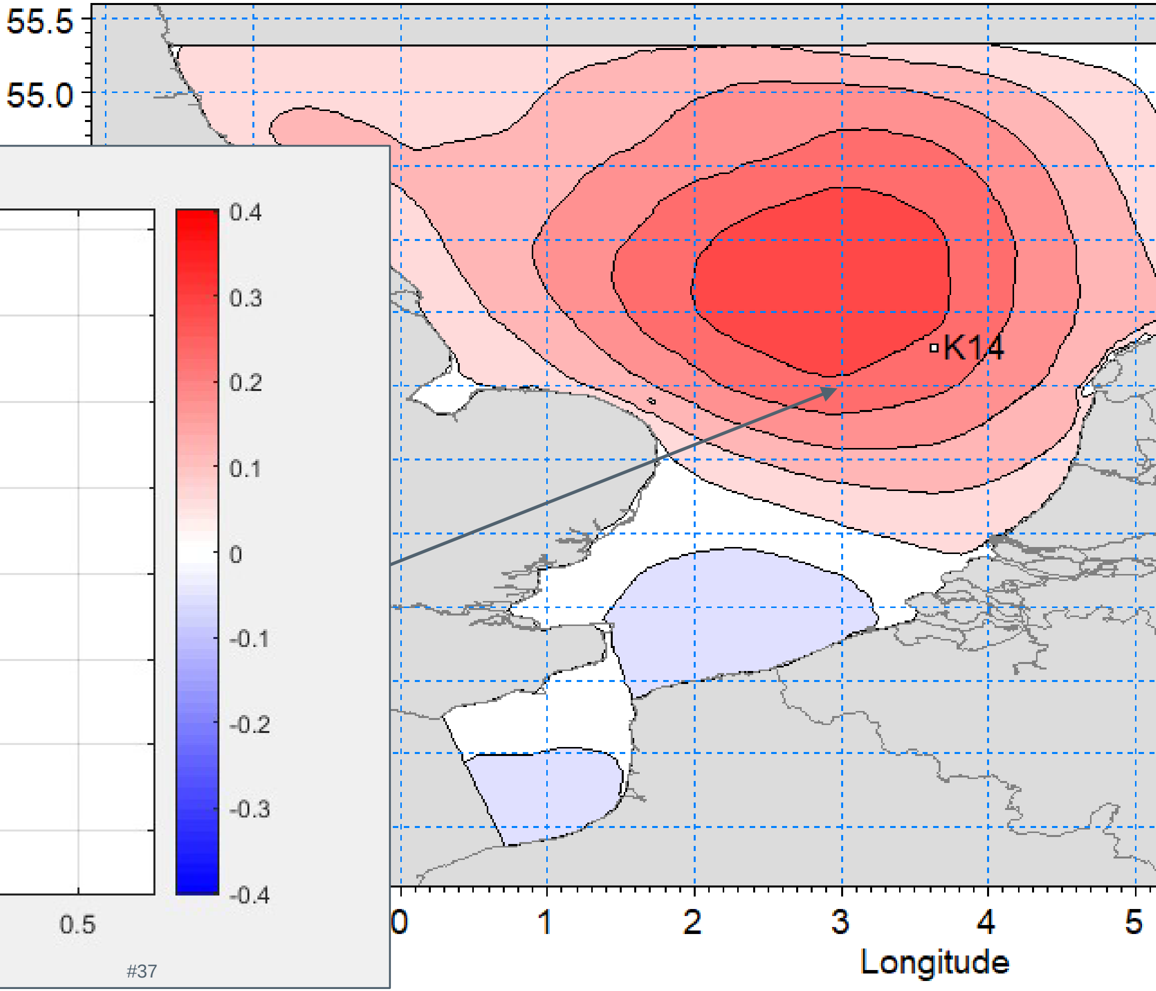
Error covariance

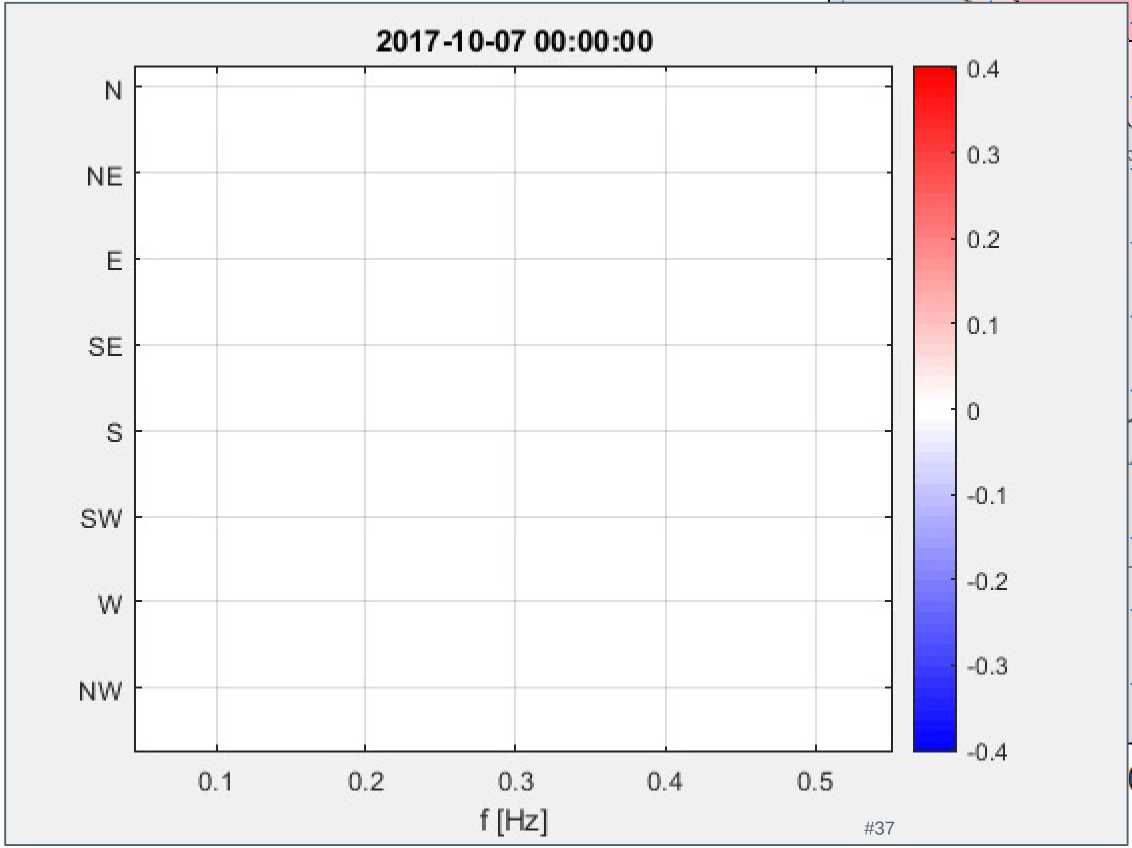
- Covariance of Hm0 with Hm0 in K14 during NW storm





Error covariance





Concluding remarks

Conclusion

- EnKF succesfully implemented for MIKE 21 SW
- Demonstrated on real metocean case
  - Improvement in Hm0 RMSE 30%
  - Not sensible to DA settings
  - More data improves the results
  - Analysis of error covariance suggests that EnKF is a good choice

Next steps

Case study

- Compare to wind measurements
- Parameter errors
- Use lower quality boundary conditions
- Testing of “steady” and EnOI
- Forecasting skill

Development

- Assimilation of wind
- Boundary forcing errors
- Ensemble Kalman Smoother (EnKS)

Questions?

Jesper Sandvig Mariegaard, DHI

Greatfully acknowledging support from NordForsk NCoE EmblA project