Response to Anonymous Referee #2's comments on manuscript hess-2017-494 (Remote land use impacts on river flows through atmospheric teleconnections)

We would like to thank anonymous review #2 for the suggestions, comments, and questions. They strongly help to increase the quality of our manuscript by letting us add additional river basins of relevance to the analyses, sharpen the presentation of our results and delve deeper in the discussions. Please see our detailed response below (reviewer quotes in blue and italic).

Main suggestions:

- Some of the descriptions, figures in the supplement should be moved to the main paper.

Thank you for this suggestion. Following also the comments from referee #1, we plan to move Fig S9 to the main manuscript, to clarify the model coupling and convergence. We also plan to move Table S1 to the main manuscript section to give a more comprehensive background to the rationale for using the current model coupling method. To better convey this difficulty to the reader, we will also move some of the discussions on climate models from the supplement to the main manuscript.

- The focus of basins should be moved from basins with high absolute delta Q (Amazon, Congo, Ob etc.) to basins with high % change (Indus, Zambezi, Odra)

We thank the referee for this valuable suggestion. Though we initially did not focus on the basins with high % change in imported precipitation, we acknowledge that big relative changes in river flows are likely to matter more from the perspective of the water users. Thus, we will add two large river basins with large relative river flow reductions (Yellow, Huai, Colorado) and three with large relative increases (Zambezi, Niger) for which river flow (i.e., P-E) simulated by STEAM matches well with river flow data. This addition will modify Fig 3 as well as the country level analyses and related discussions.

- The role of TMR should be addressed regionally. To refer to the title the differences between having the teleconnection in or not should be pointed out. What are the basins affected by TMR most and why?

Thank you for your comment. However, the analyses in this paper estimated the human land-use change effect in combination with TMR, and Fig 3 lists the basins most strongly affected by TMR given the land-use change scenario employed. Thus, the effect of TMR observed is highly dependent on prevailing winds, hydroclimate, and orography (van der Ent et al., 2010, 2014) and the land-use change scenario analysed, as we also observe in the manuscript. We will make sure to elaborate a bit more about this in a revised version.

Some other aspects have to be addressed:

P2 L31: ".. no studies .." about P I do not know, but LUC on Q a lot: See the https://www.isimip.org/ project deals also with impact of human interactions on water balance variables.

We thank both reviewer #1 and #2 for pointing out that the sentence formulation can easily be misunderstood, especially when taken out of the context. We found the formulation to be redundant upon revisiting the paragraph, and will replace the original paragraph P2L27-P2L34 by

"The previous studies that illustrated the importance of remote LUC for basin P and Q, did not examine the effect of taking moisture recycling into account for estimating LUC effects on *Q*, nor analyse the interplay between LUC within and outside the river basin. These effects are, however, important to disentangle since they can have profound water governance implications (for e.g., riparian water rights and transboundary river basin treaties) (Dirmeyer et al., 2009; Ellison et al., 2017; Keys et al., 2017). Thus, there is a missing interdisciplinary bridge between understanding the role of land-atmosphere feedback over large distances and its importance for water governance at the basin scale."

P3 L14: on long term: q = P – ETact; where ETact is actual evapotranspiration with the parts mentioned before. Further on we talk about actual ET?

I am not sure I understand the question correctly. To be clear in the manuscript, we will add the equation Q = P – E directly after the sentence ending at P3L15.

P4 L15 and S8: GRDC runoff data are used for verification. GRDC data are not referred and not explained see: http://www.bafg.de/GRDC/EN/03_dtprdcts/33_CmpR/unh_grdc_node.html). Also the data source is from 2002 (and not really "observed" runoff). Maybe a comparison with recent modelling results is more appropriated (see: https://www.isimip.org/outputdata/), also because the MSWEP precipitation data is more inline with the WATCH WDFEI dataset than the one used in 2002. But here the important part is to show that the hydrological model is more or less ok. Therefore a rough comparison might be ok. Maybe adding the explanation of the supplement is enough.

We thank the reviewer for this insightful comment. GRDC was only referred to in the Supplementary Information, and a reference was indeed omitted in the main text body. In the revision, we will make sure that GRDC data is referred to and explained in the Data section in the main manuscript where it is first mentioned. It is as the referee points out, important to note that GRDC does not represent the best discharge data available. For example in the River Niger, the GRDC discharge is around 0.2 m/y (Fig S8), while station data at Lokoja station for 1980-2013 shows that it is about 0.07 m/y (Oyerinde et al., 2017).

P4 L20: E,pot might be misleading because it is normally used for potential Evaporation

Thank you for pointing this out. We will change E_{pot} to E_{pv} instead.

P4 L22: Why Fig S8 as reference?

Thank you for the sharp observation. We meant to refer to Fig S9.

P6 Figure 1a: Irrigated crop (orange) is hard to distinguish from rainfed crops (red). From this map there is hardly any irrigation in Spain or Italy (even if it is the main land cover change). What are the green dots?. A land use change map which indicated from with land cover to which would be helpful e.g.Forest – pasture. Because it makes a difference if you change from Forest – pasture or from shrubland – pasture

Great comments. We will change the colour scheme in Fig 1a, so the differences between irrigated and rainfed will become easier to distinguish as well as add categories of in terms of the original land cover (e.g., "forest to pasture"). The map shows the main difference between current and potential land cover, and although irrigation is high in Spain and Italy, the rainfed agriculture still dominates. We will consider showing the percentage of rainfed and irrigated cropland separately in the revised manuscript. The green dots are increase in forest cover and this was not included in the legend, due to the difficulties of seeing the fine changes (i.e., tiny dots) in a world map. We will add a bar figure summarizing the land-use changes in terms original to current (e.g., total area of forest changed to pasture etc.).

P6 Figure 1b-d: Quite a drastic change. E.g. for Zambezi that is more than 100% (more than indicated in S1). Fig 1a-c are cell values.

Figure 1d are summed up for the catchment at the outlet and then again put on the whole catchment. Maybe choose another way to show this, e.g. as points. Or show this as percentage as in S1h. Also because a change of 1000 m3/s in the Amazonas (or Congo) is close to nothing while for the Elbe River it is a lot.

We will modify the subheading of Figure 1d so that it clearly says "River flow change at outlet" as well as move Fig S1h from the supplements to the main manuscript.

P6 L1-8: This part is also interesting. But it would be good to have a global map here instead only a description of some basins to see the region differences. Maybe a map of absolute delta Q and delta Q/Q. Fig S1h shows the interesting basins like Odra, Indus, Colorado, Niger, Zambezi

Absolute difference in river flows is shown in map format in Fig 1d, and we will move the map of relative differences of river flows from the supplements Fig S1h to the main manuscript. Fig 3a summarises both absolute and relative river flows by basin. In the revised manuscript, we will add the basins with large relative river flow change to the figures.

P7 Figure 2: This is a necessary figure to show that the high values in fig 1 are well based inside other literature. Please put a table or part of it or another way of displaying results here in order to make it independent from the supplementary.

Good point, we will add a legend to Fig 2 that lists all cited literature.

P8 Much more interesting than the Congo (less than 5% change) is the Zambezi with almost 100% change.

Excellent point. We will add Zambezi (among others) to the analyses.

P8 Fig3: The y-axis is not only hydrological flow [m3/s]

The figure has two y-axis, m3/s to the left and % to the right. We will add a remark about this in the caption.

P10 L 21ff:

- Precipitation and evaporation over the sea is not in

Yes, it is true that the ocean precipitation and evaporation is not accounted for. Following also the comments from referee #1, we suggest to add a discussion of these issues to the revised manuscript.

The land-use change over land may affect above ocean processes mainly through modification of the energy balance and circulation in monsoon regions, which as stated, are not accounted for in the study. At P2L25, we refer to the PhD thesis of (Tuinenburg, 2013), which specifically examined the role of circulation change in estimates of land-use change effects on precipitation. In our current model set-up, an increase in irrigation leads to an increase in regional precipitation. Tuinenburg (2013) showed how precipitation might actually decrease by taking monsoon circulation response into account. Fully coupled ocean-atmosphere global climate models further increases the noise in simulation results.

Changes in fresh water discharge to ocean might have implications ocean circulation and climate as studies of for example river discharge to the Arctic Ocean shows (Peterson, 2002, 2006). However, moisture recycling's buffering effect (which mitigates river flow changes), should in fact have a mitigating effect on the ocean's response to fresh water inflow. Otherwise, precipitation over ocean can influence ocean salinity (IPCC, 2013) and precipitation patterns over land can be influenced by sea surface temperature (Xie et al., 2010), but we consider this outside the scope of our study and likely to be of minor importance for the research questions that we address. More generally, landuse change over land is connected to the biogeochemical cycle. As part of the climate system, perturbation of the e.g., the carbon balance and land surface roughness through land-use change may also be connected to the ocean's surface temperature and wind speeds that might affect ocean evaporation feedback (Trenberth, 2011; van der Werf et al., 2009) .

- Changes in atmospheric circulation is not in. it seems the model assumes the same patterns (see S1e)?

Yes, this is explicitly stated in this section. By moving some of the discussions on climate models from the supplement to the main manuscript, we hope this will become clearer as well. See also our reply to Reviewer #1's comment no. 4.

- Are you sure that dams are not indirectly in. e.g. Zambezi big dams as major land cover change from shrubland to open water?

Good point. We will include a description of this type of indirect land-use change in connection to the bar plot of land-use change we plan to add to the Result discussion, as well as in the Discussion section.

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