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Hydrology and Earth System Sciences Discussions

Interactive comment on "Modelling the hydrologic role of glaciers within a Water Evaluation and Planning System (WEAP): a case study in the Rio Santa watershed (Peru)" *by* T. Condom et al.

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We thank the Anonymous Referee #1 for the comments that would help to increase the quality of the manuscript.

First of all, we precise that the paper focuses on the use of a semi-distributed hydrological model presents the computations of water flows in the catchments and the retreat of the glaciers under the present climate which is quite unusual. Furthermore, the water-uses are taken into account in the different sub-catchments. An important result of this study is to deliver ranges of values for the segmentation of the total flow between direct flow, groundwater flow and glacial outflows. The investigation of the effect of climate

change on future river discharge is not the main subject of the present paper.

In the following parts we present the response for each specific comment.

Response to the specific comments

a) Theoretical background

The choice to use a degree-month model was driven by the availability of such hydro-meteorological data for long period (decades). The limitations induced by the use of this type of model have been discussed in detail (see parts 2.2 and 2.2.2).

The question of the sublimation is a good point to underline. In our model, we don't simulate this process as an isolated process. In reality, by using a calibrated Degree Month Model, we assume that the model integrates all the energy exchange processes by the mean of temperature. Simulating only the sublimation process at the scale of the whole Cordillera Blanca might be very difficult. Indeed without good field measurements for the different components of the energy balance we think that it will result in an increase of the complexity of the model and an over-parametrization. It is very difficult to spatialize the meteorological data like the wind or the humidity that presents high gradients in mountainous regions.

b) Model description

We appreciate the comments of the reviewer and we will revise this section to improve our presentation of the Model description to avoid the confusing parts and we will simplify complicated formalisms where we consider necessary.

The reason why we used conversion factors is because the units in which some variables are generally presented (i.e. mm for precipitation, km2 for catchment areas) needed to be converted into SI units.

We propose to revise all the equation and change the units for the revised version and to give all the parameters and variables in standard SI units.

We will correct the error in the second term of Eq. 2, and we will fix the inconsistency between kj and ks by changing the text to ks so it is the same as in Eq 1 and Eq 2.

We will also make correct reference in the text to baseflow in Eq. 2.

In this part of the text we were explaining that we eliminated the factor (exponential autocorrelation factors), but we did not argue about the origin of the differential equation resolution.

The reviewer is right in that Eq. 6 (a,b,c) are not homogeneous. We will revise the notation of VQ so it is not confusing for readers.

The hydrologic formulation within WEAP has been refined since its original presentation. When Yates 2005 was published, he called the term LAI, but in reality the factor is empirical and does not have the same connotation as LAI. The definition of RRF is 'Used to control surface runoff response. Related to factors such as leaf area index and land slope. Runoff will tend to decrease with higher values (range 0.1 to 10). This parameter can vary among the land class types.'

The model does account for snow outside the glacier coverage and we will revise our description of that process so it is clear for the readers.

Concerning the glacier accumulation, what may happen is that water that is not converted into snow freezes after contact with the ice below it.

The baseflows are assumed to represent ground water in this model. We will revise our description of baseflows and how they relate to ground water.

The way in which the glacier evolution was implemented in WEAP uses the some of the same input variables that the regular WEAP algorithm but it functions independently as a mass balance over the glaciated area. The WEAP Runge-Kutta algorithm is used in within another WEAP internal routine for solving water temperature. In general, WEAP is a flexible software that allows for the use of different algorithms to solve different components of the hydrologic cycle. In addition, WEAP allows for inclusion of

vba scripts to introduce additional algorithms to estimate other processes that may be relevant for specific applications.

c) Parameters

We agree with the fact that the calibrated parameters are in the higher values and that the temperature index model is non-linear.

d) Calibration

The criteria used for the calibration of the parameters on the outflows are described in the part 2.2.5. We use the RMSE, the BIAS and the Efficiency.

Concerning the glacier retreat, we just control for 2 dates (1987 and 1999) and for each sub-watershed the good agreement between simulated values and observed values deduced from landsat images. In order to keep the robustness of the model, the fusion parameters (aice and asnow) have been taken equal for all the sub-watersheds.

e) Climatic settings

We mentioned that mean annual values for precipitation range between 93 to 1542 mm y-1 for the period 1967-1998 according to the position into the watershed. If we consider the whole Santa catchment and if we calculate a simple average from the values issued from each altitude band we obtained 868 mm y-1. This mean value is not used for the hydrological simulations and is just an indication for the climatic settings. The use of the word "weighted" is a mistake.

The precipitation time series used are described in the part 3.3 Input data.

We don't distinguish longitudinal from altitudinal climatic gradients but the spatial variability is taken into account with the use of interpolation type IDW (see data preprocessing on part 3.3.2).

f) Input data

The authors admit that the description of the data concerning the glacier's extent was not well explained. For the observed glacier's extent we use 2 sources of data for the years 1970-1987 and 1999. For the years 1970 the glacier inventory of the Peru published by Hidrandina is used (1989). This inventory determined the surface for each glacier of the Cordillera Blanca on the basis of 168 aerial photos (146 photos taken in 1962 and 22 in 1970). For the periods 1987 and 1999, Landsat images were used.

Concerning the precipitation, we use a large number of stations and the repartition quite homogeneous. That would integrate the spatial variability. We can see this point if we consider the repartition of the weather stations (triangles) plotted on the figure 1.

g) Model calibration

The strategy for the model calibration and validation was : - first, a calibration of the glacier's parameters (aice, asnow and T0) on the period 2000-2007 on the small sub-watershed "Artesoncocha" (see figure 4) considering the outflows. - second, using the same calibrated glacier parameters for all sub-watersheds (aice, asnow and T0) the second step was to calibrate the hydrological parameters on the period 1969-1979 considering the outflows. - third, we validate the parameters on the period 1979-1989. For the glacier's extent, we first initialise for each sub-watershed the area in 1970 and then we compute the areas for 1987 an 1999.

h) Model results

We agree with the reviewer for the first remark and the bias is equal to -7% for La Balsa Station.

Concerning the second remark, the figure 6 presents the results for Chuquicara (Area : 9640 km2 and 4% area ice in 1970); La Balsa (Area : 4696 km2 and 9% area ice in 1970); and Quillcay (245 km2 and 19% area ice in 1970). The papers of Wagnon et al. 1999b deals with the Zongo watershed that has an area of 2.1 km2 and an ice area of 77%. The area of the Zongo catchment is small in regards with Chuquicara, La Balsa

or Quillcay. On the contrary, the proportion of the glacier runoff in the total outflow is higher. The same remark could be done for the Llanganuco catchment (area 86.4 km2 and 34 % ice area) used in the paper of Juen et al. 2007.

i) Discussion

In our study, we assume that during the last thirty years climatic conditions have not drastically changed for the region of the rio Santa watershed, so that the degree-day factor (or degree-month factor) stays stable. This point is assumed if we consider a paper written by Racovitaneu et al. (2008) where it is stated that during the last 30 years no significant decrease or increase in annual precipitation occurs and a moderate increase in annual air temperature exists (0.5 °/decade).

Concerning the climate change impact study in the last part of Sect. 4, we agree with the reviewer and we propose to move these results in discussion (part 5).

Technical corrections

The first month of the hydrologic year is September. The other technical corrections and the references would be added in the revised version of the paper.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 8, 869, 2011.