<u>Reviewer #3 Comments and Responses:</u>

Comment #1: The manuscript "Re-evaluating the link between the Laacher See volcanic eruption and the Younger Dryas" by Baldini et al proposed Laacher See Eruption (LSE) as a potential trigger of the YD cold interval during the last deglaciation. The manuscript is good written and easy to follow.

Response #1: Thank you for these positive comments.

Comment #2: The authors argued that radiative effect of the LSE could lead to a cooling over the Northern Hemisphere, which eventually triggered the YD due to the existence of "sweet spot" of millennial-scale variability during glacial periods and positive feedbacks. I do see the potential of this mechanism, which enables an improvement of our understanding of YD dynamics.

Response #2: Again, we thank the reviewer for these positive comments and for summarising well what is essentially a very simple idea. We agree that there is clear potential for the LSE to have triggered the YD, and we very strongly feel that the hypothesis merits further consideration.

Comment #3: However, I'm a bit suspicious of its reliability. Some points are summarized in the following: 1) Responses of ocean circulation (AMOC) to a Northern Hemisphere volcano eruption is not that supportive of authors' argument. According to Pausata et al 2015 (PNAS), eruption's effect on AMOC is positive (strengthening) rather negative (weakening) at the first 20 years after the eruption, contrast to the weakening AMOC during YD.

Response #3: As we noted in our preliminary response online, the reviewer is correct that Pausata et al (2015) found that an eruption would strengthen AMOC. Other modelling studies based on historical data also suggest that eruptions may strengthen AMOC (Ottera et al., 2010; Swingedouw et al., 2014; Ding et al., 2014). However, other models suggest that AMOC may intensify initially, but then weaken after about a decade (Mignot et al., 2011). A modelling study by Schleussner and Feulner (2013) suggested that volcanic eruptions occurring during the last millennium triggered increased Nordic Sea sea ice extent which weakened AMOC and eventually cooled the entire North Atlantic Basin. Other research finds that North Atlantic sea ice growth following a negative forcing weakened oceanic convection and northward heat export during the Little Ice Age (Lehner et al., 2013). These are all studies focussing on eruptions that occurred over the last 1000 years, and they still yielded contradictory results. Therefore, we feel that how an eruption might affect AMOC at ~12.9 ka BP is still essentially unknown.

We thank the reviewer for raising this point, and we have now included the following text in an enhanced discussion to address it:

'Although the radiative effects associated with volcanic aerosols are reasonably well understood, the systematics of how volcanic eruptions affect atmospheric and oceanic circulation are less well constrained. Research suggests that volcanic eruptions affect a wide variety of atmospheric phenomenon, but the exact nature of these links remains unclear. For example, Pausata et al. (2015) used a climate model to conclude that high latitude NH eruptions trigger an El Niño event within 8-9 months by inducing a hemispheric temperature asymmetry leading to southward Intertropical Convergence Zone (ITCZ) migration and a restructuring of equatorial winds. The model also suggests

that these eruptions could lead to AMOC shifts after several decades, consisting of an initial 25-year strengthening followed by a 35-year weakening, illustrating the potential for climate effects extending well beyond sulphate aerosol atmospheric residence times. Several modelling studies based on historical data suggest that eruptions may strengthen AMOC (Ottera et al., 2010; Swingedouw et al., 2014; Ding et al., 2014) but also increase North Atlantic sea ice extent for decades to centuries following the eruption due to the albedo feedback and reductions in surface heat loss (Ding et al., 2014; Swingedouw et al., 2014). Other models suggest that AMOC may intensify initially, but then weaken after about a decade (Mignot et al., 2011). A modelling study by Schleussner and Feulner (2013) suggested that volcanic eruptions occurring during the last millennium triggered increased Nordic Sea sea ice extent which weakened AMOC and eventually cooled the entire North Atlantic Basin. Importantly, Schleussner and Feulner (2013) concluded that short-lived volcanic aerosol forcings triggered "a cascade of sea ice-ocean feedbacks in the North Atlantic, ultimately leading to a persistent regime shift in the ocean circulation". Other research finds that North Atlantic sea ice growth following a negative forcing weakened oceanic convection and northward heat export during the Little Ice Age (Lehner et al., 2013). Quantifying the long-term influences of single volcanic eruptions is confounded by the effects of subsequent eruptions and other factors (e.g., solar variability, El Niño events), which can overprint more subtle feedbacks. For example, model results looking at recent eruptions found evidence that different types of eruptions can either constructively or destructively interfere with AMOC strength (Swingedouw et al., 2014). Therefore, despite increasingly clear indications that volcanic eruptions have considerable long-term consequences for atmospheric and oceanic circulation, the full scale of these shifts is currently not well understood even over the last two millennia, and are essentially unknown under Glacial boundary conditions.'

Comment #4: 2) Effect of southward ITCZ shift will lead to an increase of salinity in the North Atlantic subtropics, which will also act as a negative feedback to a potential weakening AMOC (Schmidt et al 2006 Nature).

Response #4: We have now included the reference suggested along with a new paragraph of text:

'MWP-1B may have cooled the SH and strengthened AMOC, prompting northward migration of the ITCZ and NH mid-latitude westerlies to achieve equilibrium with high insolation conditions, thereby rapidly reducing sea ice extent and warming Greenland, but this requires further research, particularly because the source, duration, and timing of MWP-1B are still unclear. Reduced oceanic salt export within the North Atlantic subtropical gyre, as is characteristic of stadials, may have preconditioned the North Atlantic toward vigorous AMOC following the initial migration of atmospheric circulation back to the north (Schmidt et al., 2006).'

Comment #5: 3) Although the ice volume during YD is beneficial to the occurrence of millennial-scale variability (Zhang et al 2014 Nature), the high CO2 level (250 ppm) will shift the "sweet spot" to a lower level of global ice volume (Zhang et al 2017 Nature Geo). This will weaken the arguments proposed by the authors.

Response #5: We thank the reviewer for raising this potential complicating factor, and we now discuss this point:

'These results are broadly consistent with previous research (i.e., Zhang et al., 2017), but it is also possible that interplay between ice volume and atmospheric CO2 determines the timing and duration of the most sensitive interval of time, and the likelihood that a forcing produces a longer-term

cooling event (Zhang et al., 2017). Atmospheric pCO2 during the YD initiation was relatively high (~240 ppmv) and could therefore affect the timing of ideal conditions for abrupt climate change in conjunction with ice volume, but their precise interdependence is still unclear.'

Comment #6: Nevertheless, I do see a potential of LSE (or northern hemisphere volcanic eruption) as a trigger to YD

Response #6: We agree, and thank the reviewer for this supportive comment. We see no reason why a well-dated, very high-sulphur, and high-latitude eruption should not at least be considered as a trigger for a cold event.

Comment #7: Muschitiello et al (2017 Nature Comm, also cited by the authors) recently proposed that the volcanic eruptions can effectively influence the mass balance of ice sheet via altering its surface albedo. This will promote the ice-sheet melting, leading to freshwater input to the North Atlantic and weakening the AMOC. I'm not an expert on data and climate response to the volcanic eruptions.

Response #7: This is a good point, but our understanding of the mechanisms invoked by that paper are that the eruptions have to be fairly proximal to the ice sheet to cause melting, i.e., long-lasting Icelandic eruptions affected the Fennoscandian Ice Sheet. It is therefore unlikely that the LSE affected the albedo of any major ice sheet.

Comment #8: But I think if the author can well improve the robustness of their arguments (probably by rephrasing the mechanisms), this will be a nice manuscript for Clim Past.

Response #8: We have now rephrased and extended our text considerably, and we think that the arguments are indeed much stronger. We also include a substantially revised section on relevant published climate modelling results that also discuss possible mechanisms. We thank the reviewer for highlighting that this rephrasing might be necessary, and we believe that it has indeed helped.

Comment #9: Line 145: Citation "Pasauta et al 2015 Tellus B" is not proper here. It should be Pausata et al 2015 PNAS.

Response #9: This has been corrected.