

REVIEWER #1

General comments

This paper discusses a new method for creating a monthly paleoclimate reconstruction by assimilating precipitation data in the form of monthly precipitation accumulation or number of wet days per month. Experiments are performed over a 55-year time period. Performance is judged relative to a separate gridded reconstruction, and results are compared with a model-only simulation and with a reconstruction created by assimilating only the conventional observations of temperature and pressure. While there are some mixed results, the overall conclusion is that this method would be worthwhile to continue pursuing. I am particularly interested in one of the final statements in the conclusions regarding limiting the effects of precipitation on assimilation, presumably to decrease the influence of precipitation when sea level pressure or temperature observations are dense, with an asymmetric localization function. Overall, the paper is clear and concise. The methods are explained well and the results are shown clearly. I have only minor scientific and technical comments.

We thank the Reviewer for the careful revision of the manuscript and for improving the English of the manuscript. We will follow his/her recommendations to clarify the specified cases.

Specific comments

1. Lines 40-43: Could you give some quantification of what a “dense network” is in this context?

Based on the correlation figures in the paper by Gómez-Navarro et al. (2015) high correlations (>0.8) are found close to the pseudoproxies which drop to values <0.2 within a few hundred kilometers with seasonal dependency. We will add these information in the revised version of the manuscript.

The localization length scale parameter of precipitation (450 km) that is used in this study and was previously calculated by Franke et al. (2017) is in agreement with the findings of Gómez-Navarro et al. (2015).

2. Line 50: A short discussion of the necessary density of proxies for successful reconstruction here would help to link with the previous paragraph.

The EKF400 atmospheric paleo-reanalysis (EKF400; Franke et al., 2017) predominantly shows skill over the Northern Hemisphere land areas, in the vicinity (up to a few thousand kilometers) of assimilated data. However, in regions where no observations are available the reconstructions are identical to the model simulations.

We will add more details concerning the area in which skillful reconstruction can be expected such as a few thousand kms in case of temperature and sea-level pressure and a few hundred kms in case of precipitation.

3. Line 157-158: Why did you choose this order to assimilate observations (temperature, then pressure, then precipitation)?

The reviewer is correct because the order in which the observations are assimilated may influence the results in the case of serial assimilation with localization. We kept the same assimilation order used in previous reconstruction (Franke et al, 2017), that is assimilating temperature data first then pressure measurements. We assimilated precipitation data last due to the bigger uncertainties characterizing precipitation measurements. Precipitation data also affect the reconstruction within a smaller region. A similar procedure was applied in the generation of the 20CRv3 (Slivinski et al., 2019).

4. End of sections 4.1 and/or 5.1: It might be worthwhile to discuss the tradeoffs in more detail. When precipitation is assimilated, is the improvement in precipitation skill worth the loss of skill in SLP and temperature?

We agree with the reviewer that it is an important question. Ideally we would like to avoid or minimize the negative effect of assimilating precipitation information and our results suggest that assimilating the number of wet days is preferable compared to assimilating precipitation amounts, especially in summer. In future experiments, in order to reduce the negative impact of assimilating precipitation information on other reconstructed fields (e.g., sea-level pressure), the effect of ignoring/limiting its cross-covariance updates will be tested. We will discuss in more detail how the assimilation of precipitation affects the reconstruction skill in the presented experiments.

5. Section 4.2 and related figures: It may be useful to add the observation locations from 20CRv3 to Figure 7 so that the reader has an idea of what the observational network looks like in 1842 over Europe.

We will add the location of available observations to Figure 7 in the first column, the 7 time series from GHCN and the observations from ISPDv4.7 used in 20CRv3.

In addition, it would be useful to mention that the 20CRv3 analysis is an ensemble mean, and thus comes with an ensemble spread that can provide an idea of the confidence in the reanalysis at any time and location. It could be useful to add maps showing this spread, or at least add the observation locations to Fig 7 along with a few sentences noting that the reanalysis will be less reliable in locations with no observations, than in regions of dense observations.

Thank you for the recommendation. We will extend the description of 20CRv3 as suggested.

Finally, Figures 7 and S7 might be clearer if difference fields are shown. As it is, the reader is left to judge by eye which of the experiments matches the reanalysis or reconstruction best.

We will add additional figures showing the differences.

Technical corrections

The suggested technical corrections will be applied.

1. Line 34: “fist” should be “first”
2. Line 48: change to “...based on the covariances between the observed and unobserved variables.”
3. Line 50: “such as” should be “in the form of”
4. Line 57: “other” should be “others”
5. line 87: “change to ...with a correlation function that decreases as distance increases”
6. line 104: maybe replace “rains” with “drizzles”, since light precipitation is overestimated.
7. Line 117: replace “considered as a wet day” with “considered wet days”)
8. Line 126: change to “...using the following procedure for both precipitation amounts and wet days:”
9. Line 129: replace “precipitation and wet days” with “station”
10. Line 139 should be “If more than one station is available...”
11. Line 149: “A set of experiments was conducted...”
12. Line 170: Please add: “In 20CRv3 only pressure measurements are assimilated into a model with prescribed sea surface temperatures, sea ice concentrations, and radiative forcings.”
Also, could you expand on what “globally 39 observations data” means? Are there 39 distinct observation locations in 1842, or are there 39 instantaneous pressure reports within all of 1842? D

A sentence concerning assimilated observations in 20CRv3 was added: In 1842 data are available from 39 distinct locations.

13. Line 172: please replace “besides” with “In addition,”
14. Line 181: Is CRU TS3.10 completely independent from the experiments or does it use some of the same data?

The CRU TS3.10 dataset is not completely independent from the experiments, since there is an overlap between e.g., the assimilated temperature data and the temperature data used in the CRU TS3.10 dataset. However, for instance when only the number of wet days are assimilated the reconstructed temperature field is completely independent from the CRU TS3.10 temperature field.

15. Line 183 to 185: maybe change to “In Section 4.1, we show the differences between the correlations calculated from...”

16. Line 186: change “skills” to “skill”

17. Line 189-190: change to “on the anomalies from the...”

18. Line 197: remove “season”

19. Line 229-230: Change “increased localization” to “increased localization distance” or “decreased localization”, since localization itself usually refers to the method of limiting spurious correlations.

20. Lines 240-242 are unclear as written; maybe change to “The regions over central South America and South Africa that were negatively affected in the exp_W experiment show worsening skill in the exp_W_2L experiment (Fig. S4).”

21. Line 245: remove “as it should be done in the real application of the method in the future”, or describe what you mean by “real application”.

22. Line 249: change “besides not assimilating” to “except that it does not assimilate”

23. Line 251: add “...the skill of the exp_TPR and exp_TPW analyses are compared...”

In line 151, we already mention that both experiments are compare to exp_TP. “In the case of exp_TPR and exp_TPW experiments, the xf is replaced with the ensemble mean of the analysis from the exp_TP experiment.”

We added it again when the discussion of exp_TPW starts in line 262: “The experiment was repeated with the number of wet days added instead of precipitation amounts (exp_TPW)” and similarly as a reference the exp_TP experiment was used.

24. Line 296: change “weather forecast” to “weather forecasting”

25. Line 298: change “in some data assimilation methods” to “for many data assimilation methods”

26. Line 299: change “normality” to “Gaussian”.

27. Line 303: add a reference for the Shapiro Wilk test. Which ensemble was this test performed on?

We added the reference: DS Wilks (2011) - Statistical Methods in the Atmospheric Sciences It was performed on the model ensemble.

28. Line 307: Add “The hypothesis of normality in the number of wet days...”
29. Line 310: maybe add “...to be assimilated successfully.”?
30. Line 322: change “for example” to “such as”
31. Line 327: change “using the number...” to “assimilating the number...”
32. Line 335: change to “Assimilating precipitation amount or the number of wet days has a small impact...”
33. Line 343: add “assimilating precipitation amounts... performs worse than assimilating wet days...”
34. Figures S.1-S.2: Are the columns different months? Please label.

We will add the labels.