Improving Storm Surge Forecasting in the North Sea using Data Assimilation

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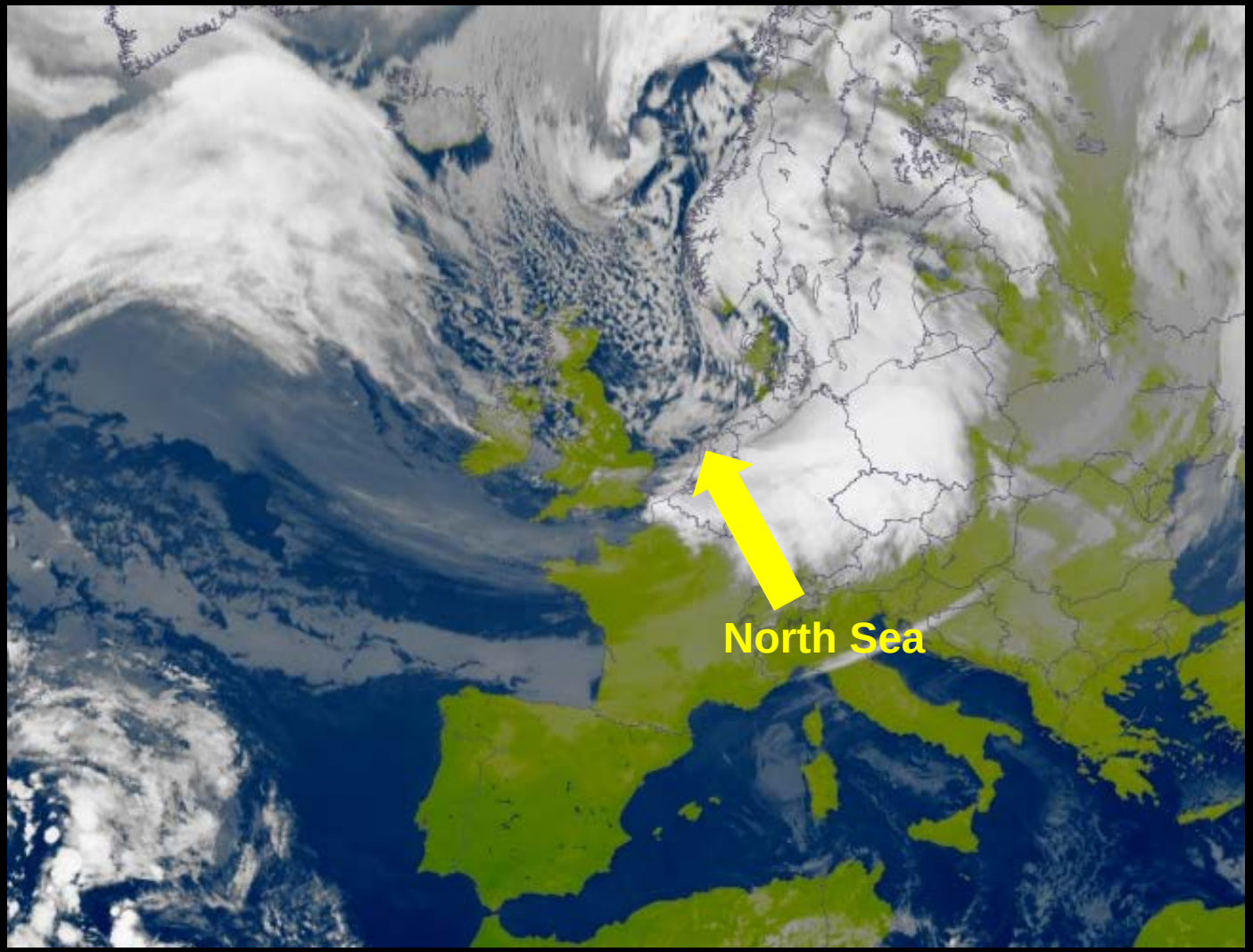

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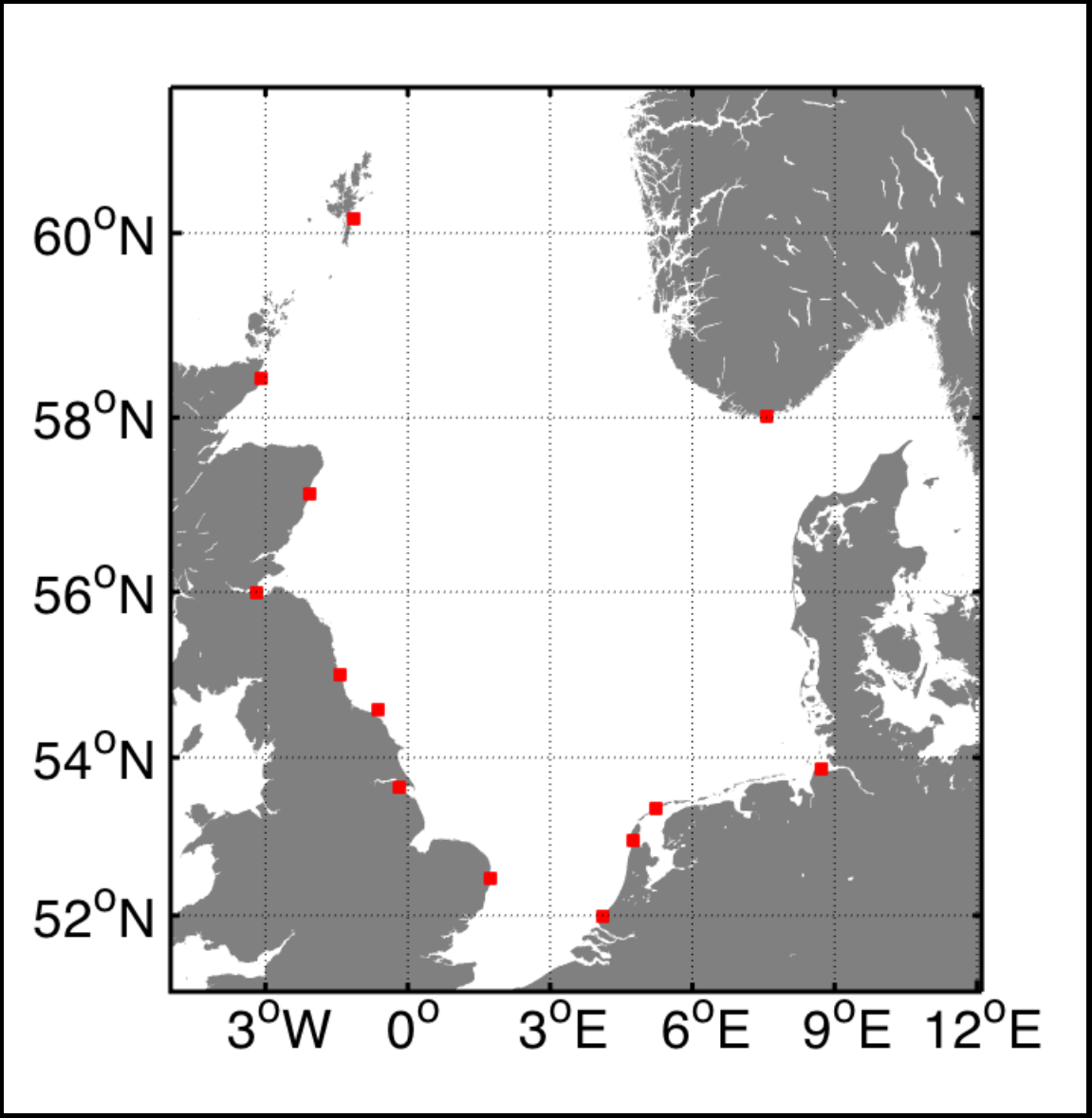
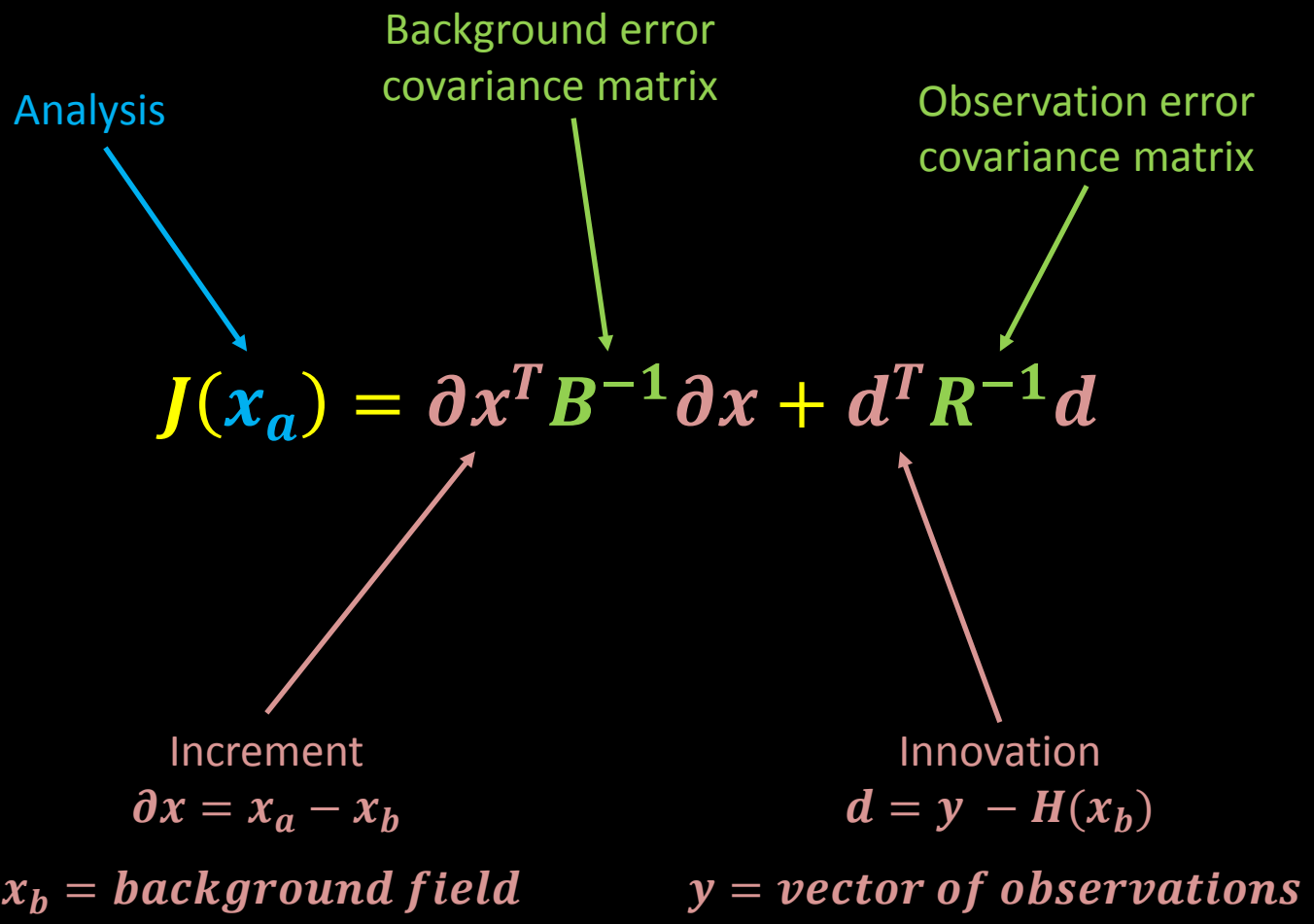
Objective



Assimilate tide gauge observations into an operational storm surge forecasting model (CS3x) and investigate improvement to forecasts.

3DVar Assimilation

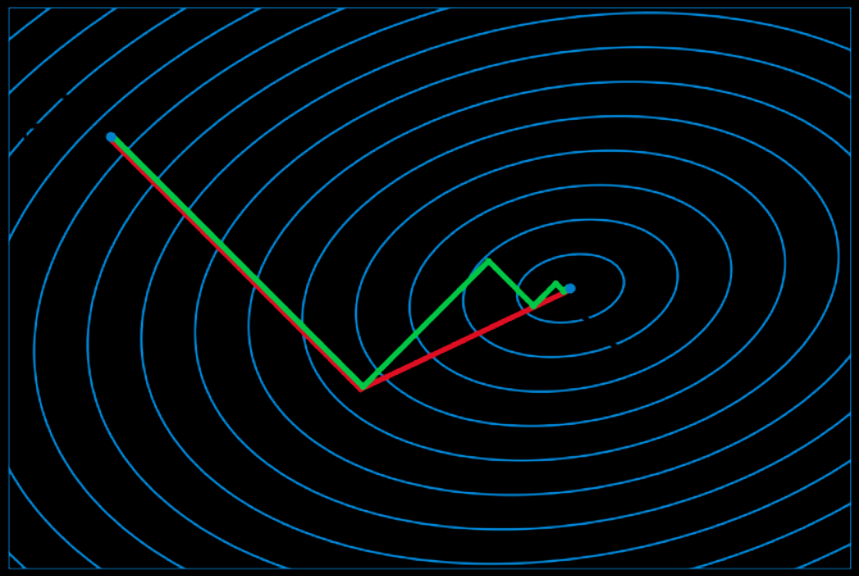


3DVar Assimilation

$$min_{x_a} \; J(x_a) = \partial x^T B^{-1} \partial x + d^T R^{-1} d$$

$$\nabla_{x_a} J(x_a) = 0$$

J is quadratic => can use **Conjugate Gradient Method** for minimization.



x_a 11918 variables

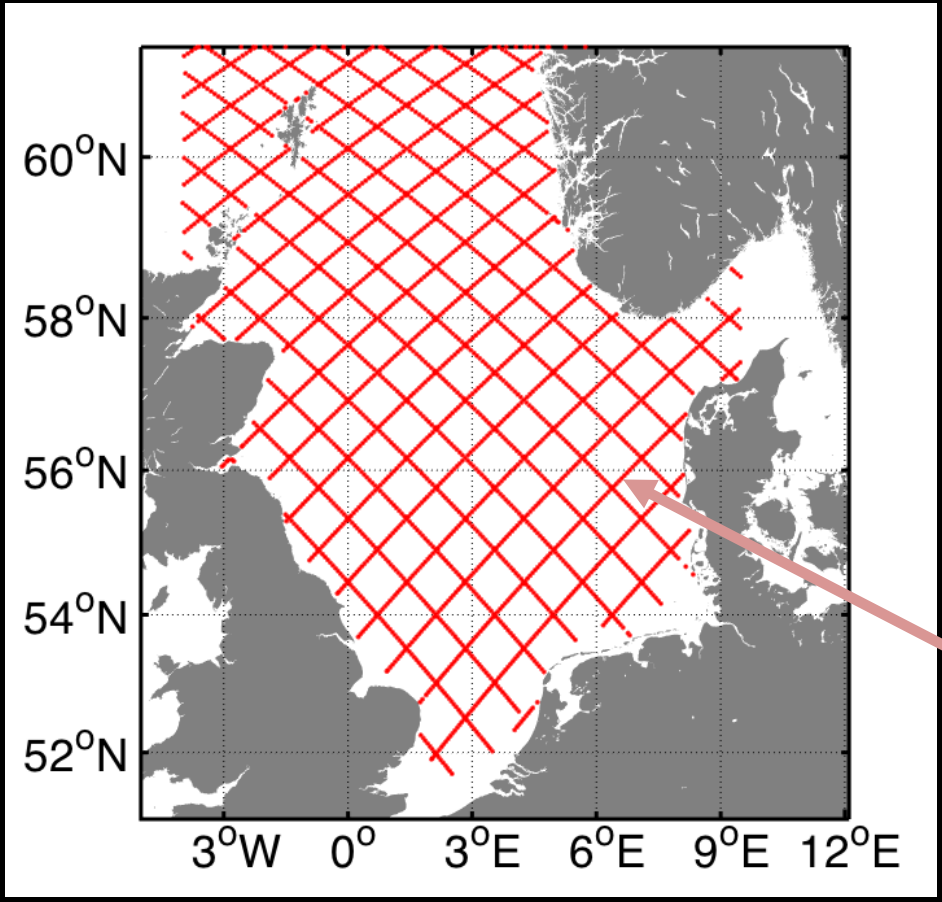
B 11918 x 11918 matrix

R n_obs x n_obs matrix

Estimating B

Use **Innovation Statistics**:

$$innovations = observations - background\ (model)$$



1. Obs spatially uncorrelated
2. Obs & Background uncorrelated

=> Innovation covariance at r > 0 is approximately background error covariance.

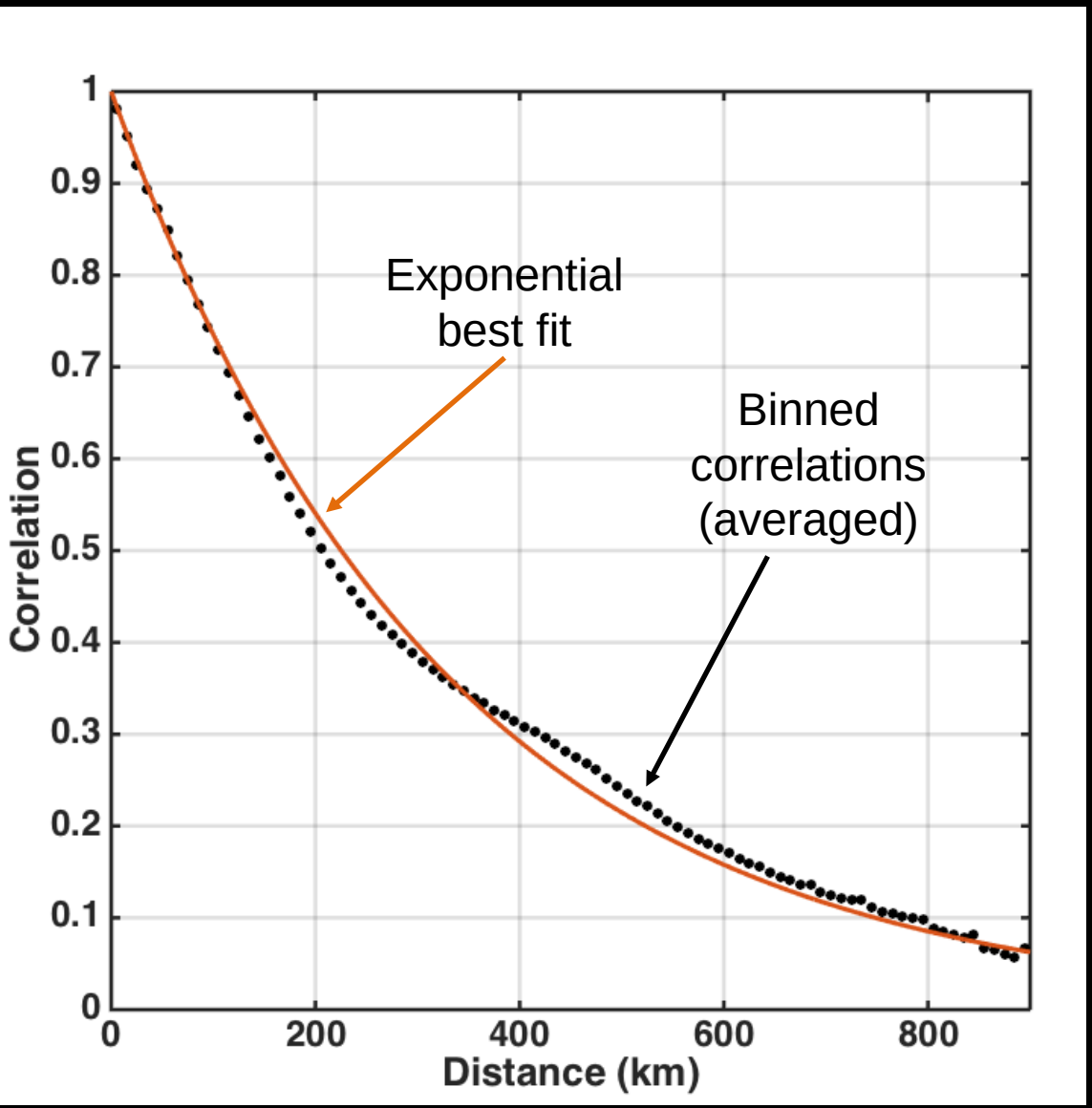
Reconstructed altimetry SSH
[Hoyer et al.] [Madsen et al.]

Estimating B

Parameterize correlations/covariance assuming

- Homogeneity (unchanging in space)
- Isotropic (correlation independent of direction)
- Time-independent.

Estimating B - Correlations



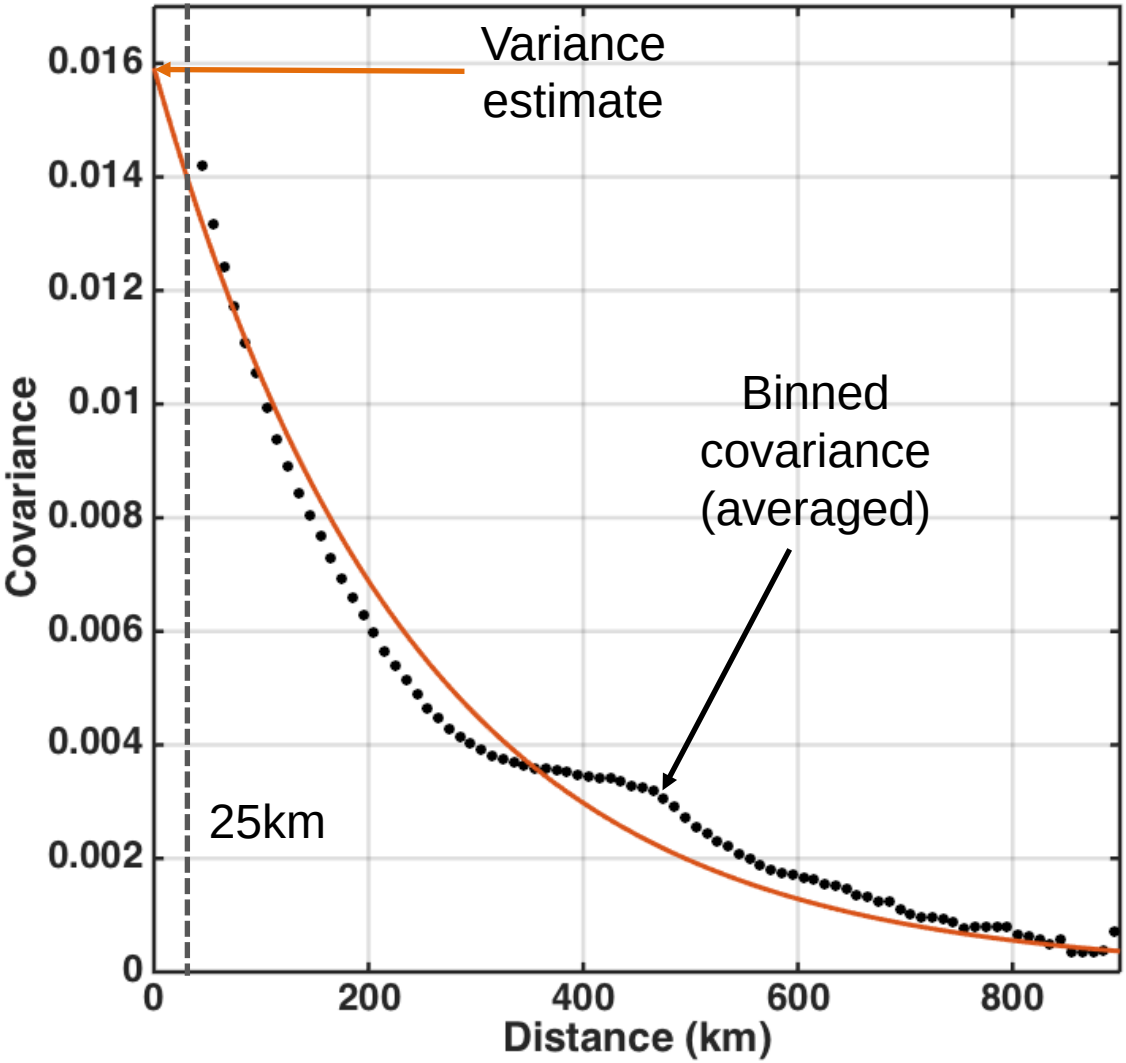
Function Criteria:

1. Generate positive definite correlation matrix.
2. Must equal 1 at zero distance.
3. Tends to 0 as distance goes to infinity.

Powered Exponential:

$$e^{-bx^t}$$

Estimating B - Variance



Powered Exponential:

$$ae^{-bx^t}$$

Background error variance estimate:

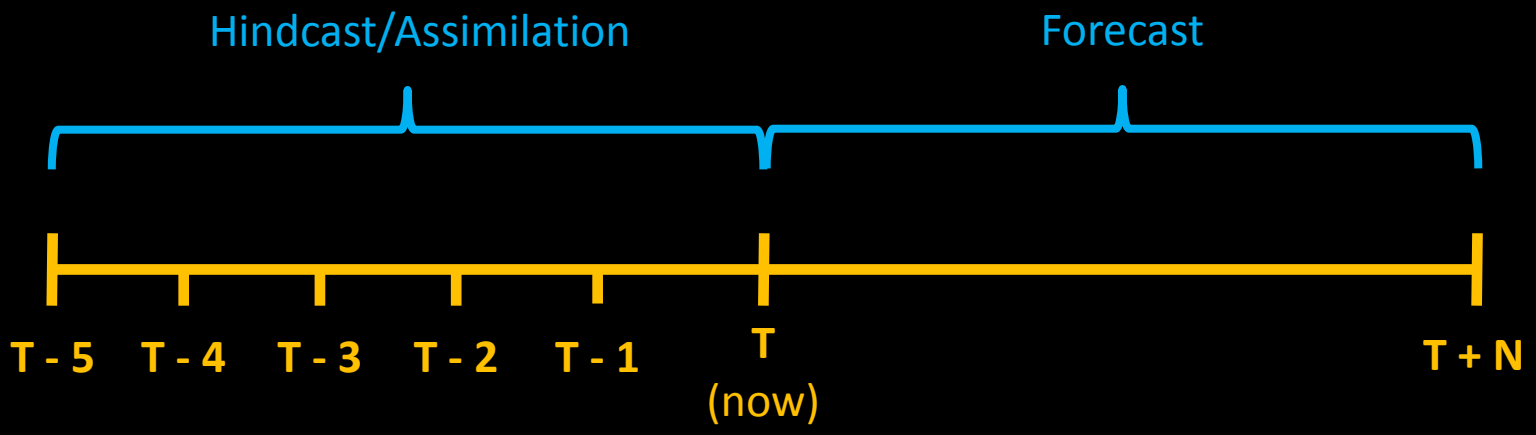
0.016

Estimating R

- White noise observation errors. No spatial correlation (R is diagonal).
- Use high pass filter on 1 year of observations.
- Use this to estimate variance of observation errors:

Var = 0.0001
S.D = 0.01m

Assimilation Procedure



1. Subtract mean sea level (19 years of data from PSMSL) from tide gauge observations.

2. Tide gauges assumed located at nearest model grid cell.

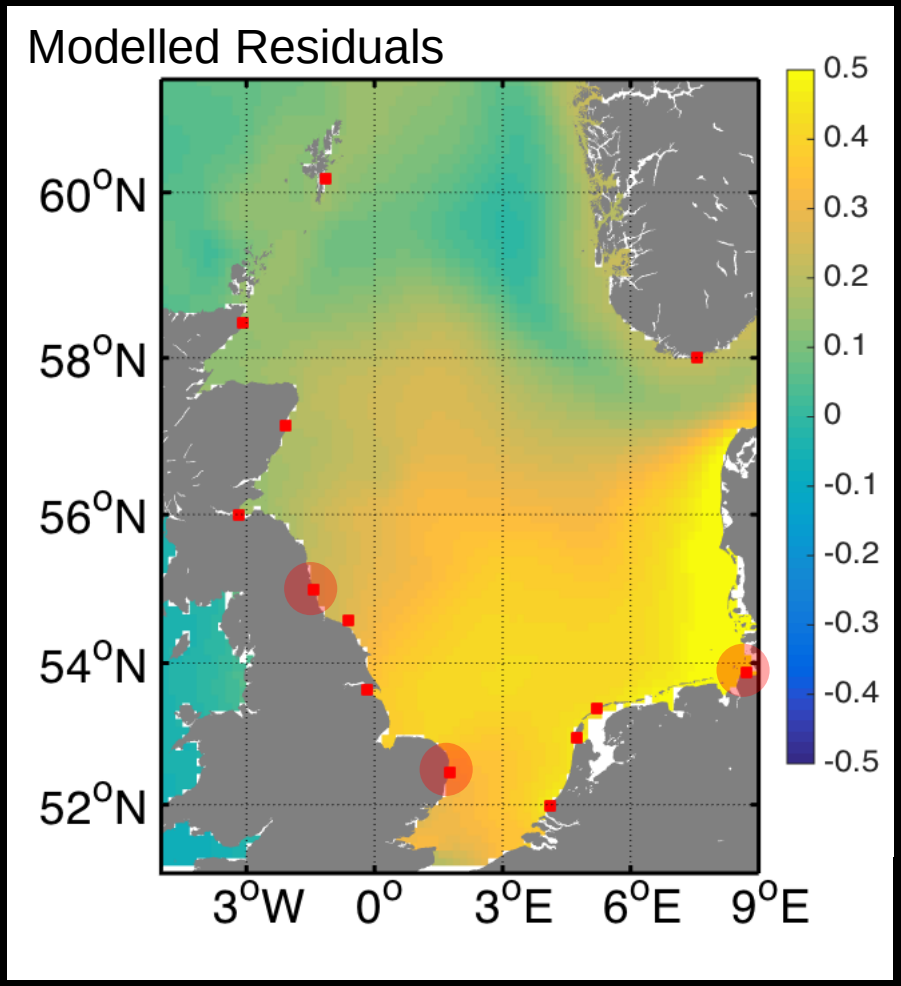
3. Assimilate once an hour for 6 hours.

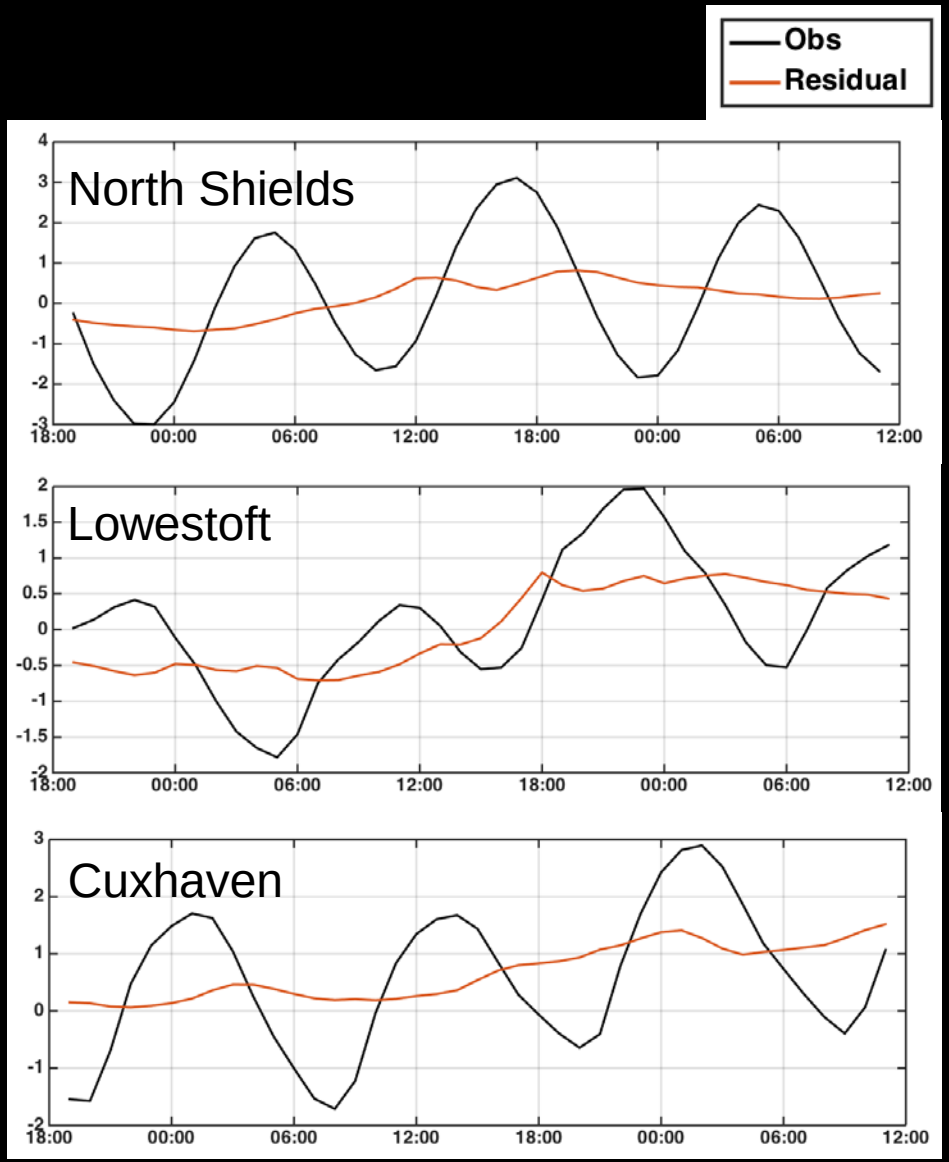
Model Experiments

Two stormy periods during January 2005

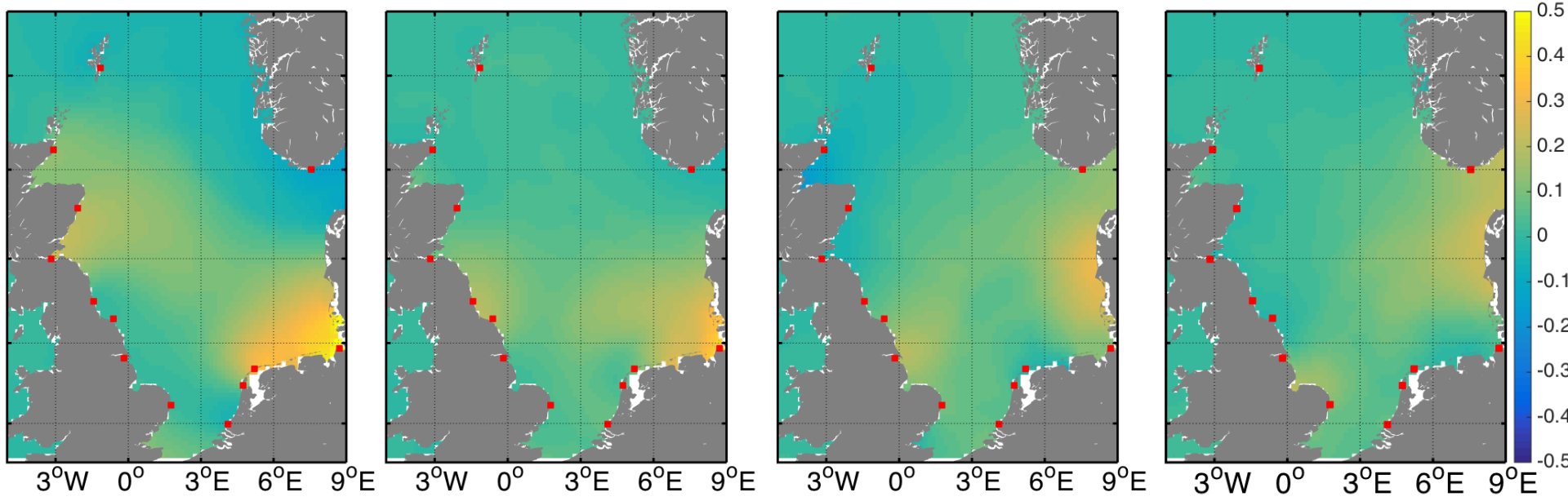
CS3X: Storm surge model used operationally for the UK.

13/01/2005


Modelled Residuals
60°N
58°N
56°N
54°N
52°N
3°W
0°
3°E
6°E
9°E
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5

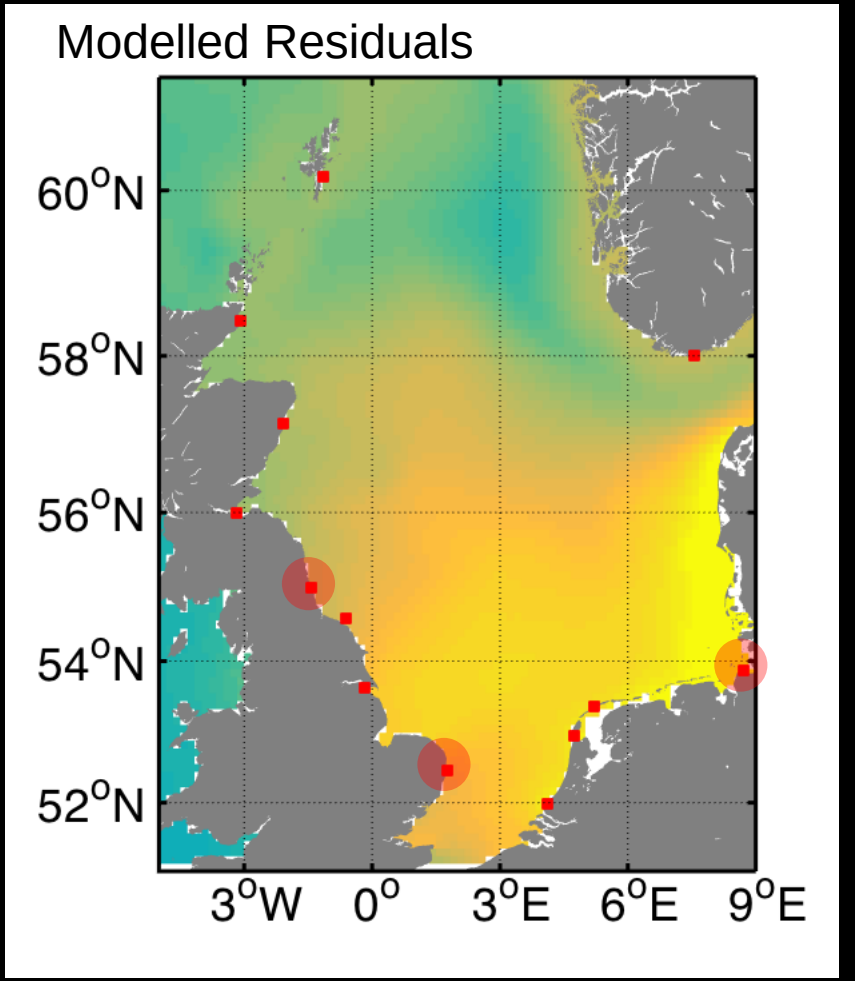

Obs
Residual
North Shields
Lowestoft
Cuxhaven
18:00
00:00
06:00
12:00

13/01/2005
TWL difference from control

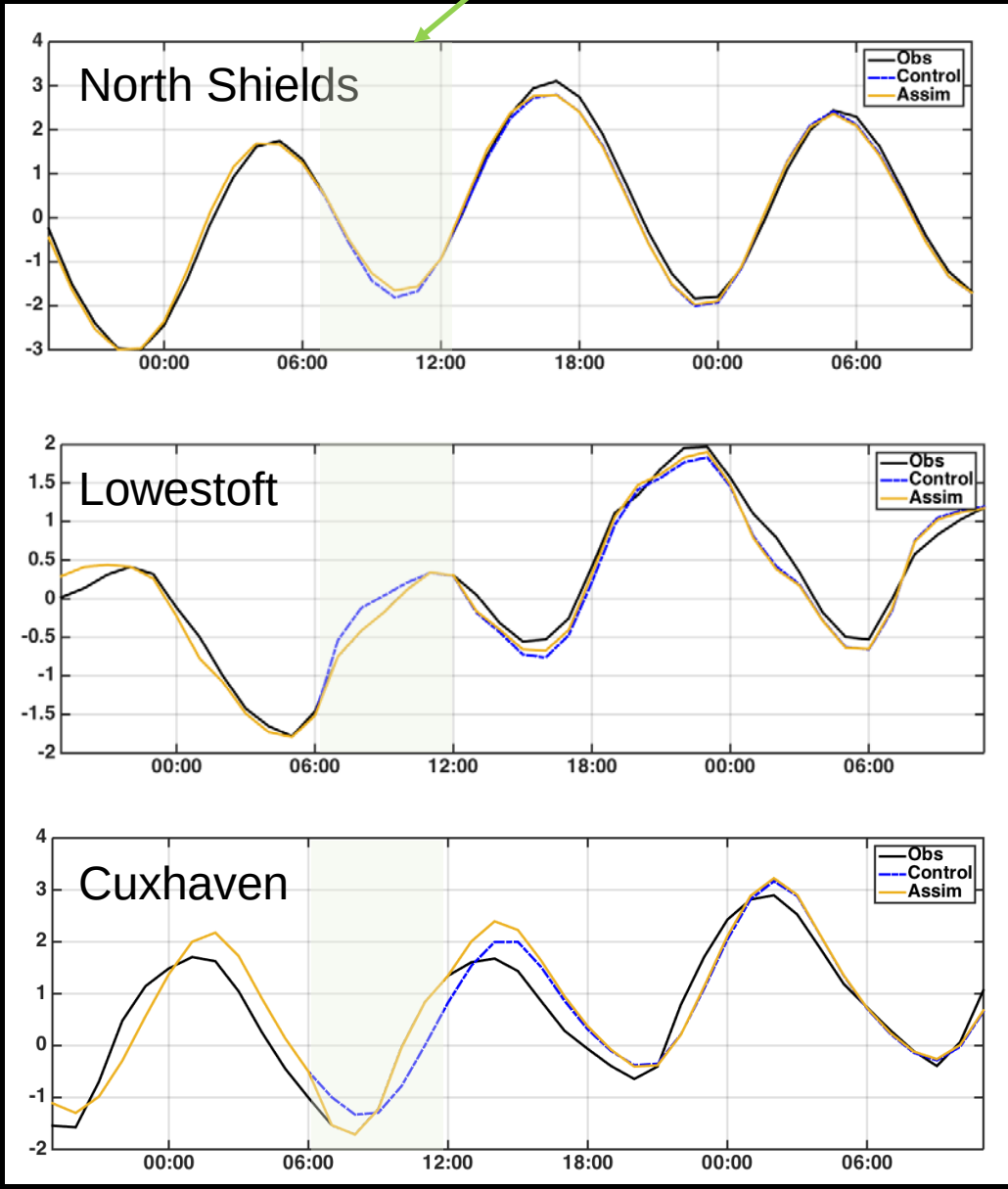


T T+2 T+4 T+6

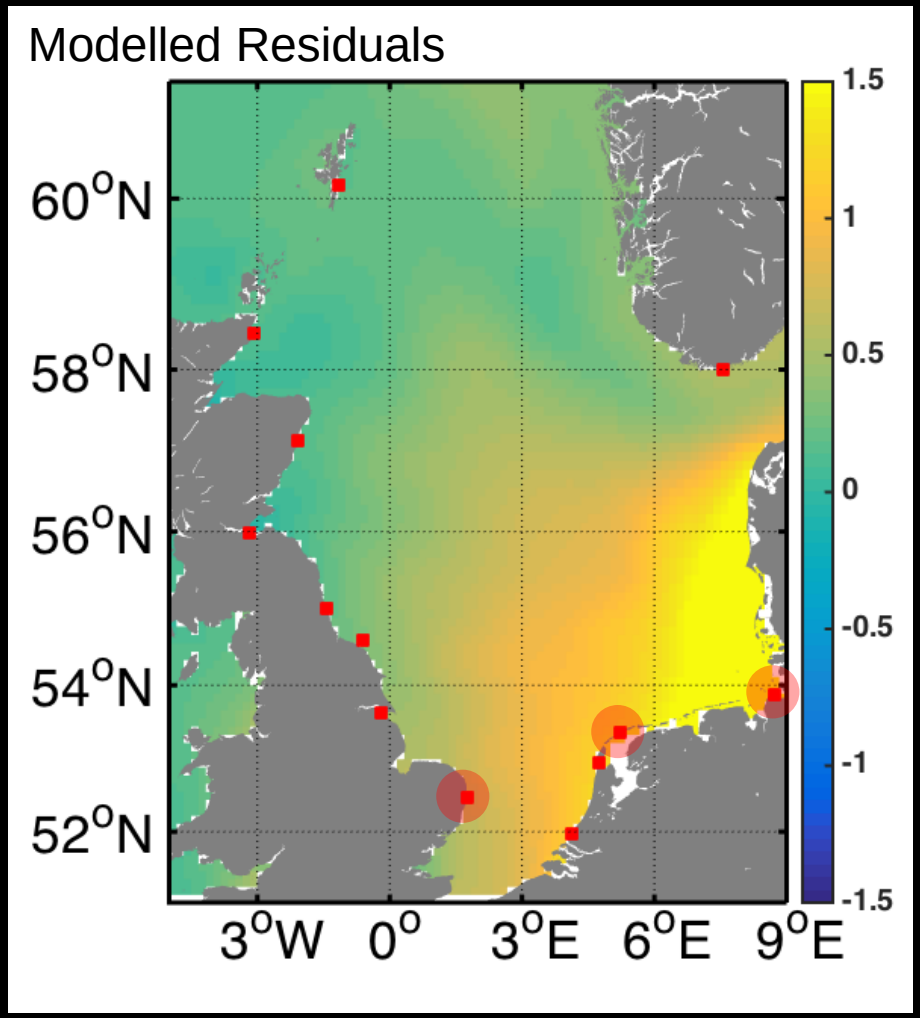
13/01/2005

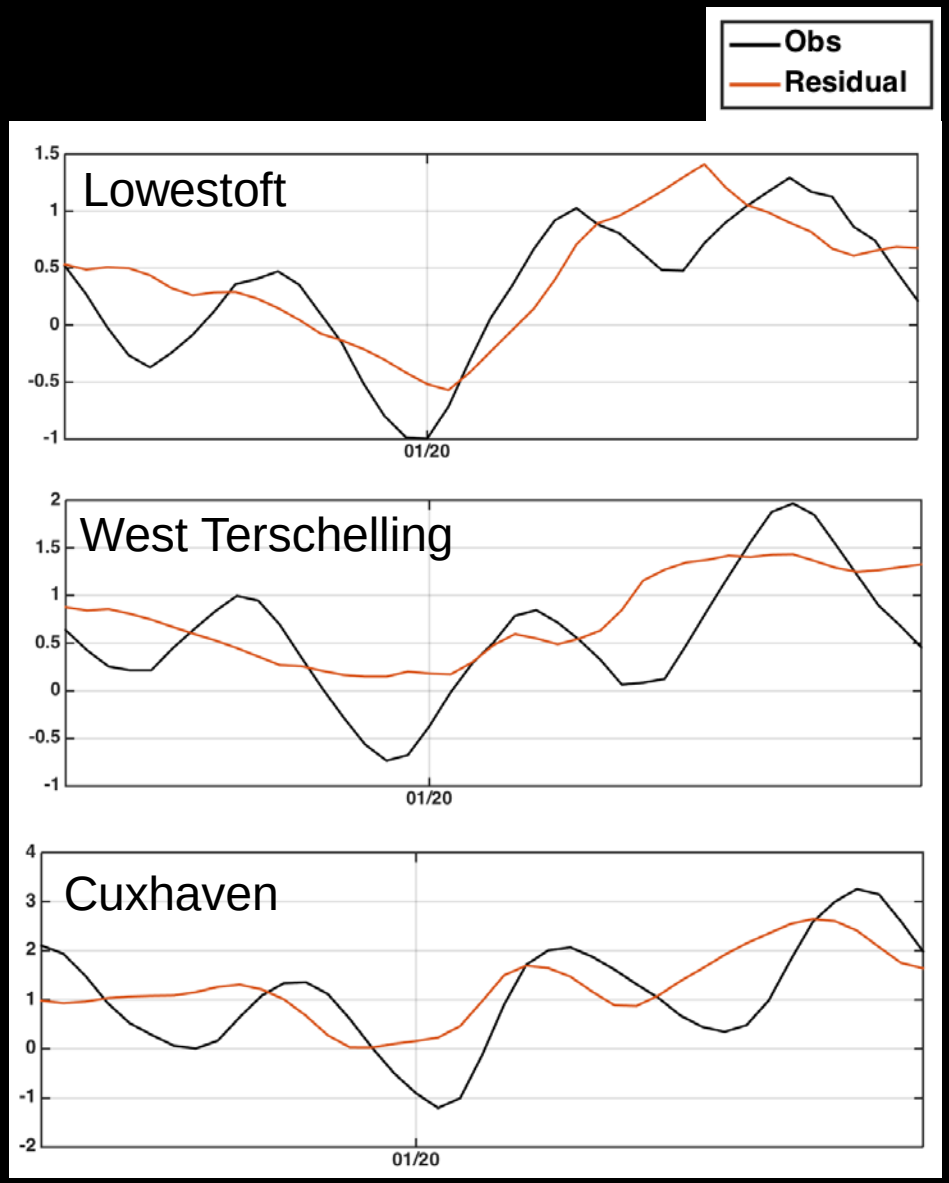


Assimilation period

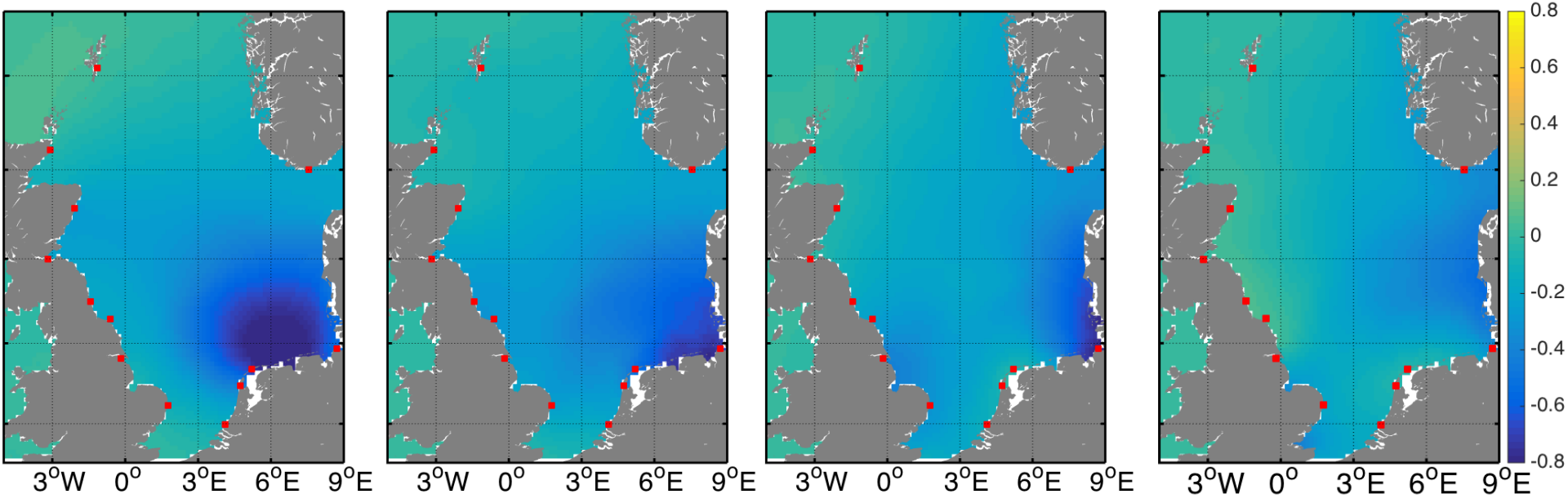


20/01/2005


Modelled Residuals
60°N
58°N
56°N
54°N
52°N
3°W
0°
3°E
6°E
9°E
1.5
1
0.5
0
-0.5
-1
-1.5


Obs
Residual
Lowestoft
West Terschelling
Cuxhaven
01/20
01/20
01/20

20/01/2005
TWL difference from control



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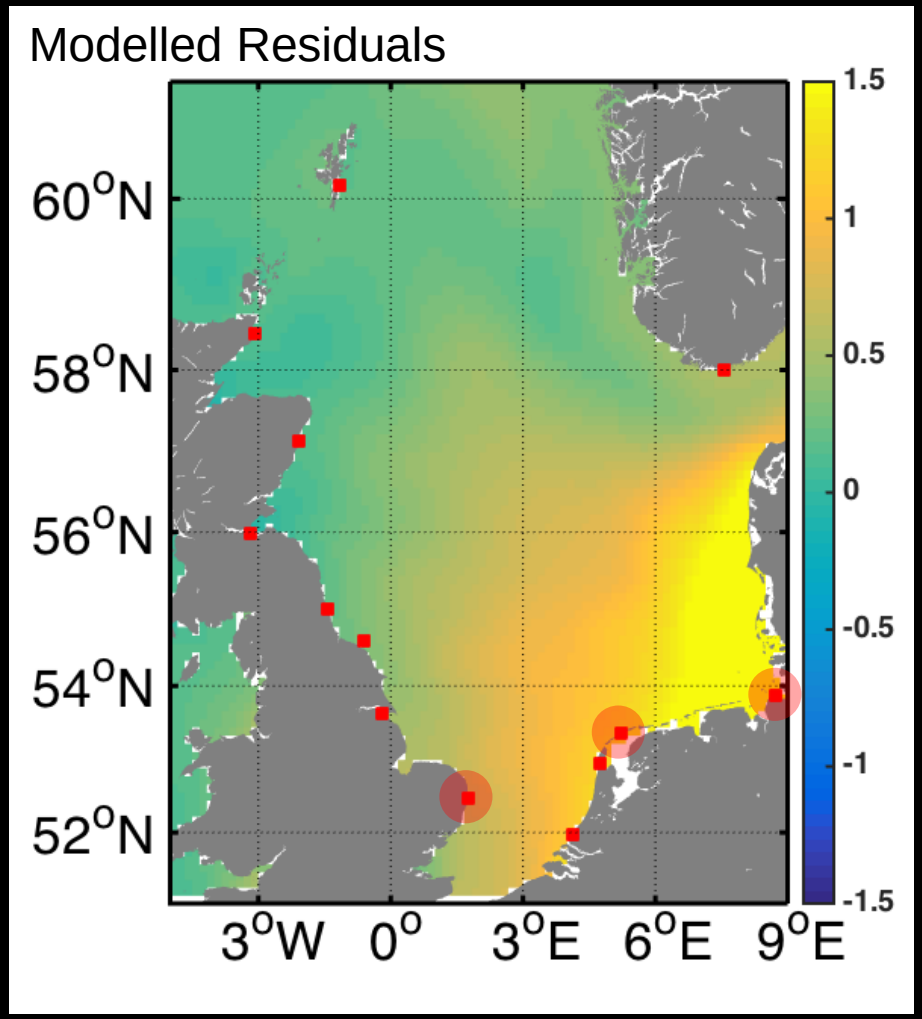
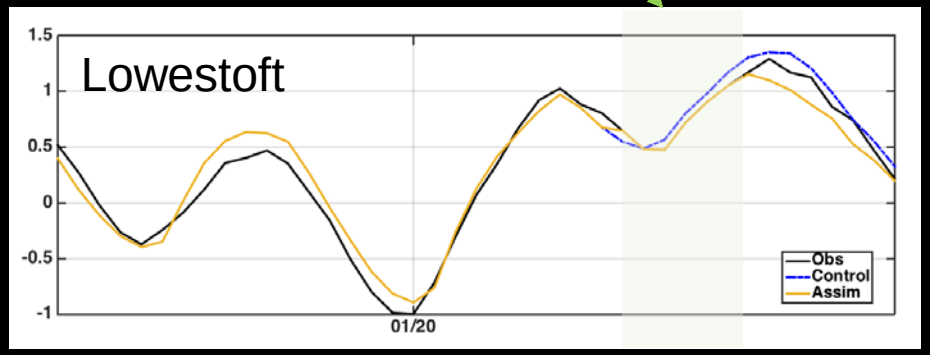
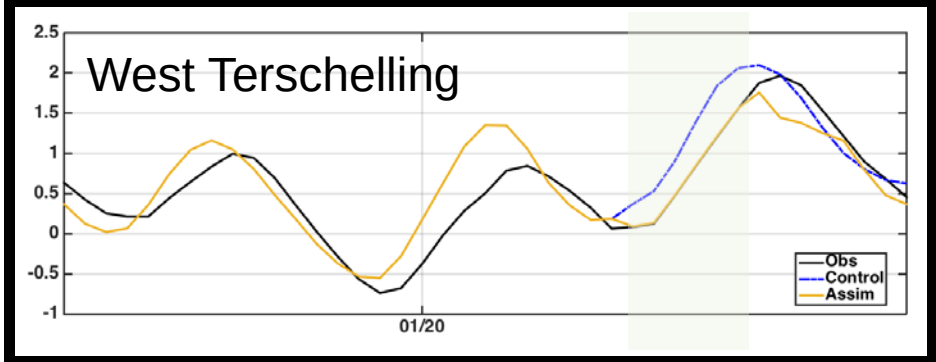
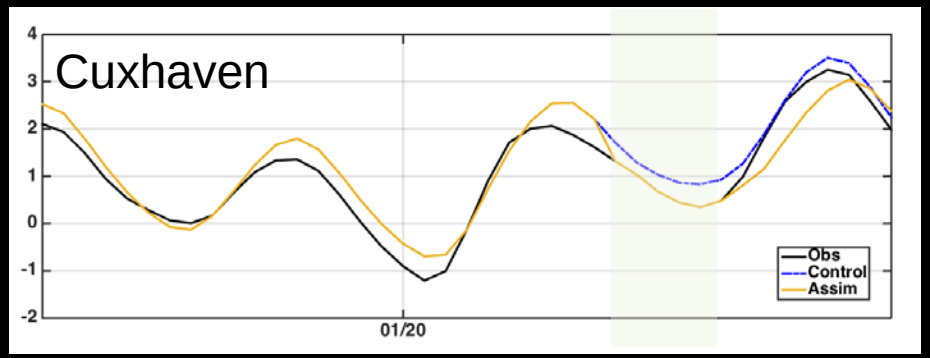


Assimilation period







Conclusions & Future Work

- Changes due to assimilation don't last long, therefore limited utility for forecasting.
- Model SSH is strongly influenced by atmospheric surface forcing and tidal boundary forcing.
- No real benefits seen due to this assimilation setup.
- Control model (CS3x) performed well anyway for chosen time periods.

- Look at better estimation of covariance matrices (anisotropy, inhomogeneity).
- Run more significant surge events (e.g. Winter 2013).
- Find events where model performed less well.

Summary

- Used 3DVar to assimilate tide gauge SSH observations into North Sea of CS3 Model.
- Generated correlations using homogeneous, isotropic 2D function.
- Performed assimilation experiments for two events in January 2005.
- Assimilated time series converge back to control time series within approximately 8 hours.
- Little benefit to TWL forecasting at the locations studied.

References

J. Hoyer and O. Andersen, Improved description of sea level in the North Sea, *J. Geophys. Res*, **105**, 2003

K.Madsen et al.,Blending of satellite and tide gauge sea level observations and its assimilation in a storm surge model of the North Sea and Baltic Sea, *J. Geophys. Res*, **120**, 2015