Project: **960**

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

Principal investigator: **Claudia Timmreck**

Report period: **2019-01-01 to 2019-12-31**

The central goal of project 960 is to investigate the climate impact of upper tropospheric and stratospheric aerosol. For 2019, 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 are performed. At present (Fall 2019), the performance of the MPI-ESM1.2-LR simulations for VolMIP has been started. It is expected that this will last until early 2020

In the first half of 2019, the VolMIP preparatory work has been continued in project 960. Using the eVolv2k data set (Toohey and Sigl, 2017) and the Easy Volcanic Aerosol v1.0 (EVA, Toohey et al., 2016), we have compiled three forcing time series for the early 19th century: a central estimate, consistent with that used in VolMIP; a high-end estimate, corresponding to the best estimate plus two times the (1σ) sulfur emission uncertainty; a low-end estimate, corresponding to the best estimate minus two times the (1σ) sulfur emission uncertainty. Using these different volcanic forcing data sets we have performed 90 experiments of different length (5 years up to 30 years) in the period from 1800 to 1830. With this early 19th century ensemble we have tested whether different realistic volcanic forcing magnitudes for the 1815 Tambora eruption yield distinguishable ensemble temperature responses (Zanchettin et al., 2019). We found that forcing uncertainties can overwhelm initial-condition spread in boreal summer, while the effect of initial conditions predominate in winter. Uncertainties in current initial-condition can hamper inferences on magnitude of the Tambora eruption in relation to the “year without summer”. Applying a state-of-the-art event attribution method we have also tested whether the ‘year without summer in 1816’ in Europe with anomalously cold conditions and unusual wetness have been caused by the eruption of Mount Tambora in April 1815 (Schurer et al., 2019). We found that in climate models, including the forcing by the Tambora eruption the European cold anomaly is up to 100 times more likely, while the precipitation anomaly became 1.5–3 times as likely, attributing a large fraction of the observed anomalies to the volcanic forcing. At present, different scientific aspects of these runs are further analyzed, e.g. the atmospheric response in Northern Hemisphere winter, carbon cycle feedback processes and ocean atmosphere sea ice coupling mechanisms. In addition analysis is also ongoing with respect to the unidentified eruption of 1809 (Timmreck et al., in prep).

Another focus of StratoCLIM is the simulation of unperturbed and enhanced stratospheric aerosol under past, present and future conditions with the global aerosol model ECHAM5-HAM. One of the three big volcanic eruptions in the 20th century is the eruption of the Indonesian volcano Mt. Agung in March 1963. It is also the eruption whose radiation forcing is the most uncertain as there are no global satellite observations. A closer look at the volcanic activity of Mt. Agung in 1963 revealed that there was not only one eruption high enough to enter SO_2 into the stratosphere, but two (Self and Rampino, 2012). The first eruption on March 17th injected roughly twice as much SO_2 into the stratosphere as the second eruption on May, 16th (Self and Kiang, 1996). In recent volcanic emission data sets these eruption phases are merged together to one large eruption phase for Mt. Agung in March 1963 with an injection rate of 7 Tg SO_2. To test if there is a significant difference when simulating two medium eruptions instead of a single large one only, we performed ensembles of two model experiments, one with a single eruption of 7 Tg SO_2 (AGUNG1) and a second one with two eruptions (AGUNG2) of 4.7 Tg SO_2 and 2.3 Tg SO_2 (Niemeier et al., 2019). The two smaller eruptions result in a lower burden, smaller particles and 0.1 to 0.3 W/m^2 (10 - 20%) lower radiative forcing in monthly mean global average compared to the individual eruption experiment (Figure 1). The differences are the consequence of slightly stronger meridional transport due to different seasons of the eruptions, lower injection height of the second eruption and the resulting different aerosol evolution. The differences between the two experiments are significant but smaller than the variance of the individual ensemble means. Overall, the evolution of the volcanic clouds is different in case of two eruptions than with a single eruption only. We conclude that there is no justification to use one eruption only and both climatic eruptions should be taken into account in future emission datasets.

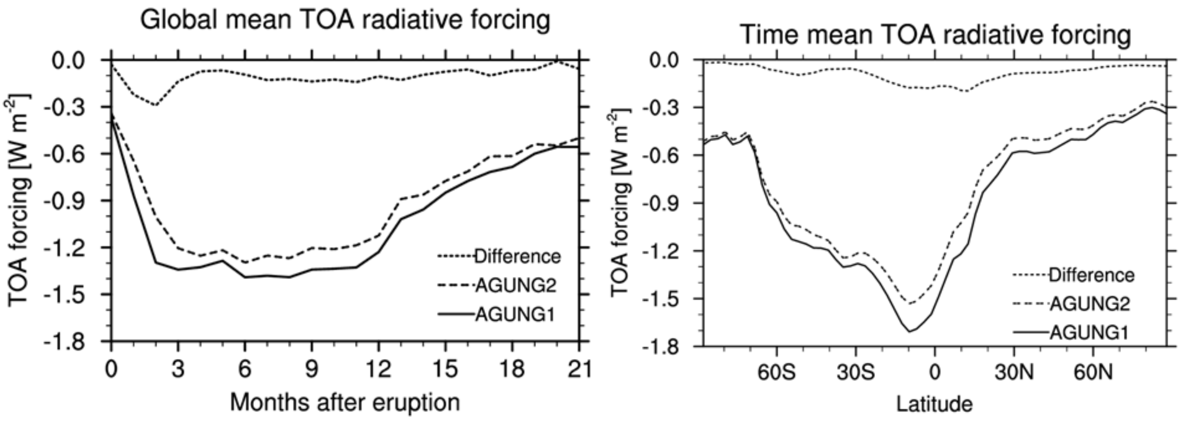

Figure 1: Top of the atmosphere (TOA) radiative forcing of sulfate aerosols under all sky conditions. Left: Global mean TOA forcing over time. Right: Zonally averaged radiative forcing as average over time (21 months). Results of the single eruption case (AGUNG1), the two eruption case (AGUNG2) and the difference (AGUNG2 minus AGUNG1) are shown. Figure from Niemeier et al. (2019).

References:

Eyring, V., Bony, S., Meehl, G. A., Senior, C. A., Stevens, B., Stouffer, R. J., and Taylor, K. E.: 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.

Niemeier, U., Timmreck, C., and Krüger, K.: Revisiting the Agung 1963 volcanic forcing – impact of one or two eruptions, Atmos. Chem. Phys., 19, 10379–10390, https://doi.org/10.5194/acp-19-10379-2019, 2019.

Schurer, A., Hegerl, G., Luterbacher, J., Brönnimann, S., Cowan, T., Tett, S., Zanchettin, D. and Timmreck, C.: Disentangling the causes of the 1816 European year without a summer. Env Res Lett, 14: 094019. doi:10.1088/1748-9326/ab3a10, 2019.

Self, S. and King, A. J.: Petrology and sulfur and chlorine emissions of the 1963 eruption of Gunung Agung, Bali, Indonesia, Bulletin of Volcanology, 58, 263–285, doi:10.1007/s004450050139, 1996.

Self, S. and Rampino, M. R.: The 1963–1964 eruption of Agung volcano (Bali, Indonesia), Bulletin of Volcanology, 74, 1521–1536, doi:10.1007/s00445-012-0615-z, 2012.

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.

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., Jungclaus, J., Bittner, M., Lorenz, S. and Rubino, A.: Clarifying the relative role of forcing uncertainties and initial-condition unknowns in spreading the climate response to volcanic eruptions. Geophysical Research Letters, 46, 1602-1611. doi: 10.1029/2018GL081018, 2019.