Answer to review of a manuscript for NPG (RC1)

Detecting dynamical anomalies in time series from different palaeoclimate proxy archives using windowed recurrence network analysis by J. Lekscha and R. Donner

In the following, we provide answers to the Referee's comments to our manuscript.

Overall:
In this manuscript the authors test the suitability of the earlier developed windowed recurrence network analysis (wRNA) for detecting dynamical anomalies in paleoclimate proxy times series. The method skills are tested on the suite of stationary and nonstationary timeseries of forward modelled pseudoproxies with known dynamical properties. This work is a natural continuation/extension of the earlier studies of the group on the application of networks to the analysis of (paleo)climatic data

The paper is clearly written and results are well presented. I therefore consider the manuscript deserves to be published after some very minor modifications /additions to the content if the authors/editor finds them relevant.

We thank the Referee for this positive assessment of our work. Our replies to the suggested modifications and additions are given below.

Minor comments
Page 3 Line 59: "for estimating embedding delay...autocorrelation function" is it a global or a windowed estimate? Please be specific

It is a global estimate. We will clarify this in the revised version of the manuscript.

Page 3 Line 66: why namely the maximum norm is used? Is it possible to justify the choice? Did the authors check the sensitivity of the results to the use of other norms?

We use the maximum norm because there is a direct analytical relationship between the network transitivity and the dimensionality of the dynamics of the system for it, as shown in Donner et al., EPJB, 2011. Thus, using the maximum norm is particularly useful when assessing the network transitivity to study the system's dynamics. Moreover, due to its specific form, the calculation of the maximum norm of a given vector in Euclidean space is particularly simple. This is also why this specific norm has been particularly widely used in previous works on recurrence network analysis and other recurrence plot based techniques. We will clarify this in the revised manuscript.
In our present work, we did not explicitly check the sensitivity of the results with respect to the use of other norms for the sake of conciseness. However, we performed similar sensitivity tests for other (similar) time series and typically found the results to be qualitatively robust when, for example, using the Euclidean norm instead of the maximum norm. We expect this to also hold for the present work.

Page 3 Line 71: "...such that a fraction \rho of all possible links in the network is realized": is the threshold global or window-based?

For each window, we construct a recurrence network and thus, set the threshold \epsilon for every window separately. That is, in each window, a fraction \rho of all possible links are realized. We will clarify this in the revised manuscript.

Page 3 Eq. 4 please indicate that |i-j|=|v-i|=1

In this equation, the summation is performed over all i, j and v and not only over neighboring indices. In fact, the network transitivity as given by Eq. 4 can be interpreted as the probability that two random neighbors of a randomly chosen node are mutually connected. Assuming that the randomly chosen node has index v, the denominator of Eq. 4 counts how many combinations of all i and j are neighbors of v. By summing over all possible v, the denominator equals the number of all possible triangles in the network. The nominator then counts how many of the possible triangles are actually realised.

Page 5-6: forward proxy model for tree rings. One should not that the juvenile growth is not modelled/accounted for in the model used. Hence an effect of its subtraction, which can be substantial, depending on the species used, technique applied and the entire age structure of the tree-ring network (archive) is also discarded. It is worth mentioning in a context of results demonstrated for tree rings.

We thank the Referee for drawing our attention to this important point. Indeed, the model does not take into account juvenile growth and it would be very interesting to compare the results to those of a model that does account for this effect in future work. We will add a corresponding comment in the revised manuscript.

Page 8 table 2: Please check if the amount of measured foraminifera is correct (number of species? Sample weight?) please indicate units

For this model, we used the default values for the amount of measured foraminifera, mixed layer thickness, and abundance of species of the TURBO2 model which are unitless (compare Trauth, Comp. Geosci., 2013). Of course, it would be very interesting to compare the results for varying values of these parameters. Unfortunately, such a systematic study on the effects of different model parameter settings was beyond the scope of our present manuscript and is thus left as a topic for future work. Generally, we expect here more quantitative rather than qualitative changes if the mentioned parameters are varied within some reasonable ranges.

Page 11: Use of nonstationary Røssler system: How realistic this model actually is for climate applications? Are there any larger-scale climatic processes that can potentially be associated with this model?

Unlike the Lorenz system, which has been originally introduced as a simplified toy model for atmospheric convection processes, the Rössler system has no such close climatological interpretation to the best of our knowledge. One of the main motivations for introducing this model (inspired by chemical reaction kinetics in Rössler's (Phys. Lett. A, 1976) original work) was to provide a chaotic dynamical system model with somewhat simpler behavior than the Lorenz system (i.e., without a double-scroll structure). This simpler type of attractor topology, along with the still non-trivial and rich cascade of bifurcations, was the main motivation for us to use the Rössler system as a generator for complex input dynamics to our proxy system models. Notably, we expect that this well studied model is known to a vast majority of the readership of Nonlinear Processes in Geophysics. By contrast, we did not attempt here to reach any dedicated level of realism in making the input variable particularly similar to real world climate dynamics. We will clarify this point in our revised manuscript.

Page 12 Line 309: "...respond to temperature rather than to precipitation..." mind that compared with a temperature, precipitation is not reproduced in the models that well, though for this particular case (boreal forest), temperature indeed will be a stronger limiting factor.

As we chose the model parameters for the tree ring width model to simulate tree growth in Eastern Canada, we were indeed expecting that the temperature and not the precipitation will be the limiting factor for the model in this case. However, we fully agree with this comment, and will add a brief explicit statement on this fact to our revised manuscript.

Page 13 Line 322: "...closely follow the respective temperature input", note my comment on the used forward proxy model for tree rings. Such a good concistency can partly be attributed to a lack of juvenile growth effect in the model.

We agree with the Referee that the good correspondence between the temperature input and the tree ring width model output can partly be attributed to the lack of correction for juvenile growth in the tree ring width model. We will comment on this in the revised manuscript.

Page 17 Line 368: "....lower-dimensional dynamics during the MCA.....higher-dimensional... during the LIA" Can the authors elaborate a bit more on this result? What are the actual features in the analyzed timeseries manifested in wRNA as lower and higher network \Tau?

The MCA has often be attributed to more stable climate conditions while the LIA has often been attributed to more variable climate conditions even though this imprint has varied locally and has been mainly discussed for Europe. As described, for the LMR data from Eastern Canada, we do not find any significant periods in the model output data meaning that we cannot detect any dynamical anomalies in the model output. Still, for the tree ring width model output, we observe higher values of the network transitivity roughly coinciding with the MCA and lower values of the network transitivity during the LIA. As the network transitivity (\mathcal{T}) has been shown to be related to some proxy for the dimensionality of the system's dynamics (m) via the relation m=\log(\mathcal{T}) / \log(3/4) (cf. Donner et al., EPJB, 2011), we tentatively conclude that the higher values of the network transitivity during the MCA and the lower values of the network transitivity during the LIA reflect a lower/higher dimensional dynamics of the system at this particular location (in terms of complexity of temporal variations rather than just a change in variance). In terms of the time series properties for the different periods, we indeed additionally observe an increase in variance of the time series from the MCA to the LIA, which is very likely also reflected in the different recurrence networks and, thus, the resulting network transitivity. We note that this non-stationarity in variance along with the MCA-LIA transition in the European/North Atlantic sector has also been reported as being reflected in other nonlinear characteristics, which have been previously interpreted as a hallmark of some dynamical anomaly (Schleussner et al., Clim. Dyn., 2015; Franke & Donner, Clim. Change, 2017).
We will add a corresponding more detailed discussion of the results to the revised manuscript.

Page 19 Lines 403-404: Did the authors consider block shuffling of surrogates (same as in block bootstrapping) as a possible method to tackle this problem?

We did not consider block shuffling of surrogates in this work, but rather addressed this issue by using iterative amplitude adjusted Fourier transform surrogates (that is, surrogates that exactly preserve the probability distribution and linear correlation structure of the data) for the areawise significance test.
We thank the Referee for suggesting using block shuffling as a possibly less computationally demanding alternative and will keep this option in mind for further work on significance tests. For the present work, we think that adding an additional type of surrogate data would primarily increase the already large amount of material presented without providing topically relevant results markedly deviating from those reported. Still, we agree that this is a very important topic, and suggest that

apart from block shuffling surrogates, also other surrogate routines should be studied more systematically for time series with different autocorrelation properties.

References

Donner, R. V., Heitzig, J., Donges, J. F., Zou, Y., Marwan, N., and Kurths, J.: The geometry of chaotic dynamics — a complex network perspective, The European Physical Journal B, 84, 653–672, 2011.

Franke, J. G., Donner, R. V.: Dynamical anomalies in terrestrial proxies of North Atlantic climate variability during the last 2ka, Climatic Change, 143(1-2), 87-100, 2017.

Rössler, O.: An equation for continuous chaos, Physics Letters A, 57, 397 – 398, 1976.

Schleussner, C.-F., Divine, D., Donges, J. F., Miettinen, A., Donner, R. V.: Indications for a North Atlantic ocean circulation regime shift at the onset of the Little Ice Age, Climate Dynamics, 45, 3623-3633, 2015.

Trauth, M. H.: TURBO2: A MATLAB simulation to study the effects of bioturbation on paleoceanographic time series, Computers & Geosciences, 61, 1 – 10, 2013.