Science Outcomes from the 2011 Midlatitude Continental Convective Clouds Experiment (MC3E)

Michael P. Jensen, *Brookhaven National Laboratory*

With Contributions from many others!

ARM CLIMATE RESEARCH FACILITY

ASR Atmospheric System Research

BROOKHAVEN NATIONAL LABORATORY a passion for discovery

ARM/ASR Joint User Facility and PI Meeting
16 March 2017, Leesburg, VA

U.S. DEPARTMENT OF ENERGY | Office of Science

Quick Overview of MC3E

Who? DOE Atmospheric Radiation Measurement Research Facility
NASA Global Precipitation Measurement Ground Validation
(Walt Petersen)

What? Ground-, Aircraft-based obs. of convective cloud systems.

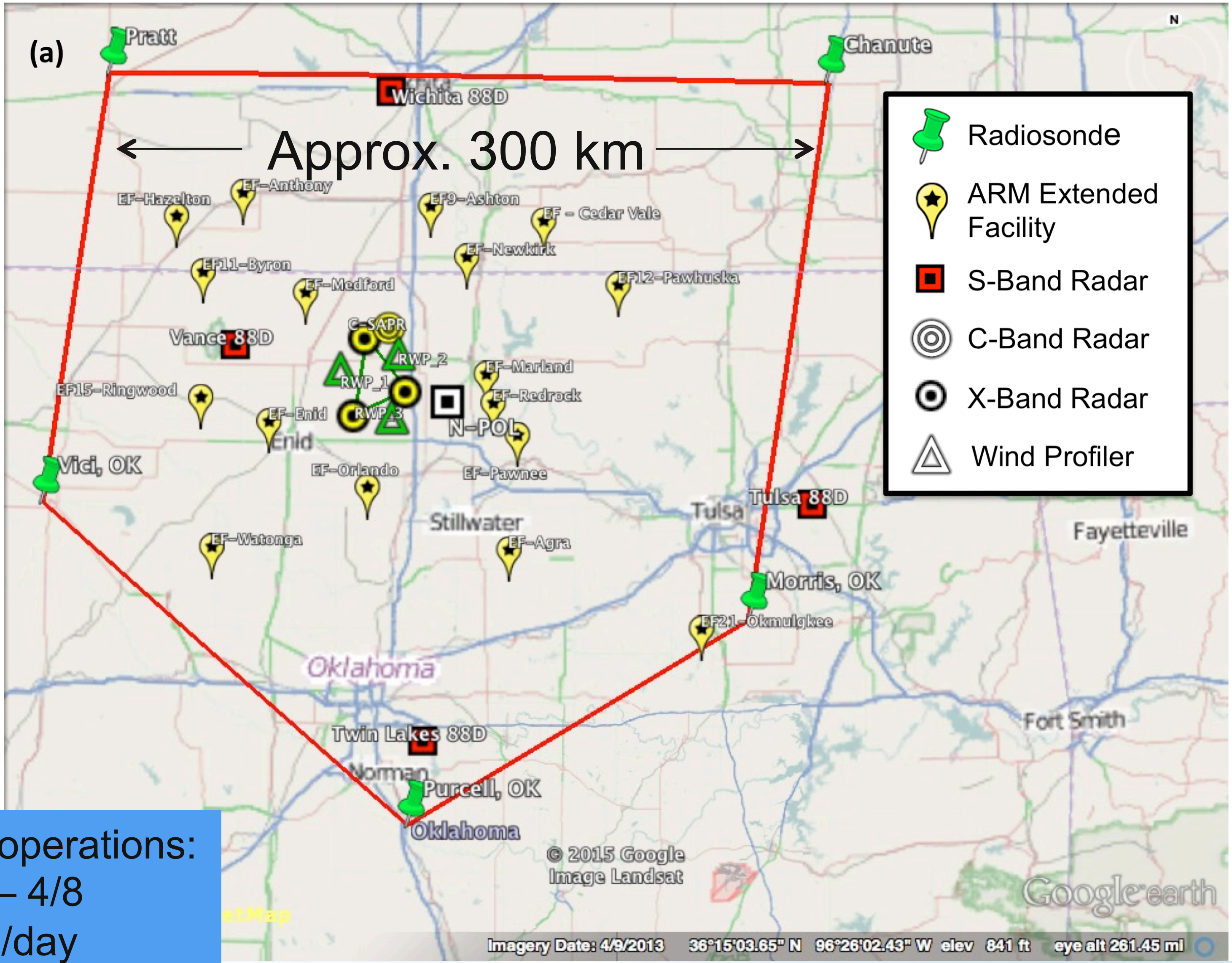
Where? ARM Southern Great Plains site

When? April 22 – June 6 2011

Why? 1) Improve our understanding of convective parameterization
2) Improve satellite estimates of precipitation over land.

Jensen, M. P. et al., 2016: The Midlatitude Continental Convective Clouds Experiment (MC3E). *Bull. Amer. Meteor. Soc*., 97 (9), 1667-1686. doi: 10.1175/BAMS-D-14-00228.1.

MC3E Ground-based operations (full domain)



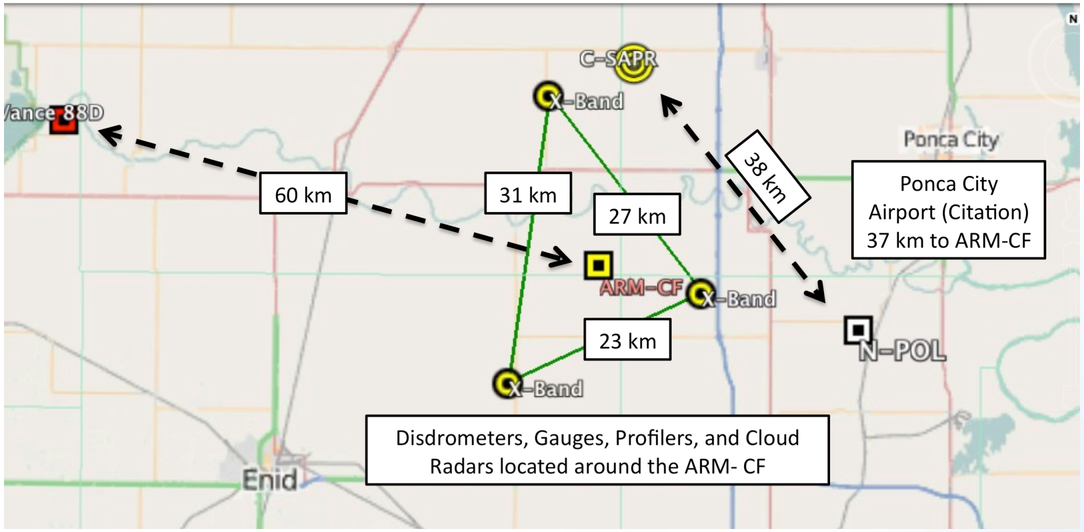
Balloon operations:
25 staff – 4/8 balloons/day
> 1300 balloons

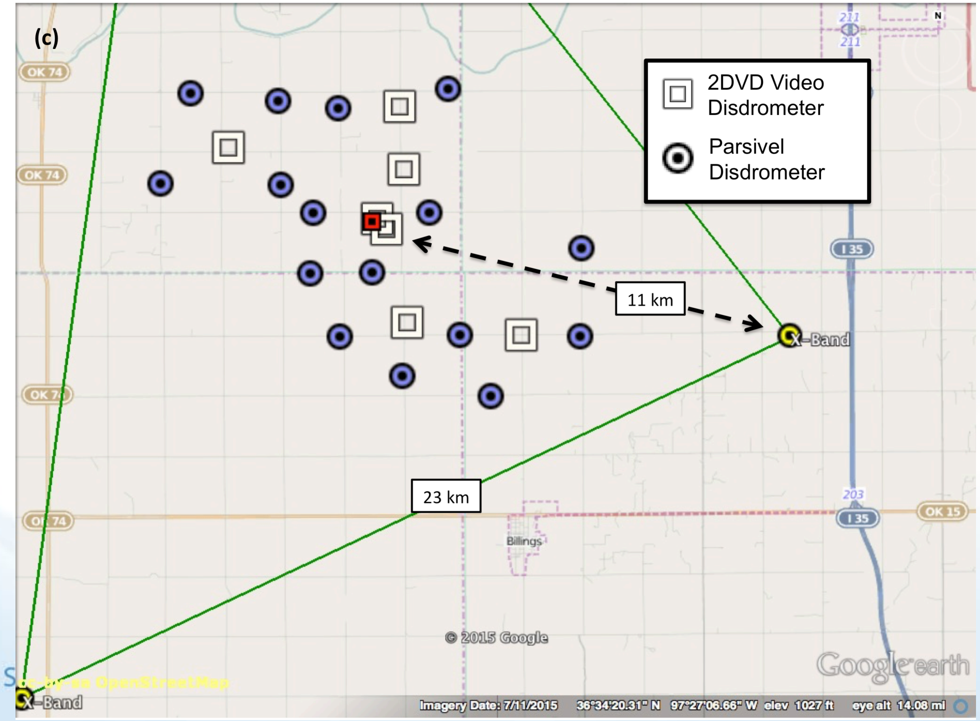
From Jensen et al. 2016

MC3E Sampling: Ground

- Multi-Freq./ Doppler / polarimetric/ profiling radars
  - Sub-pixel DSD/rain variability
  - 3-D (solid/liquid/mixed) HID
  - Cloud water
  - Kinematics

- Network embedded in sounding array
  - CRM Forcing
  - Budgets





NASA Disdrometer network

- 7 2DVD 3rd generation, compact
- 18 Parsivel (Autonomous)
- 4 Joss (915 Profiler collocated)
- 16 Rain gauge pairs collocated
- Deployed w/in ~6 km radius of CF

From Jensen et al. 2016

GPM Airborne Assets during MC3E

GPM Core Satellite "Simulator"

- NASA ER-2: Satellite simulator
- 9 science flights
- Base: Omaha, NE Offutt AFB

Instrument	Characteristics
AMPR (Radiometer, H +V)	10.7, 19.35, 37.1, 85.5 GHz
Resolution @ 20 km range	0.6 km (85.5 GHz), 1.5 km (37.1 GHz), 2.8 km (10.7-19.35 GHz)
CoSMIR(Radiometer, H+V)	37, 89, 165.5, 183.3+/-1, 183.3+/-3, 183.3+/-8 GHz
Resolution @ 20 km range	1.4 km footprint at nadir
HIWRAP Ka-Ku band Radar	13.91/13.35 GHz, 35.56/33.72 GHz
Transmit peak power	30 W (Ku), 10 W (Ka)
3 dB beamwidth	2.9º Ku, 1.2º Ka
MDS (dBZ$_e$, 60 m res., 3.3 µs chirp pulse, 10 km range)	0.0, -5.0 dBZ$_e$

In Situ MIcrophysics

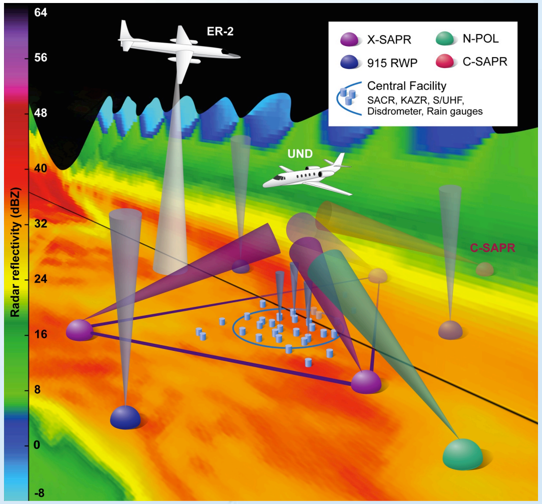
- UND Citation
- Microphysics
- 15 science flights
- Base: Ponca City, OK

Instrument	Measurement
King	Cloud liquid water
PMS 2D-C/CIP	Cloud particle spectra
HVPS	Precipitation particle spectra
CPI	Cloud particle images
CDP	Cloud droplet spectra
Nevzorov	Total water content
Rosemount icing probe	Supercooled liquid water
UHSAS	Aerosol
CPC	Aerosol -CN

Summary of conditions sampled during MC3E

Cate gory	Description	# days sampled	Days
1	Convective Line / Cell events	8	**4**/22,25; **5**/11,18,20,23,24,31
2	Widespread Stratiform Rain	3	4/27, 5/1, 5/10
3	Elevated Weak (Overnight) Convection	3	**4**/23, 24; **5**/18
4	Boundary Layer Clouds	10	**4**/26; **5**/5,13-15,19,27-29;**6**/1
5	Mid- or Upper-level clouds	7	**5**/2,3,8,9,25,26; **6**/2
6	Clear	14	

- Coordinated aircraft missions focused on categories 1 & 2
- Dedicated boundary layer cloud flight by UND Citation 5/27 & 5/30
- Enhanced sounding operations focused on categories 1-3



MC3E Publications (50 and counting)

Cloud and Precipitation Microphysics (15)

Adiirosi et al. 2014; Bringi et al. 2015; D'Adderio et al. 2015; Fridlind et al. 2016; Gatlin et al. 2015; Giangrande et al. 2016; Heymsfield et al. 2015; Kumjian et al. 2016; Kumjian and Pratt 2014; Marinescu et al. 2016; Tian et al. 2016; Testik et al. 2017; Wang et al. 2015; Williams 2016; Wu and McFarquhar 2016;

Model Evaluation (11)

Coniglio et al. 2013; Fan et al. 2015; Gustafson et al. 2014; Iguchi et al. 2012; Mechem et al. 2015; Pu and Lin 2015; Suhas and Zhang 2014; Tao et al. 2013, 2016; Van Lier-Walqui et al. 2016; Van Weverberg et al. 2015;

Satellite Retrieval Algorithms (9)

Battaglia et al. 2014; Heymsfield et al. 2013; Lang et al. 2014; Leppert and Cecil 2015; Matsui et al. 2013; McLinden et al. 2013; Olson et al. 2016; Short et al. 2015; Turk et al. 2014;

ARM Observations (4)

Borque et al. 2014; Jensen et al. 2015; Rhyzkov et al. 2016; Tridon et al. 2013;

Parameterization (3)

Liu et al. 2015; Elsaesser et al. 2016; Wong and Ovchinnikov 2017;

Convective Environment (2)

Berg et al. 2015; Xie et al. 2014;

Convective Vertical Velocities (2)

Giangrande et al. 2013; North et al. 2016;

Precipitation Estimation (2)

Giangrande et al. 2014; Stenz et al. 2014;

Aerosol Impacts on Convection (1)

Saleeby et al. 2016

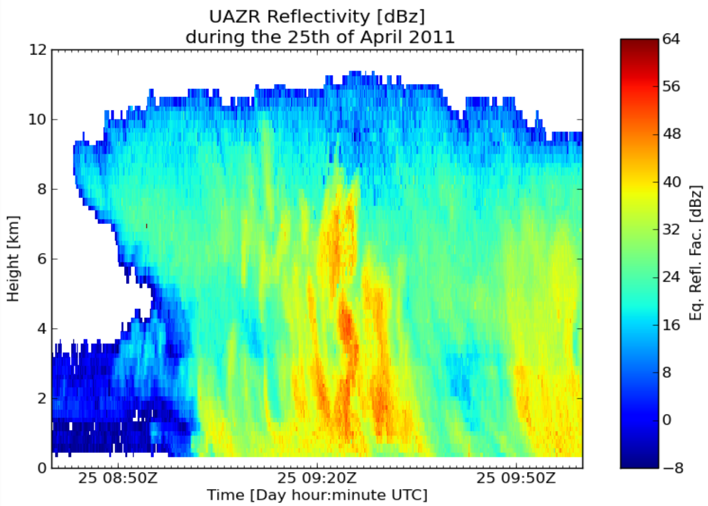
Overview (1)

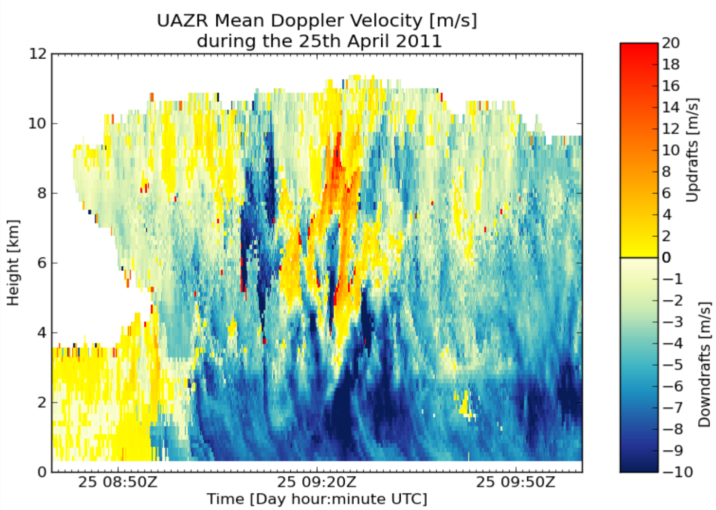
Jensen et al. 2016

A Summary of Convective-Core Vertical Velocity Properties Using ARM UHF Wind Profilers in Oklahoma

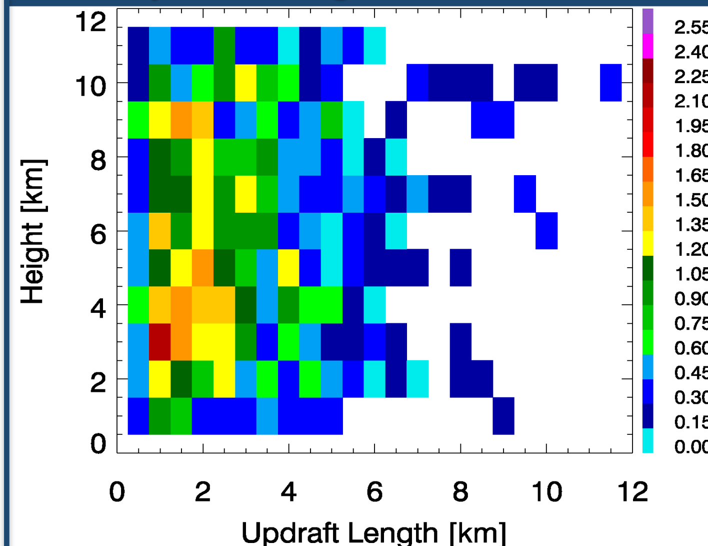
Scott E. Giangrande, Scott Collis, Jerry Straka,
Alain Protat, Christopher Williams, Steven Krueger

RWP Reflectivity Factor and Vertical Velocity Estimates





Updraft Mass Flux as a Function of Updraft Length and Altitude



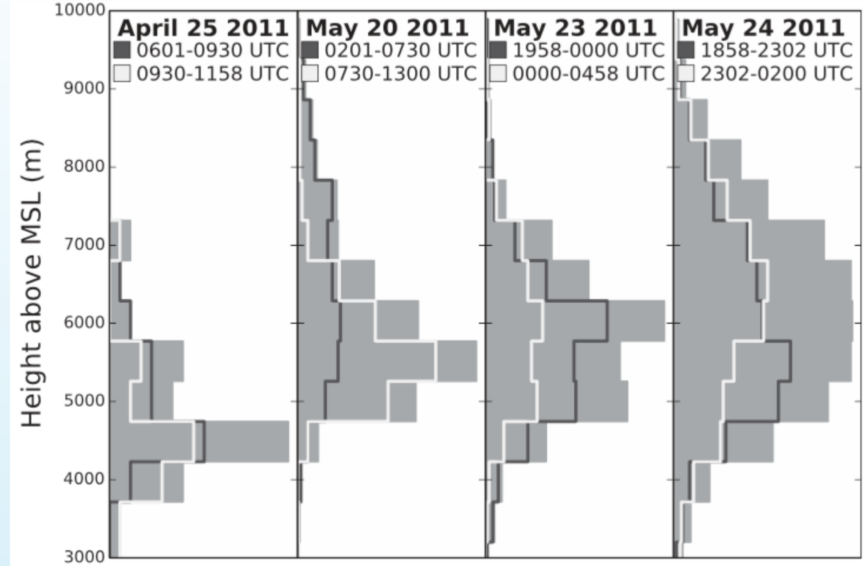
Key Findings:

- Net upward mass flux above 6 km; Cores routinely exceeding 15 ms^{-1} observed.
- Weak correlation between updraft intensity and length.

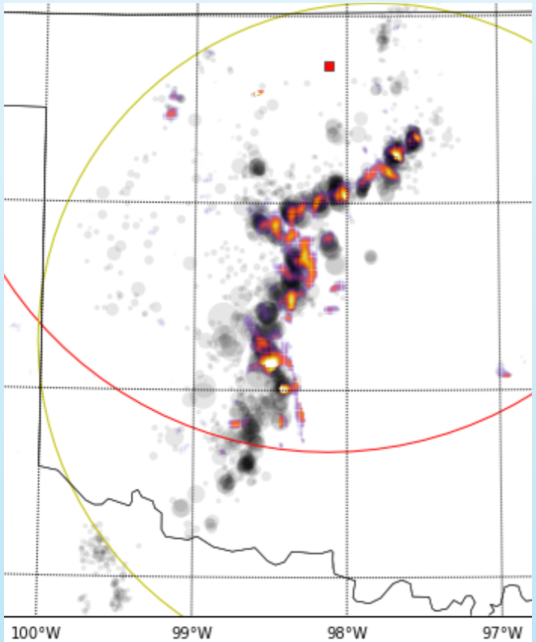
Scott E. Giangrande et al. 2013: A Summary of Convective-Core Vertical Velocity Properties Using ARM UHF Wind Profilers in Oklahoma. *J. Appl. Meteor. Climatol.*, **52**, 2278–2295. .

Collocated polarimetric radar and lightning data indicate very robust signatures of convective updrafts

- **Problem:** nearly all outflow from strong storms originates within strong updrafts, but virtually no robust observations exist to quantitatively constrain weather and climate simulations of updraft physics
- **Approach:** investigate whether specific differential phase fields derived from a recently upgraded NEXRAD S-band radar and a research-grade DOE ARM C-band radar yield robust updraft signatures



Storm-to-storm (panel-to-panel) and within-storm (white-to-black) variability of specific differential phase column heights indicate robust signatures of microphysics within updrafts.



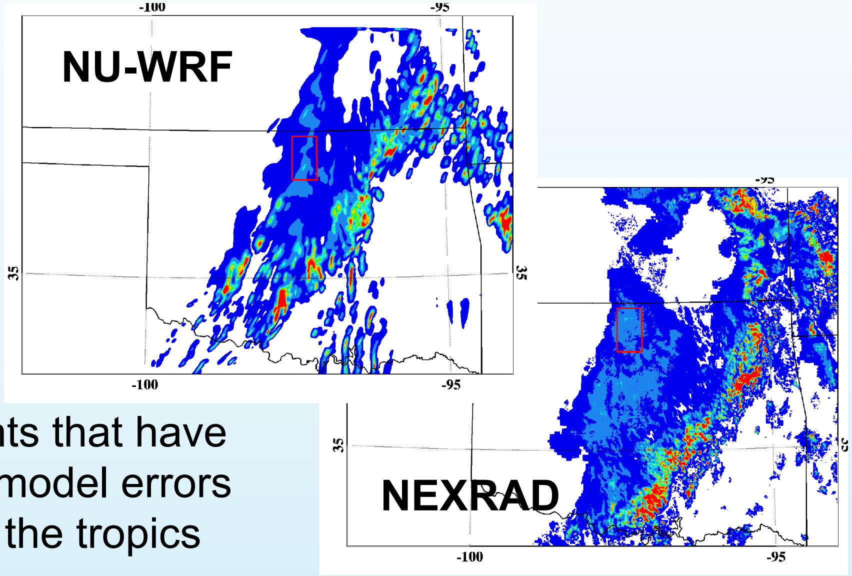
Lightning flashes (black circles) are concentrated around locations of enhanced specific differential phase above the melting level (color-filled contours) from NEXRAD, indicating that updrafts are very well tracked by polarimetric radar.

- **Findings:** polarimetric radar can very well be used to both locate and "see inside" updrafts using specific differential phase derived in-house
- **Future work:** use this powerful information to constrain cloud-resolving simulations, starting with quantities easily calculated from any typical model snapshot, such as "nearest updraft neighbor" distance statistics

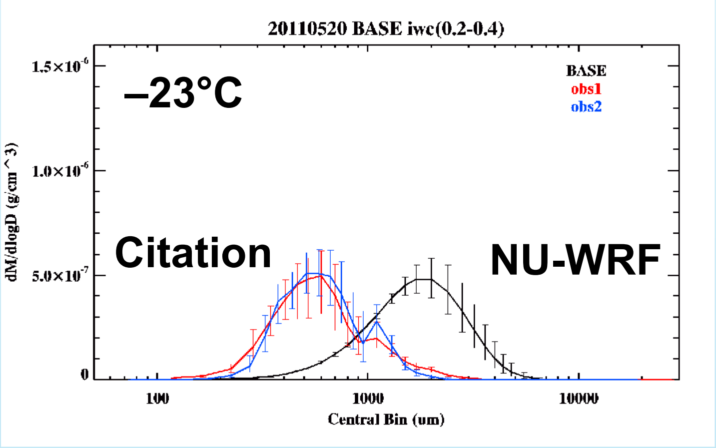
Publication: Van Lier-Walqui, M., A.M. Fridlind, A.S. Ackerman, S. Collis, J.J. Helmus, D.R. MacGorman, K. North, P. Kollias, and D.J. Posselt, 2016: Polarimetric radar signatures of deep convection: Columns of specific differential phase observed during MC3E. *Mon. Weather Rev.,* doi:10.1175/MWR-D-15-0100.1

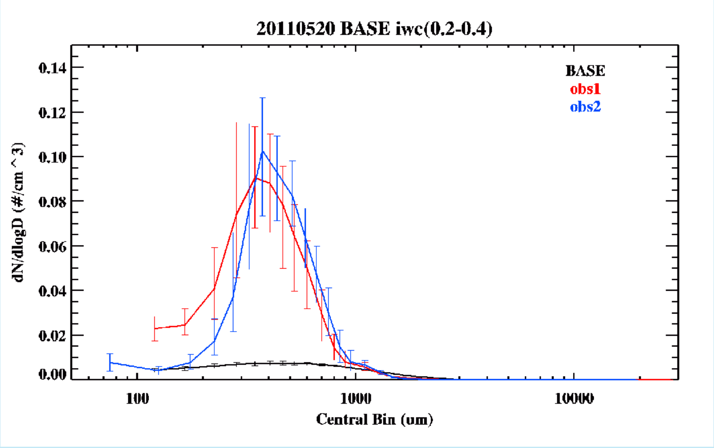
Evidence of warm-temperature ice multiplication not well understood nor well represented in models

- **Problem:** can detailed cloud-resolving models reproduce widespread stratiform outflow ice properties that are well-sampled by aircraft?
- **Approach:** use observation-based hygroscopic aerosol profiles in NU-WRF simulations with two-moment microphysics, for example
- **Findings:** properties of observed stratiform outflow ice surprisingly similar to recent tropical measurements that have been linked to warm-temperature multiplication, and model errors also similar to those reported by other models and in the tropics



Ice particles simulated are substantially smaller and substantially less numerous than observed in the long-lived stratiform ice deck, similar to errors linked to warm-temperature ice multiplication in the tropics [e.g., Ackerman et al. 2015]



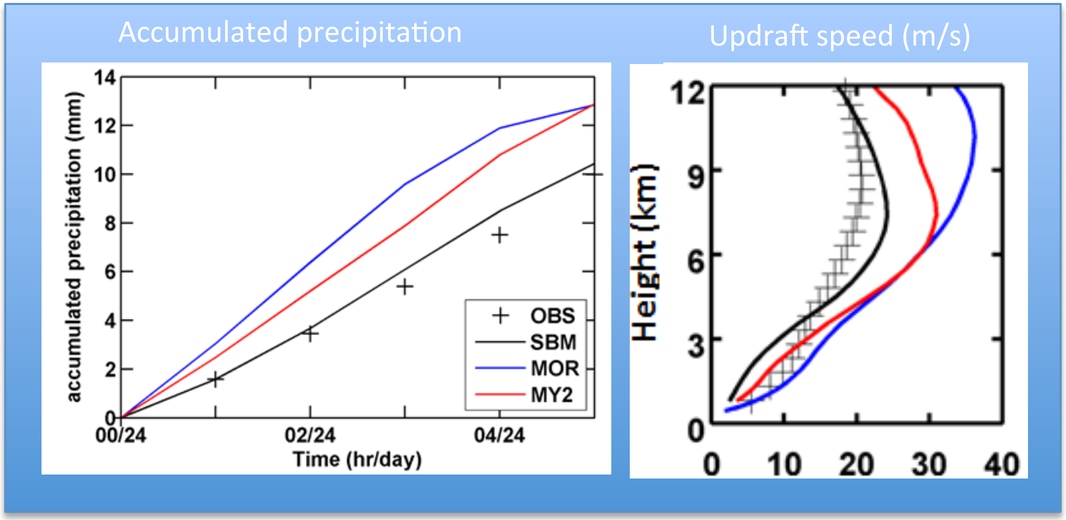


Publication: Fridlind, A.M., X. Li, D. Wu, M. van Lier-Walqui, A.S. Ackerman, W.-K. Tao, G.M. McFarquhar, W. Wu, X. Dong, J. Wang, P. Zhang, M.R. Poellot, A. Neumann, and J.M. Tomlinson, 2016: Use of an observation-based aerosol profile in simulations of a mid-latitude squall line during MC3E: Similarity of stratiform ice microphysics to tropical conditions. *Atmos. Chem. Phys. Disc.*, doi:10.5194/acp-2016-948

Simulating convective properties with the physical spectral-bin and parameterized bulk microphysical models

Objective

- Do high-resolution simulations with a physical spectral-bin model (SBM) better simulate convective updraft properties than parameterized bulk models?
- To provide better benchmark simulations for developing scale-aware cumulus parameterization.



SBM (black line) reproduces precipitation and updraft speeds, while bulk schemes (color lines) overestimate them.

Approach

- Simulations at 1 km resolution with SBM and the bulk schemes to simulate MCSs from MC3E and TWP-ICE field campaigns.
- Evaluate convection and cloud properties using multi-Doppler vertical velocity retrievals and radar reflectivity observations.

Impact

- Use of SBM can alleviate much of the overestimation of updraft speeds produced by bulk schemes and reproduce the observed convection intensity well.
- Suggest the key measurements such as mass flux and cloud microphysics for convective updraft that are critical to further the understanding and improve simulation of convective clouds.

J. Fan et al. (2015), J. Geophys. Res. Atmos., 120, 3485–3509, doi:10.1002/2014JD022142.

Improving Representation of Convective Transport for Scale-Aware Parameterization

Objective

- Improve the representation of convective transport for scale-aware cumulus parameterization in R/GCM.

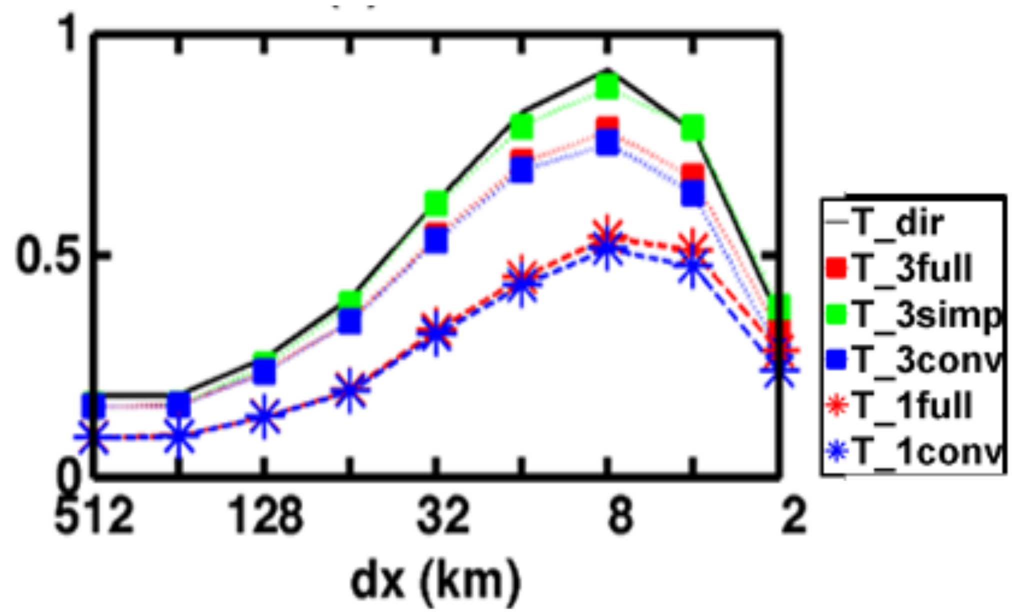
Approach

- Based on the traditional Z-M scheme, analyze CRM simulations for the cases validated with MC3E and TWP-ICE data for different convective cloud systems to develop a better cumulus scheme

Impact

- Better representation of convective transport across all grid scales with a new cumulus parameterization, which is an update of the commonly used Zhang-McFarlane (Z-M) scheme for mesoscale to global model to use.

Vertical transport of moisture (g/kg m/s)

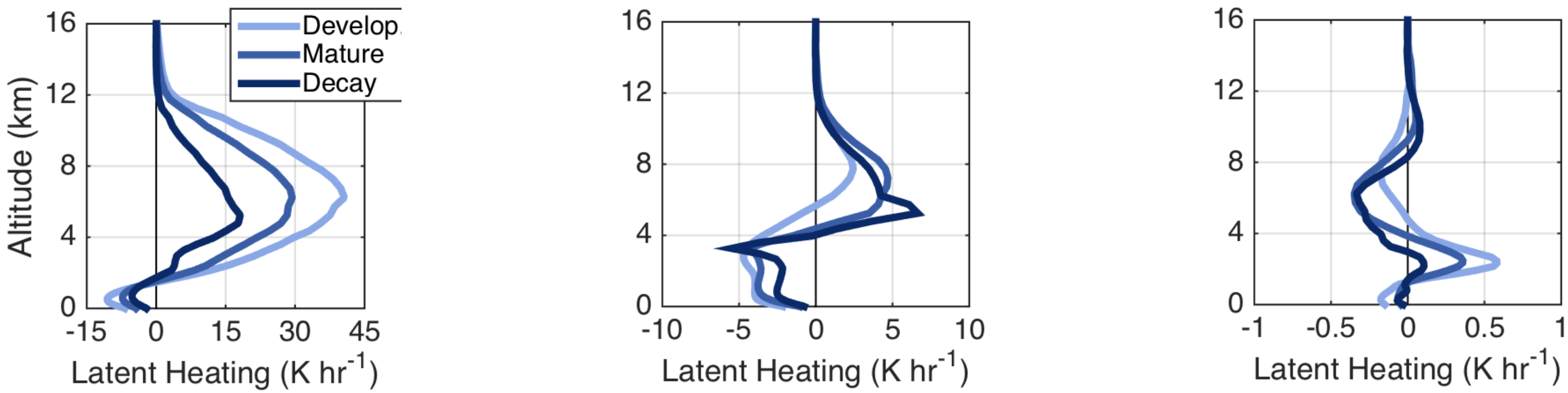


Vertical transport of moisture (VTM) calculated from our new formulation (T_3simp) agrees very well with CRM results (T_dir). Others, such as the Arakawa approach (T_1conv) underestimates VTM dramatically. (MC3E 5/23)

Liu, Y.-C., J. Fan, G. J. Zhang, K.-M. Xu, and S. J. Ghan (2015), Improving representation of convective transport for scale -aware parameterization: 2. Analysis of cloud-resolving model simulations, *J. Geophys. Res. Atmos.*, **120**, 3510–3532, doi:10.1002/2014JD022145.

How do MCS latent heating profiles vary with MCS lifecycle and within different MCS regions?

- MCS simulations partitioned into Convective, Stratiform and Anvil regions and development, mature and decay stages



<u>Convective</u>:
~Linear decrease over time with constant shape

<u>Stratiform</u>:
Profile shape evolves with time (flow regimes; i.e., front -to-rear ascending flow)

<u>Anvil</u>:
Relatively small changes in latent heating profile

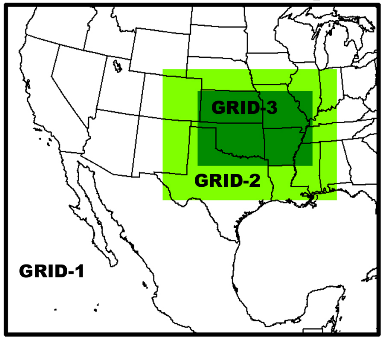
- Quantified latent heating evolution with MCS lifecycle and attributed evolution to specific cloud processes
- Understanding this evolution can be used to assist in developing parameterizations in models that do not resolve cloud process

Marinescu, P. J., S. C. van den Heever, S. M. Saleeby, and S. M. Kreidenweis (2016), The microphysical contributions to and evolution of latent heating profiles in two MC3E MCSs, J. Geophys. Res. Atmos.

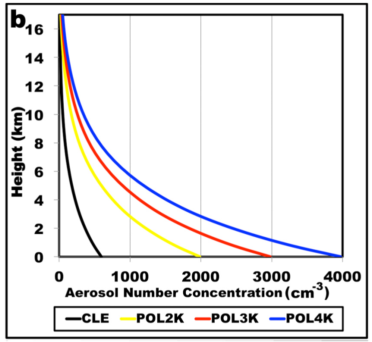
Aerosol effects on the anvil characteristics of mesoscale convective systems

Simulated Squall Lines on 20 May & 23-24 May, 2011

RAMS Setup



Aerosol Profiles



*The impacts of aerosol on cloud water led to less lofted cloud water mass but more lofted number concentration.

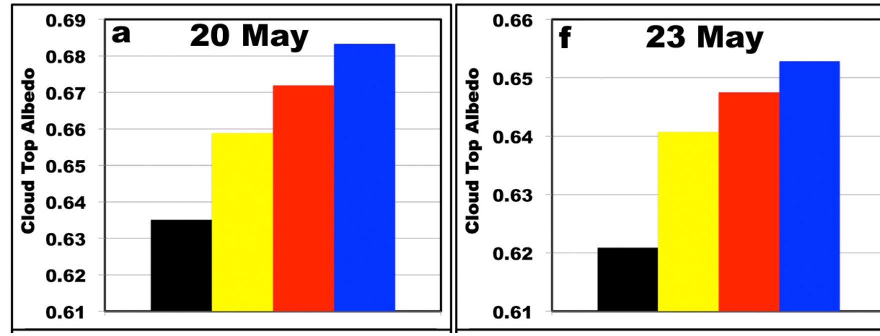
*This led to less anvil ice mass but more Numerous ice crystals with slower fall speeds.

*The end result of aerosol loading was:

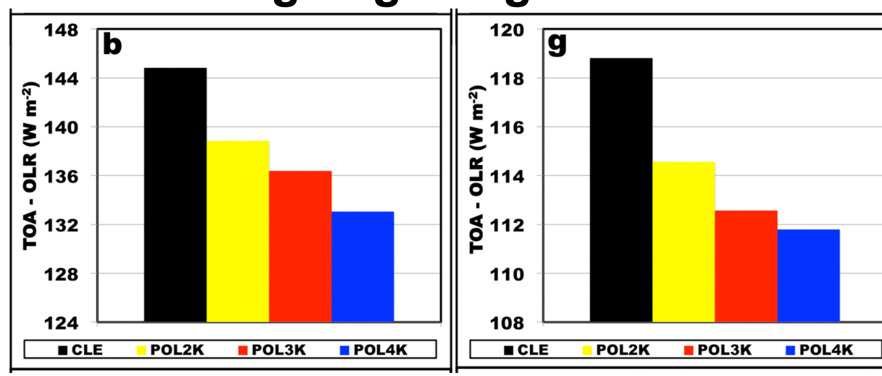
a. Greater cloud top albedo.
b. Reduced cloud top OLR.
c. Greater reduction in net radiative flux. (Reduced cooling effect which is really a net warming impact of adding aerosols)

Saleeby, S. M., S. C. van den Heever, P. J. Marinescu, S. M. Kreidenweis, and P. J. DeMott (2016), Aerosol effects on the anvil characteristics of mesoscale convective systems, J. Geophys. Res. Atmos.

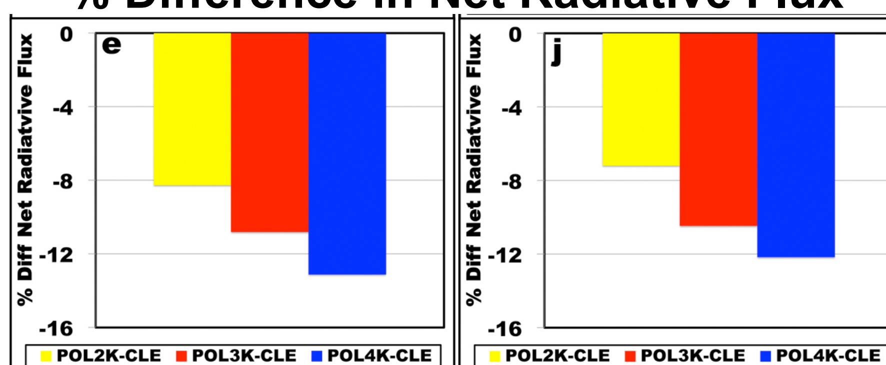
Cloud Top Albedo



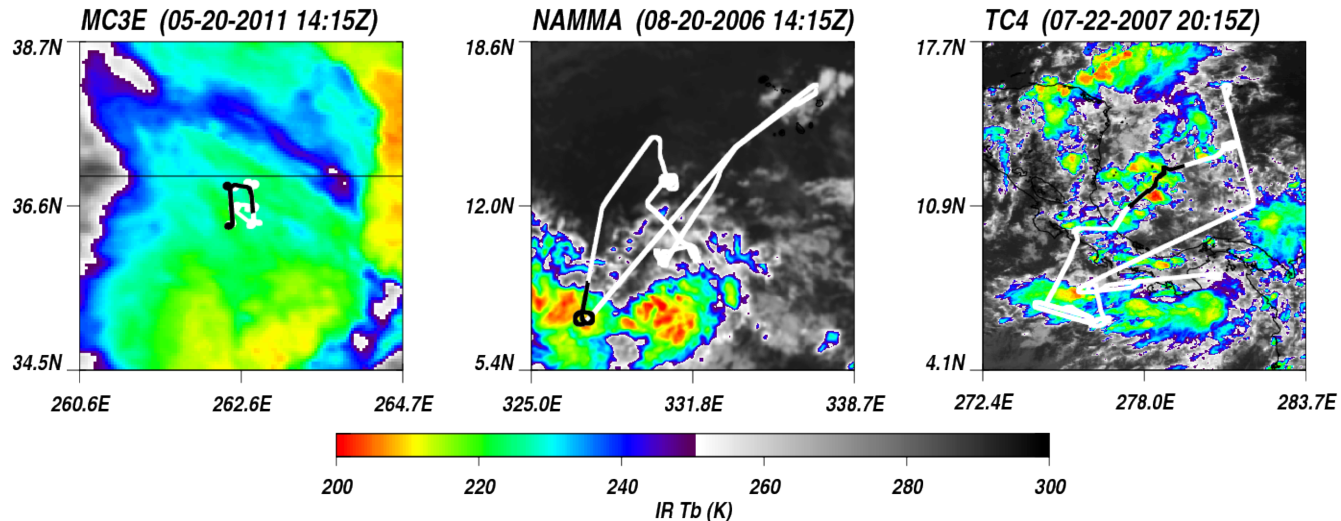
TOA – Outgoing Longwave Radiation



% Difference in Net Radiative Flux

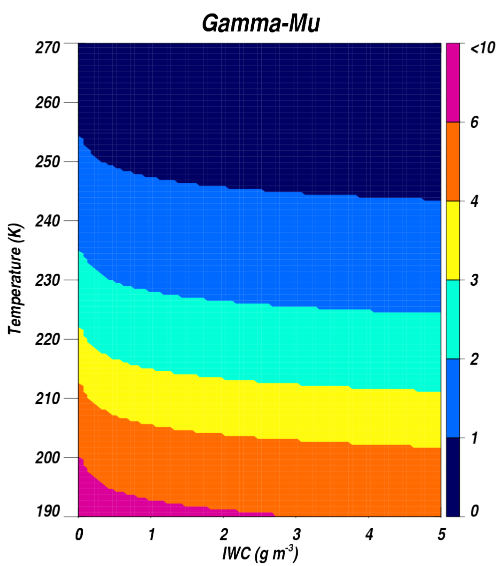


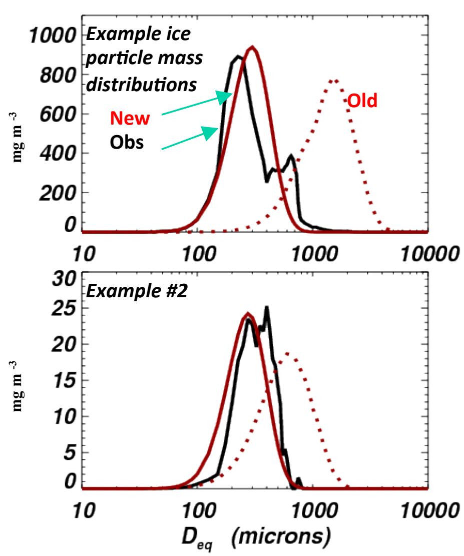
Detrainment informed by field experiment data (Elsaesser et al., 2017)



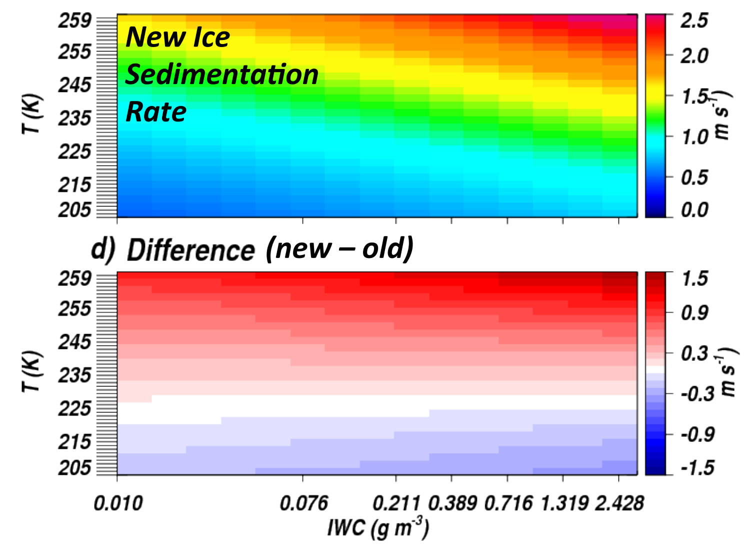
In situ PSDs from flight legs near deep convection (black line segments)

Gamma distribution fits to PSDs, with gamma-μ varying with IWC/T. Example fits (red) to obs. particle mass PSDs (black), new vs. old model





Heymsfield et al. (2013) formulations for particle $V_{fall}(D)$: smaller particles but faster fall speeds



Still plenty of science to do……..

- CMDV-MCS, CMDV-RRM
- CAUSES
- Inner Domain Thermodynamic Profiling
- Field of “7 lambdas” (W, Ka, K, S, UHF 449 MHz, DL)
- UND Citation dedicated cloud flights
- Nighttime Convection during PECAN

MC3E Acknowledgements

DOE ARM and ASR
NASA GPM

A. S. Ackerman, T. Ahlstrom, C. Alvarez, E. Atallah, A. Bansemer, S. D. Bang, M. J. Bartholomew, A. Battaglia, N. Bharadwaj, M. Bobbit, V. N. Bringi, P. Borque, K. Bowley, J. Callison, P. Cardwell, L. D. Carey, D. J. Cecil, A. Chandra, V. Chandrasekar, D. Chaney, P. E. Ciesielski, R. Cline, S. M. Collis, J. Comstock, D. Cook, K. Crick, J. Cunningham, M. Dawson, A. D. Del Genio, P. J. DeMott, B. Dolan, M. Dowell, J. Duncan, G. S. Elsaesser, J. Fan, W. Ferrell, A. M. Fridlind, S. Galemore, P. Gatlin, N. Gears, J. Gerlach, S. J. Ghan, S. E. Giangrande, K. Gleicher, C. A. Grainger, M. Green, M. Grey, N. Guy, T. Hall, D. Harnos, D. Hartsock, J. J. Helmus, A. Heymsfeld, G. Heymsfield, D. L. Holdridge, A. Y. Hou, P. Huitt, M. James, P. Kollias, S. M. Kreidenwies, S. Krueger, J. Kyrouac, F. Lafontaine, T. J. Lang, Y. –C. Liu, D. R. MacGorman, D. Marks, P. J. Marinescu, J. H. Mather, T. T. Matsui, T. Messer, V. Menuier, T. Meyer, R. Moore, S. Muegge, L. Nelson, S. W. Nesbitt, A. Neumann, T. Newman, K. North, B. Orr, P. Patina, W. A. Petersen, M. Peterson, J. Pippett, M. Poellot, D. J. Posselt, C. Prince, A. Protat, K. Reed, A. Reynolds, S. Ringarud, J. Rowland, S. A. Rutledge, S. M. Saleeby, J. Schatz, M. Schwaller, S. Schovanec, R. Seigel, J. Sepulveda, B. Sewell, M. Shaffer, C. Sholten, D. Simmons, D. L. Sisterson, K. Srinivisan, J. Straka, C. Summers, W. K. Tao, L. Theilen, E. Thompson, M. Thurai, L. Tian, A. Tokay, J. Tomlinson, D. D. Turner, S. C. van den Heever, M. van Lier-Walqui, A. C. Varble, M. Vega, C. L. Wall, J. Wang, M. Watson, J. Wegman, C. R. Williams, A. Wilson, M. Wingo, W. J. Wiscombe, D. B. Wolff, D. Wu, K. –M. Xu, G. J. Zhang, E. J. Zipser **and others I have forgotten**…………

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Thank you for your attention!
Any questions?

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