Author response to comments from two reviewers and the Editor

Tsuyoshi Kinouchi, Tong Liu, Javier Mendoza and Yoshihiro Asaoka

We would like to thank the two referees for their efforts in reviewing our manuscript. We also would like to thank the Editor for the suggestion given to our possible revision. Our responses to each comment from two reviewers and the editor are summarized in this document. References used in this document can be found in our manuscript.

Reviewer #1

General comments: The paper in principle addresses an important overall topic.
Glacier retreat, particularly in distinct wet-dry climates as in the tropical and outer tropical Andes, is a serious concern for the local population. The specific objective and research questions of the study are however not clear. In principle, the authors apply a semi-distributed model to simulate runoff from a partly glaciated catchment. The model approach has been used in many other studies before (as stated by the authors), and it remains unclear, if the authors have further developed or adjusted the model for this study and the specific conditions of the case study region and thus provide an added value that is of interest for the scientific community. Since the objective of the article seems more to aim for climate change impact information in the study regions, rather than to provide technical or methodological improvements, my biggest and most serious concerns are related to the available observational data and the scenarios use in this study. In my view, both are far from allowing any scientifically sound conclusion! A 2-yr-observational record and a scenario based on the 2-yr-record and one single GCM scenario can for many reasons in no way be the basis of a scientifically sound climate change study (see also specific comments below). The organization of the article is unfortunately not supportive for an improvement of the understanding and clarity of the study. Data description, methods, discussion etc. are all mixed up in several chapters, and thus a comprehensive description of data and methods, results, discussion is missing. Most of the time the description etc remains very much cursorily, often physically not sound and without the needed context. The figures are in principle nicely produced, however, they could also be much more supportive and corresponding with the text. My final conclusion/recommendation is that the idea of this article should be postponed till several years of good data is available, or the focus of the paper needs to be completely changed. In the later case, I would recommend to undertake a

comprehensive study of current observed climate and glacier conditions of the target catchment only, maybe including a broad sensitivity study to better understand the ongoing processes in the region. A second study could focus on scenarios, but much more work is needed for a scientifically sound analysis of climate scenarios of the target region.

Authors

The authors would like to thank reviewer #1 for insightful comments and helpful suggestions. As described in the introduction part, the specific objective of this study is to develop a semi-distributed conceptual model for the use in the prediction of available water resources in the Tuni Lake catchment under changing climate. Research questions or challenges are to establish a model that can be used to reasonably quantify the runoff considering the inherent characteristics in our study area, i.e., a partially glacierized high-mountain catchment located in the tropical Andes. Although the study area is a major source of water resources supplied to the urban centers of La Paz and El Alto, there have been few studies of runoff modeling and limited data available for this purpose. These are all challenges throughout this study. We conducted intensive field measurements of meteorological and hydrological conditions to develop the model presented in this paper considering the characteristic situations of the study area. Regarding the reviewer’s concern related to the limited data and future predictions, we decided to focus more on the model development and undertake the calibration of the model parameters by fully utilizing available dataset and introducing a sensitivity analysis for parameter calibrations. We will apply a multi-step procedure to calibrate the model using different kinds of observed data, including the flow rate measured at a proglacial site in this catchment. In addition, we will validate our model by the data observed since June 2013. Instead, we will delete all the part related to future predictions using the scenarios of climate change and GCM outputs.

Specific comments

1 Introduction: The first part of the introduction is mentioning some references from past glacier studies in the area of the tropical Andes in a very general sense and often somewhat imprecise. Also, the focus region of the article (Cordillera Real) is not put into a (climatologically, glaciological, etc.) context compared to other regions of the Andes (or the world). In a second part the authors start to focus on glaciated and non-glaciated catchments with example from different mountain regions on earth. The passage from

tropical glaciers to partially glaciated catchments is not very sound, and in principle not coherent with the title of the article.

Authors

In the introduction part, we intended to finally focus on our study area, firstly referring to studies conducted in the same region. As pointed out by the reviewer, we should have described our study area in terms of climatological and glaciological settings, namely the outer tropics with both ablation and accumulation taking place during the wet season, leading to the sensibility to the climate change. The second part starts from referring to the study from the Cordillera Blanca, Peru, and mentioned about the lack of studies for partially glacierized catchments in our study region. In the last paragraph in page 13096, we referred to the modeling study applied to the tropical Andes, rather than starting from a focus on examples from different mountain regions on the earth. Because the non-glacierized area is larger than the glacierized areas in our study catchment, the glacier melt is shown to be less important during specific seasons. Therefore, we will consider to change the title if it is possible.

p.13095; l7: 99% in numbers, area, volume?

Authors

More than 99% of glacier surface areas is located in South America (Kaser, 1999).

p.13095; l18: As it is written here, one could assume that the message is that in particular tropical glaciers (also compared to non-tropical glaciers) are an important indicator for climate change.

Authors

Tropical glaciers are known to be especially sensitive to climate (Rabatel et al., 2013), mainly because of high humidity, high elevation, and its climatic conditions (Wagnon et al., 1999, Bradley et al., 2006, Rabatel et al., 2013).

p.13095; l24: Please express yourself more clearly and sound (in general); here for example: decrease in meltwater because of area and volume loss, or enhanced variability -> why?

Authors

In general, decrease in meltwater occurs due to the decreased volume and area of glaciers if it crossed a critical transition point, which was analyzed for glaciers in Cordillera Blanca for example (Baraer et al., 2012). We can say that smaller glaciers tend to show this characteristics. On a larger spatial scale, the climate variability influences the change in the amount of meltwater, mainly through the variability in the mass balance resulting from meteorological variables such as precipitation, solar radiation, air temperature and humidity.

p.13096, paragraph.1: provide a figure illustrating the situation in the C. Real (enhance Fig. 1 and refer to it already here)

Authors
We would like to improve Fig. 1 and refer it in this paragraph for better understanding the paragraph.

p.13096; l17: Strange sentence, and 'vulnerable' is certainly not a correct word here

Authors
This expression was used based on the understanding that glaciers in this area are undergoing accelerated retreats. We would change this part to more appropriate expression.

2 Study area: A figure showing the location of Huayana West headwater catchment would help to locate and understand the situation better (see also comment above – Fig. needs to be improved)

Authors
The location of Huayana Potosi West headwater catchment in the mother domain (Tuni Lake catchment) is indicated in Fig.1. The location of Huayana Potosi Glacier area in this catchment is included in P.13098, L.7. We would like to show the location of study area in a regional map, as answered to the previous comment.

3 Characteristics of: : :: Fig.1 and 2, and the corresponding text should be improved for easier reading and understanding. The section is a very general description of the measured data in the catchment. There is no information about data quality, no reference to the general climatological situation in the region, in particular, how the two

years of measurements fit to longterm observations of the area. There is also no focus on relevant analyses needed for the objective of the study.

Authors

The information of instruments used for AWS was lacking, thus we will add the information with its quality specifications. The climatological situation in the region can be characterized by the distinct wet and dry seasons. In the wet season, ablation and accumulation occur simultaneously. The meteorological conditions in our study area are not so much different from those observed in the Zongo glacier area, which is located on the east side to our study area and the observed meteorological data in Zongo is available for a longer period. The meteorological conditions shown in Fig. 2 were used to show the lapse rate and vertical gradient of precipitation in Figs. 3 and 4, and this information was further used for the model application.

4 Glacier melt and runoff modelling This section describes detailed (incl. many equations) the approach used in this study, an approach that has been used in many other studies in the past, as stated in the text. That is, it is not clear if there is something newly developed etc for this study. Information about input and output data, specific parametrisations and experiences from using this model in tropical mountain areas is not provided. For the reader a lot of important information is thus hidden and does not allow a sound understanding of the overall approach.

Authors

The model introduced in this section and used in the study was newly developed by authors. The important aspect is that it considers three major components in runoff, i.e. surface runoff, subsurface runoff and groundwater recharge. Runoffs from glacierinzed and non-glacierinzed areas are calculated individually. Evapotranspiration is calculated to account for the depletion of soil moisture during the dry season and periods with no precipitation. As this area is characterized by the high elevation, steep slope and tropical climate, the models for snow melt and glacier melt consider the effect of shading, and the temperature-index model with the inclusion of incident solar radiation and air temperature succeeded in reproducing actual variation of albedo on the glacier surface. The effect of lakes (and wetlands) was included, while many of the similar model do not include this process. Information about the input data is provided in the section “5 Input data and parameter settings”. Parameters and calibration were also explained in this section. As this model is a newly developed one, no experience exists before this study.

5 Input data and parameter setting Paragraph 1: the information (data and method) provided about the delineation of the glacier catchments is very sparse. The rest of the section is basically a description of the model tuning, however, scientific argumentation or consideration of local conditions of the study sites are not provided.

Authors

We used a watershed delineation tool available in ArcGIS to get the catchment boundary. Scientific consideration of local condition can be found in many aspects in this section. For example, effect of shading is considered because of the topographic conditions over this area. Glacier area and volume relationship is based on the scientific findings of many past researches. Formulation of runoff coefficient in non-glacierized ground surface is based on our understanding of local conditions. The basic idea of using relevant information and parameters are already described in the section of modeling.

6 Simulation conditions for future prediction Most of this section is a quick review of other studies, unfortunately without a critical analysis for the study region of this article. The finally used approach is not sound. As written on p13112, the first case bases on "current observed conditions: : :." This is highly problematic with a 2-year observation record only! And for case (2) it is simply not sound as well to only use output from one GCM, without any evaluation. On page 13113 (final paragraph and Table 3) the authors write about a bias correction for solar radiation and wind velocity and it is absolutely not clear what here has been done, however, it is very clear that this is by no mean anyhow sound, above all because of the 2-year observations only.

Authors

Our objective was to understand the possible results of glacier shrinkage and its impacts on streamflow in terms of the magnitude and seasonal variations. As the study area is located in the environment difficult to get sufficient data, there was substantially no data usable before this study. Mainly due to this limitation, we had to depend on 2 yr dataset, and we applied a simple scenario with the use of current data. As we wrote in the response to the reviewer's general comment, we will delete all the part related to future predictions using the scenarios of climate change and GCM outputs.

7 Model application First paragraph: The authors write that Figure 6 shows that the model reproduces well the observations and they also explicitly mention the good simulation of the peaks. This is however too be expected, because in section 5 it is explained that the model is tuned to meet the peaks! The following discussion of deviation where it is argued with spatial snowfall differences, wind, albedo, etc is in my view an over-interpretation because the model and observations available (at least according to the information provided in the article) is not able to go into such detailed process analyses.

Authors

We would like to validate the model by using the data we obtained since June 2013. As for the second comment, we tried to find the reasons of the gap between observed and simulated during these specific periods, but it might be over-interpreted. So, instead of focusing on these particular periods, we would like to conduct a sensitivity analysis to show parameters important for overall performance of our model.

An example of a sentence that is showing the general cursoriness of the article is for example on page 13115m line 8-11. What is for example meant by ‘high’ temperature?

Authors

This part (p.13115 line 5 to 10) discusses about the validity of simulated albedo during the period of missing observed data. As a consequence of high temperatures and solar radiations observed during the end of October until the early December, three peaks of flow rates were observed, suggesting that the lowest albedo simulated during the same periods corresponds to the generation of three peaks of discharge.

Reviewer #2

General comments

Several aspects of the manuscript represent a significant interest for the HESSD readers. The paper presents an hydro-meteorological dataset from a region of the tropical Andes that has not been extensively studied yet and the density of weather stations presented by the authors makes it of particular interest. The hydrological model developed for the study exhibits originalities in the structure. The use of supplementary measured variables such as the albedo for the calibration of model parameters appears as a promising approach. The subsurface and deep groundwater parts of the model especially are designed to better take into consideration these two hydrological components compared with what is typically done in similar environments. Unfortunately, the paper includes several doubtful facets that will require major revisions before publishing. Among those, the use of a conceptual model for analysing parameters it was not validated for represents the weakest point of the manuscript. The length of the time series chosen for model calibration is also a major handicap for the representativeness of the model outputs, especially when those are generated based on hypothetical climatic scenarios. Finally, there is an apparent lack of rigour in data analysis, some statements made at different points of the manuscript not being supported by robust evidences. The meteorological dataset collected so-far by the authors at the Huayna-Potosi West headwater does not appear being sufficient to allow proper calibration and validation of a semi-distributed conceptual model at a daily time step. I therefore encourage the authors to reshape the manuscript by placing more emphasis on the modeling and calibration techniques and less on model outputs based hydrological analysis.

Authors

The authors would like to thank reviewer #2 for insightful comments and helpful suggestions. As was pointed out, the limited period of available data from our study area prevented us to validate the model with calibrated parameters. In addition, calibration of some sensitive parameters were manually done. To improve these weak points for obtaining reliable model outputs, authors would like to perform parameter calibrations in a more rigorous way by introducing a multi-step calibration procedure. As we have been observing flow rate at a proglacial site of the Huayna Potosi West Glacier since December 2012, we would like to utilize this data during the calibration procedure. The multi-step calibration will utilize 1) albedo and mass balance (of a neighboring glacier) to calibrate relevant parameters for snow melt and glacier melt, 2) flow rate at a proglacial site to calibrate parameters related to runoff from glacierized areas, 3) flow rate monitored at HH1 (see Fig. 1 of original paper) to calibrate parameters related to runoff from non-glacierized areas. The manual calibration will be changed to the optimum parameter retrieval by searching the domain of possible ranges of significant parameters. The validation of the model is possibly done by the flow rate data obtained since June 2013.

Specific remarks

- The hydrological model used in the study uses more than 16 parameters, factors, coefficients that are either fixed arbitrarily either estimated during a calibration exercise. In these conditions, the two years of field observations and measurements are not enough to realise a proper calibration and validation. Using the model to assess watershed hydrological response to climate change scenarios without verification of its ability to do so is not appropriate.

Authors

As explained in the answer to reviewer's general comments, we would like to put more focus on modeling, calibration and validation, and would like to delete the part of long-term simulation with future scenarios.

- Model outputs are used to depict runoff components evolution with time, both for calibration years and for future projections. The ability of the model to reproduce such characteristic was not verified and not intended to be. The way the model is designed makes that the simulation output are highly influenced by the way parameters, factors and coefficient are fixed. As seen here above, nothing in the calibration process justify using the model simulation in such way.

Authors

We would like to limit the discussion of runoff components to glacier melt, snow melt and runoff from glacierized and non-glacierized areas, because these components can be validated after the calibration using measured albedo, mass balance, and flow rate.

- The length of the field measurements, limited to two years, does not allow long term evaluation of climatic and hydrological watershed specificities.

Authors

As mentioned before, we will undertake a major revision by deleting the part relating to long-term simulations.

A different occasions, the authors overstate on these limited monitoring results or does not provide evidences for affirmations:

o Page 13098; lines 17-19. “Therefore, both the wetland and the lake likely play a role in retarding the runoff from the glacierized and non-glacierized areas.”

Authors

We might have overstated the function of the wetland and the lake without any comparison with evidential data. Therefore, we would like to use our additional information of flow rates measured at a proglacial site, which is located just after passing through a small lake, to show the effect of the lake for regulating the outflows.

o Page 13099; lines14-16. “A good correlation for air temperature was found between MH1 and MHG ($R2=0.77$) during the two years, implying that similar variation may have occurred in the ablation zone.”

Authors

This is just the implication our observed data can give, because the ablation zone is located between the two sites (MH1 and MHG).

o Pages 13099 - 13100; lines 25-29 and 1-3. Especially: “ We found that air temperature was more strongly correlated with flow rate during this period, with a phase lag of about 5 days, ...”

Authors

This sentence is based on the comparison between the flow rate at HH1 with the air temperature and the solar radiation observed at MH1. We checked our data and the exact phase lag was found to be 3 to 4 days. Therefore, we would like to modify the original sentence to reflect the exact condition and show the phase lag more quantitatively because the phase lag is important to infer the dominant process for the runoff generation and water transport.

o Page 13114; lines 19-21. “This implies that wetlands and lakes in the tropical Andes play significant roles in buffering runoff from glacier melt and supply this water gradually”

Authors

As mentioned before, we would like to quantify the effect of the lake by using the observed flow rate at a proglacial site, and we will revise this part. Besides, it is hard to show the effect of wetland by any direct evidence. Therefore, we will limit to say the effect of wetlands.

o Pages 13120; lines 25-27. “The trend of relative humidity derived from historical records is not significant (Vuille et al., 2008); thus if this trend continue into the future, the effect on melting and runoff would be minimal”

Authors
This part will be deleted along with the deletion of long-term simulation results.

- Maintaining a weather station during two years on a glacier surface is a challenge, mainly due to the motion of the ice as well as the effect of melt or accumulation of the surface. The manuscript lacks of description of how the measures from the MHG station remained unaffected by these factors.

Authors
The station was kept to be positioned at the same location, and a quite slow motion of the glacier helped keeping this condition. The effect of melt or accumulation was eliminated by re-placing the instruments to keep a certain distance from the glacier or snow surface.

Technical remarks:

- The use of objective functions to evaluate the performance of the model in reproducing measured parameters is sometimes inconsistent. It goes from three objective functions at page 13114 paragraph two to none at the third paragraph of the same page.

Authors
In the second paragraph in page 13114, three indices (R^2, RMSE and NSE) were calculated for the flow rate to show the difference of results with and without the retarding effects. Besides, the performance of calibrated parameters in the snow melt model was only shown by Fig. 7, without any information of those indices. For more quantitative judgment of the performance of the snow melt model we applied, we would like to include R^2 and RMSE obtained with the calibrated parameters.

- Page 13094. The use of the world “validate” in the abstract is misleading as no validation of the model performance (comparing model outputs to measurements not used for the model calibration) was conducted in the study.

Authors

We would like to validate the model by the data we obtained since June 2013.

- Page 13100. There is no unit given for the dry adiabatic lapse rate.

Authors

The unit will be given as 1.0 °C ($100m^{-1}$).

- Page 13101. The first paragraph of the page proposes a comparison between the Cordillera Real and the Cordillera Blanca melting conditions that can be considered as speculative.

Authors

We compared data of precipitation and air temperature for the Cordillera Blanca (Mark and Seltzer, 2005) and for the Cordillera Real (Ribstein et al., 1995). Our explanations were based on these data. We can find big differences in precipitation between the site at 4600 m in the Cordillera Blanca (Fig. 2 of original paper by Mark and Seltzer (2005)), where data for 11 years during 1981–1990 and in 1998 is available, and those from the site at 4700 m in Zongo, Cordillera Real, where data for 14 years during 1970-1993 (Ribstein et al., 1995) is available. Air temperatures of Zongo (4770 m) was higher than those from the site at 4600 m in the Cordillera Blanca, which was adjusted to the same height as the site at Zongo using the lapse rate of 0.6 °C/100 m.

- Pages 13102 to 13108. The presentation of the model could be improved to make it easier to read: Some parameters are explained at the wrong place (Inf); Some symbols are used to describe two different parameters (α); the presentation of equations in groups of six to seven make them difficult to understand; in equation (29) ri is used instead of γi.

Authors

This part was structured to explain the runoff modeling for glacierized area, runoff modeling for non-glacierized area, and other settings related to meteorological conditions and retardation effects. Based on the reviewer's suggestion, we will try to make this whole part easier to read by introducing sub sections. We will also pay careful attention when describing parameters such as Inf, α and γi.

- Page 13109. The use of data from the Zongo glacier for melting factors calibration may generate an error as the Zongo glacier orientation differs from the studied one.

Authors

We did not calibrate the parameters using data from Zongo. The melting factors were calibrated for our study area (Huayna West glacier) to give a better agreement of Albedo at MHG (5,150m a.s.l.) and streamflow at HH1 during the melt season. Then, those factors were validated using data of mass balance in the Zongo glacier. Although the orientation or the aspect is different between the Zongo glacier and the Huayna West glacier, the mass balance of the Zongo glacier was calculated considering local meteorological conditions. In a revised manuscript, we will consider to include the detailed results of the model calibration using the data from the Zongo glacier.

- Page 13110 first paragraph. There is a general lack of details on the way some parameters are fixed in this section.

Authors

As was pointed out by the reviewer, the detail of parameter setting was lacking, especially for the runoff coefficients for rainfall, snowmelt, and glacier melt in glacierized and non-glacierized areas. In the correspondence to this comment, we will perform the sensitivity analysis of each runoff coefficient and the calibration based on the flow rates measured at two sites in our study area, including the data observed at a proglacial site.

- Page 13132 – Figure 1. The maps provided could be improved by enlarging the study catchment, adding streams and placing the stations names directly on the maps.

Authors

The study catchment will be enlarged as suggested, with streams and names of stations overlaid on the map.

- Page 13136 – Figure 5. Variables should be explained.

Authors

All variables are the same as those appeared in the main text. This information will be added in the caption of Fig. 5.

Editor Prof. Jan Seibert

Both reviewers have provided important comments. A major limitation of the study as presented in the manuscript is the too short period of available data. While the efforts of collecting data in such a difficult environment of course must be appreciated, two years of data are just too little to support the conclusions the authors want to make in the manuscript. As the reviewers suggest, the authors will have to wait until more data is available or change the focus of the manuscript. Knowing how difficult it is to collect good data, I would prefer to be more positive, but we still cannot ignore the fact, that the available data often limits want can be done with the data. I would to ask the authors to address especially the data limitation issue in their response.

Authors
The authors would like to thank the Editor for summarizing the reviewer's comments and highlighting the points to be addressed in our possible revision. Also, we are encouraged by editor's positive evaluation to our study.

As suggested by the editor and two reviewers, we would like to change the focus from future predictions to the modeling itself and evaluation of model capability for simulating current situations. Therefore, we will delete the part of future prediction. We still consider the model we developed in this study as comprehensive as other existing conceptual models applicable to partially glacierized catchments in the tropics, because most of the important processes are retained in the model, including glacier melt, snow melt, surface runoff, subsurface runoff, groundwater recharge, evapotranspiration, and retarding effects by lakes and wetlands. However, we might have overstated the function of some components without any comparison with evidential data.

To reduce the uncertainty due to parameter settings, we would like to apply a multi-step calibration procedure that utilizes a various kind of meteorological and hydrological data available from our study area, and we will finally validate the model with the latest data monitored since June 2013. The multi-step calibration will utilize 1) albedo and mass balance (of a neighboring glacier) to calibrate relevant parameters for snow melt and glacier melt, 2) flow rate at a proglacial site, where we have been monitoring since Dec. 2012, to calibrate parameters related to runoff from glacierized areas, 3) flow rate monitored at HH1 (see Fig. 1 of original paper) to calibrate parameters related to runoff from non-glacierized areas. We will validate the model with the flow rate data observed since June 2013 up to now. In the calibration process, the errors of model simulation compared with observed data of flow rate, albedo, and mass balance will be minimized by running the model with a numerous combination of parameters that we select based on their sensitivity. By introducing this approach, although the time period is relatively short, our intensive measurement of hydrological and meteorological conditions will contribute to the better modeling of glacier melt and runoff from a partially glacierized catchment in the high-altitudinal environment.