Response to Anonymous Referee #1's comments on manuscript hess-2017-494 (Remote land use impacts on river flows through atmospheric teleconnections)

We would like to thank the anonymous review #1 for the suggestions, comments, and questions. They strongly help to increase the quality of our manuscript by letting us improve the explanation of our methods and the presentation of our results. We are currently reworking the manuscript to reflect the suggestions made by the reviewer. Please see our detailed response below (reviewer quotes in blue and italic).

1. Most of the regions show decreases in evaporation. It seems like the effect from irrigation is rather small? Any reasons? Also, I suggest to include a figure showing the irrigation water amount applied in this study that might be useful.

Our estimates of evaporation change are on the conservative side for both decreases and increases, but is in range with current model and observation-based estimates as shown in Table 1 below. We will include a table with detailed comparison in the revised manuscript as shown below.

Table 1. Overview of studies of land-use induced changes in evaporation. Pure irrigation studies are included in this comparison with irrigation water consumption reported as "E increase".

		E decreases		*E* increases		Overall *E* change	
Reference	Model; Prec. forcing	$km^3\ y^{-1}$	%	$km^3\ y^{-1}$	%	$km^3\ y^{-1}$	%
(Döll and Siebert, 2002)	WaterGAP; CRU	-	-	+1100	-	-	-
(Gordon et al., 2005)	Reference E; UDEL	-3000	- 4.5	+2600	+3.9	- 400	- 0.6
(Rost et al., 2008)	LPJmL; HadCM3/CRU	-2360	- 3.8	+1325	+2.2	-1036	- 1.7
(Sterling et al., 2012)	ORCHIDEE; NgoDuc05	-	-	-	-	- 3160	- 5.6
(Sterling et al., 2012)	Literature-GIS; -	-2800	-4.2	+750	+1.1	- 3500	- 5.3
(Wada et al., 2014)	PCR-GLOBWB; CRU	-	-	+1179	-	-	-
(Wada et al., 2014)	PCR-GLOBWB; ERA-I	-	-	+1120	-	-	-
(Wada et al., 2014)	PCR-GLOBWB; MERRA	-	-	+994	-	-	-
(Wang-Erlandsson et al., 2014)	STEAM; ERA-I	-	-	+1134	+1.5	-	-
(Jägermeyr et al., 2016)	LPJmL; GPCC	-	-	+1268	-	-	-
This study	STEAM; MSWEP	-2047	-3.0	+796	+1.2	- 1251	- 1.8

2. P2L31: "no studies have quantified the magnitude of LUC impacts on P or Q". There are several studies have quantified the magnitude of LUC on P. The definition of LUC is rather broad, irrigation, deforestation, urbanization, so please carefully check those literatures.

We thank the reviewer 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:

"The previous studies that illustrated the importance of remote LUC for basin P and Q, did not systematically assess global effects of LUC on Q, or explore the interplay between LUC within and outside the river basin. These effects are important to disentangle since they can have profound water governance implications (for e.g., riparian water rights and transboundary river basin treaties).While there has been discussions of governance implications of land-atmosphere interactions purely based on atmospheric moisture fluxes between nation states (Keys et al., 2017; Dirmeyer et al., 2009; Ellison et al., 2017), no studies have quantified the magnitude of LUC impacts on P or Q, despite its high relevance for international water law and governance. 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."

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) (Keys et al., 2017; Dirmeyer et al., 2009; Ellison 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."

3. P3L25 "P differences between model iterations converges after about four simulations." Why after four simulations is choosing? Any particular physical meaning? Also, how long is the "four simulations"? 12 hours? (4 time steps?)

The *P* difference convergence requirement is described at page 4 line 25-26 and in Figure S9, and is less than 1 % per year and 5 mm/month in any grid cell. This simply means that an extra iteration would not yield very different results, and thus does not in any substantial way alter our findings and conclusions.

With our land-use change scenario, four simulation iterations were required to fulfil the convergence criteria at the global scale. The number of simulations can, thus, somewhat vary depending on e.g., the degree of land-use change, and the spatial or temporal coverage considered.

One coupled STEAM-WAM2layers simulation covers the entire time period 2000-2013 plus spin-up. Following the reviewer's suggestion, we will move Fig S9 to the main manuscript to prevent the misunderstanding concerning simulation length.

4. P3L22-25 "P under potential land cover is obtained through a coupled model simulation. We use E output from STEAM in WAM-2layers, and iteratively adjust the current day P forcing to STEAM with the changes in P with terrestrial origin obtained by forward tracking continental moisture in WAM-2layers (SI Materials and Methods). P differences between model iterations converges after about four simulations." Based on this description of the "considering the L-A coupling", I guess this model does not take into account the effect the atmospheric nonlinearity nor the atmospheric circulations changes. While the authors have nicely summarized the different approaches in exploring the effects of LUC in Table S1. However, can the authors elaborate this further? In other words, how different the result might be if we use the couple global climate model to conduct the similar LUC experiment?

The reviewer's question about the outcomes of climate models is interesting, but difficult mainly due to low signal-to-noise ratio and considerable inter-model differences in climate model simulations. As explained in "Introduction" and Table S1, not only are coupled global climate models conducting similar LUC experiment likely to give a low signal-to-noise ratio, but comprehensive climate model inter-comparison projects (Aloysius et al., 2016; Pitman et al., 2009) have also shown that precipitation changes from land-use change are highly inconsistent between models. Thus, for these reasons, it is difficult to speculate about how our results would potentially change by the use of climate models. To better convey this difficulty to the reader, we will move some of the discussions on climate models from the SI to the main manuscript

5. P4L25:" (i.e., meeting the convergence requirement of mean annual precipitation change < 1% and monthly precipitation change < 5 mm/month in every grid cell" The threshold value should be clearly mentioned regarding the reason to choose such values of 1% and 5mm/month. Are there any sensitivity tests to achieve such values?

We thank the reviewer for this question, but we are not entirely sure about what is meant. The convergence criterion is a sort of sensitivity test in itself. It means that the annual precipitation change is <1% and less than 5 mm/month when an additional iteration would be done.

6. P5L13: "Our results show that human LUC (from potential land cover to current land use) (Fig. 1a) has" Be clearly on how to obtain the difference (or anomaly). Is from the potential land cover minus current land use? Or vice versa? Please also indication in the caption of Figure 1.

We thank the reviewer for this comment which helps us better explain our analyses. However, because land-use in our case are represented by categories, rather than a scaled number (e.g., the case of tree cover percentage), the land-use change map is not obtained through subtraction. We simply show the grid cells where current land-use differ from potential land cover in Fig. 1a. Following the reviewer's comment, we intend to rephrase the caption in Figure 1 by changing the formulation from

"Differences between the current land-use and the potential land cover scenario. Changes in **a**, land use (only shifts in grid cell dominant land-use types are shown), **b**, …"

to

"Changes in land-use and water flows resulting from the replacement of the potential land cover scenario with the current land-use scenario. Changes in **a**, land use (current land use is shown, with grid cells without major land-use change masked out), **b**, …"

The sentence at P5L13 describes how the direction of land-use change (i.e., from potential to current) has altered the water cycle, which we think is clear in its context: "Our results show that human LUC (from potential land cover to current land use) (Fig. 1a) has led to reductions in E and P, and to increases in Q, in most regions (Fig. 1b-d)."

7. Figure 3 is interesting. It might be nice to include the changes in P and E on the bar chart plots.

We thank the reviewer for this comment, but we are not sure what is meant. The changes in P and E are already included in the bar chart plot in Fig 3a.

8. Some of the figures from the supporting information can be moved to the main content for the readers to read, and there are not many figures in the main content either at this draft.

Our feeling was that many of the figures in the SI constitute supplementary information do not contribute further to the key conclusions. However, we would be happy to move some of the figures to the main manuscript. Following the referee's previous suggestions, 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.

9. The ocean's E seems to be fixed because of using the reanalysis product. So, will the LUC over land affect the ocean's E? IF yes, the ocean's responses are completely ignored in this study. The authors may want to elaborate this issue further on the discussion as well. Also, to what extent the results from this study may be altered after considering the ocean's effects?

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 (see also our response to Reviewer comment 4).

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, land-use 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).

We suggest to add a discussion of these issues to the revised manuscript, although we would like to refrain from speculating about how "the extent the results from this study may be altered" (please also see our response to Reviewer comment 4).

10. Can the model simulate the surface temperature changes due to LUC? We usually can see the changes in surface temperature accompanying with changes in evaporation. It will be nice to show the figure of surface temperature changes as well.

Changes in surface temperature are not simulated. Changes in potential evaporation (Penman-Monteith equation) are taken into account through changes in land parameters.

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