Modelling shoal margin collapses and their morphodynamic effect on channels and shoals in a sandy estuary

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Background and Model Setup

Channel bank failure and collapses of shoal margins have been recorded systematically in Dutch estuaries for the past 200 years (*Wilderom, 1961-1979*). In many locations collapses reoccur at intervals of several years to decades. The effects of these collapses on the morphodynamics of estuaries are unknown.

Objective:

1. Develop universal **parameterisations** for shoal margin collapses.
2. Analyse the **near-field morphodynamics** and **far-field** effects on **flow pattern** and **channel-bar morphology.**

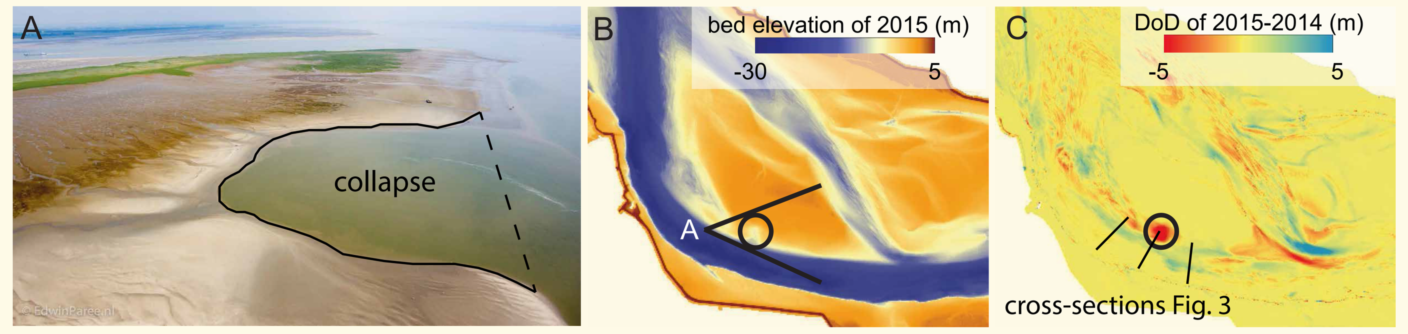


Fig. 1) Shoal margin collapse of July 2014 that eroded **800,000 m³** of the tidal flat of Walsoorden (a). Yearly bathymetry measurement of 2015 (b). DEM of Difference of illustrates the location of the 2014 collapse (c).

What are shoal margin collapses?

- Shoal margin collapses occur on the **inner side** of a bend.
- **Flow slides**, i.e., liquefaction or breaching.
- ~1 Mm³ eroded sediment → **perturbation.**

How big, and can we predict shoal margin collapses?

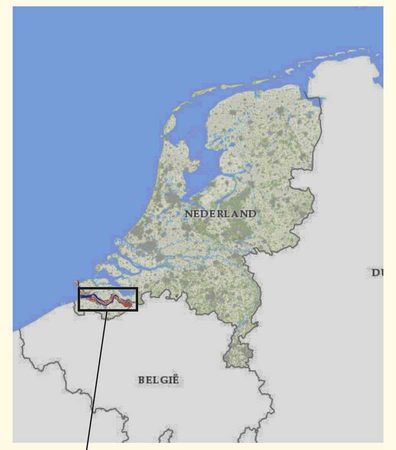
- Shoal margin collapses in the Western Scheldt have a median size of **34,000 m²**, and a median volume of **100,000 m³**, and both are **log-normal** distributed.
- The geometric shape of a collapse follows **1/3 ellipsoid**.
- Location of collapses can be predicted by the relative shoal margin **height** (H_r) as well as **slope** (α_r), according to the following equation:

$$F(SC) = \left(\frac{H_r}{11}\right)^{2.5}\left(\frac{9.5}{\cot\alpha_r}\right)^{5}\left(\frac{1}{10}\right)^{-10(0.05-\psi)}\frac{SC_{avg}}{L_{sm}} \qquad \text{equation 1}$$

where F is the frequency of shoal margin collapses (SC), ψ is relative density and L_{sm} is the total length of shoal margin in the estuary. Western Scheldt; SC_{avg} = 5 per year and L_{sm} = 300 km.

The Western Scheldt model setup

- **Multi-channel** systems (ebb- and flood-dominated).
- Spring-neap cycles, **tidal range 3.5-5 m.**
- Relatively fine sediment, **200 µm.**
- **Delft3D model** schematisation.
- **2 years** hydrodynamic simulation; MorFac of 20.
- **Tested 2 scenarios:** 1. **Initial 10 collapses of 1 Mm³**
  2. **Yearly collapses**



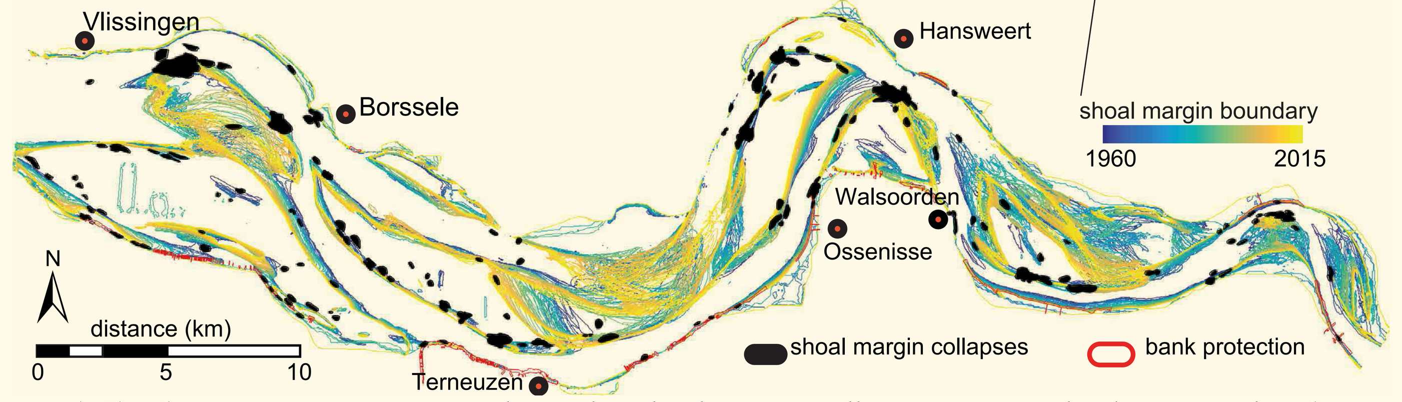


Fig. 2) **Shoal margin migration** map shows that shoal margin collapses occur at shoal margins that **do not migrate laterally** (*Van Dijk et al. Subm*).

Sensitivity Analysis

Sensitivity of the grain-size

- Finer material **spreads faster** and **deposits** at the **channel flanks**.
- **Finer material** is predominantly **seaward** → **the residual current.**
- **Coarser material** is predominantly **landward** → **tidal asymetry.**

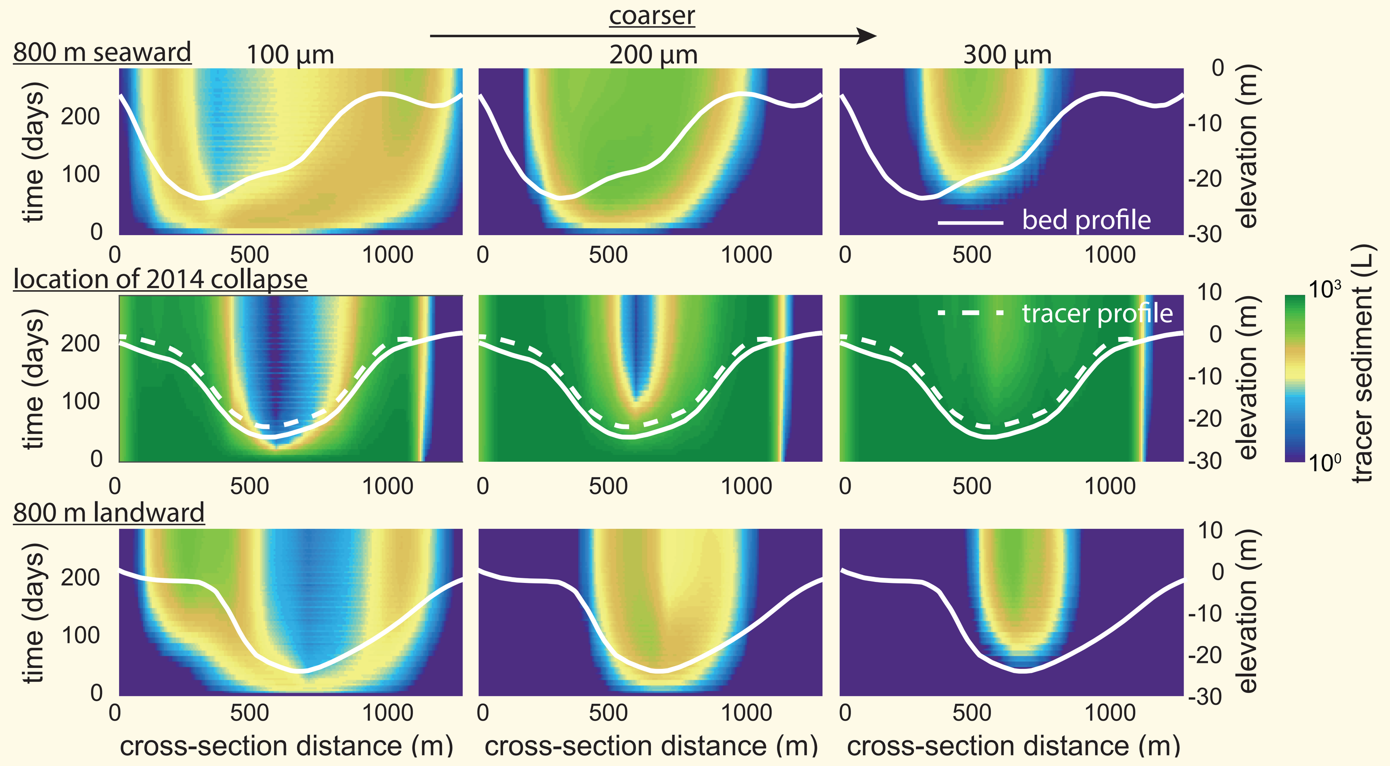


Fig. 3) The space-time diagram for three cross-locations (Fig. 1c) shows sediment spreading from artificial sill.

Sensitivity of the collapsed size and location

- Sediment from the **larger** collapses are spread **over longer distances.**
- **Larger** collapses show **tens of centimeters variation** of the mean bed elevation, compared to **centimeters for smaller** collapses.
- Sediment is transported in **ebb and flood** direction.
- **Dominant** sediment transport direction follows **residual current.**

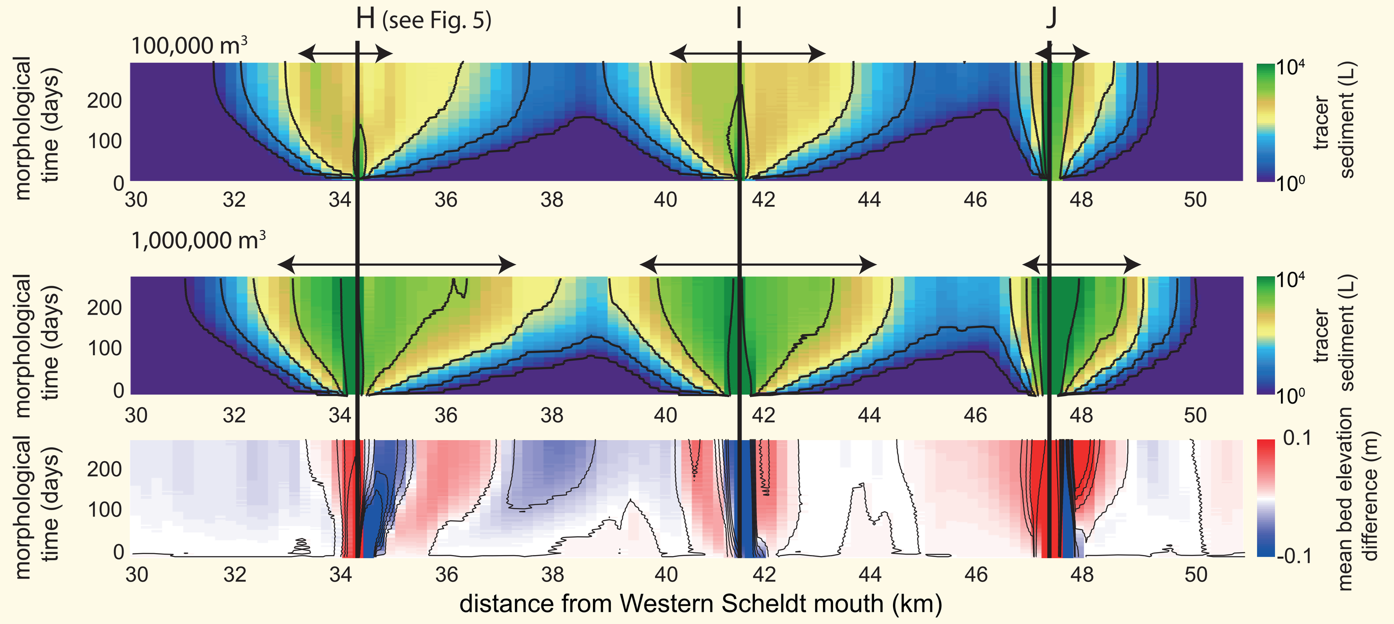


Fig. 4) Along estuary time-space diagram showing the spreading of collapsed sediment and mean width-averaged bed elevation difference between run with and without the large collapses.

Location map of the initial 10 collapses of 1 Mm³

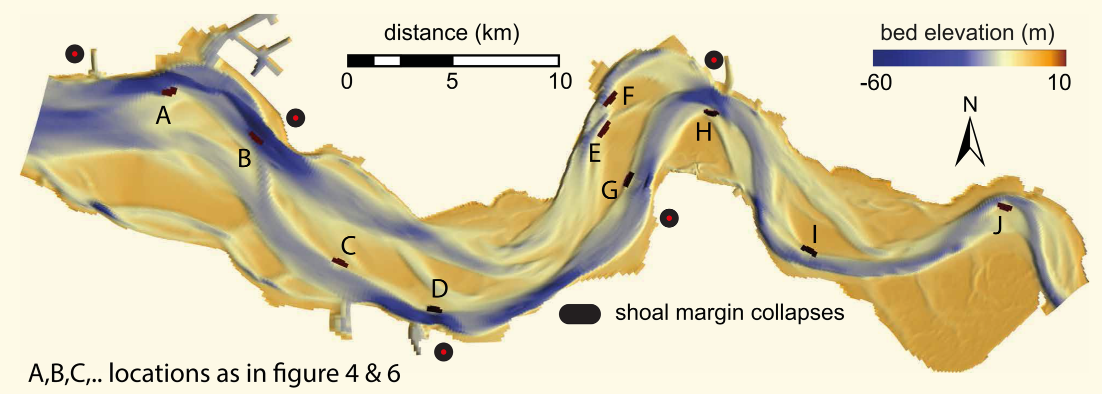


Fig. 5) **Modelled** shoal margin collapse locations for the scenario with initial 10 collapses.

Initial versus Yearly Collapses

Initial Collapses

- **Spreading** of the collapsed material is **not uniform throughout** the estuary.
- **Migration** of disturbance is dominant in **one direction,** depending on
  - **Flood-dominated channel (secondary channel), or**
  - **Ebb-dominated channel (main channel).**
- **Less spreading** in the secondary channel (e.g. locations E and F).
- Mean bed level difference **excites** over time.

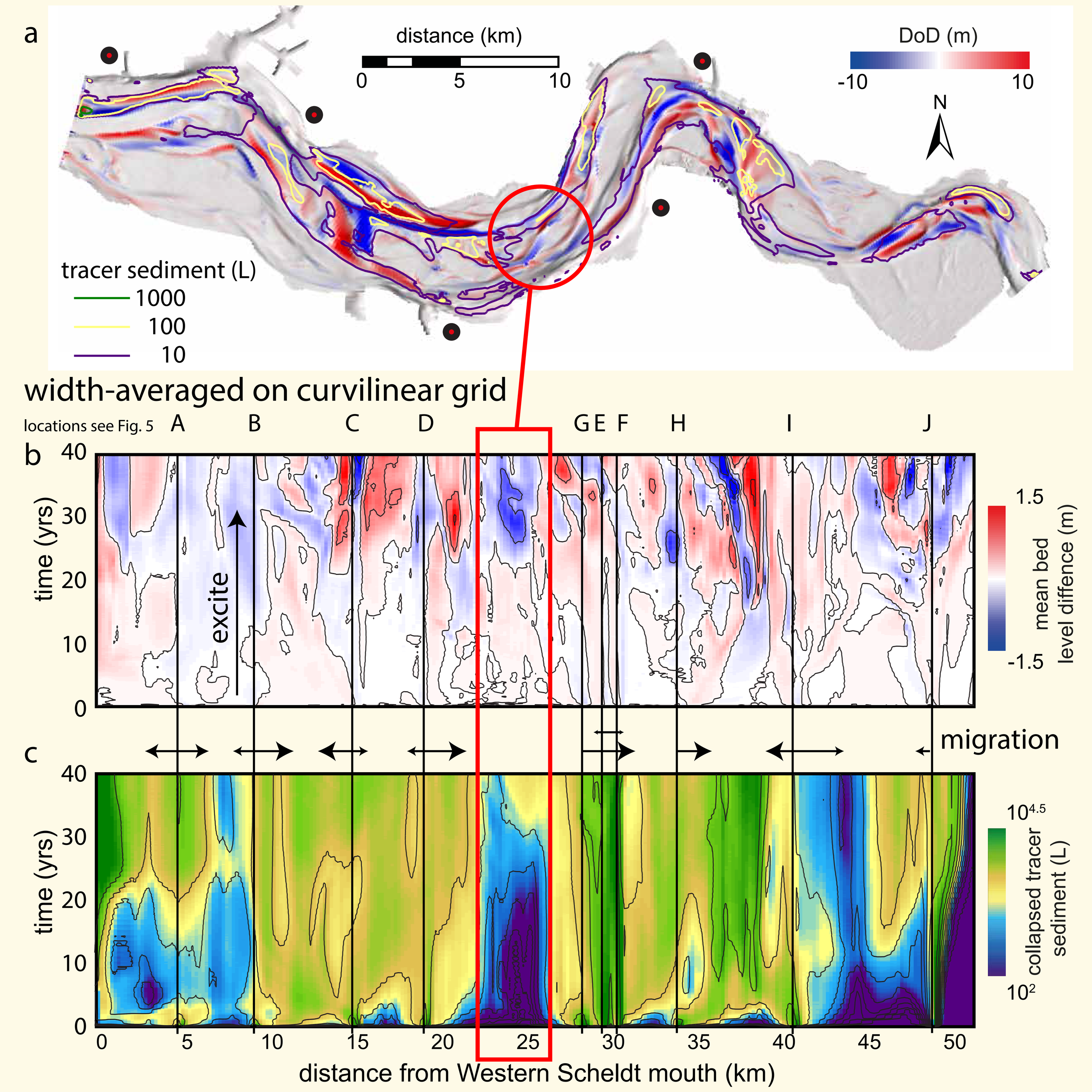


Fig. 6) a, DEM of Difference shows the difference between run with and without collapses after 40 yrs, and contours indicate distribution of the tracer sediment. Along estuary time-space diagram of the mean bed elevation difference (b) and collapsed sediment spreading (c), with indicated disturbance direction.

Yearly collapses

- **Dominant** locations with shoal margin collapses in model run.
- **Excitation** of disturbance, especially at **channel junctions.**
- **Damping** of the disturbance in **secondary channels.**
- **Migration** of the disturbance, difficult to identify for individual collapses.

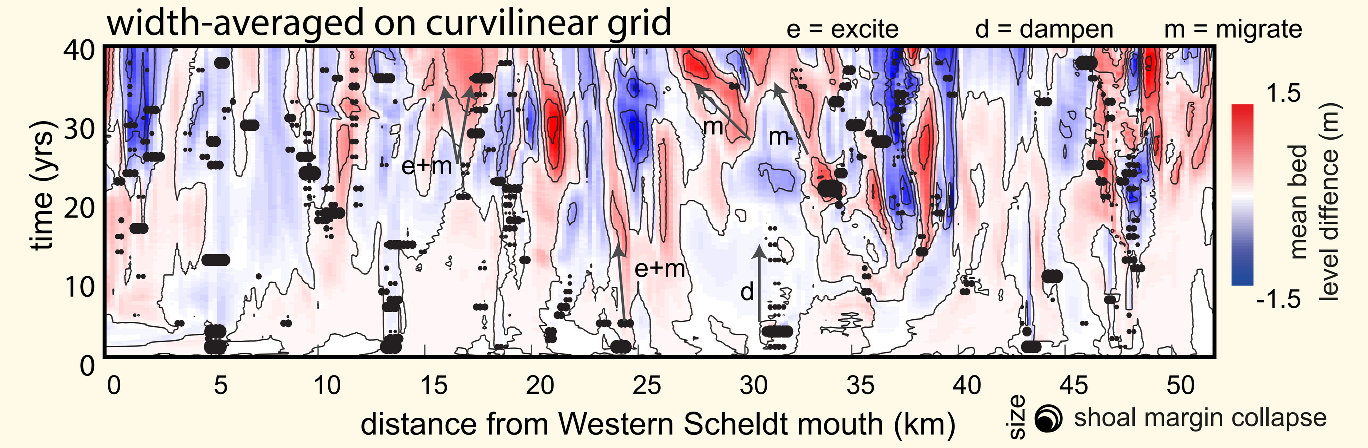


Fig. 7) Yearly collapses against run without collapses shows migration, excitation and damping of disturbance.

Channel Network Analysis *(Kleinhans et al., 2017)*

- **Various network scales** are determined: main, secondary, chute and marsh.
- Initial there is a **deep main channel** due to dredging activities.
- Morphodynamic modelling **decreases the channel depth** main channel.
- Model with **initial collapses** develops **towards** model **without disturbances**.
- **Yearly collapses** reduces the depth even more: **main equals secondary channel**.

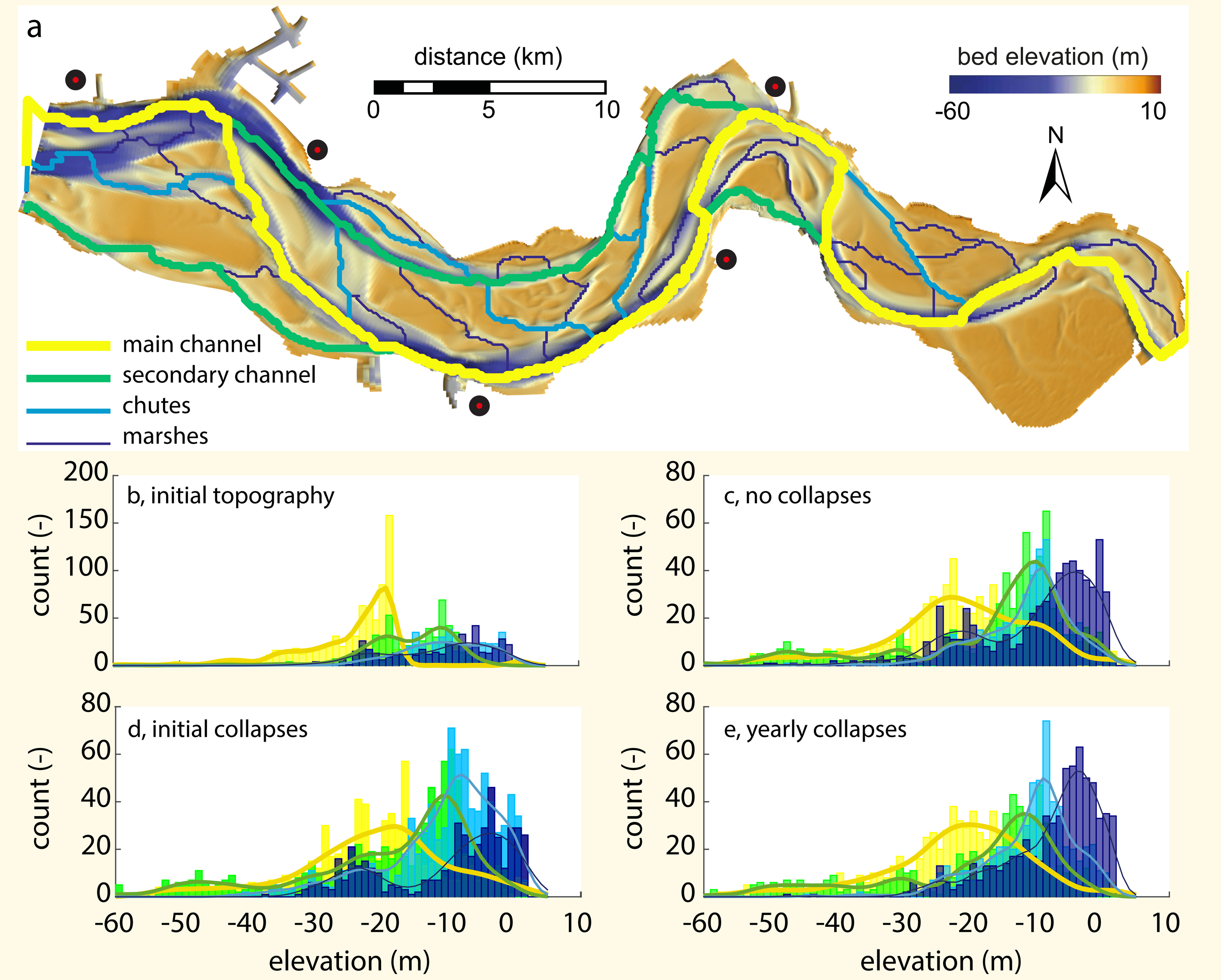


Fig. 8) Various network scales (a) and its depth distribution initially (b) and after 40 yrs morphodynamic modelling (c-e).

Conclusions

- Shoal margin collapses **excite the channel network** of sandy estuaries.
- **Volume** of the collapse and **grain-size determine magnitude** and **direction**.
- **Short-term**: the **morphodynamics** are affected by changing bed elevation in **longitudinal direction** but not in transverse direction. **Residual currents** were not affected by the collapses.
- **Long-term:** the disturbance **stimulate** morphological changes, especially when the disturbance reaches a **channel junction** affecting the bed elevation in **transverse direction** as well.
- Shoal margin collapses **reduces the depth** of the channels and **increases** the number of **smaller channels** on the tidal marshes according, which has **negative** effects for the **fairway** but **positive** effects for **ecological habitats.**

References & acknowledgements

Wilderom (1979), Resultaten van het vooroeverondervoor langs de Zeeuwse stromen (in Dutch). Technical report, Rijkswaterstaat, 1979.
Kleinhans et al. (2017), Computing Representative Networks for Braided Rivers. 33rd Intern. SoCG 2017, pp. 48:1-48:15.
Van Dijk et al. (Subm.), Probability and causes of shoal margin collapses in sandy estuary. to Earth Surface Processes and Landforms. pre-print available through doi:10.17605/OSF.IO/MYRKW (EarthArXiv)

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