Reply RC1

RC1: 'Comment on esd-2021-43', Anonymous Referee #1, 20 Jul 2021

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Climate change in the High Mountain Asia in CMIP6

Mickaël Lalande et al. (https://esd.copernicus.org/preprints/esd-2021-43/#discussion)

Review Comments

We are grateful to referee #1 for having accepted to review this paper and for his helpful comments.

Minor comments

Comments of reviewers are displayed in *italic,* replies are in normal text and when additional text is added within a paragraph (between quotation marks), it is shown in **bold**.

1. *Use the term either "Snowpack" or "Snowcover" (L: 58).*

We replaced "snowpack" with "**snow cover**" to be consistent in this paper.

2. *L: 89 sentence "Sections 6 ...." Should be restructured".*

Replaced by: "**The results are discussed in Sect. 6 and the conclusions are presented in Sect. 7.**"

3. *Meaning of the sentence in L: 220 "Whenever possible......" is not clear. What are other datasets?*

Replaced by: "**To get confidence in the model bias quantification, we use further observational datasets, including GPCP precipitation, ESA CCI snow cover as well as ERA-Interim and ERA5 reanalysis.**"

4. *A little more elaboration on the temperature is required in Section 3.2 to put light on the obtained results in the study.*

"[...]. Indeed, the multimodel mean temperature is around 2 to 3~°C below the CRU observations in winter over HMA, while models and observations are much closer in summer (Fig.~\ref{fig:ac}a). These differences are more pronounced in the HK region (Fig.~\ref{fig:ac}b) with differences noticed both in winter (4 to 5~°C) and summer ($\sim$2~°C). **The cold bias appears in the multimodel mean (dark blue line) from October/November onwards, peaks between December and January, and then decreases until April/May, except in the HK area where the bias persists in summer. Nevertheless, the multimodel spread encompasses the observation and reanalyses datasets, suggesting a certain reliability of the CMIP6 models. This spread denoted with the confidence intervals at 50~\% and 90~\% of the multimodel ensemble (dark and light shadings)**

highlight a higher dispersion between the models in winter than in summer, except for the HK region.

5. *Sentence "For temperature, ERA-Interim......." (L: 252-254) is not in the flow of the preceding text and therefore need elimination from the manuscript.*

Ok, we removed the sentence.

6. *Use either "Sect." or "Section" in different paragraphs of the manuscript.*

"Section" was removed or replaced by "Sect." where it appeared in a middle of a sentence and was kept at the beginning of sentences as indicated in the manuscript composition instructions.

7. *Why is the in-depth discussion on APHRODITE missing in this Section 3.2 ?*

We did not want to drown the results in too many discussions, of which we already touch a little (L: 280-290) and that we complement in the discussion (Sect. 6, L: 581-590).

8. *More description in Section 3.3 on the temperature, snow cover and precipitation is required to show the bias.*

"The pattern of the temperature bias widely differs from one model to another (Fig.~\ref{fig:tas_bias}). However, most of the models show a cold bias, which is reflected by the multimodel mean reaching an average bias of $-$1.9 [$-$8.2 to 2.9]~°C. The cold bias **show common general features among the models, being** generally more pronounced at high elevation (Fig.~\ref{fig:clim}a)**, in particular over HK region as highlighted in Sect.~\ref{ssec:ac}**. The largest biases are found for the CNRM and IPSL models, with biases reaching almost $-$10~°C on average and exceeding locally $-$12~°C, especially over the western part of the TP and in the Karakoram area (HK region). Other models show slight positive or negative biases around $\pm$3~°C. **Some models show a positive bias at the edges of the plateau and over the Tien Shan (e.g., CESM2-FV2 and MIROC-ES2L) that contrasts with a cold bias on the Southern flank of the Himalaya. This is probably due to the low resolution of these models which does not allow to catch the atmospheric circulation over this high elevation narrow area (Fig.~ref{fig:clim}b). The cold bias found in a large number of models is more pronounced in winter, a season during which it extends over almost the entire TP, whereas it is limited to the HK region in summer (not shown). Conversely, the warm bias found in some models is reduced in winter and exacerbated in summer.**

As for temperature, the snow cover **shows a general overestimation in the multimodel mean that extends homogeneously over the whole TP with slightly higher values northwest of TP and over HM (>30~%)** (Fig.~\ref{sfig:snc_bias})**. Surprisingly the multimodel mean shows a slight underestimation of snow cover of about 10% over the HK region, which seems contradictory with the intense cold bias pointed out simultaneously in this area. Indeed, the CRU dataset may overestimate temperature in this area due to a lack of observations, while the low resolution of the NOAA CDR simple binary product (grid cells with or without snow), might overestimate the snow cover in this often snowy area. The ESA CCI product shows a lower snow cover in general and in particular in this region (not shown). It is therefore possible that in the HK region the model biases actually reflect observation deficiencies, even if other factors affecting the model skill could be involved.** The annual multimodel mean of snow cover is overestimated by 12 [$-$13 to 43]~\% (or 52 [$-$53 to 183]~\% relatively) over HMA compared to NOAA CDR and can reach locally an absolute difference of 40~\%, while a minority of models show a slight underestimation of snow cover (e.g. MPI-ESM1-2-HR, MPI-ESM1-2-LR, NorESM2-LM). **The annual overestimation of the snow cover in most models arises mainly from a too wide extension in the inner TP in winter (not shown). While the excess of snow melts in summer in most of the models, leading to a moderate bias during this season (Fig. 2), some models keep a persistent excess of snow even in summer (e.g. HadGEM3-GC31-LL, HadGEM3-GC31-MM and IPSL-CM6A-LR), which partly explains the large dispersion between the models in terms of annual biases.**"

For precipitation, see comment 10. for further discussion.

9. *Sentence "Correlation between temperature and snow cover......." (L: 300-303) should be part of Section 3.4.*

Sentence removed because it's already said in the first paragraph of Sect. 3.4.

10. *Rather than temperature only, section heading of Section. 3.3 needs to reflect the snow cover as well as precipitation. Add more text in Section 3.3 for the discussion on precipitation.*

3.3 ~~Near-surface air temperature bias~~ -> **Spatial biases**

Additional discussion on precipitation:

"[...] The bias pattern **in terms of total precipitation** is **somehow proportional** to the climatological pattern **of precipitation**, with stronger biases in the Southeastern Himalaya, where high precipitation rates are observed **(Fig. B2). The quantification of the bias should be considered carefully for precipitation, because the APHRODITE data set strongly underestimates the precipitation rates at high elevations (Immerzeel et al., 2015). Anyway, the dry bias found in the southern flank of the Himalaya, coupled with a positive bias of precipitation over TP, suggests a too coarse resolution to represent the orographic barrier that blocks the Northward moisture flux, a limitation especially pronounced during the Asian summer monsoon that induces strong precipitation rates in the South of HMA.**"

11. *Which test was adopted for the significance of the correlation and how was the level of significance selected to declare the value significant ?*

We thank the reviewer for pointing out this point that was missing in the manuscript, here is the addition to the Sect. 2.5 (Numerical methods and computations):

L199 : "Trend computations are based on linear least-squares regression. We consider a 95~\% level of significance, corresponding to a p-value equal to 0.05, computed with a two-sided Wald test for which the null hypothesis corresponds to a slope equal to zero\footnote{\url{https://docs.scipy.org/doc/scipy/reference/generated/scipy.stats.linregress.html}}. The linear relationship between two datasets is estimated with the Pearson correlation coefficient. **We consider a 95~\% level of significance, corresponding to a p-value equal to 0.05, computed as follows: for a given sample with correlation coefficient r, the p-value is the probability that $\lvert r' \rvert$ of a random sample x' and y' drawn from the population with zero**

correlation would be greater than or equal to $\lvert r \rvert$.\footnote{\url{https://docs.scipy.org/doc/scipy/reference/generated/scipy.stats.pearsonr.html}} Note that the spatial correlation associated with p-values in Fig. 4 and Figures C1-3 does not include any dependency on the cell area. This arbitrary choice implies that the models are evaluated grid cell by grid cell and not per unit of surface. However, the impact on the spatial correlation is minor in our case, given that HMA is a relatively small area including model grid cells with areas that are relatively similar."

12. *Mention the threshold limit selected to declare the trend results significant in Section 4.1.*

L380: "Figure 6 shows a general positive trend for temperature in observations and models during both seasons. **Shading highlight the significant trends (p-value > 0.05), contours are used for not significant trends, and we consider that trends are robust when > 80 % of the models agree on its sign (hatching).**" (see RC2 for the addition of robustness)

13. *Comments on the figure and the tables have not been made at my end. Please add it!*