Clim. Past Discuss.,
https://doi.org/10.5194/cp-2018-112-RC2, 2018

Interactive comment on "What climate signal is contained in decadal to centennial scale isotope variations from Antarctic ice cores?" *by* Thomas Münch and Thomas Laepple

Anonymous Referee #2

Received and published: 28 September 2018

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Review of the article: 'What climate signal is contained in decadal to centennial scale isotope variations from Antarctic ice cores?' by Thomas Münch and Thomas Laepple, submitted to Climate of the Past.

September 28, 2018

1 General comments

The article submitted deals with quantification of climate signal versus noise in ice cores from Antarctica. It is therefore well within the scope of Climate of the Past, and addresses an important issue for climatologists. Its aim is not to present new ice core data, but to present a methodology to evaluate (quantify) the climate signal contained in a series of records.

The methodology is based on a spectral analysis of the dataset, where the spectrum of the stacked record is compared to the mean spectrum and to white noise. The method also includes a correction for diffusion and for time uncertainty. The Methodology section is concise, because details are described in Appendixes. The paragraph 3.1 in

Results is a useful complement to the methodology section, as it applies the method to an example, and provides a figure where the various steps are represented. It is well suited to an article that aims a large audience, not necessarily with statistical background, and who might overlook the equations in the methodology section and Appendixes.

In the continuation of the Results section, the figures are described in less details. Some more precision is needed here, so that the main message is not obscured by unanswered questions on the parts of the figures that are not described. The results are different for the two studied regions. At EDML, the signal to noise ratio is found to increase for longer time scales (0.2 to 1), whereas at WAIS, it is relatively stable, and even seems to decrease at long (centennial) time scales. For the first region, the authors therefore recommend to use single cores only for multidecadal or longer timescales. For the second region, oppositely, they conclude that single cores yield good regional information at interannual and decadal scales, but give a more local information at longer time scales.

In the Discussion, the authors consider the possible contribution of four processes to the climate signal, by looking at their spatial scale of coherence. They note that precipitation intermittency acts as noise or contributes to signal, depending on the scale considered.
They also discuss the unexpected decrease of signal power at WAIS for longer timescales. This coastal region is particularly sensitive to the variability in atmospheric circulation. They suggest that slow processes modifying the topography of the region may reduce the spatial coherence of the signal over long timescales.

The conclusions of the article are important regarding the confidence that we can attribute to one or several ice core records. The results for WAIS are unexpected, and

therefore may trigger more research in the area, or allow to consider differently the results from previous drillings. Lastly, as noted by the authors, the new methodology can be applied to other records, and therefore be of interest to a large audience.

The manuscript is well written and well structured, with a good use of appendixes to procure relevant information. Given that the conclusions of the article are interesting, and well supported by the Method and Results sections, I recommend that this article should be accepted by Climate of the Past with minor corrections.

2 Specific comments

P2, l12: 'the diffusion of vapor through the firn column smoothes the isotope variations, reducing the power spectral density at high frequencies'
The first part of the sentence is very clear but the second part is less straightforward. Is it possible to add an intermediary step? '...smoothes the isotope variations, with stronger impact at short distances and therefore on the high frequencies.'

P2, l. 24: 'Furthermore, knowing the timescale dependence, and thus the spectral shape of the noise, would allow the correction of the isotope-inferred variability estimates for the noise contribution.'
This sentence is complicated, it takes some time to find the subject. Is it possible to split it or reverse it?
'Furthermore, in order to correct the noise contribution to the isotope inferred variability estimates, it is necessary to know the noise distribution over various timescales, i.e. its spectral shape.'

P3, l14: 'The time uncertainty of the record chronologies, . . ., has been reported with 2 % of the time interval to the nearest tie point.'
This sentence is unclear, is there something missing? Is it 'has been reported to be 2 % of the time interval'?

P5, l8: Equations 4
Although it was only a few lines above, please repeat here what M and S are (respectively the mean of spectra, and the spectra of the stacked record along time). Also, is it possible to get another symbol for the noise (or at least a very specific font) so that it is easier to distinguish between N and N?

P5, l. 19: 'we restrict our analyses to the frequency region where G<2. This avoids large uncertainties and yields cutoff frequencies of. . .'
Based on Figure B1 in annex, G is always below 2. Its maximum value is one. This seems logical since a filter will eliminate some frequencies, not add more frequencies to the signal. Should it be 'restrict to the region where G>0.5'? (so that the short frequencies will not triple in power after correction)?
Please clarify this point in the text or in the Appendix B.
Please define the term 'cut-off frequency' (and maybe draw the limits on Figure B1).

P6, l2: 'the value of F is related to the correlation between. . .'
Is the correlation r providing more information than F (on the quality of the data) or the same information? Is the r value only for intercomparing with other studies?

P6, l20-28:

1. Is it possible to insert here the symbols used previously in the methodology sec-

tion (M, S) to facilitate the identification of the various terms?

2. The mean over all individual spectra, M, (figure1, black line) . . .

3. The mean spectrum divided by the number of records (M/15, figure 1, dashed line) . . .

4. . . .averaging across record that contain noise and additionally. . . (S. . ., Figure 1, brown line)

Furthermore, please precise 'averaging across records along the time dimension' or 'in time space' to refer to the 'time stack' S, by opposition to the spectrum mean M.

P6, l29: 'For short timescales (2 to seven years), . . ., is consistent with the null hypothesis of independent noise.'
The curves are closest between 3 and 5 years; they diverge again around 2. What causes this divergence from white noise? Is it an artefact?

P7, l6-7: 'Unlike the average spectrum across all individual isotope variations (fig1), the corrected DML1 signal spectrum shows an increase of power spectral density with increasing time scale (fig. 2a)'.

1. Please precise which line is described here (color, symbol).

2. Both the black and brown line show an increase of power spectral density towards higher timescales on Fig1 (strongest between 2 and 20, then flat area at longer timescales). This proposition has to be nuanced.

3. For the brown line, there is again an increase at very long timescales (>50) still on Figure 1.

4. On Figure 2, the 3 DML1 curves are very similar for t>20. So, the correction does not seem to have a huge effect. Moreover, the increase of power between 50 and 200 years exist with/ without correction. . .

5. Lastly, regarding the increase between 3 and 20 years on Figure 2, the correction actually reduces the slope. . .

Possible correction to this sentence:
'Unlike the average spectrum across all individual variations (M, black line on Fig 1), the corrected DML1 signal spectrum (C, solid blue line on Figure 2a) shows an increase of power spectral densities with increasing time scales at time scales larger than 50 years.'

P7, l. 7-8:'This is confirmed by the three 1000-yr long records from the DML2 data set whose signal exhibits a similar power spectrum in the range of timescales that overlap.' The two curves are not really a perfect match.
There is common behavior between 60 and 100 years (increasing) and between 5 and 15 years (increasing) but the middle part (15 to 60) is different between the two curves. DML1 is slowly decreasing (or flat), while DML2 is strongly decreasing until 30, then strongly increasing. Maybe add: '. . .for time scales longer than 50 years.'
Or split the paragraph in two, one dealing with long time scales, and the other with short time scales.

P9, l.6: '. . .decrease in signal power on centennial timescales'
Is it possible that this decrease is an artefact? How certain are we of the power of the 100-year frequency on a 200-year record?

P11, l1: 'In fact, the average correlation of 0.87 (0.94) over distances up to the maximal

intercore distance. . .'
Please add here a reference to Appendix C, Figure C1. Otherwise the origin of these numbers (and their meaning) is unknown.
Based on the figure caption, this correlation is an average (for various intercore distances). Thus, maybe the formulation 'up to the maximum intercore distance' is misleading here. Why not say the correlation for average distance between cores instead?

P12, l. 11-13; 'The raw noise spectra derived from the two DML data sets exhibit a clear imprint from the diffusional smoothing in the firn, as suggested by the smaller PSD for periods <20 years of the raw DML2 spectrum, i.e. prior to correction, in comparison to DML1 (fig. 2b).'
This is too fast. Please split in two steps:

1. first, raw to corrected for both records (DML1 and DML2): the effect of diffusion is to decrease power at high frequencies;

2. second, comparison of the raw data for DML1 and DML2: DML2 is more affected by diffusion, since frequencies between 12 and 30 are affected (low power) only for DML2.

P12, l30: 'yields a slope of the DML2 signal spectrum of roughly beta=0.6'
Is it possible to add this fit to Figure 2 or 3?

P13, l. 7: 'minimum averaging period constrained by the diffusion correction (2.5 years)'
Is it correct to compare r values at different averaging times (1 year and 2.5 years)? Could this also contribute to the higher correlation compared to previous study of the

same data?

P14, l. 1-3: 'For WAIS, the higher SNR at interannual timescales as compared to DML is consistent with the general notion that higher accumulation rates result in higher SNR.'

1. Please insert the SNR values for both.

2. For N=1 and deltat=5 years, r=0.45 at DML and r=0.51 at WAIS. The difference looks very small (especially considering the 3-times accumulation at WAIS). Why is the increase in SNR not scaled to the large increase in accumulation?

P14, l26-28: 'Together with the observed spectral shapes on the longer timescales (30-100y) our results therefore might indicate a true increase in local variability at the WAIS sites towards longer time scales, and a close-to-constant or even decreasing coherent signal variability.'
This sentence is strange. It looks unbalanced with a first part dealing with long time scales and a second part dealing with. . . probably shorter time scales?
Is it possible to correct this sentence?
To facilitate reading, maybe this paragraph could be limited to the issue of high frequencies at WAIS, since the discussion for the long timescales already existed in the previous one.
Is it possible to separate the issue of high frequencies for noise and for signal?

What are the hypotheses explaining this decrease in noise at high frequencies? Could it be something like wind blowing that would homogenize only the surface over large areas? Or large-scale evaporation of surface snow homogenizing its composition?

2.1 Appendix A

P16, l 23: 'a Gaussian convolution kernel whose standard deviation is the diffusion length σ_i that is a function of depth (time) and depends on site i.'
This is very synthetic, but not very clear. Please add a reference to Appendix B where more details are provided. Please give some values of σ_i (and possibly the associated frequencies) at various depths. Is there a formula that relates σ_i to time (for each site)? If not, the use of the term 'function' might be misleading here. Indeed, σ_i seems to answer on density, temperature and pressure, and therefore to be more similar to an adjustable parameter in the densification model.

2.2 Appendix C

P19, l8: This sentence is complicated. It would be simpler to describe the procedure at EDML, and then say that the same method is applied to WAIS.

3 Technical corrections

1. P5, l. 12: "inidividual" typo

2. P6, l. 14: Please remove 'exemplarily' which is redundant with 'to illustrate our method'.

3. P11, l. 8: 'estimated signal term' Please add a reference to the equation (5 or 6).

4. P16, l. 12: ‘core sites’ typo
5. P17, l.8: It is F(ε_i)F(ε_j)$\neq$0 only for i=j, and hence. . . Maybe ‘we have’ instead of ‘it is’?