P1.40 COMPARISON OF LARGE-EDDY SIMULATIONS WITH A SINGLE-COLUMN MODEL: IMPLICATIONS FOR MID-LEVEL CLOUD PARAMETERIZATION

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1. INTRODUCTION

Altocumulus clouds are thin, turbulent cloud layers that occur at the mid-levels of the troposphere. Studies of these clouds are desirable because these clouds often contain supercooled water, which produces an icing hazard to small aircraft and unmanned aerial vehicles (Larson et al. 2006). However, general circulation models (GCMs) tend to underpredict thin mid-level clouds (Zhang and Co-Authors 2005). As a result, it is important to improve model prediction of altocumuli, in order to enhance aviation safety. Since altocumulus clouds have small-scale features, it is important that these clouds be accurately parameterized.

In order to increase accuracy of cloud parameterization, we are developing a single-column model (SCM) that has been previously tested for boundary-layer clouds (Golaz et al. 2002b). Using this same SCM without any case-specific adjustments, we have simulated an observed altocumulus cloud. Our ultimate goal is to use these and other results to better understand the parameterization of layer clouds in large-scale models.

To provide an initial detailed simulation, we have simulated the observed altocumulus cloud using a high-resolution, three-dimensional large-eddy simulation (LES) model. This model outputs a variety of three-dimensional fields that includes moisture, temperature, and velocity. These fields may be horizontally averaged to yield vertical profiles of cloud fraction and liquid water mixing ratio, along with various moments, such as turbulent fluxes of heat and moisture. We also simulated the same cloud using our one-dimensional SCM. The SCM predicts the same mean fields and moments as the LES by use of the assumed probability density function (PDF) method. That is, the SCM prognoses various low-order moments and uses an assumption about the shape of the PDF family to close the higher-order moments. The SCM uses a joint PDF of moisture, temperature, and vertical velocity whose shape is assumed to be a Gaussian mixture.

Aircraft observations show that the observed altocumulus cloud dissipated with time. Both LES and SCM models exhibited similar time evolution, including nearly equal cloud lifetime. Additionally, both models had similar profiles of cloud fraction, liquid water, and turbulent fluxes of heat and moisture. These results indicate that our SCM simulates aspects of the cloud accurately and similarly to the LES model.

In addition to the control altocumulus case, we have also performed a sensitivity study containing multiple simulations. Each sensitivity simulation involves changing one parameter, such as the solar zenith angle, ice number concentration, or large-scale subsidence. Both models behave similarly between corresponding sensitivity runs, regardless of the physical parameter being varied. This shows that our SCM is valid over a range of conditions.

2. COMPARING THE SINGLE-COLUMN MODEL WITH A BENCHMARK LARGE-EDDY SIMULATION

In order to provide a comparison, we have created a three-dimensional large-eddy simulation (LES) of an altocumulus cloud observed on 11 Nov 1999 during the CLEX-5 field experiment (Fleishauer et al. 2002). We use the Coupled Ocean / Atmosphere Mesoscale Prediction System (COAMPS®) Large-Eddy Simulation (COAMPS-LES) model (Golaz et al. 2005). The simulation was run with a grid spacing of 15 m in the vertical. Time step was 1 s. Output provided from this simulation allows us to determine behaviors of the cloud over time and vertical space. Aircraft observations indicated that this cloud dissipated over time, and this behavior was duplicated in the LES simulation. Additional details of the Nov. 11 cloud can be found in Fleishauer et al. (2002) and Larson et al. (2001). The LES simulation is described in Larson et al. (2006).

Using data from the LES simulation, we have simulated the observed altocumulus cloud using a one-dimensional single-column model (SCM). Like the LES, the SCM used grid spacing of 15 m in the vertical. Time step for the SCM was 1 min. Additional details of the SCM are provided in Golaz et al. (2002a). Initial profiles of the SCM are identical to the initial moisture and temperature conditions used in the LES simulation. In addition, forcings used in the LES such as large-scale subsidence (sinking air), radiation, and ice physics were added to the SCM. Both the LES and the SCM simulation lasted four hours, including a 1-hour spinup to allow for mixing to occur within cloud.

Figure 1 shows initial profiles for the LES (dots) and

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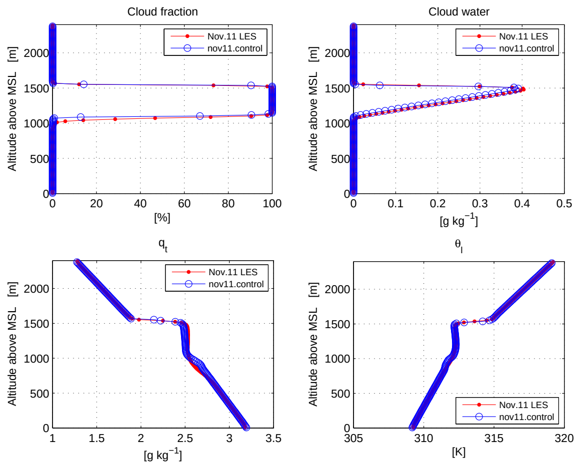


Figure 1: Comparison of vertical profiles of cloud fraction (upper-left), cloud water mixing ratio (upper-right), total water mixing ratio (lower-left) and liquid water potential temperature (lower-right) immediately after a one-hour spinup period. All SCM profiles (circles) were initialized to match the LES profiles (dots).

SCM (circles) at our initial observation time, after the 1-hour spinup period. These profiles indicate cloud fraction (upper-left), cloud water mixing ratio (upper-right), total water mixing ratio (lower-left), and liquid water potential temperature (lower-right). At the initial observation time, all SCM profiles match up with corresponding LES profiles, indicating that the SCM has been initialized properly.

Figure 2 compares higher-order vertical flux profiles obtained from both models. In our notation, w is vertical velocity, θ_v is virtual potential temperature, and q_t is total water mixing ratio. Profiles plotted are second-moment of vertical velocity ($\overline{w'^2}$, upper-left), third-moment of vertical velocity ($\overline{w'^3}$, upper-right), vertical buoyancy flux ($\overline{w'\theta_v'}$, lower-left), and vertical turbulent moisture flux ($\overline{w'q_t'}$, lower-right). All second-order flux profiles match quite well between SCM and LES. $\overline{w'^3}$ does not match well on a percentage basis, but its values are small in both SCM and LES.

Now we compare cloud evolution for each simulation. Cloud evolution is a nontrivial test, because it requires accurate calculation of many factors. Factors affecting the overall cloud evolution include turbulent transport and turbulent flux of heat and moisture. If overall cloud behavior is comparable between LES and SCM, the turbulence in the SCM can be presumed to be calculated without serious error.

Figure 3 shows a comparison of cloud water decay over time for both the LES (top) and SCM (bottom). The two simulations show similar cloud lifetimes. The outer contour (representing 1% cloud fraction) varies between the two simulations, but otherwise, cloud behavior is consistent. This shows that the SCM simulates the altocumulus well, even while using a parameterization of turbulence that is much simpler than that of the LES.

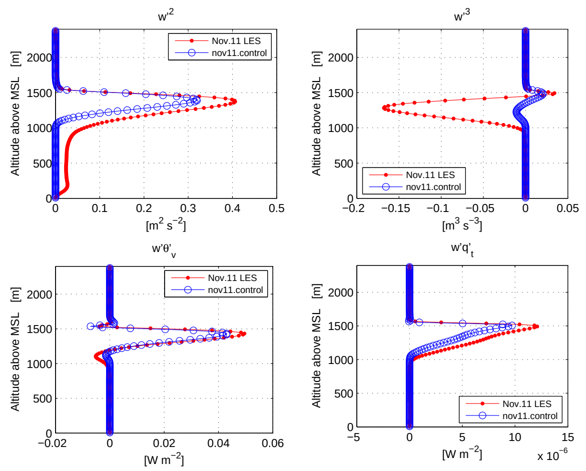


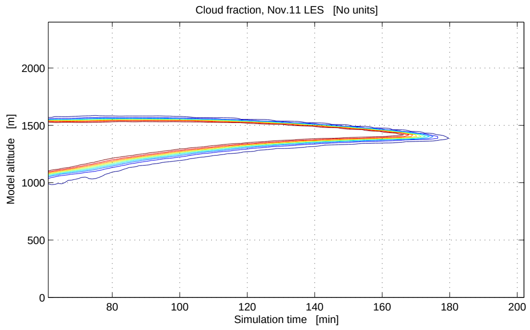
Figure 2: Comparison of vertical profiles of the second-moment of vertical velocity (upper-left), third-moment of vertical velocity (upper-right), vertical temperature flux (lower-left) and vertical total moisture flux (lower-right). All profiles are time-averaged over the first hour of observation (after the one-hour spinup period). All of these variables, except w'^3, show that the SCM (circles) produces similar profiles to the LES (dots).

3. COMPARING LES AND SCM SENSITIVITY SIMULATIONS

Although the SCM performs reasonably well for the Nov 11 cloud, this tests the model for only one case. To test the SCM over a broader range of conditions, a sensitivity study was conducted using both the LES and the SCM. Each model was used to generate a series of simulations, with each simulation containing a single perturbation from the control case. Perturbed quantities in the study included large-scale subsidence velocity, ice particle number concentration, solar zenith angle, and the amount of water vapor above cloud. The magnitudes of these four quantities are noted in (Larson et al. 2006) as influences on cloud lifetime.

Each sensitivity simulation involves adjusting one of the variables by a predetermined setting. Subsidence perturbations ranged from 1 cm s^{-1} to 8 cm s^{-1}. Ice number concentration was varied from 0 (no ice) to 3000 m^{-3}. The solar zenith angle ranged from 90°(no solar radiation) to 0°(directly overhead). Total water above cloud varied from 1.7 g kg^{-1} to 2.1 g kg^{-1}. We performed each perturbation for both the LES and SCM, and after running each pair of simulations, we recorded the resulting cloud lifetimes. Results from all sensitivity simulations are presented in Figure 4.

Each point in Figure 4 represents a single set of conditions simulated by both the LES and SCM. Each point



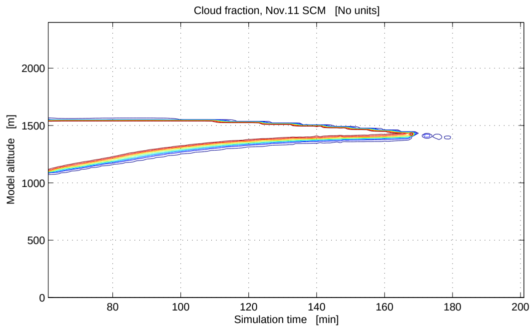


Figure 3: Observed time evolution of cloud water mixing for LES (top) and SCM (bottom). The observed clouds dissipate within 10 minutes of each other.

indicates LES cloud death time (horizontal axis) versus SCM cloud death time (vertical axis) for that sensitivity perturbation. We define cloud death to be the first minute where less than 1% cloud fraction remains at each vertical level in the model domain. The solid line denotes equal lifetimes for both LES and SCM. Points above the solid line indicate that the SCM cloud life is longer than the LES cloud life. Similarly, points below the solid line indicate the LES cloud life is longer than the SCM cloud life. Longer cloud lifetimes correspond to smaller magnitudes of forcing.

Analysis of Figure 4 shows that all but one SCM simulation have cloud deaths that occur slightly earlier than the corresponding LES simulations. One SCM simulation has a slightly later cloud death than its LES counterpart. However, differences in cloud death times are less than or equal to 20 minutes for all comparisons. This indicates that the SCM faithfully simulates processes of cloud evolution for many different perturbed cases.

4. CONCLUSIONS

This paper compares simulations of an observed altocumulus cloud, using a large-eddy simulation (LES) and a single-column model (SCM). The SCM is set up to duplicate the initial profiles and conditions of the LES. Both models are run for the same length of time, and output statistics are analyzed for comparison. Results show that the SCM produces qualitatively accurate profiles of moisture flux, heat flux, and turbulence magnitude. The SCM and LES model simulate similar time evolutions of the cloud layer when forcings are varied over broad ranges.

The SCM used here is the same model that is being used in other research to simulate boundary layer clouds (Golaz et al. 2002b). The present tests show that the applicability of the SCM extends beyond boundary layer clouds to at least one mid-level liquid layer cloud.

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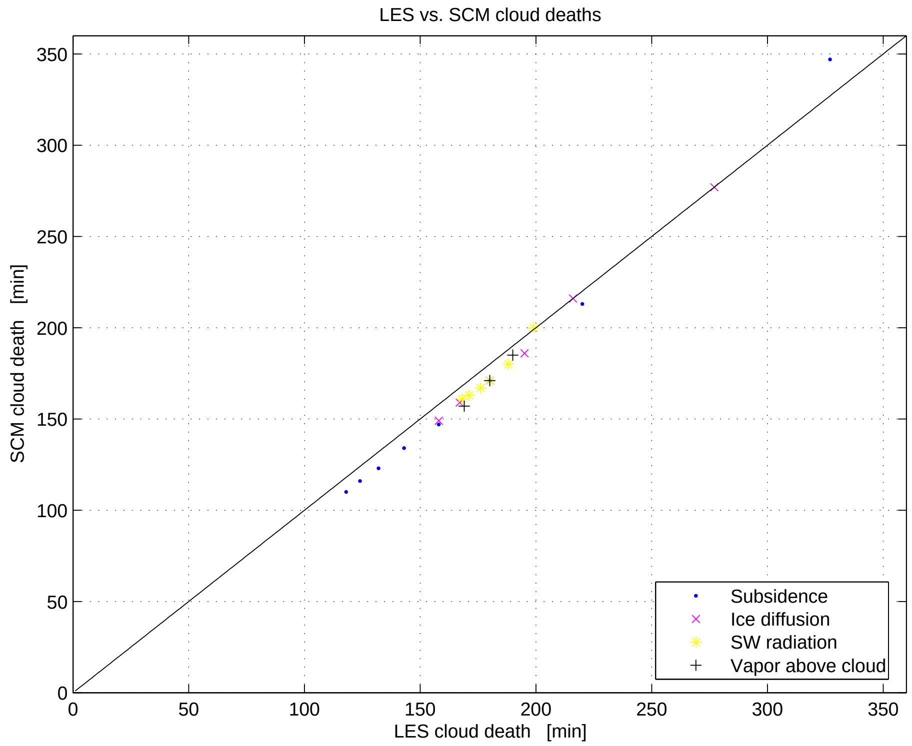

Figure 4: A comparison of cloud lifetimes for corresponding LES vs. SCM sensitivity simulations. For each perturbation being examined, we compare the appropriate LES simulation with its SCM counterpart. Points lying along the diagonal solid line have equal LES and SCM cloud lifetimes. In our study, all of our SCM cloud lifetimes are within 20 minutes of their LES counterparts. Symbols represent the specific parameters being modified. Longer cloud lifetimes correspond to weaker forcing.