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Sensitivity of a stratiform cloud-topped atmospheric boundary layer model to turbulent closures

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Abstract

A numerical model of the cloud-topped atmospheric boundary layer is presented. This model is tested against observational data and is used to study the interaction between turbulent and radiative processes in cloud layers. The physical parameterizations of the Topographic Vorticity-mode Mesoscale model (TVM) are therefore extended by including condensation/evaporation processes, shortwave and longwave radiative exchanges, and turbulent mixing. Five closure schemes are considered and compared because turbulent mixing is an important and complex process. The closure hypotheses are based mainly on data from clear-sky and consequently, the results of the model have to be compared to data obtained from the cloudy-ABL. Moreover, prognostic equations for two conservative variables, the liquid potential temperature $\overline{\theta_l}$ and the total specific humidity $\overline{q_t}$, are implemented. The buoyancy term and other turbulent fluxes of the non-conservative variables are expressed as a function of $\overline{\theta_l}$ and $\overline{q_t}$ fluxes using formulations that depend on the saturation level of the air parcel. These fluxes are combined through a weighting factor that represents the fraction of saturated air. This work is restricted to warm and non-precipitating clouds, which implies that no source term is added in the moisture equation. The ability of the TVM model to reproduce the main properties of the structure of a cloudy ABL is estimated by applying the model with its relevant physics to data obtained from two measurement campaigns, both of which involve mean and turbulent fields in the marine stratocumulus-capped mixed layer. First, nocturnal conditions are applied using data obtained during ASTEX experiments (1992). Second, daytime measurements obtained in an extensive sheet of stratocumulus over the North Sea (1982) are used. In this study, we show that in the upper part of the cloud layer, the turbulence is more intense than in the surrounding air. This is caused by the neutral or even unstable stratification, usually observed inside the clouds. For the one-dimensional simulations performed, the five local closure schemes considered in this work yield satisfactory and similar mean meteorological fields, but a wider scatter is observed in the turbulent field. Our simulations show that the $(e - \varepsilon)$ model provides the most realistic results. However, should the TVM model be used for the mean field analysis, its results are independent of the turbulence scheme. In this case, the faster to run is more suitable, but should the TVM model be used for turbulent field, $(e - \varepsilon)$ is preferable. Two-dimensional simulations are also performed for airflow over a hill. The results apply to a diurnal evolution of the mesoscale topography-induced circulation. The discussion of mean and turbulent fields predicted by the different turbulence models is based on the results of the $(e - \varepsilon)$ model because of the lack of data for similar configurations. Although patterns of the mean simulated variables are qualitatively similar, we note significant quantitative differences in mean and turbulent fields, both in cloud-free and cloudy ABL.