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Reply on RC2

Lisa-Ann Kautz et al.

Author comment on "Atmospheric blocking and weather extremes over the Euro-Atlantic sector – a review" by Lisa-Ann Kautz et al., Weather Clim. Dynam. Discuss., https://doi.org/10.5194/wcd-2021-56-AC2, 2021

Reply on RC2

The manuscript describes the relationship between atmospheric blocking over the Euro-Atlantic sector and a plethora of extreme events, starting from the more classical heat waves and cold spells up to droughts, extremes of precipitation and compound events.

The discussion is detailed, facing different aspects of both blocking and extreme dynamics, providing a comprehensive state-of-the-art of the scientific knowledge on the topic. Predictability and impacts of climate change are also analyzed.

My main concern is Figures 1 and 2 – the latter is not even referenced in the text! – as they appear as completely disconnected from the main body of the paper. Moreover, they provide much less information that what can be easily achievable with a short climatological/composite analysis.

However, the manuscript provides a useful reference for future studies on the topic, and highlights in which direction the scientific community is showing a lack of knowledge. Therefore, I believe that the manuscript can be easily published in Weather and Climate Dynamics after the suggested revisions are included in the new revision.

Reply: We thank Anonymous Referee #2 for his/her assessment and understand the criticism regarding the embedding of the Figures 1 and 2.

Major points

- As mentioned above, there is no discussion and refencing of Figure 2 in the text: furthermore, Figure 1 is barely described, and the different sectors highlighted in the panel are not analyzed in the text.

Reply: We agree. This point was also criticized by Anonymous Referee #1. We will replace Figure 1 and describe the new figure appropriately in the text. We will enhance the text to provide a better connection between the figure and the text and make the statements clearer. Please refer also to our reply to Anonymous Referee #1.

- In this direction I believe that Figure 1 will be much more informative if it shows a climatology of atmospheric blocking according to both one reversal and one anomaly

index, in a similar fashion to what done by Woollings et al. 2018. This can go hand in hand with a defining, as currently done in Figure 1, a set of "blocking regions", which should be always used in the rest of the manuscript. There is no need of lon-lat definition, but at least something more detailed of "North Atlantic blocking" should be used. Indeed, several times in the text I spotted references to "Atlantic blocking": this is a rather vague entity since it depends on which index is used, and such blurry definition may confound the reader. This is particularly true for this manuscript since we are discussing extremes, where the location of the blocking is fundamental.

Reply: Thanks for this comment. Anonymous Referee #1 has also stated that the informative content of Figure 1 should be increased and has already referred to potential expansion possibilities. We will compare the reviewers' suggestions, check which figure actually has an added value for the article and then fundamentally revise Figure 1 accordingly. We will also add clearer definitions of blocks depending on their region of occurrence at the beginning of the paper.

- Similarly, Figure 2 would be much more informative if instead of the current simplified sketch – that is completely disconnected from the current discussion – the authors can provide a composite analysis – based on one or more regions of blocking defined in Figure 1 - bringing together all the dynamical fields they mention. It would be extremely useful if such figure can be divided in both summer and winter, and perhaps if it includes two blocking indices, so that the reader can assess by himself the different nuances of summer and winter blocking and the limitation induced by the blocking index definition (which has been mentioned by the authors in Section 8 has a key issue).

Reply: We agree that Figure 2 is not sufficiently explained in the text. This point was also highlighted by Anonymous Referee #1. Thus, please also see the responses to Anonymous Referee #1, where we also explain our intention with this figure. We would like to keep the figure as simple as possible to provide a good synthesis / overview, but recognize that the distinction between the seasons is an important point. Therefore, we will split the figure into two panels so that the extremes for the warm and cold seasons are shown separately.

- Although the manuscript is in general well written, I found some imprecise discussion in the abstract and the introduction. I highlighted some of them in the minor points below, but I recommend the authors to double-check the text and the associated statements.

Reply: We thank Anonymous Referee #2 for highlighting some of these points. We will check our text again carefully.

Minor points

- L1: "regarding associated impacts". These last words seem not connected to the rest of the sentence, please rephrase.

Reply: We will rephrase this sentence.

- L9: I might have misunderstood, but why do you mention "longwave radiation warming" under clear sky condition? Perhaps you mean "shortwave" here?

Reply: This is a mistake – "shortwave radiation" is correct here.

- L11: I would say "meridional advection from higher latitudes" or "horizontal advection from continental landmasses". Horizontal advection from high latitude is by definition

meridional.

Reply: We will rephrase this.

- L12: The connection between snowfall, blocking and storm track is a bit confusing, I am not sure the three things are robustly related, so that I wonder if it is fundamental to highlight this in the abstract. Extreme snowfall events over Europe are usually associated with easterly or northerly winds of Arctic origin, it is unclear to me what is the role of extratropical cyclones here. Please clarify.

Reply: We will explain these connections better in the abstract.

- L28: The reference to derailed train, although fascinating, does not seem like a relevant information here (no reference is added).

Reply: We will remove this sentence.

- L30: please remove "layer up to 10-12 km", the troposphere height is season and latitude dependent.

Reply: We will remove this.

- L31: Why blocking is defined as a "self-sustaining tropospheric flow"? Blocking is not a flow – it blocks the flow - but rather an atmospheric pattern or structure.

Reply: In line 33, we have defined blocking systems as "self-sustaining tropospheric flow features". We will change this to "self-sustaining tropospheric flow patterns".

- L37: The plural of blockings is not commonly used in English, while "blocks" is a generally used definition in this case.

Reply: We will correct this at this point and also at other points in the text.

- L88: I would say meridional gradients instead of horizontal gradients, since both the referenced indices uses a meridional gradient.

Reply: We will replace "horizontal" by "meridional".

- L99: Northern Hemisphere

Reply: We will correct this at this point and also at other points in the text.

- L165: given that orography has been shown in the last years for being responsible of shaping the mid-latitude flow and having a relevant role in weather and climate model biases, I think this should be mentioned here (e.g., Jung et al 2012, Berckmans et al 2013, Pithan et al. 2016)

Reply: Thanks for the suggestion! We will take the references into account and make appropriate additions to the text.

- L167: A recent work by Davini et al (2021) on seasonal blocking might be of interest here.

Reply: Thanks for this reference. We will take a look at it and see how it can be included.

- L194: this sentence is a bit strange: a barotropic pressure positive anomaly will lead in

the Northern Hemisphere to an anticyclonic circulation: colocation is not a requirement, is a definition. Please rephrase.

Reply: We will rephrase this sentence.

- L246: Why there should be adiabatic compression induced by horizontal advection? Please explain.

Reply: We agree with the reviewer that the sentence can be somewhat misleading. The second part of the sentence refers specifically to the temperature increase. We wanted to say that the advected air becomes warmer and that this warming is caused, among other things, by adiabatic compression. However, this does not mean that horizontal advection automatically leads to adiabatic compression. We will reformulate the sentence in order to enhance clarity and avoid possible misunderstandings.

- L248: here – and in other instances, as far as I understand – the authors follow the perspective of an anomaly-based index. This a good choice, but it should be pointed out somewhere in the text that the authors follow this "view" (for this reason I suggest – see main points - showing a blocking climatology in Figure 1 and define a few clear geographical sectors). I would suggest the authors to pay attention to the geographical definition used in the different part of the manuscript, since for example reversal-based blocking indices will show the blocking discussed at these lines over Greenland. Indeed, when using a reversal index blocking in the "North Atlantic" might lead also to a poleward displacement of the jet.

Reply: Since we have not done own new analyses specifically for this paper, we have not limited ourselves to one particular approach. However, we understand that it is necessary to make it clearer in the text which approach was used in the referenced studies. Please also consider our reply to the first major comment on this matter.

- L249: Please remove "in the regions north of these cyclones".

Reply: We will rephrase this sentence as suggested.

- L261-270: this section makes a bit of confusion among seasons. As an example, a warm extreme can be driven by blocking in winter due to advection of warm air from the ocean for a prolonged time. I would encourage the authors to reorganize this part taking the different seasons into consideration.

Reply: Thanks for this suggestion. Our focus is on cold anomalies in winter and warm anomalies in summer. We will emphasize this more clearly in the text.

- L305: a brief discussion of marine heat waves and their relationship with blocking might have been interesting here.

Reply: We will add a short paragraph on marine heat waves.

- L324: Why Kautz reference has a *?

Reply: The asterisk was automatically taken from the Bib-file, as the first author L. Kautz and the second author I. Polichtchouk are equally contributing authors in the study. We will remove the asterisk in the text.

- L329: I guess that here we are talking about Greenland blocking (Hanna et al. 2016).

Reply: Thanks for this comment. We will compare the exact definition of North Atlantic

blocking by Cattiaux et al. 2021 with that of Greenland blocking by Hanna et al. 2016 and revise the text accordingly.

L343: what drives the wet anomaly on the eastern flank of the blocking? I can see it coming on the western flank due to the moister low latitude air, but it is a bit unclear to me how this can occur on the downstream side. Is this depending on the geographical placement, i.e., if a blocking is on land or on ocean?

Reply: We would like to formulate our reply using the occurrence of wet anomalies on the eastern flank of the blocking based on the floods in Pakistan in summer 2010 (cf. Martius et al. 2012) as an example. In this case, one crucial factor was the wave-breaking downstream of the blocking anticyclone (which itself was associated with the Russian heat wave). The breaking waves had an impact on the surface wind field so that moist air was transported towards the mountains downstream of an upper-level trough where the forced ascent lead to precipitation. In addition to wave breaking, monsoonal forcing also played an important role. This example shows that the occurrence of precipitation anomalies on the eastern flank of blocks also depends on the location and that other factors must also be included. We will clarify this point in the paper.

- L480-492: this is another example where a clear geographical region or sector definition may help. It is unclear which kind of blocking episode leads to such dry spell. An "Atlantic blocking" as referred at L487 might have moved the storm track and leads to increase rainfall over Iberia.

Reply: As noted above, the blocking regions will be better defined. We will then use these definitions consistently in the text.

- L545: again, it is not very clear here: a high latitude blocking event over the Euro-Atlantic sector might be over Scandinavia so that it can potentially have a limited effect on the storm track.

Reply: Santos et al. (2013) provides a comparison between two exceptional winters – 2010 and 2021. They have compared the location of blocking occurrence and the jet position and found that in 2010, there were an equatorward shifted jet and frequent high-latitude blocking while in 2012, a poleward shifted jet and frequent low-latitude blocking were observed. In both cases, the shifted jet has influenced cyclone activity and thus, the occurrence of precipitation anomalies. This study, which we have also cited, suggests that high-latitude blocks have an influence on the storm track.

- L555: does orography – as the Alps - play a role in such configuration?

Reply: For example, the paper of Hofherr and Kunz (2010) provides an extreme wind climatology of winter storms in Germany. They pointed out that over complex terrain, the near-surface wind field is dominated by orography. Since we focus on the influence of atmospheric blocking in this paper, we have not explained this aspect in detail in the manuscript.

- L567: I wonder if this configuration reflects the double wave breaking structure discussed by Messori et al. (2019)

Reply: We thank the reviewer for pointing this out. We will check the reference and enhance the text accordingly.

- L624: power plants?

Reply: We will replace "power plants" by "losses in power plant operation".

- L703: a comprehensive analysis of blocking duration in future scenarios has been done also by Dunn Sigouin et al. (2013)

Reply: Thanks for this reference. We will take a look at it and see how it can be included.

- L706: there are more recent references which analyze and discuss blocking trends, and I think some of the are also referenced in this manuscript (Masato et al 2013, Davini and D'Andrea 2020, etc…)

Reply: Thanks for the additional references. We will check and add them to the manuscript.

- L730: Screen (2014) might be referenced here.

Reply: Thanks for this reference. We will take a look at it and consider it to inclusion in the paper.

- Figure3/Figure 4: is this geopotential or geopotential height? Those numbers seem a little too small to me for being m2/s2.

Reply: We thank the reviewer for this question, there is indeed a mistake in the description. We do not show the geopotential in Figure 3 and Figure 4, but the geopotential height. We will correct the captions accordingly.

Some of the above references:

Berckmans, J., Woollings, T., Demory, M.-E., Vidale, P.-L. and Roberts, M. (2013), Atmospheric blocking in a high resolution climate model: influences of mean state, orography and eddy forcing. Atmos. Sci. Lett., 14: 34-40. https://doi.org/10.1002/asl2.412

Davini, P, Weisheimer, A, Balmaseda, M, et al. The representation of winter Northern Hemisphere atmospheric blocking in ECMWF seasonal prediction systems. Q J R Meteorol Soc. 2021; 147: 1344– 1363. https://doi.org/10.1002/qj.3974

Dunn-Sigouin, E., and Son, S.-W. (2013), Northern Hemisphere blocking frequency and duration in the CMIP5 models, J. Geophys. Res. Atmos., 118, 1179– 1188, doi:10.1002/jgrd.50143.

Hanna, E., Cropper, T.E., Hall, R.J. and Cappelen, J. (2016), Greenland Blocking Index 1851–2015: a regional climate change signal. Int. J. Climatol., 36: 4847-4861. https://doi.org/10.1002/joc.4673

Messori, G., et al. On the low-frequency variability of wintertime Euro-Atlantic planetary wave-breaking. Clim Dyn 52, 2431–2450 (2019). https://doi.org/10.1007/s00382-018-4373-2

Pithan, F., Shepherd, T. G., Zappa, G., and Sandu, I. (2016), Climate model biases in jet streams, blocking and storm tracks resulting from missing orographic drag, Geophys. Res. Lett., 43, 7231– 7240, doi:10.1002/2016GL069551.

Screen, J. Arctic amplification decreases temperature variance in northern mid- to highlatitudes. Nature Clim Change 4, 577–582 (2014). https://doi.org/10.1038/nclimate2268