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Monte Carlo-based subgrid parameterization of vertical velocity and stratiform cloud microphysics in ECHAM5.5-HAM2

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A new method for simulating the interplay between subgrid vertical velocity variability and cloud droplet activation in ECHAM5.5-HAM2 climate-aerosol model is presented. The new parameterizations are built on top of a stochastic cloud generator (Räisänen et al., 2004) and the Monte Carlo Independent Column Approximation (McICA) radiation scheme (Pincus et al., 2003), which allows the representation of subgrid-scale cloud radiative effects using an ensemble of subgrid columns (subcolumns) inside GCM grid-cells. Even though subgrid cloud structure and non-uniform cloud condensate are described by the cloud generator, until now, cloud droplet number concentration (CDNC) has been assumed horizontally homogeneous inside GCM grid-cells.

In the new model version, we have added a description for vertical velocity in individual subcolumns and modified key cloud microphysical processes (cloud droplet activation (Abdul-Razzak and Ghan, 2000) and autoconversion (Khairoutdinov and Kogan, 2000)) to operate in subgrid scale. A unique vertical velocity is assigned to each subcolumn cloud base level using a Monte Carlo-based sampling of a Gaussian probability distribution, which yields the subgrid CDNC.

Simulations with the new model configuration show different impacts on cloud properties in different regions. In general, explicitly accounting for the subgrid variations in vertical velocity and cloud microphysics acts to decrease the CDNC as compared to the reference model version with an effective vertical velocity applied in the GCM grid. Most of the decrease takes place in polluted continental regions, while remote marine areas and the stratocumulus regions of Eastern Pacific show only small or no decrease in CDNC. Compared to the reference model version, the global mean CDNC in the lower troposphere is decreased by 29 $\%$ when subgrid vertical velocity and CDNC are included.

In addition, the low end of the subgrid CDNC ensemble acts to invigorate the autoconversion process. This causes the global mean liquid water path over the oceans to decrease by approximately 25 $\%$ as compared to the reference simulation ($54.9\ g\ m^{-2}$). Such a shift calls for retuning of a closure parameter for autoconversion: after retuning, the oceanic LWP is increased back close to the reference simulation. However, the average lower tropospheric CDNC remains 18 $\%$ smaller than in the reference simulation.

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