We sincerely thank Referee #1 for very valuable feedbacks.

Here are the main modifications that will be considered following Referee's comments. We will consider the study of precipitation in the Northern French Alps in the paper, as the atmospheric descriptors were designed for this specific purpose. The consideration of seasonal and extreme precipitation trends in the Northern French Alps in section 4.3 will allow for more concrete and clear interpretations on the implications of large-scale circulation changes for local weather. This will also support the use of the atmospheric descriptor over the Western Europe domain to study large-scale circulation trends. In this way, the introduction and conclusions will be more specific on Alpine precipitation. The Atlantic and Mediterranean influences will be the only atmospheric influences considered in the paper as Anticyclonic conditions and Northeast circulations are not relevant for seasonal and extreme precipitation in the Northern French Alps (Fig.5 will be removed). Fig. 9 and Fig.10 will be replaced by figures providing more relevant information on LSC driving precipitation in the Northern French Alps. Furthermore, we will add in Fig.3 the maps of the differences in 500 hPa geopotential height between 20CRv2c and ERA20C for both the period 1900-1930 and 1970-2000. This will allow for a more physical interpretation of the differences in geopotential shapes exposed in Fig.2.

Please find below a detailed point-to-point reply to the Referee's comments.

General comments

In this paper the authors study the non- stationarity of large scale weather patterns (LSCs) over Western Europe, using a set of patterns developed specifically for explaining the differing dynamical origins of French precipitation patterns in Garavaglia (2010). They introduce several metrics which they use to quantify the amplitude, uniqueness and persistence of the large scale circulation patterns in different seasons, and evaluate both the long term representation of these metrics in multiple reanalyses, and more recent trends in ERA5. Both halves of this work are of interest. The reanalysis intercomparison provides an interesting perspective that clearly highlights some issues with circulation patterns in reanalyses in data-sparse time periods, which perhaps would not be so apparent using more conventional metrics. The analysis of recent trends in circulation presents an interesting approach to exploring non-stationarity in atmospheric dynamics, and shows some interesting shifts in the behaviour of the different LSCs over the last 70 years. However, in my mind there is a final step which I think would enhance the work quite significantly. As the LSCs used in this paper were developed specifically to explain precip variability, and possible impacts of the LSC changes on precip make up an important part of the conclusions of the paper, it seems a shame that changes in the actual precipitation from 1950-2019 – are not considered. For example, in the conclusion the authors write: Mediterranean circulations featuring a marked flow and stationary flow directions that are closely reproduced in the climatology are more frequent over the last 30 years in autumn, which could impact autumn extreme precipitation over the Southwestern Alps. I believe showing whether such changes can actually be observed would really strengthen the work, and improve its impact.

⇒ Thanks for this very interesting feedback. Whether or not to consider precipitation in this paper has been actually widely discussed with the co-authors. The atmospheric descriptors were indeed developed to study the large-scale circulations of interest for extreme precipitation in the Northern French Alps (Blanchet et al., 2018; Blanchet and Creutin, 2020; Blanc et al., 2021a). In the first draft of this paper, we decided to consider large-scale circulations (LSC) only to make it more focused, as studying the impact of LSC changes on precipitation represents substantial additional material. However, we understand and agree with your point, so in this second draft we will include the study of precipitation. We will add a third subsection in the results in which we will study trends in seasonal and extreme precipitation in two medium size catchments of the Northern French Alps (Isère and Drac River catchment at Grenoble), and where we will discuss the links with LSC changes. We hope that the current version of the paper will represent a more complete piece of work.

Apart from this issue, I believe the manuscript itself needs some slight reworking. Lines 27-54 in the introduction provide a very comprehensive review of the various LSC impacts on Western European weather and extremes. Its actually a very useful collation of these results, but it is incredibly dense and hard to read. Additionally, as there are few links or comparisons made in the paper between the 4 weather types used and these other LSC classifications, a lot of this paragraph is not directly relevant to this work, other than to repeatedly emphasise that LSC has important impacts on surface weather. I would suggest either synthesising these lines down in to a more readable form, or else only including in the main text those studies that are most directly relevant to the work done here, and putting the rest in a helpful reference table (i.e. of weather types against geographical region, with the documented impacts listed in each appropriate cell). I also think better motivation is needed for the various metrics used, due to the fundamentally applied motivation of the work – for example, what does a low singularity mean of an LSC for surface weather? Finally, a bit more work needs to be done in the conclusions to emphasise the implications of the results. For example, at the end of the paper I still don't know what I'm supposed to think about figure 10, or the low significance of the bimodal kdes in figure 9 when compared to the significant unimodal changes of figures 5,7, and 8.

⇒ Thanks for this valuable comment. As the new version of the paper will consider precipitation, the whole article will be redirected with a more specific focus on precipitation in the Alpine range. The introduction will be refined, considering previous studies that linked large-scale circulation to precipitation variability and extremes in the Alpine range or in France. References linking large-scale circulation to local temperature or to different variables in other regions than the Alps will be removed. We will include a full paragraph detailing the links between the atmospheric descriptors (celerity, singularity, relative singularity and Maximum Pressure Difference) and precipitation variability and extremes in the Northern French Alps – so many reasons that motivate the study of LSC changes using these descriptors. In the same vein, Figures 9 and 10 will be replaced by figures focusing more specifically on descriptors values that are relevant for precipitation variability and extremes. In this way, the implications of LSC changes for precipitation in the Northern French Alps will be clearer and the associated conclusions will be more clearly exposed.

I highlight specific technical issues below, which while quite numerous shouldn't take very long to correct. In summary, I believe this paper represents a valuable piece of work, well suited for inclusion in Weather and Climate Dynamics. I am pleased to see work on circulation pattern nonstationarity, as I consider it to be an understudied but very important area of research. However I am recommending major revisions, so that the authors can include an analysis of the impact of LSC changes on precipitation directly, and to make the more minor revisions to the manuscript I have suggested. If they would rather not include a direct consideration of precipitation, then I think *they need to do a better job of arguing why the changes in these quite regional circulation patterns are interesting enough in their own right.*

⇒ Thanks for pointing the relevance of this area of research. As said above, the new manuscript will consider precipitation. The specific technical issues will also be addressed.

Specific issues

- *I find the use of 'analogy' throughout the paper a bit confusing. It is a matter of personal taste, but I suggest the authors consider using 'analogues' or 'analogue methods' to be clearer.*

  ⇒ Thanks for this feedback. The term "analogy" is explained in more details when introducing the atmospheric descriptors, which is probably too late for a clear understanding. We have therefore decided to include the following explanation directly in the abstract: "We focus on the evolution of large-scale circulation characteristics using three atmospheric descriptors that are based on analogy, by comparing daily geopotential height fields to each other". From our point of view, the use of "analogue method" refers more to considering analog days for reconstructing local variables (such as daily precipitation or temperature) on a given region based on large-scale predictors. This is not the case here, as the analogy is only used to construct atmospheric descriptors that characterize large-scale circulation. Thus we propose to keep the term "analogy" but we hope that the explanation of the concept already in the abstract will make it easier to understand.

- *Table 2 is not incredibly easy to read and takes up a lot of space. Consider putting it into supplementary material and instead include a table summarising just the significant/interesting differences.*

  ⇒ Thanks for this comment. In this new version, we will focus on LSC that are relevant for precipitation in the Northern French Alps. Thus we will only consider the Atlantic and the Mediterranean influences and we will no longer consider the Anticyclonic and Northeast influences. Atlantic and Mediterranean influences have been shown to drive both seasonal and extreme precipitation in the Northern French Alps (Blanc et al., 2021a; Blanchet et al., 2021; Sodemann and Zubler, 2010). Table 2 will be therefore much shorter, and it will be transposed to take much less space.

- *[line no. 99] ERA20C is in fact a 10 member ensemble. You should verify whether you are using the ens mean or first member, and correct the text.*

  ⇒ A 10-member ensemble is indeed used in the construction of ERA20C. It is based on different evolution of SST and sea-ice and it considers model errors as well as uncertainties in the assimilated observations. However, this ensemble is only used to derive spatial and temporal errors that are then used as an input in the main reanalysis product, which is single-member. The most recent version of ERA20C we use (the one of Poli et al., 2016) follows the methodology of ERA20 deterministic (2015), which is itself based on the 10-member reanalysis (2013) (`https://www.ecmwf.int/en/elibrary/11700-era-20c-deterministic`). The construction of the most recent version of ERA20C is detailed in Poli et al. (2016), whose abstract clearly states that "The reanalysis is single-member, and the background errors are spatiotemporally varying, derived from an ensemble".

- *[line no. 113] I think more detail is needed here on the weather pattern classification, especially as the approach used is rather atypical. As these patterns are central to this paper, I shouldn't really have to read through all of Garavaglia 2010 to understand what you've done. A few lines explaining that its a hierarchical approach that identifies geopotential patterns associated with rainfall clusters would suffice.*

  ⇒ Thanks for this comment. That is true; we will add some explanations about the construction of the classification.

- *[line no. 255] If the underlying assimilating model tends to produce calmer, less stormy weather – as most low resolution models do – then the less-constrained reanalysis in the 19th century might be expected to produce calmer weather. This would be consistent with the celerity and singularity trends you find.*

  ⇒ Thanks for this comment. That is true, the different results from 20CR suggest that the observed trends in celerity and singularity in the second half of the 19th century are more an artefact of the data set rather than physical signals. This is what we intended to say in this sentence, in the sense that we could not physically interpret such trends. But we agree the sentence was actually not clear enough, so it will be rewritten.

- *[Line 394] 'Implications for summer heatwaves' - what are the implications? It would be best to state these explicitly.*

  ⇒ Thanks for this comment. We have decided to exclude trends in Anticyclonic conditions in the new version of the paper, as i) Anticyclonic conditions are not associated with precipitation in the two medium size mountainous catchments we study (Blanchet et al., 2021; Blanc et al., 2021b), ii) this influence features only slight changes compared to the Mediterranean and the Atlantic influences, and iii) considering trends in Anticyclonic conditions in addition to precipitation would lead to a long article. Thus, the corresponding sentence will be removed.

Technical/editing issues

- *[line no. 21] 'Over the large scale' is redundant*

  ⇒ Will be corrected.

- *[line no. 41] Something is missing: '..low amplitude through over the UK...'*

  ⇒ Will be corrected. That was actually a typing error, as we were referring to a trough over the UK.

- *line no. 55] 'Over the long run': quite colloquial, better to be more specific – what timescale?*

  ⇒ This part of the introduction will be removed as it was not essential for setting the context and the problematic.

- *line no. 55] As this is not a paleo paper is it necessary to refer to the Holocene? At least you should indicate this is the last 10,000 years.*

  ⇒ Same answer as the previous comment.

- *line no. 73] 'weather pattern'*

  ⇒ Will be corrected.

- *line no. 95] identify/determine rather than 'derive'*

  ⇒ Will be corrected.

- *line no. 109] 'Studying changes in LSC is carried out': This is not a valid construction. Perhaps 'Changes in LSC are studied using. . . '?*

  ⇒ Will be corrected, thanks.

- *[line no. 120] Trends can't really be 'rather poor'. Perhaps say 'small', 'negligible', or 'statistically insignificant'as the case may be*

  ⇒ Will be corrected, thanks for this comment.

- *[line no. 127] A bit more motivation for this score is needed as it is not so common. A brief comment explaining its somewhat similar to using a pattern correlation would help clarify I think.*

  ⇒ Thanks. The TWS score has the advantage of considering only the similarity in shape of geopotential height fields, whatever the absolute height of the geopotential. The shape of the geopotential defines the flow direction which is relevant for precipitation, especially in mountainous regions (Blanchet et al., 2021; Horton et al., 2012). This score is widely employed in the analog method to reconstruct precipitation based on analogy in geopotential height fields (Daoud et al., 2016; Marty et al., 2012; Wetterhall et al., 2005). We will highlight the relevance of the score for precipitation and we will cite these references.

- *[line no. 130] I believe I have worked out this equation now – it is a normalised sum of differences in meridional and zonal gradients at all gridpoints between 2 Z500 maps? Perhaps you could make this a bit clearer. Also 'horizontal and vertical directions' is misleading, and implies different pressure levels are being considered. 'meridional and zonal directions' would be more precise.*

  ⇒ Thanks for this comment. You're right, that's exactly what the TWS score represents. We will take your suggestions into account to clarify the description of the score.

- *[Figure 1b] You should make it clear that the black lines are showing trajectories in phase space.*

  ⇒ Will be corrected, thanks.

- *[line no. 134] 'celerity that is understood as the celerity of deformation...' This is tautological. I suggest 'the speed of deformation' or 'rate of deformation'.*

  ⇒ Will be corrected, thanks for this comment.

- *[line no. 155] 'Even more resembling than usually' is incorrect. I suggest 'Even more similar than usual'. Same for similar errors on lines 308 and 390.*

  ⇒ Will be corrected, thanks for this comment.

- *[line no. 176] 'got' is wrong, I suggest 'obtained'.*

  ⇒ Will be corrected, thanks.

- *[line no. 240] ‘Reduced quantity’ rather than ‘lower number’?*

  ⇒ Will be corrected, thanks.

- *[line no. 274] ‘found in ERA5’ rather than ‘thanks to ERA5’?*

  ⇒ We used "thanks to ERA5" because this reanalysis allows us to extend the analysis until 2019. But this is not essential to the sentence, so we will use "according to ERA5".

- *[Figure 5] ‘sup-periods’*

  ⇒ Will be corrected, thanks.

References

Blanc, A., Blanchet, J. and Creutin, J.-D. (2021a). Characterizing large-scale circulations driving extreme precipitation in the Northern French Alps, *International Journal of Climatology* .
URL: *https://doi.org/10.1002/joc.7254*

Blanc, A., Blanchet, J. and Creutin, J.-D. (2021b). Linking Large-Scale Circulation Descriptors to Precipitation Variability in the Northern French Alps, *Geophysical Research Letters* **48**(15): e2021GL093649.
URL: *https://doi.org/10.1029/2021GL093649*

Blanchet, J. and Creutin, J.-D. (2020). Explaining Rainfall Accumulations over Several Days in the French Alps Using Low-Dimensional Atmospheric Predictors Based on Analogy, *Journal of Applied Meteorology and Climatology* **59**(2): 237–250.
URL: *https://doi.org/10.1175/JAMC-D-19-0112.1*

Blanchet, J., Creutin, J.-D. and Blanc, A. (2021). Retreating winter and strengthening autumn Mediterranean influence on extreme precipitation in the Southwestern Alps over the last 60 years, *Environmental Research Letters* **16**(3): 034056.
URL: *https://doi.org/10.1088/1748-9326/abb5cd*

Blanchet, J., Stalla, S. and Creutin, J.-D. (2018). Analogy of multiday sequences of atmospheric circulation favoring large rainfall accumulation over the French Alps, *Atmospheric Science Letters* **19**(3): e809.
URL: *https://doi.org/10.1002/asl.809*

Daoud, A. B., Sauquet, E., Bontron, G., Obled, C. and Lang, M. (2016). Daily quantitative precipitation forecasts based on the analogue method: Improvements and application to a French large river basin, *Atmospheric Research* **169**: 147 – 159.
URL: *https://doi.org/10.1016/j.atmosres.2015.09.015*

Horton, P., Jaboyedoff, M., Metzger, R., Obled, C. and Marty, R. (2012). Spatial relationship between the atmospheric circulation and the precipitation measured in the western Swiss Alps by means of the analogue method, *Natural Hazards and Earth System Sciences* **12**: 777– 784.
URL: *https://doi.org/10.5194/nhess-12-777-2012*

Marty, R., Zin, I., Obled, C., Bontron, G. and Djerboua, A. (2012). Toward Real-Time Daily PQPF by an Analog Sorting Approach: Application to Flash-Flood Catchments, *Journal of Applied Meteorology and Climatology* **51**(3): 505–520.
URL: *https://doi.org/10.1175/JAMC-D-11-011.1*

Poli, P., Hersbach, H., Dee, D. P., Berrisford, P., Simmons, A. J., Vitart, F., Laloyaux, P., Tan, D. G. H., Peubey, C., Thépaut, J.-N., Trémolet, Y., Hólm, E. V., Bonavita, M., Isaksen, L. and Fisher, M. (2016). ERA-20C: An Atmospheric Reanalysis of the Twentieth Century, *Journal of Climate* **29**(11): 4083–4097.
URL: *https://doi.org/10.1175/JCLI-D-15-0556.1*

Sodemann, H. and Zubler, E. (2010). Seasonal and inter-annual variability of the moisture sources for Alpine precipitation during 1995–2002, *International Journal of Climatology* **30**(7): 947–961.
URL: *https://doi.org/10.1002/joc.1932*

Wetterhall, F., Halldin, S. and yu Xu, C. (2005). Statistical precipitation downscaling in central Sweden with the analogue method, *Journal of Hydrology* **306**(1): 174 – 190.
URL: *https://doi.org/10.1016/j.jhydrol.2004.09.008*