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Interactive comment

Interactive comment on "A Tri-Approach for Diagnosing Gridded Precipitation Datasets for Watershed Glacio-Hydrological Simulation in Mountain Regions" *by* Muhammad Shafeeque and Luo Yi

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Dear Anonymous Referee RC1,

Thank you for the assessments and valuable comments. The comments and queries are really helpful to sharpen the revised version of our manuscript. We will try to incorporate the suggestions in the revised manuscript after receiving comments from other referees as well as the editor. The detailed point by point response is given below.

Interactive Response to the Comments of Anonymous Referee #1 General

Comment 1:

The paper presents a model study on the Indus basin, in which different precipitation reanalysis products and observations are used to classify the hydrological behavior of the basin. The precipitation products used are either reanalysis or interpolated gridded observation data. The authors propose a tri-faceted approach consisting of statistical analysis, physical diagnosis, and practical simulation.

Response:

Thank you for the assessments and quick insight of the study framework.

Comment 2:

The study constitutes a contribution toward the modeling of effects of precipitation products on the simulated water balance of the Upper Indus basin, a major source of water for the Indus irrigation system. Inferences are made on the ice mass balance, a topic of high relevance for climate impact analysis in this strongly glacierized system. Depending on products used the UIB turns out to be either a gaining or a losing glacial mass system. However, the approach does not provide any clues on how to assess, which one of the reproduced behavior is closer to reality. As such it provides mainly suggestions on how to correct individual GPDs to match observed outflows, while making unverifiable inferences on ice mass accumulation/depletion.

Response:

Thank you for your comments and query. Glaciers complicate the hydrological processes. Meanwhile, the glaciers are mostly located in the high elevation zone of the basins. What is most challenging for the basin-wide hydrological simulation is that ground truth data of precipitation is commonly unavailable in the high elevation zone. Instead, GPDs derived from different sources by the different techniques are widely used in the simulation. As indicated in other comments, the GPDs may be error-effected, and thus affect the reliability of the simulation. This work is focused on an

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integrated framework for evaluating the GPDs and finding out the direction of the local corrections to the GPDs. The UIB has a relatively high ratio of glacier coverage and has been taken as a benchmark for the application of the proposed evaluation framework, demonstrating how the framework is applied to a set of GPDs and some findings. In reality, the glacio-hydrological behavior of the UIB is clearly 'gaining', which is evident based on the negative mass balance and meltwater contributions to streamflow (Bolch et al., 2019; Gardelle et al., 2013; Immerzeel et al., 2015; Muhammad et al., 2019). Here, the proposed approach efficiently captures the behaviors under different products, i.e., 'gaining' for APHRO, TRMM, and PGMFD, whereas, 'leaky' for HAR and CFSR (Figure 11). All the produced behaviors are compared with the reality "actual conditions" in the basin. The extent of 'gaining' behavior based on APHRO, TRMM, and PGMFD is quantitatively different from the reality, as presented in Figure 12. Therefore, the actual situation is not represented by any of these products. Based on the water-energy and mass balance calculations, it turns out that the products responsible for 'gaining' state (APHRO, TRMM, and PGMFD) are underestimated, and the products responsible for 'leaky' state (HAR and CFSR) are overestimated compared to the real or true water balance in UIB (can also be seen in Figure 10-12). Therefore, we recommended a local correction of GPDs before their applications in glacio-hydrological models. The corrections for the under- and over-estimated GPD may be an addition or subtraction of a quantity of water to make them represent the real situation of water balance in the basin. The actual over-and under-estimation can be different at different spatiotemporal scales in different basins (or sub-basins). We provide the quantitative estimations of actual under- and over-estimation in terms of change of glacier storage (Figure 12). As we assumed, groundwater and surface water storage negligible because baseflow/ return flow from shallow groundwater compensates this term in the water balance (Alley et al., 2002; Andermann et al., 2012; Savoskul and Smakhtin, 2013), so all the underestimation is considered as glacier mass loss, whereas all the overestimation as glacier mass gain. The correction of GPDs is suggested to get the rational outputs of both glacier changes (e.g., mass

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balance) and hydrology (e.g., streamflow) outputs, concurrently. The simulation results were obtained after an absolute (multi-objective function) calibration and compared scientifically [line: 299-314]. We clearly presented the calibration (Figure 13, Figure 14, Figure 15) and quantitative comparison results (Figure 16, Figure 17), which support our inferences on glacier mass balance. Introduction

Comment 3:

The introduction and other parts of the paper do not mention previous published work by Reggiani et al. (2017) and Reggiani and Rientjes (2015) which is concerned with the basin and compares precipitation reanalysis products for the area of interest. The study also contains a basic water balance analysis for the Indus used to infer on the ice mass balance by specifying the individual terms of the mass balance equation. Reggiani et al 2016 provide an uncertainty analysis for the Shigar subbasin based on a Bayesian analysis of multiple precipitation products.

Response:

Thank you for the recommendations. The suggested studies may be useful to support our research work, so we will try to include them in our introduction and discussion sections, while focusing on the scope of our hypothesis and objectives. However, according to our understanding, Reggiani and Rientjes (2015) and Reggiani et al. (2017) did not specify the individual terms of mass balance. They applied a simple water balance equation and made inferences on glacier mass balance based on the variations in river flows.

General comments

Comment 4:

Overall, it is not clearly explained, what the authors want to demonstrate. Different precipitation products can show very different precipitation depths, while temperatures are generally more consistent among products. For example, Reggiani and Rientjes

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(2015) have already shown inconsistencies between reanalysis data and the TRMM as well as CRU data, whereby the latter two heavily underestimate precipitation, leading to different water balance results and conclusions of the ice mass balance when applied to the UIB.

Response:

Thank you. Yes, different GPDs have different precipitation depths, which will lead to different hydrological behaviors, especially when applied in the simulation of a glacierized basin. On one hand, the glaciers complicate the hydrological processes; on the other hand, the information on glacier changes also provides a clue for the GPD evaluation. Based on these considerations, this work proposed a framework for GPD evaluation in a glacierized basin, which is to find out how a GPD represent the reality of a glacierized basin, which GPD performs better than others when GPDs are compared to each other, and the directions to locally correct the GPD. We need to sharpen the objective definition in the introduction section [line: 104-105, 109-112] in revision. As an application of the proposed tri-approach in UIB, we estimated this actual under- or over-estimation for all included datasets (Figure 12), and highlighted that some GPDs need more water to represent the plausible water and mass balance in the basin, whereas, some are just overestimated (Figure 16). The use of over- or underestimated datasets in glacio-hydrological modeling would lead to implausible results and conclusions. Besides, an important intention is to keep the approach and its application (the evaluation/correction analysis of GPDs) as simple as possible because it should be taken as a supplemental primary step rather than the main experiment/modeling in a research study. Yes, you are right; the temperature is more consistent among the different datasets and has no significant difference with the observed data. Therefore, we did not include the temperature analysis in our study. The physical diagnosis characterizes the glacio-hydrological behavior of a basin under different GPDs (Figure 11). It also provides the actual under- or over-estimation of precipitation in different GPDs in terms of glacier storage (Figure 12). The practical simulation also presents the clear

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differences among the simulated hydrology forced by different GPDs. The rationality of the glacier and hydrological outputs (concurrently) are investigated (Figure 16 and Figure 17). The results highlighted the need for local correction of GPD before their application in the glacio-hydrological models.

Comment 5:

The use of a tri-approach as proposed here does not give more insights than just using one of the three.

Response:

The Tri-Approach consists of three components, statistical, theoretical, and practical. These three components are step-wise forward. The implementation gets more complicated from statistical to theoretical and practical components. However, more and more insights can be revealed as they get more and more complicated. The researcher can apply this approach just as an initial step instead of a comprehensive analysis before actual glacio-hydrological modeling. This would save their time and efforts to select the datasets and adopt the right local correction in a simple and reproducible way. The approach efficiently can sort out the GPDs to represent the glacio-hydrological behavior of a basin and label them for which state they represent (i.e., ‘gaining’, ‘leaky’, or ‘feasible’). Moreover, the approach also identifies the actual under- or over-estimation in the selected/included GPDs based on water-energy and mass balance of a basin (Figure 11 and Figure 12). Besides, the practical simulation provides a wider insight into the hydrological behavior of a glacierized basin. As an example, this work used the SPHY model for the practical analysis. The SPHY model projects were tuned to represent the actual glacier mass balance state in the UIB (Figure 13−15). This was done (a) to avoid the equifinality (glacier compensation effect), (b) to ensure the reasonable comparisons among the simulated hydrology (Figure 16−17). Keeping the mass balance closer to the reality during simulation, is the best option to explore the rational outputs of glaciers and hydrology, concurrently, for different precipitation forc-

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ings. The observed discharge data is more reliable than the available mass balance for comparison purposes. For such conditions, it is reasonable to use mass balance data for tuning the glacio-hydrological model and the hydrology data for comparisons. The case study in UIB demonstrated how the Tri-approach can help to select a proper GPD and how to correct it locally to represent the "reality". Meanwhile, we are still open to accepting any suggestions to improve the presentation of analysis, which may be helpful to present the work from a different perspective.

Comment 6:

Spatial precipitation products are information, that is inherently error-affected. To draw different conclusions on the water balance using individual products is an interesting exercise, but the ultimate scope unclear. What is the goal of finding out that using one product the catchment turns out to be "leaky" (i.e. it stores water through glacier mass increase) and with the other product the catchment becomes "gaining" (i.e. releases water by glacial melt) and then concluding that corrections to GPDs need to be made accordingly? This does not give any insights into what is actually happening within the basin.

Response:

Thank you. Precipitation is the input of the glacio-hydrological system in a basin. Correct precipitation information is the prerequisite of proper simulation of the basin process. Due to the unavailability of the ground truth data of precipitation in the high elevation zone, the derived GPDs are generally error-affected, as you commented. Diagnosis of the GPDs is, thus, the first thing to do when they are used. The Tri-approach proposed in this work is focused on the diagnosis. Applied to the UIB, the Tri-approach selected the "best" GPDs among five datasets and found out the directions for local corrections. As demonstrated, the proposed Tri-approach provides the simplest way for a quick glimpse of the glacio-hydrological behavior represented by a GPD.

Comment 7:

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In my view, the real advantage of having multiple products is their mutual combination and exploitation of informative content as a "package". This point has not been addressed at all by the authors.

Response:

Agree, and thanks for the suggestion. The mutual combination of different GPDs is an effective way to use multiple datasets as an ensembled package for further applications. However, this is not included in the goals of our study. We may consider this suggestion in our future work to develop a direct way of combining different datasets based on their performances to represent the hydrological behavior of glacierized basins. However, this study will mainly describe the shortlisting of the best GPD and prescribe directions for its local correction (if required) based on the actual glacio-hydrological conditions in a basin.

Comment 8:

The products or the hydrological signals derived using these products must be conditioned on available ground information (flows, precipitation, snow area extent etc.), and on this basis a selection made about which products is superior, by attributing it more importance vs other, less informative ones. If done properly, the conditioning should remove bias and reduce the uncertainty given the ensemble of products.

Response:

Agree. In fact, the rationality of glacio-hydrological outputs is conditioned based on the observed flows, precipitation, ET, snow cover, and glacier mass balance in the current study. The adjusted observed precipitation (Figure 3), MODIS snow cover, and observed mass balance are used to parameterize the base model. The model is calibrated for observed mass balance (Figure 13), snow cover (Figure 14), and streamflow (Figure 15). Multi-parameter calibration is adopted to avoid the risk of equifinality (caused by glacier compensation effect). Finally, the SPHY model projects (Figure

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16) (one for one precipitation dataset) were tuned for actual mass balance, and then the simulated hydrology outputs were compared. The streamflow data is more reliable and readily available as compared to mass balance data. Therefore model was parameterized with observed mass balance data (Figure 16d), and the results were compared with observed streamflow data (Figure 16c). The calculated ET data may contain some extent of uncertainty; however, we also compared and calculated ET with the authentic derived products (Figure 2). This highlights that the methods adopted in the Tri-approach are properly conditioned based on the observed flows, precipitation, snow cover, and glacier mass balance, which remove bias, reduce the uncertainty, and support the reliability of inferences drawn in the current study.

Comment 9:

I personally see the present study as a collection of GPD applications, that lead to a qualitative classification of GPD products, but do give improved insights into glacio-hydrological behavior or clues on an improved structure of spatial hydrological model forcing.

Response:

Thanks. This work is to propose a framework for quantitative assessments of GPDs, which takes the the observed local information of climatology, hydrology, and glaciology into account. A framework for diagnosing the GPDs based on the ground truth data and theoretical principles is considered a demand of the hydrology community. And this is the reason that we presented our work here. This work thus proposed a Tri-approach framework, which diagnoses the potential problems in the GPDs from multiple perspectives and provides clues about the different data structure of GPDs and their local correction, which eventually helps to improve the glacio-hydrological modeling study and to infer plausible conclusions. It should be pointed out that the Tri-approach stood upon the shoulders of previous researchers, cited (among others) as in the reference list of the main manuscript.

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We will revise the manuscript following the valuable comments, hoping that the integrated framework for the GPD diagnosis can be shared and improved through the interested readers.

Sincerely,

Yi Luo and Muhammad Shafeeque

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