Microphysical Processes in the Stratosphere

and their nonlinear interactions with a chemical-microphysical -climate model

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KODYACS

Kopplung von Dynamik und Atmosphärischer Chemie in der Stratosphäre

Abstract

MIPS contributes to the understanding of the highly nonlinear interactions between chemistry, microphysics, radiation and dynamics, in studying the role of stratospheric aerosols and ice clouds in the global climate system. The investigations has been carried out with a coupled chemistry-microphysics climate model, which was developed during this project and validated for background and volcanic episodes. Different processes which were responsible for changes in the ozone concentration after the Pinatubo eruption e.g heterogeneous chemistry, radiation, changes in the photolysis rate have been analyzed separately.

MPI -MIPS has focused in particular on the following research activities:

- Multiannual simulations with the chemistry climate model MAECHAM4/CHEM/SAM
- Implementation of SAM into ECHAM5
- Investigation of aerosol chemistry interactions after the Mt. Pinatubo eruption

These activities are integrated in joint activities of the KODYACS partners.

Implementation of SAM into ECHAM5

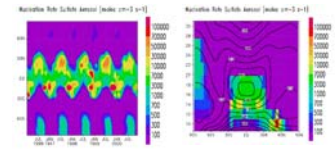


Figure 1 a
Temporal development of the calculated nucleation rate over the simulated time period of 5 years in 14km height.

Figure 1 b
Latitude-altitude cross section of the zonally averaged nucleation rate in the stratosphere with iso lines of temperature. Annual mean of the third simulation year.

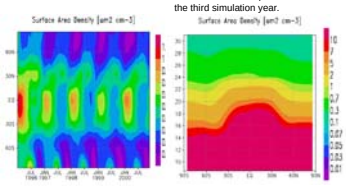
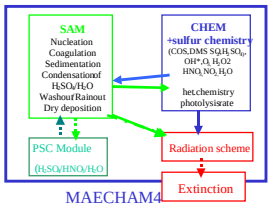


Figure 2 a
Temporal development of the calculated aerosol surface area density over the simulated time period of 5 years in 24km height.

Figure 2 b
Latitude-altitude cross section of the zonally averaged stratospheric aerosol surface area density. Annual mean of the third simulation year.

SAM has successfully implemented into ECHAM5. For the implementation in ECHAM5 SAM is rewritten in FORTRAN90 and adopted to a modular structure. A first multiannual simulation has been performed in T21 resolution (Figure 2) and is currently validated. For the near future simulations with a higher vertical and horizontal resolution are planned. In addition a coupling with the PSC module from MPI-C is intended for the summer until then both modules should run independently.

Multiannual simulation with the chemistry climate model MAECHAM4/CHEM/SAM



We have coupled the global stratospheric aerosol model SAM (*Timmreck et al.,* 2001), which explicitly calculates microphysical processes (nucleation, condensation, coagulation, sedimentation) with the MAECHAM4/CHEM (*Steil et al., 2003)* see KODYACS poster by Brühl et al. In this context SAM has been substantially revised. A new parameterisation of the homogenous nucleation rate has been implemented (*Vehkamäki et al.,* 2002). In addition we introduced COS and H_2SO_4 as new tracers in the model and together with MPI-C CHEM has been extended with a stratospheric sulfur scheme.

A first multiannual run has been performed with the chemistry climate model MAECHAM4/CHEM/SAM. In the upper troposphere highest particle concentration are found in NH midlatitudes in spring. The concentrations differ between land and ocean up to two orders of magnitude. The geographical distribution is similar as observed by CARIBIC (*Hermann et al.,2003*) with high particle number concentration in the UT in summer over the Arabian Sea and at midlatitudes over Europe and lower values in the subtropics over the Middle East. In winter the model results show also a decrease over Europe in the UT towards higher latitudes.The values are however higher as observed in particular over Europe because an anthropogenic SO_2 emission data set from the mid 80ties is used. In the lower stratosphere the maximum number concentration is found in the tropics and is strongly linked to homogeneous nucleation.

Log_{10}(number density [cm^{-3}]) JJA Log_{10}(number density [cm^{-3}]) DJF

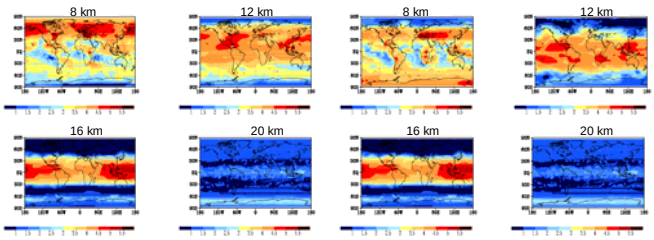


Figure 3 Decadal logarithm of particle number concentration in JJA and DJF. The model results represent a five year average of a multiannual simulation with the MAECHAM4/CHEM/SAM.

Pinatubo effect on cirrus clouds

Different sensitivity studies have been performed with the ECHAM general circulation model for 2 ½ years after the Mt. Pinatubo eruption (July 1991 to December 1993) to study the possible potential of volcanic emission to alter cirrus cloud properties (*Lohmann et al.,* 2003). Homogeneous cirrus formation caused by sedimenting sulphate particles produced in the eruption plume has been compared with homogeneous cirrus formation in the undisturbed atmosphere. The results turned out to be very sensitive to the assumed size distribution. While there is no trend on cloud microphysical or optical properties in our second scenario (trimodal size distribution), the first scenario (monomodal size distribution) shows a pronounced increase in ice water path and a noticeable impact on cloud radiative forcing

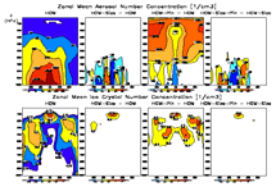


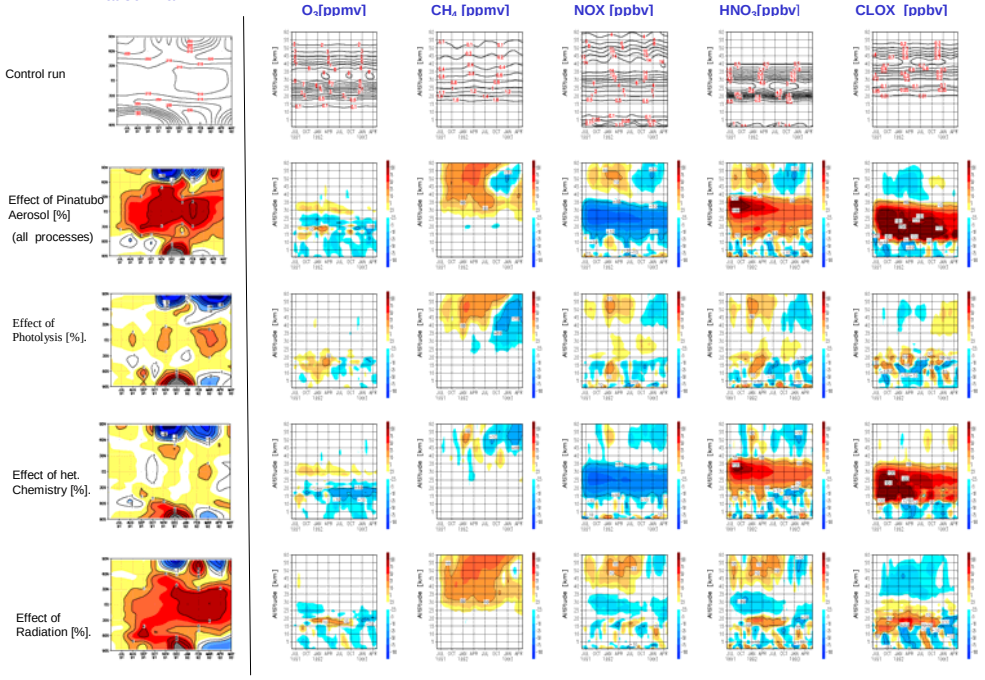
Figure 4
Zonal Mean Aerosol and Ice Crystal Number Concentrations for 1992.

AEROSOL CHEMISTRY INTERACTIONS IN THE STRATOSPHERE: A PINATUBO CASE STUDY

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. We have used the chemistry climate model **with interactive stratospheric chemistry and prognostic and interactive volcanic aerosol** to analyse these processes for the 1991 volcanic eruption of Mt. Pinatubo (*Timmreck et al., 2003*).

Temperature changes at 50 hPa

Changes of Chemical Concentration (Tropical Average (30°S-30°N))



The temperature anomaly at 50 hPa is largely due the aerosol induced radiative heating (direct effect). Heterogeneous chemistry on the volcanic aerosols particles leads to a temperature decrease of up to –1 k in October 1991 while aerosol induced changes in the photolysis rates have an opposite effect. 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. 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 ClO_X concentration up to 100% and decreases in the NO_X 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 an increase in the upper stratosphere, which can clearly be seen in the NO_X 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 NO_X

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