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Natural Hazards and Earth System Sciences
Discussions

Interactive comment on "Hydrological impacts of climate change on small ungauged catchments-results from a GCM-RCM-hydrologic model chain" *by* Aynalem T. Tsegaw et al.

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Hydrological impacts of climate change on small ungauged catchments-results from a GCM-RCM-hydrological model chain

We would like to thank the reviewer for the thoughtful comments and efforts towards improving our manuscript, which have helped us to improve the quality of the manuscript. In the following, we give responses to the comments/concerns the reviewer raised.

Reviewer 1

General comment In the manuscript the regionalized DDD model with dynamic river

network was used to study climate change impacts on hydrology by 2070-2100 in ungauged catchments in the Bergen area in western Norway. Six ungauged small rural catchments are modeled with a single high-resolution downscaled climate scenario. The manuscript is well structured and well written and bring new knowledge on estimation of climate change impacts on small ungauged basins with sub-daily time steps. However, to improve the manuscript, the results, which use input from one climate model, should be given more context in regard to other climate scenarios and some key uncertainties should be better presented.

General Answer Thank you. To improve the manuscript, we have compared in detail our study results with RCP8.5 (worst case scenarios) results of other studies, and other key uncertainties are also included in the discussion section of the revised manuscript. We have also compared results of RCP8.5 and 4.5 of other studies.

Detailed comments

Comment on Abstract: The abstract should clearly state the climate scenario (especially rcp) for which the results are based since this affects the likelihood of the proposed changes (ie. these are apparently with the rcp8.5 and are therefore likely to be the upper end of the proposed changes). The uncertainties due to use of only one climate scenario should be shortly acknowledged also in the abstract and the percentage changes of the results should be provided with less accuracy (ie. not well 256.3 % but with e.g. 260 %).

Answer We have revised the abstract section of the manuscript accordingly. We have included the uncertainties due to use of only one climate scenario. The results are also provided with rounding to the nearest integer. The revision is found in the abstract, result and discussion sections of the revised manuscript. Tables, 5,7 and 9 containing decimals, are also rounded.

Comment on Data and methods:

More background information from the Bergen area floods and the mechanism (snow or rain or both) could be provided. In discussions the results could be reflected with this.

Answer More background information on Bergen climatic conditions, floods, shifts in floods, and floods generation mechanisms are included in the revised version of the manuscript. The floods in the southern west part of Norway are mainly caused by rain in the autumn season. Revised Manuscript The included information is found in the data and methods section of the revised manuscript, lines (123 to 147).

Comment on Section 2.2: Section 2.2 includes information of the climate change input data used. However the climate change input data should be described in more detail. The climate scenario used should be more clearly stated (Global climate model, regional climate model, rcp) (NORESM-M, WSF, but the rcp is not mentioned here, apparently rcp8.5) – the corrections made to the data should be provided with more details. Is only the GCM corrected and for which variables? Is there any bias correction on the RCM data? How well do the temperatures and precipitation compare to observations? -the use of only one scenario just be better justified (since the common approach these days in to use several scenarios to enable uncertainties to be included). Why this particular model and why only one?

Answer We have revised and rewritten section 2.2. The RCP used is 8.5, and the global climate model NorESM1-M (r1i1p1) output used as forcing data at the boundaries of WRF was bias corrected before the regional downscaling. We followed the approach of Bruyère et al. (2015) and corrected the monthly mean values towards the monthly mean of the reanalysis ERA-Interim (Dee et al. 2011). The correction was performed for the skin temperature and the three-dimensional pressure, humidity, temperature and the wind components. The bias correction method used is explained in detail in the revised manuscript.

We agree that it is quite common to use ensembles of scenarios in climate impact

studies; However, in the hydrological impact study of small catchments, the short response time of small catchments requires high temporal and spatial resolution (short duration and small special scale) climate data and getting such ensembles data is a challenge. To our knowledge, no other convective permitting, century-long, dynamically downscaled climate projections is available for Norway for short duration rainfall with a small spatial scale so that a standard ensemble analysis is not possible.

Revised Manuscript The included information is found in section 2.2 of the revised manuscript, lines (160 to 228).

Comment on Discussion: Since only one climate scenario is used, the influence of this decision on the results should be discussed. Table 4 states the temperature and precipitation changes with the used climate scenario (the GCM-RCM and rcp of the scenario should be added to the table header) and on page 2 the range for rcp8.5 is stated. However, these should be compared more clearly in the discussion or elsewhere (how does the chosen scenario compare to others, is it e.g. wetter than average). Also, the range of temperature and precipitation with other rcps than just 8.5 should be provided for context. The results are currently only been compared to the rcp8.5 results of e.g. NCCS report, also some comparison with the rcp4.5 could be provided for more context. How does the use of only one scenario influence the results and what are the likely results with other scenarios (e.g. are these likely to be the top end of changes in floods which can be used as worst case scenario). Currently the results, which are stated with high accuracy, can provide false sense of certainty while this major uncertainty is not well established. (The emissions used in RCP8.5 pathway are nowadays considered by some scientists as rather unlikely due to the ongoing mitigation efforts and the sinking prices of renewables. Therefore, there has been arguments against the use of this scenario as a "business as usual" scenario).

The results showed large increase in flood risk due to climate change. Other studies are referred to but the main differences between these studies explaining the differences in the results (the inclusion of different types of catchments with more snow

dominated flooding and the use of several different climate scenarios) should be analyzed. The changes in max SWE (table 4) are very large, any comment on this? What is the influence of the snow model type used?

There is also big increase in evapotranspiration in the climate change scenario (table 4). What could explain this? And what is the influence of the relatively simple evaporation model, which is correlated to temperature and influenced by precipitation through soil moisture but does not use other input from the climate model such as changes in wind speed, cloudiness or humidity? The changes in evapotranspiration only have a limited effect the flood discharges, but the low discharges are more sensitive to these changes.

Answer The header of table 4 has been revised accordingly i.e., the GCM, RCM and RCP are added. We have compared changes in precipitation, temperature and floods between our findings and the Norwegian Centre for Climate Services (NCCS) under Climate in Norway 2100 report (Hanssen-Bauer et al., 2015) with RCP8.5. WE have also compared the findings of the report with RCP8.5 and 4.5. The comparison has been done in the discussions section of the revised manuscript.

The comparisons of the precipitation and temperature changes with our climate model and the NCCS report with RCP8.5 show that our findings are colder and wetter than the NCCS report. The precipitation and temperature changes for Norway are 17% and 3.7oC for RCP8.5 at the end of the century (2071-2100) compared to the reference period (1971-2000). Our findings show that the mean annual changes are 22% and 3.3oC at the six study catchments in Bergen area at the end of the century compared to the reference period (1981-2011). The results are generally comparable with small differences. Revised Manuscript The included comparison is found in the discussion section (4.2.1) of the revised manuscript lines (457-465).

Detail comparisons of 200 years flood changes, between the Lawrence (2016) findings with RCP 8.5 and our findings, have been done in the revised version of the manuscript.

The RCP8.5 results of the Lawrence (2016) report show slightly lower flood changes than our findings. Lawrence (2016) found that the increase in the 200 years flood is between 20% to 40% for seven of the ten study catchments used in the Hordaland county at the end of the century. Our study catchments are also located in the Hordaland county. The results of our study show that the 200-year flood changes range from 20% to 43% for five of the six the study catchments. The comparison shows that our findings are similar to the RCP8.5 report and likely at the top end of changes in floods which can be used as a worst-case scenario at the Bergen area. The slight differences in the findings are related to the temporal resolutions used (3hourly in our study and daily in the report), the bias correction methods used, the number of GCMs-RCMs used and the differences in the sizes of the catchments (less than 10km2 in our study, and 6km2 to 15499km2 in the report). Revised Manuscript The included comparison is found in the discussion section (4.3.2) of the revised manuscript, lines (621-635).

We have explained the differences in our findings and Lawrence (2016) report related to changes in flood frequencies. The main differences are the number and types of climate models, RCPs, the bias correction method, the catchment sizes and the temporal resolution used in the study. However, the comparison location is the same. We have compared our findings with results from 10 catchments in the Hordaland county (where our study catchments are located) in the report. Revised Manuscript The included comparison is found in the discussion section (4.3.2) of the revised manuscript, lines (637 - 649).

The main reason for the very large increase of changes in maximum SWE is due to a real effect of warming temperature that shifts the rain/snow boundary higher up in elevation. The other reason could be the limitations and uncertainty in estimating the snow model parameters. The snow model parameters in Distance Distribution Dynamics hydrological model are estimated from the nearby catchments which had been estimated from daily observed precipitation and temperature data in the Thomas Skaugen 2015 paper.

The big changes in actual evapotranspiration tells us that in the future period there will be more water available (to evaporate) and higher temperature (to cause evaporation) than the reference period. Yes, we agree with the reviewer in that there is a limitation with the simple evaporation model since actual evaporation is not only affected by temperature but by additional climatological factors like wind speed, humidity, cloudiness etc. This limitation could also be the other reason for a big change of actual evapotranspiration between the reference (1981-2000) and future periods (1970-2100). Revised Manuscript The limitation related to the simple evaporation model is included in the the revised manuscript, lines (657- 665).

4.4. Limitations RCPs should be added to GCMs and RCMS as source of uncertainty or limitation to the study. Answer We have included the limitations in the use of a single Representative Concentration Pathway (RCP8.5) in the revised manuscript.

Revised Manuscript The included limitation is found in the limitation section (4.4) of the revised manuscript, lines (670-676).

Please also note the supplement to this comment:
https://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2019-359/nhess-2019-359-AC1-supplement.zip

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