Anonymous Referee #1

Based on the composites of CMIP6 models, this paper shows a cold bias over the Tibetan Plateau (TP), and finds that the negative temperature anomalies over TP intensify the East Asia winter monsoon by enhancing the low-level baroclinicity in the region of the East China Sea. Then, the southern flank of the Pacific jet is reinforced. The responses of AGCM experiments support the results of CMIP6 composite. Results are interesting and a cause for concern. The manuscript is generally well written and the methods appear sound. Since there are still some points need to be revised, I would like to recommend a moderate revision before this paper can be accepted for publication.

General comments:

1.1 Why exclude December from the analysis? The period of December-January-February is usually considered as the deep winter in East Asia, and December should be included in order to assess the full climatology of TP temperature and Pacific jet. In addition, for the climate conditions in Asian region, the January-February sometimes denotes the late-winter. The temperature variability and atmospheric climatology associated with the East Asian winter monsoon have obviously subseasonal variations (e.g., Zhong & Wu, 2022, https://doi.org/10.1007/s00382-022-06610-9; Park & Kim, 2021, https://doi.org/10.1007/s00382-020-05544-4; Tian & Fan, 2020, https://doi.org/10.1007/s00382-019-05068-6) from the early- to late-winter. So, if the cold TP bias and the related dynamic processes proposed in the study are also applicable in the early-winter (i.e., November-December)?

We agree with reviewer's point, but our analysis showed that the "cold-TP composite" anomalies in temperature and 850-hPa zonal wind (as shown by supporting Figures R1 and R2 here included) based on the periods "December-January-February" and "January-February" are almost indistinguishable. Because of this, because of easier access to SPEEDY experiments, and finally for consistency with the related Portal et al. 2022 (ref. in the manuscript, using a similar experimental setup), we prefer to show the results in terms of January-February winters. Moreover, the choice of JF is not uncommon within the topic, e.g. see

Jhun, J., & Lee, E. (2004). A New East Asian Winter Monsoon Index and Associated Characteristics of the Winter Monsoon, *Journal of Climate*, *17*(4), 711-726.

Clark, M. P. and Serreze, M. C.: Effects of variations in East Asian snow cover on modulating atmospheric circulation over the North Pacific Ocean, Journal of Climate, 13, 3700–3710, 2000.

In Methods 2.1 we add the following sentence:

"The outcome is equivalent for December-January-February winters."

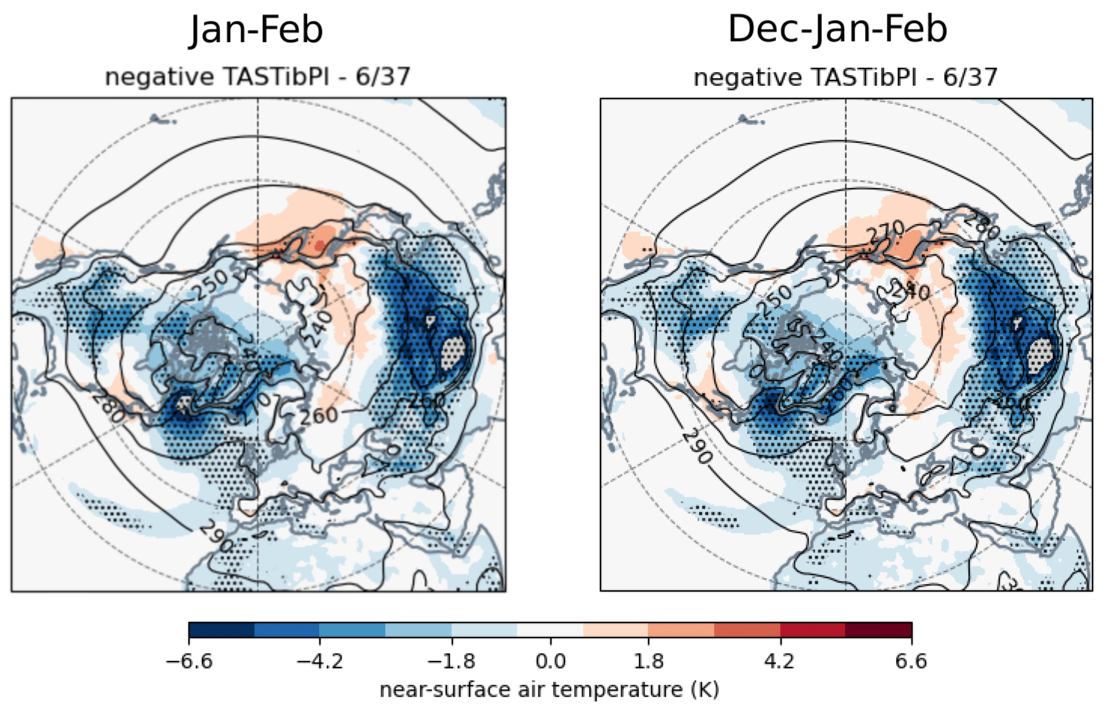

Figure R1: near-surface temperature anomaly in the “cold TP composite”, version JF (left) and DJF (right). Figure on the left is as Figure 2a from the manuscript.

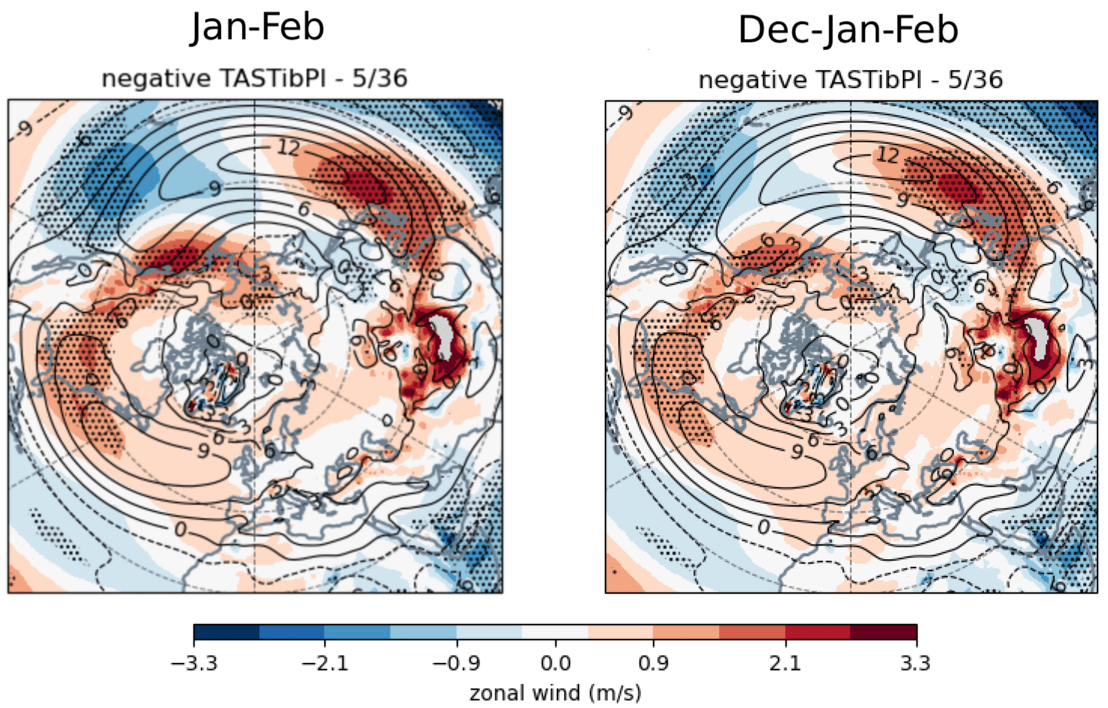

Figure R2: 850-hPa zonal-wind anomaly in the “cold TP composite”, version JF (left) and DJF (right). Figure on the left is as Figure 2c from the manuscript

1.2 Some model evaluations for the SPEEDY are needed, and at least one to be considered is the climatology of East Asian jet in AGCM and in CMIP6. Although the authors use the same surface temperature forcing as those in TP composite to drive the AGCM, the strength and position of cold advection and eddy growth rate are different (Figures 4 & 5). Compared to the CMIP6 composite, the temperature advection and eddy growth rate in AGCM are distributed farther east and closer to the Pacific and may contribute to less climate effects over the East Asian continent. Is the climatology of Asian jet in SPEEDY different from that in CMIP6 MME?

We thank Reviewer #1 for the interesting comment. Indeed, the 850 hPa zonal wind of the SPEEDY climatology and of the CMIP6 MMM are considerably different (see Figure R3 below): this is expected since SPEEDY is not a full-fledged atmospheric climate model, but relies on a simplified physics. Indeed, the eddy-driven jet in SPEEDY is weaker and shifted towards the north of the Pacific basin. However, in both cases the TP cooling affects the 850 hPa jet similarly over the East-Asian coast, with a weakening of the winds to the east of the orography. The limited eastward extension of the positive signal in the MMM (Figures 3(c) and 4(b)) is probably linked to other factors influencing the Pacific circulation within the cold TP composite (see e.g. the positive temperature advection in Figure 4(a) and surface latent heat flux Figure 2(c)) more than to differences in the mean state. We will mention this shortcoming of the composite analysis in the Results when drafting the new version of the manuscript.

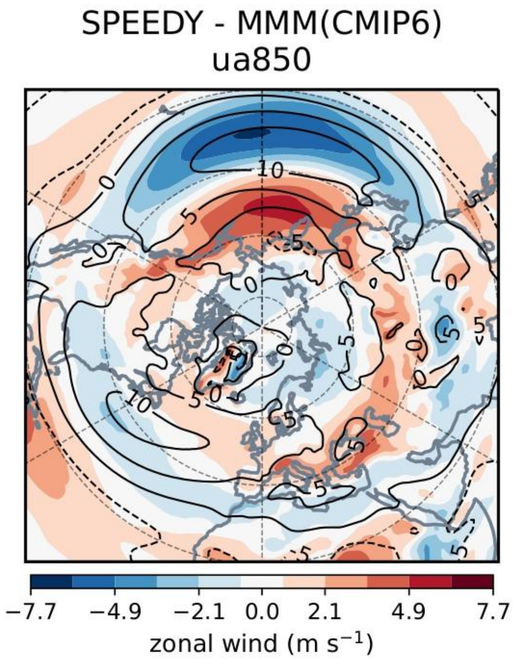

Figure R3: difference in Jan-Feb 850-hPa zonal wind between SPEEDY climatology and the CMIP6 multi-model mean.

1.3 How does the cold TP bias construct in CMIP6 climate modes, snow cover over TP or other processes related to the surface heat fluxes? More discussions should be provided in the manuscript. Additionally, for the temperature advection, the authors only present the cold advection by the mean flow (i.e., Figure 4a). However, the anomalous low-level winds are also important to advect the surface temperature. How about the temperature advection by the anomalous winds?

The following paragraph will be inserted in the Introduction to provide a plausible explanation for the TP cold bias in terms of heat fluxes.

"The CMIP5 cold Tibetan Plateau temperature bias has been examined in some detail by Chen et al. (2017). Among the climate models taking part in CMIP5 they identify a strong bias in the western region of the Plateau and show that it is more evident in terms of near-surface than surface (skin) temperature. The reason for the emergence of the strong near-surface bias is investigated by decomposing the different contributions to the low-level energy budget. Anomalous snow cover corresponds to an increase in the surface albedo, hence in the reflection of shortwave radiation, and this is anti-correlated with upward turbulent heat fluxes. While the surface temperature is weakly affected by these terms, due to compensation between incoming shortwave radiative and outgoing turbulent fluxes, a reduction in the turbulent heat flux into the atmosphere, leading to a decrease in the low-level water vapor content and thermal radiation, cools the boundary layer. By identifying physically interlinked low-level and surface processes modifying the energy budget, Chen et al. (2017) are able to explain why many CMIP5 models present a low-level cold bias over the Tibetan Plateau. These findings are likely applicable to the CMIP6 models, which show similar biases over the TP."

The temperature advection ($\mathbf{u} \cdot \nabla T$) is the dot-product between the velocity and the gradient vectors. Its anomaly from the climatological value takes into account the "cold composite" climatological anomalies from the MMM wind and temperature fields. This means that the temperature advection has not been expressed in terms of decomposition of the two linear terms (i.e. anomalous temperature advection by the MMM mean flow and MMM temperature advection by the anomalous flow). We hope this answer addresses the second part of the Reviewer's comment.

1.4 In fact, the cold bias of winter temperature is not limited to TP, but the whole East Asia which is similar to those in CMIP5 models (e.g., Gong et al., 2014, https://doi.org/10.1175/JCLI-D-13-00039.1; Wei et al., 2014, https://doi.org/10.1007/s00382-013-1929-z). I suggest that the authors should give a brief discussion about the cold bias between CMIP5 and CMIP6 models.

We extend in the Introduction the discussion of East-Asia temperature biases throughout the recent CMIP phases following the advice of the Reviewer. The suggested references will be also mentioned in the Conclusions. Here the modification that will be inserted:

"An additional motivation to approach this topic is the presence of a significant multi-model mean (MMM) temperature bias in the East Asia region, which is evident over successive phases of the CMIP and over multiple seasons. Priestley et al. (2022) detect a strong deviation from the reanalysis for summer temperature and, based on the modified thermal gradients in the low troposphere, hypothesise a role of the TP land temperature on the baroclinicity and cyclogenesis downstream. Along the same lines, East-Asia winter conditions are anomalously cold among several climate models (Wei et al., 2014; Gong et al., 2014), although improvements, associated with a closer representation of the winter monsoon, have been detected in the transition from CMIP Phase 3 to Phase 5 (Wei et al., 2014). The winter bias is especially strong over the TP (Peng et al., 2022; Fan et al., 2020, and Figure 1). Limited progress is obtained in transition from CMIP5 to CMIP6 (Lun et al., 2021; Hu et al., 2022). These studies also highlight the presence of a wide inter-model spread in year-round East-Asia and TP temperatures among the CMIP climate models,

which appears to be related with the difficulties in representing surface energy fluxes (Wei et al., 2014), in particular over regions characterised by complex orography and seasonal variations in snow cover (e.g. Su et al., 2013; Chen et al., 2017; Li et al., 2021)."

Furthermore, to better frame the role of the TP bias, and to provide more support to this discussion, the following figure, showing the Northern Hemisphere MMM near-surface temperature bias (left), and for each model the bias over the TP (right), will also be included in the updated manuscript.

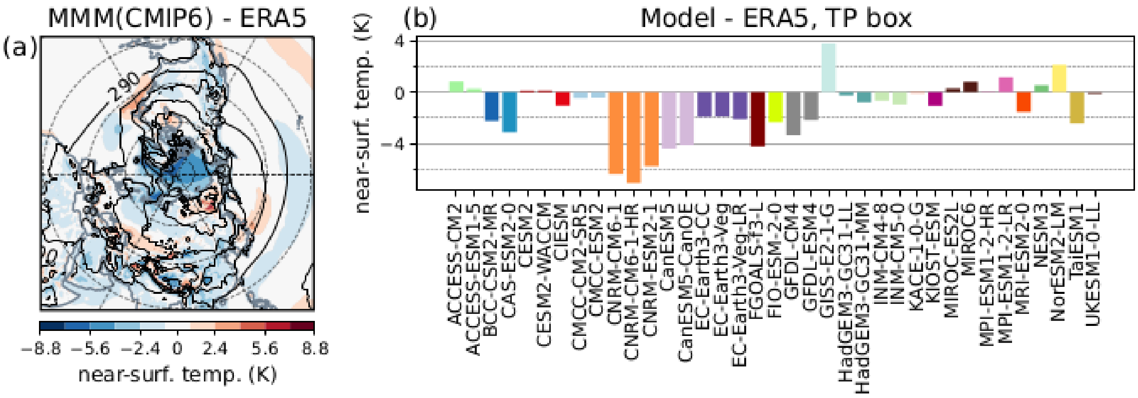

Figure 1. (a) The multi-model mean bias with respect to ERA5 in the Jan-Feb near-surface temperature climatology 1979–2008, with the ERA5 climatology in contours, and (b) the individual model biases over the TP box [25-40 N, 70-105 E] (see black box in panel (b) of Figure 2)

Specific comments:

2.1 Suggest to change the title to reflect the East Asian winter monsoon. How about “Atmospheric responses in East Asia to wintertime Tibetan Plateau cold bias in CMIP6 models”?

Following the reviewer’s comment, the title has been changed to: “Atmospheric response to cold wintertime Tibetan Plateau conditions over East Asia in climate models”.

2.2 The physical processes associated with the atmospheric responses to the cold TP bias are in line with expectations and previous analyses as illustrated in Introduction (i.e., L42-L47). So the novelty of the study needs to be better explained given these works.

We add some context to the statement of novelty of the study. We state now that the cold TP forcing amplifies the atmospheric response to East-Asian orographic forcing shown by previous works (modifications in Abstract, Results, Conclusions). As an example, we report the first paragraph of the Conclusions:

“By comparing a selection of CMIP6 historical simulations - the “cold Tibetan Plateau (TP) composite” - with an idealised AGCM simulation we show how cold temperatures over Central Asia orography influence the winter atmospheric circulation over East Asia and the North Pacific. Colder than average Asian plateaux strengthen the tropospheric heat sink and intensify the East Asia winter monsoon, leading to stronger north-westerly winds and cold advection downstream of the orographic features. The response to cooling of Central Asia orography also coincides with an overall amplification of the response to mechanical forcing from the same orography (Shi et al., 2015; Sha et al., 2015; White et al., 2017). Moreover,

this is in line with the idealised study by Ringler and Cook (1999), combining simple patterns of orographic (mechanic) and thermal forcing."

2.3 Throughout the paper, words like the "bias" and "spread" are cross-used. They should have different meanings, and it's better to define them more clearly in the paper.

We thank the reviewer for pointing this out. In the new version of the manuscript, we address this problem by using the two terms more accurately. This is helped by the addition of a new figure (Figure 1 above) displaying CMIP6 near surface temperature bias.

2.4 "Cold bias" in your title should mean the temperature difference between the model simulation and observation. However, no observation data are used and the definition of "cold TP composite" in the paper does not meet the meaning of "bias". I suggest a more appropriate word.

See answer 2.3. The word bias has been removed from the title.

2.5 In Table 1, it would be more helpful to provide the latitude & longitude resolution in degrees or grid cells for each model.

The longitude x latitude grid spacing is inserted in Table 1.

2.6 L187: Figure 2(b, d) may be Figure 3(b, d).

We thank the reviewer for the correction.