Aerosol Impacts on Mid-Latitude MCS Precipitation Intensity and Radiative Forcing

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1. Introduction

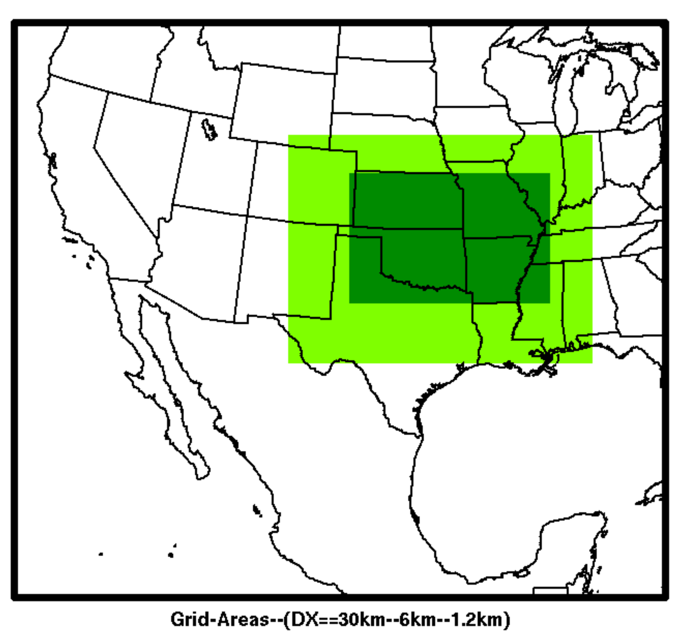
An increase in the number concentration of cloud droplet nucleating aerosols has the potential to modify cloud droplet size distributions in deep convection. Such modifications can impact the rates of key microphysical processes that influence the size distributions of precipitating hydrometeors and the cloud system evolution. (Storer and van den Heever 2013; Seigel et al. 2013; Saleeby et al. 2016).

Modification of the hydrometeor size distributions and the rates of microphysical processes in deep convection can impact the vertical distribution of condensate, and thus the precipitation rates, cloud top radiative properties, and the net radiative flux of such cloud systems.

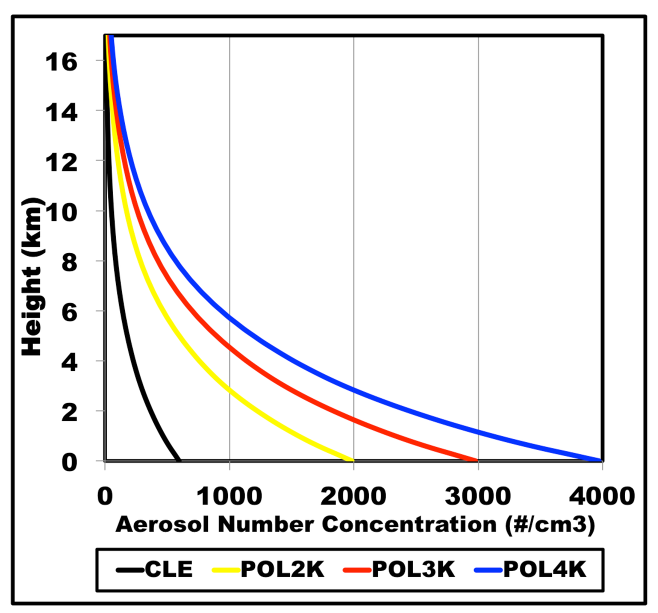
The impacts of VARIABILITY in AEROSOL CONCENTRATION on the PRECIPITATION INTENSITY and NET RADIATIVE FLUX in deep convection is explored through the use of high-resolution cloud resolving model simulations of mesoscale convective systems (MCSs) that occurred 20 May and 23-24 May, 2011 over the U.S. central plains during the MC3E field project.

2. Numerical Modeling Simulations

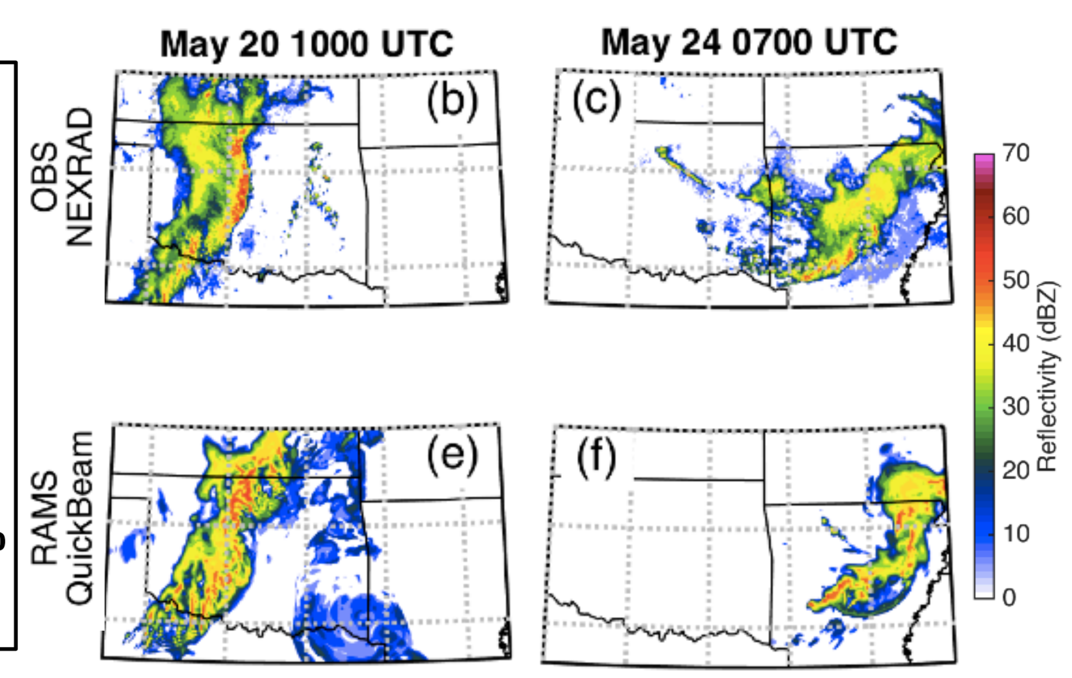
CSU RAMS model: Run with 2-moment microphysics and aerosol modules. (Saleeby and van den Heever 2013).
Model domain: Nested 3-grid setup with horizontal grid spacings of 30, 6, and 1.2km. Results analyzed on inner domain.
Initialized: With GDAS-FNL on 20 May, 2011 at 00Z. Analyzed from 03Z to 15Z on the 20th. With RUC on 23-24 May, 2011 18Z. Analyzed from 21Z 23rd to 09Z 24th.
Aerosols: Initialized aerosol field with horizontally homogeneous exponentially decreasing profiles with maximum surface concentrations guided by observations from MC3E. Aerosol fields evolve over time via advection, diffusion, and scavenging. *The radiative effects of aerosols are not included in this study.*



Nested grid domain configuration.

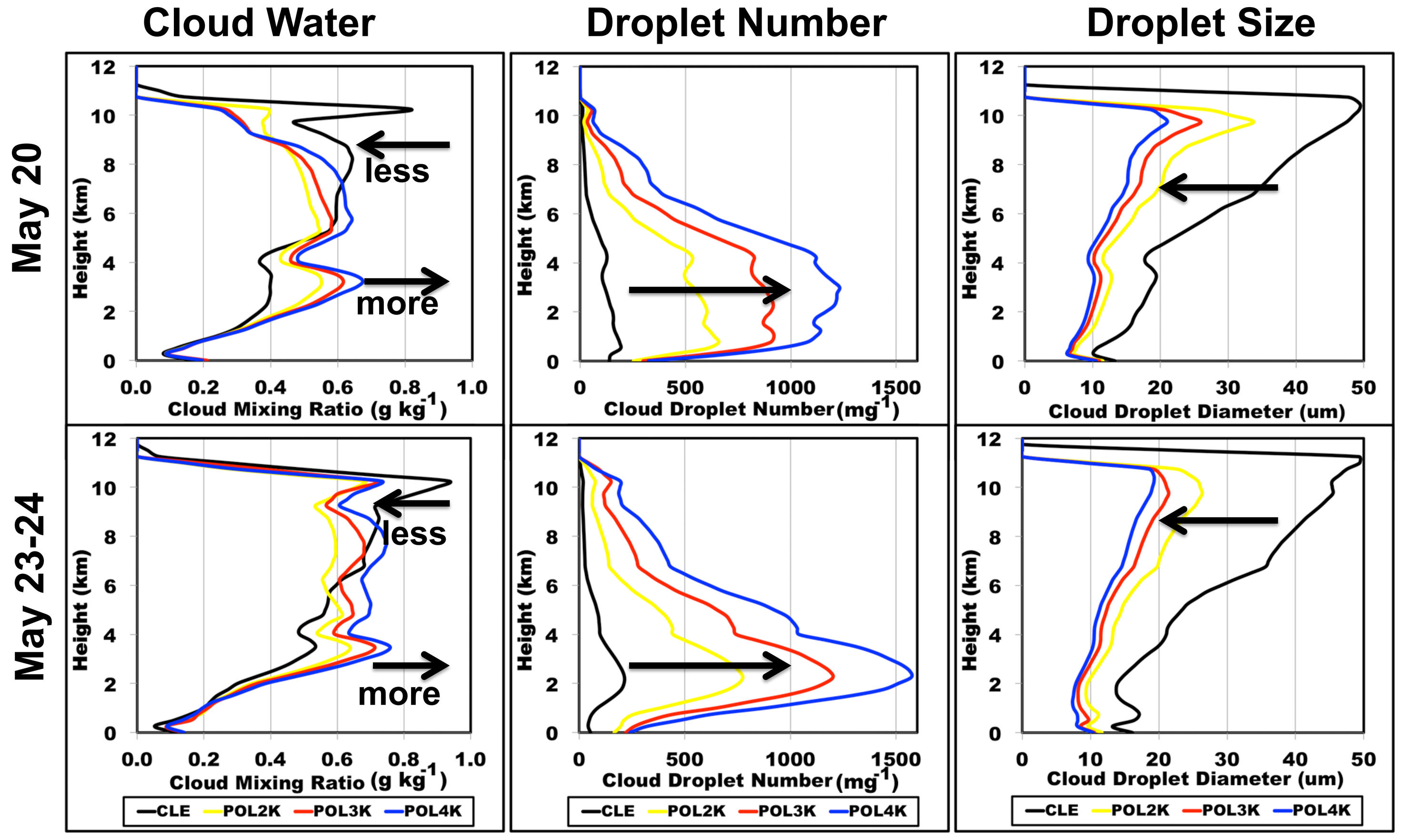


Initial aerosol vertical profiles.



Simulated and observed radar reflectivity (dBZ).

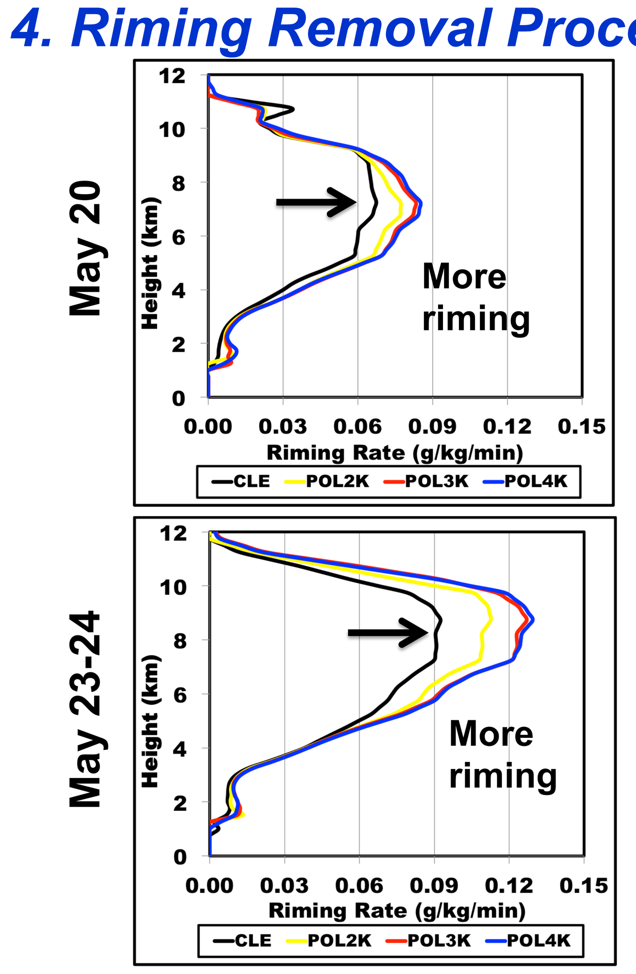
3. Cloud Droplet Characteristics



An increase in aerosol number concentration leads to more numerous but smaller cloud droplets.

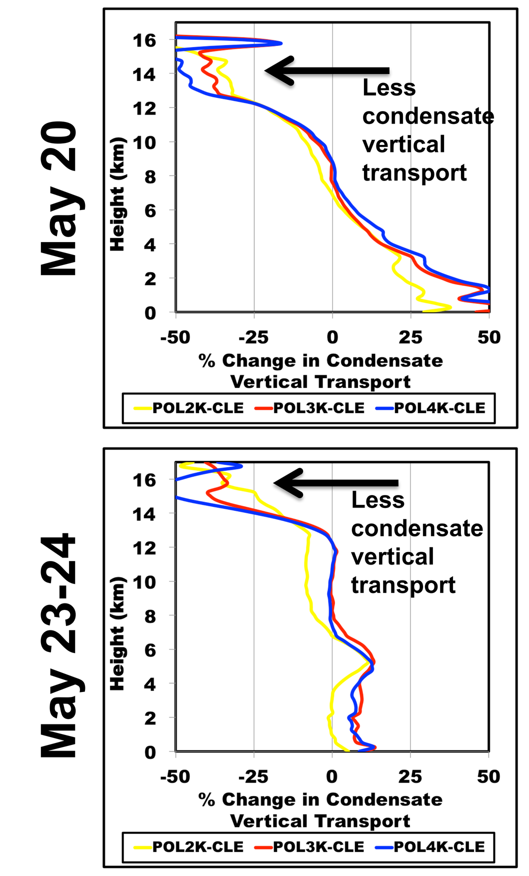
There are mixed trends in cloud water mixing ratio, with an increase at lower altitudes and decrease at higher altitudes.

4. Riming Removal Process



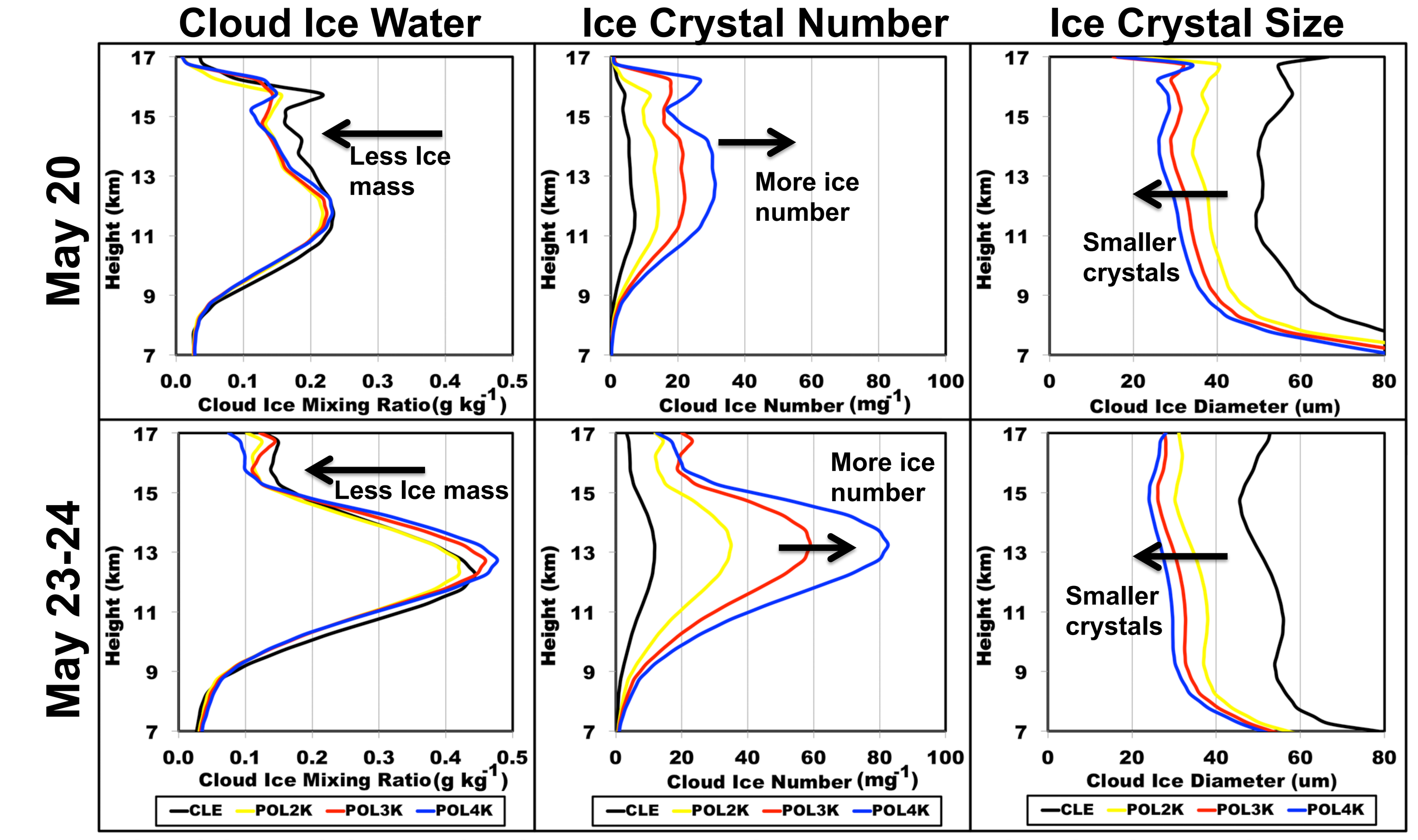
In more polluted conditions, ice particles more readily collect the more numerous cloud droplet population. The cloud droplet size reduction is not substantial enough to highly suppress collisions between ice and the far more numerous cloud droplets.

5. Vertical Transport of Condensate



Greater efficiency of rime scavenging of cloud water leads to reduced transport of condensate to the upper anvil levels.

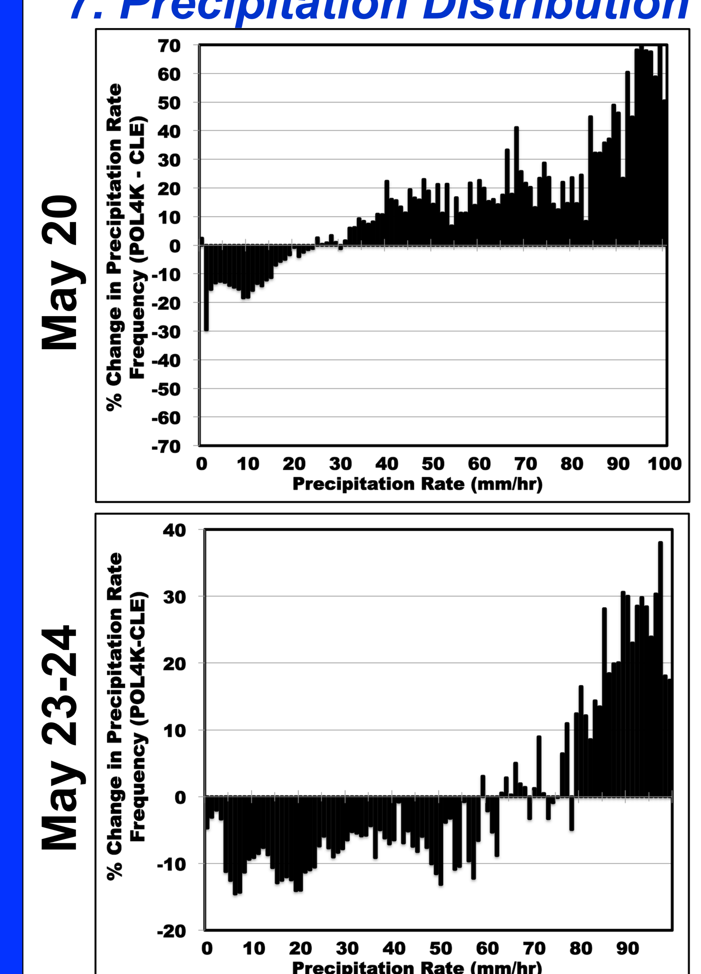
6. Cloud Ice Characteristics



Cloud ice mixing ratio decreases at the uppermost levels due to increased riming and subsequently reduced vertical transport of cloud droplets to the homogeneous freezing level.

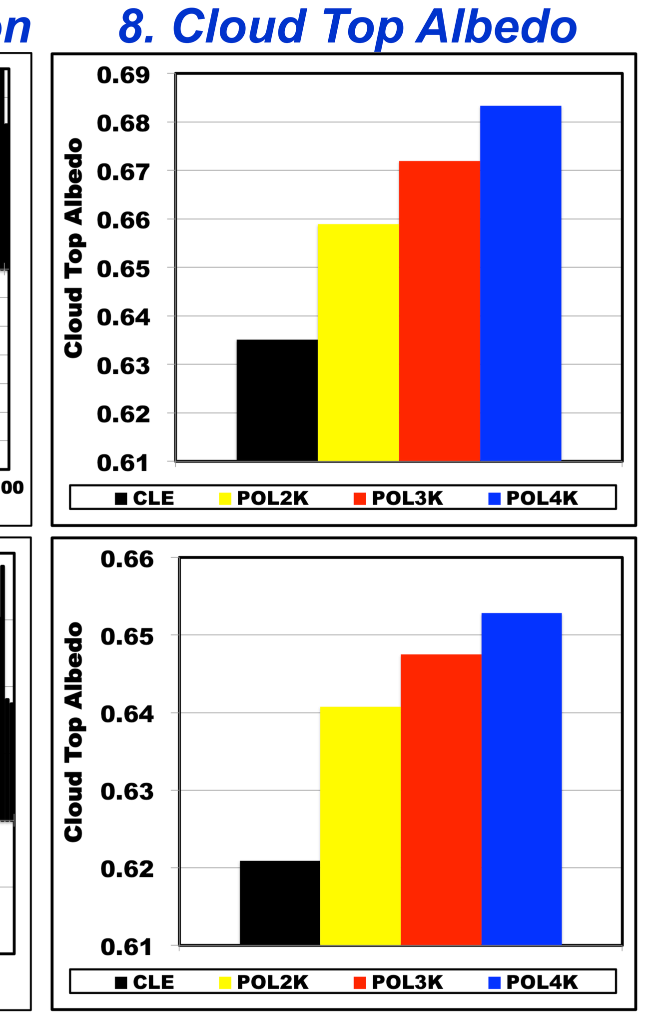
Meanwhile there are more numerous smaller crystals that tend to have longer residence times at high altitude due to slower fall speeds.

7. Precipitation Distribution



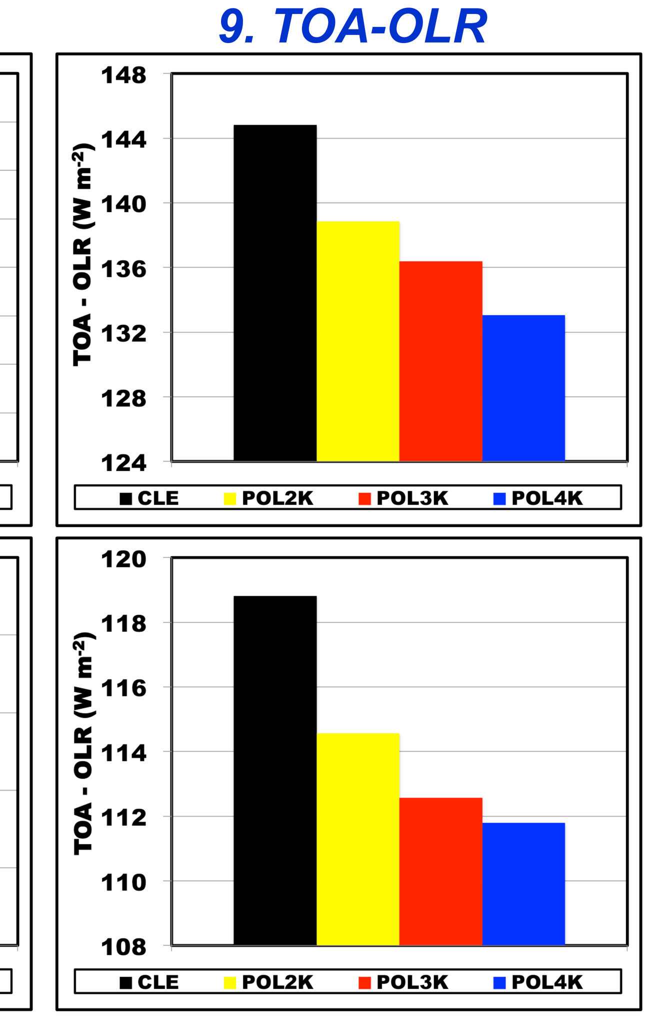
Increased collection of cloud water prevents lofting of condensate into the anvil and precipitating stratiform region. Thus, there is a decrease in the frequency of stratiform and weaker convective precipitation and an increase in the frequency of heavy convective precipitation.

8. Cloud Top Albedo



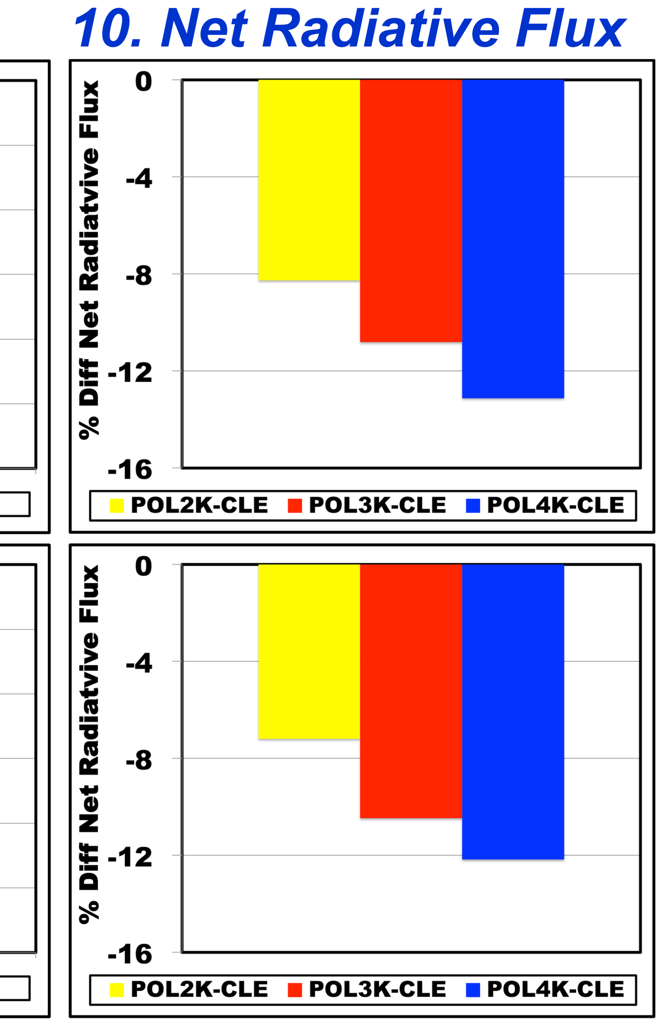
More numerous, small ice crystals leads to greater cloud top albedo via the ice hydrometeor equivalent of the Twomey effect.

9. TOA-OLR



The more numerous, smaller ice crystals reside at a higher altitude for longer periods of time due to slower fall speeds, thus reducing the emission temperature of outgoing longwave radiation and retaining more heat below cloud top.

10. Net Radiative Flux



The change in the net radiative flux to space represents the sum of the radiative changes induced by aerosol indirect effects. The amount of radiation emitted to space was decreased by up to 13% in this study, thus inducing a warming effect via aerosols.

11. Summary

✓**Aerosol loading leads to an increase in riming rate and precipitation rate in MCSs:** Greater riming leads to less cloud water lofted to the upper and rearward portions of the MCS, and it also increases growth of precipitating hydrometeors. This leads to a decrease in the frequency of stratiform and weaker convective precipitation and a subsequent increase in the frequency of heavy convective precipitation.

✓**Aerosols indirectly induce a net warming (reduced cooling) effect in MCSs:** Cirrus anvil ice spectra shift towards more numerous, smaller ice crystals. In spite of less anvil ice mass, this produces anvil cloud with longer residence time at higher altitude, greater cloud top albedo, reduced top of the atmosphere outgoing longwave radiation, and a reduction in the net radiative flux to space by up to 13%.

References

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Acknowledgements: *This work was supported by the DOE (Award # DE-SC0010569).*