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Hydrology and Earth System Sciences Discussions

Interactive comment on "Coupling a groundwater model with a land surface model to improve water and energy cycle simulation" *by* W. Tian et al.

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Thanks for the very suggestive and helpful comments provided by the anonymous referee 1#. His critical and valuable comments will help us to improve this manuscript. The comments were replied as follows.

RC1: The authors couple a 1D soil and plant growth model with a 3D variably saturated groundwater model. This is a laudable work as this type of consistent two-way coupled models is of relevance for the community in future research work especially when the impacts of land management changes or climate change are to be assessed. In the coupled model the lower boundary of the 1D soil model is given by the more regionally determined groundwater table while the recharge to the groundwater model is strongly

influenced by plant water uptake in the 1D soil column. The stepwise exchange of information between the two models allows for a more consistent, self-contained modelling. The work is not innovative as coupled models exist already (e.g. MIKESHE by DHI, Hydrogeosphere by Therrien et al.). But they are either commercial or only executables are available. Here generally available open software components are used and coupled.

Response: Thanks for your comment. Yes there are some similar coupled models such as the MIKESHE (Hughes and Liu, 2008) and the Hydrogeosphere (Brunner and Simmons, 2012). However, the focus of these models are different from ours. MIKESHE and Hydrogeosphere were coupled by the surface water model and the groundwater model and these models focused only on water cycle process. The GWSiB presented in this paper is coupled by a groundwater model and a land surface model, and it focuses on the interaction between hydrological vegetation, and energy processes.
Additionally, as indicated by the referee, our coupled model is based on open software. The source code is freely available.

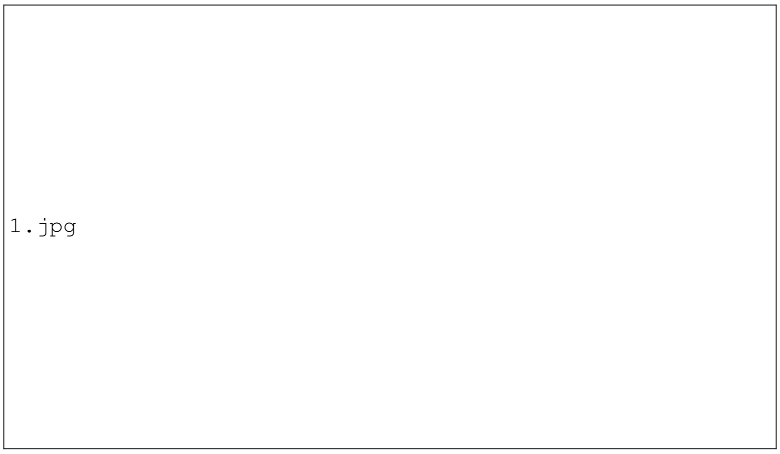
RC1: The paper claims that the model has been validated. This is incorrect. The model results have been compared with measurements at three sites. This involved a model calibration at those three points which is not specified clearly in the paper. No assessment of the model outside of these three sites has been made.

Response: The comparison between model simulations and measurements at three sites is to validate the model rather than to calibrate the model. In order to compare the coupling model and the original SiB2, the default parameters provided by Sellers et al. (1996) were used in the two models when doing comparison. We will add a description about the model calibration in the revised manuscript to make this part more clearly It is difficult to obtain the "true value" of evapotranspiration and soil moisture of each cell in the region . So the validation is difficult to be carried out in the region outside of the typical points where observation are available. However, we analyzed the rationality of the regional evapotranspiration by comparing our results with some remote sensing estimations of evapotranspiration in this region. This is described in the Section 4.4.

RC1: The coupling of the two models is awkward as the 1D-soil and plant growth model based on Richards equation is coupled to an unsaturated-saturated 3D groundwater model based also on Richards equation but in a different formulation. The paper sees this problem and addresses it. Presumably plant roots can only occur in the 1D-soil model reaching down in the applicatin to 5 m depth from the soil surface. So what about phreatophytes whose roots are much longer and extend to the groundwater table? A suggestion would be to adapt the depth of the SiB2 to the time-averaged depth to groundwater in each model cell.

Response: The Richard's equation is an important formula to describe soil water movement. The relationship between unsaturation hydraulic conductivity (K) and soil moisture potential (θ) is the key to solving Richard's equations. There are many scheme to describe the relationship between them, such as Gardner and Fireman's method (1958), van Genuchten's method (1980), and Clapp and Hornberger scheme(1978). The Different schemes would make a huge difference on the calculation of the Richard's equation. In our work, we replace the scheme of AquiferFlow (Gardner and Fireman's method) by the scheme of SiB2 (Clapp and Hornberger scheme) in order to make the simulation of soil moisture processes consecutive in the interaction of the two models.
In our model, the root zone is defined as 1.5m below the land surface, and this range is suitable for the most of the vegetation root zone in the study area. Most of the groundwater depth in the study area are more than 5m (Fig.3 of manuscript). Thus, the impact of the vegetation root zone can not reach the time-averaged depth of groundwater.
In our study area which belongs to a arid region, there is no phreatophytes vegetation dominated grid. However, when GWSiB was applied to a larger region, the root layer

thickness of the special surface types, such as phreatophytes, bedrock, etc. would be a problem. To solve the problem, we plan to modify the code of the soil layers in the coupled model.



RC1: The comparison of the SiB2 model with GWSiB leads to an obvious and trivial result which could have been reached with much less effort: Different boundary conditions at the lower end of a soil column lead to different fluxes of water. If the water table is shallow and reaches the bottom of the SiB2 soil column it will enhance evapotranspiration. A single column would have been sufficient to show this effect. A regional comparison of coupling versus not coupling should rather use boundary conditions in SiB2 which reflect the depth to groundwater. As the groundwater table is changing slowly, the "uncoupled" case (SiB2 only) could use a long term average depth to groundwater to formulate the lower boundary conditions. The fully coupled

case should then use the dynamically developing groundwater table as it is done in the paper. In such a comparison the results will differ much less and show whether it is really necessary to do the dynamic coupling over time.

Response: We agree that it is able to demonstrate the impact of groundwater on the land surface process by taking account an equivalent groundwater depth (boundary conditions) in the land surface model. In fact, many related works have been carried out, such as Liang et al. (2003), Gedney and Cox (2003), Yeh and Eltahir (2005) Niu et al. (2007). However, the defects of this approach is obvious. The main disadvantages of using the groundwater level to replace the dynamic process of groundwater are as follow.

1) The continuous changes in groundwater cannot be described using the equivalent groundwater depth. The groundwater table often has great changes during the dry season and wet season of one year in some regions.

2) The lateral flow of groundwater would been completely ignored. Some source and sink terms like pumping, river infiltration and other processes can change groundwater table by lateral flow, which affect the surface processes indirectly. If lateral flow of groundwater is ignored, these source and sink terms will lose their contact with surface processes.

3) If the groundwater depth was set to a fixed value, the water balance will be destroyed.

4) The regional data of groundwater depth are very difficult to obtain.

So we believe it is necessary to couple a groundwater dynamic model with a land surface model.

RC1: One should not overestimate the accuracy of the model. The groundwater model in itself is rather uncertain. It depends on inadequately known hydraulic conductivities, porosities and other soil parameters. So the position of the groundwater table is not only influenced by the more

consistent recharge flux in the two way-coupled model but also by the aquifer properties. Nothing is said about the regional performance of the groundwater model. Measured and computed groundwater tables should be given at least in the three sites. The depth to groundwater is not only influenced by the computed groundwater table (the accuracy of which is not given in the paper) but also by the DTM, which maybe wrong by up to 5 m. That is the depth of the whole soil zone.

Response: We agree that the groundwater model has considerable uncertainty, because the hydraulic conductivities, porosities and other soil parameters can significantly affect its simulation.

When the AquiferFlow is used in the Heihe river basin, many trial-and-error calculations have been done to adjust the groundwater parameters. It made the simulation of groundwater model close to the measurement in this region, and a comparison of measured and computed groundwater tables on December 2008 was shown in the Fig.1 to prove the accuracy of the groundwater model Although there are errors in the DTM data, the trend of DTM is correct. The groundwater depth measured at the three stations are agree with the calculated results. So we believe that the simulated groundwater depth can reflect the real condition of the study area, and can be used for the model evaluation.

RC1: As far as the overall accuracy of a regional model in computing evapotranspiration is concerned one should remember that the soil-plant model opens a can of new parameters in addition to the aquifer parameters which are also not adequately known over the whole area.

Response: Yes, when regional evapotranspiration is calculated, the more parameters lead to more uncertainty. In fact, all models which are based on the physical mechanism will have to face this problem. In our study, the parameters of groundwater model are calibrated by the measured groundwater table, and the parameters of land surface model are provided by the research of Sellers et al. (1996) From the simulated evapotranspiration of the coupled model, it can be seen that the evapotranspiration calculated by the coupling model is more reasonable than the original SiB2 does.

RC1: Two-way coupling seems only necessary for shallow groundwater table areas. So a lot of effort could be saved by having two way coupling only in zones with depth to groundwater smaller than say 3 m.

Response: We used a three-dimensional groundwater model in this study. The groundwater shallow zone is not a closed system by itself because of the lateral flow of groundwater. The scope of shallow groundwater areas is usually determined by a large range or even the entire river basin. If the model just includes the shallow groundwater areas, it is cannot simulate the groundwater changes.

RC1: The horizontal (3 km) and vertical (1.6 m) discretizations are coarse. It is not shown whether the computation results are grid convergent. A doubling of resolution is recommended to check whether changes remain small.

Response: The spatial resolution of the coupling model is coarse, because of the consideration to be computationally efficient We make the model convergence in each grid by adjusting the iteration number of model and the relaxation factor. We believe the spatial resolutions can meet the needs of the model validation in this paper.

RC1: The regional inaccuracy of the inputs is lower than that at the 3 locations chosen for validation.

Response: we have checked the result of regional evapotranspiration that simulated by the coupled model on June 24, 2008 (FiG. 10). The value in the regional evapotranspiration map are consistent with the result of 3 locations at same time. The three sits are not located in the grid with the maximum evapotranspiration (show as the

following figure). We believe one of the important reasons that the YK and LZG do not have the maximum evapotranspiration in the region, is due to the scale effect. The representativeness of leaf area index (LAI) and vegetation coverage of one calculation grid is different with one point. More detailed analysis about this problem will be added in the validation of the YK station in the revised manuscript.

2.jpg

RC1: In the three locations, the model shows that evapotranspiration is different in the two approaches as expected, when the groundwater table is shallow. In that case SiB2 is performing better than GWSiB. For a deep groundwater level, however, there are no differences.

Response: In groundwater shallow zone, the simulated results show that the GWSiB is performing better than SiB2 (see Fig. 4 and Fig. 5). The reason is that the GWSiB can describe the impact of groundwater in the evapotranspiration simulation However, the groundwater in the deeper zone is difficult to affect the land surface process, so GWSiB and SiB2 performance no significant difference in these regions. All of these were shown as expected.

RC1: In all sites the computed and (best) simulated evapotranspiration should be shown in a scatterplot in order to clearly see the correlation between the two items, which I suspect is not that good.

Response: We will revise the figure of the verification results.

RC1: In the second site, the model seems to react to the rain before the rain has started. This should be checked.

Response: Thanks. There were some errors in the original manuscript We will correct them.

RC1: In the third site evapotranspiration seems often strongly overestimated. Soil moisture in the model recedes much faster than in reality. I guess some tuning of storage related parameters could improve the result.

Response: Evapotranspiration from the July to August was underestimated in the third site (YK). The reason is that MODIS would underestimate the LAI especially in

areas with a large heterogeneity of land cover types, the detailed explanation will be described in the revise manuscript.
The reason of soil moisture receding much faster than measurement is mainly attributed to the parameters scheme of Richard's equations. The Clapp and Hornberger scheme as a Richard's equation parameters scheme is used to calculate the soil moisture hydraulic conductivity (K) which determines the flow of groundwater, but actually it is not only a function of soil moisture but also relates with the soil moisture adsorption and desorption processes (Johannesson and Nyman, 2010) It is a inherent fault which cannot be solved successfully in the Clapp and Hornberger scheme The problem is that the equation controlling the soil moisture adsorption is the same with the soil moisture desorption. That is why the model simulated the soil moisture decline with the same speed of soil moisture rises. Actually, they have different speed (which can be observed from the data of YK). In this article, we have adjusted the empirical parameters of Clapp and Hornberger scheme, which control the soil moisture conduction and storage. This makes the simulation of soil moisture rise (caused by irrigation) good, but the soil moisture regress process can not be improved at the same time.

RC1: The English language of the paper could do with some polishing.

Response: We try our best to make English fluency and have asked a professional language editor to polish the English. We hope the language can meet the requirement of HESS.

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