International Max Planck Research School on
EARTH SYSTEM MODELLING

"Towards the Assessment of the Aerosol Radiative Effects A Global Modelling Approach"

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Abstract

Aerosols play an important role in the global climate system. However, their effects on the radiation budget and even their global distribution and composition are not understood satisfactorily. The objective of this study is to advance the understanding about the global tropospheric aerosol system as basis for higher accuracy estimates of the anthropogenic aerosol effects.

In traditional global aerosol models, aerosol size-distribution and mixing-state are prescribed. This limits local representation and applicability to different climatic regimes. To overcome these deficiencies, the global aerosol-climate model ECHAM5-HAM has been developed. In the aerosol module HAM, the aerosol distribution is represented by an ensemble of interacting internally and externally-mixed log-normal aerosol modes with prognostic treatment of aerosol size-distribution, mixing-state, and composition. In the current setup, the major global aerosol compounds sulfate (SU), black carbon (BC), particulate organic matter (POM), sea salt (SS), and mineral dust (DU) are included. The simulated global annual-mean aerosol burden (life-time) for the year 2000 are for SU: 0.80 Tg(S) (3.9 days), for BC: 0.11 Tg (5.4 days), for POM: 0.99 Tg (5.4 days), for SS: 10.5 Tg (0.8 days), and for DU: 8.28 Tg (4.6 days). An extensive evaluation with in-situ and remote sensing measurements underscores that the model results are generally in good agreement with observations of the global aerosol system. The simulated global annual-mean aerosol optical depth (AOD) is at 0.14 in excellent agreement with an estimate derived from AERONET sun-photometer measurements (0.14) and a composite derived from MODIS-MISR satellite retrievals (0.16). Although on a regional basis the differences are not negligible, the main patterns of aerosol optical depth are reproduced.

The response to changes in anthropogenic emissions was analysed in a series of simulations with ECHAM5-HAM. Traditionally, additivity is assumed in the assessment of the aerosol climate impact as the underlying bulk aerosol models are largely constrained to linearity. HAM establishes degrees of freedom for non-linear responses of the aerosol system. Simulated aerosol column mass burdens respond non-linearly to changes in anthropogenic emissions, manifested in alterations of the aerosol life-times. Specific emission changes induce modifications of aerosol cycles with unaltered emissions, indicating a microphysical coupling of the aerosol cycles. The additivity of the aerosol system is analysed by comparing the response of a simulation with emission changes to several compounds with the total of the responses of individual simulations in each of which one of the emission changes was introduced. Close to the anthropogenic source regions, deviations from additivity are found at up to 30 % and 15 % for the accumulation mode number burden and aerosol optical thickness, respectively. The results challenge the traditional approach of assessing the climate impact of aerosols separately for each component and demand for integrated assessments and emission strategies.

First applications of ECHAM5-HAM towards the assessment of the aerosol radiative effects are presented. A measure of radiative perturbations (P_L), similar to instantaneous forcing on the large-scale but with degrees of freedom to locally adjust to feedback processes, is introduced. The total anthropogenic direct and semi-direct radiative perturbation P_L is negative with global annual-mean values for clear-sky of -0.49 $W\,m^{-2}$ and for total-sky of -0.12 $W\,m^{-2}$.

As basis for the assessment of the indirect aerosol effects, an extended microphysical parameterisation for stratiform clouds has been introduced into ECHAM5-HAM and coupled to the aerosol system via two optional activation schemes. The preliminary evaluation of the simulated cloud parameters shows generally a good agreement with satellite retrieved cloud data. Further sensitivity studies and an extensive evaluation are required before quantitative conclusions on the indirect aerosol radiative effects can be drawn.