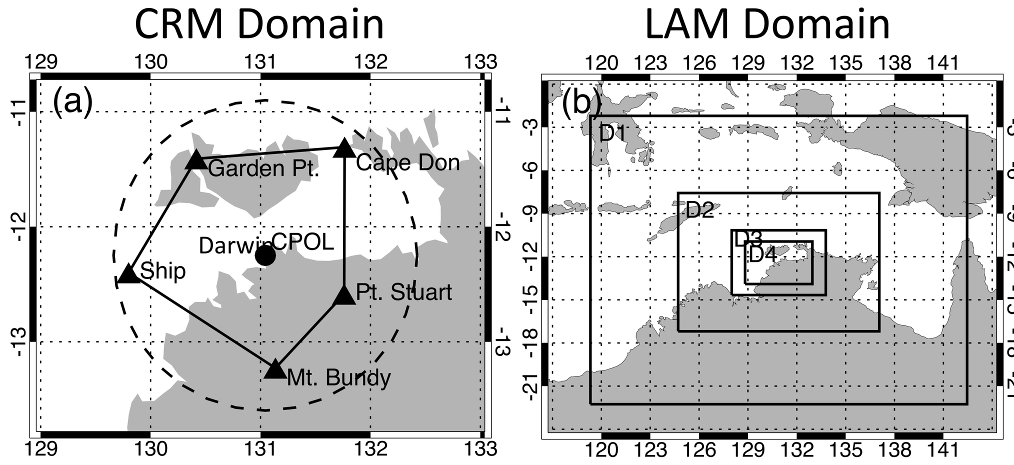
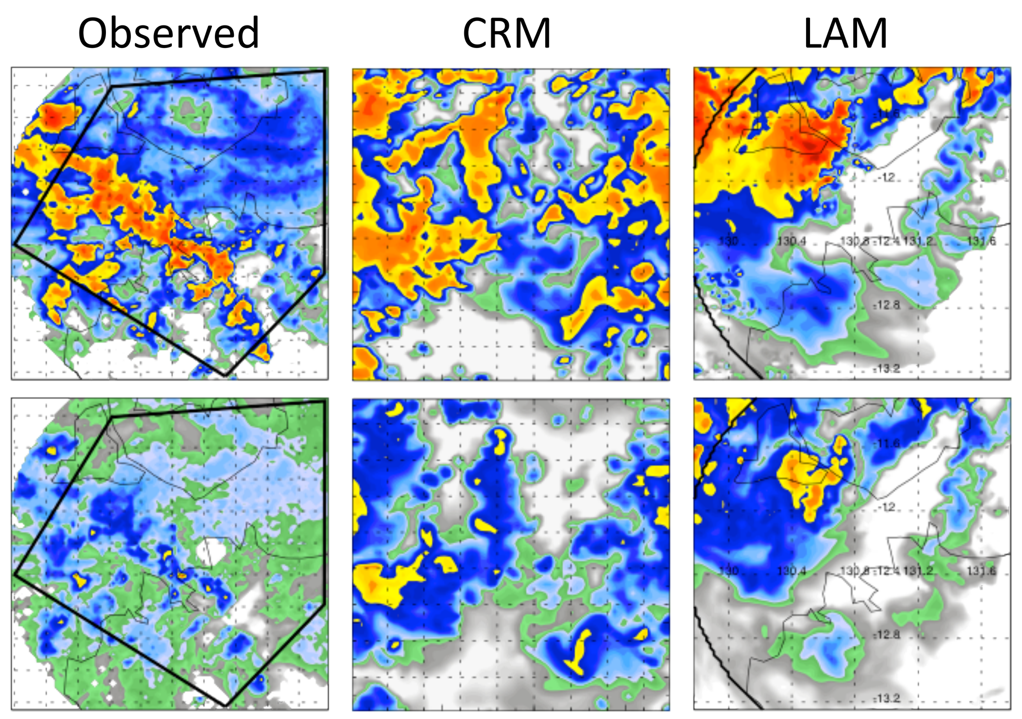
Impact of bulk microphysics scheme assumptions on simulated mesoscale convective system precipitation biases

Adam Varble[1], Ann Fridlind[2], Hugh Morrison[3], and Ed Zipser[1]
[1]Department of Atmospheric Sciences, University of Utah, [2]NASA GISS, [3]National Center for Atmospheric Research

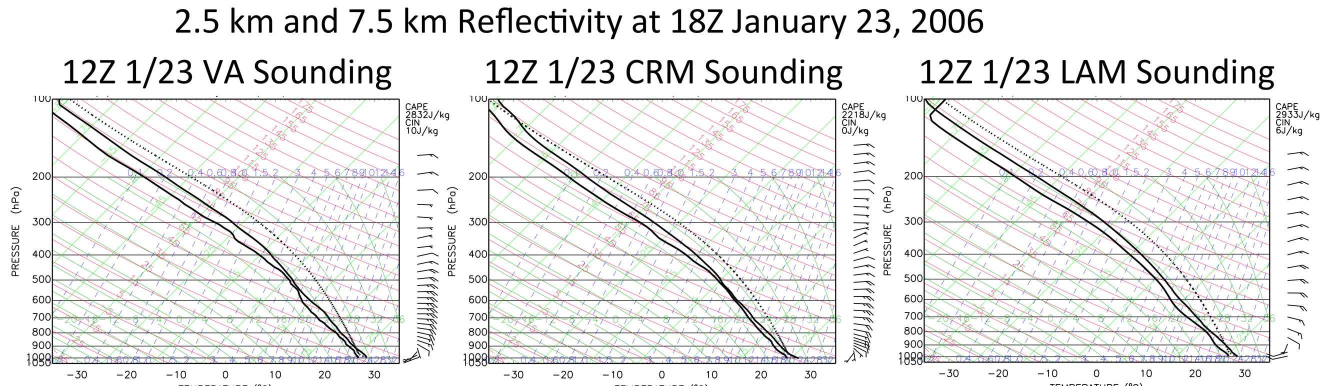
1. INTRODUCTION

Peer-reviewed literature shows high-biased CRM and LAM simulated convective area and reflectivity aloft in deep convective systems, notably for tropical oceanic conditions [e.g., Varble et al., 2011]. How much is a result of microphysics assumptions vs. convective dynamics? What is the impact on stratiform precipitation? We use TWP-ICE observations with many model setups to investigate these questions.





2.5 km and 7.5 km Reflectivity at 18Z January 23, 2006



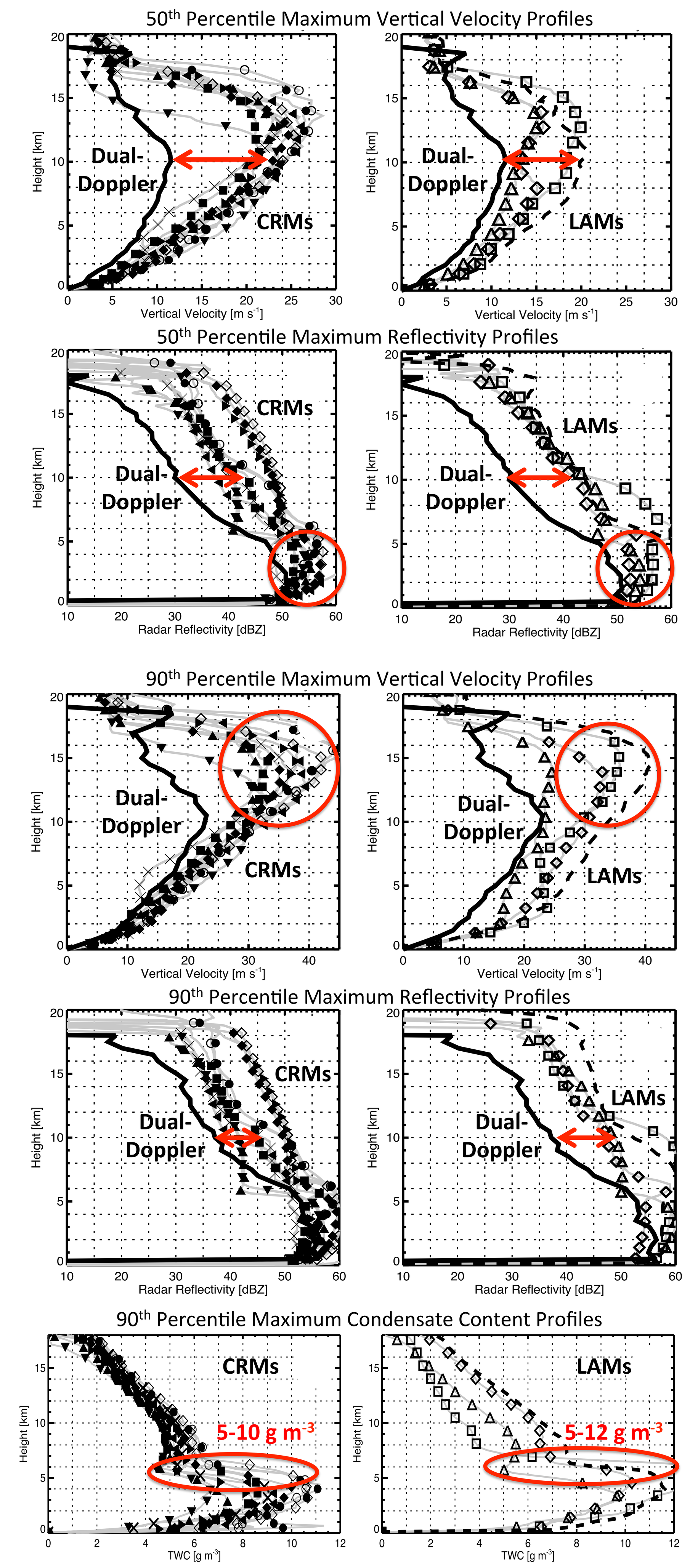
2. METHODS AND MODELS

- **Compare 10 CRM simulations and many LAM (WRF) simulations of an active monsoon MCS on January 23-24, 2006 with observations. Simulations are based on setups from TWP-ICE CRM and LAM Intercomparison Studies [Fridlind et al., 2012; Zhu et al., 2012].**
- **Simulations have 0.9-1 km grid spacing with 76-102 vertical levels.**
- **CRM domain sizes are ~176 km x 176 km, use periodic lateral boundaries with an idealized oceanic surface, and are forced with an observational variational analysis (VA).**
- **LAMs are forced by the ECMWF analysis, have 4 2-way nested domains with a 450 km x 330 km inner domain including land.**
- **All simulations use various 1- and 2-moment bulk microphysics schemes with similar setups for other physics schemes.**
- **Convective and stratiform regions are separated with a slightly modified Steiner et al. [1995] reflectivity texture algorithm.**

Varble et al. (2011), Evaluation of cloud-resolving model intercomparison simulations using TWP-ICE observations: Precipitation and cloud structure. *J. Geophys. Res., 116*, D12206, doi:10.1029/2010JD015180.
Fridlind et al. (2012), A comparison of TWP-ICE observational data with cloud-resolving model results. *J. Geophys. Res., 117*, D05204, doi: 10.1029/2011JD016595.
Zhu et al. (2012), A limited area model (LAM) intercomparison study of a TWP-ICE active monsoon mesoscale convective event, *J. Geophys. Res., 117*, D11208, doi:10.1029/2011JD016447.
Varble et al. (submitted to JGR), Evaluation of cloud-resolving and limited area model intercomparison simulations using TWP-ICE observations. Part 1: Deep convective updraft properties.

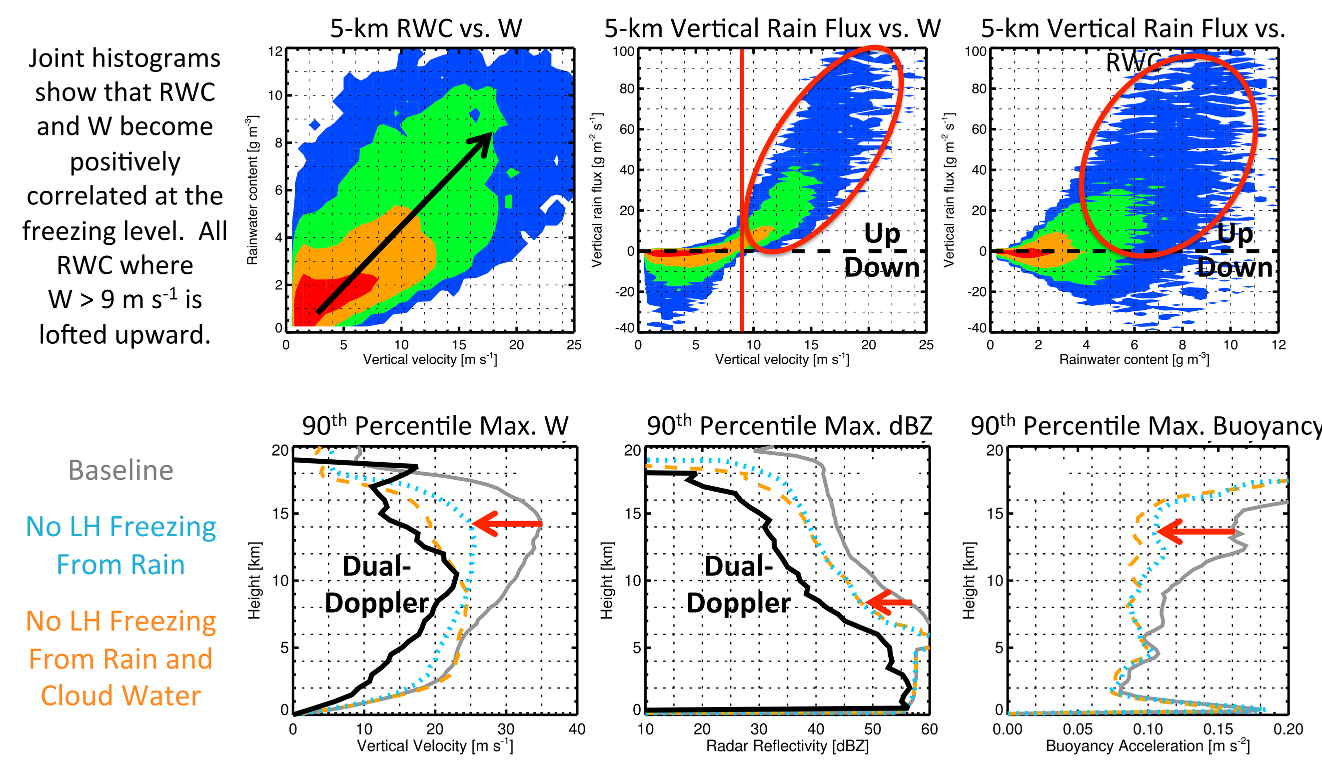
3. DEEP CONVECTIVE UPDRAFT BIASES

Comparing simulated (symbols) and dual-Doppler (black; analysis by Scott Collis) 3D-defined deep updrafts beginning below 1 km and ending above 15 km shows significantly larger reflectivities and vertical velocities in simulations. Simulated deep updrafts also contain large water content with reflectivities that are modulated by hydrometeor size distribution assumptions. Previous studies using profiler, airborne Doppler radar, and aircraft observations of near coastal overshooting tropical convection support dual-Doppler values for this case. Preliminary results (not shown) for mid-latitude continental convection from MC3E also produce high biases, but lesser in magnitude.



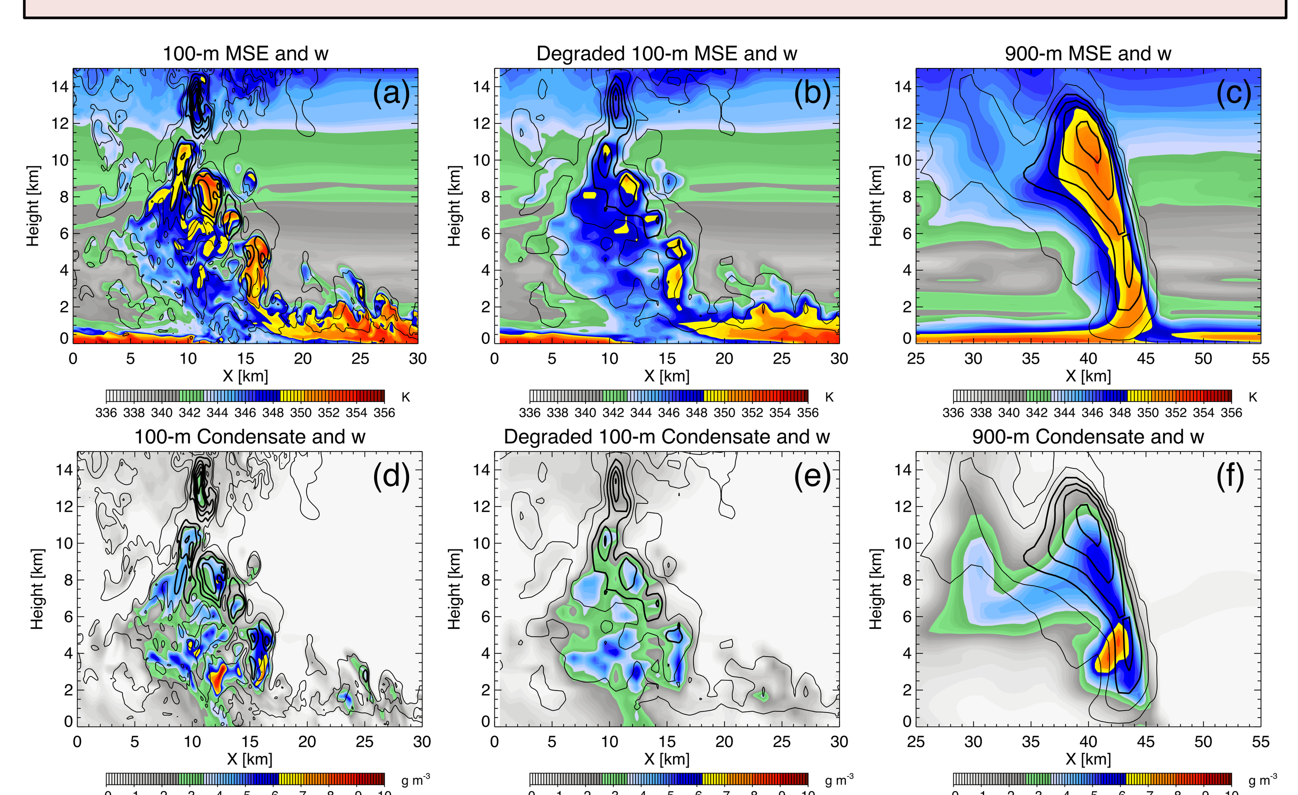
4. IMPACTS OF LOFTING AND FREEZING RAIN

Large simulated rainwater contents (RWC) are lofted and frozen. Removing the latent heat of freezing for rain in the WRF simulation removes extreme upper tropospheric vertical velocities (W) by significantly reducing maximum deep updraft buoyancy aloft.



5. IMPACTS OF RESOLUTION

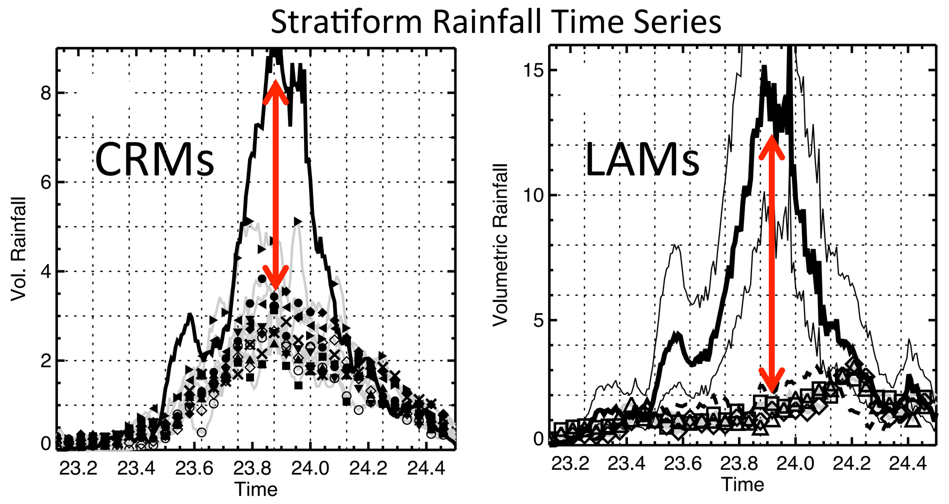
For quarter domain simulations, 100-m grid spaced simulations degraded to 900-m grid spacing have ~15% less upward mass flux, ~25% less condensate, and ~30% less upward vertical condensate flux at 10-km altitude than 900-m grid spaced simulations during the 5-hr dual-Doppler observing period, with most of this difference resulting from vertical velocities > 10 m s^{-1} or condensate loadings > 3 g m^{-3}. Vertical cross-sections through representative updrafts display this difference below (MSE filled (top panels), Condensate filled (bottom panels), and W contoured at 1, 5, 10, 15, 20, 25, and 30 m s^{-1}).



6. EFFECTS ON STRATIFORM

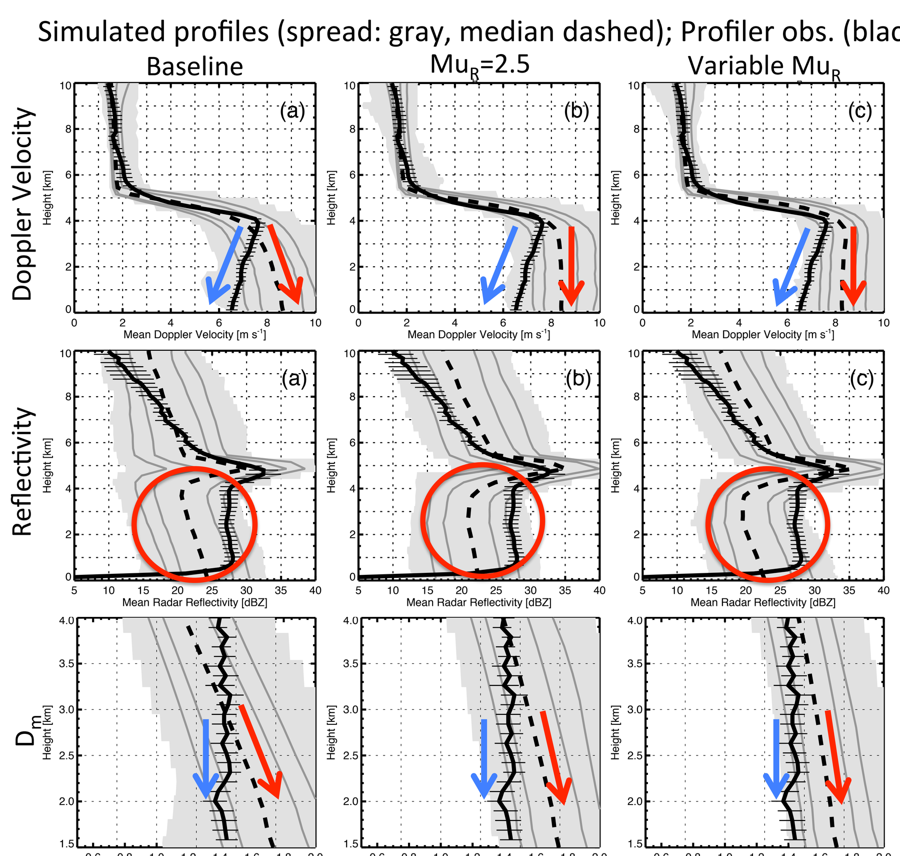
Simulated stratiform rainfall (symbols) is lower than observed (in black) because downward ice mass flux is insufficient at the melting level (not shown). This may be related to overly intense convection detraining too high in the troposphere, although model forcing and microphysics assumptions play a non-negligible role.

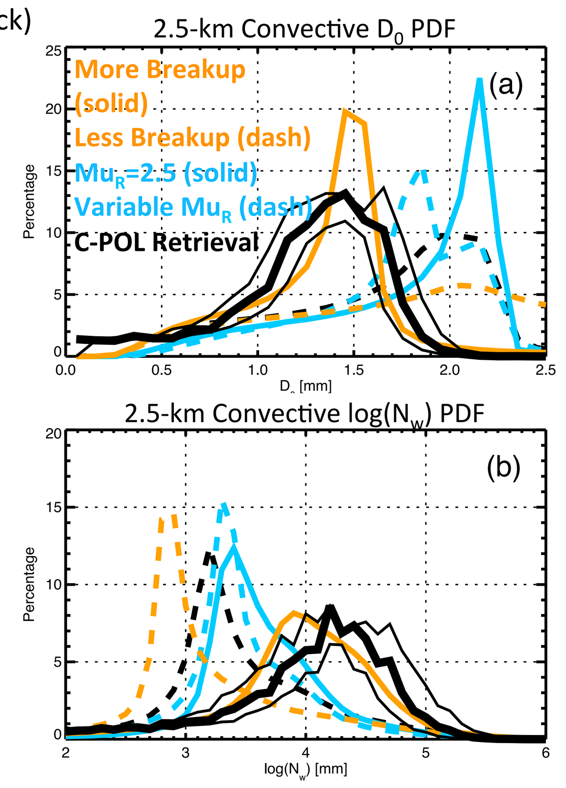
Stratiform Rainfall Time Series



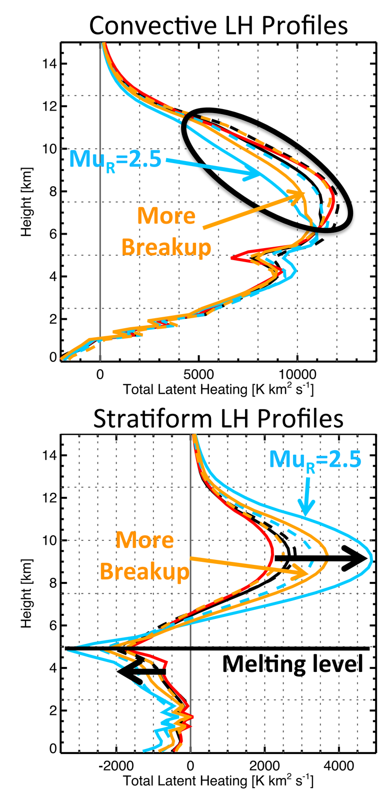
7. CONTRIBUTION FROM MICROPHYSICS ASSUMPTIONS

Using the Morrison scheme in WRF, increasing raindrop breakup and the rain gamma shape parameter (μ) produce better agreement with retrievals (courtesy Christopher Williams). Altering breakup or μ significantly impacts reflectivity and the convective-stratiform separation, but MCS evolution and deep convective updrafts are not significantly impacted. Altering the snow m-D or rimed ice fall speed can decrease reflectivity biases, but they have little impact on MCS evolution. None of these changes reduces updraft strength, but the relative amounts of graupel/hail and snow are impacted (not shown).





	Areal Fraction		Mean Rain Rate (mm/hr)		Total Rainfall (x10^4)	
	Convective	Stratiform	Convective	Stratiform	Convective	Stratiform
C-POL Radar	**0.07**	**0.44**	**16.2** (12.7-20.7)	**1.55** (0.96-2.56)	**7.5** (5.9-9.6)	**4.3** (2.7-7.2)
WRF-M2	**0.22**	**0.31**	**16.3**	**0.64**	**23.3**	**1.3**
Graupel	**0.17**/0.12	**0.40**/0.44	**12.2**/14.8	**0.64**/1.02	**12.8**/11.6	**1.6**/2.9
Hail	**0.17**/0.12	**0.41**/0.45	**12.4**/15.3	**0.66**/1.07	**13.2**/11.8	**1.7**/3.1
Snow m-D	**0.19**/0.14	**0.37**/0.42	**11.3**/13.7	**0.64**/1.09	**13.3**/11.9	**1.5**/2.9
More Breakup	**0.13**/0.09	**0.43**/0.47	**14.1**/16.9	**0.90**/1.52	**11.6**/9.5	**2.5**/4.6
Less Breakup	**0.19**/0.14	**0.40**/0.44	**11.4**/13.7	**0.58**/0.85	**13.4**/12.5	**1.5**/2.4
Mu_R=2.5	**0.10**/0.06	**0.40**/0.43	**17.8**/20.9	**1.41**/2.13	**10.8**/8.5	**3.6**/5.8
Variable Mu_R	**0.15**/0.12	**0.34**/0.37	**13.8**/16.0	**1.00**/1.33	**12.9**/11.9	**2.2**/3.2



8. CONCLUSIONS

- **Simulated deep convective vertical velocities and water contents are too high, which couples with hydrometeor n(D) assumptions to yield high biases in radar reflectivity aloft and convective area.**
- **Extreme upper tropospheric vertical winds result from lofting and freezing large rainwater contents, which amplify buoyancy and reflectivity aloft.**
- **Reducing grid spacing to 100-m weakens the most intense convection, but not enough to match observations.**
- **Intense convection detrains too high, combining with lateral boundary condition errors (not shown) to negatively impact stratiform precipitation.**
- **Realistically altering raindrop breakup, the rain gamma shape parameter, and the snow m-D relationship improves comparisons with observational retrievals, but biases still remain because of the overly intense convection.**

ACKNOWLEDGEMENTS

We would like to acknowledge the DOE ASR program for funding this research and our collaborators who provided valuable contributions: Ping Zhu, Scott Collis, Christopher Williams, Andy Ackerman, Jean-Pierre Chaboureau, Jiwen Fan, Adrian Hill, and Ben Shipway.