Response letter

In this article an analytical solution of the tidal equations is presented to study the interaction of different tidal constituents in the Spanish Guadiana and Guadalquivir estuaries. The solution is based on a method developed by Godin (1999) and Dronkers (1964) for dealing with the non-linear friction term. Different tidal constituents derived from long-term tidal records along both estuaries are compared with amplitudes and phases of these constituents given by the analytical model. Observations and model results are in fair agreement. The article is well written and well organised.
Our reply: We thank the Reviewer for his overall positive assessment of our work.

There is probably an error in figure 9; the damping numbers (as defined in table 1) do not match the x-dependence of the amplitudes of figure 8. This is repeated in the corresponding discussion (lines 320-327). When comparing figures 6 and 8, the damping of M2 tide in the Guadalquivir appears a bit stronger than in the Guadiana, but not an order of magnitude stronger.
Our reply: We thank the Reviewer for this comment. Indeed, we mixed up the unit for the tidal amplitudes imposed at the estuary mouth. The corrected Figure is displayed below (see Figure R1).

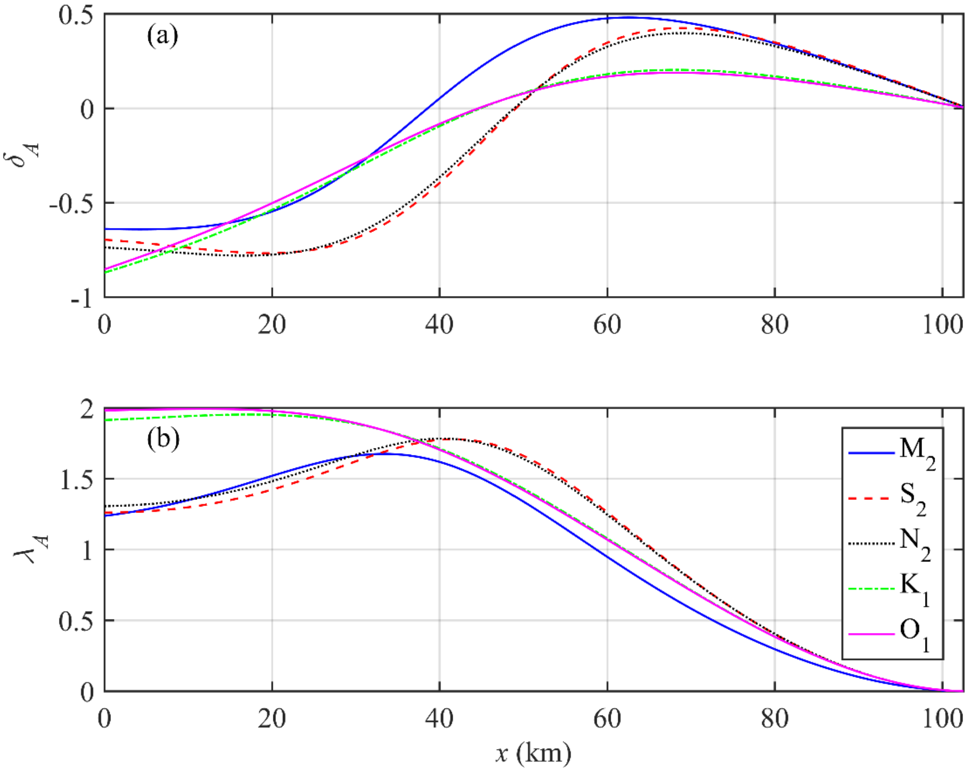

Figure R1. Longitudinal variations of tidal damping/amplification number δ_A (a) and wave celerity number λ_A (b) for different tidal constituents along the Guadalquivir estuary.

In the revised paper, we shall modify the paragraph:
"*Figure 9 shows the longitudinal variations of tidal damping/amplification and wave celerity at the Guadalquivir estuary, which are similar to those in the Guadiana estuary. In general, we observe that the dominant* M_2 *tide experiences less friction than other secondary tidal constituents although it travels at more or less the same speed as other secondary tidal constituents in the seaward reach*

(x=0~35 km). Unlike the Guadiana estuary, the damping experienced by the secondary semidiurnal tides is less than that of diurnal constituents near the estuary mouth (around x=0-7 km; Figure 9a), while the wave celerity is consistently larger in the seaward reach (x=0~38 km; Figure 9b). Similar to the Guadiana estuary, we observe that the tidal damping for the secondary semidiurnal tides is stronger than that of diurnal constituents in the central parts of the estuary (around x=7~52 km), whereas their amplifications are larger in the landward part of the estuary although wave speeds are less."

The paper can be further improved by adding some clarifications concerning the following points:

1. River discharge is not mentioned at all in the paper. The influence is probably minor in the major part of the estuary, but river discharge could play a role near the sill at the upper end of the estuary, where the tidal velocities go to zero.

Our reply: In the revised paper, we shall explicitly mention that the model does not account for the influence of river discharge on tidal wave propagation. To be more specific, in abstract part, we shall emphasize that *"The proposed method could be applicable to other alluvial estuaries with small tidal amplitude to depth ratio and negligible river discharge."* Meanwhile, in section 2.1 we shall explicitly mention that "*In order to obtain an analytical solution, we assume a negligible river discharge and that the tidal amplitude is small with respect to the mean depth and follow Toffolon and Savenije (2011) to derive the linearized solution of the system of Eqs. (3) and (4).*" In addition, in section 2.2, we shall mention that in the Guadiana estuary "*the data were collected during an extended (months-long) period of draught with negligible river discharge (e.g., always < 20* m^3/s *over the preceding 5 months).*", while in the Guadalquivir estuary "*the results apply to the low river discharge conditions (< 40* m^3/s*) that usually predominate at the estuary.*"

2. Close to the sill the tide has the appearance of a standing wave; this gives an almost infinite tidal wave celerity. Tidal wave celerity does not make much sense in this region.

Our reply: In the revised paper, we shall explicitly mention that: "*It is important to note that the wave celerity tends to approach infinity when tide propagates near the sill since the wave is characterized by a standing wave that is generated by the superimposition of incident and reflected waves (see also Garel and Cai, 2018).*"

3. The Chebyshev coefficients are the coefficients of the expansion of cos(nx) in powers of cos(x).

Our reply: We thank the Reviewer for this comment. In the revised paper, we shall clarify that "*The Chebyshev coefficients* $\alpha=16/(15\pi)$ *and* $\beta=32/(15\pi)$ *were determined by the expansion of cos(nx) (n=1,2,…) in powers of cos(x)*".

4. It should be mentioned that formula Eq. 12 gives a reasonable approximation only if the diurnal tides are much smaller than the semidiurnal tides.

Our reply: In the revised paper, we shall explicitly mention this point: "*It is worth noting that Eq. (12) is a reasonable approximation only if the amplitude of the secondary constituent is much smaller than that of the dominant one*".

5. The diurnal tides are much less damped than the semidiurnal tides. Apparently, the effects of frictional damping and channel convergence cancel approximately. This might be discussed more clearly in the paper.

Our reply: In the revised paper, we shall include a new paragraph to clarify the difference of tidal damping between diurnal and semidiurnal tides.

“*In order to clarify the behavior of different tidal constituents, we present Fig. R2 (see below) showing the longitudinal variations of estuary shape number γ (representing the channel convergence) and friction number χ (representing the bottom friction), two major factors determining the tidal hydrodynamics, in both estuaries. Note that the variable estuary shape number γ observed in the Guadalquivir estuary is due to the adoption of a variable storage width ratio r_S in the analytical model. It can be seen from Figs. 10a, c that the estuary shape numbers for diurnal tides are approximately twice larger than those for semidiurnal tides due to the tidal frequency differences (see definition of γ in Table 1). Furthermore, the effective frictions experienced by the diurnal tides are much larger than those of the semidiurnal tides due to the mutual interaction between different tidal constituents (see also Table 3). It is important to note that the propagation pattern of different tidal constituents mainly depends on the imbalance between channel convergence and friction, except for those reaches where wave reflection matters (generally close to the head). The relatively less damping experienced by diurnal tides in the seaward reach (Figures 7a and 9a) can be attributed to the fact that the channel convergence effect is much stronger than that of the semi-diurnal tides although diurnal tides experience much larger friction. In the case of the Guadalquivir estuary, we observe that the diurnal tides are more damped than those of the semidiurnal tides near the estuary mouth (x=0-7 km), which is due to the stronger bottom friction experienced by the diurnal tides. For the second (landward) half of the estuary, the less amplification experienced by diurnal tides is mainly influenced by the wave reflection from the closed end (see Garel and Cai, 2018) since both γ and χ remain more or less the same along the estuarine channels.*”

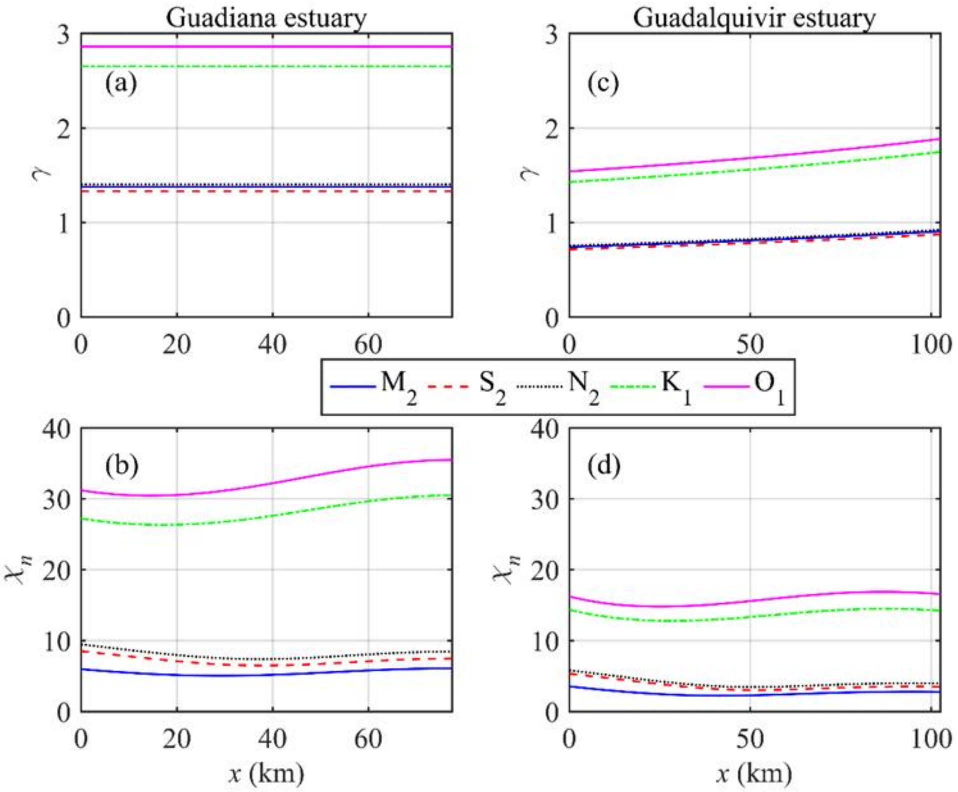

Figure R2. Longitudinal variations of estuary shape number γ (a, c) and friction number χ (b, d) in the Guadiana estuary (a, b) and Guadalquivir estuary (c, d).

6. The sensitivity of the results to the non-linear frictional interaction between the tidal constituents, being the central theme of the paper, should be discussed more explicitly. Figures 6

and 8 show the combined results of friction, channel convergence and tidal wave reflection. A figure might be added, for example, in which results with and without this frictional interaction are compared.

Our reply: We thank the Reviewer for the useful suggestion. In the revised paper, we shall include a new paragraph to illustrate the importance of mutual interaction between different tidal constituents.

"*The importance of mutual interaction between different tidal constituents is illustrated with the iteratively refined model implemented at both case studies (Figures 7 and 9). For comparison, Fig. R3 (see below) shows the analytically computed damping/amplification number* δ_A *and celerity number* λ_A *without considering mutual interaction (by setting* $f_n=1$ *in the model). In this case, the damping experienced by both secondary diurnal and semidiurnal tides is apparently underestimated due to the unrealistic friction adopted in the model (Fig. 11a, c). Similarly, the computed wave celerity for secondary tidal constituents is apparently overestimated due to the underestimated bottom friction. To correctly reproduce the main features of different tidal waves, it is required to use the iteratively refined model proposed in this study.*"

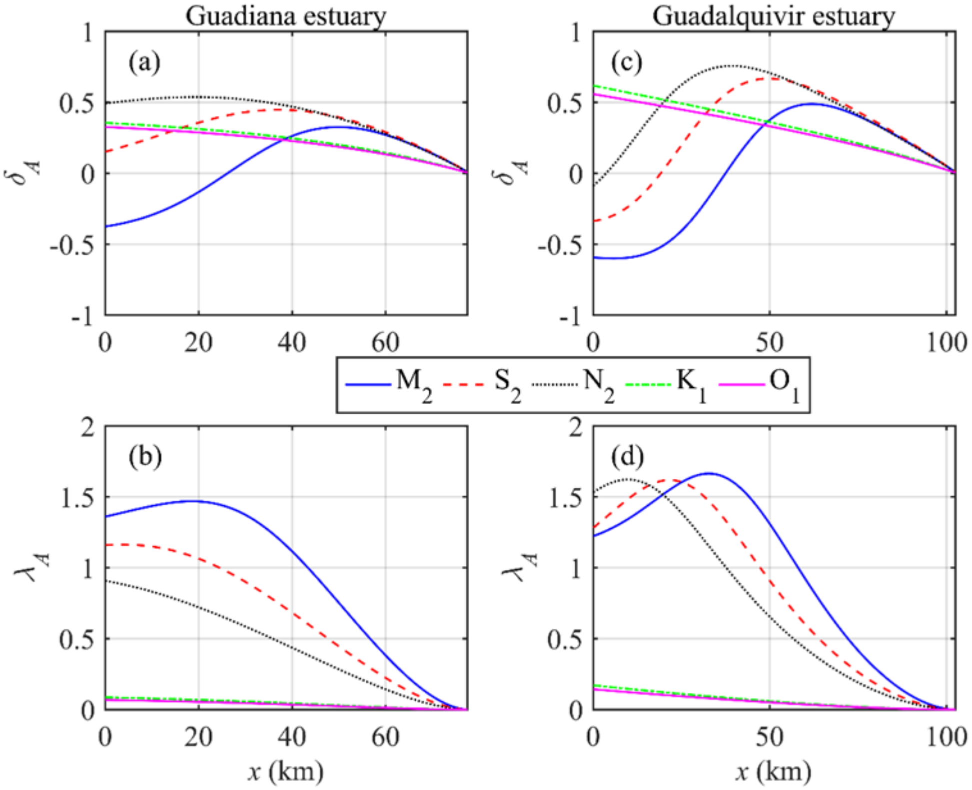

Figure R3. Longitudinal variations of damping/amplification number δ_A (a, c) and celerity number λ_A (b, d) in the Guadiana estuary (a, b) and Guadalquivir estuary (c, d) in the absence of mutual interaction between different tidal constituents.