Effects of Subgrid-scale Transports on the Development of Boundary-layer Clouds

Anning Cheng[1,2], Kuan-Man Xu[2]

1. AS&M, Inc., 2. NASA Langley Research Center, Hampton, VA

1. Introduction

With the increase of computational power, Multi-scale Modeling Framework (MMF) and global cloud resolving model (GCRM) will play an important role in addressing important climate issues, such as the global warming. The difficulties associated with the parameterization of deep convective clouds can be avoided, but those associated with the parameterization of boundary-layer clouds remains.

Low-order turbulence closure (LOC) and third-order turbulence closure (TOC) are two extensively used parameterizations for boundary-layer clouds. The subgrid-scale turbulence transports of liquid water potential temperature and total water are parameterized differently in the two types of closure. It is important to investigate the effects of the subgrid-scale transports on the simulation of boundary-layer clouds in GCRM and MMF.

2. Experiment Design

BOMEX (the Barbados Oceanographic and Meteorological Experiment, a marine shallow cumulus case) and ATEX (the Atlantic Trade Wind Experiment, a shallow to stratocumulus transition case), are simulated with System for Atmospheric Modeling (SAM) CRM and LES (large-eddy simulation). The control experiments for all the cases use the LES version of SAM with a horizontal domain of 6.4 km by 6.4 km, a horizontal grid-size of 100 m and a vertical grid-size of 40 m. We also performed LOC and TOC runs for each case, with a horizontal domain of 256 km and a horizontal grid-size of 250 m, 500 m, 1km, and 4 km, respectively, in order to explore the sensitivity of horizontal grid-size and subgrid-scale transports.

3. Results

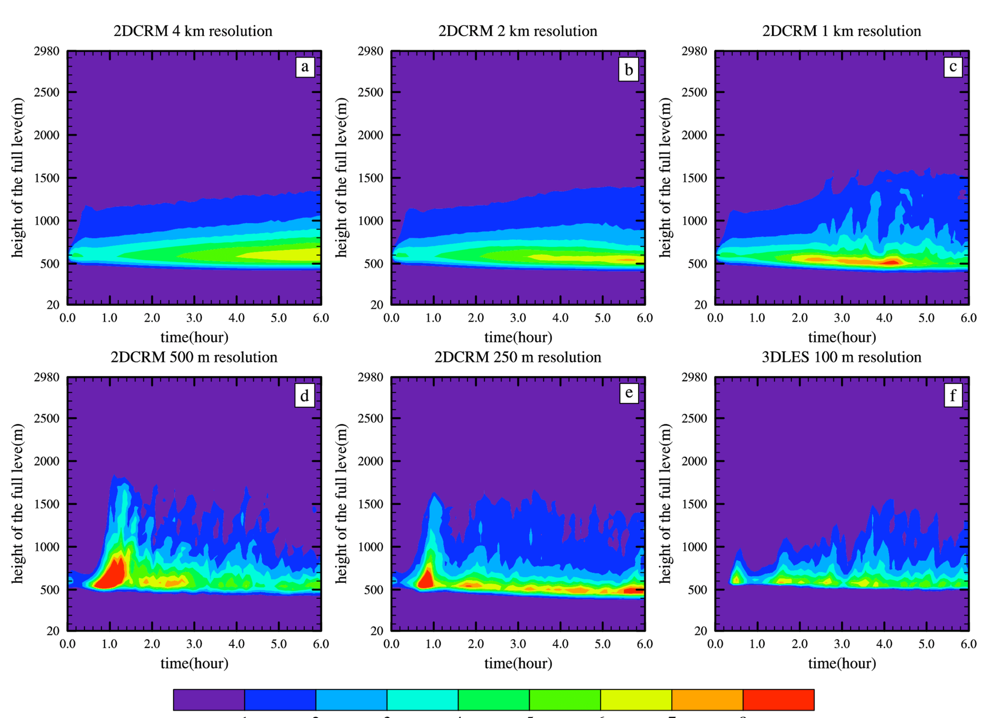

Fig. 1: Time-height cross section of cloud fraction simulated by SAM CRM with the Cheng-Xu TOC for BOMEX. The horizontal grid sizes range from 250 m (e) to 4 km (a). Results from a large eddy simulation from the SAM LES are also shown in (f).

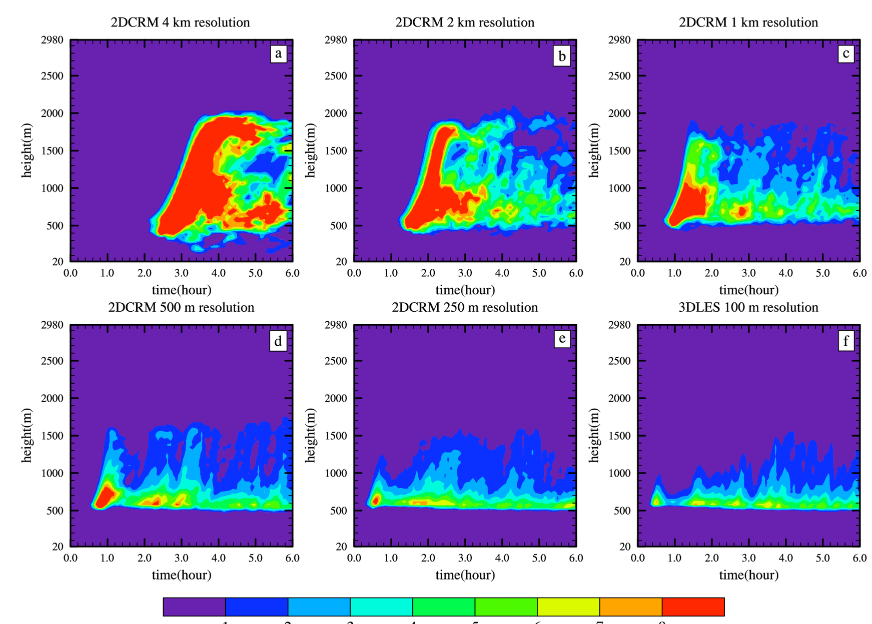

Fig. 2. Same as Fig. 1 except for simulations performed by the standard SAM with an LOC. Note the different scale for the color bar used in this figure.

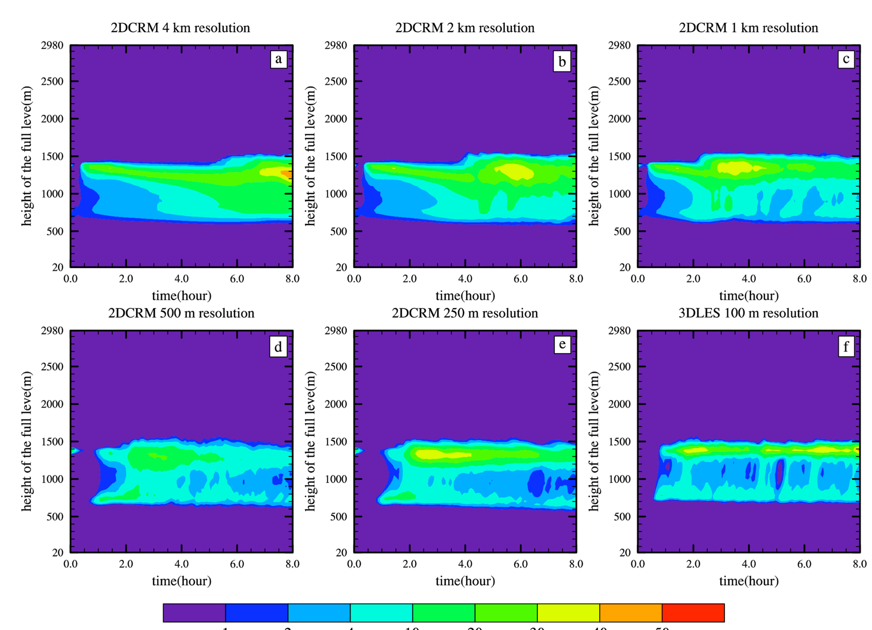

Fig. 3. Same as Fig. 1 except for ATEX

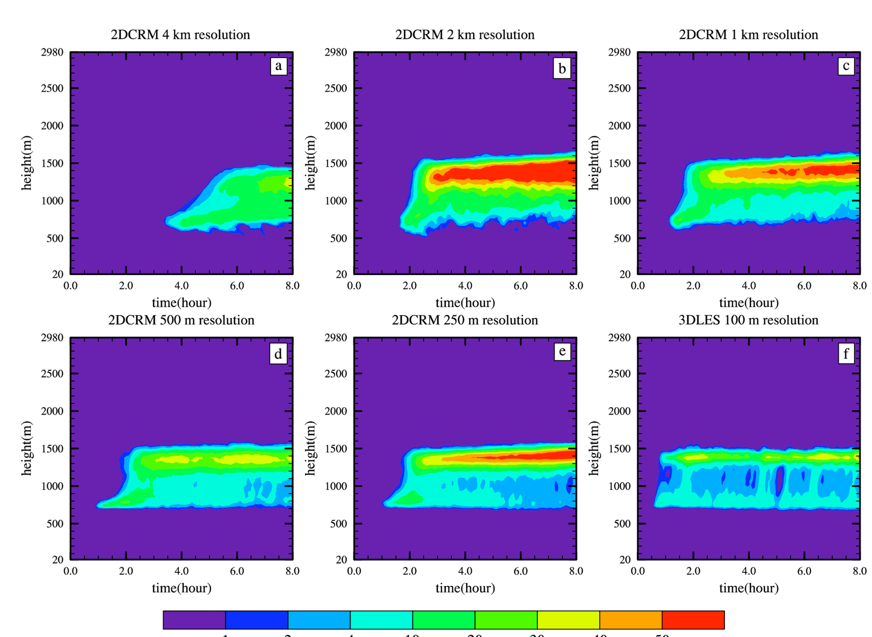

Fig. 4. Same as Fig. 2 except for ATEX

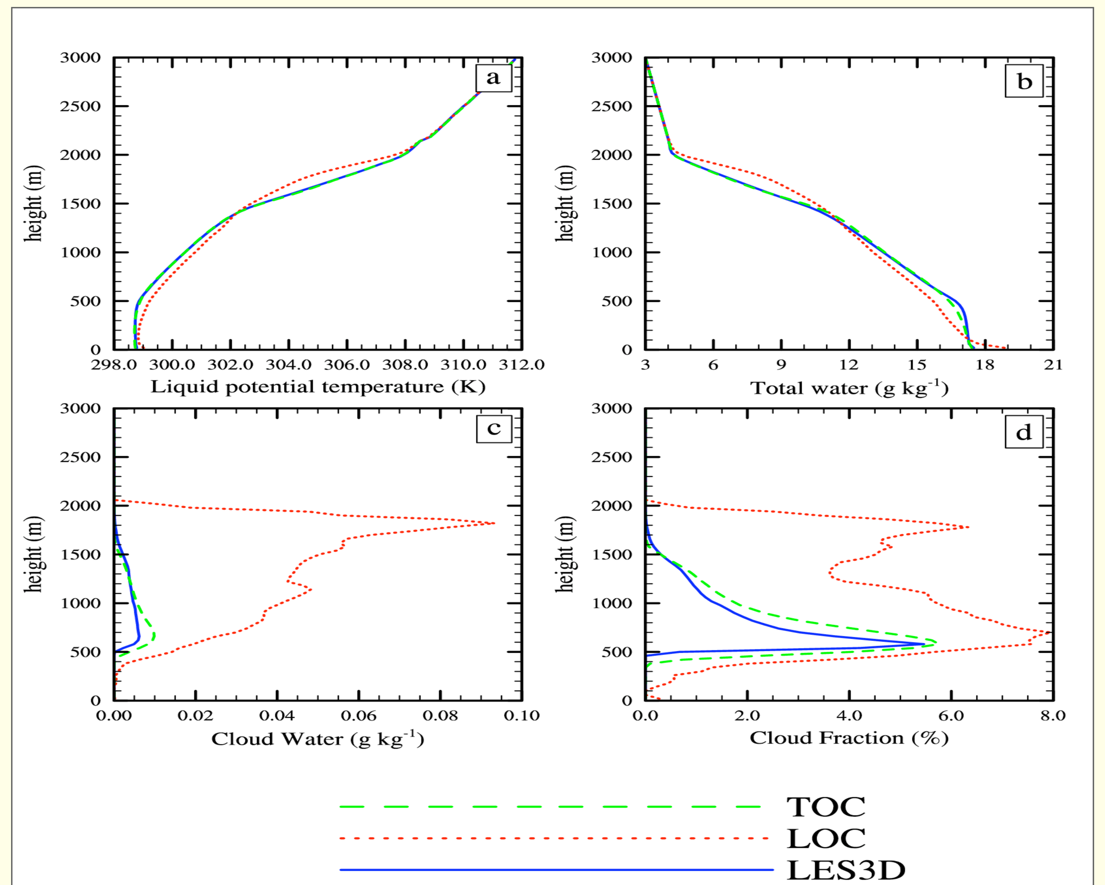

Fig. 5: Mean profiles averaged over the last two hours for BOMEX. The domain size of the CRM is 256 km, with dx of 4 km.

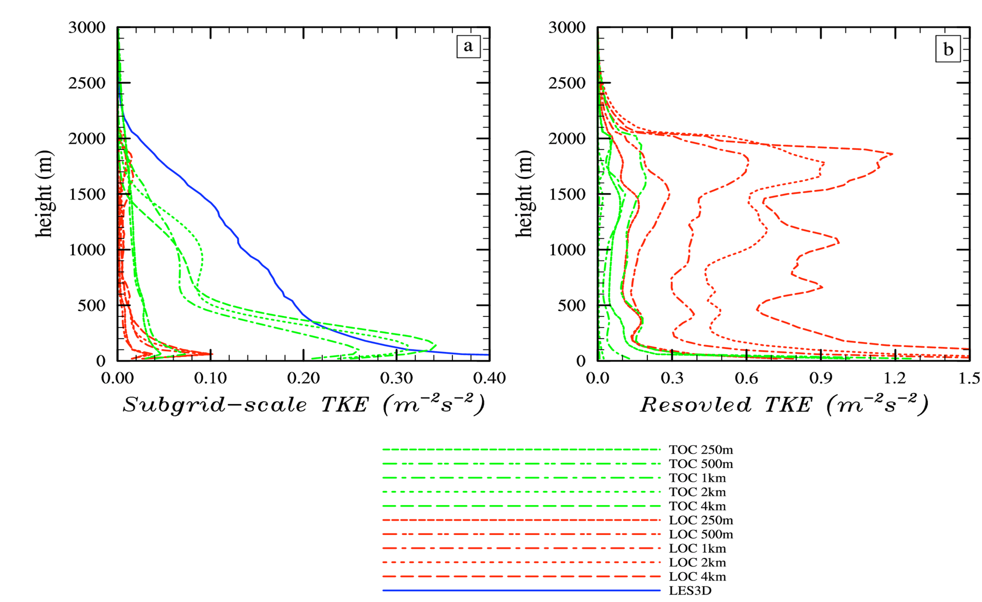

Fig. 6: Profiles of (a) subgrid-scale kinetic energy (TKE) and (b) resolved-scale kinetic energy from five cloud-resolving simulations of BOMEX with different horizontal grid sizes using a CRM that incorporates with LOC (red lines) and TOC (green lines), respectively. Results from an LES (blue line) is also shown in (a). The domain size of the CRM is 256 km, with dx from 250 m to 4 km.

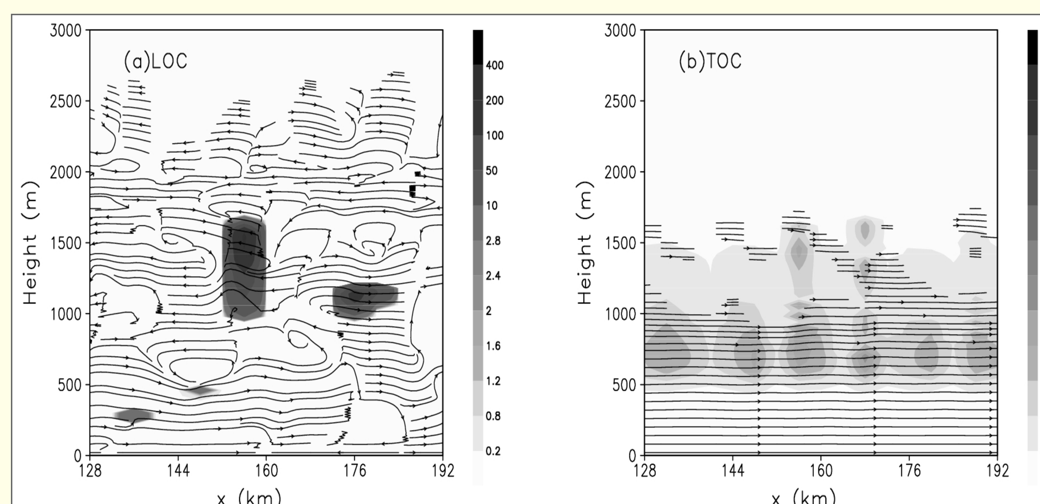

Fig. 7. Snapshots of the stream fields overlapped with the cloud water (g/kg) at the last hour of BOMEX. The vertical velocity was increased ten times in order to show the circulation.

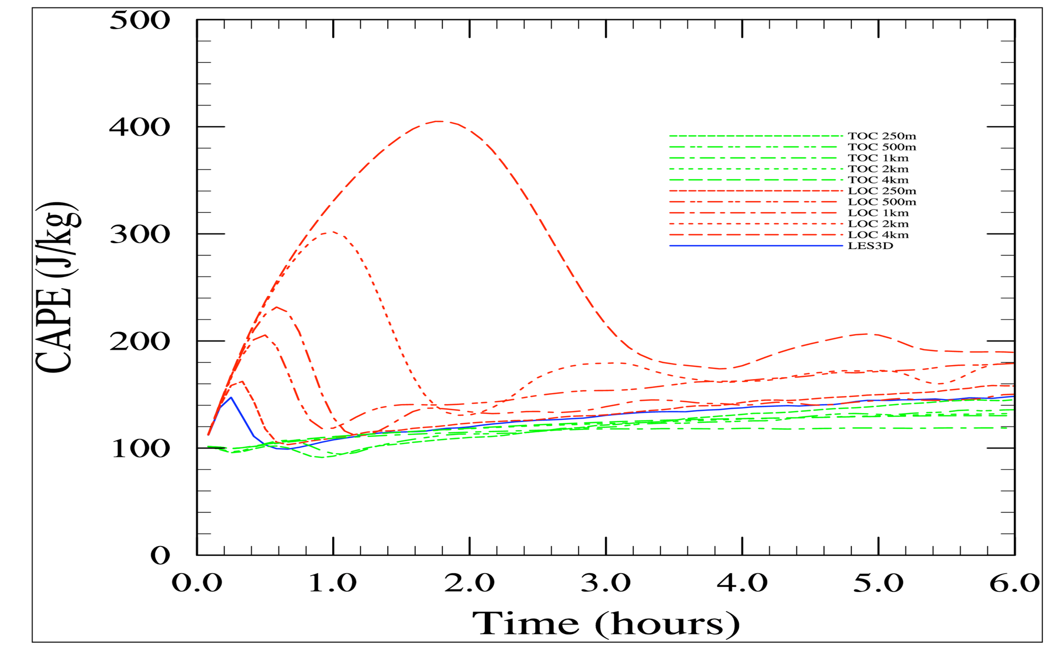

Fig. 8: Time series of convective available potential energy (CAPE) from BOMEX.

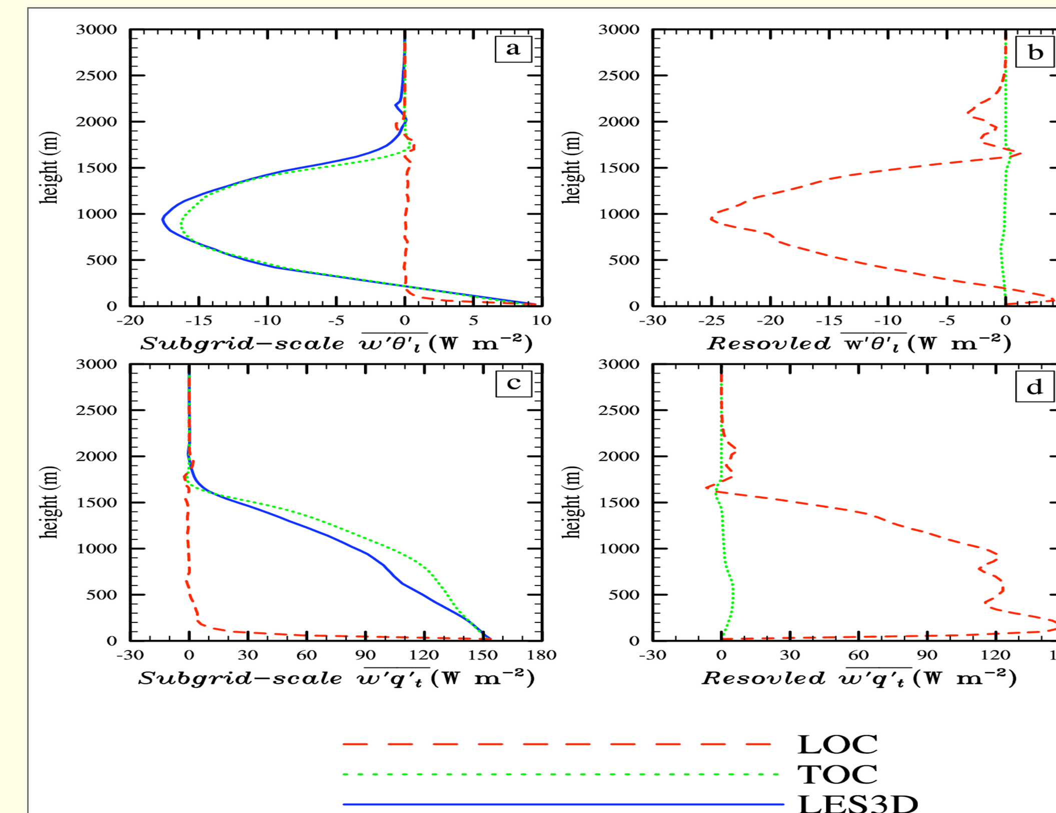

Fig. 9: Mean profiles averaged over the last two hours for BOMEX. The domain size of the CRM is 256 km, with dx of 4 km.

4. Conclusions

- The development of shallow cumuli is delayed with the increase of grid-size for LOC-CRM. A lack of subgrid-scale transports causes
  - increased convergence of moisture and temperature near surface
  - accumulation of CAPE due to inhibition of shallow convection
  - producing convection through resolved-scale circulations
- The clouds from LOC-CRM were mainly produced by the resolved-scale circulation. The resolved-scale circulation has a size of 20 km.
- The TOC-CRM produced the proper subgrid-scale transports. The cloud evolution is less resolution dependent.
- The total kinetic energies for coarse resolution runs are larger when convection occurs, due to stronger resolved circulations.
- Improper subgrid-scale transports can end up with unrealistically resolved mesoscale circulations, cloud evolution, and energy budget.