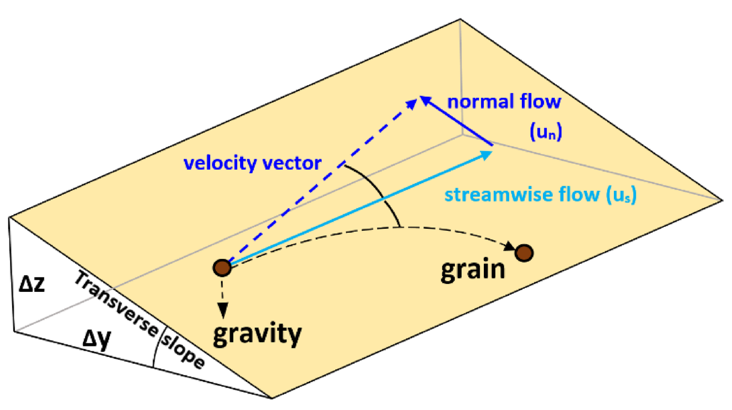
Sediment transport on transverse bed slopes in rotating annular flume experiments

Anne W. Baar, Steven A.H. Weisscher , Jaco de Smit, Wim S.J. Uijttewaal, Maarten G. Kleinhans

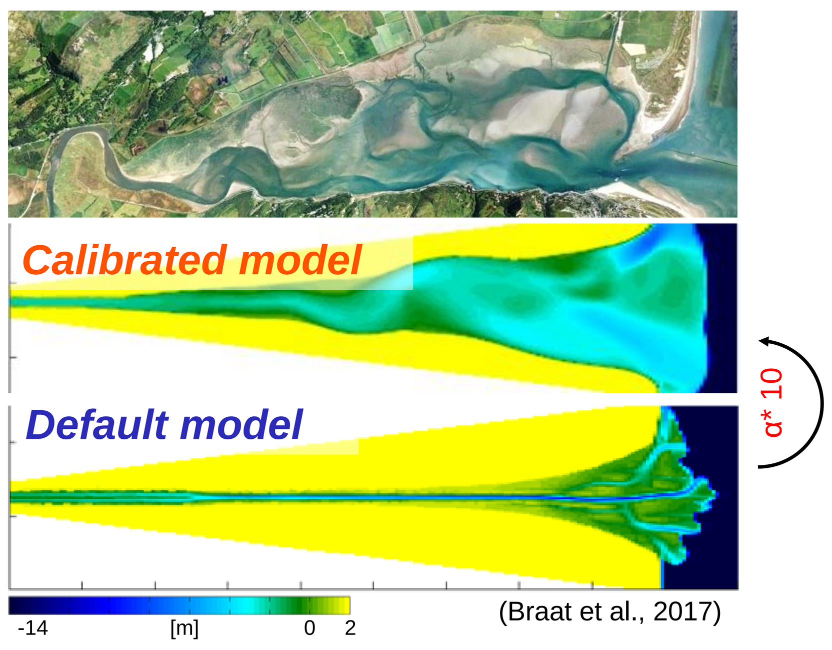
Universiteit Utrecht
Faculty of Geosciences
Research group
River and delta morphodynamics

Transverse slope effects in morphodynamic models

Current transverse slope predictors are based on a specific sediment transport mechanism, but are used in morphodynamic models where al processes act in combination. As a result, current models need to be calibrated on existing morphology



Forces acting on a transverse bed slope

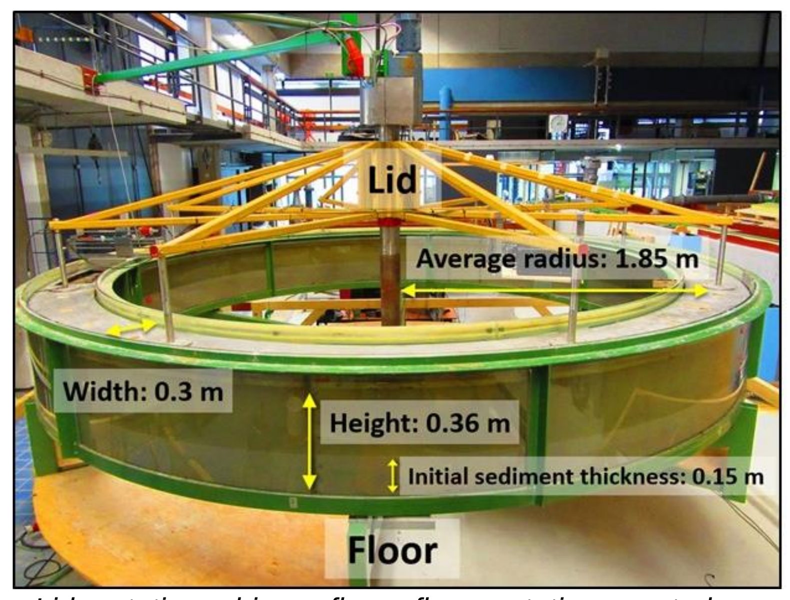


(Braat et al., 2017)

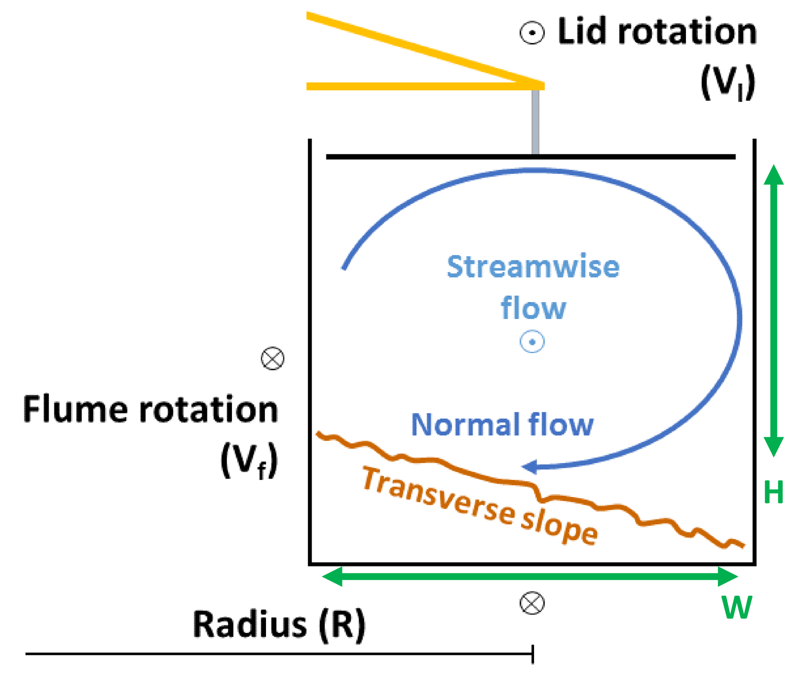
Transverse bed slope effect: $\frac{u_n}{u_s} = \alpha\theta^{\beta}\frac{dz}{dy}$

Experiments in annular flume

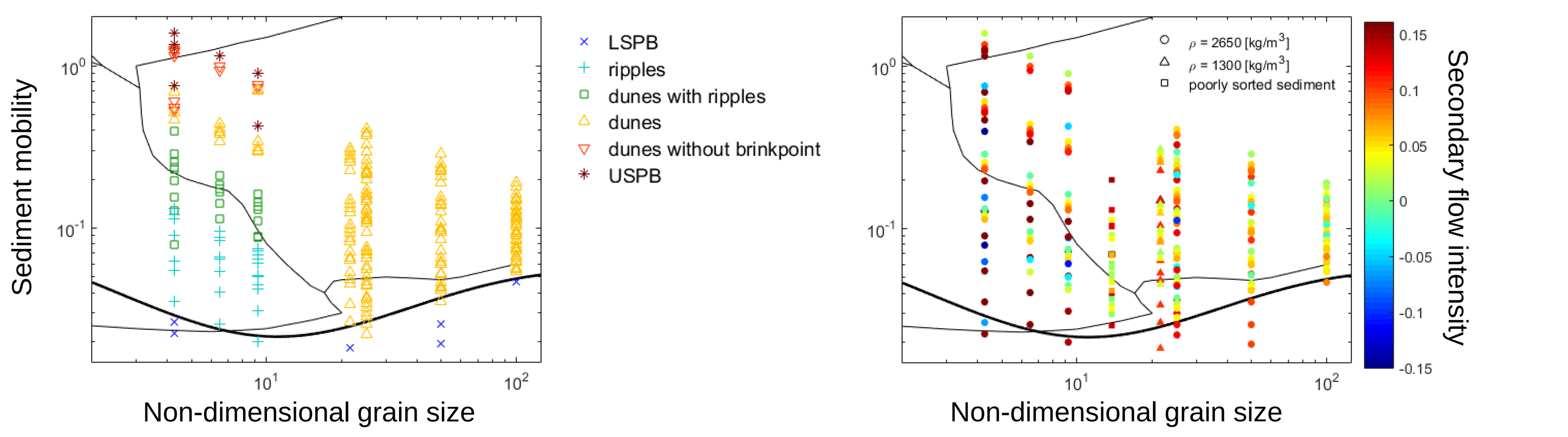
Objective: quantify slope effects for a large range of flow conditions and sediment characteristics, to obtain parameters for morphodynamic models that cover all sediment transport modes and bedform regimes.



Lid rotation drives flow, floor rotation controls secondary flow intensity



Experimental range summarized in Shields diagram



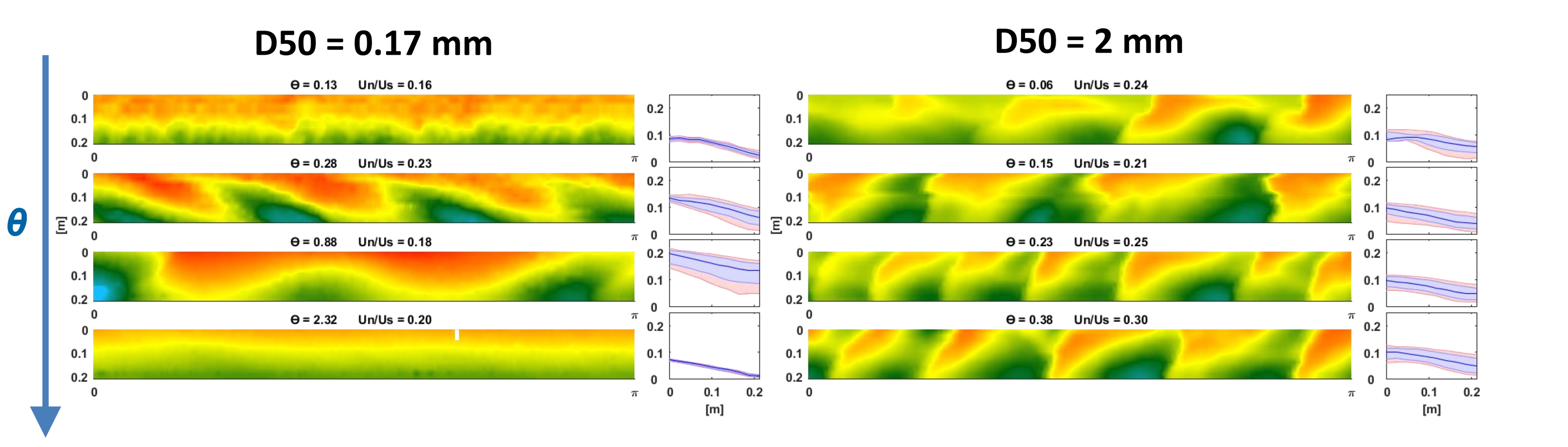
Secondary flow in the annular flume

An analytical flow model is developed to predict near-bed streamwise and normal flow velocities at any combination of lid and floor rotation. This model assumes that shear stresses and centrifugal forces caused by lid and floor rotation are balanced by frictional forces of the lid and the walls of the flume. The model is calibrated on flow velocity measurements with a Vectrino (acoustic Doppler velocimeter).

Secondary flow intensity: $$\frac{u_n}{u_s} = \underbrace{b}_{\text{calibration parameter}}\ \underbrace{\frac{HW}{R}}_{\text{mass}}\ \underbrace{\frac{1}{c_{wall}(W+H)+c_{bed}W}}_{\text{friction}}\ \underbrace{\left(V_{lid}^2 - \frac{5}{4}V_{floor}^2 - 2V_{lid}V_{floor}\right)}_{\text{centrifugal acceleration}}$$

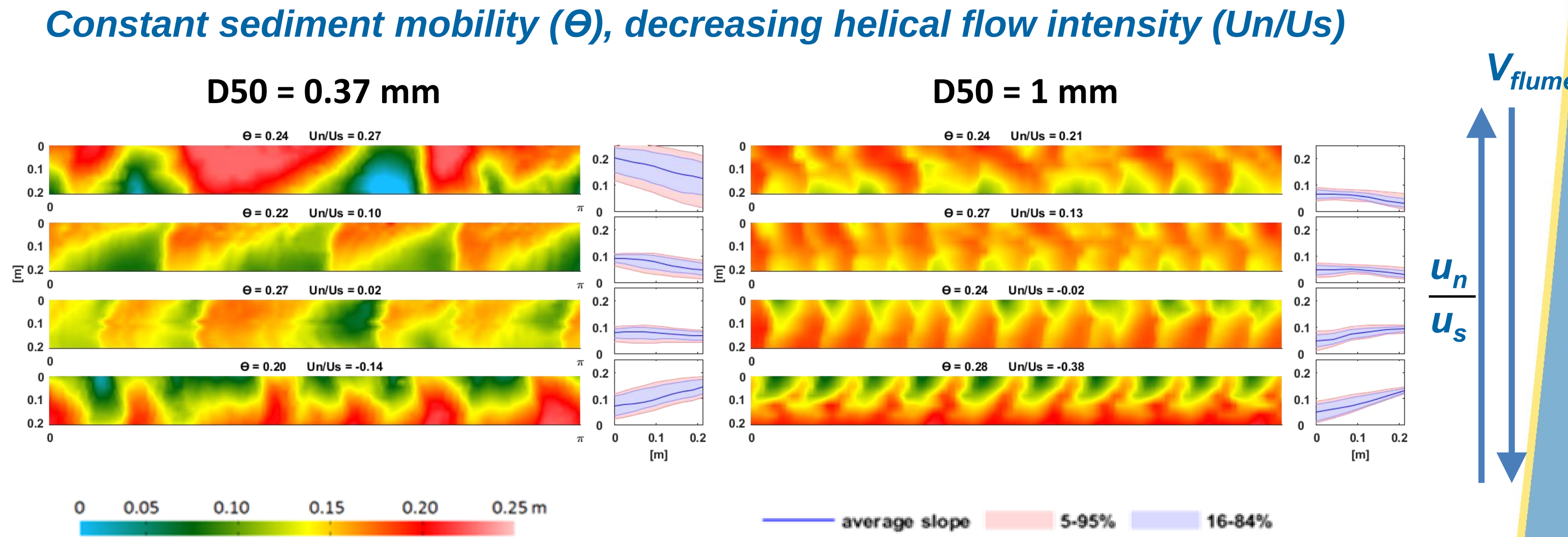
Uniform sediment

Constant helical flow intensity (Un/Us), increasing sediment mobility (Θ)

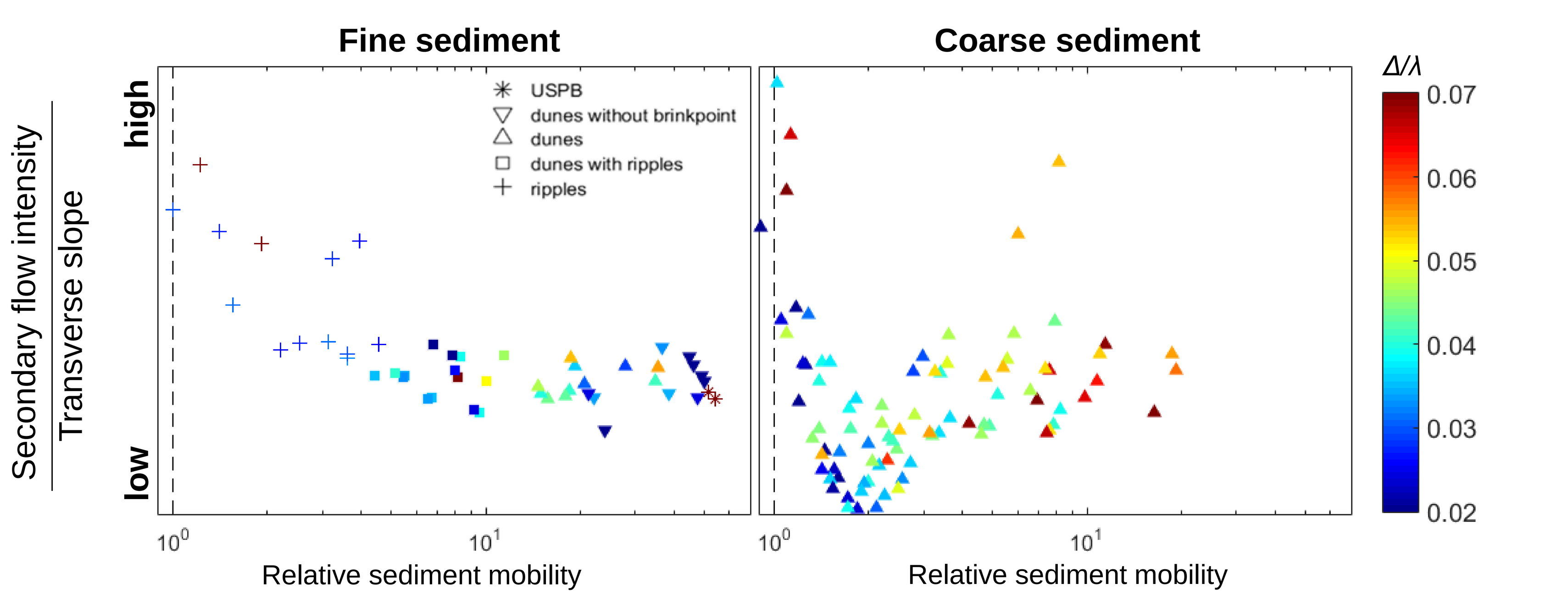


Resulting morphology (top view) of several experiments with corresponding transverse slopes. The width is measured from the inner bend

Constant sediment mobility (Θ), decreasing helical flow intensity (Un/Us)

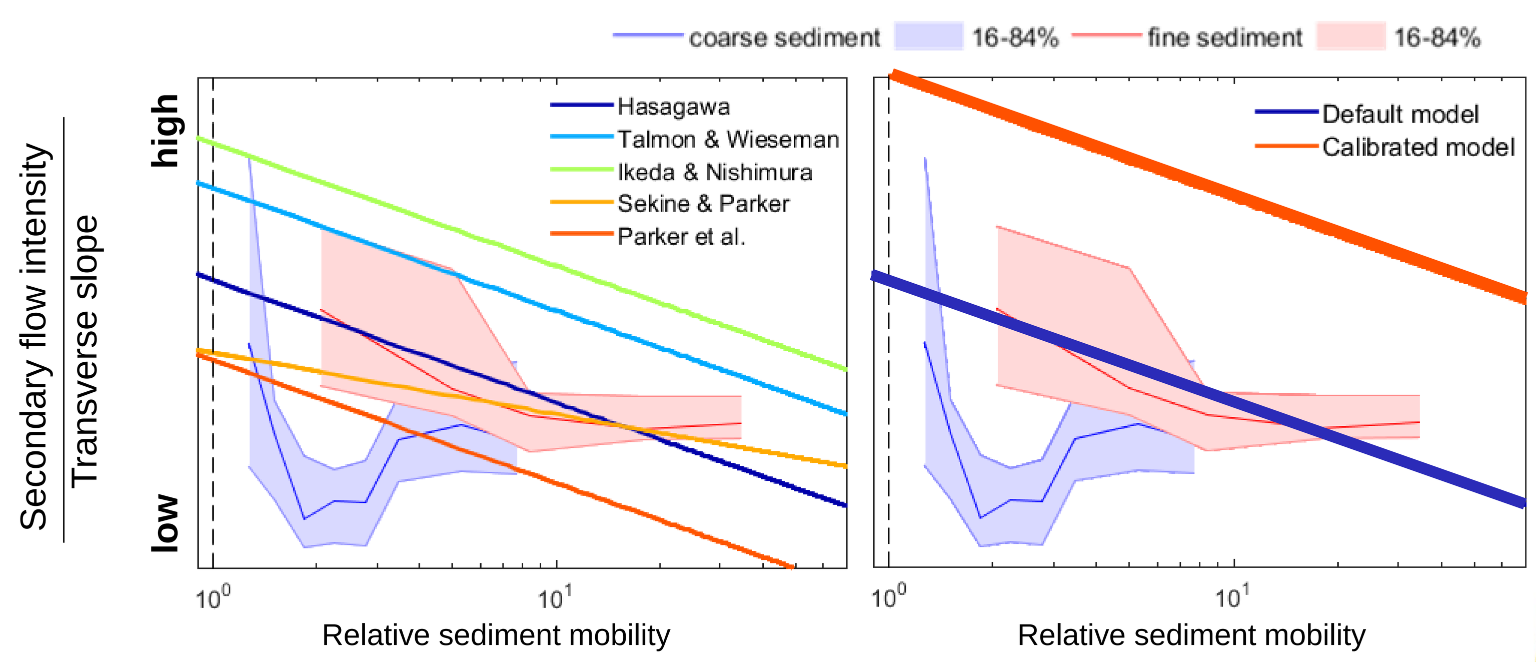


Slope effects show different trends for fine and coarse sediment



Slope effect against relative sediment mobility (θ/ θ_c). Colors indicate bedform height over length (Δ/λ) and symbols indicate bedform regime.

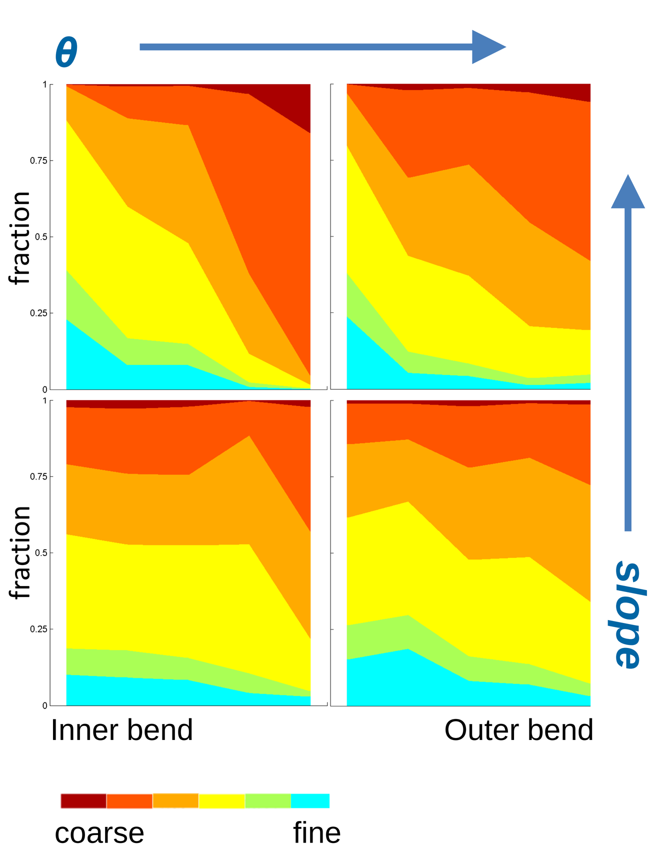
Slope effects are in the same order of magnitude as existing predictors



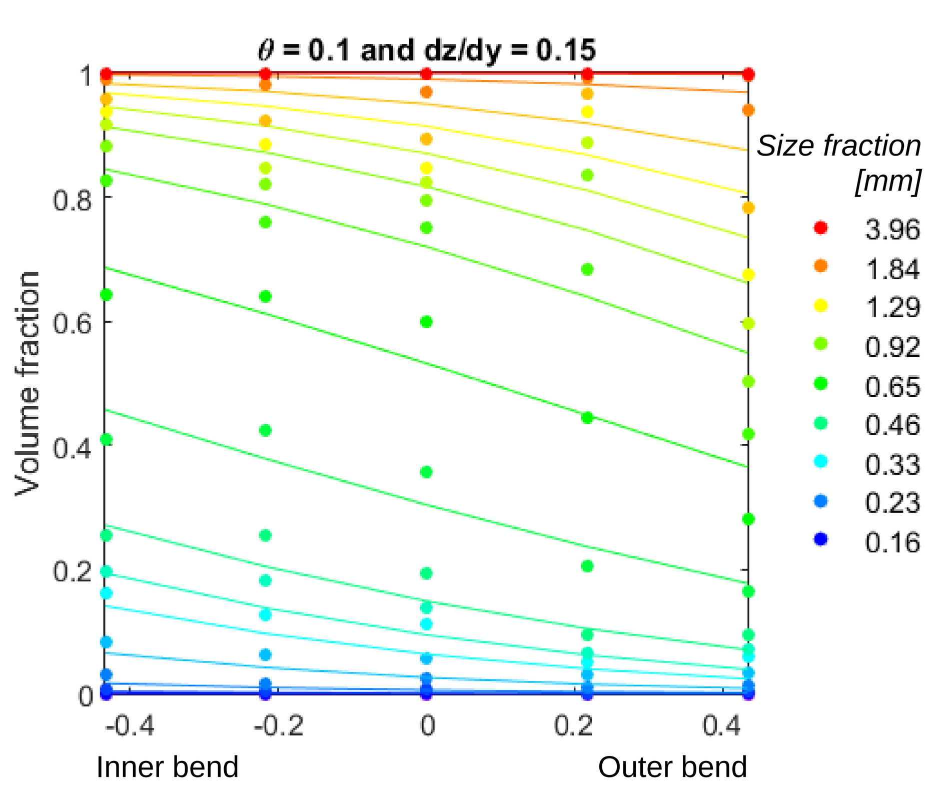
Experimentally determined slope factors compared with process-specific predictors, and with typical parameter values as used in morphological modelling.

Poorly sorted sediment

Grain sorting as function of transverse slope



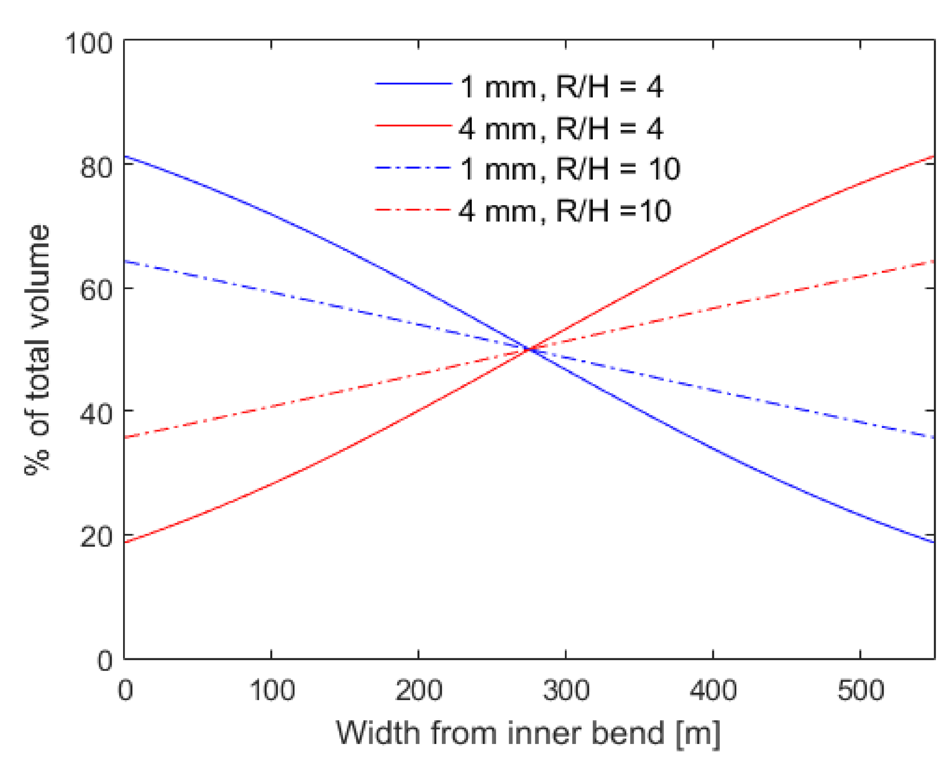
Measured sediment volumes over the radius for 4 experiments with varying transverse slope and sediment mobility. Colors indicate grain size.



Example of measured (dots) and predicted (lines) relative volumes ($F/F_{i,ref}$) of each sediment fraction ($\phi_{i,rel}$) over the relative radius ($(r-r_c)/W$). Colors indicate grain size fraction.

Bend sorting: $\frac{F_i}{F_{i,ref}} = \exp\left[\left(11\phi_{i,rel}\frac{r-r_c}{W} - \phi_{i,rel}^2\right)\frac{dz}{dy}\right]$

Next step: comparison with field data



Bend sorting function for a relatively fine and coarse fraction (D_{50} = 2 mm). In this example, the dimensions of 2 river bends in the River Rhine are used. A sharper bend results in a steeper transverse slope and thus sorting becomes more pronounced.

Conclusions

- Slope effects vary for fine and coarse sediment, since bedforms and sediment transport mode have a strong influence
- Results are in contrast with the tendency to increase slope effects in current morphodynamic models
- Bend sorting is obtained as a function of transverse slope, with the objective to improve sorting functions in morphodynamic models

Acknowledgements

NWO Applied and Engineering Sciences
Deltares Enabling Delta Life
TU Delft