

## ***Interactive comment on “Re-evaluating the link between the Laacher See volcanic eruption and the Younger Dryas” by James U. L. Baldini et al.***

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Comment #1: Baldini and colleagues present a previously published volcanogenic sulphate record from GISP2 ice cores and compile age estimates for the Laacher See tephra to argue that the LS eruption is recorded in Greenland ice cores as a large sulphate spike positioned approximately at the onset of Greenland Stadial 1 (i.e. Younger Dryas). The authors finally suggest that the LS eruption triggered the YD through a chain of feedbacks resulting from the initial volcanic-induced cooling in the Northern Hemisphere. Even though their hypothesis is tantalizing I find the manuscript excessively speculative and the conclusions very much stretch what can be observed in the reconstructions.

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Preliminary Response #1: We would like to thank Reviewer #1 for taking the time for providing such a comprehensive and fair review. We appreciate that this topic is controversial, and the worst-case scenario would be if the manuscript were published without rigorous review. We also thank the reviewer for suggesting that the hypothesis is 'tantalising'; we agree and additionally we hope to convince Reviewer #1 that the conclusions are not overly speculative.

Reviewer #1 raises some interesting challenges to the hypothesis, but ultimately our responses to these will not affect our model. The comments will however take some time to respond to thoroughly, and we would therefore like to provide an initial response to a few of Reviewer #1's comments in an effort to stimulate discussion before our more in-depth response. In particular, we appreciate the very thorough suggestions for other records to consider, and here we provide reasons why the records are or are not relevant to the Laacher See hypothesis. We assure the reviewer that we have not cherry-picked the records that were used in the manuscript. Rather these were chosen as the records with the most robust chronologies both in absolute terms and with respect to the timing of GS-1 versus the LSE. All of the records used contain both a high resolution regional temperature proxy record and either the Laacher See Tephra directly, or an excellent layer-counted chronology. In our revisions, we will make our selection criteria clearer.

Muschietello et al., 2015 Nature Geoscience: We do not doubt that meltwater pulses did occur and undoubtedly affected climate during the last deglaciation. In fact, we suggest that the YD was terminated by a Southern Hemisphere meltwater pulse that triggered long-term warming. Muschietello et al. argue that meltwater forcing affected climate from 13.1 to 12.880 ka BP. We do not argue against this. However, nothing in this paper contradicts our manuscript. In fact we note that, once again, a pronounced climate shift occurs coincident with the Laacher See eruption at 12.880 ka BP. The large inflection point in Figure 4 (Panel d and elsewhere) is indistinguishable from the date of the eruption. At this point it is therefore difficult to disentangle whether the

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forcing was a meltwater pulse from the Fennoscandian Ice Sheet (or elsewhere), a bolide impact, or the Laacher See eruption, but without publication of our manuscript, future research cannot assess the pros and cons of each.

Heiri et al. 2007: The paper presents a very interesting chironomid-based temperature record of the Younger Dryas from the Netherlands. Unfortunately, it is too low resolution to be particularly useful. The dating is also not as high precision as the records that we have chosen, though we note that the decrease in July temperature starts just after the eruption based on their chronology. Still, we chose not to include this record and others like it because of the low resolution and more uncertain chronology.

Walker et al 2012: Unfortunately the low resolution and ambiguous results make this paper a low priority for inclusion. There are hundreds of Younger Dryas climate reconstructions globally, and including all of them is simply not possible. Pollen reconstructions in particular are problematic due to the generally lower resolution of the datasets, the often less well-constrained chronologies, and the local nature of the proxy. We do not see how this paper provides a significant challenge to either a LSE, a bolide impact, or a meltwater trigger for GS-1 and the YD.

Bondevik et al., 2006: This is quite an interesting paper that we somehow had missed previously, and we thank the reviewer for bringing it to our attention. Their Figure 3 is particularly striking, and shows a pronounced inflection point in the radiocarbon concentrations precisely at the Laacher See eruption (Panels B, C, and D). They state that 'A high reservoir age during the YD could be explained by a combination of increased sea-ice cover and reduced advection of surface water to the North Atlantic', both of which are entirely consistent with our proposed positive feedback mechanism. This paper appears to strongly support our conclusions, but we would appreciate Reviewer #1 highlighting any issues we may have missed. We will probably include some of the radiocarbon data discussed here within the context of a more substantial discussion of the positive feedback.

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Bakke et al., 2009: The correlations between the data presented in this paper and the Laacher See eruption are remarkably strong, and we will include this as a new dataset in our stacked diagram or in another figure. In particular, Supplemental Figures S5 (noting of course that their data is in years b2k) and S7 show that the largest inflection point is coincident with the eruption. We will include these data in our revisions, and we thank the reviewer for bringing this supplemental material to our attention.

Comment #2: In my opinion, the present manuscript doesn't offer anything new but I brief review of the climatic implications of volcanic cooling and far-reaching speculations on the triggers for the YD.

Preliminary Response #2: Should this manuscript be published, it would open the door to the consideration of a new trigger for the Younger Dryas Event. Although we do present a review of volcanic cooling, to our knowledge the positive feedback discussed is novel within the context of the YDE. We also identify the sulphate spike associated with the Laacher See eruption, using the most recent chronology for the GISP2 ice core. Reviewer #1 is correct that Brauer et al 1999 did consider this same spike as being potentially linked to the LSE, but ultimately they decided that it occurred too close to the YD boundary and concluded that an earlier spike represented the LSE (we will include this in the discussion); so I think it is correct to say that we are the first to attribute the LSE to this particular spike, though we will discuss the fact that Brauer et al (1999) considered the spike earlier. This manuscript uses previously published data to reach new conclusions, and we therefore feel that this goes above and beyond a 'brief review'.

Comment #3: In particular, the records mentioned above clearly suggest that cooling and climate deterioration was long underway before the start of the YD, which implies that the cooling associated with the LS eruption cannot be the trigger for the YD.

Preliminary Response #3: In this response we assume the reviewer meant 'GS-1' instead of 'YD', because there is general agreement that cooling did start well before

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the start of the YD in Central Europe, and this in fact forms a key part of our hypothesis. We disagree that there is clear evidence for GS-1 related cooling well before the start of the GS-1. There may be some cooling in some records that may or may not be linked to the YD, but there is generally also a clear inflection point at the start of the GS-1. We also note that because the two highest profile hypotheses (a meltwater pulse and a bolide impact) for the YD trigger are also proposed to have coincided with the start of GS-1, any issues with 'cooling and climate deterioration' being long underway before the Laacher See eruption are also issues with the other hypotheses. Again we note that neither the meltwater pulse or the bolide impact are universally acknowledged as even having occurred (close to the start of GS-1), whereas no debate exists that the Laacher See eruption happened, has real potential to have cooled climate, and appears to be coincident with the start of GS-1 in the best records of regional climate. It is remarkable that even after decades of intense research the Younger Dryas event trigger is still unclear. Possibly this is because the trigger is still unknown; we wish to propose the Laacher See hypothesis so that it can be thoroughly tested in future research just as the other hypotheses have been.

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