Storm surge model sensitivity to uncertain inputs

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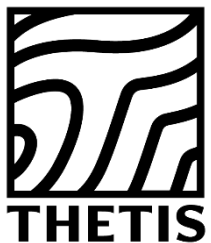
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Thetis coastal ocean model

- ***Thetis***: an adjoint-capable finite element coastal ocean model

- Implemented within Firedrake finite element framework

- Pyadjoint for adjoint code generation

- P1DG-P1DG finite element pair and Crank-Nicolson timestepper (others available)
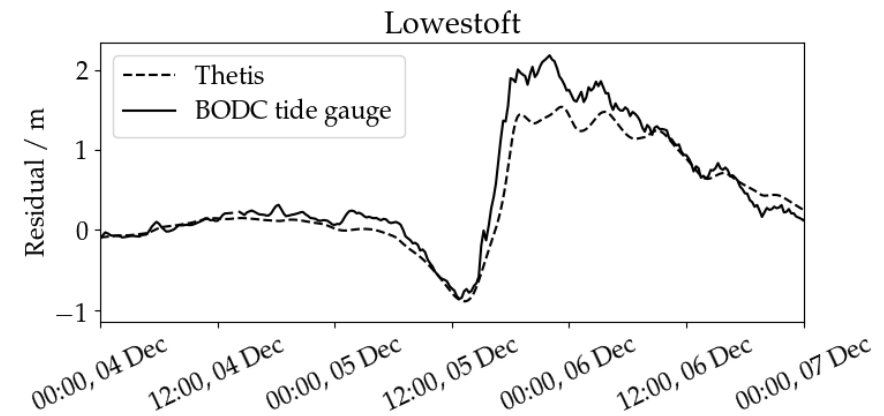
Thetis-2D has been used for:

Tides

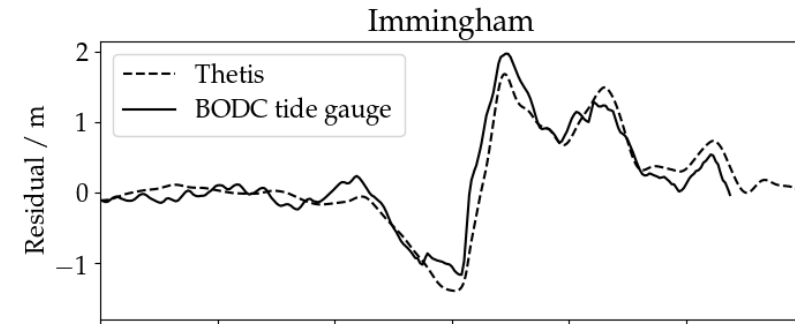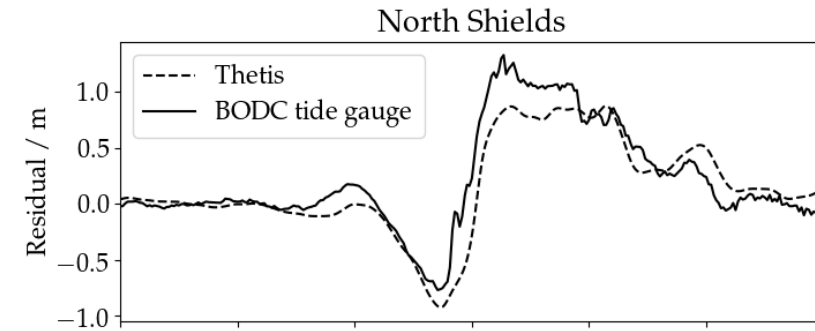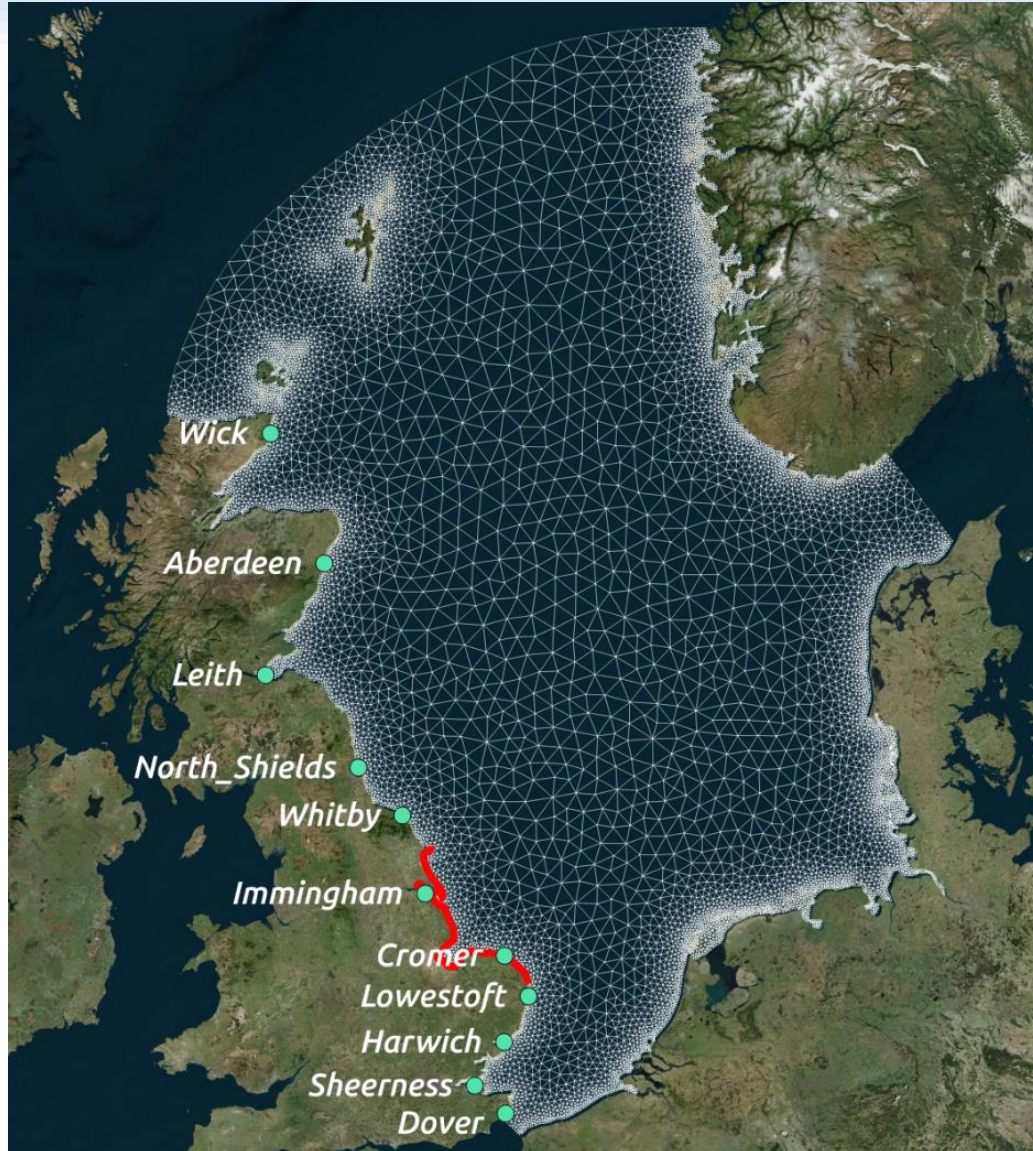Storm surge

Tsunami

Inundation

Tidal energy

# Thetis model setup: North Sea

- What are the spatial and temporal patterns of storm surge model sensitivity to its uncertain inputs?
    - Bathymetry
    - Bottom friction coefficient
    - Wind stress

- What are the similarities/differences between the sensitivities of model outputs at different locations?

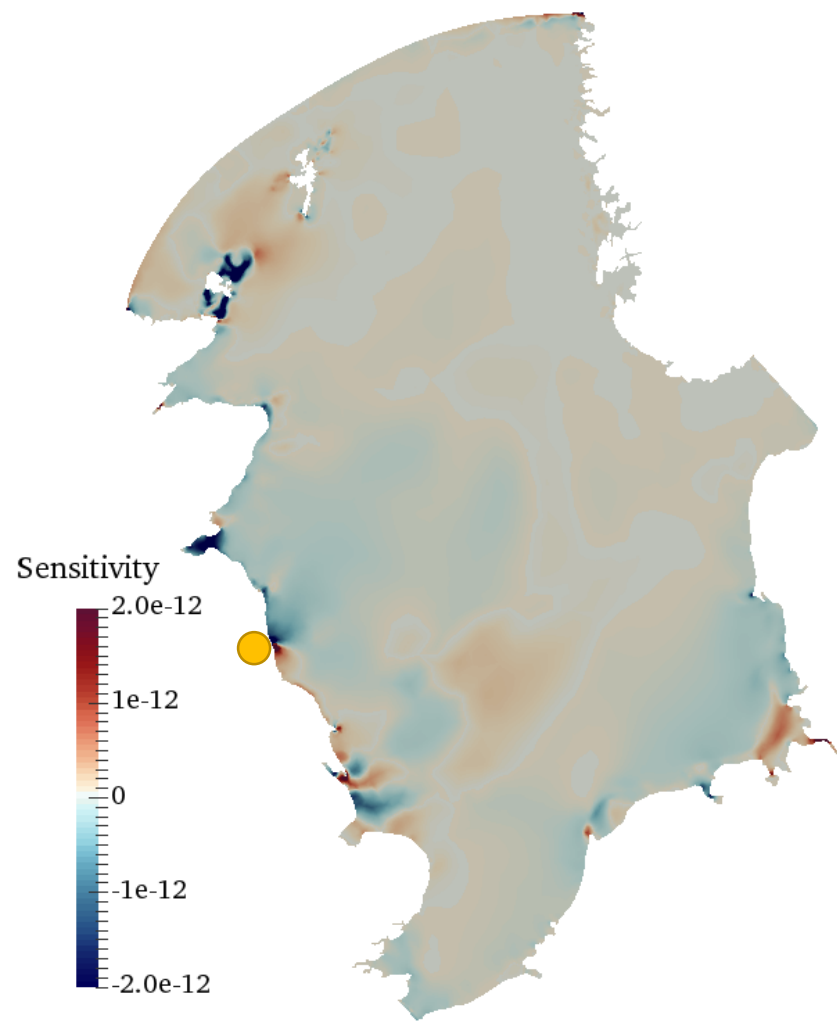- Can we compare the magnitudes of sensitivity to each of these inputs?

Adjoint methods

- Provide different information to ensemble-based methods
- Insightful, computationally efficient
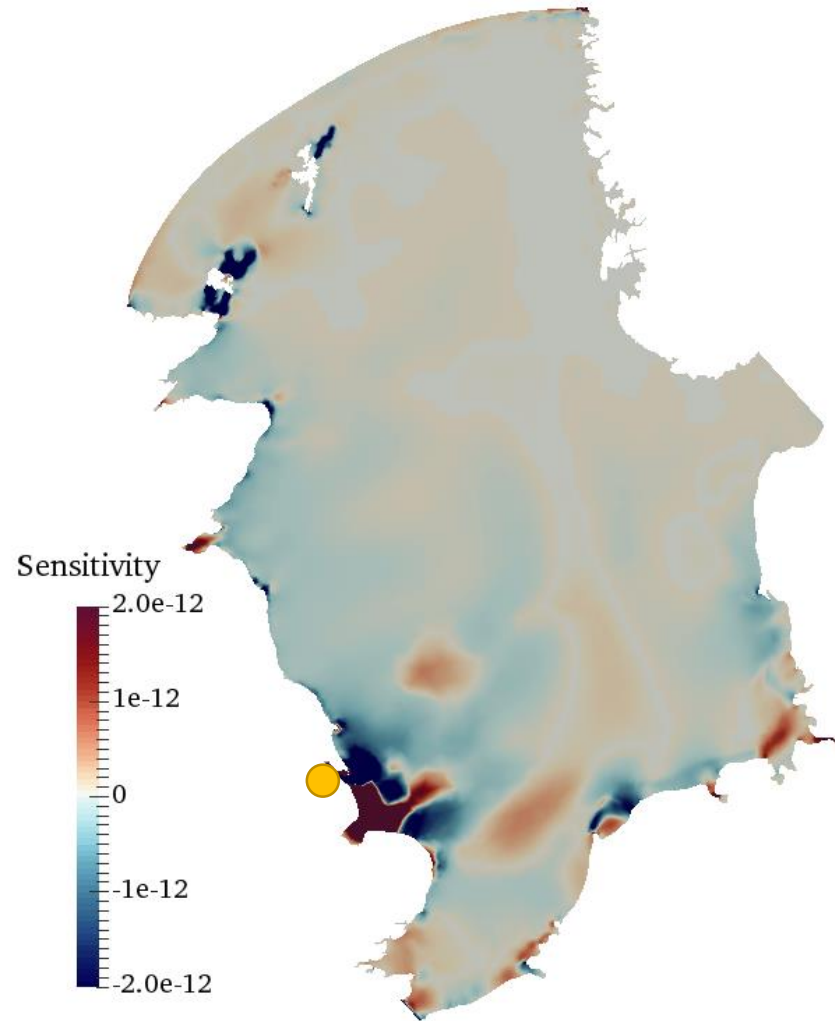- Functional J is the peak residual at a given 'target'
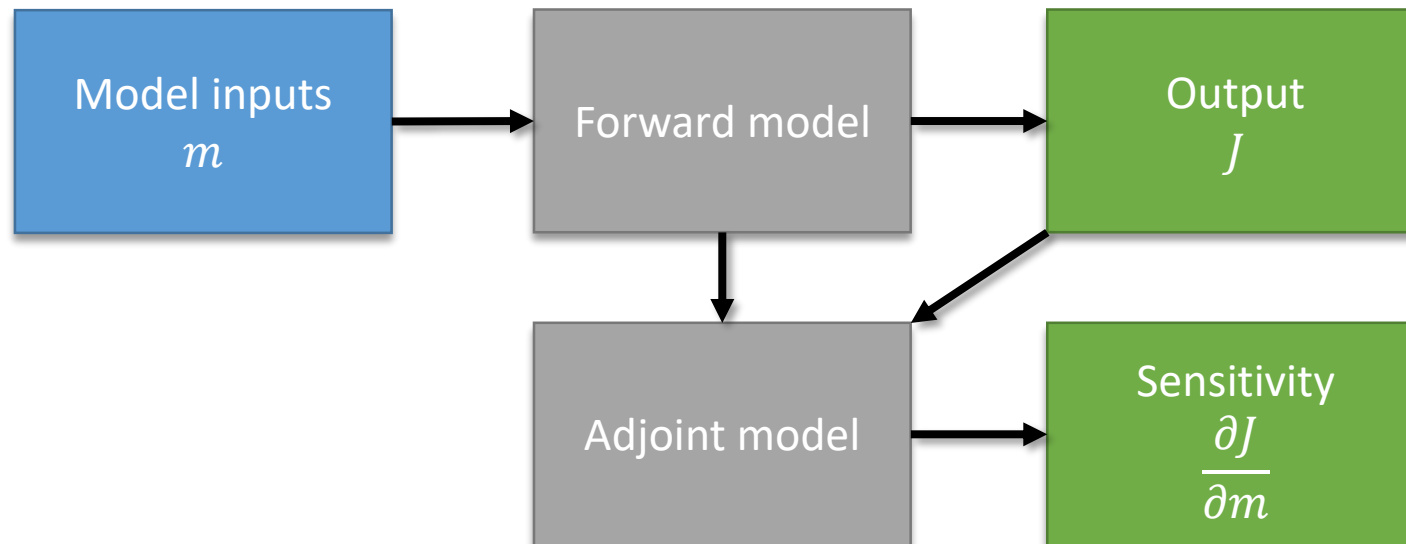
Sensitivity Results

Sensitivity of peak surge residual to bathymetry

North Shields

Immingham

Lowestoft

Sensitivity of peak surge residual to bathymetry

Sensitivity
2.0e-12
1e-12
0
-1e-12
-2.0e-12

Integral along coastline
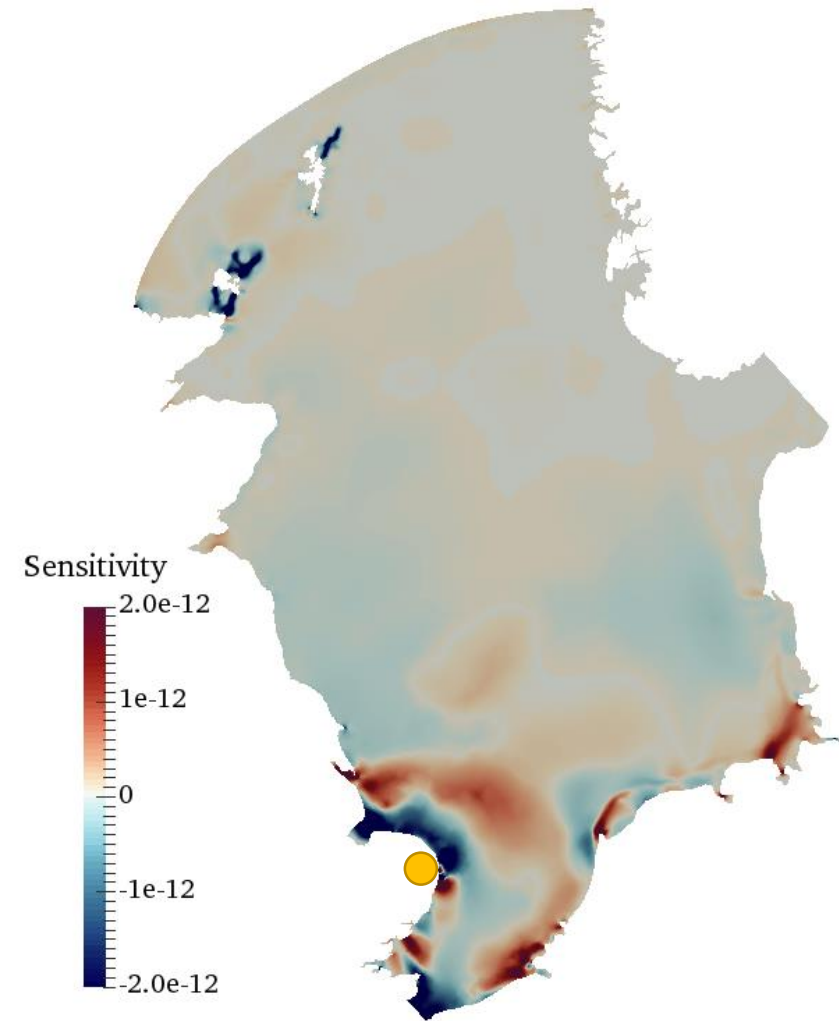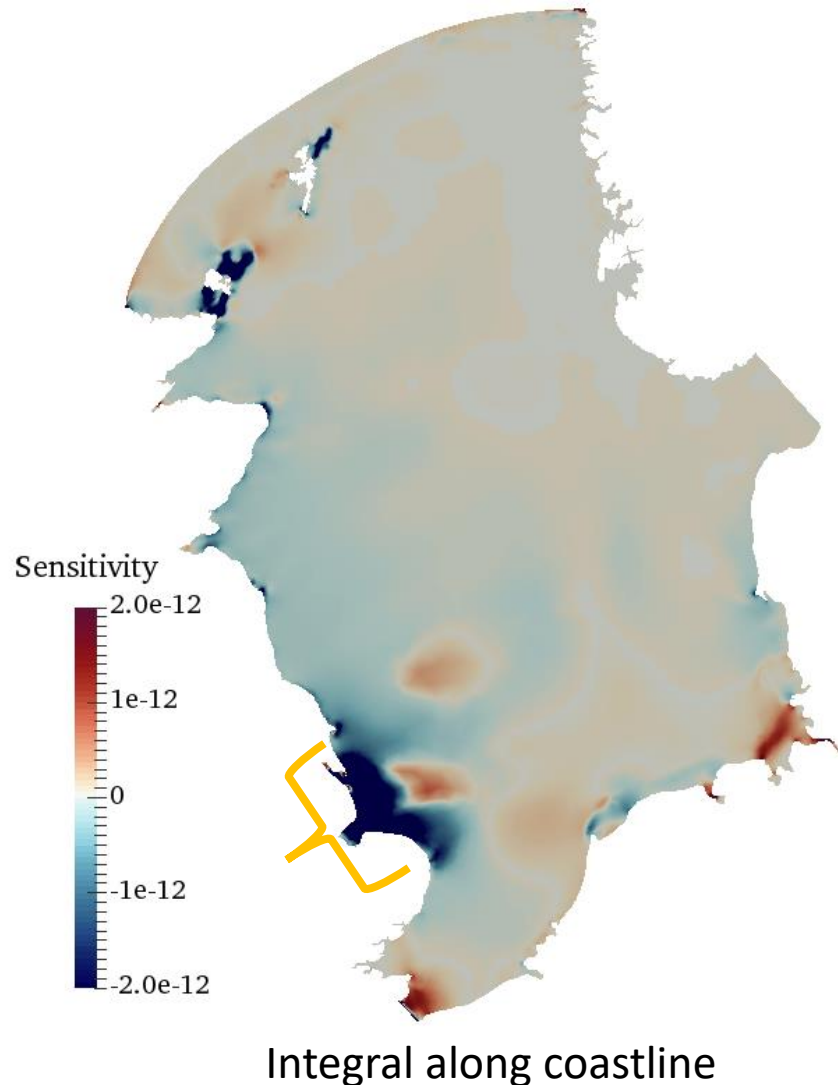
- Net influence of bathymetry is negative

- Defensive property of sand bank

- High sensitivity magnitudes in highly localised regions

- Similar far-field sensitivity patterns

- Immingham shows greatest overall (space-integrated) sensitivity

- Likely due to shallow water in vicinity of Immingham

Sensitivity of peak surge residual to bottom friction coefficient
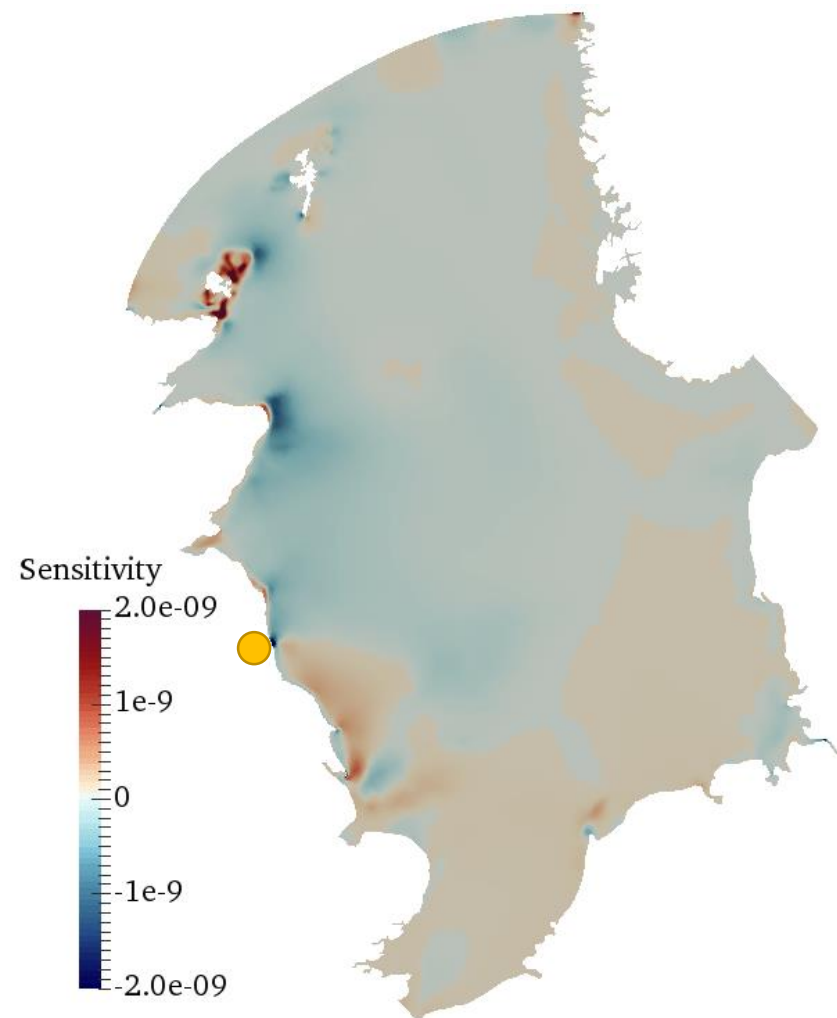
North Shields

Immingham
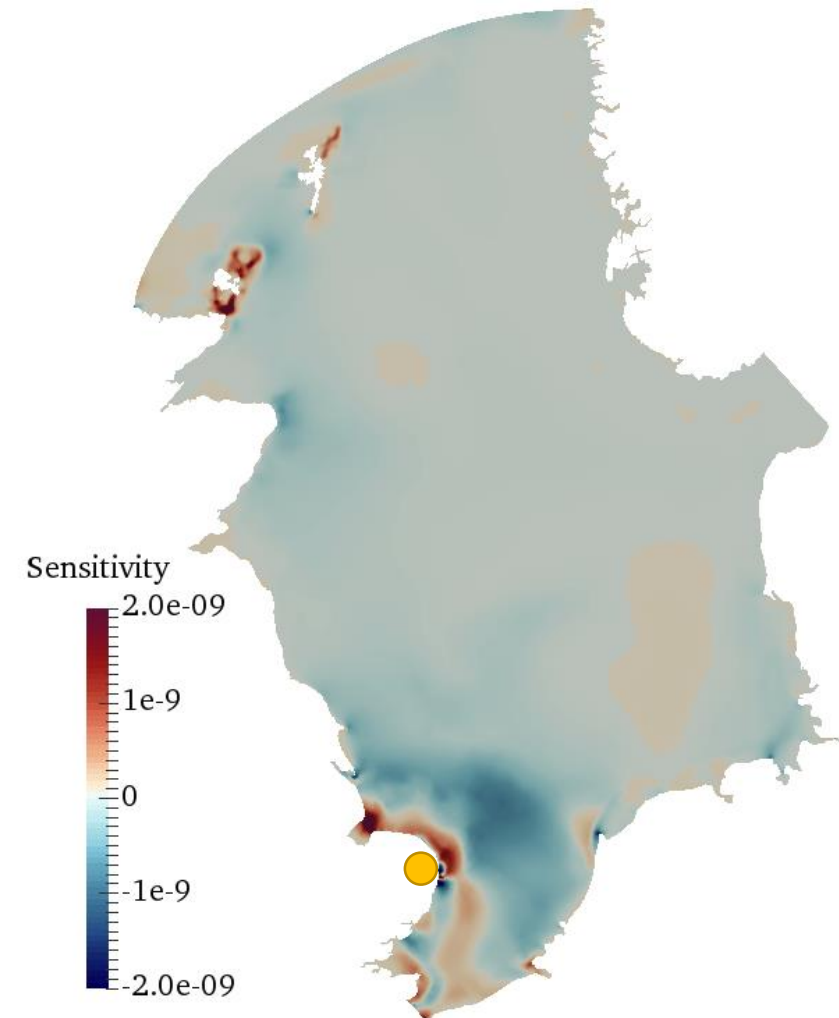
Lowestoft

Sensitivity of peak surge residual to bottom friction coefficient

Sensitivity
- 2.0e-09
- 1e-9
- 0
- -1e-9
- -2.0e-09

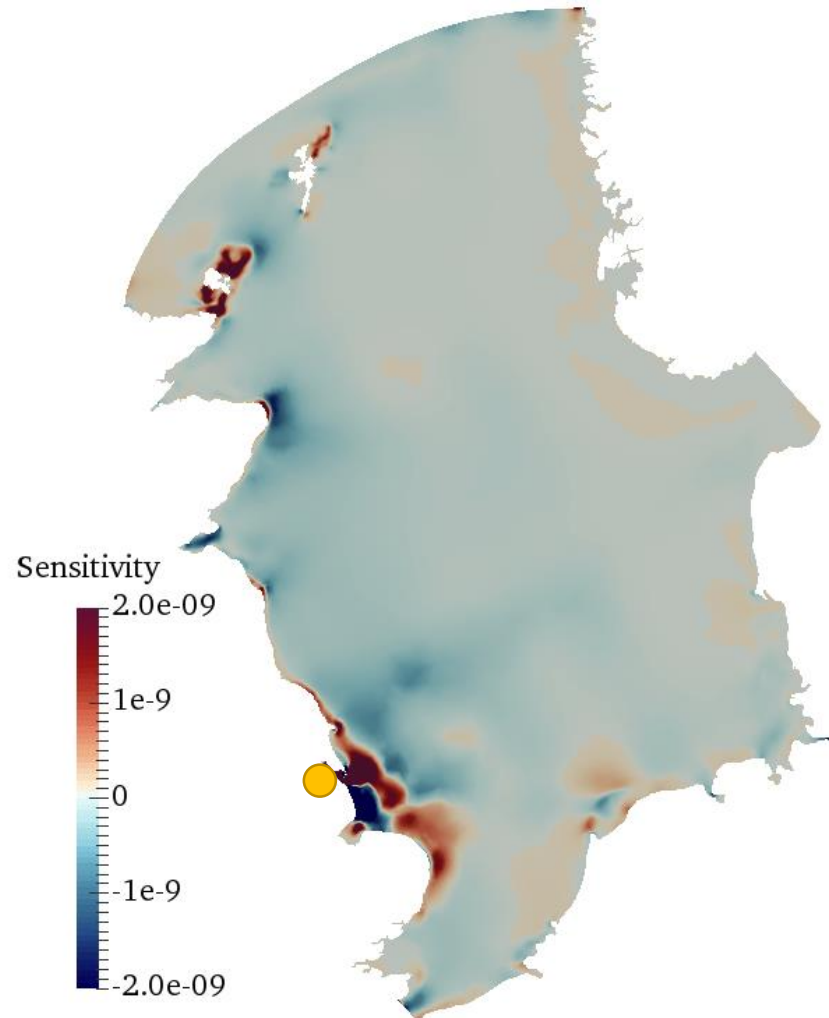Integral along coastline
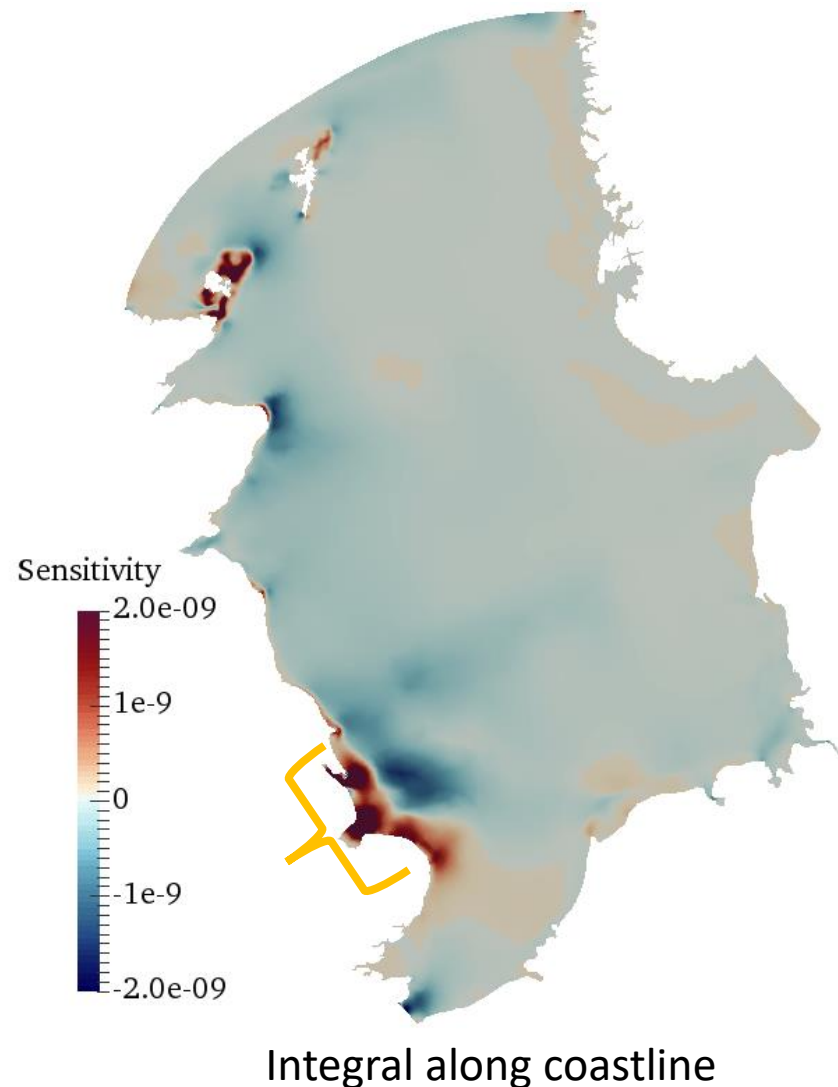
- Net influence of bottom friction coeff is negative
- High sensitivity magnitudes in highly localised regions, especially in shallow water
- Similar far-field sensitivity patterns
- Increasing total (space-integrated) sensitivity moving south
- Due to cumulative effect as surge propagates south
- Implications for the use of spatially varying bottom friction coefficient

Sensitivity of peak surge residual to wind stress

- Wind stress is time varying; so is sensitivity

- Perturbations due to wind stress travel at approximately the shallow water wave speed

- Sensitivity pattern is like shallow water wave, spreading out from observation location backwards in time (Wilson et al, 2013)

- This is both intuitive and simple to prove (Warder et al, 2019)

Time before peak: 0.1 hours

Sensitivity
- 1.000e-11
- 5e-12
- 2e-12
- 1e-12
- 5e-13
- 2e-13
- 1e-13
- 5e-14
- 2e-14
- 1.000e-14
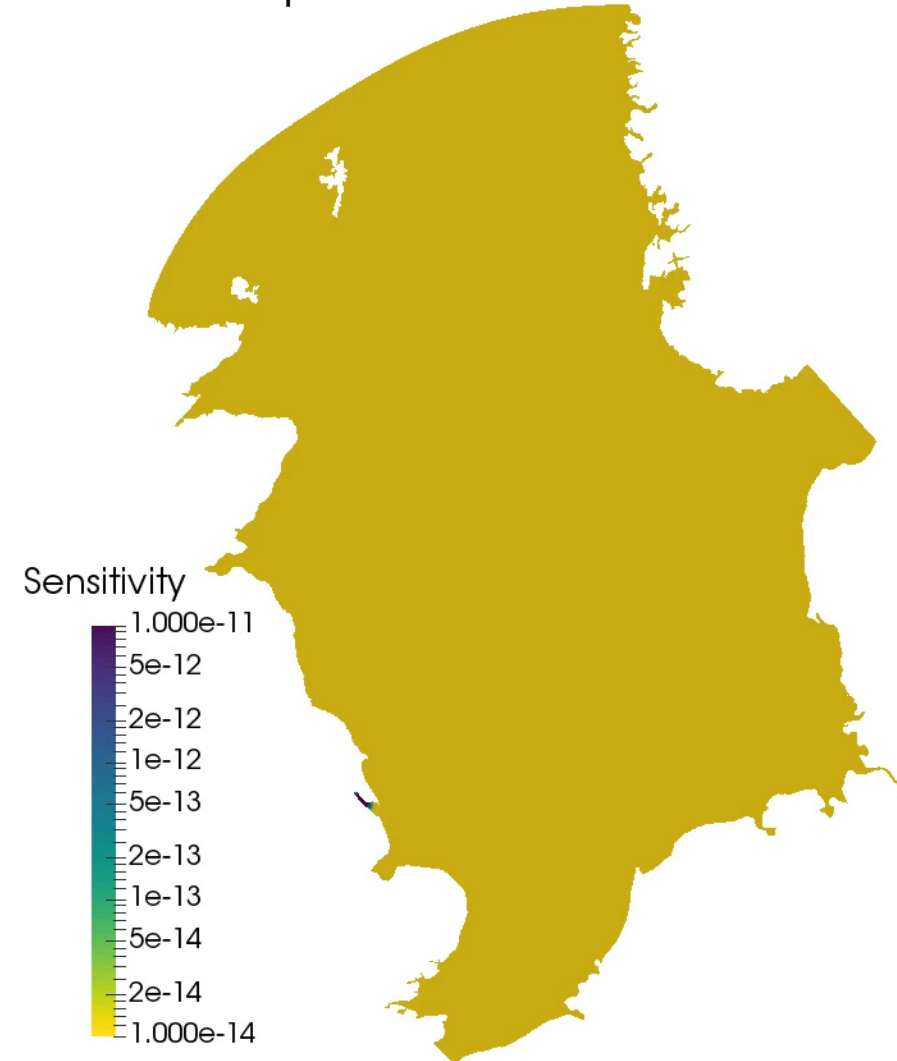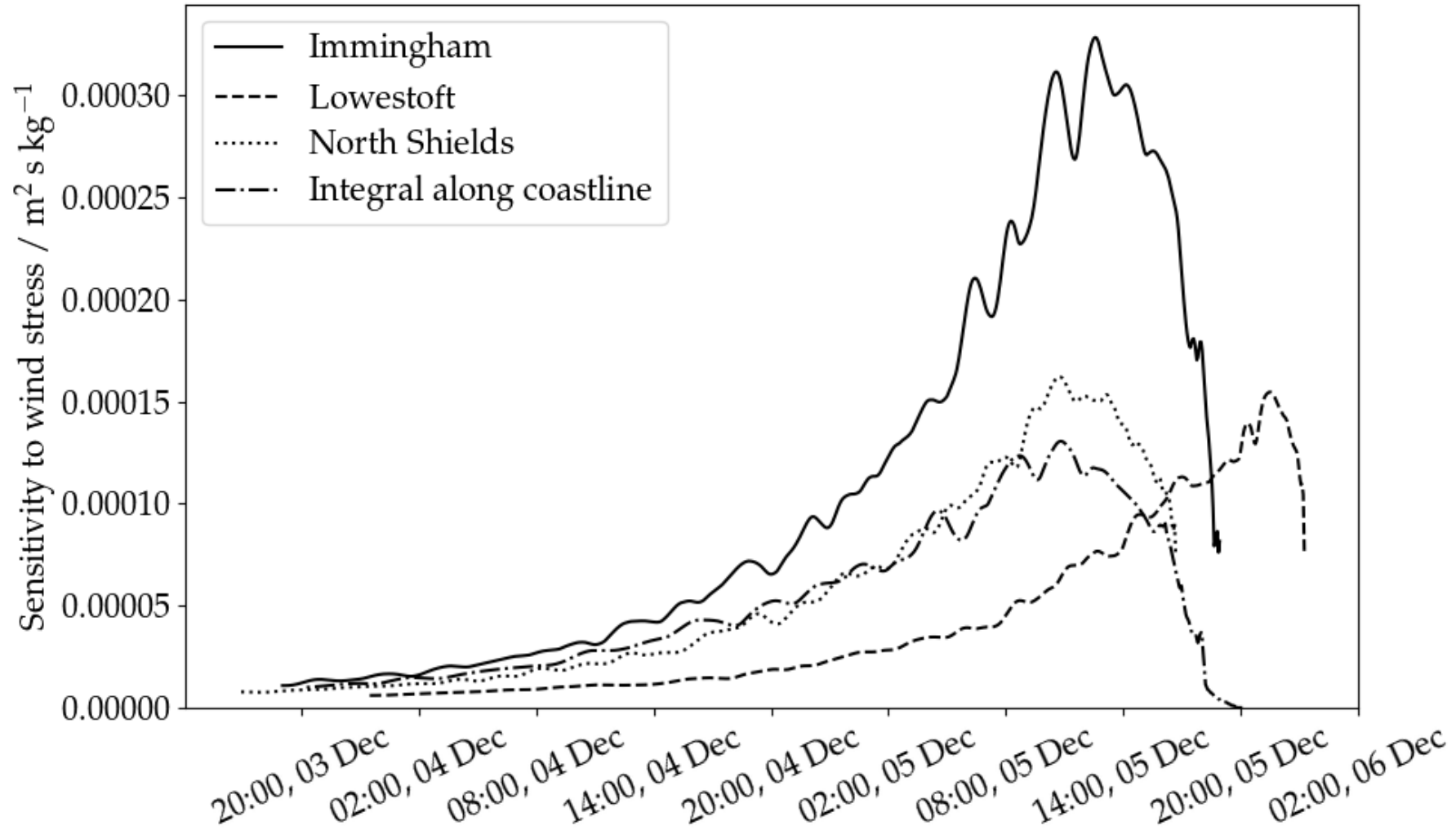
Sensitivity of peak surge residual to wind stress

Sensitivity of peak surge residual to wind stress

North Shields

Immingham

Lowestoft

Sensitivity of peak surge residual to bathymetry

Sensitivity

5.e-11
2.e-11
1.e-11
5.e-12
2.e-12
1.e-12
5.e-13
2.e-13
1.e-13
5.e-14
2.e-14

Integral along coastline
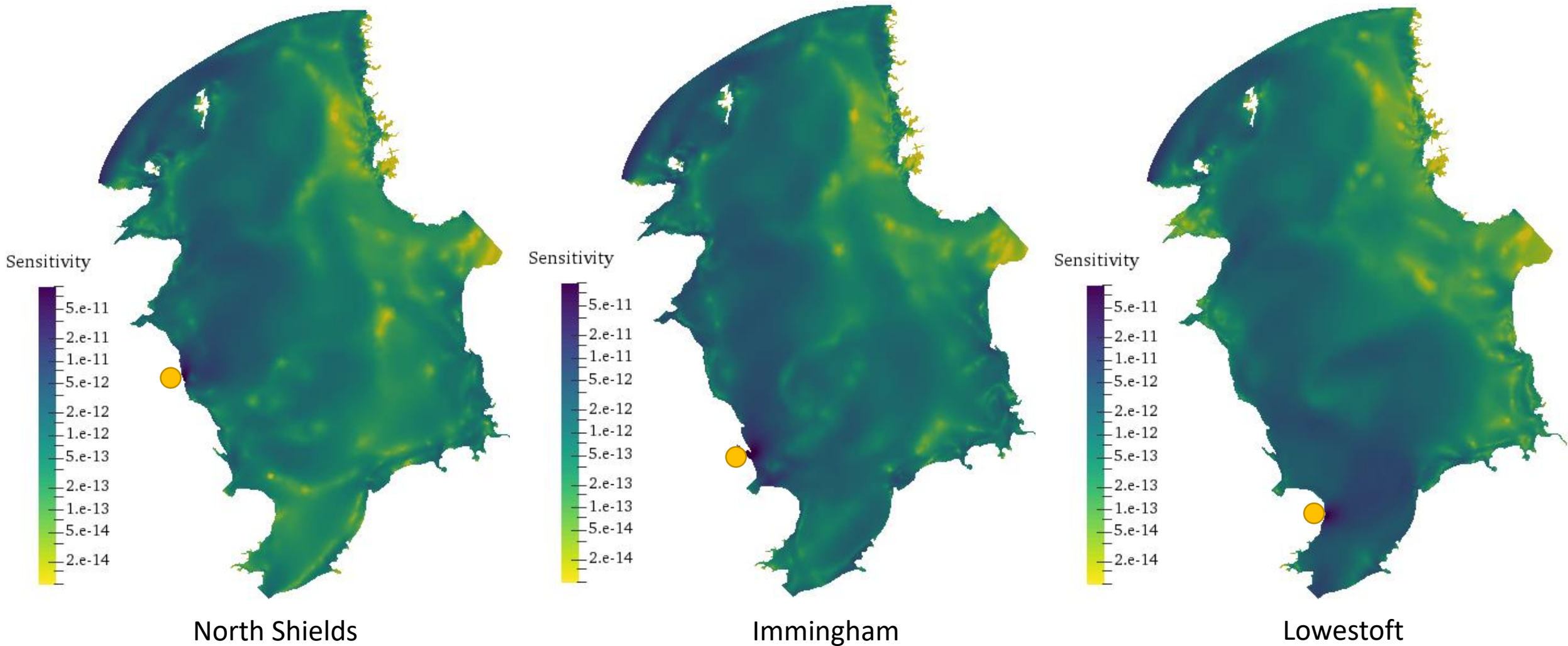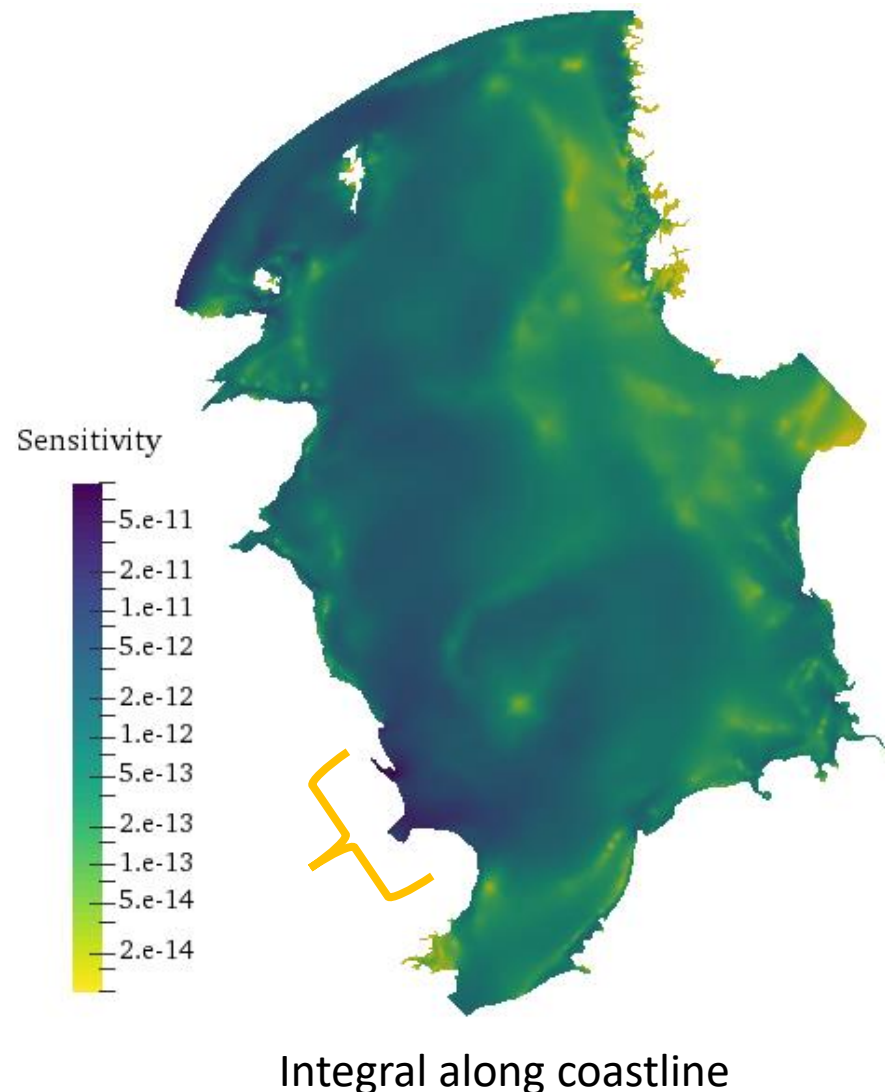
- Peak surge is mostly influenced by wind stresses in 24 hours prior to peak

- Immingham shows greatest sensitivity

- Similar far-field sensitivity patterns, plus local effects

- Errors in north of the domain propagate south with surge

Comparison of sources of uncertainty

- Comparison of sensitivity to each input requires estimate of input uncertainty

- Use multiple datasets for bathymetry, literature for Manning coeff

	North Shields	Immingham	Lowestoft	Coastline section
Bathymetry (± 2.7 m)	0.047 m	0.074 m	0.035 m	0.22 m
Manning coeff (± 0.005)	0.097 m	0.16 m	0.19 m	0.18 m

- Uncertainty in meteorological inputs varies with lead time; typical ensemble range at 24 hour lead time is O(1m)

Conclusions

- Uncertainty in surge predictions has been analysed using an adjoint surge model

- Spatial patterns of sensitivity to bathymetry and bottom friction coeff show local effects, and similarity in far field

- Implications for model calibration using spatially varying friction coeff

- Confirms what we already know – uncertainties in meteorological forcing are most important

- Adjoint-derived sensitivity is a tool for mapping input uncertainties onto surge uncertainty

- And many more?

Thank you for your attention

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