Response to comments by Referee 3

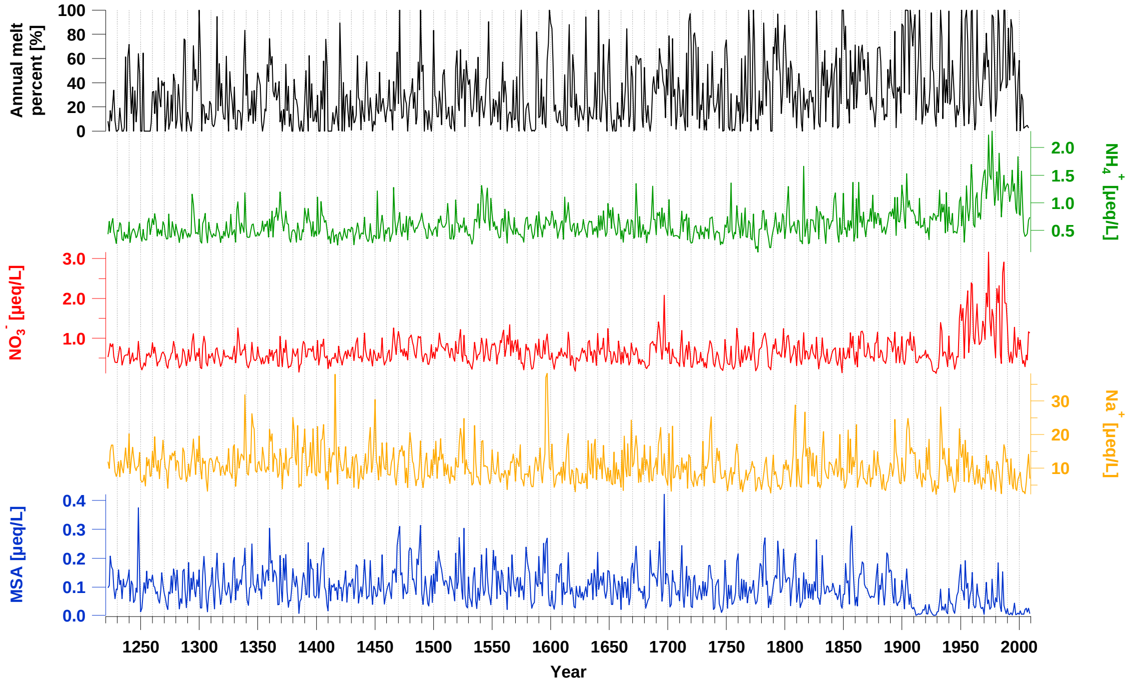
We thank the referee for the valuable and helpful comments. We believe that addressing the issues is considerably improving our manuscript.

Please see our reply to each comment below.

Note: All reviewer comments are in bold. All author responses are in normal format (blue) and changes in the manuscript in italics (red).

After the 1997 core this is the second ice core recovered from Lomonosovfonna glacier and the authors have to be commended on their sound dating of the ice core, including age uncertainties as a function of depth. However the interpretation raises questions. Most importantly the authors' claim that post-depositional effects due to percolating melt water are small and do not affect the ion records at the site is questionable. Some of the features present at the higher resolution are masked when working with decadal averages. For example, Figure S2 in the appendix shows a marked decrease in absolute concentration, concentration amplitude (smoothing) and frequency of annual spikes for nitrate, MSA and to some extent also sodium (ammonium) over two depth intervals: one between 0 and 10 m-weq (_1994-2009) and one between 30 and 42 m-weq (_1912-1955); the interval between 10 and 30 m-weq stands out with comparably larger spikes. To my eye this suggests a post-depositional artefact. Indeed, during the 20th century annual melt fractions (not percent as the y-axis suggests) frequently exceed 0.8 (Figure S3) supporting the suspicion that their may be an impact of melt on the ion record. Before making any further strong conclusions based on an ice core record potentially biased by post-depositional processes the authors need to take advantage of the available high resolution chemistry data and a) report raw data in the main paper and b) investigate in more detail the relationship between melt fraction and relative position of ion spikes. Is there any (possibly preferential) elution and displacement of the measured ions? If so, could post-depositional displacement explain some of the observed inconsistencies between the Lomo97 and Lomo09 cores (e.g. a correlation between ammonium and nitrate in Lomo97 but not in Lomo09)?

We will include a figure with annual averages of MSA, Na^+, NO_3^-, NH_4^+ and melt on a time scale into the main text. To be consistent, annual averages are presented instead of raw concentration data, since melt is available only on an annual scale.



New Figure 3: Temporal records of annual average concentrations of MSA, Na^+, NO_3^- and NH_4^+ and annual melt percent of the Lomo09 ice core.

We included a general paragraph about the amount of melt. In addition, we discuss that the observed amount of melt may have induced a maximum percolation length in the Lomo09 core not exceeding eight annual layers. The focus of this study is on decadal variability and not on short-term intra-annual variations, possibly caused by melt events. As a conservative estimate we therefore used the 10-year-average record of melt percent in the PCA to examine the influence of melt on the NH_4^+ and NO_3^- records. In the new figure with the raw data it is visible that at decadal time scales there is no relation between melt and ion concentrations. For instance the higher concentrations between 10-30 m weq (~1950-1990 AD) seen for MSA, NO_3^- and NH_4^+ are accompanied by high melt percent, whereas high melt seen at earlier times (~1900) did not result in higher ion concentrations.

Abstract: Changes in melt at the Lomonosovfonna glacier are assumed to have a negligible effect on the decadal variations of the investigated compounds.

Drilling site and meteorological settings: Measured borehole temperatures in the upper 42 m (between -1.7°C and -4.3°C) at the Lomo09 drill site are in good agreement with the average borehole temperature at the Lomo97 site of -2.8°C with a nearly isothermal profile (Van de Wal et al. 2002). Previous studies indicate that summer melt water in the study area is refrozen mostly within the previous winter's snow, and the remainder within the next two to three lower annual layers (Samuelson, 2001). Percolation length was found to be up to 8 years only in the warmest years during the 20th century (Kekonen et al., 2005; Moore et al., 2005).

Page 24675: The average annual melt percent of the Lomo97 core was 41% (Pohjola et al., 2002) compared to 31% of the Lomo09 core. We thus assume that the maximum percolation lengths in the Lomo09 core do not exceed the eight annual layers determined for the Lomo97 core. As a conservative estimate we used the 10-year-average record of melt percent in the PCA to examine the influence of melt on the NH_4^+ and NO_3^- records.

The melt percent is the only parameter that has a high loading in PC5. This suggests that on the considered decadal time scale the influence of melt on the ion concentration averages is negligible, which is in agreement with Pohjola et al. (2002) and Moore et al. (2005).

Regarding the inconsistencies between Lomo97 and Lomo09, we likewise conducted a PCA with the Lomo97 data set for the pre-industrial period. Similarly to the Lomo09, NO_3^- and MSA have a high loading in the same component. The Lomo09 and Lomo97 nitrate records agree well. This is also the case for the MSA records, but only back to 1500. Before, the Lomo97 MSA shows an unexplained decreasing trend towards 1200. For an actual comparison between the two sites, further analyses have to be performed investigating records of common time periods and resolution. This will be the subject of another study.

A few more specific comments:

p24672 - l23 As acknowledged by the authors ammonium analyse can be tricky, and the lower values compared to the Lomo97 results raise confidence in the data. However, what was the ammonium blank concentration? Is it possible that the higher values in Lomo97 are due to a higher blank, which had not been corrected for?

The procedure blanks of Lomo09 are not relevant for the measured concentrations (e.g. 0.06 µeq/L for NH_4^+). We therefore deleted the sentence about blanks from the manuscript. We do not have information how the blank was treated for the Lomo97 core. In general, at both sites, concentrations of NH_4^+ (raw data) are frequently close to the detection limits of the analytical methods during the preindustrial period. We therefore assume that the discrepancy is due to contamination and analytical issues. During our sample preparation steps we minimise NH_4^+ contamination from lab air by melting ice samples in a N_2 atmosphere.

Three observations indicate that the Lomo09 NH_4^+ concentrations are robust: 1) The preindustrial Lomo09 values are generally lower than those of Lomo97 and therefore contamination seems unlikely, 2) the Lomo09 preindustrial ion balance is close to zero, and 3) the 300 year records of NO_3^- and NH_4^+ from Holtedahlfonna (Beaudon et al., 2013) are in reasonable agreement with the Lomo09 data (Figure 3).

Sampling: Prior to analyses ice samples were melted in a N_2 atmosphere to reduce contamination from the laboratory air.

Three observations indicate that the Lomo09 NH_4^+ concentrations are robust: 1) The preindustrial Lomo09 values are generally lower than those of Lomo97 and therefore contamination seems unlikely, 2) the Lomo09 preindustrial ion balance is close to zero (Figure S2), and 3) the 300 year records of NO_3^- and NH_4^+ from Holtedahlfonna (Beaudon et al., 2013) are in reasonable agreement with the Lomo09 data (Figure 3).

p24673 - l16 annual accumulation rate vs time along with the raw ion data, as well as relative change in temperature (from d18O-H2O) to further check for post-depositional artefacts

Annual accumulation rates cannot be added since they are available only for the period which could be dated by annual layer counting (2009-1749). We also did not include a temperature proxy, since the post-depositional artefacts are not relevant on decadal time scales (see above).

p24675 - l1 Not really, Fig.3 shows that Holte05 ammonium is quite different compared to Lomo09.

NH_4^+ records of Holte05 and Lomo09 agree very well after around 1800, but reveal indeed different pattern in the 1700-1800 period.

The NH_4^+ record of another Svalbard core from Holtedahlfonna, spanning the last 300 years, shows a differing pattern prior to 1800 but a similar strong increasing trend as the Lomo09 record from the 18th century on (Beaudon et al., 2013) (Fig. 3).