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Aerosol indirect effects – general circulation model intercomparison and evaluation with satellite data

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Abstract. Aerosol indirect effects continue to constitute one of the most important uncertainties for anthropogenic climate perturbations. Within the international AEROCOM initiative, the representation of aerosol-cloud-radiation interactions in ten different general circulation models (GCMs) is evaluated using three satellite datasets. The focus is on stratiform liquid water clouds since most GCMs do not include ice nucleation effects, and none of the model explicitly parameterises aerosol effects on convective clouds. We compute statistical relationships between aerosol optical depth (τ_a) and various cloud and radiation quantities in a manner that is consistent between the models and the satellite data. It is found that the model-simulated influence of aerosols on cloud droplet number concentration (N_d) compares relatively well to the satellite data at least over the ocean. The relationship between τ_a and liquid water path is simulated much too strongly by the models. This suggests that the implementation of the second aerosol indirect effect mainly in terms of an autoconversion parameterisation has to be revisited in the GCMs. A positive relationship between total cloud fraction (f_{cld}) and τ_a as found in the satellite data is simulated by the majority of the models, albeit less strongly than that in the satellite data in most of them. In a discussion of the hypotheses proposed in the literature to explain the satellite-derived strong f_{cld}–τ_a relationship, our results indicate that none can be identified as a unique explanation. Relationships similar to the ones found in satellite data between τ_a and cloud top temperature or outgoing long-wave radiation (OLR) are simulated by only a few GCMs. The GCMs that simulate a negative OLR–τ_a relationship show a strong positive correlation between τ_a and f_{cld}. The short-wave total aerosol radiative forcing as simulated by the GCMs is strongly influenced by the simulated anthropogenic fraction of τ_a, and parameterisation assumptions such as a lower bound on N_d. Nevertheless, the strengths of the statistical relationships are good predictors for the aerosol forcings in the models. An estimate of the total short-wave aerosol forcing inferred from the combination of these predictors for the modelled forcings with the satellite-derived statistical relationships yields a global annual mean value of -1.5 ± 0.5 Wm^{-2}. In an alternative approach, the radiative flux perturbation due to anthropogenic aerosols can be broken down into a component over the cloud-free portion of the globe (approximately the aerosol direct effect) and a component over the cloudy portion of the globe (approximately the aerosol indirect effect). An estimate obtained by scaling these simulated clear- and cloudy-sky forcings with estimates of anthropogenic τ_a and satellite-retrieved N_d–τ_a regression slopes, respectively, yields a global, annual-mean aerosol direct effect estimate of -0.4 ± 0.2 Wm^{-2} and a cloudy-sky (aerosol indirect effect) estimate of -0.7 ± 0.5 Wm^{-2}, with a total estimate of -1.2 ± 0.4 Wm^{-2}.

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