Interactive comment on "Improved representation of groundwater at a regional scale – coupling of mesocale Hydrologic Model (mHM) with OpeneGeoSys (OGS)" by M. Jing et al.

On behalf of all authors, I sincerely thank Dr. Stisen for his comments. I really appreciate his effort in reading and understanding our work. We have prepared a response to each of the reviewer's comments, and have suggested how we will incorporate these suggestions into a revised manuscript.

With regards to the main comments:

1. I have read the paper with great interest and find this kind of developments within SW/GW coupling very relevant and necessary. I generally find the paper very interesting and a good step in the right direction. I especially encourage the efforts related to variable time stepping and grid resolutions between compartments. I would however encourage the authors to be more specific about the coupling and limitations hereof.

This paper focuses on two things. The first one is that the authors build a practical workflow in which mHM and OGS are dynamically coupled. This paper presents the first attempt in coupling two codes with distinct usages (mHM for predicting mesoscale catchment runoff, OGS for solving multi-physical problems in porous media), structures (mHM written in Fortran 2008 and OGS written in C++) and even philosophies (mHM seeks for a good prediction ability across multi-scale catchments in a computationally efficient way, OGS solves computationally-expensive non-linear PDEs using Finite Element Method). The second main point is we demonstrate that the groundwater head dynamics can be well characterized in the mesoscale catchment by the coupled model. The effectiveness of spatially distributed heterogeneous groundwater recharge is also tested hereby.

2. As I read it there is no feedback from OGS to mHM, meaning that mHM is merely used to calculate a distributed boundary condition of groundwater recharge to OGS, whichcould have been done using separate models? Or am I wrong? There is currently no coupling between groundwater and soil moisture/evapotranspiration or baseflow? I find the discussion part interesting when it comes to actual full coupling. This would make the potential for model application far greater since it would enable simulations of the impact of horizontal GW flow on surface water and the impact of groundwater levels on GW-SW interactions. This again would make the model useful for evaluating the effect of GW pumping on surface water flow.

In the current version of mHM#OGS, the mHM first calculates the daily spatially-distributed recharge and baseflow, then feed the two time series of fluxes to OGS through an interface which converts unit, adjusts grid and time step sizes automatically. Therefore mHM does not only provide groundwater recharge, but also provide baseflow as a boundary condition of groundwater model (please see the Figure 7 in the manuscript). Through calibration against groundwater heads (manually or automatically), one can get a plausible estimation of groundwater storage, which is very important and always missing in typical bucket-type hydrological models. The reasonable quantification of K values and storage is the basis of several important scientific questions such as storage-runoff correlation, groundwater drought, and contaminant legacy.

3. One could ask, what is the purposeof a regional scale ground water model from a water resources perspective if it does not include the interaction with surface water? I suggest that the authors: â˘A ´c

Make it very clear from the beginning of the manuscript which kind of "coupling" is performed.

I agree with the Dr. Stisen that there are some limitations of the current offline coupling approach as it does not include the feedback of groundwater dynamics to surface processes. I would also like to draw attention to the starting point of our initiative in coupling those two codes. The starting point is on the hydrogeological side, rather than on the hydrological side. The current coupling model, as the first attempt, is designed to reproduce the dynamics of groundwater head and velocity and calibrate K values and groundwater storage using the boundary condition given by mHM. The feedback to surface water processes is another topic, and is the follow-up process only if the K values, groundwater storage are carefully calibrated and groundwater head dynamics are well reproduced.

Moreover, the current coupling method can help to answer a couple of important scientific questions. For example, Kumar et al [1] have demonstrated that the Standardized Precipitation Index (SPI) has a limited applicability and low reliability in characterizing groundwater drought. Our model can be a useful tool in predicting groundwater drought & flood under different climate conditions (please check Figure 11 and 13 in the manuscript). Moreover, the coupled model can be used to quantify the catchment scale legacy nitrogen stores in groundwater reservoirs. Recent research shows that a large portion of legacy nitrogen can be older than 10 years [2]. The current version of mHM#OGS fits well with the long-term simulation of nitrogen transport in beneath-atmosphere water cycle owing to its nested time stepping.

4. Provide more details on the OGS code, is it a fully integrated 3D variably saturated code or a pure saturated GW code?

I also agree with the Dr. Stisen that I should introduce more about OGS in terms of its capability in simulating Richards flow. OGS is 3D variably saturated code. Its capability in simulating variably saturated zone flow has been verified [3,4]. OGS is involved in a model inter-comparison project and is tested based on a series of benchmark problems [5]. Due to the fact that the overall aim of the current model is to reproduce groundwater head, the unsaturated zone flow is less-important and could be simulated in a conceptualized way using mHM. Nevertheless, I fully agree with the author that the variably saturated flow should be added into the next version of the coupled model.

5. Minor comment: Figure 8 need to include specifications of a) and b) and the figure caption needs to explain what the blue and red plots represent. Also I think you should avoid adding the Rcor values for groundwater heads, since they are meaningless in a topographically varying catchment. Stick to the RMSE.

I thank the Dr. Stisen for his minor comment which are very helpful. The Figure 8 a) and b) are actually showing different goodness of matching under two different recharge scenarios. I will stick to RMSE in the revised paper following your suggestion.

References

[1] Kumar, R., Musuuza, J. L., Van Loon, A. F., Teuling, A. J., Barthel, R., Ten Broek, J., Mai, J., Samaniego, L. and Attinger, S.: Multiscale evaluation of the Standardized Precipitation Index as a groundwater drought indicator, Hydrol. Earth Syst. Sci., 20(3), 1117–1131, doi:10.5194/hess-20-1117-2016, 2016.

[2] Van Meter, K. J., Basu, N. B. and Van Cappellen, P.: Two centuries of nitrogen dynamics: Legacy sources and sinks in the Mississippi and Susquehanna River Basins, Global Biogeochem. Cycles, 31(1), 2–23, doi:10.1002/2016GB005498, 2017.

[3] Wang W, Rutqvist J, Görke UJ, Birkholzer JT, Kolditz O. Non-isothermal flow in low permeable porous media: a comparison of Richards' and two-phase flow approaches. Environmental Earth Sciences. 2011 Mar 1;62(6):1197-207.

[4] Kolditz O, Shao H, Wang W, Bauer S. Thermo-hydro-mechanical-chemical processes in fractured porous media: modelling and benchmarking. Springer International Pu; 2016.

[5] Maxwell, R. M., Putti, M., Meyerhoff, S., Delfs, J.-O., Ferguson, I. M., Ivanov, V., Kim, J., Kolditz, O., Kollet, S. J., Kumar, M., Lopez, S., Niu, J., Paniconi, C., Park, Y.-J., Phanikumar, M. S., Shen, C., Sudicky, E. A. and Sulis, M.: Surface-subsurface model intercomparison: A first set of benchmark results to diagnose integrated hydrology and feedbacks, Water Resour. Res., 50(2), 1531–1549 [online] Available from: http://onlinelibrary.wiley.com/doi/10.1002/2013WR013725/full (Accessed 18 August 2016), 2014.