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On the role of drizzle in Stratocumulus and its implications for Large Eddy Simulation

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Summary

Large Eddy Simulation of marine Stratocumulus cloud topped boundary layers show a surprisingly large sensitivity to the prescribed forcing – this being at odds with the widespread and persistent occurrence of this cloud type. However, most LES studies have not taken drizzle explicitly into account. This Note explores the damping effect (i.e. reducing the sensitivity to the forcing) that drizzle might have on the stratocumulus cloud-topped boundary layer. A single column model is used to illustrate the difference in response in one model version with drizzle taken into account and one in which drizzle is inactivated. Results are shown for a simulation of the diurnal cycle of Stratocumulus clouds over sea; they support the notion that the impact of drizzle is under-rated in the present-day modelling of Stratocumulus topped boundary layers.

Keywords: boundary-layer clouds entrainment model inter-comparisons

1. Introduction

In the recent past several Large Eddy Simulation model-intercomparisons of marine stratocumulus topped boundary layers have been performed (Moeng *et al.* 1996; Duynkerke *et al.* 1999; Stevens *et al.* 2001). In the most recent case reported in this issue (Duynkerke *et al.* 2004) a diurnal cycle is investigated. This case has shown that apparently small differences in the simulated entrainment rate result in a rather large spread in model results when integrated over a long time period. In addition Chlond *et al.* (2004) show a large sensitivity of the cloud fields to the prescribed subsidence rate. This behavior appears to conflict with the widespread and persistent occurrence of stratocumulus clouds over the subtropical ocean: How can clouds which appear to be so sensitive to small changes in the applied subsidence rate (or the simulated entrainment rate) be so common in nature?

Even more, there is another worrying aspect of most LES intercomparison cases. In most cases rather high values of the subsidence rates are used in order to get a realistic evolution of the cloud top height. For this reason Duynkerke *et al.* (1999) uses 0.15 Pa/s at 1000 m, which was set three times higher than the subsidence rate estimated from the ECMWF analysis. In Duynkerke *et al.* (2004) in this issue 0.1 Pa/s at 1000 m is used. In contrast, the background radiative driven subsidence (Betts and Ridgway 1988) suggests 0.04 Pa/s – a value in agreement with subsidence rates in most general circulation model results including the ECMWF re-analysis in Siebesma *et al.* (2004).

So, summarizing, we are facing two apparent paradoxes:

1. LES model results suggests an equilibrium state for marine Stratocumulus that requires a forcing (subsidence) that appears to be rather uncommon in Nature.
2. this equilibrium state appears to be highly sensitive to changes in the forcing (or likewise in the simulated entrainment rate) which seems at odds with the persistent and widespread occurrence of Stratocumulus.

In Duynkerke *et al.* (1999) it was already noted that the entrainment rate simulated by the LES models was larger than the entrainment rate that was inferred from measurements. Are we able to obtain a realistic equilibrium state using lower subsidence rates if we were able to lower the entrainment simulated by the LES models? Clearly, there is no problem in simulating a realistic evolution of the cloud top height since the reduced entrainment rate can be balanced with the lower subsidence rate. But, if the entrainment rate is reduced, the entrainment flux of dry air into the boundary layer is also. Therefore, given that the LES cases have used realistic surface fluxes of moisture, the boundary layer moistens.

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Drizzle acts as a moisture sink if it falls at the surface. There is ample observational evidence that drizzle might contribute significantly to the boundary layer moisture budget [see vanZanten *et al.* (2004); Stevens *et al.* (2003) and the references therein]. They show drizzle to be commonplace and estimate drizzle fluxes at the surface up to 1.0 mm/day, which is equivalent to 30 W m^{-2}. However, drizzle is neglected in most LES studies (and among these the recent Duynkerke *et al.* (2004) inter-comparison case). The rather low drizzle rates that were simulated by the LESs when drizzle was included (Duynkerke *et al.* 1999) supported the omission of drizzle. Also, observations show that drizzle is very intermittent in space, and reliable measurements of drizzle on a larger scale (representative for grid boxes of atmospheric models) have only recently been obtained (vanZanten *et al.* 2004).

Finally, could drizzle be an important factor in reducing the sensitivity shown by the LES simulations? Clearly if the liquid water contained in the clouds increases one would expect increases in the drizzle rate (and vice versa). Also, drizzle feedbacks onto the dynamics. Drizzle reduces turbulent mixing, and hence entrainment, due to its direct effect on the buoyancy (condensation at cloud top and evaporation of rain below cloud base). Also, drizzle changes the optical properties of the cloud, thereby affecting longwave radiation and hence turbulent mixing and entrainment. These feedbacks are not new and have been discussed in literature (see e.g. Stevens *et al.* 1998; Nicholls 1987) but their implications for the modelling of stratocumulus clouds might have been under-rated.

In this short note we will explore these points further in the context of the intercomparison case in this issue describing the diurnal cycle of Stratocumulus clouds. We used a relatively simple single column model (SCM) to illustrate the damping effect of drizzle on idealized simulation of Stratocumulus, and to explore the possibility of sustaining a realistic (quasi-) equilibrium state using low(er) subsidence rates.