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Explicit entrainment parameterization in the general circulation model ECHAM5-HAM

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The complex interactions affecting cloud lifetime and liquid water path (LWP) are not well captured in state-of-the-art general circulation models (GCM). A recent climate model intercomparison showed an overestimation of the positive correlation of LWP with aerosol optical depth by a factor of two as compared to MODIS data for almost all participating models (Quaas et al., 2009). As the authors suggest, a proper interaction of the boundary layer dynamics, particularly the inclusion of cloud top entrainment may lead to an improvement. ECHAM5 was one of the participating model. In this model, the turbulent fluxes in the planetary boundary layer are simulated using a turbulent kinetic energy – mixing length scheme. It has been showed that its performance diminishes when the resolution decreases, the different fluxes being not represented satisfactory with 31 vertical levels, particularly at the cloud top (Lenderink et al., 2000). We thus replace the turbulent fluxes by the explicit entrainment closure by Turton and Nicholls (1987) at the top of the stratocumulus capped boundary layers. The turbulent fluxes are weighted with the cloud cover to apply the entrainment closure only above clouds. In addition, we use an explicit term for the radiative cooling contribution in the buoyancy production term. We use the new version of the Hamburg general circulation model ECHAM5-HAM (Roeckner et al., 2003; Stier et al., 2005). The cloud scheme that is used for this study includes the double-moment cloud microphysics scheme for cloud droplets and ice crystals (Lohmann et al., 2007).

The principal effect of the explicit entrainment is to dry and warm the planetary boundary layer. The averaged profiles are more stable and the inversion is reduced. The stratocumulus deck is reduced in all typical stratocumulus regions. In a single column version of the model, the diurnal cycle simulated in cloud cover or equivalentely in cloud water is much more representative of observed subtropical stratocumulus when applying new parameterization. Moreover, even if the entrainment parameterization does not explicitly depend on the number of cloud droplets, the steep increase of liquid water path with increasing cloud droplet number concentration is reduced.

Furthermore, the turbulent kinetic energy (TKE) is crucially affected. First, its vertical profile is smoothed compared to the huge values in the standard version. Moreover, due to the explicit addition of radiative cooling in the buoyancy flux, the maximum of TKE occurs at cloud top (as in reality) and not at cloud base (as in the standard model version). Finally, the trade wind cumulus are better represented in terms of cloud cover. Indeed, the TKE source at cloud top enhances the latent heat flux, triggering the convective routine in shallow cumulus regions.

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