Reply to Review of "Extreme weather anomalies and surface signatures associated with merged Atlantic-African jets during winter" by Sohan Suresan, Nili Harnik, and Rodrigo Caballero

We thank both the reviewers for their constructive comments. Both reviewers commented on the statistical significance of our results given the ensemble size. We agree that this is a main point of concern, and we thank the reviewers for suggesting ways to explicitly address this. We performed the calculations suggested by the reviewers, and overall, the results remain similar, with a few minor changes. Specifically, we calculated:

i) The significance of all extreme distribution spatial plots using a Monte Carlo approach, modified to include the imprint of the 2009/10 winter months signal by randomly selecting winter months and an entire winter (detailed explanation below).
ii) The significance of -ZJI surface temperature extreme distribution using bootstrapping with respect to -NAO and El Nino months.
iii) The confidence interval of mean and median in the boxplots using bootstrapping.
iv) The significance of anomaly spatial plots using a two-sided Student's *t*-test.

Based on these new calculations we modified the statistical significance marking in all the figures, added one additional figure (now Fig. 2), and added 5 subplots and 1 plot (Fig.S1 and S6) to the supplementary material. We also modified the text accordingly, in particular, we toned down some of our statements in the discussion. Following is a detailed response to the reviewer's comments. The reviewers' comments are highlighted in blue font, the responses to the reviewers' comments are highlighted in black font, and the resulting corrections made in the text are highlighted in red. Note that all line and figure numbers refer to the marked-up manuscript version showing the changes made unless specified.

Response to Reviewer #1

We thank the reviewer for dedicating the time to review this paper. We appreciate the reviewer's feedback and constructive comments. The responses are as follows:

> **This paper examines 2m temperature, surface winds, and precipitation extremes associated with merged Atlantic-African jet during northern winter. It is well written with an easy-to-follow structure. The introduction is particularly well-written. However, I do have one major concern about how the statistical significance is performed.**
>
> **My worry is that the merged-jet regime is treated as an independent dynamic regime from the NAO and ENSO. It could well be that those winters involve both extratropical and tropical forcing, with the latter further involving latent heat realise in additional to tropical SSTs. More rigorous statistical significance tests are thus required to be sure that the signals are associated with the merged jets rather than the NAO, EI Nino or their combined effect.**

Many thanks, for your positive comments on the structure of the paper especially the introduction section. We also appreciate your comments on the statistical significance tests. We tried to address them by adding more statistical significance test, as detailed in the response to the next comments. It is indeed possible that such winters involve both extratropical and tropical forcing involving further latent heat release in addition to tropical SSTs. In a follow-up paper we are examining the dynamical chain of events behind jet merging in more detail, and we are finding a role for water vapor.

That said, in this paper we are trying to make a subtle claim. In theory:

- The NAO is a manifestation of wave-mean flow interactions, as is expected in an eddy driven jet regime.
- If we strengthen the mid-latitude instability, leading to stronger eddies, an equatorward "merged jet" will be pushed poleward and its variability will increase, making it an eddy-driven jet.
- A merged jet regime occurs when both the extratropical eddies are weak enough and the tropical thermal forcing of the jet is strong enough.
- Idealized models show that a merged jet regime looks similar to the negative EOF phase of the eddy driven jet.
- Harnik et al (2014) showed that an anomalous tropical heating as is observed during El Nino can influence the Atlantic subtropical jet.

Given all these, we expect the merged jet regime to project strongly on a negative NAO, and to occur when there is a strongly anomalous tropical heating, but to be different from a simple combination of both, because of a dynamical regime change of the eddy-driven Atlantic jet to a merged Atlantic-African jet that affects/enhances the extreme weather conditions. Our results aim to show this added unique signal, which is exclusive from the usual NAO, EI Nino or their combined effect.

Line.88-98: added the above mentioned thinking behind the paper in the introduction section as -- "This hypothesis is built on some theoretical foundations: (i) The NAO is generally understood as a manifestation of wave–mean flow interactions typical of an eddy-driven jet regime. (ii) When midlatitude baroclinic instability strengthens, it leads to stronger eddies that can push an equatorward merged jet poleward and increase its variability, making it behave more like an eddy-driven jet. (iii) A merged jet regime, on the other hand, is expected when extratropical eddies weaken while tropical thermal forcing intensifies. (iv) Idealized model studies suggest that a merged jet regime resembles the negative EOF phase of the eddy-driven jet. (v) Previous work, like Harnik et al. (2014), has shown that anomalous tropical heating as is observed during El Niño events, can influence the Atlantic subtropical jet. Given all these, we expect the merged jet regime to project strongly on a negative NAO, and to occur when there is a strongly anomalous tropical heating, but to be different from a simple combination of both, because of a dynamical regime change of the eddy-driven Atlantic jet to a merged Atlantic-African jet that affects/enhances the extreme weather conditions. Our results aim to show this added unique signal, which is exclusive from the usual NAO, El Nino or their combined effect."

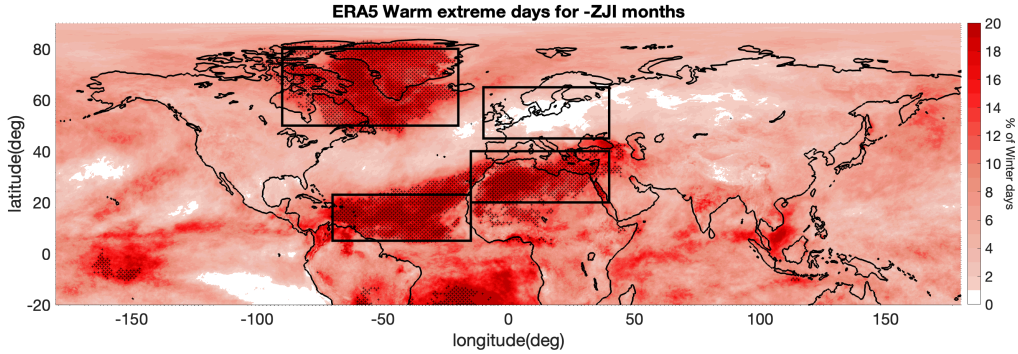

Fig.R1a

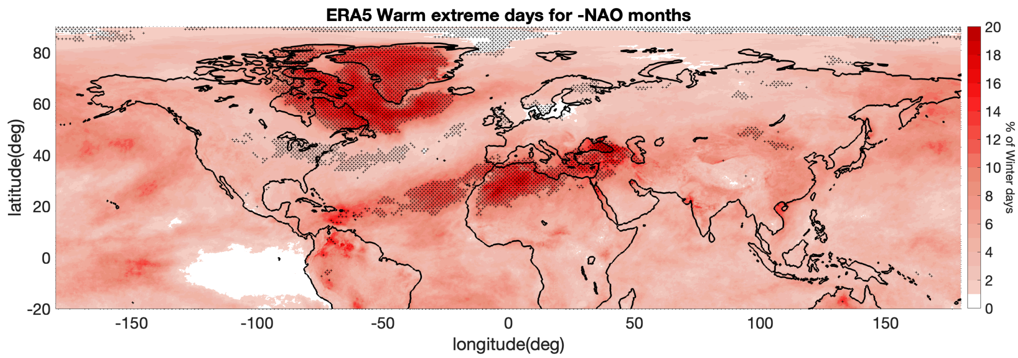

Fig.R1b

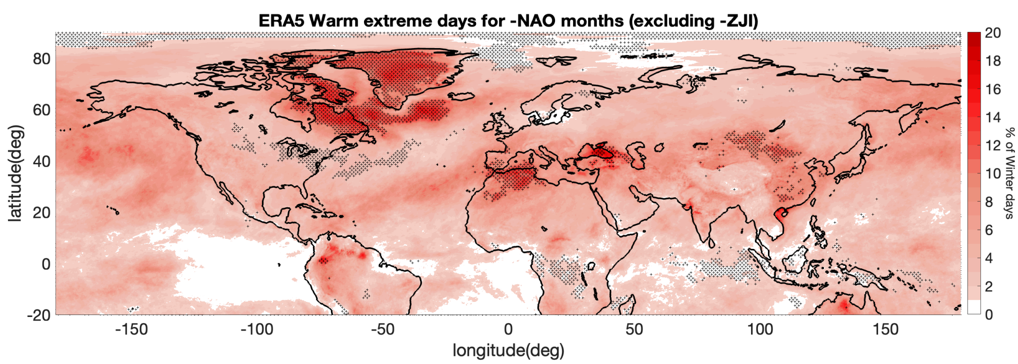

Fig.R1c

Figure R1. The distribution of the percentage of warm extreme days for (a) merged jet winter months (b) negative NAO winter months (c)negative NAO winter months excluding merged jet months. The regions stippled in black (+) represents regions significant at 99% using Monte Carlo simulation.

Quite a lot of the samples of the merged jets are associated with the negative NAO phases (-NAO, 9 out of 14) and with EI Nino (7 out of 14). With only 5 or 7 independent samples, the statistics of composite or linear regression analysis become limited and may lead to unreliable estimates. Furthermore, the merged-jet subgroup contains individual months for a given winter, e.g. 12/2009, 01/2010,

02/2010 and the signal has a strong imprint of tropical SST anomalies, which may persist over a winter. Thus, whether those months can be viewed as independent samples remains a question. To make sure that the results are truly different from -NAO and EI Nino, the authors need to explain exactly how the Monte Carlo simulation is performed. They may consider using other statistical techniques that are more robust with small sample sizes, such as Partial Least Squares Regression (PLS) or Ridge Regression that adds a penalty to the regression coefficients. Have the authors cross-validation the stability and reliability of the results using bootstrapping?

The -NAO and El Nino are in a sense necessary but not sufficient features of a merged-jet. It is true that the 2009/10 winter is a special case as this winter had a strong merged jet that persisted throughout the season, which could affect the statistical significance, thus we repeated the calculation taking into account a winter-long season in the control sampling. Initially in the submitted manuscript we have done the Monte Carlo simulation by picking 14 random winter months(DJFs) between 1960-2020 and calculating the percentile exceedance. We repeat it 1000 times resulting in a distribution at each grid point and then calculate the 99% significance over this distribution at each grid point. To acknowledge your concern about whether 2009/10 winter months can be viewed as independent samples, we have now modified the Monte Carlo simulation by randomly picking 11 winter months (D-J-Fs) and 1 whole winter between 1960-2020. This we believe will tackle the problem of calculating significance when having a signal that has a strong imprint of tropical SST anomalies, which may persist over the entire winter. A similar approach is also used for the -NAO and El Niño cases, where 26 winter months + one DJF and 29 winter months + one DJF, respectively, are selected randomly and repeated 1000 times. The resultant figures are shown in Fig.R1. We plan to use this figure in place of Fig.1 in the initial submitted manuscript respectively. We see that Fig.R1a, gives the same results as Fig.1.a except in European regions (the region in white) where the significance vanishes, implying that this region could be susceptible to warmer extremes. We did the same in -NAO composites (Fig.R1b and Fig.R1c), here we see that the polar regions appear significant implying that the polar regions are less susceptible to warm extremes during -NAO. There isn't much difference for the El Nino cases.

A Partial Least Squares Regression (PLS) as suggested was done for Figures 5, 7, 9 , which also resulted in conclusions similar to linear regression analysis.

In order to check that the -ZJI results are truly different from -NAO and EI Nino we did a bootstrapping analysis. Note that previously the Monte Carlo simulation was done w.r.t climatology (random DJF months between 1960-2020). Here we did a bootstrapping by randomly selecting 20(25) months from within -NAO (El Nino) months with repetition, and calculating the percentile exceedance. We then repeat it 1000 times resulting in a distribution at each grid point w.r.t -NAO (El Nino) months and then calculate the 99% significance over this distribution at each grid point for the -ZJI percentile exceedance plots. Fig.R2a&b below show Figure 1a of the submitted manuscript (the -ZJI extreme warm events 95th percentile exceedance plots) but with the 99% significance shading calculated w.r.t -NAO and El Nino respectively. Here we see that in Fig.R2a the tropical, western European and polar regions are significantly different from the -NAO years and in Fig.R2b we see that the regions over Greenland, Eastern Pacific, Central Atlantic, Nort Africa, Mediterranean and Europe are significantly different relative to El Nino. This indicates that these regions are more/less susceptible to warm extremes during -ZJI winter months compared to -NAO and El Nino.

Line.139-146: Explanation is added for how Monte Carlo simulation is done, and improved, from previous analysis, to include strong imprint of tropical SST anomalies from the 2009/10 winter. Fig.1,4,6 & 8 have been substituted with significant regions calculated using this Monte Carlo simulation.

Line.151-152: Added the sentence- "Given the small sample size, we also tested partial least squares (PLS) regression and found very minimal differences between the results."

Line.190-202: Details on bootstrapping method and its analysis are added**.** The corresponding figures are added in Fig.2.

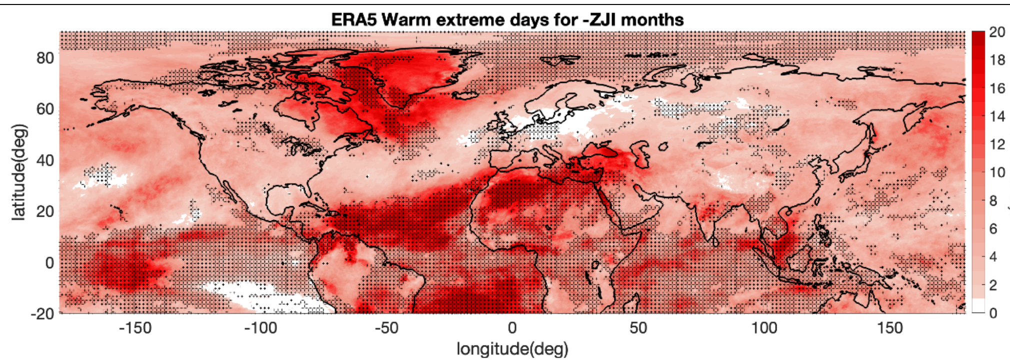

Fig.R2a

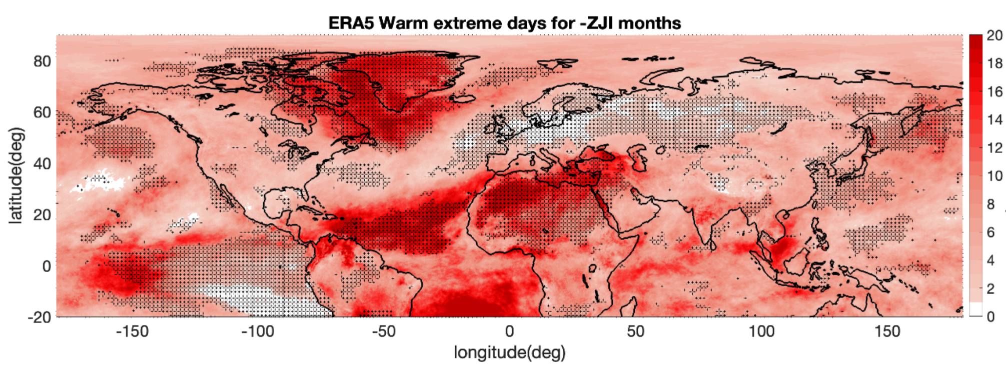

Fig.R2b

Figure R2. The distribution of the percentage of warm extreme days (defined based on a 95th percentile) for merged jet winter months, where the regions stippled in black (+) represents regions significant at 99% using bootstrapping significance w.r.t (a) -NAO and (b)El Nino months excluding -ZJI

Statistical significance tests are required for the composite differences shown in Figures 4, 6, 8, and 9.

For Figures 4, 6, 8, and 9 (in the initial manuscript) significance at 95% based on a two-sided Student's t-test against climatology is done (see R3a for T2m) and is added to the revised manuscript. The analysis doesn't change the conclusions mentioned in the manuscript.

Statistical significance using a two-sided Student's t-test against climatology is added to Fig.5,7,9 (previously Fig.4,6,8) in the revised manuscript. The significance for Fig.10 (previously Fig. 9) is added in supplementary as Fig.S6

Have you examined the composite anomalies based on the eight winter months during which -NAO and EI Nino occurred at the same time and compare with the anomalies associated with the -ZJI regime?

Yes, the 2m temperature composites of the eight winter months during which -NAO and El Nino occurred at the same time were analysed, and compared to the -ZJI months. Fig.R3a&b show the -ZJI 2m temperature composite and the same plot after regressing out -NAO and El Nino signals respectively. For comparison, Fig.R3c&d shows the 2m temperature composite of the eight winter months during which -NAO and El Nino occurred at the same time and the same plot after regressing out -NAO and El Nino signals respectively. Comparing the composites for the two groups (Fig.R3a and Fig.R3c) we see quite similar patterns, with the main difference being that the -NAO + El Nino composite has a warmer Pacific than -ZJI. It is to be noted that -ZJI does not necessarily occur during the strongest El Nino conditions. They are less intense and more central Pacific oriented than traditional Eastern Pacific El Nino conditions. The difference between these two subgroups become more apparent when regressing out NAO and El Nino signals from them. We see from a comparison of Fig.R3b and R3d that the Arctic and especially the Greenland region is warmer in -ZJI composite than in the -NAO + El Nino composite. We also see a warm subtropical Atlantic anomaly, and cold eastern Atlantic anomaly, consistent with SST anomalies forcing due to the persistent anomalous zonal wind stress occurring anomalously equatorward on the Eastern Atlantic. The anomalously warm region over Africa is also unique to the -ZJI months. We also see a stronger cold anomaly over Europe during -NAO + El Nino conditions and a stronger warmer anomaly over higher latitudes during -ZJI months suggesting a weaker meridional temp gradient during merged jet months.

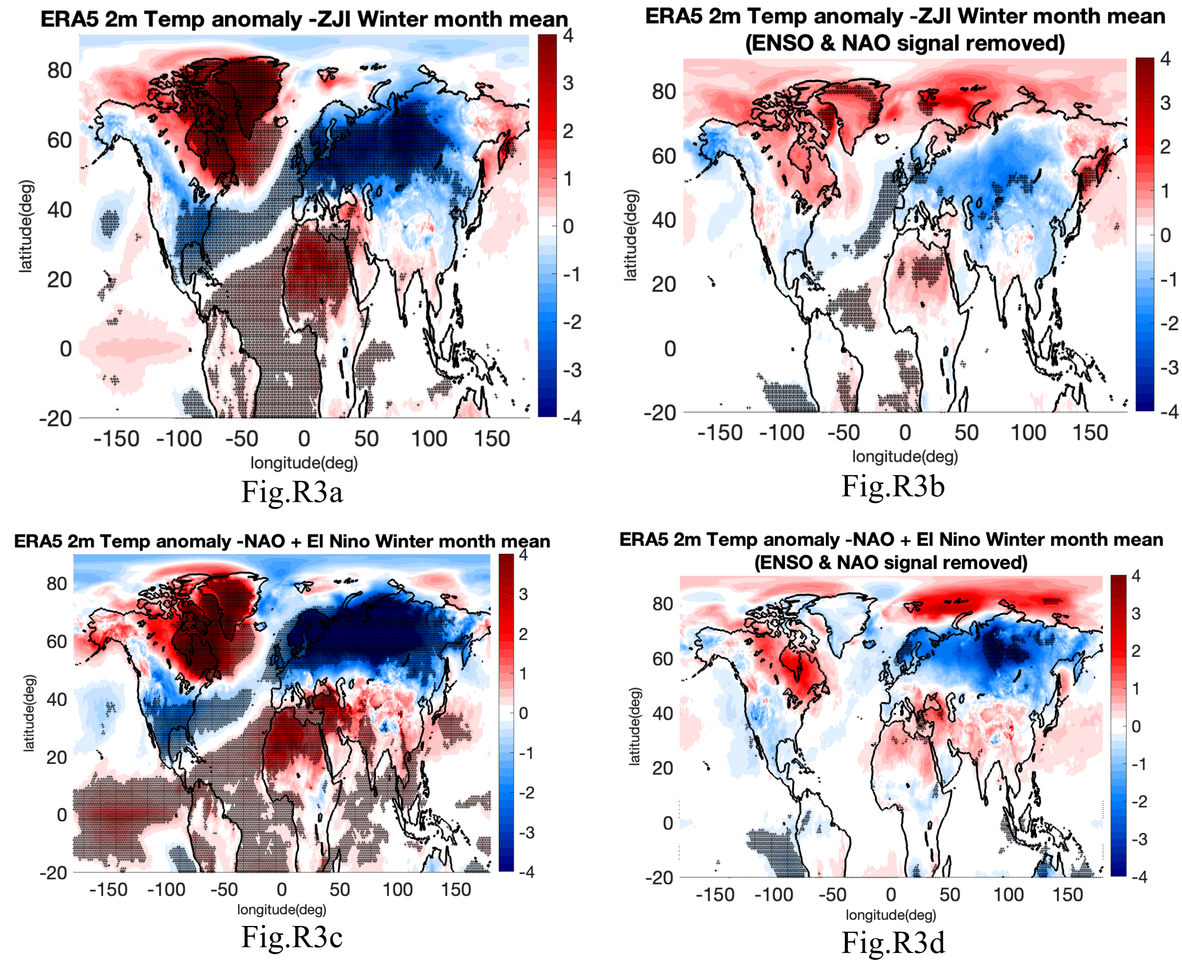

Figure R3. (a) Composite for anomalous detrended 2m surface temperature (K) for -ZJI winter months. (b) Same as (a) but the NAO and ENSO signals are removed using linear regression analysis. (c) Composite for anomalous detrended 2m surface temperature (K) for -NAO+El Nino winters. (d) Same as (c) but the NAO and ENSO signals are removed using linear regression analysis. The stipples(+) represents regions for which the composites are significant at 95% based on a two-sided Student's t-test against climatology.

The discussion about the difference of daily average surface temperatures (figures 2 and 3), surface winds (figure 5), and total precipitation using box plot for the selected regions is somehow confusing. Because no confidence intervals are shown for the median nor for the mean, these box plots do not prove those measures are either larger or smaller than the climatology statistically.

Thanks for the comment and suggestion. We added confidence intervals for the mean and median using a bootstrap method. This is done by using data from each sample of boxplots (like from -ZJI/-NAO/El Nino/Climatology) to generate a sampling distribution by repeatedly taking random samples from the known sample, with replacement, and then computing sample medians/means. We repeat it 10000 times to get 10000 bootstrap samples which gives the 10000 medians/means. Once we find this distribution, we can create a confidence interval. In our case, for a 95% confidence interval, we would find the 2.5th percentile and the 97.5th percentile of the bootstrap sample distribution. Although the confidence interval of median/mean for each boxplot is very small, we have added it to the revised manuscript. This also doesn't change the results mentioned in the initial manuscript.

All boxplots in Fig.3,4,6 and 8 are updated with confidence intervals for the mean and median using a bootstrap method.

Line.208-212: "The mean and median of each group are also marked, along with its 95% confidence interval calculated using the bootstrapping analysis. This is done by using data from each sample of boxplots (like from -ZJI/-NAO/El Nino/Climatology) to generate a sampling distribution by repeatedly taking random samples from the known sample, with replacement, and then computing sample medians/means. We repeat it 10000 times to get 10000 bootstrap samples which gives the 10000 medians/means. Once we find this distribution, we can calculate the 95% confidence interval."

Specific comments:

> **Title: during winter -> during northern winter**

The change will be made in the revised manuscript

Updated title from "Extreme weather anomalies and surface signatures associated with merged Atlantic-African jets during winter" -> "Extreme weather anomalies and surface signatures associated with merged Atlantic-African jets during northern winter"

> **Line 62-64. This sentence has little to do with the 2009/2010 winter or add anything to the paragraph. Consider removing.**

This sentence means to explicitly note that the 2009/10 winter El Nino event was unusually strong, and certain extreme events were correlated to that El Nino. It is also possible that the extreme El Nino was a main reason why the merged jet state persisted throughout the winter of 2009-10 (a true dynamical regime change). We will rephrase the paragraph to make our meaning more explicit.

Line.65-70: The paragraph is rephrased to – "The abnormally high snowfall experienced during this winter in the mid-Atlantic states of the U.S. and northwest Europe was suggested to be primarily influenced by the negative NAO, with additional contributions from El Niño too (Seager et al., 2010). Notably, the 2009/10 El Niño was the strongest since the winter of 1997-98 and ranked as the fifth most intense event since 1950 (National Climatic Data Center; "2009-2010 Cold Season"; 2010; NOAA's National Climatic Data Center, Asheville, NC)."

There are quite a few "Northern Hemisphere" in the paper. Consider abbreviating it to "NH".

Thank you for pointing out. The change will be made in the revised manuscript.

Updated

Line 67: make it clearer that the warm extremes over North Africa and Arab are linked to positive NAO and during summer, or delete this part of the sentence because your focus is on the winter season.

Thank you for your feedback. We re-read Donat et al (2014) - according to that study, the warm extremes over North Africa and the Arab regions are influenced by negative NAO during the winter (DJF) season, no summer. Since this aligns with the focus on winter in our study, retaining this part of the sentence is relevant and provides important context.

Line 73: insert "subtropical" before "eastern US coast".

Thank you for your feedback. Hope you meant Line 173. The change will be made in the revised manuscript

Line.225 : Updated

Line 125: do you mean that the eddy kinetic energy shown in figure 9 is estimated based on 10-day highpass filter?

Yes, the eddy kinetic energy shown in Fig.10 (previously Fig.9) is estimated based on 10-day highpass filter and then a 10-day lowpass filter. Please also refer next comment.

Line 126-127: I am not should that mean flow corresponds to the data filtered with a 10-day low pass filter. Quasi-stationary waves will stay in the low-passed part but they should not be regarded as the mean state of the flow, also in which figure that the low-pass covariances between the high-pass fields are assessed?

Sorry for the confusion. What was done here is that we did a 10-day high-pass filter on surface velocity data to calculate the eddies and then a 10-day low pass filter over it so that it represents a field that is slowly varying (low-frequency) component of EKE. Here we particularly try to capture EKE variations that persist longer than 10 days. This filtered EKE can highlight the influence of larger-scale processes on the eddy activity. This explanation will be improved better in the revised manuscript.

Line.152-158: Updated the explanation - "To analyze the role of synoptic-scale eddies, we compute surface eddy kinetic energy (EKE) by applying a boxcar filter to 10m wind data. High-frequency eddies are defined using a 10-day high-pass filter on the 10m wind velocity data and then the low-frequency EKE component is obtained by applying a 10-day low-pass filter to the high-pass-filtered EKE. This approach captures EKE variations that persist longer than 10 days."

> **Lines 142-150. This is a very long sentence. Try to break it into two so that the readers can understand exactly what is involved.**

Thanks for the feedback. We agree it's a very long sentence. The required changes will be made in the revised manuscript.

Line.179-183: Updated

> **Line 150: how "significantly". Consider reserve the word "significant" to statistically tested quantity.**

Thanks for the comment. We agree with you. The required changes will be made in the revised manuscript.

Line.183: Updated

> **Line 174: NAO -> -NAO and other similar expression.**

Updated

> **Lines 190-215: reads like discussion rather than results. Move to last section and make the section title to "conclusions and discussion"?**

Thanks for the suggestions. The appropriate changes will be made.

Line.379: Section "Conclusions" renamed to "Discussions and Conclusions"

Line.261-270: The sentences are removed and added to the discussions and conclusions section at **Line.402-407** and **Line.448-454**.

> **Lines 202 and 204: I do not think that you have studied the warming trend. These are anomalies associated with either the -NAO, EI Nino or the -ZJI.**

Thanks for pointing it out. You are right that they are not a trend but an anomaly. The appropriate changes will be made.

Line.255: The word "trend" has been replaced with "anomaly"

Line.257 & 402: The word "trend" has been removed

> **Line 239: can you be a little specific about "the sources of momentum"?**

Sorry for the confusion. The term "sources of momentum" in Line 239 refers to the large transport of air parcels from the equator to the subtropics, particularly originating from the tropical eastern Pacific. This transport contributes additional airflow into the jet, helping to maintain its merged state. The required explanation will be added in the revised manuscript that best fits the discussion.

Line.292-296: The statement has been removed and added at the later part of the result at **Line.309-313** rephrased as : "A previous study by Harnik et al. (2014), using lagrangian back-trajectory analysis of the Atlantic subtropical jet, demonstrated a significant northward displacement of air parcels from this tropical eastern Pacific region to the subtropics. This transport process supplies additional airflow and momentum to the Atlantic jet, supporting its intensification and the formation of the merged jet"

> **Line 239: Is the merged jet eddy driven or thermal driven? If it is too elaborated to go into the details, I would suggest removing these texts. Mixing lengthy discussion of previous work with new results can be confusing sometimes.**

Thanks for pointing it. Theoretically speaking the merged jet is mostly a mixed eddy-thermally driven. We also feel its worth mentioning that the tropical east Pacific region showing high wind activity in our result is consistent with the previous study mentioning the additional wind flow into the Atlantic jet that helps it to persist as a merged jet. We will revise this discussion to make it more concise and structured, ensuring clarity and avoiding confusion in the revised manuscript.

As mentioned in the previous comment this statement has been removed and rephrased at **Line. 309-313**. Also, the point that the merged jet is mostly a mixed eddy-thermally driven is mentioned in **Line.51.**

> **Line 249: This explains -> This is consistent with.**

Thanks for the suggestions. The change will be made in the revised manuscript.

Line.305: Updated

> **Lines 251-254: This may indicate an anomalous …". This is too speculative especially figure 6b does not involve any statistical test, the rather small sample size, and the small magnitude of the wind anomalies (< 1 m s^-1).**

Thanks for the suggestion. Figure 6b is updated with two-sided Student's t-test and the necessary changed will be made in the revised manuscript.

This sentence on **Line.307-309** has been removed and the Fig.6b (of the initial manuscript) has been updated with significant regions in Fig.7b using two-sided Student's t-test.

> **Line 272: "Additionally, there are notable extreme daily precipitation from the climatology that fall within the ZJI winter days". I wonder how can you make a**

statement like this just based on the box plot. Each box plot is associated with different subgroup of winter days with no information about the climatology. For a given day that is shared by climatology, -NAO or -MJI group, it can be shown outside of the whiskers in one boxplot, e.g. climatology, but included in other subgroups.

Thanks for pointing this out and sorry for the confusion. Here climatology refers to the entire DJF winter days between 1960-2020. So the -NAO, El Nino, and -ZJI are subgroups of the climatology but -ZJI is exclusive from -NAO and El Nino groups as we don't include merged-jet months in them. Hence, a given day that is shown outside of the whiskers in climatology, can only be included either in the -ZJI subgroup or the -NAO/El Nino subgroup, or in none of the three. The day can't fall in the -ZJI and -NAO/El Nino subgroups together at the same time. Hence by comparing the outliers, we could say that many of the extreme daily precipitation events outside of the whiskers of the climatology fall within the ZJI winter in box plots of climatology and -ZJI.

Line.206-208: mentions each group member in the box plot - "The plots show distribution during climatology winter days (all winter days between 1960-2020), El Nino winter days (excluding -ZJI), -NAO winter days (excluding -ZJI), and merged jet (-ZJI) winter days."

Line.331 : updated by adding "on comparing the outliers we see that.."

Line 314: "A significant proportion". This is not supported by the results because no statistical significance is shown in figure 9.

Thanks for the suggestion. The statement will be changed appropriately and statistical significance will be included in figure 9.

Line.374 : "A significant proportion" is replaced with "Most". Also, Fig.10 (same as Fig.9 of initial manuscript) with significance over cyclone density anomaly is shown in supplementary as Fig.S6.

Lines 247-350: again speculative sentence without any concrete results backing.

Thanks for pointing this out. Hope the mentioned line is 347-350 of initial manuscript. This will be changed accordingly.

Line.422-424: Removed the sentence.

Line 318: Conclusions -> Conclusions and Discussion. Also, I would think that the conclusion can be much more concise than what has been written.

Thanks for the suggestion. The section title will be changed to Conclusions and Discussion. We will try to better restructure the section, aiming to be concise.

Line.379: Section "Conclusions" renamed to "Discussions and Conclusions"

Line.379-454: Changes have been made throughout this section to make it more concise.

Line 335: no trend has been studied here.

Thanks for pointing this out. We will update it.

Line.402: the sentence "This anomalous warming trend …" changed to just "This anomalous warming…"

Line 337: A connection between -ZJI and Arctic Amplification may be related to the paper https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2019GL082714.

Thank you for the suggestion. The referenced paper discusses the connection between Pacific temperature changes and Arctic warming, but it does not directly address the role of Atlantic-African jet merging in Arctic Amplification. Since our study does not explicitly focus on this connection at this stage, we have not included it. However, we appreciate the insight and will keep it in mind for future exploration.

Line.403: removed the sentence "It also suggests a connection between -ZJI and Arctic Amplification, impacting atmospheric circulation patterns and potentially influencing extreme winter weather across midlatitudes."

Line 362: remove due to merged jet formation.

Thanks for the suggestion. Will be changed accordingly.

Line.438 : removed "due to merged jet formation".

Reference:

- Donat, M., Peterson, T., Brunet, M., King, A., Almazroui, M., Kolli, R., Boucherf, D., Al-Mulla, A. Y., Nour, A. Y., Aly, A. A., et al.: Changes in extreme temperature and precipitation in the Arab region: long-term trends and variability related to ENSO and NAO, International Journal of Climatology, 34, 581–592, 2014.

- Harnik, N., Galanti, E., Martius, O., and Adam, O.: The anomalous merging of the African and North Atlantic jet streams during the Northern Hemisphere winter of 2010, Journal of Climate, 27, 7319–7334, 2014.

Response to Reviewer #2

We thank the reviewer for dedicating the time to review this paper. We appreciate the reviewer's feedback and constructive comments. The responses are as follows:

> **The authors have submitted an manuscript analyzing the characteristics of the large-scale atmospheric circulation over the North Atlantic and Europe when a merged polar and sub-tropical jet occur, and specifically look into the resulting impacts in terms of cold temperatures, strong winds and precipitation. While the paper deals with an interesting topic and includes promising results, it also features several shortcomings in terms of the methodology and physical interpretation, that in my opinion hampers its potential scientific value. Thus, I suggest a major review and would be willing to review the manuscript again if required**
>
> **Major points**
>
> **i) the manuscript does not include the composites of the 5 groups (line 95ff), particularly in terms of zonal wind at 250 hPa, which makes the understanding of the rest of the paper quite difficult. Please include the composite figures and describe the possible differences**

Thank you for the valuable suggestion. Figure R4 shows the zonal wind composite at 300 hPa (as the ZJI index is calculated at this level) for the five groups, overlaining on the anomaly from climatology. We see that in -ZJI and -NAO subgroups, the Atlantic jet is anomalously equatorward, however, during the -ZJI months it is most strongly merged with the subtropical jet over Africa. In this paper we are trying to make a subtle claim. In theory:

- The NAO is a manifestation of wave-mean flow interactions, as is expected in an eddy driven jet regime.
- If we strengthen the mid-latitude instability, leading to stronger eddies, an equatorward "merged jet" will be pushed poleward and its variability will increase, making it an eddy-driven jet.
- A merged jet regime occurs when both the extratropical eddies are weak enough and the tropical thermal forcing of the jet is strong enough.
- Idealized models show that a merged jet regime looks similar to the negative EOF phase of the eddy driven jet.
- Harnik et al (2014) showed that an anomalous tropical heating as is observed during El Nino can influence the Atlantic subtropical jet.

Given all these, we expect the merged jet regime to project strongly on a negative NAO, and to occur when there is a strongly anomalous tropical heating, but to be different from a simple combination of both, because of a dynamical regime change of the eddy-driven Atlantic jet to a merged Atlantic-African jet that affects/enhances the extreme weather conditions. Our results aim to show that this added unique signal, which is exclusive from the usual NAO, EI Nino or their combined effect. Thus, while the difference in zonal jet patterns between the groups, as shown in Fig R4 is maybe not huge, the merged jet state arises from unique dynamical feedbacks render the jet more persistent, suggesting a different dynamical regime and possible a different influence on extremes.

In the revised submission, we will include the zonal wind composite at 300 hPa for the five groups. We initially omitted the zonal wind composite because the composite for -ZJI months, +ZJI months, -NAO months, and climatology was discussed in a previous study by Harnik et al. (2014) [please see their Fig. 1 and Fig. 5]. That study concludes with a discussion on the potential connection of merged jets to other atmospheric indices like NAO and ENSO, which we aimed to further explore in this manuscript.

Line.127: added the sentence "The zonal wind composite at 300 hPa of the five winter groups along with a short description of their differences are given in supplementary Fig.S1."

Also the figures (Fig.R4a-e) along with a description on the jet orientation are added in supplementary as Fig.S1a-e.

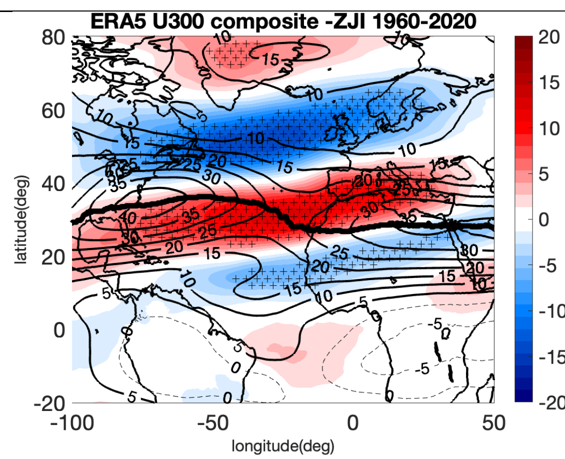

Fig.R4a

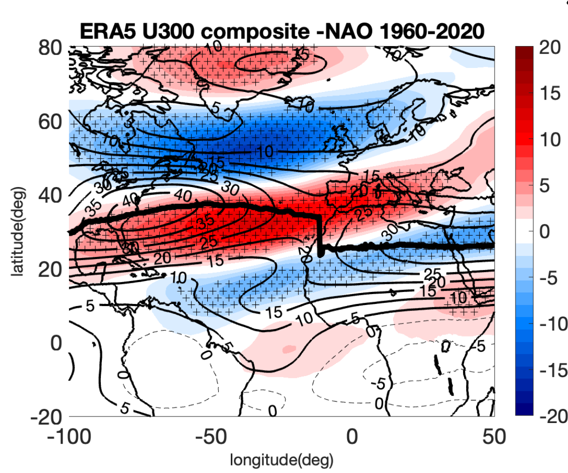

Fig.R4b

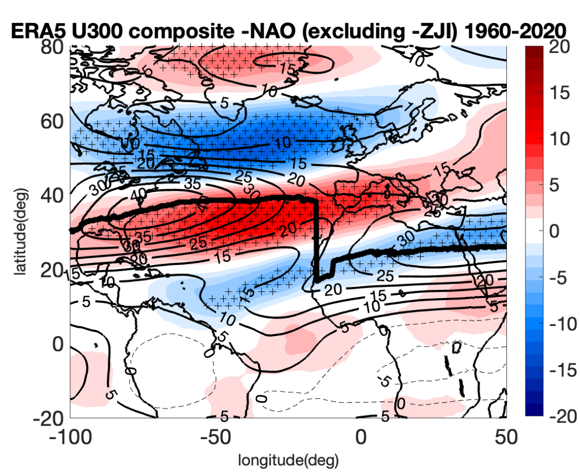

Fig.R4c

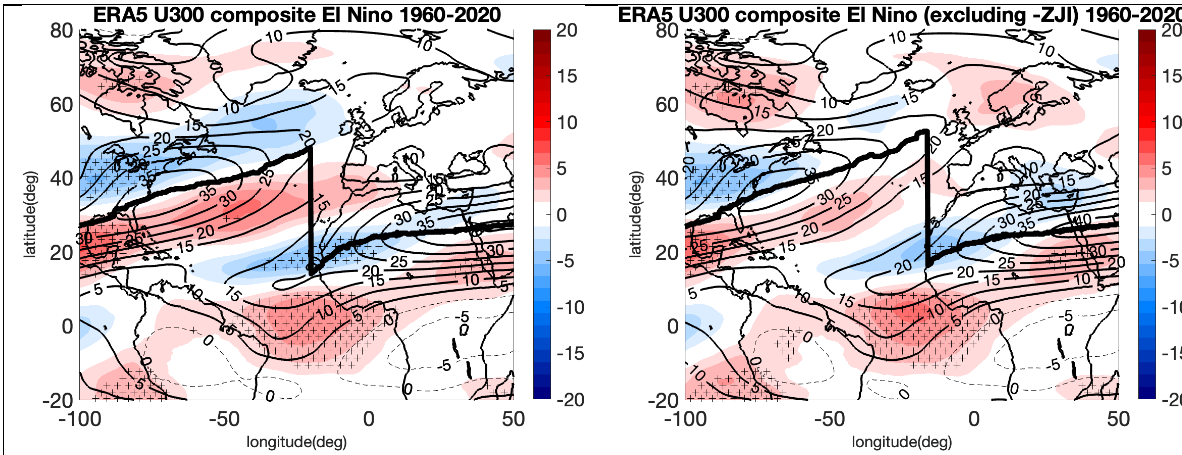

Fig.R4d   Fig.R4e

Figure R4. Composites of zonal wind at 300 hPa (in black contours) for (a)-ZJI winter months (b) -NAO winter months (c)-NAO winter months excluding merged jet months (d) El Nino winter months (e)El Nino winter months excluding merged jet months. The red-blue shading in background represents the composite of U300 anomaly from climatology. The stipples(+) represents regions for which the composites are significant at 99.9% based on a two-sided Student's t-test against climatology. Contour interval is 5m/s, negative and zero values are dashed, and the thick black line represents the zonal jet axis (latitude of maximum U300 wind).

ii) Following on the above, and specifically: from the 14 "merged jet" periods, 9 are NAO-. I would really like to know what special in the 5 periods with „merged-jet but not NAO-". For me it is difficult to conceive a „merged-jet" situation with a neutral or positive NAO, maybe this is only a question of thresholds??

Thank you for raising this concern. Yes, it is to an extent a matter of threshold, specifically we choose the NAO months based on the NAO index lesser than -1 times its standard deviation from the mean. The 4 out of 5 periods you mentioned within the -ZJI are very weakly negative NAO with the exception of one (month of 01/1973) which is near zero positive NAO. These are months with a merged jet which is not equatorward oriented like the other strongly merged jets. For example Fig.R5a and b show the zonal wind at 300hPa of two of the near zero NAO index members (NAO index=0.04 & -0.02 respectively) of -ZJI group.

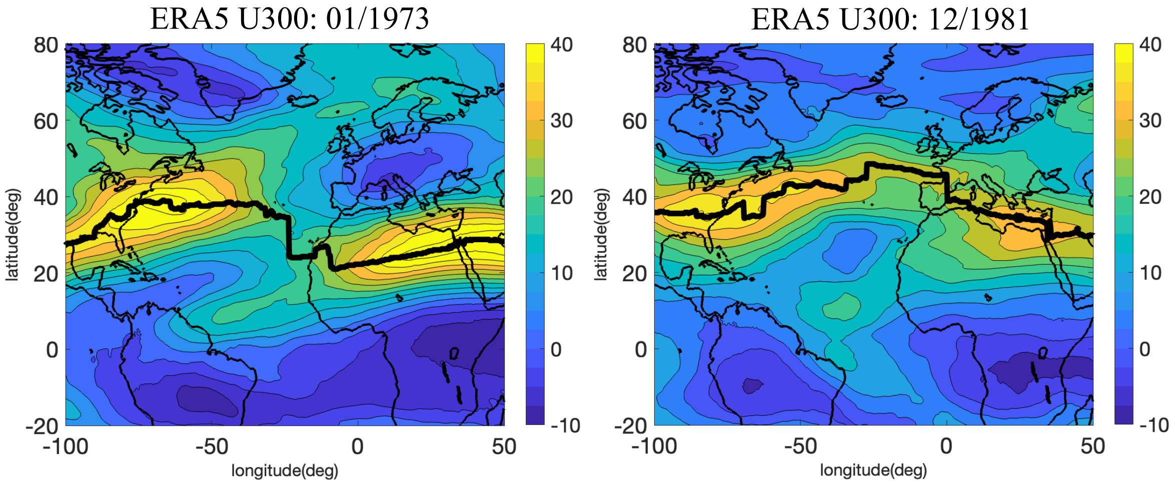

Fig.R5a

Fig.R5b

Figure R5. Monthly mean U300 (m/s) of -ZJI month of (a) month=01 & year=1973 (b) month=12 & year=1981. The thick black line represents the jet axis.

These two months represent extremes among the merged jets where the overall jet is not equatorward oriented, but its jet axis experiences an anomalously gradual latitude change in the zonal direction, compared to its jump in climatology, leading to a negative value of ZJI index. Specifically, during Jan 1973, rather than being merged, the Atlantic jet has an anomalously short eastward extension, with a longitudinal gap before the African jet starts. Ideally, if there were more merged-jet month reanalysis data it might be better to filter out months like Jan 1973 from the merged jet subsample, but since it falls within the ZJI threshold that we follow we are including these months in our analysis. Given the many statistical significance tests we have already done (see previous responses), and supporting GCM-based analyses (see below) that are done, we expect the current results to hold.

iii) I wonder in how far it is possible to obtain statistical significant information from the small samples (e.g. only 5 samples), as I imagine that the case-to-case variability will be quite high.

We are not quite sure which 5 samples the reviewer is referring to. The 5 groups in question consist of samples of 14,29,20,32 and 25 months. If the reviewer meant the 5 exclusive months (with merged-jet but not strong -NAO) we haven't compared that 5-month sample exclusively with any other, but see the response to your previous comment.

The question of the statistical significance of differences between the 5 main groups has also been pointed out by reviewer 1. To address this, we did some further statistical tests using bootstrapping (Fig.R2) which works for smaller samples, and the majority of our initial results still hold. See the response to reviewer 1 above.

To get a better handle on the dynamical drivers of merged jet events, we are currently examining jet merging in the CESM2-Large ensemble data set where we have much larger samples of each of the five groups. While we have not yet examined the statistics of extreme events as we do in this paper, an analysis of surface temperature composites suggests merged jet months are indeed distinct from -NAO and El Nino months, in ways similar to what we find here. For example in Fig R6 we see that CESM2-LENS Ensemble composite for anomalous detrended surface temperature (K) for (a) -ZJI DJF months [616 sample events] (b) -NAO DJF months (excluding -ZJI months) [1588 sample events] and the difference between them. Looking at the difference (Fig R6.c) we see that the merged jet months have a warmer tropics and Arctic, and a weaker midlatitude temperature gradient compared to the exclusive -NAO DJF months. The Greenland region in CESM2-LENS shows results that contradict the ERA5 analysis though, whereas the rest of the regions show good agreement with it. The results pertaining to Greenland are nicely consistent between the different quantities we examine, including the storm tracks, suggesting the signal is physically sound, however, its attribution to jet merging might be a result of small-number statistics. This is an ongoing work and hence not included in the current manuscript.

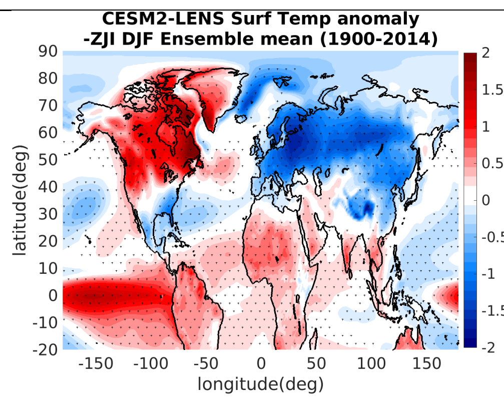

Fig.R6a

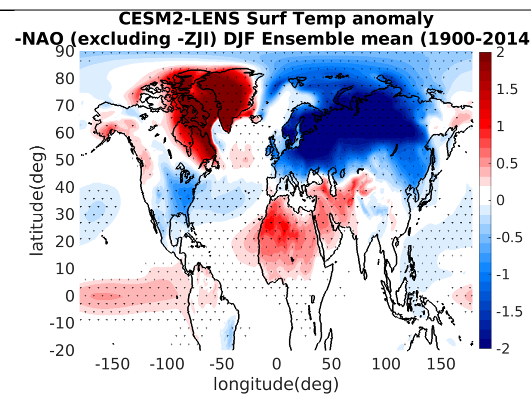

Fig.R6b

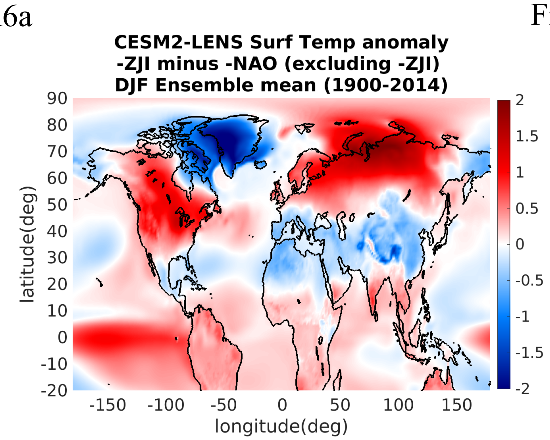

Fig.R6c

Figure R6. CESM2-LENS Ensemble composite for anomalous detrended surface temperature (K) for (a) -ZJI DJF months (b) -NAO DJF months (excluding -ZJI months) (c) difference between (a) and (b). The regions stippled in black (+) represents regions significant at 99% using Student t-test w.r.t climatology.

iv) I also wonder about the physical interpretation of the relationship to ENSO, particularly considering the small sample, the indirect influence of ENSO in the European climate and the multitude of modifiers that affect this relationship. How much is the actual explained variance???

Thanks for pointing out the concern. The influence of ENSO which we are referring to is based on the findings of Harnik et al (2014), where an anomalous central Pacific tropical heating is found during negative ZJI months. In that study, Harnik et al. (2014) use a lagrangian back-trajectory analysis to show that a large portion of air parcels flowing into the Atlantic subtropical jet originates in the tropical Pacific, joining the majority of air parcels which originate arrive from the upstream subtropics, and that their portion is larger during -ZJI months compared to non-merged jet months.

In our analysis, we find that ENSO has no direct influence on the European climate during winter as compared to NAO and ZJI (please refer to Fig.S2,S3,S4,S5 from supplementry). We note that ENSO could have an indirect influence on the European climate mainly through stratospheric interactions (Brönnimann et al., 2004) which are not explicitly addressed in this study. It is important to note that merged jets are associated with El Niño events, though not exclusively with the strongest ones.

v) Given all of the above, and even though I have refrained to provide detailed comments on the figures / text - as these will probably changed in a revised version - I would like to suggest the authors to downtone the statements regarding the current results, particularly given on iii) above.

I am looking for to re-evaluate a revised version of the manuscript.

We appreciate your suggestions and understand the importance of refining our statements regarding the current results, particularly in light of statistical significance. In the revised version, we will carefully reassess the tone and wording of our conclusions to ensure they appropriately reflect the robustness and limitations of our findings.

We are grateful for your willingness to review the revised manuscript, and we will carefully address all your comments to improve the clarity of this study in the revised version.

Reference:

- Brönnimann, S., Luterbacher, J., Staehelin, J., Svendby, T., Hansen, G., and Svenøe, T.: Extreme climate of the global troposphere and stratosphere in 1940–42 related to El Niño, Nature, 431, 971–974, 2004.

- Harnik, N., Galanti, E., Martius, O., and Adam, O.: The anomalous merging of the African and North Atlantic jet streams during the Northern Hemisphere winter of 2010, Journal of Climate, 27, 7319–7334, 2014.