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Process-based modelling of tidally-influenced estuarine morphodynamics and bar architecture

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Estuaries represent one of the most dynamic environments on Earth with continuously changing channels and shoals of sand and mud that are driven by ebb and flood currents that interact with chemical and biological processes. These transition zones between terrestrial and marine environments generally have complex bar depositional patterns due to the dominance of river processes in proximal areas transitioning to the dominance of oceanic processes in distal areas. Although modern estuaries have been studied for many years, it is largely unknown in which manner basin geometry and tidal range impact bar formation, and how this would affect the subsurface architecture. This study applies the morphodynamic model Delft3D to test models of estuarine bar morphology and stratigraphy along the fluvial-tidal transition. Observations from the modern Columbia River estuary and idealized estuaries are combined to systematically evaluate estuarine hydrodynamics, bar formation and bar preservation. A unique aspect of the methodology is that morphological as well as subsurface data are collected, thus enabling the estuarine bar morphodynamics to be related explicitly to the associated depositional product. Model results highlight the complex and dynamic flow patterns in the Columbia River estuary, which are consistent with observations from local tide gauges. By systematically varying tidal range and basin width, it is shown that estuarine bar dimensions are primarily affected by estuary width, and that tidal range has a secondary effect. An increase in estuary width results in a higher bar braiding index, a larger number of bars as well as longer bars, wider bars and thicker bar deposits. Synthetic architectures that can be compared directly to the sedimentary record show a high degree of fragmentation within estuarine bars. Statistical distributions summarising the internal structure of estuarine bars provide much-needed quantification of the preservation of estuarine bars and are expected to improve their three-dimensional characterization in geo-models of estuarine environments.