Influence of Environmental Moisture on Aerosol Indirect Effects in Simulated Deep Convection

Stephen M. Saleeby[1], Susan C. van den Heever[1], Michael Jensen[2], Dié Wang[2], Scott Giangrande[2]

[1]Colorado State University, Fort Collins, CO
[2]Brookhaven National Laboratory, Upton, NY

Introduction

- ✧ **Increased aerosol concentrations can alter cloud properties through generation of more numerous but smaller cloud droplets.** ***(e.g., Twomey and Squires, 1959)***

- ✧ **This modification of the droplet spectrum can then suppress precipitation by inhibiting collision-coalescence growth of raindrops.** ***(e.g., Albrecht et al., 1989; Rosenfeld and Woodley, 1999)***

- ✧ **Greater aerosol concentration potentially enhances convective development via cold and warm phase invigoration processes.** ***(e.g., Rosenfeld et al., 2008; Saleeby et al., 2015; Igel and van den Heever, 2021)***

- ✧ **However, the impact of aerosols on precipitating clouds is highly variable and depends upon the types of clouds and convection as well as the environmental conditions** ***(e.g., Khain et al., 2008)***

Science Question

How does variability in atmospheric moisture influence aerosol indirect effects in simulations of ordinary convection?

Data Source

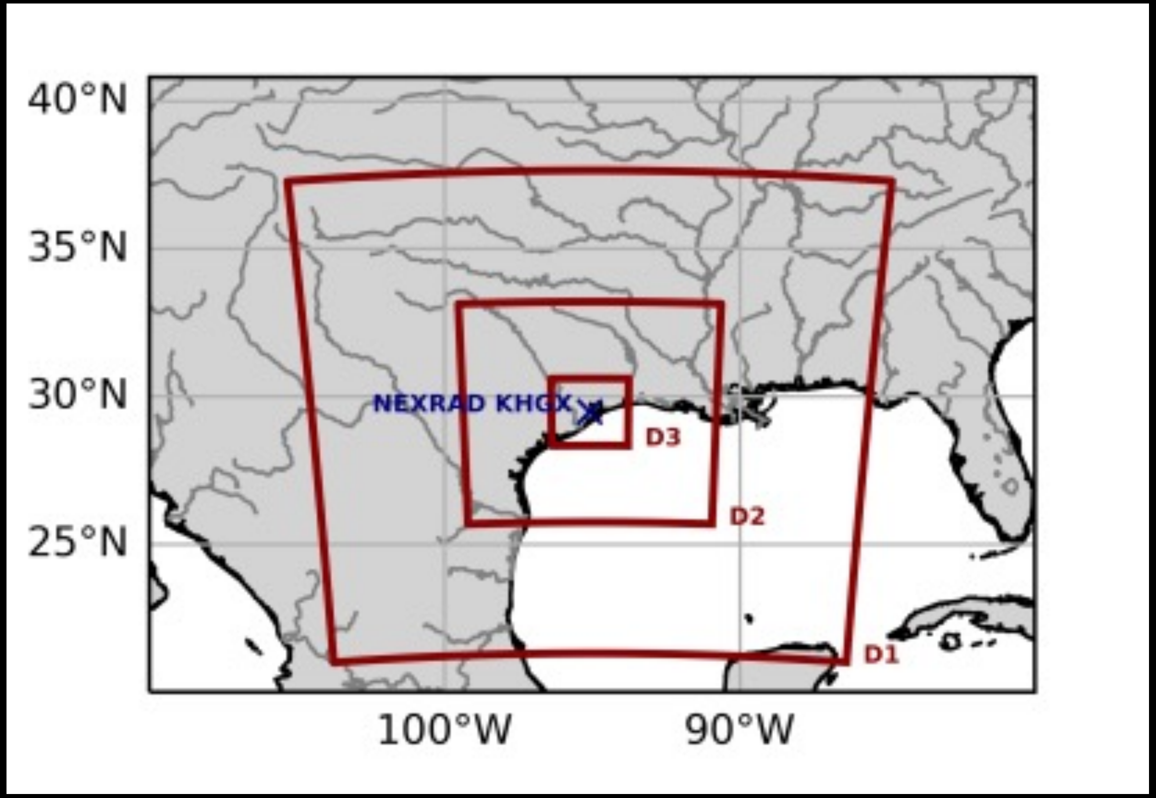
Utilize RAMS simulations of deep convection from the *Aerosol, Cloud, Precipitation and Climate (ACPC) initiative* deep convective working group model intercomparison project (MIP) as control simulations (http://acpcinitiative.org/).

Then make use of simulations in which Clean and Polluted aerosol scenarios are run for environments with +/- 10% water vapor perturbations over the full column, below 2km, and aloft above 2km.

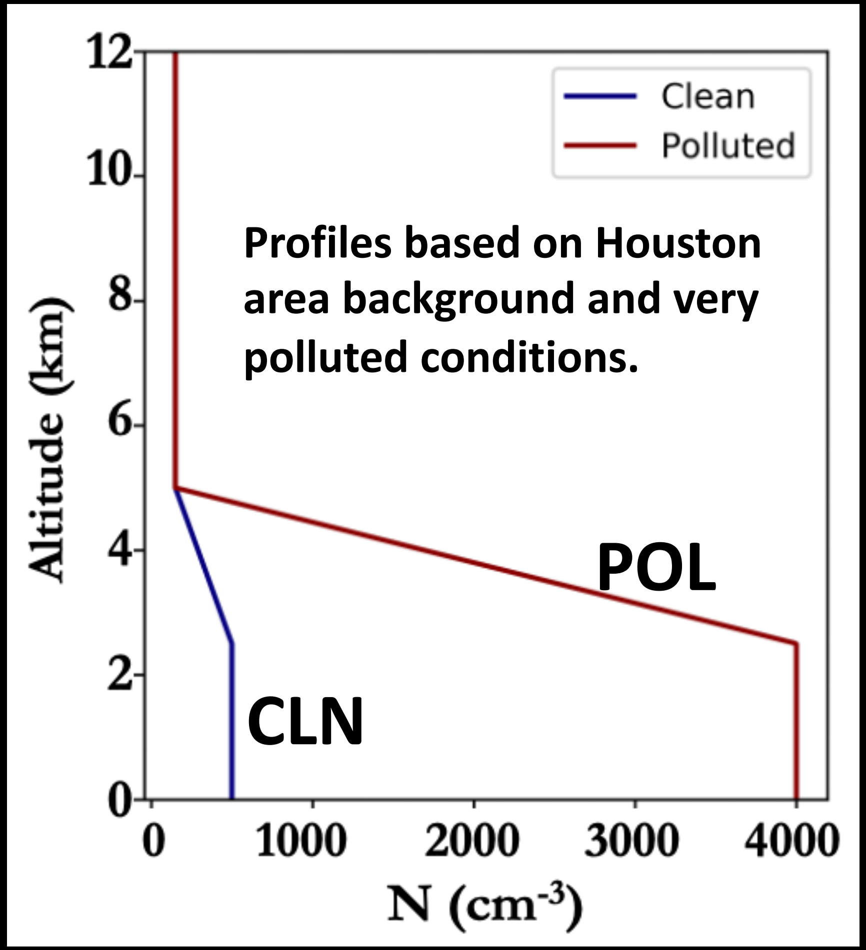
MIP Convective Simulations

Houston, TX 1600UTC 19th – 0400UTC 20th June 2013
Simulation Inner-domain Horizontal Grid Spacing of 500m

Model Domain

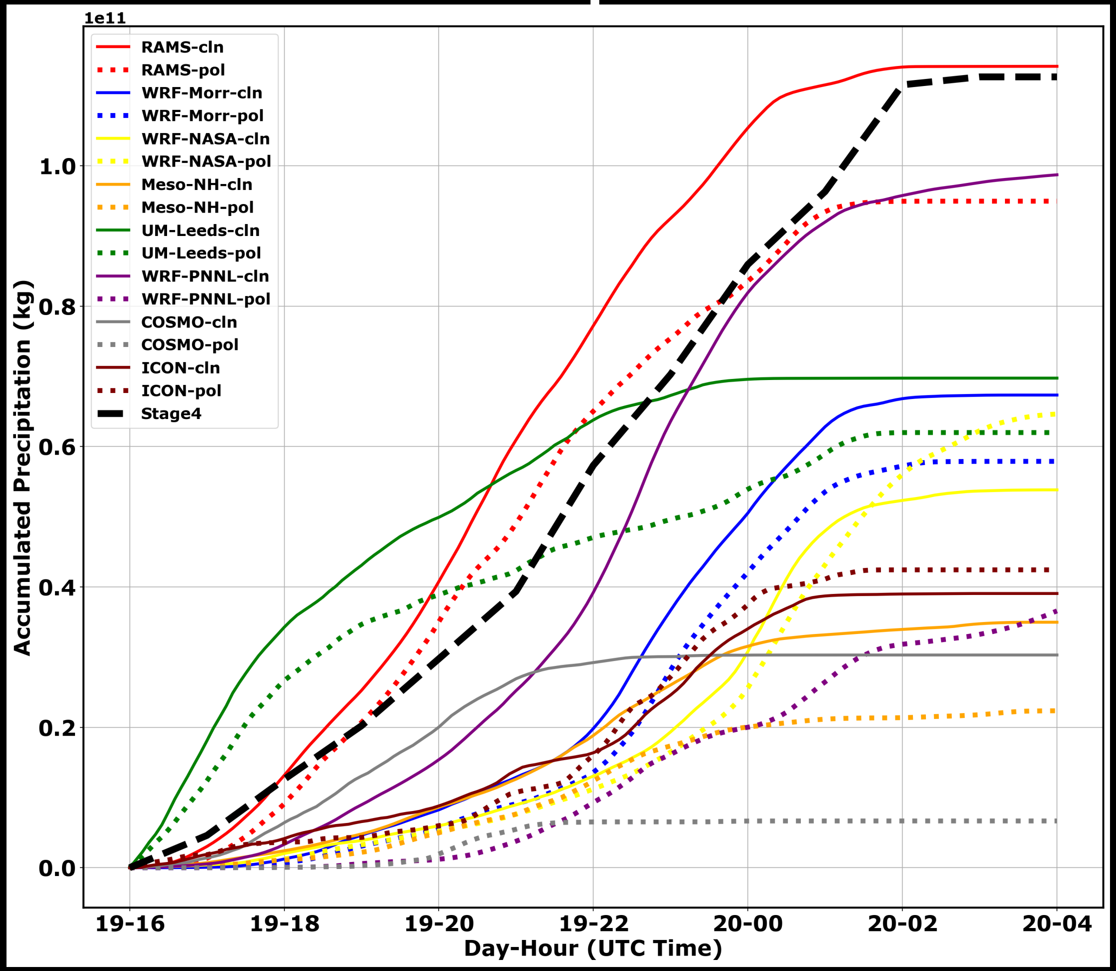


Clean & Polluted Initial Aerosol Concentration Vertical Profiles

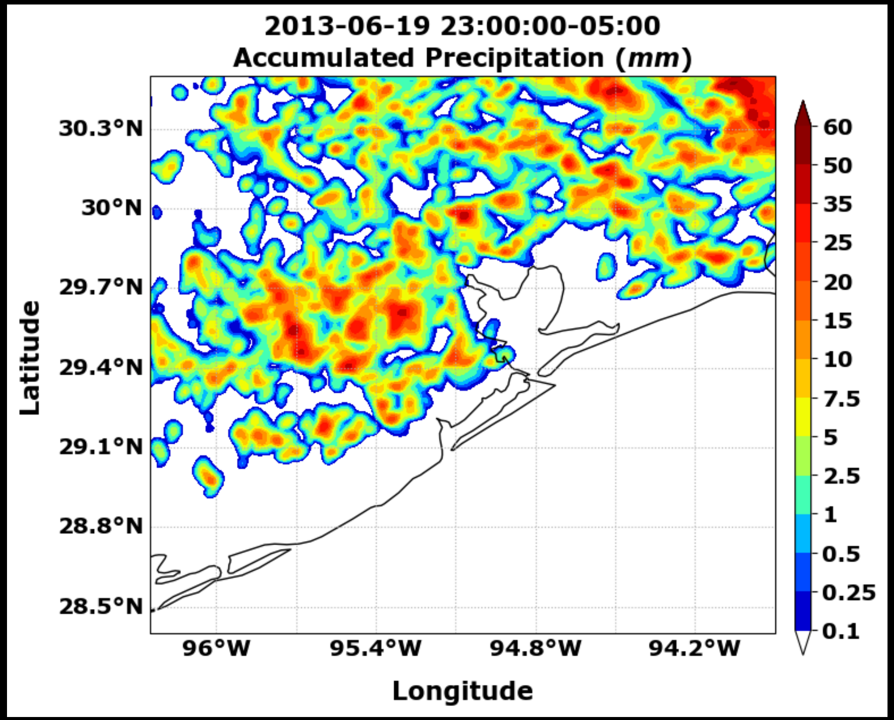


Case Study Precipitation

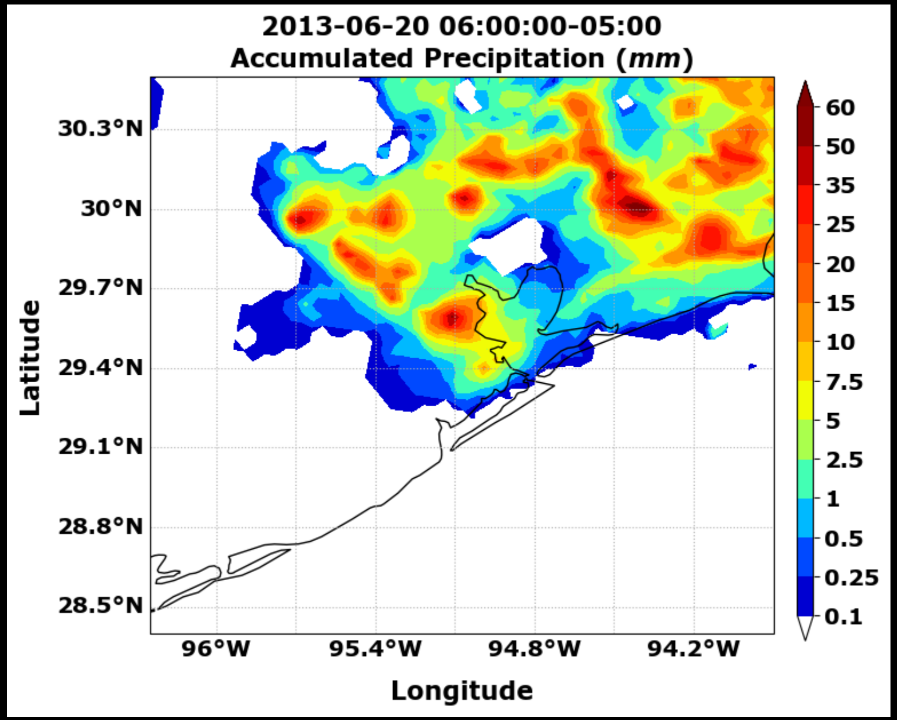
MIP Model Precip Timeseries



RAMS Total Precip (CLN)



Stage IV Precip

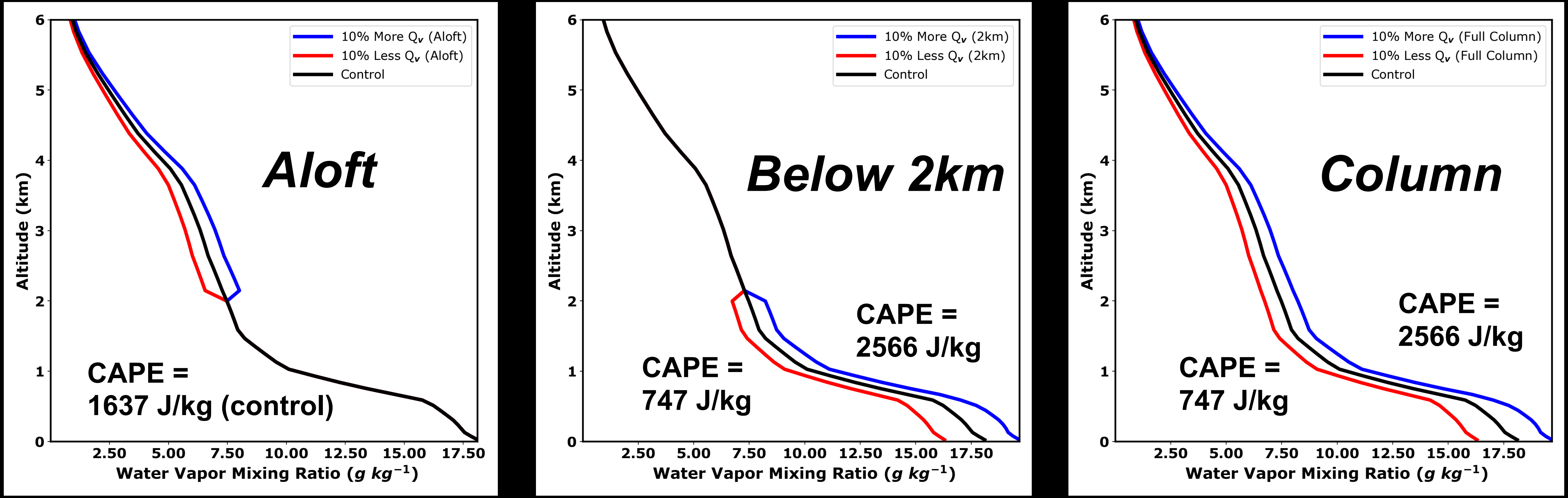


There is large variability among MIP model simulations (both CLN and POL) for this case.

All the models simulate a reduction in precipitation for an increase in aerosols.

In this study we want to see if the aerosol effect is consistent in environments with different moisture while preserving the base characteristics of the case.

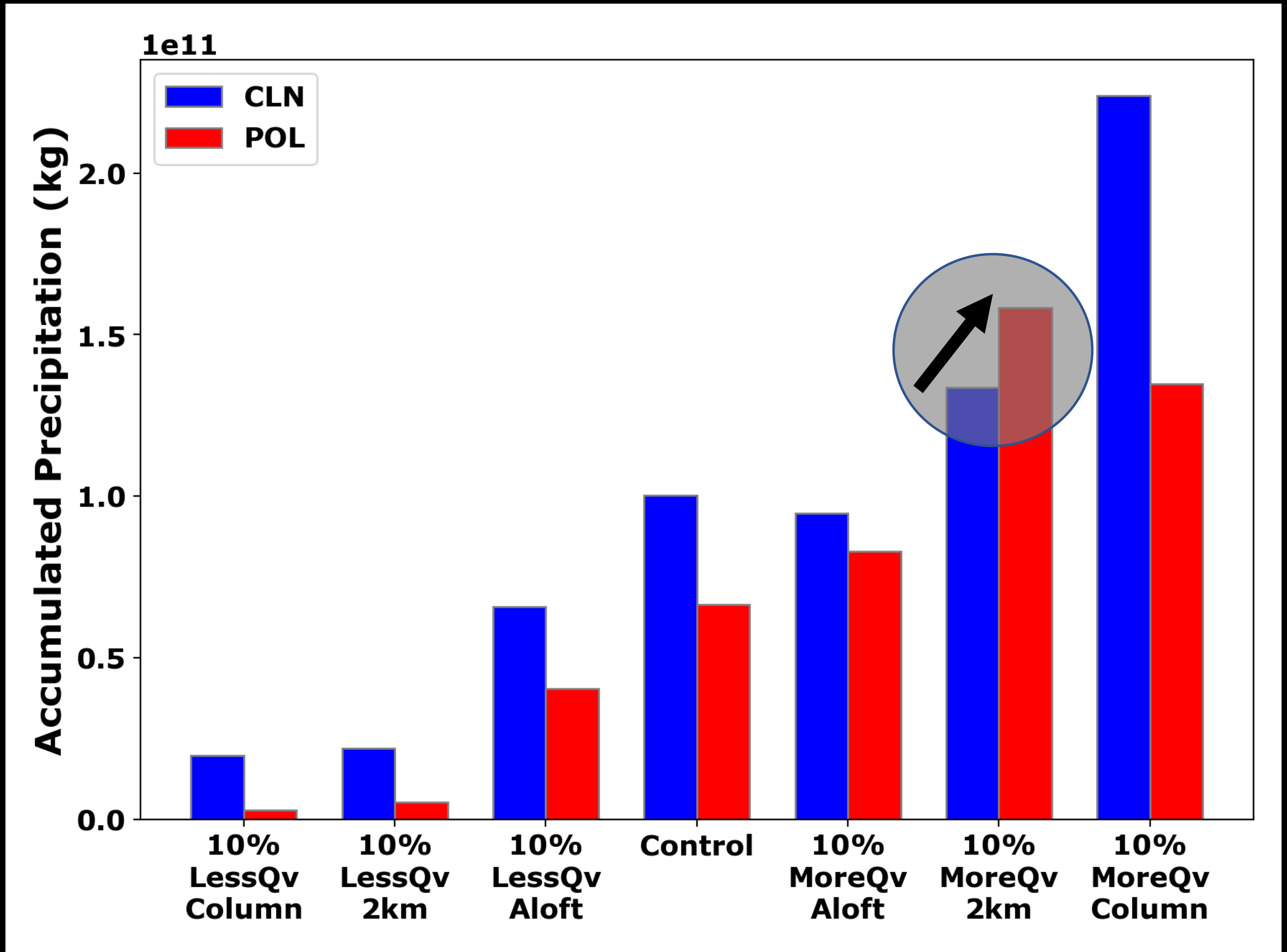
Initial *RAMS* Domain-Averaged Water Vapor Profiles



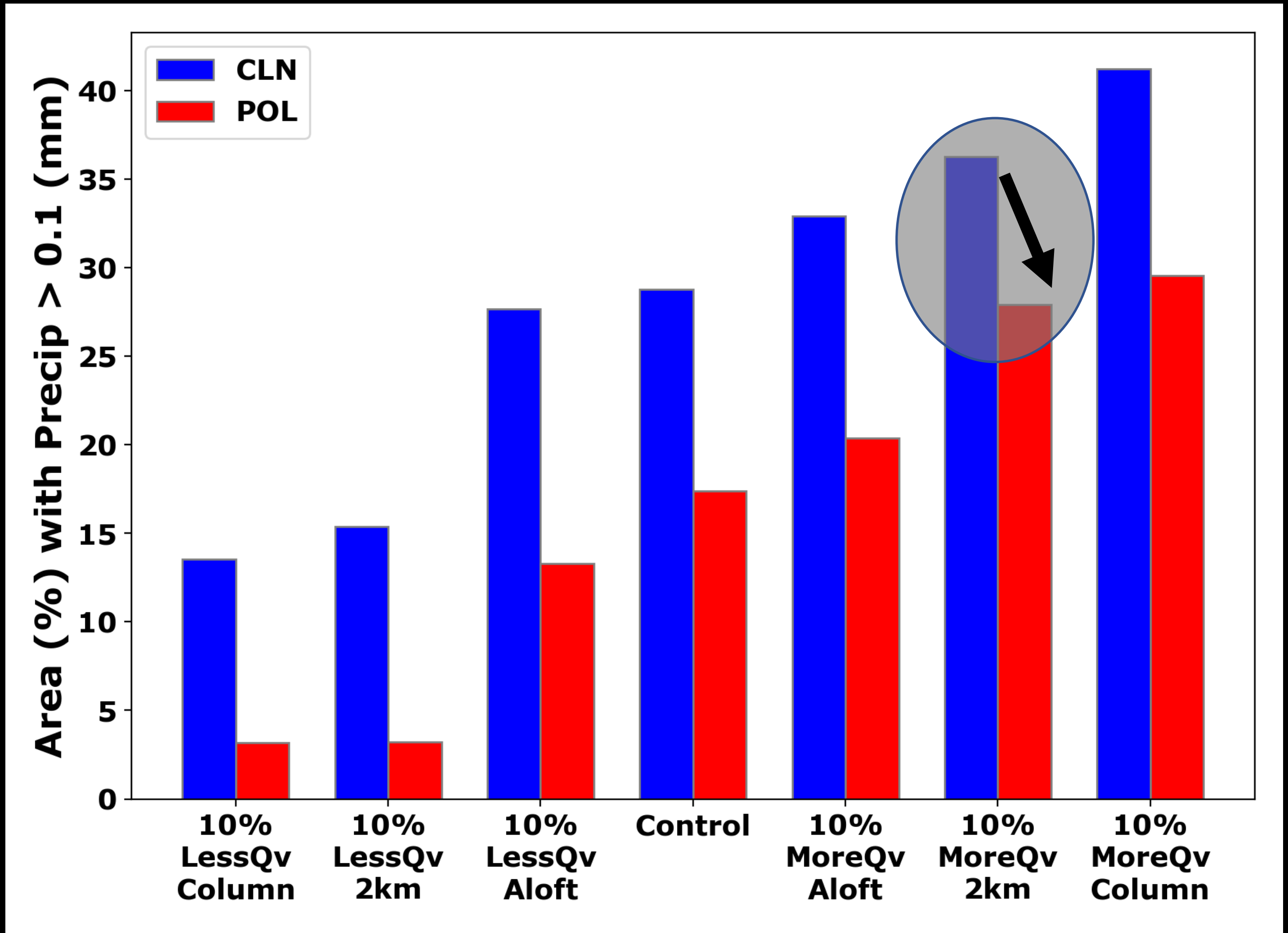
To determine the potential aerosol effect on precipitation within environments of varying moisture, we have perturbed the domain water vapor profiles by +/- 10%.

This was done over three different vertical depths to assess boundary layer vs. upper-level influence.

Total Accumulated Precipitation



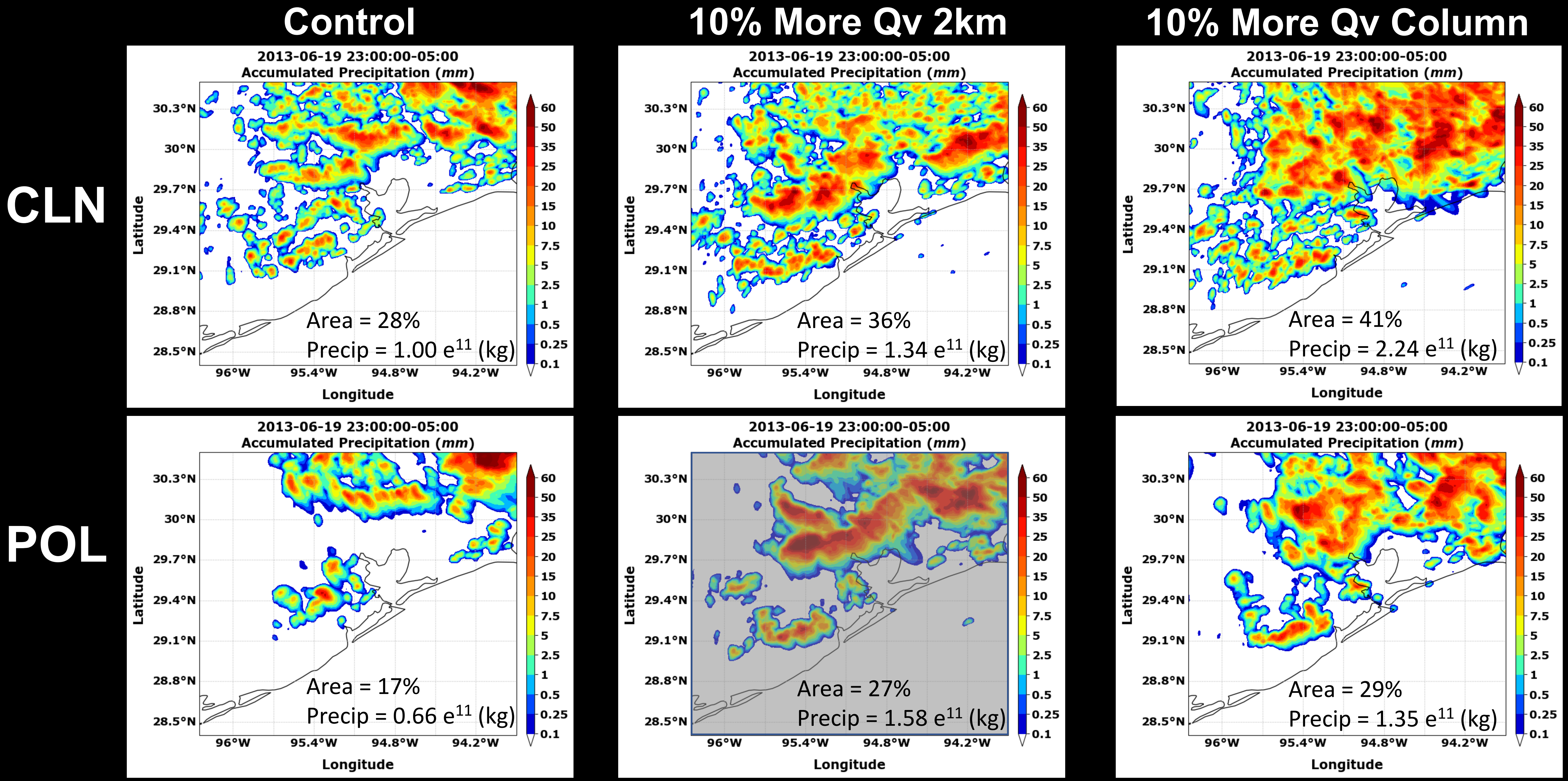
Domain Area Fraction of Precipitation



In each pair of CLN and POL simulations, all but one results in reduced precipitation when aerosol concentration is increased.

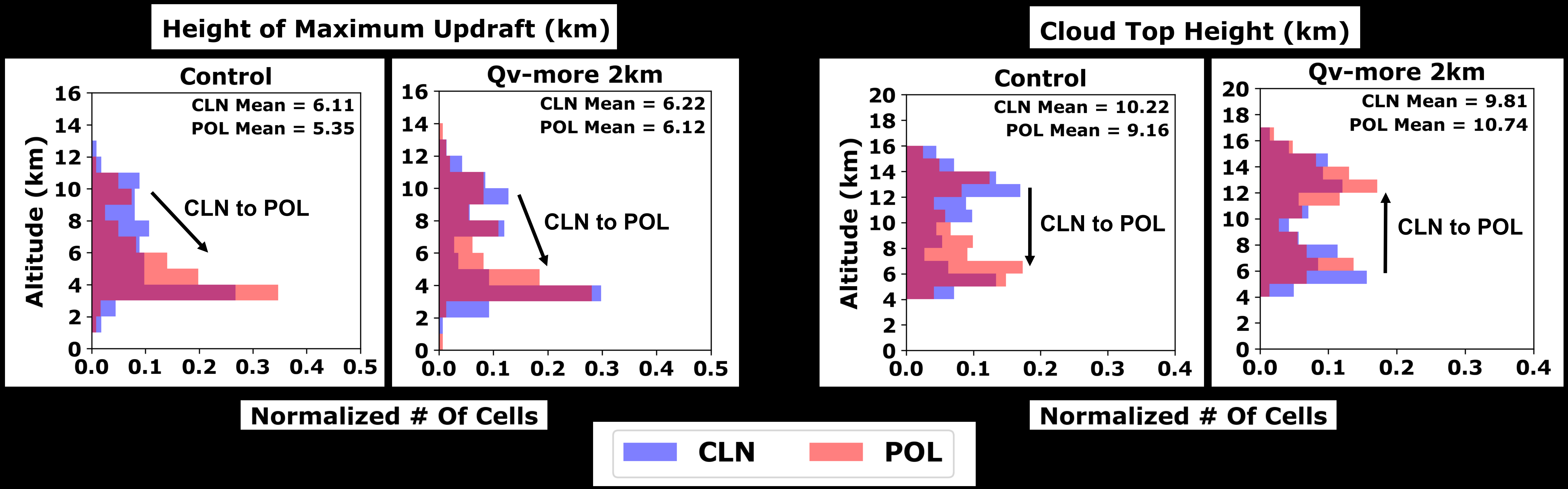
In each pair of CLN and POL simulations, ALL of them display reduced precipitation area when aerosol concentration is increased.

Total Accumulated Precipitation



The shaded figure is the outlier among simulations (10% More Qv 2km). It produces greater total precipitation for an increase in aerosol and with less total column moisture in the POL scenarios.

Normalized Histograms of Tracked Cell (updraft) Characteristics



The mean height of maximum updraft is reduced from CLN to POL in each scenario.

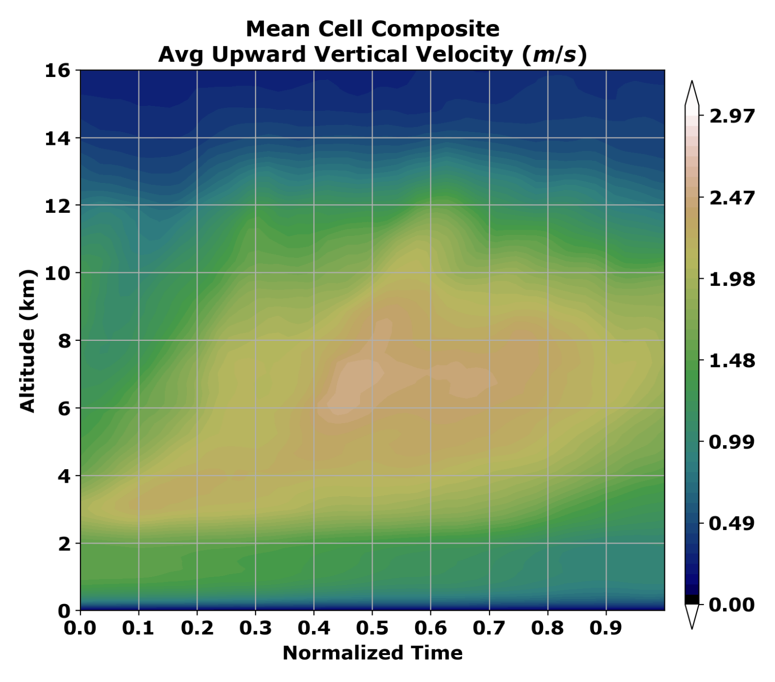
The mean cloud top height tends to be reduced from CLN to POL aside from the outlier case.

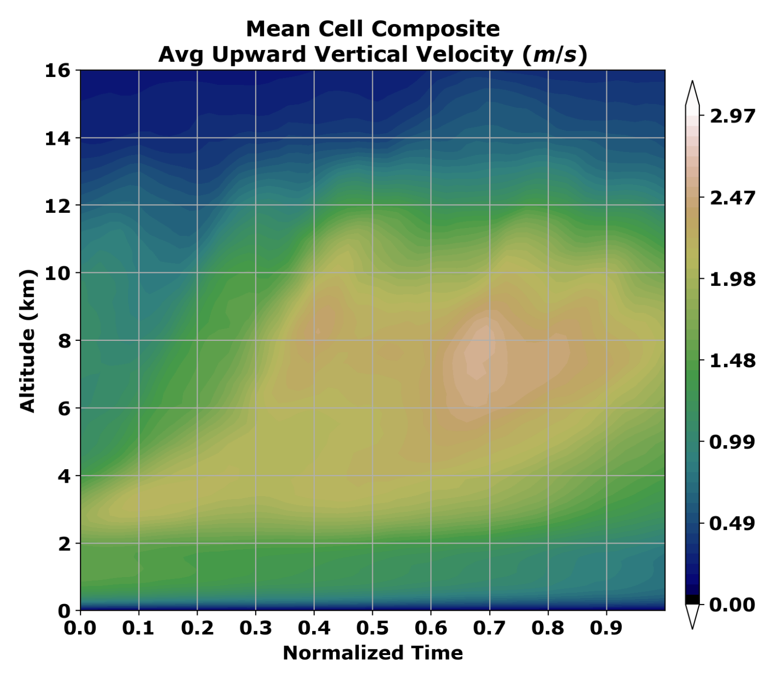
Control Run - Tracked Cell Mean Updraft Strength

Control

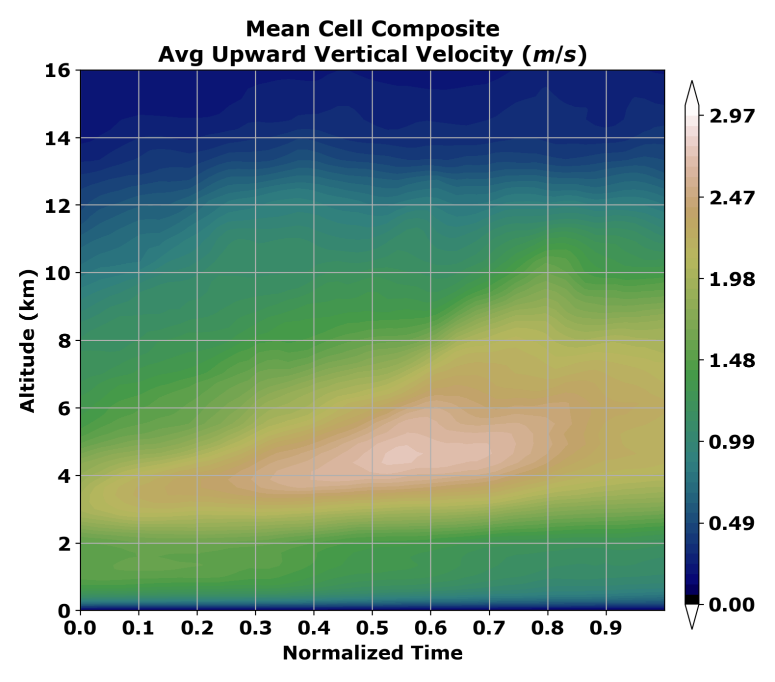
Qv-More-2km

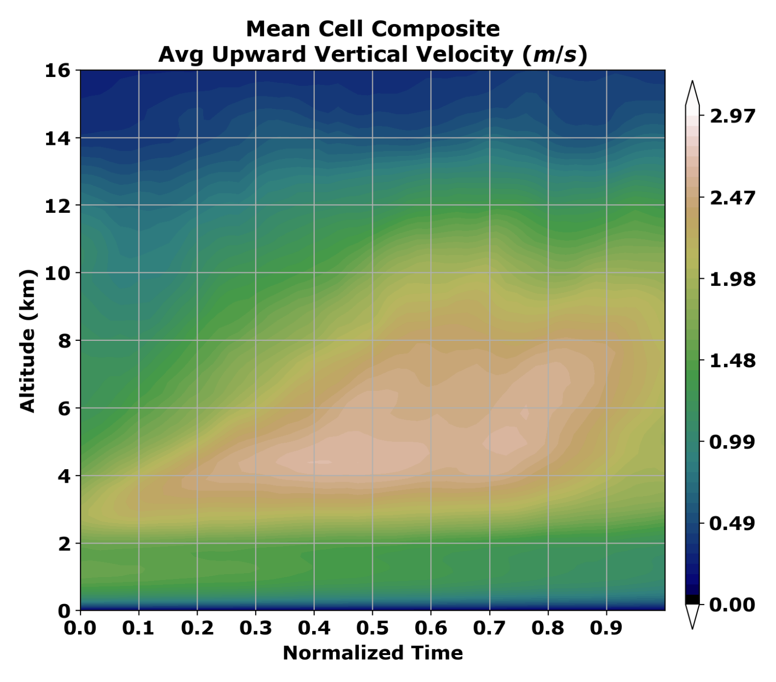
Clean





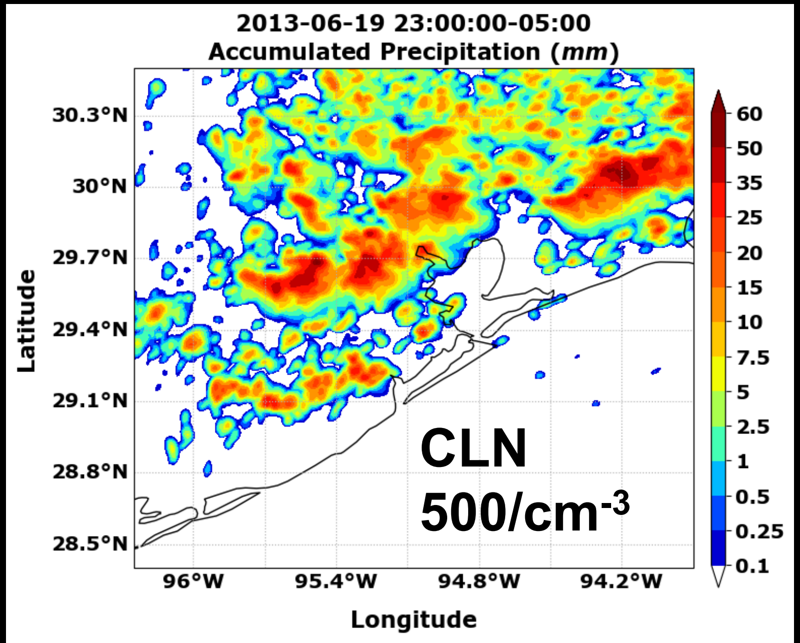
Polluted

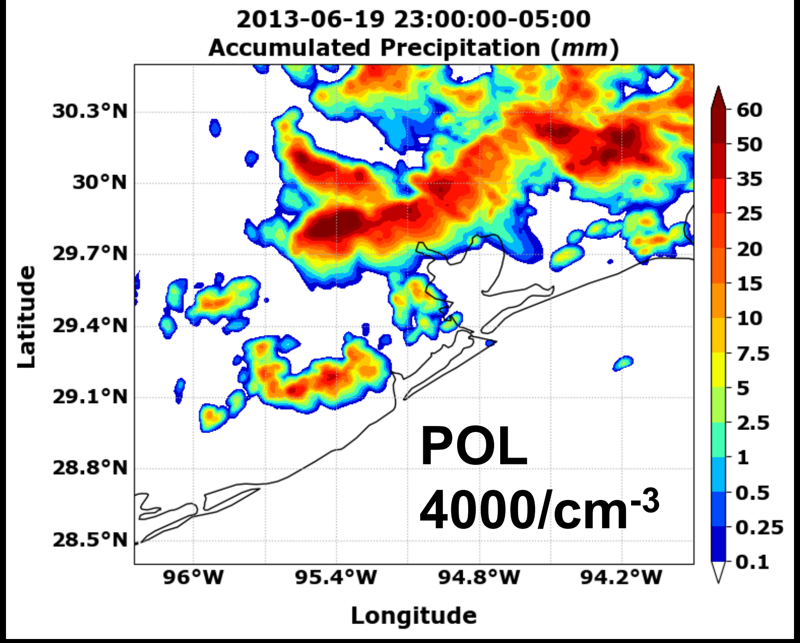




Summary

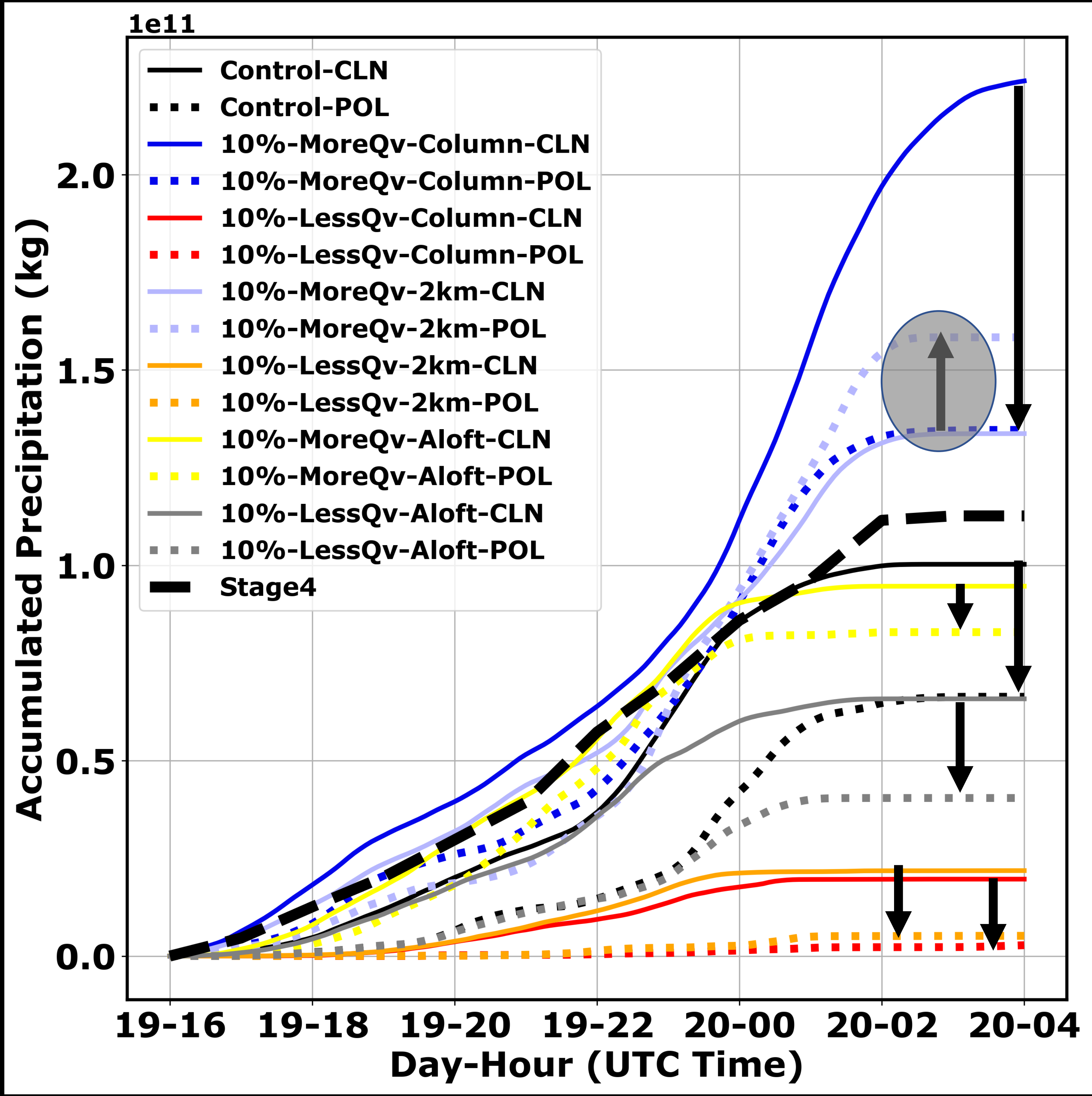
10% More Qv 2km Outlier Case





- **Decreasing or increasing moisture in a convective domain tends to impose a corresponding change in total precipitation.**
- **The aerosol indirect effect consistently leads to reduced AREA of rainfall in each moisture environment.**
- **The aerosol indirect effect typically leads to a reduction in total precipitation and in cloud top height, but contrary optimal scenarios exist.**
- **The aerosol effect on total precipitation is ultimately determined by a balance of controlling factors (e.g., precipitation suppression, invigoration, stability, optimized convective organization).**

Extra Slides



Total Accumulated Precipitation

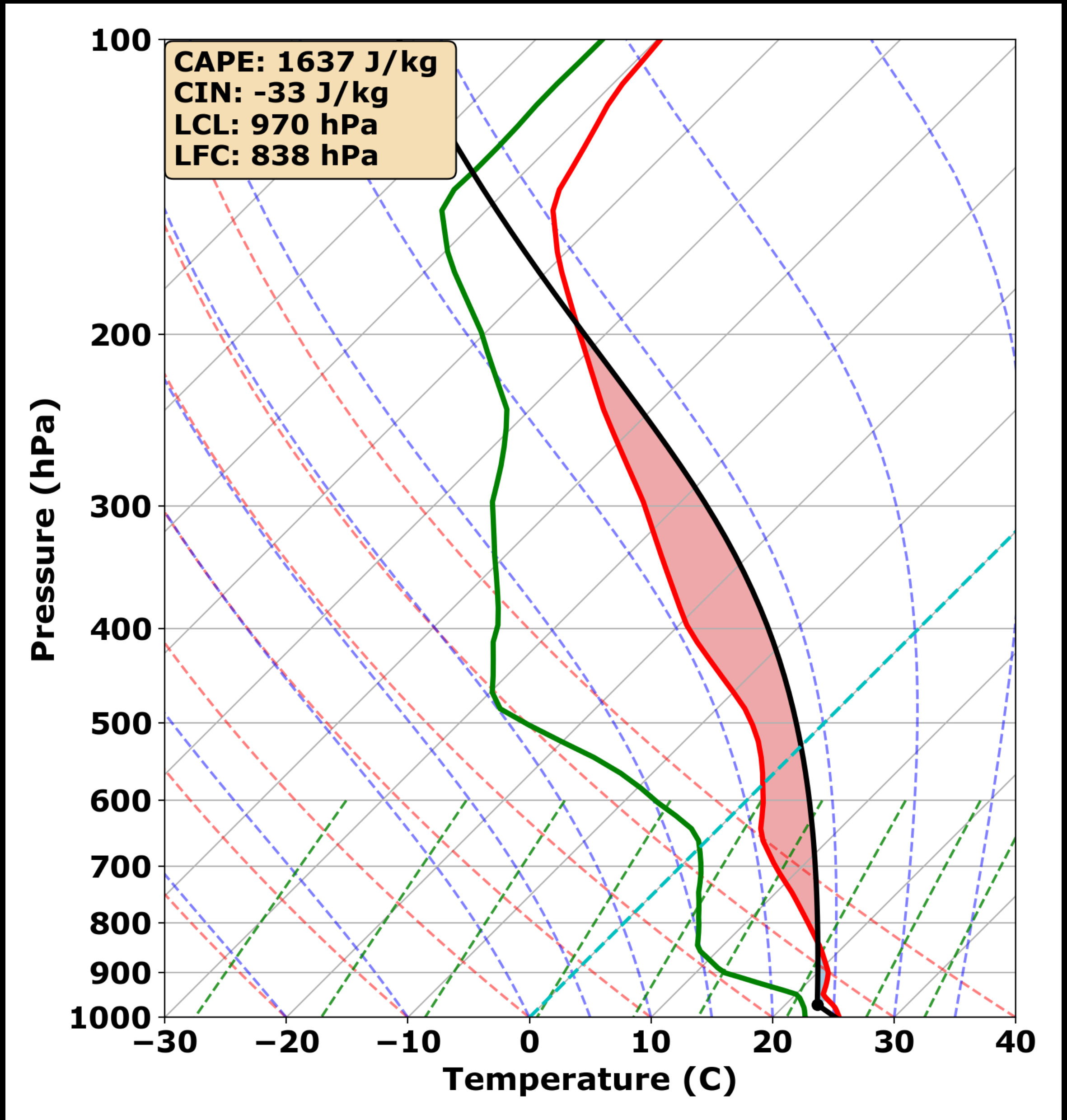
2013 June 19th, 1100 – 2300 LT

The time series of accumulated precipitation from the moisture perturbation tests tends to mimic those from the various MIP model control simulations.

So, the timing of precipitation is similar, but the intensity and totals vary.

The aerosol effect produces a consistent reduction in precipitation in all tests but one (10% More Qv - 2km).

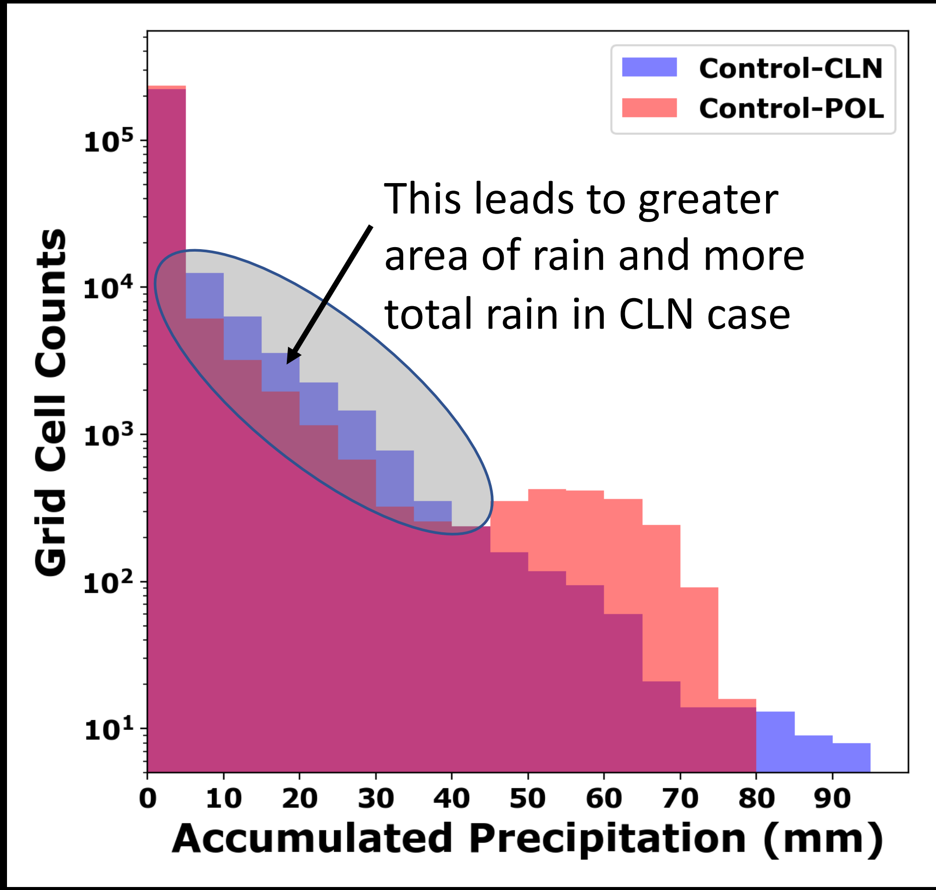
Control Simulation Sounding



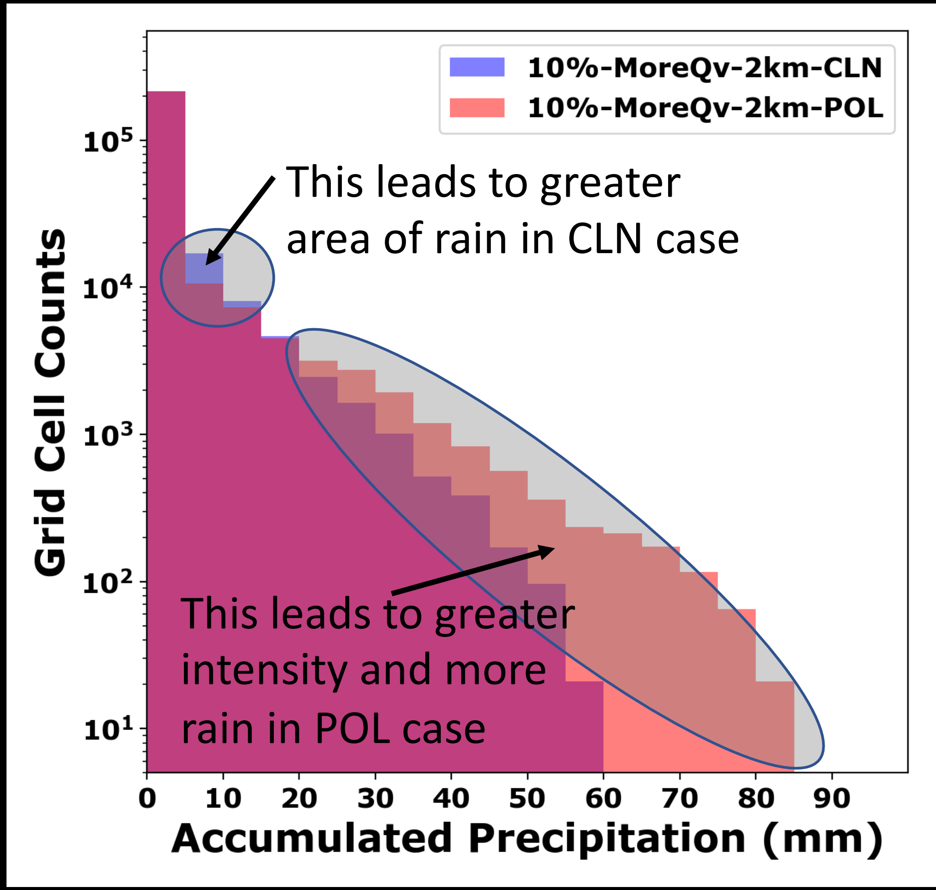
Sounding computed from initial domain averaged vertical profile.

Histograms of Total Accumulated Precipitation

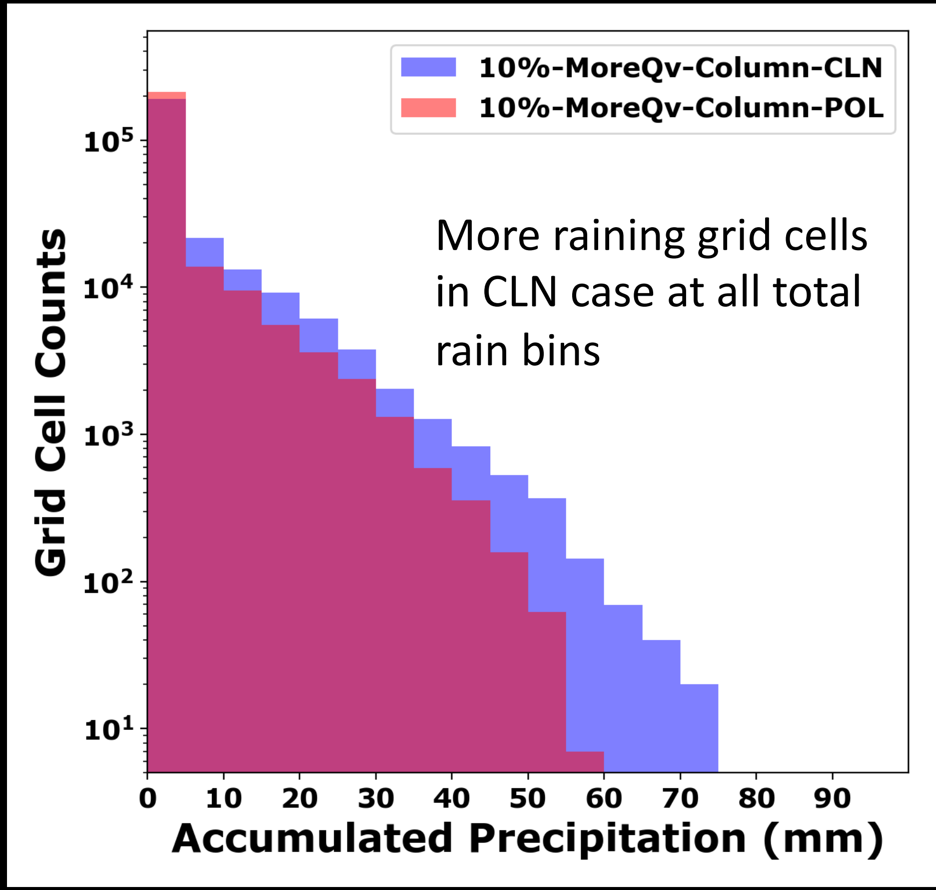
Control



10% More Qv 2km



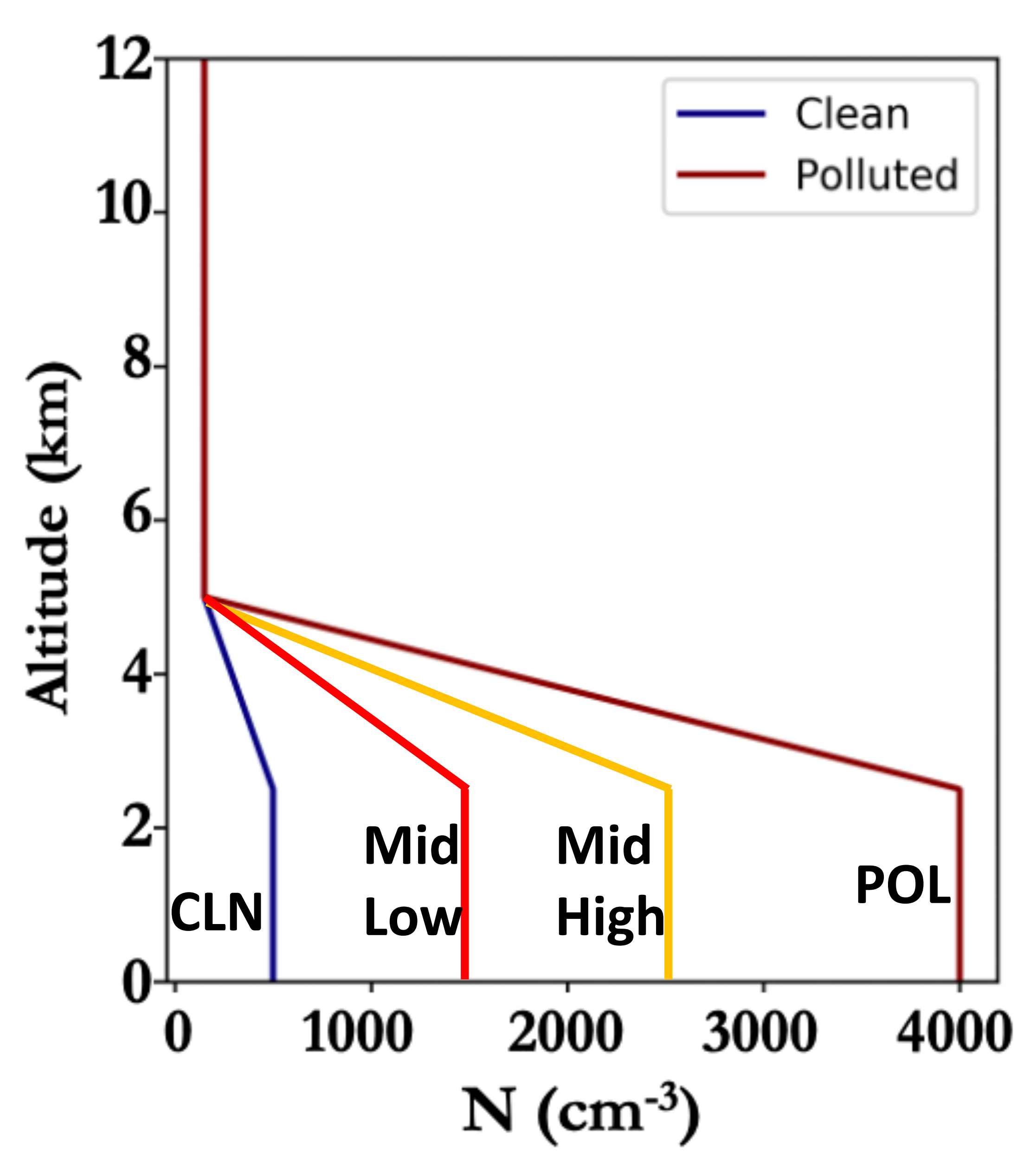
10% More Qv Column



The accumulated rainfall histogram in the outlier case (10% More Qv 2km) reveals a greater area of heavy rain but reduced area of much lighter rain.

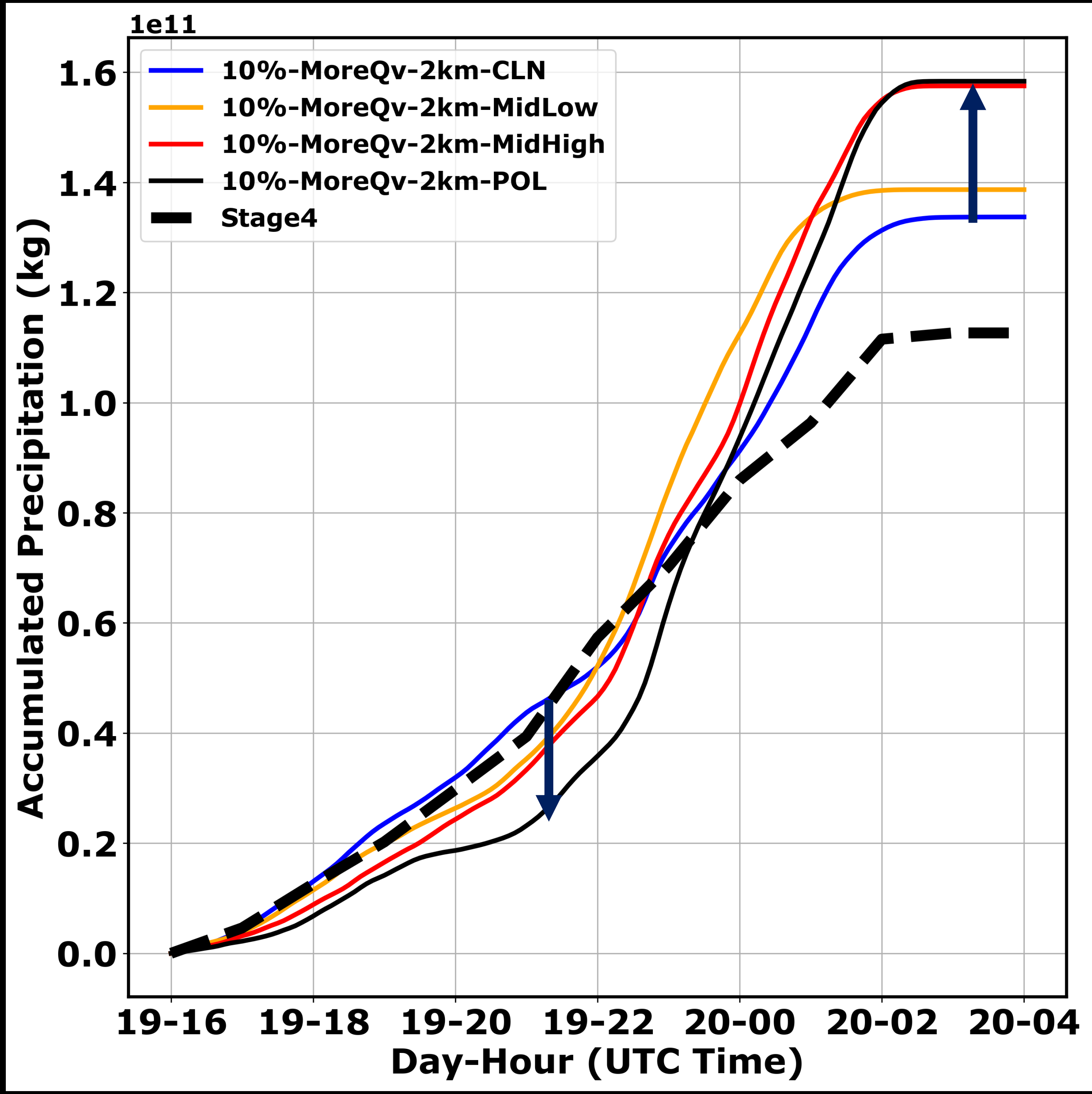
An optimal combination of factors (e.g., invigoration, less stable BL, cold pool interactions, etc.) must be leading to organization of a relatively smaller area of more intense convection and rainfall in the POL case with 10%-More-Qv-2km.

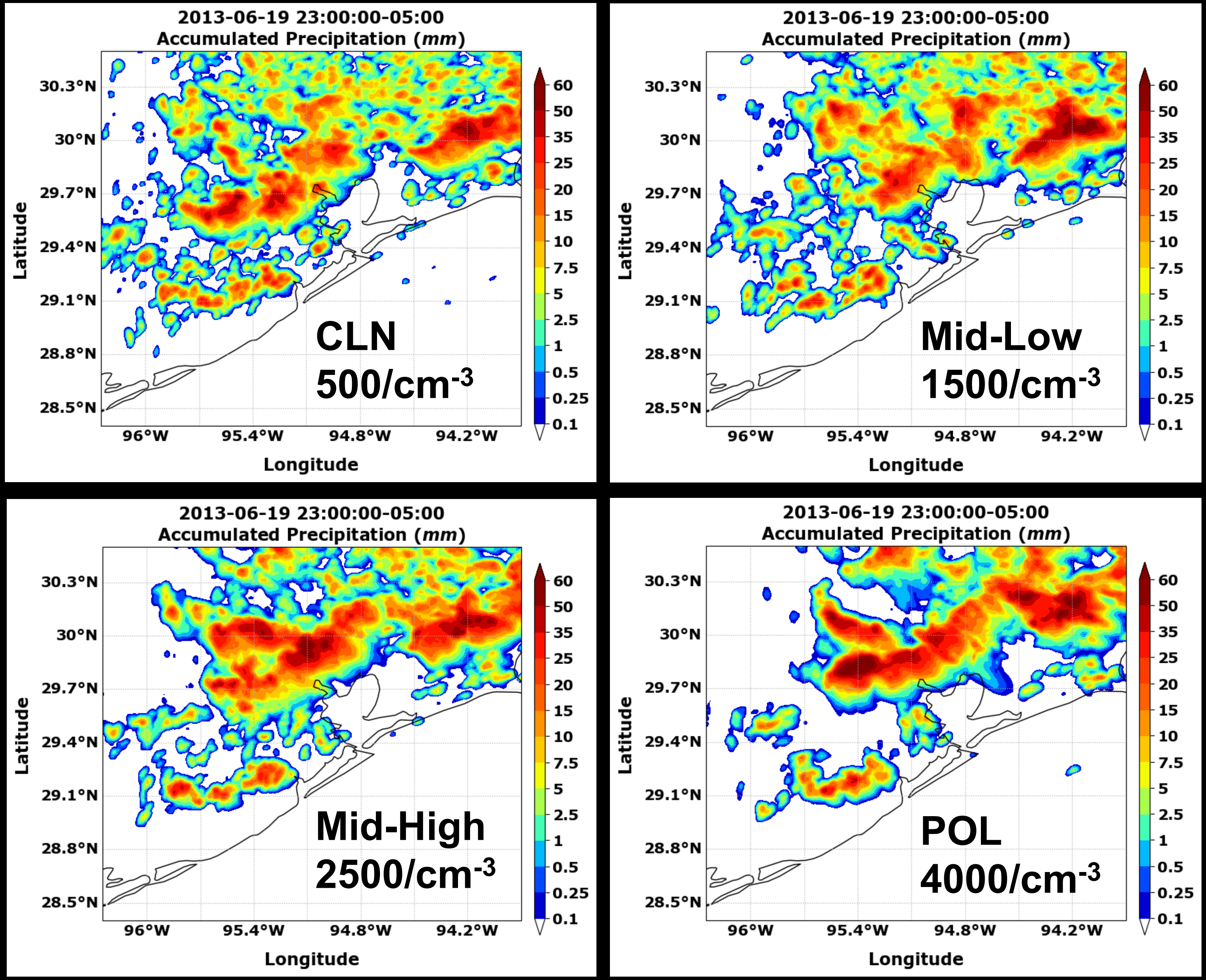
Additional Aerosol Tests for Outlier Event



To determine if the precipitation change from the CLN to POL (10%-More-Qv-2km) simulations was a monotonic aerosol effect, two additional simulations were run with more intermediate aerosol profiles.

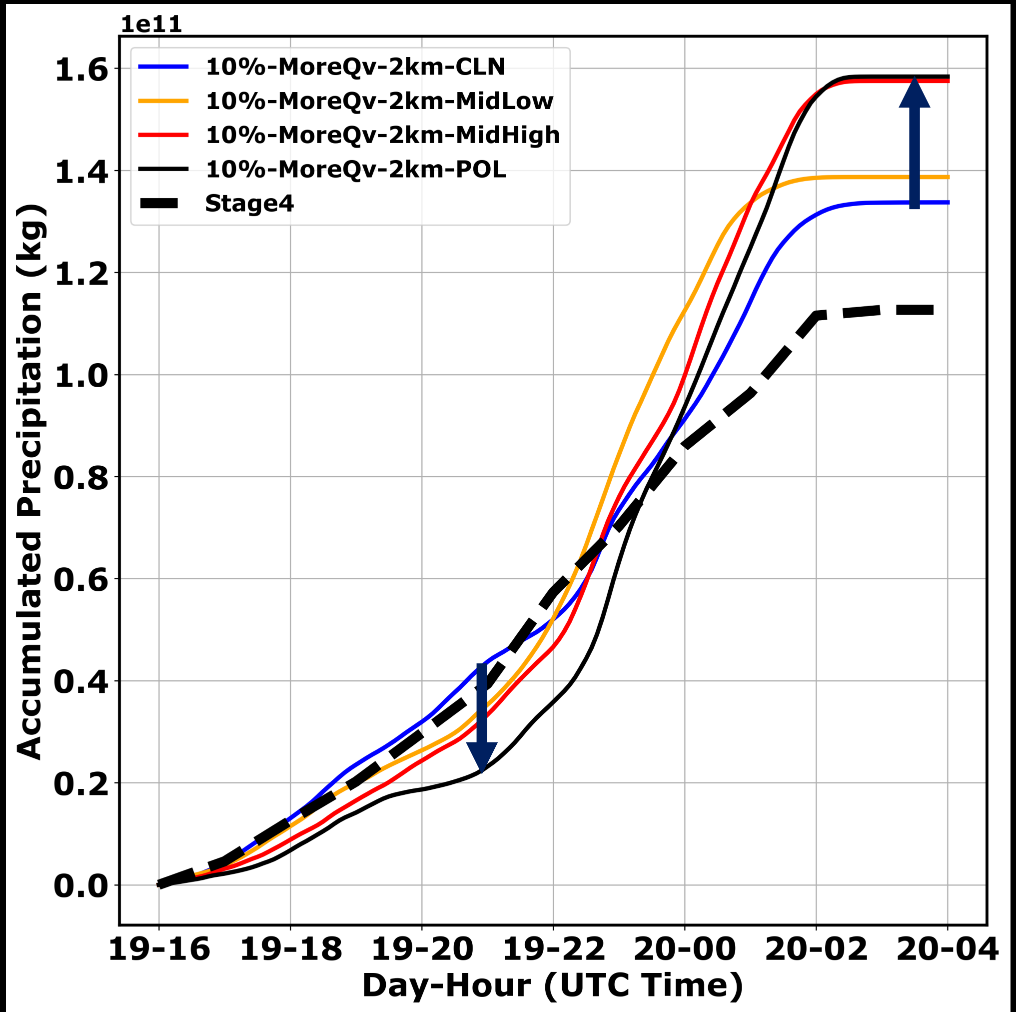
Varying Aerosol in Outlier Case (10% More Qv 2km)





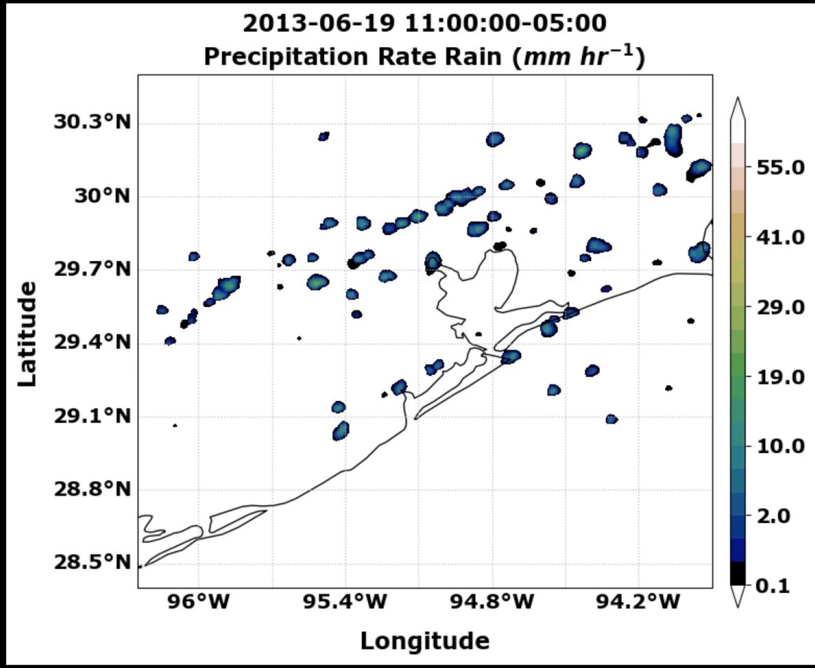
There is a monotonic suppression of precipitation early on, but a monotonic increase in precipitation by the end of the event.

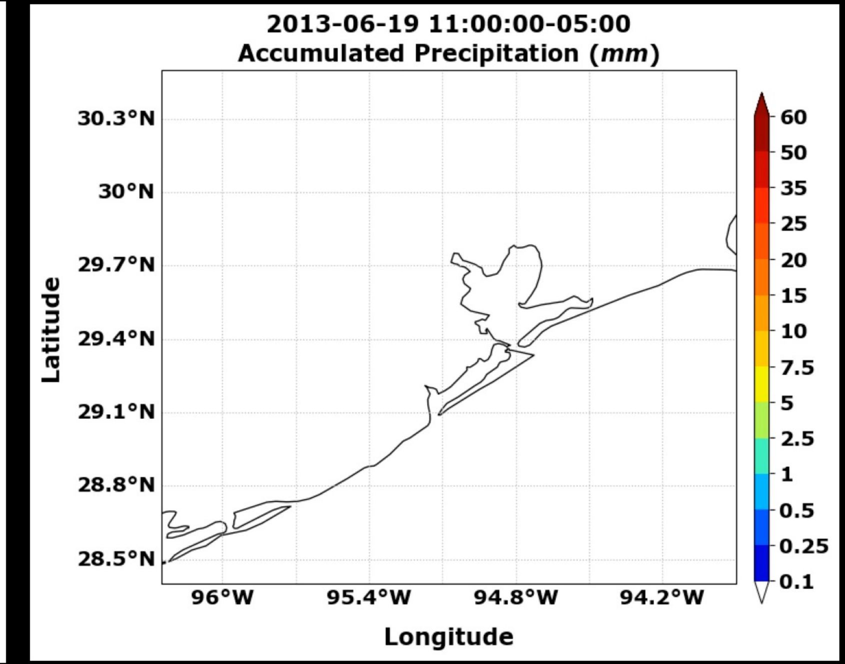
Varying Aerosol in Outlier Case (10% More Qv 2km)



Precip Rate | **Accumulated Precip**

CLN - 500/cm^{-3}





POL - 4000/cm^{-3}