Impacts of Stochastic Ice Microphysical Parameters on Mesoscale Convective System Ensemble Simulations

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Motivation and Goals

- Cloud and precipitation structure, evolution, and cloud radiative forcing of simulated mesoscale convective systems (MCSs) are significantly impacted by ice microphysics parameterizations, which typically use power law relationships with constant parameters for ice particle mass, area, and terminal fallspeed as a function of size.
- Observations suggest these parameters vary in time and space, but the effects of this parameter variability on simulated cloud and precipitation properties are essentially unknown.
- Field campaign observations from the Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) facility are used to characterize this parameter variability and develop an observationally constrained stochastic microphysics framework.
- Current goals focus on assessing (i) stochastic ensemble spread against traditional ensemble spread and (ii) potential improvement of simulated cloud properties using stochastic ice parameters through comparison of model output with field campaign observations.

MC3E Field Campaign and Observational Datasets

- Midlatitude Continental Convective Clouds Experiment (MC3E; Jensen et al. 2016)
- 22 April – 5 June 2011 at DOE ARM Southern Great Plains (SGP) Central Facility (CF) in Lamont, Oklahoma
- Investigate two well-studied convective system cases representative of different thermodynamic and kinematic morphologies:
  - (1) 20 May 2011 squall line
  - (2) 23-24 May 2011 supercell convection and evolution into MCS
- Satellite ClOud and Radiative Property retrieval System (SatCORPS) provided by NASA Langley Research Center (LaRC)
  - Provides retrieved cloud parameters that allows spatial context for high-density SGP point measurements and remote-sensing retrievals
- Ka-band ARM Zenith Radar (KAZR; Kollias et al. 2007) provides high temporal and vertical resolution of cloud structure

Stochastic Ice Microphysics Scheme Development and Implementation

- A stochastic framework has been developed using the Predicted Particle Properties (P3) microphysics scheme (Morrison and Milbrandt 2015) in WRF to account for natural variability of ice particle properties.
- Parameters are correlated in time and space via a prescribed spatiotemporal autocorrelation scale.

Stochastic *m-D* relationship coefficients (STOCH-AB)

$$m = aD^b$$

m = mass; D = maximum particle dimension

- The stochastic *a-b* scheme samples *"b"* and the bulk ice particle density, ρ_i, independently, and *"a"* is then calculated from ρ_i via the following equation:
  - $\rho_i(D) = a\frac{6}{\pi}\frac{D^b}{D^3}$, where $D = 500\ \mu m$
- Variability of ρ_i is based approximately on in-situ aircraft observations, while variability of *"b"* is based on a reasonable range of parameter values.

Stochastic Ice-Water Collection Efficiency E_{ci} (STOCH-ECI)

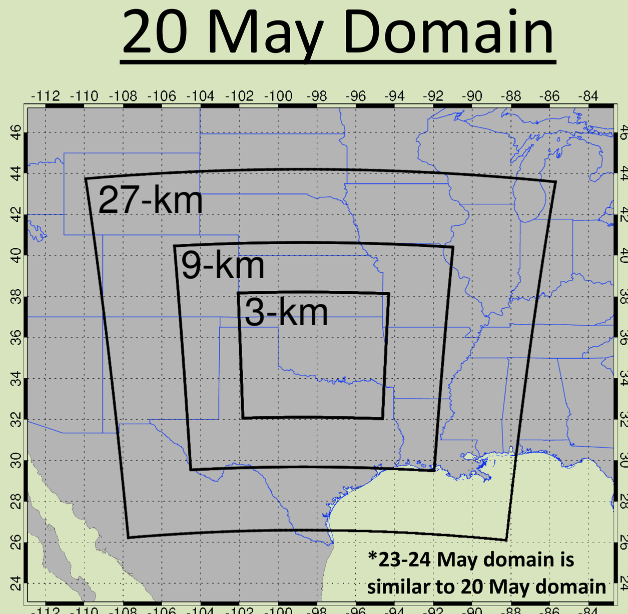
- Apply stochastic variations to riming collection efficiency, E_{ci}

Parameter	Mean	σ
a	1000 kg m^{-3}	31.6 kg m^{-3}
b	2.1	0.3
E_{ci}	0.5	0.18

Model Setup and Ensemble Descriptions

- Advanced Research Weather Research and Forecasting (WRF-ARW) model V3.8
- 27:9:3-km nested grid spacing
- 51 vertical levels
- Initialized with NCEP FNL (Final) Global Data Assimilation System (GDAS) analysis
- 20 May 2011 case: 0000 UTC – 2100 UTC
- 23-24 May 2011 case: 1200 UTC 23 May – 1200 UTC 24 May
- 3 spatiotemporal autocorrelation scales per stochastic ensemble:
  - i. τ = 600 seconds, L = 18 km
  - ii. τ = 3600 seconds, L = 100 km
  - iii. τ = 10000 seconds, L = 300 km

20 May Domain



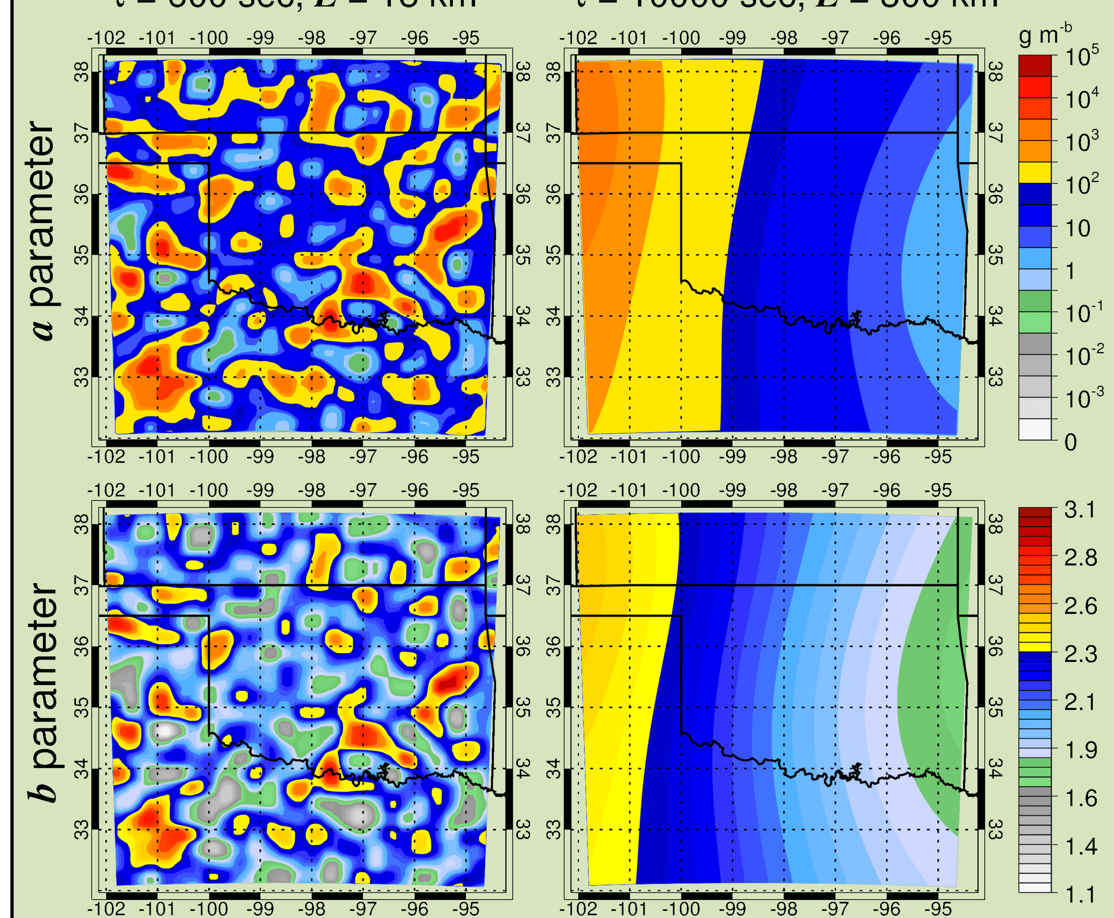
Ensembles

1. STOCH-AB: stochastic *a-b* parameters (9 members, 3 per autocorrelation scale)
2. STOCH-ECI: stochastic E_{ci} (9 members, 3 per autocorrelation scale)
3. GEFS: Initial condition perturbation ensemble in which each member is forced with a different Global Ensemble Forecast System (GEFS) member (5 members)

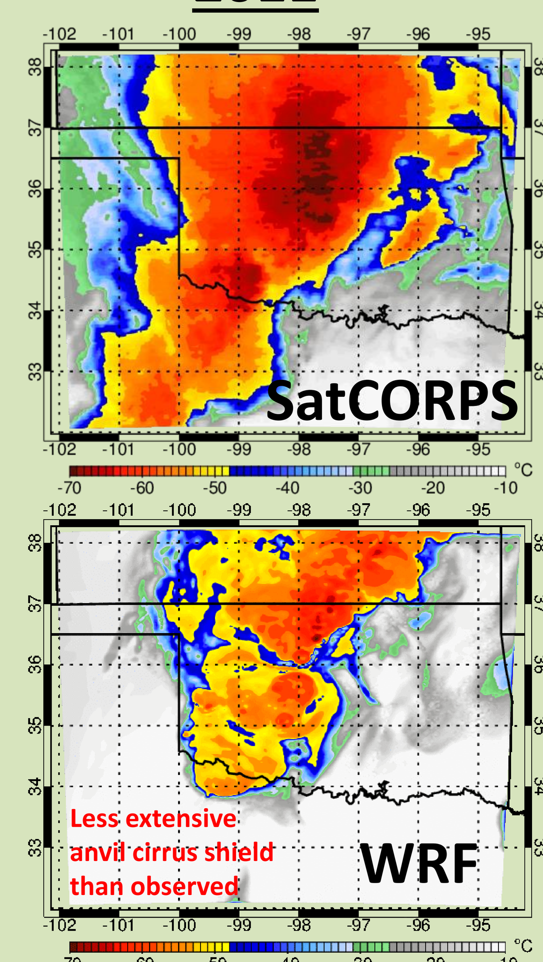
20 May 2011 Squall Line

Representative Stochastic *a-b* Parameters as a function of Spatial Autocorrelation Scale at 1200 UTC

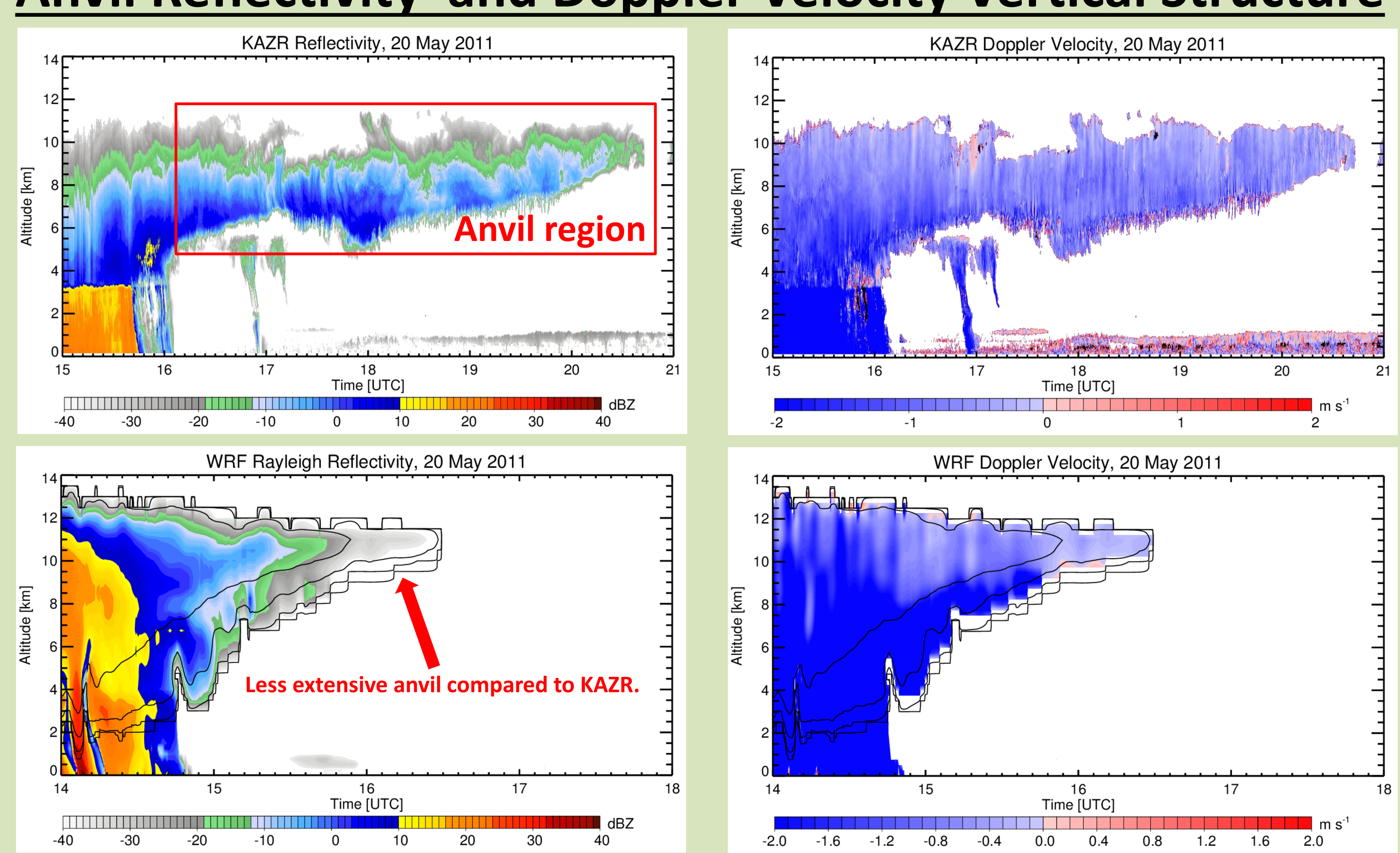
τ = 600 sec, L = 18 km   τ = 10000 sec, L = 300 km

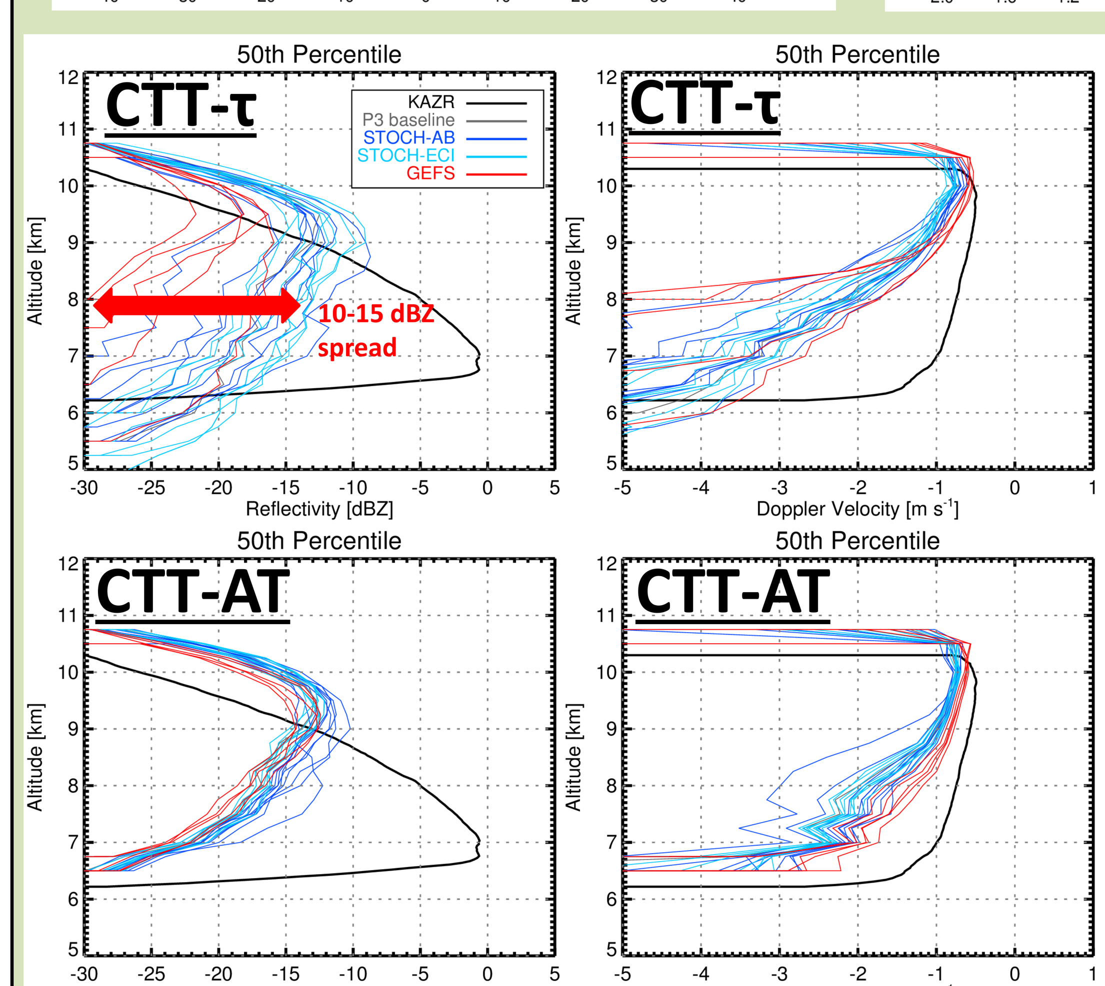


Representative OLR T_b at 1000 UTC 20 May 2011

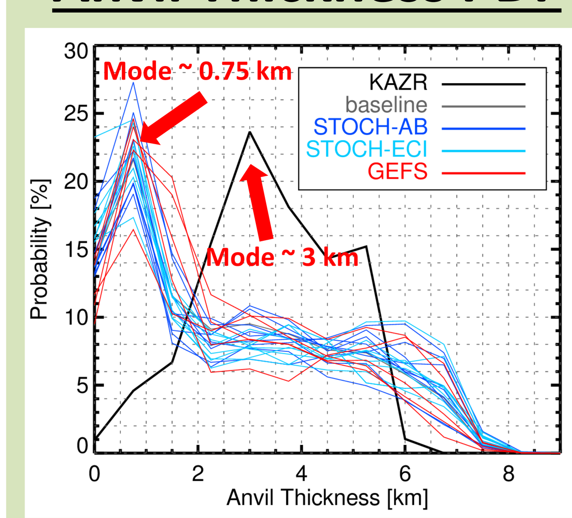


Anvil Reflectivity and Doppler Velocity Vertical Structure





Anvil Thickness PDF



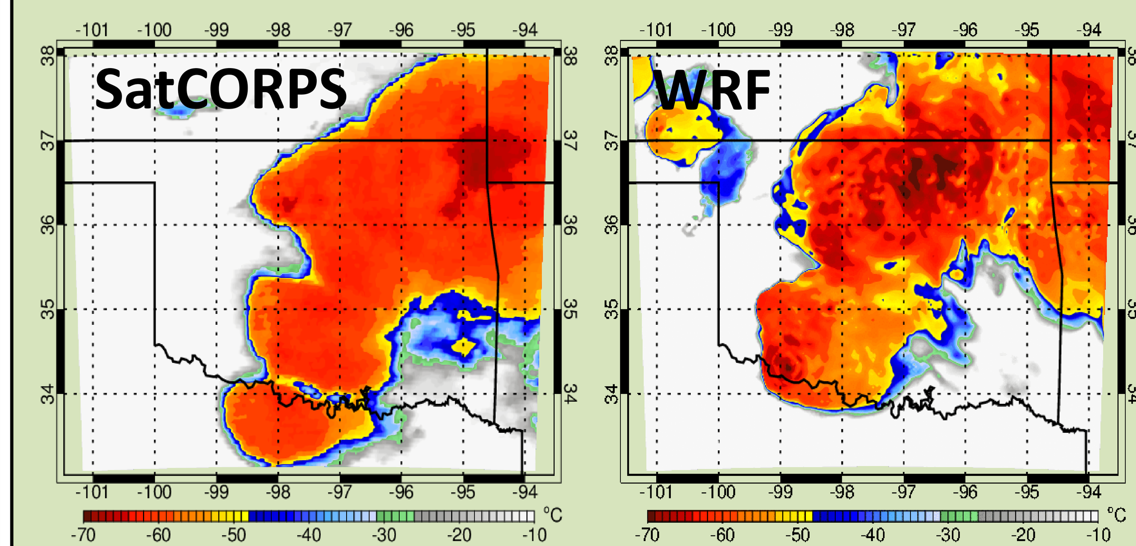
Anvil reflectivity and Doppler velocity profiles are filtered to be representative of the SGP site by locating grid points within a range of the observed visible optical depth (τ), cloud top temperature (CTT), anvil thickness (AT, defined using -30 dBZ threshold), and/or outgoing longwave radiation (OLR, used when τ is not available) as retrieved by SatCORPS and KAZR. The relative constraints are denoted CTT- τ, CTT-AT, and CTT-OLR.

Main Points

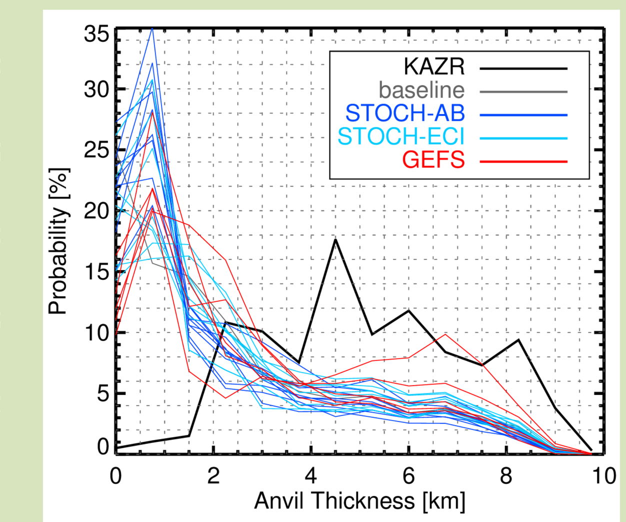
- All simulated squall lines fail to produce as extensive of an anvil cloud as observed by KAZR.
- Median anvil reflectivities for either the CTT-τ or CTT-AT constraint profiles are smaller than observed by 10-25 dBZ at some altitudes, while simulated downward Doppler velocities are lesser than observed by 1-3 m s^{-1}.
- Simulated anvil thicknesses are much thinner than observed by KAZR.
- Despite these biases, both stochastic microphysics scheme ensembles produce similar spread in anvil reflectivity, Doppler velocity, and thickness compared to that produced by the perturbed initial condition ensemble.

23-24 May 2011 Supercell Convection/MCS

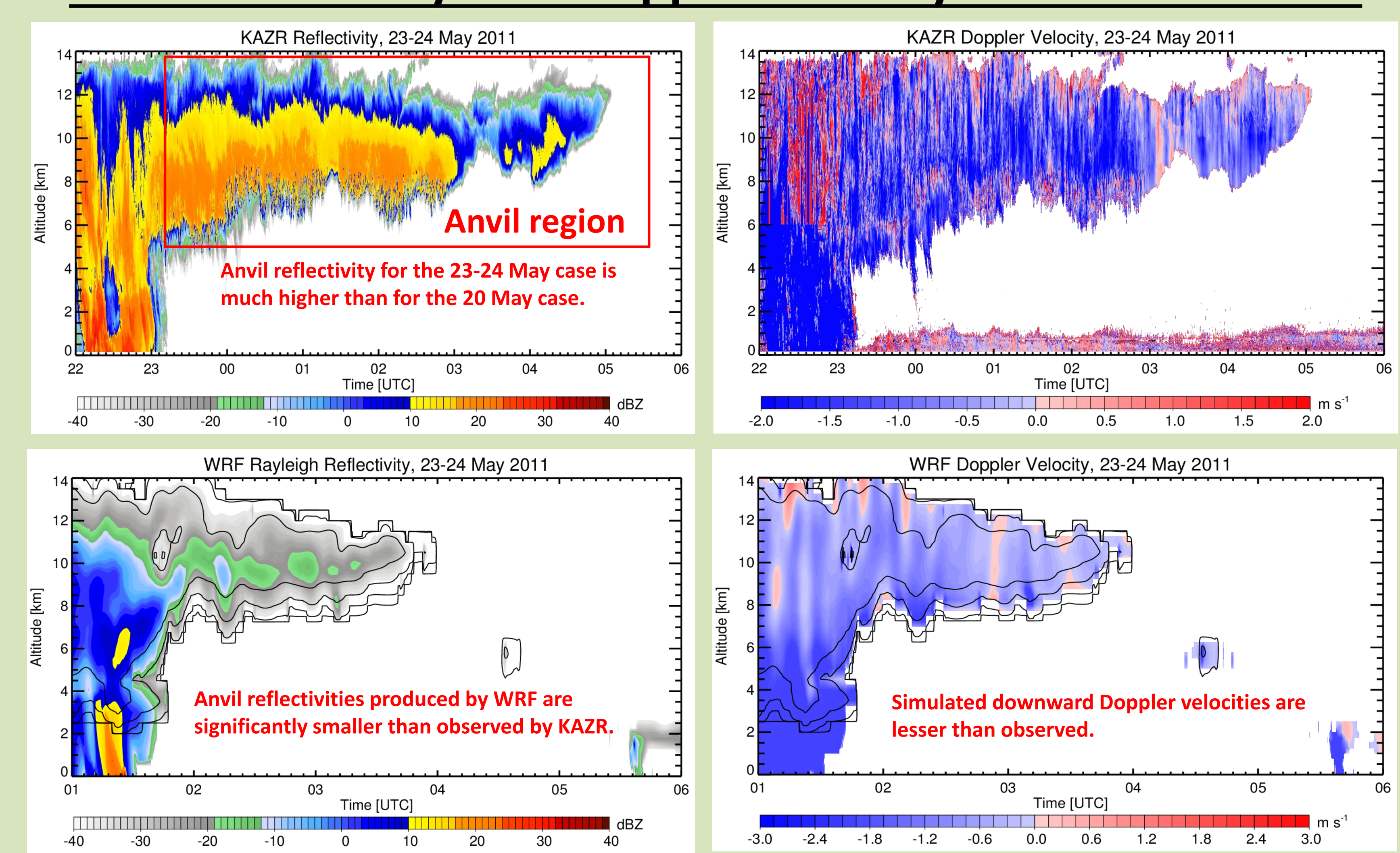
Representative OLR T_b at 0000 UTC 24 May 2011



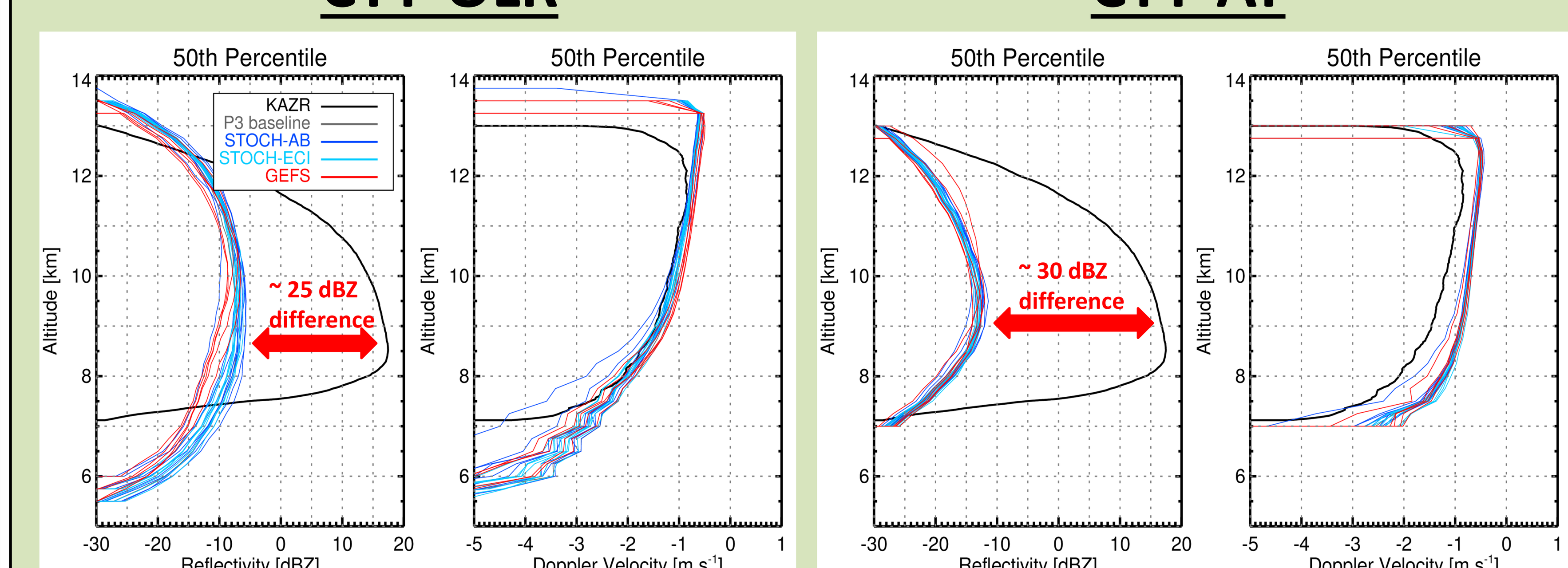
Anvil Thickness PDF



Anvil Reflectivity and Doppler Velocity Vertical Structure



CTT-OLR   CTT-AT



Conclusions and Future Work

1. A stochastic framework has been implemented into the P3 microphysics scheme in WRF to allow for variability in the *m-D* relationship coefficients and the riming collection efficiency parameter.
2. Two deep convective system cases reveal that all simulations produce thinner anvils than observed by KAZR, regardless of the stochastic parameter or ensemble used for comparison.
3. Radar reflectivities in the anvil region are typically smaller than observed by KAZR for a given cloud condition (e.g. cloud top temperature, optical depth, or anvil thickness).
4. Downward Doppler velocities in the anvil region of the 20 May 2011 squall line case are greater than observed while they are slightly lesser than observed for the 23-24 May 2011 supercell/MCS case.
5. Stochastic ensemble spread in anvil properties is similar to initial condition ensemble spread.
6. Future work will focus on further scheme development, precipitation evolution analysis, incorporation of tropical cases and investigation of causes for differences between stochastic and deterministic ice schemes.

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