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Natural Hazards and Earth System Sciences
Discussions

Interactive comment on "Linking source with consequences of coastal storm impacts for climate change and risk reduction scenarios for Mediterranean sandy beaches" *by* Marc Sanuy et al.

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RC: Referee Comments AA: Authors' Answers

RC0: #### general comments The authors present a risk assessment for coastal storm impacts to support decisions on disaster risk reductions. For that purpose a Bayesian network approach is used to link process-oriented models, that predict the hazards at the receptors, with vulnerability relations to obtain the final expected impact. In a case study two Mediterranean sandy coasts are considered. The paper is well structured

and provides a well-argued motivation and problem definition. Further the study areas are described in detail and underline the relevance of the presented study. Despite a good structure in the Methodology section, some aspects of the method remain unclear to me, which might be due to the complexity of the model chain. This affects especially the Bayesian network (BNs) application. Even though I am familiar with the construction and application of BNs, I have problems to follow the construction (i.e. parameter setting) of the BNs and to understand the motivation for and advantages of using BNs in the presented context. The results section provides an extensive analysis of different climate change and adaptation scenarios for the considered Mediterranean coasts. Yet, I did not understand which storm intensities are considered here (this might be due to a missing understanding of the methodology). The discussion names several aspects that pose challenges or are neglected in the presented model approach and might consequently be taggled in follow up studies. Yet, to my impression important critical points of the presented approach are missing, as will be specified in the specific comments.

AA: Thanks for comments and suggestions on submitted manuscript. In what follows we answer to all comments/suggestions/questions raised by the reviewer. First the reviewer's comment is literally included and it is followed by the corresponding authors' answer.

RC1: #### specific comments I found it quite difficult to keep track of all abbreviations used in the paper. AA: We understand that the use of a large number of abbreviations could be cumbersome, especially for a long text as this manuscript. We have reviewed the text and reduced the number of abbreviations to a minimum.

abstract: RC2: line 15: "a large number of storm characteristics" What is a large number? To my understanding 3-4 storm characteristics were considered. AA: When we mention "storm characteristics" we refer to storms defined in terms of a combination of Hs, duration, direction and water level. In each site, we have selected 12 storm combinations for each water level (SLR) scenario, i.e 24 storm combinations per site.

This is clearly specified in the text (including table 1). Then each storm combination is represented by 2 different simulations changing slightly the storm variables inside the category ranges. We have modified this sentence in the abstract by the following "Process-oriented models are used to predict hazards at the receptor scale which are converted into impacts through vulnerability relations. In each site, a total of 24 storms have been simulated and obtained results are integrated by using a Bayesian Network to link forcing characteristics with expected impacts through conditional probabilities."

RC3: line 17: "The tool has been proven successful in reproducing current coastal responses at both sites". I could not find any model verification in the paper. Only a reference to a paper that verifies a part of the model. AA. Thanks. In order to avoid confusion with morphodynamic model validation we have changed the sentence to "Consultations with local stakeholders and experts have shown that the tool is valuable for communicating risks and the effects of risk reduction strategies. The tool can therefore be valuable support for coastal decision making."

Section 3.2: RC4: page 7, line 7: The discretization of the variables is hardly motivated. What is the motivation for choosing 2 or 3 or n intervals for a certain variable? How are the interval boundaries selected (equidistant, equifrequent, entropy-based, ...)? How is the probable range determined (only so far observed values)? Some information about the distribution of these variables might help to motivate the discretization. What are the effects of discretizing? In the discussion it is mentioned that accuracy comes at computational costs, but this information is quite sparse (no information about number of intervals scales with computational costs or what are the computational costs of the current network for parameter determination and for inference).

AA4: To avoid confusion in this section we will remove "Storm scenarios are defined [. . .] were selected for use in the analysis." (lines.6-9), since we already explain that storm scenarios are combinations of variable values covering the typical storm condition at each study site. The description of bins only makes sense in terms of the BN, which we have not explained yet in this section. Then we will motivate the discretisation

of variables in section 3.6.1. Thus, we will add in that section the following explanation: "In the boundary conditions' variables, ranges are selected equidistant covering the so far observed values at each study site (Table 1). Additional non-observed ranges are introduced only to account for SLR. The exact number of intervals is a compromise between accuracy and computational effort. Each combination in Table 1 is simulated here twice, in order to account for variability inside bins. Then, all simulations are repeated for the DRR scenario affecting the hazard. Therefore, a total number of 96 runs of the whole model train were required in the current bin set-up. More simulations would capture in better detail variability inside source combination due to bin discretization, but as a first application of the methodology the computational effort was limited. The current work took, as a reference, 2 months of model train simulations in a 48 thread cluster for the Tordera Delta case."

RC5: page 7, line 12: "time series" of what? We have modified the sentence as "In addition, time series of waves (either bulk Hs, Tp and mean direction or spectrum) and water levels during each storm event were used when this information was available.".

RC6: page 7, line 19-20: the "(24 simulated storms)" confused me? Why do you consider 24simulated storms for 12 state combinations? See answers to comments 2 and 4. In addition to avoid confusion, the sentence is rephrased to avoid the brackets. The new sentence is "The selected source combinations are shown in Table 1. These lead to 12 combinations defining the source that must be tested in the current MSL and another 12 in the future MSL scenario. Each combination of states is simulated twice by means of slightly different storms to account for variability inside the variable ranges, leading to 24 storms in the current MSL and 24 in the future projected one"

RC7: page 7, line 24: What are synthetic triangular events? We have changed the text to: "To include a full range of combinations, the remaining eight storms were completed by using combinations of Hs-duration-direction not previously recorded. These events were modelled assuming they follow a triangular-shaped development with the peak intensity at the half of their duration (see e.g. McCall et al. 2010; Poelhekke et al., 2016).”

RC8: page 7, line 27-28: "water level and Hs are uncorrelated" <- a reference is needed? The reference is (Mendoza and Jiménez, 2008) which was located at the end of the next sentence. We have changed its position.

RC9: page 8, line 1: How are the driving variables identified? Why are the remaining variables considered to have no effects? How is the distribution of the storm defining variables defined? To my current understanding an equal amount of storms for each state combination is considered, which infers a uniform distribution of the variables. Yet, I would expect that small Hs values or smaller durations are more likely than higher values? Is this accounted for? AA9: This comment has two parts. First, the identified driving variables: In Tordera Delta it is argued that ranges of Tp are quite similar amongst storms and surge isn't a relevant variable especially when compared to waves, and both are motivated with references. For the Italian case, better motivation of the selection of drivers and justification of left-out variables is now provided. The first sentences of the Lido degle Estensi-Spina paragraph are now “For the Lido degli Estensi-Spina case study, the source variables, identified as drivers of the impacts of flooding and erosion, were the maximum Hs and maximum TWL of the storm event. The literature for the area recognizes these as main important variables with TWL having more importance (Armaroli et al 2009, 2012). In addition, the relative sea level rise (RSLR) was considered as a Boolean variable to represent the CCS. The direction of the storms was not considered as a source characteristic variable since storms are either ENE or SE, and each Hs-TWL combination is simulated twice accounting for variability inside this directional range. The source combinations were classified into the variable ranges shown in Table 1” Second, the distribution of the storm defining variables: The BN is trained with equal representation of all variable combinations, these means that once the Bayesian is trained, the “prior” probabilities of storm variables are uniform. The main reason is that the extreme value probability distributions of the source variables are not known for the two sites of interest and estimating them

was beyond the scope of this study. However, once relative frequencies of different events are available, the source nodes could be retrained and the distribution of all hazard and consequence nodes would be updated automatically. Additionally, the user could also test how different assumptions on the source variable distributions would change the hazard and impact estimates. Nonetheless, the main strength of the BN at its current stage is that it enables decision makers to explore different scenarios and helps them to design robust strategies (i.e., strategies that are successful under most scenarios.). This will be better motivated in Results section and Discussion. See answers on comments on those sections.

Section 3.3: RC10: Only one event (storm) is considered for each combination of states. Yet, similar events might result in different outcomes. Further, the applied model chain seems to provide deterministic results. Consequently, no uncertainties are considered/captured in the model construction. Since BNs are explicitly designed to capture uncertainties, I wonder why this approach was chosen here. The distribution of hazard at the receptors results from the different location of the receptors, but does not reflect the uncertainty related to the inundation or erosion at a specific object. In a strict sense, I would not judge the resulting distribution to represent probabilities. AA10: We answer the comment in splitting it in different shorter pieces: RC10.1: Only one event (storm) is considered for each combination of states. Yet, similar events might result in different outcomes. AA10.1. Two storms are simulated for each combination (we agree that this was not properly explained see previous answers). Furthermore, the user could select storms belonging to for example Hs = 3-4 meters with waves coming from the East for current MSL but leaving the duration unconstrained as an uncertain variable. In such a case the obtained output would be the integrated result from 4 simulations (2 direction categories that are represented by 2 simulations each with different values of duration). Therefore, results will account for the uncertainty on duration for a given (certain) Hs. In practice, this could be relevant because storm forecasts could contain more certainty on some variables than on others, for example as a result of ensemble forecasts. For a more detailed discussion how the BN tool can deal with ensemble forecasts also see section 5 in Jäger et al. 2017. A Bayesian network approach for coastal risk analysis and decision making. Coastal Engineering (in press). RC10.2. Further, the applied model chain seems to provide deterministic results. Consequently, no uncertainties are considered/captured in the model construction. AA10.2. Reviewer is right, we do not account for uncertainties inherent to individual models. Quantifying uncertainties of individual models is another study in itself (e.g. Wagenaar et al. 2016. Uncertainty in flood damage estimates and its potential effect on investment decisions. NHESS, 16, 1-14), and it is beyond the scope of this manuscript to do such analysis. RC10.3. Since BNs are explicitely designed to capture uncertainties, I wonder why this approach was chosen here. AA10.3. A BN can be a compact representation of a high-dimensional probability distribution. In this study, we used an existing BN approach and algorithm (Jäger et al. 2017. Bayesian network approach for coastal risk analysis and decision making. Coastal Engineering, in press) to integrate high-dimensional data from various underlying models in a compact way. As mentioned in previous answers, the main purpose is to explore scenarios (forward prediction) or to gain insight in the main drivers of hazards and impacts (backward prediction). RC10.4. The distribution of hazard at the receptors results from the different location of the receptors, but does not reflect the uncertainty related to the inundation or erosion at a specific object. In a strict sense, I would not judge the resulting distribution to represent probabilities. AA10.4. The most intuitive interpretation of the distribution of hazard and consequence at the receptors is indeed as the "expected fractions of receptors with the single hazard or impact levels". However, they could be interpreted as probability distributions for an arbitrarily selected receptor whose location is known. Nonetheless, we removed the following in the main text to not confuse the reader: Page 2, lines 27 – 29 "This implies [. . .] probabilistic-based analysis of the results." Page 26, line 6 " and their uncertainties"

Section 3.4: RC11. To model the consequences flood damage curves are applied. Those are generallyrelated with huge uncertainties (a wide range of relative damage can be observed forequal water levels), which are again neglegted and not included in

the BN. On top, adamage curve that was derived for river floodind is applied. Since the process of stormsurges is very different from river flooding the applicability should be discussed.In terms of risk levels the values selected for both study sites differ significantly. E.g.medium impact building damage ranges from 0.26 to 0.45 compared to 0.1 - 0.2. Whyare these intervals chosen? AA11. Ideally, damage curves have to be specifically built for local conditions (including associated uncertainty). However, in the study site, such information is not available and, official water management agencies recommend the use of a representative damage curve for flooding analysis. These are the selected curves used in this work (they are properly referenced). Now, we have stressed in the text the motivation and implications of the curves selection and the final risk levels. "The chosen damage curves do not include uncertainties, and are used as recommended by the administration at both study sites. This implies that damage ranges and damage-hazard relations are different at each study site and therefore the final impact levels (from none to high) are also site-specific, since they are calculated from the definition of the corresponding damage curves. This assumption aimed to better communicate results to local stakeholders."

Section 3.6: RC12. To my understanding the probability tables of the BN are constructed by simulating a storm scenario for each combination of states and running the deterministic model chain to receive a predicted hazard value for each receptor in the study area. Due to the deterministic character of the model chain, the resulting distribution for the hazard variables does not represent probabilities, but the expected fraction of receptors with the single hazard levels or impact levels respectively. See answers to comments 9 and 10.

RC13. Since no uncertainties are considered, I see no need to apply BNs in this context. The same calculations can be done by applying the model chain directly. A direct application of the model chain would also avoid the discretization of the variables and consequently achieve a higher accuracy. In my point of view the revised paper should either do without the BN approach or account for the uncertainties related to the single model components. AA13.Uncertainties due to variability inside each bin combination are included in the assessment. Is not the aim of this application exercise to account for the uncertainties of the single model components. There is no such thing as “applying the model chain directly”. Some sort of post-processing and integrating is always necessary. The use of the BN is justified by the need to integrate results from multiple simulations when assessing scenarios. If you discretized hazards and impacts according to the vulnerability curves, the only loss of “accuracy” is due to the spatial discretization. Then one could argue that it is not very useful to report the individual hazard level of every single receptor, but that an aggregation into “fractions at different hazard levels per area” is needed to convey insight to decision makers. The method can then further assess other uncertainties (related to lack of knowledge), such as knowing the distribution of Hs to be assessed but not knowing the associated durations. In this context the user can leave the duration unconstrained to integrate to results from all possible durations in the output. Additionally, we are not proposing the BN tool in this article, we are simply using it, (partly) because it is already available. That is an algorithm that automatically integrates and post-processes the model data is already available. The BN is also really useful since allows the user to gain insight in the main drivers of hazards and impacts (backward prediction). We will include on the discussion that indeed “Uncertainties related to individual process oriented models or damage curves are not included in this application. However, the methodology can easily integrate them if simulations from multiple models are used to feed the BN and uncertainties related to damage curves are known”.

Section 4: I do not understand which storm intensity is considered here? Are the presented results the joint distribution for all possible combinations of storm characteristics? If so, what is the meaning? Is this a kind of average storm? <- I don’t think so. I would rather prefer to consider specific storm scenarios in combination with their return period. E.g. what are the effects of DRR measures for a once-in-a-year oronce-in-10-years event or for an extreme event. To judge the efficiency of DRR measures, it would also be interesting to get some information about the costs of their implementation and

their probability of failure. M14. As explained before, uniform distribution of inputs is presented here as a simple application without prior statistical knowledge at the sites. It shows that a successful comparison of scenarios can be performed without “prior” statistical analysis. In fact, many kinds of results could be shown: real distributions of inputs, selected events, either equal to known historical ones or related to given return periods etc. However, they were not included because this requires prior analyses. For instance: What means a once-in-10-years event? An event calculated in terms of Hs and leaving the other variables (Tp, duration, direction, water level) free? An event defined in terms of the (multiple) joint probability of Hs-duration-direction and water level? (this needs further statistical analysis which is out of the scope of the present work) 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. Using participatory Multi-Criteria Assessments for assessing disaster risk reduction measures. Coastal Engineering, in press). To clarify this point we have included a paragraph illustrating these options provided a previous statistical analysis is performed, but stressing that the aim of the work is to show a selected application of the tool: “Uniform distribution of input Hs and duration is presented here, as a simple application assuming that there isn’t any prior knowledge of the variable distributions. This is shown to be sufficient for the purpose of exploring scenarios”. Later in the discussion section we will add “Different kinds of results could be shown with the BN: real distributions of inputs, selected events, either equal to known historical ones or related to given return periods etc. However, they were not included because this requires prior analyses. 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). Section 5: RC15. page 21, line 11: "a first test to check the method was presented" <- Where?I could not find any validation of the presented model. There is only a reference to a(not published) paper to validate the hazard component of the model chain. This is similar to comment 3 and the answer to it is the same. The sentence is not referring to models validation. We intended to state that the presented work is a simple application of the BN tool to explore its capabilities. It is a general statement that will be rephrased and moved one paragraph above, since it's common for both study sites.

RC16. page 21, line 11-15: A more detailed justification for the chosen amount of intervals and the interval boundaries, would be nice. Additionally, some information about how the computational costs scale with the number of intervals could be provided. Several uncertainties related to the study are not discussed (see comments about section 3). This is similar to comment 4 and answer is also applicable here. To clarify this point we have included the following text "In this work, a first test to check the method was presented, and a balance between computational expense and accuracy was pursued. Therefore, chosen source variables were limited to those defining most important storm features related to impacts and variable discretization was performed with equal intervals covering the whole range of so far observed values. 12 state combinations in the current situation implies 96 total simulations of the model train, which can take even months running in a 48-thread cluster." About the uncertainties, the overall additions performed in all sections, including discussion clarifies which uncertainties are not included in the assessment and how the BN approach is here used. #### technical corrections RC17. page 4, line 24: 2-3m? AA17. It has been rephrased to "The coast is about 130 km long and characterized by low-lying, predominantly dissipative sandy beaches. The coastal corridor has low elevations, mainly ranging from -2 to 3m above MSL (Regione Emilia-Romagna, 2010)" RC18. page 5, line 16-17: Armaroli et al (2012) is cited double AA18. Thanks. It has been addressed. RC19. page 11, line 19: check >0.05m or >0.5m AA19. It has been rephrased to "Erosion was considered significant (and thus, present) when

>0.05m. The erosion risk categories for each receptor were set as follows: (i) Safe: no erosion in any buffer, (ii) Potential Damage: when erosion is present in the 10-m buffer and/or is present with values less than 0.5 m in the footprint buffer, and (iii) Damage: when the erosion limit of 0.5 m is exceeded for the footprint buffer" RC20. page 14, line 31: "it also provided ..." What is "it"? AA20. It has been rephrased to "Alongside the generic structure, a c++ programme that automatically creates the BN (https://github.com/openearth/coastal-dss) is also provided"

Please also note the supplement to this comment:
https://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2017-345/nhess-2017-345-AC1-supplement.pdf

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