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Morphological evolution of an ephemeral tidal inlet from opening to closure: The Albufeira inlet, Portugal

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ABSTRACT

Like other similar coastal systems, the Albufeira lagoon is artificially opened every year to promote water renewal and closes naturally within a few months. The evolution of the Albufeira Lagoon Inlet from its opening in April 2010 to its closure 8 months later is qualitatively and quantitatively analyzed through a combination of monthly field surveys and the application of a process-based morphodynamic model. Field data alone would not cover the whole space–time domain of the morphology of the inlet during its life time, whereas the morphodynamic model alone cannot reliably simulate the morphological development. Using a nudging technique introduced herein, this problem is overcome and a reliable and complete data set is generated for describing the morphological development of the tidal inlet. The new technique is shown to be a good alternative to extensive model calibration, as it can drastically improve the model performance. Results reveal that the lagoon imported sediments during its life span. However, the whole system (lagoon plus littoral barrier) actually lost sediments to the sea. This behavior is partly attributed to the modulation of tidal asymmetry by the spring–neap cycle, which reduces flood dominance on spring tides. Results also allowed the assessment of the relationship between the spring tidal prism and the cross-section of tidal inlets (the PA relationship). While this relationship is well established from empirical, theoretical and numerical evidences, its validity in inlets that are small or away from equilibrium was unclear. Results for the Albufeira lagoon reveal an excellent match between the new data and the empirical PA relationship derived for larger inlets and equilibrium conditions, supporting the validity of the relationship beyond its original scope.

1. Introduction

Tidal inlets connect estuaries and lagoons to the adjoining coastal waters. Hence, they constitute navigation routes between inland waters and the open ocean, and they control the exchanges of water and water-borne material between the ocean and estuaries or coastal lagoons. Tidal inlets are thus of critical socio-economic and environmental importance worldwide, and a thorough understanding of their dynamics is necessary for sustainable coastal management.

The stability of tidal inlets is controlled by the relative importance of waves and tides (Bruun, 1978): wave-induced cross-shore and long-shore sediment transport promotes the inlet closure, while ebb currents foster their enlargement by flushing sediments from the inlet. When the surface area of a lagoon is small, the tidal prism is limited and the inlet may be unstable. Under those circumstances, the tidal inlets may be ephemeral. They can open naturally, following strong river discharges or major storm surges; or they can be opened artificially to enable water renewal (e.g., Morris and Turner, 2010; Moreno et al., 2010; Coutinho et al., 2012). These systems can remain open for weeks to years, depending on the incoming waves. While they are open, ephemeral tidal inlets can evolve rapidly, continuously adapting their morphology and position to changing tides and waves. The behavior of these inlets is determined by several forcings, such as the neap–spring cycle (Bertin et al. 2009c), wave action, and swell in particular (Hanes et al., 2011), and river flow (Moreno et al., 2010). Furthermore, morphological controls may also play an important role in the behavior of these systems (Lichter et al., 2011).

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The Albufeira lagoon inlet is a typical example of an ephemeral tidal inlet. The Albufeira lagoon is located on the western Portuguese coast, about 20 km South of Lisbon (Fig. 1). It has a surface area of 1.3 km^2, a maximum depth of 13 m below mean sea level and extends perpendicularly to the coast over 3.6 km. The upstream part of the lagoon, the “Lagoa Pequena”, is shallow and has about 350 m × 900 m. The downstream part, the “Lagoa Grande”, is longer and deeper. The lagoon is separated from the Atlantic Ocean by a littoral barrier and a mixture of highly mobile shallow channels and sandbanks. In front of the lagoon, tides are semi-diurnal and the tidal range varies between 0.55 and 3.86 m. The Albufeira lagoon inlet is inserted into a 24 km long beach, between the mouth of the Tagus estuary and the Espichel Cape. Because this region has shown a long-term stability and it does not have significant sediment sources and sinks nor exchanges with neighboring regions, the net sediment transport is believed to be small (Abecasis, 1997). Yet, the wave regime is severe: the annual average significant wave height offshore, computed with the hindcast model of Dodet et al. (2010), is 1.9 m. Hence, in spite of a small net littoral transport, the sediment fluxes in both directions should be significant. This contrast between the net and gross longshore transport rates was highlighted by Nahon et al. (2012a)for the particular period of this study (April–December 2010): the net northward littoral drift was estimated with the empirical CERC formula as 21,000 m^3, while the cumulative drift reached 316,000 m^3 southward in November. Also, estimates of yearly longshore sediment transport 200 km to the north, where the wave regime is similar, vary between 0,1 and 2 million m^3 (Silva et al., 2012). These values, obtained for the period 1953–2010, further support the existence of a significant longshore transport.

The inlet is artificially opened every spring, and closes naturally in weeks to months, usually in the winter. In 2010, the inlet was opened on April 15, through a small channel cut perpendicularly to the littoral barrier, and closed naturally on December 20 (Fig. 2, Nahon et al., 2012a). While these human interventions have occurred since the 15th century, it was suggested that their growing frequency causes the siltation of the lagoon (Freitas et al., 1992). Most of the time, the inlet exhibits a wave-dominated morphology, with a shallow channel, a small ebb delta and a large flood delta (Freitas and Andrade, 1994).

The main goal of this paper is to analyze the evolution of the Albufeira tidal inlet during its 8-month life span in 2010. The analysis was performed using monthly bathymetric surveys and a morphodynamic numerical model. Limitations of the morphodynamic model led to the development and assessment of new nudging techniques to seamlessly combine data and model results.

The reliability of process-based models of tidal inlets has been increasing over the past decade (Ranasinghe et al., 1999; Lesser et al., 2004; Bertin et al., 2009a; Postacchini et al., 2012). They can reproduce the empirical body of knowledge on tidal inlets (Tung et al., 2009; Nahon et al., 2012b), and several successful applications are described in the literature (Cayocca, 2001; Bertin et al., 2009b; Bruneau et al., 2011).

In spite of these successes, process-based morphodynamic models still have significant simplifications and the large uncertainties associated to the evaluation of sediment fluxes (Eidsvik, 2004; Pinto et al., 2006) force extensive model calibration. The use of data assimilation appears as a promising avenue to reduce the extent of model calibration, and it has recently been applied in morphodynamic modeling (Scott and Mason, 2007; Mason et al., 2010; Chu et al., 2011). The increasing availability of bathymetric

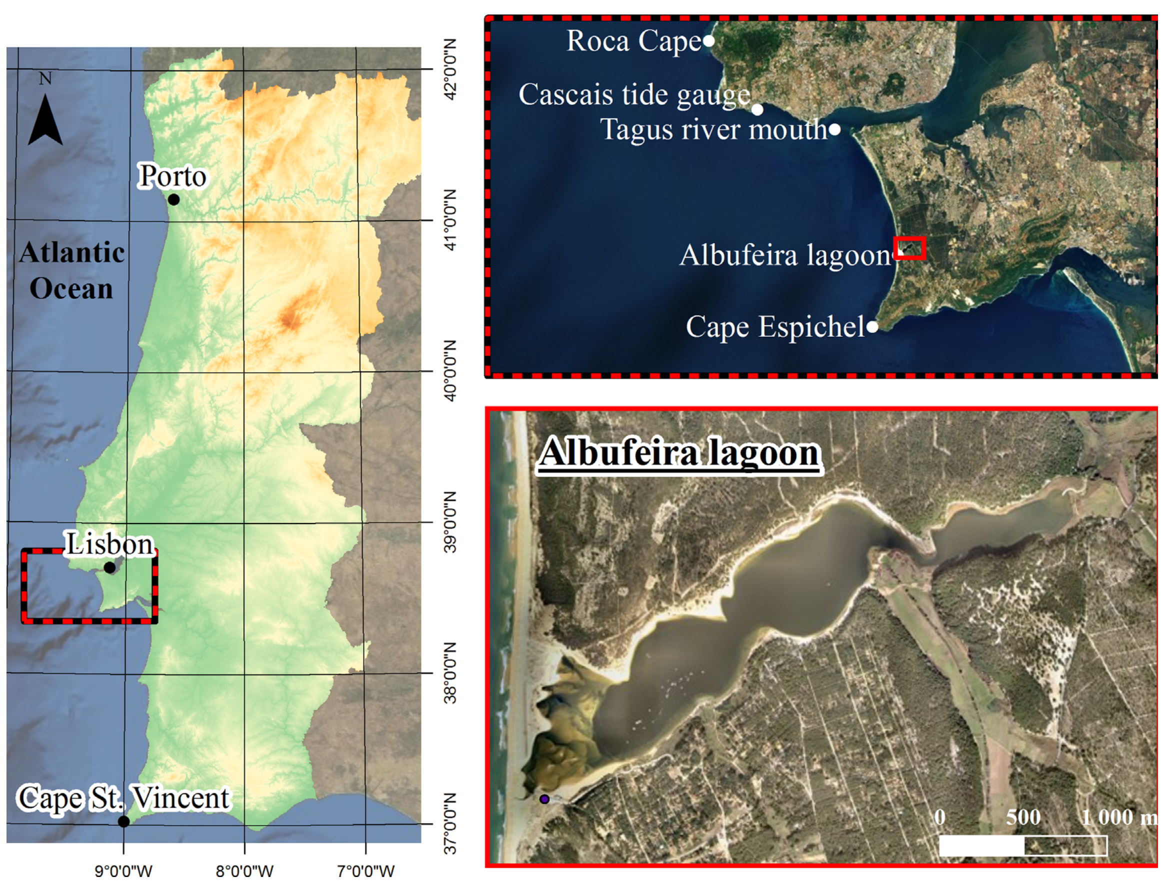

Fig. 1. The Albufeira lagoon: location, place names and data stations.