Development of a Scale-Aware Cumulus Parameterization – Part I: Evaluation of Model Simulations with Spectral-Bin Microphysics and Comparisons with Bulk Microphysics

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Introduction

- Cumulus parameterization developments/refinements rely heavily on the use of benchmark simulations by Cloud-Resolving Models (CRMs).
- Recent field measurements provide new opportunities to evaluate CRM simulations and to understand whether current CRMs can simulate observed clouds reasonably well.
- Perform extensive evaluations of the CRM simulations with available observations.

Model and experiment design

- WRF V3.3.1, grid spacing of 1 km.
- Three microphysics schemes:
  - **SBM**: Fast version of spectrum bin microphysics (Khain et al., 2010; Fan et al, 2012).
  - **MO-R**: modified Morrison scheme (Fan et al., 2012; Wang et al., 2013)
  - **MY:** standard Milbrandt-Yau microphysics scheme (Milbrandt and Yau, 2005a, b).

Case description

- Two mid-latitude continent cases (MC3E field experiments)
  - **MC3E-0523**: Mesoscale convective complex (MCC)
  - **MC3E-0520**: Squall line
- One tropical region case (TWP-ICE field experiment)
  - **TWPICE-0122**: MCC

Unique observational datasets

MC3E field experiment (2011)

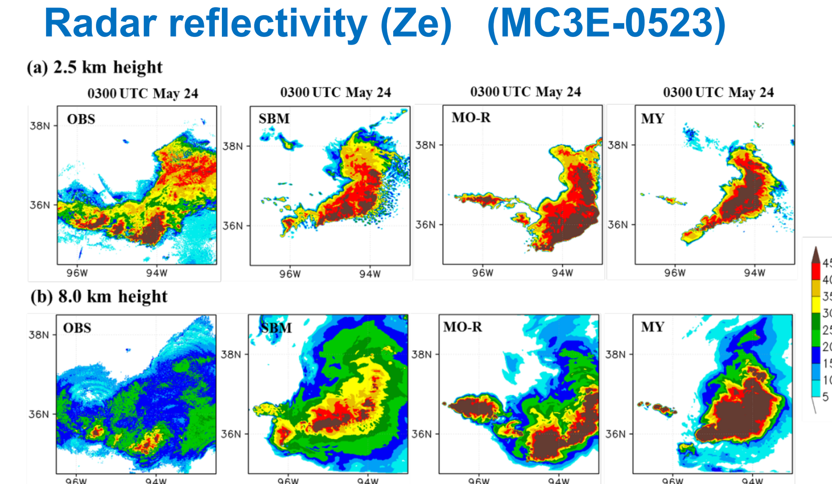
- Cloud microphysics properties from in-situ aircraft data
- 3D-dual-Doppler in-cloud wind field
- NEXRAD Radar reflectivity (Ze)
- Precipitation from Arkansas-Red Basin River forecast center

TWP-ICE field experiment (2006)

- 3D-dual-Doppler in-cloud wind field
- C-POL retrieved precipitation
- Ze from C-POL

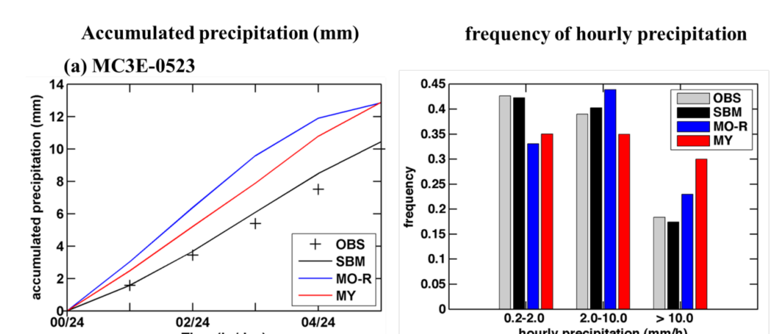
Model evaluation

Radar reflectivity (Ze) (MC3E-0523)



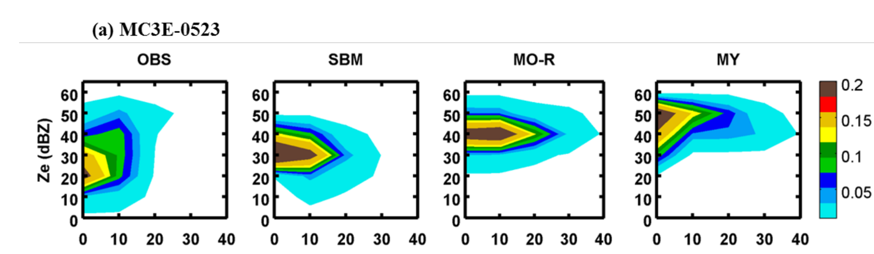
- SBM simulates the decrease of Z_e as observed, while in MO-R and MY, Z_e at 8 km altitude is even higher at the convective cores compared with that at 2.5 km.

Precipitation (MC3E-0523)



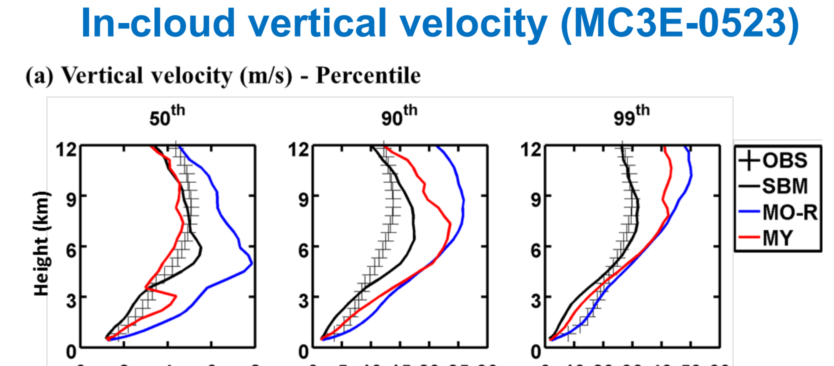
- SBM gives the best surface precipitation simulation in both accumulated precipitation and rain rate occurrence frequency.

Ze & in-cloud vertical velocity (MC3E-0523)



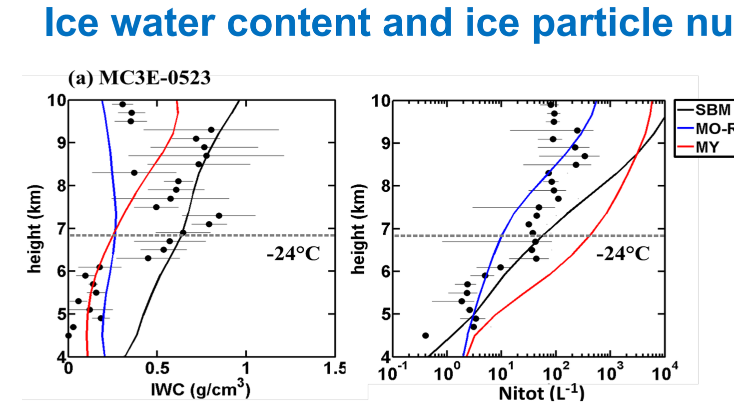
- SBM predicts the magnitudes of Z_e and w reasonably well, while both MO-R and MY predict much larger values.

In-cloud vertical velocity (MC3E-0523)



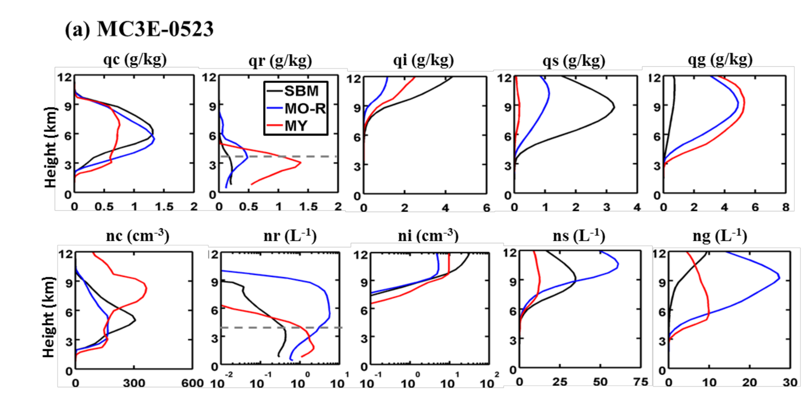
- SBM predicts w at all three percentiles reasonably well.
- Both MO-R and MY predict much stronger w than observations.

Ice water content and ice particle number concentrations



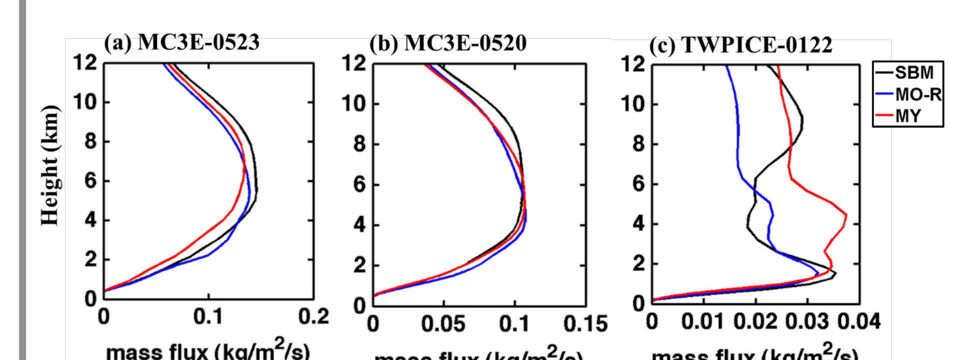
- For IWC in the ice-phase clouds, SBM agrees with observations well, while the two bulk schemes dramatically underestimate *it*.
- MO-R predicts better N_{itot}, and SBM and MY overestimate it

Cloud microphysical properties in convective cores



- SBM simulates smaller graupel mixing ratio (q_g) than the two bulk schemes.
- MY predicts much larger q_g but less or comparable N_g than SBM, suggesting larges sizes of graupel.
- Graupel can contribute to the large overestimation of *w* by
  (1) inducing stronger air motion
  (2) producing stronger cold pools.

Mass flux



- Mass fluxes are similar for the two mid-latitude convection cases, but largely different for the tropical convection case.
- For mid-latitude convection: controlled by large-scale forcing, cloud microphysics do not have a strong influence on the mass fluxes. For the tropical convection: local convection organizes into a large convective system.

CONCLUSIONS

- SBM gives better simulations than the two bulk schemes, and therefore will be used for analysis of scale-dependency of eddy transport in Part II.
- The common features of the simulations for all convective systems are
  (1) the model tends to overestimate convection intensity in the middle and upper troposphere, but SBM can alleviate much of the overestimation and reproduce the observed convection intensity well;
  (2) the model greatly overestimates radar reflectivity in convective cores;
  (3) the model performs better for mid-latitude convective systems than tropical system.
- The modeled mass fluxes of the mid-latitude systems are not sensitive to microphysics schemes, but are very sensitive for the tropical case.
- Cloud microphysical measurements of rain, snow and graupel in convective cores will be critically important to further elucidate issues within cloud microphysics schemes.

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