LINEAR EDDY MODELLING OF BOUNDARY LAYER CLOUDS

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Abstract

Mixing of entrained air in stratus clouds is an important but poorly understood process. It is a crucial ingredient of cloud-top entrainment instability (CEI). CEI has been proposed as a breakup mechanism for stratus clouds. A recently developed model called the linear eddy model was used to simulate mixing of air entrained into stratus clouds. The linear eddy model realistically simulates the mixing process by separately treating turbulent deformation, which results in scale contraction, and molecular diffusion, which ultimately mixes fluid properties, in a one-dimensional domain with sufficient resolution to include all physically relevant length scales. Molecular diffusion is implemented explicitly, while a sequence of statistically independent rearrangement events represents the effect of turbulent eddies. Inertial range scaling is incorporated.

The linear eddy model was used to simulate the mixing of one or more wisps of entrained air with a specified volume of cloud-topped boundary layer (CTBL) air. The volume was idealized to be a horizontal slab of fluid that travels from the top of the CTBL down to the surface in the descending branch of a large convective eddy. The probability density function of the mixing fraction of entrained air was determined from linear eddy model simulations as a function of time for a mean mixing fraction of 5% and three wisp sizes. The effect of the mixing on the mean buoyancy of the downdraught was then calculated using a specification of the buoyancy as a function of mixing fraction.

A buoyancy function typical of observed CTBLs was used in the simulations. Under these conditions, each unit mass of entrained air must be mixed with about nine unit masses of cloudy boundary layer air before the resulting mixture becomes negatively buoyant. The results show that such mixing requires a significant amount of time, and that the actual time depends on the size of the entrained wisp. For none of the three wisp sizes considered did the entrained air mix completely with cloudy air just below the CTBL top, nor was uniform saturation maintained. Furthermore, the mean downdraught buoyancy due to entrainment and mixing integrated over the cloud layer remained positive. This suggests that CEI is unlikely in stratus.

An additional conclusion is that using reduced spatial resolutions typical of published large-eddy simulations (LES) of CTBLs in linear eddy mixing simulations significantly underestimates the buoyancy in the cloud layer near cloud top. This may explain why low-resolution LES simulations have exhibited CEI under conditions for which CEI is not observed in the atmosphere.

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