Response to RC3

We thank Referee 3 for the very helpful and valuable comments. We will take all the comments into consideration and revise our manuscript. Our responses to the Referee's comments are shown below. The Referee's comments and our replies are numbered and shown in blue and black, respectively.

RC3-1

This study presents a high-resolution (monthly resolved) black carbon (BC) record covering the past 350 years from an ice core drilled on northwest Greenland. There has been much focus on BC during the past decades because of its impact on the Earth's radiation budget. However, BC in snow and ice can be analyzed with several different methods capturing different particle sizes, thus, there is a problem comparing the records and making conclusions about spatial and temporal variations.

The BC record presented in this paper is based on an improvement of a continuous flow analysis (CFA) system providing both BC particle size and mass/number concentrations. This new method is described in another submitted paper by the first author. The particle size analysis makes it possible to distinguish the impact from anthropogenic and biomass burning. As a results it has now been possible to more accurately pinpoint the timing of anthropogenic impact to this part of Greenland than any of the previous studies of BC in ice core from Greenland which have only based their results on mass concentrations. This is a new and important finding. In addition, the results show a shift in seasonality of the annual concentration peak of BC related to the type of impact. A backward trajectory analysis suggests North America as the main source, in agreement with similar ice core-based studies from Greenland.

The paper is generally well written, and the figures are illustrative. ***However, I consider the lack of incorporation of the accumulation record in the discussion of the temporal variability of the BC a problem. The accumulation variability will have a direct impact on the BC transport and deposition and I recommend that this is included in the paper.***

Overall, this is an important study that clearly demonstrates how ice cores and the continuous work in development of different analytical methods can help in understanding the long-range transport of BC to the Arctic.

AC3-1 We understand Referee 3's concern. In our revised manuscript, we will include the annual accumulation record and the annual BC mass flux calculated using it (Fig. A3). Since there are no apparent long-term trends in annual accumulation rates, the temporal trends in BC mass

concentrations and BC mass fluxes are consistent. We will add Fig. A3 as an Appendix while continuing to use BC concentration data in the main text.

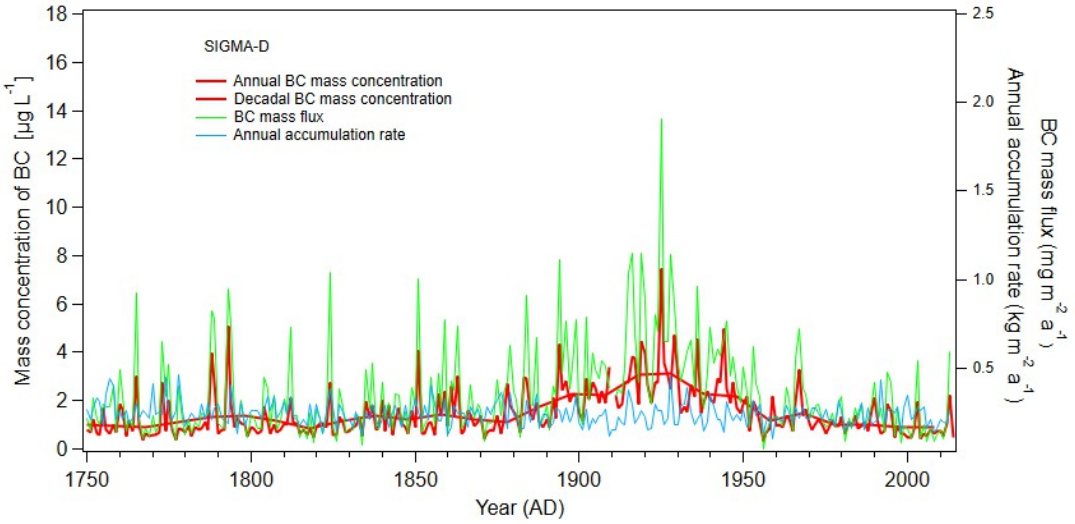

Figure A3: Annual mean and decadal mean BC mass concentrations (red) together with annual accumulation rate (blue) and annual BC mass flux (green).

Specific comments

RC3-2 Line 182-187: I appreciate the careful explanation of the dating, but nature is complex. To have distinct seasonal variability there must be precipitation all year around and the lack of such information in the papers makes it difficult to fully assess the reliability of this statement. Is there any AWS nearby? Maybe this information is included in one of the previous papers, but I think that this must be included in this manuscript since one of the main conclusions is the change of seasonality in the BC input depending on biomass burning or anthropogenic sources.

AC3-2 As we explained in our replies (AC1-1 and AC2-2) to Referees 1's and 2's comments (RC1-2 and RC2-2, respectively), our definition of "months" does not correspond to real calendar months. We will present the snow depth data from AWS in Fig. A4. The AWS experienced some issues, and we can only use data from a limited period (May 2014 – September 2015). It appears that there was more precipitation in summer than in winter at the SIGMA-D site, which could introduce some bias in monthly dating. However, precipitation occurred in all months, and the seasonal variation in

precipitation seems to exhibit significant year-to-year variability. By averaging monthly mean concentrations over 10-20 years (Fig. 11), we believe we can observe changes in the seasonality of BC.

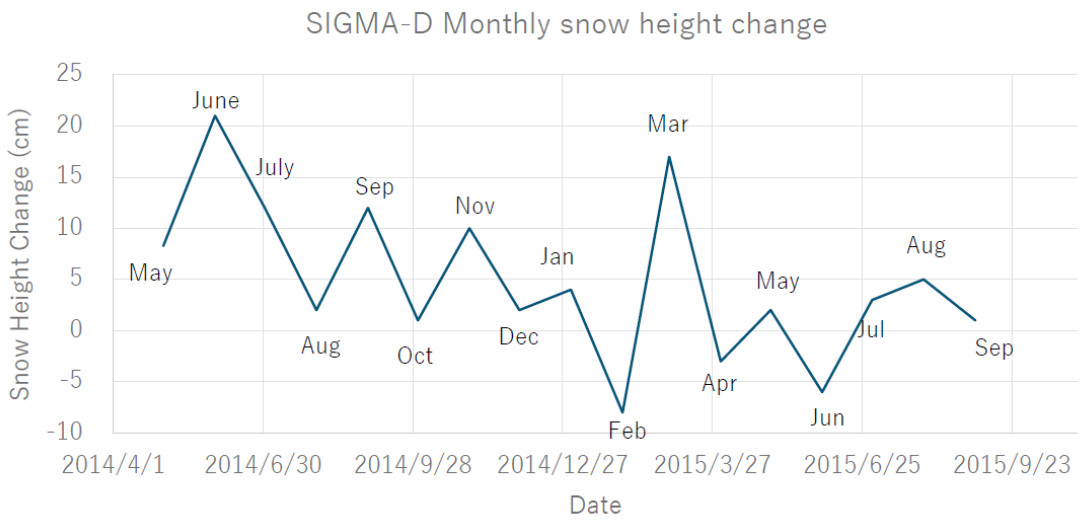

Figure A4: Monthly snow height change at the SIGMA-D site observed with an automatic weather station.

RC3-3 Line 196: The study is assuming only wet deposition of BC. What is that based on?

AC3-3 When we calculated back trajectories, we assumed only wet deposition of BC for the reasons outlined in our replies (AC1-2 and AC2-3) to Referee 1's comment (RC1-2) and Referee 2's comment (RC2-3). In our revised manuscript, we will explain this reasoning and include the results of the back trajectory calculations without assuming wet deposition, as shown in AC1-2. We will also clarify that our interpretation of the ice core data would not change if there is a minor contribution from dry deposition.

RC3-4 Line 303. In this paragraph it becomes evident that the temporal variability of accumulation is not included in the discussion in this paper. As already mentioned, I think this is such a fundamental part of the interpretation of the BC record that it cannot be left out.

AC3-4 We agree. Please refer to AC3-1 for further details.

RC3-5 With the mean annual temperature of -23ºC I assume that there are not any melt layers that is disturbing the stratigraphy but there could still be ice lenses created by solar radiation during the summer. Is that the case here?

AC3-5 We examined the melt features (ice layers and thin crusts) in the uppermost 20 meters of the SIGMA-D ice core, where increased summer melting would be expected due to recent warming. We observed occasional ice layers, with a maximum thickness of 10 mm at only three depths. The 20-meter average melt feature percentage (MFP) was just 0.47%. The maximum MFP per meter was 1.7%, and 10 out of the 20 meters had no melt features at all. Thus, the effects of melt-refreeze cycles are minimal at the SIGMA-D site. We will briefly explain this in our revised manuscript.