Response to the comment hessd-11-C1419-2014

Title: A coupled modeling framework of the co-evolution of humans and water: case study of Tarim River Basin, western China
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Comment: hessd-11-C1419-2014

First of all, we greatly appreciate the valuable and constructive comments from the referee Dr. Salvatore Manfreda. The following lists our point-to-point replies to all the comments.

General comment: This paper introduces a coupled modelling scheme for the description of hydrological, ecological, economical and social dynamics. Each of these disciplines have reached a good level in the interpretation of specific aspects, but there is a significant gap to fill in the combined use of specific sub-modules and in the understanding of their interactions. I appreciated the attempt proposed in this paper where the authors try to identify a scheme to tackle this problem. Nevertheless, I have a number of issues that require more attention.
Response: Thanks for the comments.

1) My major concern is about the organization of the paper. The authors focus mainly on the model presentation, while the presentation of the results and the discussion are very limited. In the complex, the paper seems a brutal list of equations and functions without an adequate description of the motivation behind the model construction.
Response: One of the main objectives is to develop a simple coupled modeling framework for the co-evolution of socio-hydrological system to improve our understanding of self-organization of human-water system. Therefore, the modeling framework is presented in detail. It is stated in the introduction on P3916-3917. The description of the model construction is presented on P3919-3920. After the simplification of the socio-hydrological system, 4 state variables, i.e. water storage, vegetation cover, irrigated crop area ratio and human population, are adopted to represent the 4 sub-systems, i.e., hydrological, ecological, economic, and social sub-systems, respectively. The equations to describe the subsystems are explained on P3920, P3922, P3924, and P3927, respectively. We try to improve the description of motivation behind the model construction in the revised manuscript.

2) This one is a simple model, but it has more than 60 parameters and honestly I suspect that the calibration may be a real nightmare. I'm not surprised that model calibration over a run of about 50 year provide a good description of annual streamflow, but how can we be confident that you get the right result for the right reason?

Response: This comment is similar to the short comment made by Hui Liu (hessd-11-C1656-2014). We acknowledge that there are indeed many parameters in the dependent relationships to keep the model flexible to use in the current modeling framework. In our Tarim application, however, some parameters are not calibrated at all, such as 22 λ parameters in the dependent relationships, all of which are set to 1.0. The dependent relationships including λ is shown in Equation(14) and Fig3. The parameter λ controls the slope of the transient part of the curves, i.e. the changing rate of g_{VU} *or* m_{VU} *to the change of* r_{EWSU}*. This is a basic characteristic of the relationship and there is little understanding about it in the current stage of the socio-hydrology. So it is set to be the default value, 1.0, which is used in the previous researches(Liu et al., 2012a, b). In spite of the above work, we are still not confident that we get the right results for the right reason. We hope this open question could be better addressed in the future work. Of course in the future work, the parsimonious constitutive relations should also be developed and thus the number of parameters can thus be reduced. Also, the physical background of the constitutive relations should be strengthened to make the model parameters more physical interpretable and derivable from detail socio-economical and hydro-climatic data.*

$$g_{VU} = \frac{g_{VU0}}{1 + \exp\left((r_{EWSUC} - r_{EWSU}) / \lambda_{gVU}\right)}$$

$$m_{VU} = \frac{m_{VU2} - m_{VU1}}{1 + \exp\left((r_{EWSU} - r_{EWSUC}) / \lambda_{mVU}\right)} + m_{VU1} \qquad \text{Equation(14)}$$

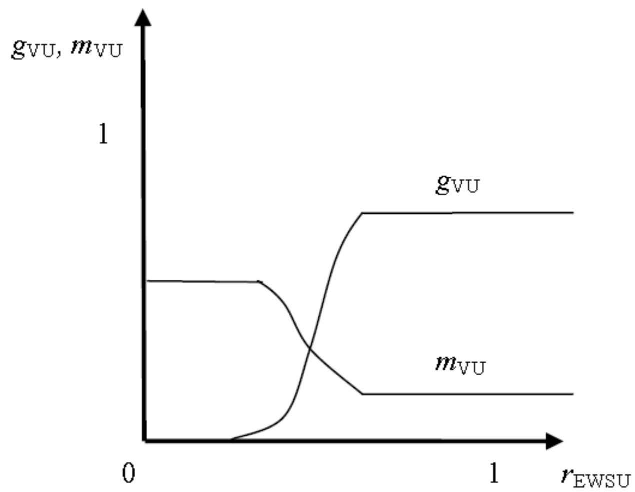


Fig. 3. Dependent relationships of the colonization and mortality of natural vegetation depending on the environmental water supply.

Liu, D., Lin, M. and Tian, F.: Simulation and evaluation of ecohydrological effect of water transfers at Alagan in lower Tarim River. Advanced Materials Research, 518-523: 4233-4240, 2012a.

Liu, D., Tian, F., Hu, H., Lin, M. and Cong, Z.: Ecohydrological evolution model on riparian vegetation in hyper-arid regions and its validation in the lower reach of Tarim River. Hydrological Processes, 26(13): 2049-2060, 2012b.

3) Looking at the model validation, it seems that the data used contains very limited information. In fact, most of the variance is smoothed away by using annual averages. Under such condition, it is extremely simple to fit the model with the observed data, but errors are even more evident. In fact, the module describing the ratio of irrigated area was not able to describe the abrupt increase of irrigated areas in the last three years (see figure 9). This aspect is not considered in the paper, but errors may represent an inspiration for further improvements.

Response: One of the main aims of the study is to build an exploratory model with the appropriate level of simplification to understand the co-evolution and self-organization of socio-hydrological systems. Due to the complex interactions between human and water, especially due to the abrupt nature of human behavior (individually as well as collectively), it is really hard for the model to predict the short-term (e.g., intra-annual) dynamics of socio-hydrological system due to the limited knowledge on the process socio-hydrology. Therefore, the objective of the proposed model is to represent the long-term (e.g., decadal) dynamics of the system. For some short-term features of the system *dynamics like the abrupt increase of irrigated areas in the last three years, some social behaviors, such as the accidental policy of the government to promote the economic, may have significant influences, which are, however, not incorporated in the modeling framework.*

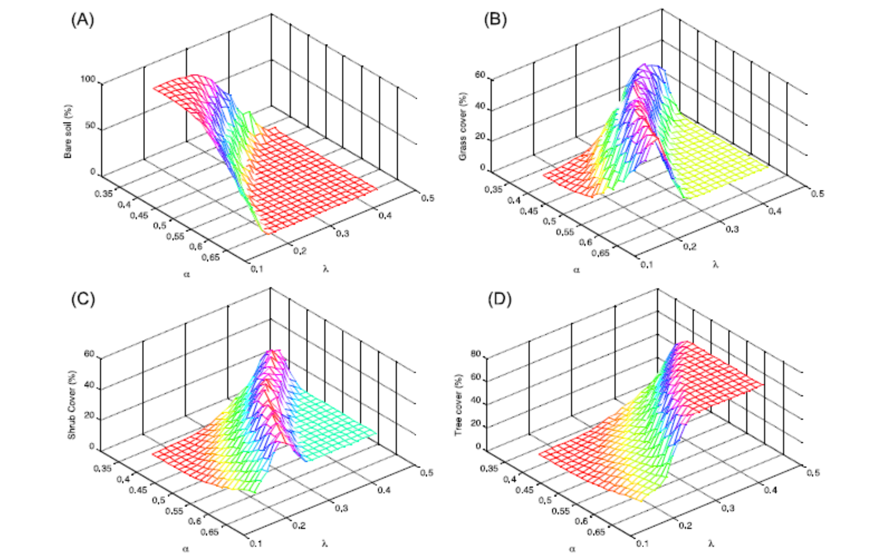
We acknowledge that our model framework could be extended with the progress of process socio-hydrology, which is aimed at gaining more detailed insights into causal constitutive relationships relating to human–water system exchanges (Sivapalan et al., 2012). The management policy, as a kind of social behaviors, should also be designed and evaluated further to improve the constitutive relationship of the water flux depending on the human activities. More discussions from this thread are supplemented in the revised manuscript.

Sivapalan, M., Savenije, H. H. G., and Blöschl, G.: Socio-hydrology: a new science of people and water, Hydrol. Process., 26, 1270–1276, 2012.

4) Model is applied at the annual time-scale. Are you sure that such scale is sufficient to represent correctly the processes of interest. In my personal experience natural processes may undergo abrupt changes that may be due to prolonged stress (see Manfreda and Caylor, Water 2013). This kind of processes cannot be modelled at the annual scale.

Response: In the study, we try to analyze the long-term evolution process at the annual scale, and the fluctuation within the year is not our focus of interest. Manfreda and Caylor (2013) describes simultaneously vegetation pattern evolution and hydrological water budget at the basin scale and the result highlighted that the relationship between climatic forcing (water availability) and vegetation patterns is strongly non-linear, which implies, under some specific conditions which depend on the ecosystem characteristics, small changes in climatic conditions may produce significant transformation of the vegetation patterns. "The approach is aimed at the modeling of the steady state conditions of a vegetation mosaic" (Manfreda and Caylor, 2013). The abrupt change of the vegetation patterns is the change of the steady states, which are produced by the CA network model forced by 400 climatic scenarios, as shown in Figure 4 in Manfreda and Caylor(2013).

Figure 4. Distribution in percentage of the types of soil cover as a function of the climatic conditions described by rainfall parameters α and λ. Percent cover of (**A**) bare soil; (**B**) grass; (**C**) shrub; and (**D**) tree.



Interestingly, our previous work also utilized a simple but comprehensive enough ecohydrological model with the pulsed atmospheric forcing to analyze the non-trivial dynamic behaviors qualitatively and numerically (Lin et al., 2013). The results confirm the existence of multiple stationary states depending on the water supply. Each stationary state is the result of the long-term evolution of the ecohydrological system.

We acknowledge that the research on the abrupt change of the steady states is not sufficient in our current study. Actually, in the current dynamical modeling of the evolution process, the state variables evolve slowly and gradually, and the abrupt change cannot appear in the transient process. However, the different steady states of the evolutionary system can be illustrated by scenario analysis. In the manuscript, we carry out the sensitivity analysis of system behaviors to initial values and boundary conditions, i.e. the precipitation, potential evaporation and inflow of the upper reach. The baseline model re-runs under different combinations of initial and boundary conditions. In our tested ranges, the system presents unique quasi-steady states without regard to initial values. The relative change rate of quasi-steady states compared with the baseline results indicates that, the changes of the precipitation have a slight effect and the relative change is in the range of -1%~ 1%. Otherwise, the potential evaporation, inflow of the upper reach and kc have significant effects especially on the vegetation cover of the lower reach (VCL). Furthermore, our test results show that initial/boundary conditions have only a slight impact on the population of the upper and the lower reaches, and the relative change is in the range of -1%~ 1 %. Generally, the boundary conditions including potential evaporation and upper reach inflow play an important role in the *system co-evolution, but the abrupt change does not appear in the test scope of boundary conditions. Future work could be done to explore the non-trivial dynamic (e.g., abrupt changes like bifurcation an chaos) features of coupled human-water system by using our current model as well as the some kinds of its extensions.*

To the authors' imagination, the abrupt change of coupled human-water system could not possibly happen within one year or so. As the time step of our model is one year, it should be enough to capture the so-called abrupt change due to the transitions of system steady states forced by external changes or internal feedbacks.

Manfreda S, Caylor K. On the Vulnerability of Water Limited Ecosystems to Climate Change[J]. Water, 2013, 5(2): 819-833.
Lin M, Tian F, Hu H, Liu D. Nonsmooth Dynamic Behaviors Inherited from an Ecohydrological Model: Mutation, Bifurcation, and Chaos[J]. Mathematical Problems in Engineering, 2013, 2013(731042): 1-9.

5) Looking at the results and more specifically comparing validation (e.g. Figure 9 or Figure 11) and projections (Figure 12.e or g), it seems that the data traces a trajectory that seems markedly different from projections in some cases. Which one is wrong? This aspect is particularly interesting and should not be neglected.

Response: As shown in the following, the simulated R_I from 1951 to 2010 in Figure 9 (validation) and Figure 12e (projection) are the same, while the ranges of the x axes are different. In the projection from 2011 to 2250, the trajectory of the R_I is approaching the quasi-steady state.

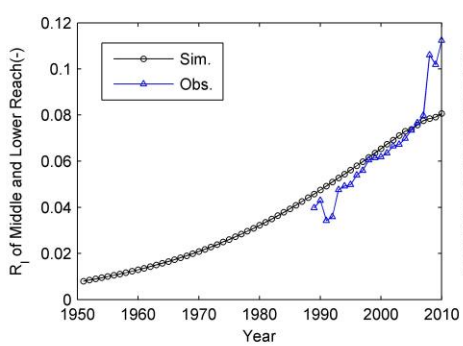


Figure 9

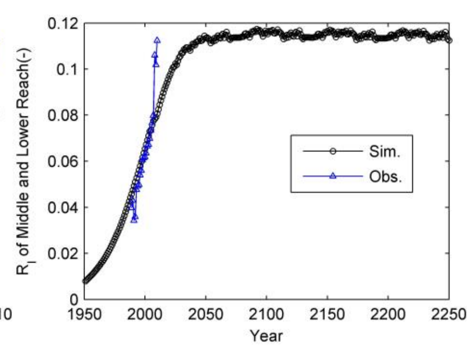


Figure12e

Similarly, as shown in the following figures, the simulated population from 1951 to 2010 in Figure 11 (validation) and Figure 12g (projection) are also the same. They look different maybe because the ranges of the x axes and y axes are different. In the projection from 2011 to 2250, the trajectory of the population is approaching the quasi-steady state.

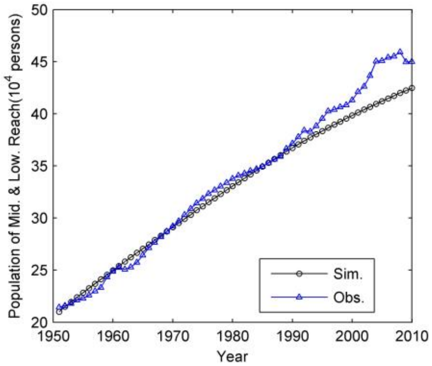


Figure11

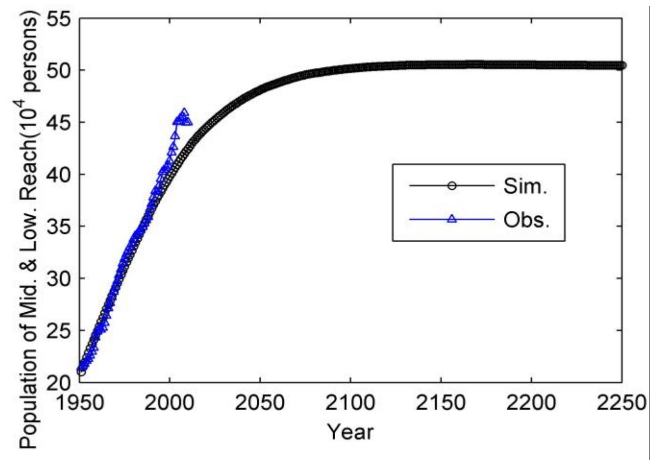


Figure12g

6) Finally, a discussion about limitations of the modelling approach and potential would be useful.

Response: In the revised manuscript one paragraph is added at the end of the Discussion to explain the limitation and potential of the modeling framework. The issues to be addressed are listed as the following.

In the current modeling framework, there are many parameters in the dependent relationships to keep the model flexible to use. In the future, the number of parameters will be reduced after the test of the forms of dependent relationships.

At current stage of the socio-hydrology, our understanding of the dominant socio-hydrological processes is limited and the social behavior, such as the accidental policy of the government to promote the economic, may have significant influences on the state variables of the system (e.g., irrigated area), which is not incorporated in the modeling framework. The model framework should be improved in both of the dominant socio-hydrological processes and the data used in the model in the future. The management policy, as a kind of social behaviors, should be designed and evaluated further to improve the constitutive relationship of the water flux depending on the human activities.

The study focuses on the modeling framework and feedback network, especially the negative feedback loops which make the socio-hydrological system more stable. The abrupt jump in the evolution, the multiple steady states of the system, the abrupt change of the steady states (Manfreda and Caylor, 2013), the tipping point, or catastrophic critical transition (Scheffer et al., 2009) are important characteristics of the system and the current model could be extended to incorporate them.

Manfreda S, Caylor K. On the Vulnerability of Water Limited Ecosystems to Climate Change[J]. Water, 2013, 5(2): 819-833.
Scheffer M, Bascompte J, Brock W A, et al. Early-warning signals for critical transitions[J]. Nature, 2009, 461(7260): 53-59.

Minor Aspects

Page 3914 – Line 15: Levins and Culver (1971) cannot be considered a paper in the field of ecohydrology, but Ecology.

Response: The "ecohydrology" was replaced by "ecology".

Page 3920 – Line 16: I suggest substituting the term evaporation with evapotranspiration in this point and also in other places throughout the text.

Response: Done.