RACORO-FASTER Case Studies for Continental Boundary Layer Clouds

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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

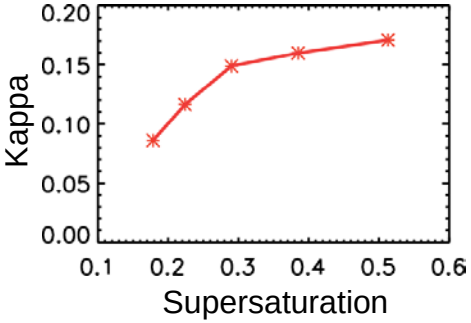
188 Satoshi Endo et al.:
2. RACORO-FASTER: Large Eddy Simulations

189 Wuyin Lin et al.:
3. RACORO-FASTER: SCM Simulations & Diagnostics

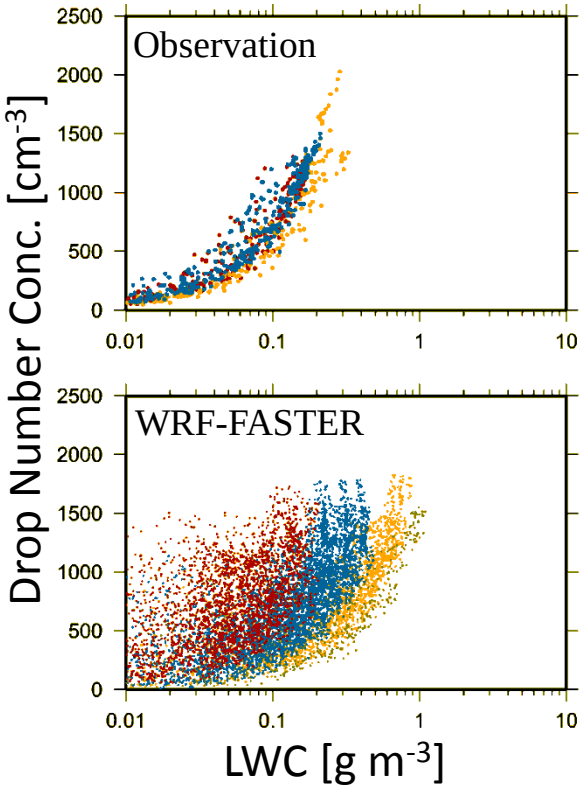
44 Sha Feng et al.:
Development of a Multi-scale Data Assimilation System

RACORO-FASTER Multi-Scale Analysis of Coupled Processes

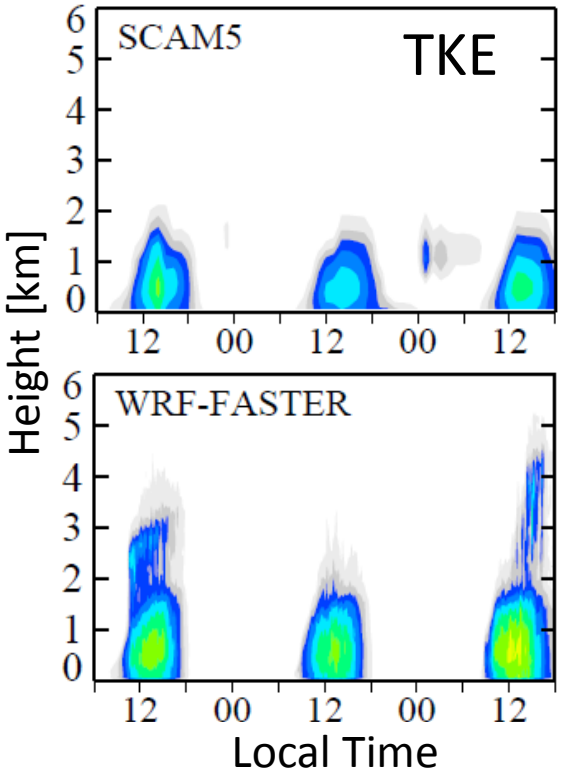
Observations



Large-Eddy Simulations



Single-Column Models



Three 3-Day Case Study Periods Selected from RACORO

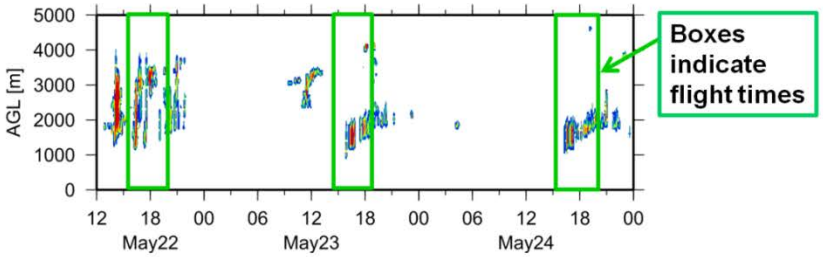
Continental vs. maritime

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

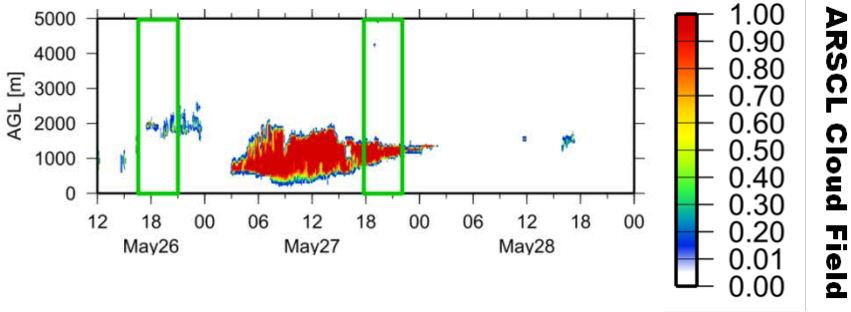
Comprehensive obs
- Aerosol size & CCN
- Cloud microphysics
- Atmospheric state
- Radiation

SGP surface obs & LS forcing

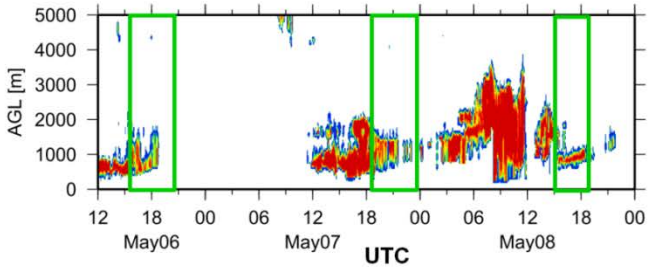
Case 1: Cumulus with Variable Aerosol (May 22-24)



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



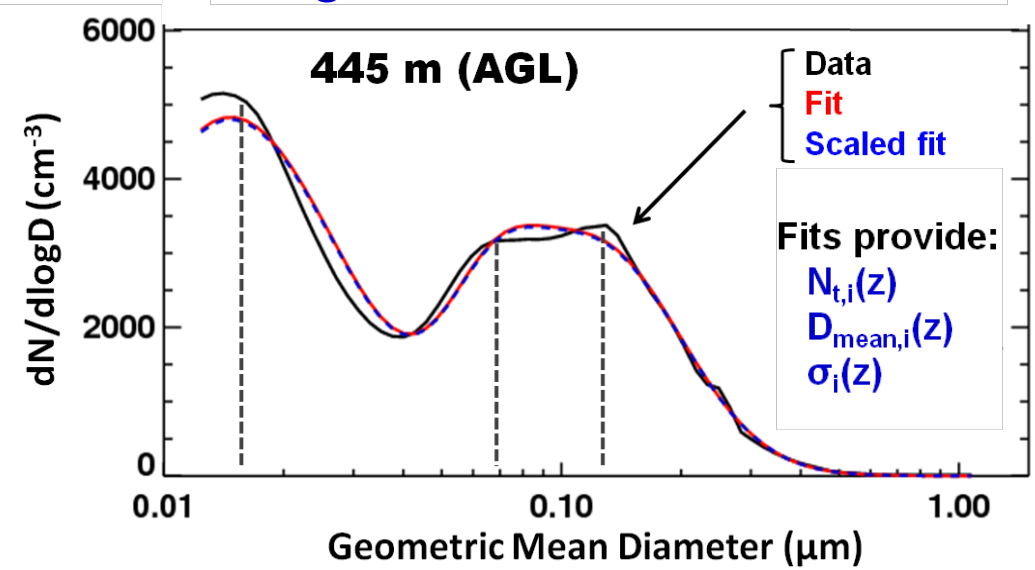
Case 3: Variable Cloud Types (May 6-8)



Aerosol Size Distribution and Hygroscopicity

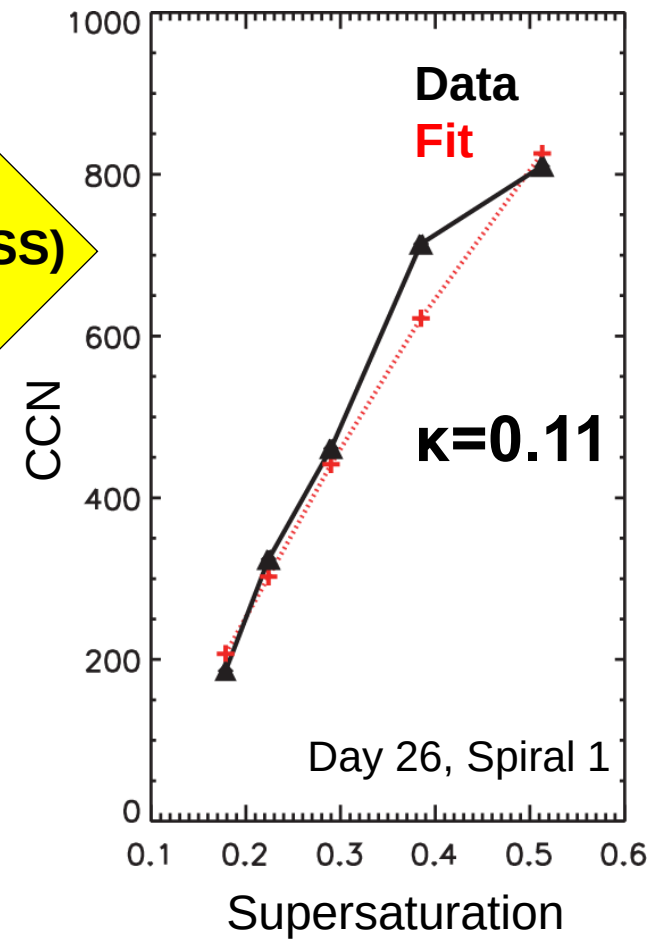
Unique aerosol profile observations of CCN (multiple SS) and size distributions

3 Lognormal Mode Aerosol Fits



+ CCN(SS)

Modal Kappa Fit



3 Flavors of Size Distribution

- Raw data
- 3-Mode Fits
- Fixed D,σ (variable $N_t(z)$)

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**

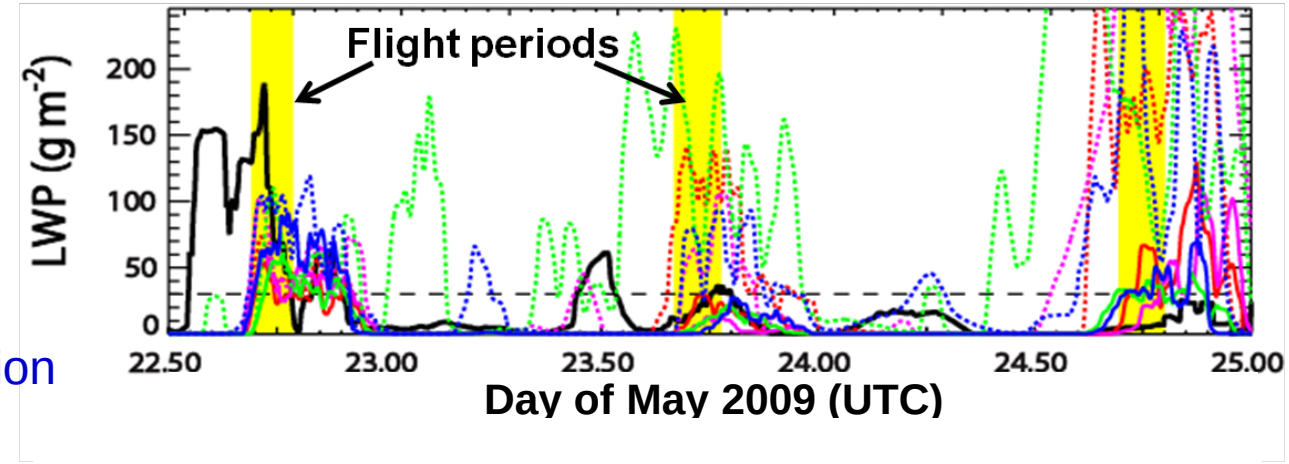
NASA GISS DHARMA

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

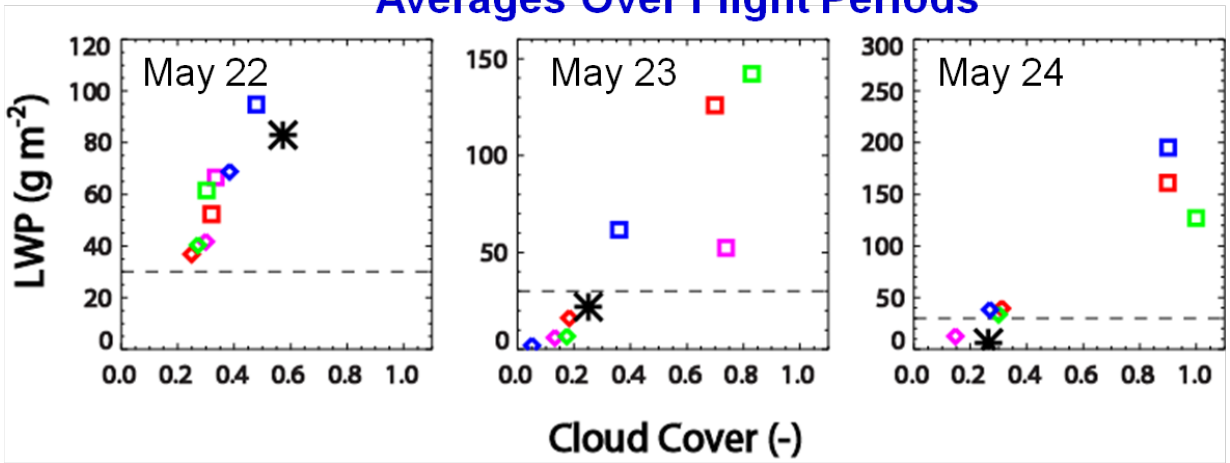
Observations

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

Time Series Over Domain



Averages Over Flight Periods



LES of the RACORO Case 1 (Cumulus Clouds)

LES Models & Setup

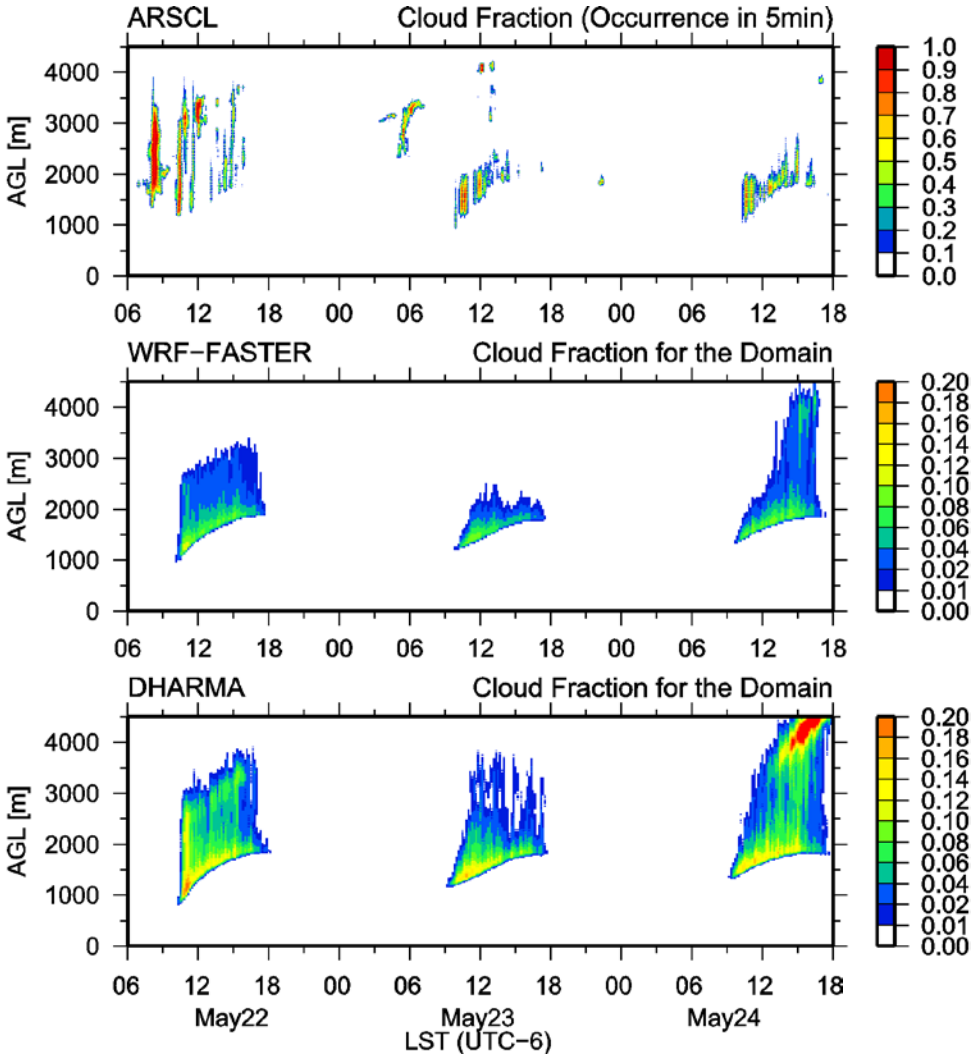
- GISS **DHARMA** and **WRF-FASTER**
- Using the **same grid spacing** in low levels
- Morrison Two-moment microphysics
- Use **diurnally varying** TOA radiation

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

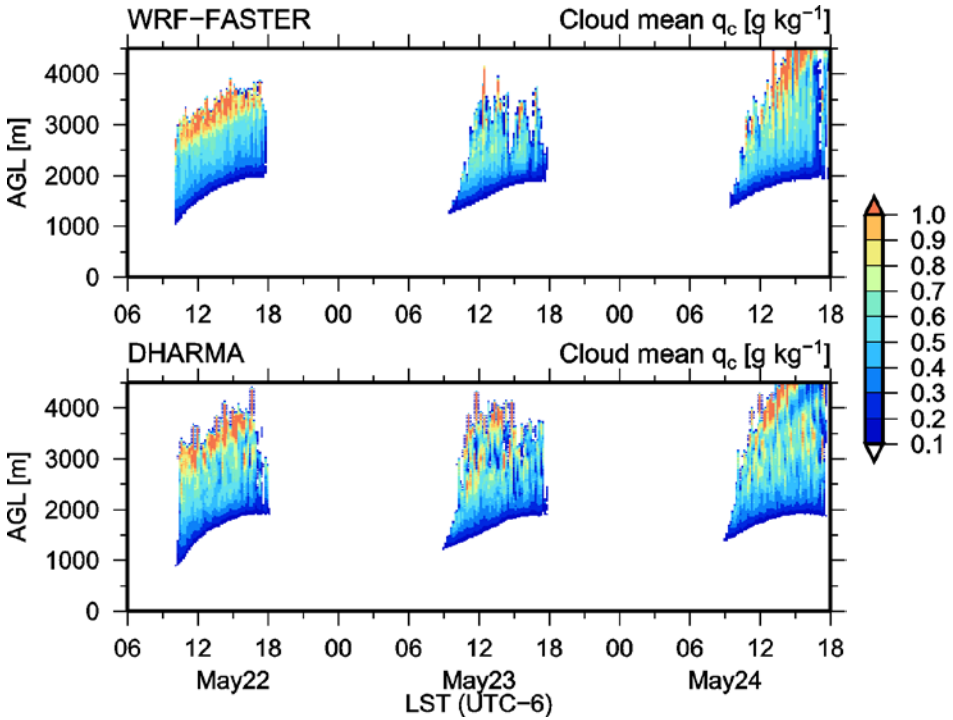
- Use ARM ground-based obs to evaluate **cloud macrophysical properties** and **boundary layer structure**
- Use **RACORO in-situ cloud obs** to evaluate cloud **microphysical** properties



WRF-FASTER and DHARMA both capture the daytime evolution of the cumulus clouds during the three days.

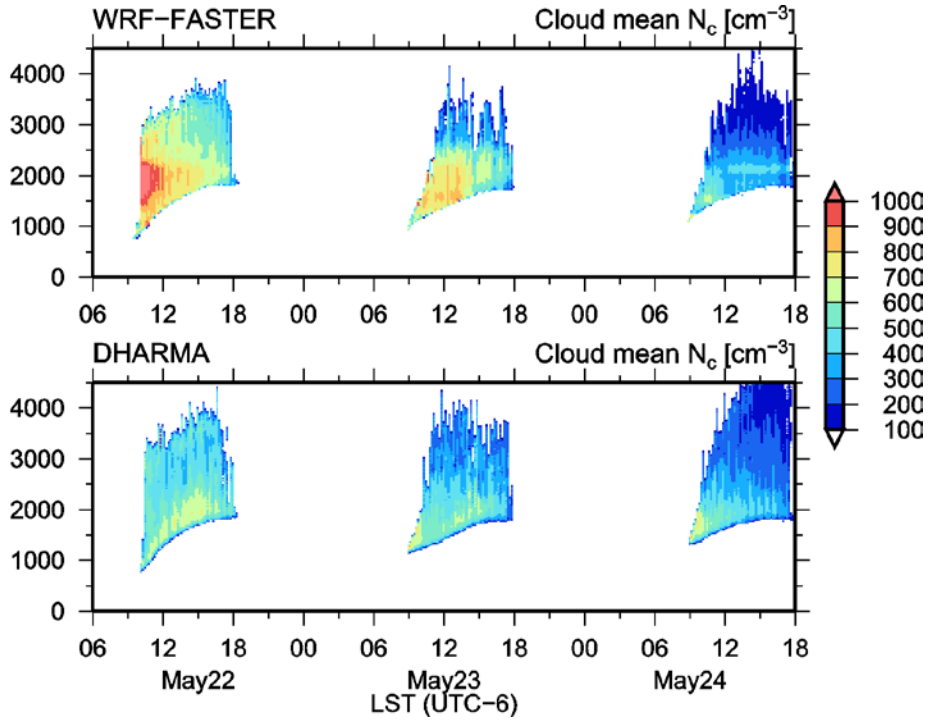
Aerosol - Dynamics - Microphysics Links

Cloud Water (cloud mean)



Cloud water increases with height, caused by the competition of **condensation from lifting** and dilution from entrainment.

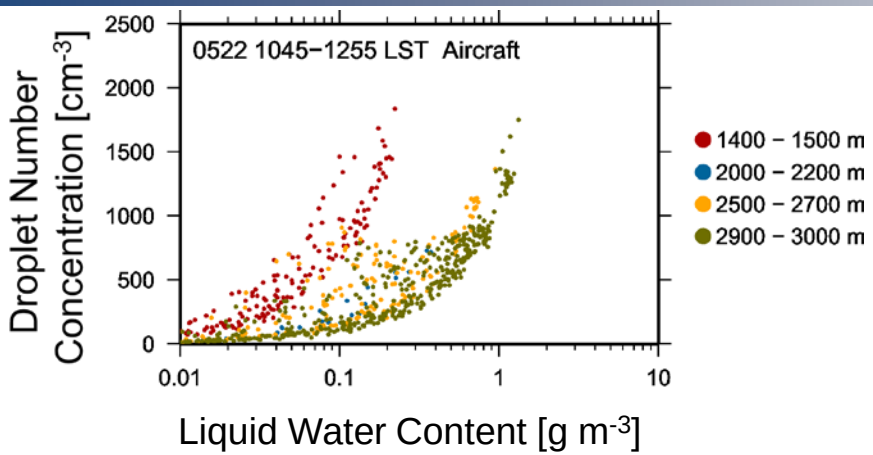
Droplet Number Conc. (cloud mean)



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.

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.

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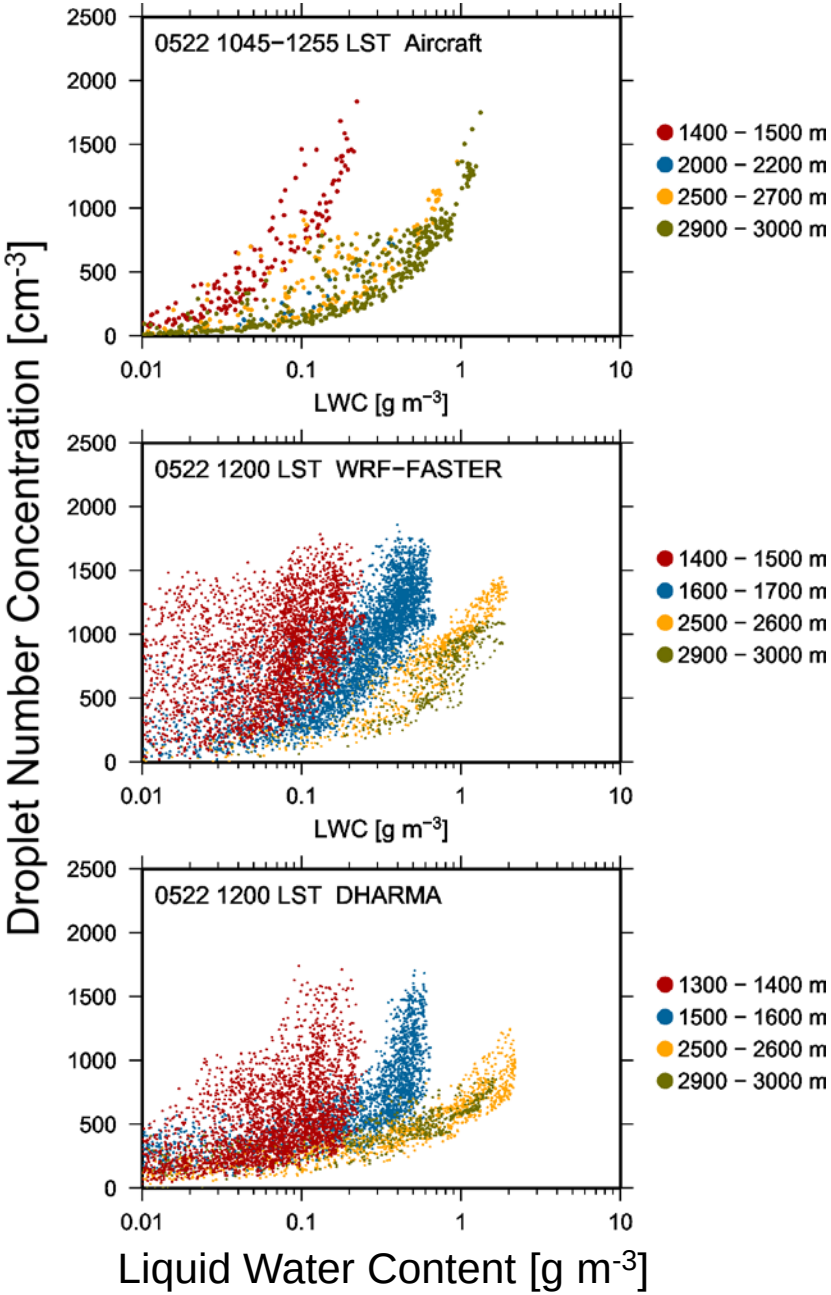

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Simulations capture the observed convex structures, and suggest an evolution of microphysical properties near cloud base.

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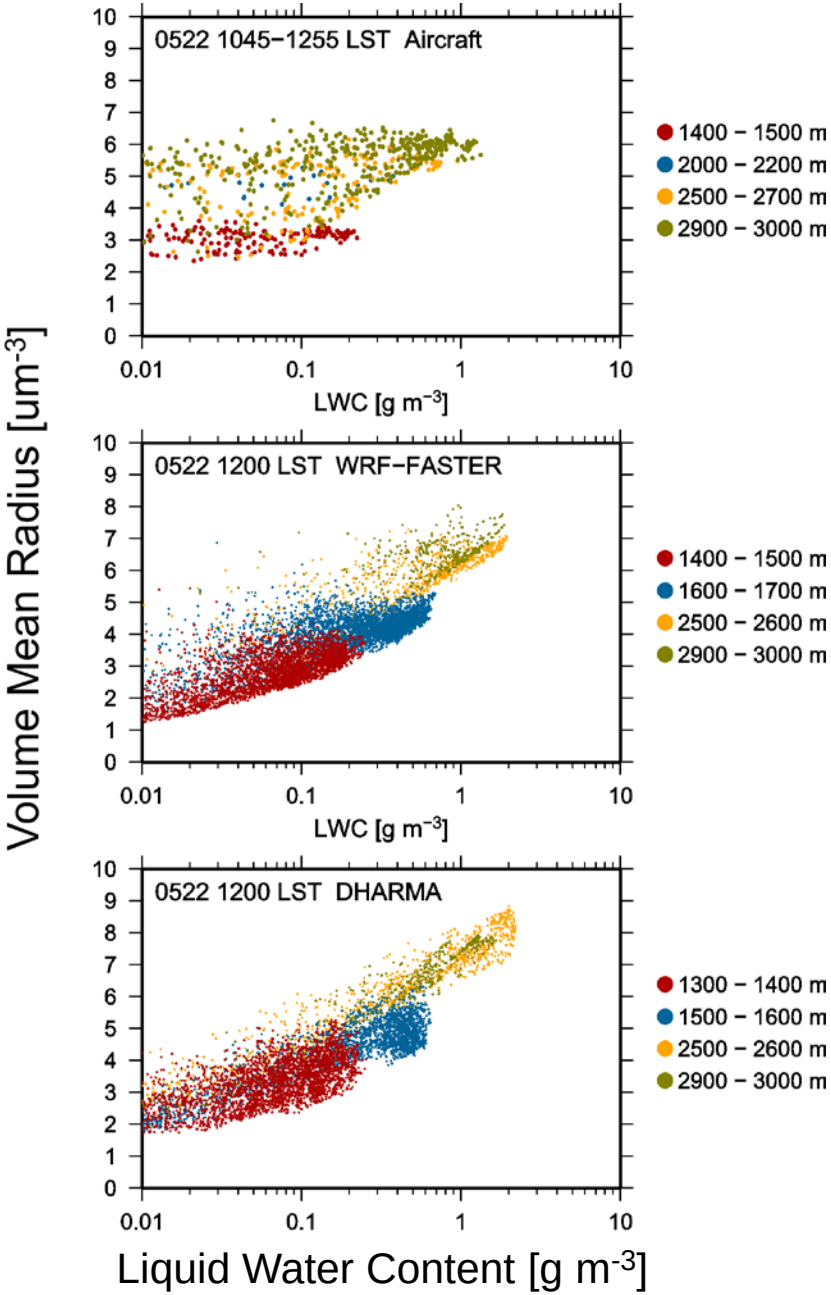

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The differences in the LWC-r_v curvatures suggest that the mixing process is more homogeneous in the simulations.

Next Steps

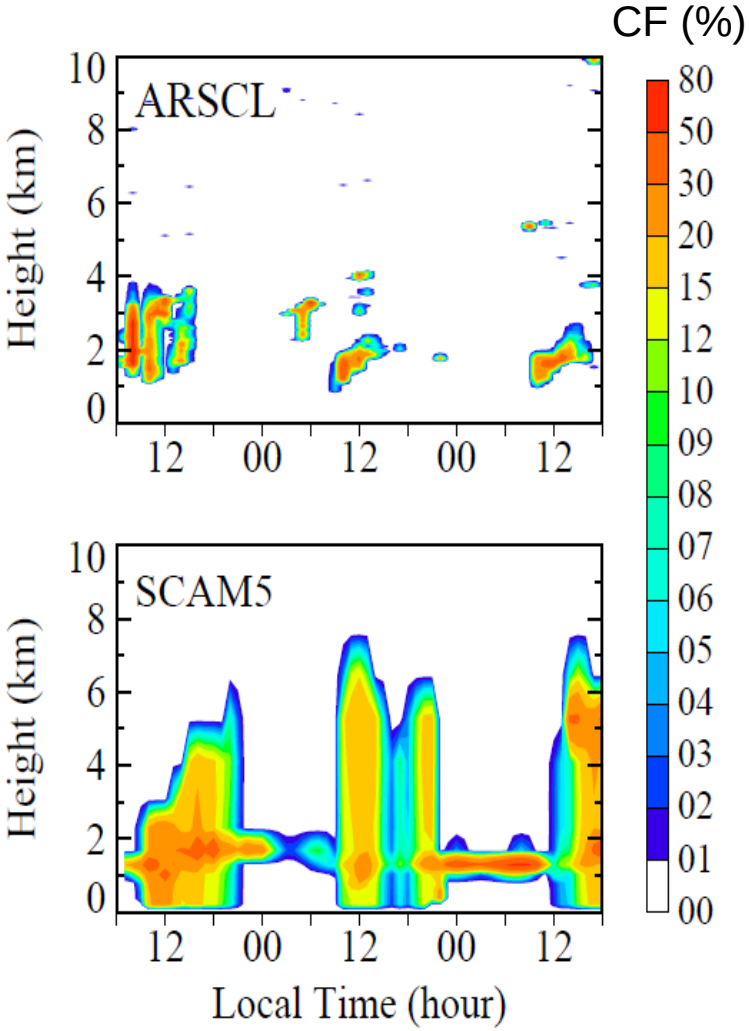
- Compare with the **bin microphysics** simulations from DHARMA
- Test a developed **mixing degree parameterization**

Single-Column Model CAM5 Investigation of Case 1

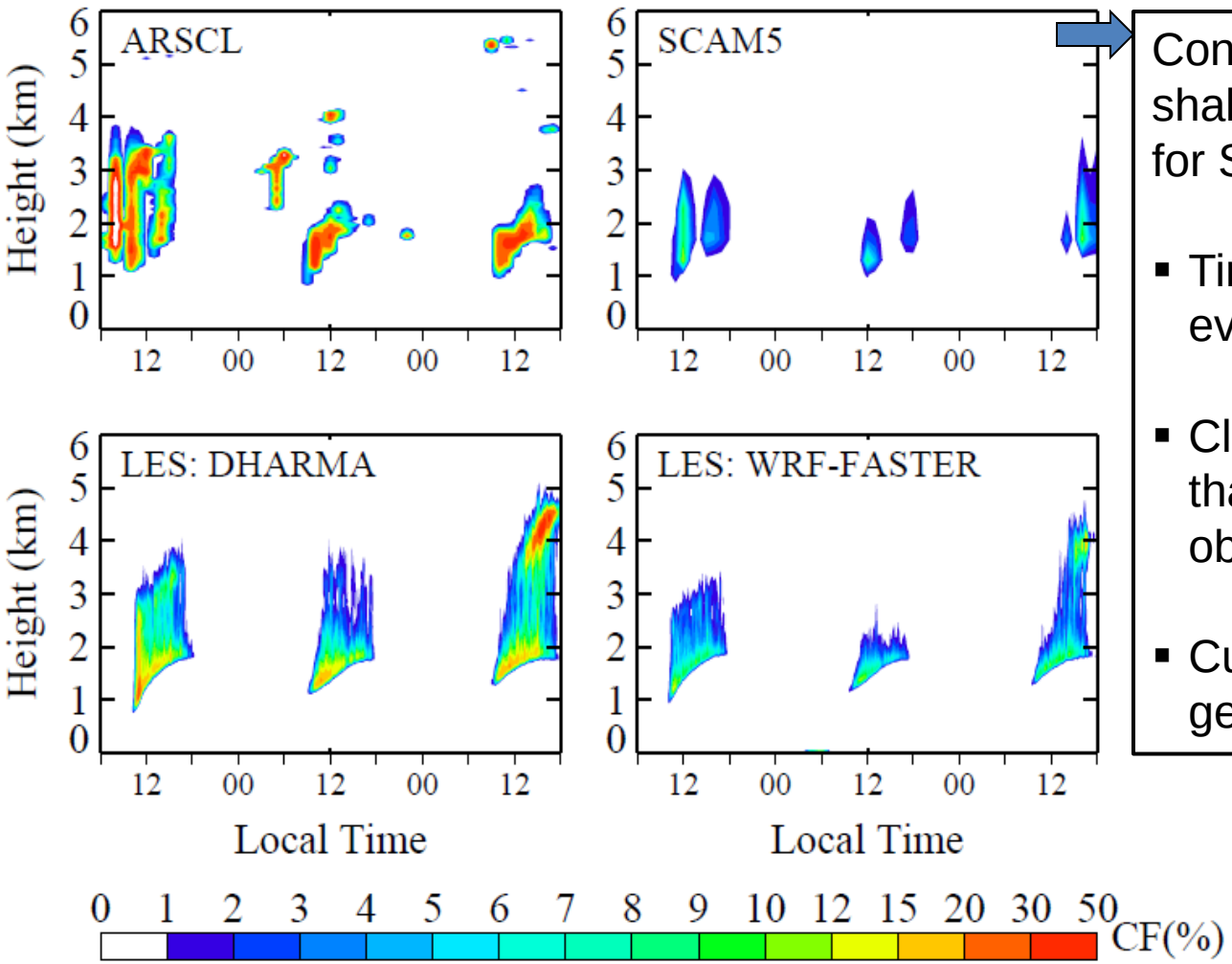
SCAM5 driven by ARM high-resolution forcing for the reduced SGP domain (Δs=150 km, Δp=10 mb):

- 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?



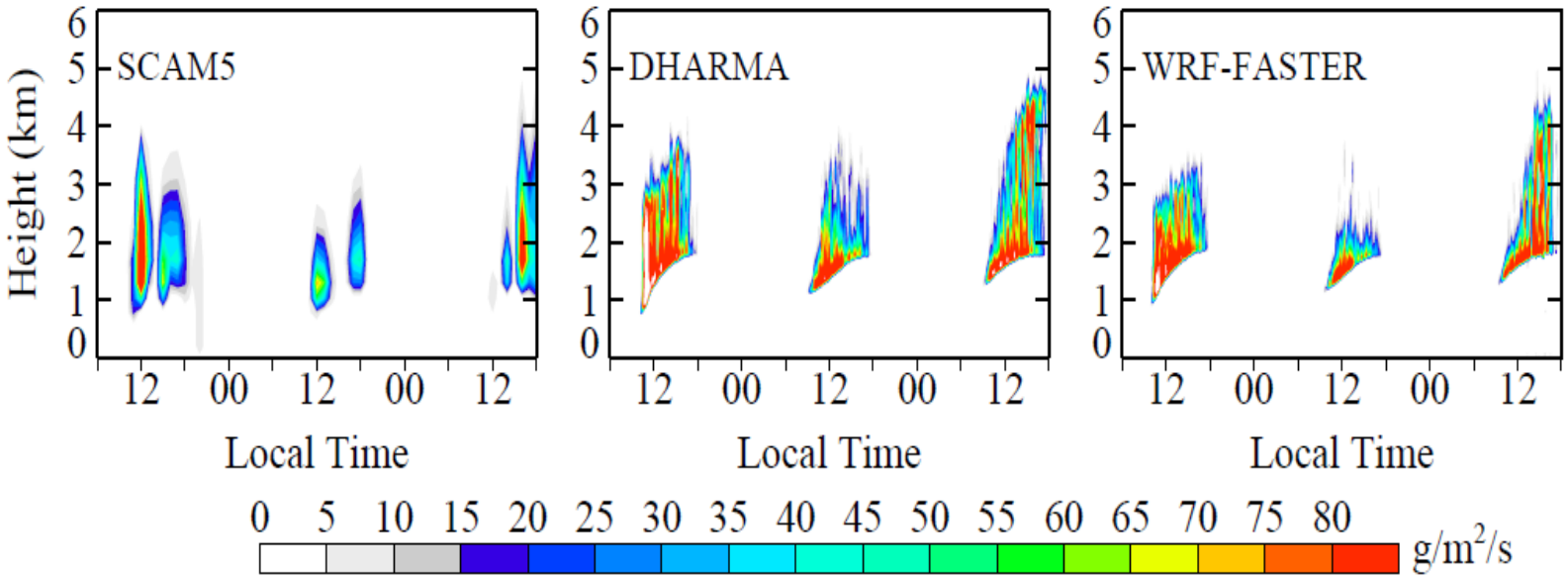
Single-Column Model CAM5 Investigation of RACORO Case 1



Convective clouds by UW shallow cumulus scheme for SCAM5

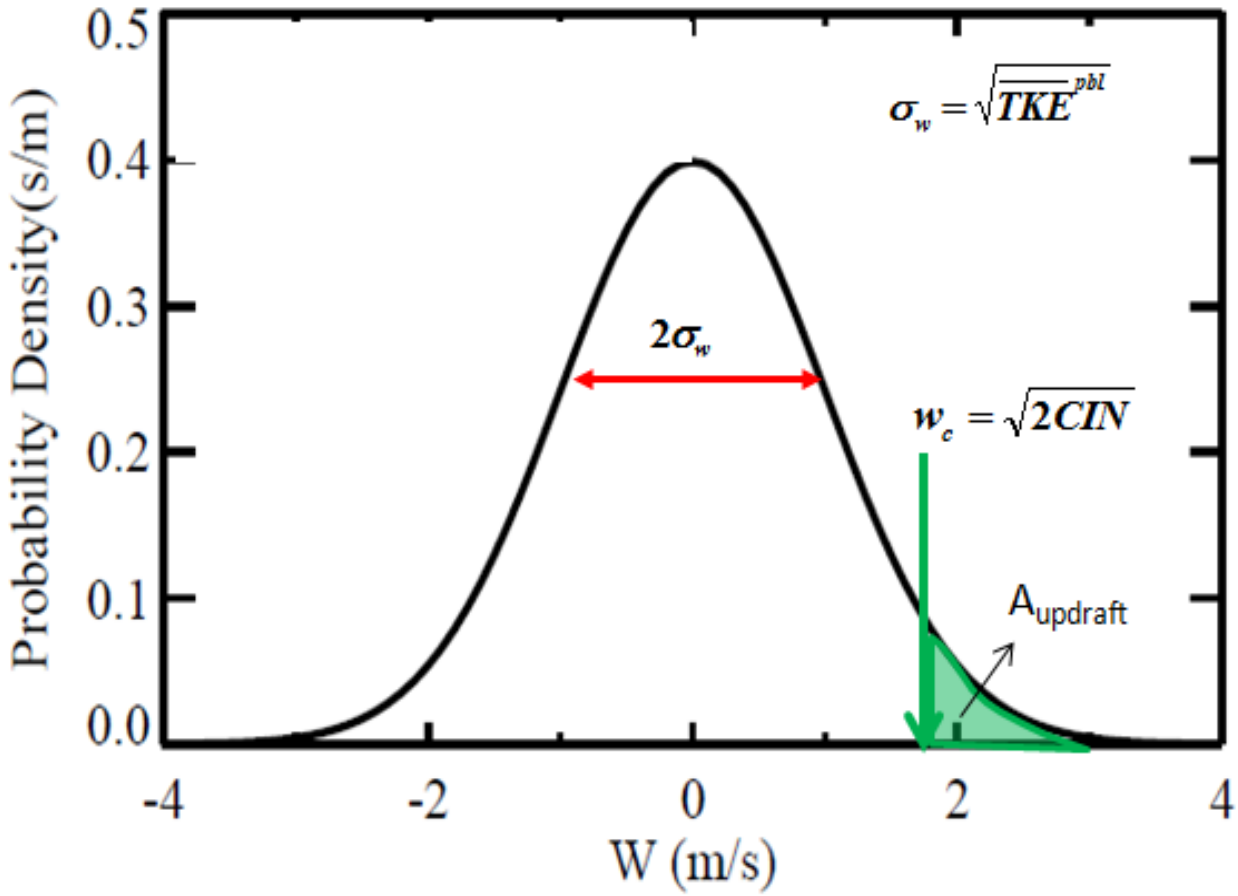
- Timing and temporal evolution reasonable.
- Cloud amount much less than LES simulations or observations.
- Cumulus cloud depth generally thinner.

Cumulus Mass Flux from SCAM5 and LES



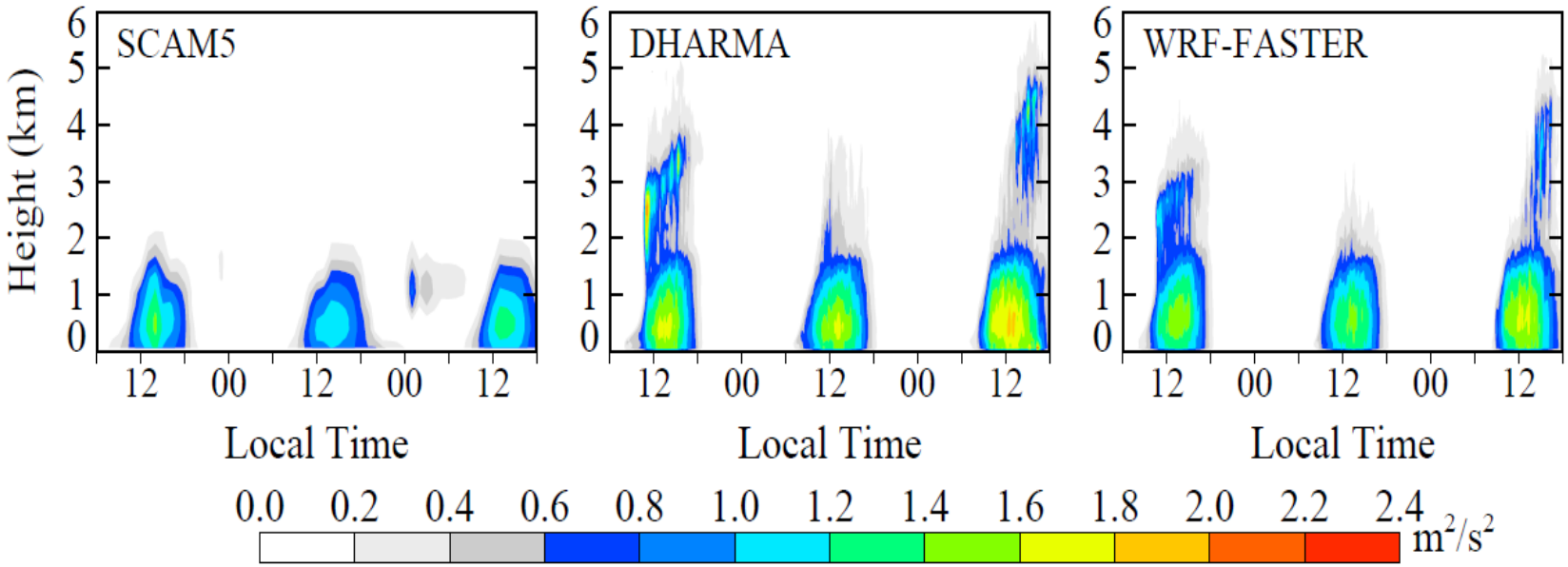
Cumulus mass flux in SCAM5 is much weaker than what the LES simulations consistently suggest.

UW Shallow Cumulus Scheme
Determination of Convective Updraft Area at Cloud Base



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.

Turbulent Kinetic Energy from SCAM5 and LES



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

↓

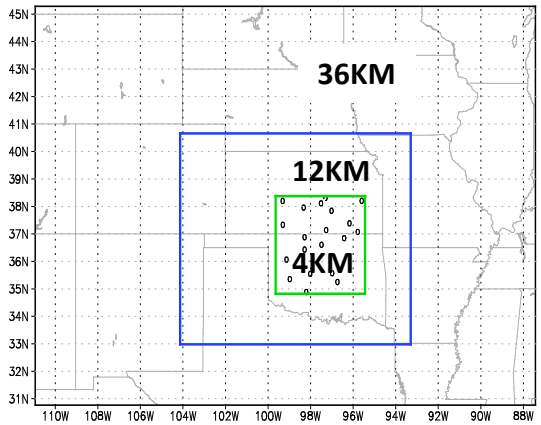
More stratiform clouds (esp. nighttime)

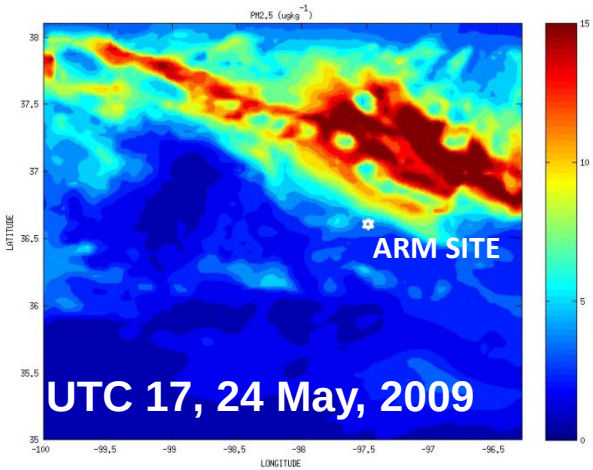
** Other factors, such as entrainment efficiency and max allowed updraft area in the UWshcu scheme also contribute to weaker cumulus activity*

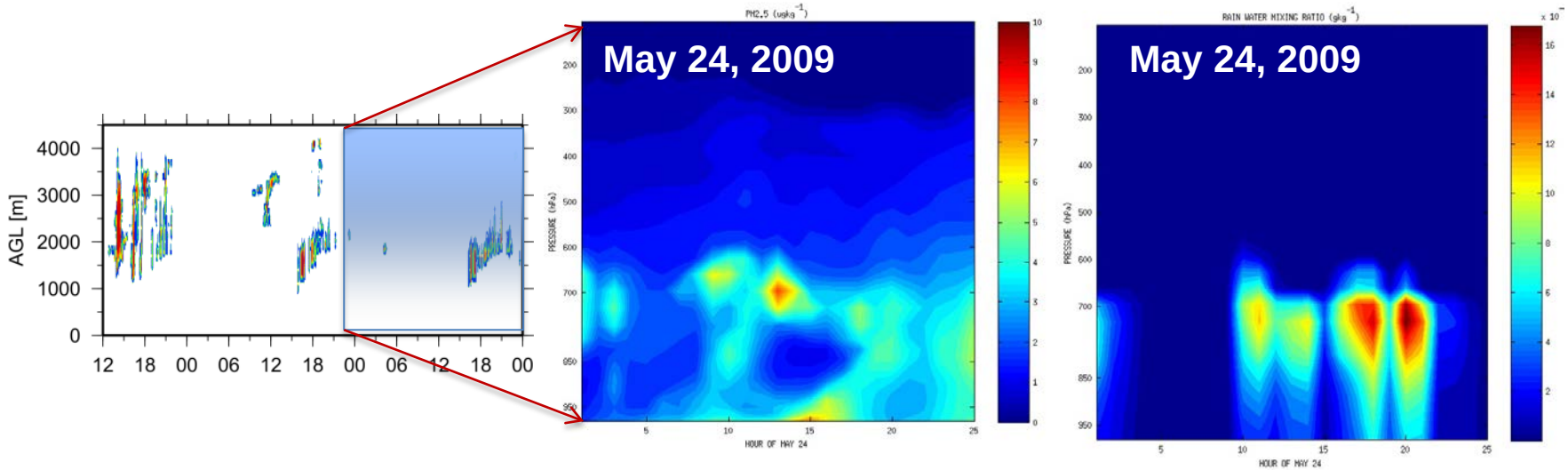
Backup Slides

WRF/Chem Aerosol Simulation and Data Assimilation

Zhijin Li and Sha Feng







High concentrations and complex spatial and temporal changes suggest a requirement on aerosol initialization and forcing

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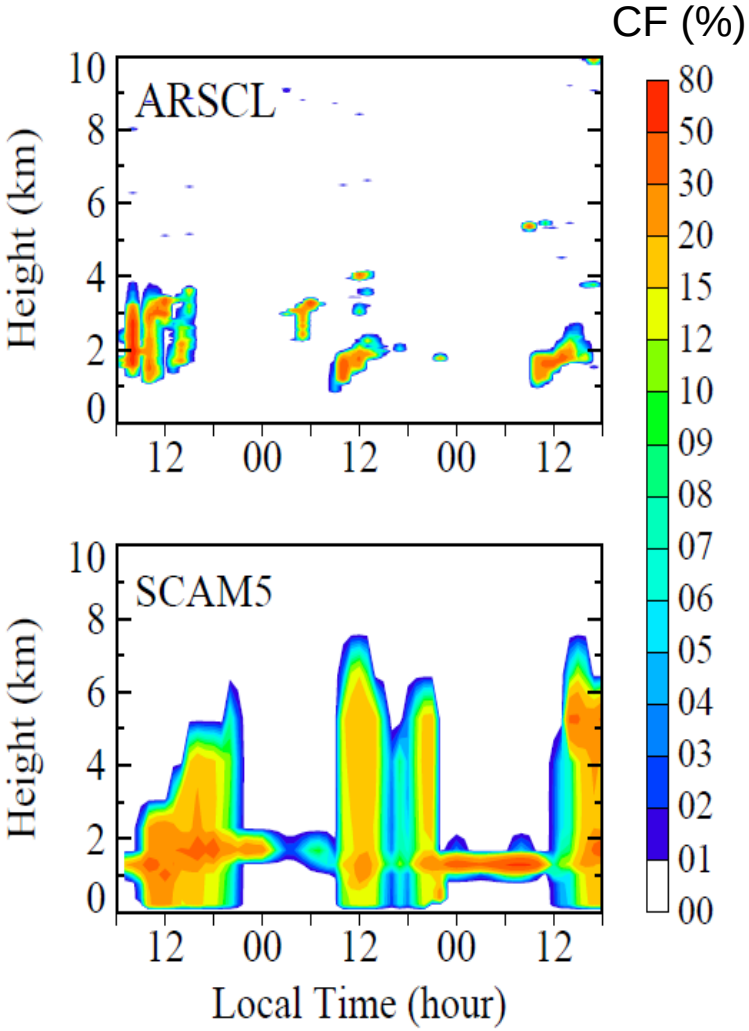
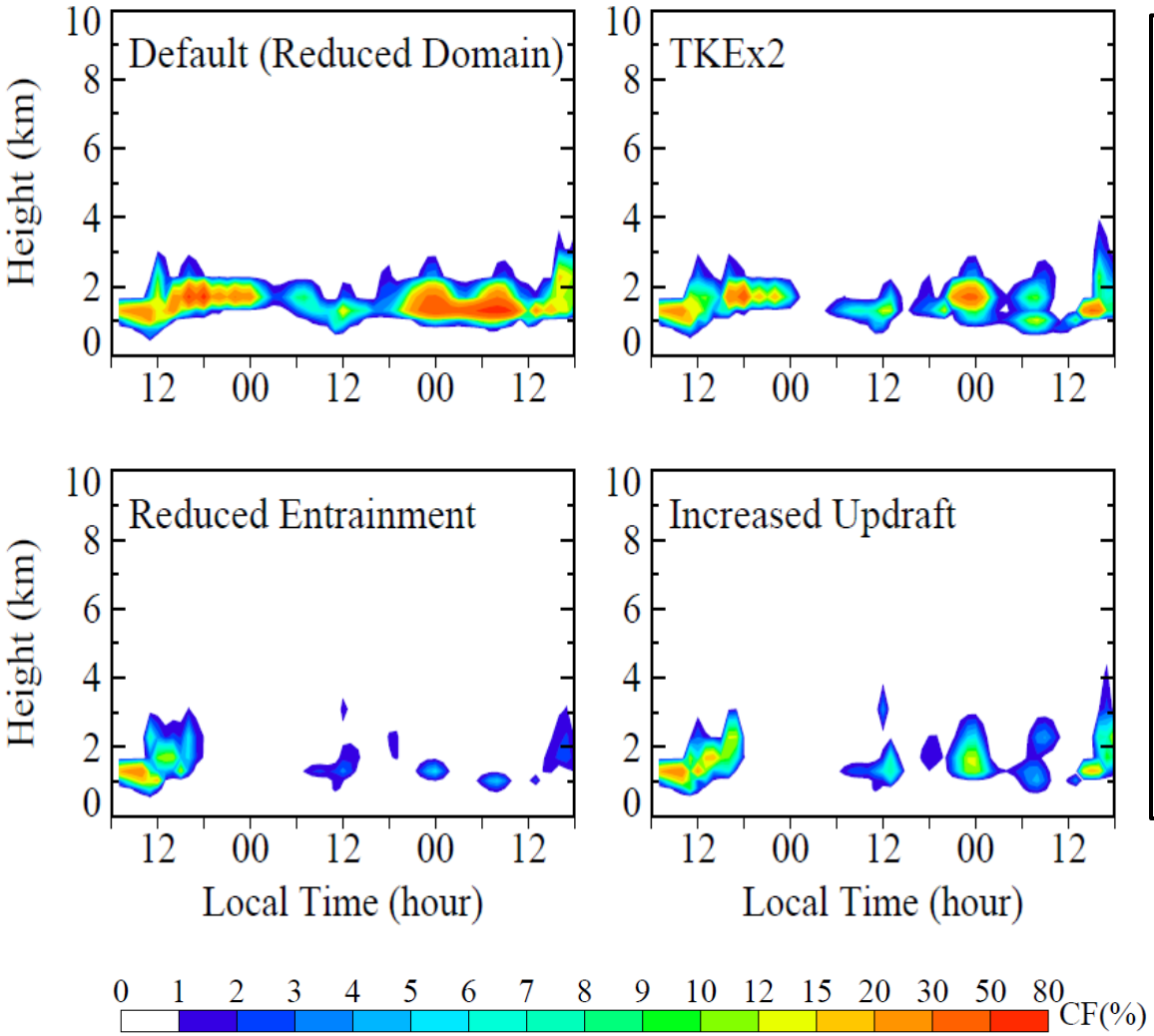


Sensitivity experiments with the cumulus scheme and impact of cumulus activity on PBL clouds

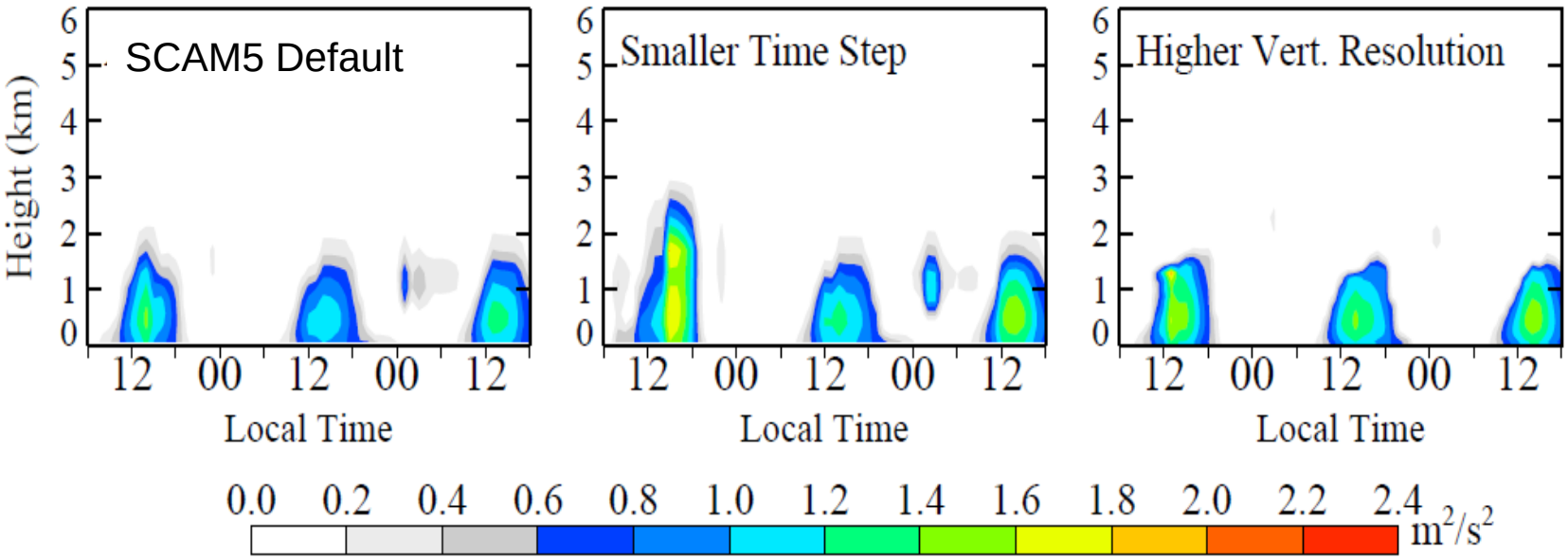


Overall model PBL clouds highly sensitive to shallow cumulus activities.

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*).