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Earth Surface Dynamics
Discussions
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Interactive comment on "The hydrological cycle in the high Pamir Mountains: how temperature and seasonal precipitation distribution influence stream flow in the Gunt catchment, Tajikistan" *by* E. Pohl et al.

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We thank both reviewers for their comments and provide a cumulative response. We first answer C618 and then C659 but refer back to previous comments if they were addressing the same issue. In some cases, we take the liberty to split up comments to answer individual parts of a comment separately.

We repeat the comments in italics and reply in regular font.

Adapted / additional figures are provided as attached figures. Changes in the manuscript are highlighted in a separate PDF-version.

The most substantial issues 1) precipitation correction, 2) relevance for surface processes, 3) a more general description of the hydrological cycle, and 4) the needed streamlining to remove redundancy resulted in a substantial reorganisation of the manuscript. This also resulted in a reorganisation of paragraphs with minor changes in the actual text. As a result, the manuscript version that highlights the differences shows changes where in fact paragraphs were only moved to a different position.

Reply to C618:

(C618-1)Authors used remotely sensed precipitation product TRMM3B42 V7,interpolated precipitation data, APHRODITE and climate model data, HAR10 in combination with MOD11C1 V5 LST to evaluate the various components of the hydrological cycle of the Gunt catchment in the south of the Gorno-Badakhshan Autonomous Oblast in south-eastern Tajikistan. They have achieved this by implementing J2000g hydrological model. The results presented shows 80% of the annual precipitation is in the form of winter snow. An interesting result is the significant groundwater contribution up to 40% in the catchment. Authors suggests a shallow and a deep aquifer system contributing to the bulk flow at Khorog. They also suggests 30% glacier melt component in the runoff.

Study is interesting, and highly relevant, especially to the HKH region. However, the results presented are mainly focused on the limitations of various precipitation products in a complex mountain terrain, importance of groundwater contribution in the hydrology of high Pamir mountain and significantly high glacier contribution. Authors failed to sketch a clear picture of the hydrological cycle of the high Pamir Mountains as suggested in the title. A section on final synthesis of precipitation/temperature and its elevation dependency across 14000 km2 study area is missing. What is the mean annual precipitation arrived through the modelling exercise?

(C618-1) We agree with the reviewer and provide an overall more detailed discussion

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on single components of the hydrological cycle. The mean annual precipitation amounts provided by the different precipitation datasets are stated in the dataset names, e.g. HAR10 (172mm) provides 172 mm of average annual precipitation in the Gunt catchment area. This principle is introduced in Sec.4.2.1. Based on the best obtained modelling results wit HAR10 (258mm), we assume that the region on average receives an amount close to 258 mm /year. Difficulties deriving from the assessment of dataset quality are discussed with much more detail now.

(C618-2) A section on general climate and hydrology of the basin, based on the 5 met. station and one discharge station data is also missing.

(C618-2) We missed to point out that the provided in-situ measurements (Fig.A1) include information about the elevation of the meteorological stations. Such information can be taken from Fig.A1. A general description of climate is provided in form of the Köppen-Geiger classification scheme, that corresponds to the observations presented in Fig.A1. Catchment-wide annual precipitation amounts cannot be provided with sufficient accuracy due to the heterogenous distribution of precipitation. We agree with the referee that a description of the general hydrology based on the available discharge data is missing. We now provide an analysis of available discharge data in Sec.2.

(C618-3) Methodology section talks about calculation of potential evaporation and actual evapotranspiration. However, there is no discussion on these parameters presented in the paper. It may be appropriate to discuss all these results to justify the title of the paper.

(C618-3) We agree with the reviewer and now address the impact of actET on the hydrological cycle. In particular, we provide an additional figure to present average monthly values for individual hydrological components. Effects of actET on the water

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budget are discussed with regards to higher summer precipitation portions of TRMM and APHRODITE in comparison to HAR10. The higher proportion of summer to winter precipitation results in characteristic higher actET values in summer (Fig.5). The importance of this finding lies in its effect on glacier mass balance (GMB). This is because a higher annual precipitation amount not necessarily contributes to a positive GMB or higher discharge if the amount is provided in summer. Instead, higher actET values in summer are the result. This finding was condensed in Sec.7.1. (P.1182, L28 to P.1183 L5), but is now described in more detail.

(C618-4) Authors mentioned 30% glacier contribution in the catchment just as a remark without any discussion and also highlighted this aspect in the abstract. This is an important finding and need to discuss in detail. What does this glacier contribution means? Whether it corresponds to annual glacier mass exchange or net mass balance? Whether it covers whole 7.5% permanent snow cover or just glaciers?. In the end reader is left with many such questions. Please see the specific comments below. The issues discussed are important and this paper merit publication.

(C618-4) We agree with the referee that this point was not presented with the needed detail. We included a paragraph in Sec.3.2. to define Q_{glac} and glacier mass balance. We further renamed Sec.4.1.3 "Land use" to "Land use and glacier extent" to explain what glacier HRUs are and what their derivation is based on. We pick up on this issue in the results and discussion as well. Also Fig.5 received a clearer figure caption.

(C618-5) Specific comments Section 2 Study area should be strengthened by giving information on 1. percentage glacier cover, number of glaciers, mean size of the glaciers and also volume of glaciers, if available, especially when authors present a 30% glacier contribution in the catchment.

(C618-5) We agree with the referee that including specific information on glaciers

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would be beneficial in Sec.2. However, we do not have detailed information about the glaciers in this region. The Randolph Glacier Inventory (RGI) lacks a comprehensive coverage of this particular region in the Pamirs (see attached figures C1 and C2) to provide sound information on glacier extent, number, and volume. To provide at least an overview, we casually sampled glacier sizes from the RGI in the study area where the RGI seems consistent and provide glacier size ranges, spatial distribution and the land cover class areas of the MODIS MCD12Q1 dataset in Sec.2 that were presented in Sec.4.1.3.

(C618-6) Please give altitude of the meteorological stations in the catchment.

(C618-6) The altitudes of the meteorological stations are given in Fig.A1, which is now stated in Sec.2.

(C618-7) Section -4.1.3 p1167- Snow cover duration in the catchment is also very critical for ground water generation. It is stated that 7.5% is the permanent snow cover in the catchment. However no information on seasonal snow cover is provided. With significant (40%) groundwater contribution in the basin, altitude wise average snow cover depletion curves will provide greater insight to these processes.

(C618-7) The unreferenced snow cover dynamics have been criticised in a previous comment on this manuscript (see C594) and we fully agree that this should be implemented. We now provide mean monthly snow cover for the Gunt catchment based on 12 years of MODIS observation (MOD10CM) and complement this in Sec.2. We do not want to go into more detail such as detailed elevation-binned dynamics because additional factors, such as precipitation gradients, and different geomorphology with e.g. elevated plateaus in the eastern part, would need a much more thorough analysis. We hope to meet the request by providing a general snow cover dynamics scheme for the Gunt catchment as a whole.

(C618-8) 4.2.1/4.2.2 The paper is discussing hydrological cycle in the high Pamir Mountains and not enough insight on orographic influence of precipitation/temperature distribution is not provided. Mean monthly precipitation and temperature data from five meteorological stations in the catchment may be presented and elaborated. Figure 3 and 4 is well appreciated. But presentation of measured monthly mean temperature and precipitation at different altitude in comparison with the best of the model result will help in better understanding of the climate of the region and its temporal and spatial controls on hydrological cycle.

(C618-8) We understand that a more detailed analysis of the spatiotemporal dynamics of precipitation and temperature in the Gunt catchment and surroundings are appreciated. However, the few and spatially-limited to valley locations ground measurements led us not to go into more detail here. Instead we provide climate diagrams for the available meteorological stations (Fig.A1) showing average annual temperature and precipitation distributions, which we use to describe a precipitation gradient with higher intensities at the western margin and lower values towards the East and a negative temperature gradient in the same direction.

We point this out more clearly now.

We also missed to include that the references on P.1161,L.18-21 address this precipitation gradient as well.

This is now included.

Regarding a more detailed description of what is presented in Fig.3 and Fig.4 and a comparison with modelled data: We intentionally did not provide a detailed spatial analysis of all individual hydrological components. The scope of this work lies in the description of the principal processes in general and to derive their influences on surface processes. We understand that this would be appreciated but we believe that

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this would be beyond the scope of the work. Instead, we provide the synthesised description of the hydrological cycle, the relationship of precipitation and discharge, as well as consequences of delayed snowmelt, high groundwater contribution, and effects of glacier runoff on surface processes. A detailed analysis with a detailed spatial focus is in preparation but not intended for this work.

(C618-9) A discussion on measured discharge at Khorog, its monthly distribution, high and low discharges, inter-annual variations etc.is missing. This will improve the understanding of the hydrological setting of the catchment and will help the reader to appreciate the model results better. Section 5 p1175 L 5-7 Please mark the hydropower station and Lake regulation site on Fig.1

(C618-9) We agree with the referee that a discussion of measured discharge at Khorog in terms of flow characteristics would help to provide a more thorough picture of the hydrological setting. We reorganised Sec.2 to include what has been at Sec.5(P.1175,L.1-12) and include additional information about the general flow characteristics. All these information are now provided in Sec.2.

The lake outline is now included in Fig.1. The power plant uptake near site Navabad is too close to be differentiable on the map. This is the reason why we do not include it in the map.

(C618-10) P1175 L9-10 It is stated that the "records from the 1960s show similar winter discharge as in 2000s". What is the percentage contribution of this winter discharge from the lake in the bulk winter flow at the outlet. Is this winter out flow from lake is treated as ground- water component?

(C618-10) We are sorry for the inaccurate sentence. The mentioned records are for station Khorog. We corrected this sentence and included an analysis of the possible impact of lake discharge on total stream flow.

(C618-11) Section 6 L 25-26 It is stated that "characteristic transition from snow to glacier melt in summer". What does this mean? Please elaborate on this aspect.

(C618-11) The characteristic transition from snow into glacier melt refers to the observed discharge components in Fig.7 (top panel) where at the beginning of the melting season melt water originates from snowmelt. Later in the melting season melt water originates from snow and glacier melt, and at the end of the melting season all water originates from glacier melt. We picked up on this aspect again in more detail in Sec.6.1 (P.1176,L.14-20). We did not want to expand it in the introductory part of the results to make it easier for the reader to get an overview. We also provide a new figure with monthly average hydrological components that we use to describe this transition. We removed the word characteristic at this point and introduce it in the described context later on.

(C618-12) Glacier discharge at the snout always have a significant contribution of snowmelt over the glacier. Are you distinguishing between glacier ice melt and snowmelt over the glacier?

(C618-12) We differentiate between snowmelt and ice melt of glacier HRUs. The presented results were displaying the combined discharge of the two components from glaciers Q_{glac}. We now provide an additional figure to display average monthly values of the hydrological components including the snow and ice melt component of glacier HRUs. Furthermore, the clarification mentioned before, i.e. the definition of Q_{glac}, and the definition of glacier HRUs should now help the reader to get a better picture.

(C618-13) It is mentioned earlier that the catchment have 7.5% permanent snow cover. Are you considering the melt from permanent snow cover as glacier melt? Is major glacier discharge comes from few big glaciers? Please see the comment on section 2

earlier.

(C618-13) We indeed consider the extent of the land cover class "permanent snow and ice" as glacier extent and hence the melt water originating from such classified areas as Q_{glac} (see answer to previous comment). We consider the area of 7.5% of our catchment area as glacierized. In our reply to C594 we already discuss the possible overestimation of the glacierized fraction in case the snow line did not reach the actual glacier. However, it is assumed that around 20% of Hindu Kush and Karakoram glaciers are actually debris covered (Scherler et al. 2011), and hence there might even be the possibility that the stated 7.5% are underestimating the actual glacier extent.

We cannot provide information whether the bulk of glacier melt originates from a few big glaciers (semi-distributed model). Glaciers are relatively small in comparison to Karakoram and North Pamir, and well distributed over the western part of the basin. Runoff most likely originates from several small glaciers rather than a few big ones. An upcoming publication (Knoche et al. in prep.) will be dealing with glacier contribution to discharge in much more detail. We now state a range of most frequent glacier sizes based on a casual selection of the Randolph Glacier Inventory in Sec.2.

(C618-14) P 1176 L 1-2 Authors mention "Strong constraint on the parameterization of ground water aquifer". What is the winter temperature range of the higher altitude regions? Significant area of the catchment may be experiencing seasonal ground freeze. Can you give brief description of stream characteristics in the basin? Is all the glacial streams are perennial? Or interrupted streams? What about non-glacial streams. This will give a clear picture on area experiencing seasonal freezing. Overall hydrology of the basin need to be explained for better understanding of the hydrological cycle response over the area.

(C618-14) We agree with the reviewer that a better discussion is needed here. The main stream is perennial which is evident from discharge measurements at Khorog.

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Few discharge measurements from the 1960s downstream of lake Yashilkul (see (C618-10)) suggest that stream flow is perennial at least up to lake Yashilkul. During field work in early spring 2013 we observed that the inflow to lake Yashilkul was entirely frozen. We have some limited oral information about the winter state of glacial and non-glacial tributaries. These information suggest frequent interruption during the winter month. There is certainly ground freeze, which extent has to be evaluated in the future to get a better picture of the area.

We now provide information about perennial and interrupted river parts. We also included a reference to Mergili et al. (2012) about potential permafrost distribution.

(C618-15) Section 6.1 L 14-20 . Authors stated that at the end of the summer, there is no snow cover left and meltwater only originate from glacier melt... This gives an impression that the glacier melt sustains the runoff during the late summer period, which is not true. Interestingly, the groundwater component in the stream flow dominates the glacier component throughout the glacier ablation season. The sentence may be modified to convey this finding.

(C618-15) We agree with the referee and changed the sentence.

(C618-16) P1178 Section 6.2 Data set characteristics. It is stated that the average annual discharge volume 3.48 km3 /yr. What is the monthly/seasonal runoff distribution?

(C618-16) We agree that this aspect did not receive enough attention. We now provide a more detailed pre-analysis of in situ discharge data and additional analysis of the model results based on the additional figure on average monthly hydrological components.

(C618-17) 30% glacier discharge means around 1.04 km3/yr glacier contribution. Is

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this 30% of the summer months or annual total. What is the estimated glacier storage volume in the catchment?

(C618-17) The mentioned 30% glacier discharge is the percentage of total annual discharge. We included this information in the figure capture of Fig.5 and in the abstract to make this more clear. The 30% glacier discharge are furthermore mentioned in the conclusions, where it is stated on P.1189,L.9. We do not calculate glacier storage volumes. The simple glacier module in our model has no defined volume and theoretically could melt or accumulate infinite water amounts. While this is of course not representing the actual conditions it allowed us to compare overestimating and especially underestimating precipitation datasets due to the compensation of the water balance by means of increased glacier runoff.

We added this information in the model description.

(C618-17) Again there is a section 7.2 discussing the data set characteristics (P 1184). Please combine these sections and could be present it under section 4.

(C618-17) We agree with the referee that there is too much redundancy regarding the presentation and discussion of the used datasets and that a reorganisation would be beneficial. We would however like to keep Sec.7.2 (now 7.1) because the discussion of datasets, and derived recommendations have such high relevance for a variety of scientific fields and should hence have a separate subsection. We split the results presented in Sec.6.2 and redistributed or removed the content. In particular we moved the first part (P.1178,L.2-9) to Sec.4.2.1. The subsequent parts are redundant and were removed.

(C618-18)P1179 L 22-23 Degree Day factor of glacier ice TMFgi is shown as 1mm/oC/d. Is any supporting data from mass balance studies in the area available for such a low value?

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(C618-18) 1mm/oC/d is certainly a low value and there is no supporting data available because reported values (e.g. Hock et al. 2003) are for particular points on glaciers. We do not think that our value is actually representative for a particular point on a glacier, instead, this value accounts for the treatment of the entire glacier area as a whole, which is due to the coarse resolution of our datasets (providing the same temperature for the entire glacier area). Based on this simplification, the apparently low value would consequently correspond to a much higher value if the actual temperature gradient along the glaciers would be considered. What the resulting value would be is highly speculative considering the spatial variability in glacier melting dynamics and its analysis (e.g. Barrand et al. 2010). Furthermore, the needed interpolation of our temperature data would be beyond the scope of this work. Albeit addressing the temperature data resolution with regard to the value of 1mm/C/d, we included the just mentioned points to make this more clear.

(C618-19) P 1181 L8-9 Effective precipitation is defined as all liquid stream water contribution from rainfall, snowmelt and glacier melt. Is it prudent to incorporated glacier ice melt to as effective precipitation?

(C618-19) We agree with the referee that our incorporation of glacier melt as effective precipitation provides a basis for criticism. The two possibilities in this case were to either include glacier melt, which then incorporates a storage component that has no immediate relation to precipitation, or to not include it, which vice versa would disregard the precipitation component that provides snowfall on glaciers and intermediately is represented by glacier runoff. In the end, we decided to include it, because it helps to show the similar behaviour of different forcing datasets with respect to the modelled hydrograph. As this similarity builds the basis to address issues of using regional datasets without validation data, we think it is prudent to include glacier melt here. Because the term "effective precipitation" alone does not presume glacier melt, we explicitly define it. We included the word "here" where we define effective precipitation to point out that this is our definition for this special case.

(C618-20) In section 7.1 hydrological cycle, one expect a detailed discussion on various components of the hydrological cycle of the catchment including basin average precipitation synthesised through the modelling effort, discussion on 30% glacier contribution as mentioned in the abstract and conclusion and actual evapotranspiration and runoff etc.

(C618-20) We agree and now discuss single components of the hydrological cycle on the basis of the provided additional figure in more depth.

(C618-21) P1185 section 7.3 Sensitivity analysis is discussed under section 6.3. Why section 7.3 cannot be discussed along with section 6.3.? Sections 7.1 could be strengthened by combining pertinent issues discussed under section 7.3.

(C618-21) We agree with the referee and relocated most of the content of 7.3 to either 6.3 or 7.1. 7.3 now deals with the general modelling concept and consequences and implications on surface processes based on obtained model results (see also reply to C659).

(C618-22) P1186 L25-30 1187, L 1-15 Discussion on hill slope processes and erosion discussed here can be avoided as it is not the focus of present paper.

(C618-22) We agree with the referee on the point that hill slope processes and erosion are not the main focus of the present paper because the description of the hydrological cycle and related difficulties with the presented approach clearly stand out. However, we think that these issues deserve a place in the discussion section. This is because detailed information on water pathways have not been part of risk and surface process assessment in the Pamirs yet. Furthermore, obtained information on spatiotemporal water mobilisation due to snow and glacier melt and their implications on surface processes are evident. We provide a reorganisation of Sec. 7 to make this point more clear. We also adapt the abstract and the introduction to make the discussion of this aspect justified.

(C618-23) P1187 L 13-14 Only discharge part of the hydrological cycle is being discussed no precipitation amount is discussed

(C618-23) We now provide a more careful discussion about precipitation.

(C618-24) P1188 L 17-30 P1189 L 1-5. This issues are not evaluated in the paper and it is only conjecture and should be avoided.

(C618-24) We agree with the referee that these issues in their current form are not suited for the conclusions. We redistributed pertinent issues to the discussion if suitable and provide the conclusion based on discussed results.

Reply to C659:

(C659-1) This manuscript describes the implementation of a hydrological model, J2000g in a large (14000 km2) watershed in the Pamirs, and examines the sensitivity of model output to precipitation and temperature input data, as well as model parameters. Simulated discharge hydrographs match reasonably well with observed hydrographs despite the large uncertainty in input data. Overall, the manuscript presents an interesting case study of an application of relatively simple hydrological model to large, data-sparse watershed. This will make a useful contribution to a journal specializing in hydrological modelling. However, I see two fundamental problems that need to be addressed before the paper is considered for publication in Earth Surface Dynamics. The

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first is the scope of the work. Although hydrological processes play an important role in earth surface processes, the relevance of this work to "the high quality research on the physical, chemical and biological processes shaping Earth's surface" (from ESurf Aims and Scope) is not clearly demonstrated in the manuscript. I think that the manuscript is a much better fit with Hydrology and Earth System Science than this journal. The second is a more technical, but important issue regarding the treatment of precipitation data. It appears that the authors adjusted precipitation data to fit the model output to observed discharge. I understand the difficulty of obtaining accurate precipitation data in the data-sparse watershed, but I have a hard time accepting the approach. There are a few other technical issues that are listed below. I would encourage the authors to revise the modelling approach, and change the scope of the work so that it will make direct contribution to improved understanding of the processes shaping Earth's surface. Alternatively, the authors could submit their work to a hydrology journal.

(C659-1) We agree with the reviewer that the scope needed to be adjusted to better fit the scope of ESurf and we now provide a thoroughly revised manuscript. We also revised the treatment of precipitation data.

(C659-2) Title. The title does not accurately reflect the content of this paper, which is hydrological modelling and model sensitivity analysis. I suggest the title be revised.

(C659-2) We re-organised the paper to provide stronger references to earth surface processes and propose a new title to match the content as well.

"The hydrological cycle in the high Pamir Mountains: Sensitivity analysis and implications on surface processes from a hydrological modelling approach in the Gunt catchment, Tajikistan"

(C659-3) Page 1160, Line 23-25. Is this the objective of this paper? If so, I do not think that the manuscript succeeds in meeting the objective. If not, what are the specific

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objectives?

(C659-3) We significantly revised several parts of the manuscript to focus more on surface processes and define the scope better. The paragraph has been changed accordingly.

(C659-4) Page 1161, Line 6. What type of cover and relief are these?

(C659-4) The used formulation is indeed too imprecise and we changed this. In comment C594 we already explained why the Gunt catchment can be seen as representative for the Pamirs in terms of hydrology, land cover, and relief. This statement is based on the high heterogeneity of the Pamirs with strong gradients in precipitation and geomorphology.

We included this in Sec.2.

(C659-5) Page 1163, Line 10. What does "simply and robustly integrated" mean? Please be more explicit.

(C659-5) We agree with the referee that the formulation was imprecise. We changed this.

(C659-6) Page 1164, Line 16. Are you sure about the "wrongly assessed temperatures"? I would think that the difference in degree-day melt factor (TMF) between glacier and non-glacier surfaces is related to the differences in ground heat flux inputs from the bottom of the snow pack. I would encourage the authors to investigate this issue more carefully.

(C659-6) We agree with the referee and now consider more reasons leading to different TMF.

(C659-7) Page 1165, Line 5-9. Hydraulic properties of coarse sediments covering a large fraction of alpine region is not adequately considered in this modelling approach, which uses "soils" to represent infiltration and retention processes. Or, it is not clearly explained.

(C659-7) We agree with the referee that this issue has not been presented with the needed clarity. A limitation of J2000g in the used form is its soil module, which expects well evolved soils that are characterised by a field capacity that prevents percolation below a certain threshold saturation. Indeed a large fraction of the studied region is coarse sediments that do not correspond to the just mentioned soil definition. This is the main reason we introduced a linear storage component as a surrogate. The resulting discharge component from this component is Q_{bas1}.

We now provide a more thorough explanation of the modules and their parameterisation.

(C659-8) Page 1165, Line 16. If I understand correctly, J2000g model does not route water laterally. Does that mean there are no river channels in the model? If so, how is runoff (surface or subsurface) routed to the outlet? Please explain it clearly.

(C659-8) J2000g does not have water routing through individual HRUs in a topological context like more complex models such as J2000, which however needs a more extensive parameterisation and according information. As a result, the modelled discharge for the catchment is the calculated sum of all HRUs' water components (surface and subsurface). Retardation effects that would result from routing through rivers and underground compartments are simulated by recession coefficients. The according information is now included in the text.

(C659-9) Page 1166, Line 14. What is the typical polygon size or resolution of this database?

(C659-9) In this data scarce region the HWSD polygons only discriminate valley floors and escarpments. The attached database, however, differentiates between several soil types that can be expected in the polygon and were associated to the digitised soil map from the Tajik Atlas, which differentiates small valleys and escarpments. A differentiation is possible at approx. 5 km resolution. We believe that this resolution is appropriate for the model concept, which distinguishes mainly two subsurface storages that behave differently. Field capacities are more important at the flat valley floors than at the escarpments, where steepest slopes dominate storage and runoff.

We included the approximated values in Tab.2.

(C659-10) Page 1167, Line 12. How was the "field observation" conducted? Was it a casual observation, or a systematic survey of vegetation density and diversity?

(C659-10) We agree with the referee that this statement was not clear. The observations were casual. We changed this sentence and included a reference (Hergarten 2004) for vegetation cover.

(C659-11) Page 1168, Line 9. The value (10E-06 mm/d) is unrealistically small for Quaternary sediments. Was this actually used in the model, or is it a typographical error?

(C659-11) The stated values on page 1168, line 9 are indeed wrong. Much higher values as upper limit for maximum percolation rates were used. This has been changed in the text.

(C659-12) Page 1169, Line 3. Correlation does increase, but there is a major bias between model- derived and field-measured precipitation data.

(C659-12) We agree with the referee and changed the text.

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(C659-13) Page 1169, Line 11. "Correction factors" were applied to precipitation data to match the model results with observed discharge. The correction factor of 1.5 indicates a 50% increase in precipitation. It is hard to justify such a major adjustment of precipitation input. A much more careful consideration should be given to manipulation of precipitation data.

(C659-13) We agree with the referee that the way we presented the precipitation adjustment was insufficient and seemed rather arbitrary. We approach this issue with much more care now.

We start by addressing quality issues of in situ data, where only site Navabad is equipped with an automatic precipitation sampler and is assumed to have the highest standards. The already mentioned possible orographic effect, i.e. orographic shielding from precipitation, that affects site Bulunkul might also be apparent at other sites due to the coarse (10km) dataset grid size and the location of meteorological stations in valleys. We address this issue and provide additional information in particular in Fig.3. The adjustment of Fig.3, which still shows the relationship of all data of all pixels encompassing meteorological stations, now includes the resulting ratios of the two individual stations Navabad and Bulunkul. As we used the mean of all stations to derive the "overestimation-ratio" of HAR10, this extended analysis shows how strongly this ratio is affected by individual sites. Bulunkul e.g. shows a 9.3-fold overestimation. Navabad on the other hand shows a 2.6-fold overestimation.

The different obtained ratios are now also addressed in Table 3 to show not only the correction factors for precipitation of HAR10 after downscaling (dividing by 4.05), but to show the overall factor if the original dataset had not been downscaled in a first step. In fact the applied factor of 1.5 after downscaling to obtain a ratio with in situ data of unity (resulting in HAR10 (258mm)) corresponds to 1/ 4 *1.5 = 0.375 (or 1/2.7). These actual factors that are applied to the original HAR10 dataset are now included

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in Table 3. In the end, the applied factor that leads to the best model results (1/ 4 *1.5) corresponds to a 2.7-fold overestimation of HAR10 that is close to the 2.6-fold overestimation resulting from the exclusive comparison of the site Navabad pixel and its in situ data.

We furthermore provide a detailed analysis in the discussion where we justify our approach because it allows to assess precipitation data quality. This is based on the comparison of modelled and observed discharge in the three distinct phases (snowmelt, glacier melt, groundwater discharge) within the annual cycle. Due to the importance of this issue it now marks the first subsection in the discussion.

(C659-14) Page 1171, Line 15. These data sets still have very large seasonal biases, even though they may average out over a long time. Please see my comment on Figure A2.

We agree and changed the text to capture this.

(C659-15) Page 1173, Line 25. Were there any attempts to validate wind speed and relative humidity data? One short season of field campaign will provide a valuable opportunity to examine the data reliability and uncertainty.

(C659-15) We gathered additional monthly relative humidity data for single years of three stations and provide them in an additional diagram. Except for late spring/early summer the curves reasonably match. We assume the mismatch to result from the already depleted snow cover at the station locations (at valley floors) contrasting a still partially snow covered catchment (average elevation of the catchment is above the elevation of meteorological stations). Our assumption is here supported by the additionally provided figure on snow cover (from the reply to C594). We were not able to obtain additional wind speed data.

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(C659-16) Page 1174, Line 5. Were there any attempts to validate sunshine duration? See my comment on wind speed above.

Unfortunately, we could not obtain such data.

(C659-17) Page 1175, Line 9. Did the authors make any effort to contact the local agency? I would expect engineers to keep some records of reservoir operation. Also, did the authors search for the data on reservoir size, or depth? That will at least give some indication of the effects of reservoirs.

(C659-17) The lake regulation is operated by a non-governmental organisation, which did not provide us with any data. Instead, we assess the possible impact of the lake regulation based on additional historic discharge data (see reply to C594).

(C659-18) Page 1175, Line 11-12. I would encourage the authors to make a rough estimate of irrigation water use, instead of simply assuming "minimum".

We include a reference stating 0.38% irrigated village areas for the entire Pamirs and provide the resulting influence of irrigation as percentage of Q_{tot}. For the Gunt catchment, 0.38% irrigated land cover yields the following area:
0.0038*14000 km^2 = 53.2 km^2 = 53200000 m^2

Assuming an irrigation period between May and September, we multiply the irrigated village areas by potET for that period and calculate the sum:
sum(53200000 * potET) = 15633724 m^3

As percentage of the average annual discharge of 3.48 km^3:
(15633724 /1000000000)/3.48 = 0.4%

We included the reference in the text and the according estimate.

(C659-19) Page 1179, Line 20. In addition to these, TMF and ETR appear to be unrestricted.

(C659-19) We included this.

(C659-20) Page 1181, Line 24. Please define P_{eff}.

(C659-20) The definition (Page 1181, Line 8) is now clearer.

(C659-21) Table 3. Are the values in bracket average precipitation over the entire watershed? Please clarify.

(C659-21) Yes, they are. The explanation is given at the end of Sec.4.2.1 and in Table 3 where we further clarified it.

(C659-22) Figure 1. Please use color scale for elevation. It is difficult to see elevation in gray scale.

We agree and coloured the elevation ranges of 3000-4000 and 4000-5000 m a.s.l. in colours to make it easier to discriminate the different elevations.

(C659-23) Figure 7. Simulated discharge curves appear to be smaller than observed in 2002. Was the spin-up period long enough to equilibrate the storage?

(C659-23) The small discharge is simply resulting from low precipitation amounts for TRMM and APHRODITE datasets. The models with HAR10 actually show a good match of simulated and observed discharge. Hence, we are confident that the spin-up period was long enough.

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(C659-24) Figure A2. TRMM and APHRO data have a large degree of scatters. APHRO data are particularly troublesome because it have a large negative bias in winter and positive bias in summer. HAR10 have the highest correlation coefficient, but it has a major bias.

(C659-24) We implemented this statement in the figure caption.

References

- Dietz, A., C. Conrad, C. Kuenzer, G. Gesell, and S. Dech (2014), Identifying Changing Snow Cover Characteristics in Central Asia between 1986 and 2014 from Remote Sensing Data, Remote Sens., 6(12), 12752–12775, doi:10.3390/rs61212752.
- Fuchs, M.C. and Gloaguen, R. (2013). Tectonic and climatic forcing on the Panj river system during the Quaternary. International Journal of Earth Sciences . Vol. 102, 1985-2003.
- Fuchs, M. C., R. Gloaguen, S. Merchel, E. Pohl, V. a. Sulaymonova, C. Andermann, and G. Rugel (2015), Millennial erosion rates across the Pamir based on 10Be concentrations in fluvial sediments: dominance of topographic over climatic factors, Earth Surf. Dyn. Discuss., 3(1), 83–128, doi:10.5194/esurfd-3-83-2015.
- Hergarten, C.: Investigations on land cover and land use of Gorno Badakhshan (GBAO) by means of land cover classifications derived from LANDSAT 7 data making use of remote sensing and GIS techniques, Master thesis, UniversitaÌĹt Bern, 2004.
- Lutz, A.F., Immerzeel, W.W., Gobiet, A., Pellicciott, A. and Bierkens, M.F.P. (2013). Comparison of climate change signals in CMIP3 and CMIP5 multi-model

ensembles and implications for Central Asian glaciers. Hydrology and Earth System Sciences. Vol. 17, 3661-3677.

- Mergili, M., Kopf, C., Müllebner, B., and Schneider, J. F.: CHANGES OF THE CRYOSPHERE AND RELATED GEOHAZARDS IN THE HIGH-MOUNTAIN AREAS OF TAJIKISTAN AND AUSTRIA: A COMPARISON, Geografiska Annaler: Series A, Physical Geography, 94, 79–96, doi:10.1111/j.1468-0459.2011.00450.x, 2012.
- Mischke, S., I. Rajabov, N. Mustaeva, C. Zhang, U. Herzschuh, I. Boomer, E. T. Brown, N. Andersen, A. Myrbo, and E. Ito (2010), Modern hydrology and late Holocene history of Lake Karakul, eastern Pamirs (Tajikistan): A reconnaissance study, Palaeogeogr. Palaeoclimatol. Palaeoecol., 289(1-4), 10–24, doi:10.1016/j.palaeo.2010.02.004.
- Palazzi, E., J. Von Hardenberg, and A. Provenzale (2013), Precipitation in the Hindu-Kush Karakoram HimalayaâĂŕ: Observations and future scenarios, J. Geophys. Res. Atmos., 118, 85–100, doi:10.1029/2012JD018697.
- Pu, Z., L. Xu, and V. V. Salomonson (2007), MODIS/Terra observed seasonal variations of snow cover over the Tibetan Plateau, Geophys. Res. Lett., 34(6), 1–6, doi:10.1029/2007GL029262.
- Scherler, D., B. Bookhagen, and M. R. Strecker (2011), Spatially variable response of Himalayan glaciers to climate change affected by debris cover, Nat. Geosci., 4(3), 156–159, doi:10.1038/ngeo1068.
- Schiemann, R., Glazirina, M.G. Schär, C. (2007). On the relationship between the Indian summer monsoon and river flow in the Aral Sea basin. Geophysical Research Letters, vol. 34, 5.

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- Schiemann, R., Lüthi, D., Vidale, P.L. Schär, C. (2008). The precipitation climate of Central Asia - Intercomparison of observational and numerical data sources in a remote semiarid region. International Journal of Climatology, vol. 28, 3, 295-314.
- Syed, F., Giorgi, F., Pal, J. King, M. (2006). Effect of remote forcings on the winter precipitation of central southwest Asia part 1: observations. Theoretical and applied climatology, vol. 86, 1-4, 147-160.
- Zech, R., U. Abramowski, B. Glaser, P. Sosin, P. Kubik, and W. Zech (2005), Late Quaternary glacial and climate history of the Pamir Mountains derived from cosmogenic Be exposure ages, Quat. Res., 64(2), 212–220, doi:10.1016/j.yqres.2005.06.002.

Interactive comment on Earth Surf. Dynam. Discuss., 2, 1155, 2014.

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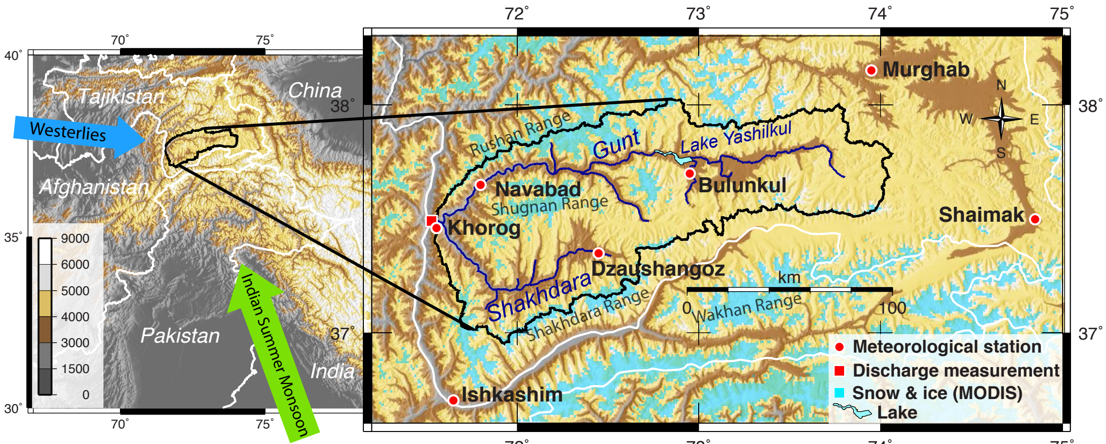

Fig. 1. Changed colours for elevation ranges of Fig.1

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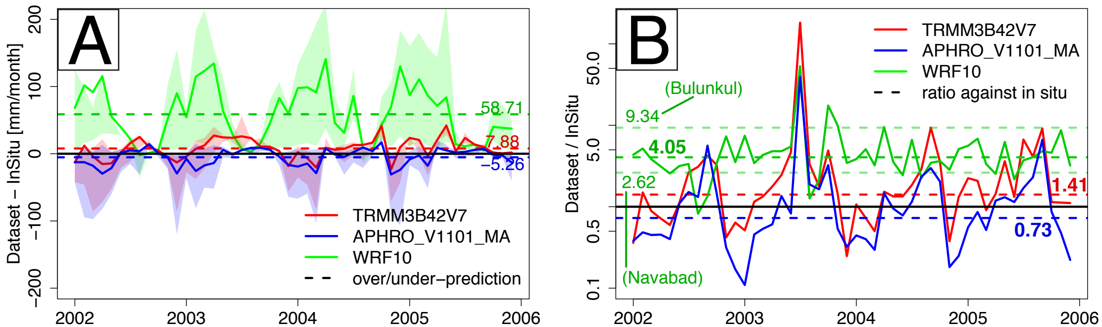

Fig. 2. Added ratios for individual sites Navabad and Bulunkul in Fig.3

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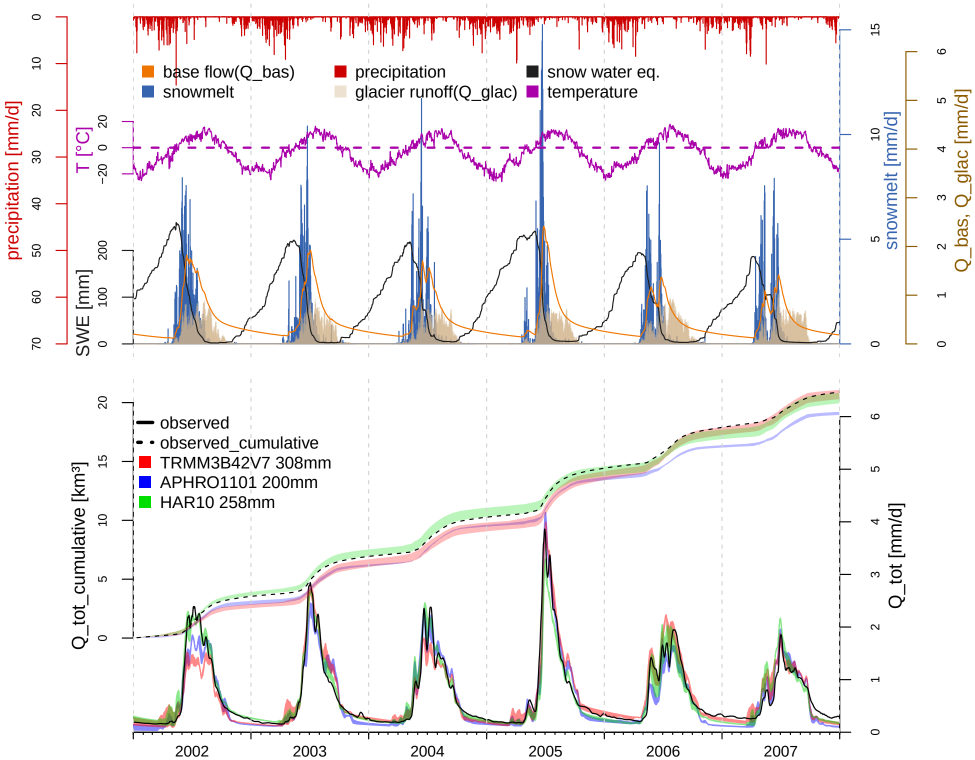

Fig. 3. Added temperature in Fig.7

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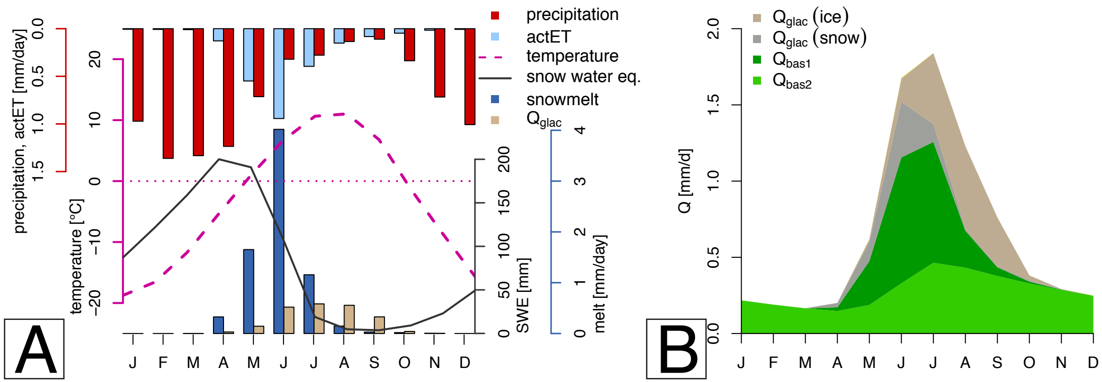

Fig. 4. Additional figure to display average annual hydrological components on a monthly scale

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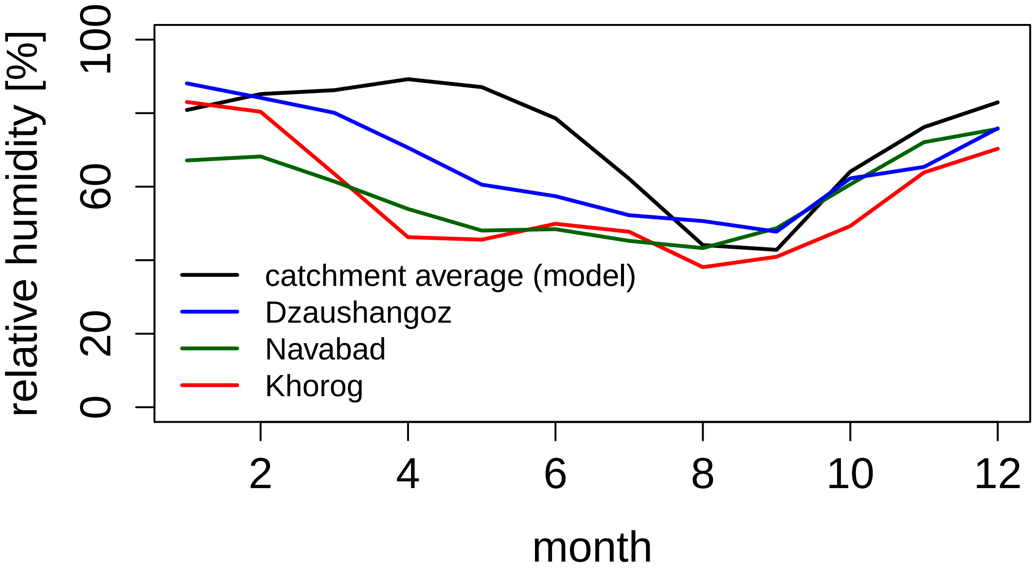

Fig. 5. Additional figure for appendix to show monthly relative humidity in 2004 for 3 sites compared to averaged monthly values obtained by the model for the same year

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