Scale effects on wave-induced sediment mobility in the Metronome tidal facility

E.P. van Onselen[1], B.G. Ruessink[1], M.G. Kleinhans[1]
[1]Utrecht University, e.p.vanonselen@students.uu.nl, b.g.ruessink@uu.nl, m.g.kleinhans@uu.nl

Universiteit Utrecht

Introduction

- Waves in the Metronome (Fig. 1) rework the ebb delta
- Aim: translate Metronome waves to natural scale to (1) study scale effects on sediment mobility and (2) place the observed morphological developments in the Metronome in a natural perspective
- Comparison to known scaling laws

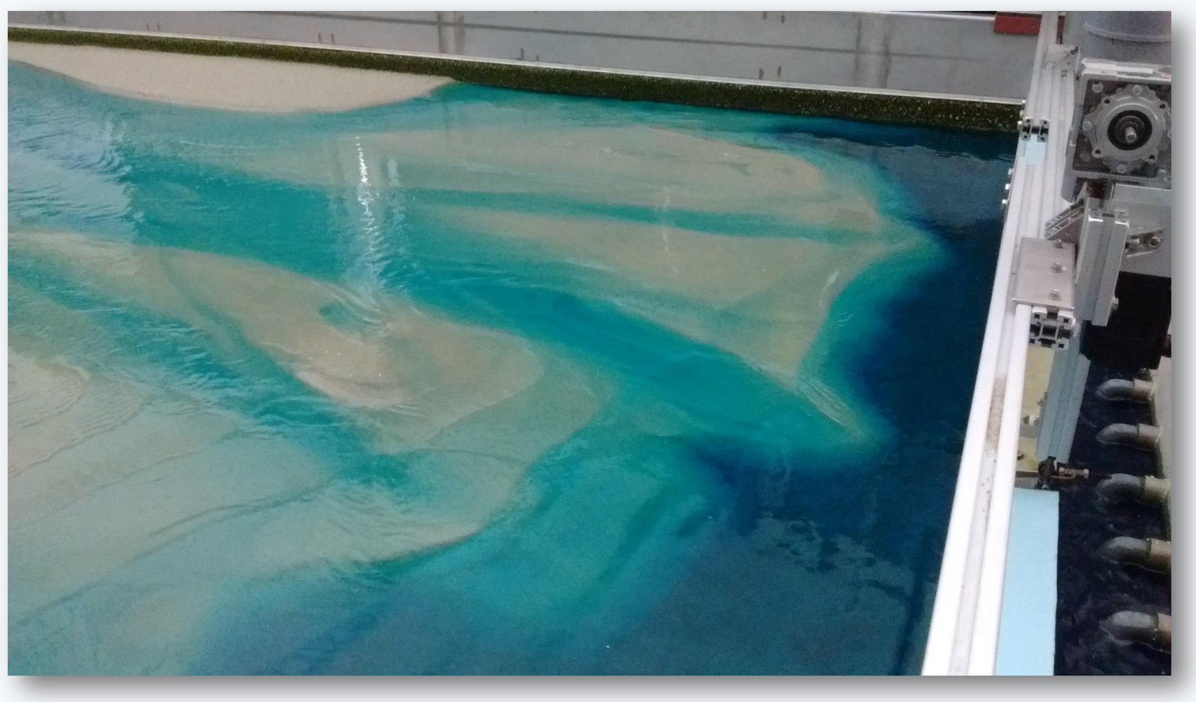

Fig. 1. In the Metronome, a 20x3 m tilting flume, we recreate entire estuaries. Shown on this photo: a self-formed ebb delta. Wave generator mechanism visible on the far right side.

Methods

Metronome scale model

- Measured time series for cross-shore positions over simplified bathymetries (Fig. 2.) Wave parameters, mobility computed from time series

SWASH wave model

- Comparison to SWASH[1] wave model at 1:1 and at 1:500 scale for varying geometric distortions using Froude-scaled input at the seaward boundary.

Scaling: creating the link between scale model and nature

- Froude scaling: Froude number constant across scales
- Steep slopes in experiment vs gentle slopes in nature: Geometric distortion.
- Sediment size scaling required to maintain similitude in sediment mobility

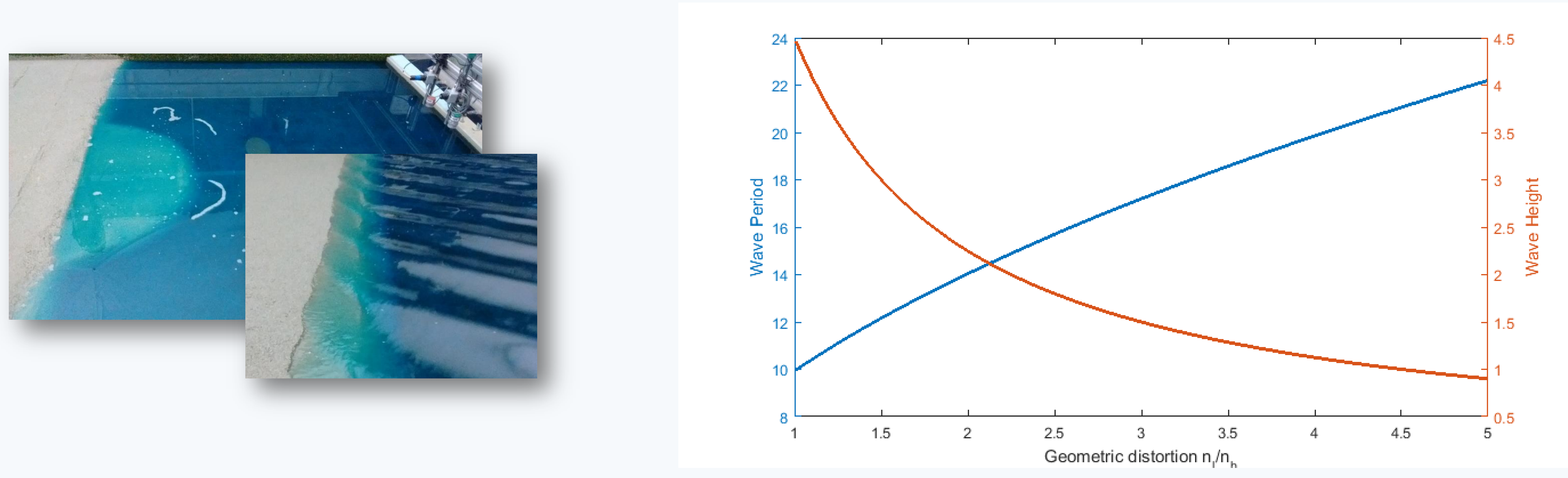

Fig. 2. Left: simple experimental ebb delta, waves; Right: wave period and height for experimental waves with H = 0.01 m and T = 0.5 s when scaled up 500 times for a variable geometric distortion (x-axis).

Results

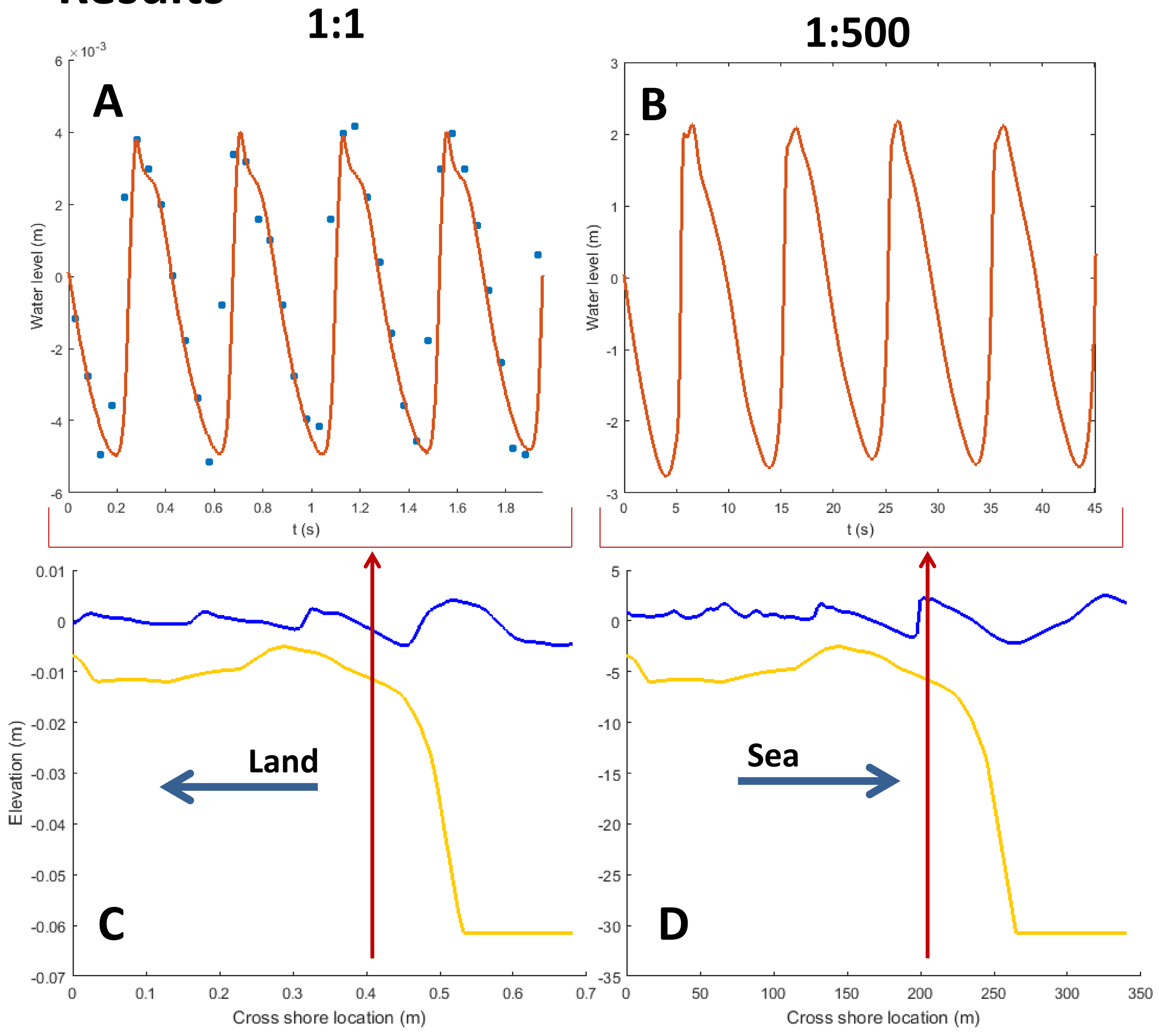

Fig. 3. **Example of measurements and model output** (A, B) example of time series corresponding to cross-shore position indicated by the vertical arrows, (A) 1:1 modelled waves, blue dots are measurements and fit over modelled waves very well; (B) is 1:500 modelled waves. (C) snapshot of waves (1:1 modelled). (D) snapshot of waves (1:500 modelled). Note scales along axes and Froude scaling: i.e. Length scale n_l = 500, wave period scale $n_T = n_l^{0.5}$

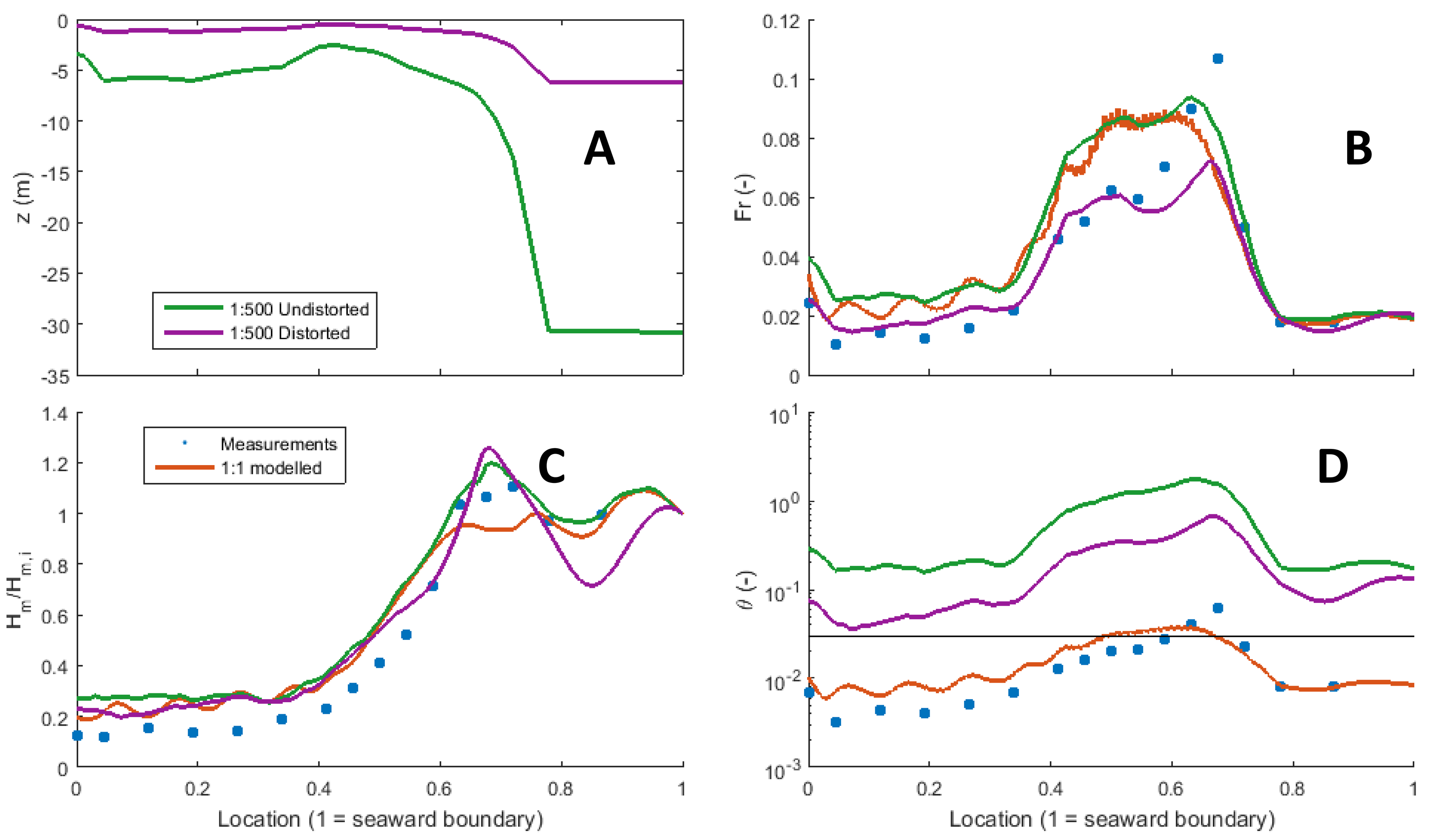

Fig. 4. **Cross shore development of measured and modelled parameters.** (A) bathymetry, (B) Froude number, (C) relative mean waveheigth and (D) Shields number (for D_{50} = 0.0006 m), horizontal line indicates critical Shields number. Note similitude of Froude number (B) and wave height/energy loss (C). Shields number is about 30x higher in the full-scale undistorted model when n_{D50} = 1. For a distortion of 5 (purple line), the Shields number is about 10x higher than in the Metronome

Main Conclusions

- Flow characteristics (e.g. wave energy loss, Froude number) in similitude between scales: measured, 1:1 and 1:500 modelled (Fig. 4B,C)
- Up to 30x higher Shields number if model is undistorted and sediment is not scaled. Overestimation decreases with distortion (Fig. 4D)
- Based on Noda's (1972) D_{50} scaling law[2],[3], we simulate long (almost infragravity) waves over a gravel bed (Fig. 5).
- For distortions up to 5, metronome wave-induced sediment mobility is lower than expected in nature
- Metronome waves should be made shorter (and higher) to more closely resemble gravity waves and to increase mobility
- $n_{D50} = n_h^y$, where y is a function of geometric distortion, rather than a fixed value (Fig. 6), although an exact relation requires more data.

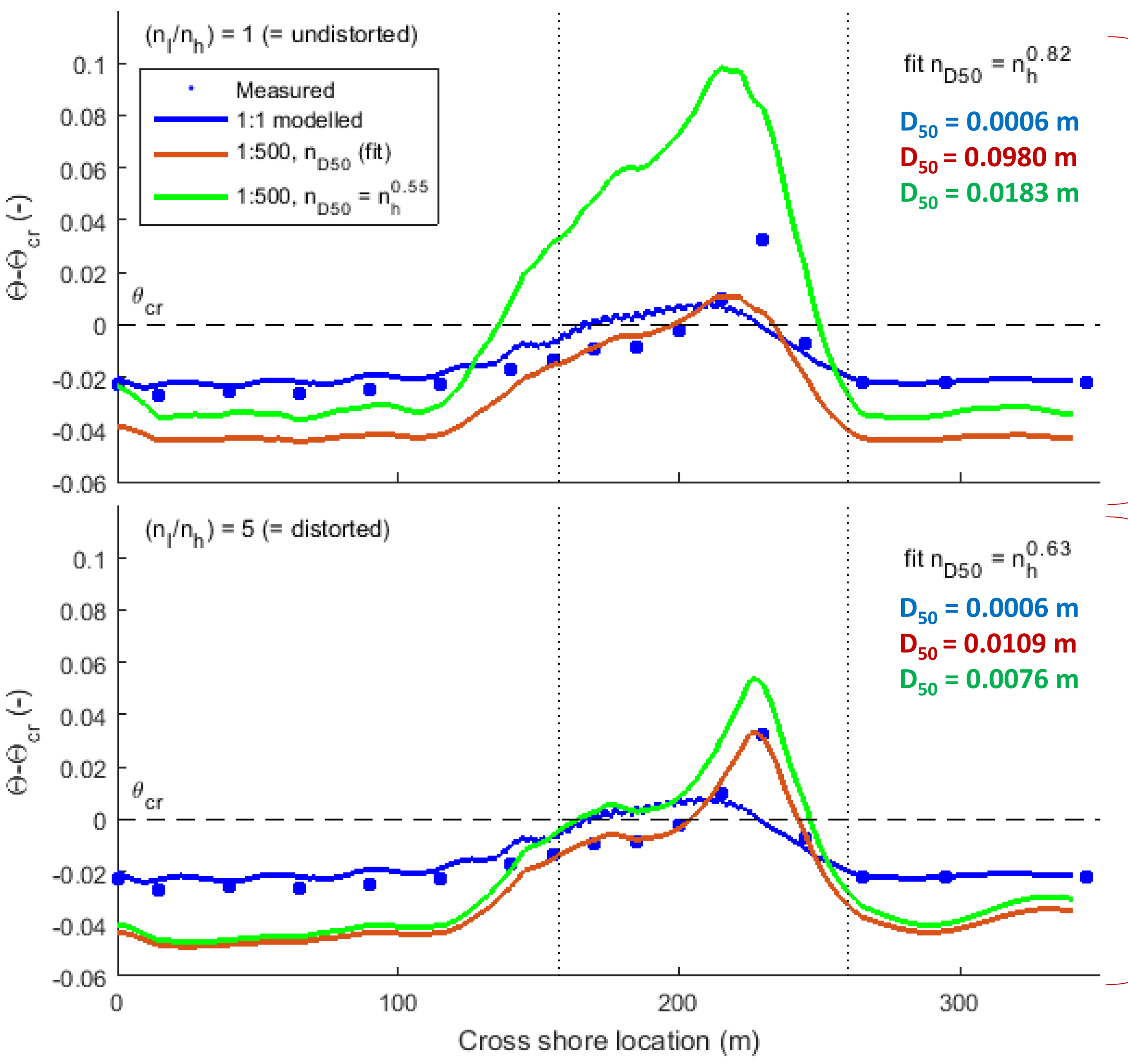

Fig. 5. **Development of ϑ-ϑ_{cr} over experimental delta for undistorted geometry (upper) and distorted geometry (lower).** Blue line shows development of ϑ-ϑ_{cr} based on measurements in the Metronome (blue crosses). Green line shows the development of ϑ-ϑ_{cr} with $n_{D50} = n_h^{0.55}$ by Noda(1972)[2], which clearly yields higher Shields numbers in the undistorted model, but holds reasonably well for n_l/n_h = 5, conform his findings. Red line gives an alternative power y in $n_{D50} = n_h^y$ which best fits to the measured result in the interval between the vertical dotted lines.

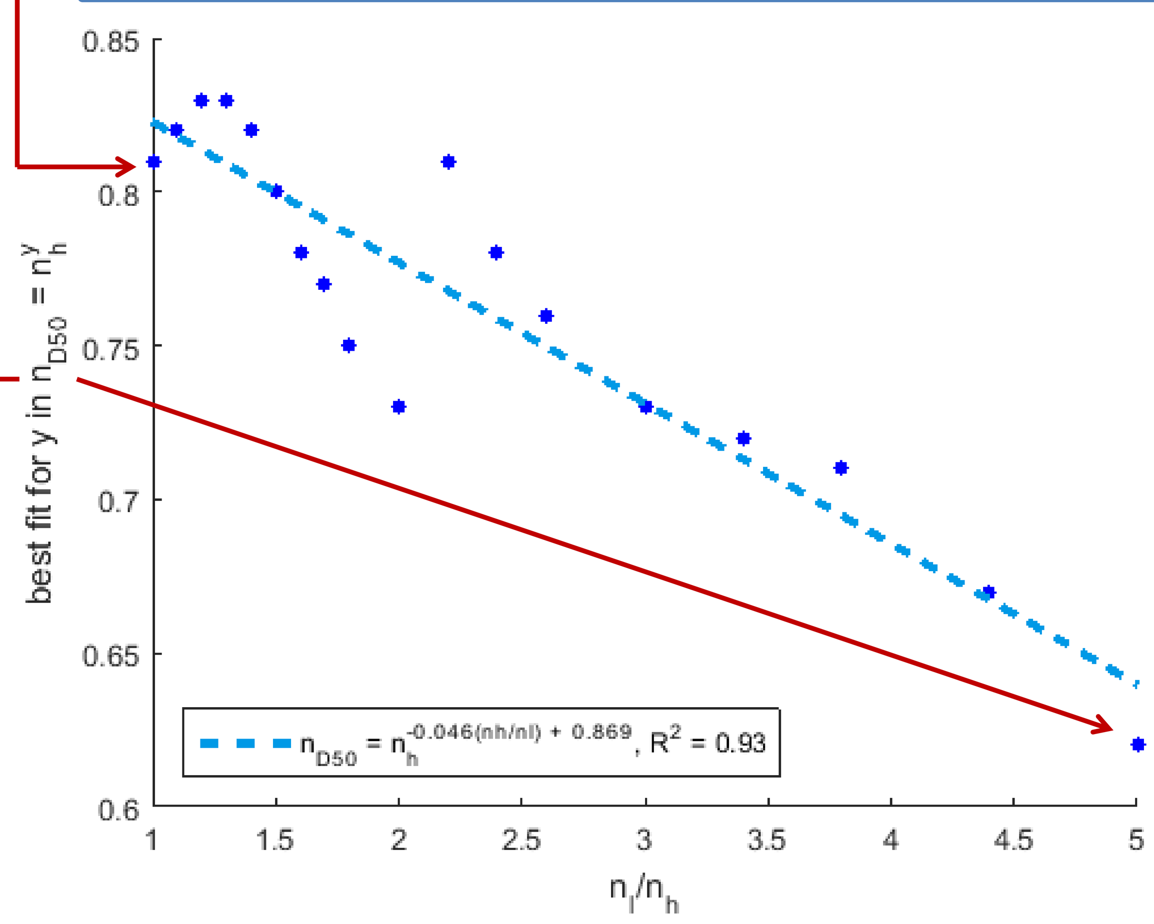

Fig. 6. **Dependence of power y in $n_{D50} = n_h^y$ on geometric distortion.** Result shows that power y is not fixed across distortion ratios. Best fit for mobility similitude requires larger n_{D50} than found in other studies.

References

[1] Zijlema, M., Stelling, G., & Smit, P. (2011). SWASH: An operational public domain code for simulating wave fields and rapidly varied flows in coastal waters. *Coastal Engineering*, *58*(10), 992-1012.
[2]] Noda, E. K. (1972). EQUILIBRIUM BEACH PROFILE SCALE-MODEL. *Journal of Waterways, Harbors & Coast Eng Div*, *98*(9367 Proceeding).
[3] Van Rijn, L. C., Tonnon, P. K., Sánchez-Arcilla, A., Cáceres, I., & Grüne, J. (2011). Scaling laws for beach and dune erosion processes. *Coastal Engineering*, *58*(7), 623-636.