RACORO-FASTER Case Studies for Continental Boundary Layer Clouds

Andy Vogelmann, Satoshi Endo, Wuyin Lin, Ann Fridlind, Tami Toto, Yangang Liu, Jian Wang, Sha Feng, Zhijin Li, Yunyan Zhang, Greg McFarquhar, Robert Jackson, Andrew Ackerman, Shaocheng Xie, Minghua Zhang

Goals:

• Assess and improve models of continental boundary layer cloud processes using RACORO aircraft and SGP observations
• Develop case studies for use by the modeling community

Posters
187 Andy Vogelmann et al.:  
1. RACORO-FASTER: Case Study Generation
188 Satoshi Endo et al.:  
2. RACORO-FASTER: Large Eddy Simulations
189 Wuyin Lin et al.:  
3. RACORO-FASTER: SCM Simulations & Diagnostics
44 Sha Feng et al.:  
Development of a Multi-scale Data Assimilation System
RACORO-FASTER Multi-Scale Analysis of Coupled Processes

Observations

Large-Eddy Simulations

Single-Column Models

Observation

WRF-FASTER

LWC [g m\(^{-3}\)]

Height [km]

TKE

Local Time

Supersaturation

Drop Number Conc. [cm\(^{-3}\)]

Kappa

Supersaturation

WRF-FASTER
Three 3-Day Case Study Periods Selected from RACORO

Case 1: Cumulus with Variable Aerosol (May 22-24)

Continental vs. maritime

Capture diverse states:
- Time variation & transitions
- Cloud type (Cu, St, drizzling St)

Comprehensive obs
- Aerosol size & CCN
- Cloud microphysics
- Atmospheric state
- Radiation

SGP surface obs & LS forcing

Case 2: Cumulus and Drizzling Stratus (May 26-28)

ARSL Cloud Field

Case 3: Variable Cloud Types (May 6-8)
Aerosol Size Distribution and Hygroscopicity

Unique aerosol profile observations of CCN (multiple SS) and size distributions

3 Lognormal Mode Aerosol Fits

3 Flavors of Size Distribution
- Raw data
- 3-Mode Fits
- Fixed D, σ (variable N_t(z))

Modal Kappa Fit

Data Fit

κ=0.11

Day 26, Spiral 1
Large-Scale Forcings & Assessments

Forcings assessed using “Toy” LES runs and bulk observations

Forcing
- ARM VA: Standard (300 km, 25 mb), Reduced (150 km, 10 mb)
- ECMWF: Standard
- MS-DA: Standard

NASA GISS DHARMA
- 4 km Domain
- 70-75 m Resolution
- ~ 1/7 Time of full run
- With and Without Relaxation

Observations
- Cloud cover: TSI
- LWP: MWRRet
- T, WV, RH: Raman Lidar

Time Series Over Domain

Day of May 2009 (UTC)

Averages Over Flight Periods

May 22

May 23

May 24
LES Models & Setup
- GISS DHARMA and WRF-FASTER
- Using the same grid spacing in low levels
- Morrison Two-moment microphysics
- Use diurnally varying TOA radiation

Aerosol Input & LS Forcing
- Idealized, observation-based, time-varying aerosol number size distribution profile & hygroscopicity
- ARM VARANAL continuous forcing
- 12-h relaxation for temperature/water vapor, 3-h relaxation for horizontal winds

Evaluation
- Use ARM ground-based obs to evaluate cloud macrophysical properties and boundary layer structure
- Use RACORO in-situ cloud obs to evaluate cloud microphysical properties

WRF-FASTER and DHARMA both capture the daytime evolution of the cumulus clouds during the three days.
Cloud water increases with height, caused by the competition of condensation from lifting and dilution from entrainment.

Droplet concentrations decrease with day, reflecting the change in the specified time variation of aerosol concentration.

The microphysical properties are constrained by the variations of cloud macrophysical properties, and the specified aerosol characteristics.
Example from Day 1:

- The in-situ observations show a convex increase of droplet number (Nd) with liquid water content (LWC).
- Two curves from horizontal legs near the cloud base and the higher levels.
Evaluation of Microphysical Properties: In-situ Obs vs LES

Example from Day 1:

- The in-situ observations show a convex increase of droplet number (Nd) with liquid water content (LWC).
- Two curves from horizontal legs near the cloud base and the higher levels.

Simulations capture the observed convex structures, and suggest an evolution of microphysical properties near cloud base.
Evaluation of Microphysical Properties: In-situ Obs vs LES

Example from Day 1:
- The in-situ observations show a convex increase of droplet number (Nd) with liquid water content (LWC).
- Two curves from horizontal legs near the cloud base and the higher levels.

Simulations capture the observed convex structures, and suggest an evolution of microphysical properties near cloud base.

The differences in the LWC-r_v curvatures suggest that the mixing process is more homogeneous in the simulations.

Next Steps
- Compare with the bin microphysics simulations from DHARMA
- Test a developed mixing degree parameterization
SCAM5 driven by ARM high-resolution forcing for the reduced SGP domain (Δs=150 km, Δp=10 mb):

- Over-triggering of deep convection.
- Persistent night time PBL clouds likely due to stratiform cloud scheme.

How do the shallow cumulus and moist turbulence parameterizations (the UW schemes), which are more relevant to this case, perform?
Convective clouds by UW shallow cumulus scheme for SCAM5

- Timing and temporal evolution reasonable.
- Cloud amount much less than LES simulations or observations.
- Cumulus cloud depth generally thinner.
Cumulus mass flux in SCAM5 is much weaker than what the LES simulations consistently suggest.
In UW shallow cumulus scheme, PBL mean TKE determines the width of assumed $w$-pdf, which is then used to define fractional convective updraft area at PBL top. Weaker TKE means smaller updraft area, all else being equal.
TKE in SCAM5 is much weaker than that in the LES simulations, and the boundary layer depth is shallower as suggested by the vertical extent of TKE.
Summary of SCM Investigation Guided by LES

Shallower PBL & Weaker Turbulence

↓

Narrower w-pdf

↓

Smaller Convective Updraft Area

↓

Weaker Cumulus convection*

↓

Weaker PBL ventilation

↓

More stratiform clouds (esp. nighttime)

* Other factors, such as entrainment efficiency and max allowed updraft area in the UWshcu scheme also contribute to weaker cumulus activity
Backup Slides
High concentrations and complex spatial and temporal changes suggest a requirement on aerosol initialization and forcing.
SCAM5 driven by ARM high-resolution forcing for the reduced SGP domain ($\Delta s=150$ km, $\Delta p=10$ mb):

- Over-triggering of deep convection.
- Persistent night time PBL clouds likely due to stratiform cloud scheme.

How do the shallow cumulus and moist turbulence parameterizations (the UW schemes), which are more relevant to this case, perform?
Sensitivity experiments with the cumulus scheme and impact of cumulus activity on PBL clouds

Overall model PBL clouds highly sensitive to shallow cumulus activities.

Sensitivity exps. suggest in SCAM5:
- Entrainment efficiency too strong.
- Updraft area too small
TKE from SCAM5 of different configurations

The existing PBL scheme in SCAM5 is expected to deliver improved results at higher horizontal and/or vertical resolutions (e.g., future model).