

## ***Interactive comment on “Impacts of climate change scenarios on runoff regimes in the southern Alps” by S. Barontini et al.***

**S. Barontini et al.**

barontin@ing.unibs.it

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### **General comments**

As the Anonymous Referee #1's comment, posted on 29 April 2009, is more likely to address the revision of the article, and not only a comment, we will surely keep into account, discuss and integrate in the article most of the suggestions provided, after we will receive the other Referees' and the Editor's comments. Here we will provide some comments, with specific replies to some key topics.

- Our work is focused on the evaluation of the change in the runoff regimes at the monthly scale which are strongly influenced by circulation patterns at the C1036

global and synoptic scale. Also, the scale of most RCMs which are being used only in recent years for climate impact studies is of the order of some tens of kilometers (see Christensen & Christensen, 2007), which is too coarse at least for the Lys target area and its two basins. Even with an RCM downscaling of precipitation and temperature would have been necessary and thus we preferred to start from GCMs data we had access to when we started our research and decided to downscale these results to the scale of interest, by means of the data we collected at a regional and local scale. In any case the use of GCM as meteorological forcing to hydrological model in basin similar to those investigated is still a standard practice Stahl et al. (2008) use the CGCM3 for IPCC AR4 to force the HBV model for a glacierized basin 152.4 km<sup>2</sup> in size. See also the reply posted to Referee #2 for a more detailed discussion.

- Temperature and precipitation data are the most easily-to-obtain data for long series in most of the meteorological stations, and particularly they were the available data we collected (Page 3098, line 21–23) over a sufficiently dense network for our target areas. Otherwise this choice merges with the methodological aim of our article. The modelling approach adopted which is temperature-based for both evapotranspiration and melting does not allow therefore to check the effect of other meteorological variables in the future scenarios.
- The Kuhn's equilibrium line concept is used to assess the areal extent change under quasi-stationary conditions, i.e. assuming that over the simulation period the glacier's size will remain constant. But because glacier's melt is computed according to the melt factor method if the mass balance will be negative future runoff will increase accordingly. So we do not expect systematic underestimation of runoff from glacierised areas. In the Oglio basin the glacierized area is just 0.6 % of the total area, one of the major glacier is a plateau glacier for which depth changes are expected more than areal changes. Another glacier, Venerocolo, is a debris covered glacier and also for it areal changes are expected to be slower

than in other white glaciers. So for the Oglio basin the impact of glacier's runoff on total runoff is negligible and we focused our discussion on evapotranspiration losses. For the Lys at Guillemore (8% glacierised) and Lys at Lake Gabiet sub-catchment (20% glacierised) the role of glacier's melt changes is more important. Because of lack of space we did not present data about Lys so in detail as for the Oglio basin. However in Figure 7 it can be observed that, for Lake Gabiet subbasin, runoff volumes in MJJA will decrease of 15 mm for 2050 compared to control PCM runs, and for the 2090 scenario MJJA runoff will be 116 mm lower than in the control run.

- For both the Oglio and the Lys basin the effect of climate change on glacier storage of water is taken into account because at higher temperatures the runoff volume is higher. In the final version of the paper we will better comment on the influence of glacier storage on total runoff for the Lys basin. We are still convinced that at a climatic scale the main effect on the reduction of the runoff for the target areas is to be mainly related to the evapotranspiration losses, and these, in our model, are strongly related to the increase of the average temperature.
- We can certainly improve our English, but the Editor was not much concerned in this issue.

### Specific comments

- **Page 3091, line 5, Page 3097, line 8–27, and Page 3101, line 6–10:** To cite exceptions, as well as to review IPCC–emission scenarios or just citing techniques of temporal–downscaling of the GCM, does in our opinion merge with the practical intent of the article. Anyway we will account for the suggestion of reducing these points.
- **Page 3091, line 20 and Page 3096, line 15:** Water equivalent mass loss and  
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total runoff are intended as areal specific contribution and therefore measured in millimeters.

- **Page 3093, line 8:** With 'autumn freezing' we mean the soil and water freezing that, in our target areas, starts in autumn.
- **Page 3094, line 18/20:** If we properly understand the note, they are not uncertainties, as addressed by the Referee, but two distinct percentages. Respectively they are in fact, the first, the contribution of two hydropower systems to the national hydropower production, and, the second, this latter one's contribution to the total national energy production.
- **Target areas:** In the two target areas, corresponding with the two main basins of the Oglio river at Sarnico and of the Lys river at Guillemore, three reference gauges were identified: Sarnico, Guillemore and Gabiet, the latter within the Lys basin. We did not intend to address the basin upstream Lake Gabiet (a subbasin of Lys at Guillemore) as an additional third target area because it was studied jointly and with the same criteria we used in the context of the study of the Lys catchment at Guillemore.
- **Page 3098, line 17, Page 3116, line 19:** We will provide further details in the final paper. Now we can anticipate that we collected data from 19 stations (19 raingauges, 12 max–min thermometers, 7 gauges of the snow–height and of reservoir storage) within the Oglio river basin and from 2 (precipitation, max–min temperature, snow–height and reservoir storage) within the Lys river basin, for the period 1970–2000. We collected the runoff data at the outlet of the 2 basins and at the third considered section at the outlet of Lake Gabiet. Due to the consistency of the data collected, some stations of the Oglio river basin were not used in the analysis.
- **Page 3098, line 18:** It refers to a time averaging (of the values projected at the  
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GCM grid cell). The considered grid cells are reported in Fig. 1.

- **Page 3100, line 15:** After discussing the projections of different GCMs for different scenarios, we selected PCM–A2 scenario for the hydrological simulations in order to evaluate the most significant changes in the hydrological forcing. This choice was due to the fact that PCM better performed in representing the control period climate, and A2 scenario is considered as a 'pessimistic' one in terms of GHG emissions and climate feedback. In the final version of the paper this choice will be explained more in detail.
- **Page 3103, line 18:** No correction was applied for liquid precipitation. It was considered of minor importance compared to the correction for the solid precipitation we applied. Often in the hydrological literature and also in climatological studies this correction is not applied.
- **Page 3111, line 8:** The two step downscaling procedure provides a time series for each of the considered raingauges: this aspect is pointed out at Page 3102, line 14–17.
- **Page 3112, line 14:** As acknowledged also by Referee #2 our adaptation of the tree–line to climate change is not usual in hydrological impact studies. We did a little step forward. The investigated basins are characterised by steep slopes and bare rocks above the pasture line at about 2600 m a.s.l. for both the target areas. Above this line the hypsometric curve is very steep, and the outcropping rock colonization by the grass is difficult, therefore any short– or medium–term change in the vegetation at these altitudes cannot in our opinion significantly affect the evapotranspiration losses of the basin.
- **Page 3112, line 24:** We agree with the Referee about the importance also of the precipitation amount and regime on the vegetation feedback to a climate

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change. Anyway we drove the attention on vegetation in general, and particularly on timber vegetation, but not on particular species, therefore we think that our approximation can be considered reliable.

- **Page 3112, line 28:** The same correction was applied to both the scenarios as, keeping into account all the approximations implicit in the procedure, no matter was found to discriminate between the two future scenarios, but only between the historical one and that of the 2nd half of the century. We will clarify the sentence in the final version of the paper.
- **Page 3113, line 1:** Maybe we did not understand properly, but from our experience (also on the field) on the glaciers of the Italian Alps an increase of the Equilibrium Line Altitude (ELA) is much more likely followed by a reduction and not by an increase in the area. Paul et al. (2007) report the same result in Table 2 for Swiss glaciers in 24 combinations in ELA0 changes and AAR0 values.
- **Page 3113, line 3:** For the Oglio catchment because of the small size and the geomorphological context of the glaciers (see above) their size was not updated. The size was update in the more glacierized Lys at Lake Gabiet and Lys at Guillemore.
- **Page 3113, line 15:** In the comment to their equation 2, Ohmura et al. (1992) say that "the effectiveness of precipitation change is not so large (...). This means that a change in precipitation of 300–400 mm w.e. corresponds to only 1°C temperature change.". The slight increase of precipitation predicted by GCM will be compensated by the lower fraction of solid precipitation and so the overall impact on the ELA changes is expected to be minor.
- **Page 3113, line 19:** Yes, for sure glaciers are not expected to reach equilibrium states throughout the 21st century. The areal change we project will be assumed

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constant within the 20 years simulation window only. Over that period ice melt can reduce the glaciers' water storage.

- **Page 3113, line 20:** We know that the Kuhn's concept was intended to estimate the dynamics of the equilibrium line and not of the terminus, and we applied it in a non-standard way: first we preferred it to other criteria, because it has a sounder theoretical background than other semi-empirical methods and because it is somehow a 'classical' method. We used the Kuhn's ELA change as an index for terminus altitude change on the following considerations. The change in the elevation of the glacier's terminus and area depends also, along with other factors, on the Accumulation Area Ratio (AAR) and on the time response of the glacier's volume which is much slower than the ELA changes. The lower the AAR the higher is expected to be the rise of the terminus altitude and the areal reduction. However for the Lys glacier the terminus altitude in the mid 80s WGI archive was 2350 and it was still 2354 from aerial surveys in 2003. This demonstrates a low time response of glacier's terminus and a relatively slower rate of the glacier retreat compared to other areas of the Alps (e.g. in the south-eastern part). Similar lower glacier retreat rates are documented by Paul et al. (2007, Figure 3) who show that the group of Swiss glaciers across the Lys watershed divide have the lowest percentage of disappearing glaciers for the 2035 scenario the Authors assumed. Also Kappenberger (personal communication) documented for recent 'critical' years also for the Basodino glacier in the nearby Swiss Ticino a relatively 'healthy' condition and it can be a result of the slight increase of the precipitation in the last decades in this area (Auer et al., 2007). So to take into account these experimental evidences we applied the same elevation rise of the ELA to the terminus. We applied the corresponding area reduction which would result of about 1 km<sup>2</sup> (about 10% of the total) referred to the 2003 total glacierized area, with a total area reduction of more than 20%, compared to the WGI data. We applied the same glacier reduction to 2050 because the 1 km<sup>2</sup> resolution of the model

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cannot discriminate the 2050 and 2090 projections.

- **Page 3113, line 22:** Paul et al. (2007) report that "for Alpine glaciers ELA sensitivities from 100 to 170 m per °C have been found". Beniston (2000, p. 106) suggested for the snow line a rise of 150 m every 1°C increase in the mean temperature. Our 240 m increase of ELA and terminus is consistent with these results.
- **Page 3113, line 24:** The projection was done for 2090 with an average air temperature increase of 2.4°C. The glacier extent was computed for the climate at the end the century, with a reduction of 30% compared to the WGI area. The ELA and terminus altitude change was computed starting from the 2003 aerial survey done by CESI which indicated a decrease of area of about 1.7 km<sup>2</sup> out of the WGI 11.8 km<sup>2</sup> for the the Lys glacier. The difference in the terminus altitude was of a few meters compared with the 2350 m a.s.l. reported by WGI (also courtesy of G. Diolaiuti, University of Milan). This experimental evidence for the Lys glacier supports the hypothesis we adopted of a slower time response of the terminus line altitude and areal change than ELA changes when applying the Kuhn's concept. Starting from the 2003 aerial survey the projected glacier extent was about 30% less than the control conditions, for a glacierised area which is 8% of the total basin area of Lys at Guillemore we report about in our conclusions.
- **Page 3114, line 9:** The dimension of a Group Response Unit may vary from one fourth to 1 km<sup>2</sup> as the computational grid cell was 1 km and the landuse information was available on a 500 m grid. All the landuse cells having similar hydrological behaviour are grouped into one unit, the size of which depends on how many cells are grouped together. Units are considered to be independent from each other, as far as runoff generation is concerned. The computed runoff from a grouped set of pixels within a grid cell is then routed by a two step procedure, first overland flow to the channel system and second, channel flow to the

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next grid cell.

- **Page 3114, line 20:** We confirm the methodology we applied enables the glaciers to be depleted by higher temperatures thus providing runoff for the two future scenarios.
- **Page 3115 line 11:** Radiation here has the same units as the evaporation rate because the power units ( $W m^{-2}$ ) have already been converted into a specific volume of water (mm) that can evaporate in 24 hours (one day) at the same constant power.
- **Page 3115 line 15:** Terrestrial radiation can be computed with trigonometry but an empirical simplification is used here. We agree with the author that 'empirical relations' is not a correct wording here: more suitable words will be used in the revised version of the paper.
- **Page 3116, line 14:** A 1 km–DEM resolution was considered suitable for our purposes, also on the basis of sensitivity analyses to grid size of an energy-balance model we applied on a 7 km<sup>2</sup> Alpine catchment (Ranzi & Rosso, 1991). The fact that the major glaciers in the Lys basin are nearby one another was accounted for this choice.
- **Page 3117, line 8:** Snowfall is computed at each time step on the basis of the observed total precipitation and air temperature. Snow and ice melting is computed on the basis of a degree–day procedure. In WATFLOOD, snow–free and snow–covered areas are modelled separately. Initially, for a deep snow pack, 100% of the area will be covered but as the snow melts, bare ground will appear. Following this, energy to melt snow is applied only to the snow covered area. The temperature index algorithm used in the WATFLOOD/SPL9 is based on the National Weather Service River Flow Forecast system by Anderson (1973). The well–known algorithm is used in many operational models and is given by

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$M = M_F(T_a - T_{base})$ , where  $M$  is the daily snowmelt depth (mm),  $M_F$  is the melt factor, rate of melt per degree per unit time ( $mm\ ^\circ C^{-1}\ h^{-1}$ ),  $T_a$  is the air temperature ( $^\circ C$ ), and  $T_{base}$  is the temperature at which the snow begins to melt ( $^\circ C$ ). For our applications a snow melt factor of  $0.2\ mm\ ^\circ C^{-1}\ h^{-1}$  and an ice melt factor of  $0.3\ mm\ ^\circ C^{-1}\ h^{-1}$  were used.

- **Page 3117, line 22:** The attention is here driven to the month of March because it is the month of minimum measured runoff and it was therefore important in order to assess the slow components of the runoff process.
- **Page 3117, line 27:** It is the Pearson  $r$ –correlation coefficient.
- **Page 3118, line 2:** Some parameters, for instance hydraulic conductivity at soil saturation, were chosen as a first trial on the basis of field and laboratory measurements (see e.g. Barontini et al., 2005, 2009 for the Oglio basin, where about one hundred of sites were sampled) and maps derived from pedotransfer functions: for the Lys basin, as reference values we used those obtained from the Benoit et al. (2003) WATFLOOD simulation of the Toce basin, a neighbour basin to the Lys one. Other calibration parameters, as the upper soil layers water storage, the lower soil layers water storage, just to say a few besides those cited at Page 3116, line 25–26, were chosen, as a first trial, after the literature and the model manual suggestions. Then the calibration by trial and error of the parameters was performed until the timing and intermittency of the peaks, the runoff volumes and the recession limb of the low flows were satisfactorily reproduced. The sensitivity of the model to the calibration of some parameters was not found to be strong if referred to the goals of our simulations. Therefore we omitted to present them. The strongest sensitivity was found instead to the upper soil layer conductivity at saturation and to the snow–melting factor: the final obtained values are reported at Page 3117, line 3–10.
- **Page 3121, line 14:** As we stated at Page 3121, line 7–9, we are aware of the

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fact that uncertainty can exceed the 'output' signal of the impact study, but the decrease of the runoff and the change of regime indicated in our opinion a future tendency of the data. We will better explain in the final version of the paper.

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