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Earth System Dynamics
Discussions

Interactive comment on "Seasonal discharge response to temperature-driven changes in evaporation and snow processes" *by* Joost Buitink et al.

Anonymous Referee #2

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General comments: Buitink et al. showed the relative importance of changes in temperature, evaporation and precipitation on changes in discharges from the 1980s to the 2010s using the dS2 model in the Rhine river basin. The manuscript reads well and has little grammatical errors, but the structure and methods could use work to help readers understand the simulations. Information on the methodology is greatly missing, which causes readers to speculate how to interpret the overall conclusions. Also greatly missing are comparisons of this work to other modeling studies. Based on my review, I would suggest major revisions before publication is merited.

Major comments: 1. Section structure: The methods section is too brief. Much of the

model descriptions are contained in the supporting information and should be moved to the main text. The swapping of variables is confusing to me. How can you realistically change temperature only affecting snow processes or evaporation? Wouldn't both processes be affected by changing the temperature? If the goal of the paper is to simulate the hydrologic response to temperature-driven changes in evaporation and snow processes, specific details on the snow processes being simulated need to be included. The term 'snow processes' is used throughout the paper, but it is unclear which snow processes are simulated. Glacier melt is considered a snow process? Increased melt from glaciers is attributed to changes in discharge later in the manuscript. Is it possible to separate the effects from snowmelt and glacier melt?

The discussion section should be separated from the conclusion to compare your results with other studies and address the overall implications from your results better.

2. Figures: Figure 2 has a lot of results, but it is difficult to interpret due to the small size of the individual panels. Panels 2a, 2e, and 2f would benefit from being stretched out to see the results in more detail. Additional comments on Figure 2:

The colors in 2a do not match the legend. I assume the darker lines are for simulated and the lighter lines are observed, but clarification would be nice.

It appears that the sum of the difference in model simulations in 2e during February are cut off by the y-axis limits?

Why are there gaps in 2f? Does this mean that the forcing variables failed to explain any fraction?

It is confusing why the cumulative effects for forcing variables are shown in 2g, but the absolute effects are generally discussed in the text. This is how the 11%, 19%, and 18% from the abstract were calculated, correct?

All of the significant differences in monthly discharge shown in Fig. 2c are larger for the 1980s compared to the 2010s, yet the sum of the differences from the forcing variables results in positive discharge differences during March and December in Fig. 2e. How is this possible?

The dotted grey line (sum of diff.) in Fig. 2e during early March is +500 m3/sec, but the solid grey line (2010s) shows a negative discharge difference for the same time, can you explain this? Similarly, during early May.

Occasionally text does not seem to align with results from the Figures:

Snow depth decreases for the majority Europe are reported in line 26 and shown in Figure 1e from ERA5 data, so why is the discharge difference from modified P in Figure 2d positive?

In lines 86-87 you write "Both variables are correctly represented, and show similar variability as the observations, even at hourly timescale." I would argue that snow storage is poorly simulated as the maximum simulated snow storage/height is twice as much as the observed maximum snow storage/height. This needs to be explained more. Could the positive discharge difference due to Modified P be due to the simulated maximum snow storage being twice as high as the observed maximum snow storage in Fig. 3b?

In lines 101-102 you write "During spring, this simulation shows higher discharge values resulting from increased snow melt." It is confusing which specific months you are referring to, but in Figs. 4b and 4c modified TSnow does not appear to have a positive effect on discharge. But during low flow conditions (Fig. 4d), TSnow has a positive effect on discharge?

In line 155: "Discharge between these two periods was significantly different for 8 out of 12 months". 10/12 boxes in 2b are full colored, representing significant differences.

Results are often grouped by months, but then seasonal changes are discussed in the text. This is confusing for the reader to speculate which particular months you are referring to. For instance, the third shaded period in Figure 4 is referred to in the text

as the "late summer low flow" period (line 120). But this time period aligns with the end of September through the beginning of November, not typically thought of as late summer. I would suggest referring to the results based on the monthly changes to remove this ambiguity.

3. Comparison between other studies: Much work has already been conducted on simulated effects of temperature changes on hydrologic response. It would be nice to see a comparison of your results to some of these studies and why your results agree or disagree from theirs. This appears to be completely missing. You list six studies that investigated these effects in lines 28-29, but do go on to discuss their results or compare yours at all.

Climate model simulations in western North America indicate that the fraction of meltwater volume produced at high snowmelt rates is greatly reduced in a warmer climate (i.e. "Slower snowmelt in a warmer world", Musselman et al., 2017). Additionally, model simulations suggest slower snowmelt decreases streamflow production ("Snowmelt rate dictates streamflow", Barnhart et al., 2016). But, in lines 161 – 163 you write "With higher temperatures, increased melt from glaciers and snow packs can offset the discharge reduction from enhanced evaporation over the majority of the year" and that "these results can be interpreted for the many different basins around the globe depending on both rain- and snowfall". These sentences are confusing and incredibly misleading. Your remarks make it seem like increased snowmelt and glacier melt offsets reduction from evaporation and results in an inconsequential effect on discharge. But in Figures 2b and 2c you show significantly lower discharge for 10/12 months and annually for the 2010s compared to the 1980s.

Minor corrections: Line 14: Higher temperatures have been shown to lead to slower snowmelt rates ("Slower snowmelt in a warmer world", Musselman et al. 2017, Nature Climate).

Lines 18-21: Changes in discharge are most likely to be strongly affected by changes in precipitation. It's probably best to focus on the runoff ratio (discharge/precipitation). Runoff ratios (or runoff efficiency) were found to be mostly unchanged in snow-covered areas of the western U.S. despite increasing temperatures and decreased snow fractions ("Warming is Driving Decreases in Snow Fractions While Runoff Efficiency Remains Mostly Unchanged in Snow-Covered Areas of the Western United States"; McCabe et al., 2018; Hydrometeorology).

Line 23: "Europe has experienced significant changes in evaporation, snow depth and streamflow over the last decades". Citation needed. Were all of the changes negative? Which decades?

Lines 24-25: "Their study shows that both changes in precipitation and evaporation had considerable effects on the streamflow." Did they observe negative changes for both precipitation and evaporation? How do changes in rain compare to changes in snow?

Line 26: "showed that snow depth decreased over the majority of Europe". From when to when?

Lines 37-38: "for example, the study by Mastrotheodoros et al. (2020) took more than 6×105 CPU hours". What resolution did they use?

Lines 42 - 44: "This study investigates the hydrological response to temperature-driven changes in evaporation and snow processes, testing our main hypotheses that both seasonal changes in snowmelt and enhanced evaporation will aggravate low flows, and that the changes will increase with temperature under realistic warming." Is snowmelt the only snow process tested in this study? If so, I would change the terms "snow processes" to "snow melt".

Lines 53-54: "The Rhine basin was selected because the climate and basin heterogeneity are representative for north-western Europe and many other basins globally". It seems like a stretch to suggest the Rhine basin is representative of many basins globally.

Line 80: "higher flows during late winter in the 2010s". Be specific about the months. It seems that from 2b discharge is lower for all months in the 2010s. I do not see higher flows during late winter in the 2010s?

Lines 101-103: "The higher temperatures of the 2010s also resulted in lower discharge values in the first few months of the year. During spring, this simulation shows higher discharge values resulting from increased snow melt." Again, it is confusing which months you are referring to. I would assume that the first few months of the year are late winter. These two sentences seem contradictory. First you say that higher temperature (affecting snowmelt) resulted in lower discharge, then you say higher temperature (affecting snowmelt) resulted in higher discharge. Was the increase in spring discharge due to an increase in the snowmelt rate of the volume of snowmelt?

Lines 107-108: "The explained fraction is lowest during spring and late summer." Be specific about which months. Are you referring to the gaps in Fig. 2f?

Line 120: "late summer low flow". Be specific about which months. The late summer period aligns with the end of September through early November, more typical of fall/autumn. Figure 4b: The effects from modified TEvap in Figure 4b are hidden by the combined effects.

Line 155: "Discharge between these two periods was significantly different for 8 out of 12 months." Is this simulated or observed? In Fig. 2c you show all but two months being significantly different?

Lines 162-163: "With higher temperatures, increased melt from glaciers and snow packs can offset the discharge reduction from enhanced evaporation over the majority of the year." This interpretation is opposite of previously published studies (i.e. slower snowmelt in a warmer world) and needs clarified.

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