Effects of wildfire pollution on the microphysical and electrical properties of pyrocumulus

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Introduction & Goals

- Pyrocumulus clouds form over wildfires when hot, smoke-filled air rises, cools and condenses. These clouds have higher cloud condensation nuclei (CCN) concentrations, which affect their microphysical and electrical properties. Lang et al. (2014) documented an electrified pyrocumulus cloud over the May 2012 Hewlett Gulch fire outside of Fort Collins, Colorado. This cloud produced approximately 20 intracloud lightning flashes.
- Motivated by their work, we investigate the microphysical differences between low CCN clean clouds and high CCN pyrocumulus. A possible charging mechanism will be inferred and compared to Lang et al. (2014). The goal is to better understand the aerosol-induced cloud-scale microphysics that cause pyrocumulus electrification to occur.

Importance

- Understanding pyrocumulus electrification could help with predictions of rapid wildfire growth
- Pyrocumulus clouds impact the radiative and chemical characteristics of the upper troposphere

Key Questions

1. How does changing CCN concentrations affect the various liquid and ice species in pyrocumulus?
2. What possible charging mechanism contributes to electrified pyrocumulus?

Methods

- Idealized simulations of a convective cloud were performed using RAMS (Regional Atmospheric Modeling System) (Cotton et al. 2003, Saleeby and van den Heever 2013).
- The initial horizontally homogeneous model environment was taken from the average 12Z May 16th and 00Z May 17th Denver soundings (Figure 1); the Hewlett Gulch pyrocumulus electrified during the afternoon of May 16th, between these two sounding times.
- Five different surface CCN concentrations were used: 100, 500, 1000, 3000, and 5000 #/mg. The initial CCN profile decreased exponentially with height.
- The 100, 1000, and 5000 #/mg CCN experiments are shown here, as they capture all of the trends.

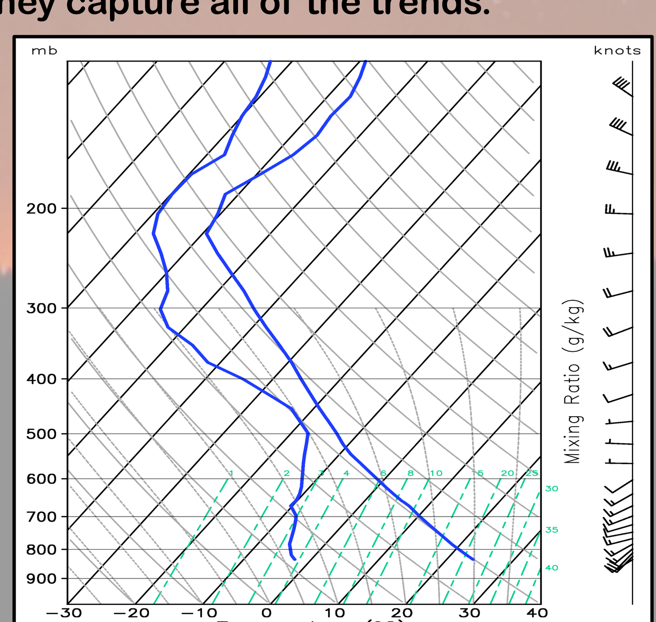

Figure 1. Average 12Z and 00Z DNR soundings

Model Setup

- 0.5 km model grid spacing (100 x 100 km domain)
- 90-minute model runtime
- 68 vertical levels
- Cloud initialized by warm bubble at the surface, resulting in convergence and upward motion

Acknowledgements

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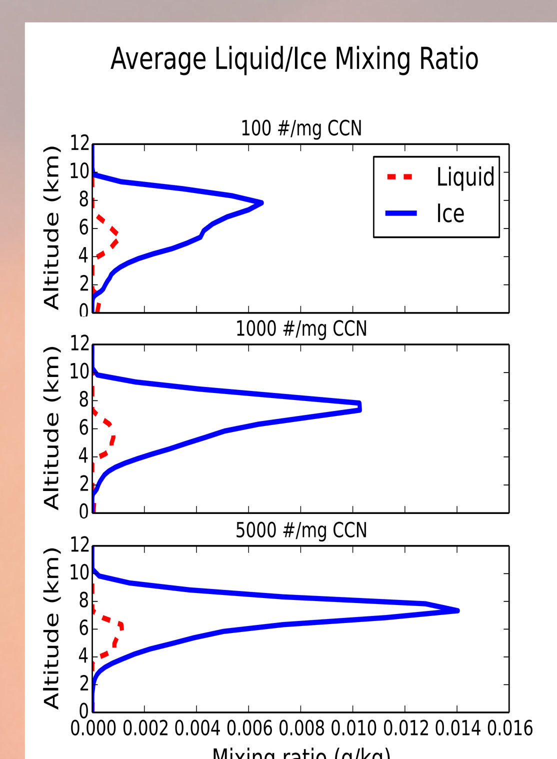
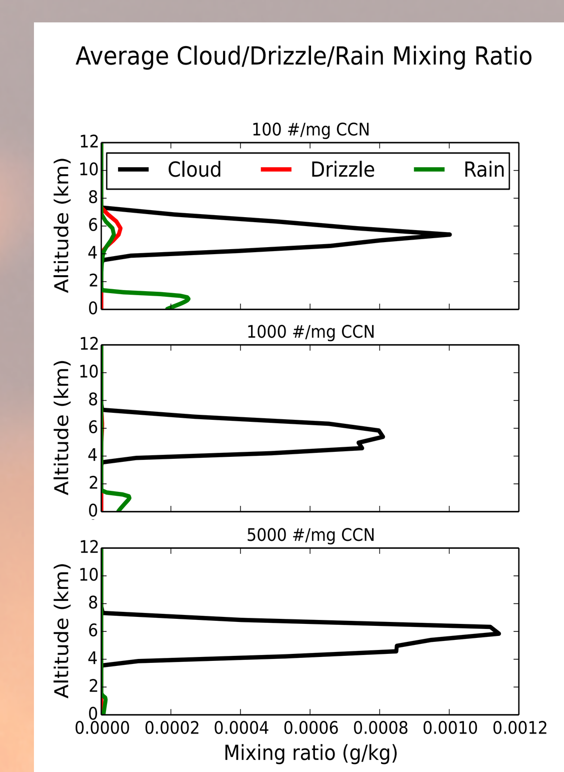
Bulk Cloud Properties

Figure 2. The amount of ice in the cloud steadily increases as clean air becomes more polluted. Cloud base (~4km) and cloud top (~10 km) remain consistent for all simulations and agree with observations in Lang et al. (2014).



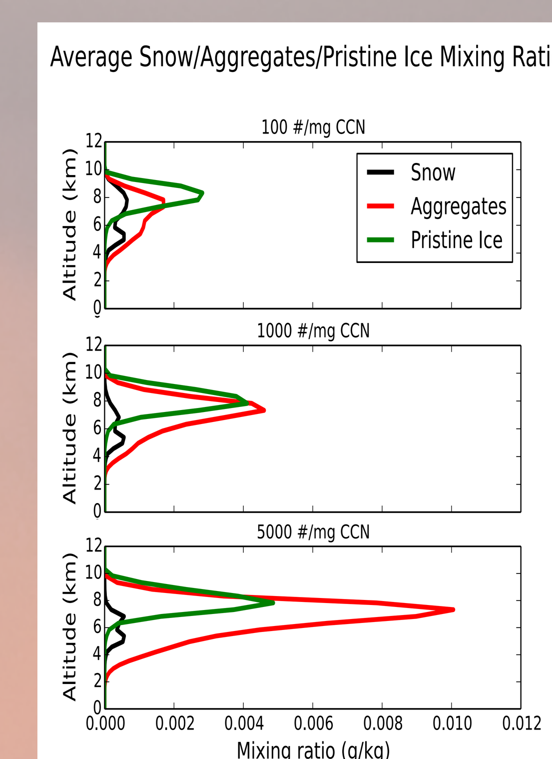
Microphysics – Liquid

Figure 3. Increasing CCN results in decreasing droplet size. Collision and coalescence shuts down, resulting in very little drizzle and rain and less precipitation reaching the ground. Cloud water decreases in the moderately polluted case as it is being collected by graupel.



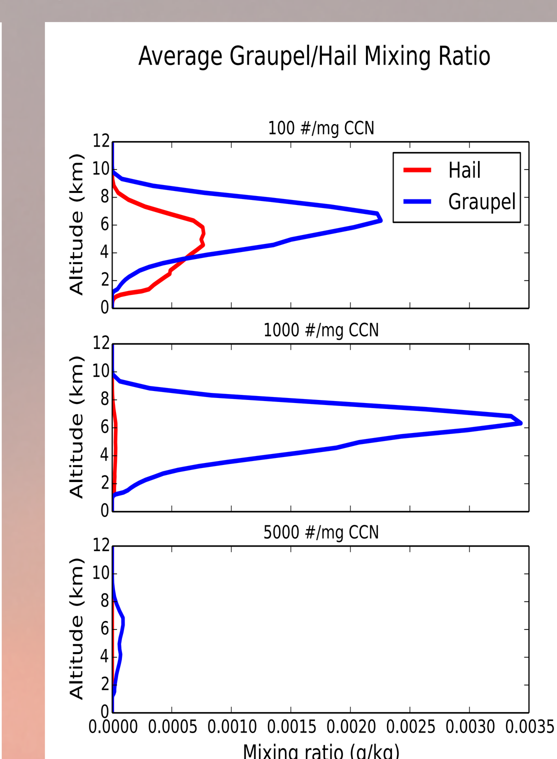
Microphysics – Small Ice

Figure 4. As droplet size decreases with increasing CCN, riming becomes inefficient and small ice becomes more prevalent. The decreased riming efficiency also explains the increase in cloud water content in the 5000 CCN case (Figure 3).



Microphysics – Large Ice

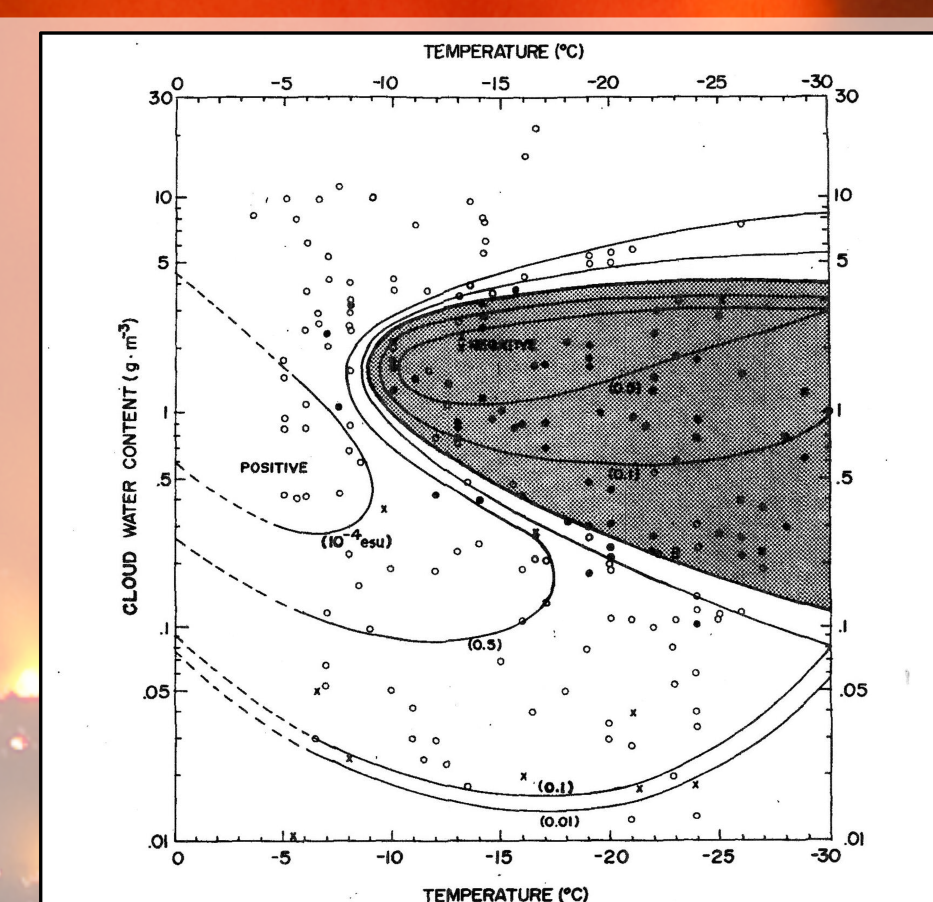
Figure 5. Graupel and hail are both produced in the cleanest case since rain water favors hail production. Partitioning to more cloud water and less rain water in moderate pollution favors graupel over hail. Above 1000 CCN, cloud droplets become extremely small and rime inefficiently, which shuts down large ice production.



Possible Charging Mechanism - Theory

- Graupel often plays an important role in the formation of lightning. Investigating its electric properties gives crucial information into the possible charging mechanism of pyrocumulus.
- Tsutomu Takahashi conducted laboratory experiments on charging mechanisms in thunderstorms and his result is a widely accepted charging theory.
- The diagram produced from his experiment is relevant for graupel and small ice crystal collisions in the presence of supercooled liquid (Figure 6).

Figure 6. (right) Takahashi's diagram which represents the charge graupel would acquire when it collides with ice crystals under different temperature and water content conditions (Takahashi 1978).



Future Work

- Look for aerosol observations to obtain an approximate CCN measurement for the Hewlett Gulch pyrocumulus case
- Investigate other possible charging mechanisms
- Use simulated dual-polarimetric radar variable output to infer which background aerosol profile is most representative of observations in Lang et al. (2014)
- Look at simulations with a larger domain, longer runtime, and 10,000 CCN addition

References

Cotton, W. R. et al. "RAMS 2001: Current Status and Future Directions." *Meteorology and Atmospheric Physics* 82 (2003): 5-29.

Lang, Timothy J., et al. "Lightning in Wildfire Smoke Plumes Observed in Colorado during Summer 2012." *Monthly Weather Review* 142.2 (2014): 489-507.

Saleeby, Stephen M., and Susan C. van den Heever. "Developments in the CSU-RAMS Aerosol Model: Emissions, Nucleation, Regeneration, Deposition, and Radiation." *Journal of Applied Meteorology and Climatology* 52.12 (2013): 2601-2622.

Takahashi, Tsutomu. "Riming Electrification as a Charge Generation Mechanism in Thunderstorms." *Journal of the Atmospheric Sciences* 35.8 (1978): 1536-1548.

Possible Charging Mechanism – Simulations

- We recreated Takahashi's diagrams for our simulations to determine under which CCN concentration this charging mechanism is most plausible.

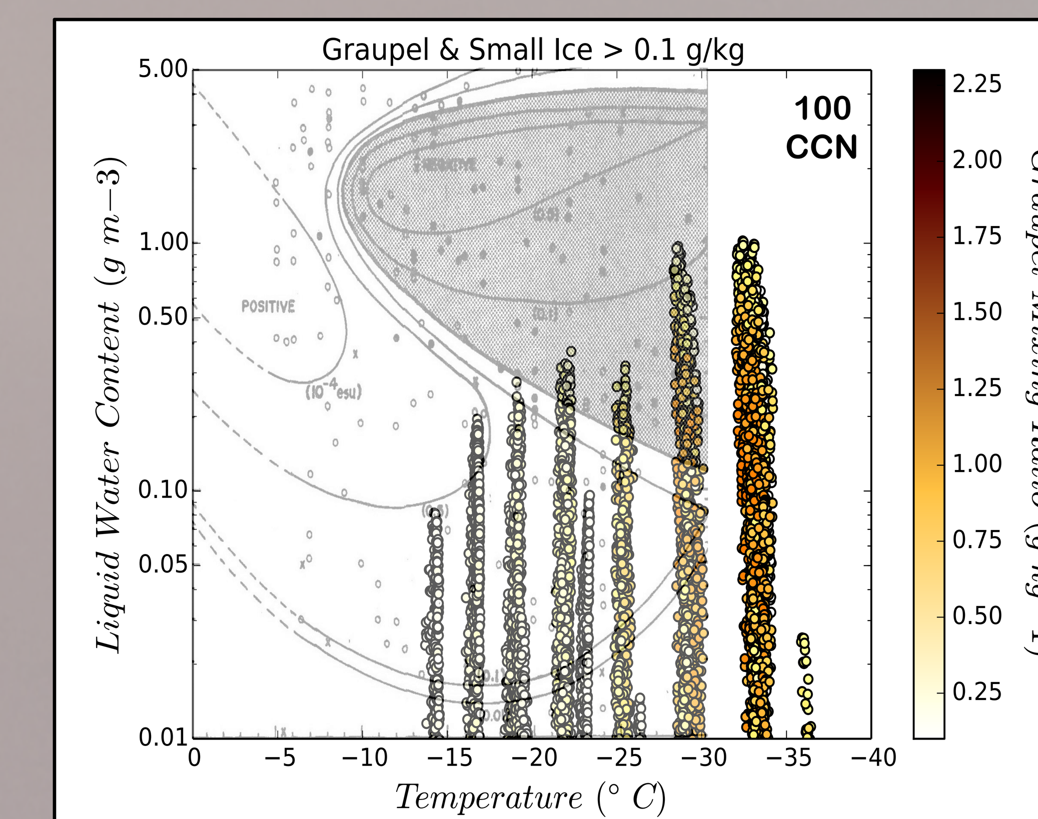


Figure 7. (above) Diagram was recreated by taking points where both graupel and small ice > 0.1 g/kg and finding the liquid water content and temperature for each point. These data were then superimposed on Takahashi's diagram. This 100 CCN diagram is a potential representation of the clean clouds surrounding the Hewlett Gulch pyrocumulus.

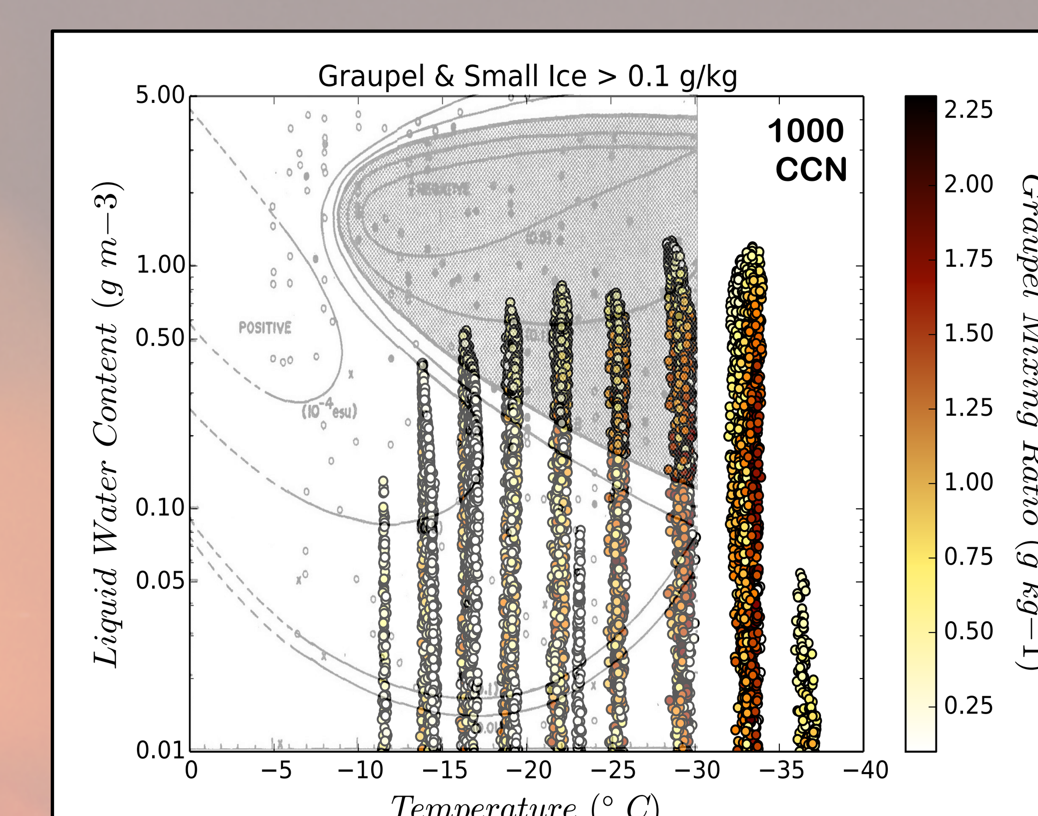


Figure 8. (above) More graupel is charging negatively across a range of temperatures in the moderately polluted case. Since graupel is heavier than small ice, a positive over negative charge separation will result which was observed in the Hewlett Gulch pyrocumulus case. Lang et al. (2014) infers this mechanism as a possible cause of electrification and we can infer this as well from our simulation for moderately polluted pyrocumulus.

Conclusions

Moderately Polluted Pyrocumulus
- Rain processes shut down while graupel production increases
- Takahashi's graupel charging mechanism is plausible for this scenario

Extremely Polluted Pyrocumulus
- Shut down of graupel production which allows for large amounts of cloud water and small ice
- Another charging mechanism would need to be at work