Response to Referee 1

We would like to thank the referee for the time and effort put into reviewing the manuscript. We greatly appreciate the constructive comments, with which we in general agree. With this response, we aim to address the issues raised in the review and propose changes to the manuscript accordingly. We believe that the implementation of such changes will considerably improve the overall quality of the revised version of the manuscript.

Comment 1

1a: The structure of the paper is not convenient. This relates in particular to section 3.3 Critical analysis of the model. Many information which are important for the reader are only given at this point as for instance the information base used to derive the INSYDE model (Table 5) which should be given already in section 2 Methodology. Otherwise the information basis used to derive the relationships in Table 1 as well as for the default values in Tables 2 and 3 and the mathematical functions for each damage component remain obscure. Further, a number of future steps are mentioned in this section which could be better included in section 4 Conclusions/Outlook.

The information basis for model development is mainly concentrated in Section 2 (methodological section) and analysed in detail in the Annex. We would like to point out that Table 5 does not provide any direct information on INSYDE, but its main aim is to present the state of the art on existing synthetic damage models. For this reason, we think it would be more useful to maintain Table 5 in Section 3.3, where we make a comparison between INSYDE and other models in the literature.

We do agree that the structure of the paper may generate some confusion. For this reason, we propose to organize the revised version of the manuscript in a slightly different way, as follows: 1. "Introduction", 2. "Model description", 3. "Model validation", 4. "Sensitivity analysis", 5. "Critical analysis of the model" and 6. "Conclusions". Additionally, the part related to future developments of the model will be moved to the conclusions.

1b: A critical evaluation of the effort to collect the detailed information required to apply the model is missing and should be described.

We agree that a discussion on the effort required to collect data for the application of INSYDE is interesting, given the number of input variables. It is certainly valuable to discuss the possibilities of model application when some of those data are missing (which in practice is often the case), either by considering distributions or default values, and discuss the implications in the uncertainty of the results. We will include some discussion on this issue in the revised version of the manuscript.

Comment 2

2a: The probabilistic element of the INSYDE model is presented as a significant and important extension in flood loss modelling. However, the value of this feature in terms of additional information as well as loss model performance is not analysed and illustrated.

We agree with the Reviewer on that the manuscript was missing a comprehensive analysis on how the probabilistic structure of INSYDE can be applied in flood loss modelling. We report here below a description which will be added in the revised version.

The derivation of probabilistic vulnerability functions for building components is based on the same principle as in the case of deterministic functions: for a given flood intensity measure, there is a probability of occurrence of damage. The difference is that, in the latter, the probability is assumed to be either 0 below a certain threshold or 1 above it, while in the former it is variable, better reflecting the non-deterministic nature of the real world.

The INSYDE model structure, in which probabilistic functions are implemented for a number of building components, can be used in two ways, depending on the user's requirements. The first consists in computing only the expected damage ratio for each component, as described in P5-L8f, and summing them to obtain the total damage of building. The second consists in taking into account the probabilities of damage of the different components to obtain a distribution of the total damage instead of a single value, enabling a treatment of uncertainties of the damage mechanisms considered in the model. The procedure to do this, analogous to the one presented by Porter et al. (2001), is the following:

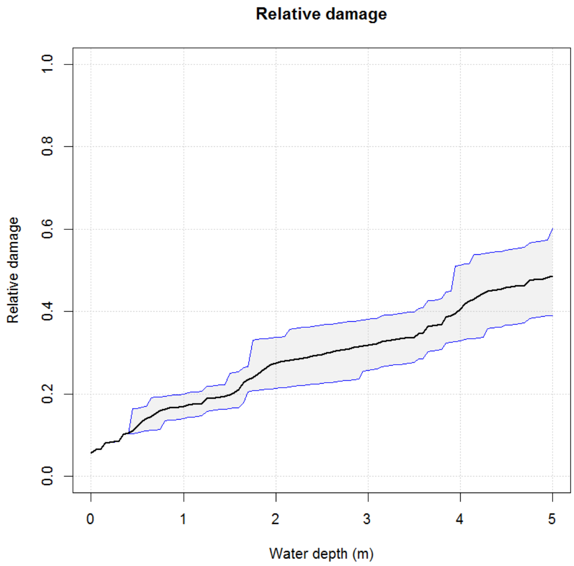
1. For each building component, a number u ~ [0, 1] is randomly generated from a uniform distribution
2. The corresponding damage states are obtained: $ds_i = F^{-1}(DS \mid im)$
3. The damages to each of the components are summed to obtain the total building damage
4. The process is repeated a large number of times

The Reviewer's first remark, mentioning that a description of the additional information that can be obtained from the model is missing, is accurate: indeed, in the original version of the manuscript only the first application described above is presented. Thus, in the revised version, the text in P5-L8f will be improved and expanded accordingly.

Regarding the second point, demonstrating the benefit of the probabilistic nature of INSYDE's damage functions in terms of model performance over a purely deterministic approach is, in our opinion, not straightforward. In the validation exercise (Section 4) INSYDE generally performed better that the other deterministic models, even if only the expected value was taken into consideration in the comparison (see also the following points). On the other hand, a meaningful comparison could only be done against an analogous, "deterministic-based INSYDE", which does not exist.

Instead, we believe that the real added value of a probabilistic framework is given by its ability to explicitly represent the complexity of real flood damages, for instance identifying uncertainty bounds of damage estimations and "forcing" the users to take into account the uncertainty of model parameters. As such, in the revised version, we propose to improve the clarity of the original manuscript to help the reader in understanding the utility of a probabilistic structure for damage models.

In addition, in order to better illustrate the probabilistic nature of INSYDE, we will include the 9-95 quantile range to the resulting damage functions shown Fig. 2. An example is presented below.



2b: In the presentation of the model validation it is not clear if INSYDE has been applied in a probabilistic mode and if so, how the probabilistic output of the model has been evaluated.

As stated in the reply to point 2a, INSYDE is inherently designed with a probabilistic structure. However, we reckon that the application in the validation exercise was not clear because the model was actually applied in a "deterministic" way. In fact, we had only considered the expected value to evaluate the results, in order to simplify the comparison with the other deterministic models. In the revised version of the manuscript, we will improve the clarity on this point and present additional results obtained from a probabilistic application of the model in the case of the 2010 Caldogno flood.

2c: Further, the probabilistic approach is implemented only for selected variables. The selection of these variables and the reasoning for defining the variation range for these variables needs to be explained and justified more in detail.

We agree on the Reviewer's suggestion, and in the revised manuscript we plan to explain better the reasons behind the implementation of probabilistic damage function. The choice of deterministic or probabilistic functions is based on our knowledge of damage mechanisms, consistently with the expert-based approach of INSYDE, and on the availability of literature information. Some damage mechanisms are well understood and in our opinion do not require a probabilistic treatment. For instance, we suppose that if a building is flooded then the basement will always be flooded (according to our experience, flood-proof measures to prevent this are very rarely implemented). Other damage mechanisms are also well explained, even though with a degree of uncertainty due to building characteristics. For instance, electrical system are damaged if some of its components are reached by flood water, but the height of these components may vary depending on the building. In this case however, we decided to overlook this uncertainty and use deterministic functions, since the variability of the height of these components is usually small. Finally, there are damage mechanisms on which the influence of hazard and building parameters cannot be determined a priori. For instance, damage to doors and windows can depend on factors like the quality of material, therefore the same combination of hazard parameters may produce damage or not. For these mechanisms, we therefore used a probabilistic approach.

2d: The sensitivity of these uncertainty sources i.e. how it propagates through the model and effects loss estimates should be analysed.

We do agree with the Reviewer on that the uncertainty introduced in the model by the probabilistic approach is a key issue, which can greatly influence the model behaviour. However, we feel that an analysis of model uncertainty would be unpractical and beyond the scope of this paper, which is focused on model structure. Indeed, for a comprehensive analysis of all possible sources of uncertainty we should take into account physical damage mechanisms together with the other model components, like economic damage functions, influence of hazard and vulnerability parameters and probabilistic functions. Obviously, such an analysis would require a dedicated follow-up paper, as we mention in the conclusions (P13-L4f). In the revised version, we will report these considerations.

2e: The conclusion drawn concerning the importance to address uncertainty is not supported by the results presented.

We agree with the Reviewer on this point. Following this comment, we plan to shorten and rephrase some parts of the first draft (e.g. P12-L19 to P13-L13, and P13-L15f) which were actually confusing and not clearly supported by the results.

Comment 3

The INSYDE model is an expert-based approach and as such it is claimed to offer several benefits in contrast to data-based models as for instance the spatial transferability. The set-up of the INSYDE model applied in this study however includes also empirical data from the 2012 flood in the Umbria region. It is then compared to a selection of alternative models. Have these other models also been calibrated with the same data? For the assessment of the INSYDE model performance it would be important to also compare a purely expert-based version of the INSYDE model.

The Reviewer is right on this point, as the use of loss data in building the model INSYDE has not been clearly described through the manuscript. As we state in P6-L18 to P7-L2, observed loss data were used to analyse the relations between hazard parameters and damage mechanisms, which led to modifications of the physical damage functions of some components. For instance, the functions for structural damage found in literature were corrected, as they were not in line with the observed damages. Such a usage is consistent with an expert-based approach, because observed data were first interpreted and then used to change parts of the models structure, rather than applied to calibrate the parameters of existing functions (on this point, we will remove the term "calibration" which was wrongly used in the first draft). Obviously, the same operation was not possible for the other models applied in the validation exercise. These considerations will be added in the revised version.

Minor comments

1. *The comparison is done for a selection of models, the literature offers far more models.*

Agree. This sentence will be reworded accordingly

2. *In this context please also discuss the following reference: Cammerer, H., Thieken, A. H., and Lammel, J.: Adaptability and transferability of flood loss functions in residential areas, Nat. Hazards Earth Syst. Sci., 13, 3063-3081, doi:10.5194/nhess-13-3063-2013, 2013.*

Thank you for pointing out this useful reference, which we will include in the revised version.

References

Cammerer, H., Thieken, A. H., & Lammel, J. (2013). Adaptability and transferability of flood loss functions in residential areas. *Natural Hazards and Earth System Sciences*, *13*(11), 3063-3081.

Porter, K. A., Kiremidjian, A. S., & LeGrue, J. S. (2001). Assembly-based vulnerability of buildings and its use in performance evaluation. *Earthquake spectra*, *17*(2), 291-312.