Author's Response to Referee Comments on Suitters et al. (2022)

We thank the two referees for their insightful comments in helping to improve the manuscript. We address their comments below. Reviewer comments are in black and our responses appear in blue. Figures included in our responses are labelled "R1, R2" etc. to avoid confusion with figures referenced in the paper.

Referee 1

This work focuses on the contribution of anticyclonic eddies to the maintenance of blocks, more particularly it investigates the relationship between anticyclonic eddies strength, zonal and meridional velocities, and the blocking persistence. Blocking events occurring in two areas of the Northern Hemisphere (the North Pacific and the North Atlantic/western Europe area) and during four seasons are studied here. The method used here to detect both the anticyclonic eddies and blocks is interesting. The science is sound; the article is well written and the figures and tables are clear. I have two major comments on this paper and a few minor comments.

Major comments:

- First, this paper is quite long for the number of results discussed here. I wonder if the authors could remove or shorten some sections:
    - Section 4.1 is a bit long as the result are very similar to previous studies. Figure 4 could be moved to the appendix and summarized in a couple of sentences.

We appreciate the fact that the results shown in Section 4.1 are similar to previous studies, but we feel that it is important to demonstrate that our blocking detection method behaves in a way consistent to previous studies. Since the Z_*' index is introduced for the first time in this piece of work, we believe it is necessary that the climatology plots (Fig. 4) are included in the main text to highlight the similarities with other indices and therefore justify the usage of the index. Having said this, we do also appreciate that the description of the figure is a bit long and does indeed repeat many findings from previous work. Therefore, the second paragraph has been replaced by one sentence summarising the seasonality of the index. The discussion surrounding the magnitude of the blocking frequencies has been retained and altered slightly following a comment from Referee 2 (see below).

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    - Section 4.2 could also be summarized and merged with section 5.1. In addition, the values shown in Tables 1, 2 and 3 could be directly added on the figures to shorten the paper.

We again feel this information is important to retain in the main body of the text. However, the discussion surrounding the figure in Section 4.2 (Fig. 5) has been made more concise and combined with the previous section where the spatial climatology was discussed. Sections 4.1 and 4.2 have therefore been combined (into a standalone Section 4) instead of combining 4.2 with 5.1 as suggested here. We think that Fig. 5 is a better fit with the spatial climatology discussion because this figure also focuses entirely on the blocks themselves, while Section 5 introduces the results concerning the AC eddies. The discussion of Fig. 5 has also been adapted to include a comment about the events lasting less than 5 days in JJA, reflecting the fact that a quarter of all sector blocks in JJA last less than 5 days. This indicates that the blocks are small in summer (so only marginally meet the area criterion for sector blocking), which we feel is an important climatological aspect of the blocks that cannot be obtained by simply looking at Fig. 4.

The comment about removing the tables and adding the information they contained was a very useful addition and we thank the reviewer for suggesting this. The number of events row from Table 1 and quartile definitions have been added to the panels in the histograms (Fig. 5), the correlations shown in Tables 2 and 3 have been added as text to the existing panels in the scatter plots (Fig. 6a-d), and the mean number of AC eddies rows in Tables 2 and 3 have been included as two additional panels (new bar charts in updated Fig. 6e-f). Language when describing "25th, 50th, 75th percentiles" in the text has been adapted to read "Q1/2/3", referring to the quartiles of persistence instead, for clarity and to be consistent with the new labels in the figures. Upon completing this task, three small errors were discovered and amended in the manuscript: (1) corr(N,A) in ATL JJA is in fact ***significant*** (not insignificant as previously asserted); (2) number of anticyclonic (AC) eddies per block have been correctly calculated now (the values in the table were incorrect previously); (3) Line 246 in updated paper: "Longer blocks are generally larger, and this relationship is strongest in ***summer*** in the PAC region" (previously stated "winter"). Removing the tables and providing this information in figure form was very helpful in finding these errors!

- The curves shown in Figure 7 could be directly added on Figures 8 and 9 to remove Figure 7. Also, Figure 9 could be move to the Appendix as it does not show strong differences between the shortest 25% and longest 25% of blocks.

We again found this particular comment especially helpful, not only in terms of data presentation but also helping with the interpretation of the results. We have updated the manuscript to remove Fig. 7 and amended Figs. 8 and 9. The updated Fig. 9 is shown below as an example (Fig. R1 here). We have implemented the suggestion of plotting the mean profile curve from Fig. 7 onto Figs. 8 and 9, and we have only plotted the profiles for the shortest 25% and longest 25% of blocks. The updated figures are much clearer and easier to interpret, with less clutter and using different colours to denote the properties of the eddies that contribute to differences in block persistences, instead of

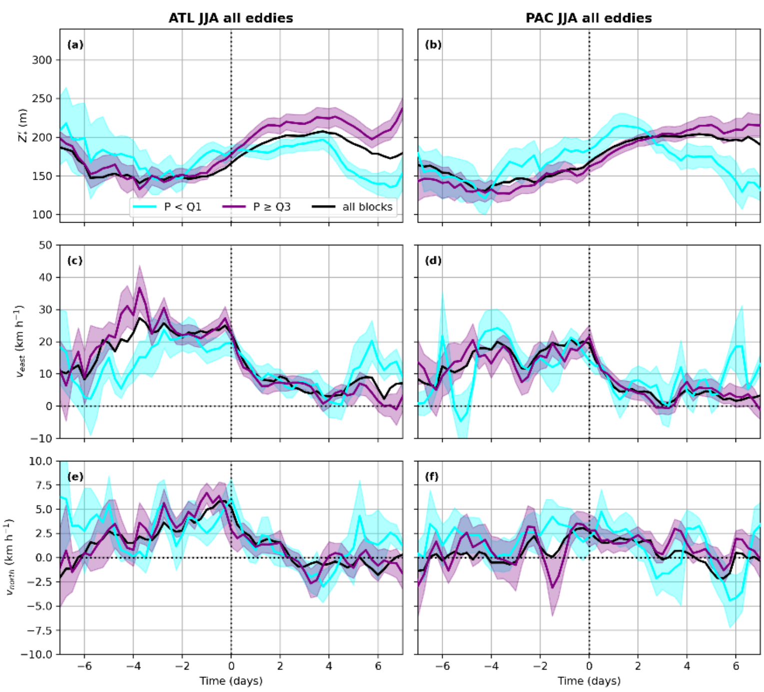

Figure R1. Updated Fig. 9 (becomes Fig. 8 in the updated manuscript) showing the time series of mean strength **(a, b)**, zonal speed **(c, d)** and meridional speed **(e, f)** for AC eddies that contribute to ATL (left) and PAC (right) blocks. Only the eddies contributing to the shortest (cyan) and longest (purple) 25% of blocks are shown, along with the mean profile of AC eddies contributing to blocks of all lengths (black). Shading indicates standard error from the mean.

different line styles. Because we have combined Figs. 7 and 8/9, we have merged sections 5.2 and 5.3.

The updated figures have in fact made it easier to change a conclusion drawn from these profiles. The (main) conclusions for the ATL domain remain unchanged – eddy strength is only different for the shortest and longest 25% of blocks in DJF (and SON), in MAM and JJA there is no significant difference. However in the PAC domain, these cleaner plots allow for a slightly different interpretation to that described in the text. Eddy strength at the point of entering the block is significantly different between the longest and shortest 25% of blocks in ***all*** seasons: in DJF, MAM and SON, the most persistent blocks result from the interaction between stronger eddies than the shortest 25% of blocks, however in JJA the longest blocks actually interact with weaker eddies. With this behaviour now evident in the PAC sector, we feel that the plots for both DJF and JJA belong in the main body of the text, and not the Appendix as suggested here. Section 5.2 (was Section 5.3) has been rewritten to reflect these new conclusions, along with the appropriate changes in the Conclusions, Abstract, and Short Summary. Once again we thank the reviewer for this suggestion as it has led to an important change in the conclusions of our work!

- Second, the paper is quite descriptive and does not address the dynamics behind the relationship between anticyclonic eddies and blocks as could be thought after reading the introduction (e.g. lines 57-60 or lines 78-81) or the title. It does not show how these anticyclonic eddies dynamically contribute to the persistence of blocks. The space gained by summarizing some sections as suggested above could be used by the authors to develop more the dynamics behind this relation.

Thank you for pointing this out – we agree that the first version of our article was more statistical than at first thought given the introduction we provided. The space gained by implementing the changes you outlined above allowed us to add two short sections describing a little more the dynamics at play here: in the context of the case study (lines 195-208 in updated paper); and a "Discussion" section (new Sect. 6 in the updated article) in an attempt to describe a little more the dynamics behind our findings.

We approach the dynamical arguments by considering the effect of the AC eddies on both the area and intensity of the blocks. Yamazaki and Itoh (2013) argue that larger and more intense blocks are harder to advect downstream, since they require more forcing from upstream. We observe that often the block area and/or intensity increases upon the arrival of an AC eddy into the block. Therefore, we argue that AC eddy interactions increase the persistence of blocks by increasing their area or intensity.

The discussion section also addresses why the relationship between block persistence and AC eddies is slightly weaker in the ATL than the PAC. We argue that two conflicting scenarios are happening in the ATL domain, where synoptic-scale anomalies are more important over continental Europe than the Atlantic Ocean (Miller and Wang, 2022). Since our ATL domain covers both, we deduce that these factors may be contributing to a slightly weaker (but still relatively large) relationship than in the PAC.

We also address why it appears that JJA PAC blocks absorb weaker anomalies when they persist longer. This is again the result of us capturing, in essence, two different blocking centres here (one near the climatological blocking maximum to the west, and another one inside the domain itself). More details about all aspects mentioned above are provided in the new Discussion section.

Yamazaki, A. and Itoh, H., 2013. Vortex–vortex interactions for the maintenance of blocking. Part I: The selective absorption mechanism and a case study. Journal of the Atmospheric Sciences, 70(3), pp.725-742.

Miller, D.E. and Wang, Z., 2022. Northern Hemisphere winter blocking: differing onset mechanisms across regions. Journal of the Atmospheric Sciences, 79(5), pp.1291-1309.

Minor comments:

- Please, give more details in the Appendix on how the anticyclonic eddies are tracked.

The following paragraph has been added to the appendix:

In this work, TRACK is used to identify anticyclones corresponding to positive Z500 anomalies with respect to the instantaneous zonal mean component, once the climatological zonal mean anomaly is subtracted. Small scales are removed by spectral filtering, lowering the original resolution of the data to T42 resolution. Once the maxima in Z500 anomaly field are identified, tracks are constructed by finding nearest neighbours in consecutive time steps rather than the more sophisticated optimization method (Hodges, 1994, 1999) as there are typically only a small number of systems in any time step and blocks are often stationary features.

Hodges, K.I., 1994. A general method for tracking analysis and its application to meteorological data. Monthly Weather Review, 122(11), pp.2573-2586.

Hodges, K.I., 1999. Adaptive constraints for feature tracking. Monthly Weather Review, 127(6), pp.1362-1373.

- Line 112: Do you mean the monthly deviation from the zonal mean Z500?

Yes, this is what we meant. Thank you for pointing this out, it has been corrected in the text.

- Figure 3: Could you plot the continent lines in a distinct colour to separate it better from the geopotential anomaly contours. In addition, maybe you should plot only the “ongoing” tracks to make the figure cleared?

Thank you for the suggestion. In the updated plot, coastlines are now plotted in grey while the geopotential anomalies remain in black. We also agree that only having the “ongoing” tracks in each panel is clearer, so this change has also been implemented.

- Figure 5: why do you show the blocks lasting less than 5 days?

We have shown these events because they still meet our definition for “sector blocking”. At the grid point level, a 5-day persistence criterion is indeed applied (as explained in Sect. 2.3), but when we define a “sector block” to be occurring, we require enough grid points to be meeting this persistence criterion inside the domain. If the system is small enough, it is possible that the area threshold is only met temporarily. A simplified example of this is shown in Fig. R2. Assuming the anomaly value of each red grid box exceeds 100m, each individual grid point in red satisfies the 5-day persistence criterion, so is classed as “blocked” according to the blocking index. However, when we invoke the 1.0 x 10^6 km^2 area threshold used to classify a blocking event, only in days 3-5 is there enough blocked points to exceed the threshold. Situations such as these occur fairly often in summer when blocks tend to be smaller (but may still be bringing impactful surface conditions), and are therefore kept in the histograms. A similar arrangement can happen when a block occurs predominantly outside of the domain, with only a small part of the block inside the domain (e.g. a Ural block with its

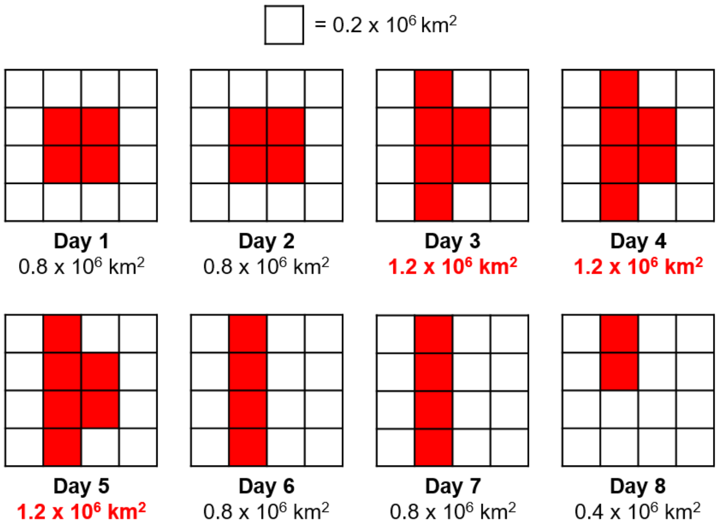

Figure R2. Schematic illustrating the difference between "grid point blocking" according to the blocking index, and "sector blocking". Each box represents an area of 0.2 x 10^6 km^2. If a box is red, it satisfies both the 100 m anomaly threshold and 5-day persistence criterion imposed by the blocking index. A "sector block" occurs when an area of > 1.0 x 10^6 km^2 is blocked in the sector (indicated by the red number below the plot for that day).

western flank clipping the ATL domain). Section 2.3 has been updated to include a short explanation of this scenario happening, and the discussion of Fig. 5 in the text has also been adapted to explain how these situations can occur fairly commonly in summer. Figure R2 has also been included in the Appendix for further clarification.

- Figure 5: Could you add in the figure the number of blocks in each area and season (as shown in Table 1)?

Thanks for the suggestion, the updated Fig. 5 has this information on it now.

- Lines 220-230: Could you add the values of the different percentiles in Figure 5?

This section has been rewritten as discussed in your earlier comment, and we have endeavoured to add the values of Q1, Q2, Q3 wherever we have stated them.

- Line 252-256: could you add the number of eddies in parenthesis as done in lines 250-251?

Once again this section has been slightly rewritten, but eddy numbers have been given in parentheses where appropriate.

- Figure 6: the colour of the dot plotted behind is not visible. Could the authors plot the relation between persistence and number of eddies in another panel? Or plot in another way the number of anticyclonic eddies

We appreciate the concern with this figure; however we feel this is the best way to display the data. If the data was plotted simply as number of eddies (N) on one axis with persistence (P) on another, there would be a much bigger issue with overlapping data points due to both values being discrete values. The area axis (A) was used in part because it allows the data points to be separated more easily, and provide a much "cleaner" plot. Having said this, we have reduced the size of the dots in the scatter plot which we believe has greatly improved the issue where certain points are not visible behind others, while appreciating that this is still not perfect. The additional panels (e) and (f) added to Figure 6 now also help in showing the relationship of larger N with larger P in a more concise way than the scatter plots do, without the issue of overlapping data points.

- Line 271: what is the duration of the anticyclonic eddies?

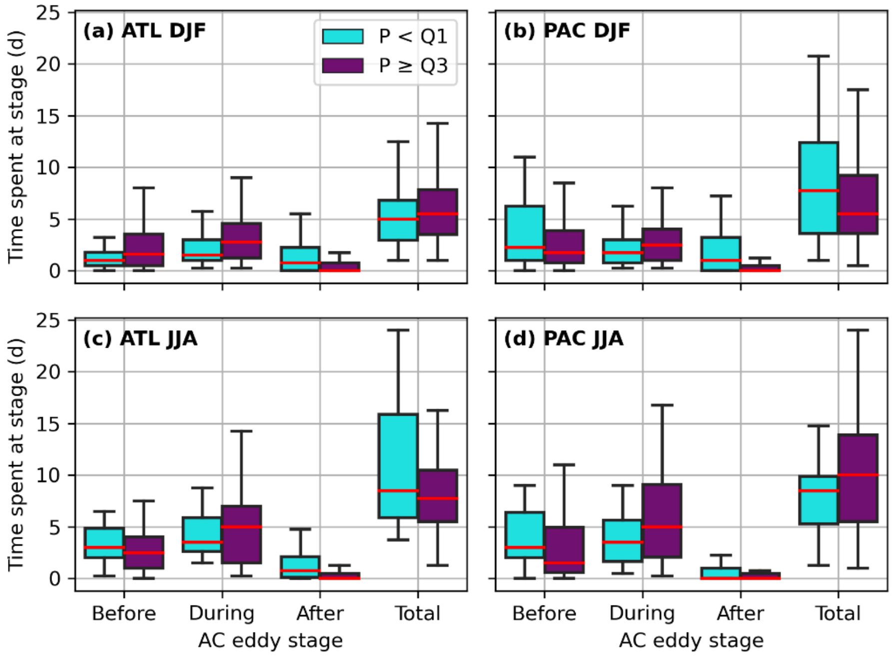

Figure R3. Duration of all AC eddies that contribute to the shortest (cyan) and longest (purple) 25% of blocks in the ATL (a, c) and PAC (b, d) domains in DJF (a, b) and JJA (c, d). Boxes show the interquartile range (IQR) of AC eddy duration at each stage of blocking, the red lines indicate the median, and the whiskers indicate 1.5 x the IQR. Outliers have been excluded from the plot. “Before” means times before the AC eddies first enter the blocks (left of the t = 0 line on Figs. 7-9 in the original text), “During” means times when the AC eddy coincides in space and time with a blocked grid point, and “After” means times after the AC eddy has first left the blocked grid points.

We thank the reviewer for this interesting question. A boxplot showing the duration of the AC eddies before, during and after blocking (and total lifetime) for DJF and JJA for the longest and shortest 25% of blocks is shown in Figure R3. The main findings from these plots are explained briefly here. Firstly, for both long and short blocks in both DJF and JJA, AC eddies have a much shorter duration after blocking than they do before/during blocking. And for the longest 25% of blocks, over half of the AC eddies contributing to their maintenance do not have any life after the block (median = 0 days); i.e. the majority of AC eddies contributing to the longest blocks decay in, or become fully absorbed by, the block itself. Meanwhile, apart from PAC JJA, the majority of AC eddies contributing to the shortest blocks do have a lifetime after blocking (median > 0 days). These findings are perhaps not surprising and match with the line plots in updated Figs. 7 and 8 in that after the eddies have entered the block (t > 0), those contributing to the shortest 25% of blocks are faster-moving (and therefore no longer quasi-stationary, which blocking requires) than those contributing to the longest 25%.

Second, an unsurprising related result confirmed by the boxplots in Fig. R3 is that the AC eddies contributing to the longest blocks have a longer residence time inside the block than those associated with shorter blocks. The increased persistence of these blocks is therefore related to the increased duration and quasi-stationarity of the AC eddies inside the block (again c.f. updated Figs. 7 and 8 in the text).

Another finding is that AC eddies that contribute to blocks (of all lengths) have a longer total duration in JJA than in DJF. Once again, by also looking at the v_{east} curves in the updated Figs. 7 and 8, we see that this longer lifespan is associated with slower zonal progression in JJA than DJF. These arguments are consistent with the fact that the summer jet is weaker and generally more variable, thus meaning that AC eddies progress more slowly along it than in winter. The ~25-50% increase in duration (in the median) in JJA from DJF marries with a ~25-50% reduction in zonal speed from DJF to JJA (updated Figs. 7, 8), implying that a similar total distance is travelled by the eddies in both seasons (excluding the few very long eddy tracks shown in Fig. R6 in response to Reviewer 2).

Finally, we find that even for the most persistent blocks, the AC eddies that contribute to them, for the most part, do not stay in the block for longer than 5 days, especially in winter. This means that in order for a block to persist for much longer than this, repeated AC eddies may be required to "top up" the anticyclonic anomaly inside the block in order for it to persist. This finding was displayed in the scatter plots (Fig. 6) and was the main conclusion of this paper.

All things considered, we do not believe that the addition of this figure would add any new information to the manuscript, since all points mentioned above can already be explained by existing figures. However, these findings are summarised and a few additional comments have been added to the main text of the paper explaining the duration of the eddies, where appropriate.

- In Figures 7, 8 and 9, there is no separation between the through and absorbed eddies?

The reviewer is correct here in that the profiles plotted on the original Figs 7-9 considered all AC eddies and did not distinguish between those that are absorbed (finish inside the block) and those that pass through the block. A brief comparison between these two types of eddies is provided here.

The profiles of absorbed AC eddy intensity, zonal and meridional speed for all blocks, the shortest 25%, and the longest 25% of DJF blocks are shown in Fig. R4. The profiles for absorbed eddies are qualitatively similar to those shown for all AC eddies for strength, zonal and meridional speed. (Note that the mean line stops just after day+6 for the shortest 25% of blocks – this is expected since these eddies are now absorbed by the block, but these blocks are short so do not last longer than 6 days). The JJA profiles for absorbed eddies are also qualitatively identical to those for all eddies.

For the most part, the through AC eddies also behave the same as all AC eddies do. The only exception is that for ATL DJF blocks, there is no discernible difference in the strength of the absorbed

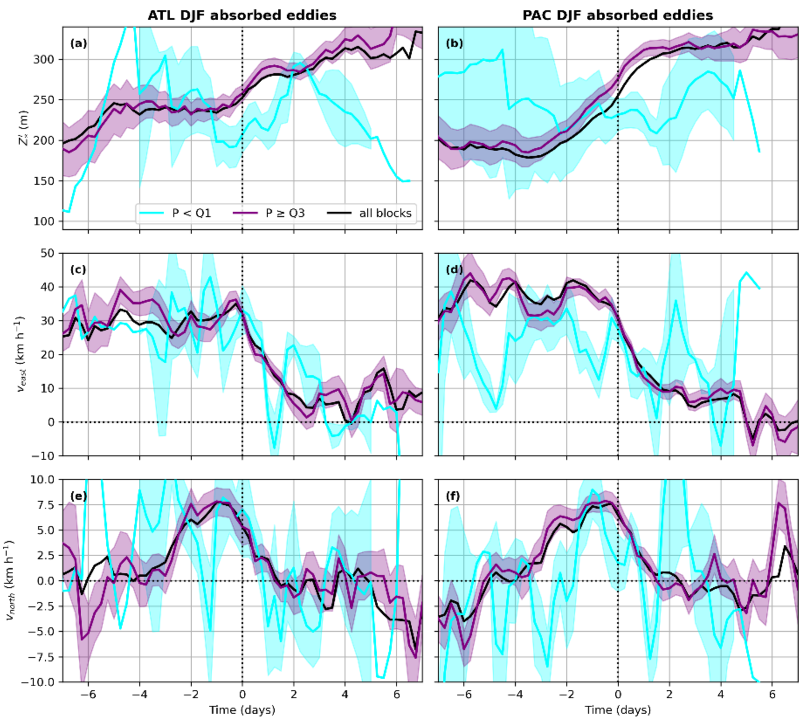

Figure R4. As in updated Fig. 7 in the manuscript, but only showing the characteristics of the absorbed AC eddies.

eddies at t = 0 for the longest and shortest 25% of blocks (not shown here). Otherwise, the same conclusions can be drawn as those for absorbed and all AC eddies.

Therefore, we decide not to separate the eddy profiles shown in updated Figs. 7 and 8 into those that are “absorbed” and those that go “through” the block. We have however added a sentence in Section 5.2 confirming the similarities between absorbed and through eddies.

- Figures 8 and 9: could you plot the shortest 50% of blocks and the longest 50% in a distinct colour to better differentiate the standard error.

This has been addressed as explained above. Instead, we plot results only for the shortest and longest 25% of blocks as this is where the starkest differences are. These are now plotted in different colours.

- Line 335: replace “Selective Absorption Mechanism” by “SAM”.

Thank you for pointing this out, this has been amended in the text.

<u>Referee 2</u>

Review of "Transient Anticyclonic Eddies and Their Relationship to Atmospheric Block Persistence" by Charlie C. Suitters, and coauthors

The authors investigate the relationship between block persistence and synoptic-eddy (especially anticyclonic anticyclone) characteristics based on the traditional eddy-feedback mechanism originally proposed by the famous paper Shutts (1983). The authors applied a cyclone-tracking method to the synoptic anticyclones that interact withã□□blocking, and discovered that i) longer blocks interact with more anticyclonic transients than less persistent blocks and ii) there is little relationship between the strength of the anticyclonic eddy and the blocking longevity except winter. In the manuscript, the authors comprehensively reviewed the blocking maintenance mechanism based on the eddy feedback mechanism and the results obtained here support importance of the eddy feedback mechanism. Also, the authors quantify the eddy feedback mechanism from both the Eulerian and Lagrangian perspectives. This paper include a lot of novel topics on the blocking mechanism and can develop the traditional eddy feedback mechanism from 1980s.

The reviewer evaluates that the manuscript is suitable for the journal Weather and Climate Dynamics that has the scopes on midlatitude dynamics, in which blocking and synoptic eddies are essential, though I also have a major comment about the correspondence between the anticyclone tracking used in this study and the Lagrangian tracking ways commonly used in previous studies. Then, the reviewer would suggest the paper is in a category of major revision. Specific comments are below.

Major comments

The authors define the anticyclonic eddies as positive anomaly from the zonal and temporal means, which seems different from typical cyclone tracking and particle tracking methods used in many studies. I think although the Lagrangian tracking used in this study is valuable to understand the eddy characteristics, but also think that many Lagrangian tracking schemes focus on the absolute (raw) fields (values) rather than their anomaly fields. Yamazaki and Itoh (2013a) mention in their paper that (raw) low PV supply is important for the blocking maintenance, and their Lagrangian tracking was done by raw (unfiltered) wind fields. More recent papers by Pfahl et al. (2015) or Yamamoto et al. (2021) which adopted the Lagrangian analysis into the blocking formation and maintenance mechanisms monitored (raw) PV values of tracked air parcels. Here, my question is that if you define the eddy intensity (strength) as a raw value (say, PV) in Figs. 7-9, does your conclusion that "there is a less clear relationship between block persistence and the strength of the AC eddies that it absorbs" change? For example, could you trace the mean column-averaged value of raw PV of 150-500 hPa (Schwierz et al. 2004) at or within an AC eddy? In addition, I think that Z anomaly as the eddy strength can be changed if latitudinal position of the eddy varies. In such perspective, I am wondering how are the track distributions of ACs that interact with blocking? To check the distributions and/or the statistics of the AC tracks may be helpful on your conclusion. The results by Yamamoto et al. (2021) might be useful.

We thank this reviewer for a thorough comment on our work. We have split our answer to these into four parts:

Could we trace the mean column-averaged value of raw PV of 150-500 hPa at or within an AC eddy?

We appreciate that previous studies have used this measure of PV to define AC eddies (e.g. Schweirz et al., 2004; Hauser et al., 2022) and blocking. However Z500 is an equally valid measure to define both metrics, and indeed has already been used for AC anomaly tracking (see Liu et al., 2018). A Z500-based blocking index and AC eddy definition was pursued as this is a more readily available diagnostic in reanalysis and model datasets, so can more easily be implemented elsewhere, if desired.

A PV-based method would be expected to give similar, but admittedly not identical, results to those presented here. Generally speaking, one would expect that ridges in Z500 would align with PV-derived ridges (through the PV invertibility principle). Generally speaking, the Z500 field is also spatially smoother than the full PV field, and is therefore easier to track anomalies in. The use of a Z500-based metric in our study also allows for theoretical block maintenance mechanisms explained using PV thinking, like the SAM, to be “tested” using another variable. Yamazaki and Itoh (2013) explain that longer-lasting blocks are larger and more intense than smaller ones, and we have shown (in the new “Discussion” section in the paper, Sect. 5) that Z500-based anomalies increase block area and/or intensity. Combined with our finding that more persistent blocks result from more (and sometimes stronger) eddies, we can deduce that our method is appropriately capturing the PV-based behaviour that the SAM describes, so is therefore valid to determine AC eddies with.

Having said this, current/future work by the authors of this manuscript is looking to attribute PV to AC eddies. In particular, the PV budget of the AC eddies at different stages of blocking is being looked in to, for a few selected case studies. Initial analysis on one case study period has shown that the AC eddy track centres used in this study align very well with local minima in vertically-averaged 150-500 hPa PV. An example of this is shown in Fig. R5. Therefore, we would expect a PV-based method to produce similar results to those presented here with our Z500-based method.

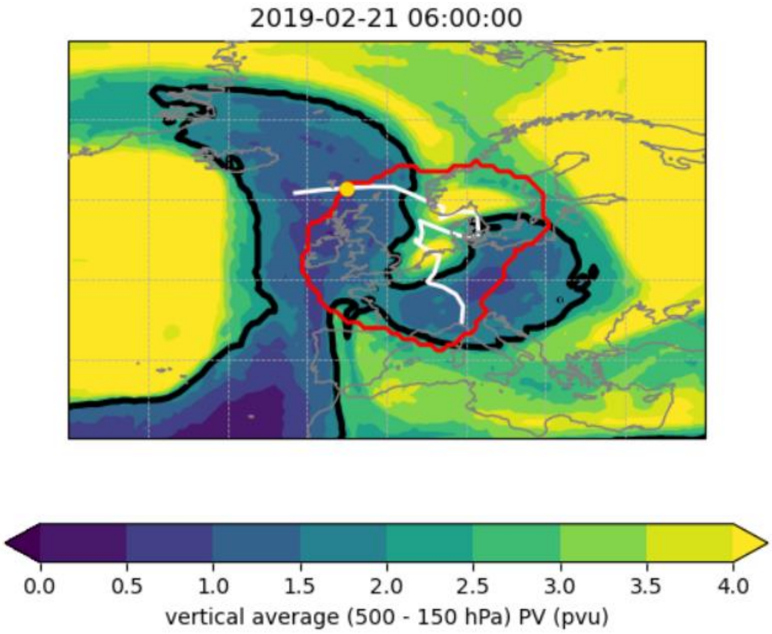

Figure R5. Vertically-averaged (500-150 hPa) PV (VAPV, shading), AC eddy track derived using the Z500-based method as described in Suitters et al. (2022) (white line, position at valid time in yellow dot), and block outline, again using the Z500-based technique (red). The dynamic tropopause (PV = 2 pvu line) is shown in black

Liu, P., Zhu, Y., Zhang, Q., Gottschalck, J., Zhang, M., Melhauser, C., Li, W., Guan, H., Zhou, X., Hou, D. and Peña, M., 2018. Climatology of tracked persistent maxima of 500-hPa geopotential height. Climate Dynamics, 51, pp.701-717.

Hauser, S., Teubler, F., Riemer, M., Knippertz, P. and Grams, C.M., 2022. Towards a diagnostic framework unifying different perspectives on blocking dynamics: insight into a major blocking in the North Atlantic-European region. Weather and Climate Dynamics Discussions, pp.1-36.

Schwierz, C., Croci-Maspoli, M. and Davies, H.C., 2004. Perspicacious indicators of atmospheric blocking. Geophysical research letters, 31(6).

Does the conclusion that there is a "less clear relationship between block persistence and the strength of the AC eddies it absorb" change if we define eddy intensity using raw PV?

Firstly, it should be noted that thanks to a comment by Reviewer 1 (above), we have slightly changed our conclusions surrounding block persistence and AC eddy strength. Now, we conclude that in the PAC region, AC eddy strength does have a relationship with block persistence, and in the ATL the same is true for DJF and SON. So, we are now able to conclude that more often than not, there is an important relationship between AC eddy strength and block persistence: (1) longer blocks result from stronger AC eddies in ATL DJF, ATL SON, PAC DJF, PAC MAM, PAC SON; (2) longer blocks result from weaker AC eddies in PAC JJA. Only in ATL MAM and ATL JJA is there no significant difference in AC eddy strength for the longest and shortest blocks. The text has been amended to reflect this new conclusion.

As discussed above, we expect that most of the time, the Z500-based AC eddies would align fairly well with the equivalent PV-based ones. We would therefore expect a similar relationship to hold true between AC eddies and block persistence if we instead defined them using raw PV. As mentioned above, certain blocking case studies will be tackled from a PV perspective in future work by these authors, so this hypothesis can be tested there instead. We do not think that this current study calls for PV thinking.

Can the Z anomaly (as a metric for eddy strength) be changed if latitudinal position of the eddy varies?

We have tried to normalise the eddy strength by its location as much as possible in our anticyclonic anomaly calculations. The strength of the eddies at any time depends on two things:

(1) The eddy's instantaneous Z500 anomaly from the zonal mean, $Z_*(\lambda, \phi)$. This value depends on the eddy's location (both its longitude λ, and latitude ϕ) and its magnitude depends on (a) how amplified the eddy's ridge is and (b) how amplified the rest of the wave guide is at that longitude. If the eddy occurs at a time where the rest of the jet is fairly zonal at that latitude, a move northwards would indeed mean an increase in eddy strength. However, an eddy that occurs among an amplified jet, with many ridges and troughs, would not necessarily strengthen as it moves north. However it should be noted that blocking is associated with the poleward transport of higher-than-normal geopotential heights, so an increase in eddy strength as the eddy moves northward is not unexpected and perhaps even desirable behaviour.

(2) The background climatological wave pattern, $\overline{Z_*}(\lambda, \phi)$, quantified by the monthly climatological anomaly from the zonal mean at a grid point, as shown in Fig. 1 in the article. This has the effect of "normalising" the anomaly strength by location and time of year, meaning that any strengthening of the eddy could be considered "real", rather than just an artefact of the method.

What are the track distributions of the ACs that interact with blocking?

Thank you for this interesting comment. We show the AC eddy tracks, genesis and lysis locations for all ATL in DJF and JJA in Fig. R6. In both summer and winter, the overwhelming majority of AC eddies that contribute to ATL blocking travel from west to east. Most AC eddies contributing to ATL blocking begin in the North Atlantic storm track region before travelling along the wave guide and entering the blocking region. This result agrees well with the finding from Ioannidou and Yau (2008) concerning where anticyclonic Z500 anomalies are formed (their Figs. 6a, 8a). Some AC eddies are generated over continental North America and even the North Pacific, and this is more common in DJF than JJA. Most blocking AC eddies finish in the ATL region itself, though a sizeable proportion propagate further downstream once contributing to blocking and decay over central/eastern Eurasia (these are the "through" eddies), again this being most common in DJF. Panels (a) and (c) confirm the results indicated in response to Reviewer 1 above, in that summer eddies travel less distance than winter ones (Fig. 3 in this document). A similar pattern is evident for PAC blocks (not shown).

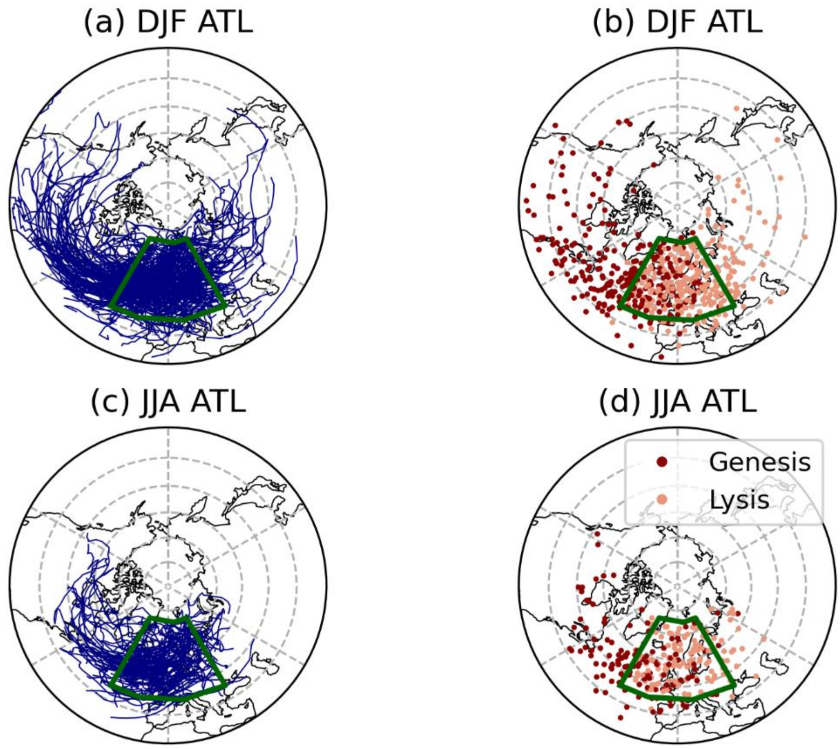

Figure R6. AC eddy track distributions for ATL blocks in winter (a, b) and summer (c, d). All AC eddy tracks are shown in the left column, and AC eddy track genesis (dark red) and lysis (pale orange) locations are shown in the right column. The ATL domain is shown in green.

Ioannidou, L. and Yau, M.K., 2008. A climatology of the Northern Hemisphere winter anticyclones. Journal of Geophysical Research: Atmospheres, 113(D8).

Yamamoto, A., et al., 2021: Oceanic moisture sources contributing to wintertime Euro-Atlantic blocking, Weather Clim. Dynam., https://doi.org/10.5194/wcd-2-819-2021.

Hauser, S., Teubler, F., Riemer, M., Knippertz, P. and Grams, C.M., 2022. Towards a diagnostic framework unifying different perspectives on blocking dynamics: insight into a major blocking in the North Atlantic-European region. Weather and Climate Dynamics Discussions, pp.1-36.

Other specific comments

1. Related to the major comment, could you show the trajectory statistics of synoptic cyclones? Since sometimes a Berggren-type blocking where there are several isolated anticyclonic or cyclonic vortices within the blocking region (e.g., Luo 2005) can exist.

While we agree that showing the trajectories of synoptic cyclones would be interesting, and often an important part of blocking, we argue that this is out of the scope of this work. The main aim of this study is to examine the extent to which synoptic-scale *anticyclones* extend the lifetime of blocking *anticyclones*. We decided to focus on the anticyclonic aspect of blocking for a couple of reasons. Firstly, the majority of previous studies have developed block detection methods purely in terms of how anticyclonic the region is, so our method is consistent with prior work. Secondly, it should be noted that not all blocking patterns are necessarily associated with quasi-stationary cyclones, but all blocks do have quasi-stationary anticyclones by definition (see Fig. 1 in Woollings et al., 2018).

We do however appreciate that tracking the cyclonic eddies associated with blocking is an interesting area of research. We have added a comment in the conclusions section about this interesting avenue of discussion. We point the reviewer to e.g., the work of Maddison et al. (2019), who looked at the relationship between upstream cyclone activity and block predictability, since cyclones are out of scope for this work.

Woollings, T., Barriopedro, D., Methven, J., Son, S.W., Martius, O., Harvey, B., Sillmann, J., Lupo, A.R. and Seneviratne, S., 2018. Blocking and its response to climate change. Current climate change reports, 4, pp.287-300.

2. How do you obtain "u" and "v" in Figs. 7 and 8? If those values are Eulerian-based (raw) winds which are the interpolated wind values at the AC centers from the ERA5 gridded data, to what extent are those values different from the Lagrangian speeds of ACs obtained by your tracking method?

Thank you for pointing this out, as it has led to the need for a clarification in our text. When we mention "u" and "v", we were simply describing the zonal and meridional propagation speeds, respectively, of the AC eddies (i.e. the Lagrangian speeds obtained by TRACK). We have changed the notation in the text and figures to v_{east} and v_{north} instead to distinguish them from the commonly-used notation for wind components.

3. Several previous papers may be useful for the introduction part:

- Zhu et al. (2007) investigated the statistics between the synoptic cyclone activity and the Aleutian low intensity.

We thank the reviewer for pointing out this study, however we feel that it is not necessary to point this out in the introduction. Zhu et al. (2007) do not examine how synoptic cyclone activity effects the *persistence* of the Aleutian low, whereas we are explicitly exploring the relationship between synoptic anticyclone activity and block *persistence.* We therefore do not feel that the introduction needs to reference this paper.

- Okajima et al. (2021) proposed a new detection method for anticyclonic and cyclonic eddies based on curvature.

- Shi and Nakamura (2021) proposed a blocking detection index based on the Rossby wave breaking.

Thank you for pointing us towards these papers. These references have been added to the discussion in the Introduction regarding blocking indices/feature tracking.

Minor comments:

- L193-194: Why are the climatological frequencies different (16% vs 30%)?

The two climatologies have different frequencies because in our work, we consider the background anomalies from the zonal mean, $\overline{Z_*}$, leading us to achieve a smaller (and probably more realistic) block frequency than that used in Liu et al. (2018). Without removing the climatological wave pattern, our blocking index would be far too sensitive in winter, falsely detecting "climatological" conditions as being blocked in Western Europe, for example, because of the naturally high Z_* here. Therefore, by removing the climatological anomaly from the zonal mean, we are able to identify actual blocks in this sector while reducing the number of false positives drastically.

Liu, P., Zhu, Y., Zhang, Q., Gottschalck, J., Zhang, M., Melhauser, C., Li, W., Guan, H., Zhou, X., Hou, D. and Peña, M., 2018. Climatology of tracked persistent maxima of 500-hPa geopotential height. Climate Dynamics, 51, pp.701-717.

- The term "standard error": Is it "standard deviation"?

We mean "standard error *from the mean*" when we mention "standard error". However, standard error from the mean is simply the standard deviation normalised by the square root of the number of eddies at each time point. In this way, we have also considered the sample size of eddy tracks at each time step – the measure of uncertainty is larger where we have fewer tracks. We have clarified the text to explicitly state "standard error ***from the mean***" to hopefully clear up any terminology confusion.

- L325 and L335: the abbreviation "SAM" is used before "Selective Absorption Mechanism"

Thank you, this has been amended in the text.

Refereces:

- Luo, D., 2005: A Barotropic Envelope Rossby Soliton Model for Block–Eddy Interaction. Part I: Effect of Topography, J. Atmos. Sci., https://doi.org/10.1175/1186.1.

- Okajima, S., et al, 2021: Cyclonic and anticyclonic contributions to atmospheric energetics, Sci. Rep., https://doi.org/10.1038/s41598-021-92548-7.

- Shi, N., and H. Nakamura, 2021: A New Detection Scheme of Wave-Breaking Events with Blocking Flow Configurations, J. Clim., DOI: 10.1175/JCLI-D-20-0037.1.

- Yamamoto, A., et al., 2021: Oceanic moisture sources contributing to wintertime Euro-Atlantic blocking, Weather Clim. Dynam., https://doi.org/10.5194/wcd-2-819-2021.

- Zhu. X., et al., 2007: A Synoptic Analysis of the Interannual Variability of Winter Cyclone Activity in the Aleutian Low Region, J. Clim., DOI: 10.1175/JCLI4077.1.