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Interactive comment on "Modelling the socio-economic impact of river floods in Europe" *by* L. Alfieri et al.

L. Alfieri et al.

lorenzo.alfieri@jrc.ec.europa.eu

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General Comments: In this manuscript, the authors report a novel methodology to quantitatively assess flood risk in Europe between 1990 and 2013. Using a high resolution observational meteorological dataset and socio-economic datasets, their model integrated a high resolution (100 m) 2D flood inundation model with an impact model focusing on estimating the population affected and the economic damage due to river floods. The authors show the results of flood risk assessment during 1990-2013 using two different approaches, an integral method and an event based method, and present a comparison of the two approaches. The paper fits into the scope of NHESS very well. I think this paper has academic value and the results are helpful to governments, international organizations, re-insurance companies and emergency responders, etc. The originality of the method and findings in the paper are up to international stan-

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dards. However, my primary concern with the manuscript is this manuscript is really short on discussion. Discussion on the sources of uncertainties of the model cannot be avoided, and more words are needed on how the integral and event based methods can be complementary as shown by their different results. Moreover, the results are not well written to present the pattern of flood risks in Europe. The authors present a combined model composed of five modules, but they did not show any equation or outputs of any intermediate modules to help readers understand how natural and socio-economic factors are linked in flood risk assessment. The figures are not well designed and their captions are not informative; I believe it will be difficult for many readers to understand the figures without reading the full paper very carefully. Below is a detailed summary of my suggestions and comments. I think this manuscript needs major revisions.

Reply: We thank the reviewer for her careful evaluation of the article and for the useful and constructive comments. We do not disagree with the vast majority of the comments, hence most of those have resulted in some change, edit and addition to the original submitted version. In the revised version we will expand significantly the discussion section, by separating it from the conclusions and by adding a specific subsection on the sources of model uncertainties. The results will be complemented with additional text to help the readers understand the differences between the two proposed methods. We decided to omit specific equations from the article as the methodology includes the combination of different models, where each model is based on a large number of equations and mathematical methods. We think that showing only few equations would wrongly suggest the readers that those are the key/core of the work. However, all models, components and datasets are adequately referenced in the literature. In addition, we have modified two figures to make them more intuitive, clarified their captions and added a new figure to the article to give a better insight on the components of the risk assessment. Some additional material was produced on the Lisflood model calibration, on the simulated flood hazard maps over Europe and an explanatory table for the ISO country codes. This material consist of two further

figures and two tables and it will be included in the Supplement material. We hope that the reviewer finds these modifications helpful for readers to better follow the methods, results and conclusions of the presented research.

Specific Comments: 1. P2, Line 5 and P11 Figure 1: "The proposed approach follows a modelling framework composed of five different steps (see Figure 1): : :: : :" As a flow chart for modelling, Figure 1 should show information on what are the outputs of each steps and what methods or control factors are critical to each steps. There are many unexplained abbreviations and asymptotic formulas, such as “PPA & PD = f(T)”. Abbreviation should be explained in the caption and the figure should be improved.

Reply: We agree with the reviewer’s comment. In the revised version we will modify the figure by removing most acronyms and replace those with more self-explanatory labels of the methods and of the input/output data. Also, the figure caption will be expanded.

2. P2, Line 11: "Streamflow maps at 5 km grid resolution are produced by forcing Lisflood with the EFAS-Meteo dataset (Ntegeka et al., 2013) : : :: : :" I think the authors can tell readers the total number of the grid points for the sake of showing them the high resolution of the modelling in the beginning of the paper. 3. P2, Line 14: "The current Lisflood version is calibrated at 693 stations across Europe against up to 8 years of daily observed discharge....." What is the reference for this claim? Add it to the paper.

Reply to #2 and #3: Following comments from both reviewers we will add in the revised version (Sect. 2.1) a substantial amount of information on the hydrological model, its calibration strategy, and some quantitative performance skill of the calibration in different river sections, including one additional figure and one table in the Supplement material. This will include some quantitative information on the simulation domain and its resolution as suggested by the reviewer.

4. P2, Line 24: "L-moment estimators are nearly unbiased for a wide range of sample sizes and distributions (Vogel and Fennessey, 1993), and are particularly useful for

relatively short samples as in this study....." What is the reference for the claim “are particularly useful for relatively short samples as in this study”? I am very suspicious of using a 24-year series to infer the peak flow of a flood with a return period as large as 500 years.

Reply: L-moments are more robust than conventional moments, as they are based on linear combinations of order statistics. While conventional moments of higher order (2nd, 3rd) can be estimated accurately only with a large sample of data representing adequately the dispersion, skewness, etc of the distribution, L-moments are less affected by data scarcity, as they are based on linear combinations. For such considerations and other details on L-moments we refer in the text to the work by Hosking (1990). With regard to the use of 500 year return period estimated from a 24 year sample, we will add that it is done following similar literature examples (e.g., Sampson et al., 2015; Winsemius et al., 2015), which clearly lead to an increase in uncertainty, but it is necessary to produce estimates of the impact of flood events in the range of magnitude commonly above that of the return period of flood protections. A comment on this will also be included in the Discussion section, in a dedicated subsection on the sources of uncertainty.

5. P2, Line 30: "Flood inundation maps for the entire European domain were produced at 100 m resolution using the Lisflood-FP floodplain model (Bates et al., 2010; Neal et al., 2012) forced by the flood hydrographs with specific return period described in the previous section. The full procedure to derive pan-European flood hazard maps is described in details by Alfieri et al. (2014a)....." The flood depth is a key parameter in the model, so you should tell readers how efficient is the Lisflood-FP floodplain model and did the model ever be validated or not. Some flood inundation map for the entire Europe is need to present the outputs of the Lisflood-FP floodplain model and to show the spatial variability of flood hazards. If the figure cannot be added into the main body of the paper, it should be putted into Supplement Material.

Reply: We will clarify in Sect. 2.3 that “The full procedure to derive pan-European

flood hazard maps is described in details by Alfieri et al. (2014a), together with some performance scores of the 1 in 100 year simulated map versus official regional maps available for Germany and UK.". In addition, visual examples of the maps produced will be shown in the Supplement material, for the entire Europe and with higher zoom for a number of selected areas.

6. P3, Line 6: "For this task we used the country specific depth-damage functions defined by Huizinga (2007) for different land uses, while the spatial variability in exposure is determined according to the refined version of the Corine Land Use provided by Batista e Silva et al. (2012)....." A representative equation for depth-damage functions must be given to help readers understand how natural and socio-economic factors are linked in the flood risk assessment.

Reply: In the revised version, more details on those functions will be included. In particular, we will add that "Depth-damage functions per each country and land use class comprise two damage indicators (Huizinga, 2007): an absolute damage value, in €m2, which is attributed to all flood depths equal or larger than 6 meters; and a damage factor relative to the maximum damage (i.e. between 0 and 1), which is defined by piece-wise linear functions. Those two indicators are derived through analysis of written documentation and data on the internet from 31 countries in Europe."

7. P3, Line 26: "This method estimates the damage of each simulated flood, rather than considering the theoretical probability of occurrence. It is based on a selection of all discharge peaks (POT) exceeding the flood protection level (by Jongman et al., 2014) at any location....." What does "POT" stand for?

Reply: POT stands for peaks over thresholds. We will clarify it in the revised version in Sect. 2.5 as well as in Figure 1.

8. P3, Line 33: "3 Results" The current Results section is not meaningful and it is difficult for readers to understand the implications of these results. In flood risk assessment, the biggest advantage of modeling over statistics is the contributions of different

factors controlling flood risks (flood hazard, exposure and their vulnerability) can be differentiated. Therefore, the authors should explain in the section the patterns of flood risks for the entire European domain; and for the regions seriously affected by floods, the reasons should be given: whether the risks mainly result from adverse basin meteorology and climate, topography, inadequate flood prevention, or exposure of large amounts of population and assets to floods, etc.

Reply: Upon the reviewer's suggestion we will add in the revised version a dedicated paragraph in Sect 3, which shows the contribution of flood hazard, exposure and vulnerability to the overall flood risk in Europe. An additional figure will be produced to better illustrate the spatial variation of the three components. In particular, we will show the maximum simulated flood return period within 1990-2013 (hazard); the potential population affected by a flood with 100 year return period (exposure); the potential damage of a flood with 100 year return period (exposure); and the return period of flood protection levels (vulnerability).

9. P3, Line 38 and P12 Figure 2: "Values plotted in Figure 2 are expressed as ratios of the respective country GDP and country population, while absolute values are shown as labels aside each color bar....." Figure 2 can be more informative if the authors sort the countries from top to bottom according to the lengths of blue or green bars. With this design readers will have a quick and clear idea which countries sufferred from largest relative damages and whose populations were most affected. In addition, a webpage link on ISO country code should be given in the caption as many readers are not familiar with country codes.

Reply: We agree with the reviewer's suggestion. In the revised version, countries will be sorted according to decreasing values of relative damage and population affected obtained with the integral method. This follows the description in Sect. 3. In addition, we will add in the Supplement material a table with ISO country codes and relative full country name, to make results of easier reading.

10. P5, Line 1 and P14: "3.2.1 Case study - Central Europe floods in 2013 The catastrophic floods hitting the Central Europe in June 2013 was selected as case study to test the performance of the event based method for rapid risk mapping. Figure 5 shows maps of damage and population affected in Central Europe, based on the simulated discharge maps from 25 May to 10 June 2013....." A few sentences are needed to tell reader the overall hazard magnitude of the 2013 floods. The meanings of two elements in Figure 5, one is the gray circles, the other is the gray areas (close to the “Rhine” and “Danube” River), are not explained either in its legend or in its caption.

Reply: Following suggestions from both reviewers we will add some information on the flood event, its formation, meteorological pattern and recurrence interval of the measured peak flow: “This was a severe, large scale event which affected several countries and led to the loss of lives as well as considerable damage in the Danube and Elbe river basins. The event was associated with a quasi-stationary upper level low located northeast of the Alps and by a significant contribution of orographic lifting (Pappenberger et al., 2013). Also, in the weeks leading up the event, rainfall totals were significantly above normal in large parts of central Europe, exacerbating the runoff process. The return period of the discharge peaks was estimated to equal or exceed 100 years in various rivers including the Isar, Inn, Salzach, Danube, Elbe, Mulde, Saale, Rhine and Neckar (Zurich, 2014)”. Also, we will add in the caption of Figure 5 that “Grey circles indicate hotspots of simulated damage larger than 100 M€ and population affected in excess of 5,000. Areas outside the simulation domain are masked in grey.” The second sentence will also be added to the caption of Figure 3, for clarification.

11. P5, Line 24: "4 Discussion and Conclusions" In my opinion, the Discussion section may include a more meaningful discussion on how the integral and event based methods can be complementary as hinted by their different results shown in Figure 2. For some countries, the results given by the integral method are smaller than those given by the event based; for another countries, the results turned out to be the very reverse. The authors should find out the reasons for these differences and the implications for

the “adaptation effect” (Di Baldassarre et al., 2015). If a larger damage is given by the event based method than by the integral method, does it mean that the overall magnitude of floods risks during 1990-2013 is larger than that in the long term? If so, does it further mean in the future fewer flood hazards might occur in these countries and they might been more adapted to and better prepared of future flood hazards? I agree that at present it is very difficult to quantify the uncertainty range of the model. But a detail discussion on the sources of uncertainties of the model cannot be avoided. “4.1 The influence of flood protections” is actually a source of model uncertainty. The authors can easily find out more sources of uncertainties by checking very steps of their modeling. For example, in the first step “Continuous hydrological simulation”, as shown in the supplement materials, the uncertainties of hydrological simulation change with the upstream basin area.

The following two parts in the Results section could be moved to Discussion and modified as the points for the sources of model uncertainties: P4, Line 20: "It is worth noting that the presented approach is focused on rivers with upstream area larger than 500 km2. Hence, the flood risk is likely to be underestimated in regions where the hydrography is dominated by smaller streams (e.g., coastal regions of Greece, South of Italy, Croatia, Norway, UK, Denmark, as well as some mountainous regions in the Alps) where local storms and flash floods are major components of the overall impact of floods. Similarly, the impact of coastal floods is not modeled in the 25 results shown." P4, Line 29: "A report by Fenn et al. (2014), prepared for the 30 European Commission Directorate-General for the Environment (DG Env), includes an assessment of financial, economic and social impacts of river floods in the countries of the European Union between 2002 and 2013. Fenn et al. (2014) addressed the scarcity of flood impact data by extrapolating the cost of major floods in the European countries on the basis of the available data, so that the overall estimated flood impact is given by the sum of extrapolated and quantified data. Figure 4 compares annual flood damage aggregated over the European Union of the event based method from 1990 to 2013 and data by DG Env for the available years. Data from the two datasets are in good

qualitative agreement. "

Reply: In the revised version we will considerably reshape the Discussion section, separating it from the Conclusions. The revised Discussion section will include three subsections: 1) the event based method, 2) The influence of flood protections and 3) Sources of uncertainty. However, we think that some of those specific comments are better fit to the results section, also to keep the presentation of results easy to follow. Further, some additional text in the Results section will be dedicated to motivating the differences in the flood impact estimates obtained with the two methods. Please note that the Discussion section will include a specific subsection on the uncertainty sources affecting the model results.

The authors should also tell readers the method of Fenn et al. (2014); they must be different from the methods of this paper. As for the claim “data from the two datasets are in good qualitative agreement”, some statistics should be shown to support the claim. As shown in Figure 4, for the year when major flood hazards occurred (2002, 2010, and 2013), estimates of flood damage using the event based method and the method of Fenn et al. (2014) have large differences. Why? Which source of model uncertainty is hinted in these differences?

Reply: We refer to the publication by Fenn et al. (2014) for all the details regarding the methods they used. Also, we will add in Sect. 3.2, that the assessment by Fenn et al. is based on post event reports and estimates from insurance companies. Some additional details will be included regarding the comparison of the two datasets. Also, we will add some statistics showing the correlation of the two datasets.

12. A separate “Conclusions” section is needed to present readers some important take-home messages.

Reply: As suggested, the conclusions section will be separated from the Discussion, and it will include a summary of the work done and some key messages.

13. After a major revision, I think the abstract of the paper should be rewritten.

Reply: the abstract will be modified and made it more consistent with the work presented in the main body of the article.

Technical corrections: P2, Line 5: "The proposed approach follows a modelling framework composed of five different steps (see Figure 1): : :: : :" “five different steps” can be changed to “five steps”; “different” is a redundant word.

Reply: Amended as suggested

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