Evaluation of Global Continental Hydrology as Simulated by the Land-surface Processes and eXchanges Dynamic Global Vegetation Model

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Response to reviewers' comments:

We would like to thank Dieter Gerten and Reviewer #2 for their constructive comments, which have helped us to improve this manuscript. We have carried out a major revision of the text in light of these comments, which are addressed here in turn.

Dieter Gerten's Comments

Main concerns:

1) "Not all of the results are convincing in terms of the quality of the model simulations."

    We realised after reading this that some aspects of the results were perhaps not presented in the most convincing way in the submitted version. Our revision attempts to be more explicit, in indicating what LPX does well, and where it does less well. It should be clear from our revised text that overall, LPX performs at least to the standard achieved by current state-of-the-art global hydrological models (even though the models was originally developed primarily as a tool for modelling vegetation and carbon cycle processes). LPX captures the long-term trend direction and interannual variability of most major catchments, albeit with some bias. Errors in the precipitation input data may be the cause of biases (this is a well established issue in the literature); we discuss this now in sections 3.1.5, 3.1.6 and 4. The differences compared to earlier runs with LPJ could be in part due to the use of different precipitation forcings (CRU05 vs. CRU TS 3.0) but may also be related to differences in several process representations (section 2.1.3 and 3.1.6). Section 2 now gives more explanation of the data sources for hydrological quantities, and section 3.2.2 acknowledges the benefit to modelling of seasonal runoff peaks that explicit river routing could bring.

2) “It is stated several times that some processes need to be improved in follow-up versions of the model yet they mostly have been addressed in a related model version (LPJmL), which should be reflected here.”

It is true that *some* of the issues mentioned in the submitted version, regarding the representation of hydrological processes in LPX, have already been addressed in LPJmL. We have accordingly modified the text to include more specific information about other DGVMs that have been applied to assessments of water resources, including (but not limited to) LPJmL (sections 1, 2.1.1, 3.2.3, and 4).

3) “The analysis of the influence of water withdrawals is doubtful, because water consumption and withdrawals appear to be mixed up.”

This is an important distinction and we agree that our earlier analysis may have overestimated the impact of water withdrawals for the reason given. In the revised manuscript, estimates of total water extractions have been replaced with estimates of water consumption (using WaterGAP: Alcamo *et al*., 2003) throughout. This change reduces the extent to which LPX runoff overestimations can be accounted for by water demands. Nonetheless, water consumption is shown to be important in accounting for excess simulated runoff in some populous regions (e.g. India, China, parts of Europe and the USA). Figure 3 has been retained in order to make this clear.

Regarding the soil moisture analysis in section 3.2.3, the values used are based on the mean of four measurement points per sample, from numerous stations within the catchment boundaries (Amur: average formed from 11 stations; Lena: 17 stations; Ob: 13 stations – section 2.2.2). So although these measurements have been made at different points to the river discharge gauge, a representation of catchment timings and relative magnitudes of monthly high and low soil moisture is still possible.

A sensitivity analysis of snowmelt, permafrost and soil thaw routines is beyond the scope of this MS but would be worthwhile in future work. For now, we simply indicate that improvements to seasonal peaks have been achieved using a modified routine in LPJ (section 3.2.3).

4) “The presentation of the results is rather descriptive and the paper would benefit a lot if some key results were discussed in relation to published literature on recent variations and trends in global runoff (and soil moisture/evaporation).”

The main point raised here concerned the presentation of a decreasing trend in global mean runoff, despite some other studies reporting an increase during the 20th century. However, the trend direction is broadly consistent with other research for the period under study (1951-2000), and appears to be a result of a decrease in precipitation (section 3.1.1). The trend has now also been tested for statistical significance (section 3.1.1) and discussed in the context of the existing literature on recent variations in the global hydrological cycle.

Regarding the PDSI analysis, global mean soil moisture has now been incorporated (section 3.2.1) and Figure 7 redrawn for clarity.

Minor comments:

We have dealt with all minor comments by implementing suggested changes, or including clarifications or corrections.

Reviewer #2's Comments

Main concerns:

1) "In order for the model to be used as a hydrologic analysis tool, it needs calibration to estimate reasonable streamflow volume (and also streamflow timing to some extent) for at least few selected river basins."

   We believe this comment is wide of the mark, because such calibration would invalidate the main purpose of using a DGVM! In contrast to the classical approach in hydrological modelling, we intentionally do *not* calibrate streamflow to fit observed streamflow for any specific basin. If we did so, we would forfeit our claim to have a generic model applicable to all regions and environments, and under changing environments. The classical approach in hydrological modelling can produce a much better fit to observations under current conditions, but does so by calibration of parameters that could, in reality, vary under changes in climate and other relevent environmental conditions, including atmospheric CO_2 concentration. Which approach should be adopted depends on the time scale of interest. We would argue that at least for the century time scale typically adopted for climate change impact analysis, there is a strong case for using a DGVM, without calibration—even if we recognize that there is a distinct need for improvement in the hydrological process representations in DGVMs, as their application to water resources is a relatively new field.

2) "It is recommended to illustrate the differences in model parameterization or set up that were different from the study by Gerten et al. (2004). Further, the authors indicate that few basins improved in streamflow estimation while few became worse. Then what is the additional contribution of this paper in improving streamflow simulations?"

   The differences in process representation and model setup relative to LPJ are presented in sections 2.1.3 and 3.1.6. Although a new and more realistic process-oriented fire regime is implemented in the model (Prentice *et al.*, in revision), and fire effects on vegetation certainly would be expected to impact on the partitioning of precipitation between evapotranspiration and runoff, there is no certainty that the demonstrated improvements in fire modelling would lead to improvements in simulated hydrology. The results presented here show that the differences in process representations lead to improvements in hydrology for some catchments, but not so for others, thus highlighting complexities in the controls of runoff.

We do *not* claim, therefore, that LPX (as presently configured) represents a major step forward in terms of runoff simulation; although we do establish that its performance in this respect is at least as good as that of earlier models. The purpose of the MS is rather to *critically evaluate* the hydrological realism of a model that represents the state of the art in DGVM development.

3) "Include a brief description how snow accumulation and ablation are represented in the LPX model (e.g. see Fassnacht and Soulis, 2002, ATMOSPHERE-OCEAN, 40 (4), 389-403)."

A description has now been included in section 2.1.1.

4) Regarding Dai *et al*. (2009) global river discharge observations: "Where were the gaps in time-series of observations? How were the data filled? Trends are sensitive to the infilling method when gaps are large."

Data infilling is described in section 2.3 (second-last paragraph) including reference to Dai *et al*. (2009), who provide full details of the procedure. Gaps in the time-series and the values obtained through infilling are shown in Figure 5 of Dai *et al*. (2009) for 24 large catchments.

Minor comments:

We have dealt with all minor comments by implementing suggested changes, or including clarifications or corrections.

Selected points of note:

3) "Was the trend statistically significant?"

An error has been corrected and a *t* test has been applied.

4) "The model tends to perform well in replicating trends and is often within, or close to the periphery of the runoff envelope shown by the composite and monthly summed converted river discharge data (Fig. 4). This is not apparent from Figure 4."

This issue has now been clarified in section 3.1.5. It is emphasised that while the model generally captures the interannual variability of runoff, it is subject to bias in some catchments. The bias is quantified at the global scale in section 3.1.3.

6) "Why LPX has a propensity to late prediction of peak intra-annual flow when the flow is available at the basin outlet within a given day?"

Difference of 0.068 months is converted to ~2 days. Reasons for slightly late runoff are likely to vary among catchments. In northern catchments, the simplistic snowmelt routine is likely to be an important issue, whereas elsewhere, the lack of explicit flow routing may be the critical point.

10) “Axes are not clear in Figure 5. Why summed monthly streamflow are higher than monthly summed precipitation (e.g. Amazon, Congo, Ob, and Lena) in Figure 5?”

> Figure 5 has been redrawn and now includes clearer axes. It should be clearer now, in the new version of this Figure, that runoff is *not* simulated to exceed precipitation in the basins mentioned. Simply for clarity of presentation, however, we have used different y-axis scales for precipitation and runoff.

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