Using TWP-ICE and MC3E Observations to Expose Dynamical and Microphysical Causes of CRM and LAM Simulated Deep Convection Biases

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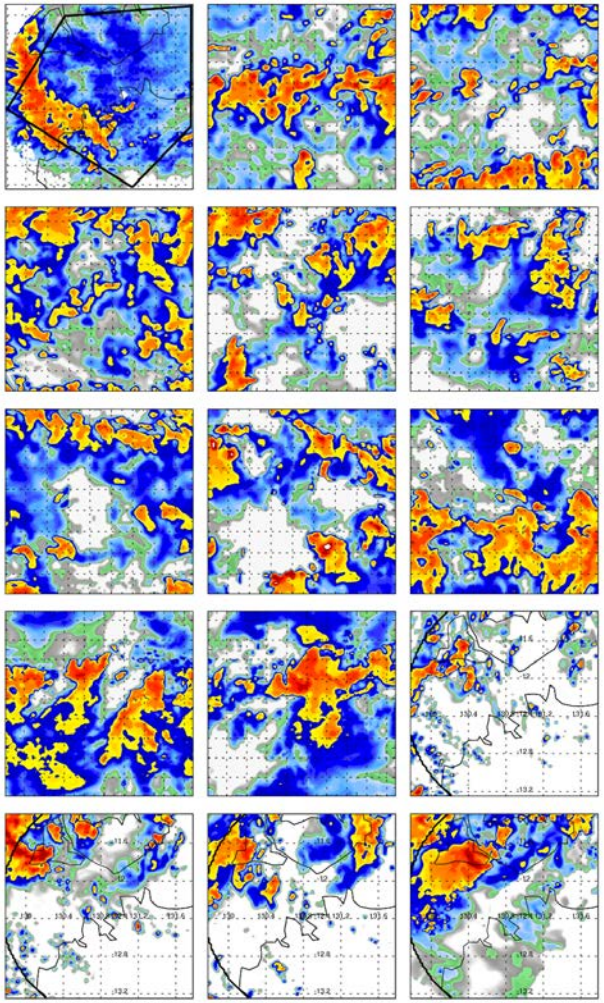
with valuable contributions from Ann Fridlind, Ping Zhu, Andy Ackerman, Scott Collis, Christopher Williams, Hugh Morrison, Jiwen Fan, Adrian Hill, Ben Shipway, and Jean-Pierre Chaboureau

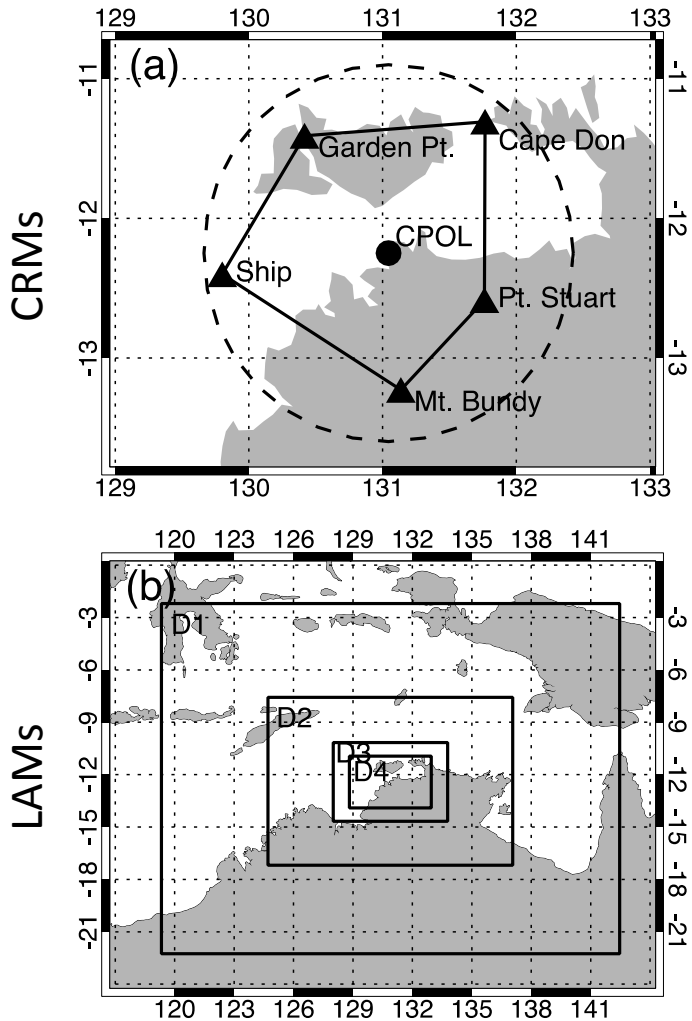


Quick Overview

TWP-ICE CRM Intercomparison Study
(see Varble et al., 2011; Fridlind et al., 2012)
Use 10 setups from this study

TWP-ICE LAM Intercomparison Study
(see Zhu et al., 2012)
Use 3 WRF setups from this study plus a 4th new WRF setup

All simulations employ various 1- and 2-moment bulk microphysics schemes with ~1 km horizontal grid spacing and ~75-100 vertical levels and produce 10-minute output for 33-hour MCS event



Common Convective Biases

High bias in convective radar reflectivity aloft

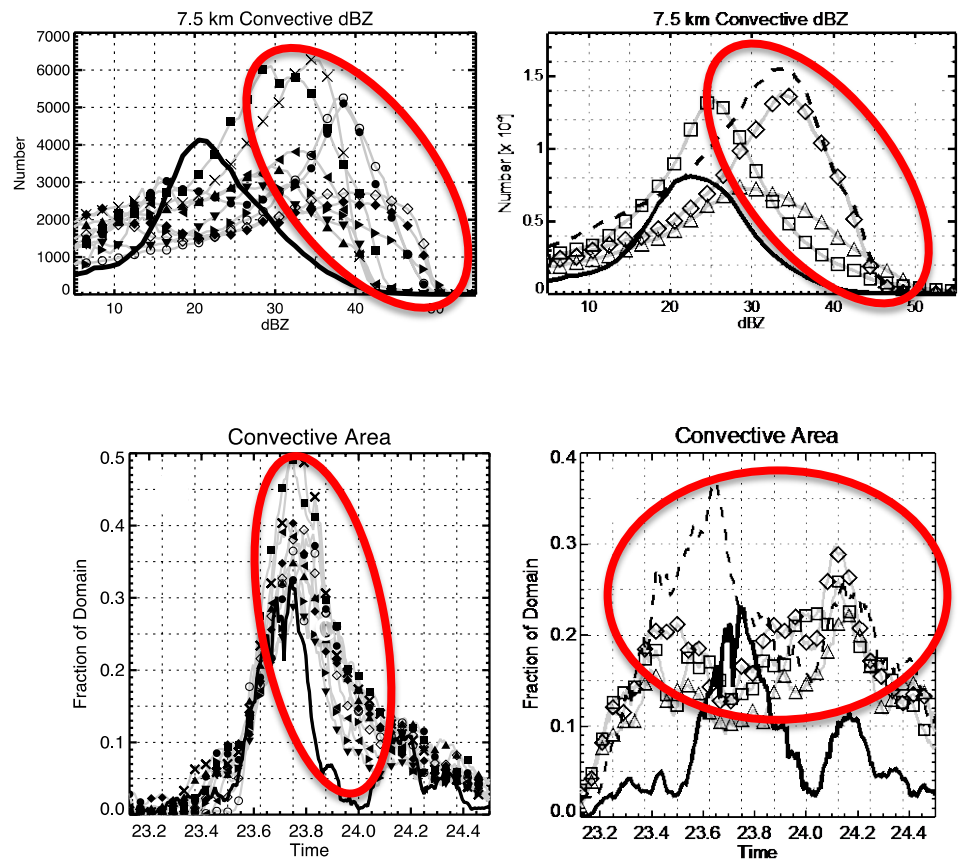
Commonly attributed to graupel, but can be due to snow in 2-moment, constant density, spherical setups

Is this an ice microphysics problem as is commonly stated in the literature?

High bias in identified convective area

(using texture algorithm such as Steiner et al. (1995))

Some due to periodic boundaries, but LAMs are even more biased



Why does this matter?

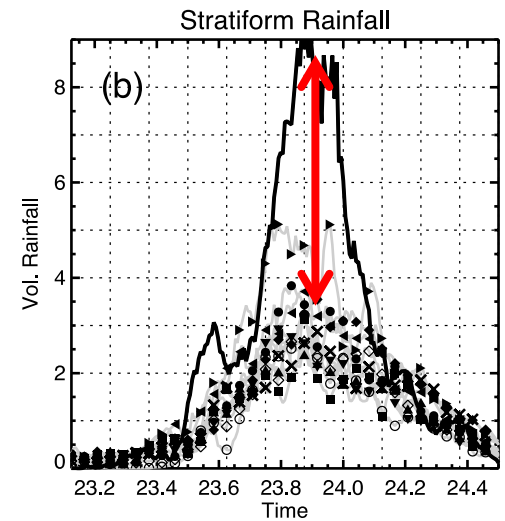
Effects on stratiform region development

- Detrainment properties (height and hydrometeors)
- Compensating subsidence
- Heating distribution

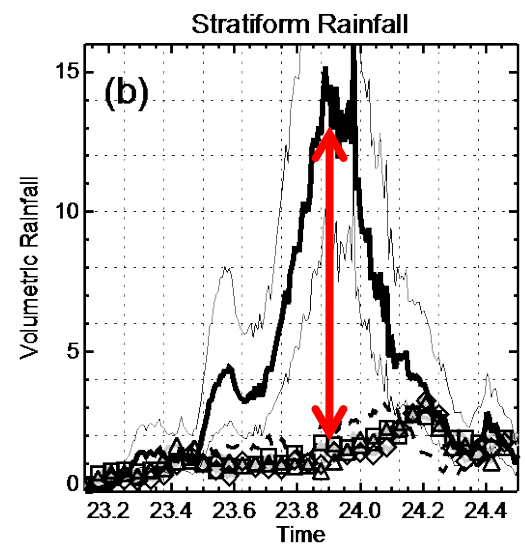
Stratiform rainfall too low

- Not due to excessive evaporation as in mid-latitude studies
- IWC at melting level too low
- CRMs have the issue of compensating subsidence and LAMs have the issue of forcing analysis errors

CRMs



LAMs



Microphysical Causes – Size and Category?

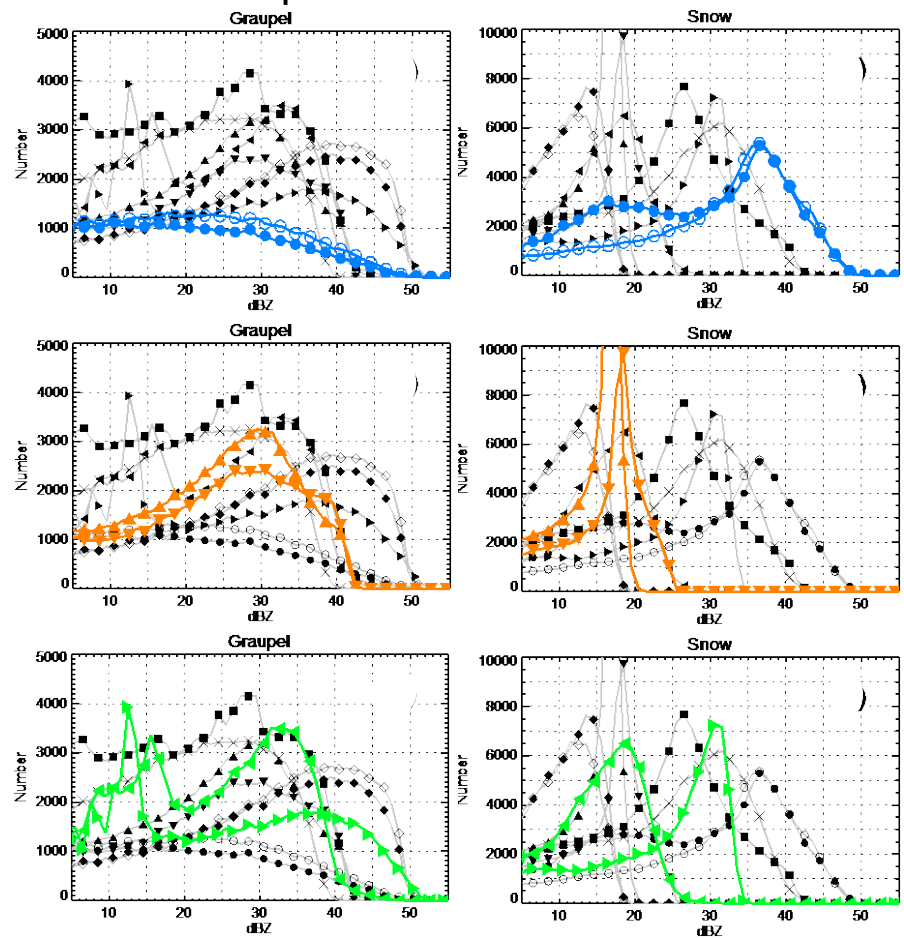
Differences in simulated precipitation structure are clearly related to different assumptions in hydrometeor properties

- Hail lowers reflectivity aloft (falls out faster)
- Non-spherical m-D lowers reflectivity by putting more mass in smaller particles
- μ > 0 can lower reflectivity by narrowing the size distribution if N is predicted
- More prognostic moments allow more realistic effects of phase changes and sedimentation on the size distribution, but more constraints by observations are needed!

BUT, all simulations over-predict reflectivity!

$$n(D) = N_0 D^{\mu} e^{-\lambda D}$$

7.5 km Graupel dBZ | 7.5 km Snow dBZ



Microphysical Causes – Amount?

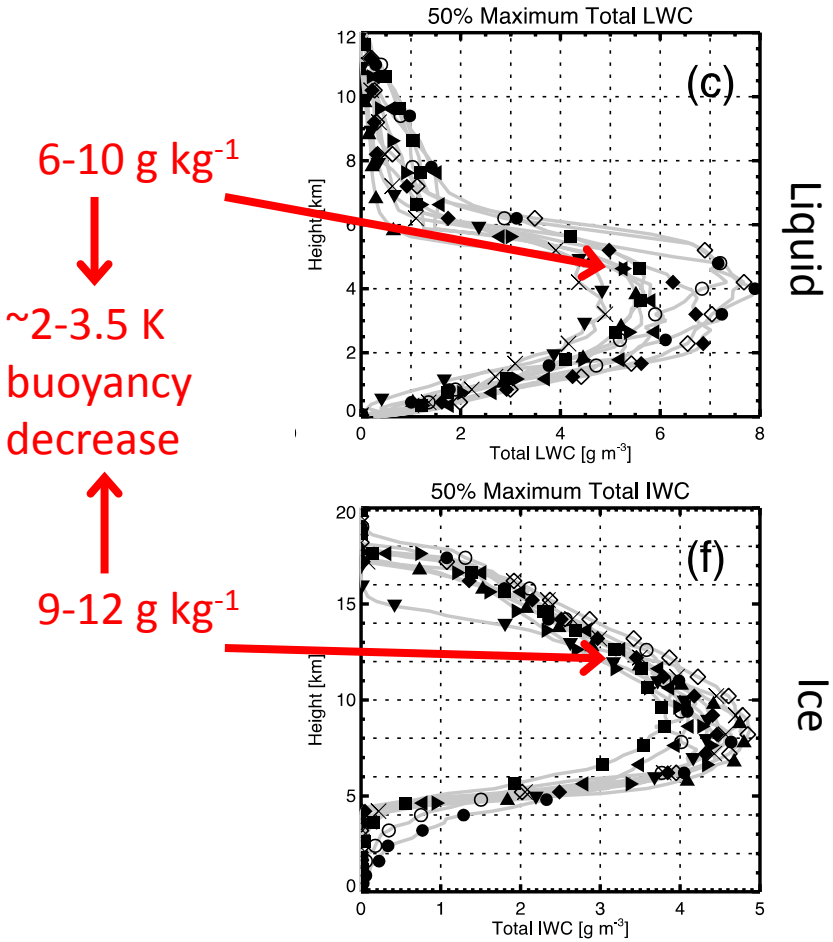
Deep convective updrafts have very high maximum condensate water contents in all CRM and LAM simulations

Large latent heating from freezing (2-4 K increase in temperature)

Large IWCs are lofted high into upper troposphere with fall speeds < 4 m s^{-1} and hence, advected over large regions → large convective area

How are these large condensate contents being produced?

Deep updraft median profiles of max. water contents



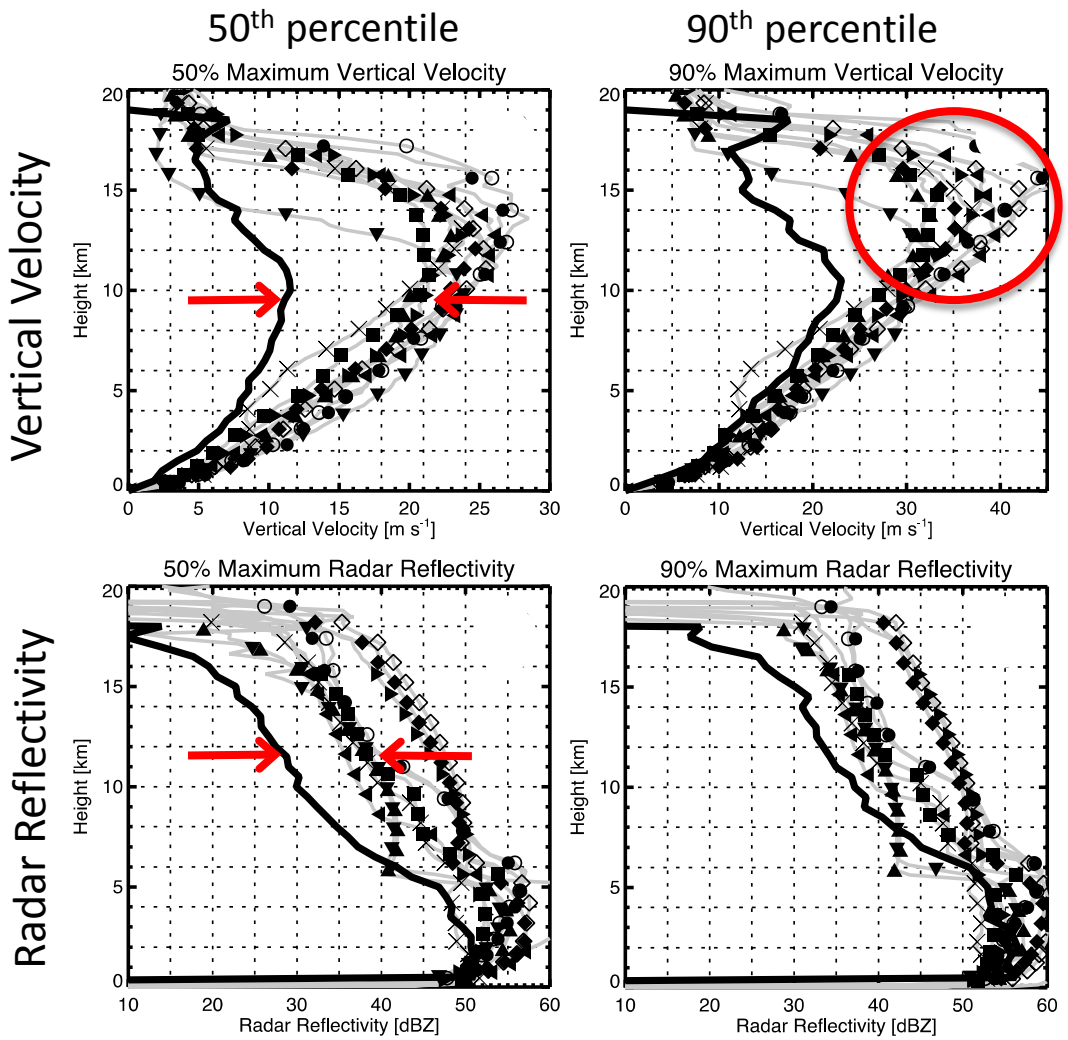
Dynamical Causes

Deep updrafts over 5-hour period during peak of event have higher vertical velocity than dual-Doppler retrievals, despite huge water loadings

Dual-Doppler retrieval shows strong updrafts, but not nearly as common

Large simulate w peak in upper troposphere likely related to excessive freezing of rain

Do we believe that such high water loadings exist in reality? If so, what prevents higher dBZ aloft and greater w aloft?



Tropical Convective Context

Large tropical oceanic w values observed at 6 km with substantial variability on scale of 100's of meters

Large (10 g m^{-3}) total water measurements (7 g m^{-3} of condensate) at 6 km trustworthy?

Mesoscale Events within a GATE Tropical Depression

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(Manuscript received 30 December 1977, in final form 7 March 1978)

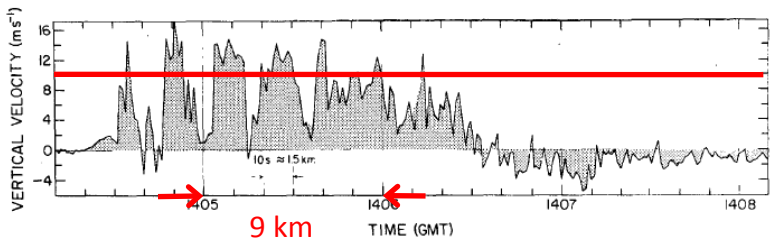

FIG. 14. Vertical velocity trace from C-130 showing cumulonimbus encounter while westbound along 14°N for 1404–1407 GMT 15 July 1974. Time resolution is 1 s.

Vertical Velocity Characteristics of Oceanic Convection

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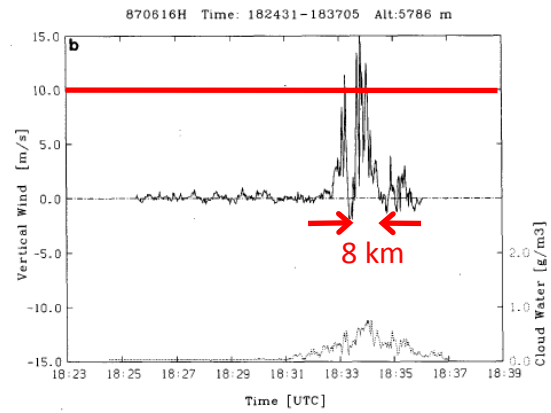
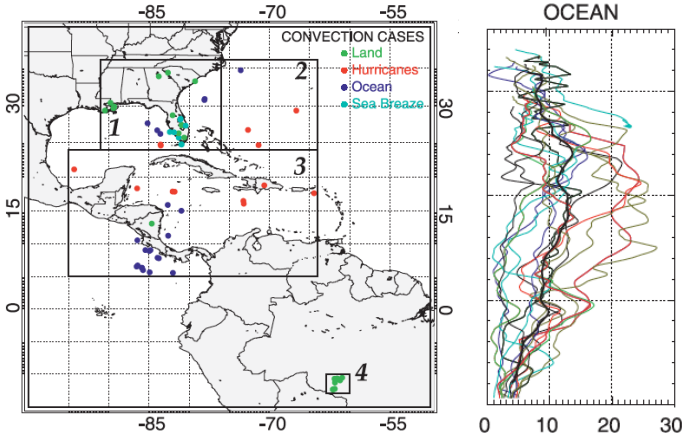
(Manuscript received 23 May 1988, in final form 11 August 1988)

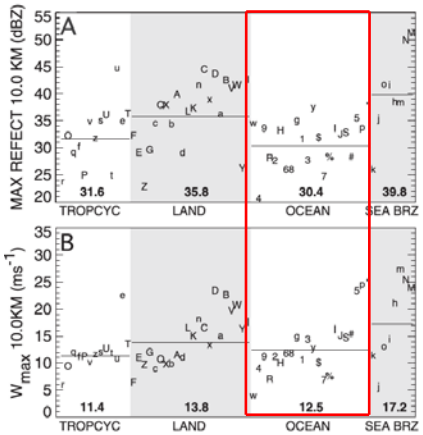


We need measurements with today's better instrumentation!
How common is this and in what environments does it occur?

Profiler and airborne Doppler retrievals of intense near coastal oceanic tropical convection fall in line with the TWP-ICE dual-Doppler retrieval at upper levels

Why are the simulated updrafts so consistently strong?





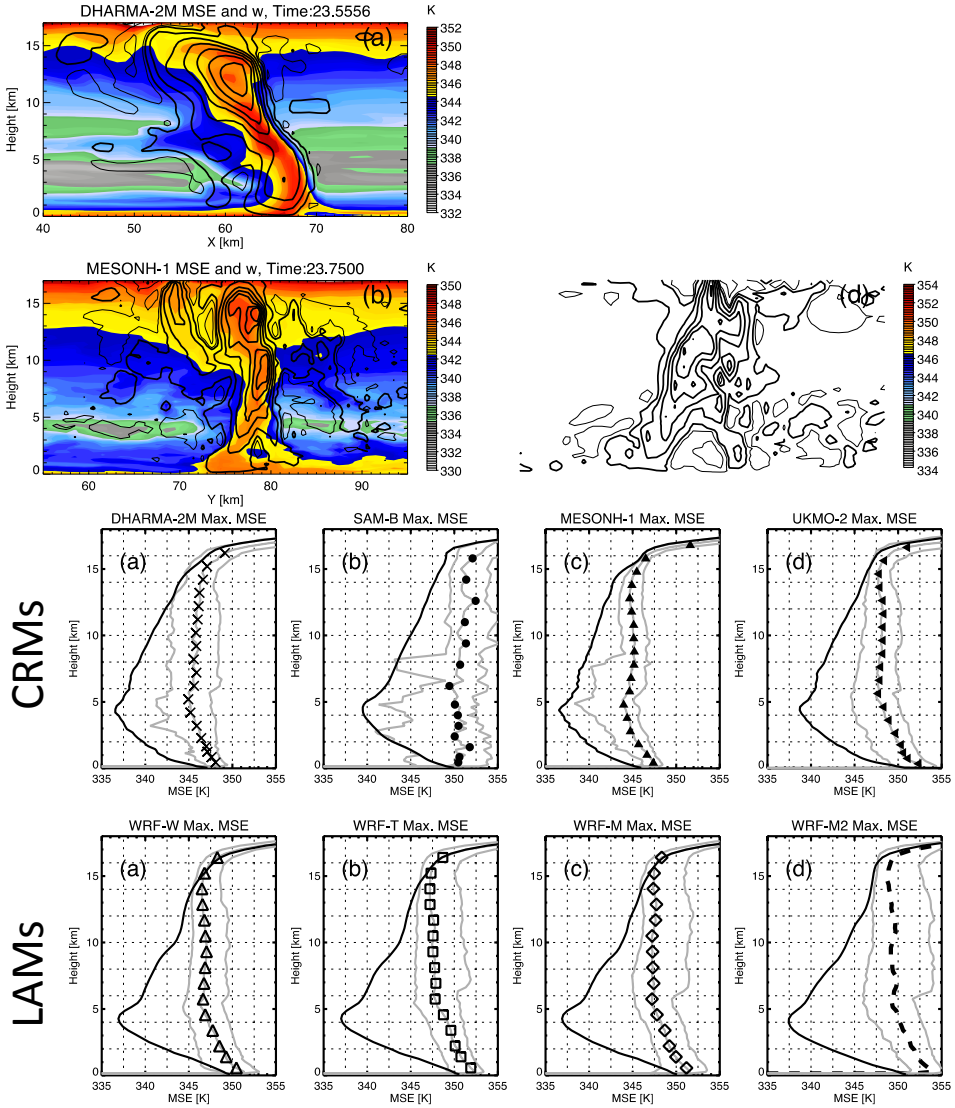
Heymsfield et al. (2010)

Is Entrainment the Problem?

Tropical oceanic convective literature cites the importance of warm rain unloading allowing continuation of the updraft at mid-levels in the face of appreciable entrainment.

Strong simulated updrafts continue at mid levels due to little entrainment in the face of appreciable water loading.

What allows minimal entrainment?



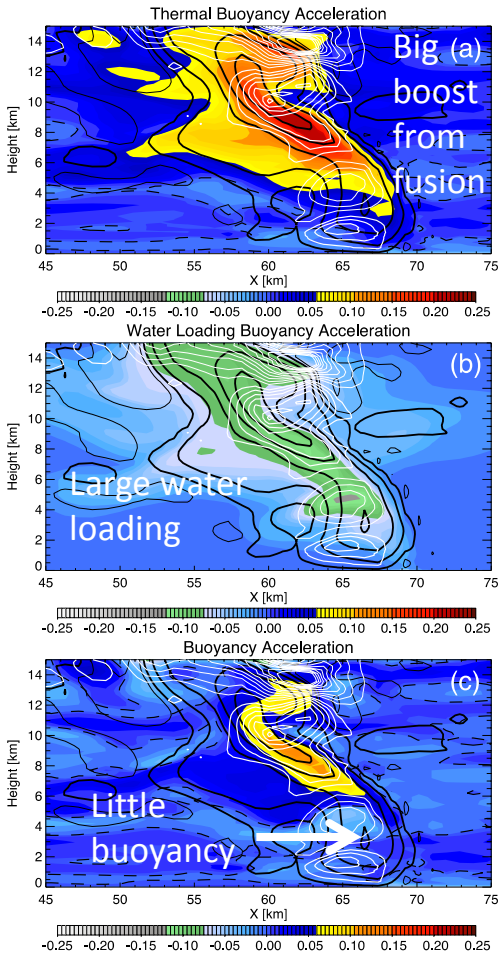
What produces large and nearly undilute updrafts?

Tilting and stretching of environmental vorticity in regions of low or negative buoyancy with some detrainment at mid levels

Strongly forced updrafts by mid-level dynamically produced negative pressure perturbations

Positive upshear pressure perturbation shields updraft

Even cells without the strong low-level pressure perturbation forcing produce substantial condensate aloft, so this is not the entire answer



What allows this in simulations, but not in observations?

Large-scale environment?

High mean CAPE and moderate mean 0-6 km vertical shear in both observations and models – perhaps variability across domain matters?

An idealized CRM setup is problematic for this MCS, which develops into a cyclone

A LAM setup is problematic because of errors in the analysis used to force the LAM

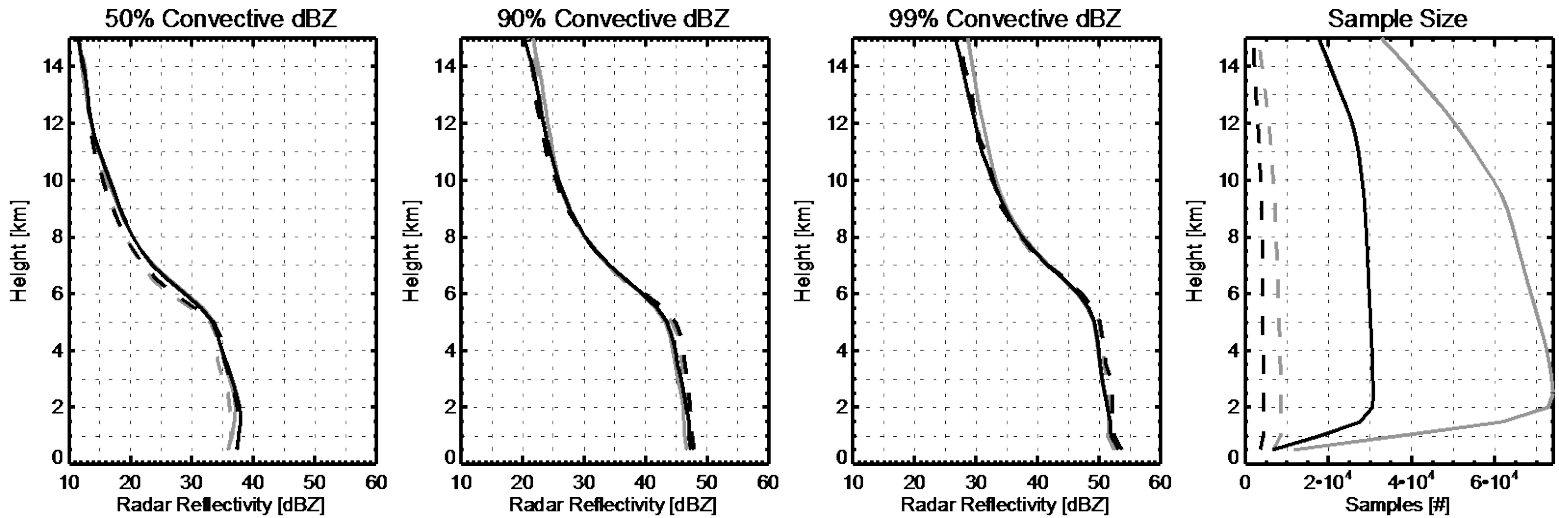
Large Eddy Entrainment?

Preliminary results from a 100 m quarter domain run by Ann Fridlind do not show much improvement aloft, even though convection entrains a bit more, producing shedding thermals in broad areas of rising motion

Combination of factors leading to feedbacks that cause a shift in dynamical-microphysical regimes?

Need more observations to start constraining the issues – MC3E is a great start

Some Conclusions

- Microphysics assumptions modulate simulated radar reflectivity differences and probably lead to some errors w.r.t. observations
- Strong updrafts are too common in simulations, which also likely contributes to convective biases and weakens stratiform region development, but the causes of such regularly strong updrafts need more investigation
- Dynamics and microphysics have to be examined together because of their major impacts on each other that can cause regime shifts, especially in weak to moderate convection in clean environments
- MC3E will act to solidify or weaken current conclusions with superior observational retrievals

Representativeness of dual-Doppler domain