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Statistical characterization of erosion and sediment transport mechanics in shallow tidal environments. Part 1: erosion dynamics

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Summary

The authors wish to thank the Editorial Board and the Reviewers for their suggestions. We carefully considered and extensively discussed the possibility of merging the two papers. However, we hold major reservations about merging the two contributions, as we firmly believe that our work can be most effectively conveyed through two separate papers.
As explained more in detail in the following, the main rationale for keeping the two manuscripts separate is content-related, as each paper conveys a distinct message. The overarching contribution of the two companion papers is to test the hypothesis of using random processes to upscale morphodynamic models. However, this cannot be limited to the analysis of erosion events presented in Part 1, because suspended sediment dynamics is not solely influenced by local resuspension but also by advective and mixing processes occurring at the basin scale. Therefore, the characterization of both erosion events and suspended sediment dynamics as Poisson processes is necessary to test the possibility of implementing a synthetic modelling framework accounting for erosion and deposition. This highlights that the two papers are not mere repetitions but rather they address complementary questions on different morphological processes.
To better highlight the complementarity of these works, we have deeply revised the introduction of both papers, as detailed below.

Legend

RC: Reviewer Comment

AR: Author Response

☐ : Modified manuscript text

Note: References to reviewers' comments are indicated as RCx.x and numbered progressively.

AR: The main rationale for maintaining the two manuscripts separated is content-related, as each paper has its own message. The most significant contribution of our study is to test the hypothesis to use random processes to upscale morphodynamics models. When describing morphodynamic changes, both erosive and depositional processes play a fundamental role. Erosion is generally related to the local BSS and deposition to the available SSC. The peak-over-threshold analysis of BSS presented in Part 1 proves that erosion dynamics can be modelled as a Poisson process. However, this offers only a partial perspective, as it does not address the possibility of modelling depositional dynamics as a stochastic process. Indeed, SSC is not solely influenced by local erosion because of advective and dispersive processes occurring at the basin scale, and, hence, must be analyzed independently. Therefore, the novelty of Part 2 lies in demonstrating that spatio-temporal dynamics of SSC can also be modelled as a random process, which is not proved in Part 1.

The characterization of both BSS and SSC as Poisson processes is necessary to test the possibility of implementing a synthetic modelling framework accounting for erosion and deposition. This highlights the difference and the complementarity of the results and clearly demonstrates that Part 2 is not a mere repetition of Part 1 but rather a fundamental component of our research.

To further substantiate this concept, we modified the introduction of Part 1 as follows:

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> (line 60) *A different perspective would be to directly consider the stochasticity of morphodynamic processes. From this point of view, the first step is to test the possibility of setting up a statistically-based framework in order to generate synthetic, yet reliable, time series to model the morphodynamic evolution on long-term time scales and compare possible scenarios in a computationally-effective way through the use of independent Monte Carlo realizations. Although the statistical characterization of the long-term behaviour of several geophysical processes is becoming increasingly popular in hydrology and geomorphology (e.g., Rodriguez-Iturbe et al., 1987; D'Odorico and Fagherazzi, 2003; Botter et al., 2007; Park et al., 2014), applications to tidal landscapes are still quite rare (D'Alpaos et al., 2013; Carniello et al., 2016).*
> *The morphological evolution of tidal systems can be described by Exner's equation:*
>
> $$(1-n)\frac{\partial z_b}{\partial t} + \nabla \boldsymbol{q_b} = D - E \qquad (1)$$
>
> *where n is the bed porosity, z_b is the bed elevation, $\boldsymbol{q_b}$ is the bedload, D and E are the deposition and entrainment rates of sediment, respectively. In mud-dominated tidal systems, sediment is primarily transported in suspension and the bedload is negligible, hence, the bed level changes can be determined by accurately describing erosion and deposition. Erosion, E, is directly influenced by the local bottom shear stress (BSS), which results from the interaction between tidal currents and wind waves in shallow tidal systems (Green and Coco, 2014). Instead, deposition, D, is linked to the suspended sediment concentration (SSC). However, SSC is largely affected by advection and dispersion processes at a larger scale and, therefore cannot be solely determined by local resuspension. Consequently, to effectively model bed-level variations, it is essential to accurately describe both BSS and SSC. This contribution focuses on characterizing BSS, while the analysis of SSC is presented in the companion paper (Tognin et al., 2023).*

In the introduction of Part 2, we added a very brief recall to Exner's equation presented in Part 1 and discussed the differences in the analysis of SSC as follows:

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(line 51) *A comprehensive understanding of morphological processes is key to addressing management and restoration strategies for shallow tidal landscapes. The morphodynamic evolution of these systems can be described by Exner's equation:*

$$(1-n)\frac{\partial z_b}{\partial t} + \nabla \boldsymbol{q_b} = D - E \qquad (1)$$

where n *is the bed porosity,* z_b *is the bed elevation,* $\boldsymbol{q_b}$ *is the bedload, D and E are the deposition and entrainment rates of sediment, respectively. Bedload is usually negligible in mud-dominated tidal systems, because sediment transport mainly occurs in suspension, and, thus, the bed level changes are essentially a function of erosion and deposition processes. In order to complete the stochastic framework introduced by D'Alpaos et al. (2023) for the description of erosion events, this study deals with the statistical characterization of suspended sediment concentration (SSC), considered a proxy for depositional processes.*

Suspended sediment dynamics in shallow tidal systems are influenced by different hydrodynamic and sedimentological factors that vary over a wide range of spatial and temporal scales (Woodroffe, 2002; Masselink et al., 2014). Both tide and waves represent key drivers controlling sediment entrainment and transport in shallow tidal environments (Wang, 2012), with stochastic wave-forced resuspension occasionally increasing by far cyclic tide-driven sediment reworking, especially under storm conditions. Wave resuspension together with tide- and wave-driven sediment transport give rise to advection and dispersion mechanisms leading to basin-wide sediment movement, which largely affect local suspended sediment dynamics (e.g., Nichols and Boon, 1994; Carniello et al., 2011; Green and Coco, 2014). Owing to the complexity of the underlying processes, suspended sediment dynamics in shallow tidal systems is rather entangled and it is not only linked to the local bottom resuspension. Therefore, to effectively describe suspended sediment transport in shallow tidal systems, a dedicated analysis is required.

Several numerical models have been developed to describe sediment transport and different techniques have been proposed to upscale the effects on the morphological evolution of tidal systems. For instance, explorative point-based models are extensively used to understand the relative importance of sediment transport processes, because of their simplified parametrization as well as their great conceptual value (Murray, 2007). Furthermore, their reduced computational burden is ideal for investigating trends over long-term time scales. For these reasons, point-based models have been largely adopted, for example, to examine salt-marsh fate under different sea level rise scenarios at the century time scale (D'Alpaos et al., 2011; Fagherazzi et al., 2012). However, point-based models potentially miss spatial dynamics associated with sediment transport and, hence, might fail to represent interactions between different morphological units. More detailed, process-based models can fill this gap and account for sediment fluxes between different points up to the whole basin scale (e.g. Lesser et al., 2004; Carniello et al., 2012). But, because of the explicit description of the short-term interaction between hydrodynamics and sediment transport, the application of process-based models to the long-term time scale is often computationally expensive or even prohibitive.