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Prognostic equations for rain in the ECHAM5 GCM: Design and Single Column Model Simulations

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Clouds and precipitation play an important role in the hydrological cycle of the earth. Changing precipitation patterns due to climate change will result in shifted vegetation zones, will have an influence on water quality, soil structure/erosion and runoff into rivers and oceans. Through feedback processes, these changed precipitation rates have an impact on cloud formation and microphysical processes which, on their part, influence the precipitation rates. The prediction of precipitation is, therefore, an important issue for the climate modeling community.

Furthermore, clouds play an important role in the energy budget of the earth. Aerosol particles and their precursors resulting from human activity are thought to change the physical and optical properties of clouds. The first indirect effect refers to an increasing cloud albedo due to decreasing cloud droplet sizes as the concentration of (anthropogenic) aerosols increase. For those smaller cloud droplets it is harder to grow into precipitation sized drops. This results in less precipitation at the surface and presumably a prolonged lifetime of clouds within the atmosphere and is referred to as second aerosol indirect effect. In contrast to most of the (small) aerosols that act as Cloud Condensation Nuclei (CCN), Giant CCN (e.g., sea salt and dust) are suggested to have an enhancing effect on the formation of precipitation (i.e., drizzle) and, therefore, might lower the second indirect effect, especially over the oceans. However, the size of both of these aerosol indirect effects is still very uncertain.

In order to improve the representation of rain within the ECHAM5 general circulation model prognostic equations for rain mass mixing ratio and rain drop number concentration were introduced. In the standard version of the ECHAM5 rain reaches the surface within one model time step or evaporates in the cloud-free air below the cloud. This approach is only true for relatively large rain drops. Smaller drops (i.e., drizzle) also sediment but may not reach the surface within one time step. Therefore, to calculate the actual rain flux from one model level to the next a the fall velocity for rain drops is introduced. The vertical velocity is obtained by a mass flux approach by assuming an exponential distribution for the rain drops and using a slightly modified version of the fall velocity for a single rain drop by Rogers et al (1993). In order to keep the sedimentation scheme numerically stable the vertical velocity is not allowed to be larger than the grid velocity. This prevents the rain drops to fall further than to the next model level. In order to better account for the microphysical processes in which rain is involved, especially accretion of cloud droplets with rain drops, the model time step is split into several sub-time steps. Furtheron, a simple break up parameterization was introduced to prevent the rain drops from growing to unrealistic sizes.

After introducing the prognostic rain treatment into ECHAM5 (ECHAM5-rain) two cases are used to test and evaluate the model: the ARM Cloud IOP (Shallow frontal cloud case - March 2000) and EPIC (Stratocumulus study - October 2001). Simulations with the ECHAM5 Single Column Model show that the precipitation pattern is slightly dependent on the number of sub-time steps used. Changes in the precipitation amount as well as a slight prolongation of the precipitation events results from the rain water staying in the atmosphere. This, in turn, causes an increase of the accretion rates with a corresponding decrease in the autoconversion rates. The evaporation of the rain drops is also dependent on the number of sub-time steps but does not show a clear tendency in either direction.