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Discussions

Interactive comment on "Climate or land cover variations: what is driving observed changes in river peak flows? A data-based attribution study" *by* Jan De Niel and Patrick Willems

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Dear reviewer

We thank you for your evaluation of our manuscript. We appreciate the constructive comments and suggestions you have made and would like to respond to them below.

Several comments deal with the lack of a discussion on the interaction effects. Hence, we investigated this further in detail and added a subsection in the results on these interaction effects. Also, we added some more discussion on the single driver effects. As such, the manuscript changed significantly, and we added a revised manuscript to

this reply.

GENERAL

I have read the manuscript entitled "Climate or land cover variations: what is driving observed changes in river peak flows? A data-based attribution study" with interest. The topic of the manuscript is suitable for the journal. Indeed, it has been widely referenced but the need to know the significance of drivers for floods in different areas still exists. In this case, 29 catchments in Flanders were selected for the analysis of the influence of catchment characteristics, climate and land use variables on floods. In general, the objective of the paper is clear, "to investigate the (relative) importance of climate variability and land cover changes related to changes in river peak flows", and results obtained are interesting. However, in my opinion, the authors should work further on the analysis and discussion of those results, trying to better explain the dependencies between drivers and floods, but specially the influence of interactions between drivers, that explain up to the 32% of the variability on river peak flows.

COMMENTS

Comment 1. The abstract is clear and concise but it lacks some general conclusion.

REPLY. We will add some more conclusions in the abstract, with respect to the interaction effects.

Comment 2. Introduction is well structured, follows a clear central theme and mentions many references, that could be used to enrich the text extracting some information from them that could help establishing the state of the art in the topic. Little is said in the introduction about the significance (in other studies) of one of the main drivers in this study: catchment characteristics, in my opinion some references should be included on this.

REPLY. We prefer to keep the introduction as it currently stands. With respect to the catchment characteristics: based on some of the other comments, the results section will significantly change in the revised manuscript. And the effects of single drivers will be discussed more in depth, where our results will be compared with literature.

Comment 3. The case study is not sufficiently described. In my opinion, a general description of the area, considering average climate, geology, slopes, hydrology, vegetation should be included (are they spatially variable?), in order to have a general idea on the study area characteristics and the representativeness of the selected catchments.

REPLY. We will add below paragraphs under the section Case study: For this case study, 29 catchments are selected, evenly spread across Flanders, the Northern part of Belgium (Figure 1). Flanders, with 6.4 million inhabitants, covers around 13,500 km2. The coastal area in the North-West of the region mainly consists of sand dunes and clayey alluvial soils in the polders. The central area, ranging between 0 and 10 mTAW, mainly consists of loamic soils. The North-Eastern part, known as the Campine region, has sandy soils at altitudes around 30 mTAW. The Southern part with silty soils has low hills op to 150 mTAW. The maximum height is 288 mTAW in the South East. The DTM in Figure 1 was taken from "Digitaal Hoogtemodel Vlaanderen" (https://overheid.vlaanderen.be/producten-diensten/digitaal-hoogtemodel-dhmv). Soil texture is available from www.dov.vlaanderen.be. Flanders has a maritime climate (Cfb, according to the Koppen climate classification), with average temperatures of 3 °C and 18 °C in January and July, respectively. There is a small gradient present with lower temperatures in the South-East (annual average of 10 °C) towards higher temperatures in the North-West (annual average of 11 °C) (data between 1981-2010); the average temperatures in Flanders, further, has been rising over the past 30 years with 1 – 1.5 °C. Average evapotranspiration was 540 mm/year in 1980 and rose to 625 mm/year in 2010. Yearly precipitation varies between 600 mm/year to 1000 mm/year, with little variation throughout the year, and little spatial differences (Brouwers et al., 2015).

Comment 4. Table 1 includes the period and the number of years of discharge data for each gauging station. These information is repetitive and in my opinion not needed, as

data used are those from 1992 to 2015 for all stations. Eliminating those columns may leave space enough for including data on fig. 3 (soil texture) in this table.

REPLY. We would like to keep table 1 as it currently stands. To estimate peak flow anomalies, we use all available data (e.g. for Grobbendonk Troon, this is 1982 – 2018). Then, the variation is explained based on the selected predictors, and due to the availability of these predictors, the period is reduced. Further, see also the comment lower related to Fig. 3 – we wish to keep Fig. 3 as is, in order to make a visual comparison between the catchments possible (wrt soil texture).

The methods section needs to be explained further as some questions are not clear enough: Comment 5. Is daily discharge data an adequate time resolution to explore river peak flows in catchments smaller than 100 km2? Many of the catchments included in this study are quite small, so that discharge response, especially during peak flows, could be lower than the daily scale proposed; could the authors justify that the selected scale is adequate for the analysis of high flows?

REPLY. Please note that, unfortunately, in the manuscript it was erroneously noted as daily discharge data (P3L16 and P3L21). However, the analysis has been carried out based on hourly data. This will be corrected in the revised manuscript to state hourly discharge data was used. The hourly discharge data is freely available through https://www.waterinfo.be/default.aspx?path=NL/Rapporten/Downloaden, under section 1A Waterlevel/riverflow select: Discharge (Hourly), and you can verify this hourly data is available.

Comment 6. Using a figure/example/scheme could help understanding better the estimation of peak flow anomalies in section 3.2.

REPLY. In the revised manuscript, we will add a figure under Section 3.2 and replace the text in order to better explain the estimation of peak flow anomalies. See the revised manuscript in supplement to this reply.

Comment 7. In section 3.3. The consideration of characteristics other than climate and land use in the analysis is interesting; however, the authors should justify the inclusion of catchment characteristics on the analysis and the selection of the included characteristics. Why those and not others? The general description of the area may help on this, if the selected characteristics are the ones that show higher variability in the area...

REPLY. Soil texture taken into account as there are significant gradients in Flanders and thus differences amongst the various catchments: e.g. L01_491 has mainly a loamic soil texture, whereas L07_286 is mainly siltic, etc. Slopes should definitely be taken into account, as this has a known/obvious impact on rainfall runoff. Similar for the river density (ratio of river length over catchment area). Catchment area is often linked to peak flow sensitivity, and thus was initially taken into account for this study. However, later in the study, this variable is discarded, based on statistical considerations. See also the start of the discussion (P6L21). Note that these characteristics also come back in the concepts of the hydrological model WetSpa when assigning runoff coefficients.

Comment 8. Nothing about soil is said in this section

REPLY. Soil texture is mentioned as possible drivers, P4L9. We don't see what you are missing here?

Comment 9. Some information is repeated in section 2 and section 3.3. The authors should decide where to include the completed information just once. For example: P3L7-9: "For land cover, the 30 classes from the ESA CCI Land Cover project (www.esa-landcovercci.org) were regrouped into the 6 IPCC land categories, i.e. cropland, forest, grassland, wetland, settlement and other land...". P4L19-22: "Land cover and land cover changes have been described in the past through the ESA CCI project (www.esalandcover-cci.org): . . .. The 22 land cover categories (or 30, when including 'level 2' or 'regional' labels) identified in this project are grouped into the six IPCC land categories, i.e. settlement, agriculture, grassland, forest, wetland and other area."

REPLY. Indeed, this was repeated in both sections. We would adjust the text in Section 3.3 to: "Six IPCC land categories (settlement, agriculture, grassland, forest, wetland and other area) are taken into consideration as possible drivers for this study.."

Comment 10. In table 2 soil textures are included. However, nowhere in the text or in other figures and tables the authors talk about textures. They base their analysis in soil textures or in soil classes?? This should be clarified and corrected.

REPLY. Analysis is based on soil textures – not soil classes. We will scan the manuscript and clarify/correct where needed.

Comment 11. The first part of the Results section, that referred to steps followed "Prior to the first step of the model building process", should not be included in this section but in methodology as no results are explained here (P5L26-P6L4).

REPLY. OK. This will move to the relevant paragraphs of the methods section in the revised manuscript.

Comment 12. Is it possible to consider at the same time variables that change spatially but not on time (catchment characteristics) and variables that change on space and time? How should results be considered? Catchment characteristics explain a high % of the variability in flood records, however, they are supposed to change only spatially, from one catchment to another, not for the same catchment from one year to the next. However, climate or landuse, explain less variability, but they change from one catchment to another and also in the same catchment on time. How should these be considered when analyzing results? Some discussion on this point would be interesting.

REPLY. Yes, temporal and spatial data can be considered simultaneously – through panel data analysis.

Catchment characteristics only show a spatial variation and no temporal variation. And, indeed, they explain a high % of the variability in flood records. Meaning that the flood responses is strongly catchment specific, and in a lesser degree depending on fluctuations of the climate, and land use changes. For the revised manuscript, we will change the first paragraphs of 3.4.1 (P4L26-29) to: “A model is built with the techniques and ideas of panel analysis, which is widely used in social sciences, epidemiology, and econometrics where two dimensional data is analysed. Typically, in those sectors data is collected over time and over the same individuals. Here, the two dimensions are space and time – input data can show only a temporal variation (climate data), only a spatial variation (soil texture), or a combination of both (LULC). Note that, typically, climate data does show a spatial variation as well. However, we assume the area of Flanders to be homogeneous with respect to the considered climate data.”

And, we would add in the conclusion (P7L13) “[. . .] topography and soil texture. The high importance of these time-invariant factors (topography and soil texture) indicate flood response in Flanders is highly catchment specific, and to a lesser degree depending on fluctuations of the climate, and land use changes.”

Comment 13. P6L10: “The final model, with 26 terms in 9 predictors. . .”. Which terms and predictors? The 9 predictors that in figure 5 are higher than the 50%? And terms? I would appreciate if the authors could specify a bit more.

REPLY. The predictors: indeed the 9 predictors in Figure 5 that are higher than the 50%. We believe this should be clear by P6L5-9.

We will include the coefficients of the final model in the revised manuscript (see table 3 in the revised manuscript in supplement to this reply). One should, however, be careful when interpreting these coefficients. E.g. the coefficient of Settlement in the final model is equal to -3.04. At first sight, an increase of settlement would thus correspond with a decrease of peak flow anomaly. However, the interpretation of the coefficients is more complex:

An increased Settlement also impacts the interaction effects, and the coefficient becomes: (-3.04 – 0.85*Slope + 6.47*Loam + 17.85*Settlement);

An increased Settlement means that Agriculture (13.08) and/or Forest (3.71) decrease – and there again, the interaction effects of Agriculture and Forest come into play. Thus, because of the dependency between variables, the interpretation of the resulting model coefficients ïĄć is not straightforward. Therefore, we did not include this table initially. However, based on this comment, we will include it in the revised manuscript.

Comment 14. Figure 6 needs more explanation and discussion in the text. Which are the most problematic catchments? Can those worse results be related to some specific aspect/characteristic of the catchment?

REPLY. Observed peak flow anomalies in catchments L07_289 (Mark at Viaene) and L08_233 (Zuunbeek at Sint-Pieters-Leeuw) have a bad correspondence with their modelled results. The Mark catchment has a long history of flooding – as from the 2000s, the local authorities have installed several mitigation measures (hydraulic structures, retention basins etc.), effectively decreasing the flood risk. This is visible in the observed peak flow anomaly, however, the regression model used in this study cannot capture such management changes. Further, for the Zuunbeek catchment at Sint-Pieters-Leeuw, increased peak flow anomalies are observed as from the middle of the period. This is due to the extreme flood season in the winter of 2001-2002 where 7 events were observed with peak discharges exceeding 6 m3/s, corresponding to empirical return periods larger than 1 year, based on data between 1978 and 2016. We will add the above paragraph in the Results section of the revised manuscript.

Comment 15. What about interactions between variables? How do they work? Which are the most significant? Does the same landuse change have same results in different climatic conditions? And for different catchment characteristics? And what about climate variability? Has the same effect under forest or under agricultural land? What else can be extracted from figures 7 and 8?

REPLY. A section on interaction effects will be added in the revised manuscript.

Comment 16. Figure 8 footnote should be corrected: “Increasing settlement area will, in most cases, lead to increased 5 peak flows". This is not what the figure shows but what the authors read from the figure. The figure shows boxplots shoing the results given by the model for all the catchments when increasing (or reducing?? See the text of P6L18) settlement percentage to reduce (or increase?) forest. . ..

REPLY. We will change the caption in the revised manuscript to: "Figure 8. Peak flow changes by increasing settlement area trough decreasing forest, grassland or agriculture."

Comment 17. What does figure 8 really show? Contradictions are found in the text: P6L18: "1% of the total area from settlement to forest, grassland and agriculture, respectively" P7L17: "1% increase in urbanization could lead in some cases to a 5% increase in river peak flows"

REPLY. We would replace the word 'urbanisation' on P7 to 'settlement'. We further don't see the contradiction? Ref. also comment higher on the caption of this figure.

Comment 18. In this figure (8) it can be observed that changes in peak flows vary depending on which type of landuse is reduced to increase settlements. Could the authors say something about that? What do other authors say about it?

REPLY. Indeed, we specifically quantified the changes in peak flows for increased urban area depending on the type of LULC that is reduced. In literature, we did not find similar studies where the independent effects were quantified. Most of the references look at the total picture by comparing the situation for two distinct periods in time and, as such, observing/modelling the integral response of a catchment due to e.g. the simultaneous decreases in forested area and agricultural area in favor of urban area.

Comment 19. The discussion and conclusion section repeats 3 times that the model explains the 60% of the flood variability, but it does not discuss which could be the reasons why in some catchments the fitting or the consistency is not good. In P6L29-30 the authors say "Since the explanatory variables all have a smooth variation over

time, it is a priori almost impossible for any simple regression model to mimic these step changes". However, there are important changes in landuse around the year 2002.

REPLY. Ref. comment 14, and reply on this comment, higher. We now looked deeper into the reasons why we see a bad fit for some catchments. For the revised manuscript, we will further take out the comment on the explanatory variables and their smooth variation over time.

Comment 20. The comment on the time span used in the analysis (P6L32-P7L3) is not a conclusion and in my opinion, should not be included neither as a discussion.

REPLY. Okay, we will delete this paragraph in the revised manuscript.

Comment 21. As the author say "Obviously, given the complexity of these environmental systems,the simple linear model will not be able to capture/describe all effects – indeed, it was seen that interaction effects between catchment characteristics, land cover and climate variability are equally important in explaining changes in river peak flows." In my opinion a deeper analysis of results and discussion on this part would notably improve the impact of the paper.

REPLY. A section on interaction effects will be added in the revised manuscript.

Comment 22. P7L16-17: "The model also showed that, for most of the considered case studies, deforestation indeed leads to increased peak flows" where can this effect be seen? Deforestation? Or decreasing forest to increase settlement, agriculture or others?. "Moreover, 1% increase in urbanization could lead in some cases to a 5% increase in river peak flows". Can these results be analyzed a bit more? In which cases? Which characteristics have those catchments??

REPLY. Correct, the use of the term "deforestation" might be out of place here, as, indeed, it is rather decreasing forest to increase settlement and others. Will replace this sentence to: "The model also showed that, for most of the considered case studies, a decrease in forested area to increase settlement area indeed leads to increased peak flows."

The catchment with the strongest influence are flat catchments with a high loamic content. In this case: L01_491, L01_492, L01_496 and L05_404 have the highest impacts. This confirms the results from the interaction effects, which will be described in a separate subsection of the revised manuscript.

Other comments: Comment 23. Which is the resolution of the DTM mentioned in section 3.3? In P4L6 the authors say "The slope at every point in the catchment are calculated", which is the resolution of those points? (1x1; 5x5, meter?)

REPLY. Resolution of the DTM is 100x100m. Will add this on P4L5 of the original manuscript.

Comment 24. P4L15. "W; (NW, N), (NE; E; SE), (S; SW); U; C; A, with N, E, S and W referring to wind directions". Please consider re-writing this sentence. Comma and semi-colon are arbitrary used. Parenthesis do not help understanding groups.

REPLY. Correct, comma and semi-colon were unfortunately arbitrarily used. Groups are separated by parentheses and semi-colons. Weather types within each group are separated by commas. We hope the following is more clear: "The remaining weather types are: W; (NW, N); (NE, E, SE); (S, SW); U; C; A, with N, E, S and W referring to wind directions, C and A to cyclonic and anticyclonic atmospheric patterns, respectively, and U to an unclassified weather type."

Comment 25. In figure 3 the word fraction should be replaced or accompanied by classes not to create confusion with soil fractions (sand, silt and clay)

REPLY. Okay, will be replaced by "Figure 3. Relative areas of soil texture classes (arenic, loamic and siltic) for the selected catchments. Data from: www.dov.vlaanderen.be" in the revised manuscript.

Comment 26. Figure 3. Information included in this figure can be moved to table 1.

REPLY. Correct, this could be included in Table 1. However, we specifically opted for this graphical representation. In this way, the reader can more easily see what the dominant soil class is for that particular catchment. The order of the catchments is the same as in Figure 2 and Figure 6, which makes a comparison between these figures easier. Also, with the current graphical representation, it is easier to compare two (or more) catchments among each other – in table format, this is a bit more difficult.

Reference list needs revision. For example:

Comment 27. "IPCC, 2014": review formatting. Doi included corresponds to: IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535pp, doi:10.1017/CBO9781107415324.

REPLY. Indeed, doi is referring to the wrong document. In the revised manuscript, this reference will be updated and formatted according to guidelines mentioned on http://www.ipcc.ch/report/ar5/syr/.

Comment 28. "Blöschl, G., Ardoin-bardin, S., Bonell, M., Dorninger, M., Goodrich, D., Gutknecht, D., Matamoros, D., Merz, B., Shand, P. and Szolgay, J.: At what scales do climate variability and land cover change impact on flooding and low flows ?, Hydrol. Process., 1247(March), 1241–1247, doi:10.1002/hyp, 2007." doi is not complet. https://doi.org/10.1002/hyp.6669 and journal volume is 21.

REPLY. This will be corrected in the revised manuscript.

Comment 29. Mediero et al., 2015. Last author surname is not complete, lacks first letter.

REPLY. This will be corrected in the revised manuscript.

Please also note the supplement to this comment:
https://www.hydrol-earth-syst-sci-discuss.net/hess-2018-385/hess-2018-385-AC1-supplement.pdf

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