Replies to the reviews of

The effect of precipitation seasonality on Eemian ice core isotope records from Greenland

W.J van de Berg, M.R. van den Broeke, E. van Meijgaard and F. Kaspar.

We would like to thank the reviewers for their constructive comments and apologize for our late response. Below, we would like to discuss how we have addressed these comments. Detailed comments that are not discussed below are adapted as suggested.

Reviewer #1

1) How is the relation between T_c and $\delta^{18}O$? ... Since the title of the paper mentions both ice cores and isotopes you should elaborate on what you are leaving out by using T_c and not δ18O.

We will extend this discussion in the introduction, as also requested by Reviewer #2. The suggested papers are cited, except for Werner and Heimann (2002). Werner and Heimann (2002) investigate the dependence of $\delta^{18}O$ on external parameters but do not dwell into the relation between T_c and $\delta^{18}O$. It should be noted that in our manuscript T_c is similar to the arrival temperature in Sodemann and others (2008) and the local inversion temperature in Werner and Heimann (2002). The revised text is now:

"Since the isotopic depletion is not simulated in the model, changes in the moisture source location, i.e. effective initial temperature on which fractionation started, are not included. Johnsen et al. (1989) showed that the moisture source location of Greenland responds to climate conditions at mid and high latitudes; the moisture source shifts to lower latitudes for colder climate conditions. The moisture origin has been proven to shift rapidly under glacial conditions (Masson-Delmotte et al., 2005), but also with the phase of the North Atlantic Oscillation (Sodemann et al., 2008). Using a fractionation model of intermediate complexity, Sodemann et al. (2008) concluded that for effect of the North Atlantic Oscillation (NOA) on $\delta^{18}O$, moisture source changes and air temperature changes contributes roughly equal to the variability in $\delta^{18}O$. Moreover, the cloud arrival temperate, which is comparable with T_c in this study, appears to be a very good proxy of $\delta^{18}O$, independent of the NAO phase, with a regression slope of about 1 ‰/K (Sodemann et al. (2008); Figure 8a). This strong correlation between cloud arrival temperature and $\delta^{18}O$ not necessarily exists for moisture source changes between preindustrial conditions and the Eemian. Therefore, Eemian changes in T_c most likely resemble a significant fraction of the change of Eemian $\delta^{18}O$, but it is not possible to quantify this contribution with certainty."

Furthermore, we added to the final conclusions:

"As a result, the anomaly in T_c (-1 to 3 K) exceeds the anomalies in T_{2m} and T_{500hPa} (both 0 to 1 K). *For comparison, if the present-day relation between cloud arrival temperature and $\delta^{18}O$ for NAO variability would be valid for these anomalies, these changes in T_c relate to -1 to +3 ‰ change in $\delta^{18}O$*. The results of our study compare well with the estimated precipitation effect on Eemian $\delta^{18}O$ as presented by Masson-Delmotte et al. (2011)."

2) Does the ECHO-G model really match Eemian proxy data, and which climate feedbacks processes are left out the simulations?

In recent years a couple of new proxy compilations have been published which were not cited in the first version of the manuscript. Turney and Jones (2010) estimated that the global mean temperature during the warmest part of the Eemian was 1.5 ± 0.1 K higher than in AD 1961-1990, for which a global mean 2 m temperatures (T_{2m}) of 14.0 ± 0.5 °C was observed (Jones et al., 1999). McKay et al. (2011) estimated a 0.7 ± 0.6 K higher sea surface temperature (SST) during the warmest part of the Eemian and the Holocene. ECHO-G simulates global mean T_{2m} of 14.6, 13.1 and 13.0 °C for present-day (Min et al., 2005), preindustrial and Eemian climate (Kaspar et al., 2007), respectively. Modeled global SST for the Eemian are also 0.1 K lower than modeled for preindustrial conditions. ECHO-G in general faithfully reproduces present and past climates. Based on these numbers, we conclude that ECHO-G underestimates the global mean Eemian T2m by about 1 to 2 K. However, the strong increase of Northern Hemisphere seasonality, driven by enhanced summer insolation, increasing the near-surface temperature seasonality by 4.6 K, is well represented in ECHO-G. ECHO-G is a coupled ocean-sea-ice-atmosphere model without dynamic vegetation, dynamic ice sheets and enhanced ice sheet runoff as freshwater source of the ocean. These feedbacks might be the source of the annual mean cold bias of Eemian simulations.

The ECHO-G representation of Eemian climate has thus a 1-2 K cold bias, but resembles the most important features of the Eemian climate well enough to allow the analysis presented in this manuscript. Relevant for the results presented in this manuscript are precipitation changes driven by the larger seasonality of the Eemian climate.

The latter considerations are added to the manuscript, replacing the last paragraph of section 2.1, by

"The climate in RACMO2 is largely controlled by the boundary conditions from ECHO-G. Global mean modeled T_{2m} temperatures in ECHO-G are 13.1 and 13.0 °C for preindustrial and Eemian climate, respectively (Kaspar et al., 2007). For comparison, the global mean preindustrial and Eemian temperatures were about 0.5 °C lower (Jansen et al., 2007) and 1.5 ± 0.1 °C higher (Turney and Jones, 2010), respectively, than the 1961-1990 average of 14.0 °C (Jones et al., 1999). The ECHO-G driven preindustrial simulation is a few degrees colder over Greenland than the ERA-40 driven recent-past simulation, both near the surface as through the troposphere. Comparably, global mean SST was 0.7 ± 0.6 °C higher during the Eemian compared to the 1961-1990 period (McKay et al., 2011). ECHO-G, however, simulates a 0.1 °C lower global mean SST during the Eemian compared to the preindustrial climate. The preindustrial ECHO-G simulation has thus a small cold bias, for the Eemian, the model bias on global mean T_{2m} is about 1 to 2 °C. This model bias could be due to vegetation feedbacks or oceanic responses to enhanced ice sheet runoff, two processes that are not included in the ECHO-G model. The Eemian ECHO-G simulation shows no global annual mean warming compared to the preindustrial simulation, but seasonal changes are large. Most importantly, 4 °C higher summer temperatures are simulated for the Northern Hemisphere land area, i.e. north of 30° N. As a result, the seasonal cycle of this region increased with 4.6 °C. This Northern Hemispheric summer warming is also observed, for example, summer lake temperatures on Baffin Island, Arctic Canada, are 5 to 10 K higher during the Eemian than observed now (Francis et al., 2006). RACMO2 simulates about 3 to 4 K higher July temperatures for Eastern Baffin Island compared to the preindustrial climate. Francis et al. (2006) noted that summer lake temperatures exceed air temperatures due to the direct heating of the lake water by sunlight. The stronger Eemian summer insulation could have increased this lake-atmosphere difference, which can explain, besides the overall model cold bias, the difference between the proxy estimate and model output."

3) Why use the ERA-40 data?

ERA-40 is the currently the best global description of the recent past climate of 1961-1990. RACMO2 simulations driven by ERA40, therefore, can provide the best estimate of contemporary condensation temperature. If this analysis would be left out, it would be impossible to qualitatively assess the uncertainty of ECHO-G climate results. Of course, RACMO2-ERA40 results are not perfect, and differences between this simulation and the RACMO2 run driven by ECHO-G preindustrial climate are partly due to the difference in climate and partly due to ECHO-G model shortcomings. Therefore, this assessment is qualitative and cannot been made quantitative.

4) In extension of the conclusions of this paper some speculations would be in order: what perspectives do the results of this study offer? How do we benefit from knowing the uncertainty in ice core reconstructions that T_c induces? And what is the next step?

The main conclusion is that $\delta^{18}O$ and atmospheric temperatures are not that well correlated to each other as sometimes assumed now. When reconstructing past temperatures with using ice core data only, this additional uncertainty is not very beneficial.

However, it could, for example, explain why ice core estimate of Eemian temperature (NEEM community members, 2013) is conflicting with other proxy data and the bounds provided by ice sheet modeling results. It is surprising that the center of the Greenland ice sheet experienced a larger warming than many (sub)-arctic land proxies, although the sub-arctic Northern Hemispheric land area responds most effective to snow-albedo feedback and drives the polar amplification of climate signals. Furthermore, the recent strong response of the Greenland Ice Sheet to a warming much less than 8 K (e.g. Nghiem et al., 2012), as well as ice sheet modeling results (e.g. Helsen et al., 2013) indicates that it is very likely that the Greenland Ice Sheet would had collapsed if the Eemian was 8 K warmer over Greenland than today.

The existence of this uncertainty can bring past climate modeling efforts and the interpretation of stable isotope records closer together. This study shows that climate modeling is required for the interpretation of ice core records, which are on their turn essential for climate model

evaluation. Masson-Delmotte et al. (2011) is a good example how climate modeling and ice core data could eventually merge into one consistent estimate of past climate.
These comments are added in condensed form at the end of the manuscript with
"This uncertainty can only been reduced by explicitly modeling the Eemian climate $\delta^{18}O$, patterns with GCMs that included isotope physics. Once these models match Eemian ice core records as well as other proxies, the range of possible Eemian warming over the Greenland ice sheet will be reduced."

Detailed comments

P270, L18-20: Indeed, water molecules with heavy isotopes have different water vapor pressures than 'normal' water molecules, not the isotopes themselves. This corrected as suggested

P271, L5-6: "The precipitation that ends up in an ice core..." reformulate to "The moisture that eventually precipitates over an ice core site...".
We have chosen for "*The moisture that eventually is deposited at an ice core site…*"

P270, L10: The two proposed original publications are cited. Nevertheless, the first proposed article is probably not accessible for most of the readers and the second is not peer-reviewed.

P271, L15: Dahl-Jensen et al. (Nature 2013) reported Eemian anomalies of +8 °C at the NEEM site.
This sentence is rephrased to:
"For example, Eemian $\delta^{18}O$ values at NorthGRIP and NEEM are about 3-4‰ higher than present. Using the temperature-isotope relation observed for the present interglacial, this represents an Eemian warming of 8 ± 4 K (NEEM community members, 2013)."

P271, L19 Does the ECHO-G simulation really compare well to proxy data?
See the discussion above.

P271, L27: Reference added.

L271, L29: Is that 1 permil in annual mean?
Yes, it is; "*annual mean*" is added to the specific sentence.

P273, L5-7 Are the correlations spatial (which area?) or temporal (which time period?).
These correlations are spatial and cover the Greenland ice sheet. Temperature data are from the GC-net and K-transect dataset (Ettema et al., 2010, Figure 4a); for SMB, 500 observations across the ice sheet from various sources are used (Ettema et al., 2009).

L274, L6: You use 125 kyr to represent the Eemian. How is this timing compared to the warmest part of the Eemian?
125 kyr BP is very close to the point of maximum insolation and in the period fo which the largest anomalies in δ18O are observed (NEEM community members, 2013).

P274, L18-22: How does this work with warmer lake temperature? I would expect the land to warm up faster due to smaller heat capacity.
I suspect that for shallow lakes, the lower albedo of water compared to land is more important than the higher heat capacity of water compared to land. For the manuscript, however, the exact mechanism is not very important.

P278, L19-20: What is the reason for the decreasing condensation altitude with latitude – can you explain this? Is it because of moisture content and air pressure?
It is predominantly due to the lower temperatures. Cold air can contain less humidity and thus can produce less precipitation. This decreases the difference between the wet and dry adiabatic lapse rate, allowing a larger vertical temperature gradient for colder surface conditions. Furthermore, the tropopause is at a lower elevation for higher latitudes, limiting precipitating clouds to lower elevations. Therefore, to specific sentence is added, "*Over the ocean, the effective condensation altitude decreases with latitude due to the colder atmospheric conditions, …*"

P280, L22-26: Perhaps replace these two sentences with something like "For a consistent analysis of

Eemian anomalies we compare the Eemian RACMO2 simulation with a preindustrial RACMO2 control run, both with boundary conditions from the ECHO-G model. Before the analysis of the Eemian simulation we compare the preindustrial control run with the ERA-40 driven run analyzed in the previous sections".

We have used an adapted version of the suggested rephrasing:

"*For a consistent analysis of Eemian anomalies, the Eemian RACMO2 simulation is compared with a preindustrial RACMO2 control run, both with boundary conditions from the ECHO-G model. Therefore, the preindustrial control run is compared with the ERA-40 driven run analyzed in the previous sections.*"

P281, L3: Is the ECHO-G cold bias well known for other studies? How can you be sure it is not a genuine difference in climate between the recent and preindustrial period?

In general, ECHO-G gives very reliable representations of climate. We are not absolutely sure that it is a model bias, but the 2-3 K lower regional temperatures simulated by ECHO-G are more than we expect to be plausible for the approximate 0.3 K cooling for the Northern Hemisphere. The specific sentence is slightly adjusted:

"The preindustrial climate in the Northern Hemisphere was colder by about 0.3 K than the recent-past climate (Jansen et al., 2007) due to the absence of anthropogenic climate warming, but this Figure shows that ECHO-G has likely a cold bias over Greenland."

P281, L21-22: Here you are discussing the Eemian climate anomalies in general, and Greenland is be affected by changes outside of the model domain. The amplitude of the annual cycle is also affected by the decrease in winter insolation south of the Arctic Circle.

That is correct. The specific sentence is extended: "*The enhanced seasonal temperature cycle is caused by the enhanced summer insolation and decreased insolation during the Northern Hemisphere winter.*"

P281, L22-24: What exactly do you want to say with the sentence "This additional insolation is efficiently absorbed by the earth and released to the atmosphere, since the Northern Hemisphere has a large fraction of land"? Maybe strike this sentence.

This sentence is removed.

P282, L1-2: This lack of warming is at least partly contradicted by proxy data (Turney and Jones 2010; McKay et al. 2011).

That is true; therefore, this sentence is rephrased to

"The RACMO2 and ECHO-G simulations displays no global annual mean warming, in contrast to Eemian anomaly of about +1 K from proxy data (Turney and Jones, 2010; McKay et al., 2011), but clearly, the Northern Hemisphere summer anomaly is much larger than the annual mean anomaly."

P284, L11-27: I find this discussion of the impact of sea ice somewhat superficial and not up to the standards of the rest of the manuscript. If you want to assess local or regional effects of sea ice I suggest you look at some parameters like changes in wind and vapor advection.

We removed this paragraph because it distracted from the conclusion that primarily stable isotope data from Northern Greenland are susceptible to be affected by changes in precipitation seasonality. Whether this is related to sea ice changes is for this conclusion not relevant. We added, therefore, the following text after P283, L28:

"Maximum contribution is not only modeled for Northern Greenland, but also along the western coast of Greenland. Concluding, the change in T_c has the largest positive anomalies compared to the change in T_{2m} in regions for which in the present-day climate precipitation is mostly received in the summer months and experienced a significant summer warming and precipitation seasonality enhancement during the Eemian. On these three factors, the Eemian precipitation seasonality change is least certain, nevertheless, these model results show that primarily stable isotope data from Northern Greenland are susceptible to be biased by changes in precipitation seasonality."

Comments to figures: Subplot indexing a), b)… should be made more clear in figures 3 and 4.

The a) and c) indexes in these figures are made white.

Reviewer #2

1) The title claims that the manuscript investigates "the effect of precipitation seasonality on ice core isotope records from Greenland", but I don't see this sufficiently dealt with here to use it as a title. It seems something along the lines of "Why precipitation seasonality could be important to interpret Eemian ice core records from Greenland" would be more appropriate.

We have changed the title to "*Importance of precipitation seasonality for the interpretation of Eemian ice core isotope records from Greenland*". The quantitative effect of precipitation is indeed not shown, but its importance for the interpretation is the main point of the manuscript.

2) More details on the Eemian climate as simulated by ECHO-G should be given in the paper. How strong is the decadal variability, and how relevant is it for this analysis? How was this particular analysis period chosen, and have you compared to another 30yr time period? How persistent is the negative SST anomaly W of Greenland shown in Fig. 4 in the Eemian climate simulation, and how relevant is this for your downscaling experiment?

We extended the comparison of the Eemian simulation with proxy data, as discussed above. Furthermore, we quantified the ranges of decadal variability, but this decadal variability is not important for the results presented here. We did not run RACMO2 for other 30 yr periods due to limited available computer time. The negative SST anomalies are persistent trough the whole Eemian simulation, which is now mentioned in the manuscript. Lower SST could lead to less water vapor uptake from the ocean and less precipitation over the ice sheet. A small regional decrease in precipitation is found for Greenland south of 72° N (Van de Berg et al., 2012, Figure 2c) which could be related to this SST decrease. No changes were observed for Northern Greenland.

The quantification of decadal variability is added to the manuscript by:

"The climate simulated by ECHO-G has significant decadal variability, for example, 30 year averages of annual means of global mean 500 hPa temperature, global mean SST and 500 hPa temperature above Greenland have a range of 0.16 K, 0.16 K and 0.5 K, respectively. For the RCM simulations, periods with a representative 30 year-mean climate within the whole ECHO-G run were chosen. Largest deviations of these periods to the integration mean are found for the sea surface temperature (SST), but all regional differences of SST are less than 0.4 K."

3) As the authors are already aware, condensation temperature is only one part of the processes governing isotopic fractionation. When interpreting condensation temperature as an isotope proxy you basically make the assumption that changes in atmospheric transport can be neglected. I find this a rather strong assumption, since with changing seasonality it could as well be expected that the atmospheric transport patterns change, e.g. due to different cyclone tracks. This implicit assumption should be more clearly stated and discussed in the introduction and conclusions.

The condensation temperature as defined here corresponds more the arrival temperature as used in Sodemann et al. (2008). Information on atmospheric transport patterns is thus not assumed to be implicitly included. In order to avoid this confusion, the following sentence is added to the fourth paragraph of the introduction:

"T_c does not reflect the initial starting temperature of the fractionation process, but the condensation temperature of the precipitation, locally at arrival."

4. Why is it necessary to seperate some material into a supplement? Consider shortening the description of the present-day climate which contains many obvious statements and incorporating the relevant figures from the supplement into one coherent manuscript.

We inserted Figures SF1(a-c) into the manuscript, between Figures 3 and 4. The other Figures from the supplementary materials were dropped. We shortened the manuscript where possible.

P 271, L. 23: Not clear what you mean by "moisture source elevation", the moisture source should be at the surface.

This is changed into *"evaporative origins of moisture"*.

P272, L5: The discussion is extended as requested.

Pg. 273, L. 25: How large was the simulation domain for the regional model?

This information is added: "

"The 11 km grid (~ 2700 x 3400 km) extends from the coast of Newfoundland to well beyond

Svalbard. The 18 km grid (~ 3700 x 4700 km) is larger to allow a proper transition from the low-resolution GCM fields."

Pg. 276, L.1: Tz is a mean temperature with respect to time or space?
It is mean in time, this has been made clearer in the manuscript.

Pg. 276, L.4: Not clear what is meant by "the mean atmospheric temperature". At what level?
It is at the average condensation elevation of precipitation, which has been added to the sentence.

Pg. 270, L. 22: an important contributor to the warming is warm-air advection, e.g. in a cyclone's warm sector airmass
That is true, but on top of that is the boundary layer better mixed. The specific sentence has been rephrased to
"T_{2m} is in general higher on days with precipitation, because precipitation coincides not only commonly with warm-air advection, but also with cloudy conditions and usually with enhanced winds, which both reduce the strength of the near-surface temperature inversion."

Pg. 282, L. 6: how robust are such ocean circulation changes, as they can be quite influential for the climate in Greenland?
These ocean circulation changes are robust in the sense that they occurred during the whole GCM integration, but their occurrence in general could be very model dependent. However, their impact on the Greenland climate is limited; the Greenland ice sheet creates its own cold katabatic boundary layer, so the climate of the ice sheet is mostly dependent on the circulation and temperature patterns in the Northern Hemisphere free troposphere.

Pg. 283, L. 5: "small but clear": formulate more quantitatively
It refers to the 0-1 K warming shown in Figure 4a. The sentence has been rephrased to
"This energy is released to the atmosphere during the winter season, causing the positive anomaly of T_{2m} over Greenland (Figure 4a)."

Pg. 285, L. 5: "biased high": not sure what you mean. Biased high in your model compared to observations?
It is concentrated to summer, so most precipitation falls in the summer months. The sentence is adjusted accordingly.

Pg. 285, L. 6: "mostly influenced by summer precipitation": I am not convinced that this statement is true in its broadness
Rephrased to *"indicating that isotopic records are strongly influenced by summer precipitation."*

Pg. 285, L. 27: "the results … are deterministic": rephrase, avoiding the use of deterministic here.
Rephrased to
"The results shown here are based on climate realizations of one GCM/RCM combination which inhibits an assessment of the uncertainty range on these anomalies."

References:

Ettema, J., van den Broeke, M. R., van Meijgaard, E., van de Berg, W. J., Bamber, J. L., Box, J. E., and Bales, R. C.: Higher surface mass balance of the Greenland ice sheet revealed by high-resolution climate modeling, Geophysical Research Letters, 36, doi:10.1029/2009GL038 110, 2009.

Ettema, J., van den Broeke, M. R., van Meijgaard, E., van de Berg, W. J., E., J., and Steffen, K.: Climate of the Greenland ice sheet using a high-resolution climate model, Part 1: Evaluation, The Cryosphere, 4, 511–527, 2010.

Francis, D. R., Wolfe, A. P., Walker, I. R., and Miller, G. H.: Interglacial and Holocene temperature reconstructions based on midge remains in sediments of two lakes from Baffin Island, Nunavut, Arctic Canada, Palaeogeography, Palaeoclimatology, Palaeoecology, 236, 107–124, 2006.

Helsen, M. M., van de Berg, W. J., van de Wal, R. S. W., van den Broeke, M. R., and Oerlemans, J.: Coupled regional climate–ice sheet simulation shows limited Greenland ice loss during the

Eemian, Clim. Past Discuss., 9, 1735-1770, doi:10.5194/cpd-9-1735-2013, 2013.
Jansen, E. J., Overpeck, J., Briffa, K. R., Duplessy, J.-C., Joos, F., Masson-Delmotte, V., Olago, D., Otto-Bliesner, B., Peltier, W. R., Rahmstorf, S., Ramesh, R., Raynaud, D., Rind, D., Solomina, O., Villalba, R., and Zhang, D.: Climate Change 2007 - The Physical Science Basis, chap. Palaeoclimate, Cambridge University Press, 2007.
Johnsen, S. J., Dansgaard, W., and White, J. W. C.: The origin of Arctic precipitation under present and glacial conditions, Tellus, 41B, 1989.
Jones, P. D., New, M., Parker, D. E., Martin, S., and Rigor, I. G.: Surface air temperature and its changes over the past 150 years, Reviews of Geophysics, 37, 173–199, 1999.
Kaspar, F. and Cubasch, U.: The climate of past interglacials, chap. Simulations of the Eemian interglacial and the subsequent glacial inception with a coupled ocean-atmosphere general circulation model, Elsevier, 2007.
Masson-Delmotte, V., Jouzel, J., Landais, A., Stievenard, M., Johnsen, S. J., White, J. W. C., Werner, M., Sveinbjornsdottir, A., and Fuhrer, K.: GRIP Deuterium Excess Reveals Rapid and Oribital-Scale Changes in Greenland Moisture Origin, Science, 309, 118–121, 2005.
McKay, N. P., Overpeck, J. T., and Otto-Bliesner, B. L.: The role of ocean thermal expansion in Last Interglacial sea level rise, Geophysical Research Letters, 38, doi:10.1029/2011GL048, 2011.
Min, S.-K., Legutke, S. , Hense A. and Kwon, W.-T.: Internal variability in a 1000-yr control simulation with the coupled climate model ECHO-G – I. Near-surface temperature, precipitation and mean sea level pressure, Tellus, 57A, 605-621, 2005.
NEEM community members: Eemian interglacial reconstructed from a Greenland folded ice core, Nature, 493, 489–494, 2013.
S. V. Nghiem, S. V., Hall, D. K., Mote, T. L., Tedesco, M., Albert, M. R., Keegan, K., Shuman, C. A., DiGirolamo, N. E. and Neumann, G.: The extreme melt across the Greenland ice sheet in 2012, Geophysical Research Letters, 39, L20502, doi:10.1029/2012GL053611.
Sodemann, H., Masson-Delmotte, V., Schwierz, C., Vinther, B. M., and Wernli, H.: Interannual variabiliyt of Greenland winter precipitation sources: 2. Effects of North Atlantic Oscillation variability on stable isotopes in precipitation, Journal of Geophysical Research, 113, doi:10.1029/2007JD009416, 2008.
Turney, C. S. M. and Jones, R. T.: Does the Agulhas Current amplify global temperatures during super- interglacials, Journal of Quaternary Science, 56, 839–843, 2010.
van de Berg, W. J., van den Broeke, M. R., Ettema, J., van Meijgaard, E., and Kaspar, F.: Significant contribution of insolation to Eemian melting of the Greenland ice sheet, Nature Geoscience, 4, 679–683, 2012.
Werner, M., Mikolajewicz, U., Heimann, M., and Hoffmann, G.: Borehole versus isotope temperatures on Greenland: Seasonality does matter, Geophysical Research Letters, 27, 723–726, 2000