Comprehensive Evaluations of Mesoscale Convective Systems Simulated in Convection-permitting WRF Model during the MC3E Field Experiment

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Abstract

Mesoscale convective systems (MCSs) are an important component of our hydrologic cycle as they produce prolific rainfall in the tropics and mid-latitudes. Recent advancements in high-resolution modeling show promise in representing MCSs in regional climate simulations. However, how well do these models represent the complex interactions between convective dynamics and microphysics in MCSs remain unknown. In this study, we take advantage of observations collected during the Midlatitude Continental Convective Cloud (MC3E) experiment to evaluate multi-scale aspects of MCSs in convection-permitting WRF model. We conducted three sets of month-long simulations with Morrison and P3 (1-ice and 2-ice categories) microphysics, respectively, at 1.8 km grid-spacing over the Southern Great Plains. MCSs in observations and simulations were tracked using a newly developed FLEXTRKR algorithm. About 15-20 MCSs were identified in the simulations, consistent with observations. All three simulations underestimate observed monthly total precipitation which are primarily from MCSs, suggesting the biases might be caused by large-scale forcings rather than microphysics. All simulated MCSs overestimate convective area and precipitation amount but underestimate stratiform rain area and precipitation. Simulated MCS convective updraft intensities are comparable with radar retrievals for moderate depths of convective cores, but are too strong for deep cores. The two P3 simulations have smaller mean ice mass aloft but more frequent heavy convective rain rate at the surface than the simulation with Morrison, agreeing better with observations (Figure 1). Simulated stratiform area ice mass in the upper troposphere are generally larger than radar retrievals, but the P3 2-ice category has relatively smaller bias. We will also use polarimetric radar 3-D rain water retrieval to further evaluate the vertical evolution of rainfall to explain differences in simulated surface precipitation.

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Poster A23L-3044

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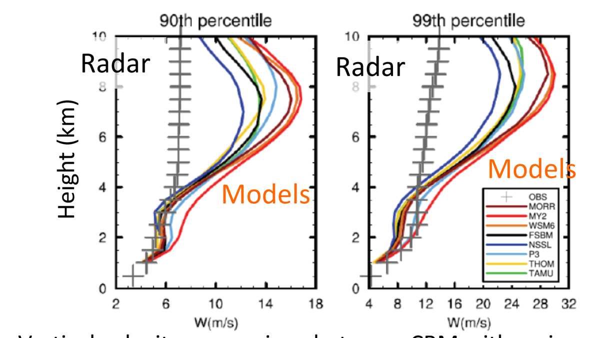
Background and Objective

- Mesoscale convective systems (MCSs) are an important component of our hydrologic cycle
- Recent studies show large errors in convection-permitting model (CPM) simulations of convective updrafts and stratiform precipitation associated with MCSs
- We use comprehensive observations collected during the Midlatitude Continental Convective Cloud (MC3E) experiment to evaluate multi-scale aspects of MCSs in CPM and sensitivity to microphysics parameterizations (MP), especially the new P3 MP with predicted ice particle evolution parameterizations

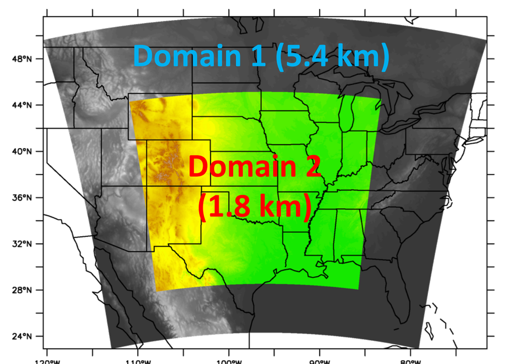


Vertical velocity comparison between CRM with various microphysics schemes and multi-Doppler retrieval for May 20, 2011 MC3E event (from Fan et al., 2017)

Model Setup and Observation Products

1. Model setup

Grid Spacing	**1.8 km** (5.4 km)
Period	**May 1-31**, 2011
Lateral forcing	GFS final analysis
Microphysics (MP)	**Morrison, P3 1-ice, P3 2-ice**
PBL/Surface	MYJ/Monin-Obukhov (Janjic)
Land surface model	Noah

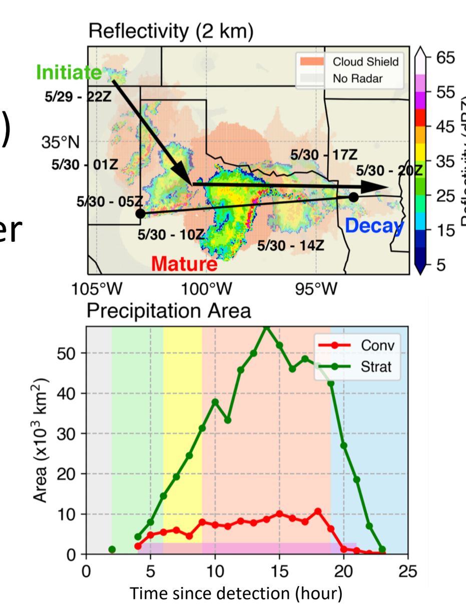


2. Observational Products

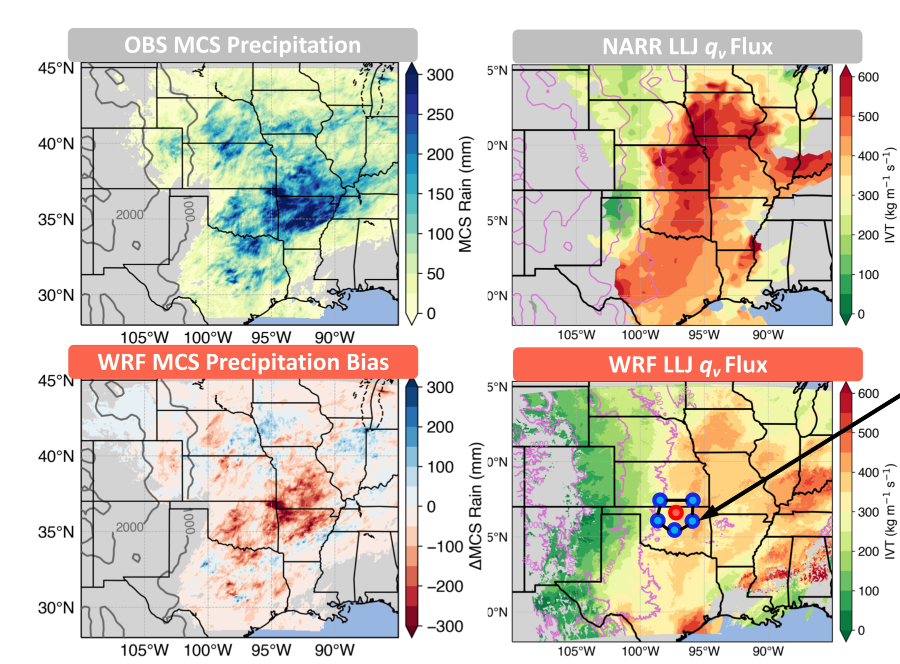
- **Operational**: GOES satellite, NEXRAD 3-D mosaic radar, NSSL Q2 precipitation
  - NEXRAD-based 3-D IWC retrieval (Tian et al. 2016)
- **ARM observations**
  - Radar Wind Profiler (RWP): vertical velocity (Giangrande et al. 2016)
  - Disdrometer: rain DSD, forward radar scattering (PyDSD)
  - Polarimetric radars (X-SAPRs): 3-D rain-rate, raindrop mean diameter
  - Sounding: LLJ analysis (Berg et al. 2015)

3. MCS Tracking

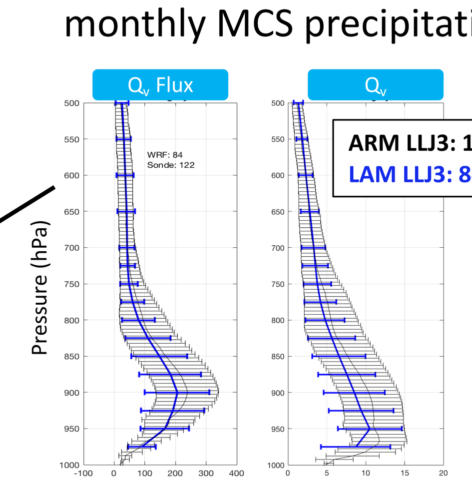
- **Use FLEXTRKR** (Feng et al. 2018) **for MCS tracking**
  - Robust MCS definition: lifetime > 6 h, Precipitation Feature major axis length > 100 km, contains 50+ dBZ convective echoes



MCS Precipitation and LLJ Moisture Transport



- Simulated 15-18 MCSs; major events agree with observations
- All 3 simulations consistently underestimate monthly MCS precipitation



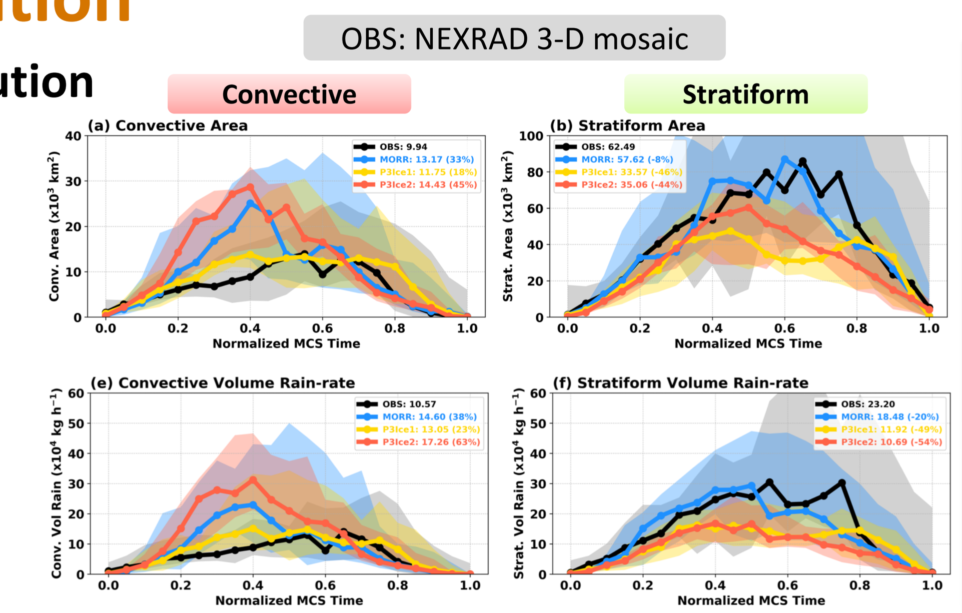
Biases come from reanalysis boundary conditions, not microphysics.

- LLJ moisture transport is underestimated over SGP, due to less frequent stronger LLJ and dry bias in precipitable water within Low-level Jet (LLJ).

MCS Characteristics Evaluation

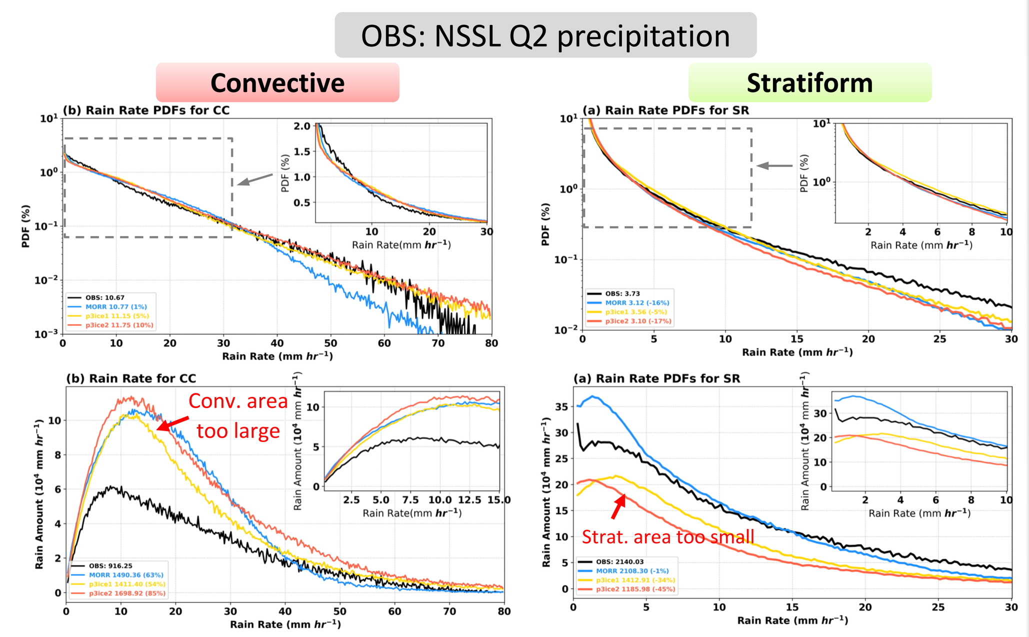
1. MCS convective/stratiform area evolution

- All MP overestimate convective area and rain volume, and underestimate stratiform area and rain volume
- P3 2-ice has larger bias than P3 1-ice and Morrison (Morr)
- Results are insensitive to minimum stratiform rain rate thresholds used (0.2 vs. 1 mm/h)



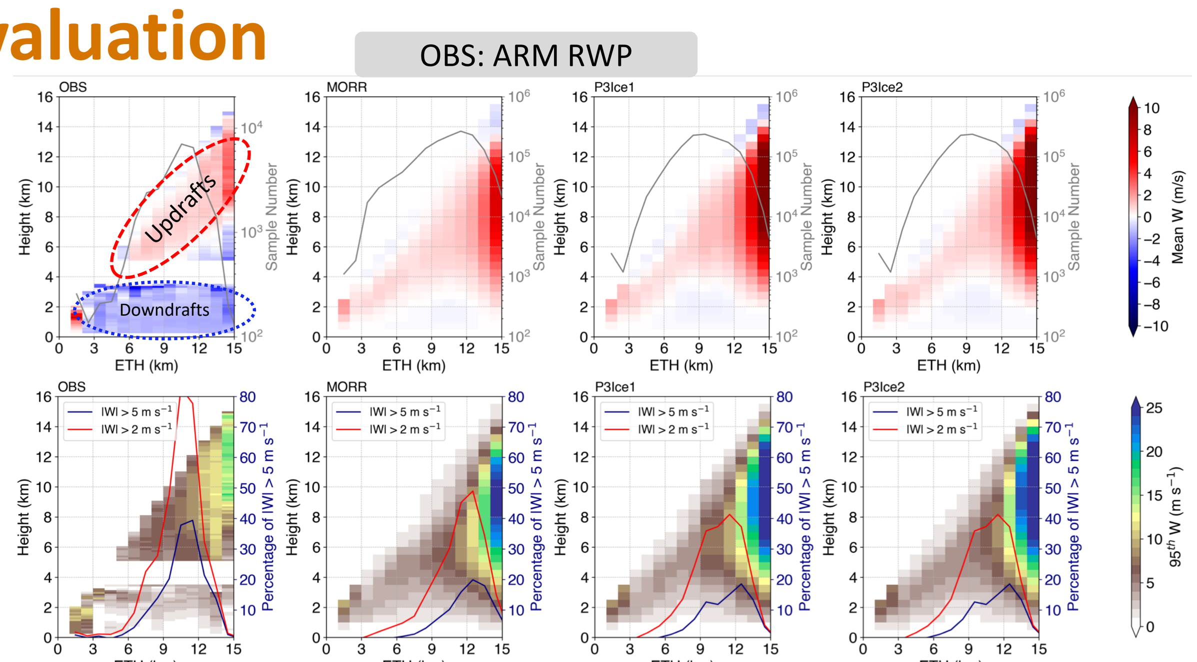
2. MCS convective/stratiform rain intensity

- P3 has more frequent intense convective rain rate, agreeing better with observations
- Too much convective rain-rate between 5–40 mm/h contributes to much of the rain amount bias
- Not enough stratiform rain-rate between 1–10 mm/h

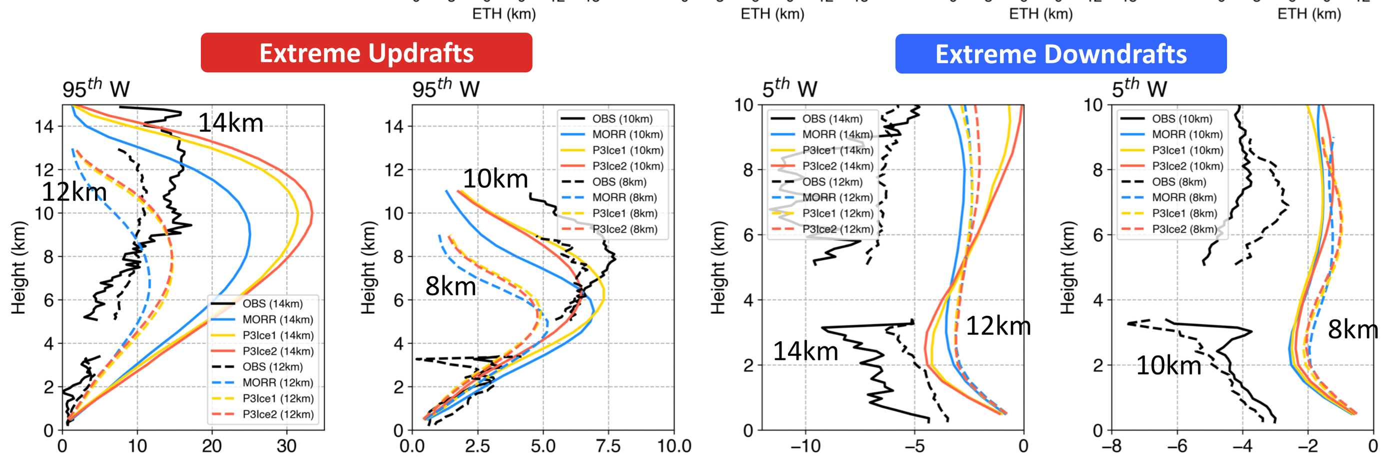


MCS Kinematics Evaluation

- All MP overestimate updraft intensity in extreme deep cores (ETH > 12 km)
- Moderate-depth cores are more comparable to OBS
- Downdraft frequencies and intensities are underestimated, P3 has smaller biases in deep cores



Extreme W profiles for selected ETHs



- P3 extreme updraft magnitude biases are larger than Morr, but the peak altitude compares better with OBS
- More intense updrafts have been linked to larger latent heating and stronger cold pools from ice phase microphysics differences (Fan et al. 2017), and is responsible for overestimating convective precipitation area and amount

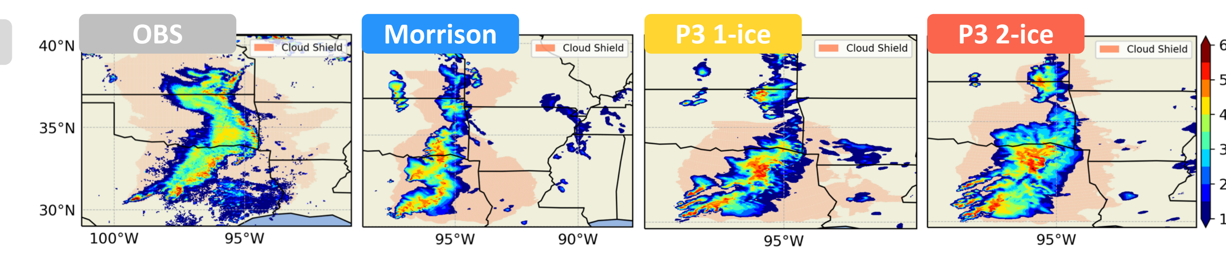
Summary

- We conducted a comprehensive evaluation of WRF simulated MCS characteristics, particularly P3 vs. Morrison microphysics (MP) during MC3E is.
- Overall, MCS total precipitation is underestimated due to low bias in moisture transport associated with LLJ from the boundary conditions.
- All MP overestimate convective intensity and rain rate in deepest cores, while downdraft intensities are underestimated. The updraft intensity bias may be related to model grid spacing not fine enough to resolve entrainment mixing.
- A case study shows all MP underestimate large IWC right above melting level in the stratiform area, particularly P3 2-ice. Due to small vertical variation in the liquid region, biases in IWC aloft result in underestimation of rain water content at the surface.
- Correctly simulating MCS precipitation hinges upon representation of the interactions between dynamics and MP, which remains a challenge with current MP parameterizations

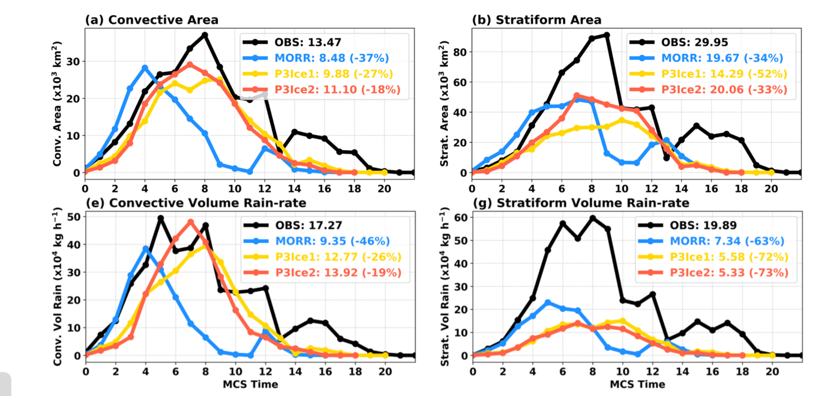
MCS Case Study: Stratiform Microphysics

OBS: NEXRAD mosaic

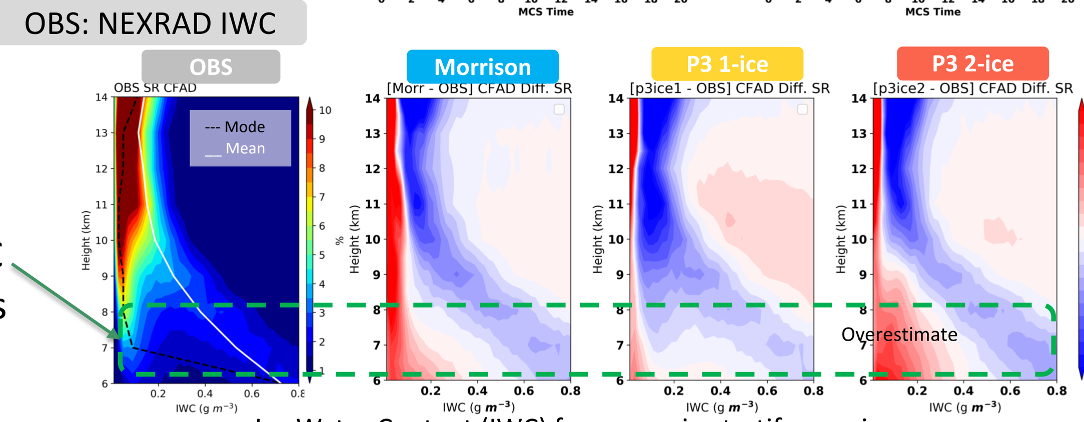
Snapshot of MCS radar reflectivity



- Simulated MCS on May 11 evolves similarly to OBS
- P3 convective area and precipitation amount are closer to OBS
- All MP underestimate stratiform rain area and precipitation amount significantly

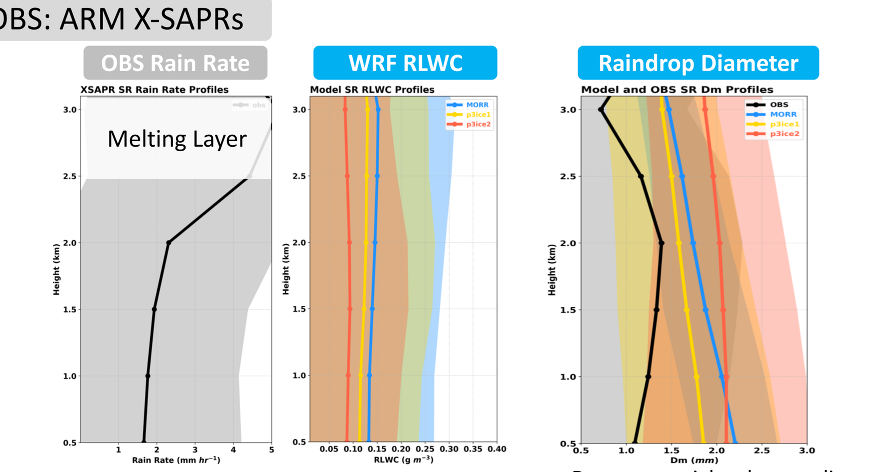


- **Upper ice region:** P3s have more positive bias in high IWC than MORR
- **Lower ice region:** all MP underestimate large IWC (> 0.6 g m^{-3}), P3 2-ice has too much small IWC



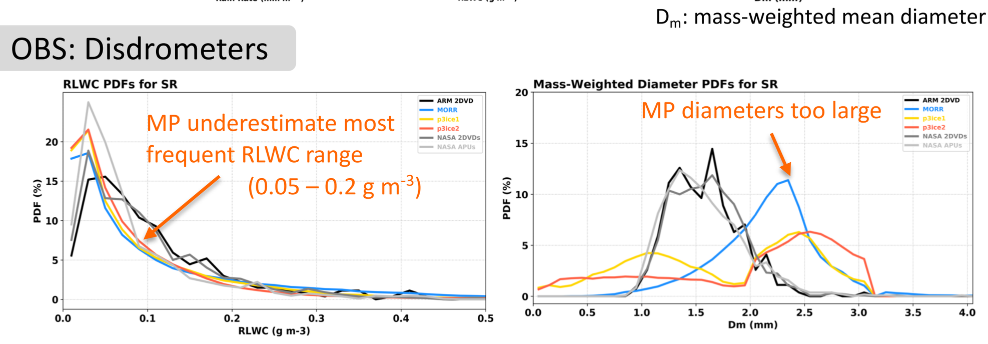
Ice Water Content (IWC) frequency in stratiform rain area

- **Liquid region:** rain liquid water content (RLWC) has small vertical variation in both OBS and model, suggesting weak evaporation. P3 2-ice has smallest RLWC among all MP, consistent with the IWC bias. Model raindrop D_m increase toward surface, opposite to OBS, indicating excessive size sorting in model.



D_m: mass-weighted mean diameter

- **Surface:** all MP underestimate RLWC, yet drop diameters are too large



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