Reviewer #2

The study 'Deep uncertainties in shoreline change projections: an extra-probabilistic approach applied to sandy beaches' explores an elegant method to deal with a combination of a aleatoric (intrinsic) and epistemic (deep) uncertainties. The methods are well explained and seem easy to apply and very helpful to better understand different kind of uncertainties. And so, the manuscript convincingly illustates the methods' attractiveness.

We thank the reviewer for her/his insightful comments that, we believe, will contribute to improve the clarity of our manuscript. Please find below our responses (in blue) and how the manuscript will be revised (preceded by an arrow).

Given the attractiveness of the method and well-written manuscript (as discussed in the last section), I am a little surprised that some major sources of (deep) uncertainties are not included. Especially, the choice to only use one set of sea-level projections that do not include high-end scenarios seems a little odd. There are multiple recent sea-level projections that explicitly included high-end contributions of the W-AIS (e.g. Le Bars et al. 2016, Wong et al., 2017).

Thank you for your comment, which suggests that we need to be more explicit when describing the design of the SLR projections used in our modelling framework. In fact, the possibility distributions of SLR projections do consider a high-end scenario that include large contributions of the W-AIS. The core of the trapezoid possibility function for the SLR projections corresponds to the IPCC-SROCC likely range, to which we assign a possibility degree of 1. The boundaries of the support correspond to the low-end (lower limit) and high-end (upper limit) regional projections published by Le Cozannet et al. (2019) and Thiéblemont et al. (2019), respectively, to which we assign a possibility degree of 0. Hence, all SLR projections between the low-end estimate and the high-end estimate have a non-zero possibility value, and are therefore considered as possible. It is important to note that both low-end and high-end scenarios have been designed so that they consider only physical-based modelling outcomes; i.e. we do not include expert judgement (e.g. Bamber et al., 2019). As shown in Table 2, the high-end estimates for the RCP8.5 scenario in 2100 for both sites reach SLR values larger than 1.8 m; this value appears to lie well within the projections of Wong et al. (2017) and Le Bars et al. (2017). Our high-end design is however very different from those of Wong et al. (2017) or Le Bars et al. (2017).

More details on the design of our high-end scenario are given in Thiéblemont et al. (2019). In short, we consider, for each contribution, the highest physically-based modelled global estimate that we could obtain from the literature and downscale it at regional scale using barystatic-fingerprints. For the sterodynamic contribution, MIROC5 and ACCESS1-0 are found to provide the largest contributions. For the glaciers component, the largest estimate (for the RCP8.5) was obtained by forcing a glacier model with HADGEM-ES (see Marzeion et al. 2012). For the Greenland component, we followed the largest model estimates of Fürst et al. (2015) that we corrected by the fact that CMIP5 models projection may underestimate future Greenland contribution since some atmospheric circulation patterns are not well represented (Delhasse et al., 2018). Finally, for the W-AIS contribution, we consider a mean projection assuming MICI, but not a worst-case model outcome because the confidence in MICI projection is still debated, and it is unsure that it will be initiated over the 21st century. In their former paper, DeConto and Pollard (2016) estimated that MICI could contribute to global sea-level rise to more than 1 m by 2100. More recently, Edwards et al. (2019) revisited the latter results by considering the full range of uncertainties of the ice-sheet model parameters used by DeConto and Pollard (2016). The statistical treatment by Edwards et al. (2019) led to revise downward the DeConto and Pollard (2016) projection to 0.8 m. The latter value 0.8 m is hence used for our high-end scenario.

- ⇨ In the revised version of the manuscript, elements to clarify our high-end projections will be added in sections 3.2 and 4.2, and possibly as in the Appendix.

In summary, we do consider several deep uncertainty sources in the design of our high-end scenario. In our study, we tried to be consistent and used a similar approach to define low-end and high-end scenarios (i.e. based on physically-based estimates). Nonetheless, we recognize that there exists several approaches (and studies) that have designed other sea-level high-end scenarios to which our possibility (and flexible) modelling framework could well be adapted.

- ⇨ We will add a point on this in the discussion (section 5.3) section and further insist on this in the conclusion (section 6).

Finally, to illustrate how flexible our framework is, we provide below an example of shoreline change projections where the possibility distribution for SLR projections is defined as a set of consecutive intervals instead of a trapezoid distribution (see Figure R4a). These intervals correspond to the global mean sea-level projections of Le Cozannet et al. (2017) but considering the SROCC likely range instead of AR5. A possibility degree of 1 is assigned to the likely range (0.61-1.10 m). The review performed by Le Cozannet et al. (2017) revealed that 3 different maximum values can be considered: 1.5 m, 2 m or 5 m, to which a weight of 0.5, 0.4 and 0.1 is assigned, respectively, to reflect a lack of consensus in the scientific community regarding the maximum possible contribution of ice-sheets over the coming century. Le Cozannet et al. (2017) quote: “Referring to the IPCC terminology, we note that a 'medium degree of agreement' exists for maximum values of 1.5 m or 2 m, whereas a maximum value of 5 m is characterized by a 'low degree of agreement'”, which translates into various degree of possibility shown in Figure R4a. Figure R4b shows the results applied to shoreline change projections. They reveal that including several “high-end” sea-level scenario leads to a strong enhancement of the gap between the lower and upper CDF near the upper tail of the possibility distribution.

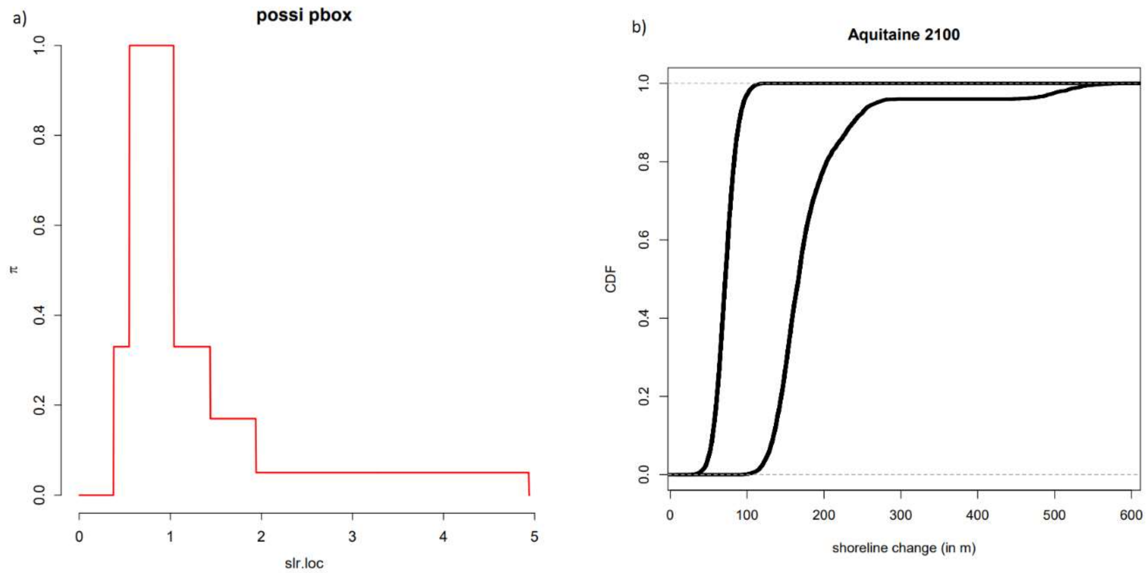

Figure R4. (b) Projected shoreline change probability boxes 2100 for Aquitaine under the RCP8.5 scenario, but including (a) multiple global mean sea-level high-end projections prescribed through a possibility distribution consistent with the review of Le Cozannet et al. (2017).

Minor:

- the applied sea-level projections need a little more explanation. Do I understand well that 21 minus 2 CMIP projections were used? Could you explain in one sentence why two runs were judged 'unrealistic' with respect to sterodynamic behaviour (and others not). And could you explain how sources of uncertainty other than sterodynamical were included (or were they excluded)?

Concerning the sterodynamical component, we indeed discarded two models out of the 21 models of CMIP5; MIROC-ESM and MIROC-ESM-CHEM. Figure R5 below shows that MIROC-ESM (grey) and MIROC-ESM-CHEM (green) models project anomalously large sea-level rise in the Atlantic and North Sea areas. If these two models are discarded, the distribution obtained by the 19 remaining CMIP5 models in these areas is no longer significantly different from a Gaussian distribution according to the Shapiro–Wilk normality test. Furthermore, by 2100, the global-mean thermosteric sea-level rise of these two models (0.5 m for the RCP8.5 scenario) exceeds the median global-mean thermosteric sea-level rise of all other models (0.3 m) beyond 5 sigma (see Figure 3 of Le Cozannet et al., 2019). Finally, the CMIP5 historical MIROC-ESM and MIROC-ESM-CHEM simulations revealed unrealistic sea-surface height values of -15 m in the Mediterranean area that may suggest important biases in the regional sea-level calculations in these two models (Landerer et al., 2014).

⇨ We will better justify why MIROC-ESM and MIROC-ESM-CHEM are removed near L283-298.

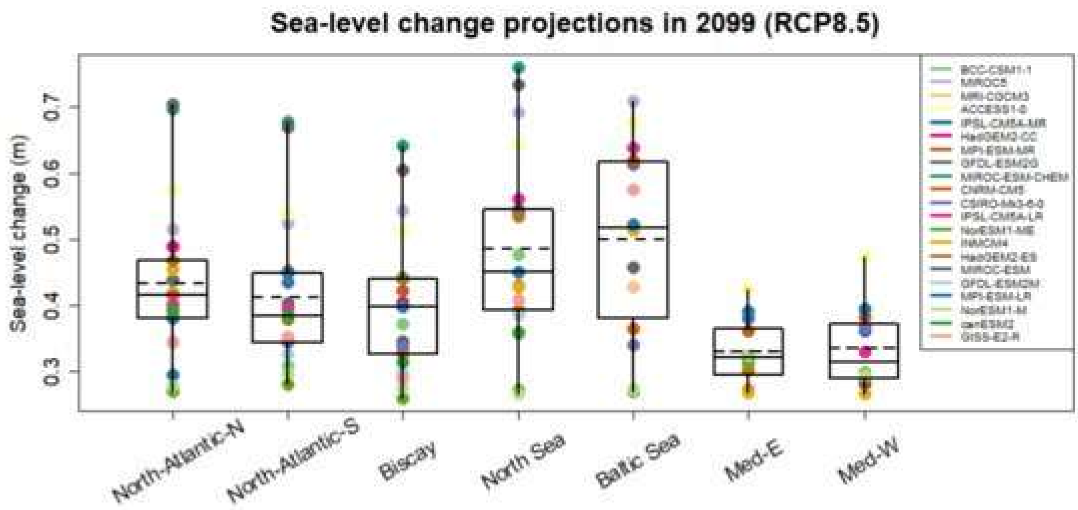

Figure R5. *CMIP5 sterodynamical projections in 2099 (ref period 1986–2005) for the North-Atlantic-N, North-Atlantic-S, Bay of Biscay, North Sea, Baltic Sea, Mediterranean-E, and Mediterranean-W Sea under the RCP8.5 scenario. Whisker boxes display the multi-model 1st* *quartile, median, and 3rd quartile and the dashed line shows the multi-model mean. After Thiéblemont et al. (2019)*

Concerning the other contributions, i.e. glaciers, ice-sheet, landwater and GIA, uncertainties are indeed accounted for although we recognize that this was not made very clear in the current version of the manuscript near lines L283-298. The uncertainty of the mean sea-level is computed as the square root of the sum of the squares of each component uncertainty downscaled regionally. Note, however, that contributions that correlate with global-mean air temperature, namely the sterodynamic and ice-sheet surface mass balance components, have correlated uncertainties and are therefore added linearly (see Church et al., 2013, for more details). This procedure provides the regional mean sea-level IPCC likely-range to which we assign a possibility degree of 1 (see L359-370 and table 2). Nonetheless, the likely-range does not cover the full uncertainty range; that is why we considered low-end and high-end estimates to bound the support of the trapezoid (see also response to first comment).

⇨ We will better explain how sources of uncertainty other than sterodynamical are included near L283-298.

- In figure 4, could you explain how the linear fit was made? In 4b, the fist black dot (yr=1989, shore line change ~ -491) seems to be excluded. Otherwise, I would expect a very different R2.

Thank you for noticing this point, which indeed deserves some clarification. Here we focus on annual values, so we apply the linear regression on annual means. However, given the irregularity of the temporal sampling, the number of points per year can vary widely; especially, recent periods are more covered than past periods. To account for this irregularity in the sampling, the regression is weighted by the number of samples per year. In that respect, the year 1989, which is represented by only 3 samples, has a very small weight. Removing the weighting procedure would lead to reduce drastically the R^2 (it falls below 0.40) but impacts the trend coefficients only modestly (we obtain 0.40(0.10) m/y instead of 0.60(0.07) m/y).

⇨ We will clarify this in the revised version of the manuscript near L164-179.

References:

Bamber, J. L., Oppenheimer, M., Kopp, R. E., Aspinall, W. P., and Cooke, R. M.: Ice sheet contributions to future sea-level rise from structured expert judgment, Proceedings of the National Academy of Sciences, 116, 11195, 10.1073/pnas.1817205116, 2019

Church, J. A., Clark, P. U., Cazenave, A., Gregory, J. M., Jevrejeva, S., Levermann, A., Merrifield, M. A., Milne, G. A., Nerem, R. S., Nunn, P. D., Payne, A. J., Pfeffer, W. T., Stammer, D., and Unnikrishnan, A. S.: Sea Level Change, In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change ed., Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA., 2013.

Delhasse, A.; Fettweis, X.; Kittel, C.; Amory, C.; Agosta, C. Brief communication: Impact of the recent atmospheric circulation change in summer on the future surface mass balance of the Greenland Ice Sheet. Cryosphere 2018, 12, 3409–3418.

DeConto, R.M.; Pollard, D. Contribution of Antarctica to past and future sea-level rise. Nature 2016, 531, 591–597.

Edwards, T.L.; Brandon, M.A.; Durand, G.; Edwards, N.R.; Golledge, N.R.; Holden, P.B.; Nias, I.J.; Payne, A.J.; Ritz, C.; Wernecke, A. Revisiting Antarctic ice loss due to marine ice-cliff instability. Nature 2019, 566, 58.

Furst, J.J.; Goelzer, H.; Huybrechts, P. Ice-dynamic projections of the Greenland ice sheet in response to atmospheric and oceanic warming. Cryosphere 2015, 9, 1039–1062

Landerer, F.W.; Gleckler, P.J.; Lee, T. Evaluation of CMIP5 dynamic sea surface height multi-model simulations against satellite observations. Clim. Dyn. 2014, 43, 1271–1283.

Le Bars, D., *et al* 2017 *Environ. Res. Lett.* **12** 044013

Le Cozannet, G., Manceau, J. C., and Rohmer, J.: Bounding probabilistic sea-level projections within the framework of the possibility theory, Environmental Research Letters, 12, 10.1088/1748-9326/aa5528, 2017.

Le Cozannet, G., Thiéblemont, R., Rohmer, J., Idier, D., Manceau, J.-C., and Quique, R.: Low-End Probabilistic Sea-Level Projections, Water, 11, 10.3390/w11071507, 2019.

Marzeion, B.; Jarosch, A.H.; Hofer, M. Past and future sea-level change from the surface mass balance of glaciers. Cryosphere 2012, 6, 1295–1322.

Thiéblemont, R., Le Cozannet, G., Toimil, A., Meyssignac, B., and Losada, I. J.: Likely and High-End Impacts of Regional Sea-Level Rise on the Shoreline Change of European Sandy Coasts Under a High Greenhouse Gas Emissions Scenario, Water, 11, 10.3390/w11122607, 2019

Wong, T.E., Bakker, A.M.R. & Keller, K. Impacts of Antarctic fast dynamics on sea-level projections and coastal flood defense. Climatic Change 144, 347–364 (2017). https://doi.org/10.1007/s10584-017-2039-4