Targeted Bulk Microphysics Improvements Through Cloud-Resolving and Limited Area Model Intercomparison and Observations

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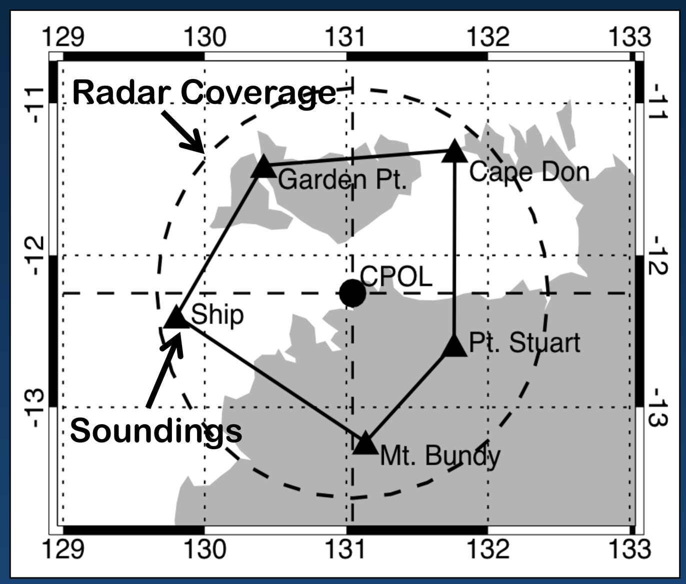
Overview

In this study, we compare 10 idealized CRM simulations, 3 LAM simulations, and observations of the tropical monsoonal MCS during TWP-ICE in an attempt to identify sources of error in bulk microphysics schemes. For more details on the simulations, see Varble et al. (2011), Fridlind et al. (2010, 2012), and Zhu et al. (submitted).



Observations
- C-band polarimetric scanning radar (CPOL)
  - reflectivity
  - rain rate
  - dual-Doppler retrieval (w/ Berrima radar)
  - D_0 retrieval (algorithm in Bringi et al. (2009))
  - multi-frequency profiler retrievals of rain DSDs (not shown)

10 CRM simulations
- 4 models: DHARMA, UKMO, MESONH, SAM
- various 1-moment and 2-moment bulk microphysics
- forced with variational analysis
- ~176 km by ~176 km domain within CPOL range
- ~1 km horizontal resolution
- stretched 100-400 m vertical resolution
- oceanic surface with constant SST

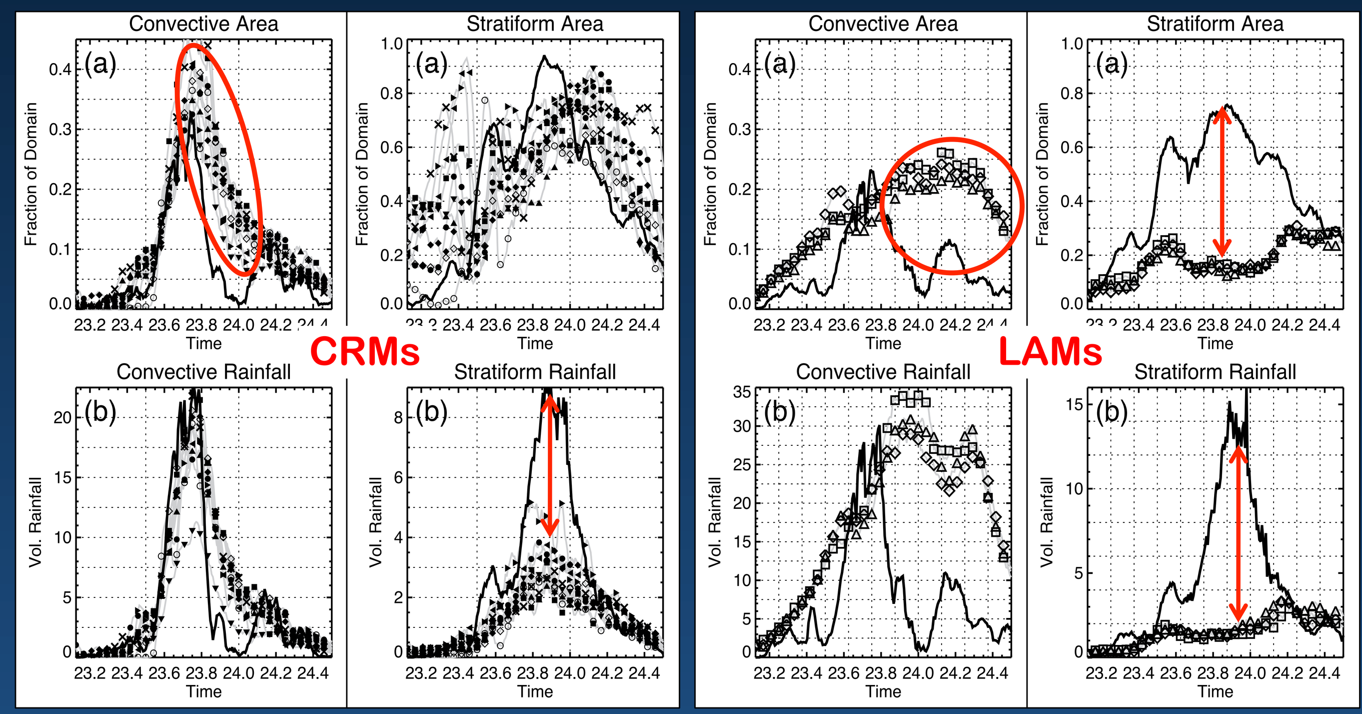
3 LAM simulations
- 1 model: WRF
- different microphysics: WSM6, Thompson, Morrison
- forced with ECMWF analysis
- 4 nested domains (outer 3 use analysis nudging)
- 450 km by 330 km domain including CPOL range
- 1 km horizontal resolution
- stretched ~100-300 m vertical resolution

CRMs vs. LAMs

- Black line is observations
- period from 3Z 1/23 to 12Z 1/24

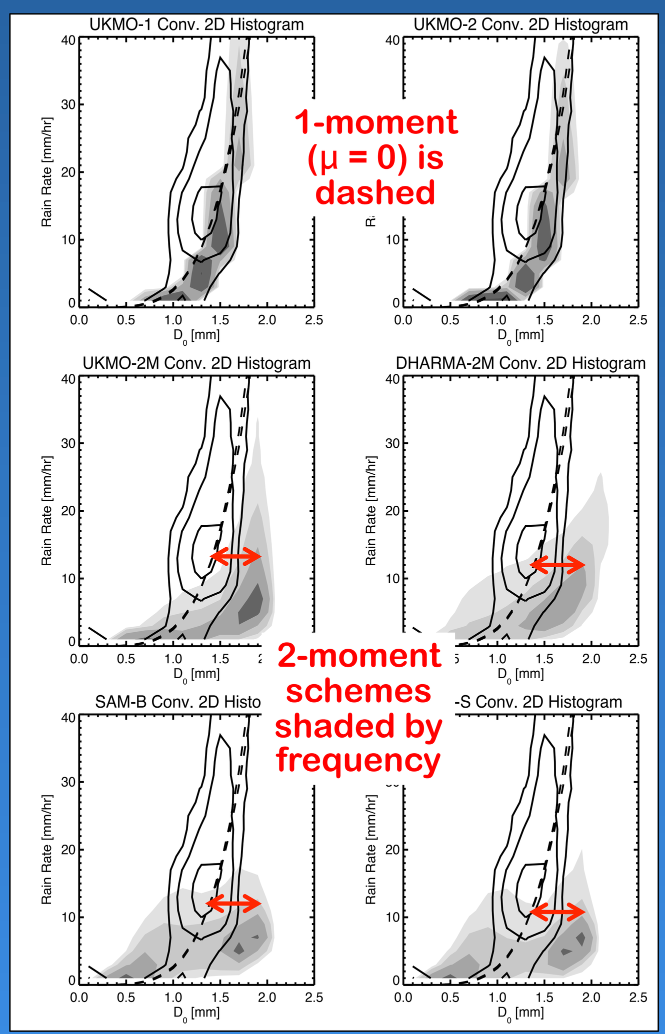
Similarities
- Convective area too high but rain rates agree well with observations
- Stratiform rainfall too low
- High biases in radar reflectivity aloft (not shown)
- Microphysics (rain, graupel, and snow) and updraft statistics

Differences
- Stratiform area is much higher in CRMs and Obs than in LAMs
- Stratiform rain rate is higher in LAMs
- Large-scale cyclonic flow in LAMs (open boundaries)

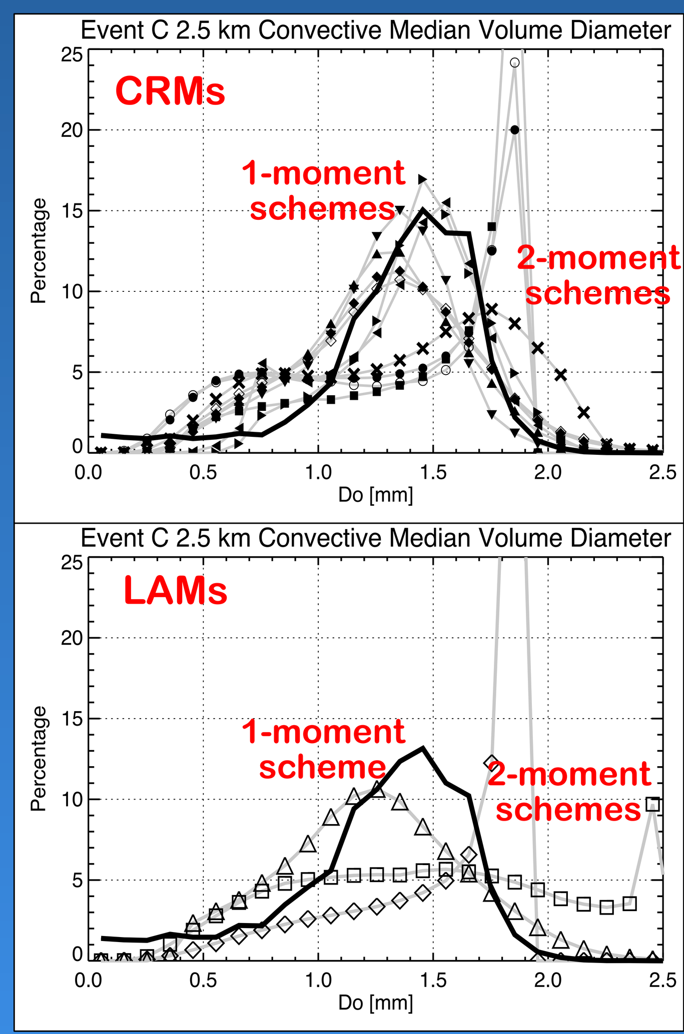


Comparison of the different microphysics schemes in the context of compared model output and observations leads us to the conclusion that many errors are due to poorly resolved turbulent entrainment and assumptions in hydrometeor properties, which we intend to test through sensitivity tests (4 of which are highlighted below) using the Morrison 2-moment bulk microphysics scheme (Morrison et al. 2009).

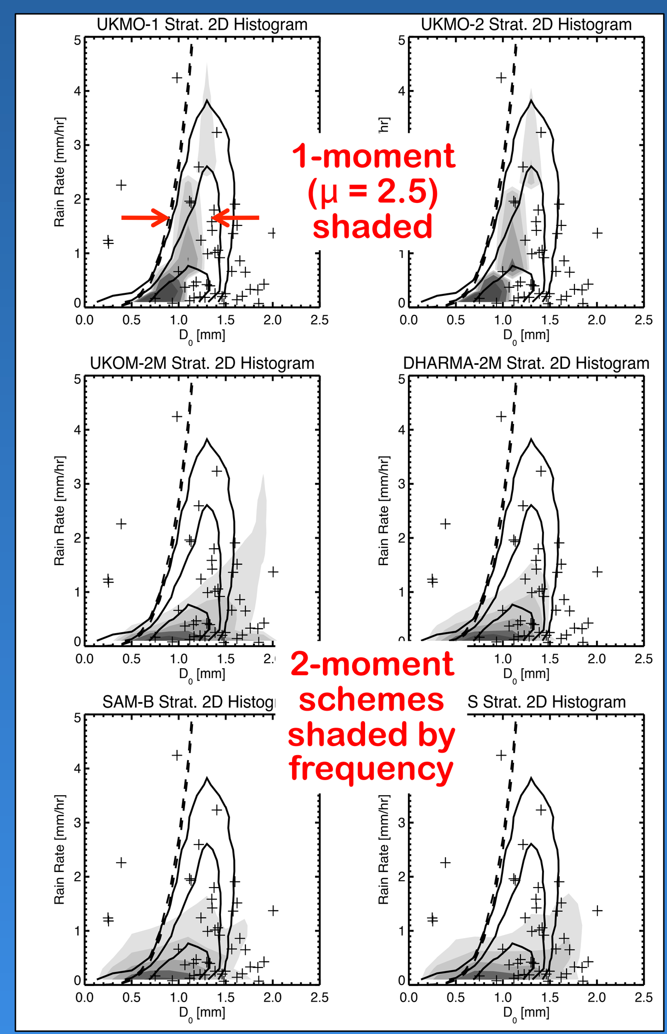
1. Convective Rain Drop Breakup



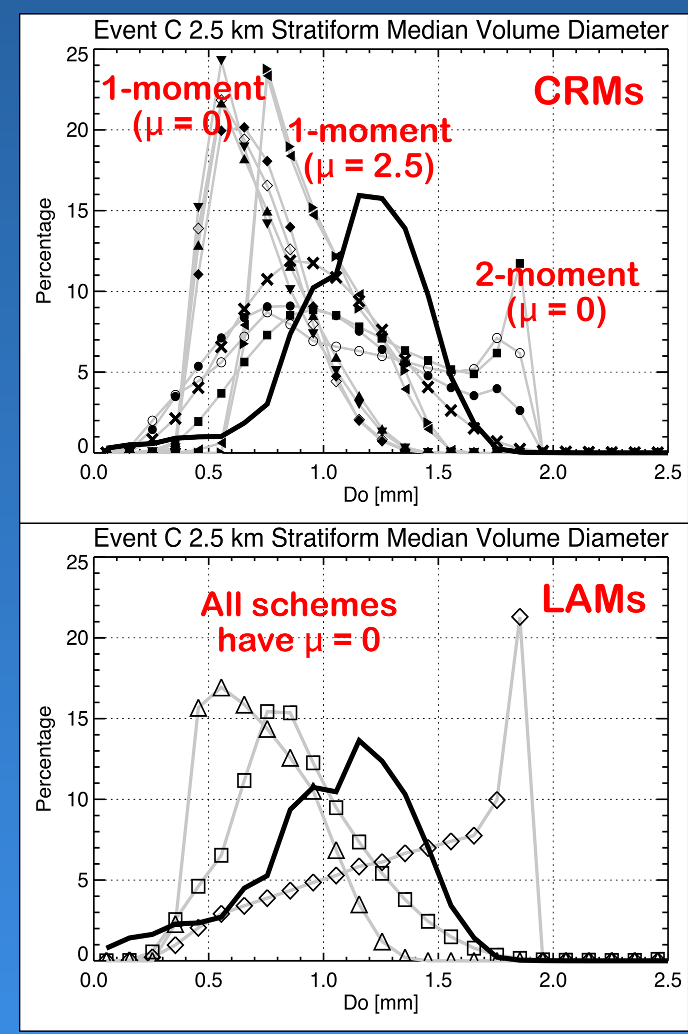
- Joint rain rate-D_0 histogram (left) and D_0 pdf (right) comparisons using radar-derived observations at 2.5 km (black contours/lines)
- 1-moment schemes emulate drop breakup with constant size intercept
- Rain drops in 2-moment schemes are too big for a given rain rate → Not enough drop breakup
- Strongly influences evaporation in convective downdrafts → cold pool properties → evolution of the precipitation system
- We will test different drop breakup parameterizations



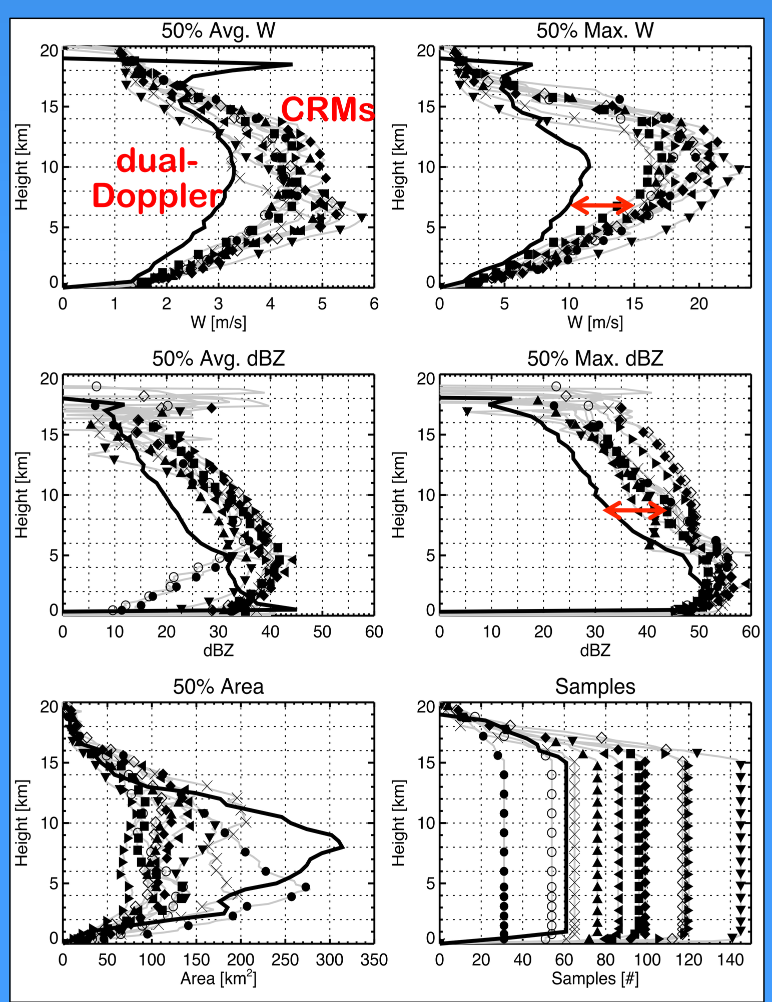
2. Stratiform Rain Size Distribution



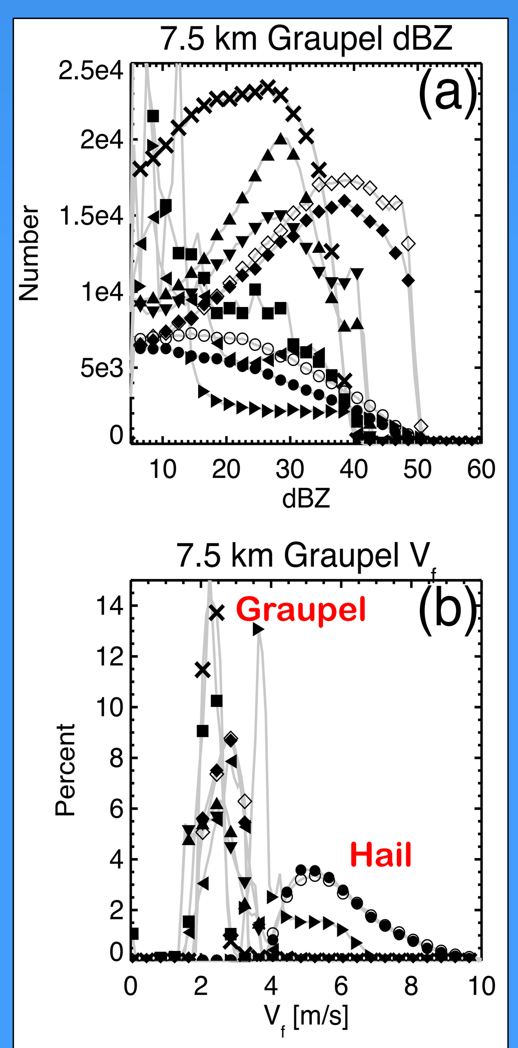
- Joint rain rate-D_0 histogram (left) and D_0 pdf (right) comparisons using radar-derived observations (black contours/lines) at 2.5 km
- Rain drops are far too small in 1-moment schemes due to a gamma size distribution shape parameter (μ) that is too small
- Increasing μ from 0 to 2.5 improves results
- 2-moment schemes are better but have too wide of a range of rain drop sizes
- This affects evaporation, LWC, and fall speeds → rain rates
- We will test diagnostic μ relationships that should improve results



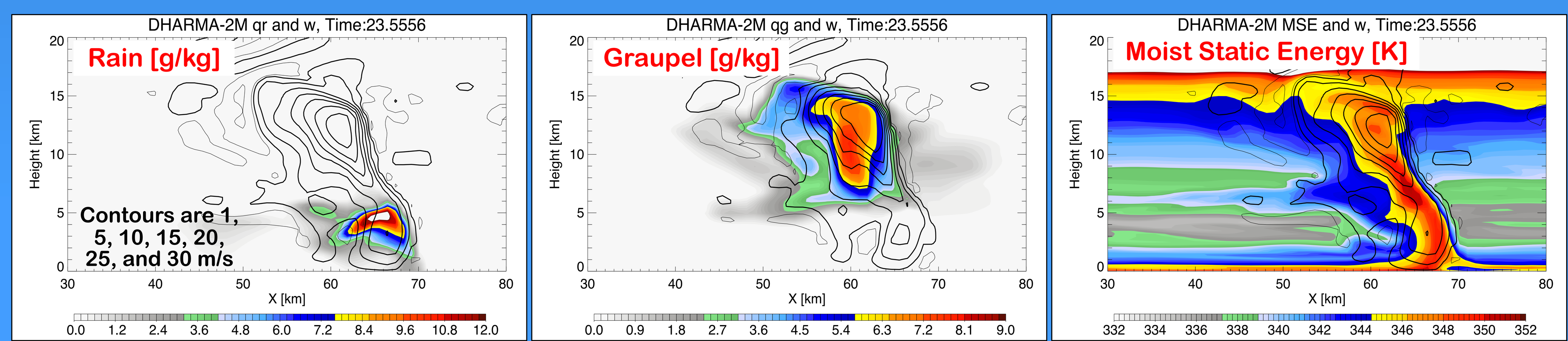
3. Rimed Ice Density and Fall Speed



- Comparison of deep updraft properties using dual-Doppler retrieval during peak of event (left)
- Models show stronger updraft speeds and higher radar reflectivity
- High bias in model dBZ primarily due to graupel (right (a))
  - Using hail instead of graupel slightly alleviates problem by lowering IWC aloft
- Graupel is lofted high and advected far because fall speeds are 2-4 m/s (right (b)) → too much identified convective area
- We will test sensitivity to rimed ice density and fall speeds



4. Resolved Turbulence (Horizontal Resolution)



- Example vertical cross-sections (above) show contoured vertical velocity (upward: thick black, downward: thin black) and filled properties
- Very high rain mixing ratios from collision-coalescence, much of which the updraft lifts and freezes, forming very high graupel mixing ratios
- MSE cross-section → very little dilution in updraft core at low/mid levels
- Updraft core CFAD of MSE shows little mixing with environment (right)
- We will test finer resolutions in an attempt to improve entrainment through better resolved turbulence