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Climate of the Past Discussions

Interactive comment on "Rapid changes in ice core gas records – Part 2: Understanding the rapid rise in atmospheric CO_2 at the onset of the Bølling/Allerød" *by* P. Köhler et al.

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This filter test is a principle matter, and the characteristics of the filter should be investigated with known input data. Therefore, we performed some tests with an artificial CH_4 time series which is comparable in the rates of changes and amplitudes with the rapid rise in atmospheric CH_4 during the onset of the BA warm period. We restrict this test to the Bølling/Allerød (BA). In our interpretation on the rapid rise of CO_2 at the onset of the BA, which is in focus of our paper, it is inappropriate to develop and describe a filter, which can also explain the CH_4 variability at the beginning and at the end of the Younger Dryas (YD) for various reasons (see below). Tests are performed in order to evalute the points raised by the reviewer:

1. In our understanding only the slope of the filtered CH_4 time series of the Greenland ice core can be compared with in situ CH_4 data from EDC, not single points. This is especially the case, because in the filtered time series shown here and in the earlier reponse letters no age correction was applied to the filtered time series, which, however, would have been necessary in order to compare if a filtered time series fits onto single EDC data points. Furthermore, these single points in CH_4 in EDC which are missed according to the reviewer were presumably those which we took for the slope calculation (circled in Fig. 1 of our last response, CPD, vol 6, p C793). Therefore, the calculated slopes heavily depend on them. One might even argue that this dependency of the slope on single points is vulnerable to errors in these points (either in their CH_4 value or their dating). Note, that ice core CH_4 measurements have a typical uncertainty of 10 ppbv. Thus, the slopes calculated from two single points from the chosen ice cores have an uncertainty of $\pm(4-15)$ ppbv per century (still neglecting the dating uncertainties). This uncertainty estimate together with the comparision of the principle filter characteristics (see below, text, Table and Fig) therefore represents a minimum concept to quantify potential errors in the slope calculation.

2. The reviewer argues that CH_4 in the YD in EDC has a flat bottom. However, we see in this time series a decreasing trend at the beginning of the YD which is also expected (e.g. from the filtered artifical CH_4 time series, see Figure 1 attached). Our filter predicts that CH_4 in the YD should be smaller in EDML than in EDC, which is not the case. The mean of the EDML raw data in the YD are 6 ppbv higher than the mean of the EDC raw data, although both should in theory record the same signal (a well mixed atmospheric CH_4 with an interhemispheric gradient, but with similar values in the same high latitudes). Understanding this discrepancy first would be of importance, but this is already within the ice core raw data and not a product of the filter.

Furthermore, with the given CH_4 ice core raw data any hypothetical filter of any width would produce a filtered EDML time series which would have higher values than EDC raw data during the YD. But from the theoretical understanding the gas enclosure process in low accumulation ice cores should average atmospheric signals over a longer time window than in high accumulation sides (thus including a larger fraction of the higher CH_4 values in the BA). Therefore, our approach seems to be too simplistic for the given evidences from ice core data during the YD. Maybe especially during periods of rapidly declining atmospheric CH_4 concentrations the gas enclosure does not follow our current understanding and expectations. This is however not of relevance for our time window of interest, in which we see a rapid rise in CH_4.

Some perspective on future work, which might disentangle this issue, is measuring the CH_4 shift continuously along ice cores having different accumulation rates, using the latest analytical setup of combining CFA with optical measurements. This was done at NEEM this summer, so a Greenland CH_4 reference relying on continuous measurements now exists for at least the start and the end of the YD, as well as for numerous D/O events (T. Blunier, J. Chappellaz, S. Schüpbach, C. Stowasser, R. Dallmayr, O. Pascual, M. Bigler, D. Leuenberger: Continuous methane concentration measurements along the NEEM core. AGU Fall Meet. Suppl., 2010, San Francisco, USA). Work in the near future will produce the equivalent record from EDC, EDML, Berkner Island and Talos Dome, depending on core availability

3. We argued in our paper with a range in E varying by $\pm$20% around our best guess of 400 yr (from 320 to 480 yr) for the onset of the BA warm period. All results obtained with E lying within this range fulfil the constrains from the CO_2 ice core data (our Fig. 5 in the paper). To finally completely understand the main result of this filter test (which is in our understanding the slope during the rapid rise), we carefully expand on the understanding how the slope of the rapid CH_4 rise will

> vary depending on gas enclosure. We therefore analysed an artifical CH_4 which mimicks the BA, but for which we know the assumed input/atmospheric data.
>
> We repeated the slope calculation for the interpolated and filtered Greenland time series by objectively identifying from the first derivative the time window, in which the gradient of the filtered time series is steepest. The mean of the slopes for the three filtering with $E = 400 \pm 80$ yr was 28 ± 5 ppbm/century.
>
> The artificial peak CH_4 in which atmospheric methane rose in 10 yr from 450 ppbv to 650 ppbv (slope of 2000 ppbv/century) would be recorded with conditions typically for NGRIP ($E = 60 \pm 12$ yr) with a slope of 234 ± 50 ppbv/century, which overlaps with the calculated slope of 171 ± 15 ppbv/century from the Greenland raw data. A second filtering of this pseudo-original record for NGRIP conditions with $E = 400 \pm 80$ yr leads to a slope of 32 ± 7 ppbv/century, again well overlaping with the filtered results of the original Greenland ice core data (28 ± 5 ppbm/century). The artificial peak would under EDC conditions ($E = 400 \pm 80$) have a slope of 36 ± 8 ppbv/century, similar to the 39 ± 4 ppbv/century of the EDC raw data.
>
> These slope calculations are summarised in the following table and are as far as we think the results of this filter test can be useful here. Again, we have to warrant, that potential errors in the ice core dating and the interhemispheric gradient in CH_4 are ignored,

From all these evidences we conclude that for our problem at hand (the rapid rise of CO_2 at the onset of the BA warm period) the used lognormal filter function and the selected width E of the gas age distribution PDF (which is based on firn densification models) are useful and valid. We will extend the manuscript based on this discussion of the characteristics of the filter function.

Slope of CH_4 rise at onset of BA warm event in ppbv per century.

	ice core data		artifical peak	
ice core	original	filtered	pseudo-original	filtered
		$E = 400 \pm 80$ yr	$E = 60 \pm 12$ yr	$E = 400 \pm 80$ yr
		interpolated		
Greenland	171±15	28 ± 5	234 ± 50	32 ± 7
EDC target		39 ± 4		36 ± 8

For this calculation the artificial (potentially atmospheric) CH_4 record is first filtered with the lognormal function with different E $(400 \pm 80, 60 \pm 12$ yr), representative for ice core conditions at EDC, NGRIP, respectively. Thus, the EDC target record and so-called pseudo-original methane peaks for conditions comparable to the NGRIP ice core is generated. Then, the pseudo-original NGRIP time series is filtered a second time with EDC's gas enclosure characteristics ($E = 400 \pm 80$ yr). In doing so we are able to illustrate how the gas enclosure in NGRIP impact the test with real ice core CH_4 data. The uncertainty in the original ice core data is based on the measurement uncertainty of single points of 10 ppbv. The range given in the analysis of the artificial peak depend on the variability of E by $\pm 20\%$.

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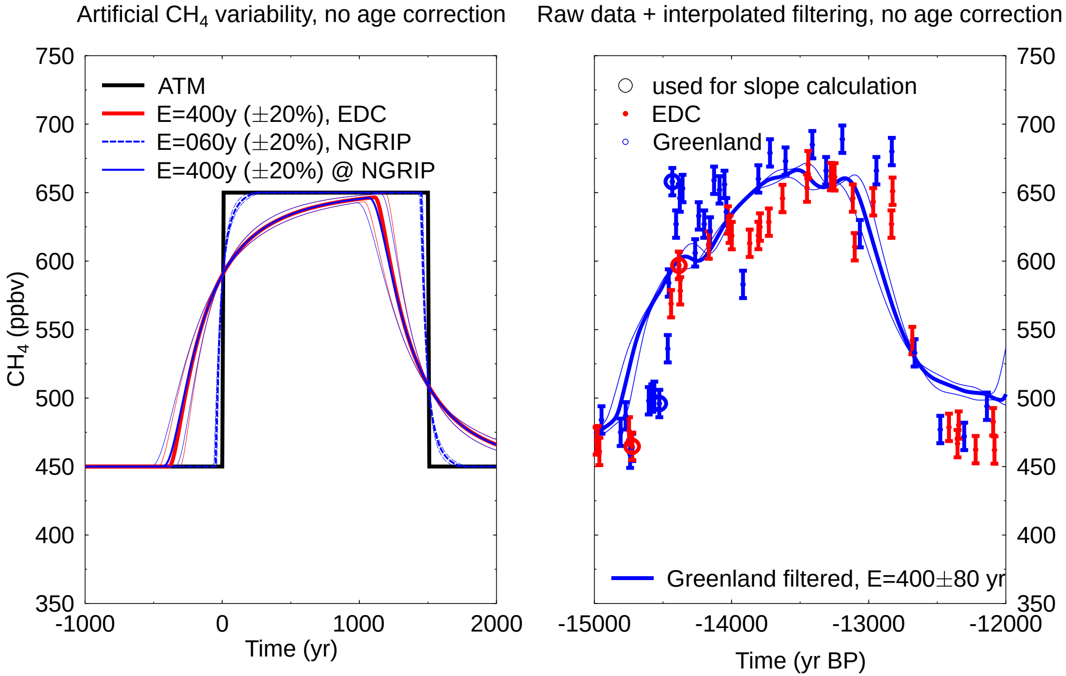

Fig. 1. Left: Hypothetical methane peak, filtered with the lognormal function with various E. Interhemispheric gradient in CH4 is not considered. Right: Ice core data from EDC, NGRIP and NGRIP filtered data.