Interactive comment on "Impacts of human activities and climate variability on green and blue water flows in the Heihe River Basin in Northwest China" by C. Zang et al.

Knowledge on the dynamics of streamflow with climate variability and human interferences is very important for water resources managements. However, it is difficult to separate impacts of climate variability and human interferences from streamflow and meteorological records. This paper tried to separate them using a semi-distributed hydrological model SWAT via different scenarios. Doing in this way is smart but this paper was not strong enough at current stage. I am reporting below a few main comments and some specific remarks, which I hope the authors will find to be useful while revising their manuscript.

GENERAL COMMENTS

(1). The novelty of this study was very limited at current stage

Essentially, what was investigated in this paper was the partition of precipitation between ET and runoff. Storage change was neglected in this study and quantity changes in ET and runoff were the same, so this study should be defined as impact of human activities and climate variability on ET or runoff. It is not necessary at all to dress up this issue with "New Clothes", i.e., "green and blue water".

To my understanding, this study is about assessing human activities and climate variability on the catchment water budgets at mean annual time scale. For this kind of issues, complex process-based model may be not a good option because this method subjected to various uncertainties, difficulties in validation and scale issues (*Blöschl and Sivapalan*, 1995; *Sivapalan et al.*, 2003a; *Nalbantis et al.*, 2011). As a result, complex bottom-up model may not be able to provide more reliable and more accurate estimations. An appropriate scale-dependent parameterization might be more robust to for a certain hydrological issues (*Sivapalan et al.*, 2003b; *Beven and Cloke*, 2012). Some empirical methods based on data analysis in a top-down manner may be more reliable to solve the issues in this study (e.g., *Koster and Suarez* (1999), *Zhang et al.* (2001), *Milly and Dunne* (2002), *Zhao et al.* (2010), *Li et al.* (2012), *etc.*). The authors also can try to use both bottom-up and top-down methods to find interesting coupling relationships and derived more reliable estimates (*Sivapalan et al.*, 2011).

For the impacts of human activities, I would like to see that human and natural are coupled systems. Human activities can change water cycle dynamics and they basically co-evolute with societal driver and climate variability (*Liu et al.*, 2007; *Sivapalan et al.*, 2012). Regarding irrigation, I would like expect coupling between water demand and climate variability. Unfortunately, human activities in this modelling experiment are just a simple prescribed scenario. Coupling between human activities and climate variability were not discussed.

(2). Land use change and irrigation expansion scenarios and modelling results.

From the manuscript, it is difficult to know how land use change and irrigation expansion scenarios were set in the SWAT model. To my knowledge, land use and land cover information in the SWAT model can be significantly different from that was provided in Table 2, which was derived from remote sensing products and considered as real changes. Because small patches of land use types was usually neglected when hydrological response units was delineated in the SWAT model. About 309 HRUs were generated considering both land use (23 types) and soil types (63 types) for the whole catchments about 240000 km^2. On average, area of a HRU was about 800km^2. It could result in that land use patches, which smaller than 100 km^2, were all neglected. Distributed land use types including villages, towns, and stream networks may be not considered in the SWAT model. Furthermore, how land use change scenario was set in SWAT model was also not provided. To my knowledge, land use change scenarios can only be set with the HRUs. The HRUs cannot be changed once they were delimitated, and they has unique land use or soil types. So, land use change information provided in Table 2 was also not helpful at all for understanding the modelling results. Regarding irrigation expansion scenario, it is difficult to know how much irrigated land increased, how much water was used and where did the water come from (streamflow or groundwater). Similarly, estimated change in irrigated land from remote sensing products did not equal to that was modelled in the SWAT model. These should be introduced in the data section.

From Figure 3 and 5, it seems (cannot see clearly) that land use change has caused ET and runoff changes in the headwater region, and irrigation expansion has caused changes in ET and runoff not only in the irrigated districts but also non-irrigation expansion regions. I was wondering that whether estimated water flux changes in this study can support the "natural flow" estimated in the previous study by Zang, *et.al.* (2012). If the headwater region can be considered as "natural", water flux of the headwater region should not be influenced by the land use change or irrigation expansion. I was also wondering that how irrigation expansion (shown in Figure 4) can change ET and runoff in the headwater region and un-connected sub-basins in the down streams (eastern and western tributaries).

Anyway, the authors may be right but more information on how scenarios were set should be provided and why land use change and irrigation expansion caused relatively different changes in ET across different sub-basins should be interpreted.

(3). Problems with separated impacts of climate variability, land use change and irrigation expansion.

Assuming that catchment actual evapotranspiration $E = f(\mathrm{C, L, I}, \ldots)$, where C for climate, L for land use and I for irrigation. Function f is a highly nonlinear one. Then, changes in E due to C can be approximated as:

$$\Delta E_C \approx \frac{\partial f}{\partial C}\Delta C + \frac{1}{2!}\frac{\partial^2 f}{\partial C^2}\Delta C^2 + \cdots$$

Similarly, changes in E due to L and I can be approximated as:

$$\Delta E_L \approx \frac{\partial f}{\partial L}\Delta L + \frac{1}{2!}\frac{\partial^2 f}{\partial L^2}\Delta L^2 + \cdots$$

$$\Delta E_I \approx \frac{\partial f}{\partial I}\Delta I + \frac{1}{2!}\frac{\partial^2 f}{\partial I^2}\Delta I^2 + \cdots$$

Differences between scenario B and scenario A in this study are ΔE_C here. The differences between scenario C and scenario A are:

$$\Delta E_{CL} \approx \Delta E_C + \Delta E_L + \frac{1}{2!}\frac{\partial^2 f}{\partial C \partial L}\Delta C \Delta L + \cdots \approx \Delta E_C + \Delta E_L + (nonlinear - \mathrm{int}\, eraction)$$

If impacts of climate and land use change on E are independent, then nonlinear interaction terms are usually negligible. However, E of land use is usually dependent on climate conditions, epically for vegetated land (*Zhang et al.*, 2001; *Troch et al.*, 2009; *Cheng et al.*, 2011). So, separated impacts of land use change (difference between scenario C and B) in this study, i.e., $\Delta E_{CL} - \Delta E_C$ here, included not only impacts of land use change but also changes in E of land use caused by changes in climate conditions. This is likely the reason why ET and runoff of headwater regions, where supposed to be under natural and land use should be not changed, were changed. Similarly, separated impacts of irrigation expansion were not solely changes caused by irrigation. Differences between scenario D and scenario C included impacts of irrigation expansion, interactions between E of vegetated land and changes in climate conditions as well as interactions between E of irrigated land and changes in climate conditions (assuming that impacts of land use change and irrigation expansion were independent). This is likely the reason why separated impacts of irrigation expansion can change ET of all sub-basins no matter whether there was irrigation.

Therefore, this study cannot be considered purely as either sensitivity analysis or scenarios analysis. It is not an assessment of real conditions at all and cannot be considered to benchmark the water resources in the Heihe River basin or as a general approach as claimed by authors.

(4). Storage changes

Storage changes in snow cover, soil water content and groundwater were not mentioned in this the manuscript. I suspect that estimated impacts may be biased by the storage change. For this large catchment (0.24 M km^2), 1.0 mm differences in the depth of water can resulted in 240 million m^3 change in the ET or runoff. In this study, estimated biggest change was ET caused by climate variability ~469 million m^3, which was only about 2 mm changes in depth and it can be smaller than errors in water balance or bias in estimated areal rainfall.

To my understanding, inter-annual variability of ET or runoff is much smaller than precipitation, which infers that inter-annual soil water storage can change significantly to stabilize annual ET flux. Storage between two different periods can be large if one is picked out from a wet period and the other is picked out from a dry period. Moreover, storage difference between beginning and ending of a short period, for instance, 3 years in this study, can also much larger than 2 mm. The authors mentioned that irrigation relies on not only surface water but also groundwater. I believe that sharp increase in water use irrigation in arid region, such as scenario set in this study, can cause significant change in groundwater storage. Authors provided glacier area was about 180 km^2. The glacier coverage decreased about 2% and temperature of the glacier covered region increased significantly between two periods. This can also resulted in significant storage change. Another storage may change is water storage in reservoirs, authors indicated that area of reservoirs and lakes interpreted from 1km^2 resolution satellite images was about 450 km^2. I guess that this area may be much larger if small water bodies were considered. I was wondering whether water bodies were modelled in SWAT in this study and previous study and whether there was storage change between two periods or due to irrigation.

Regarding the separated values, ET and runoff were exactly the same in quantity. It suggests that storage change was zero. I am not sure how it was achieved between two 3-year long scenarios. The author should carefully do water balance check considering changes in water flux in depth is very small.

SPECIFIC REMARKS

(1). P9478L12: "water flow increased from 1980 to 2005". Water flux of two different periods (1986s and 2005s) was compared and it was not appropriate to say that increased from 1980 to 2005.

(2). P9478L12: it is better to use mm rather than m^3 in this study.

(3). P9479: Introduction section: climate variability, climate change and global change were all mentioned. I think that they are not similar and have different research scopes. And, introduction was not well written.

(4). P9482L1: mountains are land cove types?

(5). P9482: simulation experiments: add figures show land use changes were set in the SWAT model and provide more information about how irrigation scenario was set.

(6). P9483L5: Is interception accounted in actual ET in the SWAT model?

(7). P9483L16-18: Both Ens and R^2 quantify correlation between predicted and observed time series. If two series are closely correlated but with huge differences in total quantity, very high Ens and R^2 can also be expected. Another systematic balance criterion should be used.

(8). P9483L21: "natural conditions were defined without considering human activities". I was wondering whether streamflow was influenced by human activities. If it was, how model was calibrated using human interfered streamflow how "natural flow" was estimated. The "natural flow" is very important information for this study. Please provide more information.

(9). P9483L25: Ens and R^2 were estimated on which time scale?

(10). P9484L2: What was the modelling period? There was a missing year 2006 in the second period, i.e., 2004-2006.

(11). P9484L11: add "subscript" before "0 indicates…" and "i indicates"

(12). P9484L28: Was soil depth modelled 100cm in depth across the whole basin?

(13). P9485L21-22: how much groundwater for irrigation was set in this study?

(14). P9486L10: how much did precipitation change at different regions and over whole basin? This information is important.

(15). P9486L12: There was a sub-basin in the downstream showing decrease in blue water in Figure 3. Not all.

(16). P9499-P9501: please change order of Figure 4 and Figure 3. I think that change in depth is more informative than relative change rate in Figure 3 and Figure 5. What does the residential points means in Figure 4? Does every point represent a certain population density?

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