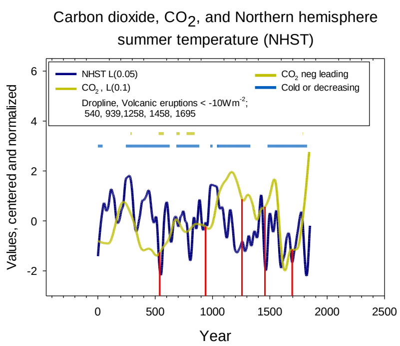
Identifying climate variables that interchange with volcanic eruptions as cooling forces during the Common Era's ice ages

1. From referee #1. The claim on lines 529-530 that "Volcanic eruptions instigated directly or indirectly increases in atmospheric CO_2 concentrations for 136 ±42 years" is completely wrong and based on statistical artifacts of the analysis that have no basis in physics.

The text that the referee refers to is on lines 526 -531:

Carbon dioxide, CO_2. (-, 16%) Volcanic eruptions instigated directly or indirectly increases in atmospheric CO_2 concentrations for 136 ±42 years, Fig. 3b. This increase could counteract the increase in NHST caused by aerosols. The sources for the increase in atmospheric CO_2 emissions from subaerial volcanic regions, Werner et al. (2019, Fig 8.3) and Buono et al. (2023), and emissions from oceans in the Southern Hemisphere that get warmer. Figure 3b shows that atmospheric CO_2 increases after volcanic eruptions and Fig. 4a (dark yellow line segment from 1230 to 1319) suggests that volcanic eruptions lead to a short cycle period in CO_2. (Figure 4 in main text)

We could have been more careful, for example written: "Volcanic eruptions appear to instigate directly or indirectly increases in atmospheric CO_2 concentrations with time lags from zero to 40 years. We have not identified conclusively the sources for the increases in CO_2"



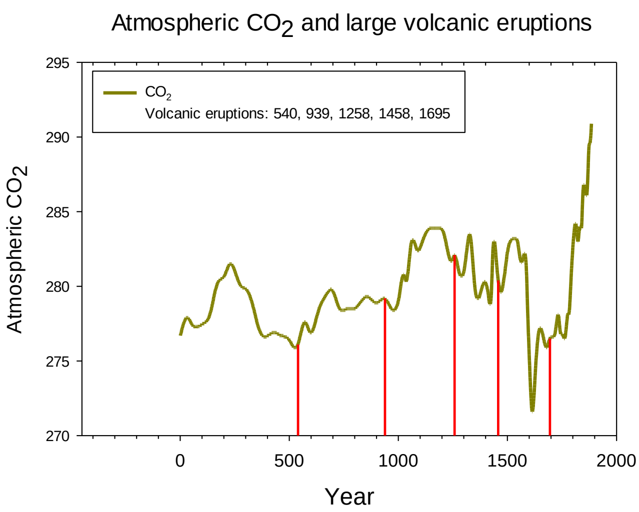
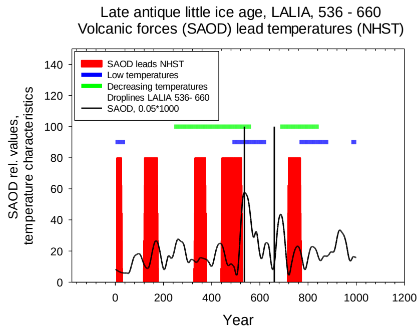


Figure 3 b in the manuscript is shown to the left. The right figure shows CO_2 and large volcanic eruptions. The eruptions tend to be followed by increases in CO_2, but some with lags 10-40 years.

2. From referee #1: The conclusion that CO_2 changes are as important as volcanic eruptions is ridiculous, if you account for the magnitude of their forcings, except for the period since 1850 when CO_2 and other greenhouse gases dominate.

Our text starting on line 268: The lower blue horizontal lines show periods with low temperature and the horizontal upper green lines show periods with decreasing temperature. The red bars show when SAOD is leading NHST. Altogether, there are seven periods lasting on average 75 ± 32 years (range 10 to 96 years) before and during the LALIA where other variables decrease or maintain low temperatures.

We could have been more careful and written: "Over short periods, ≈ 2 years, large volcanic eruptions, e.g., <-10Wm^{-2}, may cause dramatic cooling. However, over longer decennial time spans decreases in CO_2 may cause volatile, but persistent decreases in NHST during the Common era, but before the start of the industrial revolution.



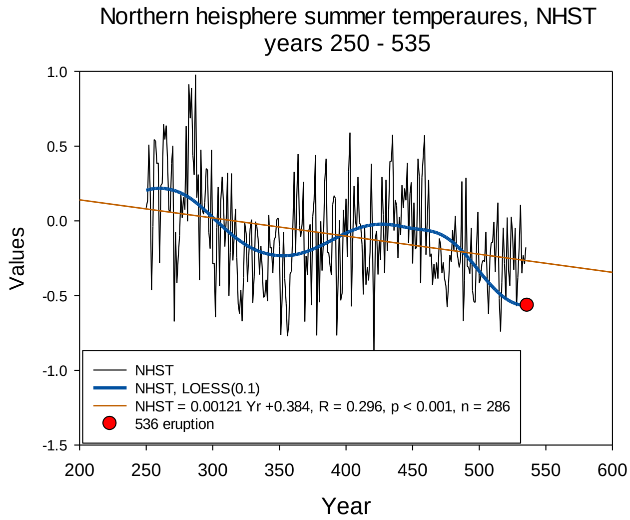


Figure 2 c in the manuscript is shown to the left. The upper left green line shows a period with decreasing temperature. The right figure shows the downward sloping trend corresponding to the horizontal green line.

3. From referee# 1: "By treating SAOD, TSI, NAO, IPO, and CO_2 as normalized time series, and not with units and actual radiative forcing, the results are meaningless, particularly as NAO and IPO are internal variability and not forcing"

The NAO is measured as air pressure. It is normal to refer to the NAO as being in positive or negative phase. See figure from NOAA below. The target variable for the study is the Northen hemisphere summer temperature and the conversion from NAO in air pressure units to temperature in the Northern hemisphere is complex.

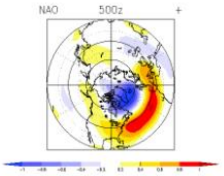
We think statistical-and difference modeling complement each other. The first method require careful evaluation of possible cause - effect results (cross validation would secure that the cause comes before the effect), and centered and normalized data are frequently used in that context. Difference modeling require much more data that often will consist of non-linear relations, e.g., Seip (1991).

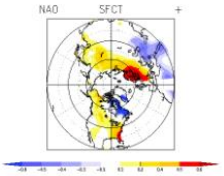
NAO time serieshttps://psl.noaa.gov/data/timeseries/daily/NAO/

North Atlantic Oscillation (NAO)

Description:
Pattern of variability in the North Atlantic.
Image:

Postive Phase:





Calculation Method:
The indices are based on centers-of-action of 500mb height patterns. These time series utilize the NCEP/NCAR R1 dataset. The area averaged region 55-70N;70W-10W is subtracted from 35-45N; 70W-10W. The 1981-2010 period was used as climatology. Before computing these indices the 500mb height fields are spectrally truncated to total wavenumber 10 in order to emphasize large-scale aspects of the teleconnections.
Time Interval: Daily
Time Coverage: 1948-near present

References

Buono, G., Caliro, S., Paonita, A., Pappalardo, L., & Chiodini, G. (2023). Discriminating carbon dioxide sources during volcanic unrest: The case of Campi Flegrei caldera (Italy). *Geology*, *51*(4), 397-401. https://doi.org/10.1130/G50624.1

Seip, K. L. (1991). The ecosystem of a mesotrophic lake- I. Simulating plankton biomass and the timing of phytoplankton blooms. *Aquatic Science*, *53*(2/3), 239-262. https://doi.org/1015-162/191/030239-24

Werner, C., Fischer, T., Aiuppa, A., Edmonds, M., Cardellini, C., Carn, S., & Allard, P. (2019). Carbon Dioxide Emissions from Subaerial Volcanic Regions: Two Decades in Review. In B. Orcutt, I. Daniel, & R. Dasgupta (Eds.), *Deep Carbon: Past to Present* (pp. 188-236). Cambridge University Press.