Project: **963**

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

Principal investigator: **Claudia Timmreck**

Report period: **2021-11-01 to 2022-10-31**

In the reporting period we have analyzed the CMIP6[1]/VolMIP[2] volc-pinatubo-full experiment, which is based on an ensemble of Pinatubo volcanic forcing-only climate simulations with the same volcanic aerosol dataset across the participating models. The simulations are conducted within an idealized experimental design where initial states are sampled consistently across models from their CMIP6-piControl simulations. The multi-model ensemble includes output from an initial set of six participating Earth system models (CanESM5, GISS-E2.1-G, IPSL-CM6A-LR, MIROC-E2SL, MPI-ESM1.2-LR and UKESM1). The results show overall good agreement between the different models on the global and hemispheric scales concerning the surface climate responses. However, small yet significant inter-model discrepancies are found in radiative fluxes, especially in the tropics, that preliminary analyses link with minor differences in forcing implementation; model physics, most notably aerosol–radiation interactions; the simulation and sampling of El Niño–Southern Oscillation (ENSO); and, possibly, the simulation of climate feedbacks operating in the tropics (Zanchettin et al., 2022). We have now started with the analysis of the VolMIP volc-long-eq simulations also in a multimodel framework.

As the VolMIP effort focuses on comparison across different models, an open question remains about how different configurations of the same model affect the comparability of results. We have therefore performed the CMIP6/VolMIP MPIESM1.2 simulations with two model resolutions for an idealized Pinatubo-like (volc-pinatubo-full) and an idealized Tambora-like (volc-long-eq) eruption. The MPIESM1.2-LR (Mauritsen et al, 2019) employs an atmospheric resolution of T63 (200 km), and nominal ocean resolution of 1.5°. The MPIESM1.2-HR, (Müller et al, 2018) employs twice of the horizontal resolution of its atmospheric component (T127, 100 km) with a spontaneously generated QBO, and an eddy-permitting ocean resolution of 0.4. We have started with the analysis already in 2021 but figured out that a direct comparison between both eruption strengths is biased due to different amount of ensemble members; 25 for the Pinatubo-like and nine for the Tambora like eruption. In order to make the experiments more comparable we have extended the VolMIP volc-long simulations from 9 to 25 ensemble members in 2022 using for both experiments the same initial conditions. The results are currently analyzed under various aspects (Timmreck et al, in prep. 2022). In general, the results are resolution independent but for the volc-long experiments the -HR data show for example a faster recovery of tropical ensemble mean near surface temperature anomalies (Figure 1).

So far climate models have difficulties to represent the long-lasting cooling in the early 19th century as has been seen in observations. We therefore analysed PMIP[3]past1000[4]/CMIP6VolMIP volc-cluster experiments where we have tested a new volcanic forcing dataset including more small-to-moderate eruptions between 1733-1895. We have performed a “Large-Only” cluster experiment with standard forcing and a “Small-Included” cluster experiment which includes the small-to-moderate volcanic eruptions as well. In addition, we run a “No-Volcano” experiment, which does not include any eruptions, as a transient control simulation. All experiments have 20 ensemble members and run for 40 years (1791-1830) for distinct ocean states (Fang et al., in prep. 2022). We find that indeed the small-to-moderate eruptions can induce significant surface cooling and help explaining the long-lasting cooling after the large eruptions in 1809 and in 1815 (Tambora) which is also seen in tree-ring reconstructions (Figure 2).

We have also prepared VolMIP simulations for publication in the ESGF. The-LR simulations are already published, the -HR will be put in the ESGF as soon as the MPIESM1.2 VolMIP experiment overview paper is submitted.

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[1] CMIP6: Coupled Model Intercomparison Project, Phase 6 (Eyring et al., 2016)
[2] VolMIP: Model Intercomparison Project on the climate response to Volcanic forcing (Zanchettin et al., 2016)
[3] PMIP4: Paleoclimate Model Intercomparison Project Phase 4 (Kageyama et al., 2018)
[4] past1000: Pre-industrial millennium experiment from PMIP4 (Jungclaus et al., 2020)

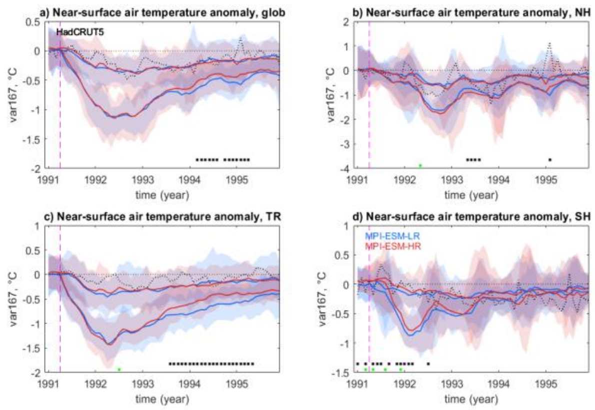

Figure 1: Time series of 2mt global (a) tropical (c) and northen and southern hemispheric (b ,d) mean near surface air temperature anomalies of the pinatubo-full and volc-long experiments. The MPI-ESM LR simulations are in blue the -HR simulations in red. For each experiment, the shading illustrates the ensemble envelope, and the line the mean. Squares at the bottom indicate when one experiment output is significantly different ($p < 0.05$) from the ensemble members of the corresponding experiment in a different resolution according to the Mann–Whitney U test (green:pinatubo-full, black: volc-long. The vertical dashed magenta line indicates the approximate timing of the eruption (1815-/1991). Observed HadCRUT5 (Morice et al, 2021) anomalies (ensemble-means as deviations from the 1990 average), are plotted as dotted black lines for comparison. Figure from Timmreck et al in prep. (2022).

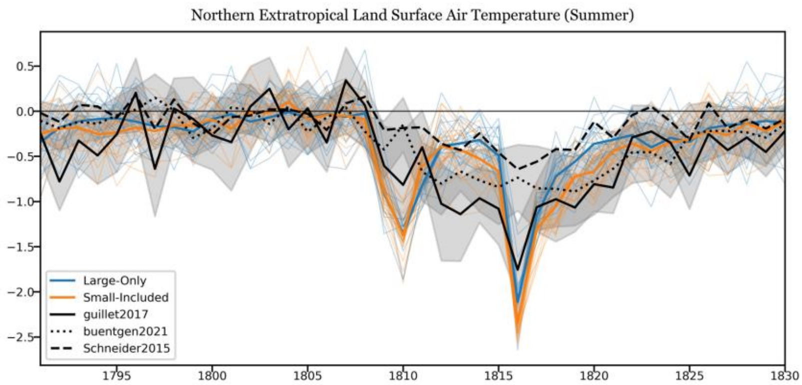

Figure 2: Northern extratropical (30° N to 90° N) summer land surface air temperature anomalies of the large volcano-only experiment (blue) and the experiment including small-to-moderate eruptions (orange). The think lines are the ensemble mean from 20 members. The black lines are for the anomalies from the different reconstructions and the gray shadings are their uncertainties. The reconstruction anomalies are offset with the difference from the ensemble mean of the Large-Only experiment over 1800-1808 for lining with the Large-Only experiment. The uncertainty of guillet2017 (solid; Guillet et al., 2017) is provided in the dataset and the uncertainty for the buentgen2021 is calculated by the one standard deviation of the 15 ensemble members (R1 to R15; dotted; Büntgen et al, 2021) and Schneider2015 is dashed (Schneider et al., 2015). Figure from Fang et al in prep. (2022).

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