Rhodes et al. reply to Anonymous Reviewer #1

We thank the reviewer for their thoughtful comments and suggestions. We address each one directly below and outline changes that will be made to a revised manuscript.

Specific Comments

1) Snow salinity. After reading section 2.3.2, it is unclear to me what salinity is used for Arctic snow on sea ice. The authors mention the BLOWSEA project with 0.3 psu for Antarctic snow salinity. Is that the value used in the standard model shown in Figure 3?
In section 3.3.1 (page 8), the authors mention a sensitivity simulation with 2-fold and 3-fold salinity. What is that with respect to? 0.3 psu? This is confusing, and it would be clearer to directly specify the actual numerical value of the salinity used. Is the 2-fold salinity 0.6 psu and 3-fold salinity 0.9 psu? Which one is used in Figure 4? I suggest that the author discuss the different salinities used in section 2.3.2 and then refer to them in the sensitivity studies.

0.3 psu is the mean value of the salinity distribution of snow-on-sea-ice measurements from the top 10 cm of snow collected in the Weddell Sea, Antarctica. For Fig. 3, Fig. 4C and others (now called the base simulation) we use double the values of this salinity distribution for snow on Arctic sea ice. The mean salinity used in simulations is therefore 0.6 psu and Fig. 4D (3x salinity) uses a mean value of 0.9 psu. Labels on Fig. 4 have been changed to clarify this. The wording of Section 2.3.2 is confusing and it will be re-written in a revised manuscript.

2) Sea salt emissions. Can the authors compare their emissions (in TgNa/yr) for both OOSS and SISS to Huang and Jaegle (2017)?

Yes, this is something we have done for our own information and can include the results in an additional table (below). A comparison between GEOS-chem and p-TOMCAT will be included in section 3. Essentially the table suggests that both models simulate OOSS emission, transport and deposition in a similar way. p-TOMCAT has higher rates of emission and deposition of larger SISS particles, causing a lower burden and lifetime in the Arctic region. This difference arises from Huang and Jaeglé's assumption that each blowing snow particle produces five sea salt aerosol, whereas in p-TOMCAT one aerosol is produced from each blowing snow particle. There is no evidence to determine with parameterisation is more realistic.

Table x: Comparison between Arctic (>60ºN) sea salt aerosol budgets simulated by this study (black) and by Huang and Jaeglé (2017) (blue) for 2005 AD. For comparison with Huang and Jaeglé (2017) all values refer to mass of total sea salt aerosol (Na mass multiplied by 0.326). Please see footnotes for definitions of each term.

	OOSS			**SISS**		
This study	0.01<dryr<= 0.57 μm	0.57<dryr<= 4.5 μm	Total	0.01<dryr<= 0.57 μm	0.57<dryr<= 4.5 μm	Total
Huang and Jaeglé 2017	0.01–0.5 μm	0.5–4 μm	Total	0.01–0.5 μm	0.5–4 μm	Total
Emission rate (Tg yr^{-1})	0.69 0.78	24 29	25 30	0.41 1.0	8.4 1.6	8.8 2.6
Burden (Gg)	3.0 12	24 32	27 45	1.6 14	1.9 3.3	3.5 17
Surface concentration (μg m^{-3})	0.07 0.19	0.50 1.0	0.57 1.2	0.11 0.4	0.13 0.17	0.24 0.57
Deposition rate (Tg yr^{-1})	0.85 1.3	25 33	26 34	0.34 0.78	8.3 1.7	8.6 2.4
	1.3	0.35	0.38	1.7	0.08	0.15

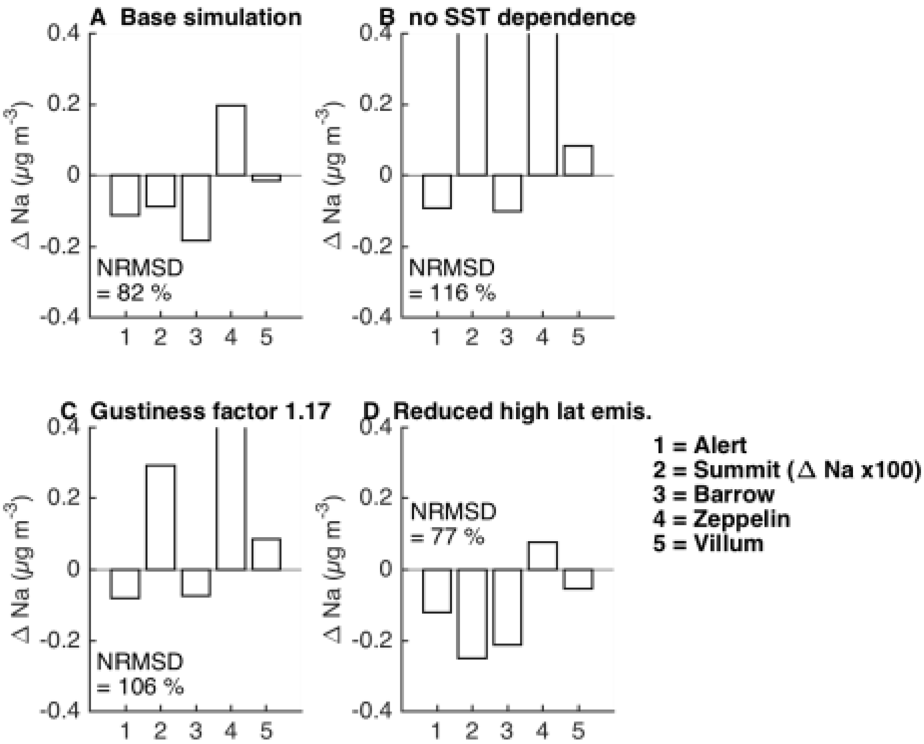
Lifetime in Arctic region (days)	3.3	0.35	0.48	6.6	0.73	2.6

Emission rate: Mean rate of sea salt aerosol emission across the Arctic for 2005 AD; Burden: Annual mean total mass of sea salt aerosol present in the Arctic atmosphere (entire column) in 2005 AD. Surface concentration: Mean concentration of sea salt aerosol across the Arctic region in the surface layer of the atmosphere (as defined by model, in p-TOMCAT ≈ 46-72 m height) in 2005 AD; Deposition rate: Mean rate of sea salt aerosol deposition (wet and dry removal) across the Arctic for 2005 AD; Lifetime: Lifetime of sea salt aerosol in the Arctic region calculated as Burden (Tg) /Deposition Rate (Tg yr^{-1}). This value will be influenced by import or export of sea salt aerosol to/from Arctic region (which must be occurring when Emission Rate ≠ Deposition Rate.

3) This is the fourth paper using the Yang et al. (2008) blowing snow parameterization in P-TOMCAT (Yang et al., 2010; Levine et al., 2014; Legrand et al., 2016). In each of these papers different assumptions are made in terms of OOSS source functions, as well as blowing snow parameters (salinity, snow age, gustiness, etc...). It would be useful to discuss the overall impact of these different assumptions on emissions. In particular, I suggest adding a table that lists Arctic and Antarctic emissions for Na for both OOSS and SISS (this could be use to address my comment 2) above). This table should also include mean surface concentrations or tropospheric burdens of Na.

Good idea, OOSS and SISS emissions and tropospheric burdens can be added to the new table, as above.

Additionally, we have run several tests for the year 1997 to quantify the impact of choices made in the OOSS parameterisation. Capital letters refer to new figure below: B) OOSS emissions with no SST dependence (as Levine et al., 2014 and Legrand et al., 2016); C) Gustiness factor of 1.17 used to increase surface winds speeds involved in OOSS and SISS emissions (as Levine et al., 2014). Note this change also impacts dry deposition; and D) f(SST) = 0.25 when SST <5°C & no OOSS emissions in grid square if < 50% water (modifications of Huang and Jaeglé (2017) made to Jaeglé et al. (2011) scheme). The results will be included in a supplementary figure (below).



We have also run a 5th variation of the SISS emissions parameterisation where the snow age parameter is set to zero/neglected. Results will be included on Figure 4 (below) and Figure S4.

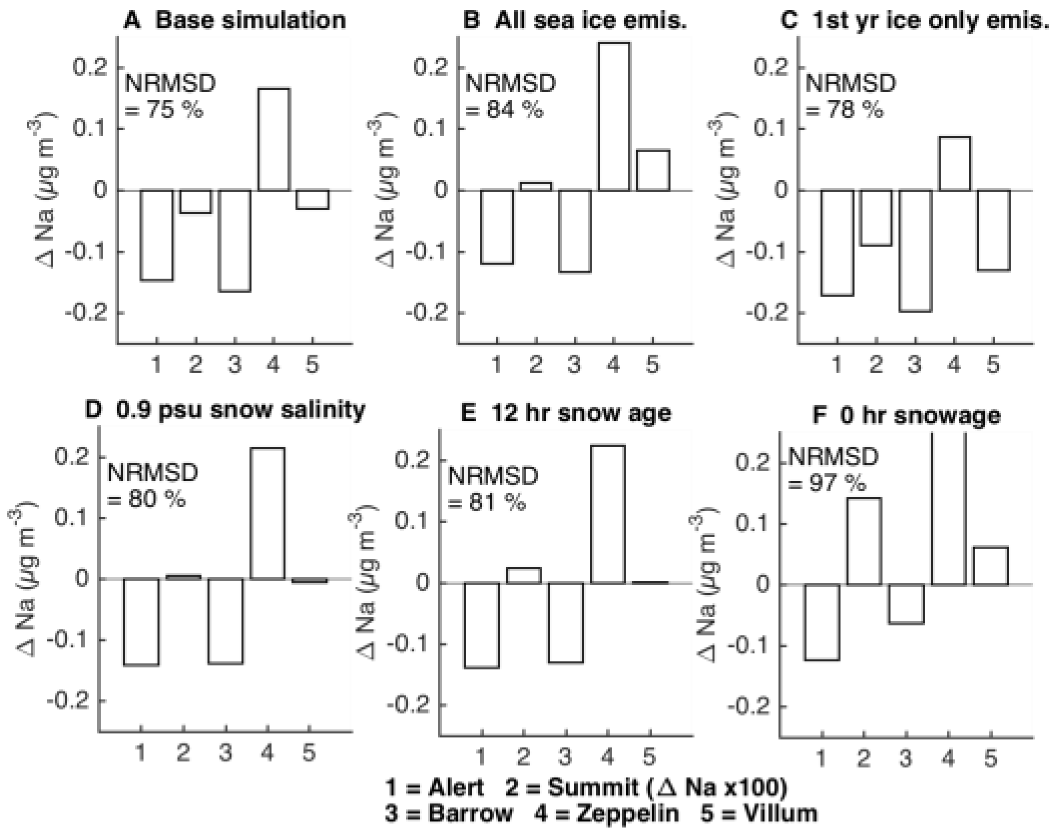


Figure 4: Sensitivity of p-TOMCAT Na aerosol simulations for 1997 AD at 5 Arctic locations to parameters associated with SISS emissions via blowing snow. Each panel (A-E) displays the mean difference between monthly (not including July-September) model results and observations (ΔNa) for each site. Positive [negative] values indicate that p-TOMCAT over- [under-] estimates aerosol Na concentration. The normalised root mean square difference (NRMSD) between model simulations and aerosol data is calculated for each of the 5 sites and the mean NRMSD across all 5 sites is displayed on each subplot. Plots of simulated monthly Na concentration at each site, under each scenario, are displayed in Fig. S5. In the base simulation, SISS emissions are reduced by 50% over multi-year sea ice relative to 1st year sea ice, mean snow salinity is 0.6 psu, and snow age is 24 hr.

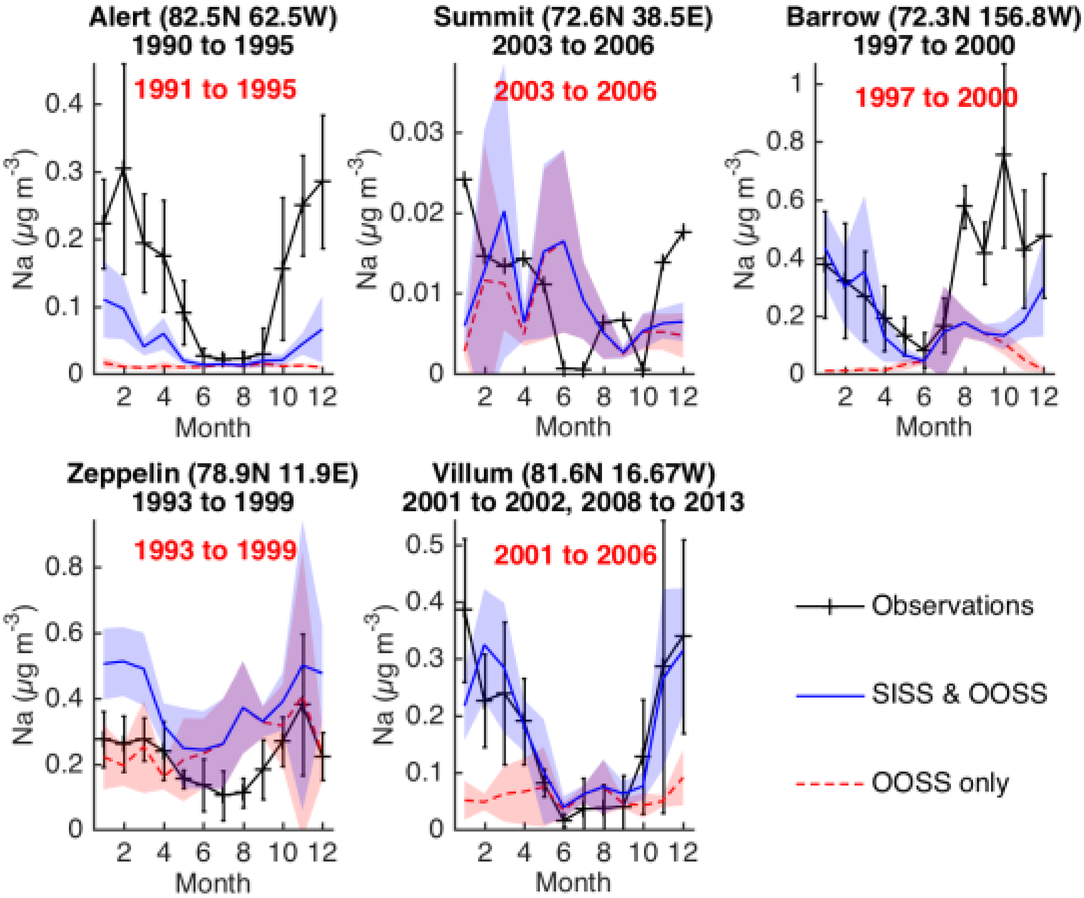
We note that there are major differences in the precipitation schemes (and therefore wet deposition) between Yang et al., (2008), Levine et al., (2014), and Legrand et al., (2016). Changes to the OOSS and SISS emissions are not responsible for all the difference between the studies. This study uses the same precipitation scheme as Legrand (2016), which is the most accurate as it is forced towards observational data.

4) Snow age. Page 5, line 22. The choice of 24 hour snow age seems arbitrary, especially as a previous study with the same model used a snow age of 5 days. A better justification of this value would be to use the meteorological fields to infer a mean time between snow precipitation over the Arctic.

The snow age parameter was originally included in the SISS emission parameterisation of Yang et al. (2008) to reflect how the sintering together of snow flakes/crystals over time may cause them to be less likely to be lofted up during blowing snow events. Although the precipitation amount in the Arctic region is simulated well in p-TOMCAT at the monthly or annual scale, the frequency and/or intensity of precipitation events may be less accurate. For this reason, one value of snow age was adopted for the entire Arctic or Antarctic by Levine et al. (2014). The snow age parameter has therefore become more of a tuning tool with little physical basis. Levine et al. (2014) used a value of 5 days, which effectively counteracted their high snow salinity (relative to this study). The impact of neglecting the snow age parameter will be reported (see answer to 3).

5) Comparison to atmospheric observations (Figure 3). The observations at the different sites are for different time periods ... but the model simulation is the average for 1991-1999, which in the case of the Greenland sites doesn't overlap with the observations. For the other sites, there is some overlap, but the model years are not selected to match the observation years. Given the large interannual variability in Na observations (and in the simulations) can the authors justify this approach? I suggest that at a minimum the authors select the model years that match the observations for Alert, Barrow, Zeppelin. Extending their simulation by a few years would also allow them to have a more rigorous comparison to the Greenland sites.

Great suggestion. A revised Fig. 3 (below) shows only overlapping years of model simulation and aerosol data for all sites (where possible). We have been able to extend the model run to 2006 AD. Years in black text indicate aerosol data and year range in red text refers to the model simulation.



6) Section 3.3 and figure 4. The sensitivity studies shown in Figure 4 are conducted for a single year (1997), while the observations are for multiple years – at least this seems to be the case based on Figure S4. How representative is 1997 compared to the 1991-1999 simulations? At some sites, such as Villum (Figure S4) there appears to be significant differences between 1997 and the 1991-1999 average.

1997 was chosen for the sensitivity tests because, across the 5 aerosol sites, it is close to the 1991-1999 mean (mean value of 5 sites NRMSDs between yearly results and 1991-1999 mean is 45%, at Villum only it is 37%). 1992 is slightly closer to the 1991-1999 mean (37% NRMSD), but 1997 overlaps better with aerosol observations.

Is panel A in Figure 4 for 1997 only or for 1991-1999 (corresponding to Figure 2)? Based on this single year simulation, my understanding that authors choose the option with multiyear sea ice emissions decreased by 50% (panel C) for subsequent simulations (page 9, line 15). The authors should justify this. If this is the simulation they choose, it should be the one they show in Figure 3. To clarify the assumptions for the various simulations, the authors should include a table in the supplementary material with the actual assumptions that are made. For example what salinity (over what sea ice) and snow age are used in Figure 4E?

All panels on Figure 4 represent results for 1997 only (equivalent to Fig. S4) – the caption will be altered (as above). The same settings are used to produce Fig. 4 C for 1997 and Fig. 3 for 1991-1999. We agree that this could be much clearer, particularly in identifying Fig.4 C as the base simulation. As discussed above, the salinity and snow age values have been added to Figure 4 (please see Figure 4 above).

7) Page 10 line 15. Do the authors have any potential explanations for why the observations at Barrow are reproduced by the SISS simulation during the first part of the year, but not the second part? Are the meteorological conditions (windspeed) not captured as well?

We speculate that the snow salinity on the sea ice surface should vary seasonally with the cycle of sea ice formation and melt. Maybe in the Autumn and early Winter when the sea ice is still forming and holds more brine, the surface snow is saltier, possibly causing saltier SISS aerosol? More observations are needed.

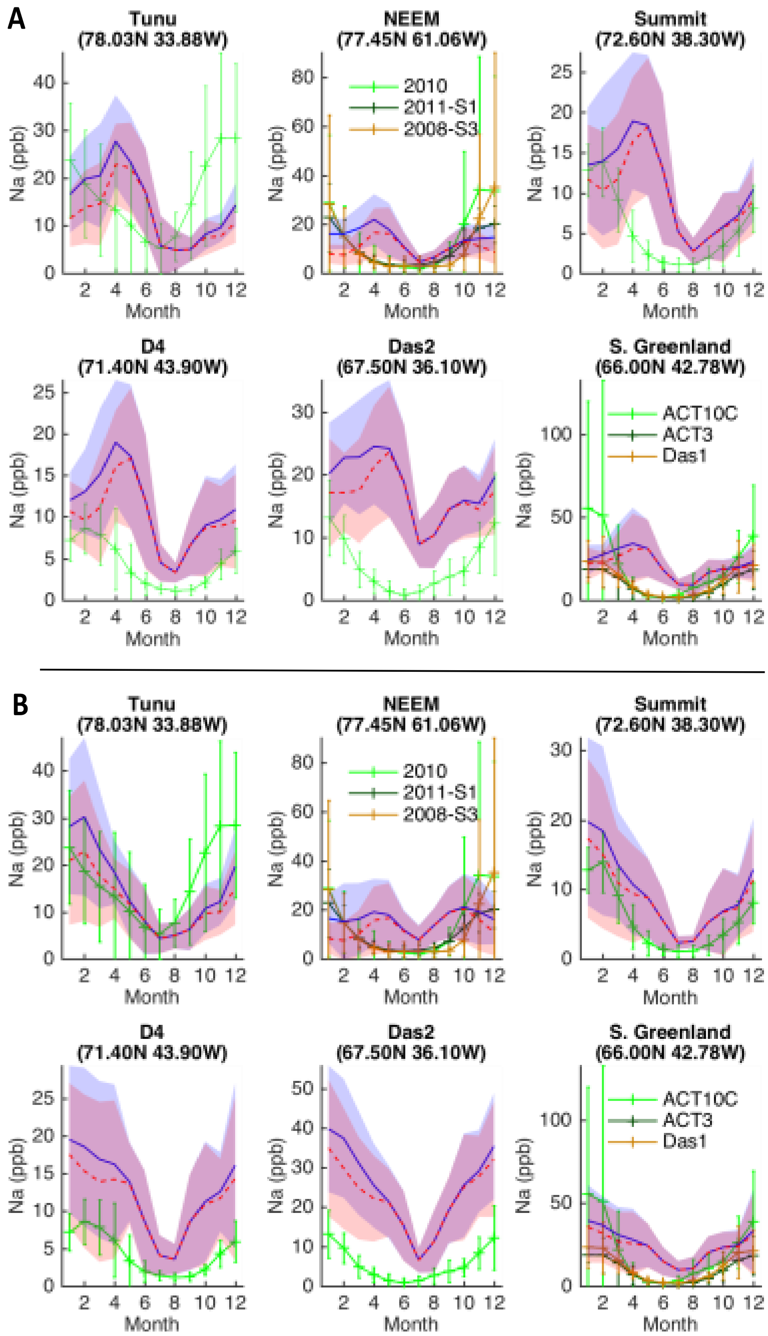
We don't know of any reason to doubt the ERA interim wind data at this location.

8) Seasonal variability of Na in ice cores. The authors compare the p-TOMCAT simulation to ice core observations over Greenland, finding that the model captures the observed seasonality with a winter maximum (section 4.3.2). Figure 5 shows that this seasonality is mostly due to the open ocean SS aerosol (dashed red line), with little influence from the sea ice SS sources. This is contrast to the open ocean (OOSS) simulation of atmospheric Na at ground sites in the Arctic (Figure 3). Can the authors explain the reason for this different modeled seasonality in the atmosphere and in ice cores for the OOSS simulation?

Most of the Arctic aerosol sites on Fig. 3 show little seasonality in OOSS but the model results for Summit do suggest seasonality in aerosol OOSS at that location. This is then in agreement with the model results for Greenland ice cores (including at Summit) on Fig. 5. Because the Greenland ice cores are located further south than the aerosol sampling sites (excepting Summit, Fig. 1), they are influenced more strongly by OOSS sources. The reason for the simulated OOSS seasonality at Greenland ice core sites is difficult to isolate. It may be related to the seasonality of precipitation in the model, which controls wet deposition occurrence.

Also the comparison between p-TOMCAT and ice core measurements is a little difficult to follow as different sites are shown in different figures. For example, Tunu is missing from figure 5, but is shown in Figure 7. I suggest that the authors add Tunu in Figure 5, especially as it appears that the modeled influence of sea ice sources might be large at this site.

Tunu was not originally included on Fig. 5 because it is a relatively low accumulation site (~11 cm water/year), meaning that the seasonal signal in [Na] is not as well-defined as at other sites, particularly in deeper (older) sections of the core. However, for the 1990s, the data look good and Tunu is the most northerly ice core with a relatively high proportion of SISS so the D5 ice core will be replaced with Tunu on Fig. 5. Please see revised figure below.



9) Section 5. Based on the comparison shown in Figure 5, it seems that the sea ice sources do not really lead to a better simulation of the ice core measurements. At most sites the influence of sea ice sources is small. The largest modeled sea ice influence is at the NEEM site, where the model does not capture the observed seasonal cycle. Thus this comparison is inconclusive in terms of the role of a sea ice source in influencing ice core measurements.

The first sentence of section 5 will be re-phrased to emphasize that the importance of SISS to the ice core [Na] budget differs geographically, SISS does not make an “important contribution” in southern Greenland. At NEEM the model captures the seasonality (max in winter, min in summer) in [Na], again the ice core [Na] peak might occur in early spring but be fixed to Jan 1st by the ice core dating technique. We believe the other statements in section 5 are sound and do not overstate the influence of SISS on Greenland ice core [Na].

Technical corrections:

- Page 8 line 20-22. This sentence is confusing. The Weddell sea salinity (0.3 psu) multiplied by two is 0.6 psu, while this sentence implies it is 0.12 psu. The Mundy observations of 0.1 psu of surface snow over the central Canadian Arctic thus imply that the salinity used by this study (0.6 psu?) is too large.

We agree, this is confusing. The *median* Weddell sea salinity x2 is 0.12 psu, which is similar to the *mean* salinity reported by Mundy for surface snow (0.11 psu).

- Page 15 line 16. "SISS contributes to the winter maxima observed in all the ice cores, but that in some cases, OOSS alone can produce winter maxima and summer minima in sea salt in ice cores" There is no evidence of this in the manuscript. Figure 5 shows that OOSS reproduces the observed seasonal cycle at all sites except for NEEM. At NEEM, adding the SISS source doesn't lead to a better simulation.

In the text the quotation above starts with the qualifying statement "Our simulations...suggest that...". Fig. 5 shows simulations that indicate SISS contributes to the winter [Na] maxima at ice core sites. Because adding the additional SISS input in winter months causes the simulated values to increase further beyond the measured ice core values doesn't mean that the SISS input does not occur or is not important. At most sites the summer OOSS Na concentrations are higher than the ice core measurements, suggesting that deposition of OOSS over Greenland is over-estimated by p-TOMCAT.

Other technical corrections will be addressed in a revised manuscript.