International Max Planck Research School on Earth System Modelling

Impact of Inhomogeneities on non-linear Cloud Processes

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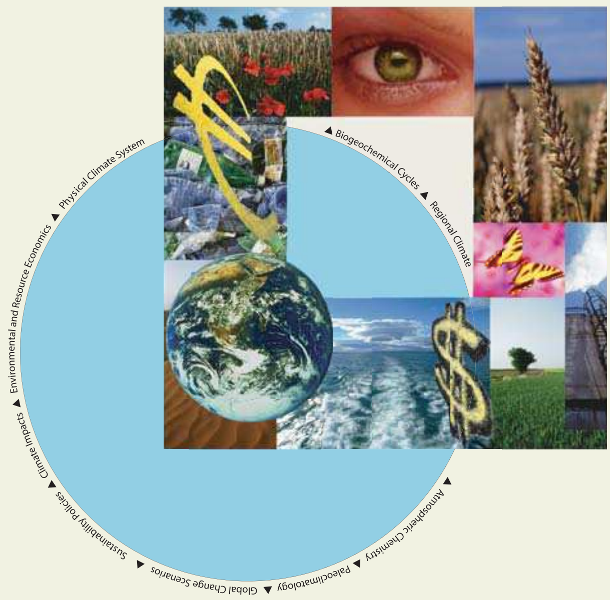

Abstract

The deficiencies in parameterizations of subgrid-scale processes, such as cloud processes, are one important source of uncertainties in modeled climate scenarios. Neglecting subgrid-scale horizontal variability of clouds introduces biases to all non-linear cloud processes, e.g., formation of clouds and precipitation formation. In order to reduce these biases, a prognostic parameterization for the subgrid-scale variability of water vapor and cloud condensate was implemented by Tompkins (2002) in the ECHAM5 climate model. The scheme uses a probability density function (PDF) of the total water mixing ratio to calculate the horizontal cloud fraction. The PDF used here is a beta-distribution whose variance (distribution width) and skewness (shape-parameter q) are prognostic variables in the model and evolve as a function of atmospheric processes such as turbulence, convection, and large-scale cloud microphysical processes.

In this study, the cloud cover scheme was evaluated using data of the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite instrument. The results show that the mean total water path (TWP) and the mean cloud cover are on average relatively well simulated. However, large deficiencies are revealed by the evaluation of both variance and skewness of the PDF. Systematically negative deviations of variance were found for almost all regions of the globe. Skewness of the TWP is strongly overestimated in the Tropics, and underestimated in the extratropical regions. Sensitivity tests were made to improve the parameterization of variance and skewness. Improved results were obtained with the distribution width increased by reducing the dissipation caused by horizontal and vertical eddies. In particular, the large positive bias in skewness in the Tropics could be reduced by modifying the influence of deep convection on the PDF. Moreover, some model experiments were carried out to allow for negative skewness in the cloud cover scheme. Especially, the modeled skewness in the Tropics could be improved through the combination of allowing negative skewness, reducing the dissipation of distribution width caused by vertical eddies, calculating skewness increase only for detrainment from ice-containing deep convection and generally increasing positive skewness (shape-parameter q) by 20%.

In the second part of this work, the impact of the subgrid-scale variability of cloud liquid water on the autoconversion process was investigated. For this purpose, the statistical PDF approach was incorporated in a continuous autoconversion parameterization. Thus, the revised autoconversion rate is calculated by an integral of the autoconversion equation over the PDF of total water mixing ratio from the saturation vapor mixing ratio to the maximum of total water mixing ratio. An evaluation of the new autoconversion parameterization was carried out by means of a one year simulation with the ECHAM5 climate model. The results indicate that the new autoconversion scheme causes an increase of occurrence in autoconversion for higher rates and a decrease for lower ones compared to the original scheme. This can be explained by the applied PDF of total water mixing ratio which emphasizes areas of high cloud liquid water and the non-linearity of the autoconversion with respect to liquid water mixing ratio. A similar trend as in the autoconversion was observed in the accretion process resulting from the coupling of both processes. As a consequence of the altered autoconversion, large-scale surface precipitation also shows a shift of occurrence from lower to higher rates. Moreover, the affected vertically integrated cloud liquid water, total cloud cover, cloud radiative forcing and total precipitation estimated by the model are compared with observational data derived from ground based measurements and satellite instruments, showing slight improvements. The artificial “tuning” factor for autoconversion could be reduced by almost an order of magnitude.