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Hydrology and Earth System Sciences Discussions

Interactive comment on "Elevational dependence of climate change impacts on water resources in an Alpine catchment" *by* S. Fatichi et al.

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Dear Editor Bettina Schaefli,

Please find below our responses to the comments of reviewer-2. These are intended as rebuttal and to further stimulate the ongoing discussion.

Sincerely,

S. Fatichi, S. Rimkus, P. Burlando, R. Bordoy, and P. Molnar

Replies to reviewer 2

Referee: *This manuscript presents a study where a climate impacts on runoff in an*

alpine catchment have been investigated using a catchment model which had been extended to consider the effects of human (mainly hydropower) activities. This is certainly an important issue which the scope of HESS and the authors put obviously considerable efforts in their study to implement all details of anthropogenic impacts. However, as already discussed by previous comments there are major concerns with this manuscript.

My main concern it remains unclear, what the main focus of this contribution is and what exactly the additional contribution to knowledge is. If the goal is the development of a model that includes anthropogenic impacts then these model extensions need to be much better described, discussed and, most importantly, analysed. In this case it is not enough to say, this is the best we could do with the available data, but it also needs to be investigated what effects certain assumptions or simplifications have and what alternatives have been tested. Some assessment of uncertainties would also be necessary. If the main focus should be the quantification of climate change impacts then several aspects of the study are not fully convincing:

Reply:

The overall goals of the manuscript are:

(i) to present a distributed investigation of the propagation of climate change effects on streamflow throughout the entire range of elevations, i.e., from the headwater catchments at high altitudes to the main streams in the valleys at lower altitudes (P3746 L 19-23), this is done by analyzing the effects on a large number of streamflow characteristics (e.g. mean, seasonality, maxima, minima) and related aspects (e.g. hydropower reservoir levels);

(ii) to investigate the magnitude of the change and its uncertainty given by the intrinsic variability of climate obtained forcing the distributed hydrological model by means of stochastically dowsncaled meteorological time series.

To our knowledge this is the first contribution in the literature that analyzes these aspects at such fine spatial and temporal scales using a comprehensive hydrological model that also includes the available information on anthropogenic controls.

As we wrote in the introduction of the manuscript, the previous studies focused on small headwater mountainous catchments and therefore they provided only a local picture of the overall climate change impact in the Alpine region, which, as demonstrated by our results, shows conversely significant differences across elevations and space scales throughout the catchment. In achieving our goal, we carefully (i.e. to the largest extent made possible by the data) accounted for the existing hydraulic infrastructure, which are of utmost importance in controlling the water budget of many river reaches of the upper Rhone. Although, we were forced to accept some assumptions with respect to unknown variables or unavailable data, we implemented what we currently consider the best set-up possible.

With regard to the quantification of uncertainty, our effort was devoted to include stochastic variability of climate that is possibly the most important source of uncertainty, definitely more important than hydrological model parameterization (see also discussion in Schaefli et al., 2007, HESS, for a comparison of the climate role with regards to other uncertainties sources, and our literature argument further below). We made this choice given the limitations posed by the computational effort that would have been required to analyze all the sources of uncertainties at the spatial and temporal resolution that were used to run a distributed model such as Topkapi-ETH for a large basin (from a catchment hydrology point of view) as the upper Rhone. We strongly believe that preserving detailed topographic variability and carrying out simulations at the hourly-scale, also accounting for stochastic variability, is important to overcome the limitations of existing studies.

Referee: *1) The use of only one GCM and two RCM (and only one emission scenario) – this is in the days of ENSEMBLE and other ways to obtain GCM/RCM data simply not stateof- the art anymore. Several studies have highlighted the need for using en-*

sembles of GCM/RCM and the argument that the use of a weather generator would compensate is not really true – systematic biases and random variations are not the same!

Reply: We agree with the reviewer that using an ensemble of climate models combined with a stochastic analysis would have given more insight to the analysis compared with the use of only one GCM and two RCMs. We are well aware of this, see also discussion in Fatichi et al. (2013, Climate Dynamics) We acknowledged and clearly discussed this problem in the manuscript (P3748 L17-P3749 L5). The decision on the driving climate models and emission scenarios was agreed within the scope of the EU funded ACQWA project with the purpose of having a coherent and uniform climate forcing throughout different studies.

Moreover, as we argued in the introduction, there is an increasing amount of evidence in literature that, especially for near future (up to 2050, as in the case of our study), internal climate variability is the most important source of uncertainty and can explain almost entirely the multi-model ensemble variability, especially for variable such as precipitation (e.g. Hawking and Sutton, 2011, Deser et al., 2012, Fatichi et al. 2013, and Deser et al., 2012b, Nature Climate Change). Therefore, we argue that the underestimation of the overall uncertainty using only three driving models plus stochastic variability is relatively minor in comparison to the use of an ensemble of GCM/RCM. There is also the possibility that for precipitation we even account for more uncertainty than that produced by multi-model ensembles, which do not typically account for stochastic variability.

Referee: *2) In this alpine catchments, the glaciers of course are crucial for the long-term changes in runoff. The area-thickness scaling approach used here to estimate ice-thicknesses seems a very crude assumption. Such equations might be useful at a larger scale, for which they usually have been derived but are in general not very satisfactory for smaller areas.*

Reply: The assumption related to the initialization of the ice thickness at the beginning of the simulations is indeed “critical”. This can have important consequences on the timing of glacier thinning (retreat) and ice melt reduction and in the occurrence of a more or less abrupt transition. If we overestimated the initial ice thickness we have delayed the glacier retreat. If we underestimated it, we have accelerated the process. The latter might be the case in our simulations but as shown by Gabbi et al., (HESS 16, 4543–4556, 2012) the acceleration is likely to be less than 10-15 years. In both cases, all the conclusions of the manuscript and especially the elevational dependence of climate change, remain valid but are just shifted in time by some years. Furthermore, because we do not aim at providing exact projections for specific years and we rather discuss the differential character of the response between high elevation and downstream rivers we are persuaded that this is not a crucial weakness of the study. We already explicitly mention this limitation in the original manuscript (P3769 L14-17). We will expand the discussion of the problem in the revised manuscript, to make sure that this limitation and its implication are clear to every reader.

In this respect, we would like to emphasize here that the size of the basic computational elements (grid elements), which were used in the hydrological simulations, is 250m x 250m. While this resolution can be considered very detailed for distributed catchment hydrology, especially for simulations at the scale of the entire upper Rhone (5338 km2), it is still far from allowing to solve features such as the heterogeneity of the ice thickness distribution. After discussing the problem with glaciologist working on this specific topic, and considering that detailed distributed maps of ice thickness for all the glaciers of the upper Rhone were basically unavailable (at least to us), we adopted what was considered the best compromise solution.

Referee: *3) The assumption of unchanged operation rules in the future (p3767) seems unrealistic if we assume runoff changes in the future.*

Reply: We fully agree that future energy demand (and market controls) might have an impact on reservoir operations and we will emphasize this point in the discussion by

adding an additional comment to the text (P3771 L4 –L7). However, the assumption of unchanged operational rules for the reservoirs was basically the only possible at the moment, without venturing into a speculative exercise that would not be more realistic than assuming unchanged operation. In order to get future operational rules we will need to know changes in the electricity market and changes in the energy policy of Switzerland (both rather uncertain). These changes will further interact with changes in the resource that our study has investigated. In the EU-ACQWA project, which has funded this study, there are partners that on the basis of our results will work to anticipate possible changes in hydropower operations. We are confident that on the basis of their results, additional investigations will address the combined effect of climate change and changes in reservoir operations as well as feedback mechanisms.

Referee: *Looking at the conclusions, I am also wondering about the exact novel contribution of this manuscript. The first conclusion, namely that hydraulic infrastructure has had a larger effect than climate change might have is in general not surprising, although a detailed discussion could be useful, but this comparison actually can’t be found in the manuscript! Also the conclusion on the importance of ice melt is not new and given the crude representations of glaciers I am not sure what new insights this study provides. My other concerns are the not fully satisfactory presentation and the lack of an uncertainty assessment.*

Reply: In addition to our reply to the reviewer’s opening comment we can summarize the novel contributions of this manuscripts as follows:

- We provide a quantification of the effect of climate change on a typical catchment of the Alpine region by means of simulations carried out through a fully distributed hydrological model. The simulations describe the basin response across the entire river network, from small headwater glacierized catchments to large catchments downstream, and thus allow to investigate *the differential effect of climate change with elevation and basin size* as measured by streamflow characteristics and other hydrological variables. Hence, the title of the manuscript.

- We provide, across more than 290 control points in the catchment (characterized by different elevation, drainage area, topography and fraction of glacierized area) *an estimate of changes of many metrics that were not typically presented before*, for instance, projected changes in maximum and minimum discharge, at various temporal scales up to the hourly one.
- We provide *an estimate of the uncertainty related to the stochastic variability of climate*, which we argue (timely with contemporary literature, see our reply above) to be, by far, the most important source of uncertainty in climate change effects on streamflow regime. The reviewer seems to neglect entirely this point when he/she asks for uncertainty assessment.
- We provide *a detailed and unprecedented implementation of the anthropogenic infrastructure and physical characteristics of the upper Rhone* from which we can simulate both the natural hydrological regime and that altered by the operation of hydropower systems (see Figure 4 in the manuscript), thus being able to investigate the net effect of the imposed human alteration and how this could be affected by climate change. In this regard the reviewer is correct in writing that we need to give more emphasis in the discussion to this point. We will.

To our knowledge all these points make this paper a very distinct and unique contribution in terms of both methodological approach and level of detail of the results.

Referee: *As already pointed out by referee #1 there are a number of small issues like places where the language needs to be improved or where the reader has to guess what actually has been done. For instance, it remains rather unclear how the factors of change have been derived (additive/multiplicative, seasonal variation, : : :..) how these change factors relate to the (which?) bias correction that apparently has been used. As a reviewer it is an awkward situation if you have to guess what might have done!*

Reply: We will account for most of the writing and stylistic comments of Referee #1 in the revised version of the manuscript. We recognize that in the effort of conveying to the reader just the most important information, without excessively increasing the length of the methodological part, we might have excluded some explanation that would have facilitated the understanding of the manuscript. However, the stochastic downscaling methodology is described in Bordoy (2013) and in Bordoy and Burlando (2013b, under review but it will likely be available soon), both cited. We will provide additional information in this manuscript (e.g., the factors of change are computed for each month as ratio between statistics of precipitation and air temperature at different temporal aggregations simulated by the RCMs/GCMs for the control and future scenarios) although we believe that a detailed description of the downscaling methodology is not strictly necessary in this paper, as it might distract the reader from the main message we are conveying.

Referee: *The authors argue against model calibration. Even if model parameters in TOPKAPI have a physical meaning, many of them (such as the degree-day melt factor or the outflow coefficient of the linear groundwater reservoir) are not measurable at the catchment scale. The argument that automatic calibration would result in a poor parametrization might be valid if one would calibrate looking only on something like the RMSE of runoff. The advantage of manual calibration is that hydrological understanding can be considered, but this understanding can to some degree also be considered in automatic calibration if the objective function is formulated in a good way. Using automatic calibration would require to explicitly state the calibration criteria (which actually would be quite useful). A somehow automated calibration approach would also have the benefit to allow for an uncertainty assessment, which is largely missing so far.*

Reply: We believe that including hydrological understanding in automatic calibration would be rather difficult and it would be mostly difficult to eliminate the “calibration bias” toward over-weighting model performance on streamflow, rather than on other processes for which observations are unavailable.

In this specific case, given the remarkable influence of the extensive anthropogenic infrastructure, we are convinced that automatic calibration cannot add anything to the correct description of the hydrological functioning of the basin. Since, we are using the model to simulate relative changes induced by a modified climate forcing rather than to mimic perfectly the observed streamflow values, we are firmly convinced that it is scientifically more sound to make a "best" expert choice of the parameters given the available data and information than relying on automatic calibration. This position is based also on several investigations that were carried out in our research group on model calibration strategies (e.g., Foglia et al., 2009; Water Resour. Res., 45, W06427; Finger et al., 2011, Water Resour. Res., 47, W07519), and on a recent (unpublished) comparison of our "best" expert choice with a sophisticated automatic calibration of Topkapi-ETH. This was carried out for a natural catchment located near the upper Rhone, required several weeks of computational time and showed that the performance improvement after automatic calibration was absolutely marginal and unjustified.

Finally, with regard to the quantification of uncertainty of model parameters, we are confident that this would be rather small when compared to the uncertainty induced by stochastic climate variability.

Referee: *To summarize, while the authors put great efforts into their model development, the manuscript in its present form is lacking a clear focus. As outlined above, there are possibilities to go into different directions and if the authors can address all the concerns expressed above and by the other more detailed comments, the manuscript might make an interesting contribution. In its current form, however, I have to admit that I do not really see, what exactly the scientific contribution of this manuscript is (i.e., what have we learnt by this study?).*

Reply: At several instances in our reply we have express the elements that, on our opinion, characterize the *scientific added value* of the manuscript. We would like to add that the study has also a practical added value, since the results presented in this manuscript are the driver of several impact studies within the EU ACQWA project. If

the reviewer is aware of publications that we overlooked and provide similar or superior contribution with respect to the investigated research questions, we are glad to include them in our discussion. However, we think the reviewer is at variance with the state-of-the art on the topic, which is characterized by contributions, even recently published, that have a more local scope than our (e.g., Rossler et al., 2012; Uhlmann et al., 2012; Finger et al., 2012; Farinotti et al., 2012) or simply advance hypotheses on possible changes in the hydrology of the upper Rhone explicitly demanding for additional quantitative and distributed analysis as the one we presented (Beniston, 2012, recently published article in Journal of Hydrology).

References

Beniston, M., (2012) Impacts of climatic change on water and associated economic activities in the Swiss Alps, J. Hydrol., 412-413, p. 291-296,

Bordoy, R. and P. Burlando (2013a) Bias correction of a Regional Climate Model in a region of complex orography, J. Appl. Meteor. Climatol., 52(1), pp. 82-101,

Bordoy, R. and P. Burlando, (2013b) Stochastic downscaling of precipitation to high-resolution scenarios in orographically complex regions. Part 2: Downscaling methodology, Water Resour. Res., in review.

Bordoy, R., (2013) Spatiotemporal downscaling of climate scenarios in region of complex orography, PhD thesis 21201, ETH Zurich, Switzerland.

Deser, C., Phillips, A., Bourdette, V., and Teng, H. (2012) Uncertainty in climate change projections: the role of internal variability, Clim. Dynam., 38, 527–546,

Deser, C., R. Knutti, S. Solomon, and A. S. Phillips (2012b), Communication of the role of natural variability in future north american climate, Nature Climate Change, 2, 775-779.

Farinotti, D., Usselmann, S., Huss, M., Bauder, A., and Funk, M., (2012) Runoff evolution in the Swiss Alps: projections for selected high-alpine catchments based on

ENSEMBLES scenarios, Hydrolog. Proc., 26, 1909–1924.

Fatichi, S., Ivanov, V. Y., and Caporali, E. (2013) Assessment of a stochastic downscaling methodology in generating an ensemble of hourly future climate time series, Clim. Dynam., 40 1841-1861, doi:10.1007/s00382-012-1627-2,.

Finger, D., F. Pellicciotti, M. Konz, S. Rimkus, and P. Burlando (2011), The value of glacier mass balance, satellite snow cover images, and hourly discharge for improving the performance of a physically based distributed hydrological model, Water Resour. Res., 47, W07519.

Finger, D., Heinrich, G., Gobiet, A., and Bauder, A., (2012) Projections of future water resources and their uncertainty in a glacierized catchment in the Swiss Alps and the subsequent ef- fects on hydropower production during the 21st century, Water Resour. Res., 48, W02521, doi:10.1029/2011WR010733

Foglia, L., M.C. Hill, S. Mehl, P. Burlando, (2009) Sensitivity analysis, calibration, and testing of a distributed hydrological model using error-based weighting and one objective function, Water Resour. Res., 45, W06427, doi:10.1029/2008WR007255

Hawking, E. and Sutton, R. (2011) The potential to narrow uncertainty in projections of regional pre cipitation change, Clim. Dynam., 37, 407–418, doi:10.1007/s00382-010-0810-6.

Rossler, O., Diekkruger, B., and Loffler, J., (2012) Potential drought stress in a Swiss mountain catch- ment – ensemble forecasting of high mountain soil moisture reveals a drastic decrease, de- spite major uncertainties, Water Resour. Res., 48, W04521, doi:10.1029/2011WR011188

Schaefli, B., Hingray, B., and Musy, A. (2007) Climate change and hydropower production in the Swiss Alps: quantification of potential impacts and related modelling uncertainties, Hydrol. Earth Syst. Sci., 11, 1191–1205, doi:10.5194/hess-11-1191-2007,

Gabbi J. D. Farinotti, A. Bauder and H. Maurer (2012). Ice volume distribution and implications on runoff projections in a glacierized catchment Hydrol. Earth Syst. Sci., 16, 4543–4556

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