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Elucidating the ice formation pathways in the ECHAM6-HAM2 GCM through an improved representation of cloud ice

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The ongoing increase of spatial and temporal resolution in climate models makes it possible to represent ever smaller eddies and thus provides the basis for the simulation of physically based cloud formation. This development is essential for further progress in climate modeling. At the same time, the optical properties of the cloud and its lifetime are determined by the interaction of its constituent hydrometeors, taking place on the micrometer scale. This is out of reach of what a computer simulation of the atmosphere can represent so these interactions need to be parameterized.

Due to the coarse temporal resolution in climate simulations, cloud water has traditionally been divided into proportions of cloud and precipitation in order to isolate the treatment of rapidly falling raindrops and snowflakes. This subdivision is ambiguous, especially for cloud ice.

The transition from cloud ice to snow takes place abruptly which, in traditional parameterizations, leads to a jump in hydrometeor properties and distorts the interaction with the surrounding cloud. This arbitrary and discontinuous transition is a problem for a simulation which claims to represent the phase transition and the subsequent growth of cloud ice based on physical principles.

This work explores the potential of a scheme that does not predefine ice categories and treats ice hydrometeor properties continuously with a single category. This is made possible by a local reduction of the time step which allows to resolve the trajectory of rapidly falling snowflakes. The number of degrees of freedom in the development of the new scheme is significantly reduced. This means that the formation and evolution of the simulated cloud does not rely on heuristic development decisions (which processes are calculated for the respective categories?) and parameter values (what is the size separating cloud ice and snow?).

With this scheme, we are now in a good position to explore the climate effect of clouds, especially with respect to cloud phase. Satellite data show that rain over the continents arises preferentially from clouds containing ice. Our model confirms this observation. Furthermore, coupling to the comprehensive aerosol module HAM allows to elucidate the ice formation pathways and assess the relative importance of different freezing mechanisms on a global scale. On climate timescales we are interested in the response of cloud phase to a warming atmosphere and its consequence for Earth's equilibrium climate sensitivity (ECS). With the scheme developed here we build upon recent studies and estimate ECS more reliably.