Interactive comment on "NGRIP temperature reconstruction from 10 to 120 kyr b2k" by P. Kindler et al.

Answers to **Anonymous Referee #2**

Kindler et al. completed Greenland temperature reconstruction for a full interglacial cycle (10-120kyr) using d15N in trapped air in NGRIP ice core, combining published and new data. The reconstructed temperature record is an important contribution for the paleo-climate community. In addition, the application of d15N paleo-thermometry through the entire glacial cycle allowed them to reveal important insights on the relationship between temperature and d18O of ice as well as accumulation rate. Especially, alpha reconstruction and relation to obliquity are interesting and novel. The authors also looked into some technical issues of the calculation of temperature from d15N, which is also an important contribution. The paper is certainly relevant for Climate of the Past, but the paper is still quite rough and needs major revision before publication.

We thank reviewer #2 for the comments and suggestions which will help to improve and clarify the article.

- *For the new version of the article we enhanced the temperature reconstruction in some periods. Due to the ongoing discussion among the co-authors, we noticed that the mentioned temperature bumps (DO 21 and 23, discussed on p. 4109, line 16-19 in CPD) and the partial significant accumulation decreases (discussed on p. 4118, line 1-26 in CPD) are most probably not real and should be improved. This will be done in the revised version. Consequently, Fig. 5 will be removed. The main conclusions of this paper will not be altered due to revised and updated model adjustment.*
- *A new figure will be included in the revised version to illustrate the absent relationship between the duration of Greenland stadials and NGRIP temperature amplitude (discussed on p. 4111, line 21-p. 4112, line 3 in CPD).*
- *The article will be partly rearranged to improve consistency and legibility.*

The comments are answered below.

General comments: The organization of the paper lacks in balance and focus. Many of the sentences are very difficult to read. From the way of writing, it seems that many of the findings are already being made in earlier studies. Therefore, it is important to clarify and emphasize what are the added values from the current analyses. The introduction contains very general description of the glacial climate, which is not discussed in the later section and so not relevant for the current paper. It should be deleted or moved to later discussion if relevant discussions are made. Then, the introduction should be rewritten to introduce materials about issues discussed in the main body of the paper.

The introduction will be significantly shortened and focused on issues discussed in the manuscript. It will be revised in major parts.

Specific comments:
P4100-P4104:

Current introduction contains too general information but lacks necessary information. As this paper bases upon many earlier studies of NGRIP d15N studies, more information on these papers and important issues should be described in introduction. Some materials about general glacial climate should be moved into discussion section and integrate them with your analyses.

Will be taken into account.

P4104,
Line 19: The methodological issue is one of the main themes of the paper. Therefore, the current issues and problems in d15N temperature calculation should be described concisely in introduction.

The section about the damping will be rearranged in the paper.

P4105,
Line 10: Put references after " occurs below the LID".

Will be taken into account.

Line 14: Insert " during surface warming" after "at the bottom of the firn".

Will be taken into account.

Line 21: Temperature in firn does not become truly uniform owing to constant climate fluctuation and geothermal influence.

You are principally right, but we explain here the effects of thermal diffusion in an idealised case. To take also other influences ("constant climate fluctuation") into account would make it more complicated for the reader to understand the basic mechanism. Unpublished results from M. Guillevic and P. Kindler, where two models are compared, the Schwander model (heat diffusion only to 1300m depth) and the Goujon model (heat diffusion from surface to bedrock) show that a geothermal influence for the NGRIP site can only be detected during the LGM. The induced thermal signal is about -0.008 ‰ in this period and therefore smaller than the measurement uncertainty of the d15N data measured at the University of Bern (KUP).

Line 23: You need to define delta age and delta depth.

Will be done.

P4106
Line 14: Why is the Holocene temperature not reconstructed, although you have data? This needs explanation.

We have only NGRIP d15N data until to the beginning of the Holocene. The reconstruction covers the full time period for which data are available without gaps.

Line15: Please explain what are "bags".

The word "bag" will be replaced.

Line 16-20: It is not clear. Please rephrase.

Will be partly rewritten.

P4107
Line 7-10: It is not clear. Please rephrase.

It means that the model input, once on the ss09sea06bm time scale and once on the GICC05 age scale does not lead to major changes in the model output.

Line 16: Why did you use 200 year? It seems longer than normal smoothing. Please explain. This will affect reconstruction of the magnitudes of temperature changes significantly.

A 200 yr spline of the d18O input data was chosen to approximately match the variability in the measured d15N data by the model d15N. We have tested several cut-off periods and there are indeed influences, however, it needs to be compared with the effect of the d15N dampening signal during the bubble enclosure process, which is for 200 years of the same magnitude.

Line 20: You adjust temperature and accumulation rate to fit d15N and delta age. How much are temperature and accumulation rate independent? Would it be possible to fit observed and modeled d15N and delta age by only adjusting temperature? If oxygen isotopes don't capture temperature signals, can you still reconstruct temperature from this method? Changing alpha and beta basically assumes that oxygen isotopes capture temperature singles with the relationship changing with time, but in some cases oxygen isotopes may be totally independently changing with temperature.

We do not know how much temperature and accumulation are independent. The used accumulation rate (ss09sea06bm time scale, NGRIP Members, 2006, (Nat); Johnsen et al., 2001, (JQS)) is a modeled one, and probably overestimates the accumulation in some periods (e.g. Huber et al., 2006, (EPSL); Guillevic et al., 2013, (CP)). So, our adjusted accumulation rate which deviate from the published (maybe partly imprecise) accumulation rate (Johnsen et al., 2001) do not necessarily imply a changing temperature to accumulation relationship.
As you can see in Fig. 4, it is not possible to adjust both, d15N and Dage by temperature variations only. Dage will be underestimated up to 400 yr in the period 10 to 60 kyr when using 100% of the accumulation rate. Therefore, an accumulation rate change is required.
It may be that temperature and d18Oice are some sort of decoupled on a short time scale (years), but probably not on timescales (100 to 200 yr) of the temperature reconstruction done here. So, with the additional constraint Dage, it should be mostly possible to reconstruct the temperature. However, during relatively stable periods, such as the interstadials of DO 23 and 21, where clear Dage points are missing, the reconstruction is more delicate. This will be mentioned in the revised version of the paper.

Line 25: Also specify time step.

The word "step" in line 25 on p 4107 belongs to the first step of the model adjustment.

P4108
Line 27-29: It is not clear.

Will be rewritten.

P4109
Line 14: Is it possible to estimate the uncertainties of the reconstructed temperatures for the entire period by comparing observed and modeled d15N?

No, even if you match the measured d15N perfectly with the model, one has uncertainties mainly due to the d15N measurement uncertainty.

Line20: “had to” is awkward. Just say “specified”. Also change “had to” in other sentences.

Will be adjusted.

P4110
Line 10-26: Difficult to follow. Please rephrase sentences.

Will be reformulated.

P4112 [P4111 (?)]
Line 21: What is “linear relationship”? This paragraph is not clear. Please rephrase it.

[p. 4111 (?)] The relationship between Greenland stadial durations and the corresponding AIM temperature amplitudes is linear, see EPICA Community Members, 2006, Nature, Vol. 444, pp. 195-198, Fig. 3.

Paragraph will be partly rewritten.

P4113
Line 26: “the cold state“ needs more explanation.

Change to “initial cold state”. The damping of a signal is determined by the enclosure processes at the bottom of the firn. Colder temperatures lead to a slower gas enclosure and therefore to a more pronounced damping. In case of a rapid surface warming, the gas is still enclosed at the bottom of the firn at colder temperatures due to the initial cold temperature (cold state). We will reference to figure 3.

“On the other hand,. . ...” is not clear to me.

We give two reasons why the used assumptions in our damping calculations are not fully correct. First, the d15N signal is created in the firn itself and not at the surface. Second, we use for our calculations a constant age distribution for the smoothing. As the temperature at the bottom of the firn will increase (with a time delay) after the initial surface warming, air is quicker enclosed and therefore the age distribution will get narrower (less damping). But this changing age distribution cannot be enclosed in the used model. So we consider a rapid DO event where we can assume that the signal of the surface warming is still enclosed at the bottom of the firn at the initial cold temperatures.

Line 27: “increasing length” Do you want to say “increasing amount”? This sentence is not clear. Please rephrase.

[p. 4114 (?)] With “increasing length of the temperature rise” we mean the length of the time period in which the temperature is increasing. We think the sentence should be clear enough. We will rephrase it with the use of the term “duration”.

P4115:
Line10: if the 200 yr spline is appropriate, you should say your temperature reconstruction is for multi-centennial scale temperature variation. However, the magnitude of smoothing should also depend on the temperature and accumulation rate. So, ideally you need to change the smoothing function or age distribution with time.

We adjusted the modeled d15N to the measured data. In general, measured d15N variations can be matched well when a temperature input is used which is based on 200 yr-splined d18Oice data. If the measured d15N variations exhibit in some periods shorter time scale variations, they were adjusted in step 3 of the adjustment procedure by manual tuning. So, modeled d15N is in agreement – as far as possible and reasonable- with the measured data. You are right; the smoothing depends on temperature and accumulation, as written in Sect. 3.2. Basically not the d18Oice data should be splined depending on temperature and accumulation but the smoothing should be included in the firn densification models which are used for the temperature reconstructions. However, at the moment, there is to our knowledge no such model available.

Line 9: "closely follow obliquity" is not accurate as it has only three cycles and third cycle does not show a good agreement. It is possible that it is just a coincidence. So, it is important to calculate correlation coefficients with confidence interval considering autocorrelation.

[p. 4121, line 8 (?)]
Indeed, the expression using closely is rather strong and we skip this term. However, we cannot understand that an autocorrelation would be of help here. When considering only fully independent α values in Figure 7 (each fifth point) the variation still follows obliquity.

P4123:
Line 6: the Holocene is not part of the reconstruction.

Will be changed to "beginning of the Holocene".

Line 9: Write uncertainties of temperature reconstruction.

Will be done.

P4135:
Fig. 1. The difference between red and green is not clear. You better use different period to illustrate improvements after each step?

The green curve is obtained after adjustment step II, the partly additional manual adjustment – where needed- is shown in red (step III). As some of the manual adjustments are only of minor extent, the green and red curve differ not a lot in these periods. For the graph, we choose a period which covers the newly measured data and shows well the idea of the adjustment, which is the case for DO 4 to 7.

Fig. 2
It is too small. As this is the main figure of this paper, this should be bigger and well-illustrated. You may want to use different figure number for b, c, d. Temperature reconstructions by earlier studies should also be plotted together with this reconstruction to illustrate difference and robustness.

The size of the figure should be bigger in the final version. We think that all important data (measured and modeled d15N, temperature, d18Oice and H events) are included. More information would make the figure more difficult to read. If the reviewer has concrete ideas of what should be added ("well-illustrated"), we will consider these suggestions.
As the sub-plots b, c, and d are zooms of plot a, we would like to keep them in the same figure to enable the reader to compare the plots easily.

We think that additional temperature reconstructions from previous publications in the same figure would complicate to read it. It would also make no sense to add them because some of the publications focused on the temperature jump only and not on a continuous reconstruction (publications from Capron et al. 2010 (CP), 2012 (GRL)).

"Technical corrections" Readability need to be checked thoroughly after the next revision.

Will be done.

References: There are numbers after each reference. What are these?

The numbers indicate the page number of the discussion version, where the references appear. They will disappear in the final version.