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Hydrology and Earth System Sciences Discussions

Interactive comment on "A simple groundwater scheme in the TRIP river routing model: global off-line evaluation against GRACE terrestrial water storage estimates and observed river discharges" *by* J.-P. Vergnes and B. Decharme

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Referee #1 (C3674) :

Section 2: The Trip Model

Comment: It could be interesting to present how the TRIPGW model compares with other global groundwater modellings. Indeed, I only know one such model, the Watergap model (Alcamo et al., 2003) which is quite simplier in many aspects.

Response: Niu et al. (2007) have also developed a global groundwater model. They extended the soil column of a land surface model by adding a simple groundwater reservoir. Capillary rises are taken into account when the water table reaches the soil, no horizontal fluxes are allowed, and aquifers are defined all over the world with constant parameter. In TRIPGW, we choose to have a more hydrogeological-oriented approach by using a diffusive two-dimensional model. Only major aquifers are taken into account and the GW parameters depend on the type of soils. As described in the introduction, some studies use also a linear groundwater reservoir to decay the slow groundwater flow to the river at global scale (Arora et al., 1999; Decharme et al., 2010; Ngo-Duc et al., 2007). The approach used in Alcamo et al. (2003) is similar, with a set of linear and non-linear reservoirs to representing groundwater, lakes or wetlands (Döll et al., 2001). These approaches do not compute a dynamic water table head like TRIPGW. Such dynamic variations are useful to have more realistic river-groundwater exchanges. It will help us to couple the TRIP groundwater scheme with the soil of ISBA.

C: Page 8219: line 10: Isn't W the river width, since L is the river Length?

R: "river length" has been replaced by "river width"

Section 3

C: Page 8220 Line 6: I suggest to add "the elevation of" before "each grid cell is computed as the mean value of the first decile of the actual 30 arcsec resolution topographic values within the grid cell, ranked in ascending order."

R: done

C: Page 8221 line 9: Is there just one category or several categories?

R: "This category" means the "complex hydrogeological" structures. The paragraph has been rewritten in consequence.

C: The extension of the aquifer is not easy to see on figure 1. Would it be possible to have some ideas of the surface covered by the aquifer, at least, on the basins listed in table 2?

R: A new map has been added to have more information on the extension of the aquifer. (Fig. 1)

Section 4.1 River Discharges

C: Page 8224, line 14: It is not clear if the efficiency is computed on daily or monthly values, can you precise ?

R: All the scores are computed in monthly values. A sentence has been added to clarify it.

C: Figure 3 and last paragraph of page 8225: can you give provide the number of river gages by continents?

R: The number of river gages is now given per continent in Figure 3 (not shown).

C: Figure 4 and line 5 of page 8226: can you explain how the monthly anomanlies are computed? Is it the monthly riverflow minus the average riverflow (either simulated or observed)?

R: The monthly anomalies are computed by removing the monthly mean annual cycle of the time series. A sentence to clarify how we compute the monthly anomalies has been added. Section 4.3 Sensitivity to precipitation

C: Lines 6-7 page 8229 : "This shows that the groundwater scheme does not seems to be affected by the precipitation forcing": I would rather say that the impact of precipitations is larger than the impact of the water transfer simulation.

R: The conclusion has been rewritten to take into account this comment.

Section 5: Discussion

C: I understood that the results were obtained without calibration, as the parameters

are set according to a relationship with the rock type. This should be emphasize in this. A sentence has been added to take into account this comment on the parameters.

C: Page 8233 lines 12-15: Again, I'm not sure that the groundwater model is not sensitive to the precipitation, but I think that the precipitation dominate the signal (see comment above).

R: See previous comment.

Section 6 : Conclusions

C: P8234 line 5: I would rather write groundwater instead of it in the sentence "In the regions where the ratios are improved, it contributes storage for some of the surplus of water and improves the simulated mean annual river discharges, even though they are still over estimated. The simulated GRACE TWS are also improved with the new groundwater"

R: done.

Referee #2 (C3899) :

Model description (Section 2)

C: Are T and T really different? W should be river width.

R: The term "river length" has been replaced by "river width". In the model, $T\theta$ and $T\varphi$ are computed by taking the geometric mean of the transmissivity of two adjacent cells (see Appendix of Vergnes et al. (2012)). They are not so different, except when the type of rocks changes inside the aquifer.

C: There is a unit inconsistency around qriv and Qriv, which are written to be in m/s and m3/s respectively, whereas L13 p 8219 says that Qriv has to be converted to kg/s

R: The diffusion equation is written in m/s, but its discretized form is in m^3/s. As a consequence, this equation is solved in m^3/s, while the initial TRIP version was solved in kg/s. So when Qriv is computed in Equation (3), it must be converted in kg/s (multiply by the density of water) before to be introduced in the Equation (1). This part has been modified to better explain these unit conversions.

C: I would appreciate a better explanation of the different elevations and heights than a mere reference to Decharme et al. (2012). A sketch could be useful here.

R: A sketch has been added to better explain the multiple height and elevation (Fig.2)

Model parameterization (Section 3.1)

C: What is the advantage of GMTED2010 against the widely-used Hydro1k hydrologically conditioned DEM?

R: In Vergnes et al. (2012), we used the GTOPO30 elevation dataset to compute our elevation. Since this study, a new global elevation dataset (GMTED2010) has been released. A complete description of this dataset can be found on this website: http://eros.usgs.gov/#/Find_Data/Products_and_Data_Available/GMTED2010). Since GMTED2010 has been designed to replace GTOPO30 for large-scale applications, we choose to use it to compute our elevation both at 1/12°, and then at 0.5°.

C: P8221, L9: what is "this category"? According to the text, it should be the latter one, thus the "complex hydrogeological structures", but since they are overlooked in the model, "this category" must rather be the first one, thus the "major groundwater basins". Please clarify this.

R: This category means the "complex hydrogeological structures". A couple of sentences has been added to clarify this statement.

C: Like Reviewer 1, I would have liked some complements on the final ground water layer in the TRIP model: fraction of the continents with modeled aquifers, % of the modeled aquifers covered by the different lithologies/parameter sets of Table 1.

R: A new map has been added to Figure 1 in order to have a better representation

of the aquifers. A sentence clarifies now the percentage of continents covered by the aquifer (43 %). Moreover, Table 1 exhibits now the percentage of aquifers covered by the different lithologies.

C: I did not understand whether carbonate-rock aquifers were removed only the upper Mississippi basin or world-wide (p8221, L20-21). If not world-wide, how do you justify this? Do you have information about the actual karstification?

R: As described in the article, a supplementary map has been used to refine the mask of the United States. It concerns only the northern part of Mississippi river basin. It is now clarified in the text. WHYMAP classify this part as "complex hydrogeological structures" (Fig. 3, top). According to the description of the USGS map, the carbonate-rock aquifer system that are exposed at land surface (encircled in red in Fig. 3, bottom) are composed mainly of karst topography (Ground Water Atlas of the United States http://water.usgs.gov/ogw/aquiferbasics/carbrock.html, (Miller, 1999)). Such aquifers do not correspond to our model, which simulate regional groundwater flow in slow porous medium, so we decide to remove these areas. Another region has also been removed. It concerns the areas denominated as "other rocks" over the USGS map (encircled in green in Figure 1). Again, this region is described as having local and sparse aquifers with low permeability. Finally, we keep only the sandstone aquifers, encircled in blue, since no reasons justify to remove them. There is actually no global dataset of karstic areas. In the future, if this information becomes available, it could be useful to refine our global map.

C: I would also have appreciated a brief discussion about the relevance of the selected aquifer systems for global land surface and climate modeling, in particular regarding the water table depth (WTD), which is known to be crucial for groundwater/surface interactions. Section 3.2 mentions the computation of an equilibrium WTD for initialization, and the mean WTD over the 1960-2008 period could also be calculated. I would be very interested by the spatial and even more by the statistical distribution of this WTD. If I understand that a thorough validation of this field is not devisable because of the scale mismatch between wells and TRIP grid-cells, couldn't some regional assessments be made in densely surveyed zones, such as in the US (see Fan et al., 2007)? If such assessment was made in France in Vergnes et al. (2012), couldn't you remind the main conclusions?

R: Fig. 4 show the mean water table head for the 1960-2008 period. Since the model diagnostic a water table head, we compute this water table depth, by taking the elevation Z minus our water table head. The spatial distribution of WTD (in meter) corresponds logically to the spatial distribution of precipitations, that is the WTD is deep in arid or semi-arid regions where no rainfall occurs, while it is nearer the surface in humid zone. Evaluation of the water table head was made in (Vergnes et al., 2012) at fine (1/12°) and coarse (0.5°) resolution against a large database of observed pieozmetric heads. In this study, observed and simulated piezometric wells compare relatively well at fine resolution, even though some deficiencies appeared due to the simple TRIP parameterization (each grid cell considered as a river cell, values of porosity, aquifer limits...). At 0.5°, we compare the spatial mean of water table variation over each large aquifer at the 0.5° and 1/12° resolutions. The results show a good comparison, except that the coarser resolution seems to overestimate the seasonal amplitude of water table variations compared to the 1/12° resolution. This larger amplitude is favored by lesser horizontal exchanges occurring at 0.5° resolution, and a weaker hydraulic gradient between cells.

Main evaluation results (Section 4.1 and 4.2)

C: My first concern is about the definitions of the annual ratio and efficiency, which are not reserved terms and need to be specified. This should include a reference to Nash and Sutcliffe (1970) for the efficiency, and the meaning of RMSE should be stated. Reviewer 1 asked if the efficiencies were computed on daily or monthly values, and the same question applies to the correlations. I also wonder if it is really useful to give the used statistics on the full time series and on the monthly anomalies, since the responses are logically very similar.

R: A paragraph has been added to clarify the meanings of Ratio, Efficiency and RMSE scores.

C: Why is there a deterioration of the river discharge score with ground water in North America?

R: The deterioration of the river discharge scores with groundwater in North America are mainly located over the sandstone aquifer under the Great Lakes. Fig. 5 gives some insight about these deterioration with results over two gauging stations. GW underestimates the amplitude of the signal compared to NOGW. It seems that the buffering effect of groundwater is too important over this region. Moreover, our tests show that without simulating aquifer on these regions, the simulated river discharges in the upstream part of Mississippi rivers are better reproduced with groundwater. A "drastic" solution could be to remove this region, classified as "complex hydrogeological structures". But according to the literature, no valid reasons arise for removing it. It is therefore difficult to establish the causes of this problem : uncertainties of our groundwater parameters (porosity or coefficient of river-groundwater exchanges) or errors in the forcing fields. Currently we choose to keep these regions, and to wait to have a complete system, that is a coupling between ISBA and the aquifer, to further investigate this problem. Moreover, this is the only major deterioration that we have all around the world. Some sentences have been added to clarify this.

C: Is there a simulated aquifer in the Mekong basin? More generally, it would be nice if the areas where aquifers are simulated could appear on the maps, maybe by hatching.

R: According to Whymap, there is only a small part of the downstream part of Mekong which is underlain by an extensive porous aquifer. We choose not to add hatches over the map, since Figure 1 gives now the extensions of the aquifers inside the river basins. Moreover, it makes the maps unreadable.

C: Most of the remaining flaws in simulation GW are attributed to the absence of flooding processes in TRIP: can't other processes be poorly be represented, such as river velocity in TRIP, or the surface water budget in ISBA (especially where the annual ration is significantly different from 1)?

R: Another sources of uncertainties in TRIP come from the determination of the parameters in the Manning's formula used to compute the river velocity. The computation of river width is based on an empirical formulation (Arora et al., 1999; Decharme et al., 2010). The calculation of riverbed slope depends also of the accuracy of the topographic database. At last, ISBA computes the partition of precipitation between evapotranspiration, surface runoff and deep drainage. The physic of ISBA is characterized by some deficiencies, in particular the absence of capillary rising from groundwater in the unsaturated zones. Errors in the precipitation forcing fields could also explain the overestimated annual ratios.

C: Lastly, it is written that "In general, groundwater increases the memory of the system by shifting the TWs signal" (p8228, L6-7). The simulation design would allow the authors to go beyond this very general statement, and to provide interesting pieces of evidence, using for instance lagged correlation or spectral analysis.

R: Such analysis could be effectively useful to better support our result. Nevertheless, the objectives of this study is to prove the feasibility of using our model at global scale. So we consider that our skill scores are actually sufficient to evaluate the results of this evaluation. In the future, such analysis could be useful, particularly when looking to the soil moisture response to groundwater influences. We choose to keep this sentence, but if the reviewer doesn't agree, we can remove it.

Sensitivity to the precipitation forcing (section 4.3)

C: I found this part rather weak compared to the rest. I would suggest either to remove it, or to strengthen it, by explaining the rationale of this sensitivity analysis, in particular with respect to groundwater modeling. It would also be interesting to give some quantification of the differences induced by the precipitation forcing, for instance using histograms for TWS and precipitation itself. Spatial means would also give interesting

quantitative insights.

R: An explanation on the rationale of this sensitivity analysis has been added to the text. Such analysis is of interest in groundwater modeling because the precipitation determines, as well as topography and geology, the temporal and areal distribution of inputs to the groundwater system. To justify the better results obtained with GPCC, new histograms have been added to the TWS correlation difference map, and the text modified in consequence. (Fig. 6)

Discussion and conclusion

C: These two sections exhibit many repetitions and could probably be condensed into one section. Moreover, some conclusions are overly strong, because not well supported by the results. It is the case regarding the memory of the system (see above), the water table head distribution (P8230, L20-22; p8234, L10-12), the advantage of GPCC over CRU (p8232, L27-28), or the more realistic baseflow (p8234, L4). A more specific comment egards the deterioration of efficiency scores in some areas, including the eastern part of the Mississippi river, which is related to deficiencies in the WHYMAP data base (P8230, L20 to P8231, L11). Yet, Section 3.1 mentions that a USGS hydrogeological map was also used in the US. Could you please discuss this more thoroughly?

R: Some of these remarks have already been corrected (deteriorations in the Mississippi rivers, use of a USGS hydrogeological map). The conclusion on water table head distribution, on the more realistic baseflow and on the memory of the system have been rewritten to better reflect the results. These conclusions have been tempered to be more supported by the results.

Technical corrections :

All theses errors have been corrected.

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Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 9, 8213, 2012.

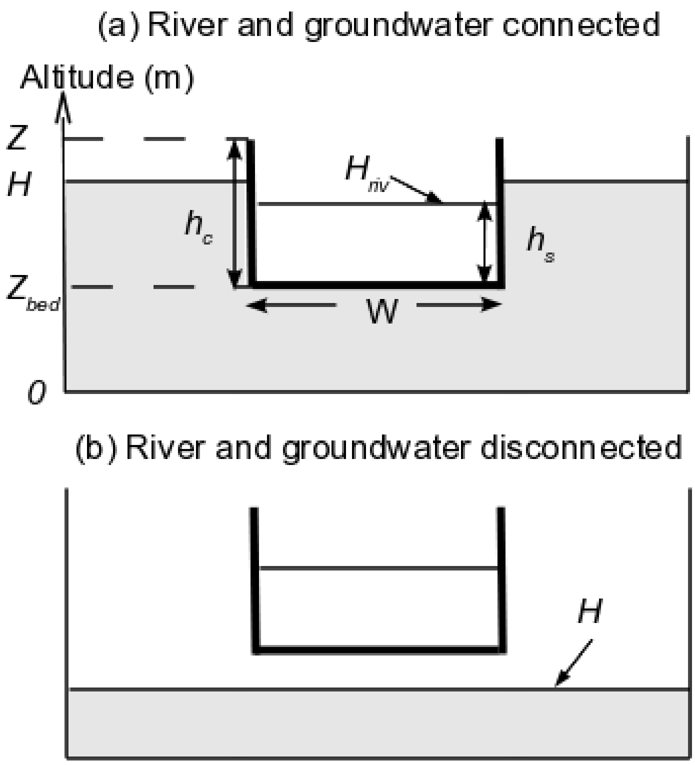

Fig. 1. Groundwater-river interactions with river and groundwater (a) connected and (b) disconnected. The geometry of the river is also shown.

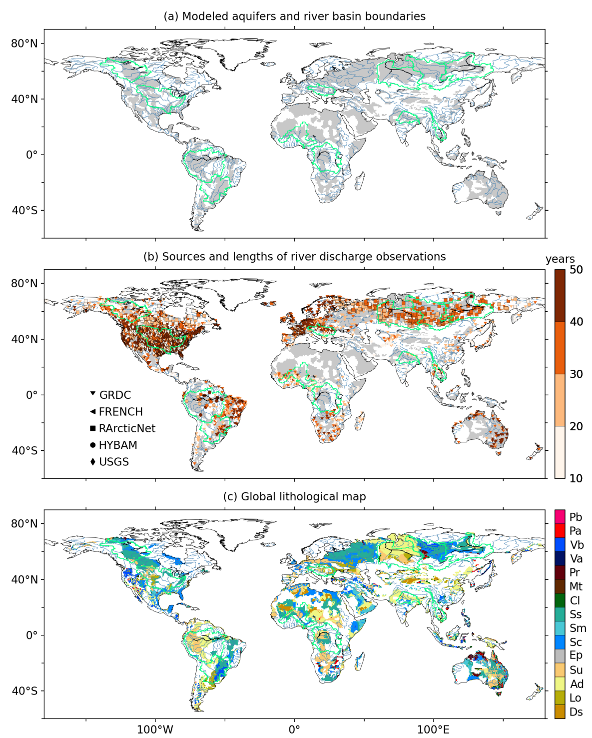

Fig. 2. (a) Modeled aquifers and river basin boundaries, (b) sources and time length of the in-situ gauging stations with the aquifers defined at 0.5 ° in gray-shaded zones, and (c) global lithological map of

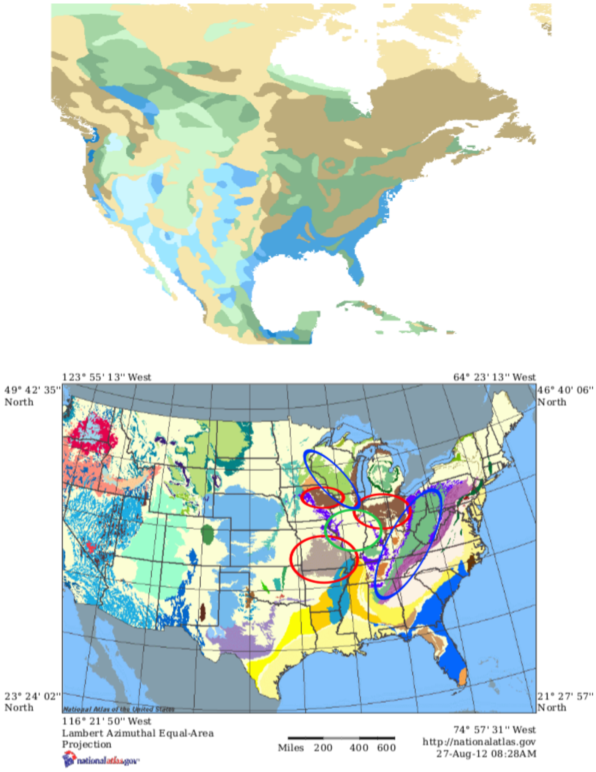

Fig. 3. (top) WHYMAP on the USA. The “regional aquifer” are in blue, the “local and shallow aquifer” in brown, and the “complex hydrogeological structures” in green. (bottom) Aquifer of USA (USGS)

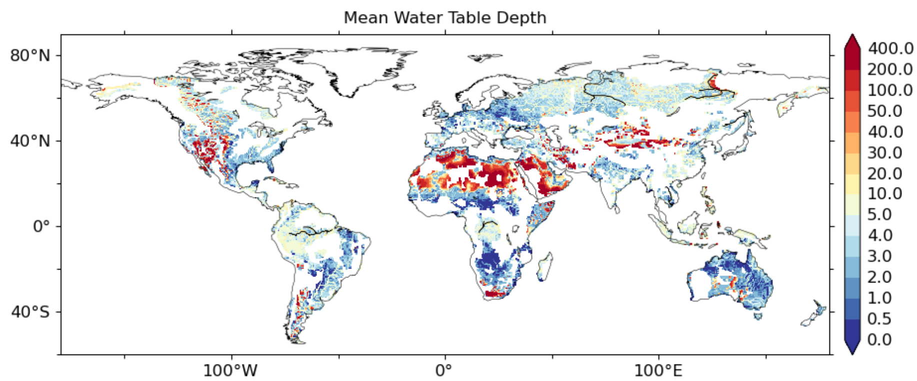

Fig. 4. Mean water table depth in meter.

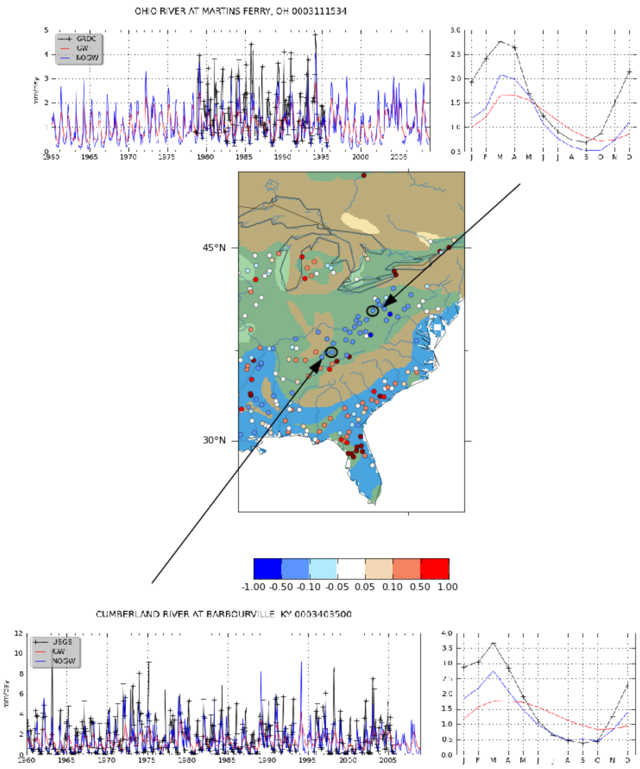

Fig. 5. Two examples of deteriorated stations over North America. Temporal series and annual cycle are shown.

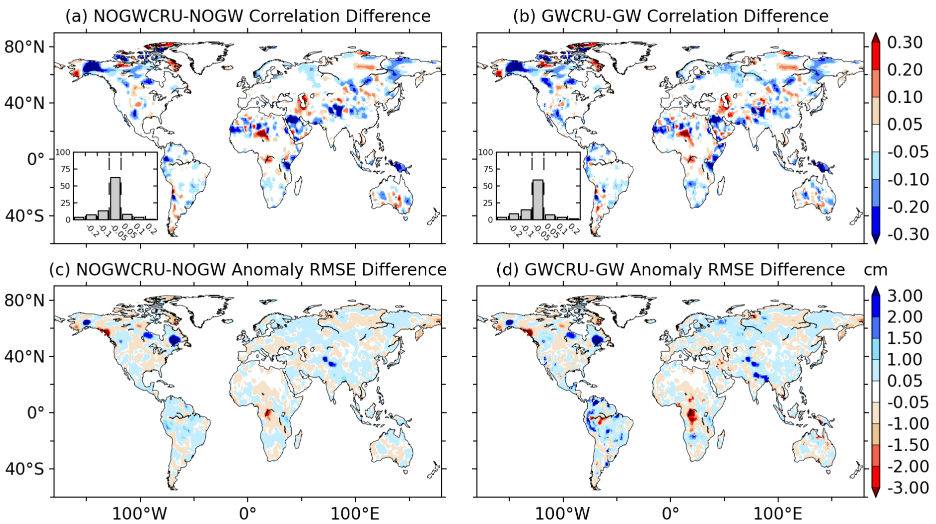

Fig. 6. Score differences between the CRU and GPCC simulated TWS. Correlation differences are shown (a) without and (b) with groundwater, together with monthly anomaly RMSE differences (c) without and (d) wit