Tidal bedforms dynamics, Weser Estuary, Germany

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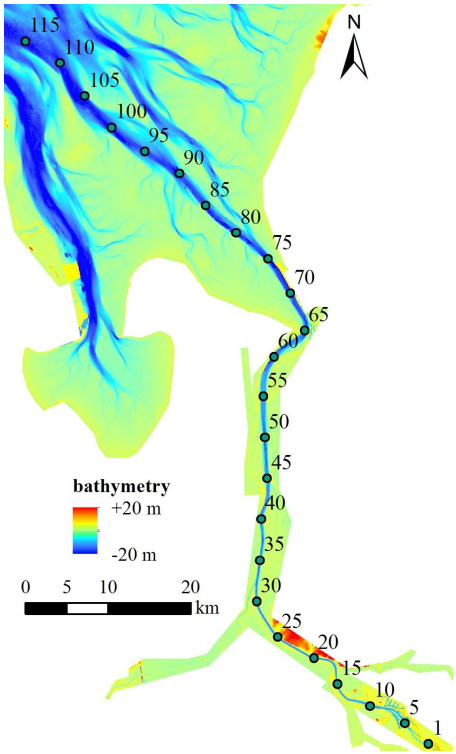
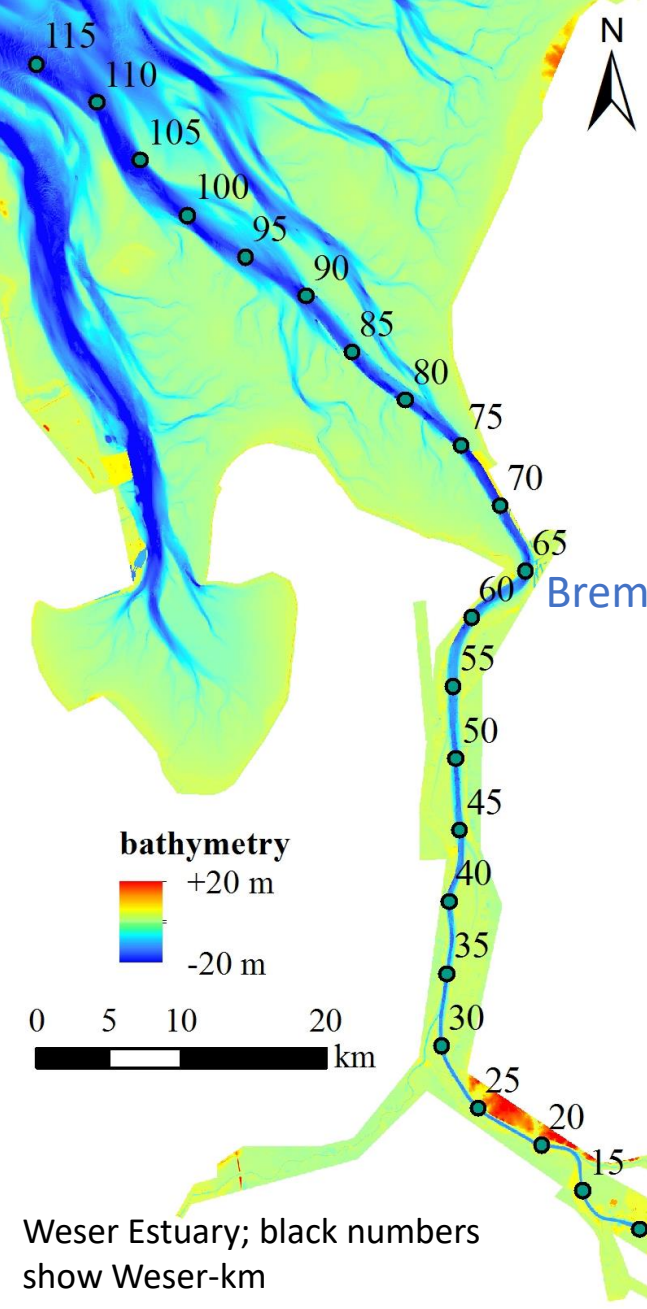
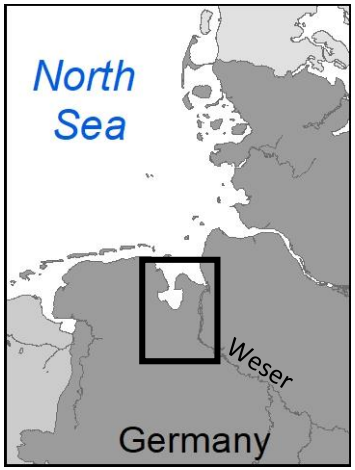


Study area: Weser Estuary, Northern Germany from Weser-km 0 (in Bremen close to the tidal weir) to Weser-km 111 (in the North Sea)

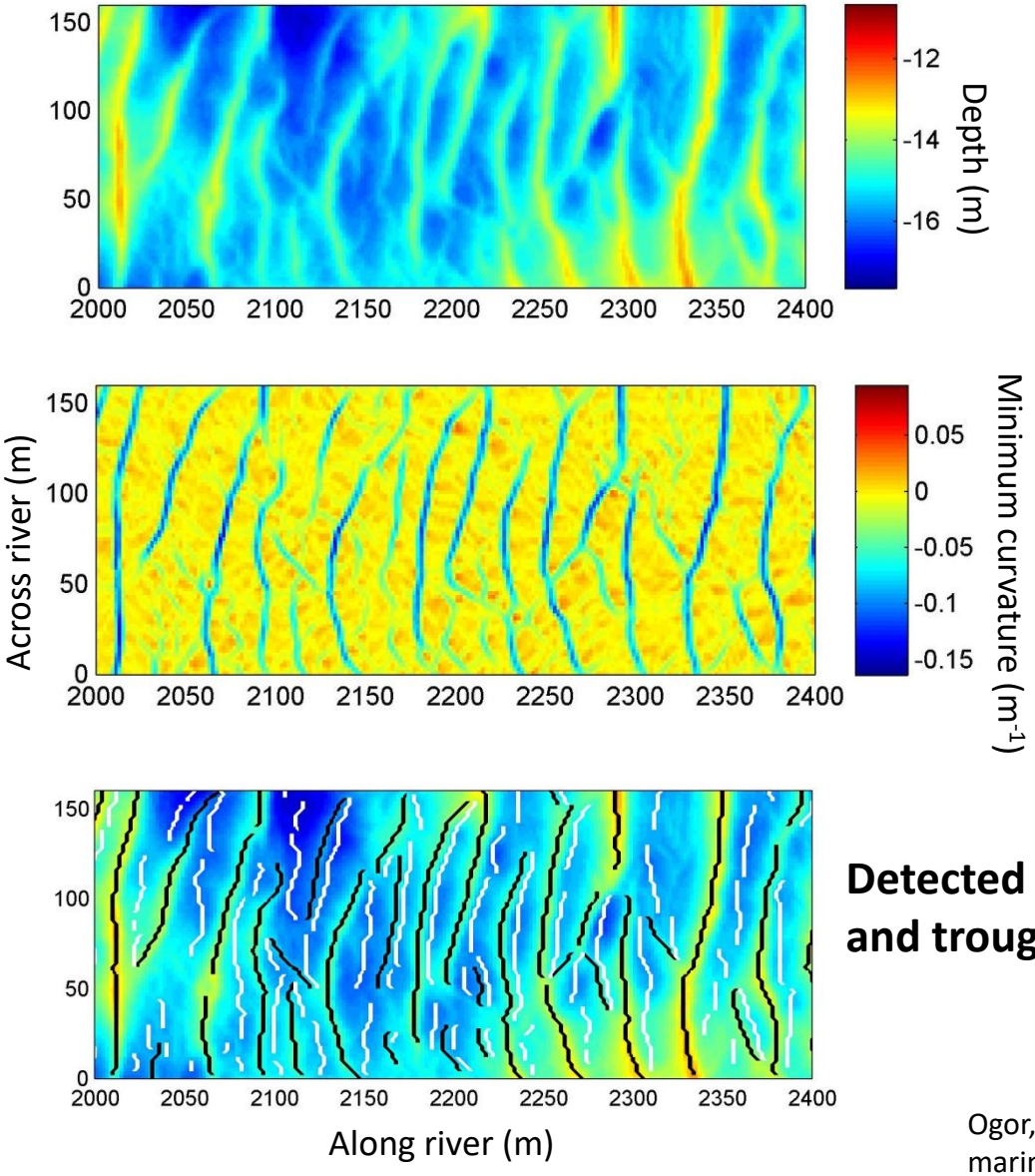
Fresh water discharge = 120 - 1200 m³/s
Semi-diurnal tide, mean tidal range in Bremerhaven = 3.76 m
in Bremen = 4.12 m
Sediment = medium to coarse sand
apart from Weser-km 55-70 = mud (Estuarine Turbidity Maximum)



Weser Estuary; black numbers show Weser-km



Analysed data:
Gridded bathymetry (grid size 2 m),
100 m on each side of the waterway
Available ca. every month
Years 2009-2011



Bedform detection

Crestlines detected in 3D using minimum curvature (following Ogor, 2018) + image analysis

Trough lines detected first as minimum elevation between 2 crests + image analysis

Detected crestlines (black) and trough lines (white)

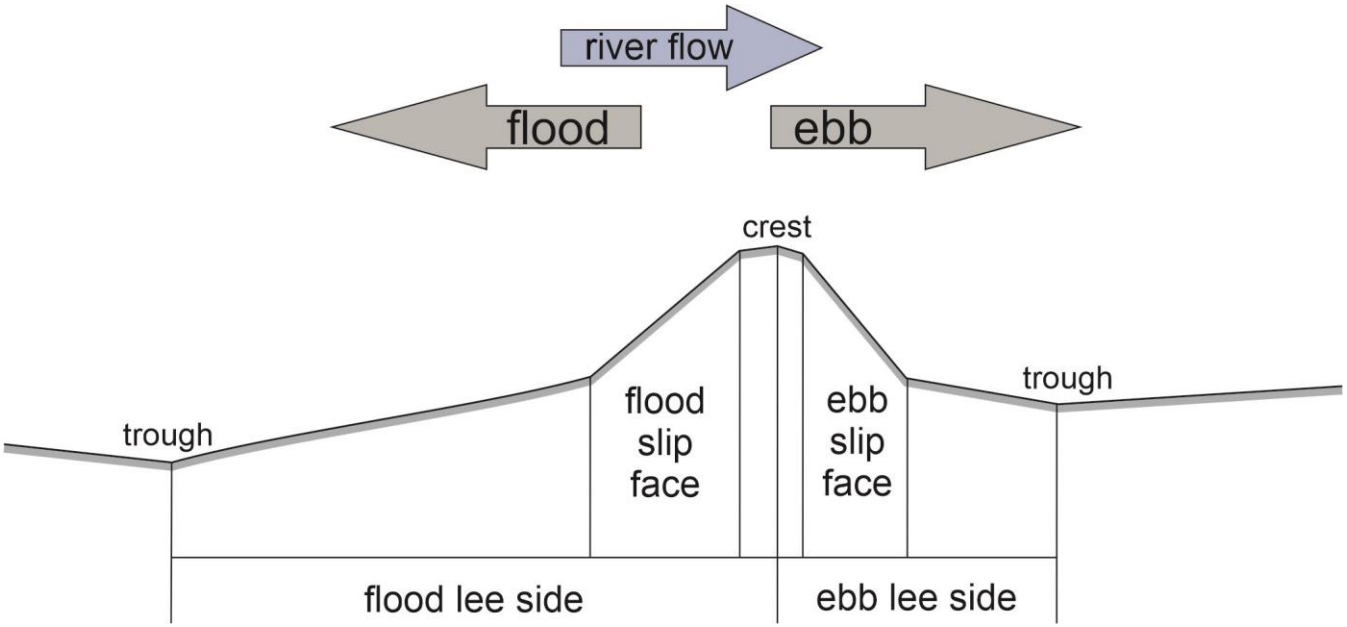
Ogor, 2018. Design of algorithms for the automatic characterization of marine dune morphology and dynamics. PhD Thesis, ENSTA Bretagne

Quantities calculated for each bedform:

Length & height
Height and length of ebb and flood lee sides
Asymmetry (L flood / L bedform)
Mean & maximum angle ebb and flood lee side
Number & % of ebb slip face, flood slip face, “both” slip face

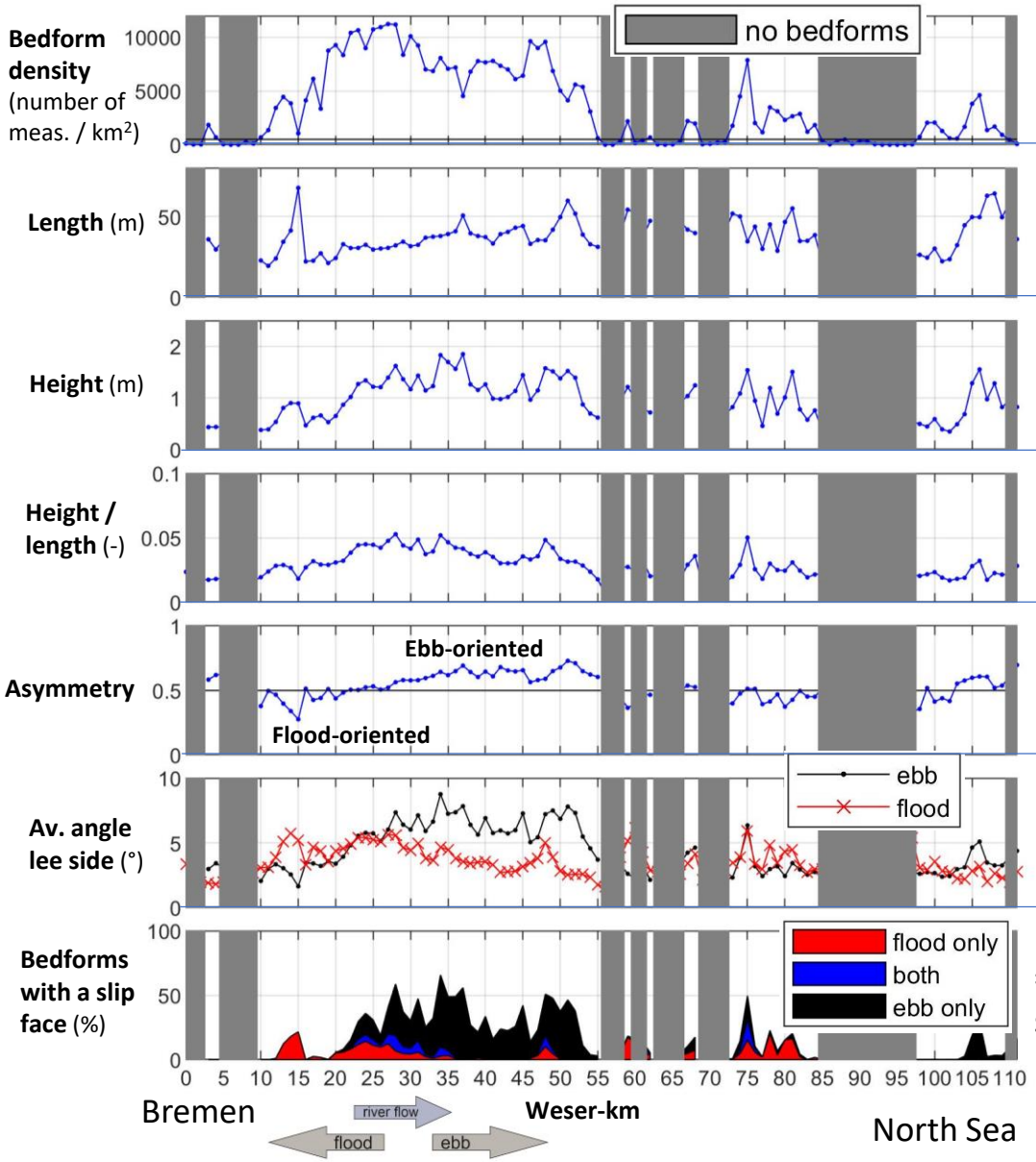
Quantities averaged every km
Bedform density (number of bedforms / km^2)

Slip face: angle >= 15°
Likely presence of flow separation & turbulent wake
➔ Proxy for bedform roughness (Lefebvre, 2019)



Lefebvre, A., 2019. Three-dimensional flow above river bedforms: Insights from numerical modeling of a natural dune field (Río Paraná, Argentina). Journal of Geophysical Research: Earth Surface, 124, 2241– 2264. https://doi.org/10.1029/2018JF004928

Average 2009-2011



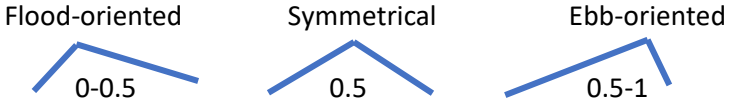
Bedform density = measure of bedform presence
Bedform density < 500 bedforms / km² = no bedform

Mean length 40 m
Standard deviation 20 m

Mean height 1 m
Standard deviation 0.4 m

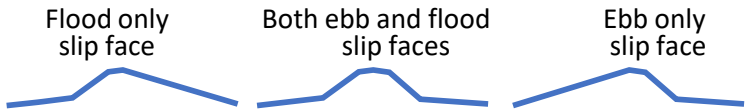
Height / length = measure of bedform steepness;
generally 0.01 < dunes < 0.1

Asymmetry = measure of bedform orientation

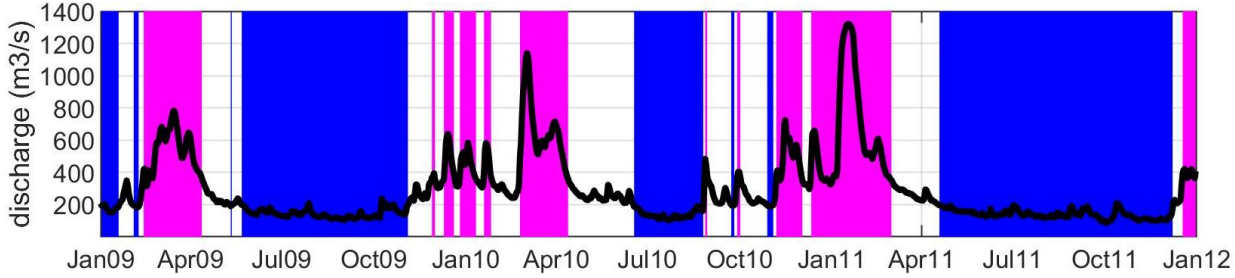


Average angle of flood and ebb lee side =
measure of bedform steepness and orientation

Percentage of bedforms with a slip face (angle > 15°)
= measure of bedform shape + potential for flow separation, turbulent wake and roughness



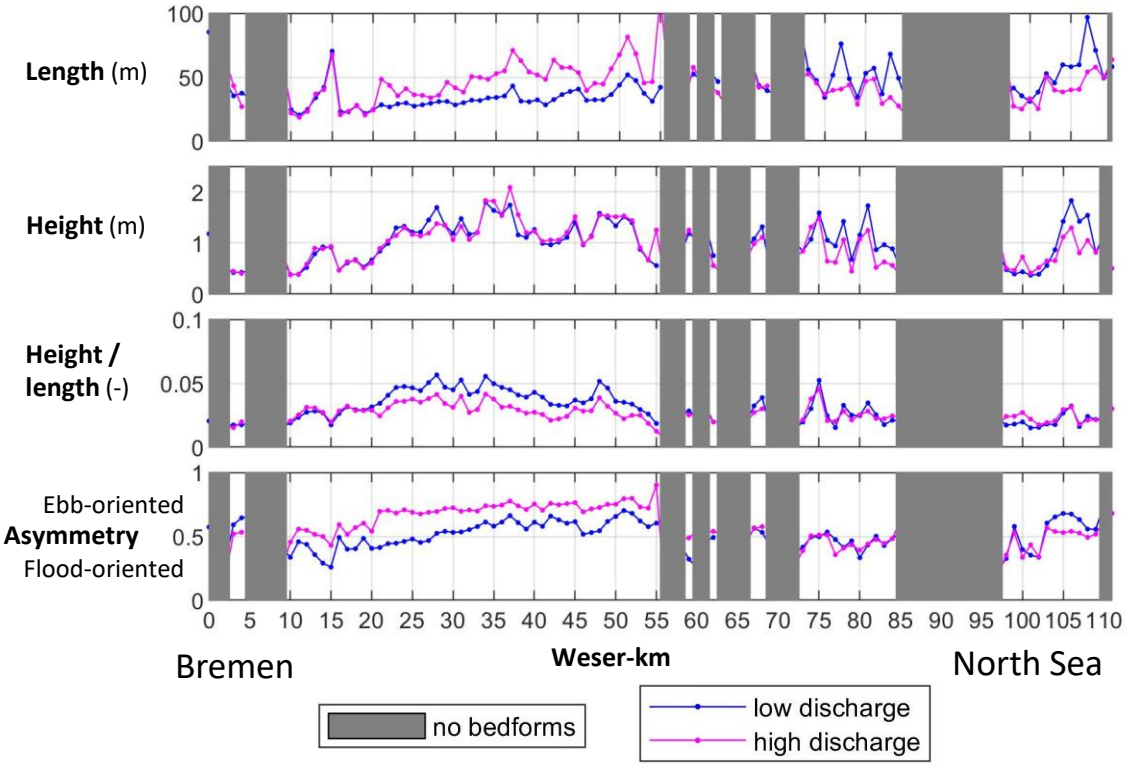
Difference between high and low discharge



High discharge: winter & spring discharge > 350 m/s^3

Low discharge: summer & autumn discharge < 200 m/s^3

Average high discharge & low discharge

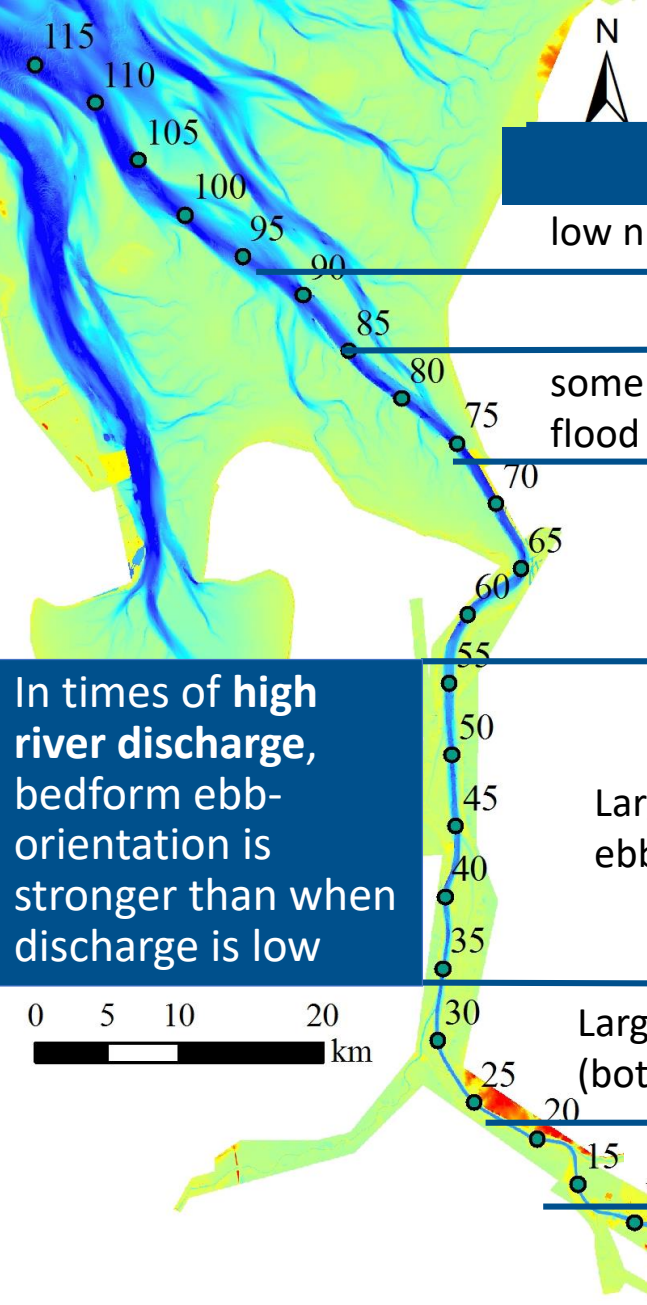


In times of high discharge, bedforms are longer and steeper than during low discharge;
only small influence of discharge on height

In times of high discharge, bedforms are generally ebb-oriented

In times of low discharge, bedforms transition from flood-directed in the inner estuary to ebb-oriented in the middle estuary

Preliminary interpretation and summary



Bedform morphology	Driving processes
low number of relatively flat bedforms	Outer estuary: strong local variations in tidal asymmetry, + maintenance dredging
no bedforms	
some symmetrical & steep (mainly flood slip face) bedforms	
no bedforms	Estuarine Turbidity Maximum: high mud content prevents bedform formation
Large number of high and steep ebb-oriented bedforms	Ebb dominance
Large number of high steep & symmetrical (both ebb and flood slip faces) bedforms	
Increasing number of flood-oriented to symmetrical bedforms	Flood dominance
No bedforms apart from a few small bedforms km 3-5	

In times of **high river discharge**, bedform ebb-orientation is stronger than when discharge is low