The influence of large volcanic eruptions on stratospheric circulation and trace gas concentration

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Motivation

Major volcanic eruptions have a significant impact on stratospheric and tropospheric climate, chemical composition and circulation. Changes in the atmospheric trace gas concentration are a combined effect of heterogeneous chemistry, and of perturbations in the heating rates and in the photolysis rates.

Model set up

We use the stratospheric mesospheric version of the Hamburg climate model (MA/ECHAM4) **with interactive stratospheric chemistry and prognostic and interactive volcanic aerosol** to analyse the influence of large volcanic eruptions on the stratospheric ozone concentration. GCM simulations are shown for the 1991 volcanic eruption of Mt. Pinatubo.

The circulation model MAECHAM4 (Manzini et al., 1997):

- vertical resolution: 39 layers from the surface to 0.01 hPa
- horizontal resolution: T30 (3.75° x 3.75°)
- time step: 15 min for dynamics and physics
- the radiation scheme is calculated every 2 hours
- prognostic variables: temperature, divergence, vorticity, logarithm of surface pressure
- Spitfire advection scheme (Rasch and Lawrence, 1998)

The Chemistry Scheme CHEM (Steil et al., 1998)

- 19 prognostic variables: CH_4, N_2O, H_2, CO, H_2O_2, HCl, HNO_3+NAT, CH_3O_2H, H_2O+ICE, $ClNO_3$, F11, F12, CH_3Cl, CCl_4, CH_3CCl_3, O_x(O_3+$O(^3P)$+$O(^1D)$), ClO_x (Cl+ClO+HOCl +$2Cl_2O_2$+$2Cl_2$), NO_x (N+NO+NO_2+NO_3+HNO_3 +$2N_2O_5$)
- Family members, radicals (like HO_x= H+OH+HO_2) are calculated analytically
- 110 photochemical reactions
- Heterogeneous reactions on PSC's (NAT, ICE) and sulfate aerosols
- Photolysis rates are calculated on line (Landgraf and Crutzen, 1998)

Treatment of Volcanic Aerosol

- No explicit calculation of microphysical processes: SO_{2x} + OH -> SO_4^{2-} I. At present we are working on the implementation of a fully explicit microphysical scheme SAM (Timmreck, 2001).
- Tropospheric sulfur cycle (Feichter et al. 1996)
- 4 additional prognostic variables DMS, SO_2,SO_4 and SO_{2x}
- Relation between mass and size (Grainger et al. 1995) $A = 8.406 * V^{0.75}$ $r_e = 0.357 * V^{0.249}$
- The standard deviation is kept constant $\sigma = 1.86$.
- Water vapor equilibrium is assumed

Radiative Calculations

- Table look up for normalized optical parameter
  - Extinction coefficient (r,W)
  - Absorption coefficient (r,W)
  - Asymmetry factor (r,W)
- 20 Radii (µm): 0.01, 0.025, 0.05, 0.075, 0.1, 0.125, 0.15, 0.175
- , 0.2, 0.225, 0.25, 0.27, 0.3, 0.35, 0.4, 0.45, 0.5, 0.75, 1.0, 2.0
- 6 concentrations: 0.25, 0.38, 0.5, 0.75, 0.84, 0.95
- Mie calculation for the broadband intervals of the ECHAM4 radiation scheme
- Refractive indices of sulfuric acid (Palmer and Williams, 1975)

Results

The Pinatubo cloud encircles the Earth in three weeks and stays in the first three months in a latitude band between 30°S and 30°N in good agreement with observations.

Enhanced meridional northward transport takes place in October with the change from summer to winter circulation, which is associated with an amplification of Planetary scale waves in high latitudes.„Fat filaments“ transport volcanic aerosol from the tropical region to high latitudes. Hence, the model fails to reproduce the observed tropical aerosol maximum since December 1991 (**Figure 5,6,7**).

The aerosol surface area density corresponds well with observations from the NH midlatitudes. Deviations are related to difficulties in the simulated long range transport e.g.Overestimation of the meridional transport.,vertical diffusion (**Figure 3,4**).

The aerosol induced stratospheric temperature increase is stronger (about 2 K) in comparison to observations. This possible results from an overestimation of the aerosol heating. The model is able to simulate the strengthening of the polar night vortex in winter 1991/1992 and a warming in midwinter. In the second winter the vortex breaks down in contrast to the observations (**Figure 8,9**).

Column ozone decreases in the tropics about 4% in autumn 1991 in good agreement with the observations. The strong ozone decreases in polar winter is reproduced by the model. The positive ozone anomaly in winter 1992/1993 at NH high latitudes reflects the false dynamical feedback (**Figure 10**).

The changes in the chemical concentration due to the volcanic aerosol. are a combined effect of changes in the photolysis rates, in the heterogeneous chemistry and the heating rates (**Figure 11**).

The change in the photolysis rates caused by an increase in the stratospheric particle concentration leads to two effects: a direct effect (chemistry) which is largest below the aerosol cloud and indirect effect (transport) which leads to enhanced upward transport in the first year after the eruption. Heterogeneous chemistry plays the dominant role in the aerosol containing layers between 20-30 km with increases in the CLOX concentration up to 100% and decreases in the NOX concentration of more than 50%. Aerosol induced heating leads to an uplifting of the trace gases. This results in a decrease in the aerosol containing layers and in the upper stratosphere, which can clearly be seen in the NOX concentration.

The tropical O_3 concentration decreases below 30 km due to heterogeneous chemistry and upward transport and increases above 30 km due to a decrease in NOX .

The simulated changes in the atmospheric trace gas concentration looks reasonable, the values might change with respect of BrOX chemistry and a more sophisticated sulphur chemistry, which are not considered in the present model runs

Note: It is difficult to evaluate the response of the model from a single realization. Ensemble runs are necessary !!!

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A Pinatubo case study

Initialization of Pinatubo

Initialization of 17 MT SO_2 according to TOMS observations in four model layers between 47-15 hPa (21.5-29.5km)

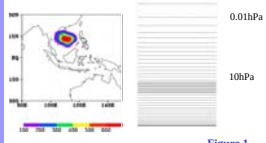


Figure 1

Stratospheric Aerosol Loading after Pinatubo

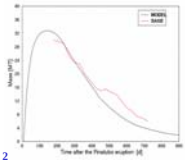


Figure 2

Surface Area Density [µm²cm⁻³] at 41°N

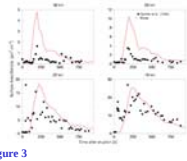


Figure 3

Transport of the Pinatubo Cloud

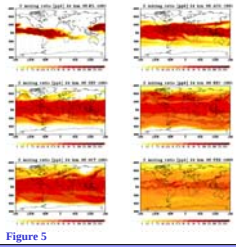


Figure 5

Optical depth at λ = 0.5 µm

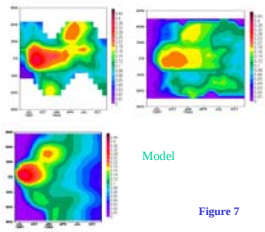


Figure 7

Surface Area Density [µm² cm⁻³] at 41°N

Comparison with OPC measuremnets (Deshler et al. 1993)

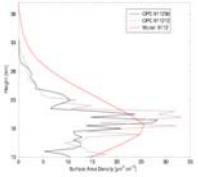


Figure 4

Meridional Cross Section of S Mixing Ratio

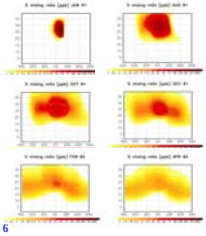


Figure 6

Perturbations of Heating rates [k/d] (total)

Comparison with ECHAM4 Simulations with PADS (Kirchner et al. 1999)

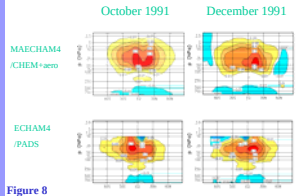


Figure 8

Changes of Chemical Concentration

Tropical Average (30°S-30°N)

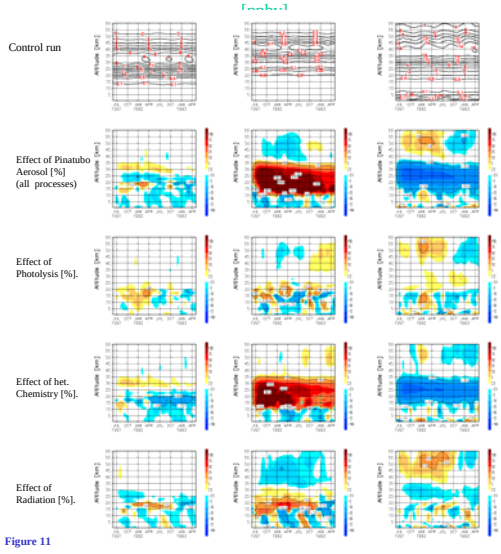
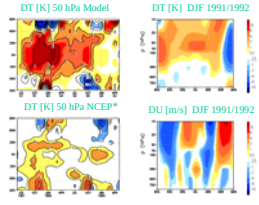


Figure 11

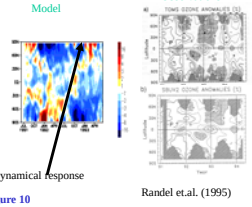
Dynamical Response



*Calculated with respect to the 1968-1997 climatology (Kalnay et al. 1996)

Figure 9

Total Ozone Changes [%]



Randel et.al. (1995)

Figure 10

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