Project: **960**

Project title: **StratoClim Stratospheric and upper tropospheric processes for better climate predictions**

Project lead: **Claudia Timmreck**

Report period: **2018-01-01 to 2018-12-31**

The central goal of project 960 is to investigate the climate impact of upper tropospheric and stratospheric aerosol. For 2018, CMIP6 (Coupled Model Intercomparison Project, Phase 6, Eyring et al., 2016) related work was planned in the frame of the "Model Intercomparison Project on the climate response to Volcanic forcing" (VolMIP, Zanchettin et al; 2016). In VolMIP different time scales are considered: the seasonal-to-interannual atmospheric response to a 1991 Pinatubo-like volcanic eruption (volc-pinatubo) and the long-term (up to the decadal time scale) climate response to very strong volcanic eruptions, like the 1815 Tambora eruption (volc-long). In this project the VolMIP volc-long experiments will be performed

However, the VolMIP MPI-ESM runs could not be carried out so far because the MPI-ESM-LR PiControl run and the scripting environment for CMIP6 were not available. There are now expected for late 2018, which will be the start of the VolMIP volc-long experiments in StratoClim. In 2018, the VolMIP preparatory work which has started in 2017 has been continued. Using the eVolv2k data set (Toohey and Sigl, 2017), we have compiled three sulfur emission time series: a central estimate, consistent with that used in VolMIP (Best); a high-end estimate, corresponding to the best estimate plus two times the (1σ) sulfur emission uncertainty (High); a low-end estimate, corresponding to the best estimate minus two times the (1σ) sulfur emission uncertainty (Low). Based on these sulfur injection estimates, the Easy Volcanic Aerosol v1.0 (EVA, Toohey et al., 2016) module has been applied to produce 3 different volcanic aerosol forcing sets.

In 2018, the original ensemble of 30 experiments has been extended to 90 experiments with different volcanic forcing (Best, High and Low) and different simulation time periods between 1800 to 1830. The 90 experiments includes a 30 year (1815-1830) ensemble for all three volcanic forcing estimates with 10 members each, a 15 year (1815-1830) ensemble for the Best forcing estimate with 30 members and 5 year (1815-1819) ensembles with 30 members for each of the three forcing estimates. At present, different scientific aspects of these runs are analyzed, e.g. the atmospheric response in Northern Hemisphere winter, the carbon cycle feedback and ocean atmosphere sea ice coupling mechanism. Below the most advance study is briefly presented.

To quantify the relative contribution of forcing uncertainties and initial-condition spread to post-eruption climate anomalies we have tested in 2019 how three climate simulation ensembles using the same set initial conditions but different realistic volcanic forcing estimates are distinguished by a blind cluster analysis (Zanchettin et al., submitted).

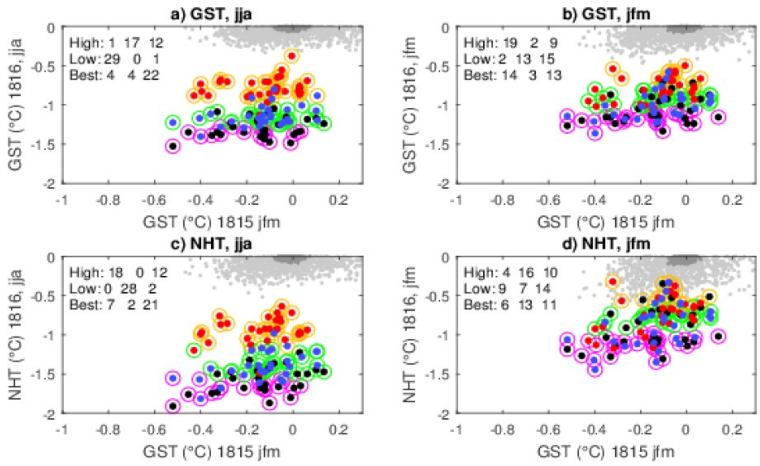

Figure 1: Scatterplot of climate response (y-axis) versus initial conditions (x-axis) for global surface temperature (GST) and Northern hemisphere temperature (NHT), for the summer 1816 (left) and winter 1815/16 (right) responses. Small filled circles are the original ensembles (red: Low, blue: Best, black: High); large empty circles are the clusters. The top three text lines in each panel report how the members of each of the original ensembles are redistributed across the clusters. The clouds of small grey dots show the range of variations that can be associated to internal variability (light: single simulation; dark: 30-member ensemble mean. From Zanchettin et al. submitted.

Figure 1 shows scatterplots of initial conditions versus climate response for boreal summer (June-July-August) and winter (January-February-March) near-surface air temperatures spatially averaged over the whole globe (GST) and the Northern Hemisphere (NHT) At the global and hemispheric scales, summer responses are clearly stratified, with colder anomalies for the High ensemble and smaller negative anomalies for the Low one; there is anyway at least some overlap between all ensembles. All simulations are outside the range of internal variability, in both GST and NHT (Fig. 1a,c). In winter, stratification of original ensemble responses is less clear, hence ensembles more strongly overlap in particular for NHT; a few realizations lie within the range of internal variability (Fig. 1b,d). In all cases, the clusters differ from the original ensembles. For summer, this especially occurs because of the overlaps between the Best and High ensembles, as almost all simulations in the Low ensemble fall instead into the same cluster, whereas the High ensemble is almost split in two. In winter, simulations in the original ensembles are always distributed across all three clusters.

Overall, the imposed volcanic forcing largely determines the summer temperature response at global to continental scales. Nonetheless, initial conditions influence the response in winter already at the global scale, causing substantial overlapping of the ensemble distributions and thereby producing, occasionally, indistinguishable responses. Similar implications can be drawn at the hemispheric and continental scale (not shown), where a tendency toward a stronger spread of original ensembles into clusters by means of initial conditions compared to GST and NHT is found, and post-eruption winter anomalies more closely superpose on the range of internal variability.

Another focus of StratoCLIM is the simulation of unperturbed and enhanced stratospheric aerosol loading under present and future conditions with the global aerosol model ECHAM5-HAM. A global aerosol model study for the Tambora eruption with four participating models incl. ECHAM5-HAM has revealed large differences for example in the sulfur deposition among the models (Marshall et al., 2018). It is important to understand these differences for a more reliable estimate of stratospheric aerosol forcing. StratoCLIM will therefore also contribute to the international SSiRC (Stratospheric Sulfur and its Role in Climate, http://www.sparc-ssirc.org) stratospheric aerosol model intercomparison project ISA-MIP (Timmreck et al, 2018), which aims to address existing uncertainties and differences among the models with respect to stratospheric aerosol radiative forcing and its climate response. The ISA-MIP experiments originally planned for 2018 had to be postponed as well, as the experimental design has only recently be completely fixed. They will be carried out in late 2018 and 2019.

References

Eyring, V. et al..: Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization, Geosci. Model Dev., 9, 1937-1958, doi:10.5194/gmd-9-1937-2016, 2016.

Marshall, L., Schmidt, A., Toohey, M., Carslaw, K. S., Mann, G. W., Sigl, M., Khodri, M., Timmreck, C., et al..: Multi-model comparison of the volcanic sulfate deposition from the 1815 eruption of Mt. Tambora, Atmos. Chem. Phys., 18, 2307-2328, https://doi.org/10.5194/acp-18-2307-2018, 2018.

Schneider, L., et al.:., 2015. Revising midlatitude summer temperatures back to A.D. 600 based on a wood density network. Geophys. Res. Lett. 42, 4556e4562. http://dx.doi.org/10.1002/2015gl063956, 2015.

Stoffel, M., et al.: Estimates of volcanic-induced cooling in the Northern Hemisphere over the past1,500 years, Nat. Geosci., 8, 784–788, doi:10.1038/ngeo2526,2015.

Timmreck, C., et al.: The Interactive Stratospheric Aerosol Model Intercomparison Project (ISA-MIP): motivation and experimental design, Geosci. Model Dev., 11, 2581-2608, https://doi.org/10.5194/gmd-11-2581-2018, 2018.

Toohey, M., Stevens, B., Schmidt, H., and Timmreck, C.: Easy Volcanic Aerosol (EVA v1.0): An idealized forcing generator for climate simulations, Geosci. Model Dev., 9(11), 4049–4070, doi:10.5194/GMD-9-4049-2016, 2016

Toohey, M. and Sigl, M.: Volcanic stratospheric sulfur injections and aerosol optical depth from 500 BCE to 1900 CE, Earth Syst. Sci. Data, 9, 809-831, https://doi.org/10.5194/essd-9-809-2017, 2017.

Wilson, R., et al., 2016. Last millennium northern hemisphere summer temperatures from tree rings: Part I: the long term context. Quat. Sci.Rev. 134, 1e18. http://dx.doi.org/10.1016/j.quascirev.2015.12.005.

Zanchettin, D., Khodri, M., Timmreck, C., et al.: The Model Intercomparison Project on the climatic response to Volcanic forcing (VolMIP): experimental design and forcing input data for CMIP6, Geosci. Model Dev., 9, 2701-2719, doi:10.5194/gmd-9-2701-2016, 2016.

Zanchettin, D., Timmreck, C., Toohey, M. et al.: Clarifying the relative role of forcing uncertainties and initial-condition unknowns in spreading the climate response to volcanic eruptions, submitted to Geophys. Res. Lett, 2018.