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Interactive comment on "Volcanic imprint in the North Atlantic climate variability as recorded by stable water isotopes of Greenland ice cores" *by* Hera Guðlaugsdóttir et al.

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Response to reviewer #1 Dear reviewer, We are thankful for your instructive comments that will indeed serve as an improvement to our study. It is clear that several factors needs improvements. Other factors seem to cause confusion that need further clarifications. We have provided some answers/clarifications to the reviewer's comments here below:

1) Selection of the timespan/stable isotope ice-core proxies: The time span of this study is mainly selected so the Greenland ice cores's results can be compared to the reconstruction from Sjolte et al. (2018), with the motivation of being able to identify the

imprint of volcanic eruptions using few ice cores raning further back in time than the reconstruction by Sjolte et al (2018). Dye-3, GRIP and Crete ice cores dates back to 551 AD (winter d18O), and it is true that it is well possible to add more eruptions for the ice core analysis. This we have done and a comparison of the results between the timespan of 1241-1978 and 551-1978 will be added into the manuscript.

2) Selection of the volcanic eruptions: We agree on what is said here. It is difficult to select NH eruptions since they are a) quite frequent and b) their signal can be influenced by EQ eruptions. Therefore we have extended the time period for the Greenland ice core analysis to 551 (as stated above) and added more NH eruptions (in total eight eruptions). Some of the eruptions mentioned by reviewer do have a mixed signal due to other NH eruption occuring close in time. As a result, the number of NH eruptions used for the short-term climate signal using ice cores spanning the time period 1771-1970 will decrease (1918 eruption removed) to four. Therefore more robust statistical methods will be used to evaluate the significance of the signal identified.

3) Effects of secondary eruptions on the baseline and persistency: Due to the reassessment done in our respones to comment Nr. 1 and 2, this has also been taken into consideration and relevant eruptions removed from the analysis to form a more solid baseline.

In addition here below are the authors response (AR) to the additional comments:

L. 23: Typo; Atlantic Ridge: AR: Ok.

L. 40: this statement is a bit too general; also tropospheric eruptions can impact cli-mate, e.g. when emissions are pervasive as was the case for Laki 1783, Eldgja 934,Holuhraun 2014.: AR: Ok, this will be changed. However, Laki is considered to have been a mixed eruption (both tropospheric and stratospheric) (Thordarson and Self, 2003) (Ref: Thordarson, T., & Self, S. (2003). Atmospheric and environmental effects of the 1783–1784 Laki eruption: A review and reassessment. Journal of Geophysical Research: Atmospheres, 108(D1), AAC-7.)

L. 97: As outlined before the issues have been resolved by Sigl et al., (2015) and they are not critical for your kind of analyses (directly comparing ice-core vs. ice core). AR: Ok, we will clarify this in a revised manuscript.

L. 125: Typo; Extracting a volcanic signal. AR: Ok.

L. 130: Typo; extracting the long term response .AR: Ok.

L. 130: Typo; significance is estimated.. AR: Ok. Table 1: Replace Eruption year with Ice Core Year (in some cases the eruption occurred one year earlier). AR: Ok.

Check Spelling of Krakatao, Huaynaputina and others. AR: Ok.

L. 140: Typo: another. AR: Ok.

L. 144: No! Many NH eruptions have the potential to alter the climate system (Toohey et al., 2019), there may be an absence of very large NH eruptions between 1241 and1970; but there are many examples of strong climate impact following eruptions in the NH, the 536 AD event probably being the most prominent example. AR: We agree and this sentence does not reflect what we meant to say. This will be clarified.

L. 145: largest in which respect? It is the SO2 amount emitted that is most important for the climate impact. AR: Indeed that is true and we will rephrase this sentence.

L. 152-153: VEI is not the right parameter to select eruptions for the purpose of this study. AR: Ok.

L. 157: better: North Atlantic climate response following equatorial eruptions. AR: Ok. Figure 2: What does the stippling represent? AR: Here it represents standardized SLP values, where the mean=0 and standard deviation=1. AR: We will add this in a revised manuscript where appropriate.

L. 181-82: Wouldn't one expect to find an agreement given that both reconstruction use the same d18O data? AR: In principle, yes, but in this case we are comparing the raw data of 13 ice cores to a reconstruction based on fitting modeled d18O with

8 ice cores. There are statistical and methodological differences, which high light the challenges in detecting the volcanic response in individual ice cores. We have clarified this in the text.

L. 186-187: The spatial spread of ice cores appears rather limited, as you later describe. Is a positive NAO+ the only possible explanation for a negative anomaly ofd18O in Central Greenland? Couldn't the low d18O values simply be the result of post-volcanic cooling, potentially prolonged by increased sea-ice formation along the Greenland coast? AR: This is indeed a possibility, but then the spatial pattern could indicate the origin of the center of the cooling. Especially after equatorial eruptions, the increase in arctic sea ice extent would suggest a gradient with negative anomalies from west-east or north-south (or there between). We will assess this further and add a note on this if appropriate.

L. 192-287 incl. Figs 4-6: Especially in this section it appears critical to me to discuss the potential role of secondary eruptions. You could try to remove the d18O data following secondary eruptions or stack also the volcanic forcing records so the reader can judge if the anomalies at 8-11 and 17-20 years overlap with increased volcanic activity. AR: As a result of the re-evaluation in relation to the main comments, this will also be re-assessed in a revised version.

L. 289: better: North Atlantic climate response following extratropical NH eruptions. AR: Ok.

L. 292: three of the five events occur during a time with already strong anthropogenic forcing (GHG, tropospheric aerosols). AR: Ok, will consider.

L. 294: this statement is too general; the eruption year itself can have a strong climatic perturbation given the shorter lifetime of aerosols from high-latitude eruptions. It is rather a coincident that the two largest eruptions among these five have occurred in June (Laki, Katmai) so the climatic impacts were stronger in the following year. AR: Ok, will rephrase sentence/paragraph in a revised version.

L. 324-333: All but two (V1477 and Laki 1783) of your 7 or 8 eruptions analyzed produced comparable small sulfate deposition rates over Greenland (i.e. <10 kg km-2yr-1;Sigl et al., 2015). Almost all of them were also followed by additional eruptions 1477->1480; 1721->1729, 1739; 1755-> 1762, 1766; 1947->1956, 1963 in many cases exceeding your investigated events regarding sulfate mass injection. I am very reluctant to interpret the apparent long term changes in d18O is a long-term effect on the climate system from the original eruption. How sensitive is the outcome of the analyses from the choice of your eruptions? AR: Again, as a result of our re-assessment to the main comments, this will be re-evaluated in a revised version.

L. 403-408: What are the prospects to incorporate more records from North Greenland? What are the limitations? AR: In this study we focus on the winter signal. The climate becomes more continental going further north, which mean less winter precipitation and a degradation of the signal to noise ratio in the records (e.g. Zheng et al., 2018) (Ref: https://www.clim-past.net/14/1067/2018/). Accumulation also decreases which makes it difficult to retrieve the seasonal signal due to diffusion obliterating the d18O annual cycle

L. 413: Typo: Check sentence. AR: Ok.

L. 419-420: Is ECHAM5 the only model that does not produce a NAO+ after the eruption? The only one that is suggested to overestimate surface cooling? Is the surface cooling overestimated globally? AR: No, the CMIP5 models generally tend to overestimate surface cooling after volcanic eruptions and the dynamic NH climate response following equatorial eruptions. This will be clarified.

L. 421: Which reconstructions? AR: The reconstructions of Sjolte et al. (2018). This will be clarified in text in a revised manuscript.

L. 424: I agree that more data is certainly needed; including more eruptions of higher magnitude. AR: Ok.

L. 428-29: I haven't read their papers but I can imagine it is hard to link sea-ice variability with certainty to a mode of the NAO. AR: Perhaps it is hard to imagine, but their work/argument is solid and robust and is ongoing within this subject.

L. 433-436: It is difficult to understand the different responses of the climate system to different volcanic eruptions since there are many parameters that may have an influence. Eruption source parameters (season of the eruption, plume height, aerosol size) may be different as well as the background state of the climate system in different time windows (sea-ice, previous volcanic eruptions, other forcings). AR: Indeed, this is an ongoing research subject with many unanswered questions.

L. 490-506: If I understand correctly you are implying that a positive NAO index leads to less precipitation over Greenland. However, you restrict your analyses to test this to the last 300 years and comparable small volcanic eruptions, leading to rel. weak observed changes in accumulation. You could easily extend this analyses to other ice cores and longer timescales. Both NGRIP and NEEM have an annual-layer counted chronology covering most of the Common Era. This would allow you to get access toa larger number of eruptions (at least about 50 events tropical and 50 NH) of larger magnitude, which should narrow your confidence intervals. So most of the needed data is already there. AR: We see your point and we will assess if additional data will be added to support our hypothesis in a revised manuscript.

L. 560: Which NAO index are you showing? Please add citation. AR: The one we have calculated using the reconstructions of Sjolte et al. (2018). We will underline this better since this is not clear.

L. 572: Here you state that anthropogenic forcing also interplays with atmospheric circulation, yet in your previous analyses you do not exclude those eruptions occurring under strong anthropogenic forcing (20th century). AR: We thank the reviewer for his excellent precision and we will assess if a comparison will be added in a revised version.

References You could include in your study a few recent papers added below (*) aiming at analyzing the effects of volcanoes and other aerosols on climate variability in the Northern Hemisphere. AR: We thank the reviewer for these relevant reference suggestions that will be added.

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