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Hydrology and Earth System Sciences Discussions

Interactive comment on "A conceptual glacio-hydrological model for high mountainous catchments" *by* B. Schaefli et al.

B. Schaefli et al.

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Response to anonymous referee #1

Comment 1: " The benefit of using glacier mass balance data is not really shown. "

For the presented modelling context, the expected benefit of using mass balance data was not to improve the daily discharge simulation but to ensure that the overall mass balance is well reproduced. We agree with the referee that a consequent approach would need to be completed by a validation of the obtained mass balance simulations for another period. We would however like to point out that long series of mass balance observations are difficult to obtain. Its noteworthy that many published series of mass balance data are in fact the result of a hydrological water balance estimation (for the Rhone glacier such a series is published on http://hades.unibe.ch). These series could be used for the validation of the mass balance simulation but they do not encode an additional source of information as they are also related to the discharge measurement.

Note that additional information about long-term glacier evolution to calibrate / validate the model for other catchments in the Swiss Alps could become soon available through the new Swiss glacier inventory (Kääb et al., 2002).

We would also like to highlight another important aspect. It is well known in hydrological modelling, that the bias and the Nash objective function calculated on discharge are often highly antagonist, i.e. it is not possible to optimise both objective functions at the same time but a compromise has to be found (this result is also obtained for the presented model, (Schaefli, 2005). For the studied catchment, we have shown that the bias function calculated on the mass balance data is also antagonist to the Nash value of the daily discharge (see (Schaefli et al., 2004)). This means on one hand that the use of the bias function cannot enhance the quality of the daily discharge simulation and on the other hand that an optimisation without the use of the bias function will inevitably result in a biased estimate of the water balance.

If no glacier mass balance is available, the model has to be calibrated using only the bias function calculated for the daily discharge. We propose to use the point of the identified curve asnow = α * aiceβ + γ of minimum discharge bias having the best Nash value. For the Rhone glacier, the parameter set with the best Nash value corresponds to aice = 10.4 mm°C-1d-1 and asnow = 7.2 mm°C-1d-1. The corresponding simulations of the annual mass balance are respectively 753 mm, 38 mm and -1147 mm for the considered period 1979/80 to 1981/82. These values show that using only the discharge data for model calibration leads to a worse estimate of the annual mass balance (see Table 8).

We will include some of the above information in the revised version of the paper.

Comment 2: Calibration of threshold temperatures

This referee comment concerns the threshold temperatures for snow- / rainfall division and for melting. In the following, they are discussed separately.

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Interactive Comment

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a) Snow- / rainfall threshold temperature

We should have been more precise in our statement concerning the calibration of this temperature threshold. We agree in fact that the threshold temperature (as all other parameters) can be calibrated using powerful automatic optimisation methods and we have tested it in other model applications (where we have however shown that no unique best value can be found through calibration, (Schaefli, 2005). We still think that this value is difficult to calibrate in a semi-automatic approach as the one proposed in the present paper.

We agree with the referees that we could have fixed it based on meteorological measurements. At the weather stations of the Swiss Meteorological Institute MeteoSwiss, the instantaneous form of precipitation (liquid/ solid or mixed) is recorded. This data can be used to determine a threshold temperature Tc1 below which precipitation is always solid and a threshold temperature Tc2 above which precipitation is almost always liquid. Such thresholds Tc1 and Tc2 have been determined for another study within our research group; they are respectively around 0°C and 2°C for a number of weather stations located in the Swiss Alps. The hydrological model used for the mentioned study simulates the discharge however at an hourly time step. This time step is close to the available instantaneous measurements contrary to the daily time step of the study in the present manuscript. We thus believe that these thresholds cannot be directly used for the snow-/rainfall separation at a daily time step.

Another problem has to be mentioned. The thresholds Tc1 and Tc2 can be estimated for a given weather station a given elevation. We could assume that these thresholds are constant for all points of a modelled catchment. But an additional difficulty arises from the fact that for the hydrologic discharge simulation, the catchment is divided into elevation bands for which only one representative temperature series is estimated and used for snow-/rainfall separation. Each elevation band corresponds to an aggregation of a number of points having different elevations. For a given temperature (corresponding to the mean altitude of the elevation band), precipitation may fall as snow in the upper part of the elevation band but as rainfall in the lower part. This suggests that the range between the thresholds Tc1 and Tc2 should be enlarged. How could this larger range be determined?

The lack of more reliable information concerning the above considerations motivated the use of a simple binary function for snow-/rainfall separation based on a unique threshold that was set to 0°C. We however agree that we could have chosen a more realistic value and we will revise the paper in this sense. As suggested by Referee 2, we will especially see the work of Rohrer et al. (1994).

b) Melting threshold temperature

We tried to determine the snowmelt threshold temperature based on the snow heights measurements at the automatic weather stations. We could however not find any exploitable relationship between the calibrated threshold temperatures for the different stations. This parameter would have been especially difficult to spatially interpolate and we have therefore chosen to fix it to 0°C.

Comment 3: Data quality Drance catchment and calibration results

We first would like to highlight the difference in data quality for the two periods: Both series contain negative values during the low flow period. A minimum measurement error can be estimated assuming that on the corresponding days the true discharge was zero and that the negative values constitute a sample of a measurement error having zero mean. The so estimated standard deviation is 0.21 for the calibration period and 0.54 for the validation period. For the calibration period, 3 % of all observed discharges are negative whereas for the validation period 30 % are negative. A model calibration on the validation period is therefore difficult (if not impossible) for the parameters encoding the low flow. On the other hand, the period can be reasonably used as a validation period, the total annual discharge is well estimated through the used method for discharge measurement and the influence of the daily measurement error on the high flow discharges can be supposed to be small (the highest observed negative discharge value is -2.5 mm compared to the maximum observed discharge of 40.0 mm.

Considering the estimated minimum observational error, for the validation period 45 % of all simulated values are contained in the 90 % confidence interval of the observations whereas for the calibration period this value corresponds to 28 %.

A further investigation of the effects of inverting the periods would have been interesting for all three catchments - especially with regard to an investigation of the effect of the use of a warm or cold period for the calibration - but this would have been beyond the main objective of this paper.

Comment 4: Mass balance underestimation for the year 1981 / 82

We agree that the total mass balance over the three-year period shows a significant error but as pointed out this is essentially due to the last year. For the purpose of the model calibration, we are interested in the simulation of the individual annual mass balance values as the observed period is too short to consider the long-term mean value.

We agree with the referee that this underestimation could be avoided by setting a reasonable initial ice volume to each elevation band. We do however not know how to define this initial volume. We agree that if corresponding data was available, this could improve the daily discharge, but it is noteworthy that the available ice volume is a limiting factor only for the lower elevation bands. Using 10 elevation bands for discharge simulation, at most the two lowest glacier elevation bands are concerned by this problem representing 21 % of the catchment surface (for the higher elevation bands, the simulated total annual ice melt never exceeds 2.5 m of water equivalent that can be reasonably assumed to be less than the available ice volume).

As we do not know how to set the initial ice volume, we prefer not to set any arbitrary limit. In return, if the model is used for long time periods, the glacier surface has to be updated.

Technical corrections

In the following, we discuss some of the technical corrections. All corrections that are not explicitly mentioned here will be addressed in the revised version of the manuscript according to the suggestions of the referee.

- Page 77, line 14-16: “Please add information on how the ice-covered and bare areas in the catchment were separated.”- The ice-covered areas have been separated based on available digital (vector-based) land cover data with a digitalization scale of 1:25’000 (SwissTopo). This will be specified in the revised version.

- Page 82, line 2: “What is the input to the glacier store if covered by snow? It can not be rainfall as supported by the text (equation 4).” - The equation and the text are correct: If ice is snow covered, the input into the glacier store is zero as in this situation the ice melt Mice is zero and the liquid precipitation falling on ice Pliq,ice (mm/d) is also zero: Since the ice is snow covered, no precipitation falls on it. Will be specified in the revised version.

- Page 87, section 4.1: “How are the calibration criteria used in detail?” - We should have given more details on the selection of the initial parameter set. The selection is based on objective criteria only (Nash value and bias). The exact procedure will be specified in the revised version.

- Page 89,line 20: “If no glacier mass balance data are available, Nash efficiencies and discharge bias appear to have been used for local refinement. What is the difference to the selection of the initial parameter set? Please clarify.” - It is stated in the text, that if no glacier mass balance data is available, the choice of the parameter couple aice and asnow is based on the classical Nash criterion computed for all local optima of the bias response surface.

- Page 90, line 13-19: “The motivation of using glacier mass balance for calibration should be placed at the beginning of the chapter." - We assume that this comment refers to page 89. As the motivation of using glacier mass balance data is already stated in the introductory section, we think that it is not necessary to modify the structure of this section.

- Page 104, Table 4: "The headers of Table 4 seem to be wrong." - Error occurred during paper publication process and will be corrected.

- Page 108, Table 7: "Please remove glaciation rates, as they are not a criterion for Calibration." - Some of the tables will be rearranged (see also comment Referee 2)

References

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