Reconciling Differences Between Large-Eddy Simulations and Doppler-Lidar Observations of Continental Shallow Cumulus Cloud-Base Vertical Velocity

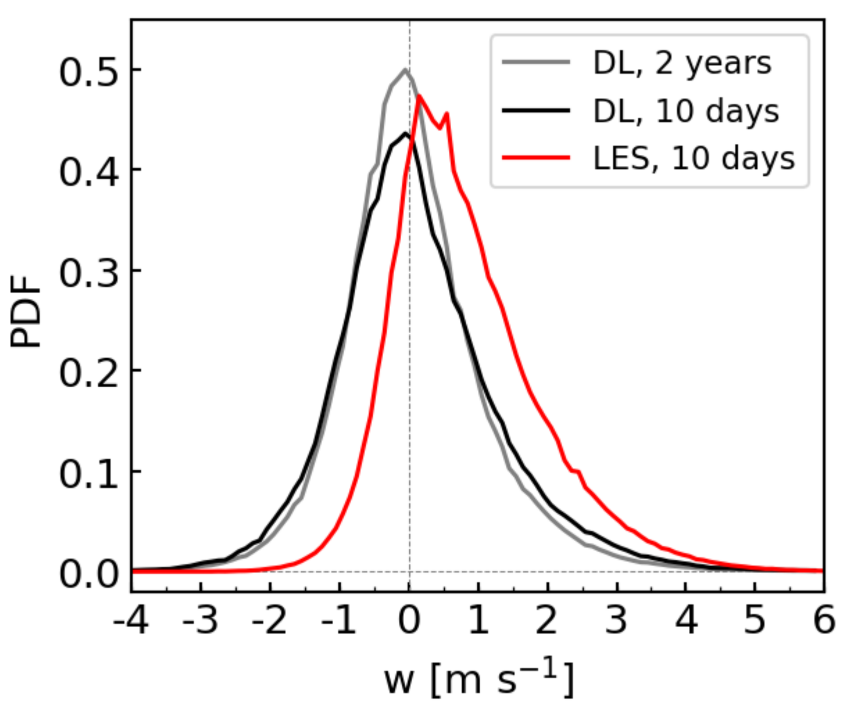
Satoshi Endo[1] <sendo@bnl.gov>, Damao Zhang[1], Andrew M Vogelmann[1], Pavlos Kollias[1,2], Katia Lamer[3], Mariko Oue[2], William I Gustafson Jr[4], Heng Xiao[4], and David M Romps[5]

[1] Brookhaven National Laboratory [2] Stony Brook University [3] The City College of New York
[4] Pacific Northwest National Laboratory [5] Lawrence Berkeley National Laboratory

1. Motivation

- Earlier studies suggest that large-eddy simulation (LES) produces cloud-base vertical velocity dominated by updrafts, which is inconsistent with measurements that also show the presence of considerable downdrafts.
- Analysis using LES conducted by the LES ARM Symbiotic Simulation and Observation (LASSO) project and 5-site Doppler Lidar (DL) observations at SGP confirmed the discrepancies.

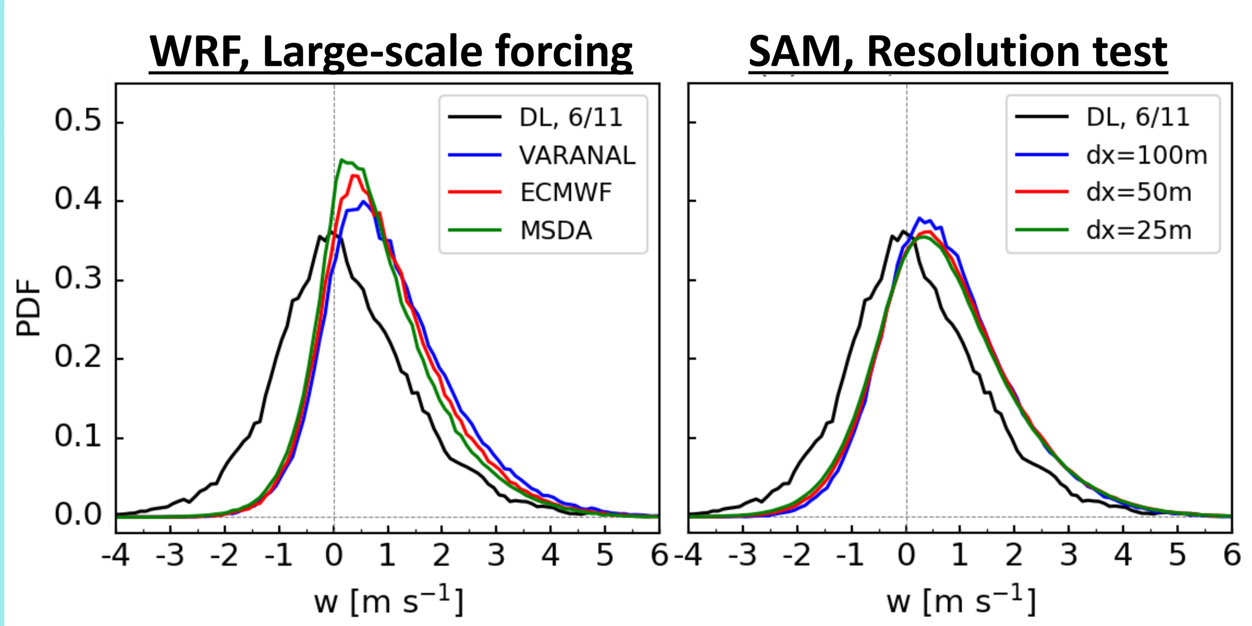
Probability Density Function (PDF) of cloud-base vertical velocity



The current work attempts to pinpoint the factors responsible for such discrepancies using sensitivity studies.

2. Sensitivity to Large-Scale Forcing, Choice of LES model, Grid Spacing

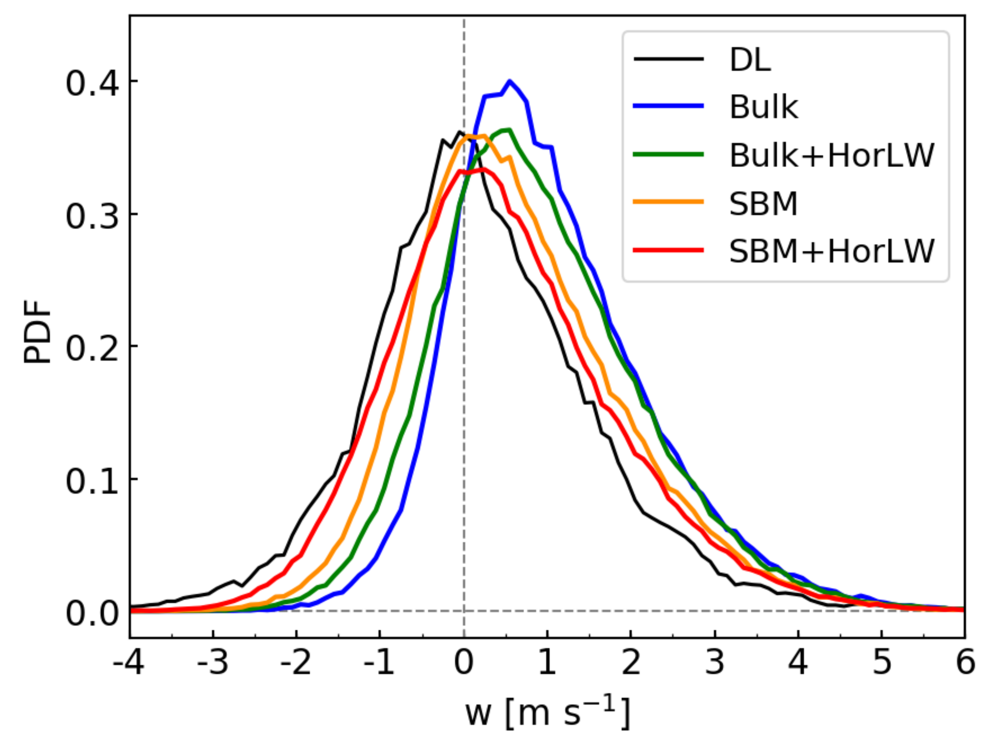
- Given the similarity of all cases simulated and observed, we chose to use the June 11, 2016 case to investigate the factors possibly related to the missing LES downdrafts.



The simulated vertical velocity PDF is insensitive to the large-scale forcing, choice of LES model, grid spacing, and various numerical, physical, or dynamical choices (e.g., coefficients in subgrid-scale turbulence scheme, microphysics parameters for the bulk microphysics, aerosol concentration)

3. Reconciling the LES-DL differences

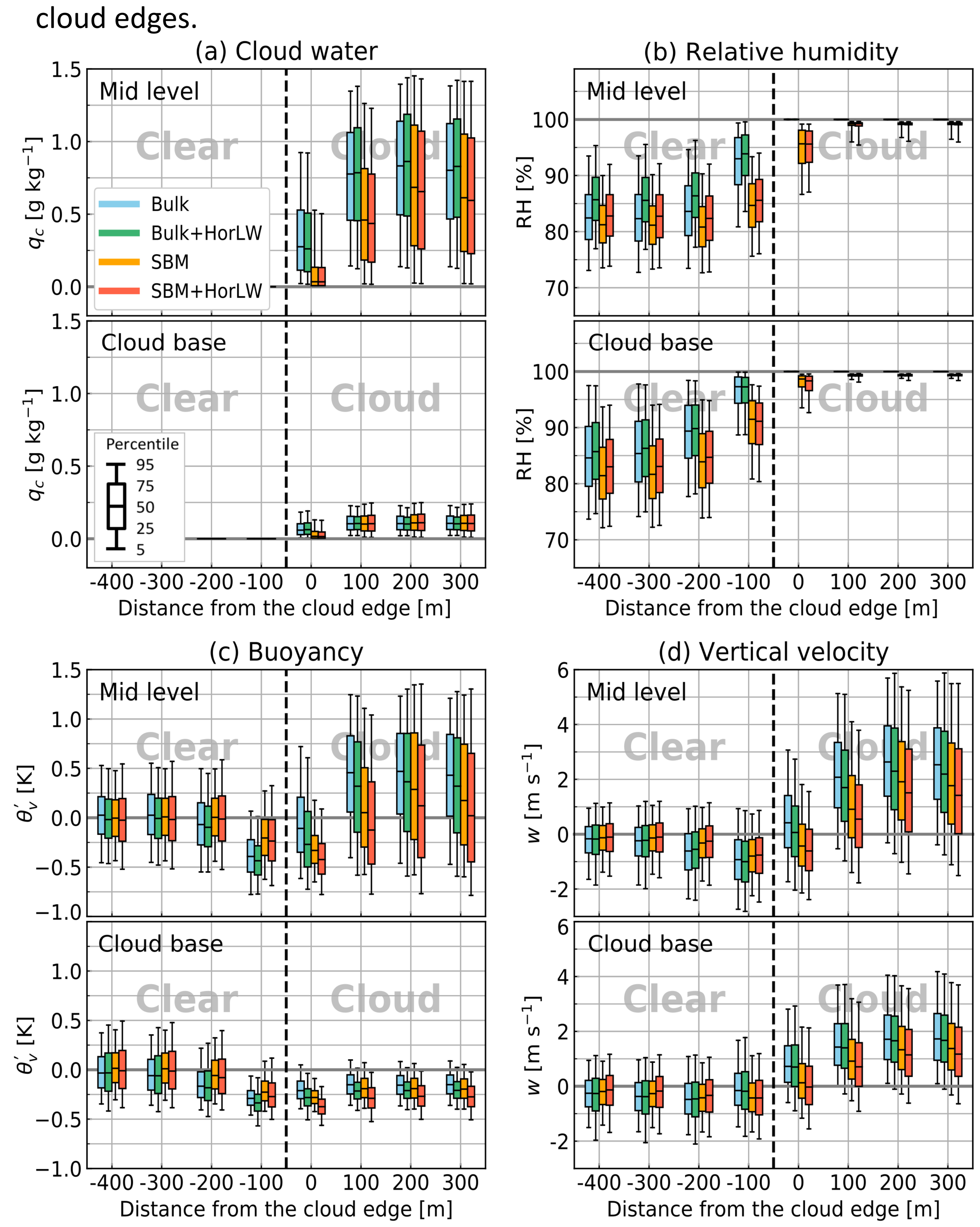
- The cloud-base vertical velocity is found to be improved by:
  1) Switching from a bulk microphysics (Bulk) scheme to a spectral-bin microphysics (SBM) scheme.
  2) Implementing a simple horizontal longwave radiation (HorLW) scheme.



Switching to SBM improved the vertical velocity PDF, particularly with HorLW.

The LES using both SBM and HorLW most closely produced the DL-measured PDF.

- To understand how the SBM and HowLW schemes improved the PDFs, cloud-edge statistics are produced by sampling gridpoints near the cloud edges.



- **Size-resolved microphysics (SBM)** can treat droplets in subsaturated air that lead to more evaporative cooling in the "cloudy" region.
- **Horizontal longwave radiation (HorLW)** leads to flux divergence and, thus, radiative cooling in the cloudy regions near the edge.

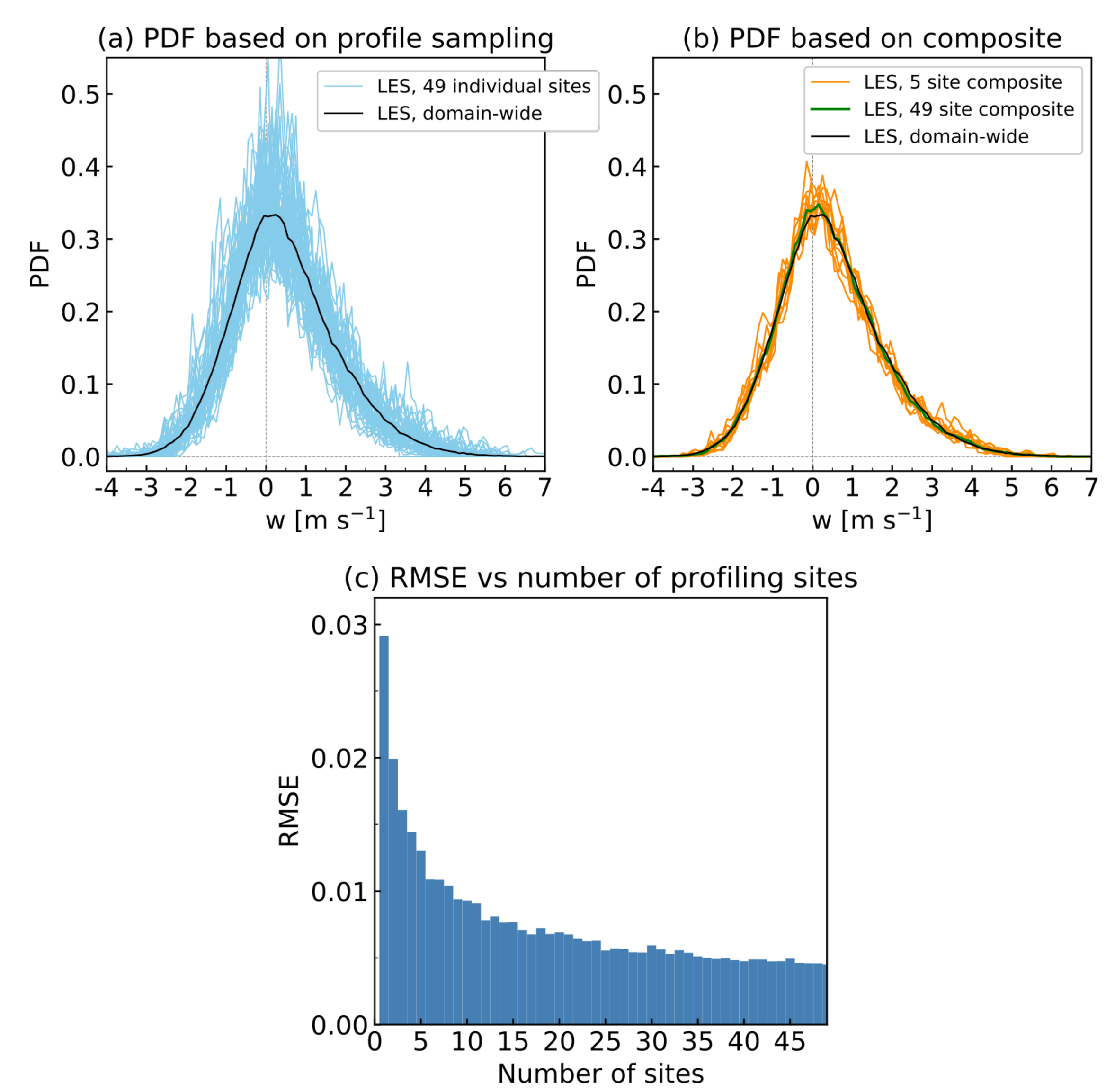
Both of the processes enhance negative buoyancy and downdrafts in cloudy regions near the edge, that helps the downdrafts reach the cloud base.

5. Summary

- Investigated the cloud-base vertical velocity differences between DL observations and LES simulations.
- The underestimation of simulated downdrafts is found to be a robust feature, being insensitive to various numerical, physical, or dynamical choices.
- LES can more closely reproduce observations only after improving the model physics to use size-resolved microphysics and horizontal longwave radiation, both of which modify the cloud buoyancy and velocity structure near cloud edges.
- The results suggest that these physical treatments are needed for the proper simulation and subsequent parameterization development of shallow cumulus vertical transport.

Profiling Measurement Test

- The ability of the 5-site Doppler lidar network to accurately sample cloud-base statistics has been assessed using a finite sampling test of LES output where the vertical velocity profiles were stored at 1 s intervals at 49 locations.



Increasing the number of sites from 1 to 5 reduces the root-mean-square error (RMSE) of the resulting PDF to about 0.013, which is less than half of the 1-site RMSE.

The dense DL network is necessary for the model diagnostics.

Funding provided by the DOE Office of Science Biological and Environmental Research Program through its Climate Modeling Development and Validation activity