

Reply to reviewer 1

Review in black, reply to the reviewer in blue, changes in the manuscript in green

This particularly fascinating article proposes to go back 600 years in the past of Europe in order to identify, using proxy and instrumental data, reanalyses, and numerical simulations, whether the combination of certain spring weather / climate conditions is, significantly, heralding hot summers (a terribly topical subject!).

Given the quality of this work, I have no negative criticism to make. I would just like to ask a few questions and propose some suggestions to the authors, which may possibly improve the understanding of certain points and results that seem particularly interesting to me.

1) Would it be possible to specify what is the influence of the climatic context of the Little Ice Age (and its more or less severe / attenuated internal oscillations) on the frequency of atmospheric circulation types and their manifestations in terms of weather conditions highlighted in this study?

- NAO+ and NAO- phases;
- blocking patterns;
- occurrence of megadrought events.

If the Little Ice Age (LIA) is seen as a low-frequency climatic anomaly, then there should not be a dependence since our analyses are based on high-pass filtered data. Furthermore, extreme summer droughts can be traced back to 1252, i.e. before the start of the LIA around 1350. However, the LIA was also a period with more frequent volcanic eruptions. They can lead to cool summers, which is an additional forcing unrelated to winter-spring precipitation. This is captured in the regression model used.

The NAO (for which we have many reconstructions, including ModeE-RA) shows a cluster with negative values in the second half of the 17th century, but overall does not exhibit a particular behaviour during the LIA. For blocking this is more difficult as our reconstructions do not allow analysing centennial scale changes. Note that both the NAO and blocking are relevant mainly for the cold-season circulation.

To address the link to the LIA, we introduce it in the Introduction:

“We thus cover the Little Ice Age (LIA) as well as the transition to the era of anthropogenically caused global warming.”

Then we discuss the results in the light of the LIA mainly in the Discussion section.

“No direct connection to the LIA is seen. Extreme summer droughts can be traced back to 1252, i.e. before the start of the LIA around 1350. However, the LIA was also a period with more frequent volcanic eruptions, which cause cool summers due to direct forcing unrelated to winter-spring precipitation. This could make the composite statistics worse, but is included in the regression model. The NAO showed a cluster with negative values in the second half of the 17th century, but overall does not exhibit a particular behaviour during the LIA, neither do EA or SCA (Brönnimann et al., 2024) or the jet indices.”

Brönnimann, S., Filipiak, J., Chen, S., and Pfister, L.: The weather of 1740, the coldest year in central Europe in 600 years, *Clim. Past*, 20, 2219–2235, <https://doi.org/10.5194/cp-20-2219-2024>, 2024.

As to megadroughts, we cite Cook in the paper as to the 15th century dry period. We now also add the “megadrought” around 1800 from the same paper: “They also address the period around 1800 as a megadrought.”

2) Climatic conditions (interannual variability and multi-year alternately warm / cool oscillations) and atmospheric circulation that occurred during the transition between the end of the Little Ice Age and the period of contemporary global warming, did they influence certain results?

The last phase of the LIA was strongly affected by a series of volcanic eruptions in the early 19th century, to which the Earth system reacted strongly and perhaps with delayed effects. Volcanic activity remained high throughout the 19th and early 20th century. The transition to the modern period of global warming therefore was a continuation of volcanic forcing and slow recovery from the cluster of eruptions in the early 19th century. We add the following sentence to the discussion:

“The last phase of the LIA was caused by a series of volcanic eruptions in the early 19th century, to which the Earth system reacted strongly (Brönnimann et al. 2019). The following decades might still have been characterized by recovery, while volcanic activity remained high throughout the 19th and early 20th century. There are no notable dry-spring-hot-summer events in this period.”

Brönnimann, S., J. Franke, S. U. Nussbaumer, H. J. Zumbühl, D. Steiner, M. Trachsel, G. C. Hegerl, A. Schurer, M. Worni, A. Malik, J. Flückiger, and C. C. Raible (2019) Last phase of the Little Ice Age forced by volcanic eruptions. *Nature Geoscience*, **12**, 650-656

3) Possibility of an influence of the type of data used and analyzed on the results?

Compared to proxy data, what impacts and what importance could have precisely the measurements carried out from the seventeenth century onwards and their development (increasingly numerous across Europe) over the following centuries, in the analyses and on the results obtained in this work?

The reviewer is right that we try to rely on measurements as much as possible. We have no alternative (e.g., tree-ring only) within our reconstruction family. From the late 17th century onwards, mega-droughts can potentially be identified on the basis of temperature and precipitation measurements, initially in Paris (Rousseau, 2022; Pliemon et al., 2023; Slonosky, 2002) and soon afterwards in other regions. The main impact of the increasing number of measurements is an increase in the reconstruction skill, along with a decrease in the reconstruction spread. The influence of the prior (i.e. the model simulations ModE-Sim) becomes weaker.

We add the following sentence to the Methods: “From the late 17th century onward, ModE-RA is increasingly using measurements, leading to an increase in the reconstruction skill (a decrease in the ensemble spread), while the influence of the prior (i.e. the model simulations ModE-Sim) becomes weaker.”

4) Among the questions asked by the authors themselves about highlighting characteristics specific to South-Eastern Europe climatology in the interpretation and understanding of the results, maybe the classification of atmospheric circulation patterns used in this work is not precise enough? If the classification used is relevant at the scale of the European continent, it is probably less so at smaller scales. Would the use of a more detailed classification such as that of Hess-Brezowsky circulation types (Großwetterlagen), if possible in the context of this work, be better suited to this regional scale?

Yes, the addition of a specific south-eastern European weather type classification would be beneficial, but we do not have that. In our paper we used the specific CAP9 weather types for Switzerland back to 1728. The only alternative we have are the Lamb weather types back to 1781, but they also do not specifically cover southeastern Europe.

In the revised paper, we add a sentence in the discussion section: “To further study the interaction over southeastern Europe it would be useful to have long reconstructions of daily weather types over this region, or types relevant for entire Europe. Our blocking reconstruction is based on Swiss weather types and may not well capture southeastern Europe.”

Reply to reviewer 2

Review in black, reply to the reviewer in blue, changes in the manuscript in green

Review of ‘Historical climate extremes in Europe and the connection between spring precipitation and summer heat’ submitted to *Climate of the Past*.

The manuscript is well written and clear, and the scientific significance of its content and outputs fits the scope of *Climate of the Past*. The topic is of paramount concern and importance. The methodology is adequate and explained to ensure traceability and reproducibility. The figures and supplementary materials are of adequate quality and quantity.

Minor comments and suggestions are provided below:

1. Introduction

The authors give proper credit to related work and clearly indicate their own contributions by citing prior studies to support their arguments. However, further information is required for clarity to inform an international and/or non-expert readership of the manuscript:

1. Why is this study important?
2. Mention compound events and why they are important.
3. It would be great to provide references on long-term trends and projections of spring & summer precipitation and summer heat waves; linking past and future.
4. Expand why you have selected these specific historical extremes as case studies (e.g. what makes them stand out in the long record).

Thanks for the comment.

We rephrase the introduction by first referring to this current summer in the second sentence:

“The latest example is 2026, when numerous heat records were broken across Europe after a very dry spring.” and later point more to the relevance of the study, including compound events

“Studying this connection is relevant for understanding climate variability and change, but also for seasonal forecasting. Often compound heat and drought events develop as the summer starts from an already low water balance.”

We also add information on the trend in projected future precipitation from EURO-CORDEX, but we add this to the discussion rather than the introduction:

“For the future, according to the EURO-CORDEX simulations, precipitation will likely increase in the north and decrease in the south of Europe with the zero line shifting north from winter to summer. Southeastern Europe, which was identified as a key area, is likely to see an increase in precipitation in winter and spring (e.g., Ivušić et al. 2024), whereas Europe south of ca. 50° N will suffer from a decrease in summer precipitation.”

Ivušić, S., Güttler, I. & Horvath, K. Overview of mean and extreme precipitation climate changes across the Dinaric Alps in the latest EURO-CORDEX ensemble. *Clim Dyn* **62**, 10785–10815 (2024).
<https://doi.org/10.1007/s00382-024-07476-9>

As to the selection of cases for the Appendix, this included outstanding events that are well documented.

2.2. Documentary data

Lines 110 – 111: “In the English countryside, spring was perceived as an event rather than a season.”
Why? Expand and provide references.

The reference is at the end of this section: Pribyl and Cornes (2020).

Pribyl, K. and Cornes, R.C. , 2020: Droughts in medieval and early modern England, part 1: The evidence. *Weather*, 75: 168-172. <https://doi.org/10.1002/wea.3599> (10th Aug 2026)

2.3. Methods

Line 124: Rephrase as ‘Atlas of European climate extremes since 1421’.

Done.

2.3.2 Seasonal precipitation and temperature

Justify and/or present references for why you have chosen precipitation anomalies below the 10th percentile and temperature anomalies above the 90th percentile (e.g., the significance of the impacts of these extremes).

We add the following text to the methods section:

“A threshold of 10 percent means we are selecting a one-in-ten year event. This is an often-used threshold, including in the IPCC (2021) report. It corresponds very roughly to a 1.5 °C warmer summer or a winter-spring season with 30% less precipitation. These are relevant anomalies, while at the same time the sample is large and reconstruction quality good.”

2.3.3 Atmospheric circulation

Provide references for the data used.

We add the reference to Valler et al. (2024) – it is the same data set as the precipitation and temperature analysis described in the previous section.

It would be great to have a brief explanation of the importance of the NAO, the East Atlantic pattern, the Scandinavian pattern, and the three indices of the jet stream over the Atlantic-European sector.

We added a sentence with references on why the NAO, the East Atlantic pattern, the Scandinavian pattern are important:

“These patterns have been shown to be relevant both for winter-spring precipitation and summer drought in Europe (e.g., Wang et al., 2011, Halifa-Marín et al., 2025)”.

As to the jet indices, we refer to our previous paper from which we took the jet indices, where we found a strong relation between jet latitude and drought. We add the remark “especially jet latitude was shown to be strongly associated with summer drought”.

Halifa-Marín, A., M. A. Torres-Vázquez, R. Trigo, et al. 2025. “Beyond the NAO: The East Atlantic Pattern's Role in Early 20th-Century Meteorological Droughts in Western Europe.” *International Journal of Climatology* 45, no. 13: e70045. <https://doi.org/10.1002/joc.70045>.

Line 171: “We then used a regression approach to predict JJA 2 m temperature from spring predictors.”
Provide references (e.g., a statistical textbook) to ensure reproducibility for other researchers.

Thanks, we added a reference to Wilks, D. S. (2020) *Statistical Methods in the Atmospheric Sciences*, Fourth Edition. Elsevier.

Line 177: Same comment as above; please provide a reference.

We added the same reference also there.

Further results suggestion:

It would be interesting to reference the Little Ice Age to see how the frequency and characteristics of events have changed over time and to link this to the ‘Appendix: Documentary data for hot summers that followed dry springs’.

Reviewer 1 had a similar comment. We do not think that there is a relation to the Little Ice Age. However, we added some information on this to the discussion.

“No direct connection to the LIA is seen. Extreme summer droughts can be traced back to 1252, i.e. before the start of the LIA around 1350. However, the LIA was also a period with more frequent volcanic eruptions, which cause cool summers due to direct forcing unrelated to winter-spring precipitation. This could make the composite statistics worse, but is included in the regression model. The NAO showed a cluster with negative values in the second half of the 17th century, but overall does not exhibit a particular behaviour during the LIA, neither do EA or SCA (Brönnimann et al., 2024) or the jet indices (Brönnimann et al. 2025).”

Brönnimann, S., Filipiak, J., Chen, S., and Pfister, L.: The weather of 1740, the coldest year in central Europe in 600 years, *Clim. Past*, 20, 2219–2235, <https://doi.org/10.5194/cp-20-2219-2024>, 2024.

It would be interesting to include a figure that illustrates or presents original documentary data to highlight the impacts associated with one of the historical case studies (e.g., a painting, illustration, manuscript, or newspaper).

We added a figure to the Appendix showing an excerpt of a text from vine-grower Hans Stolz in Guebwiller (Alsace, France) about the severe drought and its impacts in 1540.

Stolz, W., *Die Hans Stolz'sche Gebweilet Chronik. Zeugenbericht über den Bauernkrieg am Oberrhein*. Stolz, Freiburg 1979. [no ISBN available].

Discussion and conclusion

This section must be expanded. What is the importance of these findings?

Thanks. In the revised paper we come back to the relevance statements made in the Introduction and take them up again. We also follow up on the heat summer of 2026, which was preceded by a dry spring as was mentioned in the Introduction. Here we also refer to a figure of spring precipitation anomalies and summer temperature anomalies in 2026 (ERA5, relative to 1991-2020), which we append this to the Atlas. Furthermore, we refer to the possible future changes in precipitation. In addition to the discussion of the LIA (see above), we added the text:

“Establishing the relation between a winter-spring precipitation deficit and summer heat is relevant for understanding climate variability and change, as the most recent summer of 2026 has demonstrated. The Europe-wide spring precipitation deficit, also covering southeastern Europe, was followed by an exceptionally hot summer in Western and Central Europe (a figure showing the anomalies in ERA5 with respect to 1991-2020 is appended to the Atlas). In this case, as in most others, the summer heat was accompanied by a lack of rainfall, thus exacerbating the already low water balance and leading to severe compound heat and drought. For the future, according to the EURO-CORDEX simulations, precipitation will likely increase in the north and decrease in the south of Europe with the zero line shifting north from winter to summer. Southeastern Europe, which was identified as a key area, is likely to see an increase in precipitation in winter and spring (e.g., Ivušić et al. 2024), whereas Europe south of ca. 50° N will suffer from a decrease in summer precipitation.”

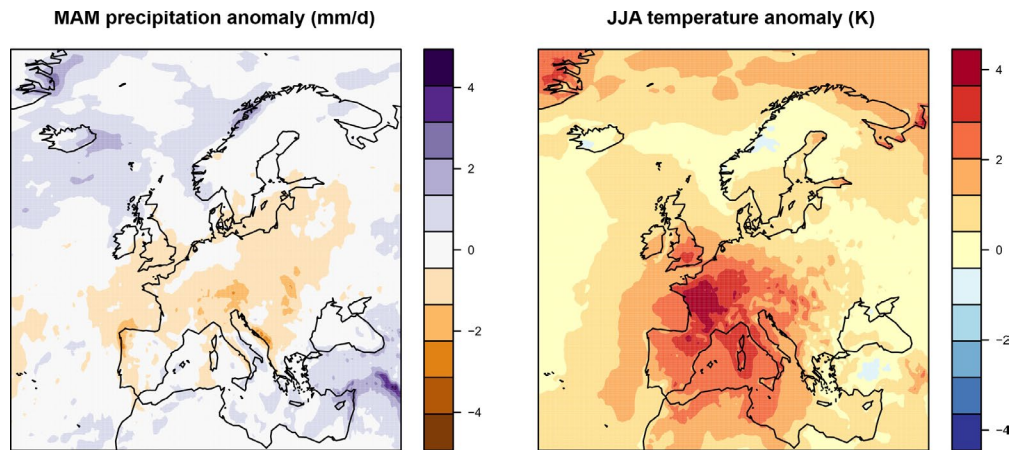


Figure appended to Atlas: Anomalies of MAM precipitation and JJA temperature in ERA5 in 2026 relative to 1991-2020 (JJA 2026 uses data until 22 August and is extrapolated with climatology).

Furthermore, the section is also expanded due to the comments of Reviewer 1.

Lines 382-383: “We find a link between dry springs and warm summers in climate reconstructions, consistent with other studies.” Provide examples of previous studies/references.

Thanks, we added several references: “(e.g., Vautard et al., 2007; Fischer et al., 2007; Seneviratne et al., 2010; Rousi et al., 2023; Böhnisch et al., 2024, Padro et al., 2024)”.