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Revisiting the Agung 1963 volcanic forcing – impact of one or two eruptions

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The simulations for this study were performed with the middle atmosphere version of the general circulation model (GCM) ECHAM5 (Giorgetta et al., 2006). The aerosol microphysical model HAM (Stier et al., 2005) is interactively coupled to the GCM. ECHAM5-HAM simulates the evolution of sulfate from the injected SO_2 to sulfate aerosol and includes transport and sink processes like sedimentation and deposition (Niemeier et al., 2009).

1 Ensemble

We performed a set of six ensemble-members for both, AGUNG1 and AGUNG2. A 20-years control simulation, which was performed with ECHAM5-HAM under background conditions, was the basis of the ensemble. Two years of the control simulation show a QBO phase similar to observations before the Agung eruption. Thus, the restart files of these two years were taken to start two members of the ensemble. We started all simulations of the ensemble in January 1962 with nudged QBO. We enlarged the ensemble by using one of the above restart files for four additional simulations. We set the factor by which stratospheric horizontal diffusion is increased from one level to next level above to 1.001, 1.0001, 0.999, 0.9999, respectively, instead of 1 in these simulations in 1962. This method is used regularly to disturb the atmosphere and creates a different state of the dynamical situation. Thus, we got six different states of the atmosphere to start our volcanic eruption simulations. Finally, all six simulations were used to calculate an ensemble mean. The sulfate burden simulated in the single simulations of the ensemble are given in Figure 1.

2 Injection at different altitude

Self and Rampino (2012) give a range of possible altitudes for the main injection height of the two eruptions: 19 to 26 km for the March eruption and 19 to 23 km for the May eruption. The average of this range resulted in the eruption altitudes of 50 hPa (22.5 km) and 70 hPa (21 km) in our simulations. We took the range of possible injection altitudes and the related uncertainties into account by performing a single simulation with an eruption altitude of 50hPa in both eruptions.

Effective radii increase compared to the corresponding single eruption of the AGUNG2 ensemble around 10% in the tropical volcanic cloud (Fig. 2). The radii are also slightly larger than in the corresponding single simulation of the AGUNG1 ensemble (up to 5%), similar to Laakso et al. (2016). The higher injection altitude results in a larger burden than in the AGUNG2 case. The resulting global forcing is in the first 6 months after the first eruption very similar to the corresponding AGUNG2 simulation. Thereafter, the forcing is larger than in AGUNG2 and follows closely the results of the single AGUNG1 simulation.

3 Reduced OH concentration in volcanic cloud

ECHAM5-HAM does include stratospheric chemical reactions only for sulfate chemistry. NOx, ozone (O_3), OH concentrations are prescribed on a monthly mean basis. The model includes a simplified OH-limitation for super-volcano eruptions (Timmreck et al., 2010). We adapted this parameterization to sulfur loads after smaller volcanic eruptions.

We reduce the OH concentration when the SO_2 concentration is larger as the ratio $SO2 > \frac{k_2 * O3}{k_3}$ with k = reaction rates; OHc = climat. OH concentration $k_1 = k_{(HO2+OH)}, k_2 = k_{(O3+OH)}, k_2 = k_{(SO2+OH)}$ to this values:

- 10% of the monthly mean OH concentration for the first nine days after the eruption.
- 50% of the monthly mean OH concentration for day 10 to 29 after the eruption.
- 75% of the monthly mean OH concentration for day 30 to 60 after the eruption.

This limitation of the OH concentration slows the formation of sulfuric acid and sulfate. The simplification cannot reflect different sulfate concentrations and may not apply for small eruptions. Figure 4 and 5 show the AOD for a single simulation (dashed line) compared to the same simulation without OH-limitation, both with one eruption. The formation of sulfate is slower and, thus, the onset of the meridional transport is later with OH-limitation (Figure 4). The version without OH-limitation fits better to the measurements around 30°S in the early phase after the eruption. Opposite, the later arrival of the volcanic cloud at the south pole with OH-limitation represents the measurements better. Figure 5 shows too low AOD in the first month after the eruption with OH-limitation. The results of both model versions do not simulate the higher AOD values half a year after the eruption.

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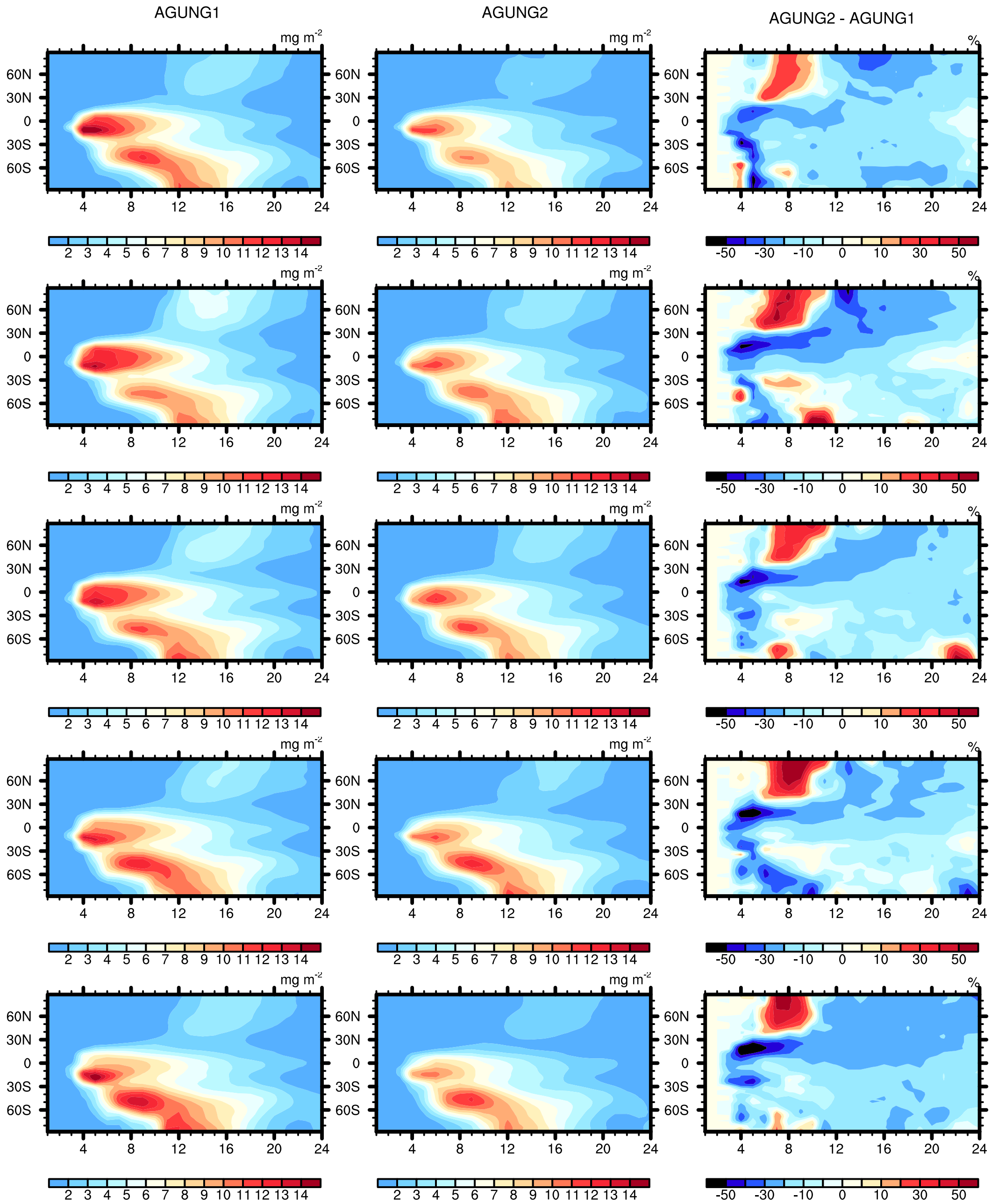

Figure 1: Sulfate burden of single simulations of AGUNG1 (left), AGUNG2 (middle) and the relative difference (right). X-axis gives the 24 months of the period 1963 to 1964.

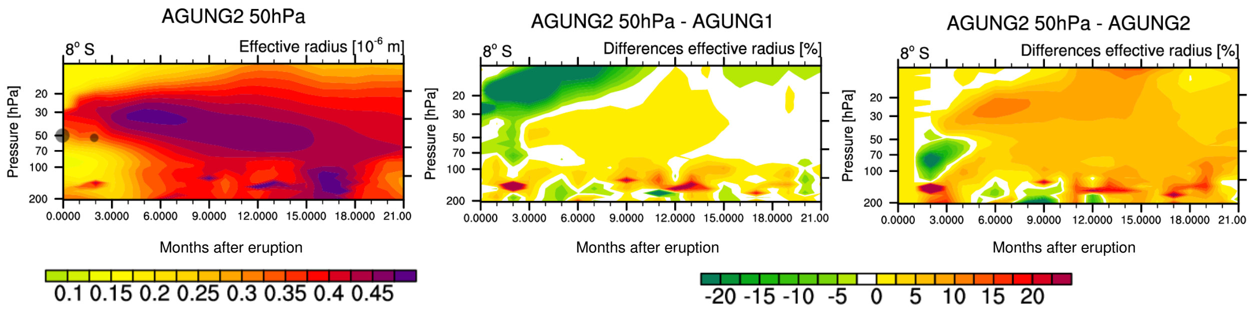

Figure 2: Hovmøller diagram of monthly mean effective radius µm of sulfate at the grid point corresponding to 8°S. Left: Simulation with two eruptions at the same height. Middle: Difference to AGUNG1. Right: Difference to AGUNG2. X-axis shows time after eruption.

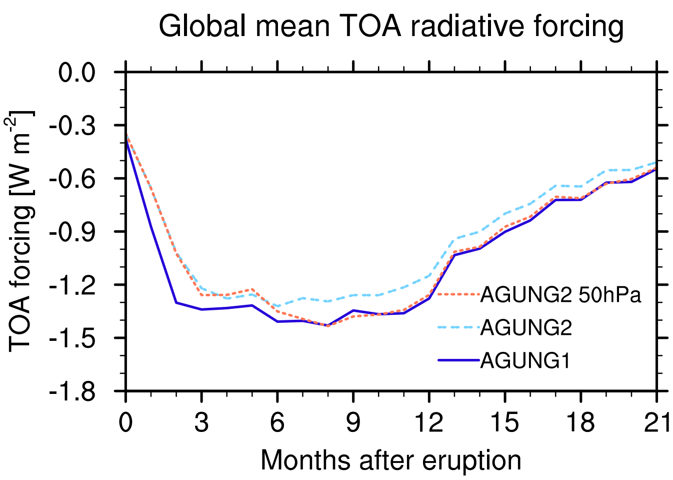

Figure 3: Top of the atmosphere (TOA) radiative forcing of sulfate aerosols under all sky conditions over time. Aerosol forcing was calculated using a radiation double call.

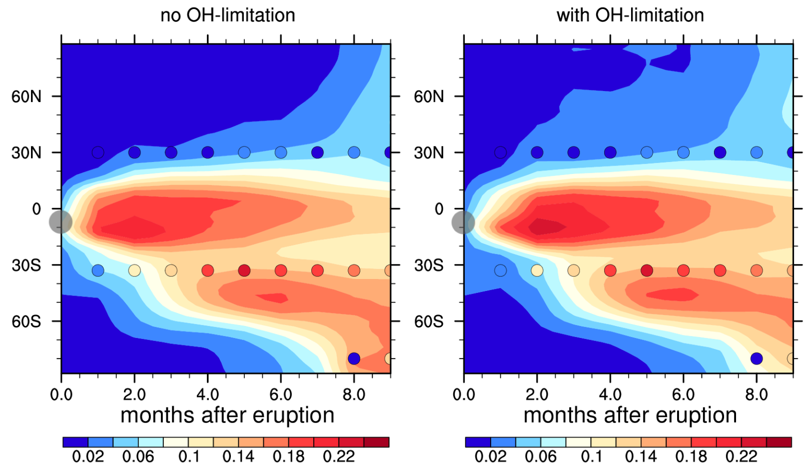

Figure 4: Zonally averaged monthly mean AOD over time for a simulation with climatological OH values (left) and a parameterized OH-limitation (right).Both simulations use one single eruption Colored circles show an average ob observation, representative for 20°S to 40°S, 20°N to 40°N, and 80°S taken from Stothers (2001).

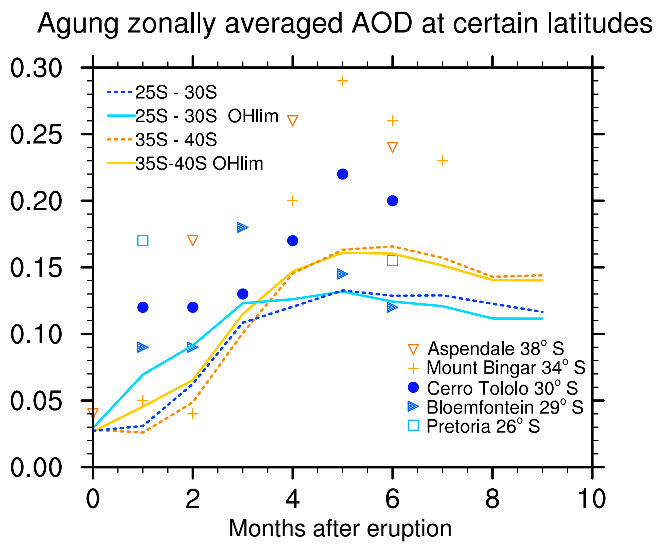

Figure 5: Monthly mean AOD over time. Colored lines show model results averaged over 25°S to 30°S and 35°S to 40°S, for one single simulation result without limited OH (solid line) and with limited OH (dashed line). Single markers show measurement data, estimated from Figure 1 in Stothers (2001).