Simulation of long-term morphodynamics of the Western Scheldt

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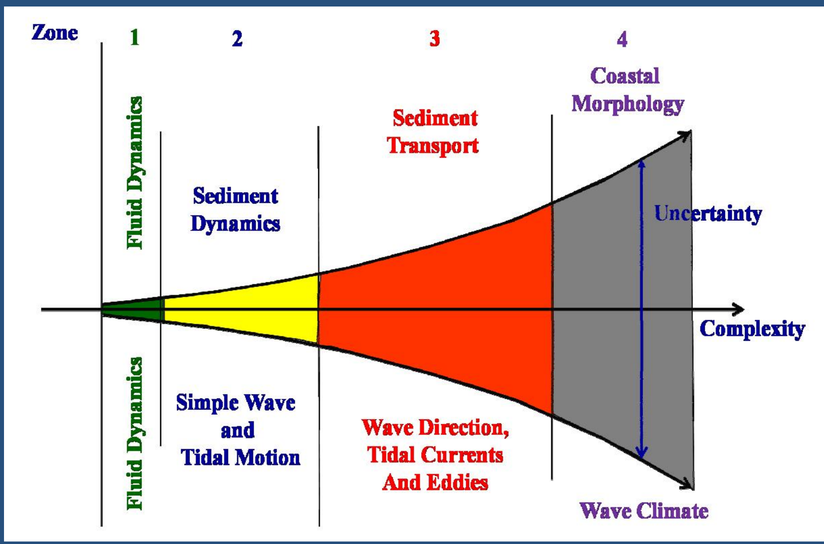
Research question

What is the value of long-term morphological modelling in estuaries using a process-based model?

(long-term = decades – century timescale)

Uncertainty trumpet (Kamphuis, 2013)



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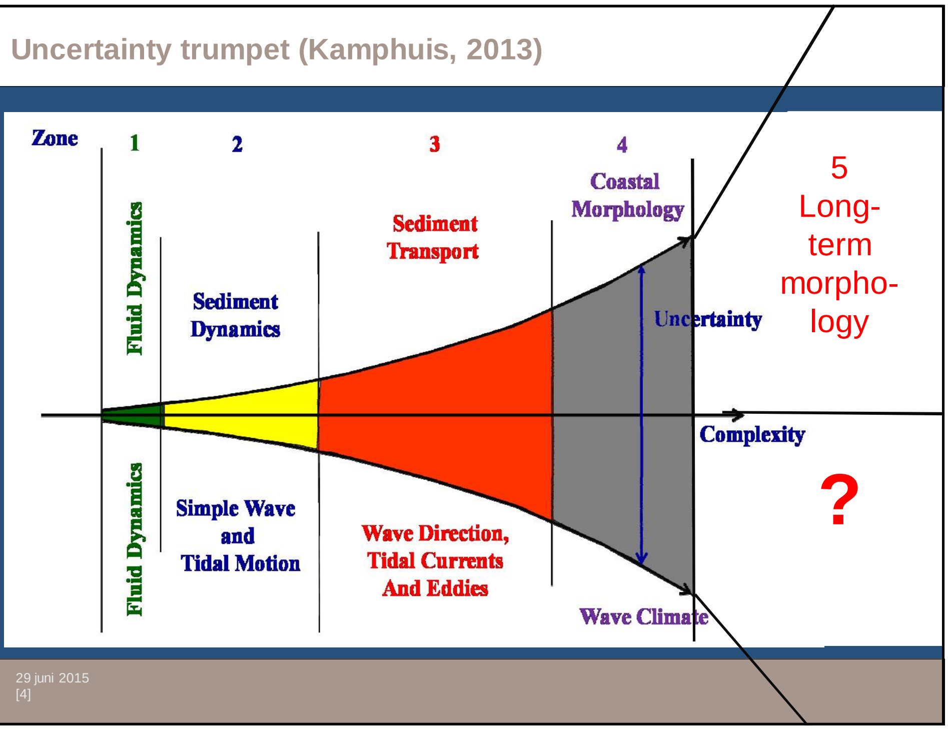
Uncertainty trumpet (Kamphuis, 2013)



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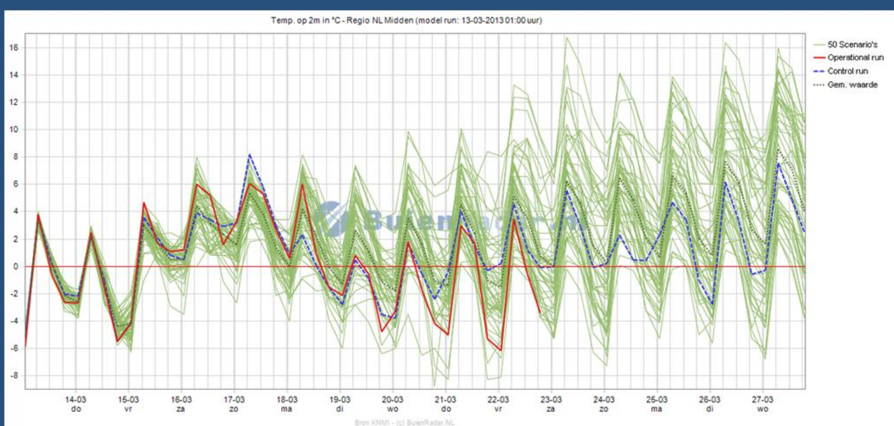
General view on performance of long-term morphology of process-based models

Morphological models drift away from reality over time due to:
-Build up of errors;
-Non-lineair interactions that are unpredictable over time;
-Processes are missing (simplification of system).

Weather forecast



(www.buienradar.nl)

Approach

Process-based model to hindcast long-term morphology in Western Scheldt

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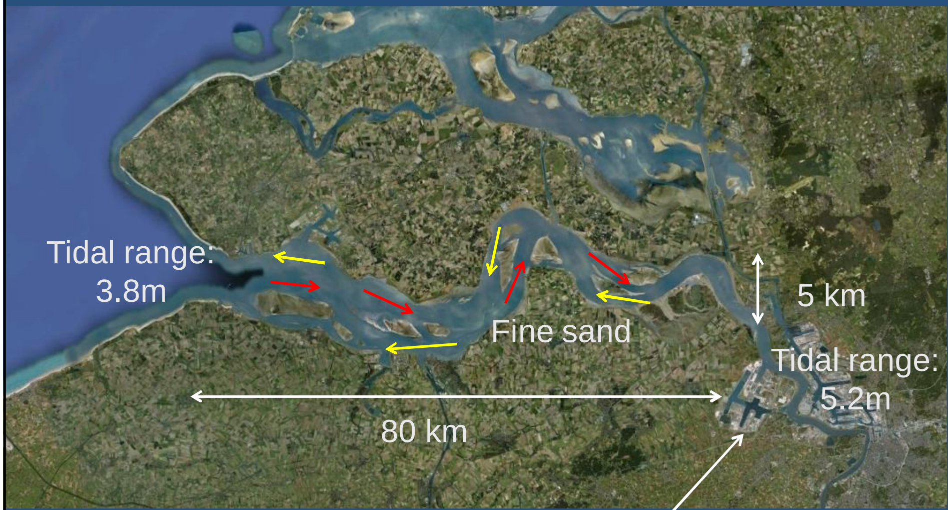
Case study: Western Scheldt estuary, The Netherlands



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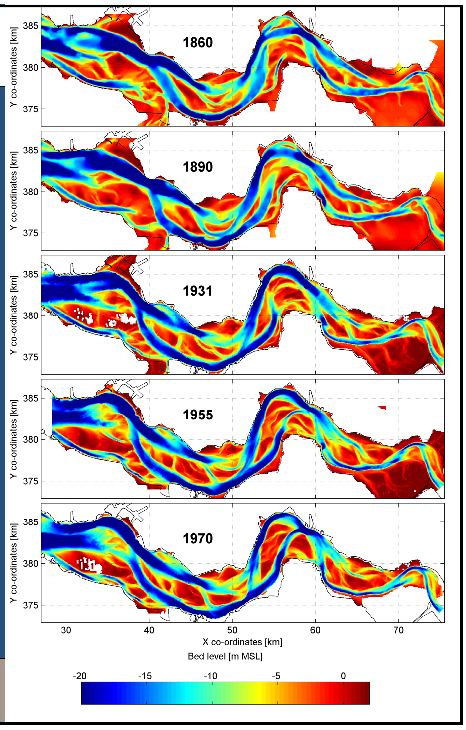
Port of Antwerp

Hindcast of 1860-1970 period:
(110 years)

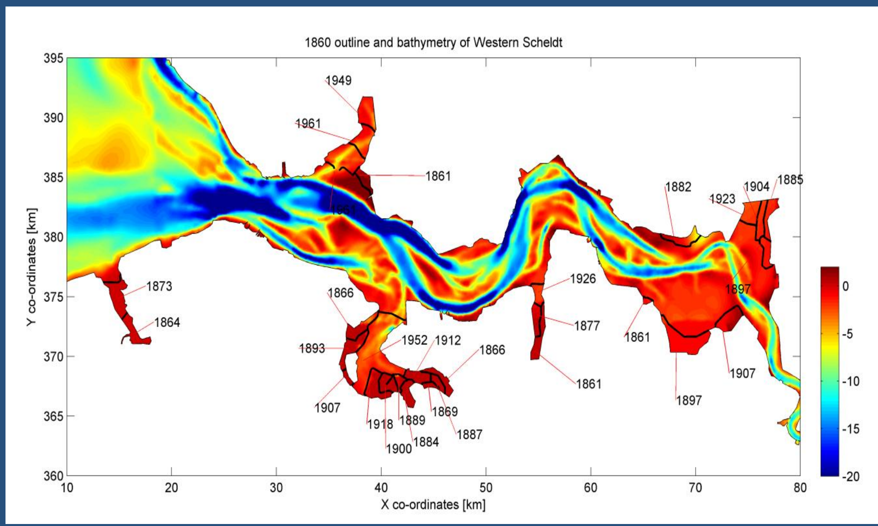
Measured bathymetries in:
1860
1878
1890
1905
1931
1955..1970



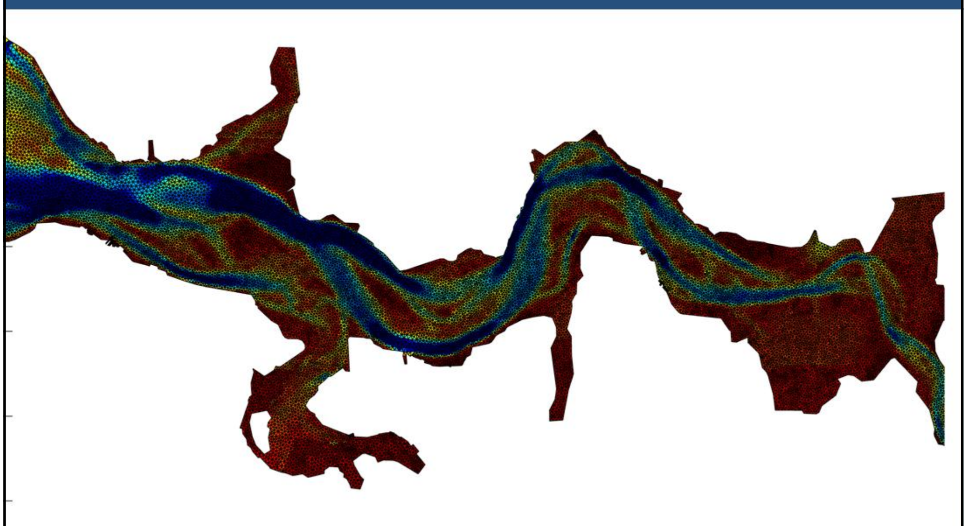
Morphological process-based model:

FINEL2d model by Svašek Hydraulics:
- 2Dh simulation of water and sediment transport based on finite elements method;
- Only tidal forcing; small constant river discharge; no waves
- Engelund-Hansen sediment transport formula
- 1 fraction of sand
- Roughness constant in time and space
- MORFAC: 24.75
- Measured non-erodable layer
- Parameterisation of spiral flow
- Extensive calibration on water motion

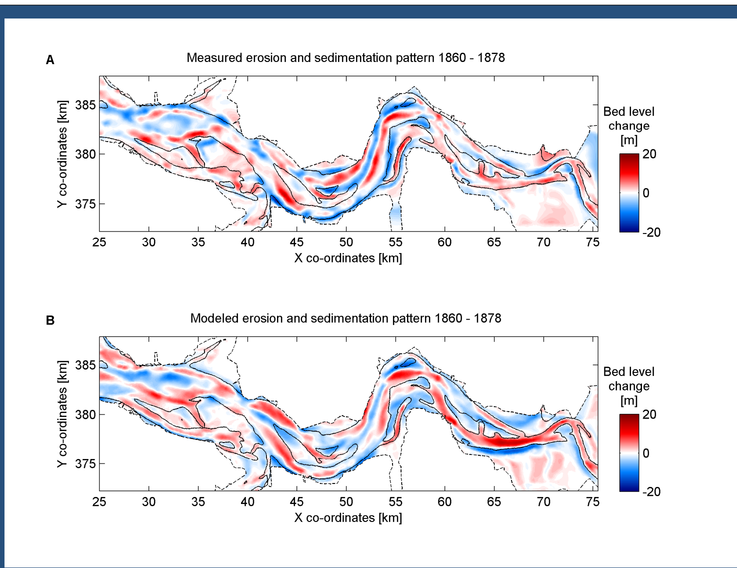
1860 bathymetry, outline and land reclamations



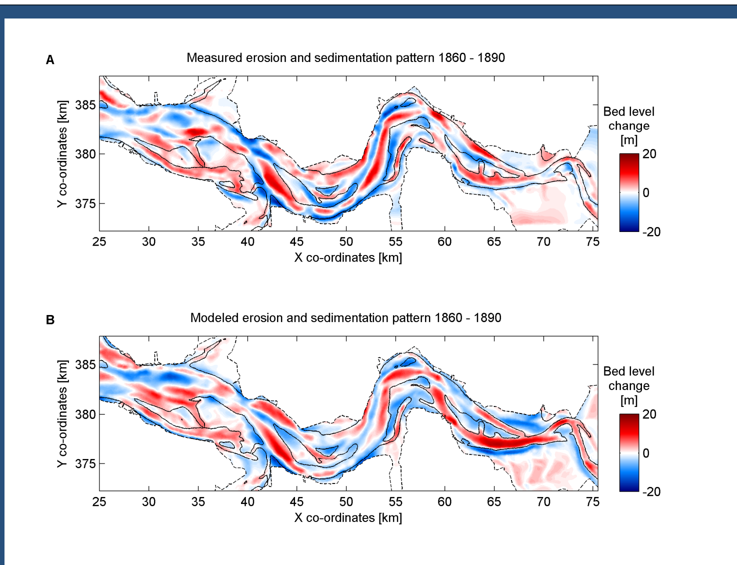
1860 computational grid and bathymetry



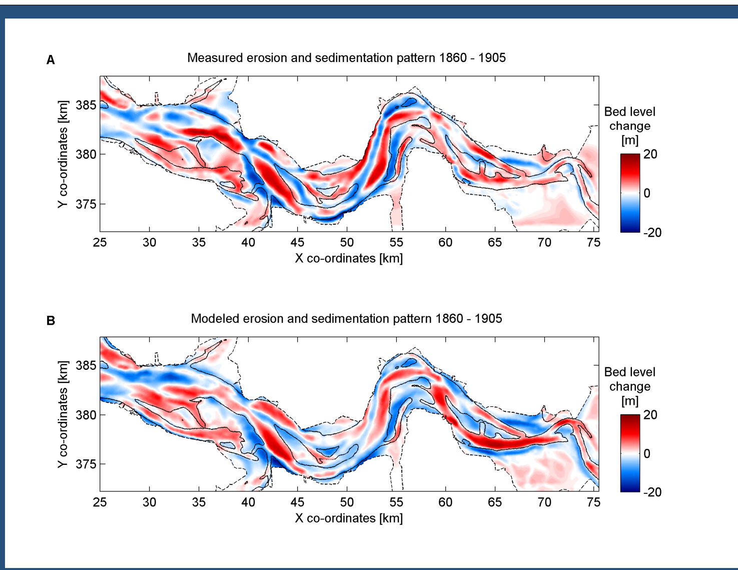
erosion-sedimentation pattern 1860 – 1878 (18 years)



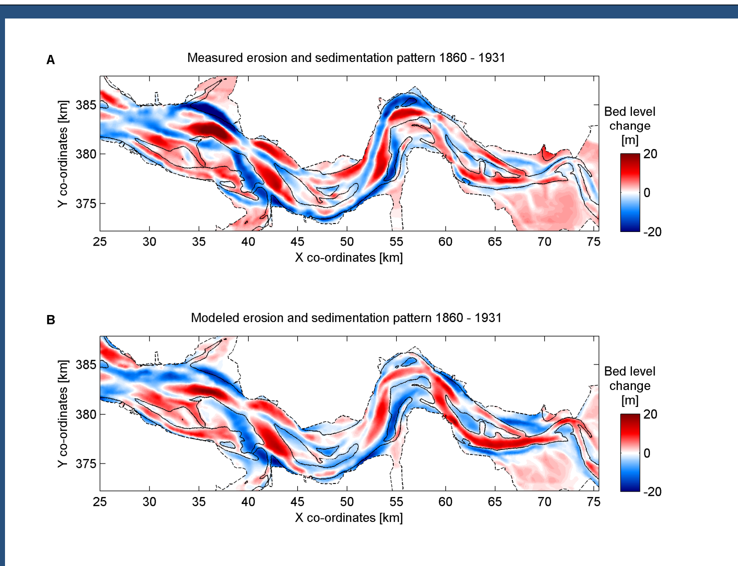
erosion-sedimentation pattern 1860 – 1890 (30 years)



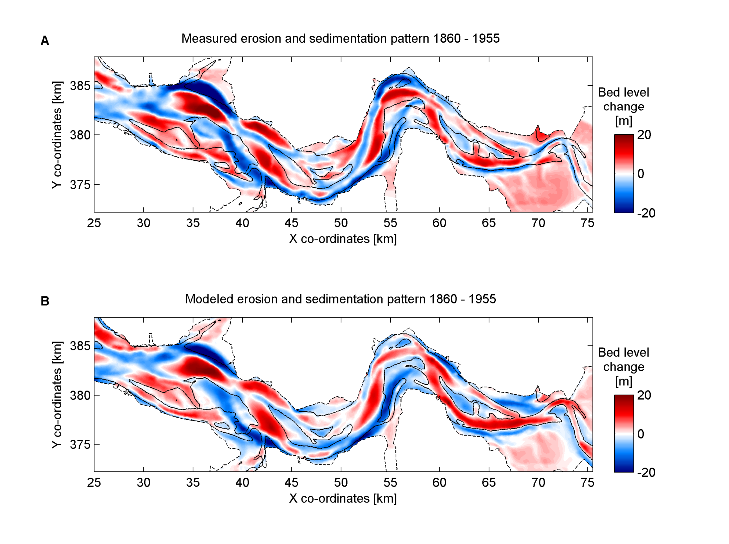
erosion-sedimentation pattern 1860 – 1905 (45 years)



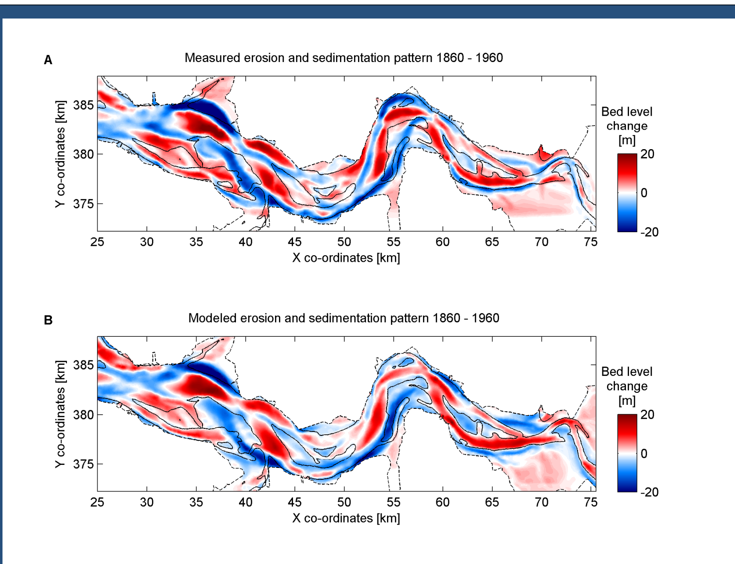
erosion-sedimentation pattern 1860 – 1931 (71 years)



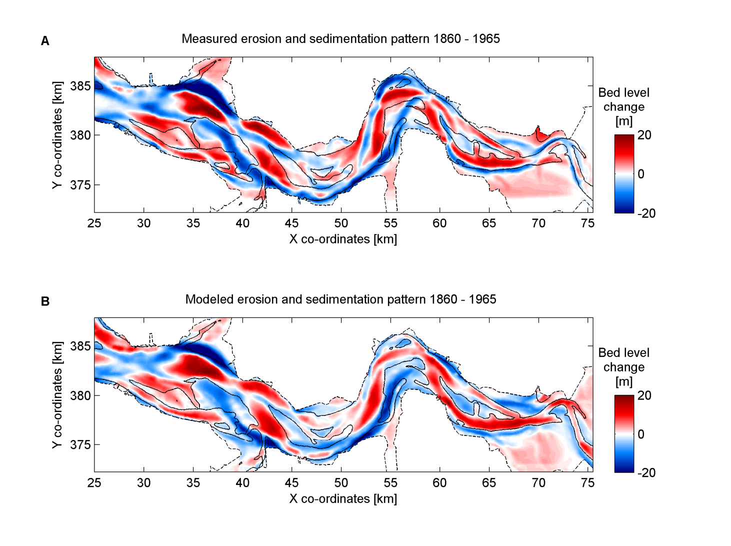
erosion-sedimentation pattern 1860 – 1955 (95 years)



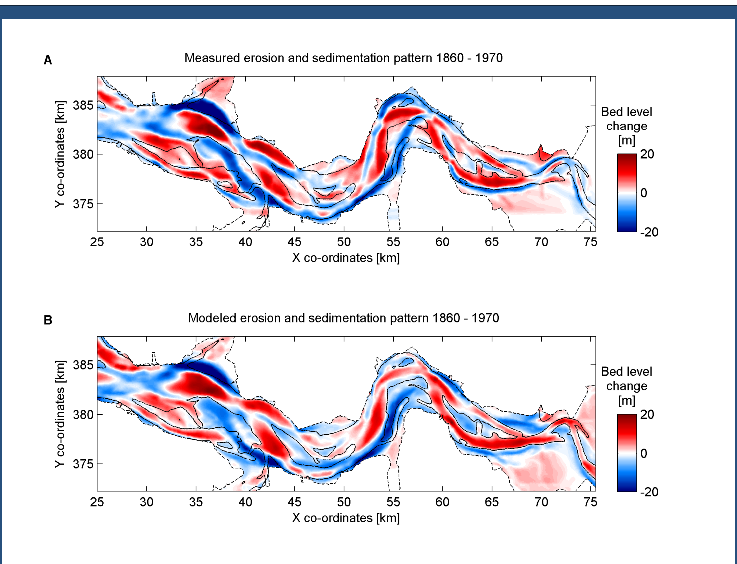
erosion-sedimentation pattern 1860 – 1960 (100 years)



erosion-sedimentation pattern 1860 – 1965 (105 years)



erosion-sedimentation pattern 1860 – 1970 (110 years)



Brier-skill score (Sutherland et al., 2004)

$$BSS = 1 - \frac{\left\langle (Y - X)^2 \right\rangle}{\left\langle (B - X)^2 \right\rangle} = 1 - \frac{\left\langle error^2 \right\rangle}{\left\langle signal^2 \right\rangle}$$

Where:
Y=Bed level prediction at time T
X=Bed level observation at time T
B=Bed level at t=0
And the <> denote the arithmetic mean.

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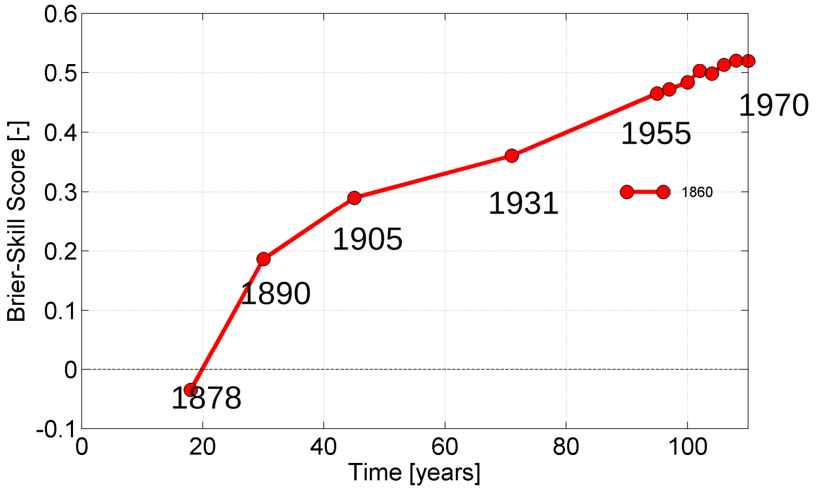
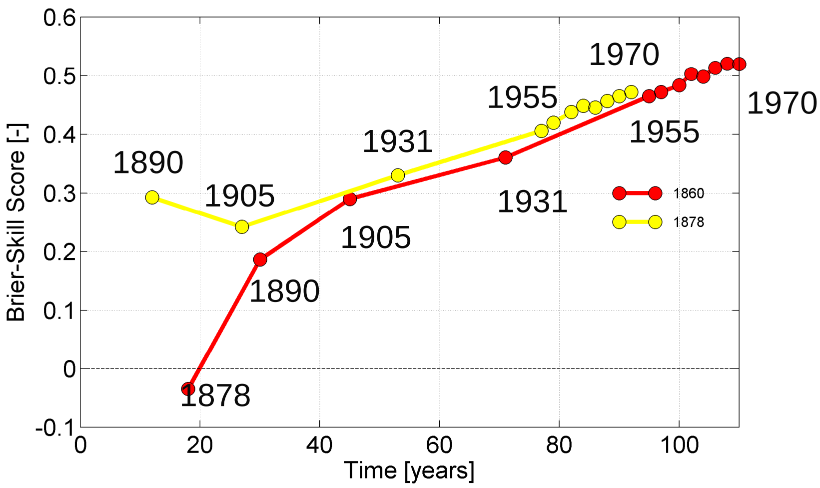
Rating (van Rijn et al., 2003):
<0 : Bad
0– 0.3 : Poor
0.3- 0.6 : Reasonable/fair
0.6- 0.8 : Good
0.8- 1.0 : Perfect

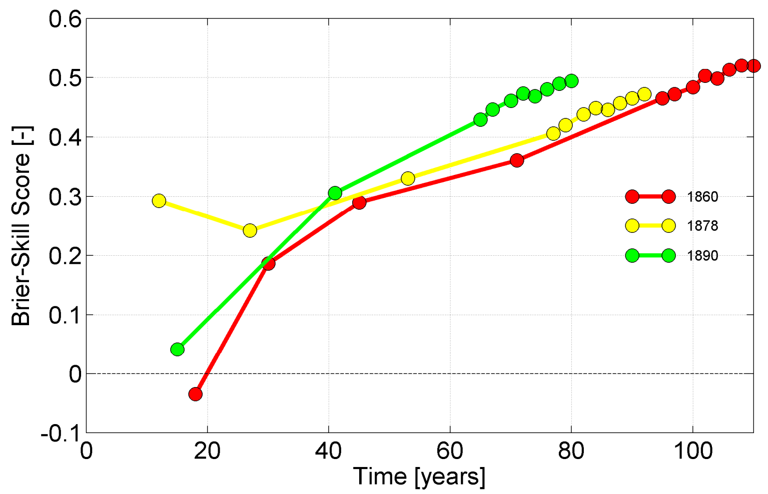
Brier-Skill Score 1860-1970



Brier-Skill Score



Brier-Skill Score



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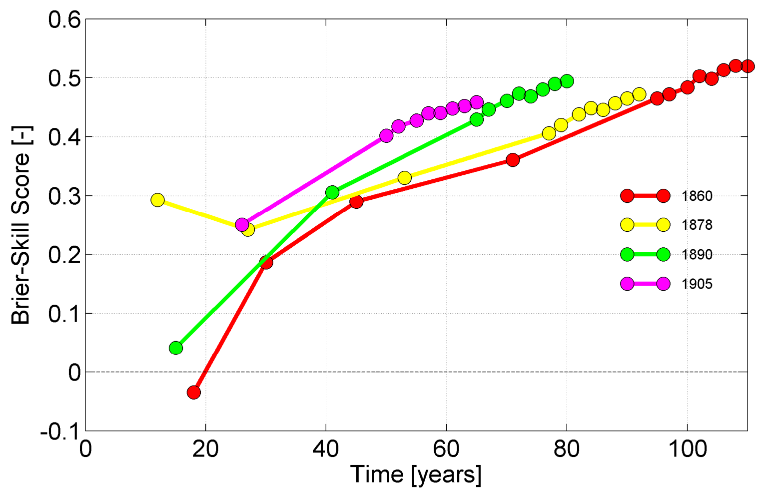
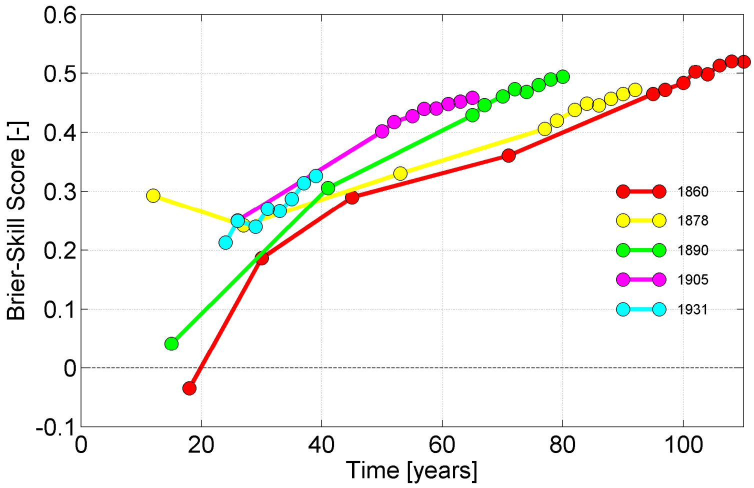
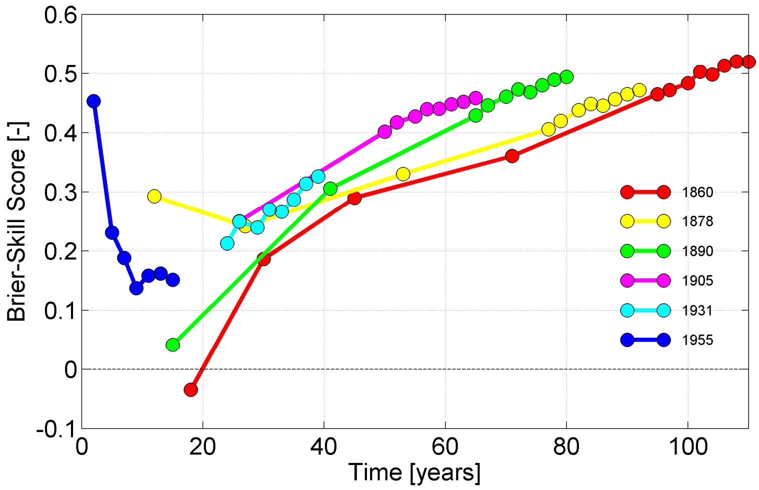


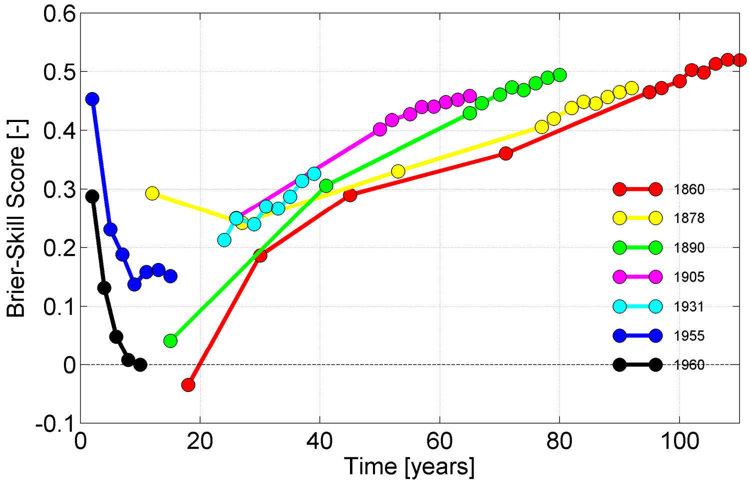
Brier-Skill Score



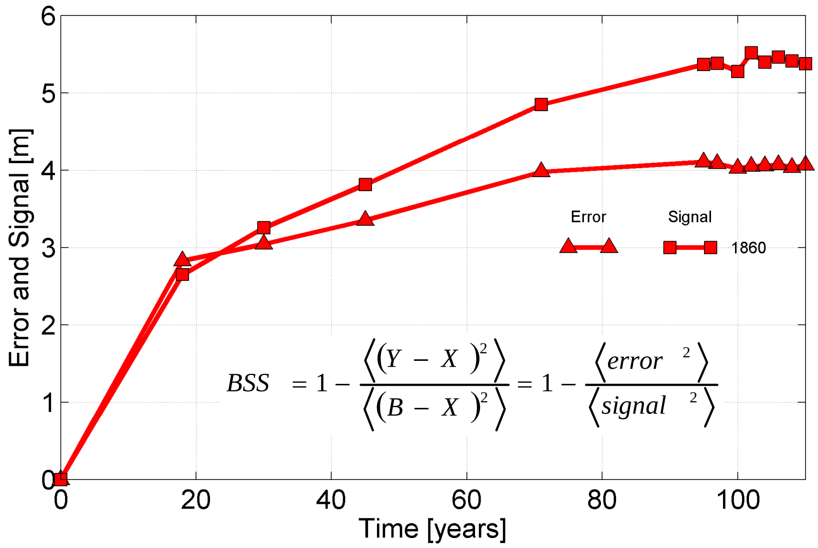
Brier-Skill Score



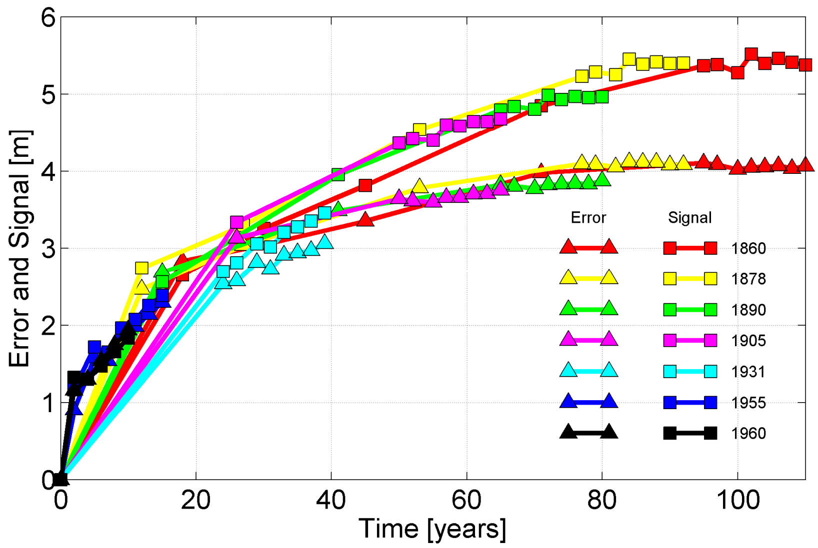
Brier-Skill Score



Error and signal 1860 – 1970 simulation



Error and signal



Conclusions

- Research question: Is it possible to model long-term morphology using process-based models? In this case: YES!
  - Reasons:
  - Tide is dominant forcing in Western Scheldt
  - Geometry plays an important role
  - Western Scheldt mainly consists of fine sand

- Furthermore: short-term morphology seems to be unreliable! requires 20-30 years before positive BSS scores are obtained.
- On short timescales other processes might be important (storms), but are overruled on the long term

Question

Why does the morphological model show good behaviour over this 110 year period?

Theory

An estuary under constant forcing strives for minimum energy dissipation (Langbein, 1963).

This leads to less gradients in shear stress and sediment transport (Rodriquez-Iturbe et al, 1992).

Eventually resulting in morphological equilibrium (Cowell and Thom, 1994, Woodroffe, 2002).

These are indictators of self-organising behaviour of the system (Philips, 1999)

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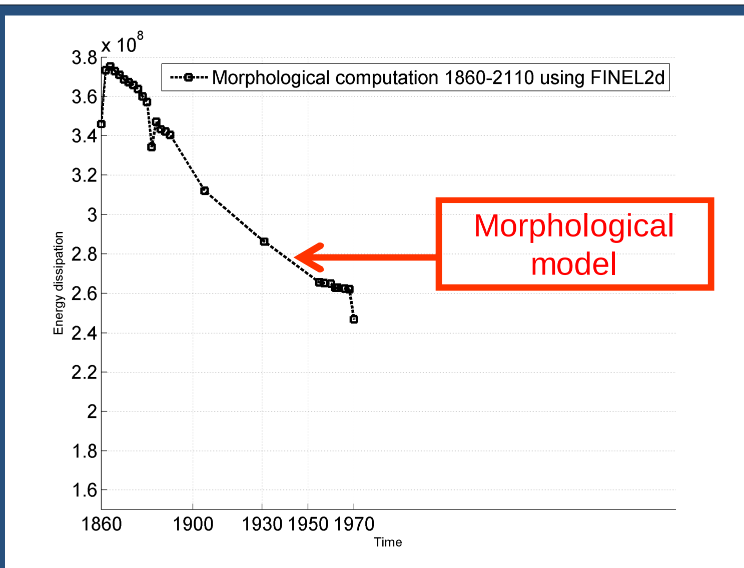
Energy dissipation

- Energy dissipation is calculated using hydrod. model for
- - Computed bathymetries from the morphol. model
- - Measured bathymetries

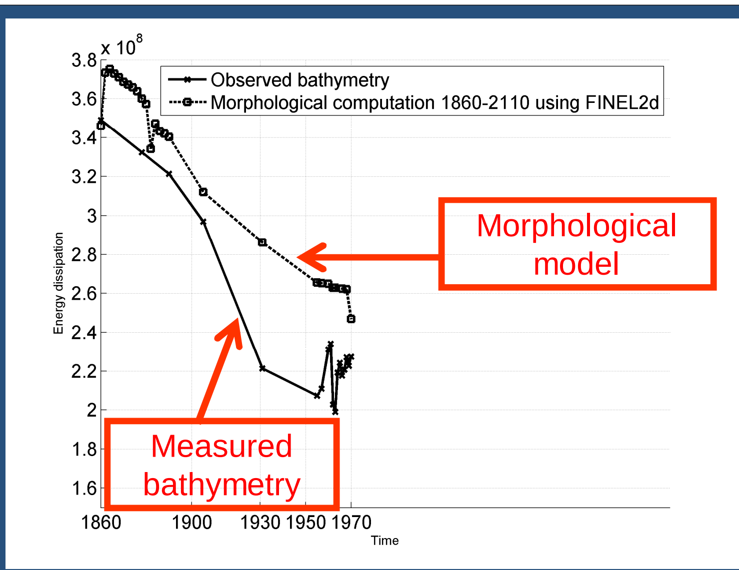
- Energy dissipation is integrated
- - over the entire basin
- - over a complete neap-spring cycle

$$Pcell = \left(c_f \rho_w \left(u^2 + v^2\right)^{1.5}\right) \bullet area$$

Energy dissipation 1860 – 1970; entire Western Scheldt



Energy dissipation 1860 – 1970; entire Western Scheldt



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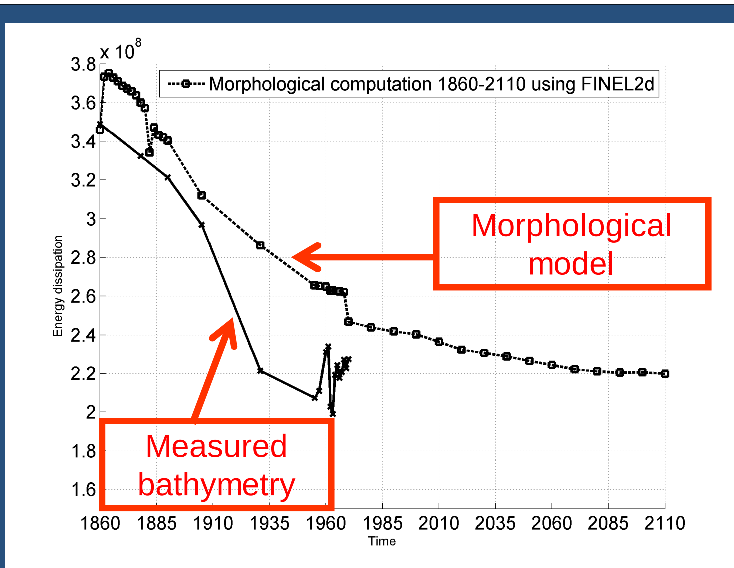
Energy dissipation 1860 – 2110; entire Western Scheldt



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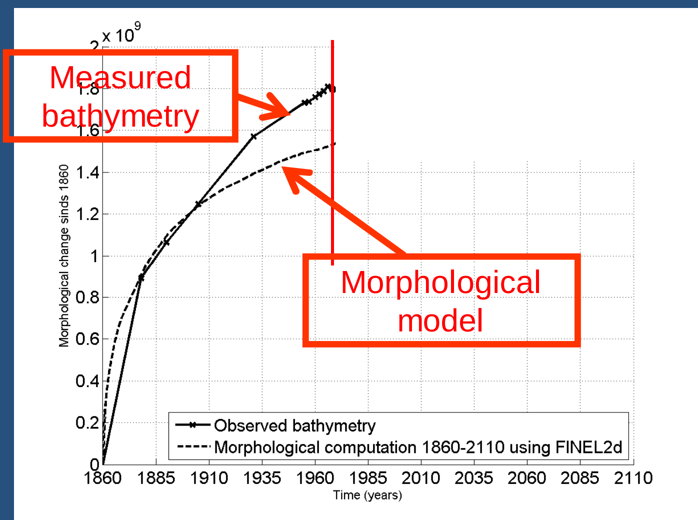
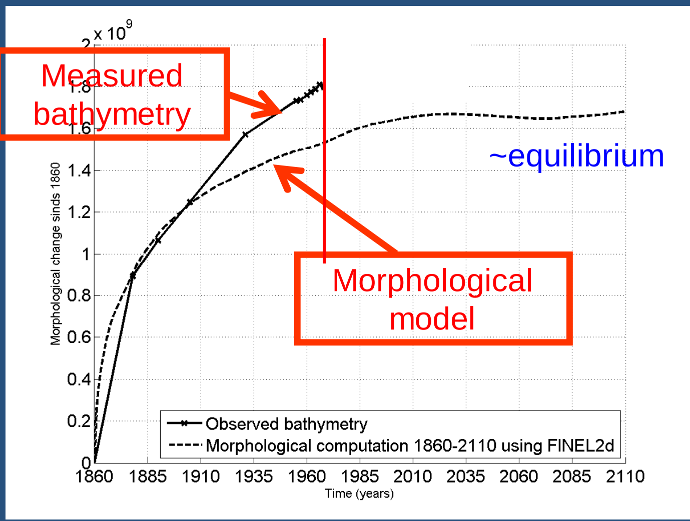
Morphological activity 1860 – 1970; entire Western Scheldt

Morphological activity = erosion volume + deposition volume (starting in 1860)

Morphological activity 1860 – 1970; entire Western Scheldt



Morphological activity 1860 – 2110; entire Western Scheldt



Conclusions

•Long-term morphology is predictable using a process-based model.

•Reasons:
•Estuarine morphology is ruled by self-organisation and is not chaotic:
• Both reality and model show:
•- Less energy dissipation over time
•- Less morphological activity over time (equilibrium)

•Morphology is changed in such a way that the system become more efficient in transporting water in and out of the estuary; (predictable!)

•Model results are further enhanced by:
•geometry of the basin; presence of non-erodable layer; well

Conclusions

Process-based models are excellent tools to investigate long-term morphology in estuaries

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