Project: **963**

Project title: **Volcanic Forcings Model Intercomparison Project (VolMIP)**

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Report period: **2025-11-01 to 2026-10-31**

Volcanic eruptions cause global climate perturbations, but their impacts are hard to predict because of the interaction between external forcing and internal climate variability. In the reporting period, we use a statistical model to assess how the pre-eruption climate affects post-eruption global cooling. The model uses a Bayesian statistical framework and combines transient historical, volcanic-only and natural-forcing experiments, as well as the VolMIP Pinatubo experiments. We could show that pre-eruption temperature anomalies provide a constraint on simulated post-eruption cooling, but they account for only a small part of the response variability. Conditioning on the pre-eruption state changes the expected response, but only slightly improves the predictive skill. Spatial analyses show organised large-scale variability not fully captured by the pre-eruption global-mean temperature anomaly. Accounting for ENSO-related variability provides additional, albeit limited, predictive information. Overall, our results show that the climate response to Pinatubo forcing is probabilistic. It can be constrained conditionally on the pre-eruption temperature anomaly, but not precisely predicted even under well-characterised forcing (Zanchettin et al., Sci Rep. in revision, 2026).

We also looked at the influence of natural forcing in different climate states. Under global warming, the Arctic warms faster than the rest of the Earth—a phenomenon known as Arctic Amplification (AA). However, whether volcanic cooling exhibits a similar amplified response in the Arctic, and how this response changes in a warming world, remains largely unknown. To assess how high-latitude climate responds to two massive 19th-century volcanic eruptions across three climate states, we have performed MPI-ESM-LR ensemble simulations for the cold early 19th century (Fang et al., 2022), the warmer present and the ice-free future (4xCO2) with natural forcings correspond to those of the early 19th century. We find that while the Arctic consistently cools more than the global average, this extra cooling effect weakens as the background climate warms. Interestingly, the season contributing the most to AA reverses, shifting from winter in cooler climates to summer under warmer regimes. This seasonal shift occurs because losing sea ice alters how heat is exchanged between the ocean and the atmosphere above. These results imply that future cooling events — whether from major volcanic eruptions or solar geoengineering — will be less effective at restoring Arctic sea-ice loss, leaving the region resilient to temperature reductions even as the rest of the planet cools. (Fang et al., in prep.).

Whether major volcanic eruptions are capable of modulating the North Atlantic Oscillation (NAO) towards a positive phase, associated with Eurasian winter-time warming, has been a long-standing question and also been addressed in the reporting period. Specifically, we investigated this hypothesis using the VolMIP Pinatubo experiments, both with and without volcanic forcing, under pre-industrial climate conditions. We find significant stratospheric warming in the tropics following the volcanic eruption but not at northern high-latitudes. As consequence of the strengthened stratospheric temperature gradient the stratospheric polar vortex (SPV) accelerates. An important finding of our study is that this strengthening occurs independent of the dynamical background state. While a strengthened SPV is associated with a positive NAO phase, no robust shift in the NAO emerges in the first post-eruption winter in the model experiments. In tandem with this lack in NAO response no Eurasian warming response is identified (Perny et al., in prep.).

During the reporting period, we have also continued with the analysis of the CMIP6/VolMIP[1] volc-long (Khodri et al., in prep), volc cluster (Camelia et al., in prep.), the analysis of the MPI-ESM Holocene simulations (van Dijk et al., 2026), and of the PMIP4 past1000[2]/simulations (Wilson et al., 2026, Thompson et al., 2026).

[1] VolMIP: Model Intercomparison Project on the climate response to Volcanic forcing (Zanchettin et al., 2016)

[2] past1000: Pre-industrial millennium experiment from PMIP4 (Jungclaus et al., 2017)

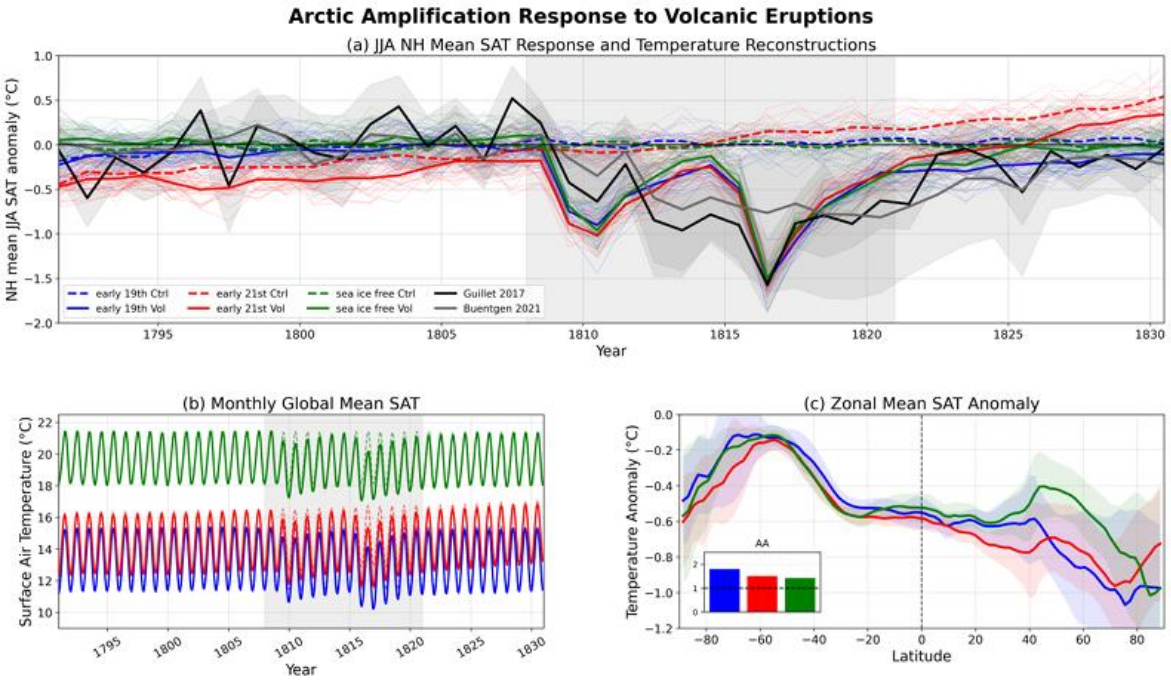


Figure 1. Arctic surface air temperature (SAT) response to volcanic eruptions in the early 19th, early 21st, and ice-free experiments. (a) Time series of Northern Hemisphere (20°–90°N) summer (June-July-August, JJA) mean SAT anomalies, together paleoclimate temperature reconstructions (Guillet et al. 2017; Büntgen et al., 2021). Dashed and solid lines represent the control and volcanic simulations, respectively. (b) Monthly global-mean SAT. (c) Zonal-mean SAT anomalies with shaded regions indicating one standard deviation across ensemble members. The inset shows the Arctic amplification (AA) factor, defined as the ratio of the absolute Arctic (60°–90°N) mean response to the absolute global mean response. Both the Arctic and global-mean SAT responses are negative in all three experiments during 1808–1820. AA values greater than 1 indicate Arctic amplification. (Figure from Fang et al. in prep.)

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