The answers to the questions of Reviewer #1

General comments

As stated in my comment to the editor, I think that this study is very timely, however, I miss a more general review of the palaeoclimate literature on this topic. What has been done so far and how does this study improve our knowledge compared to these studies. This includes on the one-hand palaeoclimate studies that have applied such approaches and on the other hand studies that discuss different smoothing/interpolation techniques. This speleothem-based study [3] is an example. They have used a very similar technique and approach as presented in this study, though there are some minor differences but the idea behind is the very same as for this study. But there are also other techniques for sedimentary archives, such as from [4].

Thank you for the suggestion, the paper of Cosford et al. (2008) was indeed relevant from multiple aspects. Therefore, besides extending the introduction with other examples, Cosford et al. (2008) has been incorporated in lines 64-69 as: "A more complex approach combining spline smoothing and linear interpolation was presented in a multi paleoproxy study, where in addition the spectral characteristics of the data were assessed using multiple methods as well (Cosford et al., 2008). However, any transformation which adds data to or removes it from the original record unavoidably changes its spectral characteristics. This is a factor, which can easily be overlooked even in advanced studies although it must deserve high attention."
In the last sentence we implicitly refer to the study of Cosford et al. (2008) who only used the Nyquist frequency of the data to determine a cut-off period. On the contrary, the procedure in the present paper considers the spectrum specific characteristic when determining a cut-off frequency.

Unfortunately, the study of Lisiecki (2002) mainly deals with signal matching and even states that hiatuses may produce erroneous results in his approach, thus we would not include this paper in the reference list.

Reference added:

Cosford, J., Qing, H., Eglington, B., Mattey, D., Yuan, D., Zhang, M., and Cheng, H.: East Asian monsoon variability since the Mid-Holocene recorded in a high-resolution, absolute-dated aragonite speleothem from eastern China, Earth and Planetary Science Letters, 275, 296-307.

Furthermore, the authors should provide some more backups for using a cubic spline to fill gabs in an un-evenly spaced time series (e.g. [5] [6]). What is the rational to use a cubic spline (or any other technique) for increasing (gab filling) the temporal resolution of time series, i.e., generation information?

Thank you for the comment, the papers below have been incorporated. Thus, the text regarding the benefits and drawbacks of spline interpolation has been thoroughly extended and it is now briefly compared to linear interpolation, the Lomb-Scargle Reconstruction method and the Kondrashov and Ghil technique.

References added:

Musial, J.P., M.M. Verstraete, and N. Gobron, Comparing the effectiveness of recent algorithms to fill and smooth incomplete and noisy time series. Atmospheric chemistry and physics, 2011. 11(15): p. 7905-7923.

Hocke, K. and N. Kämpfer, Gap filling and noise reduction of unevenly sampled data by means of the Lomb-Scargle periodogram. Atmospheric Chemistry and Physics, 2009. 9(12): p. 4197-4206.

Kondrashov, D. and Ghil, M.: Spatio-temporal filling of missing points in geophysical data sets, Nonlin. Processes Geophys., 13, 151-159, doi: 10.5194/npg-13-151-2006, 2006.

For the illustrated example, the used approach is probably fine for the youngest part of the speleothem proxy time series, with a very high temporal resolution, but the oldest part of the speleothem proxy time series, is much smaller compared to the youngest part. However, what is strikingly illustrated in Figure 1 of this manuscript is that the variability of younger part is much higher compared to the older part. Therefore, don't you assume that the higher variability in the younger part is noise?

The main aim was to create an equally sampled dataset which has/resembles the spectral characteristics of the original data. During the procedure, the signal to noise ratio of the original data is not assessed, only the bias (introduced artificial noise) caused by the interpolation itself as shown in Section 2.2.1.

I think this approach needs a more rigorous test, whether it is adequately working or not by testing it with artificial time series using e.g. an AR-1 or AR-2 model.

My suggestion is to generate an equally spaced time series (with known spectrum), which is than un-equally resampled n-times. Use these n un-equally spaced artificial time series to test your approach. Ideally you use different kinds of artificial time series to test your approach, e.g. AR-1, AR-2. For the WTC analysis you may consider to use an artificial time series, which is forced by the observed NAO index – add some noise or regional factors such as temperature – and test your approach again, this time including the WTC. I think these steps are necessary to really quantify the quality of your approach, but also to add new results to this topic (see comment on literature).

Based on the Reviewer's suggestion, we selected a well-studied record with pronounced periodic signals to test the performance of our approach. Seasonal averages were computed

from the monthly mean total sunspot number (WDC-SILSO, 2017) and randomly resampled. Seven data points were taken randomly from each block of 10yrs to replicate the sub-annual resolution of the Baradla speleothem (avg. 0.7 stable isotope data/yr). This was repeated a 100 times, so an ensemble of 100 randomly resampled time series were obtained which replicate the resolution of the Baradla $\delta^{18}O$ records. As a final step in line with the proposed protocol the 100 randomly resampled time series were spline interpolated and annual averages were formed and were processed using REDFIT to assess their spectral characteristics and compare them to the spectra of the annual averages of the original (sunspot) record.

All the 100 redfit Lomb-Scargle Periodigrams (rLSPs) replicated the well-known ~11 yr sunspot cycle (α>0.95). Moreover, most of the rLSPs of the un-equally spaced artificial time series mirrored even the smaller peaks (e.g. ~8yrs). However, the noise caused by spline interpolation surfaced in the high-frequency domain (Fig. R1).

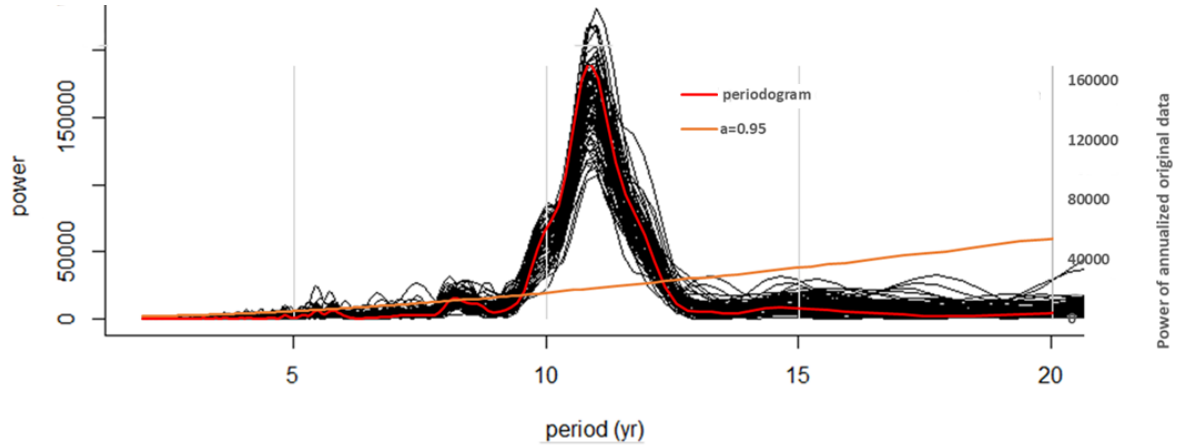

Fig. R1. rLSP of the annual mean sunspot numbers (red); and rLSPs of the 100 un-equally spaced artificial (sunspot) time series randomly resampled, spline interpolated and annualized from the monthly mean sunspot numbers (black). The bias-corrected 95% chi-squared limit of a fitted AR(1) process for the rLSPs is shown in orange.

The results shown above have been added to the MS in lines 166-170 and in a detailed form in Section S1 of the supplementary online material.

Data source:
WDC-SILSO, Solar Influences Data Analysis Center (SIDC), Royal Observatory of Belgium, Av. Circulaire, 3, B-1180 BRUSSELS Currently at http://www.sidc.be/silso/datafiles accessed on 08.09.2017

Comments:

Line 33: Please change the statement on the dating. The advantage of speleothems is, that they can be precisely dated by speleothems. My suggestion is: they can be precisely dated by U-series techniques (e.g. U-Th)

The sentence in question has been rephrased in line 30.

Line 34: I would suggest rewriting part on multiple proxies. My suggestion is: they provide multiple independent proxy that are suitable to reconstruct past climate conditions.

Accepted and corrected in lines 28-33.

Line 36: Fairchild and Baker is not review article but a book. My suggestion is to change review to overview.

Accepted and corrected

Line 37-39: Please rephrase and split this sentence; it is quite complex and not very reader friendly. What does 'composition' mean here? I would also suggest to use 'determine' instead of 'govern'.

The confusing sentence has been removed.

Line 39-40: I think you have to distinguish between different proxies in this sentence. From what we know about proxies some are really modified by global processes (e.g. d18O) but others are clearly locally controlled, such as trace elements (TEs).

Accepted and corrected. Your suggestion has been added to lines 35-36. as: "Although, some proxies are more likely to be influenced by large scale factors (e.g. oxygen stable isotope content), while others are clearly locally controlled (e.g. trace elements)."

Line 44: I would change 'behaviour' to 'dynamics' or 'climate'.

Accepted and corrected, behavior has been changed to dynamics.

Line 44-45: You don't really get information on speleothem formation processes by cave monitoring but information on speleothem formation. I would suggest to delete processes here.

Accepted and corrected, the word processes has been removed.

Line 46-48: I think you have to be more specific here, when you refer to seasonality. Readers may not be familiar with cave monitoring and to cave parameter to which you refer seasonality (I think). E.g. seasonality of cave air temperature or wind.

Accepted and corrected, the sentence has been extended in line 45.

Line 56-58: You need to rephrase and improve the English of his sentence. Be more specific on the moving average and what it means for TIME series.

The paragraph in question has been removed.

Line 60: Delete the 'and' between 'statistical' AND 'time series', because it does not make sense at the moment. You refer to statistical time series analysis.

The sentence has been rephrased in lines 54-55

Line 66: I think you should add that these 'common' statistical tools can only be used for evenly spaced time series.

Accepted and corrected in line 66

Line 66: You should add 'unevenly spaced' before sedimentary records.

Accepted and corrected.

Line 67: There is 'by' missing. BY using.

Accepted and corrected.

Line 67: include 'techniques' after non-linear.

Accepted and corrected.

Line 68: What are 'insufficiently documented methods'? Can you be more specific?

We would rather not extend this sentence in the MS. We referred to methodologies insufficiently documented in published papers to such an extent, that make reproducibility impossible.

Line 72: Where is Baradla Cave located?

Accepted and corrected, the sentence has been extended and a reference has been added to Section 2.1 in line 71 as: "… Baradla Cave (NE Hungary for details see Section 2.1)…".

Line 71-73: This is a very long sentence and I would suggest to split and rephrase it.

Accepted and corrected.

Line 75: include 'packages' after software.

Accepted and corrected.

Line 78-79: This last sentence makes no sense in the context of the previous sentence.

Accepted and corrected, the sentence has been removed.

Line 83: I think it is helpful for the reader to give a short rationale why these two stalagmites were used compared to the other two of the same caves, e.g., from the summary/conclusion of the original study [7]. Line 87-90: How are the age models constructed of these two stalagmites? How large are the age uncertainties? Is it reasonable, based on the age uncertainties' to merge them?

Accepted and corrected. Section 2.1 has been thoroughly extended with a discussion on the similarities of the two speleothems (NU2 & VK1) the composite was derived from, regarding the most important aspects: age model construction and synchronization; see lines (80-92). This was mainly extracted and summarized from Demény et al. (2017). Moreover, two new panels (A & B) have been added to Fig. 1 showing the complementary characteristics of the stable isotope records of the two speleothems.

Line 90: I think you should use a different symbol for the merged record than Δ, which is used for clumped isotopes and for differences between time series for example. It is okay to use here.

Accepting the permission of the Reviewer, we keep the notation defined in lines 95-96, but we took special care to use $\Delta^{13}C_{Baradla}$ and $\Delta^{18}O_{Baradla}$.throughout the whole MS (including figures) to avoid any misunderstanding with $\delta^{13}C$ and $\delta^{18}O$ values. Moreover, the figure legends have been updated accordingly.

Line 93: You can delete 'totals'.

We would like to keep it.

Line 152-153: Why do you low-pass filter your data? This is in principle not necessary if you use WTC, because you can neglect any observed coherence (if any) below your threshold frequency. In this case you do not alter the meteorological observations and your interpolated time series and reduces further uncertainties.

The Reviewer is right, it can be a viable approach to neglect the frequency band below the chosen threshold frequency in a specific case of WTC. However, the idea here was to make the methodology universal and the last step was omitting the frequency bands that might have been biased by the interpolation. The main result is this output which can then be passed on to tools that require equally spaced data.

Line 165: I suppose you mean "In THIS study" not "In the study".

Accepted and corrected.

Line 167-168: The fact that other speleothem studies have used the Morlet mother wavelet is no argument. I suggest to delete this part of the sentence.

Accepted and corrected.

Line 171: What is a "positive signal"? I suggest to rephrase this sentence; be more specific.

Accepted and corrected, the term positive has been removed, it was indeed unnecessary.

Line 174-176: This is a very nice approach, but it needs a more detailed explanation. Maybe show some results and draw the steps you perform until you find the final result.

Accepted and corrected, a more detailed explanation was provided with exact examples in lines 198-204.

Line 184-186: How about the small periods? There is quite a difference between the original and interpolated time series between 32 and 64 years.

As stated in lines 170-173 the main idea was to match the peaks of the interpolated data's rLSP to the significant peaks of the original composite's rLSP. In this sense, the peak between the 32

and 64yr periods is insignificant not only in the original composite record's spectrum, but in the interpolated one as well at the 80% significance level. Please see Fig. R2 below.

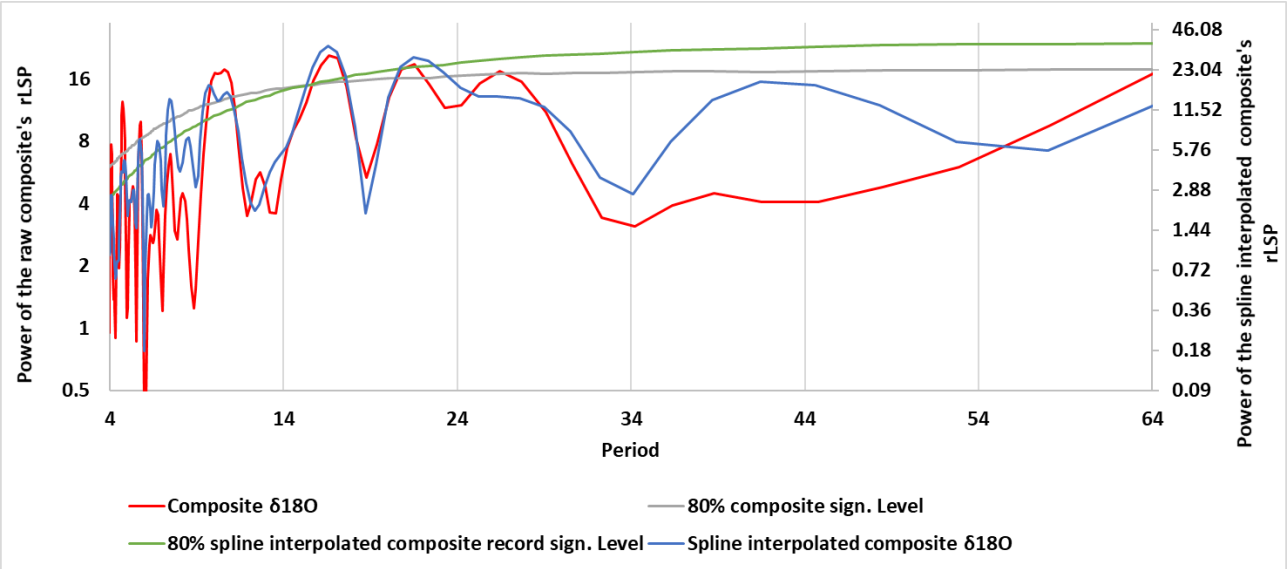

Fig. R2: rLSPs of the original, and the spline interpolated $\Delta^{18}O_{Baradla}$ records of the Baradla speleothem. The bias-corrected 80% chi-squared limit of a fitted AR(1) process for the raw composite's and the spline interpolated composite's rLSPs is shown in grey ad green respectively.

Line 188: What is the rational to determine the threshold exactly at 4.5 years?

Accepted and the text has been corrected and the Reviewer is referred to lines 211-216 of the MS.

Line 197-198: What is the rational to determine the threshold exactly at 7.5 years?

Accepted and corrected, the text has been extended in lines 226-229.

Line 203-205: See my comment on line 152-153.

Please see our answer below your comment referring to lines 152-153.

Line 226: What are the primary climate parameters? Although it is stated in Figure 4, please include it in this sentence. Why not write "precipitation and temperature" instead of "primary climate parameters"?

Accepted and corrected, precipitation and temperature is now used in the sentence.

Line 226-229: Apart from Kaiser (2001), Lachniet (2009) and Dansgaard (1964) generally explain global phenomena. Is this also the case for local precipitation d18O values?

The text has been rephrased to be more specific, and an additional paper has been cited in lines 261-263 as: "Drip water composition is directly related to meteoric water composition governed by atmospheric temperature and moisture origin in the mid-latitudes (Dansgaard, 1964) and has been documented in the surroundings of the study area (Bottyán et al., 2017; Kaiser et al., 2001).

Reference added:

Bottyán, E., Czuppon, G., Weidinger, T., Haszpra, L., and Kármán, K.: Moisture source diagnostics and isotope characteristics for precipitation in east Hungary: implications for their relationship, Hydrological Sciences Journal, 62, 2049-2060,

Line 239- 241: Are there references for this statement?

The sentence in question has been shortened, the criticized part has been moved to Section 2.1. and extended and completed with supporting references in line 101 as: "Large scale tropospheric circulation controls precipitation amount and water stable isotope composition over Europe (Comas-Bru et al., 2016; Field, 2010)."

References added:

Comas-Bru, L., McDermott, F., and Werner, M.: The effect of the East Atlantic pattern on the precipitation δ18O-NAO relationship in Europe, Clim Dyn, 47, 2059-2069, 2016.

Field, R. D.: Observed and modeled controls on precipitation δ18O over Europe: From local temperature to the Northern Annular Mode, Journal of Geophysical Research: Atmospheres, 115, 2010.

Line 241-243: What is your definition of "strong"? Does it refer to the Wavelet power or the length of the period during which you observe a significant coherence. However, the coherence between the two NAOi and the interpolated d18O time series is low apart from a 10 year long period in the beginning of the 20th century.

The text has been extended with a reference to the wavelet powers. However, in the sentence we only stated that among all the available multi monthly averages, the one in Fig. 5 was found to be the strongest.

Line 244-245: Please state clearly which years you mean or identify these years in Figure 5.

Accepted and corrected in line 278 stating ~1955- ~1970.

Line 252-253: Please state a reference for this or cite Kaiser earlier in the paper.

The sentence in question has been removed from the text.

Line 266: Can you show the results of the redfit-x analyses in an additional figure in the supplementary information. Line 269-270: See my comments on low-pass filtering. Line 271: The relationship of what? d18O or d13C? Where are the results of this comparison?

Accepting the request of Reviewer #2 the corresponding Section 4, has been removed.

<u>Figure captions:</u>

Figure 3: Please include a detailed description of the arrows. When is the signal inphase, pointing right? Left?

Accepted and corrected.

Figure 5: Can you rescale the time axis (figure) of panel b that the time on panel a and b can be compared. This makes it easier for reader to compare the coherence between the two different NAOi and the interpolated d18O time series.

Accepted and corrected, please see Fig. 5 in the MS.