Development and Testing of a Stochastic Representation of Ice Microphysical Properties in WRF

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MOTIVATION AND GOALS

Parameters that control ice particle characteristics (e.g., concentrations, masses, shapes, densities, fall speeds, aspect ratios, scattering) are usually specified as constants in models. Observations show large variability of these parameters over scales smaller than typical model domain sizes, and significant correlation in the variability of parameters. The effects of this parameter variability on simulated cloud and precipitation properties are essentially unknown. ARM field campaign observations are being used to characterize this parameter variability, and develop an observationally constrained stochastic microphysical framework that can account for it. By running simulations of well-observed field campaign cases that employ this new framework, project goals include:

1) quantifying impacts of including ice microphysical parameter variability on deep convective cloud and precipitation processes,

2) characterizing the spread of ensemble solutions generated from different realizations applying the stochastic scheme, with practical implications for ensemble weather and climate prediction,

3) identifying specific parameters that cause the greatest impacts on cloud and precipitation properties when varied, thereby motivating a focus on measuring of these parameters in future field campaigns, and

4) assessing potential improvement and causes for improvement of simulated cloud properties using stochastic ice parameters through comparison of model output with field campaign observations.

STOCHASTIC FRAMEWORK

A parameterization framework has been developed that incorporates stochastically-varying microphysical parameters. This has been implemented into the 1 ice category version of the Predicted Particle Properties microphysics scheme (P3, Morrison and Milbrandt 2015) within the Weather Research and Forecasting model (WRF).

We initially focus on varying the "*a*" and "*b*" mass (*m*)-size (*D*) relationship parameters for unrimed and partially-rimed ice, given by $m = aD^b$.

THE METHOD:

1. Sample *b* and density $\rho_{i(500\ \mu m)}$ at a reference size (D_f = 500 µm) as random Gaussian-distributed variables at each grid location and across several time steps. *b* has a mean of 2.1 and standard deviation of 0.32. Based on initial aircraft observations analysis, $\rho_{i(500\ \mu m)}$ has a mean of 100 kg m^{-3} and standard deviation of 32 kg m^{-3}. *b* and $\rho_{i(500\ \mu m)}$ are assumed to be uncorrelated, which is reasonable based on the observational analysis.

2. Apply a running mean filter to generate spatially and temporally autocorrelated *b* and $\rho_{i(500\ \mu m)}$. The filter has a width in the time, horizontal, and vertical dimensions of τ_t, τ_h, and τ_v, respectively. "Ghost" points are added outside of the domain and prior to the initial time to ensure a consistent number of points are included for all grid locations and time steps when applying the running mean filter.

3. Multiply the sampled *b* and $\rho_{i(500\ \mu m)}$ by constant coefficients to ensure that the variance equals the original variance before applying the running mean filter.

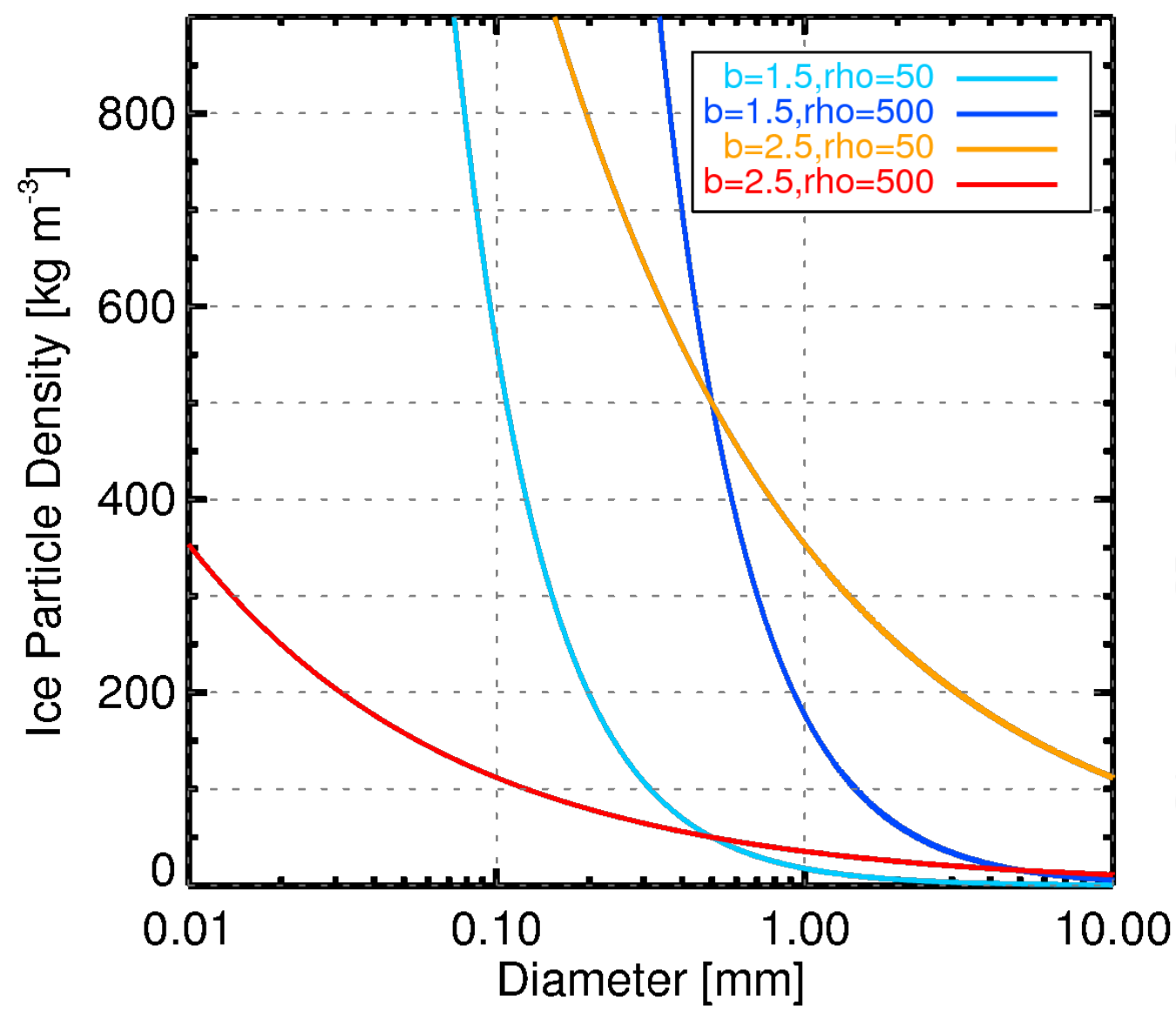
4. Calculate *a* from $a = \rho_{i(500\ \mu m)}\pi D_f^3/(6D_f^b)$.

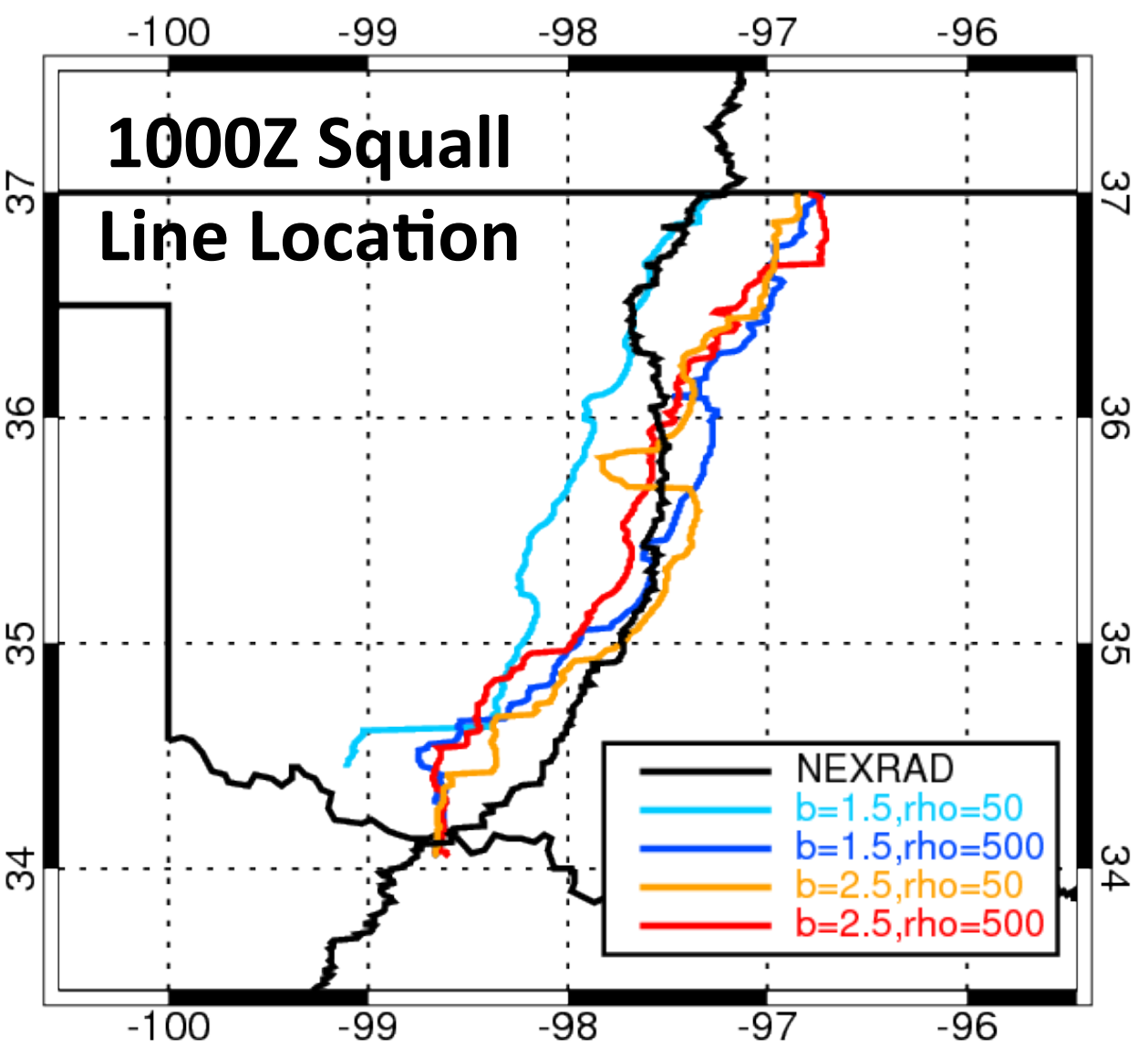
IMPACT OF ASSUMED M-D RELATIONSHIP ON MC3E SQUALL LINE STRUCTURE

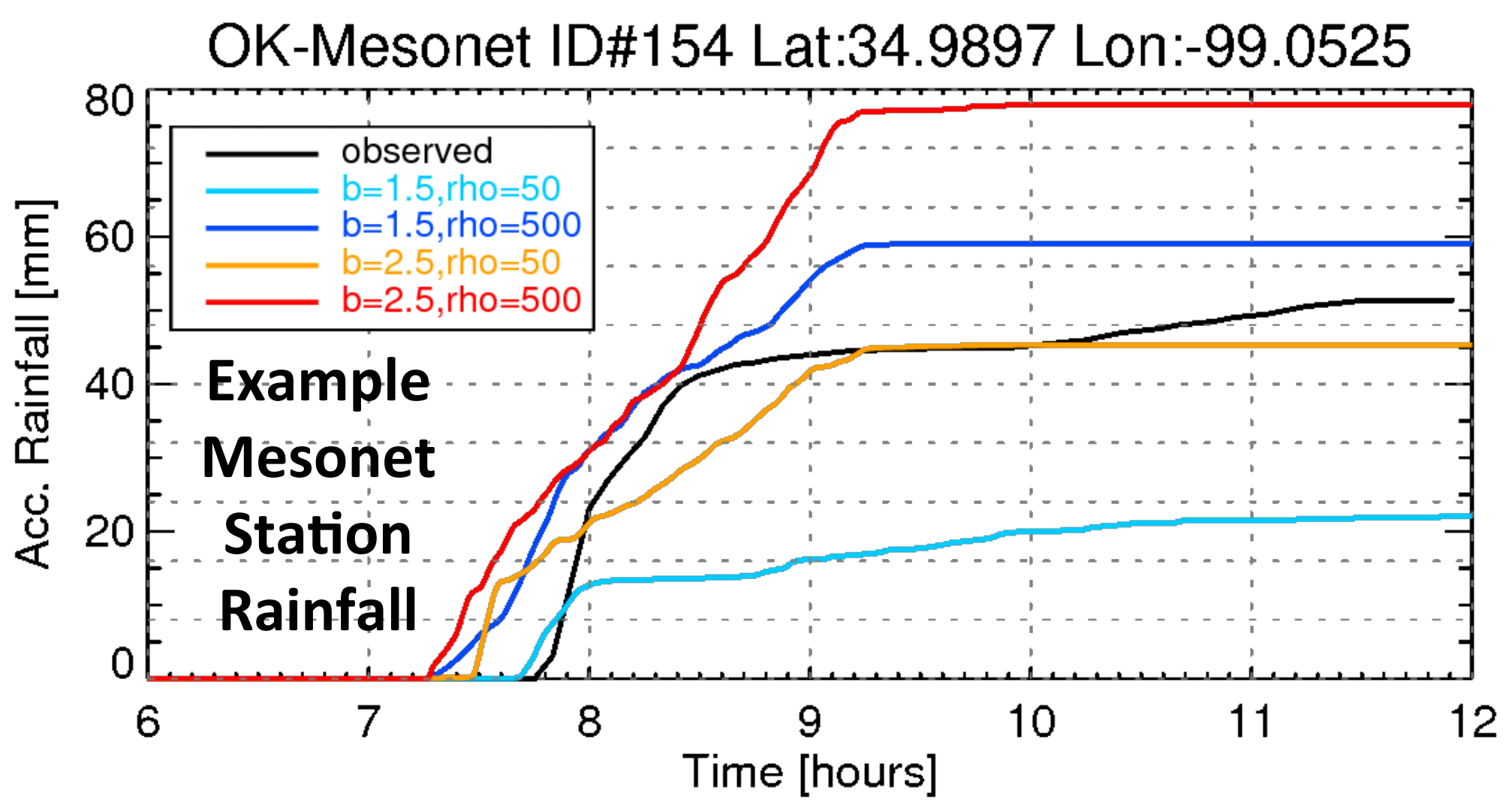
The *a* and *b* parameters of the *m-D* relationship for vapor-grown ice in the P3 scheme are constant. We evaluate the impact of diagnosing 4 *a-b* pairs on the structure and evolution of the 20 May 2011 MC3E squall line case. Bulk ice particle density (ρ_i) as a function of diameter for the 4 *a-b* pairs are shown to the right.

The 4 *a-b* pairs evaluated here are the following:

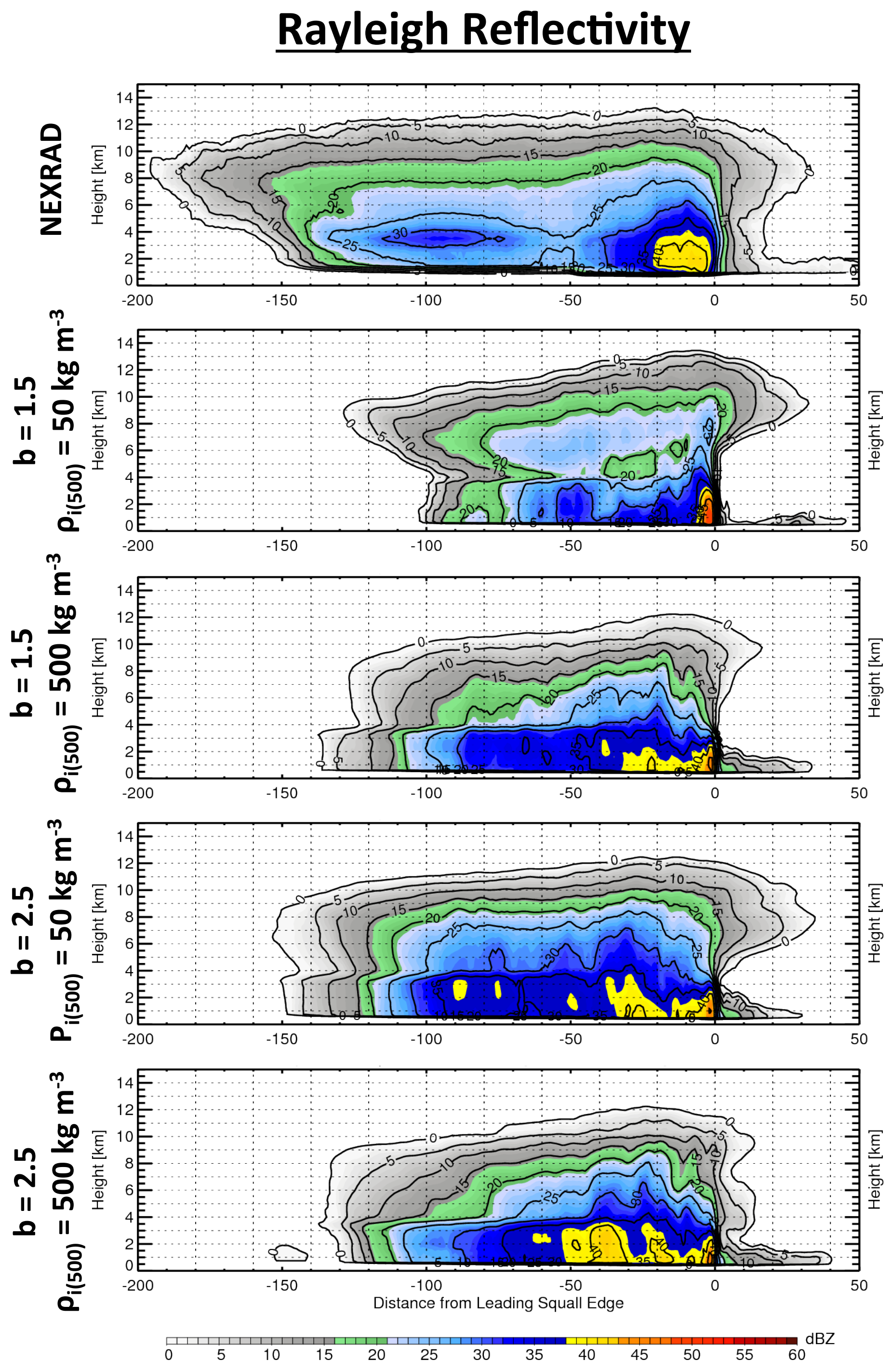
(1) $b = 1.5$, $\rho_{i(500\mu m)} = 50$ kg m^{-3}, $a = 0.000293$
(2) $b = 1.5$, $\rho_{i(500\mu m)} = 500$ kg m^{-3}, $a = 0.002927$
(3) $b = 2.5$, $\rho_{i(500\mu m)} = 50$ kg m^{-3}, $a = 0.585401$
(4) $b = 2.5$, $\rho_{i(500\mu m)} = 500$ kg m^{-3}, $a = 5.854013$

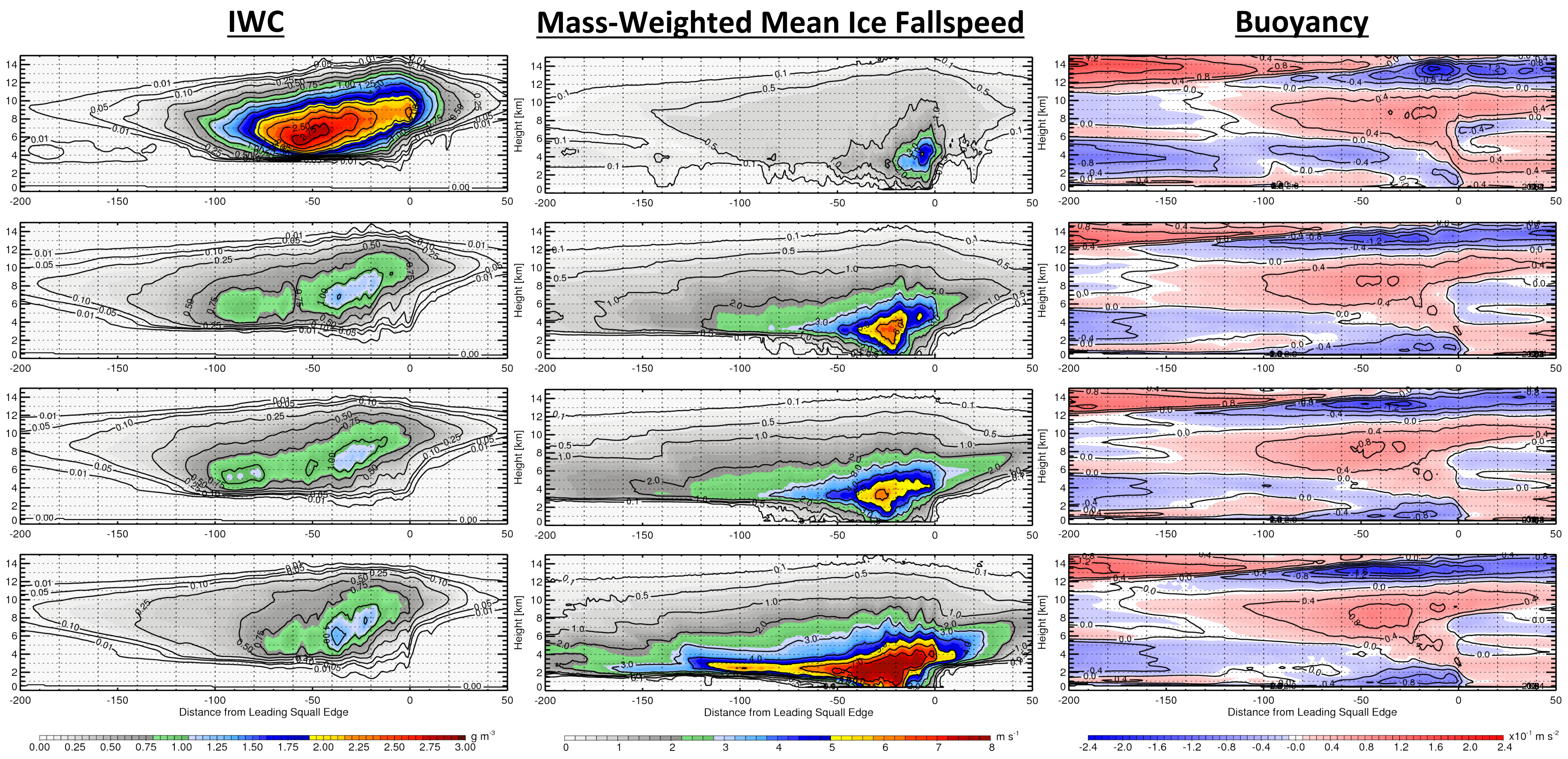






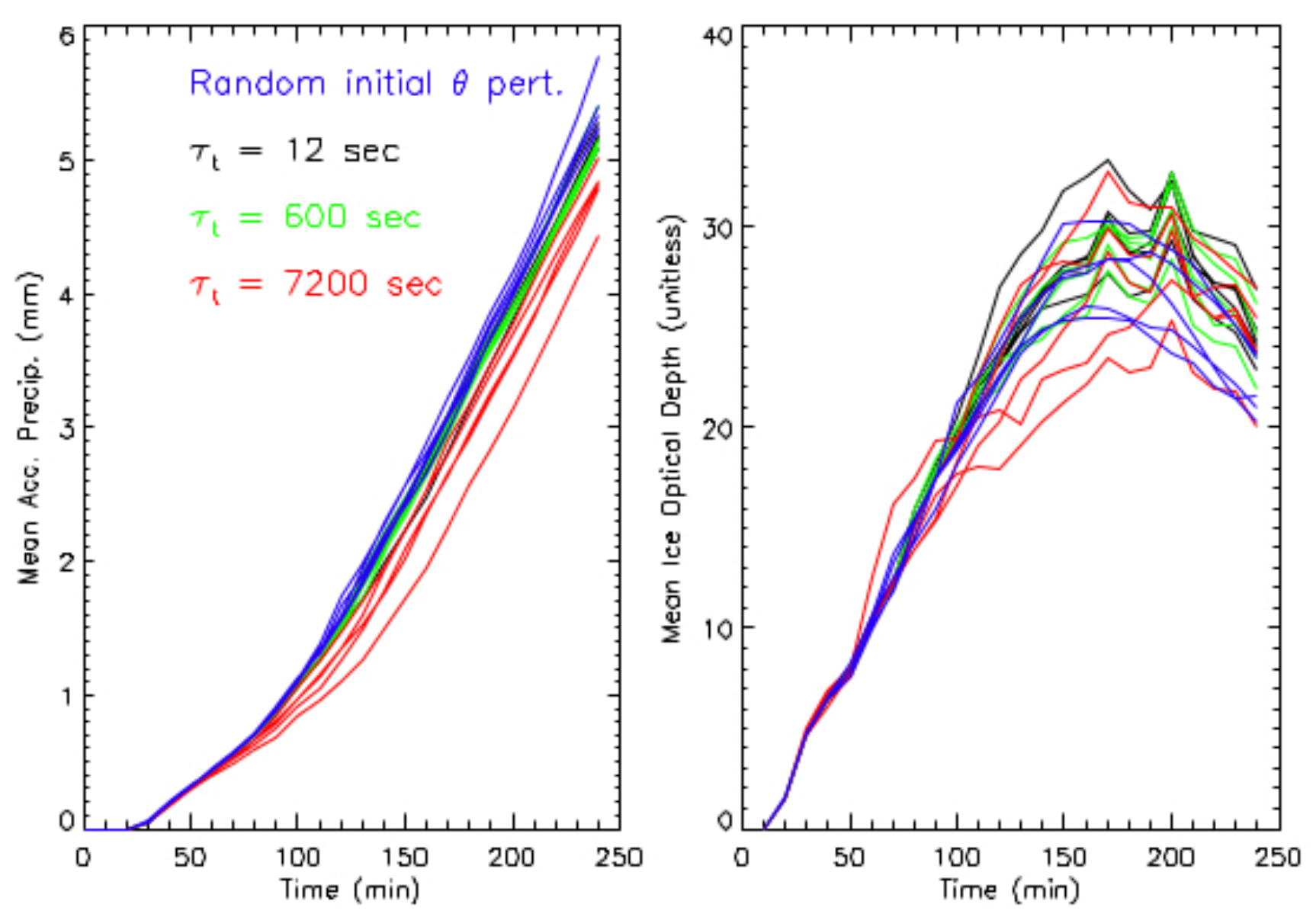
- Increasing $\rho_{i(500\mu m)}$ from 50 to 500 kg m^{-3} for a given *b* and increasing *b* from 1.5 to 2.5 increases surface precipitation accumulation.
- The *b* = 1.5, $\rho_{i(500\mu m)}$ = 50 kg m^{-3} simulation produces the narrowest convective and stratiform regions with the slowest ice fall speeds, leading to very high IWC, a more realistic trailing anvil reflectivity, and more upright convection like observed, but with a weaker cold pool and slower squall propagation than observed.
- Increasing *b* to 2.5 or $\rho_{i(500\mu m)}$ to 500 kg m^{-3} produces wider precipitation regions with stronger cold pools and faster propagating squall lines.
- No *a-b* combination reproduces the observed reflectivity structure, but different *a-b* combinations clearly impact surface precipitation as well as ice size, number, fallspeed, and bulk mass both directly and indirectly through dynamical feedbacks associated with cold pool strength.

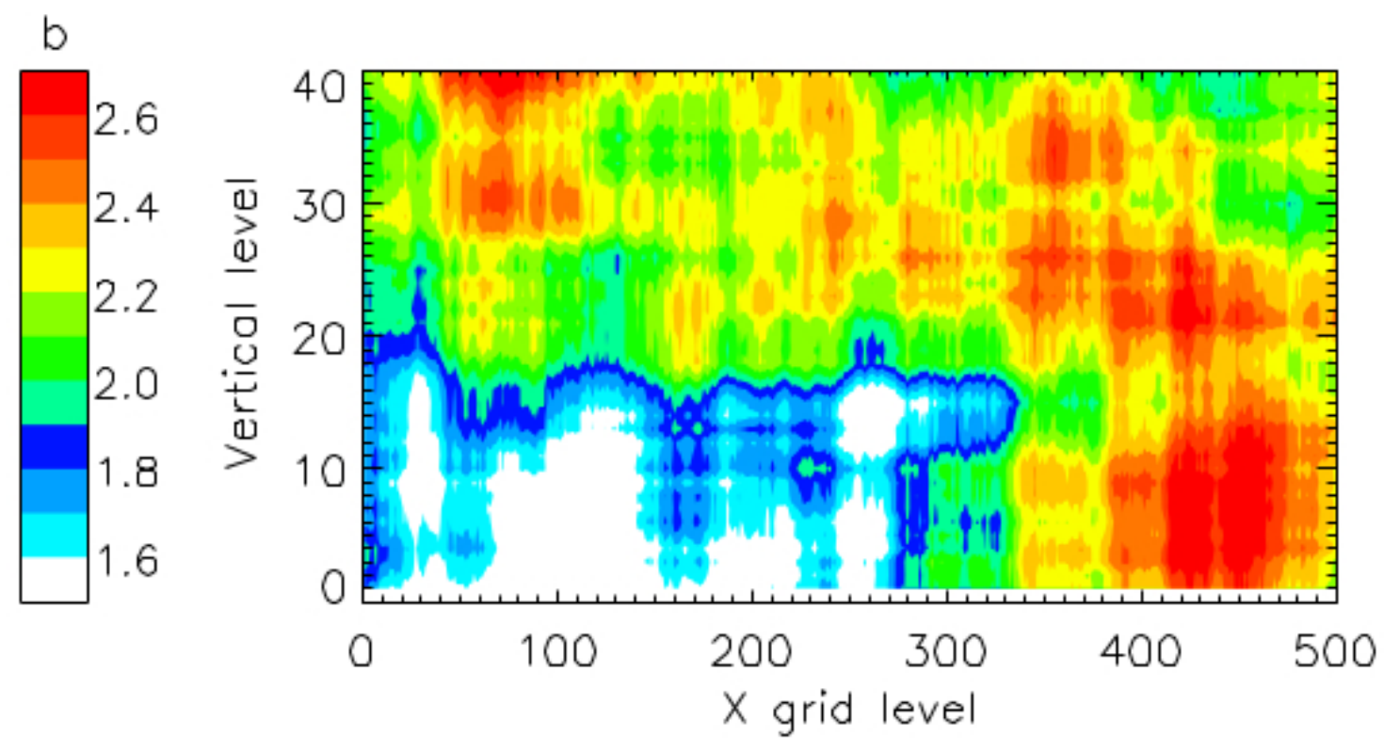




IDEALIZED STOCHASTIC 2D SQUALL ENSEMBLES

The stochastic parameterization is tested using the idealized WRF 2D squall line case. Five ensemble members with different random number seeds are run for each configuration. Three different configurations were tested using various temporal autocorrelation scales τ_t. In all runs the spatial autocorrelation scales τ_h and τ_v are 100 and 20 grid points, respectively (approximately 100 and 10 km). An additional configuration stochastically varied the initial perturbation potential temperature of the warm bubble that initiates convection, sampling a uniform distribution between +/- 0.1 K.





Above: Time series of horizontally-averaged accumulated surface rainfall (left) and ice optical depth (right). Each line represents a single ensemble member.

Left: Example of the random autocorrelated "*b*" parameter over the model domain at a single instance in time. Note that *b* is specified for all grid points, even though some grid points do not contain ice.

CONCLUSIONS AND FUTURE WORK

Simulated squall line precipitation evolution and ice properties are sensitive to the parameterized mass-size power law coefficients for non-heavily rimed ice because of direct impacts and indirect impacts through alterations in cold pool strength. Idealized 2D squall line stochastic *m-D* runs show a significant sensitivity to the parameter temporal autocorrelation scale. There is an increase in ensemble spread and a decrease in accumulated rainfall for all ensemble members when the autocorrelation timescale is long (2 h).

Future work will include:

- Increasing the number of members for the 2D ensembles
- Incorporating more realistic parameter value probability distributions
- Constraining ice parameter autocorrelation scales with aircraft observations
- Incorporating the stochastic scheme into "real" 3D simulations of MC3E cases with further observational validation using meteorological and radar data
- Incorporating further ice characteristic parameters into the stochastic framework such as particle size distribution µ and area-size coefficients

REFERENCES: Morrison, H., and J.A. Milbrandt, 2015: Parameterization of cloud microphysics based on the prediction of bulk ice particle properties. Part I: Scheme description and idealized tests. *J. Atmos. Sci.*, **72**, 287-311.

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