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Hydrology and Earth System Sciences Discussions

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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.

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Reply to the Comments by Referee #1 for Manuscript hess-2017-569

We greatly appreciate the referee for thorough reading of the manuscript and valuable comments, which resulted in significant improvement of our manuscript. We have substantially revised the manuscript, following the referee's comments/suggestions. Below please find our item-by-item replies to the referee's comments.

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Discussion paper

Major comments:

1. *The paper lacks any comparison with other papers. What is improvement in using the PRUDENCE output with respect, say, to other global and regional Earth system models? I guess, at least some comparison with the CMIP3/CMIP5 simulations should be included.*

$\Longrightarrow$ We appreciate the referee for pointing this out. Although we have included some references related to this matter in the original manuscripts, we tried to include more relevant references in the revised manuscript, focusing on regional climate modeling over Europe and/or Italy. In this context, we added the following paragraphs by distributing to adequate positions in the revised manuscript (mostly appear just above Sec. 2.1), which include general overviews of CMIP3/CMIP5 and PRUDENCE, and summarized the previous studies that addressed the relevance of PRUDENCE in evaluating the regional climate and compared outputs from PRUDENCE and CMIP3:

> In recent decades, the coupled atmosphere-ocean general circulation models (GCMs) improved significantly, and standard protocols of numerical climate model experiments were developed in the Coupled Model Intercomparison Project (CMIP) Phase 3 (CMIP3; Meehl et al., 2007); the CMIP3 dataset provided the scientific basis for the IPCC Fourth Assessment Report (AR4) based on the Special Report on Emissions Scenarios (SRES) emission scenario. The CMIP Phase 5 (CMIP5) dataset (Taylor et al., 2012) was developed based on the Representative Concentration Pathways (RCP) scenario that considers radiative forcing due to greenhouse gas concentration, and contributed to the IPCC Fifth Assessment Report (AR5).
>
> Usually GCMs are calculated in relatively coarse grid spacings; thus representing the regional topography and climate inappropri-

ately (e.g., Bhaskaran et al., 2012). Therefore, downscaling of the GCM variables to regional scale is necessary for better depiction of regional climate: the dynamic downscaling uses regional climate models (RCMs) with a higher resolution (typically 10–50 km) and the same principles of dynamical and physical processes as GCMs (e.g., Wilby and Wigley, 1997; Christensen et al., 2007; Jury et al., 2015). It is demonstrated that RCMs significantly improves the model precipitation formulation (e.g., Frei et al., 2006; Gao et al., 2006; Buonomo et al., 2007; Boberg et al., 2009). In this context, an interdisciplinary project, called the Prediction of Regional Scenarios and Uncertainties for Defining European Climate Change Risks and Effects (PRUDENCE), had been undertaken aiming at providing high resolution climate change scenarios for Europe at the end of the 21st century via dynamical downscaling of global climate simulations (Christensen et al., 2007). Déqué et al. (2005), in comparison of results from GCMs and RCMs for the IPCC A2 radiative forcing, found that GCMs and RCMs behave similarly for the seasonal mean temperature with higher spread in GCMs; however, during summer, the spread of the RCMs — in particular in terms of precipitation — is larger than that of the GCMs, which indicates that the European summer climate is strongly controlled by parameterized physics and/or high-resolution processes. They also concluded that the PRUDENCE results were confident because the models had a similar response to the given radiative forcing.

In this study, we have employed RegCM3 from the PRUDENCE project to provide meteorological inputs to UTOPIA. Déqué et al. (2007) showed that, despite some uncertainties due to errors in sampling, model, and boundary and radiative forcings, the signal from the PRUDENCE ensemble is significant in terms of the minimum expected 2 m temperature and precipitation responses for the IPCC A2 scenario. Jacob et al. (2007) demonstrated that RCMs in PRUDENCE generally reproduce the large-scale circulation of the driving GCM. Coppola and Giorgi (2010) assessed the 21st century climate change projections over Italy from the CMIP3 global and PRUDENCE regional model experiments, and found a broad agreement between the projections obtained with the CMIP3 and PRUDENCE ensembles. They also made a fine-scale (20 km) single model experiment using RegCM3, and found that the temperature biases of RegCM3 simulation are in line with those found for the individual PRUDENCE model simulations and both the temperature and precipitation changes through RegCM3 are in accordance with the CMIP3 and PRUDENCE results. These studies indicate that results from the PRUDENCE and CMIP3/CMIP5 experiments are roughly equivalent for the Mediterranean region and the Alpine sector.

$\Longrightarrow$ We also included statements showing the consistency between our results with previous studies, specifically over the region of our study (i.e., 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**).

2. *How specific are the UTOPIA simulations with respect to other land surface models? At least, some peculiarities of this model should be discussed in the context of other land surface models.*

$\Longrightarrow$ Although UTOPIA was shortly described in Section 2 of the original manuscript, we agree with the referee on this point. In the revised

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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.

3. *Why the CMIP3 scenarios SRES A2/B2 are used? Now they are superceded by the RCP scenarios family.*

$\Longrightarrow$ As the referee has remarked, the SRES scenarios are now superceded by the RCP scenarios; however, it does not necessarily mean that the SRES scenarios are useless or wrong. Furthermore, both scenario families are not completely different but have somewhat similar features. We included the following statements concerning about this issue adequately in the revised manuscript:

> Riahi et al. (2011) mentioned that SRES A2 is comparable to RCP 8.5. Ward et al. (2011) found that the RCP 4.5 and SRES B1/A1T scenarios are broadly consistent with the fossil fuel production forecasts at that time. Rogelj et al. (2012; R12 hereafter) pointed out that the RCP scenarios span a large range of stabilization, mitigation and non-mitigation pathways, resulting in a larger range of temperature estimates than the SRES scenarios, which cover only non-mitigation scenarios (see Table 2 in R12); thus the SRES scenarios can be considered as a subset of the RCP scenarios in the context of global temperature projections by the end of the 21st century. They also indicated that the quantitative analysis of the differences between RCPs and SRES is hardly affected at all, and pairs with similar temperature projections over the 21st century can be found between the two sets: RCP 8.5 similar to A1FI, RCP6

to B2, and RCP 4.5 to B1, respectively (see Table 3 in R12). Their findings ensure that SRES A2 is considered to be intermediate between RCP 6 and RCP 8.5. Matthews and Solomon (2013) showed that the cumulative CO_2 emission and corresponding warming at near-term (2030) are approximately the same across all emission scenarios, whereas those at longer-terms (2100) are similar between close counterparts of the selected SRES and RCP scenarios: A1FI to RCP 8.5, A1B to RCP 6, and B1 to RCP 4.5, respectively. Baker and Huang (2014) found that the SRES A1B simulations in CMIP3 and the RCPs 4.5 and 8.5 simulations in CMIP5 produced common drying trend in the 21st century trend over the Mediterranean region. It is also indicated by Cabré et al. (2016) that SRES A2 has similarities to RCP 8.5 in terms of radiative forcing, future trajectories ($\sim$8 W m^{-2} by 2100), and changes in global mean temperature (2.0 – 5.9°C for 2090–2099 compared to 1980–1999 for A2; 2.6 – 4.8°C for 2081–2100 compared to 1986–2005 for RCP 8.5). In R12, differences in warming rates existed between the scenario families due to different transient forcings; however, with a 30-year average for each scenario as in our study, the results and conclusions by using the SRES A2/B2 scenarios would not be significantly different from those by using the close RCP counterparts.

We have added statements addressing this point in the revised manuscript (see the early part of Sec. 3). Further discussions on this issue are provided in “Reply to Referee #2, Major comments #1” with citations of more relevant references.

4. *And the most important one: Which new knowledge does the paper deliver to us?*

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⟹ 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.

Minor comments:

1. *ll. 6 and 7: I guess 'FC' in the abstract is difficult to understand. Please be more specific (e.g. replace it by time interval '2071–2100').*

⟹ We agree with the referee and have modified the abstract as the referee suggested in the revised manuscript.

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2. *l. 10: ‘Annual or seasonal variations...’ What is the difference between them? Probably, authors mean ‘interannual’ in place of ‘annual’?*

   $\Longrightarrow$ We appreciate the referee for pointing this out. To avoid any confusion, we modified the sentence by leaving just ‘seasonal’, since we were interested in underlining the variations within a year.

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