The Impact of One- and Two-Moment Microphysical Schemes on Precipitation in an Ordinary Thunderstorm

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1. Introduction

One- and two-moment microphysical schemes are commonly implemented in atmospheric models that are used for research or forecasting. In one-moment schemes, typically the mixing ratio of a cloud species is predicted, and either the number concentration or diameter is fixed. In contrast, double-moment schemes predict both the mixing ratio of the property and the number concentration. This way, all three properties can vary throughout the cloud, which creates a more realistic simulation. However, most forecast models use single-moment schemes because they are faster and cheaper. In this study, the sensitivity to the choice of parameters in single-moment schemes is explored through examination of the changes to dynamical and microphysical processes in an ordinary thunderstorm.

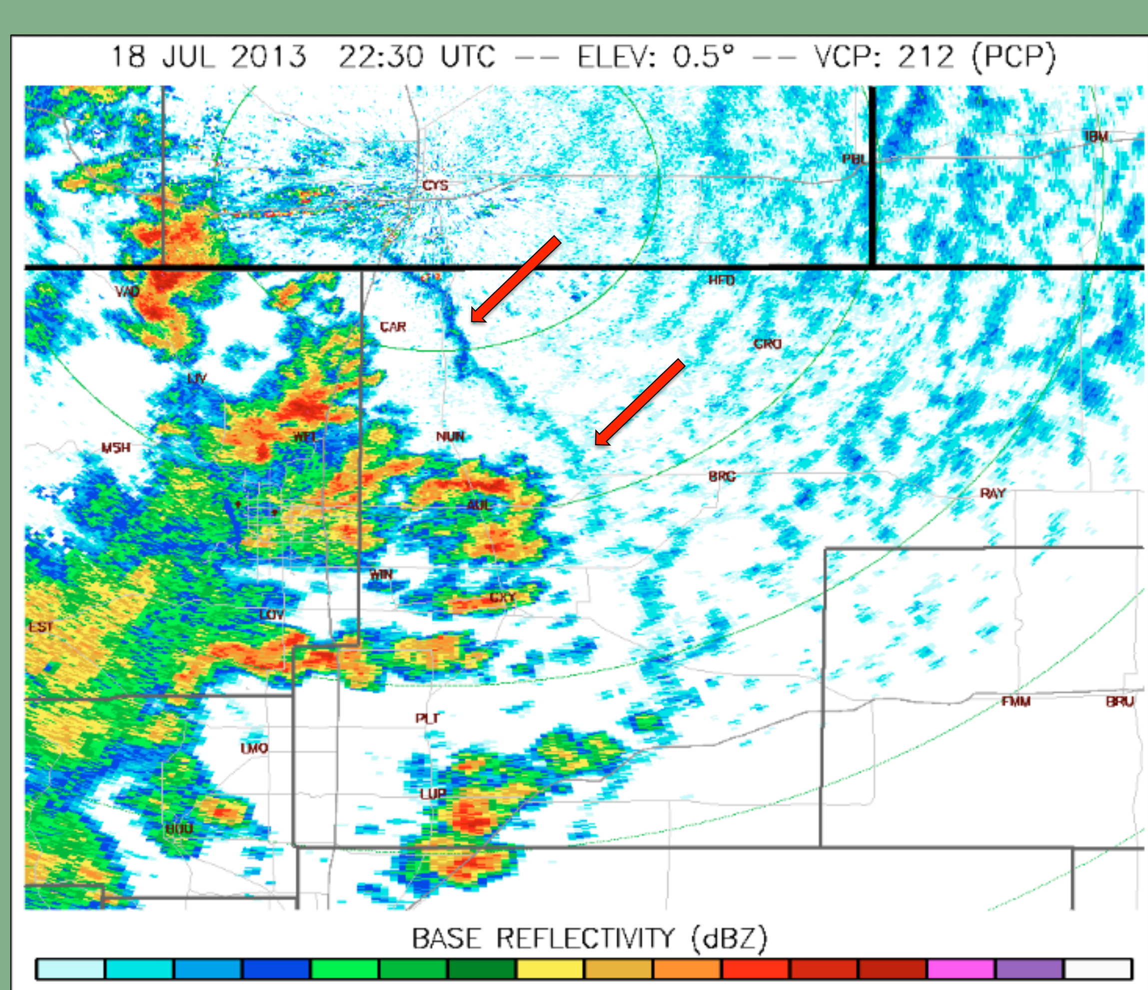
2. Objectives and Methodology

Five different idealized thunderstorm simulations were examined using RAMS (Regional Atmospheric Modeling System; Cotton et al, 2003):

- Four used single-moment schemes, the values of which were chosen as approximate lower and upper limits of the two parameters (Walko et al, 1995):
  - Two fixed mean cloud droplet diameters of **5 µm** and **25 µm**.
  - Two fixed cloud droplet number concentrations of **100 mg^{-1}** and **1000 mg^{-1}**.
- The fifth was double-moment with a predicted mixing ratio and number concentration (Meyers et al, 1997).

The objectives of this research project were to:

- Examine and explain the variations between cloud droplet diameter and number concentration.
- Analyze the dynamical and microphysical processes to explain the resulting differences in precipitation.
- Link each process to the cold pool intensities.
- Demonstrate why double-moment schemes are a more realistic alternative to single-moment schemes for use in forecast models.



Above is a radar image taken on July 18th, 2013 from the Cheyenne radar site. It shows the leading edge of a cold pool, or the gust front. Cold pools are important lifting mechanisms. When cloud droplet diameter or number concentration values are changed in the model, differences in cold pool intensities can develop that impact precipitation amounts.

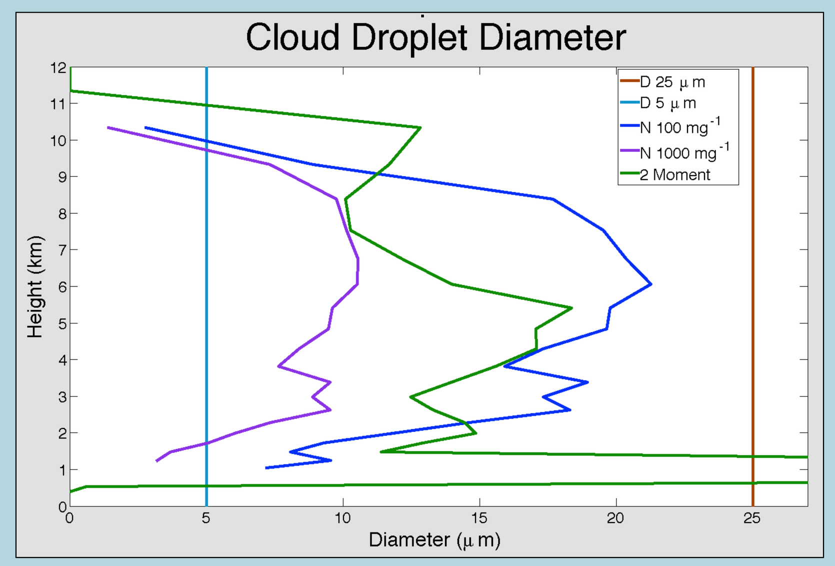
3. Cloud Droplet Properties

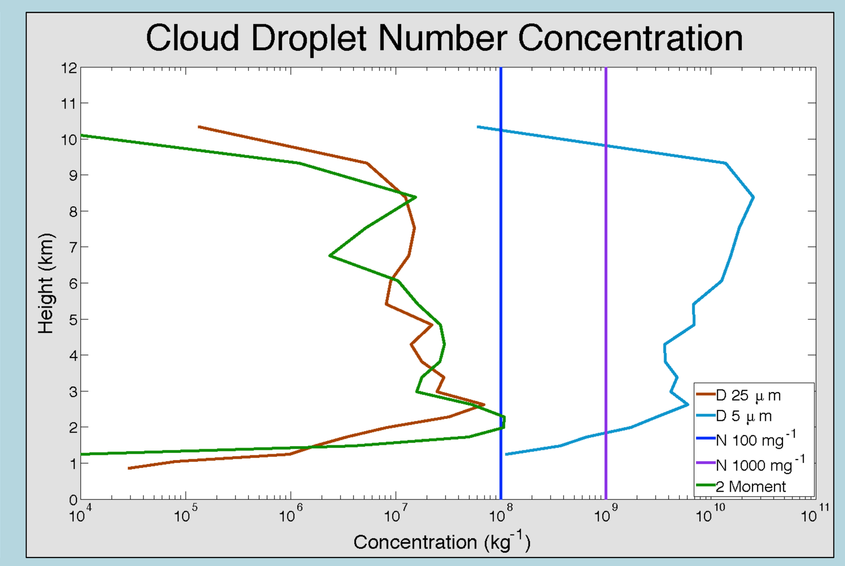
Cloud droplet diameter and number concentration were calculated using the equation:

$$r = N * D^3 * \pi/6 * \rho_{water}$$, where

- r is the mixing ratio
- N is the number concentration
- D is the diameter, and
- $\pi/6$ and ρ_{water} are constants

This equation states that in order to keep the mixing ratio constant at individual levels in the cloud when either number concentration or diameter is fixed, the other has to compensate for these changes.

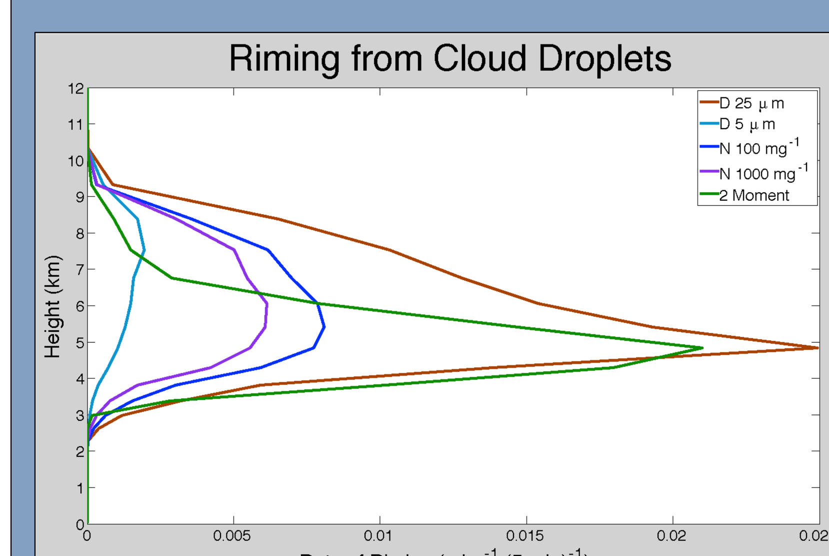


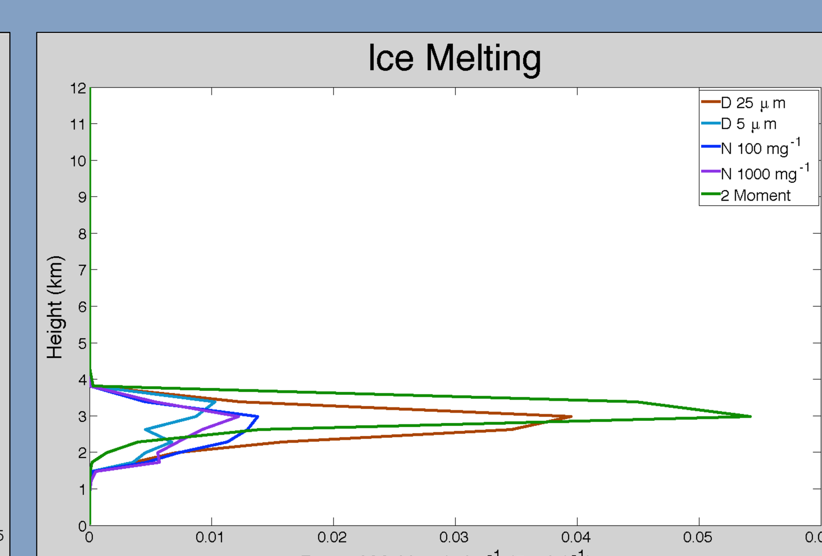


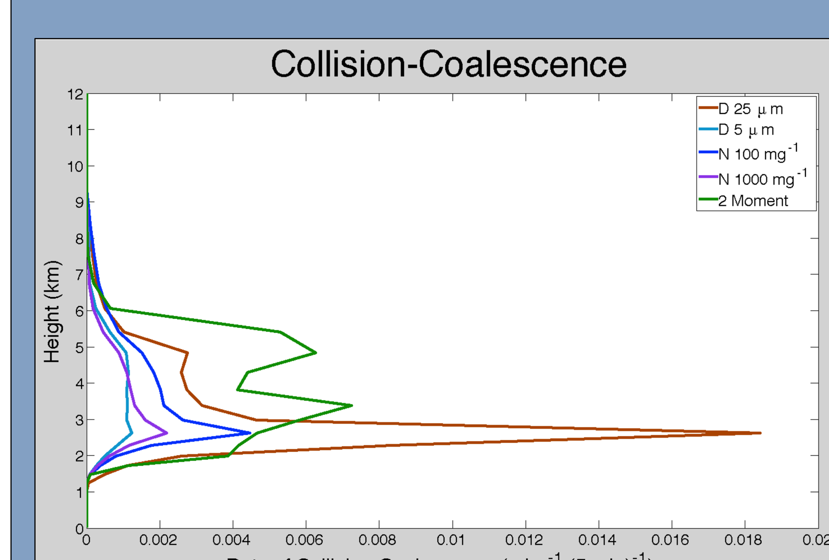
The figures above show cloud droplet diameter and number concentration for all five simulations. As expected, **100 mg^{-1}** has a larger diameter than **1000 mg^{-1}**, and **5 µm** has a much higher number concentration than **25 µm**. The predicted cloud droplet diameter for **2-Moment** lies right in the middle of the two fixed cloud droplet diameter values, and its number concentration is among the lowest.

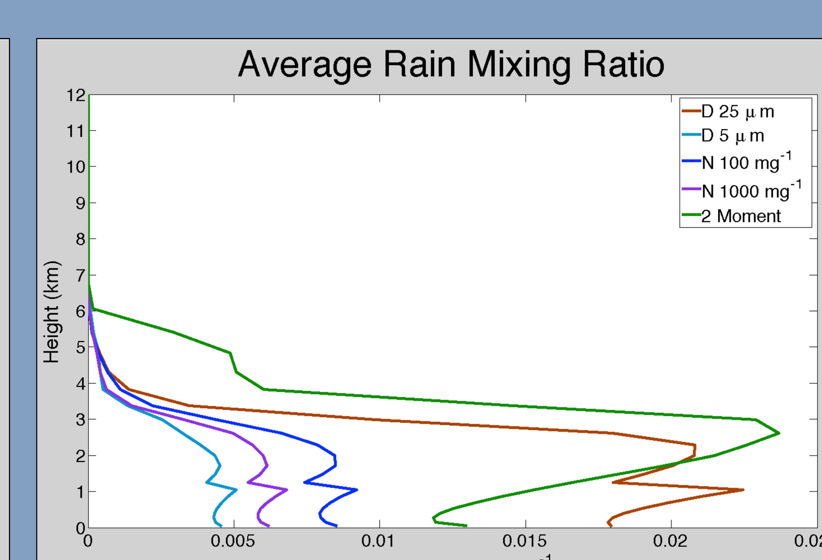
4. Rain Producing Processes

The two primary ways to produce rain are through collision-coalescence and melting. Melting will be indirectly linked to cloud droplet properties through riming.





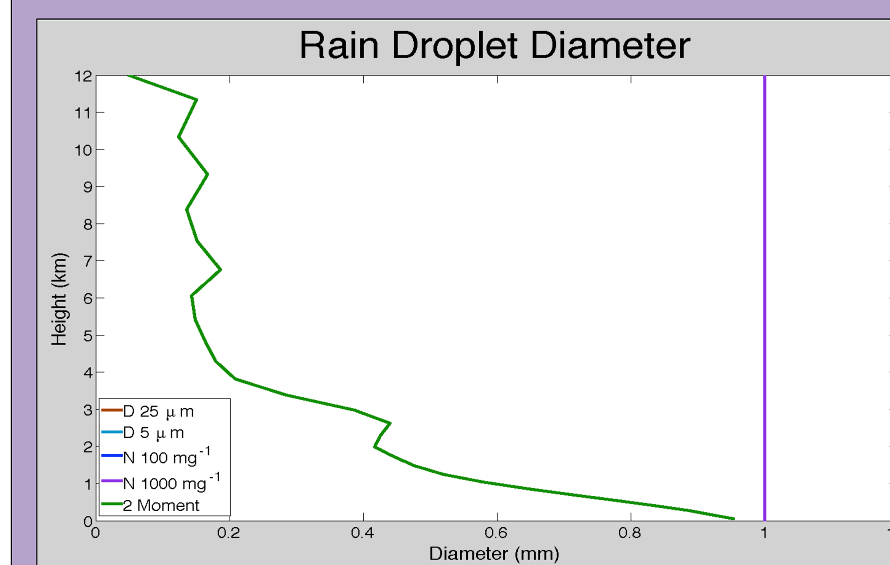


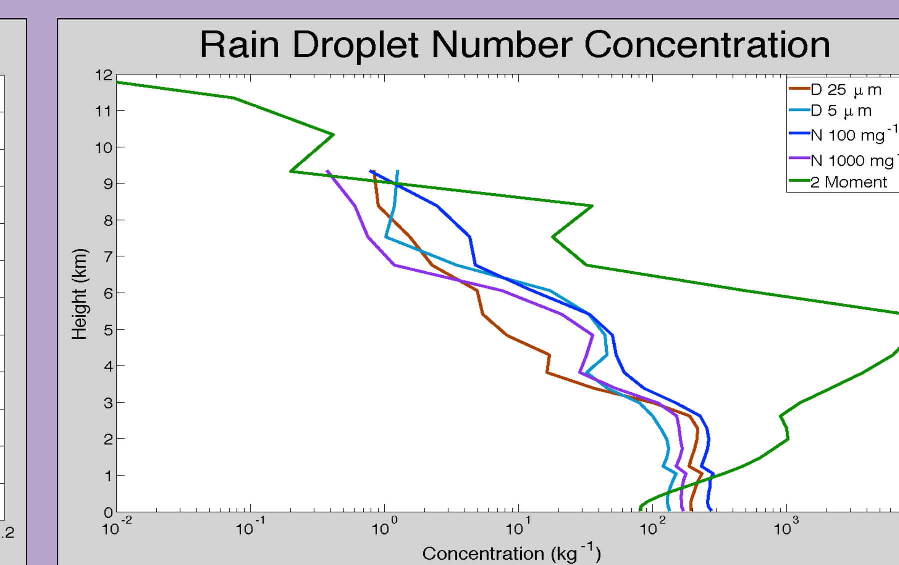


Collision-coalescence and riming are more efficient when larger cloud droplets are present. **25 µm** and **2-Moment** produce the most rain, and therefore have the highest rain mixing ratios, in part because these two simulations contain large cloud droplets. The maxima for **2-Moment** at 3 km coincides with its ice melting maxima at the same level.

5. Rain Drop Properties

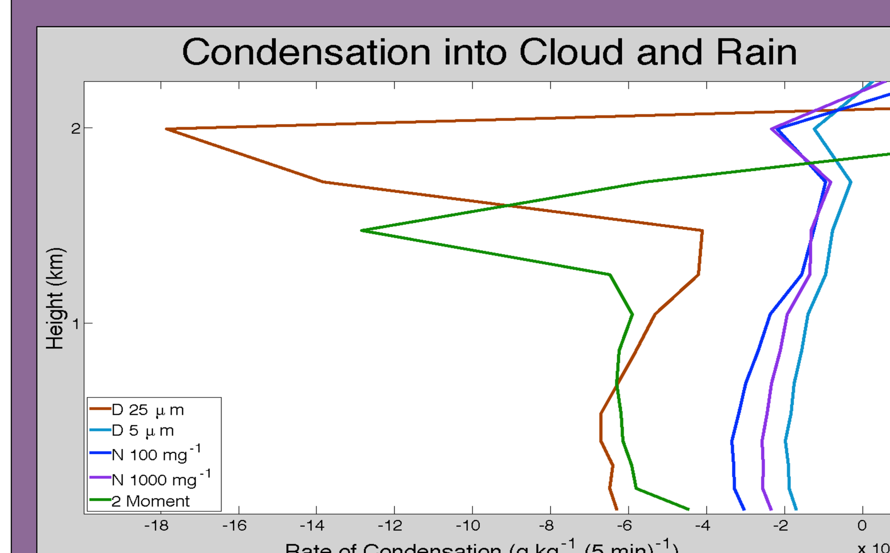
The standard size for rain droplet diameter used in RAMS is 1 mm, which seems unfitting, as the predicted **2-Moment** diameter was significantly less. The changes in rain properties seen below also feedback to the changes in rain production and cold pool intensity.

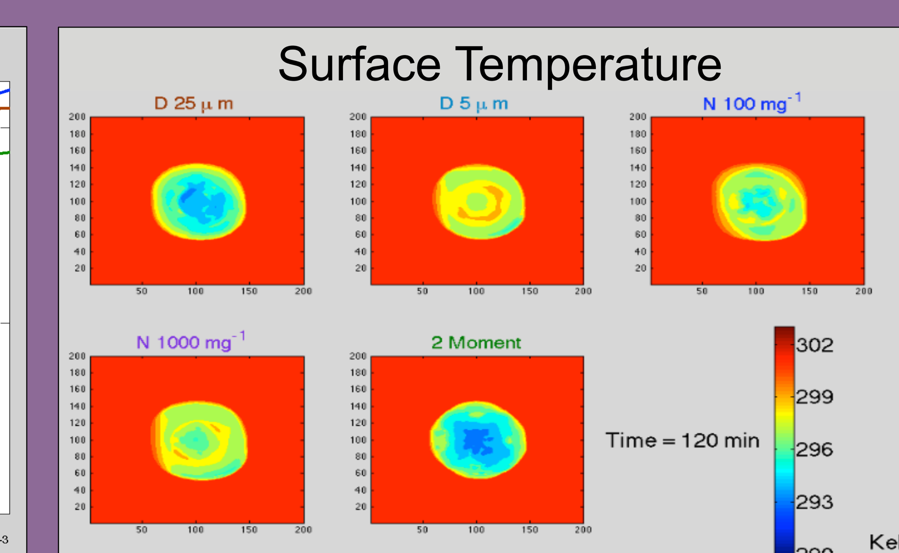




6. Condensation and Cold Pools

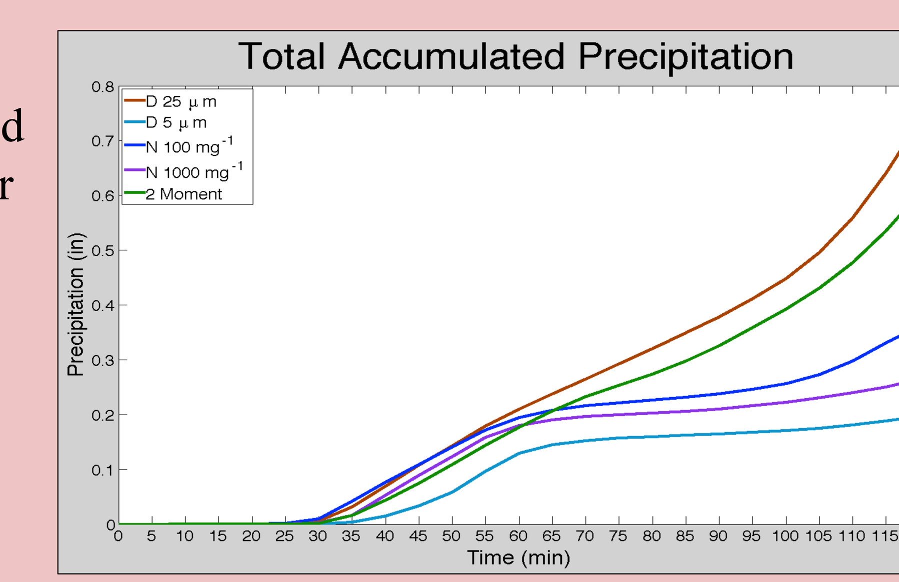
Most small rain drops evaporate before they reach the ground and produce cold pools; cold, dense air at the surface that blows out ahead of storms and collides with relatively warm, less dense air. This can generate lift and create additional convection and precipitation. Both **25 µm** and **2-Moment** have the highest amount of evaporation and the strongest cold pools.





7. Precipitation

Throughout the 120 minutes of each simulation, **25 µm** and **2-Moment** precipitated continuously and the most. This is due to their ability to better create rain and to the strength of their cold pools which produced a dynamical feedback system. The other simulations, **100 mg^{-1}**, **1000 mg^{-1}**, and **5 µm** all had weaker dynamical systems and could not sustain themselves.



8. Conclusions

- The **25 µm** and **2-Moment** schemes were better able to maintain a storm through cold pool production and associated forcing.
- Precipitation production was much more sensitive to a change in cloud droplet diameter than a change in number concentration.
- Single-moment schemes are cheaper and faster, but a switch to double-moment schemes should be considered because they are more realistic.

References

RAMS: Regional Atmospheric Modeling System.
Cotton et al, 2003. RAMS 2001: Current status and future directions. *Meteorology and Atmospheric Physics,* **82:** 5–29.
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Acknowledgements

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