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Hydrology and Earth System Sciences
Discussions

# *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 #2 for Manuscript hess-2017-569

***General Comments:*** *The manuscript 'Climate change over the high-mountain versus plain areas: Effects on the land surface hydrologic budget in the Alpine area and northern Italy' presents climate change impacts on evapotranspiration, precipitation and soil moisture over the Alpine and northern Italy using regional climate model and land surface process model. Authors well deliver the changes of hydrological budget under climate change. However there are a few concerns described below.*



We appreciate the valuable comments by the referee along with many helpful suggestions, which helped us improve the manuscript significantly. We have substantially revised the manuscript following the referee's comments/suggestions. In the following, we have provided an item-by-item reply to the referee's comments.

***Major comments:***

1. *Authors used RegCM3 in this study. Newer version model dose not necessary mean that having better performance but authors need to justify why older version model with older scenario (AR4) was employed in this study.*

   $\Longrightarrow$ We admit the existence of a newer version of RegCM (i.e., RegCM4) and totally agree with the referee that newer version model does not necessarily has better performance. We decided to employ RegCM3 for the following reasons:

   1) RegCM3 had been employed in several important projects, including PRUDENCE, ENSEMBLES and CECILIA, whose outputs had been used in numerous studies focusing on Europe (e.g., Christensen and Christensen, 2007; Blenkinsop and Fowler, 2007; Ballester et al., 2010; Coppola and Giorgi, 2010; Herrera et al., 2010; Rauscher et al., 2010; Kyselý et al., 2011; Torma et al., 2011; Heinrich et al., 2014; Skalák et al., 2014; Faggian, 2015);
   2) It had also been widely used, even most recently, for the studies of climate projections or sensitivities/evaluations over a geographical region including the target areas in our study — the Alpine and adjacent areas (e.g., Gao et al., 2006; Smiatek et

al., 2009; Coppola and Giorgi, 2010; Im et al., 2010; Coppola et al., 2014; Nadeem and Formayer, 2016; Alo and Anagnostou, 2017);

3) Since a plenty of model outputs were available from several relevant projects (e.g., PRUDENCE, ENSEMBLES, CECILIA, etc.) and we had limited computing resources and man power for exploring all available data sources, we decided to select a well-known model which had been extensively used for such kind of studies.

These points are now clearly addressed in the revised manuscript (see the early part of Sec. 2).

⟹ We also acknowledge that the scenarios used here (SRES A2/B2) are older than the RCP scenarios used in IPCC AR5. However, scenarios are designed to depict possible future developments with some uncertainties that reflect different understandings of the current/intermediate socio-economic and/or greenhouse gas emission circumstances; thus, each scenario has its own value and philosophy, and older scenarios do not necessarily mean that they are useless or wrong. Numerous previous studies on climate projections/impacts had been conducted based on the SRES scenarios, which we cannot totally neglect even though new scenarios have emerged. Rather, there have been some studies to check similarities/differences between the two scenario sets for a given projection period or to address the value of using both scenario sets for future climate projections. We added the following statements in appropriate positions in the revised manuscript. In addition, explanations on more relevant references are provided in "Reply to Referee 1" (see Major comments #3 and references therein).

In the last decade, numerous studies on climate projec-



tions/impacts had been conducted using the SRES scenarios. After the emergence of the new RCP scenarios, there have been studies to check similarities/differences between the two scenario sets for a given projection period (e.g., Rogelj et al., 2012; Baker and Huang, 2014) or to address the value of using both scenario sets for future climate projections (e.g., Peters et al., 2013; O'Sullivan et al., 2016; Nolan et al., 2017). It turns out that both SRES and RCP scenarios are generally in good agreements, for pairs of closest counterparts, in projecting climate in the 21st century. For example, Rogelj et al. (2012) pointed out that the RCP scenarios spanned a larger range of temperature estimates than the SRES scenarios, and indicated similar temperature projections for pairs between the two scenario sets: RCP 8.5 similar to A1FI, RCP6 to B2, and RCP 4.5 to B1, respectively. Baker and Huang (2014) reported a common drying trend, over the Mediterranean region, between the CMIP3 simulations based on SRES A1B and the CMIP5 simulations based on RCPs 4.5 and 8.5. Peters et al. (2013) projected global warming through all available emission scenarios, showing that RCP 8.5 and SRES A1FI and A2 lead to the highest temperature projections and RCP3-PD (peak and decline in concentration) would keep global warming below 2°C in 2100. Most recently, O'Sullivan et al. (2016) and Nolan et al. (2017) assessed impacts of climate change on temperature and rainfall, respectively, by mid-21st century in Ireland using both SRES and RCP scenarios, and provided a wide range of possible climate projections. O'Sullivan et al. (2016) found that future summers had the largest projected warming under RCP 8.5 while future winters had the greatest warming under A1B and A2. Nolan et al. (2017) created a medium-to-low emission ensemble using the RCP4.5 and B1 scenario simulations and a high emission ensemble using the RCP8.5, A1B and A2 simulations, which enabled to have 25 high and 21 medium-to-low emission ensemble comparisons: they found significant projected decreases in mean annual, spring and summer precipitation amounts — largest for summer, with different reduction range for different scenario ensemble.

Furthermore, the SRES scenarios have often been adopted in most recent studies even long after the release of the RCP scenarios because the old scenarios were in accord with their objectives (e.g., Dunford et al., 2015; Jaczewski et al., 2015; Kiguchi et al., 2015; Kim et al., 2015; Casajus et al., 2016; Harrison et al., 2016; Mamoon et al., 2016; Stevanović et al., 2016; Tukimat and Alias, 2016; Zheng et al., 2016; Hassan et al., 2017; Park et al., 2017; da Silva et al., 2017). We employed the SRES marker scenarios because of their long-term consistency in assessing the impact of climate change on global/regional factors of socio-economy and environment during the last decade — including air quality (Jacob and Winner, 2009; Carvalho et al., 2010), water quality/resources (Wilby et al., 2006; Shen et al., 2008, 2014; Luo et al., 2013), energy (Hoogwijk et al., 2005; van Vliet et al., 2012), agriculture/forestry (Lavalle et al., 2009; Calzadilla et al., 2013; Stevanović et al., 2016; Zubizarreta-Gerendiain et al., 2016), fisheries (Barange et al., 2014; Lam et al., 2016), health/disease (Patz et al., 2005; Giorgi and Diffenbaugh, 2008; Ogden et al., 2014), climate/weather extremes (Déqué, 2007; Marengo et al., 2009; Jiang et al., 2012; Rummukainen, 2012), wildfire (Liu et al., 2010; Westerling et al., 2011), ecosystem/biodiversity (Araújo et al., 2008; Feehan et al., 2009; Jones et al., 2009; Fronzek et al., 2012; Walz et al., 2014), and so forth. Although an ensemble approach with all possible sce-



narios would increase the spread of hydrologic budget simulations, due to the limited resources, we decided to select two representative marker scenarios: A2 as the higher-end and B2 as the lower-end emission scenario, respectively.

All these points addressed above are adequately reflected in the revised manuscript (see the early part of Sec. 3).

2. *In this study, authors employed single RCM and single land model. Authors need to discuss about model uncertainties comparing to the multi-model approaches.*

$\Longrightarrow$ We totally accept that a single model approach has relatively larger uncertainty: it is desirable to employ an ensemble approach, using multiple models and/or initial conditions, to estimate the range of climate projections. Our decision to employ the single-model approach is mainly due to limitation in computing resources and man power to perform multi-model ensemble simulations for both RCM and LSM. Given such limitations, a high-resolution single model is often not a bad choice, compared to an ensemble of coarse multi-models, especially over a complex terrain. Coppola and Giorgi (2010) pointed out that the CMIP3 GCMs showed a much larger range of bias for temperature and precipitation than the PRUDENCE RCMs: they also made a fine-scale (20 km) single model experiment using RegCM3 and found that both the temperature and precipitation changes through RegCM3 were in line with the CMIP3 and PRUDENCE ensemble results. Generally speaking, multi-model ensembles tend to decrease the errors compared to an individual model; however, due to the averaging operation (e.g., ensemble mean), the spatial and temporal variability of the signal tends to decrease. Furthermore, many previous studies on various climate change impacts/projections had been performed using the single RCM approach (e.g., Dankers and Feyen, 2008; Beniston, 2009; Im et al. 2010; Krüger et al., 2012; Zanis et al., 2012; Tainio et al., 2013; Park et al., 2017). However, as uncertainty of the projected changes related to model bias and ensemble variability is quite large, future projections based on a single RCM should be interpreted with caution. Further research is needed to obtain more robust results from an ensemble approach. In the revised manuscript, we have addressed these points and mentioned limitations of our study in terms of the single-model approach (see the last part of Sec. 3).

3. *I do believe there are quite a few previous studies over the study region. Authors need to introduce them.*

   $\Longrightarrow$ Following the referee's suggestion, we have added statements in the revised manuscript by citing more relevant references of the previous studies on climate projections over the study region (generally Europe including the Alps and northern Italy). 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**).

4. *Authors discussed about possible agricultural impact due to the lower soil moisture. However, in this study, vegetation type in UTOPIA were set single type of vegetation (short grasses) all over the domain. Have you done any sensitivity test on vegetation types?*

   $\Longrightarrow$ 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 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 (see the middle part of Sec. 3; staring last paragraph of page 8).

***Minor comments:***

1. *Page 1. Remove all acronyms in abstract.*

   $\Longrightarrow$ We minimized the use of acronyms in Abstract; however, we kept acronyms of the model names (i.e., RegCM3 and UTOPIA) because most readers recognize the model names by their acronyms.

2. *Page 2, line 15. Global circulation models. Is this different one as GCMs previously defined?*

   $\Longrightarrow$ We appreciate the reviewer pointing this out. Usually GCM can represent either Global Climate Model or General Circulation Model. As the global climate is usually simulated using the general circulation model, we re-defined GCM as Global Circulation Model and modified the text accordingly in the revised manuscript.

3. *Page 3, line 22-24. Related with major comments 1. EURO-CORDEX has RegCM4 with higher resolution.*

⟹ We have explained the reason to choose RegCM3 in Major Comments #1. However, as the referee pointed out, the statement "***... one of the existing datasets with the highest resolution currently available (20 km)***" may not be true because of the existence of RegCM4 with higher resolution (about 12 km). We have modified the expression in the revised manuscript as "***... one of the high-resolution datasets currently available***".

4. *Page 4, line 5-19. Move to methods section.*

   ⟹ Done.

5. *Page 4, line 20. Energy variables are critical part of your argument. Please include the figures as a supplementary.*

   ⟹ The land surface energy balance is an important issue itself, and we prepared a companion paper dealing with the energy budget components in the same study area — it is ready to be submitted. We put the companion paper to the References and cited appropriately in the revised manuscript.

6. *Page 4, line 25. I cannot find the PR minimum shifts in the figure.*

   ⟹ Actually the figure shows the trends of variables for PC in Fig. 2a, and the anomalies of variables (i.e., the differences between FCs and PC) in Figs. 2b and c. Thus, it is quite difficult to see the trends of variables in FCs from Figs. 2b and c. By looking at the individual trends related to A2 and B2 simulations (not shown in the paper), the mentioned shift becomes noticeable. To avoid any confusion, we have modified the expression "***with the PR minimum shifted to August in FC$_{A2}$***" to "***with the PR minimum shifted to August in FC$_{A2}$ (not shown)***".

7. *Page 4, line 26. ET of FC$_{B2}$ shows double peaks rather than shifting in Fig. 2b.*



   ⟹ As we explained above in #6, it is because the lines referred to FC$_{B2}$ represent the anomalies, i.e., the differences between FC$_{B2}$ and PC (i.e., FC$_{B2}$ minus PC). Again we modified the expression "***the ET maxima shift towards July/August, in both FC$_{A2}$ and FC$_{B2}$***" to "***the ET maxima shift towards July/August, in both FC$_{A2}$ and FC$_{B2}$ (not shown)***".

8. *Page 4, line 29-31. It looks like the large variation stems on future PR variation. Can you explain why PR has large variation?*

   ⟹ As reported by some other studies (e.g., Gao et al., 2006), in winter the increase in southwesterly flow across the Alps causes a maximum of positive precipitation change over the southern Alps while in autumn the main circulation change is in the easterly and southeasterly direction. This explains the positive precipitation change at south of the Alps. We have added this explanation in the revised manuscript.

9. *Page 6 line 27-29. Can you include the names of geographical location on the map (e.g. Fig. 1)*

   ⟹ We added additional map representing the names of geographical locations in Figure 1, as requested by the reviewer.

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