Review of “On the role of moist and dry processes for atmospheric blocking biases in the Euro-Atlantic region in CMIP6” by E. Dolores-Tesillos, O. Marius and J. Quinting

In this study, the role of biases in the background flow, dry and moist processes for the misrepresentation of atmospheric blocking in a subset of CMIP6 models is investigated. The misrepresentation of blocking in Climate models is of high scientific relevance and this study is a very valuable contribution to the scientific literature which contributes to an increased understanding. The data and methods which are used are suitable, the paper is well structured and well written. I therefore recommend the acceptance with Minor revisions.

Major comments:

1) Performance of ELIAS2.0 with climate model simulations

Of course, I fully understand that it is not possible to calculate Lagrangian trajectories to identify WCBs in different climate models due to the high computational costs and because the necessary output of wind data on model level and a time resolution of 6h is often not available. However, it would be beneficial for the paper to discuss more carefully possible biases in the WCB climatology in CMIP6 which might arise from the calculation of WCBs with ETLIAS2.0. For example, from Joos et al., 2023 we know that WCB trajectories in ERA-Interim ascend faster than in CESM1. In case this would be similar in the CMIP6 models, would that have an impact on the predicted ascent and outflow regions? This could be added to the discussion (line 311 onwards or extend what you already wrote in paragraph lines 332…).

2) Discussion of causalities

In your manuscript you state that the background flow and jet is too zonal and too far to the south and that the underestimation of the eddy activity in the North Atlantic is associated with WCB inflow and outflow biases. However, could you also argue, that due to a misrepresentation of the WCB inflow and ascent frequencies, WCBs do not disturb the upper level waveguide in a reasonable way (for example not often enough), such that in consequence, the amplification of upper-level ridges or the initiation of Rossby waves and/or blocking (or more general, a poleward shift of the dynamical tropopause) is too weak and therefore the jet and the time mean flow gets too zonal? I think these questions can not be disentangled from your study, but I would appreciate a more precise discussion of these aspects.

3) Introduction

It would be nice to include very clear research questions / objectives at the end of the introduction section and to make very clear what is new in this paper. It helps the reader to understand even better what the questions are that will be answered in this publication.

4) Section 4.3

Here you discuss how WCB can influence the upper-level waveguide. I would appreciate a little bit more detailed discussion on what determines the impact on the waveguide and which processes could lead to the observed differences. This includes

(i) bias in the frequency and or location of the outflow, (ii) a bias in the PV anomaly that is produced by the WCB. Here, the representation of microphysical processes or the simulated outflow height could have an impact on the PV value with which the WCB reaches the upper level. If this PV value is not correct, also the impact on the waveguide will be wrong, even if the predicted frequency and location is correct. So the questions is, what exactly determines the PV value in the WCB outflow. (iii) It could also be that the location of the WCB outflow, the outflow height and the PV value in the outflow is simulated correctly, but that the climatological tropopause height in CMIP6 models is not correct. Thus, even if the WCB is perfectly represented, its impact would be wrong just because the tropopause is e.g. too high or too low. A more detailed and careful discussion of all the effects that might play a role would strengthen the manuscript further. These aspects could also be discussed in the discussion section.

Minor comments:

L3: strong bias in frequency → only frequency or also location of these features

L12,13: gradients are equatorwards shifted → are shifted equatorwards

L29-30: connect the two sentences with e.g. ..., however in recent years, research has shown....

L34: ...undergo diabatic processes. → ....undergo diabatic processes whereas the influence of these processes differs in different regions of the world.

L34: Moist diabatic processes which are linked to the formation or dissipation of clouds contribute prominently to block development....

L38: new line for "The impact of moist diabatic processes...."

L58: applying anomaly block indices → what exactly do you mean here? Can you explain?

L61: ...the finer horizontal resolution could improve → improves

L71: ..by increasing horizontal resolution on a scale of storm resolution. Please clarify what you mean here.

L80: mention somewhere that in Joos et al., 2023, WCBs have been calculated in a climate model based on Lagrangian trajectories.

L85: ELISA2.0 → ELIAS2.0

L 98: please clarify: Of the possible qualitative levels for model performance .... → what exactly do you mean here?

Table 1: I don't understand what the label adequate (satisfactory/unsatisfactory) means here. Can you please clarify?

L110: Marco Rohrer and Wild, 2019 → Rohrer and Wild, 2019 , check reference

L121: lambda denotes longitude from 180W-179E and phi the latitude from 75S to 75N

L125: …featuring a Rossby wave breaking. What do you mean here? Please clarify.

L160: "…probabilities of WCB inflow, ascent and outflow". I would appreciate a lot a more detailed description on how these probabilities are calculated. Do the inflow, ascent and outflow regions correspond to a specific pressure range? How do you differentiate between these three categories? This section would also be a potential place to discuss the reliability of the ELIAS WCBs when calculated with CMIP6 data.

L160: here you mention "WCB masks". This terminology might not be clear to every reader, I would clarify.

L180: …blocking frequency by more than 80%. …this value does not correspond to the colour scale which is shown in Fig.1, please adapt.

L182: … Figs. 1i and 2e. → which figures are you referring to?

L190 ff: This paragraph does not read very well, please rewrite (for example: Although the biases are calculated for each climate model, we present the multi-model CMIP6 mean bias for concision. Fig. 2a,b show the mean and mode of Z for ERA5. A closer spacing of Z contours can be observed when considering the mode rather than the mean value)

L194: Using the mode results in sharper gradients in the mid-latitudes as Swanson (2001) → Which has also been described in Swanson (2001).

L205: … Fig. 2d? → which figure do you mean here?

Fig. 3d: the black and green lines could be thicker, and I would use solid and not dashed.

L228: …divergence in Figure 3d → difference of divergence between CMIP6 and ERA5?

L237: …looking at the biases → …looking at the differences?

L276: …tend to produce less frequent WCB outflows

L275: …of WCB inflow frequencies.

L281: …bias over eastern Europe → …bias over western Europe?

L288: …ascending trajectories by the WCB activity are crucial → …ascending WCB trajectories are crucial

L312: …analysing WCB outflow frequencies.

L313,314: i) misrepresenting diabatic processes → maybe more precisely “diabatic heating and the associated cross-isentropic flow”.

Fig. 5d and L328-331: Can you explain in more detail how the eddy heat flux is linked to the WCB inflow, what is the role of this flux for WCBs? And why is its maximum to the north of the main WCB inflow regions?

L369: yellow region in Fig.6 → there is no yellow region, please adapt

Fig.6: I very much like schematic summaries. However here you might also reconsider the causalities I mentioned above when describing the figure in the text and figure caption and formulate the conclusion a little bit more careful.