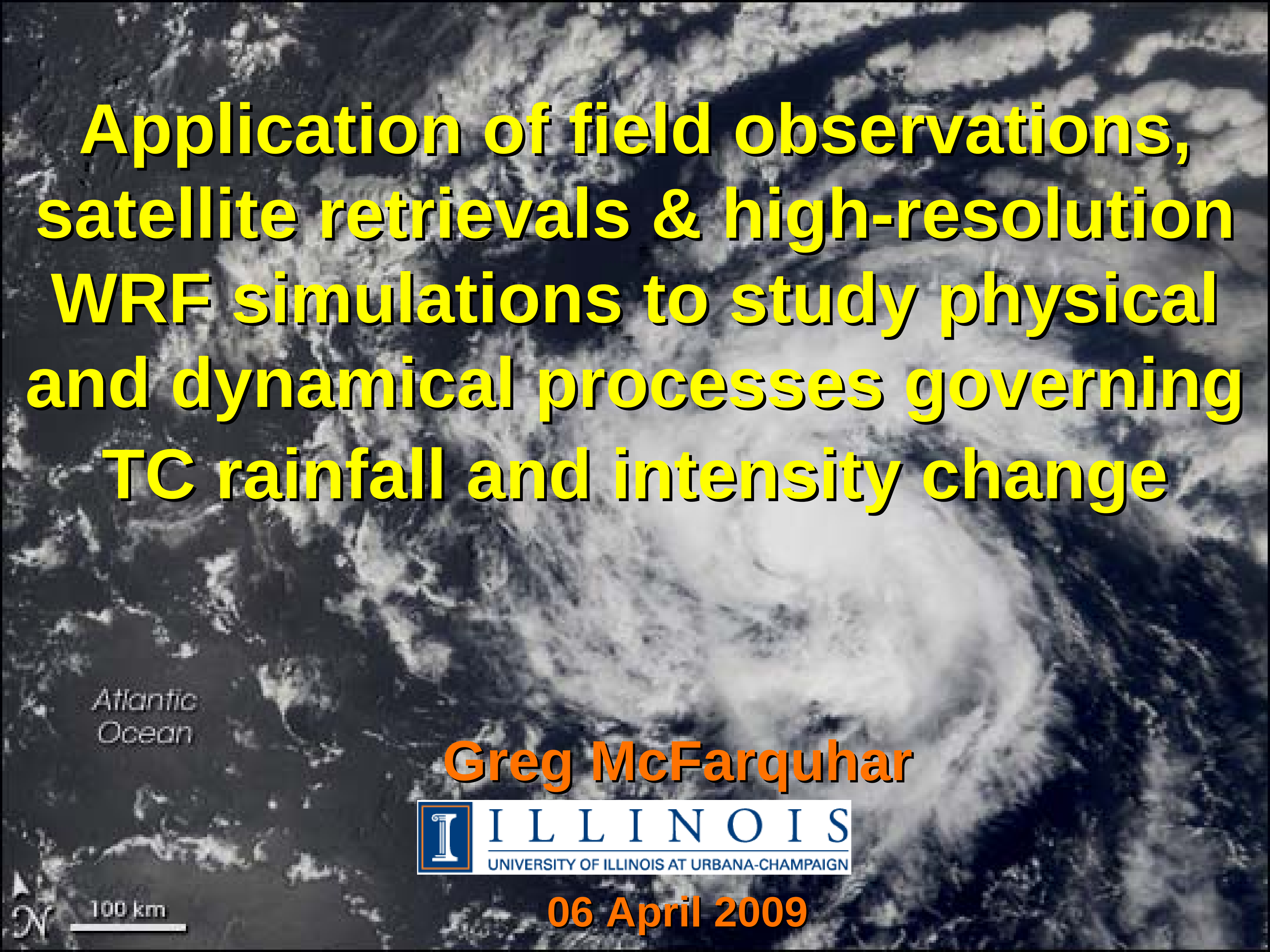
Application of field observations, satellite retrievals & high-resolution WRF simulations to study physical and dynamical processes governing TC rainfall and intensity change



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- **Amanda Dooley, Matt Freer, Brian Jewett, Eric Meyers, Steve Nesbitt, and Eric Schneider - University of Illinois**
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- **Henian Zhang - Georgia Tech University**
- **Paul Lawson and Brad Baker - SPEC Inc.**
- **Andy Heymsfield - NCAR**

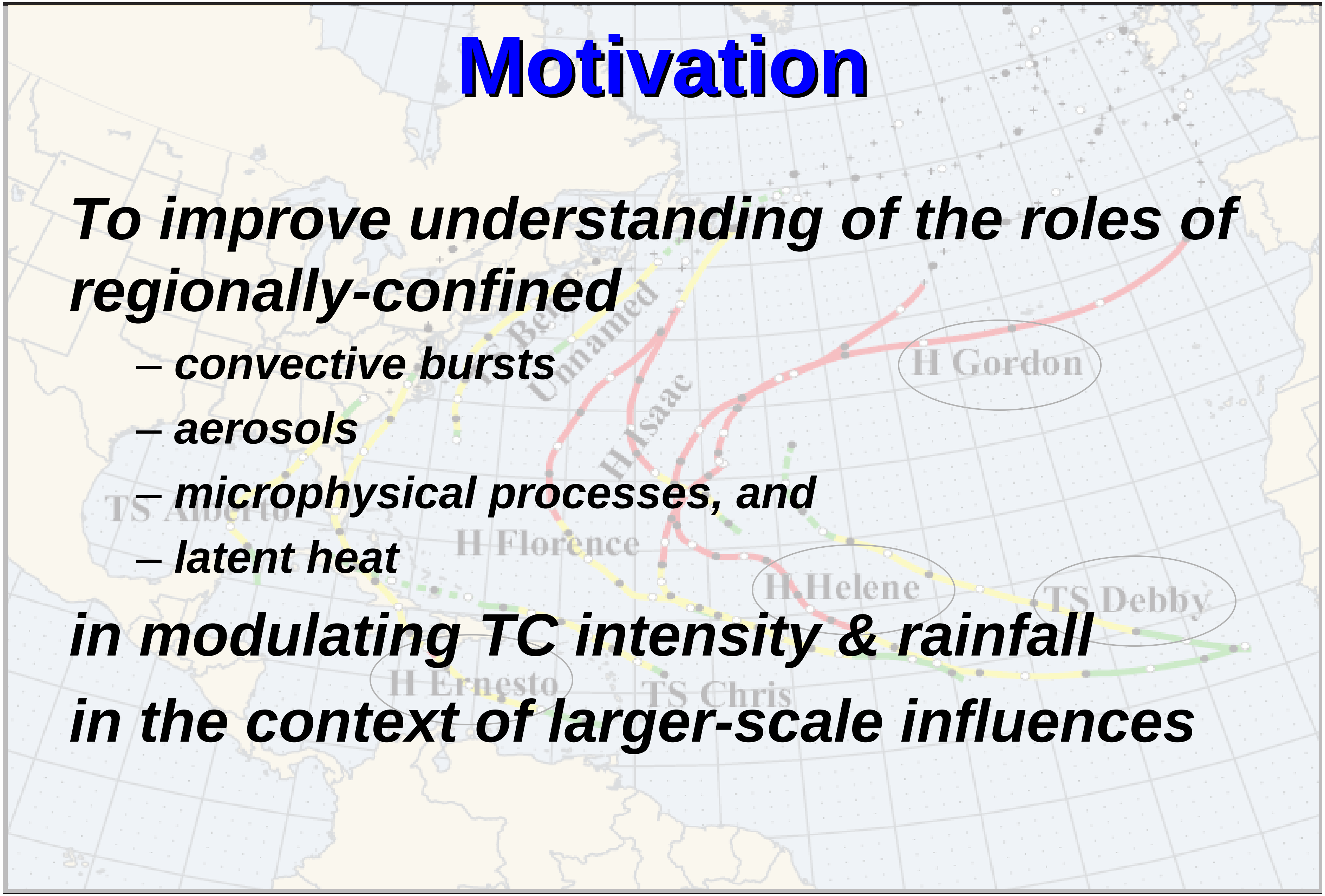
Motivation

To improve understanding of the roles of regionally-confined

- ***convective bursts***
- ***aerosols***
- ***microphysical processes, and***
- ***latent heat***

in modulating TC intensity & rainfall

in the context of larger-scale influences



Addressing role of clouds in TCs

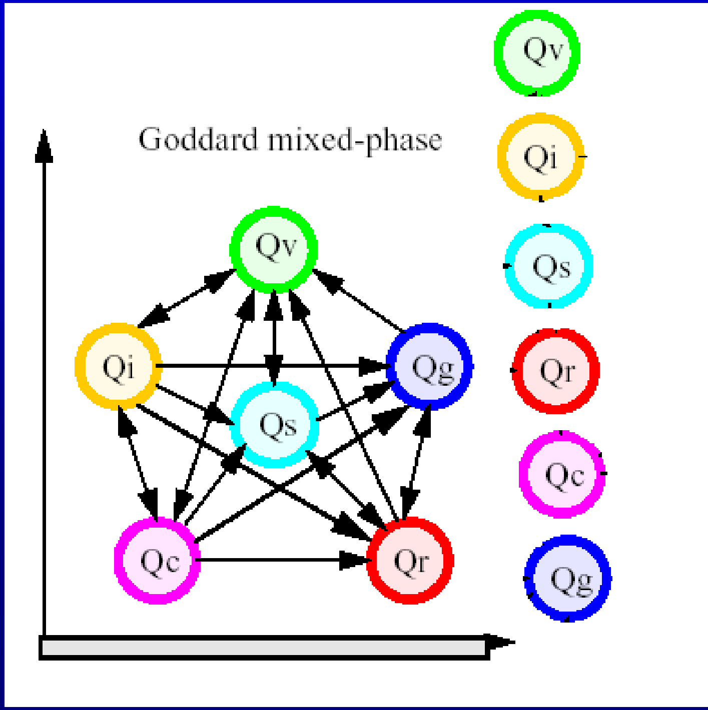
1. In-situ TC observations to improve the representation of microphysics in mesoscale models
2. WRF simulations to examine the relationships among convective up/downdrafts, microphysics, and TC rapid intensity change
3. Microwave & radar observations to examine the role of microphysical structure, precipitation production on the morphology of TCs.
4. RAMS simulations to examine the role of SAL on TC evolution through role as CCN, GCCN and IN

Projects using TCSP and NAMMA data

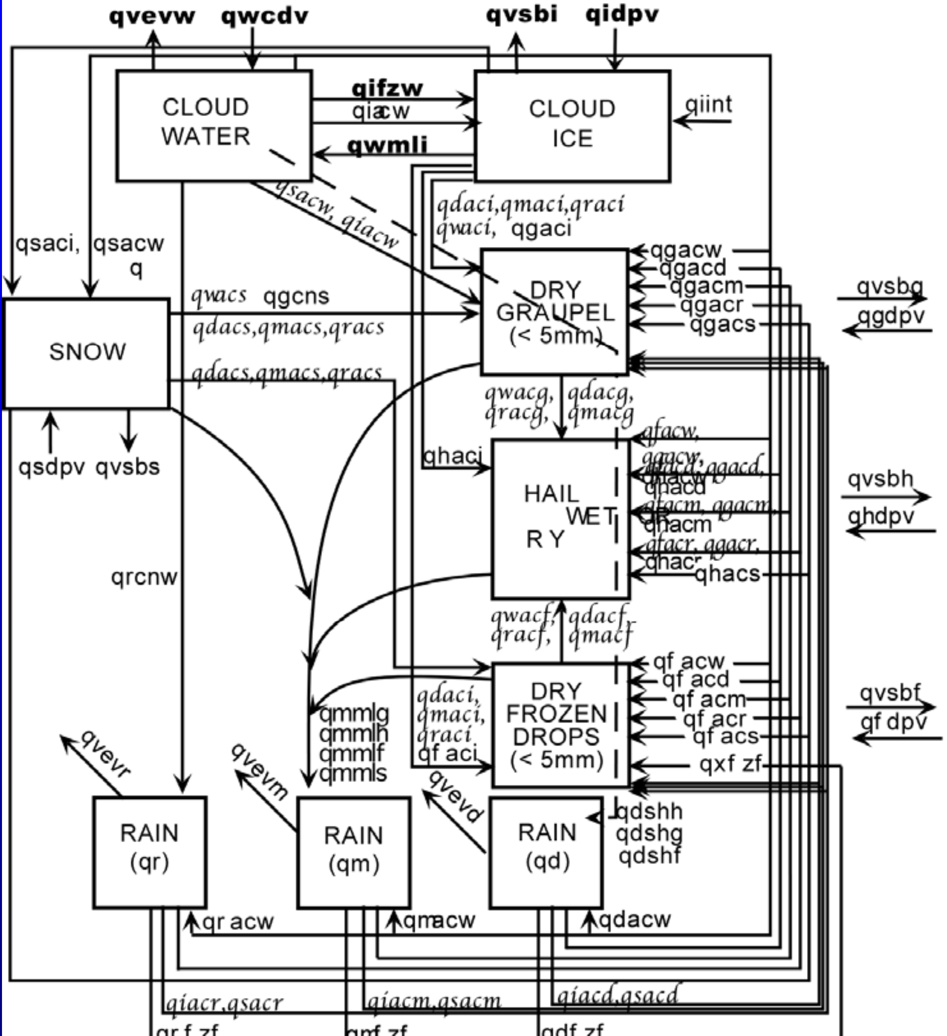
What models need from in-situ data

Parameterization schemes predict 1 or 2 moments of the size distribution for a variety of hydrometeor categories

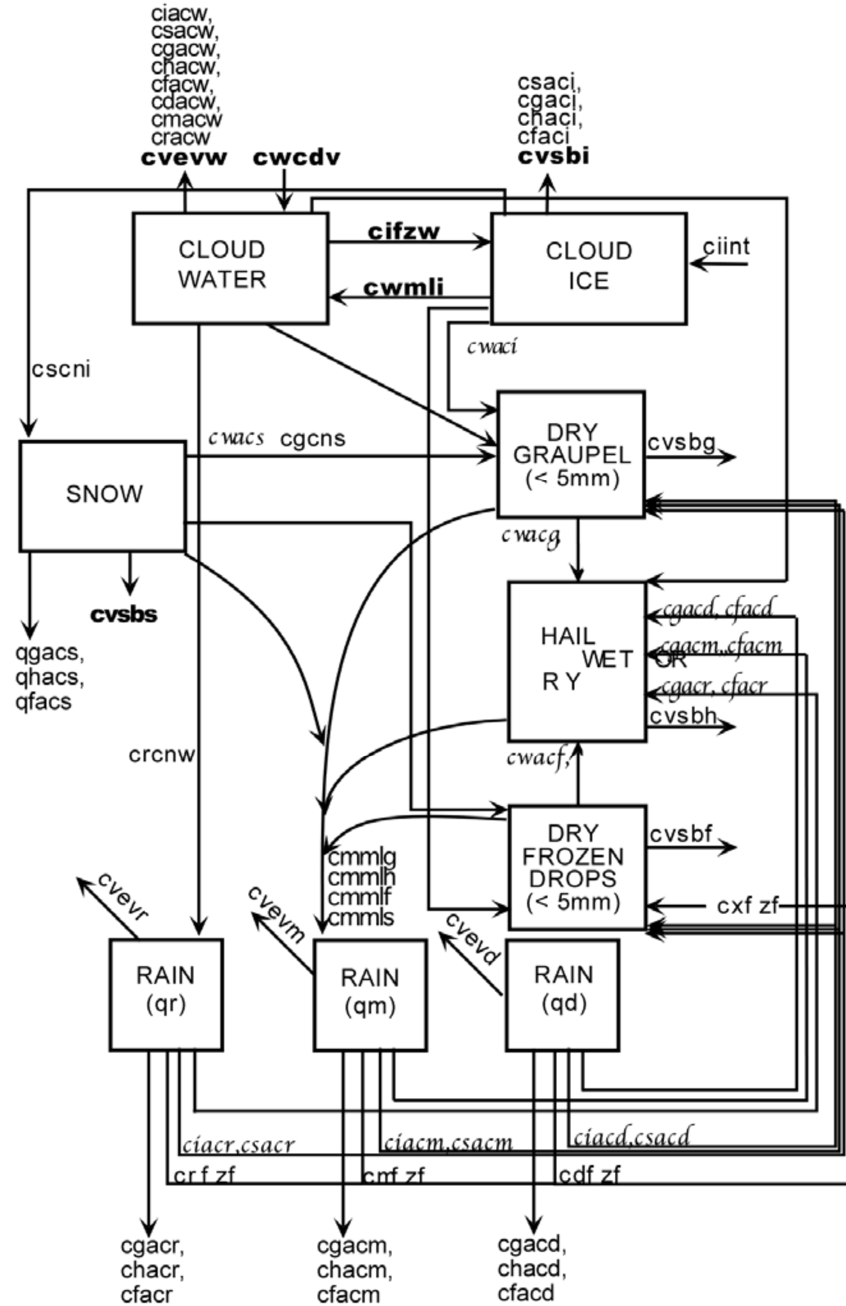
Schemes require information about cloud microphysics to accurately calculate conversion rates between species



MIXING RATIO RATES



CONCENTRATION RATES



Straka and Gilmore 2006

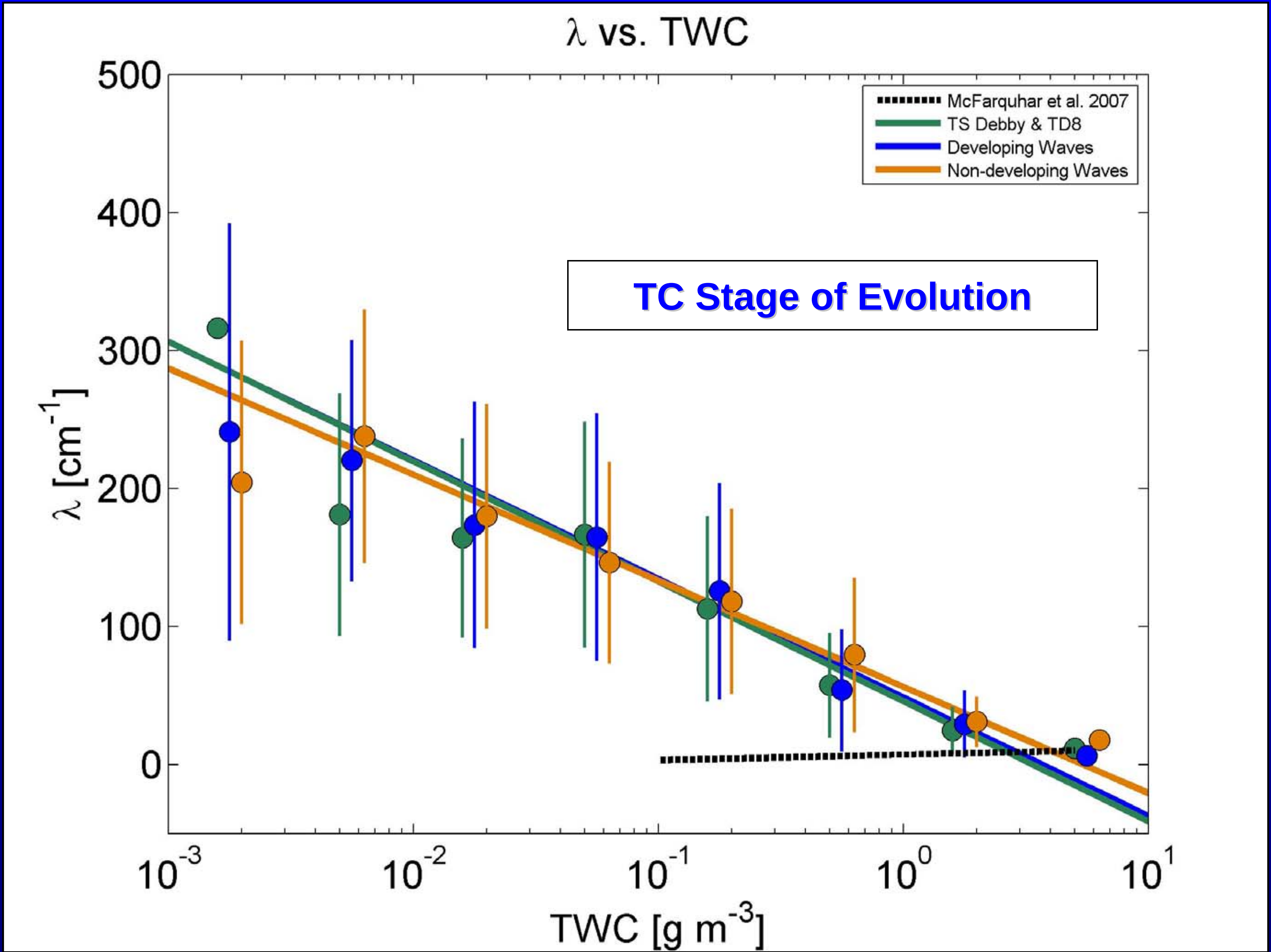
What models need from in-situ data

- Fits to SDs $n(D) = N_0 D^{\mu} e^{-\lambda D}$
- Shape & phase of particles
- Crystal fall speeds, $V = aD^b$
- Mass/diameter relations, $m = \alpha D^{\beta}$
- Single-scattering properties (g, ω_0, P_{11})
- Collision/collection efficiencies

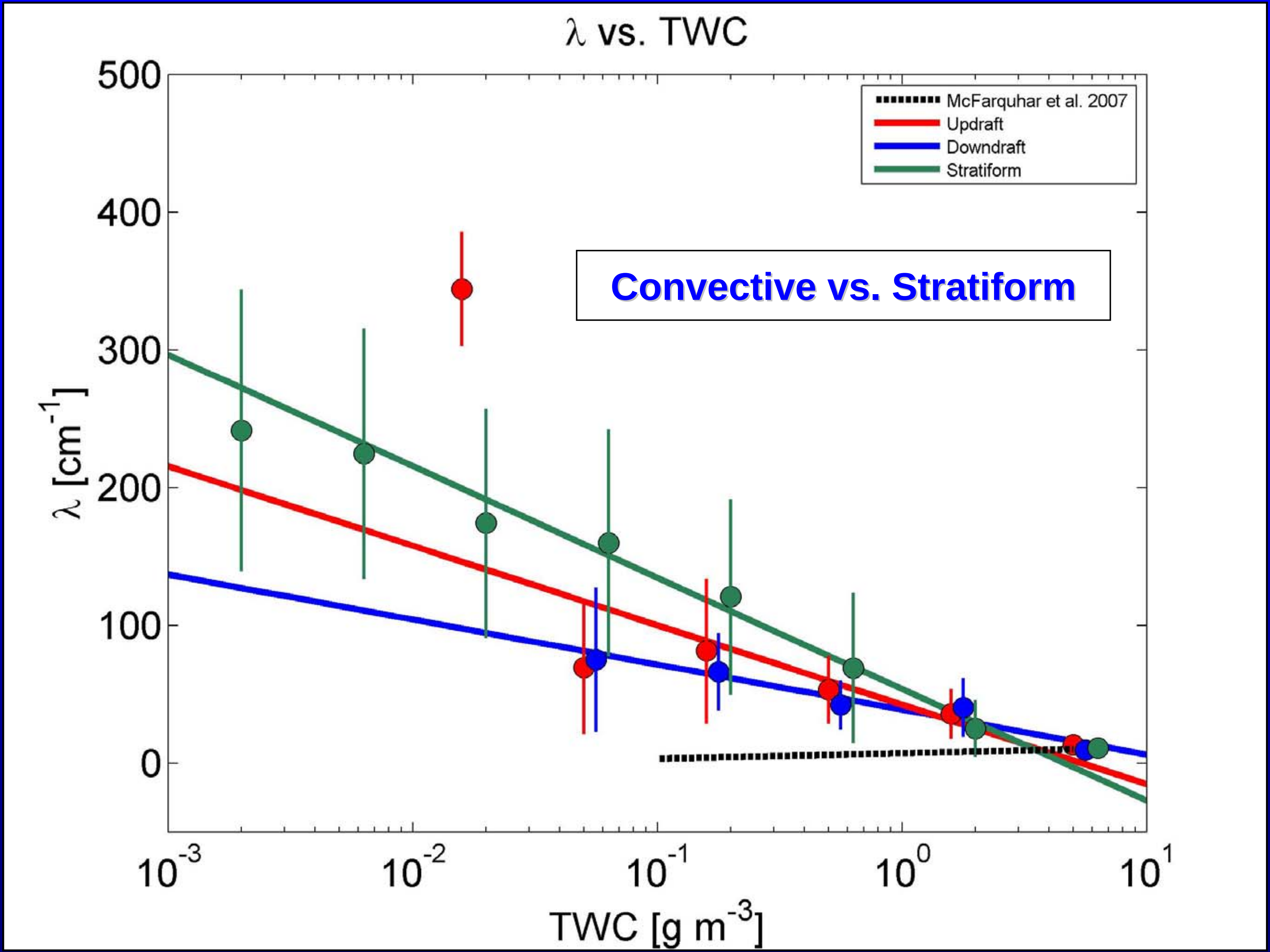
Do these coefficients vary depending on type of system, location, or life cycle of hurricane?

NAMMA: Different Storms sampled

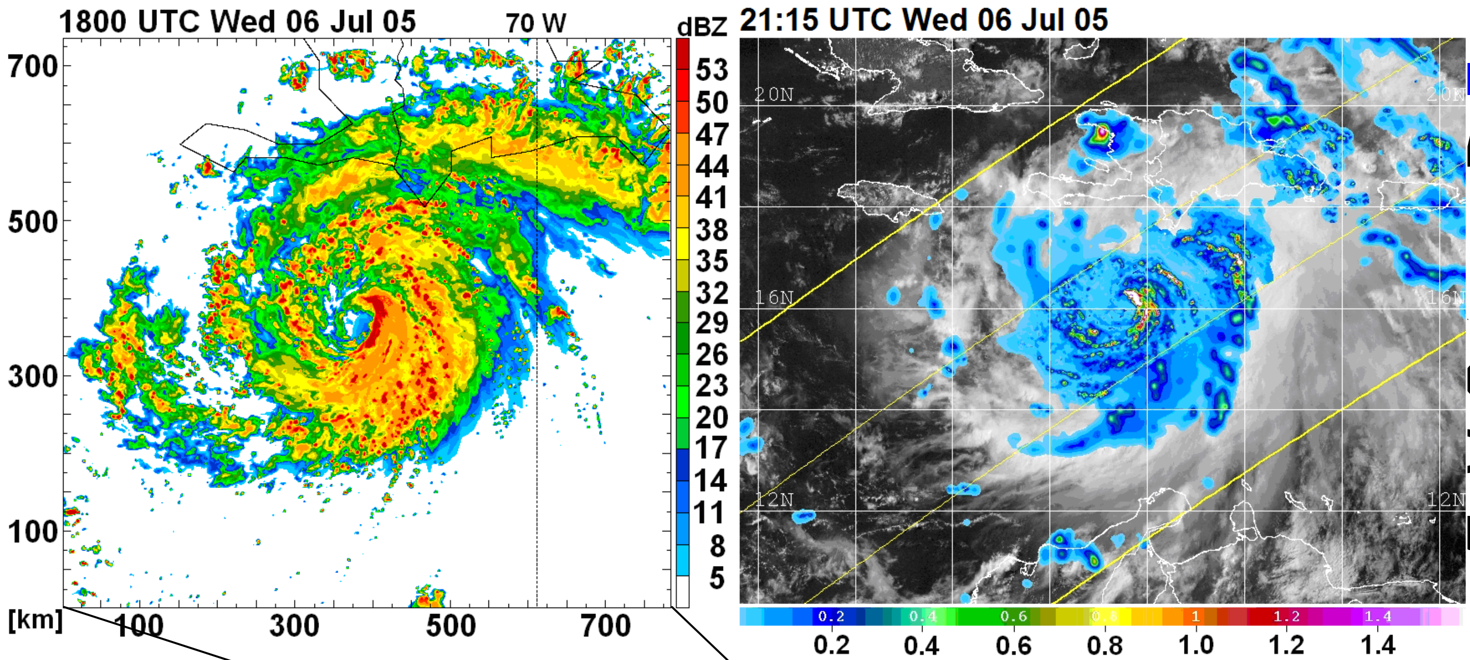
Category & Name	# of days of data
Tropical Storm Debby	1
Tropical Depression 8 (H. Helene)	1
Developing Waves (2): Pre-Ernesto Pre-Gordon	4
Non-Developing Waves (3)	4
Total	10



λ vs. TWC
McFarquhar et al. 2007
TS Debby & TD8
Developing Waves
Non-developing Waves
TC Stage of Evolution
500
400
300
200
100
0
λ [cm^-1]
10^-3
10^-2
10^-1
10^0
10^1
TWC [g m^-3]


λ vs. TWC
500
400
300
200
100
0
λ [cm^-1]
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
TWC [g m^-3]
McFarquhar et al. 2007
Updraft
Downdraft
Stratiform
Convective vs. Stratiform

Dennis 2005 WRF Simulations



W, v3.0.1

vortex

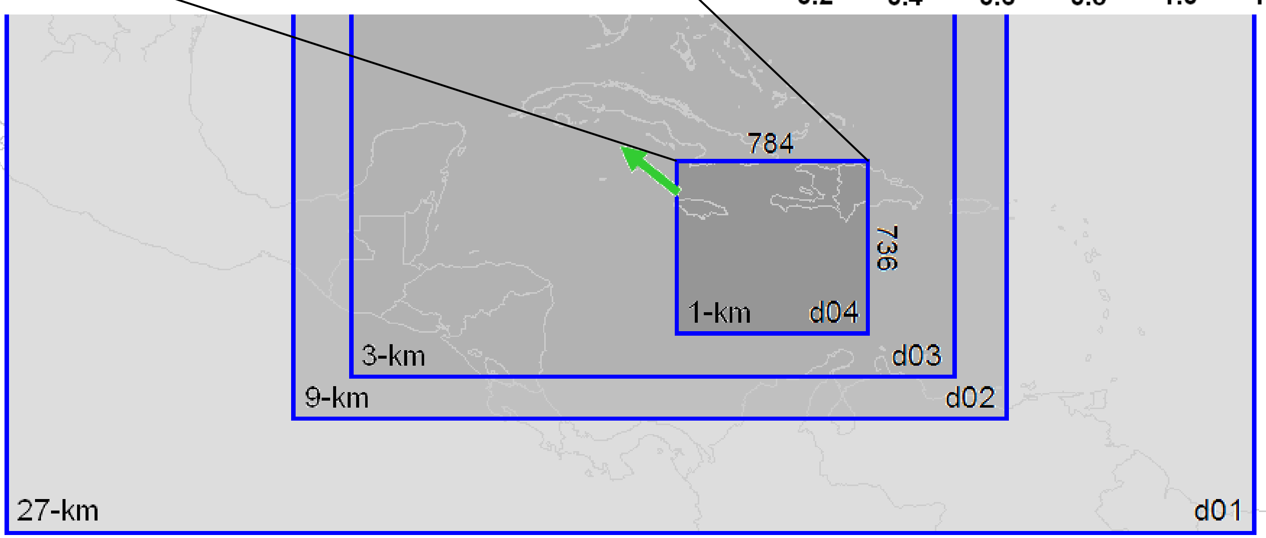
ing

evels

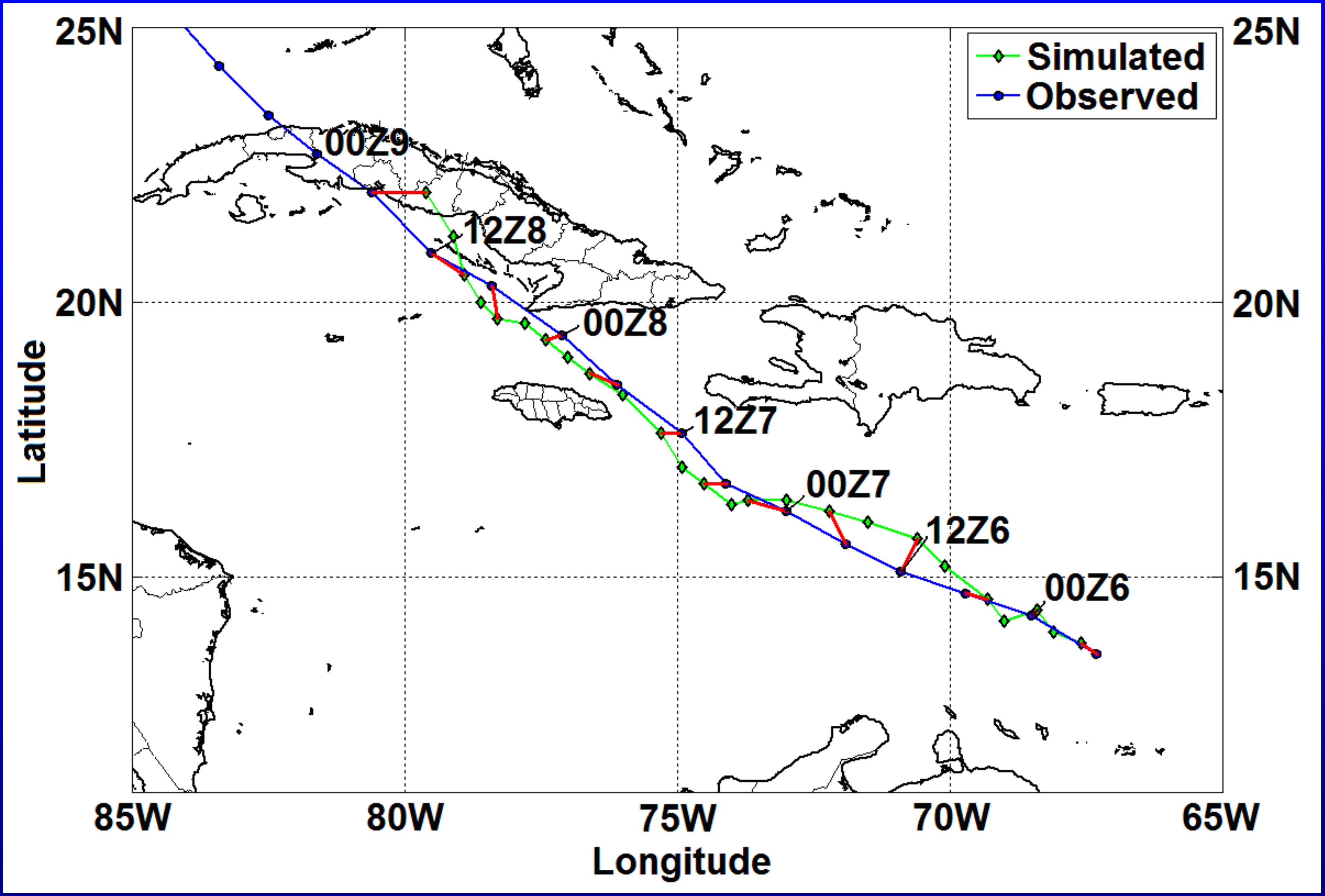
L/GFS initial

undary

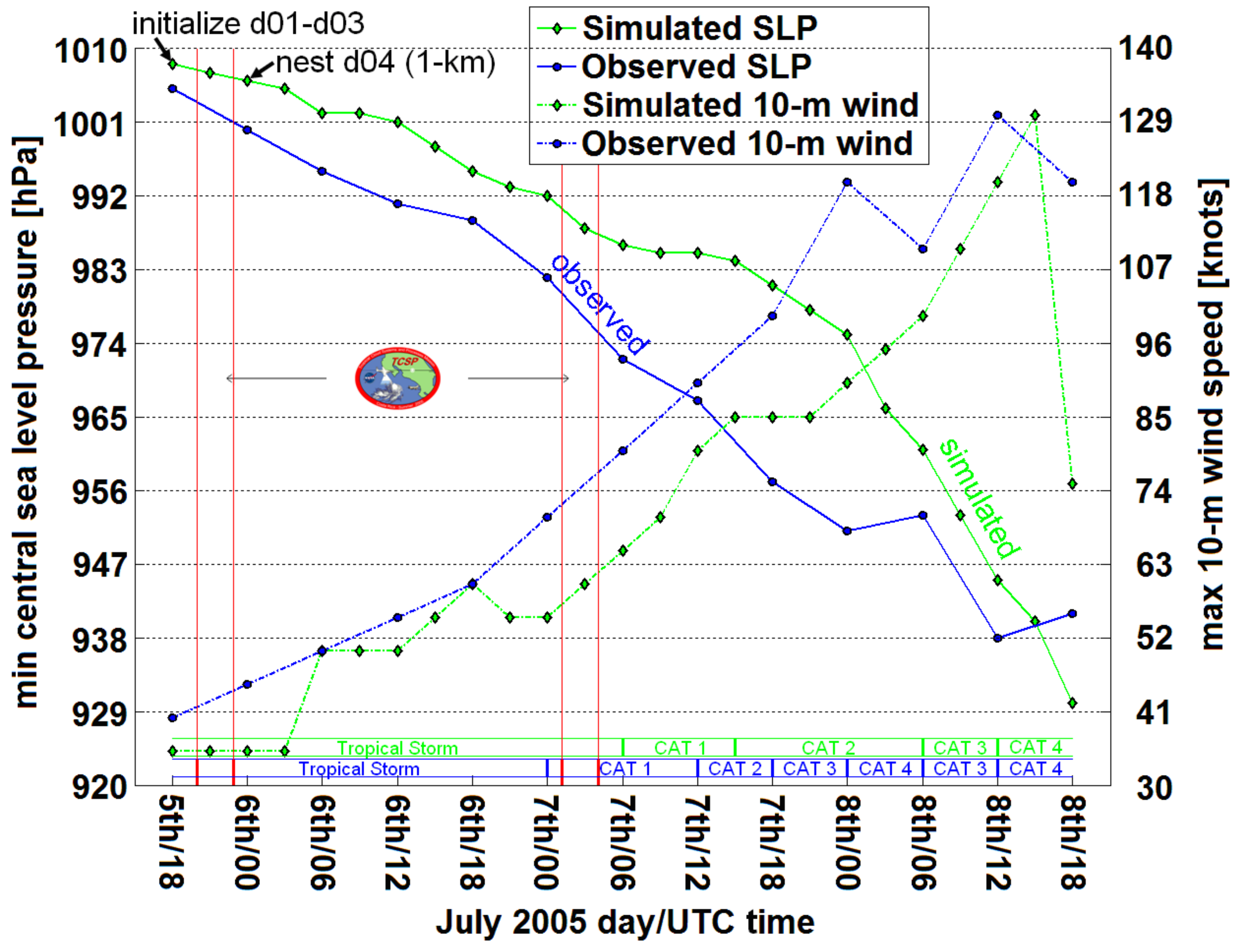
itions



- d01-d03 u,v 4-D data assimilation
- Thompson '07 microphysics
- d01 Kain-Fritsch
- Yonsei PBL scheme



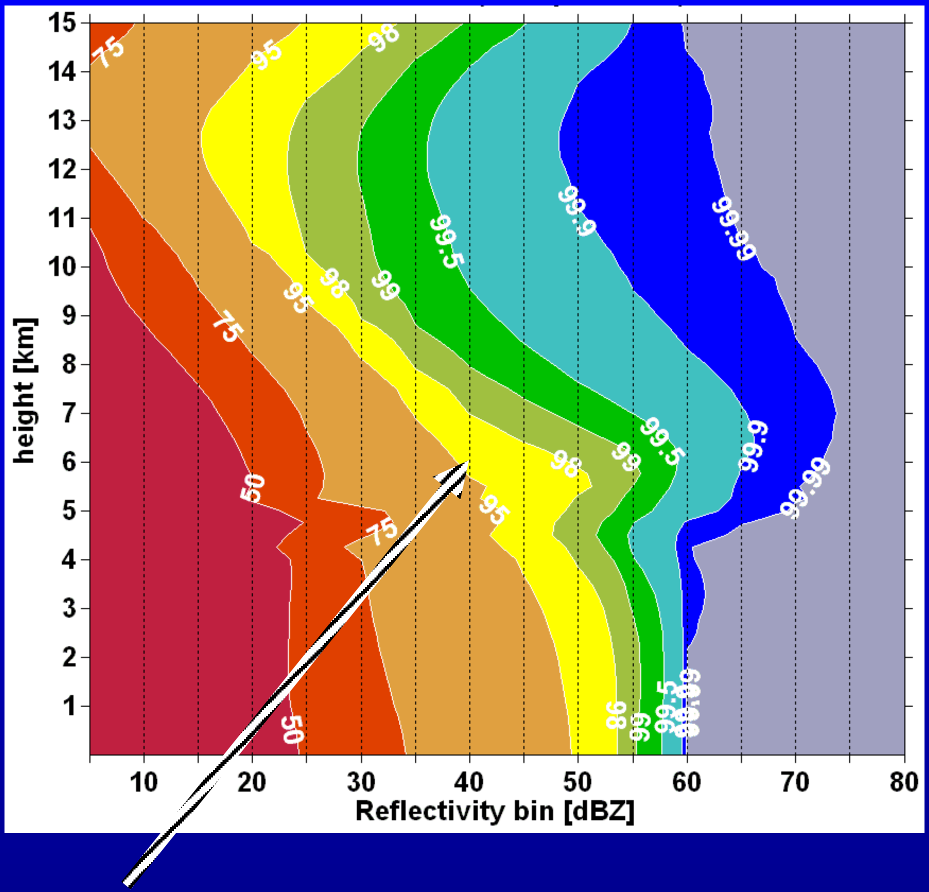
Reasonable simulation of track needed for accurate simulation of intensity…



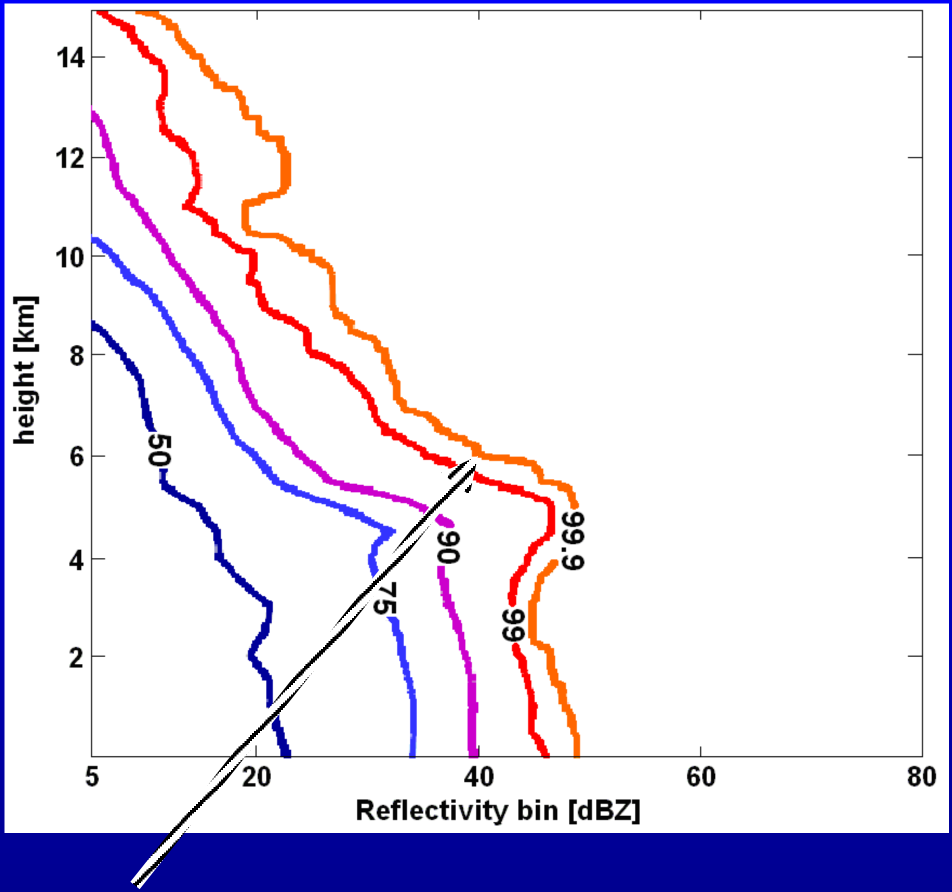
…which, in turn, provides a basis for evaluating simulated rapid intensification in the context of TCSP observations

Example Comparison during CAT 1 (07 July IOP) Stage

Model-derived



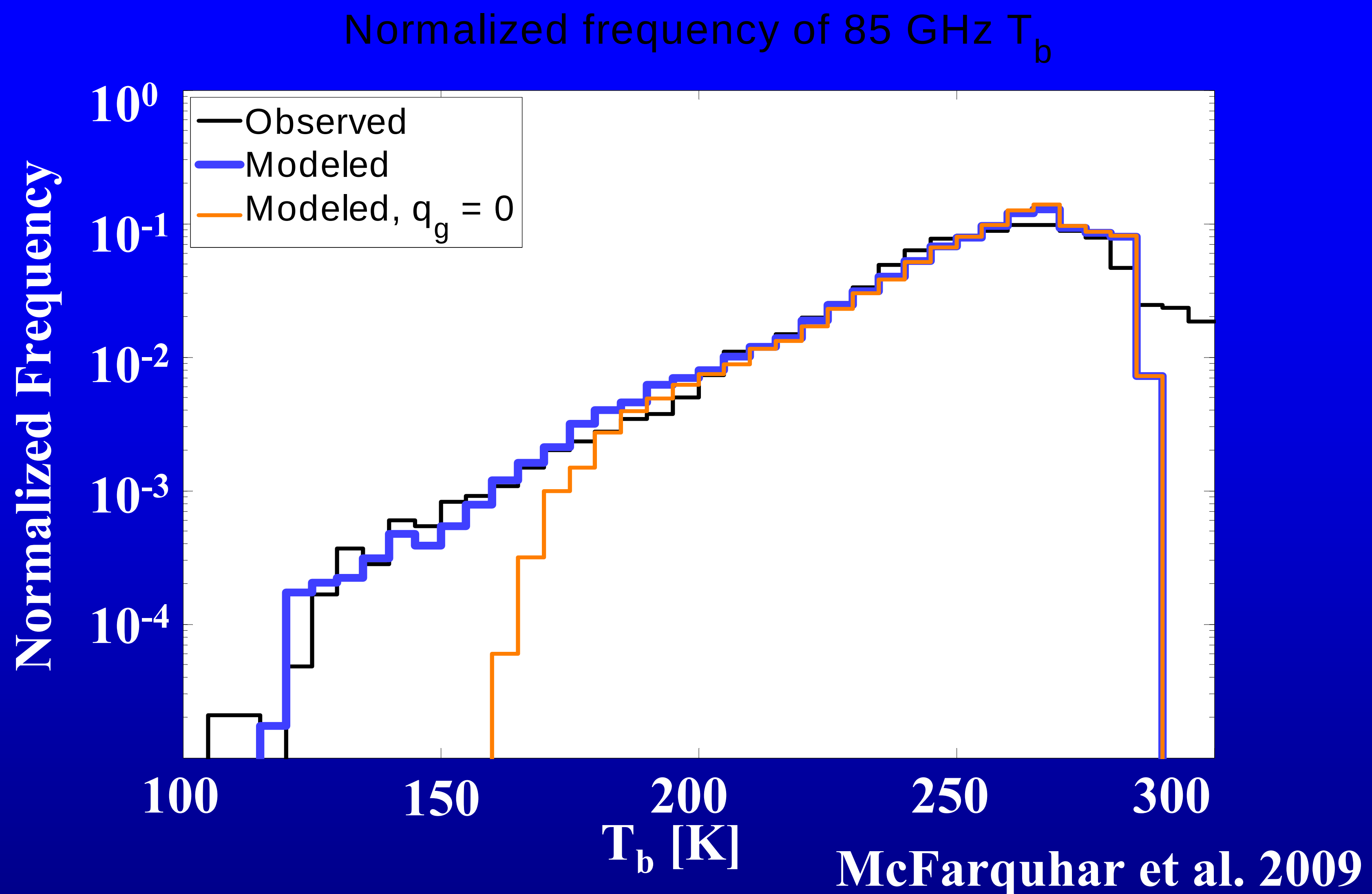
Observed (EDOP)



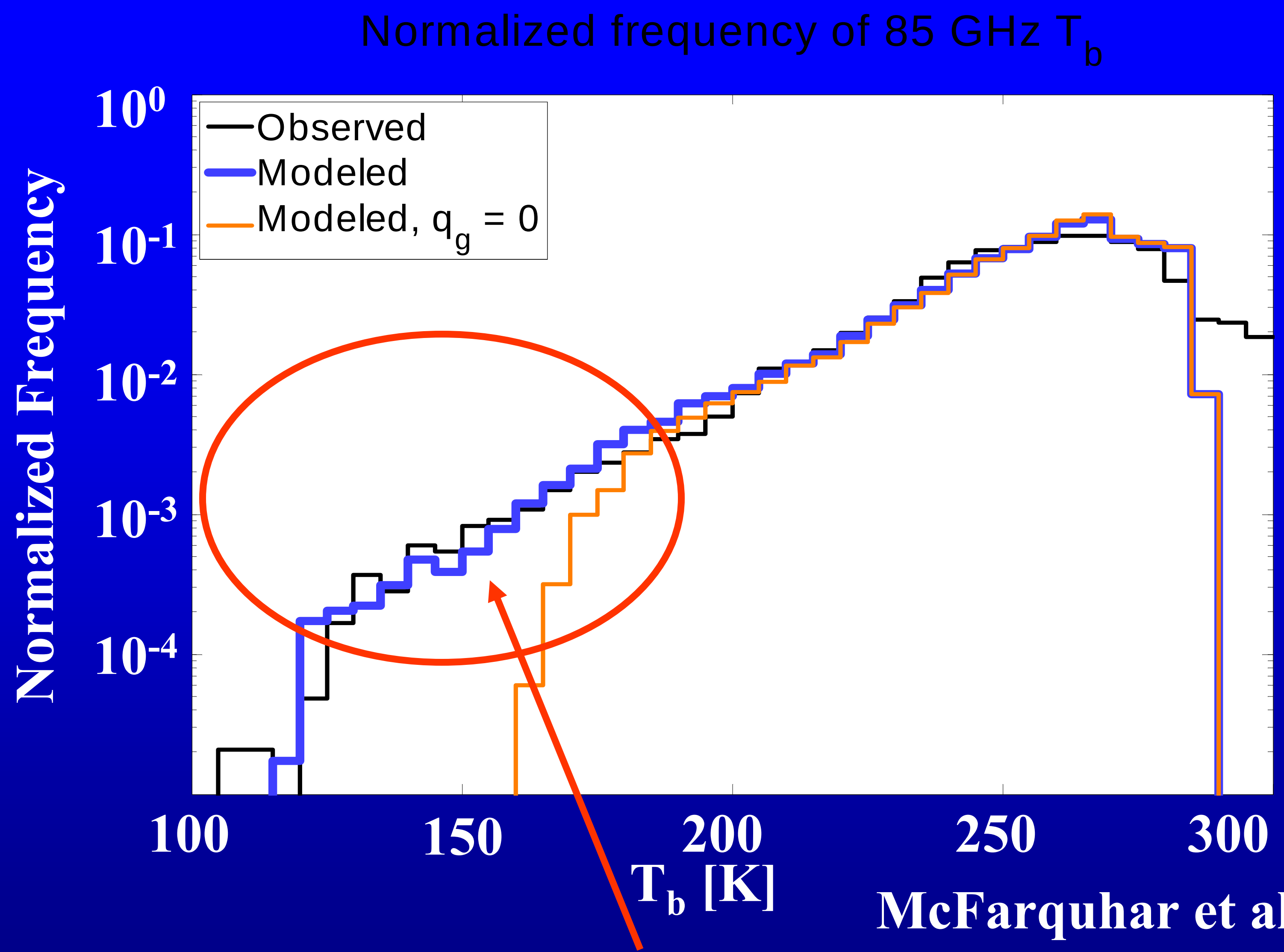
4.6% of Z > 40 dBZ at 6 km

0.1% of Z > 40 dBZ at 6 km

Simulation exhibits overprediction of large Z, better evaluated by regional partitioning



Normalized frequency of 85 GHz T_b
Observed
Modeled
Modeled, q_g = 0
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
Normalized Frequency
100
150
200
250
300
T_b [K]
McFarquhar et al. 2009

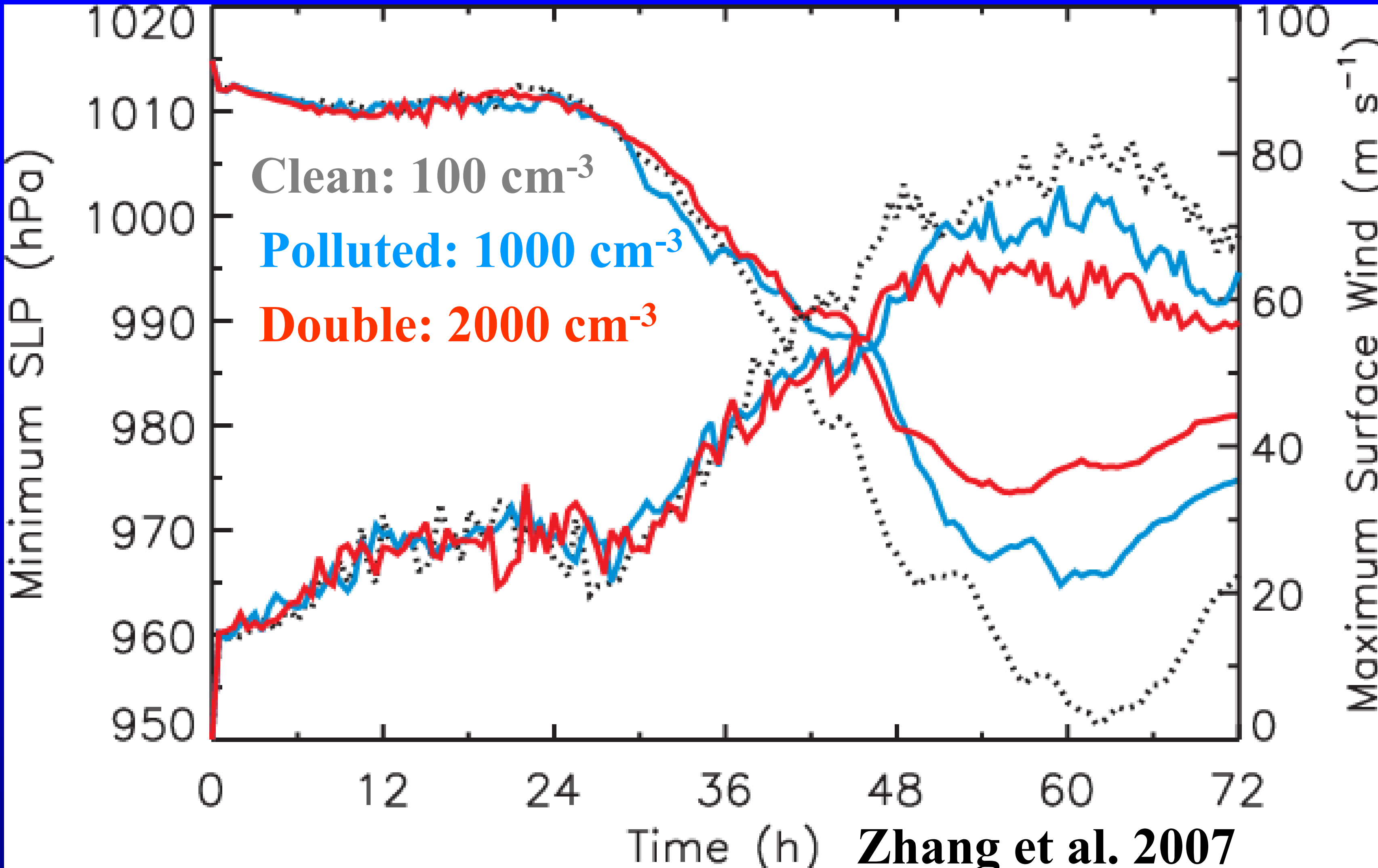


McFarquhar et al. 2009

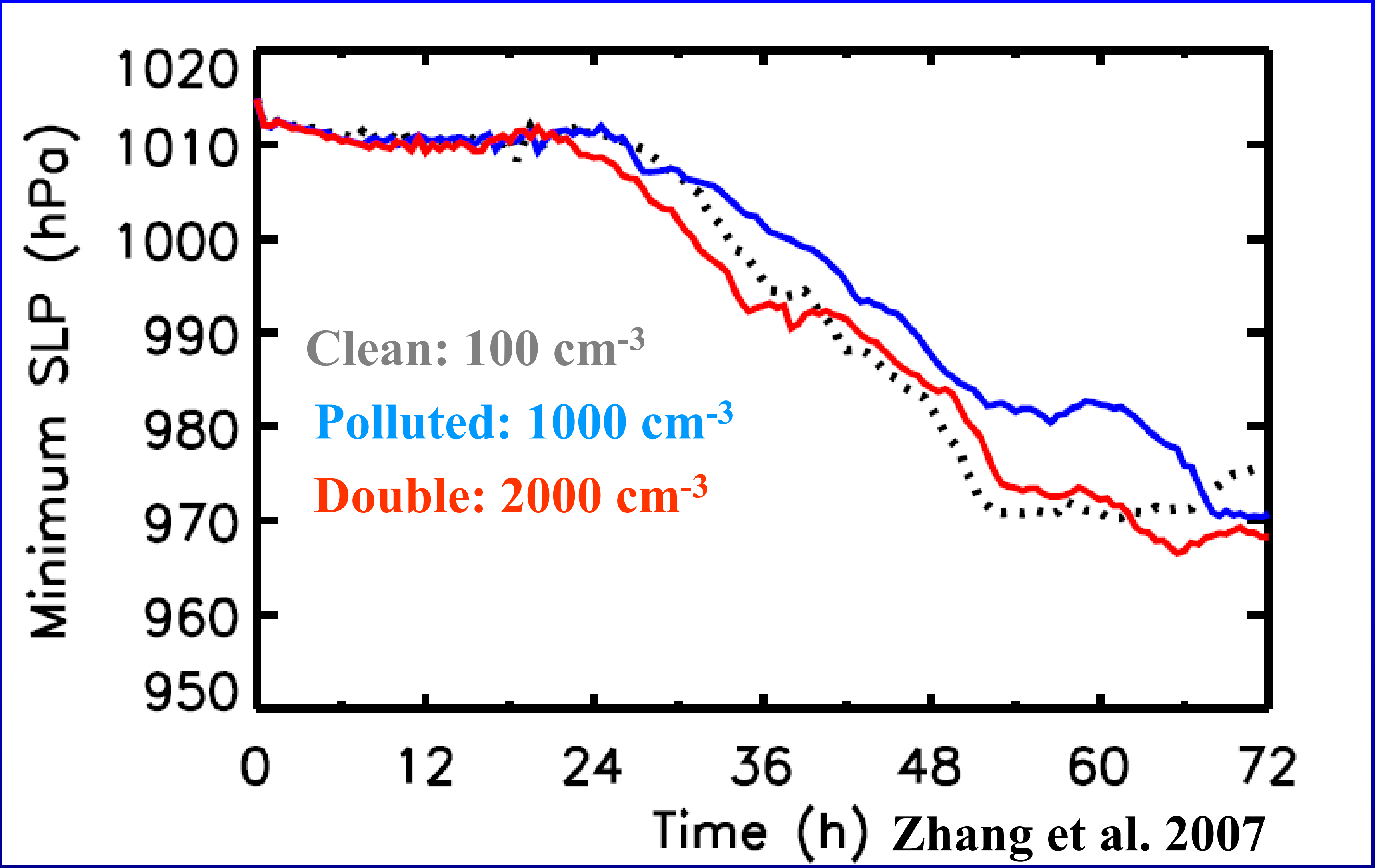
Our earlier simulations of Dennis (with Thomson μphysics) showed observed & simulated T_b at 85 GHz match much better than our simulations of Hurricane Erin

Effect of SAL (as CCN) on TCs

- SAL affects TCs by increasing stability, wind shear & temperature inversion
- Does it have an effect acting as CCN?
- Idealized simulation with RAMS
- Double-moment microphysics
- Δx = 2 km
- Mean Atlantic hurricane sounding
- Add CCN at varying stages in life cycle
- Zhang et al. (2007 and 2009)

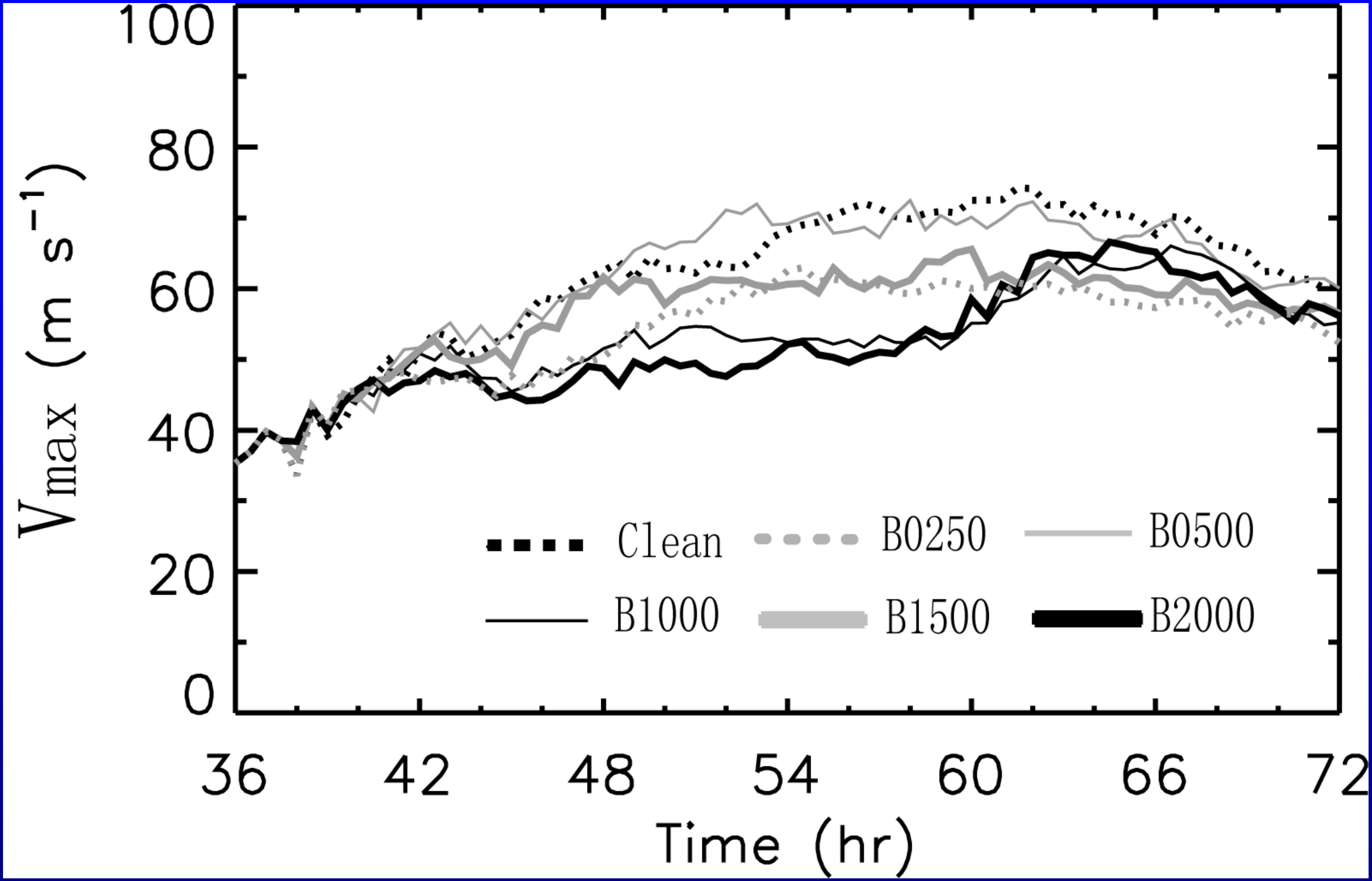


For base simulations, it appeared that increasing CCN reduces storm intensity



BUT, simulations with different input profile do not show same trends in how CCN affected storm intensity

→ Need to understand how CCN modifies storm



When adding CCN to mature TC, still no clear trend in how CCN affect TC intensity

Zhang et al. 2009

- **CCN affect eyewall *directly* through latent heat release & *indirectly* by modulating rainbands**
- **Convection in rainbands negatively correlated with that in eyewall.**
- **Rainband development released latent heat away from eyewall, blocked surface inflow & enhanced cold pools.**
- **Maximum impact of rainbands on eyewall had time lag of 3.5 - 5.5 hr.**
- **Convection in eyewall & rainbands not monotonically related to input CCN due**

Microwave retrievals and radiative transfer, TC structure and intensity

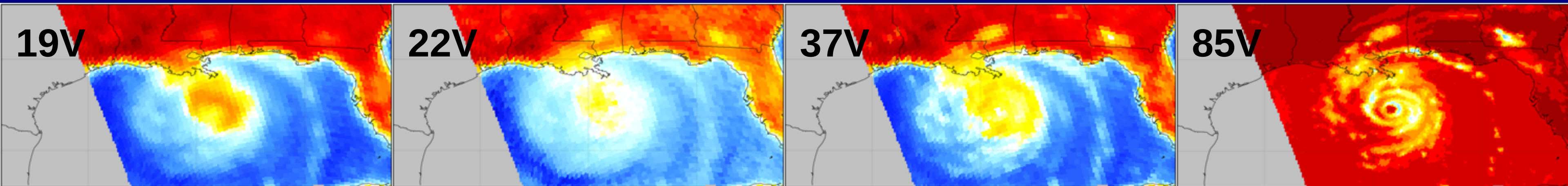
Forward modeling of WRF-simulated TCs

- Examine PMW precursors of TC intensity change as simulated by WRF, link to modeled physical processes

- Use database of TC microphysical data collected in NASA hurricane experiments to examine sensitivity of RTM simulations to assumed PSD's

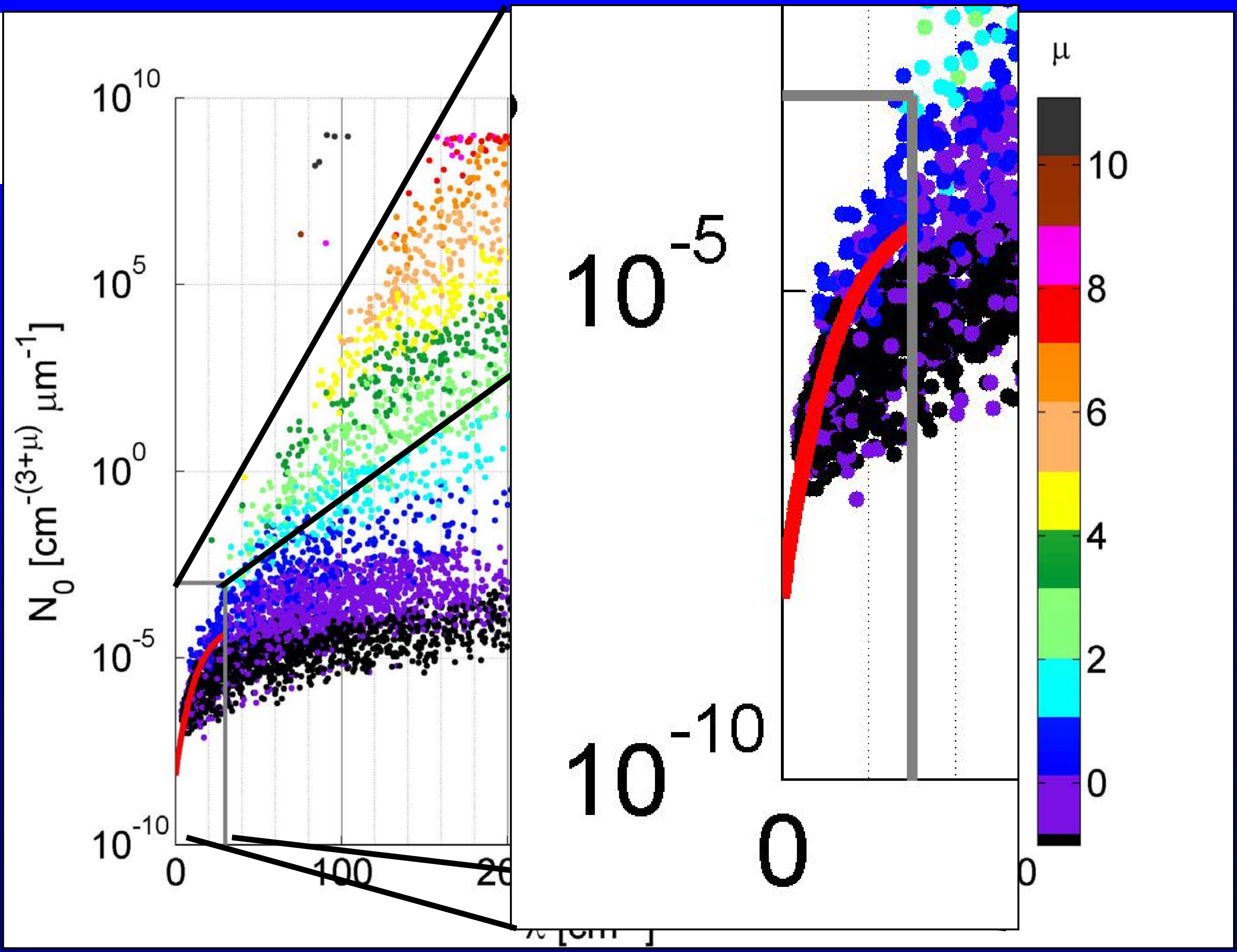
Advanced data mining of TC PMW structures

Quantitatively identify structures related to TC intensity change in PMW imagery (NCDC HURSAT-MW database)



Summary

- Analysis of in-situ data refining constants used in parameterization schemes
- WRF simulations of hurricanes
  - Evaluated against observations to test parameterized hydrometeor distributions
  - Analyzed regionally to asses the role of microphysical processes associated with convective bursts in driving rapid intensification
- Study of SAL impact on TCs through role as CCN offers no clear cut relation
  - Non-linear feedbacks complicate understanding cause/effect relation
  - Case studies needed



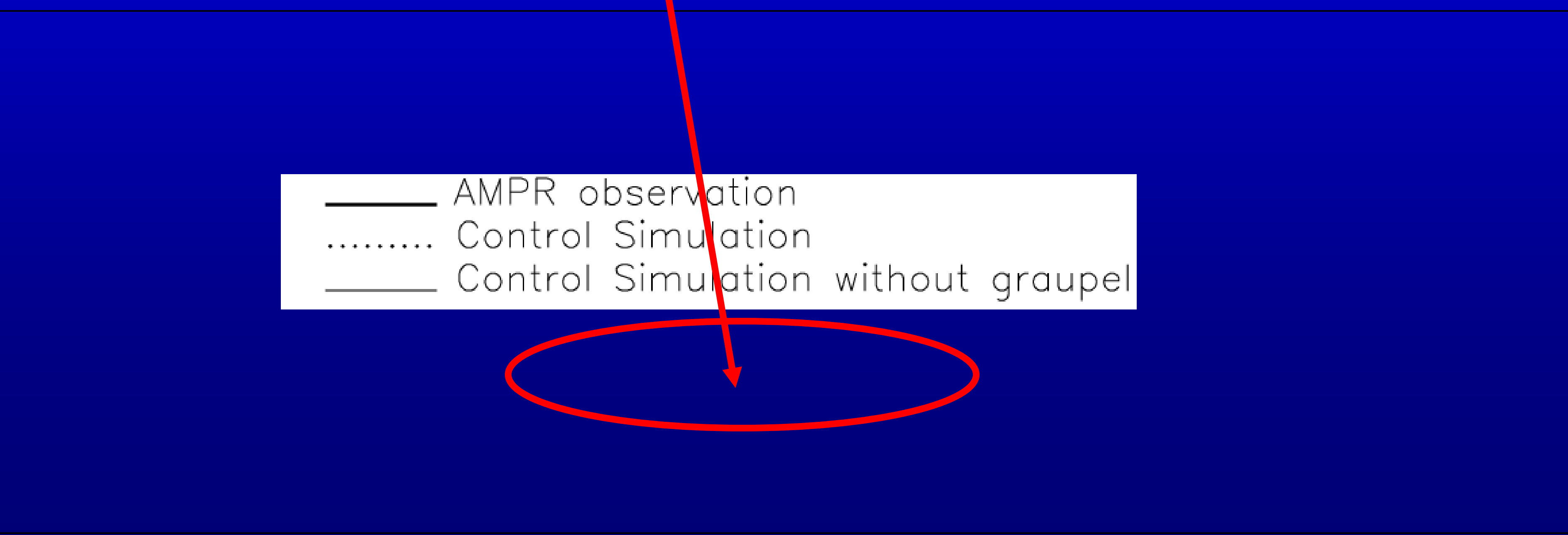
10^{10}
10^{5}
10^{0}
10^{-5}
10^{-10}
N_0 [$cm^{-(3+\mu)}$ μm^{-1}]
0
100
10^{-5}
10^{-10}
0
μ
10
8
6
4
2
0

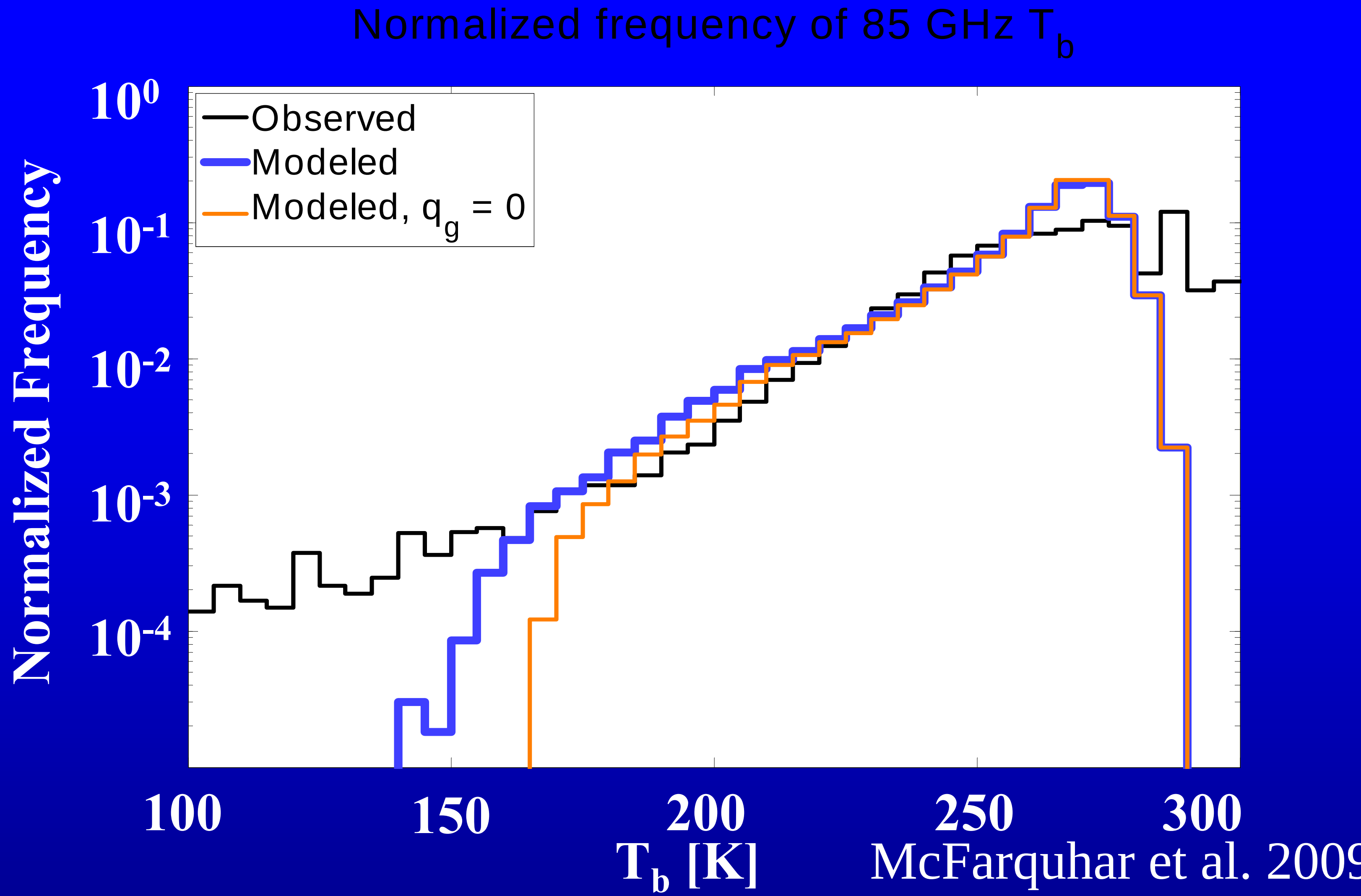
Problem with graupel?

- Our MM5 simulations of Hurricane Erin 2001 showed graupel over-prediction by comparing simulated T_b with that observed by AMPR during CAMEX-4

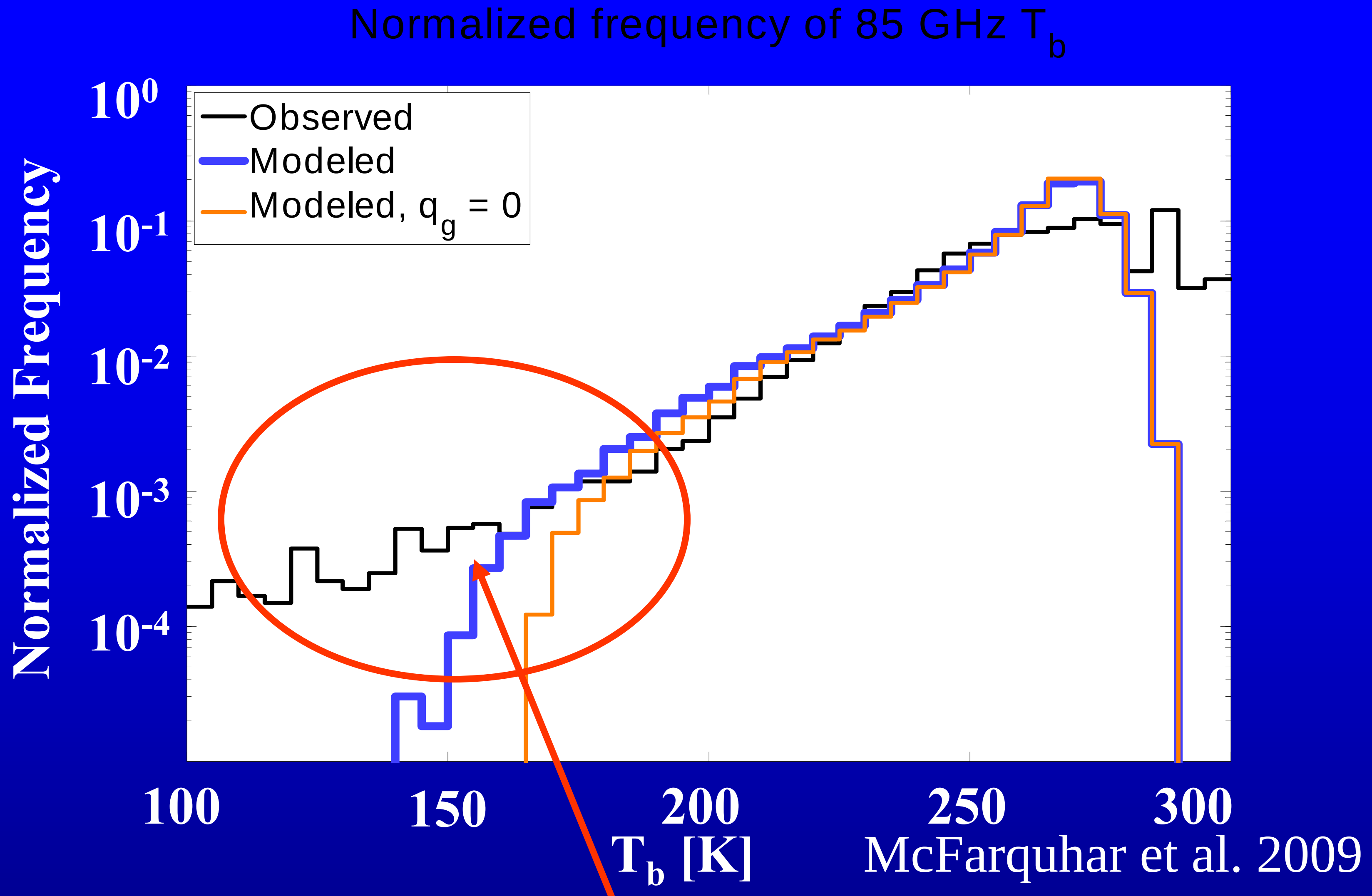
Problem with graupel?

- **Our MM5 simulations of Hurricane Erin 2001 showed graupel over-prediction by comparing simulated T_b with that observed by AMPR during CAMEX-4**





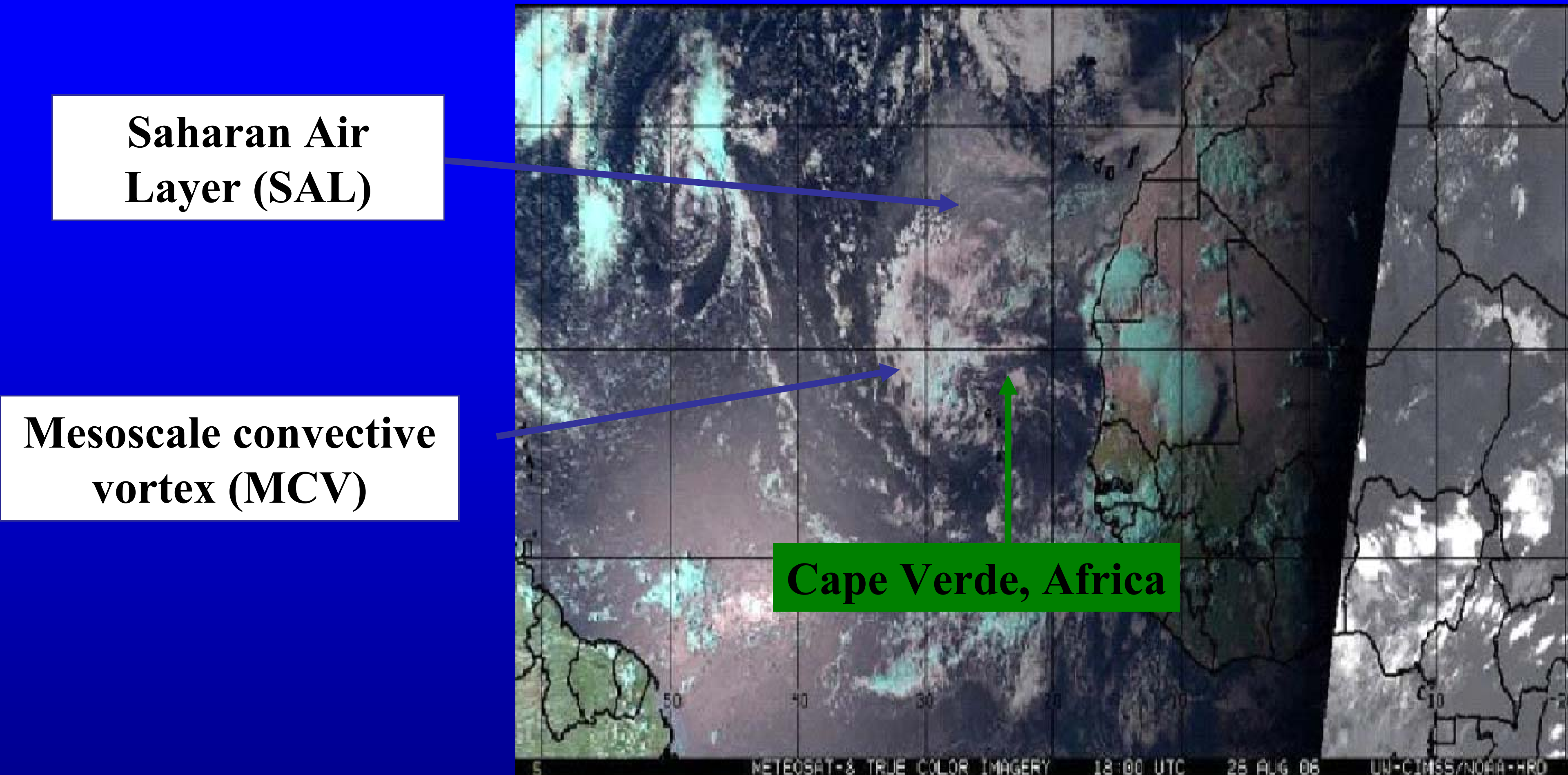
McFarquhar et al. 2009



McFarquhar et al. 2009

At category 1 hurricane stage, model under predicts T_b at 85 GHz suggesting amount of graupel may be under predicted

Impact of SAL on TCs



On 8/26/06, hot dry & dusty air from SAL drawn into MCV

- Increases stability, wind shear & temperature inversion

Do microphysical effects also matter?