

Interactive comment on “Climate change over the high-mountain versus plain areas: Effects on the land surface hydrologic budget in the Alpine area and northern Italy” by Claudio Cassardo et al.

Claudio Cassardo et al.

spark@ewha.ac.kr

Received and published: 27 January 2018

Reply to the Comments by Referee #3 for Manuscript hess-2017-569

General Comments: *The paper presents assessment of changes of land water budget terms in Northern Italy under future climate changes. The regional climate model RegCM3 simulations are used as a forcing for the land surface scheme UTOPIA. The modeled seasonal and spatial patterns of precipitation, evapotranspiration, runoff, soil storage, net radiation are examined, and implications for regional economies are formulated.*

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⇒ We appreciate the referee for careful reading and valuable comments, which helped us improve the manuscript significantly. We have revised the manuscript substantially, following the referee's comments/suggestions. Please find our item-by-item responses to the referee's comments below.

Major comments:

1. *There is no proper comparison of results obtained to other similar studies conducted for this region, elucidating what is the new knowledge attained. Some of other relevant papers are cited (Lautenschlager et al., 2008; Jacob et al., 2007), but the comparison is very limited.*

⇒ We have included statements showing the consistency between our results with previous studies, specifically over the region of our study (i.e., generally Europe including the Alps and northern Italy), by referring to more relevant references. We actually added a separate subsection dedicated to this matter in Sec. 4 of the revised manuscript (see **4.4 Comparative discussion on previous works**).

⇒ In terms of the new knowledge attained, we also have replied to the other referee's comment (Major comments #4 by Referee #1), and it is repeated here:

We admit that there exist several previous studies on the climate projections and related hydrologic changes around the Alps, using GCMs and/or RCMs; however, none of them studied projections of full water cycle by assessing all hydrologic components — precipitation, evapotranspiration, runoff and soil moisture — as in our study. Most of the previous

studies focused on just some specific component(s) of water cycle, e.g., precipitation and/or surface runoff. For instance, Giorgi and Lionello (2008) studied climate change projections for the Mediterranean region, focusing on precipitation and temperature; Coppola et al. (2014) studied the impact of climate change on the Po basin, addressing discharge; and Torma et al. (2015) carried out ensemble RCM projections over the Alps, centering about precipitation. Compared to other previous studies, we think that our study is more exhaustive and has its own uniqueness: our study provides more complete analyses on all hydrologic components, including soil moisture, for both reference climate and future projections. Furthermore, with a companion paper on the land surface energy balance, we provide discussions on the linkages between the hydrologic and energy components. These enable us to better quantify some significant variations in the frame of changing climate in the Alpine area, in which the climatic change shows a larger variability. We have addressed these points adequately in the revised manuscript, which mostly appear in Sec. 4.4.

2. *The physical analysis of simulation results is somewhat superficial. The simple effects are explained, whereas the more complicated ones (like the absence of spatial correlation between evapotranspiration and precipitation, lines 1-4 on p.7) are commented by too general statements. In this respect, the striking separation of regions with large dry and wet days numbers anomalies at Figure 7 is left without deserving physical analysis (lines 25+, p.7 are merely descriptive text).*

⇒ We appreciate the referee for pointing this out. In the revised manuscript, we have tried to include more physical interpretations in our results. For example, for Fig. 7, we may extend the analyses and interpretations in previous figures: Overall, in the plain areas including the Po Valley, ΔET is positive while ΔPR is weekly negative and ΔSM is moderately negative (especially

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during summer as in Figs. 2 and 3). With more significant overall increases in NR over plains, the combined effect will bring about larger evaporation and lower soil moisture, thus overall increase in the number of dry days, mostly attributed to much drier climate in summer. Meanwhile, over the high-mountain areas, PR, SR and SM increase while ET shows little variation in spring and winter (see Figs. 4 and 5). As SM is large over high mountains, we have more source of atmospheric moisture through evaporation there. Then, through the combined effect of terrain-induced convective motion, increase in NR (though less significant) and pre-existing snow, we can have more snow melting (during spring) and more liquid precipitation (especially during winter), resulting in more wet days, again mostly attributed to much wetter climate in winter. Such kind of discussions with physical interpretations are appropriately added in the revised manuscript.

3. *No general description of UTOPIA model is provided together with necessary references to previous work, where the model has been shown to be robust for the particular region under study.*

⇒ We appreciate the referee for pointing this out. Although UTOPIA was shortly described in Section 2 of the original manuscript, we agree with the referee on this point. In the revised manuscript, we have substantially amended this part by separating the original section “**2 Models and experimental setup**” into two independent sections as “**2 Description on models**” and “**3 Experimental design**”; then, in the updated Section 2, we included 2 subsections that are dedicated to RegCM3 and UTOPIA, respectively, by describing the main characteristics of the models in more detail. We have also added a paragraph that cite relevant references to previous work, where UTOPIA has demonstrated its robustness for the region of our study.

Specific comments:

1. *The period 1961-1990 is hardly can be used to reflect “present climate”. The period 1980-2010 is more appropriate.*

⇒ We generally agree with the referee about this point, and it is common nowadays that the climatological 30-year statistics are updated every ten years. However, the former period 1961–1990 still remains the official normal period defined by WMO, and numerous previous studies on climate change projections/impacts, including several projects (e.g., CMIP3/CMIP3, PRUDENCE, ENSEMBLES and CECILIA), employed this period as “present climate” (or control/reference/baseline period), even most recently (e.g., to mention just a few, Giorgi and Lionello, 2008; Smiatek et al., 2009; Ciscar et al., 2011; Kyselý et al., 2011; Torma et al., 2011; Heinrich et al., 2014; Perez et al., 2014; Skalák et al., 2014; Belda et al., 2015; Dunford et al., 2015; Faggian, 2015; Casajus et al., 2016; Harrison et al., 2016; Gang et al., 2017; Paeth et al., 2017). Furthermore, as requested by the referees, we need to make comparisons between our results and previous studies over the region of current study. For this purpose and fair comparisons, we need to keep consistency with the period that represent “present climate” (i.e., 1961–1990) in many previous studies. On the other hand, we agree with the referee that this period may not reflect “present climate” in practical sense; thus we decided to define it as “reference climate”, which can be acceptable in general sense. We have modified “present climate (PC)” to “reference climate (RC)” in the text and figures in the revised manuscript. This issue is now addressed at the beginning of Sec. 3.

2. *p.3, line 30. There seem to be no physical reason for interpolating in time the precipitation and radiation fluxes by different methods. Does cubic spline interpolation conserves the sums of radiation fluxes? Were the output radiation data from RegCM3 presented as accumulated radiation sums or as fluxes?*

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⇒ We applied the cubic spline to the non-intermittent variables like temperature, humidity, and radiation (flux), whereas we simply redistributed the intermittent variable, e.g., precipitation to keep its sum. There is a reason for having used different methods for radiation and precipitation: the input data of precipitation was the precipitation cumulated over the timesteps of the RCM output, and this datum cannot be interpolated with splines. Of course, we could have converted precipitation to precipitation rates, interpolated them using splines, and then reconverted to cumulated precipitations over the smaller timestep of UTOPIA. However, the result of such a complicated procedure was almost equivalent to using the method described in the text. Regarding radiation, we used the splines for the sake of uniformity with other variables (wind components were also interpolated in this way). We further controlled some unrealistic values (e.g., negative radiations): we controlled the daily means (or cumulated values) of input data (from RegCM3) and output data (for UTOPIA) from the spline interpolation method to be equivalent, with positive or null values. We have addressed these points in the revised manuscript.

3. *p.4, line 1. "Short grasses are assumed to cover the whole domain". Not clear. Where there any other vegetation types in the domain?*

⇒ The domain includes the Alps, the Apennines, off-alpine and hilly areas, and plains; thus there is a wide range of vegetation in the domain. Regarding plains and hilly areas, vegetation includes pastures, grasslands and some forested areas: mountain areas are mostly covered by trees, and the highest parts are without vegetation or covered by permanent ice (few grid points). We decided to set the vegetation type equal for all grid points (i.e., short grasses) for the following reasons: 1) for the "reference climate", to avoid any problem in interpretation of results due to the differences in vegetation; and 2) for the "future climate", to alleviate the uncertainty in vegetation type

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at the end of 21st century. In terms of meteorological variables, this is not a bad assumption because most observation stations are normally installed over short grasses.

By the way, in terms of plant height, root depth and vegetation characteristics, short grasses can be roughly regarded as most common cereals (wheat, maize, etc.), and would not be quite different from such kind of agricultural products. Finally, we have also performed simulations using the “true” vegetation (as deduced by detailed databases), and the results with the pastures and agricultural areas have generally been confirmed, though the numerical values of the variables were slightly different. Unfortunately, we did not publish papers about this topic yet. We have addressed these points in the revised manuscript.

4. *The authors confined their analysis of soil moisture changes to examination of the water content of the top 5-cm-thick layer of the land model. Why not considering the whole root-occupied layer?*

⇒ Actually, for the short grass vegetation category considered in these simulations, the root layer is only 5 cm deep, as the grass is only 10 cm high. Despite this value seems too low, it represents the typical height for the landscapes of Italian Po valley (at least in its portion occupied by natural vegetation). Furthermore, the upper soil layer represents the greatest effect of the atmosphere-land surface-soil interactions. Given that we are interested in the present vs. future hydrologic budget components, we decided to focus on the top soil layer. More specifically, we wanted to show the water content of the soil layer that represents the largest variations of moisture: it is subjected to direct evaporation, to the transpiration from vegetation roots, to the gravitational drainage to the second soil layer, to the capillary suck of moisture from the second soil layer, and finally to the eventual precipitation, eventual vegetation drainage, and eventual snow runoff. In other occasions,

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we have also analyzed the behavior of the full root zone layer, and/or of a deeper portion of soil; however, we noticed that the behavior of the upper portion of soil can also give a qualitative and quantitative idea of what is happening in the deeper soil. Last but not least, if we consider deeper portions of soil, the behavior can differ depending on the soil property such as hydraulic conductivity: soil with a large clay component creates a larger vertical moisture gradient than that with a large sand component. We have addressed these points in the revised manuscript.

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