EFFECT OF TIDAL INLET STABILIZATION ON BARRIER ISLAND MORPHODYNAMICS

JAAP H. NIENHUIS

Global Change Geomorphology, School of Geosciences, Utrecht University, Princetonlaan 8a, Utrecht, NL. j.h.nienhuis@uu.nl

Abstract: Barrier islands are dynamic environments threatened by sea-level rise. Humans alter barrier island morphodynamics with potentially important but unknown long-term consequences. Here we use a new barrier island model to study how tidal inlet stabilization (jetties, dredging) affect barrier islands. We find that stabalization reduces the capacity of inlets to build flood-tidal delta deposits: jetties limit inlet bypassing and can increase downdrift barrier overwashing. In scenarios where flood-tidal delta deposition is required for barrier rollover during sea-level rise, inlet stabilization increases the risk of barrier drowning.

Introduction

Accelerated sea-level rise of the 21st century is a major threat to often densely populated barrier islands. In natural settings, storm-driven overwash and tidal-inlet-driven flood delta deposition allow barrier islands to migrate landwards as sea levels rise (Lorenzo-Trueba and Ashton 2014; Pierce 1970; Simms *et al.* 2006; Stolper *et al.* 2005). Human activity on barrier islands (e.g. beach nourishment, jetty placement, development) has greatly altered the morphodynamics of tidal inlets and adjacent coasts (McNamara and Lazarus 2018; Miselis and Lorenzo-Trueba 2017), with important consequences for barrier islands subjected to sea-level rise (Rogers *et al.* 2015). Leatherman (1979) showed how inlet stabilization and downdrift shoreline erosion can locally enhance barrier landward migration, but long-term effects of inlet engineering on barrier islands, including the risk of barrier island drowning, remain poorly understood.

Methods

Here we use the new barrier island inlet (BRIE) model to investigate long-term (centennial timescale) inlet and barrier coast morphodynamics for both engineered and natural systems. BRIE is a reduced complexity model that combines barrier overwash and shoreface formulations (Lorenzo-Trueba and Ashton 2014) with alongshore sediment transport (Ashton and Murray 2006), inlet hydrodynamics (Escoffier 1940; de Swart and Zimmerman 2009), inlet migration, and flood-tidal delta deposition (Nienhuis and Ashton 2016). The model accounts for feedbacks between overwash and inlets through their mutual dependence on barrier geometry. Overwash fluxes that lead to barrier widening or barrier accretion are a function of the deviation of barrier width and height from a certain equilibrium geometry (following Lorenzo-Trueba and Ashton 2014).

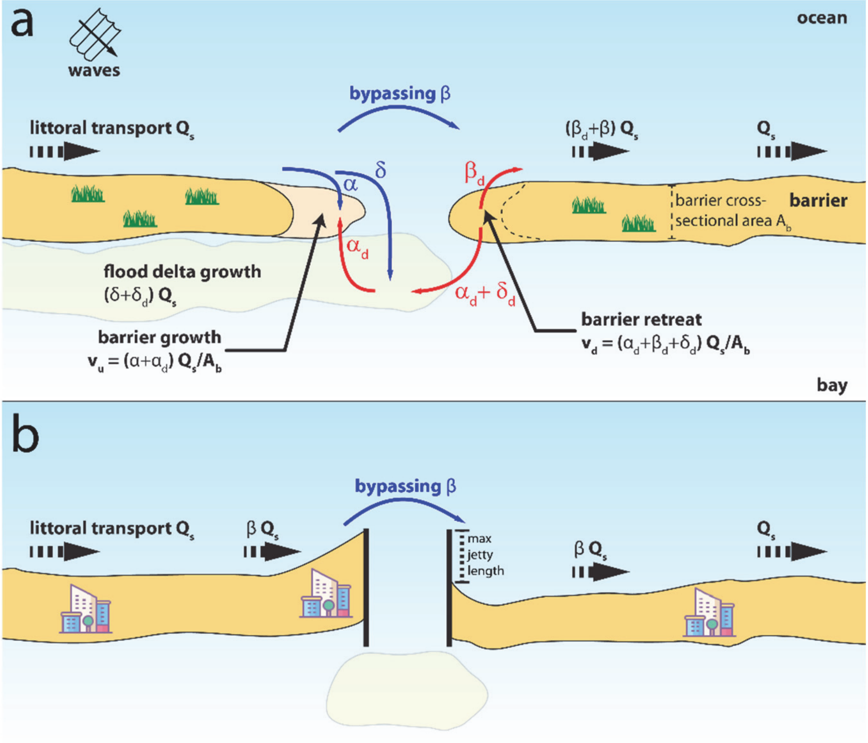

Fig. 1. Sediment dynamics of (a) a natural tidal inlet, adapted from Nienhuis and Ashton (2016), compared to (b) the hypothesized dynamics of an engineered inlet.

The barrier island can breach and form a tidal inlet if there is sufficient potential for tidal flows. Their hydrodynamics are controlled by equilibrium parameterizations first suggested by Escoffier (1940), where tidal inlet width and depth are a function of the tidal prism and bed friction (de Swart and Zimmerman 2009). Inlet migration and flood-tidal delta deposition is paramaterized following Nienhuis *et al*. (2016) (Fig. 1a). Wave-driven littoral sediments can be transported towards the updrift bank of the inlet, the flood-tidal delta, or be bypassed around the inlet, with fractions governed by inlet hydrodynamics from Delft3D experiments (Nienhuis and Ashton 2016). Within BRIE, inlets can open, close, migrate, merge with other inlets, and build flood-tidal delta deposits.

We parameterize inlet engineering by restricting inlet migration, flood-tidal delta deposition, and alongshore sediment bypassing (Fig. 1). When an inlet forms, a jetty is built such that sediment is trapped updrift of the inlet. Accretion cannot exceed the length of the jetty (here set at 100 m); alongshore transport is then bypassed around the jetty and the inlet towards the downdrift barrier island. Note that, although bypassing is 100%, reorientation of the coastline updrift of the inlet effectively restricts sediment transport towards the inlet.

Results

In two example simulations, we compared the morphodynamics of jettied and natural inlets (Fig. 2). Natural inlets are migrating and building flood-tidal delta deposits. More rapid transgression compared to overwashing results in convex shaped barrier islands. In this scenario, we calculated the contribution of flood-tidal deltas to the total transgressive sediment flux (F) at approximately 30%.

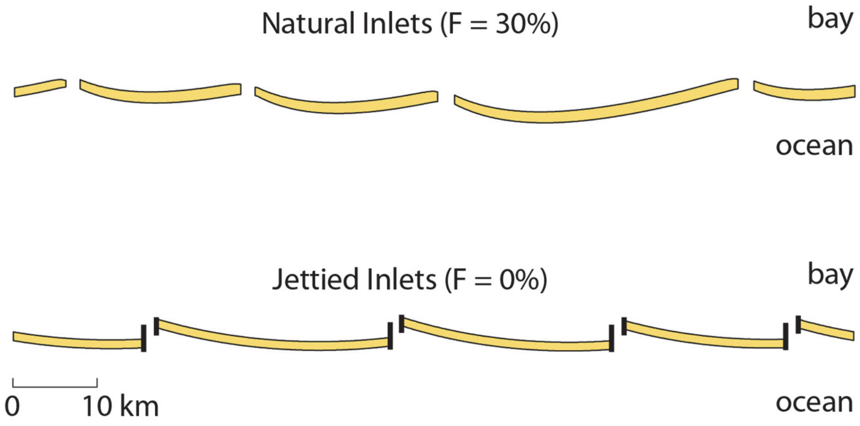

Fig. 2. Model simulations of a barrier island with and without jetties.

In contrast, jettied inlets remain in place (Fig. 2). Restricted bypassing results in downdrift erosion, leading to overwashing and barrier retreat. Bypassing around the inlet ensues when the shoreline offset exceeds the jetty length. In this scenarios, we obtain a stable state where the entire barrier chain overwashes at roughly the same pace and the fraction of the transgressive flux contributed by inlets (F) is 0. In both simulations the barrier island chain is maintained.

For high sea-level rise rates, barriers can drown if the landward directed sediment flux is insufficient (Lorenzo-Trueba and Ashton 2014; Mellett and Plater 2018).

We performed simulations where we subject barrier islands to various sea-level rise rates and compare cases with and without engineered inlets (Fig. 3). We find that by restricting inlet migration and bypassing, barrier island become susceptible to drowning for lower sea-level rise rates. The maintenance and restricted migration limits flood-tidal delta deposition and indirectly prevents the formation of new tidal inlets along the barrier island coast. Downdrift portions require high overwash rates, and drown relatively quickly (e.g. Assateague Island). Wave climatology affects the response of barrier islands to sea-level rise. In scenarios with limited wave-driven alongshore transport, modelled natural and jettied inlets behave similarly, and drown for similar sea-level rise rates. In other scenarios where inlets without jetties would migrate rapidly, natural barrier islands can maintain higher sea-level rise rates because of the extra transgressive flux of inlets.

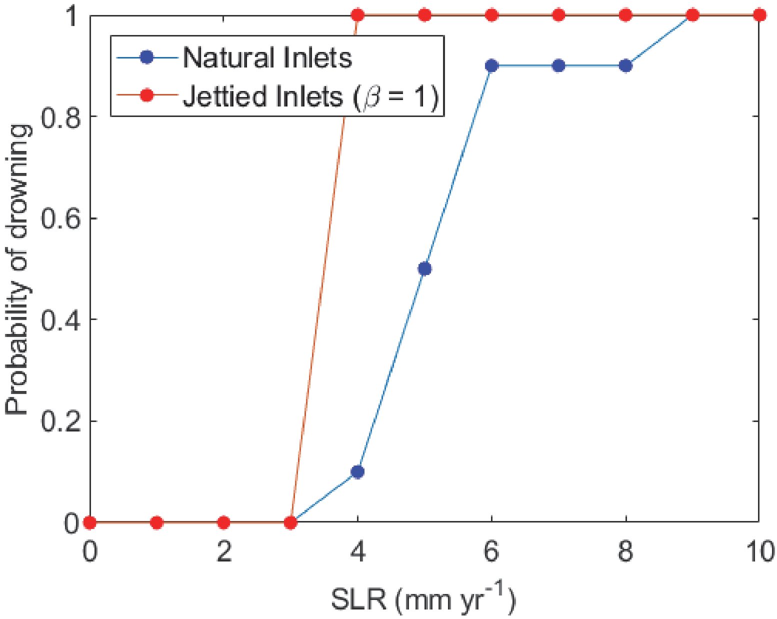

Fig. 3. The probability of barrier island drowning for jettied inlets compared to natural inlets for varying sea-level rise rates. The probability is derived from model outcomes of 10 different wave climates.

Conclusions

Our reduced complexity morphodynamic barrier island (BRIE) model is able to parameterize inlet engineering and assess its effects on centennial timescale barrier morphodynamics. We find that inlet maintenance can reduce barrier island resilience to high sea-level rise rates, with potentially important consequences for densely populated coastlines considering the predicted acceleration of sea-level rise into the 21st century.

References

Ashton, A. D., and Murray, A. B. (2006). "High-angle wave instability and emergent shoreline shapes: 2. Wave climate analysis and comparisons to nature." *Journal of Geophysical Research*, 111(F4), F04012.

Escoffier, F. F. (1940). "The Stability of Tidal Inlets." *Shore and Beach*, 8(4), 114–115.

Leatherman, S. P. (1979). "Migration of Assateague Island, Maryland, by inlet and overwash processes." *Geology*, 7(2), 104–107.

Lorenzo-Trueba, J., and Ashton, A. D. (2014). "Rollover, drowning, and discontinuous retreat: Distinct modes of barrier response to sea-level rise arising from a simple morphodynamic model." *Journal of Geophysical Research: Earth Surface*, 119(4), 779–801.

McNamara, D. E., and Lazarus, E. D. (2018). "Barrier Islands as Coupled Human–Landscape Systems." *Barrier Dynamics and Response to Changing Climate*, L. J. Moore and A. B. Murray, eds., Springer International Publishing, Cham, 363–383.

Mellett, C. L., and Plater, A. J. (2018). "Drowned Barriers as Archives of Coastal-Response to Sea-Level Rise." *Barrier Dynamics and Response to Changing Climate*, Springer International Publishing, Cham, 57–89.

Miselis, J. L., and Lorenzo-Trueba, J. (2017). "Natural and Human-Induced Variability in Barrier-Island Response to Sea Level Rise." *Geophysical Research Letters*, 44(23), 11,922-11,931.

Nienhuis, J. H., and Ashton, A. D. (2016). "Mechanics and rates of tidal inlet migration: Modeling and application to natural examples." *Journal of Geophysical Research: Earth Surface*, 121(11), 2118–2139.

Pierce, J. W. (1970). "Tidal Inlets and Washover Fans." *The Journal of Geology*, 78(2), 230–234.

Rogers, L. J., Moore, L. J., Goldstein, E. B., Hein, C. J., Lorenzo-Trueba, J., and Ashton, A. D. (2015). "Anthropogenic controls on overwash deposition: Evidence and consequences." *Journal of Geophysical Research: Earth Surface*.

Simms, A. R., Anderson, J. B., and Blum, M. D. (2006). "Barrier-island aggradation via inlet migration: Mustang Island, Texas." *Sedimentary Geology*, 187(1–2), 105–125.

Stolper, D., List, J. H., and Thieler, E. R. (2005). "Simulating the evolution of coastal morphology and stratigraphy with a new morphological-behaviour model (GEOMBEST)." *Marine Geology*, 218(1–4), 17–36.

de Swart, H. E., and Zimmerman, J. T. F. (2009). "Morphodynamics of Tidal Inlet Systems." *Annual Review of Fluid Mechanics*, 41, 203–229.