Answer to #2 referee's review of paper by Sanuy et al.: "Linking source with consequences of coastal storm impacts for climate change and risk reduction scenarios for Mediterranean sandy beaches"

Introduction

This paper presents an approach to integrated risk assessment for coastal areas with regard to storm impact on beaches (*i.e.*, flooding and erosion), considering climate change. Two case studies are presented from the Mediterranean Sea, one from the northern Spanish coast and one from the Italian coast in the northwest part of the Adriatic Sea. The methodology employed involves simulation with deterministic models for a fixed number of storm scenarios, subsequently being generalized to involve a probabilistic approach using Bayesian statistics.

Overall Assessment

The paper presents an interesting and potentially useful methodology for estimating the risk associated with storm impact in coastal areas. It is in general clearly and well written; however, the paper is rather long and "wordy", presenting a lot of detailed information not really needed. On the other hand, certain aspects of the study should be discussed and explained more.

In summary, the following weaknesses of the paper should be addressed: (1) reduce the length of the paper by eliminating detailed results from the study sites; (2) expand the discussion on how coastal managers may use the results of the proposed risk assessment in their work; (3) motivate the selection of models in the approach; (4) discuss the importance of other factors influencing long-term coastal evolution not considered in the approach; (5) clarify the discussion of the methodology and concepts used; (6) comment upon the effects of antecedent morphology and chronology of forcing; and (7) explain the description of beach response to sea level rise.

I recommend that the paper is accepted after major revisions.

The general comments are given in more detail below followed by comments to specific points in the paper.

AA. The authors thank the referee's effort and comments. We will address all of them, giving a specific response for each of them in what follows.

General comments

The authors are requested to address the following comments of a more general nature:

1. Reduce the length of the paper by eliminating detailed results from the study sites. The paper is rather long and could be shortened by cutting some of the detailed results from the two study areas. The results from these areas are interesting mainly as an illustration of what the methodology can produce; the specific values are of little interest to the readers in general. Thus, many of the figures 10-18 can be eliminated without loss of information.

AA1.We agree that the manuscript is "wordy" manly due to details provided about results of case studies. Following reviewer's suggestion, we shall reduce the length of the paper. Thus, we propose eliminating Figures 12, 13 and 14 from the Tordera Delta results and Figure 16 from Lido degli Estensi-Spina results. Thus, the inundation assessment will be presented for the campsite receptors and the erosion assessment will be presented for the infrastructural receptors for the Tordera Delta, whereas concessions will be the only receptor presented in the results section for the Italian case. With this we can still show the same trends between current a future situation and also show the performance of the DRR.

In addition, the text will be cut down accordingly, and also, no mention to specific values will be made, explaining only qualitatively the trends, and leaving the figures as elements where the reader can roughly check the values. With this we are taking out 4 of the 9 figures and corresponding associated text that this section has in the current version of the manuscript.

2. **Expand the discussion on how coastal managers may use the results of the proposed risk assessment in their work.** The discussion section is very good and informative, indicating strength and weaknesses of the methodology. However, I would like to see the authors present more of their thoughts on how managers can use the results coming out of the proposed risk assessment and advantages compared to how things are done presently. Also, are coastal managers ready to grasp this type of information, especially when it involves probabilistic concepts? In the end risk levels are presented in a qualitative manner through different categories. Would it be possible to be more quantitative?

AA2. We propose adding the following sentence in the discussion section: "*The aim of the presented application is to assess the efficiency of measures in terms of impact reduction, not to select the best alternative (as e.g. based on multicriteria (MCA) analysis including economics, endurance, ecological, stakeholders' perception, etc). The BN provides an output that can be combined with other information in such MCA analyses (e.g. Barquet and Cumiskey, 2017).*" The reader is referred to the Barquet and Cumiskey, 2017 paper (Barquet and Cumiskey, 2017. Using participatory Multi-Criteria Assessments for assessing disaster risk reduction measures. Coastal Engineering, in press) where it is detailed how the results of the BN are used to inform stakeholders about the scenarios and then, and MCA participative assessment takes places. The advantages and feedbacks from the MCA analysis are also presented in that paper.

About the last question "would it be possible to be more quantitative?" The answer is yes: in the methodology section, the reader can see how relative damage is the actual output from the BN for the inundation hazard. Thus, post process with quantitative results could be performed (e.g. economic impact estimation derived from relative damage), but this was out of the scope of the present work. We are presenting results as they were showed to the stakeholders, qualitatively and easy to read and assess efficiencies. This is the basis of the MCA analysis explained in Barquet and Cumiskey (2017) where the addition of other information and the participation of multiple stakeholders is key to finally obtain a DRR selection.

3. **Motivate the selection of models in the approach.** The basis of the methodology is deterministic simulations that are employed in a probabilistic approach through the Bayesian model. What was the reasoning when selecting the present deterministic models, which are rather detailed and time-consuming to run? Could simpler models have been employed for which many more simulations could have been made? How was the balance selected between the deterministic and probabilistic parts of the approach?

AA3. In principle any model can be used but results will be as good as accurate the model will be. With this in mind, the model selection is the result of the balance between accuracy and cost. Since the evaluation system is not designed to run on-line (as an Early Warning System would do) computation time is not a major issue. Due to this, we have selected a process-oriented model specifically designed to simulate coastal storm-induced processes which is able to provide integrated information on inundation and erosion, the Xbeach model. At present it is becoming the S-O-A model on coastal systems. However, the proposed framework can work with different (simpler) models provided they are able to

simulate the target processes (inundation and erosion). The motivation of model selection will be stressed using what's formerly explained, in the first paragraph of section 3.3
With independence of the model to be used, it provides the deterministic response of the system. The probabilistic character is provided by the forcing (i.e. storms). The BN works as a result integration and post-processing tool. The balance between deterministic and probabilistic will depend on the information available at the study site and the way the BN is feed. It will be stressed, as this was one of the main focus of referee#1 comments, that the present application is rather deterministic, but has the capability of dealing with a fully probabilistic feeding (see answers AA9, AA10 and AA12 to referee#1 on this topic). Therefore, more insight on this will be given in the general part of the results section (small note) and in the discussion section.

4. **Discuss the importance of other factors influencing long-term coastal evolution not considered in the approach.** The approach focuses on the impact of storms, specifically flooding and erosion. However, storms are only one of the many factors controlling beach evolution. On some coasts storms will be the primary drivers of beach change, but quite often other processes, such longshore transport gradients, sediment input from rivers, and subsidence, must be included to determine how the beach evolves over longer time periods. Typically there is a coupling between longshore and cross-shore processes that needs to be taken into account in estimating beach evolution. Add some discussion.

AA4. The reviewer is also right. However, it has to be considered that the framework here presented is designed to analyse storm-induced coastal response. In spite of that, other factors affecting coastal response can also be added to the framework as we have done with SLR. As an example, the existence of a gradient in longshore transport will induce a background erosion which will modify the morphology of the coast where the storm will impact. This will be the case with any additional processes acting on a system. It must be considered that the presented framework is not forecasting the coastal morphology at any given time (where it should be necessary to couple all processes) but it predicts the expected storm-induced changes for a given coastal configuration. In that sense, a long/medium term model could be used to forecast a future coastal morphology under a given climate scenario and then, use it as initial configuration to forecast storm-induced changes. In any case we shall include a paragraph stating that the initial configuration will be controlled by medium/long term processes and that they must be taken into account to produce initial coastal configurations when the framework is used for future risk predictions. This extra information could be included in the BN, which will automatically output the uncertainties due to future positions of the shoreline and/or the corresponding differences between scenarios.

5. **Clarify the discussion of the methodology and concepts used.** The paper is rather clear on the methodology, but sometimes it is a bit difficult to follow and the sentences become long and affected by jargon. I also have a bit of a problem with how the source-pathway-receptor model is translated to the storm case. The storm is the source and erosion/flooding is the pathway; this seems a bit different (and less logical) from the experience I have in looking at pollution transport. Anyway, may be the writing about and motivation of the schematization could be made a bit clearer. Also, although abbreviations make things a bit easier, if there are too many it is difficult for the reader to remember all of them.

AA5. If we state that erosion and flooding happen IN the pathway it will match the use of the concept more commonly experienced in other fields. We will address this in the schematization methodological section. In addition, as we also got the same comment from

referee#1, we will only leave common abbreviations such as MSL, Hs, Tp, and we will use full wording for all other concepts.

6. **Comment upon the effects of antecedent morphology and chronology of forcing.** Morphological response are very much a function of the antecedent conditions as well as the chronology of the forcing, especially when it comes to storms. For example, if a large storm is followed by a similar large storm the second one will cause much less erosion. Thus, looking a storm impact as individual events will cause some limitations in terms of the impact assessment. Please add some discussion on this.

AA6. The authors agree with the statement about the chronology of forcing and consecutive storms. This is another process controlling initial coastal configuration (morphology) where the storms will impact. See answer to question 4 (AA4).

7. Explain the description of beach response to sea level rise. The response of a profile to sea level rise requires some assumption about the evolution of different morphological features, for example the dune (e.g., will the dune grow to its pre-SLR shape?). Some additional discussion on the assumptions made in this respect would be interesting.

AA7. The current state of the description of the application of the Brunn rule is "*This was accomplished assuming an equilibrium coastal profile response following the Bruun rule (Bruun, 1962), resulting in landward and upward displacement of the beach profile*" (P12 L11).
We will specify here that dunes preserve the pre-SLR shape when there's enough accommodation space, and the shape was cut where there wasn't enough space. Then in the discussion we will add a note saying that this assumption has some uncertainties that are assumed to not be significantly affecting the goal of the work (first check on DRR performance on present and future conditions), but should be addressed if the goal was a detailed future scenario impact assessment. In that case, other models could be tested and integrated in the BN to estimate the role of that uncertainty on the outcomes (see e.g. Le Cozannet G, Garcin M, Yates M, Idier D, Meyssignac B (2014) Approaches to evaluate the recent impacts of sea-level rise on shoreline changes. Earth Sci Rev, 138: 47-60. doi:10.1016/j.earscirev.2014.08.005). In addition, SLR projections itself have uncertainties that may be larger than their associated morphological response. All this together could be analysed using the presented BN schematic approach but was out of the scope of the present application. This will be also stressed when we state that the BN has enough flexibility to integrate many different kinds of assessments depending on the scope.

Specific comments

In the following specific comments are given to the paper (L = Line number; P = page number).

P4, L14
"wave-induced run-up" Includes wave setup? Any consideration of duration with regard to having water at a certain location?

AA. It is a general statement comparing the contribution of run-up (including set-up and swash) to the total water level (astronomical tide + residual (surge) + run-up). During storms, the contribution of the first two is low (0.25 cm astronomical tide and 0.2-0.6 surge) compared to the contribution of wave-induced run-up (in the order of several meters

depending of the beach slope and period). We are not considering any time duration here, since tide and surge are never the direct cause of flooding in the NW Mediterranean, being this the wave-by-wave overtopping. Thus, the surge only plays the role of "lowering the freeboard of the beach some centimetres (tens in the worst case)", and was considered not to be significant enough compared to waves' contribution to include it as a variable in the BN (i.e. having multiple classes of MSL for the current situation).

P5, L19
"thresholds" How sensitive are the methods to the selected thresholds? Were this selection based on impact or purely on the forcing properties (offshore wave conditions)? The probability of extreme events with regard to the former and the latter are typically different.

AA. The authors are well aware of the different statistical results obtained by the event approach (selection based on storm characteristics) or the response approach (statistics based on impacts/hazards) and have studied its effect of inundation hazard statistical identification. The presented method is not sensitive to the thresholds to identify events the way it is applied. We are not assigning probabilities or return periods to a given inundation. We are integrating results from multiple scenarios by equally representing them (same storm simulations for each source characteristic state of variables). In this section we are only explaining how storm events are usually identified in the study sites, for the reader to know what a storm means in the Adriatic or in the NW Mediterranean.
In addition, obtaining storms by thresholds on impacts, would imply having available time-series data of multiple years of storms, which is not the case in the Italian study site and may not be the case in other locations.

P8, L18
"XBeach model" How good was the calibration/validation?

AA. Currently we are providing only the reference to the study at the Tordera Delta were the validation is explained in detail (currently submitted to Coastal Engineering). We will include a note at each study site paragraph describing briefly how good the validation was, in terms of BSS score or qualitative comparison respectively, so the reader can have some additional info in the present manuscript and not only the references.

P9, L14
"intersecting" Meaning in this context?

AA. Polygon intersection, between receptors 2D layout and the Xbeach grid. This way we identify which grid nodes affect each receptor. We will clarify

P11, L16
"footprint" What is this?

AA. Is the receptor polygon layout in 2D. We will use "receptor limits in the ground".

P12, L14
"a directional change" But the wind did not change, right (L3)? What is causing this.

AA. The study reporting change in wave direction (Casas-Prat and Sierra, 2012) predicts the change in direction by applying statistics to the current past 60-year evolution of wave records, and obtaining the prediction of the future wave mean climates. Therefore, there is no information/evidence in that study linking that change to any specific forcing (wind,

wave current interaction…). It is a scenario we wanted to explore as a "what if" future situation.

P13, L14
"winter dune" What is this?

AA. It's the name they give to a trapezoidal sandy dune, that they artificially build from beach scrapping every winter to protect concessions. We'll add clarification

P18, L18
From here on some of the figure numbers are wrong. Please check.

AA. This will be addressed, since some figures will be supressed and the whole text on the results section reviewed and reduced.

P18
Some of the DRR measures taken seem to increase the risk. What is the explanation/logic behind this? Does it mean that the characterization of impact is not proper?

AA. This is the case when the DRR affects the hydrodynamics at the nearshore and or swash zone, and while protecting locally some receptors, but the erosion is increased down coast and other receptors get more exposed than before. Overall it can be observed how this increase isn't significant in any case.
Nevertheless, the figure containing this effect will be supressed due to comment 1 (AA1), and thus, it will not induce confusion to the reader or require further explanation by the authors.