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Multidecadal evolution of tidal patterns in a highly turbid macrotidal river and implications for sediment dynamics

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Abstract

Estuarine tidal propagation is modified by bottom friction, basin topography, and river discharge (Friedrichs and Aubrey, 1988; Sassi and Hoitink, 2013). Quite recently, considerable attention has been paid to evaluate the effect of morphological changes (natural or human-induced) on tide characteristics and turbidity maximum zone (Schuttelaars et al., 2013; Winterwerp et al., 2013; De-Jonge et al., 2014).

The Gironde estuary (S-W France, Fig. 1.a) is a macrotidal and highly turbid system formed by the confluence of two tidal rivers (Garonne and Dordogne). During the last decades, besides the weak natural morphological changes (Sottolichio et al., 2013), this estuary has undergone regular dredging of navigation channels. In addition, a region of a length of about 30 km in the tidal Garonne River was deepened between the 60’s and 80’s for gravel extractions (Fig. 1.b). Compared to observations before these human interventions, the TMZ is nowadays stronger and has shifted upstream. It has been demonstrated that the long-term decrease of river flow is one of the factors contributing to the TMZ intensification (Jalón-Rojas et al., 2015). However, the influence of changes on the tidal wave propagation has not been investigated yet.

The goal of this work is to analyse the evolution of tidal characteristics over the last 6 decades in the tidal Garonne river, in order to: (i) analyse the modulation effects of river discharge on tides; (ii) evaluate the effect of morphological changes on tidal range and asymmetry; (iii) evaluate the links and possible feedbacks between changes in tidal patterns and suspended sediment trapping in the estuarine fluvial region.

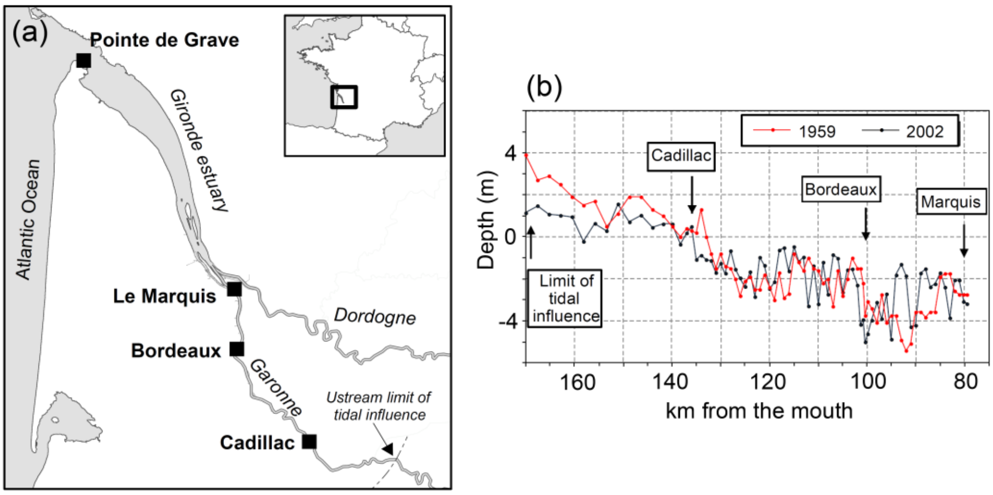

Figure 1. (a) Location map of the Gironde fluvio-estuarine system. Black squares locate tidal gauges. (b) Average depth along the Garonne tidal river for the years 1959 and 2002.

To answer these questions, observations are analysed and combined with model results for interpretation. Time series of continuous water level of 6 years (1953, 1970, 1981, 1994, 2005 and 2014) (Fig. 1.a) are analysed in four sections: Pointe de Grave (0 km from the mouth), Le Marquis (80 km from the mouth), Bordeaux (100 km from the mouth) and Cadillac (135 km from the mouth). At Cadillac, there are no data available for 2005 and 2014 as the tidal gauge operation was stopped in 1995. The tidal range is calculated as the difference between the maximal and minimal values of each tidal cycle. Tidal asymmetry is evaluated with the duration ratios of ebb and flood, and the amplitude

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ratios and relative phases of M4 and M2 harmonics. Time series of harmonic amplitudes and phases were obtained through Complex Demodulation (Bloomfield, 1976). A semi-analytical model (Schuttelaars et al., 2013) is used to test the causes of historical changes in tide and suspended sediments dynamics.

Tidal wave amplification and interactions at the upper estuary depend strongly on river flow that enhances tidal friction and reduces tidal energy. For example, a tidal range of 4.5 m at the mouth can be amplified up to 6 m at Cadillac for river discharges lower than 150 m^3s^{-1}, but damped below 0.8 m for river discharges higher than 3,500 m^3s^{-1}. The modulation of tidal interactions by river flow is reflected by an enhanced M_4 generation.

The tidal range has undergone a progressive increase over the last 6 decades at the three upstream sections. Figure 2.a shows the tidal range evolution as a function of tidal range at the mouth. Only data during periods of similar river discharge (<400m^3s^{-1}) were represented to discuss tidal range amplification due to morphological changes. For periods of low river discharge, the tidal range at Bordeaux in 2014 is, in average, 25% higher than in 1953. Figure 2.b illustrates the multidecadal evolution of the amplitude ratio of M4 and M2 harmonics as a function of tidal range at the mouth and for river dicharges lower than <400m^3s^{-1}. The absence of a clear temporal evolution of tidal distorsion demonstrates that mophological changes barely affected this tidal characteristic.

Bottom friction influences tidal range even at seasonal time scale. During wet years, the tidal range at Bordeaux is up to 10% higher during the presence and expulsion of the turbidity maximum than before its installation for a given river flow, which is attibuted to a shift from a muddy to a gravel-dominated bed. During dry years, there are no changes of tidal range between both periods, as fluid/soft mud covers the bottom all over the year (Jalón-Rojas et al., 2015).

The observations are compared with the simulated hydrodynamics obtained with the semi-analytical model. The resulting physical explanation of the long-term changes on hydrosedimentary dynamics, together with the observed trends, will be discussed in the presentation.

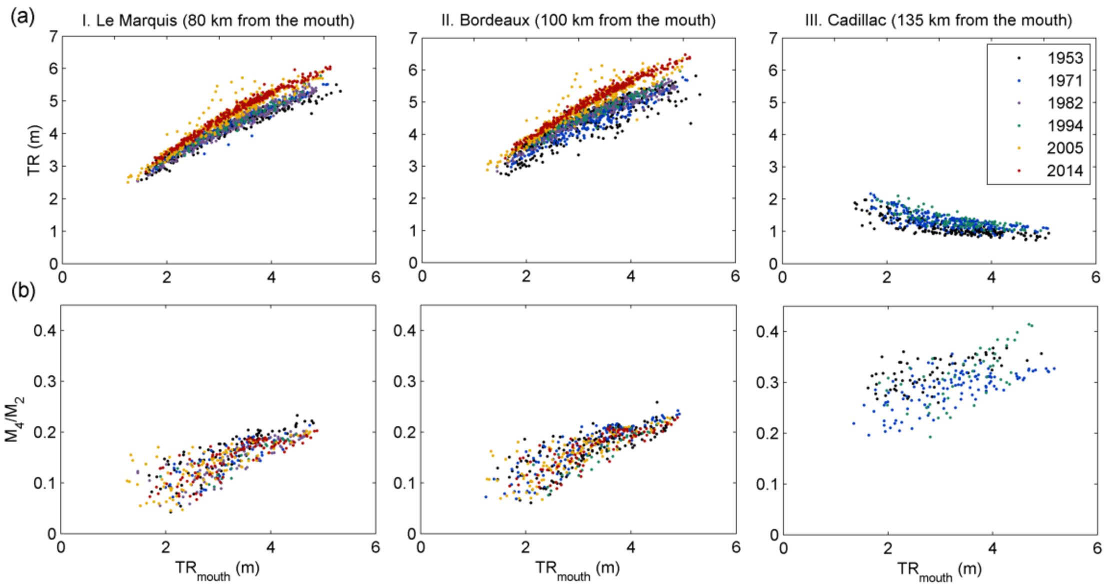

Figure 2. Tidal range (TR, a) and tidal asymmetry (M_4/M_2, b) for each studied year for river discharge below 400 m^3s^{-1} at the Garonne River's stations: Le Marquis (I), Bordeaux (II) and Cadillac (III)

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