Clim. Past Discuss., 8, C3501–C3510, 2013
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Climate of the Past Discussions

CPD
8, C3501–C3510, 2013

Interactive Comment

Interactive comment on "Glacial-interglacial dynamics of Antarctic firn columns: comparison between simulations and ice core air-δ^{15}N measurements" *by* E. Capron et al.

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Capron et al, present an impressive compilation (including new data) of d15N data from firn cores in Antarctica. Those data are in conflict with what d15N should be according to firn densification models during glacial periods. They offer three hypotheses for the origin of this mismatch: faulty input parameters to the model, convective zone, and snow to ice metamorphosis susceptible to impurities in the snow. Several options to solve the problem are discussed. The manuscript reads very hard. The discussion of reasons for the model data mismatch is not very clear. Several points are taken up in different sections. The manuscript needs to be written much more to the point and

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Discussion Paper

shortened.

->We did our best to shorten and, hopefully, to provide a clearer and shorter manuscript. For that purpose:

1-We follow the reviewer's suggestion and put all the methodological details about Δdepth determination in the Appendix of the revised manuscript. As a result, it reduces considerably Section 5.2 in the revised manuscript.

2-Both JRI and BI ice cores now benefit from some glaciological modelling to derive their respective chronologies. It enables:

-To propose more coherent manuscript and figures with all the δ15N profiles displayed on an age scale (Figure 4 and Figure 5). It enables also to perform modelling only with the Goujon model.

-The Section 3.2 on ice core timescale has been shortened and details on how JRI and BI timescales have been derived are given in the Appendix.

-We have now an estimate of the β parameter from Equation (4) for JRI and BI through the glaciological modelling, so that, we do not present and discuss anymore two scenarios of past accumulation rate in the main manuscript. This enables us to present a clearer and shorter description of the modelled results, together with the comparison with the datasets for those two sites.

3-Section 5.3 has been modified as well as the conclusion and hopefully, we now highlight better what are the important finding of our study. We hope that the reviewer will be satisfied with this shorter version of the manuscript. In the following, we answer point by point to his other comments/suggestions.

The nomenclature is confusing. Speaking about d15N as data and as a model parameter needs to be clearly distinguished. I suggest using 'diffusive column height' as the model parameter and then adding another axis to the figures.

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->We do not feel comfortable with this suggestion. Indeed, gravitational δ15N follows the isobaric equation (Equation 1 in the manuscript) and thus, it is not simply proportional to the diffusive column height (noted z, in the equation) but is also affected by the temperature (noted T) in addition to the temperature effect on the diffusive column height itself. As a result, we can only compare the measured δ15N with a modelled δ15N on Figure 4 and Figure 5. However, to make it clearer in the text which δ15N we are referring to, we introduced two notations: we systematically refer to DATA-δ15N when describing δ15N measurements and MODEL-δ15N when mentioning δ15N simulated with the firn densification model. We hope that it is a clearer way to describe and discuss our results.

There are too many figures in the manuscript; figures 4, 5 and 6 can be combined.

->We have combined Fig 4, 5, 6 and 7 from the CPD manuscript into one single figure (which is now Figure 5, see below our answers to the comments) in the revised manuscript. Figure 9 from the CPD manuscript is not anymore in the main manuscript and has been moved to the Appendix.

Specific remarks Page 6054, line 21: 'continuous snow material' should maybe be replaced with 'homogeneous'.

->Done

Page 6059, lines 18-26: How big is the effect of where the diffusion stops? Why take 21%?

->We have run the Goujon model for the EDML site with 3 different closed porosity thresholds to define the base of the LID: 13%, 21% and 37%. These values have been defined through total gas and firn air measurements (Goujon et al., 2003). Considering this range of closed porosity in the three simulations, we have observed that the effect of where the diffusion stops is not large considering the δ15N levels and variations we are discussing in the paper. Indeed, the mean standard deviation on the LID definition based on those three values along the EDML record is 1.7m and it leads to a change in δ15N values of 0.009 permil. As the lack of data unable us to set precisely for each site a closed porosity threshold to define the LID and considering that the sensitivity tests show such a small impact, we arbitrarily decided to apply to the model the 21% value which has been defined at the Vostok site. To be clearer on that in the new manuscript, we have rewritten the paragraph in the revised manuscript.

Page 6060, line 3: 'configuration of the BI drilling site'. I guess what is meant is the flow regime of BI.

->Yes it does but the sentence including "configuration of the BI drilling site" has now been removed in the new manuscript.

Page 6061, line 15: Typo Dd18O should be d18O.

->Done.

Equation 1: Delta mass should have the unit of kg/mol not g/mol. The delta value is given in per mil which is not obvious. Per mil is a prefix; therefore delete the factor of 1000 in the equation.

->Done.

Page 6055, line 17: the Goujon and Arnead models are no longer the 'most recent' once. Replace 'most recent' with e.g. 'state of the art'.

->Done.

Section 5.2: The title of this section is confusing. Also the entire section can go into the appendix and be replaced with the last sentence referring to Parrenin et al., 2012b.

->In the revised manuscript, the section is now named: "5.2. Absence of a deep glacial convective zone at EDML". We also follow the suggestion of Reviewer 2 and we now have put all the methodological details on the Δdepth determination in the Appendix at the end of the paper.

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On several occasions there is claimed that 'the successive patterns of d15N trends during the deglaciation' is similar in the d15N data and model output. That is hard to see and I would like to see an in depth analysis of that statement.

->By such a statement "the successive patterns of δ15N trends during the deglaciation", we mean that, on some particular sections of the deglaciation, the model is able to reproduce the same trend that the one measured even if the absolute δ15N levels are not the same, except for TALDICE. For example during phase 1 and phase 3 in the new Figure 5.d, the model predicts increases of δ15N and we do measure δ15N increases. For TALDICE, the δ15N tendencies over the 3 phases and the Early Holocene (EH) are predicted by the model. Over the EH, phase 2 and phase 3, the absolute TALDICE DATA-δ15N levels are reproduced as well. We have changed the text in the revised manuscript and we hope that it is clearer now.

One of the main points of the discussion is the different response of the firnification models to accumulation and temperature changes. This very important point (including figure 8) should be introduced early on in the manuscript.

->We have followed this suggestion and we introduce now the different responses of the LID in firnification models to accumulation and temperature changes in the introduction. Consequently, we have also moved forward Figure 8 from the CPD manuscript, which is now referred as Figure 2 in the revised version. We have added onto the figure two arrows to emphasise on the respective impact of temperature (horizontal black arrow) and accumulation rate (vertical black arrow) on the LID and thus on the δ15N (please, see the revised figure 2 below).

We are grateful to the reviewer for his valuable comments and recommendations on how to improve our paper.

New Figure 2 caption: δ15N evolution (‰ versus accumulation rate and temperature calculated by the Arnaud model (2000). Scenarios of past temperature and accumulation rate evolution used as model inputs (see Section 3.3 for details) are plotted for

EDML (blue), EDC (turquoise), TALDICE (green) and BI (purple). Present climatic surface conditions are indicated for each site (black marker). Note that in response to an increase in accumulation rate, the LID and consequently the δ15N increase (vertical arrow) while in response to an increase in temperature, the LID and consequently δ15N decrease (horizontal arrow).

New Figure 4 caption: Experimental and modelled results on the JRI ice core. Left panel: all new δ15N measurements on a depth scale. Right panel: δD (grey, Mulvaney et al., 2012), MODEL-δ15N (red, this study) and DATA-δ15N (blue, this study) over the time interval 7-30 ka. Note that the water stable isotope variation suggests an unrealistically fast deglaciation compared to all other Antarctic records, related to an unconformity present in the early deglacial interval in the JRI ice core (Mulvaney et al., 2012). This prevents us to discuss the MODEL-δ15N along the deglaciation and as a result, we only comment on the mean MODEL-δ15N levels for LGM (Last Glacial Maximum) and EH (Early Holocene) climatic conditions.

New Figure 5 caption: Experimental and model results for EDML, TALDICE, BI and EDC ice cores. Three phases over the deglaciation (1. from the LGM to the ACR; 2. the ACR; 3. from the end of the ACR to the EH) are indicated by vertical dashed light grey lines.

a)TALDICE, Left panel, from top to bottom on the TALDICE1 age scale (Buiron et al., 2011): δD profile (grey; Stenni et al., 2011, new δ15N data (black diamonds), modelled TALDICE δ15N (red curve), “Acc-δ15Nmod”curve (pink) which represents δ15N simulated in response to accumulation changes only, and “Temp-δ15Nmod” curve (purple) simulated when considering only the effect of temperature change. Right panel, from top to bottom on the depth scale: Dust concentration profile (green; Albani et al., 2012), new δ15N data (black diamonds).

b)EDML, Left panel, from top to bottom on the Loulergue et al. (2007) age scale: δD profile (grey, Stenni et al., 2010), published δ15N data (black diamonds, Landais et al., 2006), new δ15N data (blue diamonds) and modelled δ15N (purple curve). Right panel, from top to bottom on a depth scale: Dust concentration profile (light green; Ruth et al., 2008) and Ca2+ concentration (dark green; Fischer et al., 2007), δ15N data (black diamonds; Landais et al., 2006) and new δ15N data (blue diamonds). Red rectangle highlights δ15N data used to infer Δdepth estimates (from 1363.2 m to 1387.8 m).

c) Berkner Island, Left panel, from top to bottom on an age scale (F. Parrenin, perso. comm.): δD profile (grey, R. Mulvaney, pers. comm.), new δ15N data (black diamonds) and modelled δ15N with Scenario A (β equal to 0.0156; violet curve) and with Scenario B (β equal to 0.0065; pink curve). Right panel, from top to bottom on the depth scale: Dust concentration profile (light green; this study, see Lambert et al., 2008 for experimental details for dust concentration measurements), new δ15N data (black diamonds)

d) EDC Left panel, from top to bottom over Termination I (TI) on the EDC3 age scale (Parrenin et al., 2007a): δD profile (grey, Jouzel et al., 2007), δ15N data (Dreyfus et al., 2010) and modelled δ15N (purple curve) Right panel, from top to bottom on the depth scale over Termination I (TI): Dust concentration profile (green, Lambert et al., 2012), δ15N data (Dreyfus et al., 2010).

Interactive comment on Clim. Past Discuss., 8, 6051, 2012.

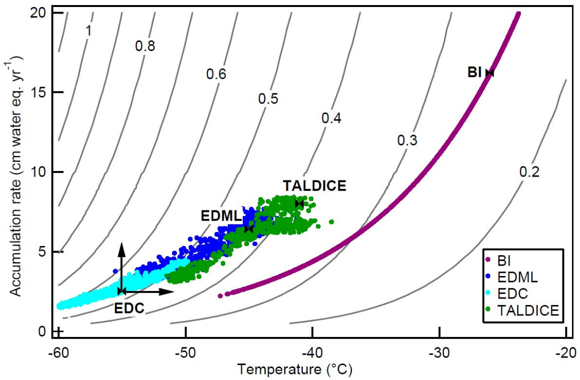

Fig. 1. New Figure 2

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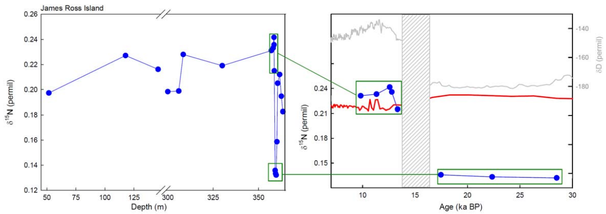

Fig. 2. New Figure 4

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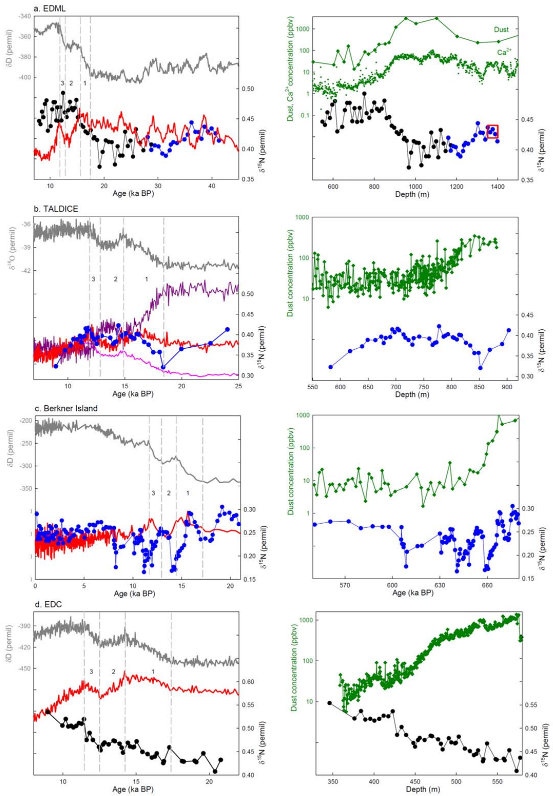

Fig. 3. New Figure 5