

Interactive comment on “Changing correlation structures of the Northern Hemisphere atmospheric circulation from 1000 to 2100 AD” by C. C. Raible et al.

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Review response to review of SJ Phipps

General comments

This manuscript studies the stability of spatial teleconnection patterns within the Northern Hemisphere, using a combination of reanalysis data and climate model simulations. The authors find that significant shifts take place in the centres of action of the North Atlantic Oscillation and the Pacific North American pattern, apparently as a result of natural internal climate variability. These findings challenge the assumption of station-

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arity that underlies the use of palaeoclimate proxies to reconstruct past changes in atmospheric modes. The manuscript tackles a crucial question in palaeoclimatology – that of the stability of teleconnections. It is clearly within the scope of *Climate of the Past*, and makes a significant contribution towards our understanding of the stability of teleconnection patterns. The methods are appropriate and the presentation is generally clear. There is, however, some potential to polish the English language and grammar; I make some specific suggestions in this regard below. I recommend that the manuscript be published in *Climate of the Past*, subject to the authors considering the following comments.

Specific comments

1. P4989, L11: This sentence implies that different teleconnection patterns are found in the Northern Hemisphere only. Perhaps it could say something like “However, teleconnection patterns can also consist of two or more anti-correlated centres of action” instead.

Changed to:

“Teleconnection patterns can also consist of two or more anti-correlated centres of action. For the Northern Hemisphere, different teleconnection patterns are identified. Among others the most important ones of the Northern Hemisphere for boreal winter are the North Atlantic Oscillation (NAO) and the Pacific North America (PNA) patterns . . .”

2. P4993, L19-20: How is this achieved? This is explained in the caption of Figure 1, but it would be better to explain it here.

We included the following in the text:

“The external forcing is slightly different from the CCSM3 simulation (Fig. 1). The greenhouse gas forcing of the transient ECHO-G simulations is based on slightly older reconstructions. The volcanic forcing is only included as total solar irradiance changes; thus it only takes the direct shortwave effect of volcanic eruptions into account.”

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3. P4994: The authors should provide further information on the teleconnectivity maps developed by Wallace and Gutzler (1981). I had to read this paper before I could understand the figures in the current manuscript, particularly the derivation and meaning of the arrows. This should not be necessary, and the manuscript would benefit from a longer description of this technique at the start of Section 3.

The teleconnectivity is better explained, as suggested. Therefore we include the following:

“These axes are identified using a one-point correlation technique, i.e., correlating a centre of action with the Z500 field and searching the point which delivered the strongest negative correlation.”

4. P4994: I can see no explicit statement that the authors analyse data for the Northern Hemisphere. This is obvious from the figures, and perhaps from the title and introduction too, but it should be explicitly stated at the start of Section 3.

To clarify this we start the section with:

“In this section teleconnection patterns of the Northern Hemisphere are investigated. Therefore, we first compare the long-term mean behaviour. . .”

5. P4994, L21: Figure 2 should be referenced at the end of this sentence.

Done as suggested.

6. P4995, L15: Is this agreement relative to the full period, or only to 1971-2000?

For the Pacific the teleconnection patterns are similar when using the full period or 1971-2000. To clarify this we added the following:

“The simulated teleconnectivity maps of the control experiments exhibit agreement over the Pacific and Siberia with the observed pattern of the full period (1871-2008) and the recent period 1971-2000 (Fig. 2c,d). ”

7. P4995, L21-22: True, but the teleconnections generally become much weaker. This should be stated.

This is now stated:

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“The transient experiments of each model configuration resemble the biases of the Ctrl experiments and their strengths of anti-correlation generally become much weaker. Thus...”

8. Section 3.2: This is too long to be a single subsection: it currently consists of more than four pages of continuous text. I would suggest breaking it into at least two subsections, perhaps beginning a new subsection after line 8 on page 4998.

We agree with this suggestion and separated the subsection. The new subsection 3.3 is entitled “Spatial differences of teleconnection patterns”.

9. P4995, L27: The authors could clarify by stating “... change in the strength and spatial pattern of correlations structures ...”.

Done as suggested.

10. P4996, L17: From Figure 3a, I’m not sure if I agree with this statement. To me, it is the period 1971-2000 that appears to be anomalous.

This was maybe not fully clear. The important point is that the pattern correlation is a rather strict measure to compare fields. Thus, we would not expect that the pattern of 1971-2000 will have a correspondence ever in observations or simulations as just small changes of the field will reduce the pattern correlation. We tested this by selecting other periods (either in observations or in the simulations) and one never finds a full agreement ($r \sim 1$). Note that the comparison to the ensemble members of TCR does not result in a pattern correlation of one (grey line in Fig 3 and 4 in the revised version of the manuscript) and the pattern correlation to a different reanalysis product is also reduced to roughly 0.95 (see Fig. 2 in this response). Therefore due to the measure selected each period will be somehow anomalous in Fig. 3. To clarify this we included a discussion about the range of pattern correlation where the pattern correlation coefficients are significant at the 1% level. Given the reduction of the degrees of freedom (due to the high autocorrelation of the field, leading to roughly 19 degrees of freedom (DoF) for the Atlantic and roughly 12 DoF the Pacific) we estimate that

the correlations must be above $r = 0.53$ for the Atlantic and above $r = 0.65$ to be significant (or in other words that both patterns agree). Thus if the pattern correlation goes below these values, we interpret these pattern to be different. This is now included in the manuscript.

11. P4996, L28: Negative values are not shown in Figure 3, so the range of values spanned by CCSM3 cannot be determined by the reader.

This is correct; we now show the full range.

12. P4997, L1: ...relative to the 1971-2000 baseline.

Done as suggested.

13. P4997, L17-19: This sentence is not clear to me. Could the authors please clarify? ***This part is rewritten and the results are now shown in Fig 3 and 4. We analysed the ensemble members of TCR separately and then took the ensemble mean of the pattern correlation. This is compared to when we just use the ensemble mean of TCR and then apply the analysis to this data. One could see that there is a difference between the two ensemble means prior to year 1915, which we attribute to the fact that prior to this year the reanalysis data is not well constraint in the TCR for the Pacific (which is not surprising as there a nearly no surface pressure data available during the early period, see Compo et al. 2011).***

14. P4997, L22: This is the first reference in the manuscript to the fact that this period is more reliable. Perhaps this should be stated earlier? Also, given this fact, perhaps it would be useful to show the teleconnectivity map for this period in Figure 2 – does it differ much from the map for the full period?

The change in reliability is only an issue for the North Pacific and not for the Atlantic as the TCR is better constraint in the Atlantic due to better data coverage than over the Pacific. Therefore we think this should be stated here and not earlier. In a way it is one result of our study that for our analysis the data prior to 1915 are not reliable for the Pacific. We hope that with our response to point

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13 this is clarified. We tested also the shorter period for Fig 2b and there only minor differences, please see Fig. 1 in this response(at the end of the responses). Therefore we decided to show the full period.

15. P4997, L28: ...relative to the 1971-2000 baseline.

Done as suggested.

16. P4997, L7-8: What range of values did the authors try? How about 100 years, or 138 years – which is the same duration as the TCR?

We guess the reviewer mean page 4998. We tested up to 50 years. The reason for using a 30 yrs window is that this is the classical period defined by the WMO as climatological mean period and that some reconstructions (e.g. Luterbacher et al 2002) used NCEP reanalysis data to calibrate there reconstruction which is 45 yrs. Moreover using longer periods will focus on a different time scale (centennial) and from a statistical point of view we would have only ten independent periods in a millennium simulation.

We added the following at the beginning of the subsection:

“To investigate the time dependence of the teleconnection patterns on decadal to multi-decadal time scales, the teleconnectivity based on Z500 is deduced in using a 30-yr running window.”

17. P4997, L11-15: This sentence is not clear to me. Could the authors please clarify?

We guess the reviewer mean page 4998. We clarified the description of the composite analysis used:

“Therefore, the time series of pattern correlation are used as an index. If this index exceeds two standard deviations, the corresponding teleconnectivity maps are selected and averaged in order to obtain the mean teleconnectivity map, which shows the closest agreement with the 1971-2000 baseline. If the index is below two standard deviations, the mean teleconnectivity map illustrates the pattern, which disagrees with the reference pattern of 1971-2000.”

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18. P4999, L10-11: I don't see this shift from Figure 5d. If anything, there is a northward shift in CCSM3?

We find in CCSM3 also a pattern in the western part of the North Atlantic. However we agree with the reviewer and mention that the southern centre is shifted northward:

“CCSM3 simulates the western shift of the NAO-type pattern, however the southern centre of this western pattern is shifted northwards with respect to Fig 5b. Moreover, CCSM3 does not show the pattern over Europe.”

19. P4999, L24: Could the authors clarify exactly how the period 1915-1944 was chosen?

The period was chosen as it shows the lowest pattern correlation with respect to the 1971-2000 baseline for the Pacific area. Fig. 4a shows that in earlier periods we find lower pattern correlation however this part is not reliable (see also comment 13/14).

We added the following:

“The observed disagreeing period is from 1915 to 1944 AD where lowest pattern correlation is found for the reliable period 1915-2008 (Fig. 4a). The corresponding teleconnectivity (Fig. 6) exhibits a . . .”

20. Section 4: I consider that the analysis in this section could be achieved using an alternative methodology that would be both simpler and clearer. Currently the authors define two hypothetical new indices (WADP and AWAVE), based on the dominant teleconnection patterns during the period 1940-1969. They then derive correlation maps for these indices, and compare them with the correlation maps for different indices (NAO and PNA) and a different period (1971-2000). However, this does not reflect the manner in which proxies are used to reconstruct atmospheric modes. Proxies are used to reconstruct the evolution of a specific mode over time, not to reconstruct the dominant mode at all points in time. Hence, I suggest that the authors restrict themselves to using just the NAO and PNA, and then compare the correlation maps for these two

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indices for the periods 1940-1969 and 1971-2000. The differences between these two correlation maps would still demonstrate regions where the sign of the teleconnection has changed over time. However, these changes could now be directly related to the use of proxies to reconstruct known climate modes (the NAO and PNA). This would also avoid the need the authors to invent arbitrary new indices, which I consider to be strongly undesirable.

Since both reviewers address this issue, we completely revised this section to hopefully make our ideas clearer. At the example of the NAO: the correlation maps for NAO are quite robust, as proxies can pick up the dipole structure of the NAO relatively easy. We wouldn't be the first to show this. However, when one restricts him/herself to reconstructing one specific mode like the NAO, then one will always "find" the NAO, even when it was not the dominant mode (as in our disagreement period). Given the evidence that is accumulating for multi-decadal mobility of the teleconnections, it is worth considering other modes that, together with the NAO, provide a more comprehensive picture of atmospheric circulation. Knowing that the dominant mode can change and with that the proxies' relation to the dominant mode illustrates the limitations of the proxies. They will always reconstruct what one tells them to reconstruct. However, knowing the dominant mode during a period in the past would offer more opportunities to correctly interpret other proxies that sit outside the correlation centres. Unfortunately, determining the dominant mode from the currently available proxies is still impossible.

Considering our definition of new indices (which we decided to keep): our WADP is largely congruent with the BWA index (Shabbar et al. 1997), as rightly pointed out by G. Moore, so we adapted the name. The AWAVE is an upper-troposphere structure with a surface pressure signature that is not equivalent barotropic. Nevertheless, we are able to show that it explains significant parts of continental climate variability and therefore proves useful. The shifted PNA is closely related to the classical PNA (with only one of its four nodes significantly shifted), there-

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fore it is not really a new index. Hence, we refrain from introducing a new name for this pattern.

21. P5000, L23-25: How is the index derived from these two time series: addition? Subtraction?

The formula is now included in the manuscript. The northern centre is subtracted from southern centre.

22. P5000, L26-27; P5001, L21-22 and L24-25: Format this text as equations, rather than inline.

Done as suggested.

23. P5001, L5-7: True, but this is not how proxies are used. It is the stability of the relationship with a specific mode that is important for the purposes of reconstruction.

See point 20 and the revised section 4.

24. P5001, L4-6: Do the authors know why this earlier study reached a contradictory conclusion?

We are not sure to which statement this question is related to. On page 5001 there is in our view no contradiction mentioned to another study. Maybe it relates to page 5003. The reason for the disagreement to Ulbrich and Christoph (1999) is hard to assess. Clearly they use a different technique and focus on shorter time scales (10 yrs). However our simulations do not show a systematic shift at the end of the 21st century. As to Ulbrich and Christoph (1999) only use one simulation and we only have a mini ensemble of three simulations from two different models we are rather cautious with our statement. Preliminary results from an analysis of CMIP5 indicates no systematic shift in the teleconnection pattern also in a larger model ensemble. We decided to clarify this:

“This contradicts earlier findings by Ulbrich and Christoph (1999) who suggested a north-eastwards shift of the NAO centers of action under greenhouse gas induced warming utilizing one simulation. As our analysis shows no systematic

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change the hypothesis by Ulbrich and Christoph (1999) is questionable. However, our ensemble of opportunity encompasses only three simulations for the A2 scenario, so a proper assessment of this needs further investigations in a wider pool of simulations such as CMIP5 (Taylor et al., 2012)."

25. P5003, L28: I don't think any of the analysis in the paper investigates whether or not proxies are able to determine the dominant mode, so I suggest removing these words.

True, but by definition a single proxy is unable to determine the dominant mode as it has no reference to the surface climate at other locations. To reconstruct the dominant mode one would require (i) a much denser proxy network that allows to robustly determine sign changes across a number of proxies along the concept shown in Figs. 7 and 8 in our first version of the paper or (ii) a robust gridded reconstruction of sea level pressure. As we do not provide this analysis in detail, we revised this section to reflect this (see also point 20).

26. P5004, L1-2: From Figures 7 and 8, this appears to be predominantly a consequence of the distribution of the proxies, rather than a consequence of a difference in the stability of the teleconnection patterns. I suggest wording this sentence more carefully.

We added a clarification that this is largely due to the proxy locations and does not allow to conclude on the stability of the teleconnection.

27. Figure 1: The radiative forcings in panel a are shown as anomalies. What baseline was used?

We added the reference period used:

“(a) Solar and equivalent CO₂ forcing anomalies (including CO₂, CH₄, and N₂O) with respect to mean of the period 1500-1899 and ...”

28. Figure 2: In panel a, should the arrow over Siberia be cyan, rather than red?

The colouring of the arrows is avoided in the revised figure, instead we denoted

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the name of the mode at the arrows.

29. Figure 3: I suggest plotting negative values as well.

Changed as suggested.

Technical corrections and suggested edits

P4988, L2: Replace “to understand” with “in understanding”.

Done.

P4988, L5-6: Replace “allows scrutinizing these concepts and assumptions” with “allows these concepts and assumptions to be scrutinised”.

Done.

ââ P4988, L11: Replace “center” with “centres” (note that Climate of the Past uses British English, and so “center” should also be “centre” throughout).

Done and we also checked for other expressions.

P4988, L14 and hereafter: Replace “in the period” with “during the period”.

Done.

P4989, L1: Replace “in” with “using”.

Done.

P4989, L4: Replace “are” with “have been”.

Done.

P4989, L16 and hereafter: Add “the” before “Azores”.

Done.

P4989, L24: Perhaps insert “interests of the” before “climate”.

Done.

P4989, L25: Replace “the last” with “recent”.

Done.

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P4989, L26: Replace “in” with “of”.

Done.

P4990, L11: Replace “reliable” with “reliably”.

Done.

P4990, L18: Remove “climate”.

Done.

P4990, L24: Insert “have” after “studies”.

Done.

P4990, L29: Insert “the” before “Central”.

Done.

P4991, L3: Insert “a” before “continuum”.

Done.

P4991, L11: Reverse the words “measure” and “teleconnectivity”.

Done.

P4991, L21: Replace “conclusive” with “concluding”.

Done.

P4992, L3: Replace “bases” with “is based on”.

Done.

P4992, L5 and hereafter: Remove “the” before “NCAR”.

Done.

P4992, L13: Perhaps insert “, a horizontal resolution of” before “T85”.

Done.

P4992, L25 and hereafter: Remove “the” before “CCSM3”.

Done.

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P4992, L16: Replace “condition” with “conditions”.

Done.

P4993, L10: Remove “over”.

Done.

P4993, L27: Remove the comma after “simulations”.

Done.

P4995, L27: Replace “hints” with “hint”.

Done.

P4996, L1: Replace “in” with “using”.

Done.

P4996, L9: Replace “shows” with “show”.

Done.

P4996, L10: Replace “deteriorate the correlation pattern” with “cause the correlation pattern to deteriorate”.

Done.

P4996, L23: Replace “a disagreeing” with “an anomalous”.

Done.

P4996, L26: Replace “problems to correctly simulate” with “deficiencies in their simulation of”.

Done.

P4996, L29: “indicates” would be better than “means”.

Done.

P4997, L24: Remove first instance of “the”.

Done.

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P4997, L26; Perhaps “support” would be better than “confirm”.

Done.

P4997, L7-8: Perhaps say “Moreover, the results are not sensitive to the window size.”.

We guess the reviewer means P4998. Done.

P4997, L11: Insert “an” before “index”.

We guess the reviewer means P4998. Done.

P4998, L20: Insert “is” before “the”, and remove “is” after “analysis”.

We changed to: “ If the absolute range of teleconnectivity is not strongly affected, the mean teleconnectivity pattern has a similar range as a single pattern of a 30 yr period. Only in this case is the application of a composite analysis trustworthy.”

P4999, L9: Insert “the” before “North”.

Done.

P4999, L10: Replace “resembles” with “resemble”.

Done.

P4999, L20: Replace “of” with “in”.

Done.

P4999, L24: Replace “disagreeing” with “anomalous”.

Done.

P5000, L5: Replace “favoring” with “favouring”; insert “the conclusion” before “that”.

Done.

P5000, L6: Replace “appear to be” with “are”.

Done.

P5002, L12: Replace “of” with “for”.

Done.

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P5002, L21: Replace “of under-representing” with “from under-representation of”.

Done.

P5002, L23: Do the authors mean “demonstrates” rather than “resembles”?

Yes, thank you for the suggestion.

P5003, L1: Insert “temporal” before “variability”.

Done.

P5003, L2; Perhaps insert “significantly” before “different”.

We would like to avoid the wording “significantly” as a reader could misinterpret it as statistically tested.

P5003, L15: Insert “the” before “Atlantic”.

Done.

P5003, L17: Replace “like” with “such as”.

Done.

P5003, L19-20: Replace “future research foci” with “to be the focus of future research”.

Done.

P5003, L28: Insert “us” after “allow”.

Done.

P5003, L29: Replace “how” with “what”.

Done.

Table 1: In the caption, “SRE” should be “SRES”; in the top row of the table, capitalise “forcing” and “model”.

Done.

Figure 1, caption: Insert “the” before “visible”.

Done.

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Figure 4, caption: Replace “1880-1909” with “1940-1969”; “(g,h)” should be in bold; the second instance of “(e,f)” should be “(i,j)”.

The reviewer probably means Fig 5. We applied the changes suggested.

Figure 6, caption: The reference period for panel b is also different from Figure 5.

Done.

Additional figures for the responses (please see next two pages)

Fig. 1: Comparison of teleconnectivity (based on Z500) for (a) the period 1871 -2008 and (b) the period 1915-2008 using TCR ensemble mean data. Please see also Fig. 2 in the revised version of the manuscript.

Fig. 2: Running spatial correlation time series using a 30 yr window and the reference teleconnectivity pattern (inset in Fig 3a or 4a in the revised manuscript) for (a) the Atlantic and (b) the Pacific. The correlation is estimated for the ensemble mean of TCR from 1871 to 2010 and ERA40 data. Please note that the y-axis has a different scale compared to Figs 3 and 4 in the revised version of the manuscript.

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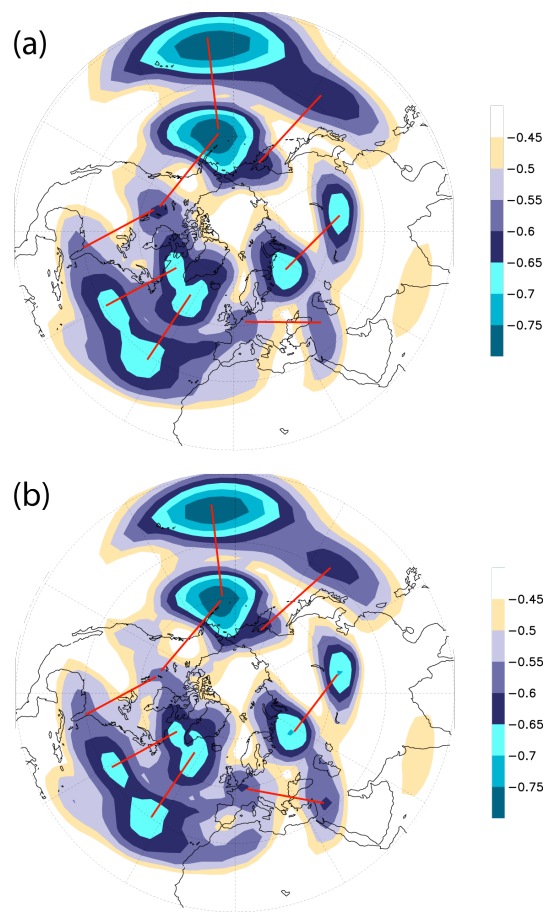
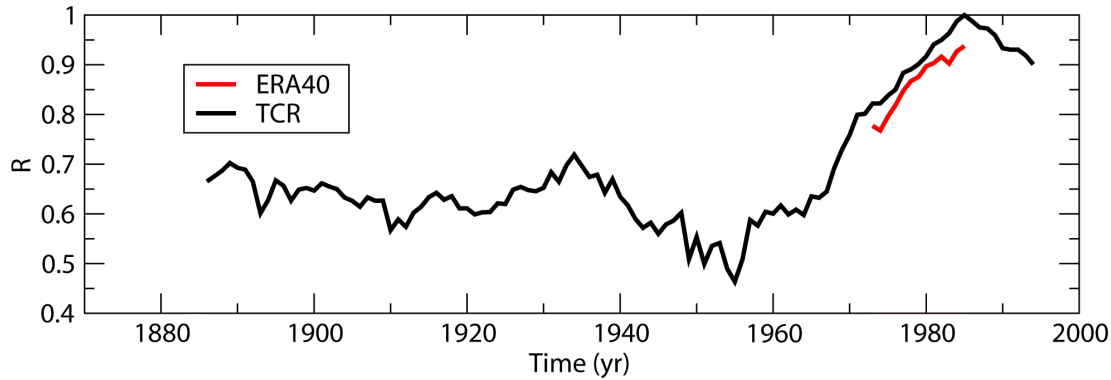


Fig. 1.

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(a) Atlantic



(b) Pacific

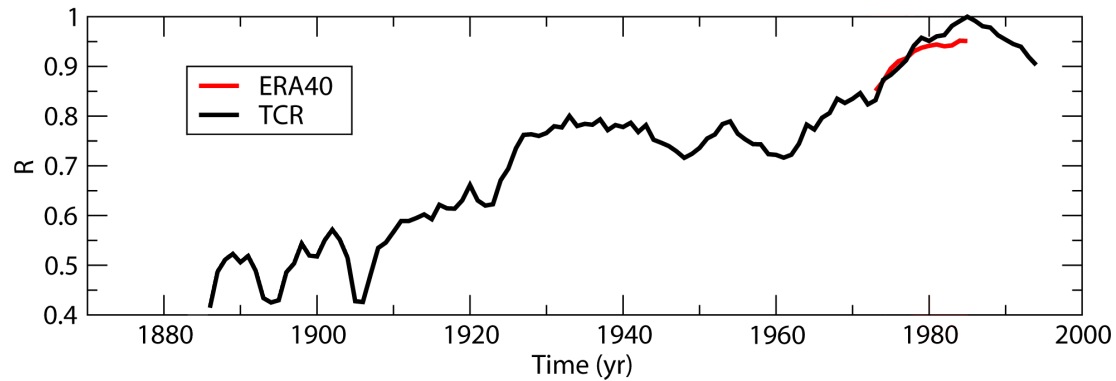


Fig. 2.

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