

## Response to reviewer 2 of manuscript “What controls the isotopic composition of Greenland surface snow”

We are grateful to the constructive and thorough comments of reviewer 2. We believe that the many very good suggestions have improved the manuscript. We have below answered the individual comments using **Green text**.

The study compares stable isotope ratios of water vapor, precipitation and surface snow samples from the NEEM site, NW-Greenland, in order to study the influence of post-depositional processes and the exchange between atmosphere and snowpack between snowfall events. The methods are sound, the results interesting and not yet fully explained, which shows that a lot more is to be done in this field before it is really possible to interpret stable isotope ratios from ice cores quantitatively. The paper is generally well written, the English is mostly ok; however, the usage of definite and indefinite articles (or better the non-usage) seems a bit arbitrary and sg./pl. are not always correct either. Generally, many sentences are very long and should/could be divided into two for better understanding. Sometimes the logic of a sentence or the logical connection of two (sub)sentences is not clear/exact or not quite suitable expressions are used. Thus I have quite a few, but mostly minor comments. The paper is highly interesting, contains new data and concepts, original work and therefore is definitely suitable for publication in CP after minor revision.  
Specific comments: (format changed after submission for unknown reasons, sorry about that)

We have specifically been updating the manuscript to limit the number of long sentences. Thank you for pointing this out.

6037: L4: amongst glaciologist the term post-depositionAL processes is more common

Corrected

17: the top

Corrected

L8/9: “measurements”: repetition

Corrected

L21: the phase transition from vapor to solid is called deposition (according to the AMS Meteor. Glossary) If you want to use different terms, please define them.

Corrected

L22: “synoptic weather”: weather is always synoptic.

We have corrected it to “Synoptic variations” instead

6038 L4: directly provide

Corrected to “provide direct”

6038/39: please rewrite the explanation of (i), this can be expressed more clearly

Corrected: from (i) precipitation intermittency and the covariance between precipitation and temperature

6039: L6: atmospheric general circulation models (GCM)

Corrected

L22: not always anti-correlation, especially at upper levels of snow/ice (Schlosser et al., 2008?) ..impact of changes in condensation temperature on. . .Not very clearly formulated, please rewrite

We agree – however by writing ice cores we refer to the part of the core below the firn. We have specified in the text now that we refer to stadial-interstadial time scales.

By writing condensation temperature we are referring to the cloud condensation temperature.

6040: L23: “whether”? I think we know that postdepositional processes (not “post-deposition”) have detectable impacts, the question rather is how they impact the T-stable isotope relationship. (iii): the structure of the sentence is not logical here. The processes have no impact on the processes

We agree and have corrected the sentence accordingly:

The motivation for our study is to investigate the impacts of post-deposition processes on (i) the isotope--temperature relationships; (ii) the d-excess vs.  $\delta^{18}\text{O}$  relationships; and (iii) the surface snow isotopic composition in-between precipitation events.

We notice that Waddington et al. 2002 spell it post-depositional

L25: “in-between”: between would be enough, also in the following

We have changed the wording to “in between” instead.

6041: How do you define “high d-excess events”?

High d-excess events were defined in Steen-Larsen et al. 2013 using a cluster analysis and subjectively defining the high d-excess events to be measurements which was more than 3 standard deviations outside the main cluster.

L15: originating from the Arctic: Greenland is part of the Arctic, please specify

Yes – however as argued in Steen-Larsen et al 2011, 2013 the predominant moisture arriving at NEEM seems to originate south of Greenland. However when a majority of the moisture have an Arctic origin we observe high d-excess.

L18: delta rather than d

Corrected

L20: delete “altogether” at least once

Corrected

6042: L.13: automatic weather station (AWS)

Corrected

L15. Using a Campbell. . .

Corrected

L16: using an RM. . .

Corrected

L21: estimated to

Corrected

L22: 2.5 and 4.5 are not fractions, but factors, if I understand S-L2011 correctly.

We would like to keep using “fractions” here. We have changed it to (between a factor 2.5 and 4.5)

L25: what are extra sensors? At additional layers?

It should say “thermistors” – it is now corrected.

6043: L4: at the edge

Corrected

L5: from the nearest..

Corrected

L10: were placed..

Corrected

L16: calibrated in the beginning. . .

Corrected

L21,22: delete “of”

Changed to “at”

L24: was discarded

Corrected

L25: was measured continuously except for 15min every hour when the 20cm level was measured.

Corrected

6044: L4: when

Corrected

L20: delete “off”

Corrected

L23: previously, by taking surface snow

The text has been changed to:

“ The surface snow was sampled every 12 \,h (a~few (25) samples were only collected every 24\,h in beginning of 2012) by collecting the surface from a~\$15 \times 15\,\text{cm}\$ area. Altogether, 51 samples were collected in 2011, and 122 samples in 2012.

“

L28: until the measurements

Changed to “until being measured”

6045: L12: because the results. . .

Corrected

L20: Calculation

Corrected

6046: L3: ”the reason.. due to “ is not logical (double expression), please, reformulate

We agree. The text now reads “). We justify the calculations assuming liquid water by the fact that the summer temperatures at NEEM are close to 0\,\text{{}^\circ\text{C}} (Fig.~1).”

L6: GCM

While we acknowledge that we have earlier defined GCM we choose to keep the complete text.

L12: with a resolution

Corrected

L17: frost= deposition? What is calving in this context? This paragraph is a bit hard to understand for people not familiar with the model.

We put “(deposition)” after frost and have defined “calving” as forced removal. The text defined calving (forced removal) to occur when the snow layer exceeds 3 meters.

6047: L3: delete “exchanged”

Corrected

L5: forcing was. . .

Corrected

L9: explain GC-NET

Corrected

L10: linear correlation: how about a correlation coefficient and a significance level?

This is corrected (R= ~0.95)

L21: “reliably calculate the vapor fluxes”: it surprises me that the vapor fluxes should be correct if precipitation rates already have an error of 100

The vapor fluxes are calculated by CROCUS but the accumulation rates are forced from reanalysis and is therefore not related.

6048: L4: the use of “respectively” seems a bit unusual, also at other places

We think that it make sense to keep “respectively” in the place

L6: delete “probably”, due to an increase in downwelling long-wave radiation Many “dues” anyway, maybe better: because the clouds lead to an increase in downwelling long-wave radiation (rather than “greenhouse effect”). You could also refer to the long-wave radiation balance, because the upwelling long-wave radiation changes, too, of course.

Corrected

L8: changes in the large-scale . . .

Corrected

L13: delete “to occur” Grey band: melt or precip? Figure caption says precip. Contradictory, please clarify.

Corrected. We use text to highlight the melt events.

L14: do you mean: “melt had occurred before (so far) only in summer 2005”

Yes – during the period from 1987.

L15: delete “been

Corrected

L16: by rather than from

Corrected

L17: how do you define “spring-summer transition”?

This is subjectively defined as the shift from -30 to -5 in air temperature over 2 days in line with general observations that “summer” arrives in Greenland over few days.

L20: the difference of minimum and maximum temperature during the warming is not a good measure for the amount of warming, better compare minima or maxima before and after what you call spring-summer transition

We acknowledge that the “spring-summer” transition is very loosely defined. We do however only use this as a time marker and not for any analysis.

6049: Fig.1: it would be easier for the reader if you used the real date rather than Julian days and you refer to real dates in the text. Like ref.1 I miss the precip data in 2012.

Unfortunately we do not have the isotopic values of the precipitation in 2012.

L4: are representative. . .

Corrected

L5: strongly rather than very depleted

Corrected

L8: clear-sky conditions

Corrected

L12: explain synoptic variations

Corrected inserted “large-scale cyclonic variations”

L17: delta rather than d, changes in the..

Corrected

L20. In preparation

Corrected

L21: event is a strange expression here, explain

We could use the word “anomalies” but we feel that this is not really the best word either. By using the word “event” we simply refer to situations which are not seen before.

L22: replace “if” by “with”

Corrected

L23,. Spring-summer: see above

We do not quantitatively use the change for any analysis. Instead we here show a observations which has not been documented before. It is a priori hard to have foreseen that such large changes in water vapor isotopes could occur as well as the very sharp transition observed later in the season.

L23: fastest event, expr.

We use the word “fastest” to match the wording “largest” used before. One could argue that the word which should be used is “most rapid”.

L25. Atmospheric river: does not mean much, better describe the synoptic situation that led to the warm air advection

This is described in a paper by W. Neff, which is currently in review. If accepted we plan to include this reference as well.

L29: ..of variations is observed General: tenses: past or present? Be consistent.

Corrected

I do not agree with referee 1 concerning removal of the results from LMDZiso, since you do need them for your argumentation. So, please, keep them in the figure.

We argue for keeping this figure as well.

6050: L2: are comparable

Corrected

L4: all show

Corrected

L5. Synoptic events, see above Anti-correlation only for synoptic events? Any explanation of this?

We do not have a robust explanation for this. In general would it be expected from a Rayleigh distillation that d-excess and d18O should be anti-correlated for synoptic events.

L6: why do you isolate this period?

We assume that the processes during the “spring-summer” transition are different from the synoptic variations observed during the summer.

L18: the range of values is smaller than for vapor

Corrected

21: A similar..over the same

Corrected

L23: the summer

Corrected

L24: value rather than level

Corrected

6051: L1: averaging over the same. . . yields..

Corrected

L3: delete “we observe that”

Corrected

L6: this is not logical

Corrected – the text now reads “variations in the isotopic composition of the snow surface are easily observed in-between precipitation events”

L25: delete “in”

Corrected

Fig.2 and 3: some of the regressions look kind of “daring”, esp. precip and surface snow 2011 and . Are those statistically significant??

We agree that particularly the precip and snow surface in 2011 is not really statistical significant. We have in the figures shown both the 1 standard deviation for the fit as well as the correlation coefficients. We just give the values in the figure and in the table for information but do not use it for any analysis.

6052: Fig.4: explain the shaded areas in the fig. caption General: surface snow, not snow surface when you talk about samples

Corrected

L10: the daily. . . What do you mean, daily mean?

Yes – corrected

L24: in table..

Corrected

L25: delete “appear to”

Corrected

6053: L1: while between precipitation events a better agreement is found for calcul. . .

Corrected

L16: For different years a comparable.. is found

Corrected

L19: exist for vapor and . . .

Corrected

6054: L4: at play Can you specify those processes?

We are not able to precisely specify, which processes are significant. Probably the processes of importance are the source region for the majority of the vapor and the transport from source region to NEEM.

l12: move “for one period” to the end of the sentence

Corrected

l.15: decreases by..

Corrected

l.17: damped: better dampened or attenuated, in this case you could also simply say “lower magnitude”

Corrected

6055: L1: but not in d-excess.

Corrected

L2: predominantly does not make sense here

Corrected

L3: ambiguous? Do you mean “less uniform”?

We mean that we cannot draw any conclusions. We would therefore like to keep “ambiguous” here.

L6: From this co-evolution the following question arises:

Corrected

L11: delete “resort to”

Corrected

L13: delete “isotopes”

Corrected

L16: if this were the case

Corrected

L18: the majority is decreasing, so why “however”?

We choose to keep “however” here because 33% of the cases are however increase despite that they hypothesis being tested indicate that they should decrease.

L23. Delete able

Corrected

24: any mechanism that could. . .

Corrected

6056: It would be good to define the sign of the fluxes here, too. And see above: why should sublimation be largest during precip events?

We looked more into the simulated mass flux and found that it was not always such that the sublimation was larger during precipitation event. We notice for example that for 2011 day 212 show the largest mass flux despite being outside a precipitation event. On day 193 we find a similar large sublimation flux also outside a precipitation event. For 2012 we see that day 164, 196, and 198 is similarly very large despite them all being in between precipitation event. We notice that for these days of high sublimation, which are in between precipitation events, it a common feature is lack of diurnal variability in temperature. This corresponds to cloudy days.

We investigated this observation more in details in the CROCUS model outputs and found that in general the skin surface temperature is found to be larger than 2-meter air temperature during cloudy days and no inversion is formed during the night. This is a result of a typical summer polar situation when both high LW down and SW down is occurring.

It was documented in Steen-Larsen et al. 2011 that precipitation events and strong wind often occurred during the same period. This is also observed in the forcing of CROCUS. Stronger winds enhance the sublimation. This is particularly the cause for the high sublimation during the 2012 period from day 171 to 177.

L9: what is the top layer exactly?

Since we collect the top 0.5 cm of the snow surface everyday we see this as the top layer. Our estimates of relative mass flux is based on this. The mass flux does naturally only originate from the very top of the surface probably a few mm but this is probably difficult to state precisely as the surface is very porous.

L11: this is not exactly true. Please distinguish between physics and model assumptions.

The presented data clearly indicate that some kind of change in the snow surface grains occur during

sublimation. However it is assumed by Dansgaard, 1964, Town et. al, 2008, and Neumann and Waddington, 2004 that sublimation from the snow grain occur by “peeling” layer by layer off without fractionation and therefore without changing the isotopic composition of the snow grain.

6057: L1: we therefore do. . .

Corrected

7: condensation: see above

We are unfortunately not exactly sure what to correct here.

L11: please explain self-diffusion

Corrected - (diffusion inside the ice matrix)

19: synoptic changes, see above

We define synoptic changes as changes, which are caused by large scale circulation changes and not local changes as for example diurnal variations in temperature.

6058:

L1ff: this is not understandable without reading (Pinzer et al 2012).

We have added that the results of Pinzer were obtained using x-ray computed tomography.

6059: L1: logic: show much weaker relationships between GL delta 18 O and temp. in summer than in winter. Any explanation for this?

One could argue that with these new results there is no correlation between the precipitation isotope signal and the temperature (climate). The results of Pinzer show that if the snow surface is subjected to a temperature gradient of 0.5 C/cm up to 60% of the total mass is diffused. Probably one would expect during the winter that no daily temperature gradient would exist due to the lack of solar insulation. However it should be remembered that during the winter advection of air masses create large changes in the near surface temperature. This would create a temperature gradient as well. This is clearly something, which should be studied more in details using a model like CROCUS.

L24: Tape recorder: not really scientific language, also not too good a comparison anyway

We kind of like the analog description using the tape recorder played in reverse. However we have moved this part to the end of the sentence such that we just use it as an extra description

We also show that sublimation does not make the surface reveal earlier precipitation and snow surface isotope values similar to a~tape recorder played in reverse.

6060: L14: an excellent site for a case study

Corrected

27: damp, better: attenuate

Corrected

References: Neumann and Washington: volume number missing (169)

Corrected