

Answer to Reviewer #2

Detring et al. present an analysis of long-term blocking changes over the past 30 years in the Northern Hemisphere. Using a novel method based on the kinematic vorticity number, the authors distinguish between long-term changes of Omega-blocks and High-over-low blocks. Though a general change of the blocking frequency over the 30 year period is not found, the authors identify pronounced changes when investigating trends on a monthly or seasonal basis. A key outcome is that Omega blocking is more likely to occur and to be more persistent than the High-over-Low blocking pattern.

To understand the changes/trends of blocking is an important topic in our science. Thus, the analysis is timely and the topic is likely to be of interest to the readership of WCD. However, there is a number of issues which need to be addressed before the manuscript can be published.

We thank the reviewer for carefully reading our manuscript, and for the constructive comments. In the following we will respond to the comments and point out any changes we intend to make. The line numbers and figure references in the reviewer's comments refer to the original manuscript. The reviewer's comments are in black italic; our responses are in blue.

Most important comments

- 1) *At many places trends/long-term changes are reported. However, most of the times, statements concerning the statistical significance of the results are missing. Further, the computation of the confidence intervals is not explained so that it remains unclear which of the results are "real" results. Investigating and commenting on the significance is particularly important since some of the results are likely to be based on small sample sizes. For example, it is reported that 13 (10) blocks occur per year in the large (small) domain. When breaking this down to a monthly basis the average number of blocks per month decreases to 1-2.*

We estimate occurrence and transition probabilities using binomial and multinomial logistic regression realised in the framework of (vector) generalized linear models fitted with iteratively reweighted least squares [Yee, 2015]. Confidence intervals are derived based on the assumption of asymptotic normality, i.e. $[\hat{\theta} \pm 1.96 \sigma_{\hat{\theta}}]$. We state this now accordingly at the end of section 3.5. Figure 6 shows the number of blocking events, an event last minimum 5 days, i.e. $5 \cdot 4 = 20$ time steps. In the following, we use the number of blocked time steps which is on average 24 time steps and thus the number of events is not as small as it appears from Fig. 6. In principle, a small number of events is not a problem for the binomial or multinomial model. However, the likelihood-based estimator can indeed be biased for small occurrence probabilities but here we are not in a critical range [cf. King and

Zeng, 2001]

- 2) *The trends inferred from the logistic regression approach are quite pronounced when considering individual months. For example, the logistic regression suggests that the probability of omega blocks during February has increased by a factor of three over the past 30 years. To better compare these results to the "observations" it would be beneficial if the actual numbers of blocked time steps were included in the corresponding figures. For example, vertical bars (in the same colours as the modeled probabilities) showing these numbers could be included in the panels of Fig. 8.*

You are right, there are few events that are used in the regression on a monthly basis. Nevertheless, due to our temporal resolution of 6 hours, each blocking consists of at least 20 time steps that are taken into account in the models (see also previous answer). It can be seen in Fig. 7 (initial manuscript) that an annual view shows no significant change in blocking (black line), but a split into seasons (coloured lines) does. To get an more detailed overview of the blocking probability for the individual months, we calculated the probability for every year for every month. This is shown as boxplots in Fig. 1 below for the whole domain. This figure shows that there are several month with only a few blocked time steps and others with quite a lot blocked time steps. This analysis is shown for blocking in general (upper panel) and *High-over-Low* and *Omega* blocks (lower panel). In addition the total number of blocked years for every individual month are shown as a line. We will include this Fig. 1 as well as the corresponding figure for the Euro-Atlantic sector ($40^{\circ}W-30^{\circ}E$ in the supplementary material.)

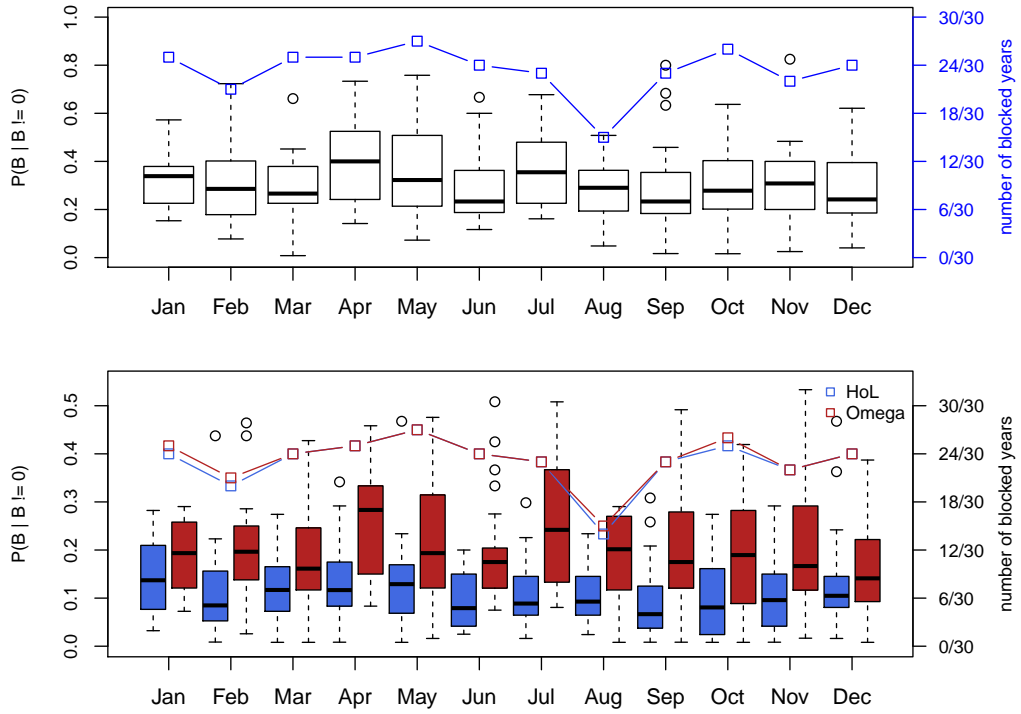


Figure 1: Boxplots for blocking probabilities estimated for individual months for blocking in general (upper panel), as well as separately for *High-over-Low* (blue) and *Omega* (red) for the Northern Hemisphere ($90^\circ W-90^\circ E$). The probability is calculated for each year under the assumption that there is a corresponding blocking (B , HoL , $Omega$) in that year in the respective month ($P(B | B \neq 0)$). The absolute number of years in which a blocking occurred in the respective month is also given as the lines.

- 3) *A focus of the study is on observed blocking trends. However, references to related studies are missing in the introduction (Section 1). To put the results in context to previous studies, I strongly encourage the authors to provide information on observed trends found in other studies. To avoid an excessively long introduction, the discussion of weather regimes and Grosswetterlagen could be shortened considerably.*

Thank you very much for this very valid comment. We will rewrite the introduction to include literature on blocking trends. Moreover, we will try to shorten the paragraph on *Grosswetterlagen*, as suggested.

- 4) *The discussion in Section 5 is in large parts a repetition of Section 4. Many results are listed so that it is difficult for the reader to really identify the key outcomes of the study. In my view the discussion part would improve considerably if the authors formulated the key outcomes of the study more clearly and discussed their broader implications. For example, three key questions are raised in Section 1. Coming back to these questions in Section 5 would be one way to list the key results. Also, what are the broader implications of changing transition probabilities? Are some of these transitions particularly relevant for high impact weather or certain extremes? A further comment on Section 5 is that several caveats of the methodology are mentioned but it remains unclear whether and in which way these caveats affect the results. Though I generally advocate such critical discussions, clearer statements regarding the effect on the results are mandatory.*

Thank you for this hint! In order to emphasize the key outcomes, we have rewritten and reordered the discussion section. As suggested, we have revisited the three main questions we introduce in Section 1 for Section 5 and discuss them here. We slightly changed the three questions in the revised version to:

1. Can we find a method to automatically distinguish between the two atmospheric blocking types High-over-Low and Omega blocks?
2. Do blocking occurrence probabilities undergo long-term changes? Do these changes depend on season or month?
3. Do onset, decay or transition probabilities from one blocking type to another undergo long-term changes? Do these changes depend on season or month?

We will come back to these questions in the Discussion/Summary sections. This will hopefully highlight the main results more clearly. In addition, we now only discuss significant results. Furthermore, we will discuss the implications of the results as suggested. For example, the location of the low(s) relative to the high is relevant for high-impact weather such as high precipitation amounts. An observed trend in *High-over-Low* or *Omega* blocking therefore can have impact on the location of these precipitation events, too. Moreover, we will do additional tests to validate the significance of specific results, and to estimate the uncertainty of the methods, respectively.

Minor comments

Thanks for carefully reading and commenting on our paper! We will address every comment in the following.

- *Title: The title is very general. Please try to be more specific. For example, "Observed frequency and transition trends of Omega and High-over-low blocks" would be a more specific title which might help to increase the visibility of the article.*

Thank you for highlighting that our title was too general. We have followed your suggestion and agreed on the following new title: "Occurrence and transition probabilities of Omega and High-over-Low blocking"

- *l. 1: Consider to replace "very high" with "anomalously high". In some regions of the world "very high" may not mean "very high" in other regions of the world.*

Done

- *l. 2: I'd suggest to use the wording "flanked by" instead of "in combination with".*

Done

- *l. 6: here and elsewhere: Northern Hemisphere with capital letters.*

Done

- *l. 8: "temporal development" is quite unspecific. Do you mean the long-term change/trend of blocking probabilities?*

Yes, you are right. Temporal development is unspecific. We changed it to "long-term change".

- *l. 14: Initially and also later in the manuscript you talk about "weather patterns". Here, you introduce "weather regime". I suggest to use one of these terminologies consistently throughout the paper. In my opinion, "weather regime" is better suited than "weather pattern".*

Thank you. It is indeed important to use a formulation consistently. However, our intention is to investigate the blocking as Langrange'ian system rather than a weather regime which would be a Eulerian view. The underlying theory behind the trapezoid method is, that a system of two to three interacting vortices form the block. We will follow the high in time and – depending on the location of the surrounding lows – decide if the vortex system represents a *High-over-Low* or an *Omega* block. This is why the term "weather regime" does not fit so well. "Weather pattern" seems to fit better. We will discuss the terminology in the manuscript, too, and will use it consistently.

- *l. 24: Consider to write "steady ridges" in italic font since this is a third type of blocking.*

Done

- *l. 27: "can" instead of "could"*

Done

- *l. 27: Please provide a reference showing that these transition can be "often" observed.*

Thanks! We adapted the text and deleted the word "often". One aim of our paper is to analyse such transitions and our results show that transitions occur often. However, there are not many previous papers that already looked at the different types of blocking. A publication [Schielicke, 2017] showing a single case of transitions in summer 2010 is cited in the subsequent sentence.

- *l. 32: Please specify that this statement refers to central Europe (I guess).*

Yes, we mainly meant central Europe. We changed the text accordingly. Thanks!

- *l. 36: The Deutscher Wetterdienst invalidated the record of 42.6° C recently (https://www.dwd.de/DE/presse/pressemitteilungen/DE/2020/20201217 annullierung_lingen_news.html) Please adapt the manuscript accordingly.*

Thanks for pointing this out! The "annulling" of the record was published shortly before we submitted the paper and we were not aware of this fact. We adapted the text to the new records, that occurred on the same day at two stations in Germany and added the reference.

- *l. 46: Please remove brackets around (Helmholtz, 1858).*

Done

- *l. 47: Missing full stop after circulation.*

Done

l. 47: Why do you introduce the terminology "positive circulation" and "negative circulation"? This terminology is not used at all in the manuscript.

The terms "positive/negative circulation" are important for the blocking identification method (trapezoid method). However in this paper, we condensed the description of this method, since it was described already in detail in the publication of Hirt et al. [2018] Hence, you are right and we can delete the sentence in the introduction.

- *l. 83: Please use capital "S" when referring to a specific section (e.g., Section 2, Section 3, Section 3.2 etc).*

Done

- *l. 93: Please explain why you decided to focus on the period 1990 to 2019. The NCEP-DOE Reanalysis are available for the period 1979-2020. Why did you decide to not include the 1980s period for your analysis? Since you are looking at*

long-term changes, 10 years of additional data may help to make your statements more robust.

It is a good point and you are right, a longer climatology would most probably give more robust results. We decided to use the data starting with the year 1990 since we based this work on the previous paper of Hirt et al. [2018] whose data basis also started in 1990. Unfortunately, an additional analysis would be too time-consuming at the moment, but we would like to apply the method to a longer and also to different data sets in the future.

- l. 93: Better write "close to zero" instead of "very low". "Very low" could also mean "negative".

You are right, thanks!

- l. 113: Better write "identify" or "capture" instead of "catch".

Done

- l. 120-122: Please clarify this explanation. Does this mean you disregard one block if two blocks occur at the same time in different parts of the area? Or do you simply assign the two blocks to the same blocking type (HoL vs Omega)?

Yes, we disregard the second block if two blocking are identified at the same time in different parts of the region. We have adjusted the paragraph to better describe the procedure.

- l. 140: Do you employ any criteria concerning the minimum size of the vortex patches?

No, even a single grid-point that has a kinematic vorticity number $W_k > 1$ counts as a vortex patch. Keep in mind, that each grid point is associated with an area of $2.5^\circ \times 2.5^\circ$ (latitude-longitude grid).

- l. 142: I fully understand that you are not providing all details of Hirt et al. 2018. But could you at least mention the step size at which the size of the box increases? Is it 2.5° ?

Yes, in a first step, we identify the area associated with the high pressure systems. The box, that encloses the high, is then extended equatorwards by steps of 2.5° latitudes to obtain the box that minimizes the total circulation within the box. However, only negative circulation northwards the low centroid and positive circulation southwards the high centroid are taken into account for the calculation of the total circulation. This box shape represents the *High-over-Low* configuration. At the same time, we search for a minimum of total circulation within a trapezoidal shape, which represents an Omega configuration. Therefore, we enlarge the southern boundary of the original box symmetrically by steps of 2.5° longitudes

(on each side) up to a total length of the southern trapezoid boundary of 2.5 times the east-west-length of the box around the high center. The northern boundary remains fixed and only grid points whose centers lie within the trapezoidal shape are counted. Again, only certain areas of the trapezoid are attributed to the high (everything north of the mean latitude of the low centers), to the western low (everything below and west of the high centroid) and the eastern low (everything below and west of the high centroid).

- *l. 152: What exactly do you mean by "below the high center"? Do you mean south/equatorwards of the high center?*

Yes, we meant south. Thanks. We adapted this in the text.

- *l. 158: Replace "where we" by "who".*

Done

- *l. 160: What exactly do you mean by "large jumps"? Please be more specific and provide the threshold in km or degree longitude.*

Thanks for pointing this out. We will add a sentence to the script. It means, that we split the blocking periods to smaller periods, if the position of the high centroid changes by either 10 degrees latitude (≈ 1000 km in north-south direction) or 15 degrees longitude (≈ 1000 km in west-east direction) in successive time steps, i.e. in a period of 6 hours. Although we allow for slow motions of the blocks, these "large jumps" rather indicate that a different high pressure system enters the configuration. In order to obtain configurations associated with the same high, we split such periods to two or more smaller periods. Of course this reduces the maximum duration of the blocking periods, but is also more consistent with following the block as a system of vortices (instead of a weather regime).

- *l. 157: How are the "circulation centroids" in Fig. 3b identified? This needs to be explained in the text.*

Thanks! We will add a description of the circulation centroids identification to the text.

- *l. 165: The information on the life time is redundant and could be removed from the manuscript.*

Do you mean from the whole manuscript or just in this sentence? Later in our analysis, we take a subset of the data for the Euro-Atlantic region. In this case, the system might stay for less than 5 days within the region. Otherwise, in an earlier step of the analysis, we split the IBL identified periods (which initially were ≥ 5 days) if the high centroid location jumps too largely from one time step to the

other. Hence, we think, it is worth pointing out at which steps of the analysis the 5 day criterion holds.

- *l. 168: Please use consistent terminology for the "Euro-Atlantic sector" (here you are using "European sector" elsewhere it is "Euro-Atlantic sector").*
Thanks, we adjusted this and use only Euro-Atlantic sector/region.
- *l. 219: Better provide a reference to the work of Andrey Markov.*
We will look for a suitable reference.
- *l. 248: Remove brackets around "e.g., Baclawski, 2008".*
Done
- *l. 256: Do you mean "seasons" instead of "Seas"? Or did I miss the definition of this acronym?*
Yes, you are right. We mean season and now we define this acronym "Seas", which is an operator in our equations, here.
- *l. 271: Are you really displaying a frequency in Fig. 5? Or is it rather the number of events in the 30-year period?*
Yes, it is the number of events in the 30-year period. We adjusted the label accordingly.
- *l. 279: Please avoid descriptive information which can also be derived from the figure caption*
Descriptive information about the regions were removed.
- *l. 293: Please insert "a" between "of" and "blocking".*
Done
- *l. 300: I could not find the "straight-line estimates" in Section 4.1.2. My suggestion would be to include the straight line estimates in Fig. 6 (also for the benefit of the discussion in Section 4.1.2).*
We added the straight line estimates for mean and maximum durations and made further tests on the uncertainties.
- *l. 300: Please see my comment on line 279.*
Thanks, we try to avoid descriptive information that can also be derived from the figure captions.

- *l. 302: Insert "The" before "Average".*
Done
- *l. Please be cautious concerning the terminology of "probability". Sometimes probability is used to describe a fraction (e.g., 301 $p=0.24$), here probability is used to describe a percentage. I'd suggest to be consistent regarding the terminology*
We will reread the text carefully and use the term "fraction" in these cases.
- *l. 305: Please include references to the corresponding subfigures (Fig. 7a, b and so on).*
We will add the references to the corresponding subfigures to the text.
- *l. 314: In Section 4.1.2 on average 10 9.8 blocks are found per year. When describing blocking probabilities on a monthly basis, did you not encounter any issues regarding the small sample size. Apologies if I missed this information.*
Thanks for this comment. On the one hand, we look at blocked (vs. unblocked) time steps so a blocking could partly lie in two months. On the other hand, the absence of blocking in specific months is an important information with respect to blocking trends, too. Imagine that blocking occurs for the first 15 years of a time series regularly in one month and is for the last 15 years of the time series absent. From this follows, that there must be some process that leads to the absence over the last years. We added a figure (see Fig. 1) to the supplementary material, that additionally displays the total number of years accounting for the statistics in each month. From this figure you will get additional information about the number of blocked years for the different blocking types for the individual month. For every month and year the probability of blocking is calculated and displayed as boxplots. This information helps to better assess the underlying data.
- *l. 321: Use "For example" instead of "E.g." at the beginning of a sentence.*
Done
- *l. 332: I'd suggest to write "...that September to March are characterized...". It is a bit odd to include "September" in the winter season.*
Done
- *l. 335: Clarify that it is not the "Euro-Atlantic" region which peaks in April, but the blocking frequency which peaks in April.*
Thanks! We rewrote the sentence accordingly.
- *l. 346: Please remove "the" before "both".*
Done

- l. 354: Please include "the" before "probability".

Done

- l. 359: "a" instead of "an".

Done

- l. 377: The terminology "offset" is a bit awkward. Please reconsider this terminology. The term "decay" is used more frequently to describe the transition from blocking to no blocking.

Thank you for this comment, which we also received from the first reviewer. As already written as a answer to the first review we can understand this argumen-tation, but will nevertheless stick with the term "offset". From a meteorological point of view, the use of the word "decay" describes the transformation from a blocked state to an unblocked state with the right words, as it is a process. In our work, we focus on the model view, in which there is only the state "on" or "off". Therefore we use the term "offset". However, when introducing the terms "onset" and "offset", we will add a sentence that addresses the underlying processes of the formation and the decay of a blocking.

- l. 390: Why is the change in transition probabilities of particular interest? Are these associated with particular weather phenomena so that any long-term changes would have an immediate impact?

The trend analysis of transition probabilities can for example give insight if the transitions between the *High-over-Low* state and the *Omega* state has changed. Due to their different configurations, weather phenomena such as extreme precip-itation events associated with the low(s) of these blocked states occur in different regions. So yes, you are right, that particular weather phenomena would have an immediate impact. We hope to encourage further studies on the reasons and un-derlying physical processes why different blocking types occur. Our method shows, that it is possible to differentiate between the different blocking types. Since the method does not change over the 30-year period. Changes in the blocking type probabilities, stems from the block climatology itself.

- l. 394: What about the persistence? According to the bottom right figure, the per-sistence of blocking has decreased which would indicate shorter blocking durations. In Section 4.1.2 however, a slight increase in blocking duration is reported. Can you comment on this contradiction?

Thank you very much for pointing this out. Are you talking about Figure 13 (bottom right, initial manuscript) that describes the persistence of blocking? This indeed seems to be slightly decreasing. However, this result is not significant. The straight-line fits described in section 4.1.2 are also not significant. We will do more

tests and hope to answer your open question!

- *l. 394: Please label subfigures with a), b), c) etc. If subfigures are not discussed in the text (e.g., top left and bottom right in Fig. 13) this can be deleted from the manuscript.*

Thanks, we will follow your advice! However, Figures 13-16 are the matrix representation of possible transitions (analogue to Eq. 11 and 12), hence, picking out single subfigures while deleting others gives an incomplete picture. Since Fig. 13 and 14 do not show any significant results, we have decided to include them in the appendix.

- *l. 396-400: Are these conclusions only valid for JJA or is it for all seasons? Please clarify in the manuscript.*

In our revised manuscript, we added to each discussed result if it is significant or not. Moreover, we try to avoid the discussion of insignificant results.

- *l. 396: A legend is missing in Fig. 14. This makes it hard to follow the discussion.* Yes, you are right. We had forgotten the color bar/legend in Fig. 14 and also in Fig. 16, which we have now added. We have moved Fig. 14 to the appendix.

- *l. 404: The subfigures need to be labeled and referenced in the text. Otherwise, it is difficult to follow the discussion. Please consider to delete subfigures from the manuscript which are not discussed in the paper.*

We have labeled the subfigures and added to every discussion the corresponding subfigure. Hopefully it is easier to follow our discussion, now. As already mentioned above the subfigures of Fig. 13-16 are arranged accordingly to the transition matrices (analogue to Eq. 11 and 12) and deleting would give an incomplete picture.

- *l. 421-430: This paragraph basically only tells the reader what has been done and is thus a repetition of Section 4. Unless the authors have a strong argument on why this paragraph is important, I strongly recommend this paragraph from the manuscript.*

Yes, you are right. We have deleted this paragraph from the discussion section.

- *l. 435: Where is it shown that the increase can be attributed to blocking events that occur over western Russia? Either show a Figure or reference other studies which support this interpretation.*

Thank you very much for pointing this out! Because of your and the other reviewer's comments, we started to do additional tests to estimate the uncertainties of the method. We found that this increase is insignificant! Hence, we removed

this statement completely from the manuscript.

- l. 442: Replace "E.g." with "For example".
Done

- l. 443: Can you comment on the discrepancy between the study by Brunner et al. (2017) and this study? According to Fig. 8, the probability of blocking in February has increased by a factor of three (0.08 to 0.24). Do you have any explanation on why the conclusion in Brunner et al. (2017) is completely different?

One point is definitely that our methods are different. In our case, we search for a coherent blocking structure, that needs to have a minimum lifetime of 5 days (in the larger region) and should be composed of the same high (lows are allowed to change in time). Our initial IBL identification is moreover only a one-dimensional method. In Brunner et al. [2017] the identification of blocks is done with a two-dimensional blocking index. Blocks are long-lived (at least 5 days) and synoptically large ($\pm 7.5\circ$ longitudes). However, a blocking is counted whenever at least one of these blocked grid points is within the Euro-Atlantic region ($45^\circ-72.5^\circ N, 30^\circ W-45^\circ E$). In our case, at least half of the block, more precisely the circulation centroid, needs to be inside the Euro-Atlantic region (40W-30E). Summarized, there is no easy answer. We will do more tests and try to answer your question! Thanks a lot! This is also relevant for our discussion section.

- l. 459: Can you be more specific about this statement? Does "deviations" mean that the trends reverse when using different parameters?

Thanks for your question! We will test if the trends remain stable! However, what we meant was a bit simpler: imagine, that the criterion for the minimum blocking duration is reduced to 4 days (instead of 5 days), then we would identify more blocked time steps. Otherwise, if we increase the minimum duration criterion to 6 days, we would detect less blocked time steps. We will try to be more specific here. Especially, we will try to discuss the impact to our results.

- l. 498: In my opinion you could easily find out whether your results coincide with the results of Drouard and Wollings (2018). For example, you could display the occurrence frequency of High-over-Low and Omega blocks as a function of longitude. Though I do not expect such a figure in the manuscript, I would be very interested to see such an analysis to better put this study in context with previous studies.

This is very good idea. We plotted the total number of blocked time steps with respect to the blocking types and longitudes of occurrence in Fig. 2 below. Our method prefers more *Omega* blocks compared to *High-over-Lows* in general. This has two reasons: (i) on the one hand, it depends on the width of the box south of the center of the high, that is inspected regarding the mean vorticity within the middle Box 2 compared to the outer flanks Box 1 and 3 of the box (cf Fig. 3 in the original manuscript); (ii) on the other hand, the method searches for the

minimum total circulation within the trapezoidal and box shapes associated with the block. The *Omega* block has more freedoms to minimize the total circulation within the trapezoid. However, we observe that the fraction of *High-over-Lows* is highest between about $0^\circ - 40^\circ\text{E}$ and between about $60^\circ\text{E}-75^\circ\text{E}$. The fraction of *Omega* blocks is highest for longitudes west of -25°W and for a the region between about $40^\circ\text{E}-60^\circ\text{E}$. This is indeed comparable to the results of Drouard and Woollings (2018) for their regions between $0^\circ - 55^\circ$. Their composites for the areas of Western-south central Europe ($0-20^\circ\text{E}$, $40-50^\circ\text{N}$); Central Europe ($20-40^\circ\text{E}$, $50-60^\circ\text{N}$) and Western Russia ($35-55^\circ\text{E}$, $45-55^\circ\text{N}$) indeed showed rather *High-over-Low* patterns for the first two regions and an *Omega* pattern for Western Russia. Note, that our analysis in Fig. 2 is based on the whole year, while Drouard and Woollings [2018] looked at the summer months June to August.

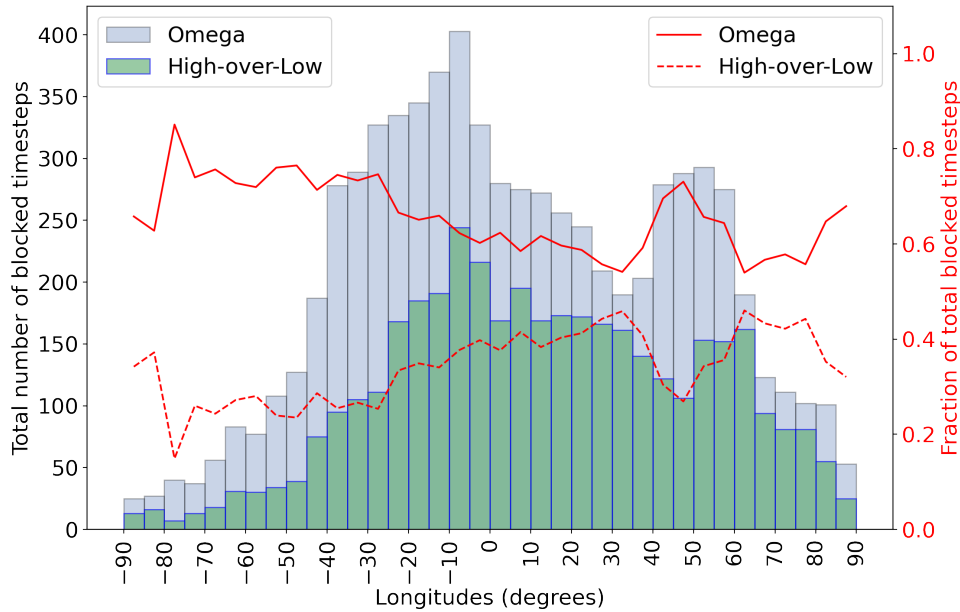


Figure 2: Number of total blocked timesteps for *Omega* and High-over-Low blocks (columns) and fraction of all blocked time steps associated with each blocking type (red lines). Note that this analysis is based on the whole year.

- *l. 510-516: How do these results relate to previous studies? Are these in line with previous results or do they contradict earlier studies?*

We will rewrite the conclusion, highlighting how comparable our results are to previous studies.

- *l. 518: A verb is missing in this sentence.*

We deleted this sentence.

- l. 521: *This sentence needs clarification. As it stands now "an increase in overall probability for blocking" and "a higher proportion towards the end of the study" somewhat mean the same thing. I guess you want to say that the number of all blocks increases and that the fraction of Omega blocks increases, too.*

Yes, you are right. We adapted the sentence accordingly: "While in July the proportion of *Omega* blocks is only about 25% of all observed blocks in 1990, we find an increase in the number of blocks in general as well as a higher fraction of *Omega* blocks towards the end of the study period."

- l. 525: *Replace "this" with "these".*
Done

References

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