Improve and evaluate model parameterizations using ARM and NEXRAD

Jiwen Fan

Contributions: listed on relevant slides

2019 ARM/ASR meeting

CMDV

Mesoscale Convective Systems

Pacific Northwest NATIONAL LABORATORY

1. Improve and evaluate parameterizations in E3SM

2. Evaluate parameterizations in WRF (CPM and CRM scales)

Improve Hydrometeor Vertical Overlap in Subcolumns of GCM

Mikhail Ovchinnikov, Scott Giangrande, et al.

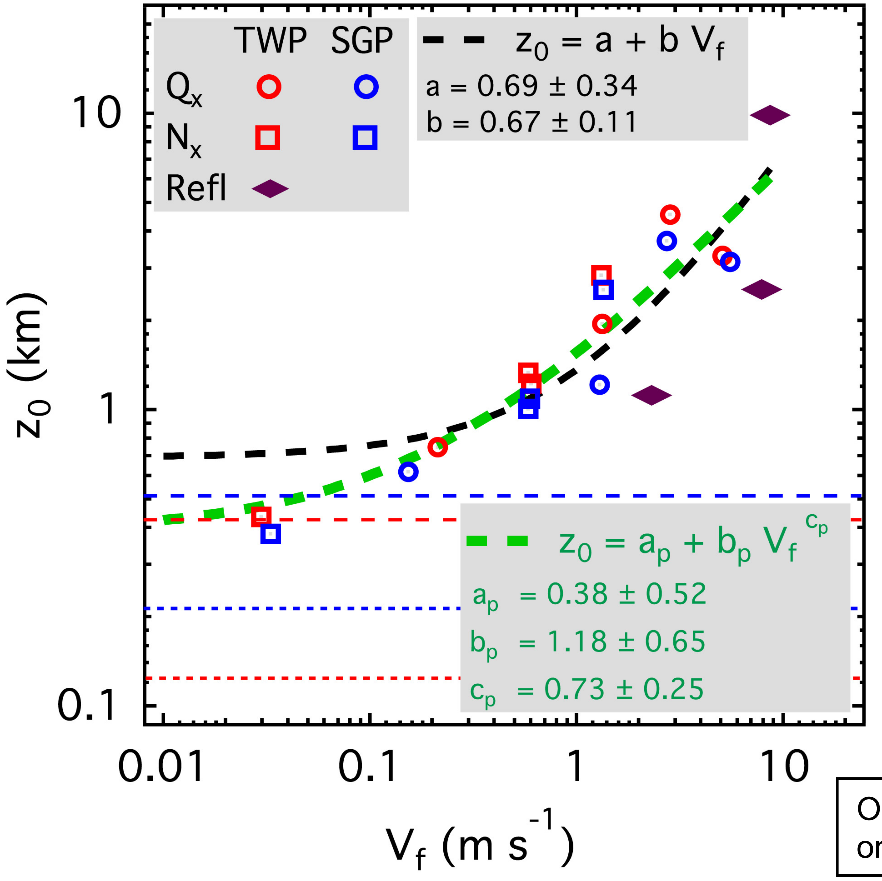
Mesoscale Convective Systems

Objective

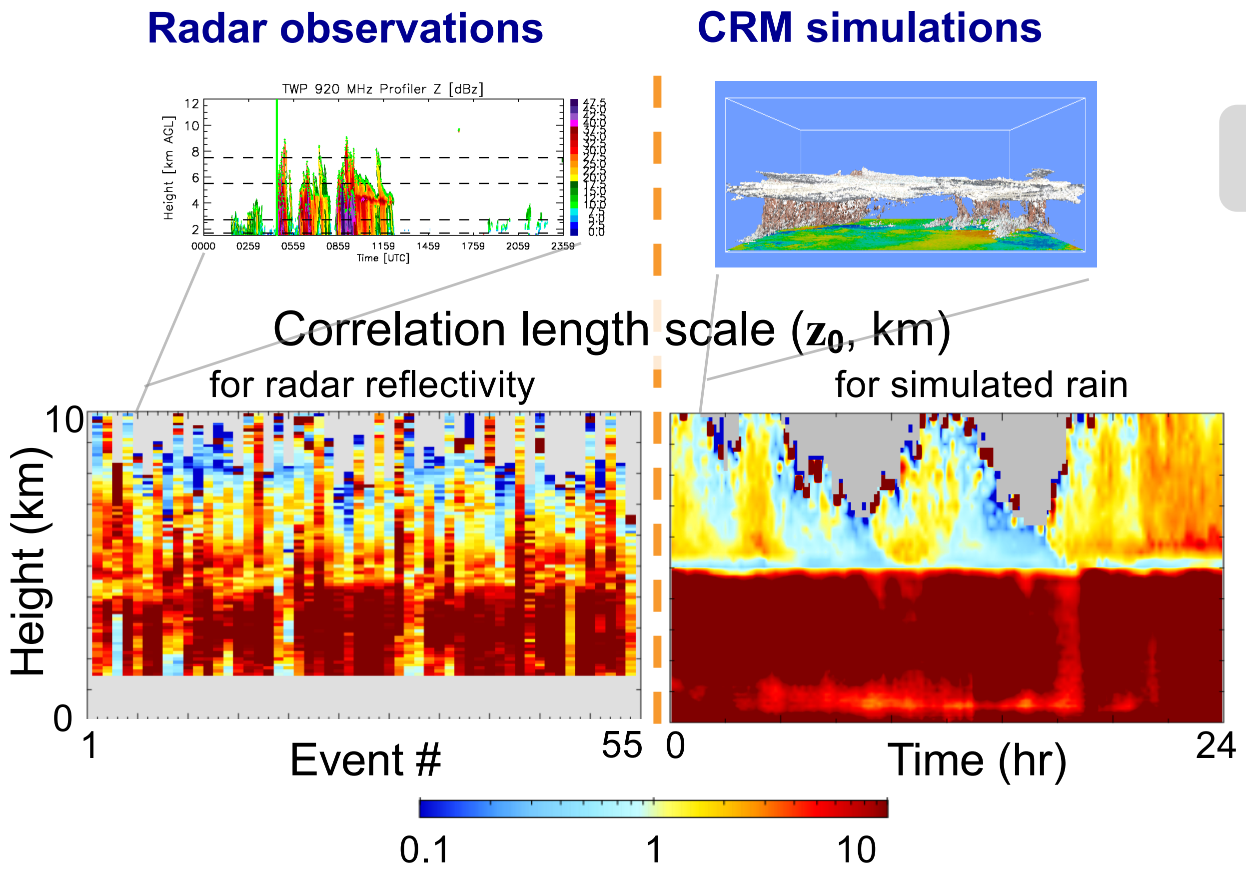
- Improve representation of unresolved cloud and precipitation structure in E3SM

Approach

- Quantify vertical alignment (correlation) of cloud properties using ARM observations and cloud-resolving model (CRM) simulations of observationally driven cases (ARM97, TWP-ICE, MC3E)



OBS: RWP



Impact

- Vertical correlation is a strong function of mean fall speed (V_f) of cloud and precipitation properties
- Wind shear reduced alignment of slow-falling hydrometeor species but had limited effect on faster-precipitating hydrometeor categories
- These findings provide basis for a consistent treatment of cloud and precipitation overlap in radiation, microphysics, and instrument simulators

Ovchinnikov M, S Giangrande, VE Larson, A Protat, and CR Williams. 2019. “Dependence of Vertical Alignment of Cloud and Precipitation Properties on Their Effective Fall Speeds.” *Journal of Geophysical Research: Atmospheres* 124(4):2079–2093, https://doi.org/10.1029/2018JD029346.

Evaluation of Modeled INP Concentration

Xiaohong Liu, Yang Shi, et al.

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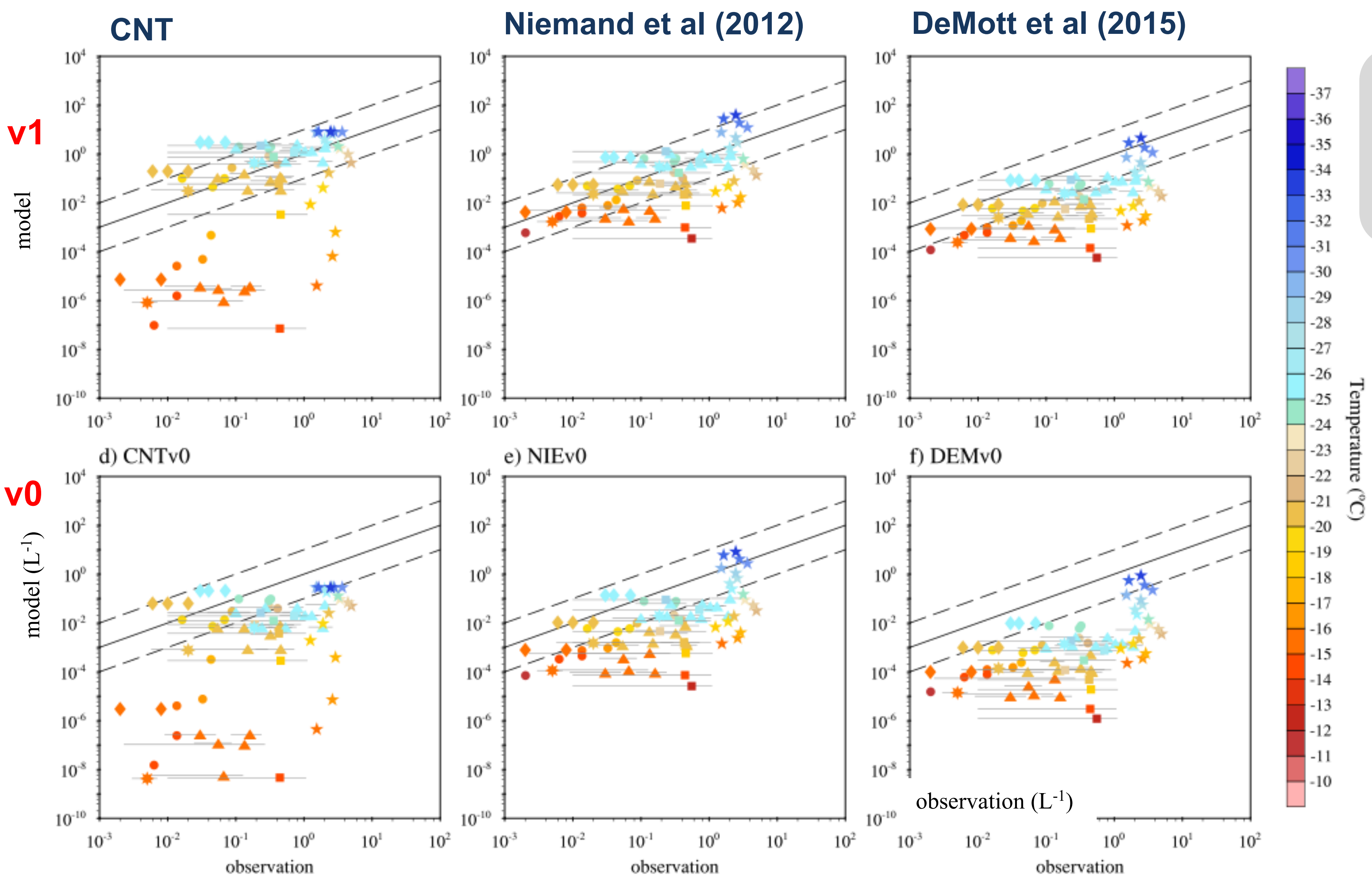

■ Barrow (Oct 2004) Prenni et al. (2007)

★ Barrow (Apr 2008) McFarquhar et al. (2011)

▲ Alert (Mar-Jun 2014) Mason et al. (2016)

✱ Alert (Mar 2016)

● Zeppelin (Jul 2016)

◆ Oliktok Point (Mar-May 2017)

OBS: ARM aircraft and surface-based data

- E3SM v1 better simulates INP concentration than v0 at the Arctic because of more dust transported to the Arctic.
- DeMott et al. (2015) performs the best (1 order of magnitude underestimation matches the 1 order of magnitude low bias of dust concentrations).

Shi, Y., and Liu, X. (2019): "Dust radiative effects on climate by glaciating mixed-phase clouds". Geophysical Research Letters, doi: 10.1029/2019GL082504, In press

Evaluate E3SM RRM ¼ and 1/8 Degree Simulations

Jingyu Wang, Jiwen Fan, et al.

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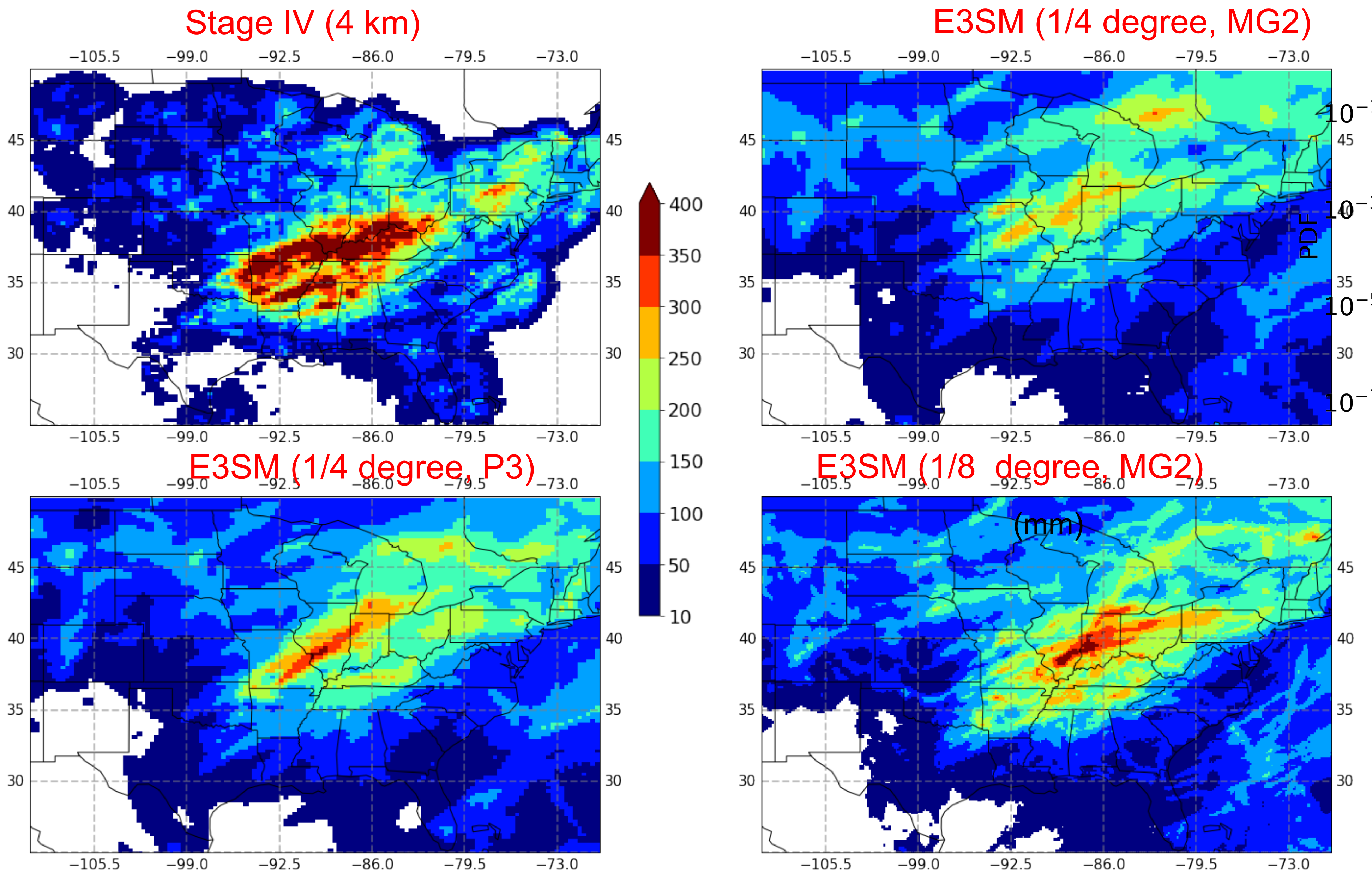
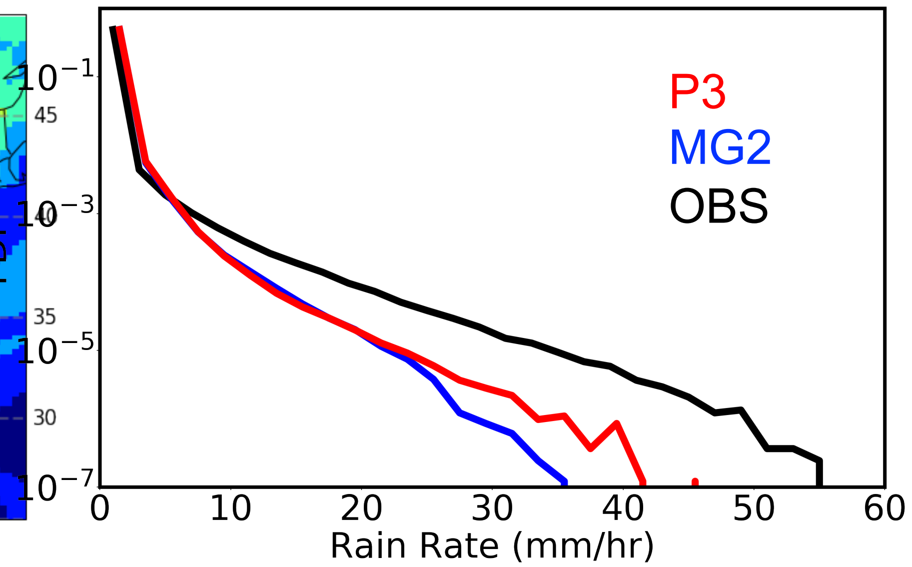
Accumulated Precipitation



Rain rate PDF at ¼ degree



Compare with ARM data at 1/8 deg (e.g., heating and microphysics)

2011 April

1. Improve and evaluate parameterizations in E3SM

2. Evaluate parameterizations in WRF (CPM and CRM scale)

Improve Rain Microphysics Parameterization

Marco Paukert, Jiwen Fan, et al.

Mesoscale Convective Systems (CMDV)

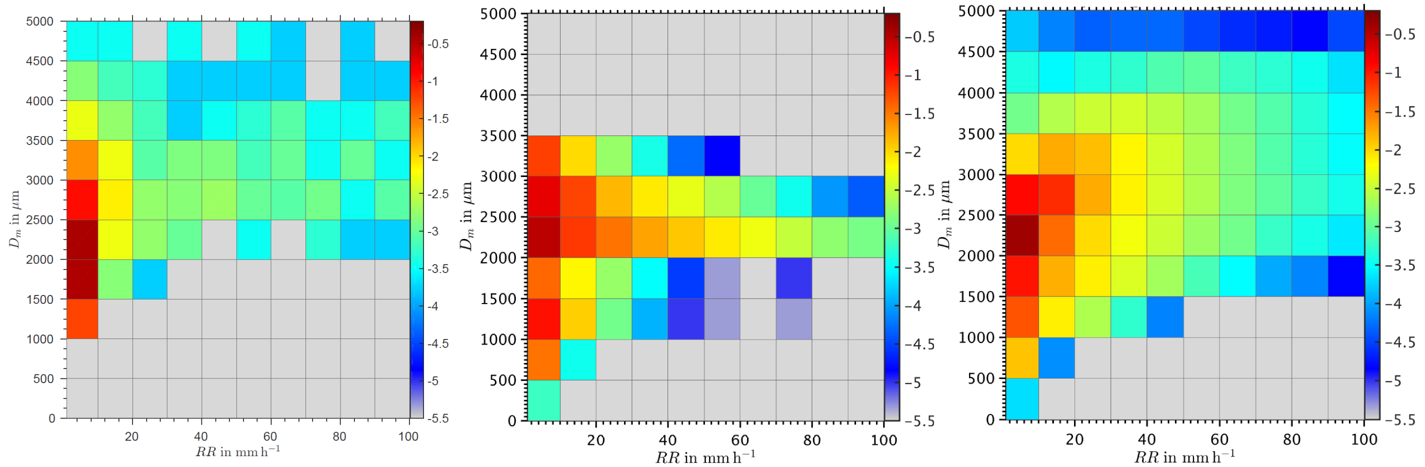
Objective

- Develop 3-moment cloud microphysics parameterizations for E3SM with a purpose of improving simulations of properties associated with convective system in E3SM.

Approach

- Based on the original 2-moment P3 microphysics, add additional moment to represent rain size distribution shape and develop a new parameterization for raindrop collision and breakup processes based on explicit physics.

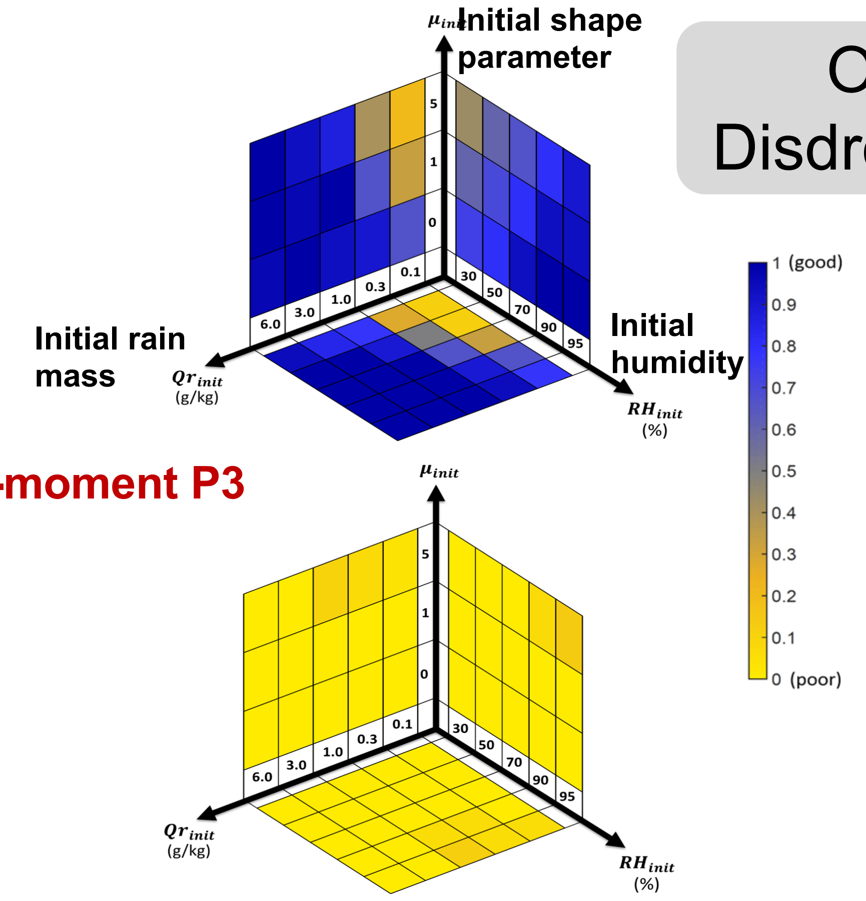
Disdrometer **2-moment P3** **P3 with 3-moment rain**



Plots show that the observed variability of mean drop sizes **from May 20 MC3E** is much better simulated with the new 3-moment scheme. Colors show the log10 of the occurrence frequency.

P3 with 3-moment rain

OBS: Disdrometers



Under a wide range of atmospheric conditions, the new 3-moment scheme showed a considerable improvement: up to 95% of simulations produced rain properties with biases within ±20% of the reference results, whereas only 4% with the original two-moment scheme.

Paukert M, J Fan, PJ Rasch, H Morrison, JA Milbrandt, J Shpund, and A Khain. 2019. "Three-Moment Representation of Rain in a Bulk Microphysics Model." *Journal of Advances in Modeling Earth Systems* 11(1):257–277, https://doi.org/10.1029/2018MS001512.

Evaluation of Simulated MCS Kinematic Structures: Updraft Size-Intensity Comparisons at Different Model Scales

Die Wang, Scott Giangrande, et al.

Objective

To inform on Mesoscale Convective System (MCS) individual draft properties using unique U.S. DOE ARM radar wind profiler (RWP) datasets and how well higher-resolution models capture draft characteristics.

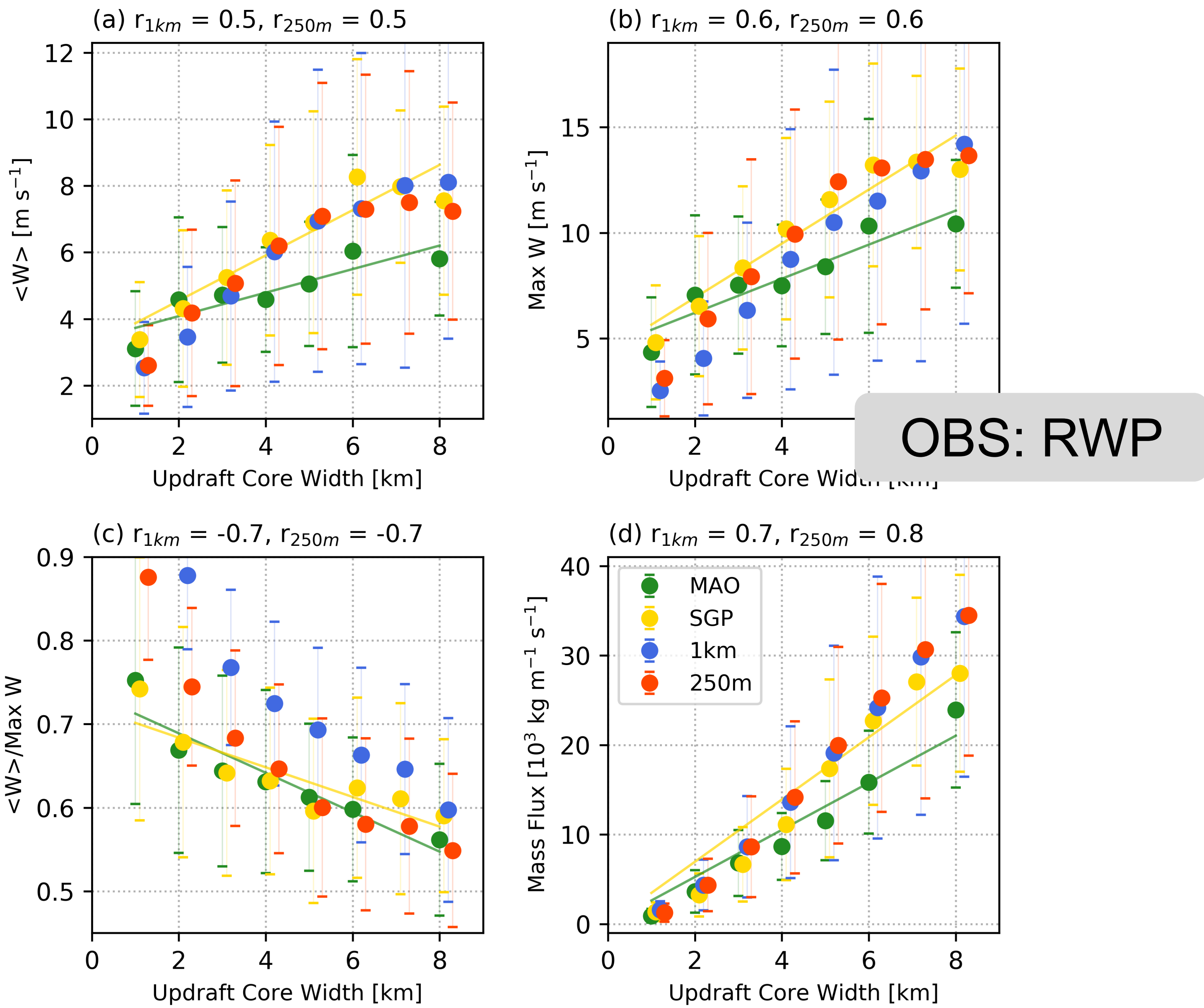
Approach

We explore the up- and downdraft properties of mature stage MCSs in terms of **draft core width, shape, intensity, and mass flux** characteristics using RWP and surveillance radar for midlatitude (Oklahoma, USA) and tropical (Amazon, Brazil) examples. We also perform comparisons of these properties with idealized WRF simulations at different model grid spacings (4 km to 250 m).

Impact

- Mature Oklahoma MCSs exhibit more intense, larger convective drafts than Amazon systems.
- Draft intensity is positively correlated with core width, and increases with altitude.
- Higher model resolution simulations (dx < 1 km) better capture observed draft intensity, width, shape, and mass flux.

Idealized *WRF simulations vs. ARM SGP and Amazon updraft characteristics.*



Wang D., S. E. Giangrande, Z. Feng, J. C. Hardin, A. F. Prein, Updraft and downdraft core size and intensity as revealed by radar wind profilers: MCS observations and idealized model comparisons. J. of Geophysical Research: Atmospheres, **Under review**.

Factors Contributing to Simulated Biases and Variability in a squall line MCS

Bin Han, Jiwen Fan, et al.

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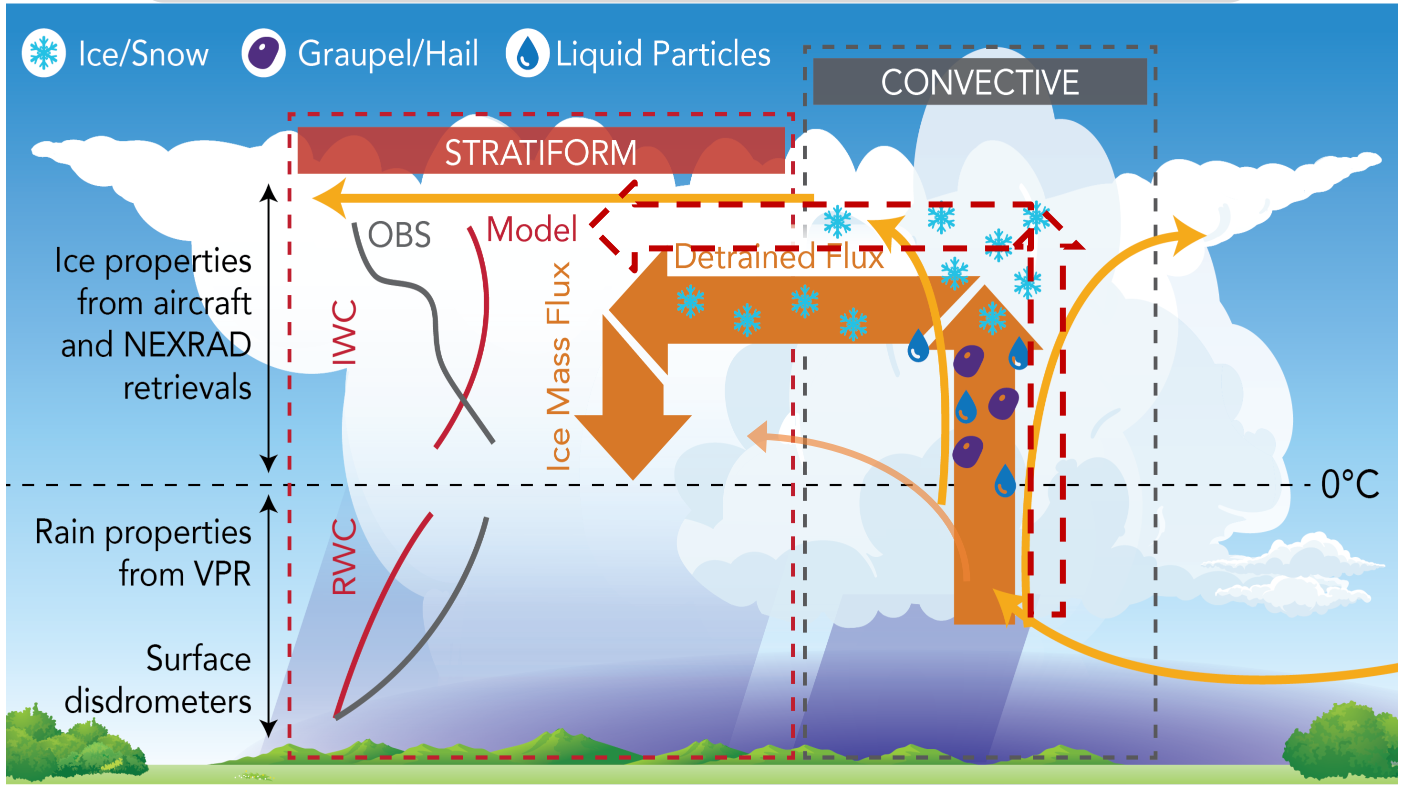
Objective

- Examine model biases and variability for various cloud microphysics schemes, and identify major factors and processes leading to those differences.

Approach

- Use high-resolution (1-kilometer) model simulations of a well-observed squall line mesoscale convective system from the MC3E field campaign with eight microphysics schemes
- Systematically evaluate simulated convective and stratiform properties with radar and in situ aircraft measurements, focusing on vertical evolution

OBS: 3-D multi-Doppler, in-situ aircraft, RWP, DSD, soundings, NEXRAD retrievals



Biases

- Simulations overestimate convective intensity and underestimate stratiform precipitation and area.
- Simulations overestimated ice water content (IWC) at high levels but produced a decreasing trend approaching the melting level, opposite of aircraft observations. This led to a underestimation of rain water content.

Variability

- The spread in updraft velocity correlates well with spreads in cool pool and buoyancy magnitudes that are mainly attributed to ice microphysics. Convective-detrained condensate properties significantly controlled stratiform precipitation and area.

Fan J., Bin Han, Adam Varble, Hugh Morrison, et al. (2017). Cloud-resolving model intercomparison of an MC3E squall line case: Part I—Convective updrafts, J. Geophys. Res. Atmos., 122, 9351–9378, doi:10.1002/2017JD026622. http://onlinelibrary.wiley.com/doi/10.1002/2017JD026622/full.

Han B, J Fan, A Varble, H Morrison, CR Williams, B Chen, X Dong, SE Giangrande, A Khain, E Mansell, JA Milbrandt, J Shpund, and G Thompson. 2019. "Cloud-Resolving Model Intercomparison of an MC3E Squall Line Case: Part II. Stratiform Precipitation Properties." *Journal of Geophysical Research: Atmospheres* 124(2):1090–1117, https://doi.org/10.1029/2018JD029596.

Evaluation of month-long LAM simulations with different microphysics in MCS properties

Jingjing Tian, Zhe Feng, et al.

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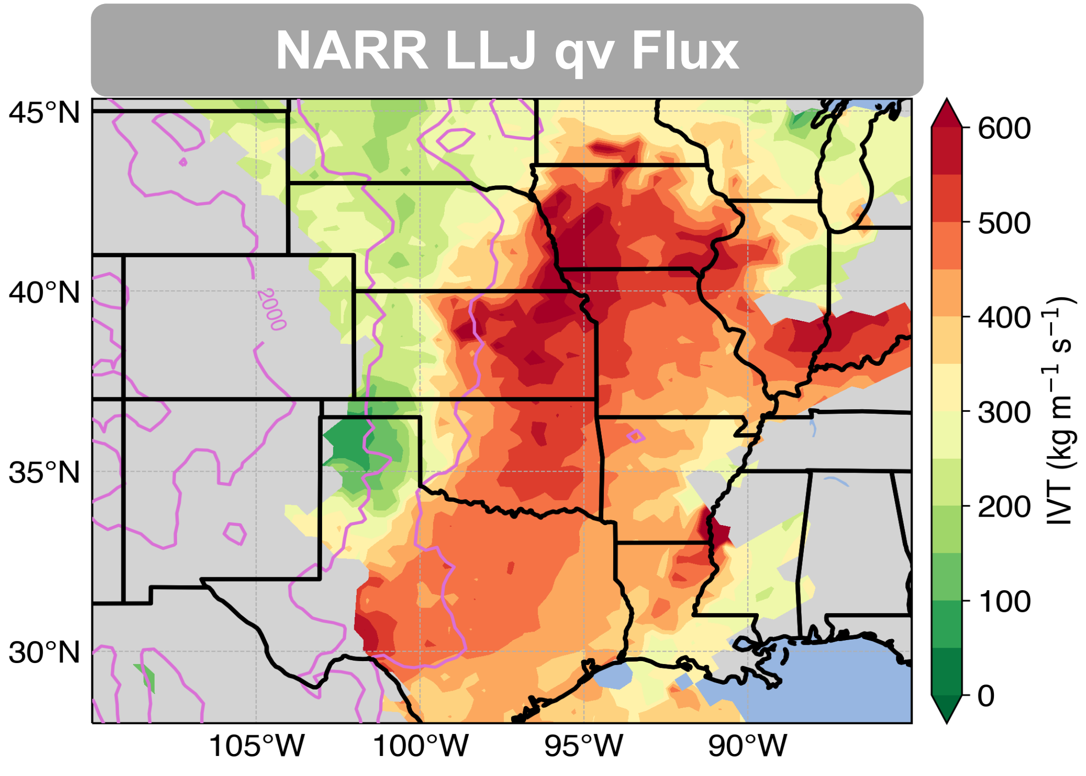
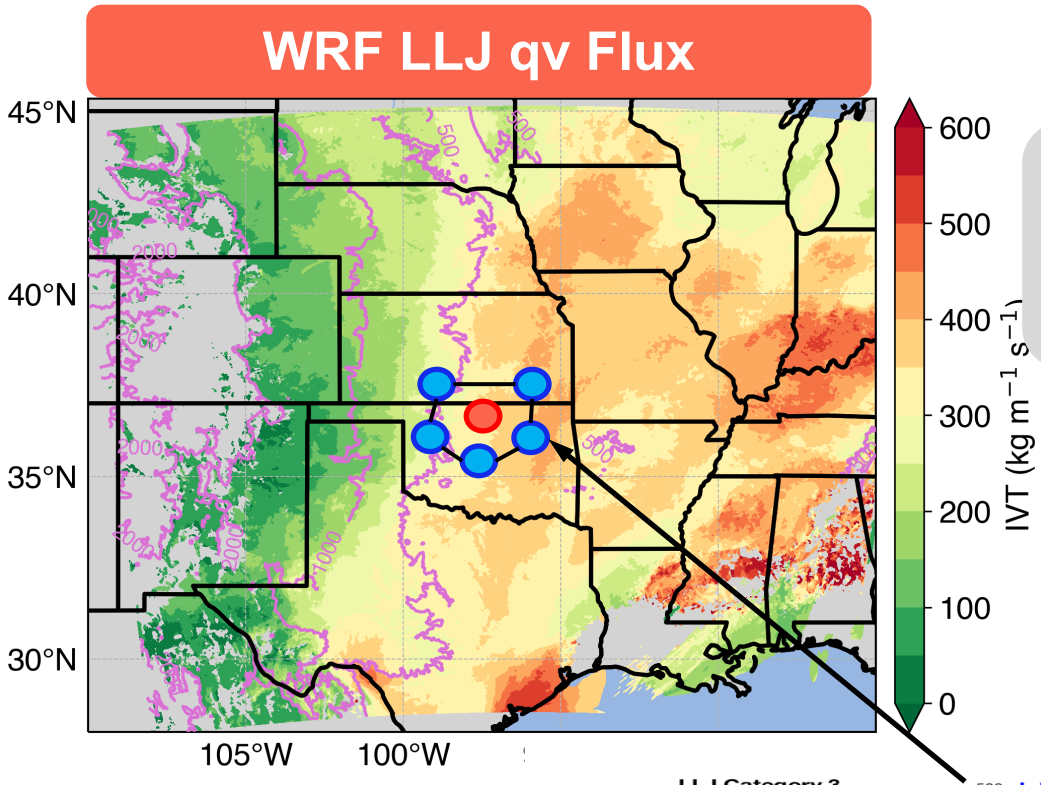
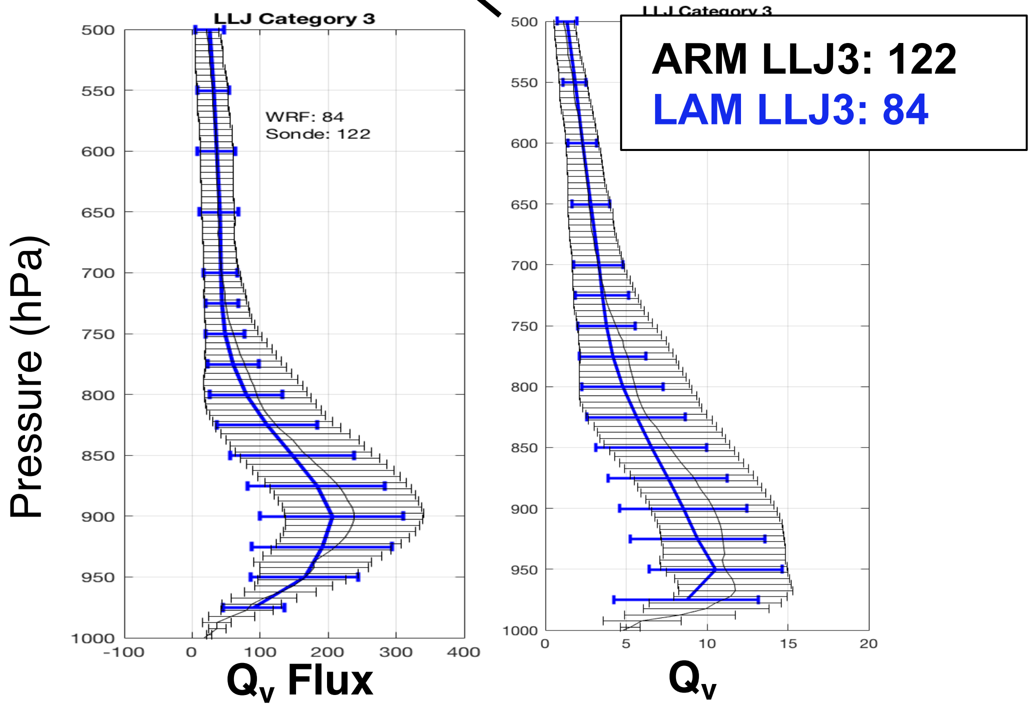




OBS: ARM sounding network and NARR

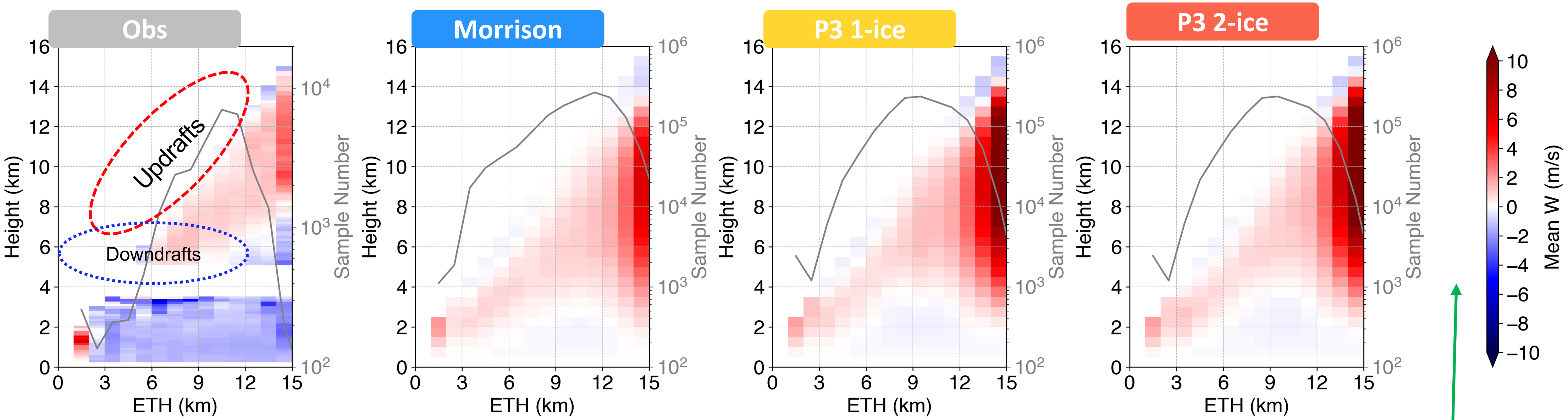


- **Underestimation of MCS precipitation**: Moisture transport associated with LLJ are underestimated in a broad area over SGP
- Mainly due to underestimating frequency of stronger LLJ, and dry bias in precipitable water within LLJ
- Low bias in humidity from the lateral boundary forcing, not microphysics

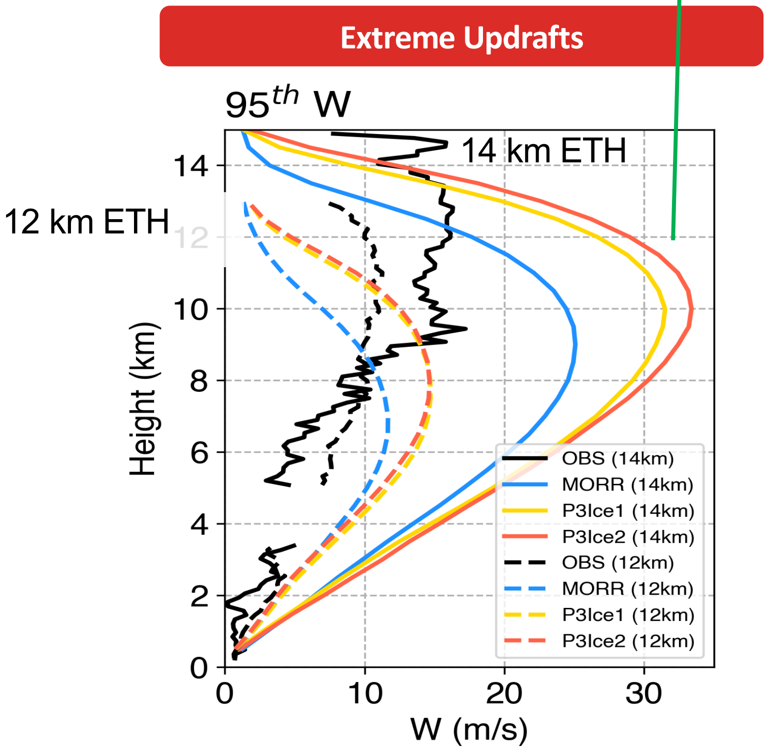
Evaluation of Simulated MCS Updrafts and Downdraft Statistics

OBS: RWP

Binned Mean-W vs. Cloud-Top



- 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 slightly smaller biases in deep cores
- P3 extreme updraft magnitude biases are larger than Morr, but the peak altitude compares better with Obs



CMDV Observational Products

- **From ARM observations**
  - Vertical velocity, Precipitation Profiling / Echo Classification from RWPs
  - 3-D Vertical velocity from ARM Scanning Radars
  - 3-D rain rate, HID from polarimetric radars (CSAPR/X-SAPR)
  - Rain DSD from disdrometers
  - A python library for disdrometer (PyDSD)
  - Cloud Microphysics (size, number, and mass) from Aircraft
  - LLJ product based on sounding

- **From operational observations and GPM satellites**:
  - 4-D IWC and LWC retrieval from NEXRAD
  - MCS database for CONUS based on GOES satellite and NEXRAD