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Interactive comment on "Spatial variations in snowpack chemistry and isotopic composition of NO_3^- along a nitrogen deposition gradient in West Greenland" *by* Chris J. Curtis et al.

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RESPONSES TO REVIEWERS

We thank both anonymous reviewers for their very detailed and constructive comments which have allowed us to propose major improvements to the manuscript, and which we believe strengthen our arguments for postdepositional processing as the most important mechanism driving spatial differences in snowpack isotopic composition. We have responded to both reviewers in turn and provide additional explanatory text and discussion for inclusion in a revised manuscript. Since several issues were raised by both reviewers we include new text in the response to Reviewer 2 uploaded separately.

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Discussion paper

RESPONSES TO REVIEWER 1

RC1.1 Curtis et al report measurements of ion concentrations and nitrate isotopes in 3 locations representing different snow accumulation regimes in western Greenland. All observations show gradients from the coast to the inland site on the ice sheet, with sea salt and sulfate concentrations highest at the coast while nitrate concentrations are highest inland. Most of their discussion focuses on nitrate and its nitrogen isotopic composition, where they conclude that postdepositional processing likely determines the observed spatial gradient. Given that the latter has been somewhat contested in the literature, such a study is important. They also provide estimates of the deposition flux of nitrate, ammonia, and sulfate at each location. The authors otherwise do not do as much analysis of the other data sets, such as the ions other than nitrate and oxygen isotopic composition of nitrate.

Response: In the interests of space we restricted the discussion mainly to nitrate and its isotopes, but included deposition estimates for sulfate and ammonium, given the paucity of such data in the Arctic and their relevance to linked ecological studies in the region. But see proposed new text below.

RC1.2 Although the manuscript is well written as far as English language and grammar, it's missing some important background information making it somewhat hard to follow the analysis of the data. Some specific comments on this are below. The technical details seem scientifically sound. Abstract: The authors should start the abstract with a motivation for this study. Why should one be interested in the observed spatial gradients?

Response: We accept that more detailed motivation could be provided and would add this to the final manuscript. The study forms part of a larger study into the relative roles of N deposition vs. climate change in causing ecological change in Arctic lakes, as stated in lines 15-20 on page 2. The study region was selected because of the wealth of published ecological and palaeolimnological studies showing ecological change in

a region which showed no evidence of climatic change for most of the 20th century. Hence we are interested in the possible role of N deposition in causing differential changes in coastal versus inland lakes, some of which are recorded in the lake sediment N isotopic record – hence our focus here on the N isotopes in snowpack. However, given the interesting spatial patterns observed here along with new discussions around postdepositional processing, we accept that further analysis and interpretation of the oxygen isotopes is merited and include further discussion proposed for the final manuscript as outlined below.

RC1.3 Introduction: The introduction needs more background information. It is very short relative to the length of the entire paper. The introduction should present the potential sources of the observed ions in Greenland and discuss what controls the isotopic composition of nitrate. It should include a discussion of postdepositional processing, which is never really defined.

Response: New introductory text is provided below for the final version, including more introduction to isotopic sources, signatures and postdepositional processing.

RC1.4 It should explicitly discuss why one should care about the observed spatial gradients, which seems to be the main motivation of the study.

Response: See above – related to published differences in lake sediment records between inland and coastal lakes

RC1.5 Methods: Please state over what snow depth the snow samples were collected. Over the first 10 cm? Deeper? Shallower?

Response: The whole snowpack was sampled down to ground level and hence represents an integrated sample incorporating the net effects of postdepositional processing over the winter season (described as “depth-integrated” on Page 4 Line 7 in original text; see also Table 3a/b). New explanatory text will be added.

RC1.6 Figure 1: What do the colors mean?

Response: Thank you for the comment. A figure legend will be added to explain the colour shading of 100 m contour intervals, ice sheet/land/sea/ and inland waters.

RC1.7 Section 4.3.1: Provide a reference for the statement that “gas-phase aerosol NO3- may be enriched in 15N compared to wet deposited NO3-“. Also, “gas-phase aerosol NO3-“ does not make sense. Nitrate is either the gas-phase or the aerosol phase (i.e., equilibrium partitioning between the two phases).

Response: The word "and" between "gas-phase" and "aerosol" was inadvertently omitted. Relevant references added to support this statement are Heaton (1987), Freyer (1991), Garten (1996) and Elliott et al. (2009).

RC1.8 Section 4.3.2: This section was particularly hard to read because postdepositional processing is never defined. Many studies on ice sheets have shown that photolysis dominates postdepositional processing, but this is not even mentioned until the very end of this section. Perhaps if the authors properly introduce this process in the introduction, it will make it easier to clarify this section as well.

Response: We hope that we have clarified this in the new introductory text – see substantial new section below.

RC1.9 It would be useful to give the fractionation factors for the processes involved.

Response: Fractionation factors have been included in the new text below.

RC1.10 Conclusion: Like the abstract, the conclusion focuses on the observed gradients with out explicitly stating why this matters. Again, a more thorough introduction may help with this.

Response: Again, hopefully the revised introduction will assist here and we have refocussed the conclusions to reflect the drivers of the spatial patterns observed.

RC1.11 Some relevant references that could be included in the introduction and/or discussion and data comparison: Kunasek, S.A., Alexander, B., E.J. Steig, M.G. Hast-

ings, D.J. Gleason and J.C. Jarvis, Measurements and modeling of Δ17O of nitrate in snowpits from Summit, Greenland, J. Geophys. Res., 113, D24302 (2008). Geng, L., M.C. Zatko, B. Alexander, T.J. Fudge, A.J. Schauer, L.T. Murray and L.J. Mickley, Effects of post-depositional processing on nitrogen isotopes of nitrate in the Greenland Ice Sheet Project 2 (GISP 2) ice core, Geophys. Res. Lett., 42, 5346-5354, DOI: 10.1002/2015GL064218 (2015)

Response: Thank you for the suggestions. We have consulted and added these references to the discussion, along with many others.

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