Interactive comment on “Climate uncertainty in flood protection planning” by Beatrice Dittes et al.

Author comment on the comment of anonymous referee #1

The authors thank the referee for the thoughtful and detailed comments. In the following, we respond to the individual suggestions, with referee comments highlighted in *blue*.

> *General: It is difficult to follow the different steps and methods applied. Including an additional figure / flow chart illustrating the whole processing chain may help to understand the methods*

We rephrased p2/l22-26 such that they form a separate, longer paragraph and included a flowchart:

“In this paper, we show how to incorporate into the flood planning process the visible uncertainty from an ensemble of climate projections as well as hidden uncertainties that can not be quantified from the ensemble itself but may be estimated from literature. When combining uncertainties, special care is taken to account for uncertainty and bias in projections as well as dependencies among different projections. We provide reasoned estimates of climatic uncertainties for a pre-alpine catchment, followed by an application of the previously proposed Bayesian decision framework, sensitivity and robustness analysis. The process is shown in Fig. 1: 1) Projections of annual maximum discharges (see Sect. 2.2) and 2) an estimate of the shares of various uncertainties that are not covered by the projection ensemble (see Sect. 2.5) form the inputs to the analysis. 3) For each projection individually, a likelihood function of annual maximum discharge is computed. This is done such that bias is integrated out and projections later on the horizon are assigned diminishing weights, making use of the hidden uncertainty shares (see Sect. 3.2). 4) The likelihoods of individual projections are combined using the method of effective projections (Pennell and Reichler, 2011; Sunyer et al., 2013) *in order to account for dependencies among them (see Sect. 3.3). 5) The Bayesian decision framework of Dittes et al. (2017) is used to obtain 6) a protection recommendation based on the likelihood of extreme discharge. The qualitative basis of the framework is outlined in Sect. 3.4.”*

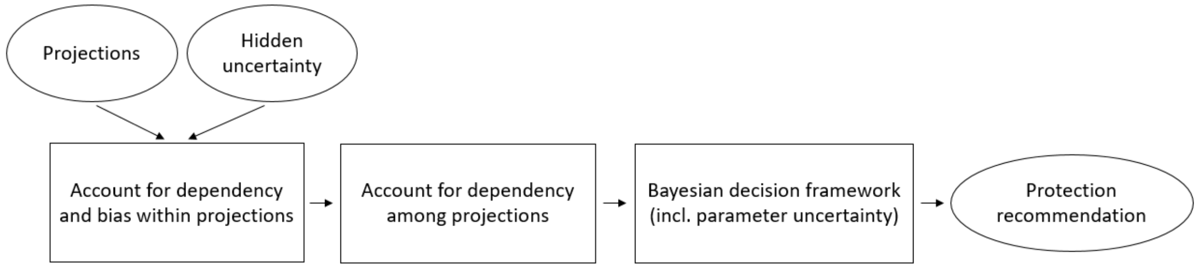


Figure 1. Process of finding the recommended planning margin from projections and hidden uncertainty estimate.

> *Abstract: What is the goal of the paper? Is it introducing a new framework to model uncertainties in extreme discharges?*

We have realized that we were not sufficiently clear on our goals in the original manuscript. The main goal of the paper is to introduce a methodology that allows dealing with uncertainties in extreme discharges in practical applications, where data and model availability is limited. As part of this, we present a method to model uncertainties in such situations.

We now made multiple changes to the manuscript to clarify the goals, including a change of the title. This is discussed in our general author comment to all reviewers.

> *Introduction: The authors thoroughly motivate the need for the study at hand, but they do not introduce the Bayesian decision making framework in enough detail. References and literature on quantitative Bayesian decision making should be added. Further, the choice of the method should be motivated based on a comparison with similar competing approaches.*

The corresponding passage has been revised to incorporate the comments of the referee as follows: *"We have previously proposed a fully quantitative Bayesian decision making framework for flood protection (Dittes et al., 2017). Bayesian techniques are a natural way to model discharge probabilistically (Coles et al., 2003; Tebaldi et al., 2004). They also make it easy to combine several sources of information (Viglione et al., 2013). Furthermore, Bayesian methods support updating the discharge distribution in the future, when new information becomes available (Graf et al., 2007). Our framework probabilistically updates the distribution of extreme discharge with hypothetical observations of future discharge, which are modelled probabilistically. This is an instance of a sequential (or 'preposterior') decision analysis (Benjamin and Cornell, 1970; Davis et al., 1972; Kochendorfer, 2015; Raiffa and Schlaifer, 1961). This enables a sequential planning process, where it is taken into consideration that the measure design may be revised in the future. Furthermore, it naturally takes into account the uncertainty in the parameters of extreme discharge. The output of the framework is a cost-optimal capacity recommendation of flood protection measures, given a fixed protection criterion (such as the 100-year flood). To protect for the 100-year flood is common European practice (Central European Flood Risk Assessment and Management in CENTROPE, 2013) and is also the requirement in the case study."*

> *Section 2: Subsection 2.1 and 2.2 should be a separate section devoted to the description of the catchment considered and the data only.*

Yes and no: On the one hand, this would increase structure. On the other hand, the description of catchment and data (Subsections 2.1 and 2.2) is closely linked to the discussion of uncertainties in the catchment and data (Subsections 2.3 to 2.6). Furthermore, a Section consisting only of Subsections 2.1 and 2.2 seems quite short.

> *Section 2: Move Subsections 2.3 to 2.6 to Section 3 in order to gather all methods in a single section and hence improving readability.*

This ties in with the previous point: we intend Section 2 to be a predominantly qualitative description of uncertainties in extreme discharge, with a focus on the catchment at hand. There are no novel methods contained (other than the suggested prior transformation of Eq. (4), which we do not feel merits shifting the entire Subsection). As such, we feel that the logical structure of the paper is best served by leaving Subsections 2.3 to 2.6 together, preferably, as in the originally proposed paper, together with 2.1 and 2.2 (see previous point).

> *Section 2: Subsection 2.4 is too long and does not contain any new scientific findings. Should be shortened.*

Was shortened.

> *Section 2: Subsection 2.5 How are the relative contributions of the different sources of uncertainty specified? Please clarify.*

These are ball-park figures, based only on the sources and considerations already specified in Subsection 2.5. The results of the case study show that the sensitivity of the planning recommendation to variations in uncertainty is low (see Sections 4.2 and 5), thus an exact quantification is not necessary. We added a sentence to clarify this*: "Note that this is done as a rough estimate, since uncertainty quantification is not the focus of this paper. As will become clear in Sect. 4.2 and 5, an exact quantification is also not necessary for the proposed decision making process."*

> *Section 3: Subsection 3.1 contains a very general discussion comparing visible and hidden uncertainties. This should be move to the introduction Section 1.*

Since the uncertainty categorization is the starting point of the novel methodology, we would prefer to leave it as Subsection 3.1.

> *p1/l15: Rephrase. Maybe, a formulation like: "Therefore, planning authorities increasingly incorporate discharge projections into the assessment of future protection needs, rater. . ."*

We changed this sentence as suggested. (We assume the referee meant line 25).

> *p2/l12: Please put only the years into brackets, if the reference is part of the sentence. This should be corrected throughout the manuscript.*

Was changed throughout. (We assume the referee meant line 2).

> *p2/l17-23: Difficult to understand. Please clarify the framework in more detail.*

Yes, see the answer to the comment on the introduction.

> *p2/l27-31: Paragraph out of sync. Either explain it in more detail here or move it to Section 3.*

Was moved to Section 3.4.

> *p4/l11: What about rain on snow events?*

As per analysis of the available discharge record as well as of accounts of large historic floods, these play a minor role in Rosenheim.

p6/l5-6: Why?

This assumption was made based on the available projections and we have re-phrased the sentence to clarify this: *"In the available projections, the absolute amount of internal variability did not change in time significantly and was thus assumed to be stationary."* The assumption is not necessary: the methodology presented in the paper can just as well be used with non-stationary internal variability.

p8/l1-6: How are the parameters estimated in this study? Is this source of uncertainty considered?

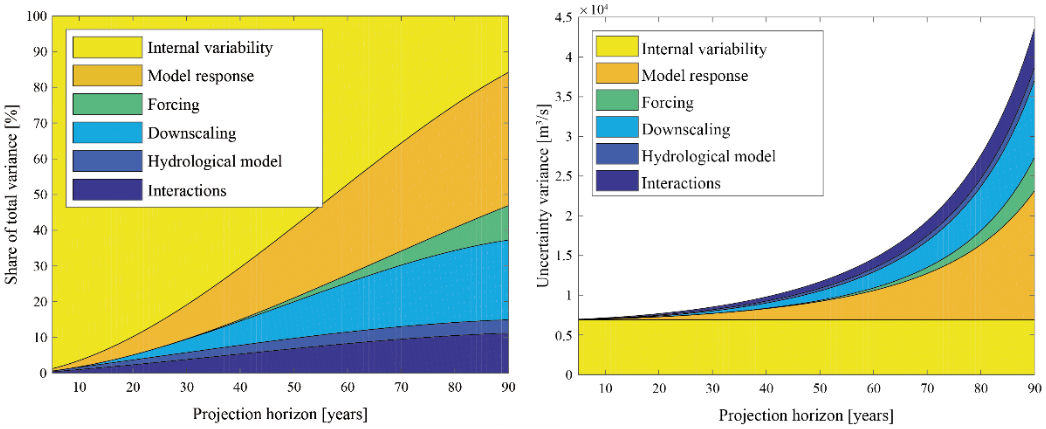
They are assumed to be part of the hydrological model uncertainty and thus enter the hidden uncertainty as a ball-park figure (see Section 2.5). The results of the case study show that the sensitivity of the planning recommendation to variations of the hidden uncertainty is low (see Sections 4.2 and 5), thus an exact quantification of its components is not necessary.

p8/l20&29: Please provide another reference that is publicly available.

The graphs provided to us by Prof. Hawkins closely resemble those shown in Fig. 11-8 of (IPCC, 2013) and on his website http://climate.ncas.ac.uk/research/uncertainty/precip/plots.html, where one can also download the papers outlining the methodology (Hawkins and Sutton, 2009, 2011). With the consent of Prof. Hawkins, it may be possible to provide the data in a supplement to this paper.

Figure 2: Add a 2nd panel containing the same plot in absolute units in order to avoid misleading conclusions on the changes in uncertainties over time

We produced and included the requested 2nd panel below. Note that the absolute values differ from projection to projection, we used CCLM here. The description was updated as follows: *"The results of the estimation are shown in Fig. 3. Figure 3 (a) shows the resulting relative uncertainty shares and Fig. 3(b) the resulting absolute uncertainties for the projection CCLM"* Note that due to adding the flow chart, Figure 2 became Figure 3.



(a) (b)

Figure 3. (a) Share of different uncertainty components (variance) for extreme discharge in Rosenheim. (b) Resulting absolute uncertainties for CCLM. Uncertainties that are 'visible' in our case study are shaded yellow/orange, 'hidden' ones blue/green.

> *p10/l4&11: colons not needed*

This seems to be a matter of taste, we prefer to keep punctuation in sentences with equations.

> *p10/l16: viz. is a unusual abbreviation. Do you mean see/refer to? Please check this throughout the manuscript.*

Yes. We replaced this by the more common "see".

> *p12/l9: the time index t=1,..,N is confusing. Here it denotes future time steps, in Section 2.6 t=1,. . .,N denotes historical years.*

t denotes years in both cases. We changed the *N* to *N'* in Section 3.2 to indicate that the number of years is not necessarily the same.

> *p12/eq7: Do you mean* $\$\backslash Delta_{\{i,t\}} \backslash sim \backslash N(0,\backslash sigma\_\{i,t\}\hat{}\{(hidden)\})\$$ *?*

It is true that one could re-formulate the equation to include the normal distribution explicitly. When the notation *N(mean, standard deviation)* is used, the equation given by the referee is correct, though one more commonly uses the notation *N(mean, variance).* To avoid such confusion, we would prefer to leave the equation as it is.

> *p13/l11: "is applied"*

Was changed.

> *p16/l5: "which is common practice in the literature"*

Was changed.

> *p16/l7-9: duplicated citations*

Was changed.

> *p16/l20&21: Why? The error may be larger, but just not represented by the ensemble of climatological predictions.*

The fact that the ensemble may only reflect part of the climate system is accounted for by the hidden uncertainty. One may think of more error sources, but the results of the case study show that adding further uncertainty does not significantly change the planning recomendation.

> *p18/l17: "Hence, we recommend that planners make use. . ."*

Was changed.

> *p19/l14: Why is this expected?*

Because the cited papers have found this.

> *p19/l16-18: Could you elaborate a bit more on this topic, since it seems to be related to an important research question.*

We appended the following sentence to the paragraph in question: *"We asumed a linear trend in the case study for simplicity, but the proposed methodology is general. To use a different trend representation, one just has to change the definition of* $\boldsymbol{\theta}$ *(see Sect. 4.1) accordingly."*

> *p19/l19-21: Difficult to understand, please rephrase.*

We rephrased as follows: *"Finally, we discuss the impact of varying size of uncertainty on planning. To investigate this, we evaluated the recommended planning margin when not adding any hidden uncertainty, when using the estimated amount and when using double the estimated amount of hidden uncertainty (see Sect. 4.2). The effect was small, in particular between adding the estimate vs. double the estimate of hidden uncertainty. The share of hidden uncertainty is larger in the farther future, where its effect is limited because of discounting. We conclude that hidden uncertainty should be considered in decision making, yet the sensitivity to its exact amount is low and when there is already a considerable level of uncertainty, including more has little effect."*

> *p19/l24-25: Please rephrase.*

We rephrased as follows: *"We believe that the low sensitivity of the protection recommendation to the size of the hidden uncertainty in the presented case study can be explained by the considerable visible uncertainty present: the capacity to project the future extreme discharge is already extremely limited and can barely be reduced by adding more uncertainty."*

> *p20/l10-18: Also a bit difficult to understand, rephrasing it a bit may help*

Rephrased as follows: *"In the proposed methodology, we quantitatively include these aspects in learning the probabilistic distribution of flood discharge. Both 'visible' and 'hidden'* *uncertainty are included in a time-dependent Bayesian likelihood function. Dependence between projections is accounted for by using the concept of effective projection number. The uncertainty analysis proposed in this paper was used with the optimization framework of (Dittes et al., 2017) to find protection recommendations for a pre-alpine case study catchment. The results show that when there is sizable visible uncertainty, the protection recommendation is robust to further uncertainty and moderate changes in trend. However, hidden uncertainty should not be neglected in planning as this would lead to insufficient protection recommendations."*

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