Diagnosis of Differences Between Stratiform Clouds and Simulated by Large-Eddy Simulation and Single-Column Models

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Introduction

An adequate parameterization of cloud microphysics is essential for estimating the indirect aerosol effect in large-scale models. Such a parameterization must rely on a physically sound treatment of spatial variability that affects many microphysical processes in a complex and non-linear way. For regional and global climate models, much of this variability falls into a subgrid scale and must be parameterized. Large-eddy simulation (LES) models, on the other hand, can resolve the cloud structure explicitly. By using identical microphysical parameterizations in an LES model and a single-column model (SCM) driven by identical boundary conditions, we can isolate the differences caused by the treatment of small-scale spatial variability. Following this approach, a single layer warm cloud observed at the Southern Great Plains (SGP) site on September 25, 1997, during the SCM intensive observation period is simulated using LES and SCM frameworks. The prescribed aerosol characteristics, horizontal advective tendencies, and surface boundary turbulent fluxes are the same for both models and were derived from objective analysis of available measurements. The LES model is run with 100 m horizontal and 40 m resolution for a 10 km by 3.2 km domain. Cloud microphysical processes are either neglected, treated explicitly, or parameterized with a bulk scheme similar to that used in the SCM. The SCM is run with 48 levels, 20 of which are in the lowest 2 km. Cloud microphysical processes are either neglected or parameterized in terms of the bulk cloud water and droplet number concentration using the Khairoutdinov and Kogan (2000) scheme. Droplet number is either prescribed or predicted following Ghan et al. (1997). Subgrid variations in cloud water are either neglected or treated by expressing the subgrid probability distribution of total (water vapor plus cloud) water as triangular function, with the variance of total water related to the turbulence kinetic energy and the vertical gradient of the total water. The grid cell mean cloud fraction, cloud water, and autoconversion rate are determined by integrating over the subgrid frequency distribution of water. Subgrid vertical transport is parameterized using a level 1.5 turbulence closure scheme.

Figure 1 compares the liquid water path (LWP) simulated by the LES model and SCM. The LES model consistently simulates much smaller LWP than the SCM. Microphysics depletes the cloud water by 30% in the mature cloud. Microphysics also depletes the cloud water in the SCM simulation, with little sensitivity to the subgrid treatment of microphysics when the Khairoutdinov and Kogan (2000) autoconversion parameterization is used. However, much greater sensitivity is found with the (discontinuous) Tripoli and Cotton (1980) autoconversion.

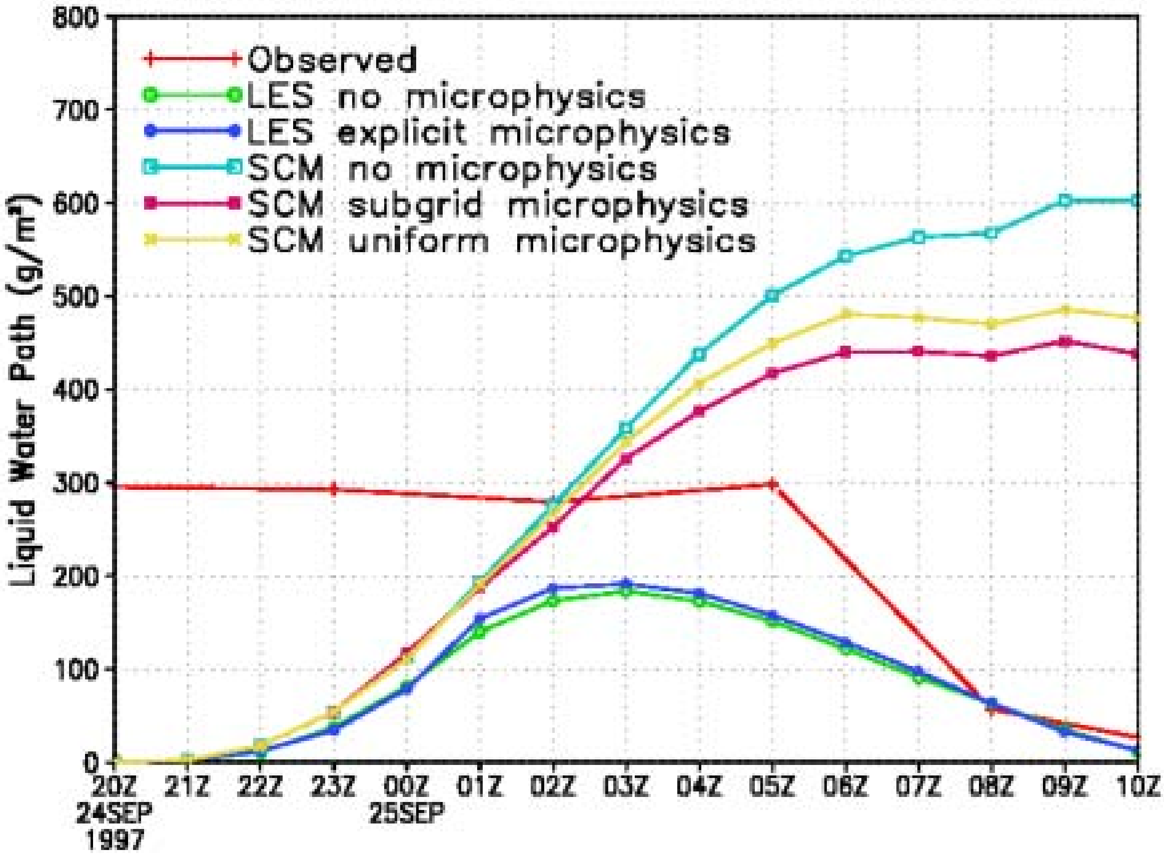

Figure 1. LWP simulated by the LES model and by the SCM for a variety of configurations.

Why does the SCM simulate larger LWP? Figure 2 compares vertical profiles of total water and water vapor mixing ratio at 03Z September 25 as simulated by the SCM and LES models with microphysics turned off. The SCM cloud forms at a much lower level than the LES cloud and is much thicker. The SCM boundary layer is well mixed, while the LES boundary layer is not.

Differences in the vertical distribution of heat and moisture transport cause the difference in the cloud simulation. Figures 3 and 4 compare the vertical profiles of the heat and moisture budgets simulated by the SCM and LES models at the same time. For both heat and moisture the primary difference between the SCM and LES simulations is the vertical mixing term. In the SCM simulation subcloud drying and warming occurs at all levels below cloud, while in the LES simulation the drying and warming are confined to lower part of the cloud. This suggests the cloud in the LES simulation is decoupled from the rest of the boundary layer, but in the SCM simulation the cloud is coupled all the way down to the surface. This conclusion is substantiated by much deeper and stronger turbulence in the SCM simulation (Figure 5). This produces larger droplet number concentrations in the SCM simulation when microphysics is treated, and of course larger LWP.

How can these differences be resolved? We suspect the treatment of cloud-top entrainment in the SCM needs more attention.

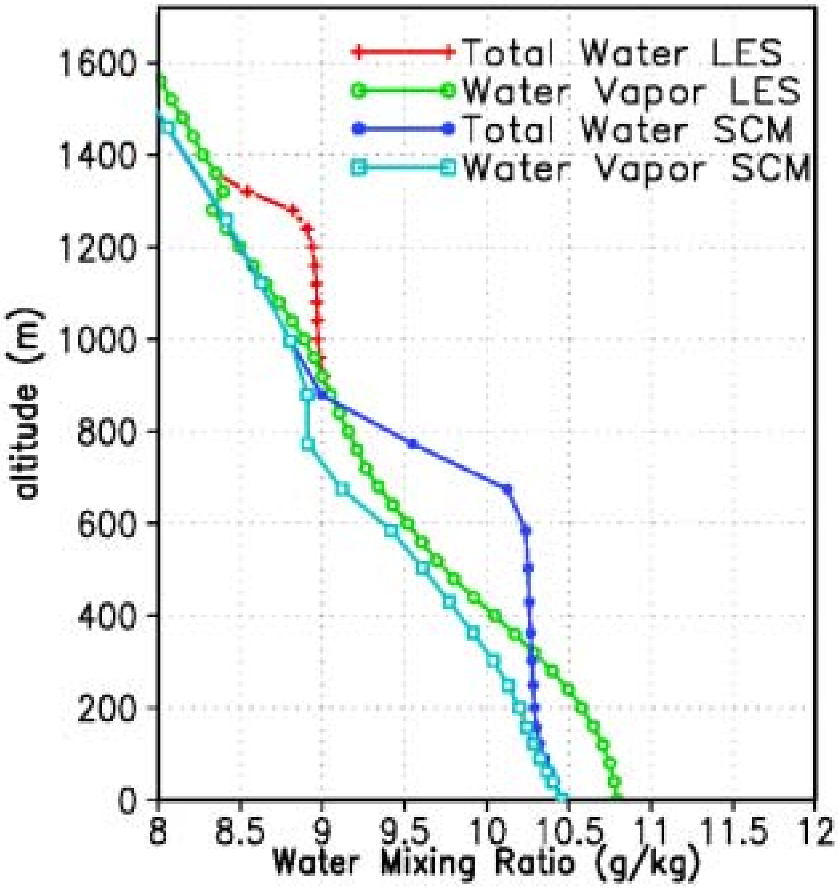

Figure 2. Vertical distribution of total water and water vapor mixing ratio at 3Z September 25 simulated by the LES model and by the SCM.

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References

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Tripoli, G. J., and W. R. Cotton, 1980: A numerical investigation of several factors contributing to the observed variable intensity of deep convection over South Florida. *J. Appl. Meteorol.*, **19**, 1037-1063.

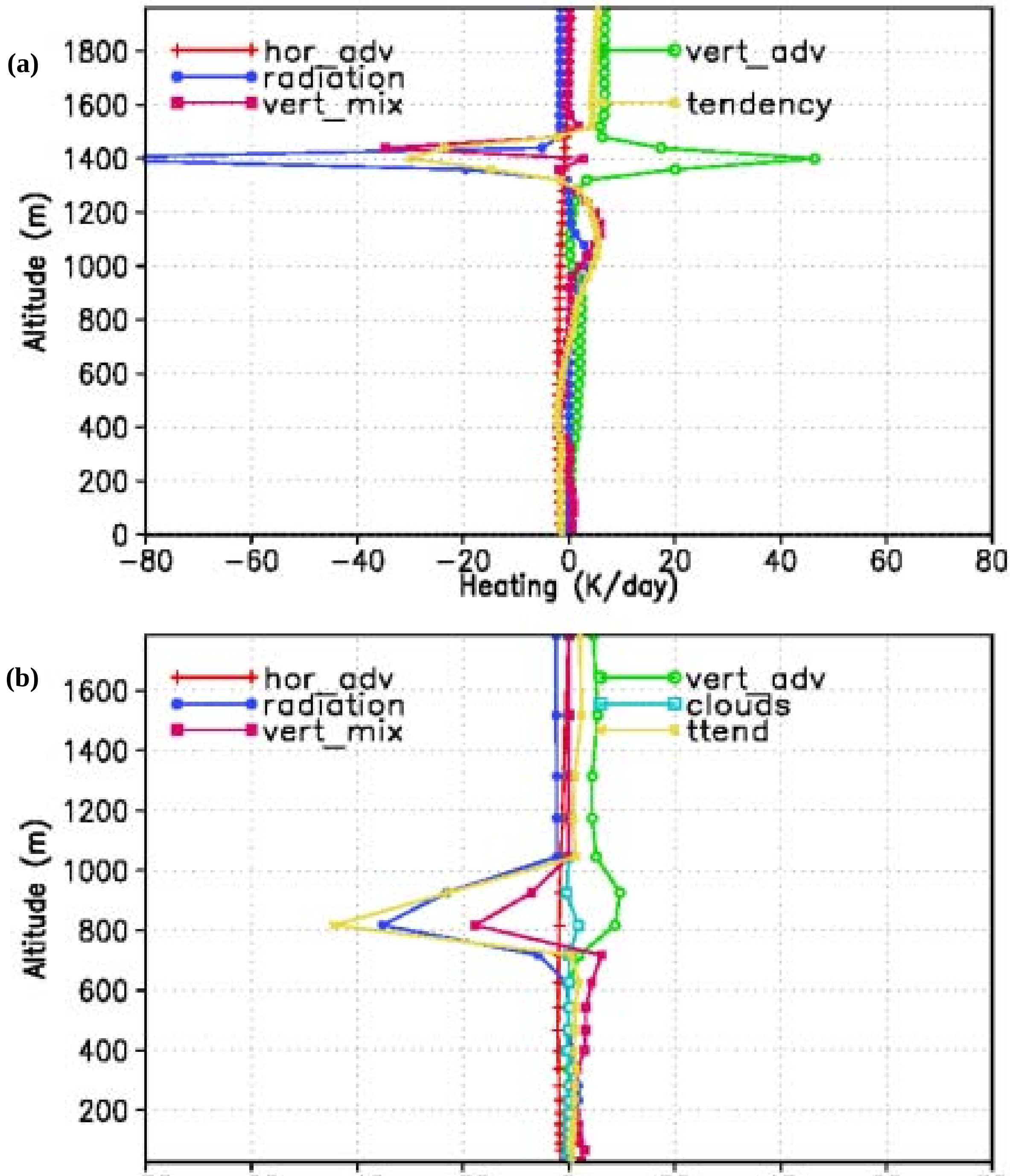

Figure 3. (a) Vertical distribution of heat budget at 3Z September 25 simulated by the LES model and (b) by the SCM.

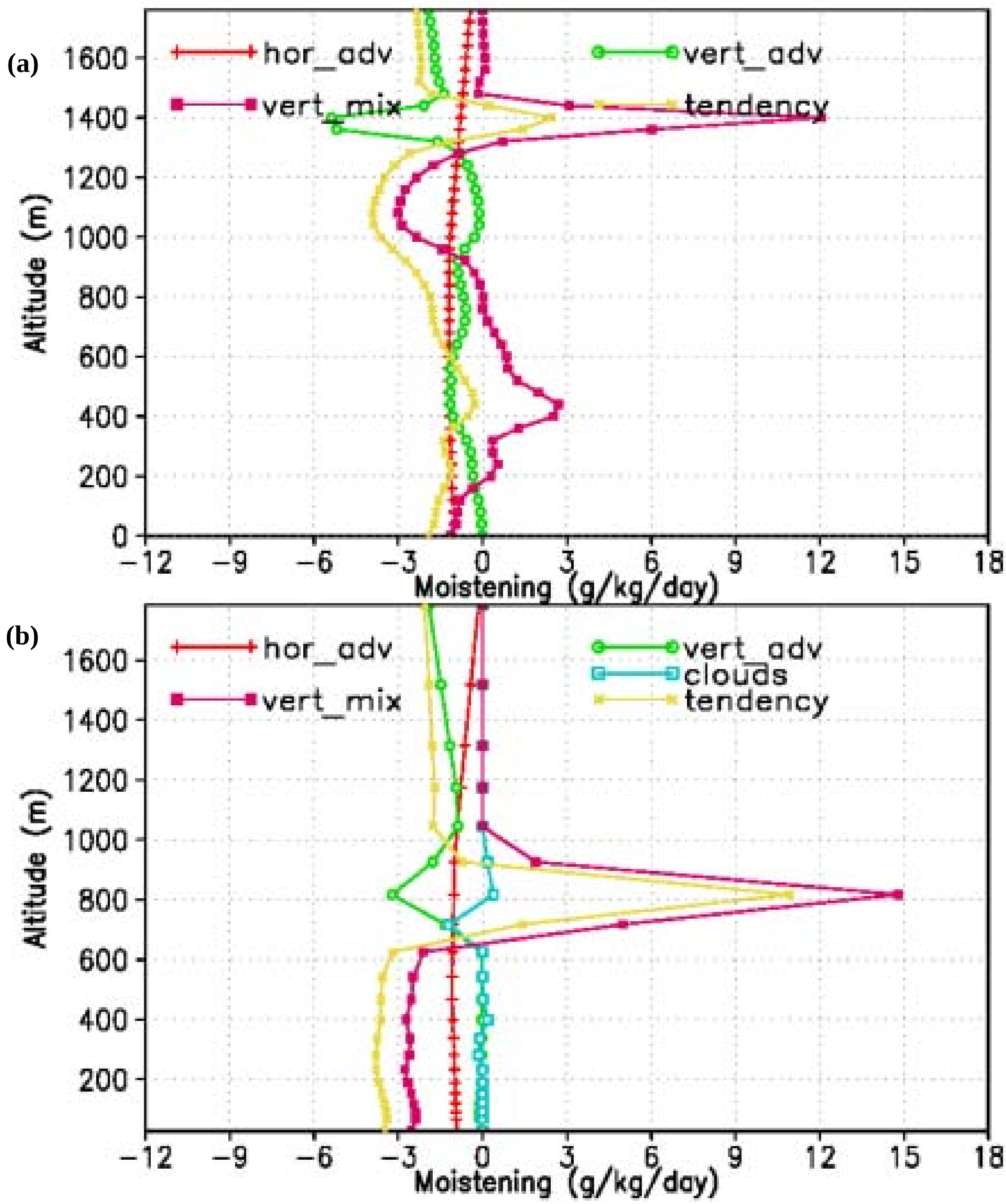

Figure 4. (a) Vertical distribution of moisture budget at 3Z September 25 simulated by the LES model and (b) by the SCM.

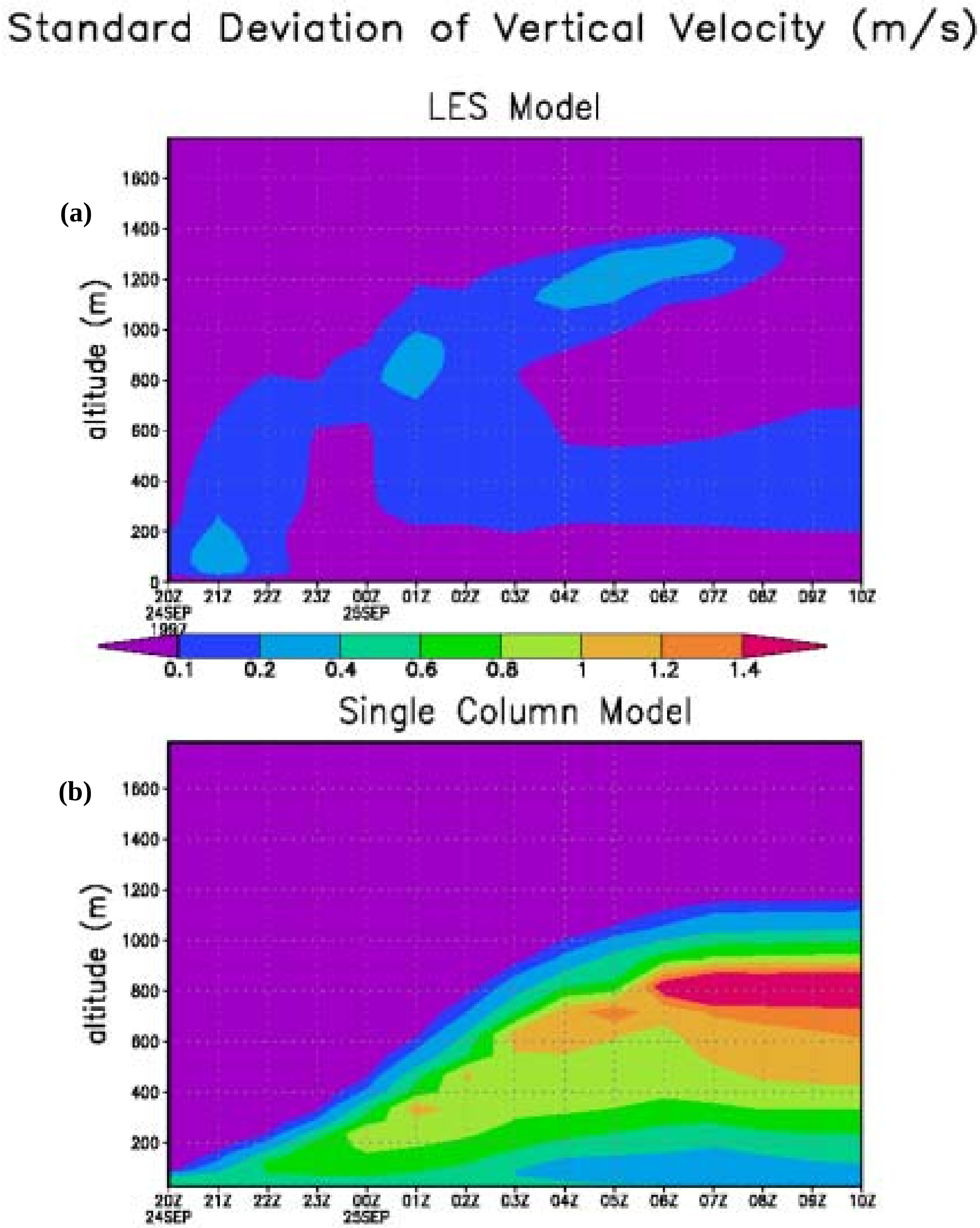

Figure 5. (a) Standard deviation of vertical velocity (m s^{-1}) simulated by the LES model and (b) by the SCM.