Response to comments from Nir Krakauer

We thank the reviewer for the positive response to our paper and thoughtful comments that allowed us to significantly improve the paper. We have modified the manuscript accordingly, and address the reviewer's comments in detail below. In the following the reviewer's comments are given in italics and our replies in regular font.

Reviewer 1: Nir Krakauer

The work presented here involves a global simulation of steady-state groundwater movement that employs the popular groundwater model MODFLOW, which is usually used in basin-scale and regional studies. Global datasets of lithology and permeability are combined with some assumptions and calibration to observed groundwater levels. While this work is interesting and valuable in that it moves in the direction of expanding the capabilities of groundwater models and integrating them with land surface models over large domains, there are some changes that could be made to render it of wider applicability.

The authors should mention new work by Krakauer et al. (ERL 9:034003 2014) on the relationship between model spatial resolution and lateral flow volume and by Gleeson et al. (GRL, in press) on higher-resolution global permeability and porosity maps.

We took notice of the suggested literature and added this to the introduction of our manuscript.

The water level observation database needs a citation (probably Fan et al. 2013), not just a URL.

We included the reference to the paper of Fan et al. (2013), where the data is presented.

It will be very difficult for anyone else to reproduce the global configuration of MODFLOW developed, particularly given the reliance on stochastic methods for parameter estimation. Therefore, I strongly recommend that the authors post their MODFLOW input files and control scripts under an open-source license in a suitable repository such as GLOWASIS, so that they can be evaluated and improved on by the hydrology community.

In our study we aim to explore the possibility to develop a high resolution groundwater model using existing globally consistent datasets. As such, our parameterization is subservient to the sensitivity analysis that we have performed here and samples the uncertainty of existing datasets, most notably that on permeability of Gleeson et al. (2011) and the data we have compiled here. The resulting products are not meant to have any definite status as a unique global geo-hydrological parameterization and for that reason, we will not publish the data online in their present form. However, we are willing to provide the input data to researchers who are interested in exploring the parameter space covered by our realizations upon request .

Figure 3: It is not clear what "cumulative probability" means.

With the ‘cumulative probability’ we mean the frequency distribution of the aquifer thickness, as described in the text. We changed this is the caption of Figure 3.

Figure 5: Most of the land area has a beige tone in all 4 panels. What does this indicate?

The beige tone indicated the value (around) 0 (indicated in the colour bar).
What can be seen from Figure 5a is that overall the coefficient of variation of groundwater depth is small. Higher values are found for low recharge areas (e.g. Sahara , Australian dessert) and for areas with shallow groundwater depths with higher transmissivities and recharge rates (e.g. Amazon basins, Indus basin) (explained on p. 5231 l. 20-25). Figure 5b shows saturated conductivity is the main driver of changes in groundwater depths.

Accordingly to the comment of reviewer 3 (Mary Hill) we improved this figure by showing the coefficient of variation of the overall analysis (with changing parameters for aquifer thickness, groundwater recharge, and saturated conductivity) and for saturated conductivity. The other two parameters are of minor importance for the variance in groundwater table depths.

Figure 6: What is the criterion for considering a water table to be “local and perched”?

The spatial difference between observed and simulated groundwater depths (Fig. 7) show that in general groundwater depths are overestimated compared with observations for steeper and higher elevated terrains. This is explained by the grid resolution, which is to coarse to capture small local valleys (see also in p. 5233 line 27). As a result, smaller local aquifers in local valleys are left out and the simulated groundwater heads present the regional scale continuous and deep groundwater tables, rather than local water tables. Similarly, water tables on hillslopes that temporarily exist in the regolith soils perched on top of less permeable bedrock are not captured by the groundwater model (in fact they are treated in the land surface model as sources of interflow). We assume that for steeper and higher elevated terrains local and perched water tables are likely to occur, but stay uncaptured by the model. The shallow groundwater depths observed for these areas confirm this assumption (shown in Fig.6). We will clarify this further in our manuscript.

Additionally we rewrote the caption of Fig. 6 to: “ Scatter plots of observed heads against simulated heads. A) For the best performing run, B) for the best performing run if only observations in estimated sediment areas were used.”

Figure 7: I am not sure if displaying “relative residuals” makes sense here. Would this quantity be infinite when the observed water level is zero?
Indeed the relative residuals will be infinite if observed groundwater depths are zero. But in the used dataset of Fan et al. (2013) no groundwater depth of zero occur.

We show relative residuals here to make clear that although the absolute error for higher elevated and steeper terrains is large, the relative error is small. In other words this means that there were deep groundwater is simulated observed water can be more shallow, however it still is deep.

*Figure 8: The long groundwater flow paths, for example around the Gulf of Bothnia and Gulf of Finland, are remarkable. I am not very familiar with these areas, but maps such as http://www.ymparisto.fi/en-US/Waters_and_sea/Hydrological_*

situation_and_forecasts/Hydrological_forecasts_and_maps/Hydrological_forecasts_ and_maps(26174) for Finland show them to be fairly well drained. Is the simulation resolving the river network in such regions as a groundwater sink?

With our groundwater model we simulate the regional scale deeper groundwater flow. Due to the grid resolution, which is too coarse to capture small local valleys (see also in p. 5233 line 27), smaller local aquifers area left out. For the steeper and higher elevated terrains local and perched water tables are likely to occur, but stay uncaptured by the model.

In the case of Finland deep regional scale groundwater depths for the basement rocks are simulated, as these rocks are defined as acid plutonic and metamorphic rocks in the used lithological map(GLiM Hartmann and Moorsdorf 2012). Consequently long flow paths are simulated. Local streams draining saturated cover materials (e.g. glacial till, blanket peats etc.) are not captured by the groundwater model, but are part of the land-surface model PCR-GLOBWB.