Clim. Past Discuss.,
https://doi.org/10.5194/cp-2019-99-RC1, 2019

Climate
of the Past
Discussions

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.

Anonymous Referee #1

Received and published: 7 October 2019

Summary:

The authors study the impact of volcanic eruptions on the atmospheric circulation in the North Atlantic. In order to do so they use previously published, seasonally resolved stable isotope (d18O) records from Greenland and previously published reconstructions of d18O, SLP and temperature using isotope-enabled ECHAM5-wiso GCM model simulations. The authors aim to show the different effects on atmospheric circulation (with NAO+, NAO-, Scandinavian Blocking and Atlantic Ridge as the four leading modes in the region) as imprinted in the winter d18O of the ice core records of tropical eruptions versus extra-tropical Northern hemisphere eruptions. Overall, the authors observe a

tendency that tropical eruptions are more frequently followed by a NAO+ mode (inferred from the negative d18O anomalies in the Greenland ice cores), whereas extratropical NH eruptions tend to be followed by a NAO- mode (i.e. positive anomaly in d18O). The authors further suggest that the atmospheric response persists for up to 20 years potentially involving feedbacks from ocean/atmosphere coupling.

Comments:

With this study the authors are setting out on difficult task, given the high inter-annual variability of atmospheric circulation. I am no expert in the reconstruction of weather types using stable isotopes, but I am familiar with some of the difficulties in isolating climate signals in proxy records following volcanic eruptions. Especially the criteria for (I) selecting the timespan of the analyses, (II) the climate proxy records as well as (III) the individual eruptions require further discussion and clarification.

1) Selection of the timespan / stable isotope ice-core proxies

First, a table of the stable isotope records used in your analyses would be helpful (e.g. in the SOM) so one does not need to trace them in the original publication by Vinther et al., 2010. Why does your analyses of the full timespan 1241-1978 CE only employ 3 ice cores, when there are 8 ice cores used in Sjolte et al. (2018). What are the criteria to select Dye3, GRIP and Crete? Would the outcome of your analyses be different if you used the 5 retained ice-core records? You mention that the key motivation to restrict your analyses to 1241-1978 CE is the dating issues described in Sigl et al., (2015). But this is not a valid argument, since you are basically comparing ice-core indicated d18O changes relative to ice-core indicated volcanic eruption signals. The analyses can be done independent of the absolute age accuracy of ice-core records. Volcanic reconstructions and stratigraphic age markers in Dye3, GRIP and Crete are also available on the previous chronology from Greenland (i.e., GICC05). Extending the analyses into the time period before 1241 CE would allow to include many more volcanic eruptions, especially such of large magnitudes in the NH (e.g., Katla 1179, 934, 822; Changbaishan Millennium, Churchill White River Ash; unknown eruptions in 626 and 536). Such large eruptions (with high SO2 emissions and strong negative radiative climate forcing) are currently underrepresented in your analyses. I don't know if the d18O records have enough resolution to retain a winter d18O signal before 1241 CE.

2) Selection of the volcanic eruptions

The climate impact of volcanic eruptions is primarily due to the emissions of SO2. This is well reflected in your selected tropical eruptions, but is somewhat unclear in the selected extratropical NH eruptions (Table 1). There appears to be a bias towards Icelandic eruptions, including such eruptions with no detectable sulfate in many ice cores from Greenland (i.e., Hekla 1300, Öræfajökull 1362). The VEI is a poor indicator for the climate impact potential of volcanic eruptions. A number of larger eruptions regarding their sulfate injection are missing in the list (e.g., Tarumai 1739, 1667; Fuji 1707; unidentified eruptions in 1646, 1480 or 1329. I believe the amount of sulfate deposited over Greenland available online (Sigl et al., 2013) would be a more objective criteria for selection. It would arguably also be better suited to study the climatic impacts in the North Atlantic.

3) Effects of secondary eruptions on the baseline and persistency

With roughly 300 eruptions detectable in the ice cores over the past 2500 years (Sigl et al., 2015) it is difficult to isolate the climate effects following an individual eruption, especially on decadal timescales. This is even more difficult since volcanic eruptions tend to cluster forming "double events" or "triple events" and the climate effects following such compound events are believed to be especially pronounced (Buntgen et al., 2016; Toohey et al., 2016). Isolating the effects of an individual eruption on climate and analyzing the long-term persistency – as is done in this study – requires to appropriately account for this clustering. The 10-year pre-event background period should also not be influenced by strong eruptions. In your current analyses this is often the case

(e.g. 1453 -> 1458; 1809 -> 1815; 1831 -> 1835; 1912->1918). When analyzing the long-term response up to 20 years after an eruption it is important to know that there are also many cases in which additional eruptions occured (e.g., 1258->1276 =18 yrs; 1276->1286 =10 yrs; 1458->1477 =19 yrs; 1884 -> 1902 =18 yrs; 1982 -> 1991 =9 yrs; 1963 -> 1982, 19 yrs). If these additional eruptions are not removed from the analyses it remains impossible to judge if the long term changes of d18O you discuss (centered at around 10 and 18 years) are indeed an indication of some persistency in the climate system, or simply the effects of additional volcanic events.

In summary, the current analyses provide some indications of potentially different atmospheric circulation responses following volcanic eruptions in the high-latitudes vs. eruptions from the low latitudes. The study and the robustness of the results could, however, benefit by increasing the number of volcanic eruptions in the analyses, a better tailored selection towards sulfate rich eruptions and a cleaning of the d18O records to remove the superposed effects of additional eruptions pre- and post-event.

Additional Comments:

L. 23: Typo; Atlantic Ridge

L. 40: this statement is a bit too general; also tropospheric eruptions can impact climate, e.g. when emissions are pervasive as was the case for Laki 1783, Eldgja 934, Holuhraun 2014.

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).

L. 125: Typo; Extracting a volcanic signal

L. 130: Typo; extracting the long term response

L. 130: Typo; significance is estimated . . .

Table 1: Replace Eruption year with Ice Core Year (in some cases the eruption occurred

one year earlier)

Check Spelling of Krakatao, Huaynaputina and others

L. 140: Typo: another

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 and 1970; but there are many examples of strong climate impact following eruptions in the NH, the 536 AD event probably being the most prominent example

L. 145: largest in which respect? It is the SO2 amount emitted that is most important for the climate impact.

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

L. 157: better: North Atlantic climate response following equatorial eruptions

Figure 2: What does the stippling represent?

L. 181-82: Wouldn't one expect to find an agreement given that both reconstruction use the same d18O data?

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 of d18O 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?

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.

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

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

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.

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?

L. 403-408: What are the prospects to incorporate more records from North Greenland? What are the limitations?

L. 413: Typo: Check sentence

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?

L. 421: Which reconstructions?

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

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.

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).

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 to a 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.

L. 560: Which NAO index are you showing? Please add citation.

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).

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.

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Toohey, M., Kruger, K., Sigl, M., Stordal, F., and Svensen, H., 2016, Climatic and societal impacts of a volcanic double event at the dawn of the Middle Ages: Climatic Change, v. 136, no. 3-4, p. 401-412.

*Zanchettin, D., Timmreck, C., Toohey, M., Jungclaus, J. H., Bittner, M., Lorenz, S. J., and Rubino, A., 2019, Clarifying the Relative Role of Forcing Uncertainties and Initial-Condition Unknowns in Spreading the Climate Response to Volcanic Eruptions: Geophysical Research Letters, v. 46, no. 3, p. 1602-1611.

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