Interactive comment on "Probabilistic characterisation of coastal storm-induced risks using Bayesian Networks" by Marc Sanuy and Jose A. Jiménez

Anonymous Referee #2
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I have reviewed the manuscript entitles 'Probabilistic characterization of coastal storm induced risks using Bayesian Networks' by Sanuy and Jimenez. Overall the article is very well written and of high quality. It presents a new framework/ approach using the SPRC framework to examine coastal vulnerability to erosion and inundation at an area within the Spanish coastline exposed to Mediterranean storms. The methodology uses Bayesian Networks to take the SPRC inputs/outputs to create a probabilistic outcome of risk assessment. I believe that the article is well within the journals scope and will be of interest to the readers. However, I believe some changes are needed and points clarified as detailed below.

We thank the reviewer for constructive comments. We have performed a thorough revision to address all the comments and incorporated all the suggestions in the manuscript, as detailed below.

<u>General comments:</u>

Unclear to me the reasoning behind running XBeach on the scenario cases for 5, 10, 20 years? As you've just done a linear retreat of the shoreline/ profile and there is no account for changes in storminess or SLR [L482-485], are the results not just XBeach present day + retreat (Where a retreat is limited by hard structures such as seawalls)? I was a bit confused on how you did the retreat as well for the cases where structures were present. My general understanding is that a linear retreat (at all elevations) was done which essentially translated the profile intact. If the profile reached a structure, the landward translation stopped at that elevation, but the rest of the profile was allowed to continue to retreat? Or no? Figure 5 suggests that is not the case but it's not clear what was done? In reality, I think if it ran into a structure (like a seawall) the lower elevations would erode more than the linear trend as there would not be the sand from the land to compensate.

[R1] XBeach was run for different scenarios (5, 10, 20 y) to assess how expected changes in geomorphology may affect future risks. This may be relevant for decadal-scale retreating areas where (a given) current morphology is only representative of a relatively short (few years) period. We did not include changes in storminess since for the study area (NW Mediterranean) existing projections do not predict significant changes in storminess. We will include a paragraph where this is explicitly stated. Moreover, we will also recommend to perform the analysis using corresponding future storm climates when existing projections indicate a significant change in storminess.

These simulations are not exactly equal to "present day scenario" + "retreat" since the study site has not a homogeneous alongshore behaviour. Thus, the area has been divided (in terms of its decadal scale behaviour) in three different sectors, each one with its corresponding (and different) retreat rate. As a result of this, the alongshore configuration of the delta is slightly different across scenarios, with differences increasing with time due to the cumulative contribution of the background evolution. This change in morphology may affect alongshore processes and therefore the coastal response to storms (which is resolved with the 2DH - XBeach model).

With respect to the situation when the profile reaches a fixed structure limiting the landward translation, we have assumed that, locally, the beach has disappeared and the profile does not continue to retreat. We recognize that beach behavior in front of seawalls/revetments is more complicated than this, with different processes taking place at different time scales which may affect beach profiles in front of exposed seawalls (Kraus, 1988). In fact, the observation raised by the reviewer on a larger erosion of the lower elevations due to a lack of compensation of material from the emerged part of the beach is one of the typical ones when cross-shore processes are being considered (e.g. Dean, 1986). In spite of this, existing works have documented different responses under different situations. Thus, whereas variations in hydrodynamics and sediment transport at short-term scale have been reported in front of exposed revetments (e.g. Miles et al. 2001), other authors have found that, in spite of differences in short-term behavior, long-term volume erosion rates are not higher in front of seawalls (e.g. Basco et al. 1997).

References:

Basco, D. R., Bellomo, D. A., Hazelton, J. M., & Jones, B. N. (1997). The influence of seawalls on subaerial beach volumes with receding shorelines. *Coastal Engineering*, *30*(3-4), 203-233.

Dean, R. G. (1986). Coastal armoring: effects, principles and mitigation. In: *Proc 20th ICCE*, ASCE, 1843-1857.

Kraus, N. C. (1988). The effects of seawalls on the beach: an extended literature review. *Journal of Coastal Research*, SI4, 1-28.

Miles, J. R., Russell, P. E., & Huntley, D. A. (2001). Field measurements of sediment dynamics in front of a seawall. *Journal of Coastal Research*, 195-206.

Thus, the answer given to reviewer 1 on assumptions to simulate the profile retreat (R3) is also valid for this comment, and we replicate here:

Future (morphological) scenarios have been defined to consider the background evolution of the area. This is important when assessing risks in dynamic areas because if not, the assessment will strictly be valid just for current conditions (small time scale, few years) and, in consequence, of limited validity for coastal (risk) management. This is the key message, the need of updating beach coastal morphology for an effective risk assessment. <u>We will reinforce this message in the text</u>. With respect to how to do it, it will depend on the specific conditions of the area and on the used tool to mimic/simulate such evolution. Whereas there are many different options, we have chosen a simple one by extending shoreline rates of change to reproduce nearshore bathymetric changes, although as mentioned in the work, it can be substituted by a different choice (e.g. by using a morphodynamic model valid at the appropriate time-scale, e.g. Hanson et al. 2003).

In the study area, observed shoreline retreat is the result of the deltaic front reshaping due to a decrease in river sediment supply whereas the wave-induced littoral dynamics maintained its intensity. Transferring this shoreline retreat to the entire active shoreface implies to apply a hypothesis about the shape of long-term (decadal) profile changes. Thus, the most widely used hypothesis used to convert longshore transport – induced shoreline changes to sediment volume is the one applied in one-line models, where a horizontal displacement of the profile from the emerged beach to the closure depth is assumed (e.g. Hanson, 1989). On the contrary, other works on deltaic reduction processes assume that whereas the shoreline is rapidly eroded, the submerged front retreats at a slower rate (e.g. Refaat and Tsuchiya, 1991). This pattern would be consistent with a wedged-shaped change over the closure depth (instead of a parallel one as before). Other type of approach is the one adopted by Stive and de Vriend (1995) when modelling the long-term shoreface evolution. They proposed a varying type of change through the shoreface, from an upper part experiencing a parallel displacement, to a declining/inclining lower shoreface down to the inner shelf limit. As it can be seen, there are different options to reconstruct beach profiles from a modelled/forecasted shoreline, from which we selected one of the most used (albeit not necessarily the best one).

Regardless of the method used, the most important message is that it is necessary to anticipate future coastal morphology in order to make a reliable risk assessment valid not only for current but also for future conditions. We will highlight this in the discussion section and will also introduce a text discussing how the scenarios were constructed (similar to the previous one, but shorter).

References:
Hanson, H.: GENESIS: a generalized shoreline change numerical model, J. Coast. Res., 1-27, 1989.
Hanson, H., Aarninkhof, S., Capobianco, M., Jiménez, J.A., Larson, M., Nicholls, R.J., Plant, N.G., Southgate, H.N., Steetzel, H.J., Stive, M.J.F, and de Vriend, H.J.: Modelling of coastal evolution on yearly to decadal time scales, J. Coast. Res., 19, 4, 790-811, 2003.
Refaat, H., and Tsuchiya, Y.: Formation and reduction processes of river deltas; theory and experiments, Bull. Disaster Prevention Res. Inst. Kyoto Univ., 41, 177-224, 1991.
Stive, M.J.F., and De Vriend, H. J.: Modelling shoreface profile evolution, Mar. Geol., 126(1-4), 235-248, 1995.

Data independence: I have several questions around data independence that I'd like to see addressed.

First, while the data set is 60 years long, there are 179 independent storms (43 of these are multi-peak storms). It's not clear to me (from an erosion sense) why you'd split these 43 up into multiple storms to augment your data set to 237 storms (Which is still quite small in terms of BNs). Similarly, on L 155-160 it's again described about the multi-peak storms where a single multi-peak storm is run and the outputs from the cumulative are saved, but also those of the 'first peak' (but the cumulative output after each peak is saved?). Should (ii) not be the peak of each 'sub-peak' in a multi-peak storm and should the output not be the volume (for example) between the 2 peaks, rather than the cumulative over the full event? As an aside - Your wave height cutoffs (98 and 99.5%) are also quite high, so you could lower these and get more smaller storms (say the 95% level – see Masselink et al).

[R2] *With respect to creating a dataset based on storm peaks instead of storms.*
Individual storm events have been identified and isolated by using the P.O.T method that ensures they are independent. Then, from there, any storm consisting in more than one peak is treated by its individual (cumulative) peaks, as the idea was to create a dataset of storm peaks (not to artificially augment the dataset with additional storms). For each peak, we retain its duration, together with the total accumulated event duration, and the previous energy (i.e. single-peak storms are always characterised as peaks with "peak duration" equal to "event duration" and with "zero previous energy"). This was done for a parallel analysis on morphodynamic response where we found that peak sequencing was a key aspect to predict local beach retreats. These variables were included in the network to assess their impact into output risk variables, but for the sake of simplicity only a selection of them, focusing on other variables, is presented here, and due to this they have been shortly described, which could

generate some confusion. We will give more extension to variable description in the revised version.

The reviewer is fully right affirming that each "sub-peak" should be considered (not only the first). In fact, the original dataset contains ALL sub-peaks. Text in L155-160 refers to the fact that in order to create the subsets for the future scenarios, and with the objective of reducing the number of time-consuming simulations, the first peak of a multipeak storm is also used as a proxy of "single-peak-storms of the same characteristics". We will rephrase part of the "Storm characterisation" section to clarify this point.

With respect to threshold selection.
The used thresholds when applying the P.O.T method (98% and 99.5% percentiles of the wave height distribution) have been previously used in other works in the study area (Sanuy et al., 2019; Sanuy and Jiménez 2020). Obtained results (identified storms) have been compared with storm conditions associated with representative storm classes (Mendoza et al., 2011) and they fit with values obtained therein for Class 1 and Class 3 storms. Class 1 storms have the minimum Hs historically used in the Mediterranean as threshold for extreme events (2 m), while Class 3 events have the minimum Hs that actually induces hazardous coastal response. This is equivalent to define storms as starting and ending with a Class 1 magnitude, and having at least Class 3 at the peak. This permits to assure that all included events will induce a relevant coastal response from the risk-oriented standpoint.
The obtained event density of 3.5 events/year is appropriate for extreme-climate analysis, and lowering the threshold would increase this frequency by including not too extreme events which would not significantly contribute to overall risk. Due to this, we will maintain the proposed thresholds which have been locally validated for this use. In spite of this, we will stress the meaning of the thresholds, specifying that the levels are site-dependent both in the Storm Characterization" and "Discussion" sections.

References:
Mendoza, E. T., Jimenez, J. A. and Mateo, J. 2011. A coastal storms intensity scale for the Catalan sea (NW Mediterranean), *Nat . Hazards Earth Syst . Sci*, 11, 2453–2462.
Sanuy, M., Jiménez, J. A., Ortego, M. I. and Toimil, A. 2019: Differences in assigning probabilities to coastal inundation hazard estimators: Event versus response approaches, *J. Flood Risk Manag*., 13, e12557.
Sanuy, M., Jiménez, J. A. and Plant, N. 2020. A Bayesian Network methodology for coastal hazard assessments on a regional scale: The BN-CRAF, *Coast. Eng*., 1572019, 1–10.

Second, my understanding is that inputs to the BNs are meant to be independent, so closely spaced receptors which are highly correlated shouldn't be included. I couldn't find details on the spacing of the receptors, but they don't look spatially independent to me (Eg. Fig 3). Beuzen et al. (2019 – JGR) I think discussed this and found the alongshore spacing allowed where correlations dropped off (This would be site specific but in his case it was _500m I think). So I suspect you've padded your BN with a bunch of data that's highly correlated which isn't best practice.

[R3] This answer is related with R5 (see below). Beuzen et al. (2019-JGR) deals with morphological patterns at regional scale (~400 km). They aim for a predictive BN and therefore they cannot allow for correlations in the input. Indeed, distances would be case specific, and places as the Tordera Delta (curvilinear shoreline with significant alongshore morphological variability, and beach-structure interactions inducing local processes such as flanking effects) these distances would be much lower, as we found by analysing the morphological response sector by sector (analysed in a companion morphodynamic oriented-paper, currently under review).

However, this is out of the scope of the current paper, which is risk-oriented. Here, the individual receptors must be represented as they indicate the spatial extension and magnitude of the impacts induced by a given coastal response (e.g. its not the same from the risk perspective 100 m of eroded dune in front of 1 receptor than the same 100 m of eroded dune in front of 2 lines of 20 receptors). Thus, we have adopted the Source-Pathway-Receptor-Consequence (SPRC) scheme as in Poelhekke et al 2016, Jäger et al., 2018, Plomaritis et al., 2018 and Sanuy et al., 2018 to account for the actual receptor density and typology at the local scale.

References:
Jäger, W. S., Christie, E. K., Hanea, A. M., den Heijer, C. and Spencer, T. 2018: A Bayesian network approach for coastal risk analysis and decision making, Coast. Eng., 134, 48-61.
Plomaritis, T. A., Costas, S. and Ferreira, Ó. 2018: Use of a Bayesian Network for coastal hazards, impact and disaster risk reduction assessment at a coastal barrier (Ria Formosa, Portugal), Coast. Eng., 134, 134-147.
Poelhekke, L., Jäger, W. S., van Dongeren, A., Plomaritis, T. A., McCall, R. and Ferreira, Ó.: 2016. Predicting coastal hazards for sandy coasts with a Bayesian Network, Coast. Eng., 118, 21–34.
Sanuy, M., Duo, E., Jäger, W. S., Ciavola, P., and Jiménez, J. A. 2018: Linking source with consequences of coastal storm impacts for climate change and risk reduction scenarios for Mediterranean sandy beaches, Nat. Hazards Earth Syst. Sci., 18, 1825–1847.

Similarly, it's not best practice (And I think even discouraged) to augment your data by multiplying your synthetic cases by the number of storms that were in that bin (L144-146). I know it has been done in the past by others (including myself and I've learned from others this was incorrect) but that doesn't make it correct now. I appreciate you are wanting to keep the original distributions but I'm not sure there is a proper way to do this beyond running each case.

[R4] We agree that this is a shortcoming compared to running all cases. However, this method was proposed to reduce computational time when generating future scenarios (which are affected to other additional uncertainties as well). In statistical terms, the method behaves consistently and it is validated by comparing the distributions obtained with the subset with those of the original dataset (for the baseline scenario). This means that for the purposes presented in the current work, i.e. obtaining risk-oriented variable distributions, the obtained subsets can be considered statistically similar to the original dataset (although for more detailed analyses, such as morphological-oriented ones, this may not be enough).

How probabilistic is your output? Your BNs (Fig 6 and 7) are quite complex and in some cases, highly discretised. This immensely increases the number of data points needed to ensure the priors are well represented. As the challenge is with much geophysical data, you look to have a lot of near empty bins in your outputs. How many of the relationships are really deterministic rather than probabilistic?

[R5] We understand our BN is probabilistic in the sense that it is is used to adopt the SPRC model by using a probabilistic representation of the source (i.e. a probabilistic representation of the storm climate of the study site).
The reviewer is right when pointing out the complexity of the BN, and the data requirements that this involves to properly fill it. In this case, all Source-related parent variables are connected between them (differently e.g. to Beuzen et al., 2019) to ensure that when conditioning is made on these variables all other priors are updated so as not to have noise propagation onto the output variables. In this sense, our BN would fit into the descriptive BN category according to

Beuzen et al. (2018). This does not mean that the output is not probabilistic (which is by the schematization of the SPRC and the treatment of the Source) but that the main purpose of the BN will not be a predictive one, as e.g. in Beuzen et al. (2019).

We shall properly address this point in the Discussion section of the reviewed version of the manuscript. Additionally, the main (and novelty with respect to previous works) purpose of the BN, which is the probabilistic representation of the source, will be also better stressed, as suggested also by reviewer 1 (see answers to reviewer 1 general comments).

References:

Beuzen, T., Splinter, K.D., Marshall, L.A., Turner, I.L., Harley, M.D., Palmsten, M.L. 2018. Bayesian Networks in coastal engineering: Distinguishing descriptive and predictive applications. Coast. Eng. 135, 16–30.

Beuzen, T., Harley, M. D., Splinter, K. D., & Turner, I. L. 2019. Controls of variability in berm and dune storm erosion. *Journal of Geophysical Research: Earth Surface*, *124*(11), 2647-2665.

What's the difference between distance to public domain (Fig 7) and distance to beach (Fig 10-12)? I feel they must be similar if not the same so why not use the same classification and binning for the 2?

[R6] Indeed, they are the same since the line of public domain is running along the inner limit of the beach. The name in figure 7 (and related text) will be changed. The binning is actually the same, but in figures 10-12 the outputs of two lowest bins are summed under the name "Beach to 10m", and the outputs of the four highest bins are summed under the name "> 75 m"

Specific Comments:
[L74]: 'were' should be 'where' in: "study area were"
[R7] This will be addressed in the updated version of the manuscript.

[L204]: "Risk to life was also been" should be either 'Risk to live was also' or "Risk to life has also been"
[R8] This will be addressed in the updated version of the manuscript.

Fig 5 - can you tell the reader what section these are in and the erosion rate used?
[R9] This will be included in the new version of the figure.

[L355] "affecter" should be 'affected'?
[R10] This will be addressed in the updated version of the manuscript.

[L341] "front a of a" should be "front of a"
[R11] This will be addressed in the updated version of the manuscript.

[L427] "relation" should be "relationship
[R12] This will be addressed in the updated version of the manuscript.