Modeling Aerosol Impacts on MC3E MCSs

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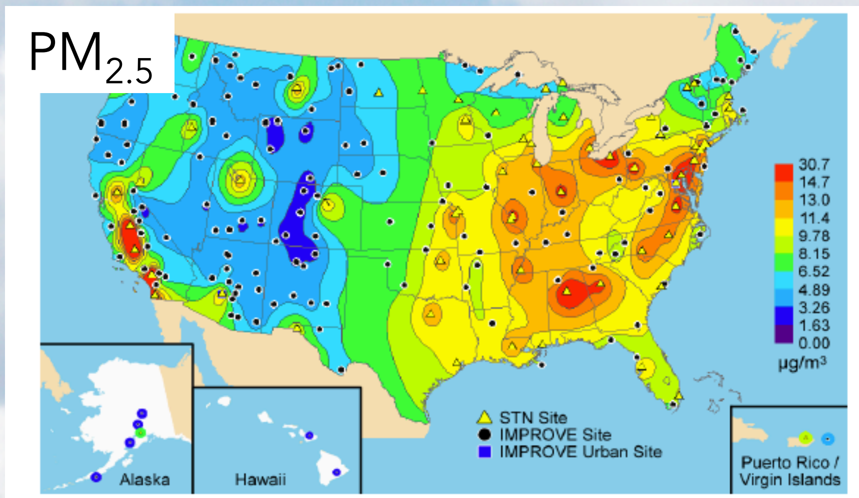
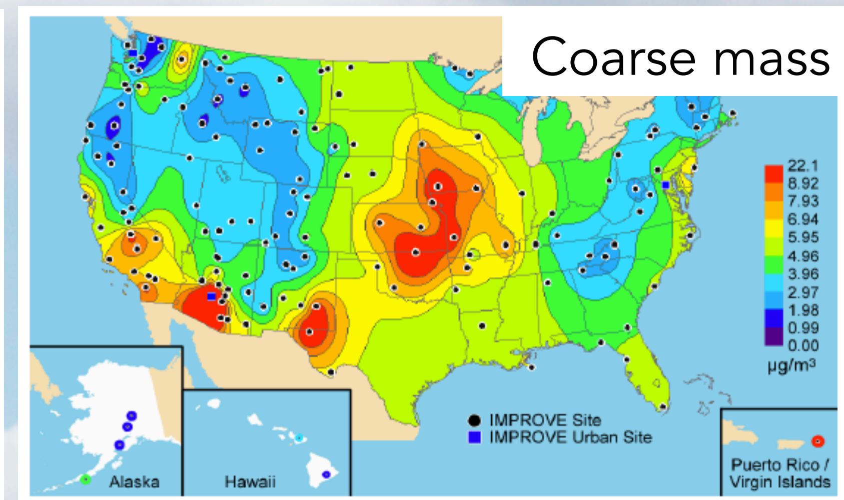
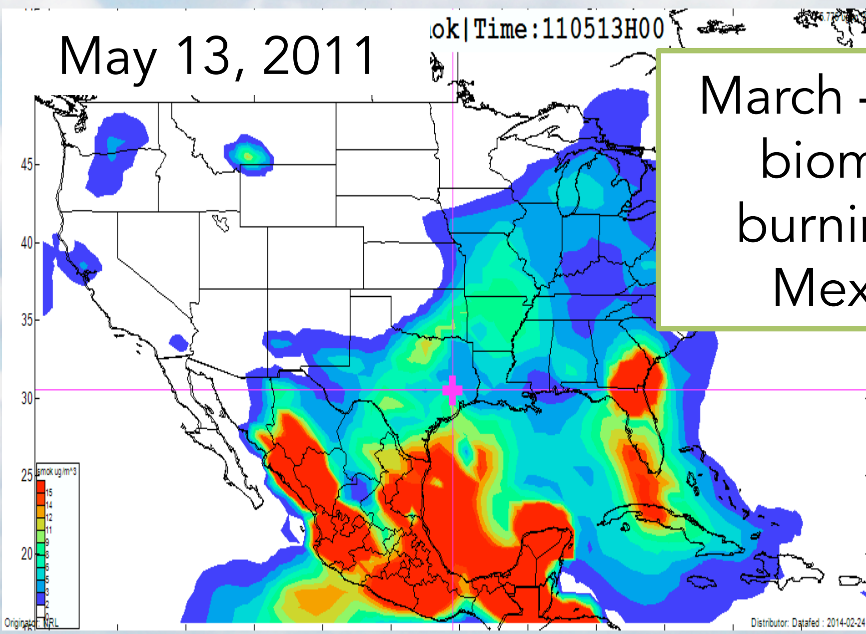
Mesoscale Convective Systems (MCS)

- Important in the hydrological and energy budgets of the midlatitudes and the tropics
  - poorly represented in GCMs
- Southern Great Plains
  - Active MCS region (springtime)
  - Both local and long-range transported aerosol
- Midlatitude Continental Convective Clouds Experiment (MC3E)
  - April–May 2011

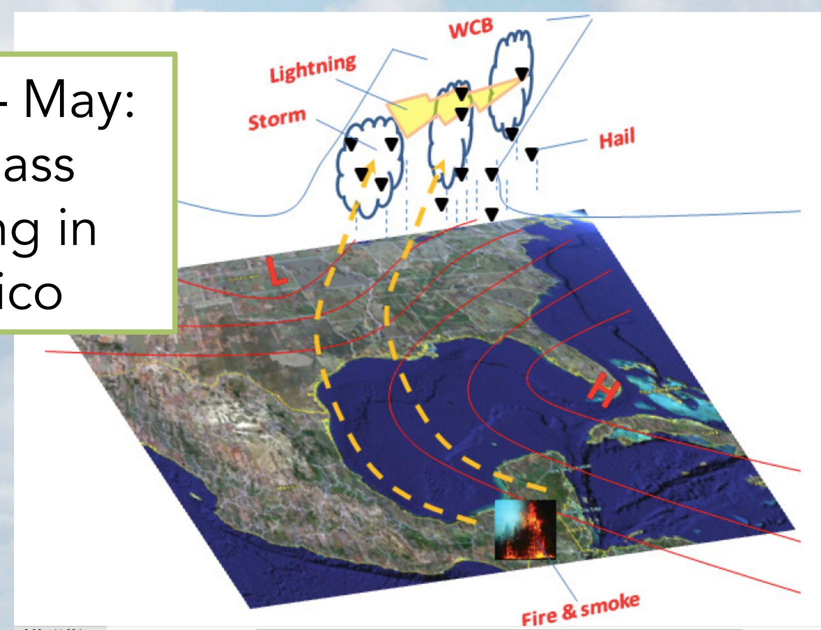
Surface aerosol gradient across U.S.







March – May: biomass burning in Mexico

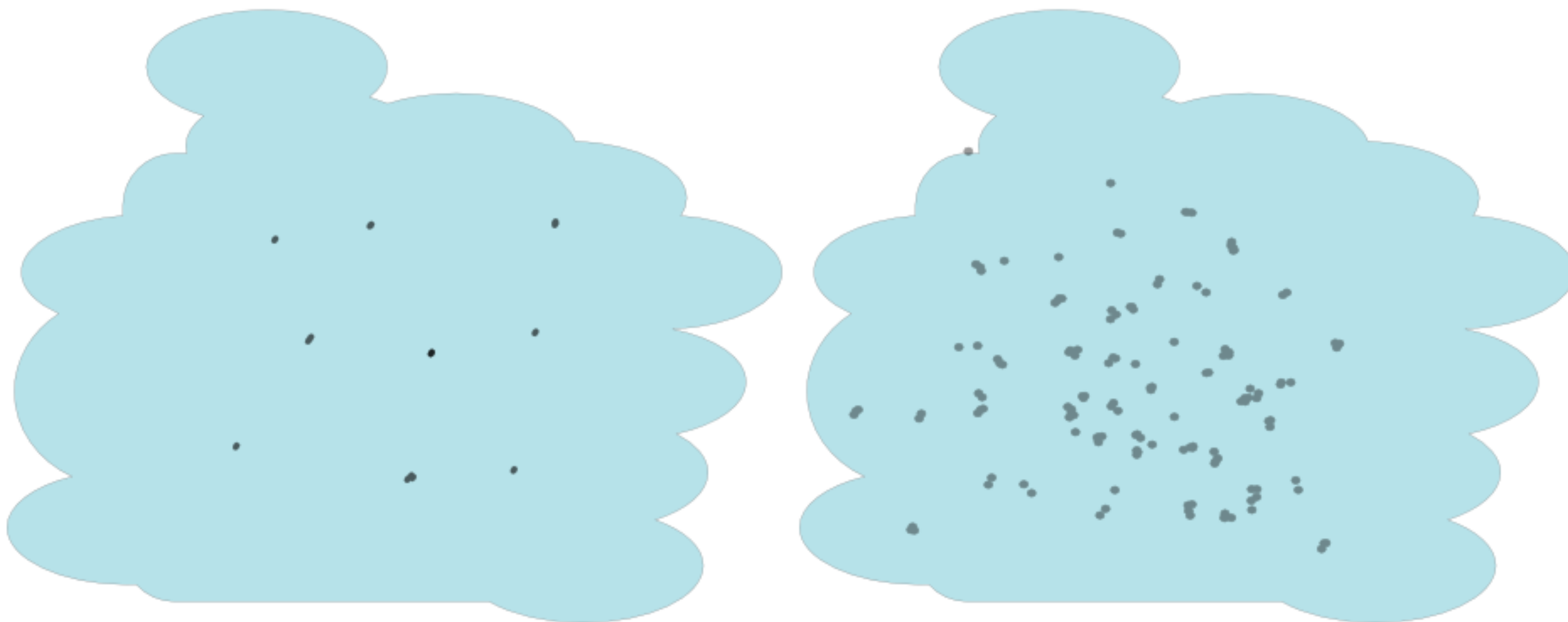


Navy Aerosol Analysis & Prediction System

Wang et al., 2009

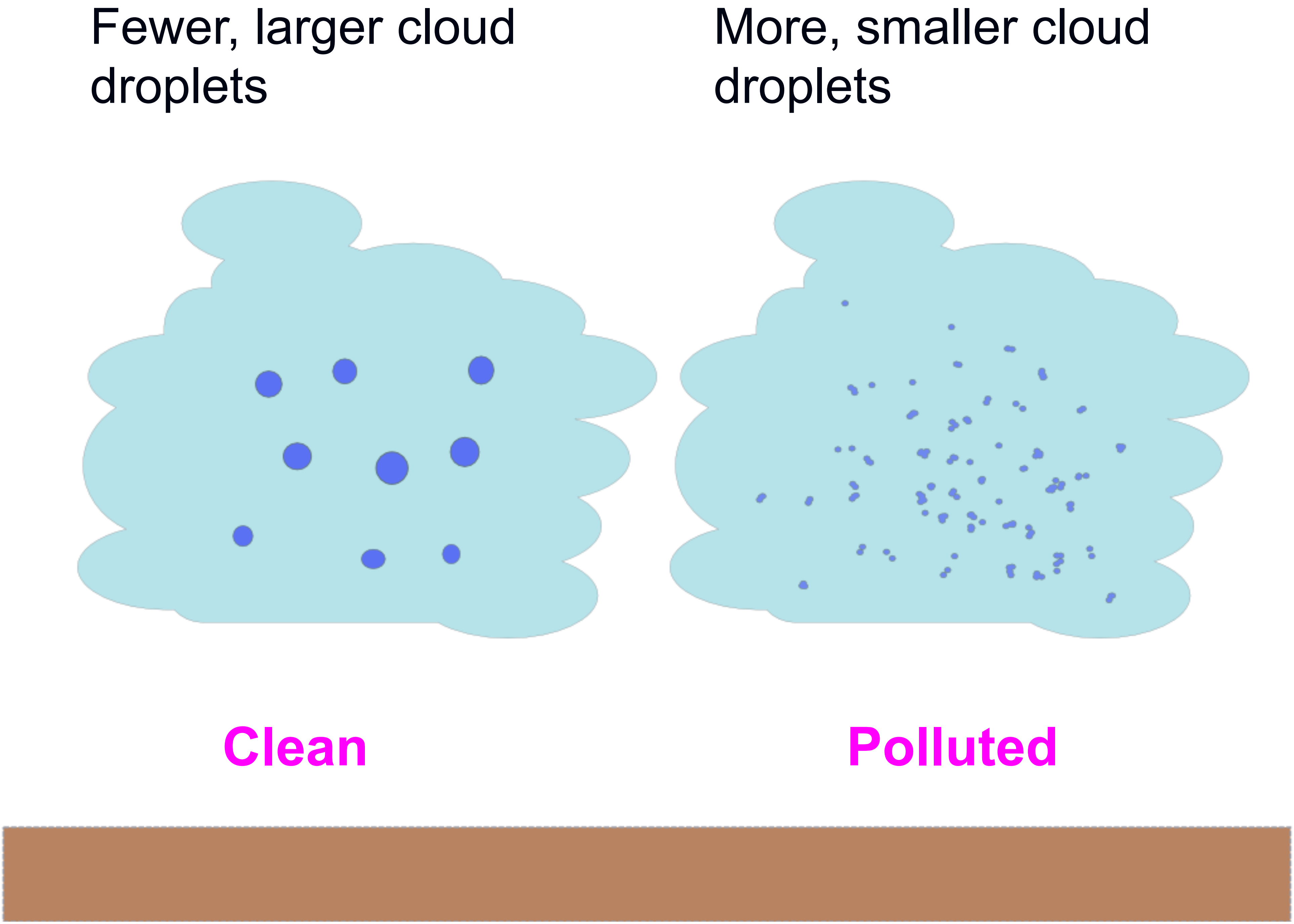
Aerosol Invigoration Theory

For the same liquid water content .....

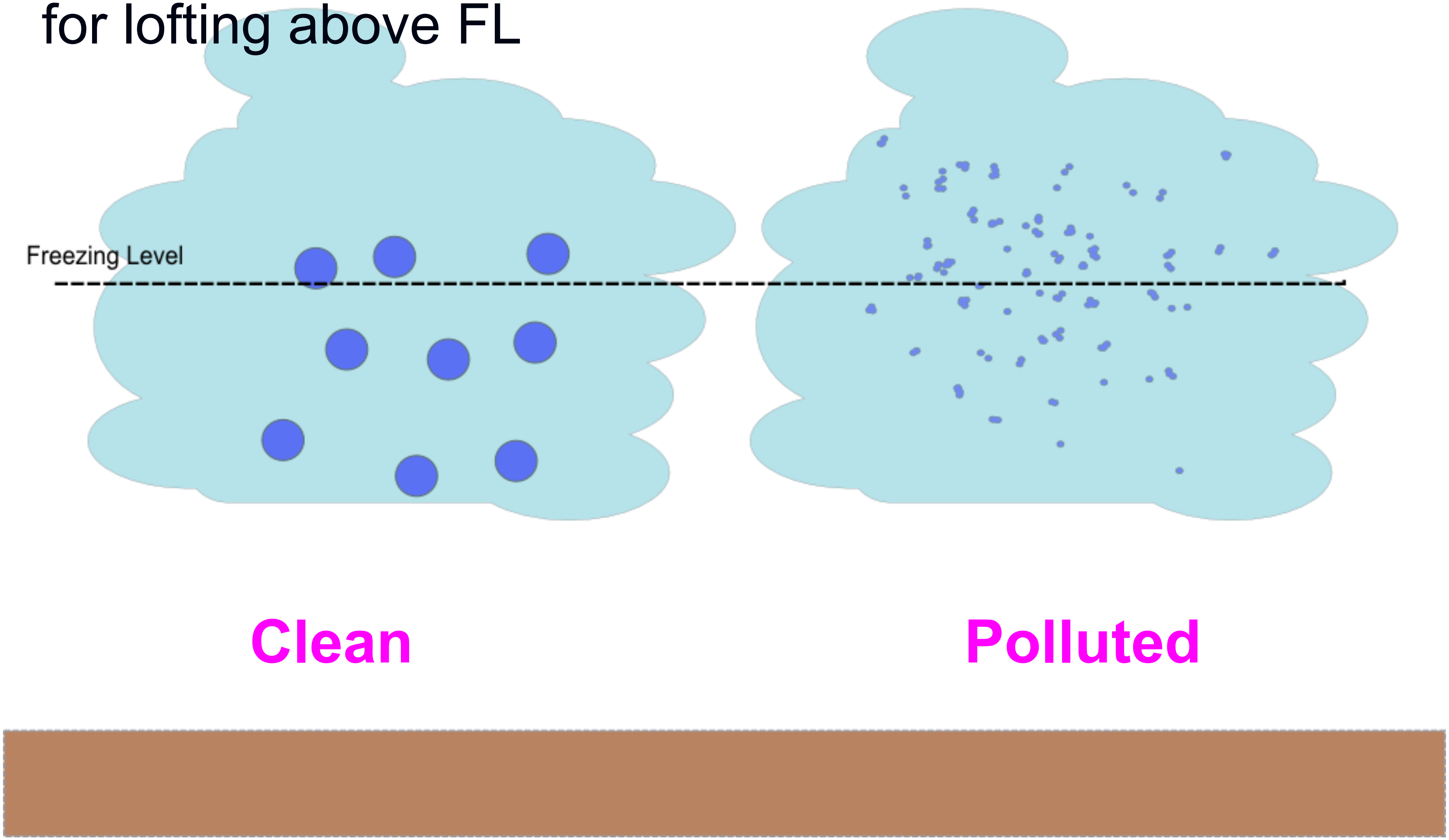


Clean **Polluted**

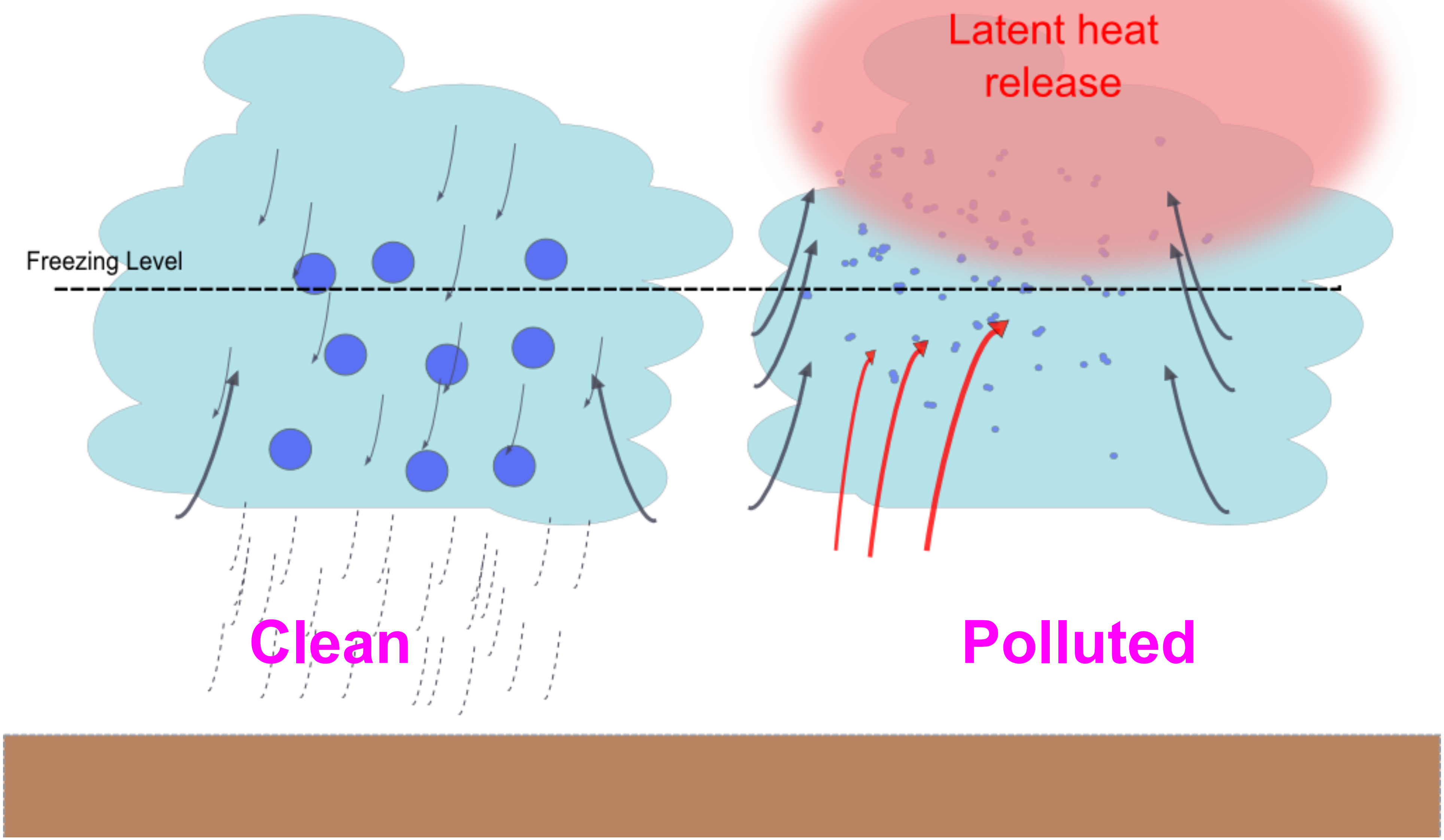
(Andreae et al 2004; Khain et al 2005; van den Heever et al 2006; Rosenfeld et al 2008)


Fewer, larger cloud droplets
More, smaller cloud droplets
Clean
Polluted

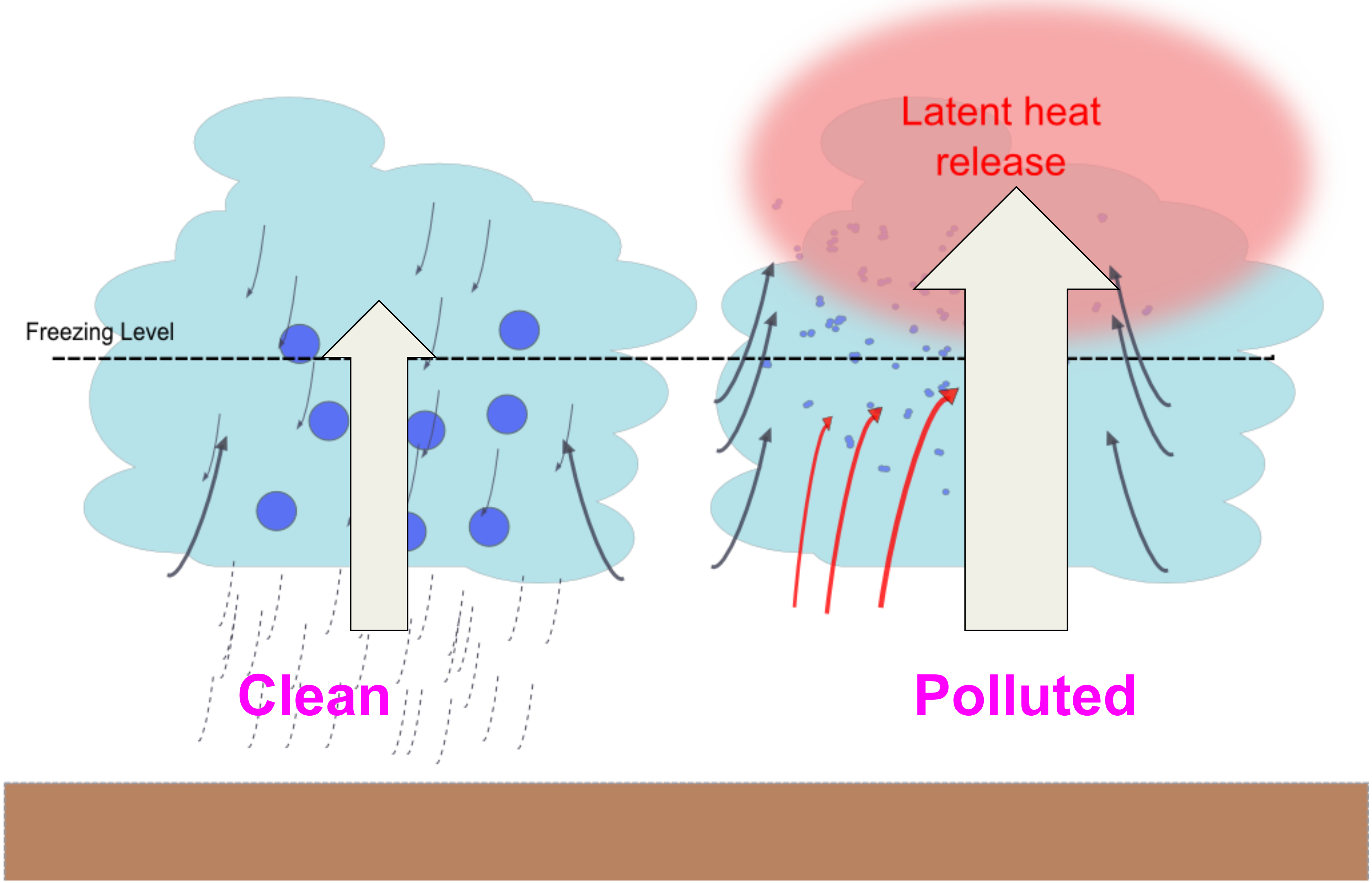
More efficient warm rain process => more rain at surface and less cloud water available for lofting above FL



Suppressed collection
=> more cloud water lofted
=> freezes and releases lh



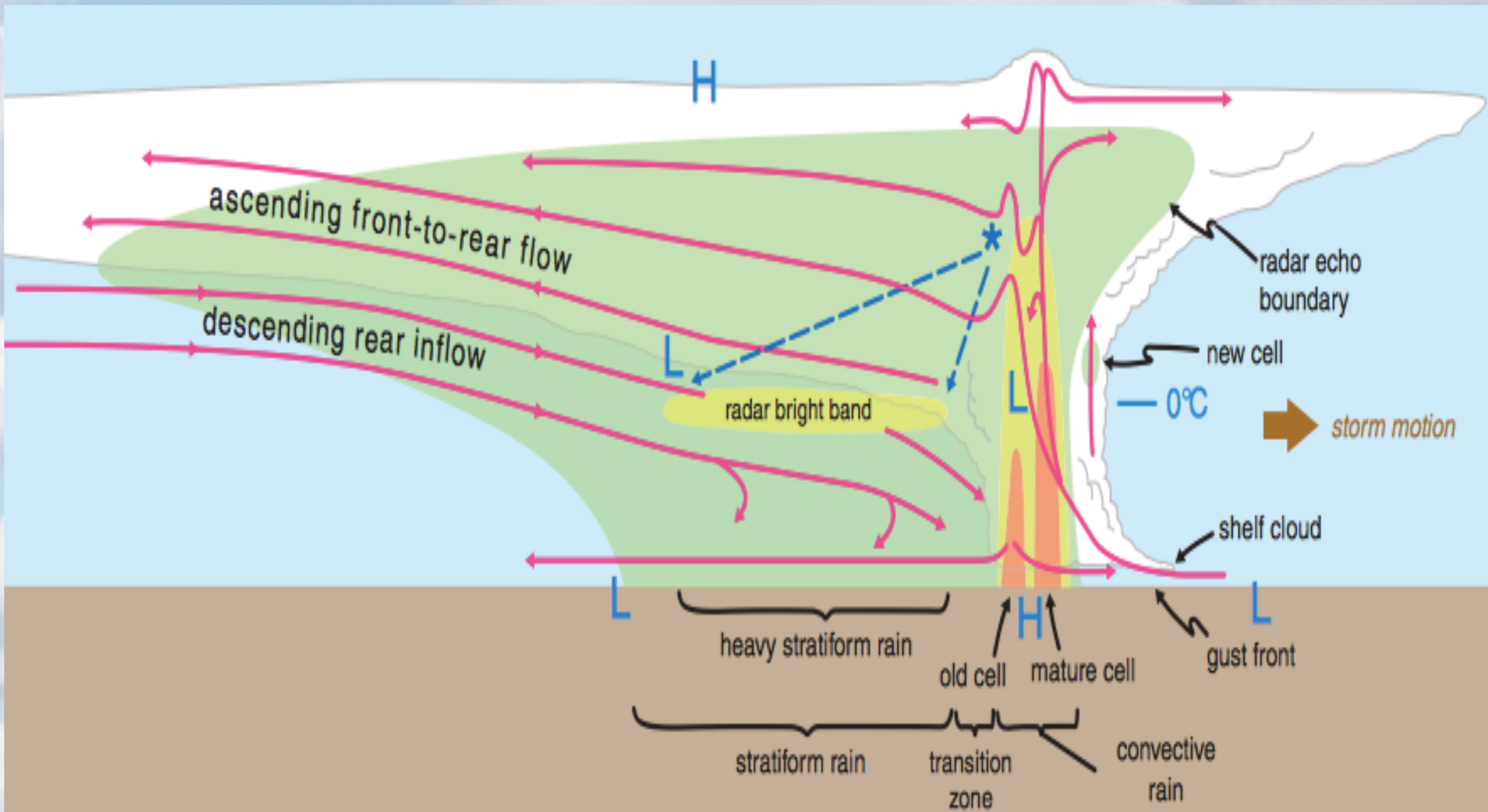
Stronger updrafts through convective invigoration



Research Question

- What are the aerosol indirect effects (AIEs) from polluted conditions (e.g. from biomass burning events) on MCS development and precipitation in the Southern Great Plains?

Squall Lines – Possible Aerosol Impacts



Markowski and Richardson, 2010, adapted from Houze et al., 1989

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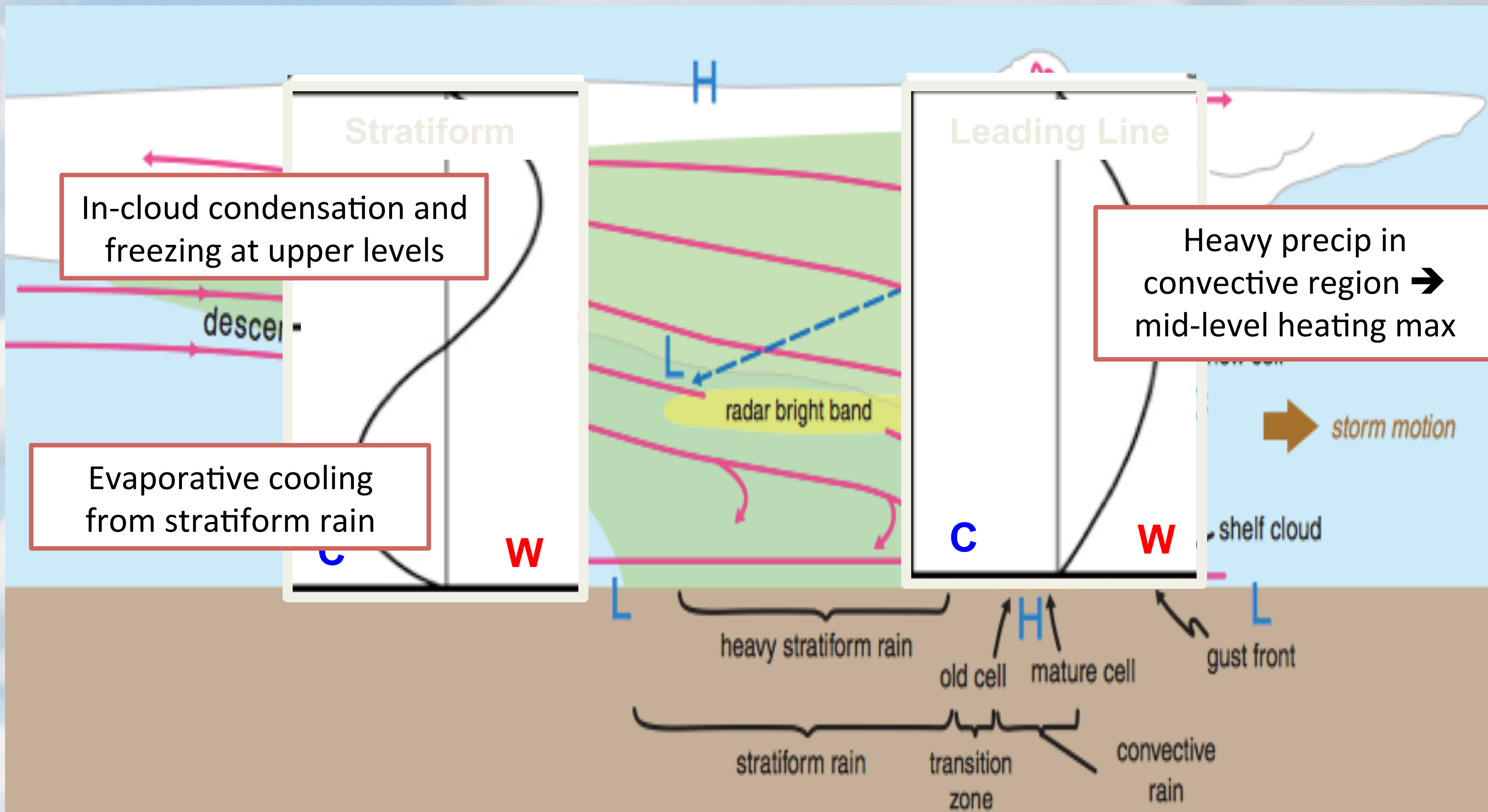

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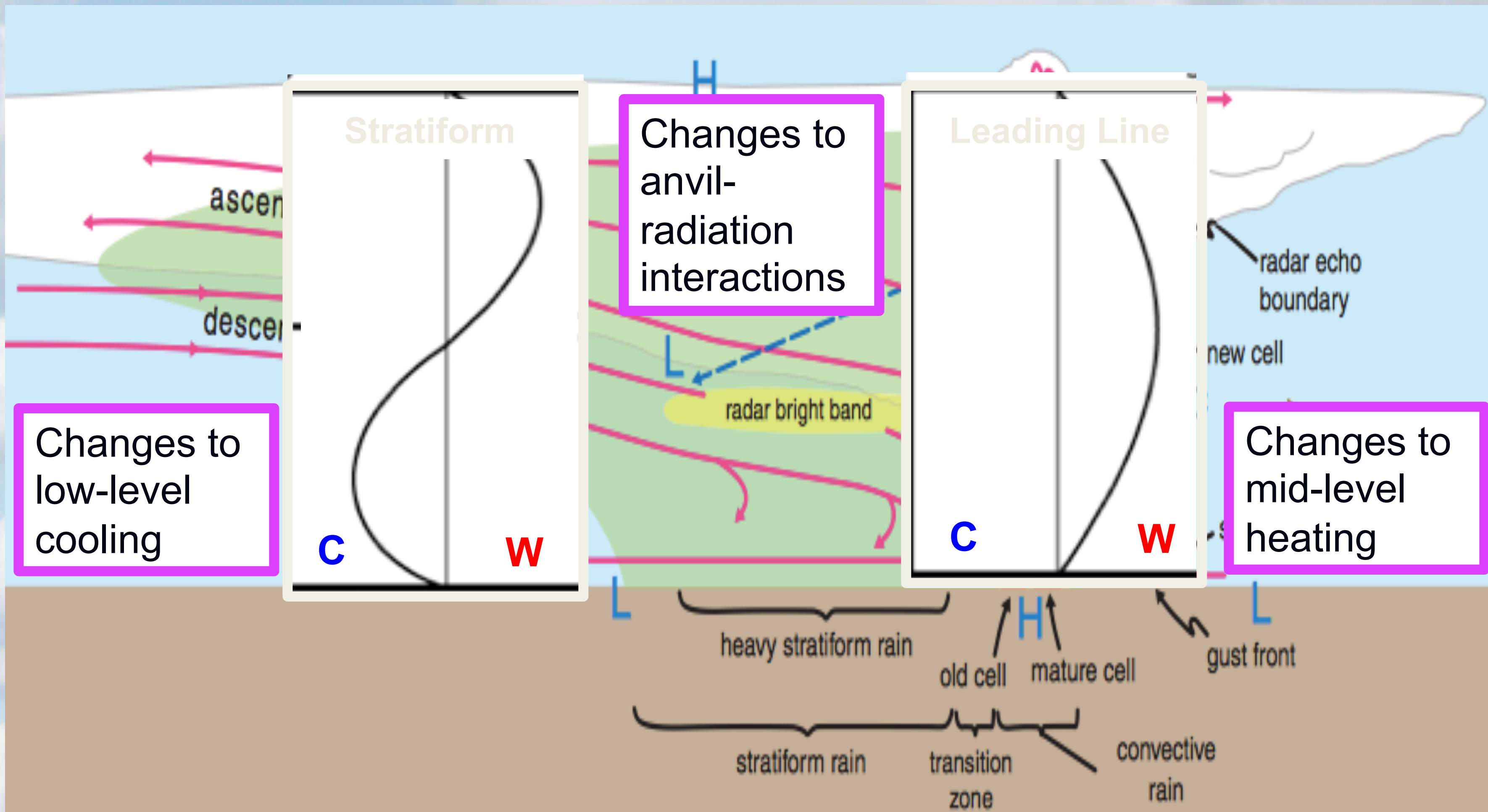
Squall Lines – Possible Aerosol Impacts



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Hypotheses

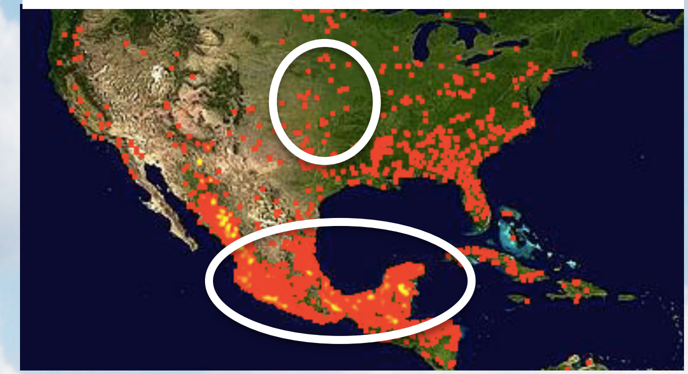
- Potential aerosol effects on convective leading line:
  - more latent heating in updrafts, stronger updrafts, more condensate lofted to anvil, impacts on anvil ice number and mass
- Potential aerosol effects below anvil:
  - fewer raindrops that are larger in size - reduced bulk evaporation rates, reduced cooling signal in lower levels, weaker cold pools

Steps for Testing

- Analyze SGP aerosol environment
  - develop representative profiles of particles capable of serving as CCN and as INP
  - Both “clean” and “polluted” conditions
- Develop baseline simulations of MC3E cases
  - Comparison with observations to confirm fidelity
  - Analyze processes leading to convective and stratiform precipitation and anvil formation
- Sensitivity studies to perturb only aerosol initialization
  - What are the impacts on storm development, precipitation fields, and anvil characteristics?

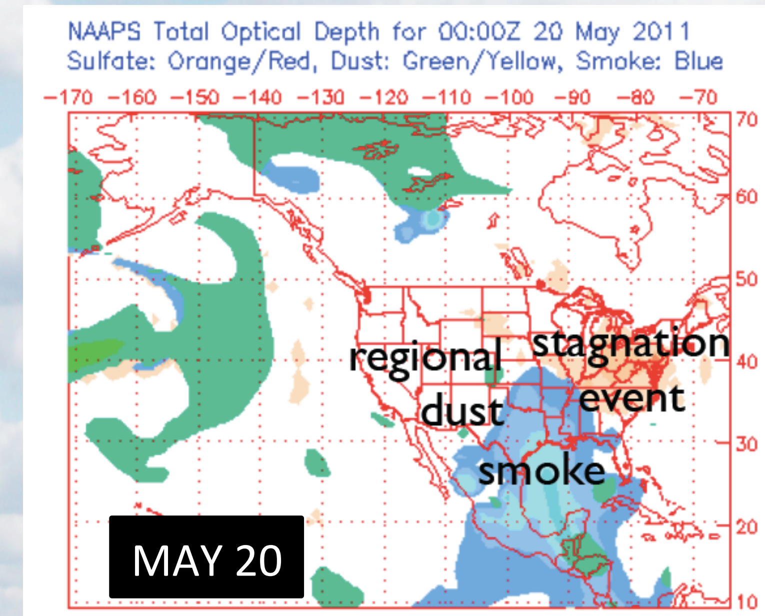
May 20 and May 23 case studies

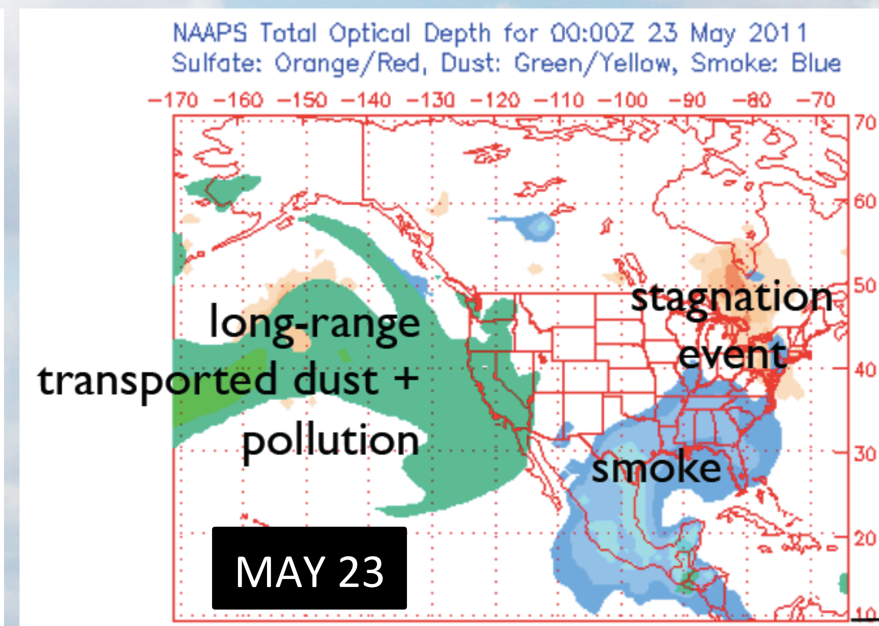
MODIS Fire Count Product
05/20/2011 – 05/30/2011



Complex aerosol environment

NAAPS forecast model predicts that Central American smoke is transported in elevated layers

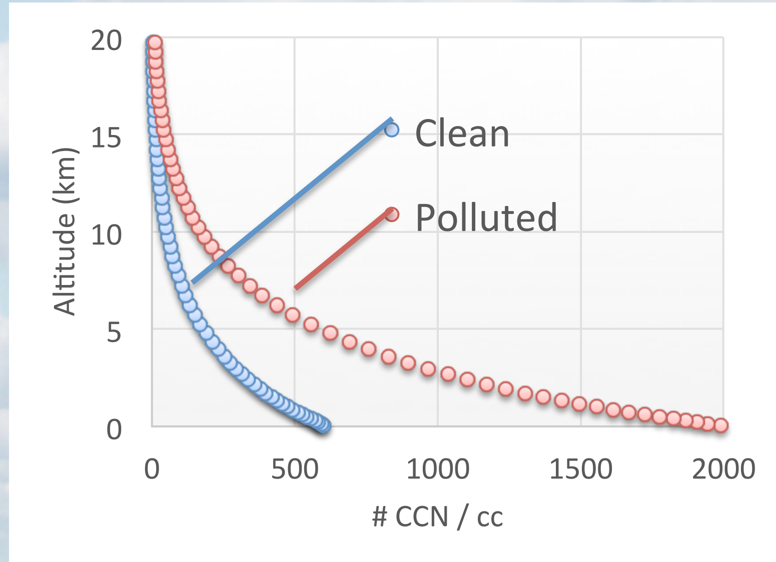




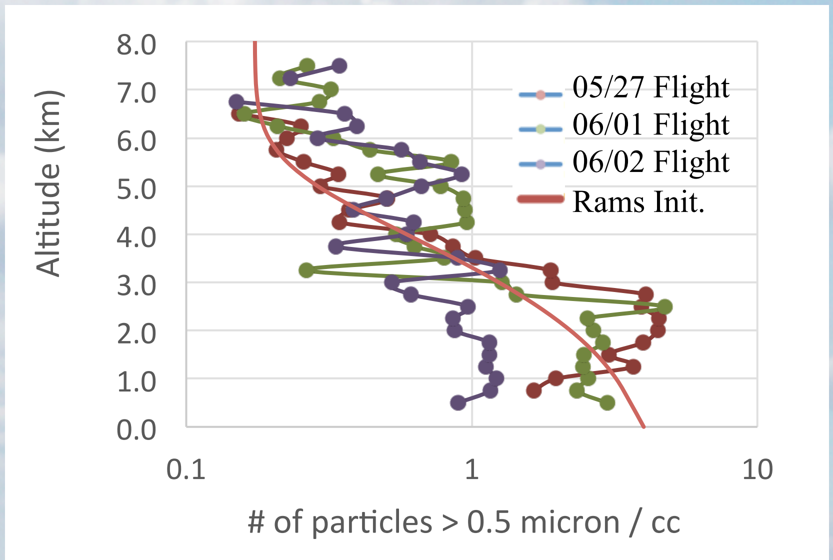
Aerosol Initialization

- CCN and IN characteristics based on surface observations (hygroscopicity, particle size)
- Exponentially decreasing CCN profiles (arbitrary; other vertical profiles being tested)
- INP profiles based on UND-Citation Flight Data and DeMott et al. (2010)
- Both profiles constrained by ARM-SGP particle observations at surface

Cloud Condensation Nuclei Profiles

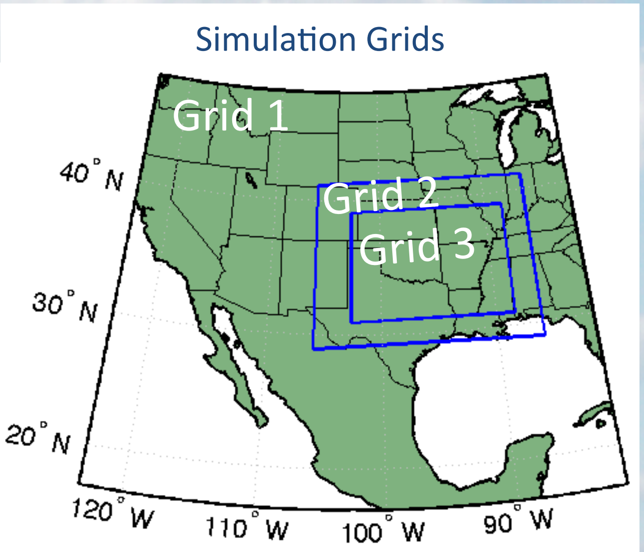


Ice Nuclei Profile



Simulation Set-Up

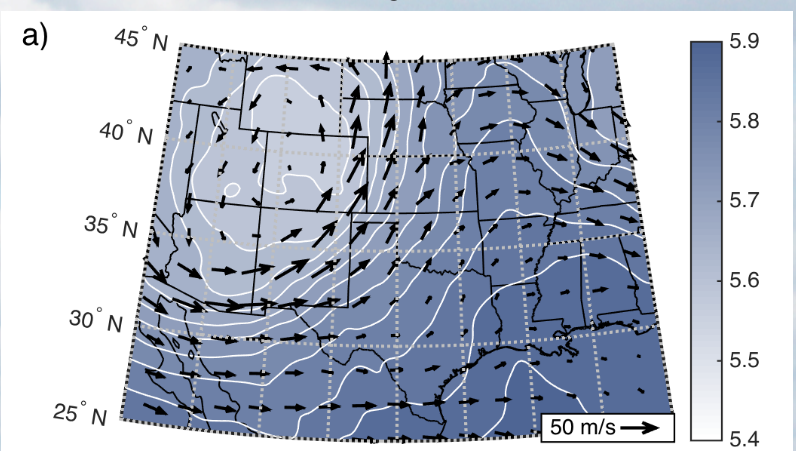
- RAMS (Regional Atmospheric Modeling System)
  - 2-moment bin-emulating bulk microphysics
  - 8 hydrometeor types
  - Aerosol parameterization scheme (Saleeby and van den Heever, 2013)
- Initialized with GFS pressure level data, soil moisture and temperature
- 3 nested grids
  - Grid 1: $\Delta x = \Delta y = 30km$
  - Grid 2: $\Delta x = \Delta y = 6km$
  - Grid 3: $\Delta x = \Delta y = 1.2km$
  - 60 stretched vertical levels



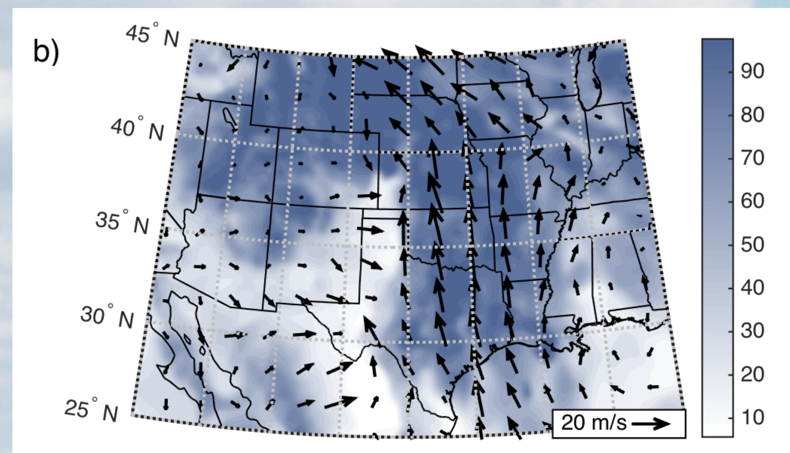
May 20 Case Overview

- Leading convective line, trailing stratiform MCS traversed the MC3E domain
  - This case has been a focus of other studies assessing diurnal precipitation (Tao et al., 2013), and ice microphysics (Lang et al., 2014)
- Strong synoptic, upper-Level trough
- Low level dry-line and jet

Upper Levels
300 hPa Wind vectors
500 hPa Geo. Heights Contours (km)



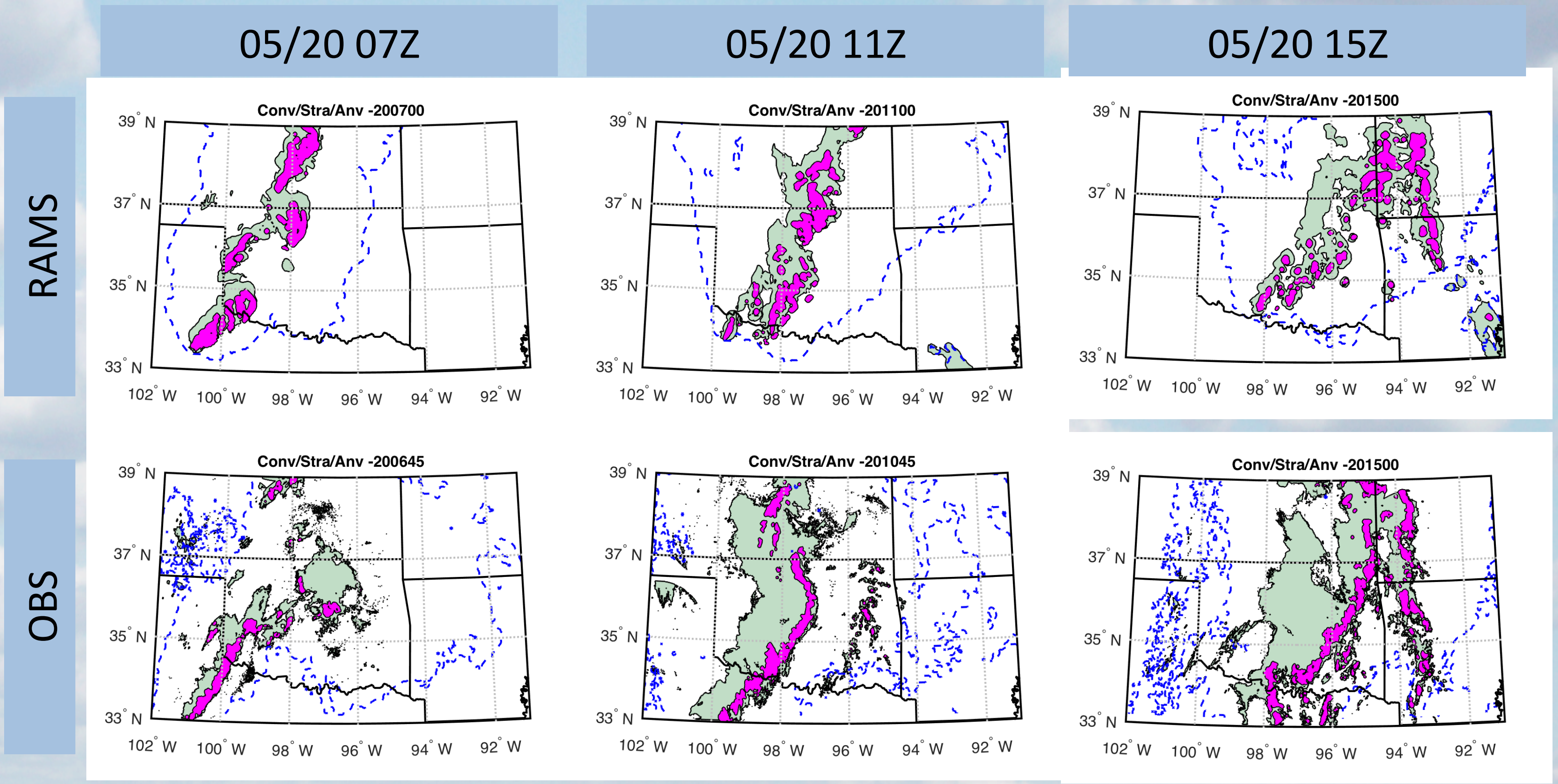
Lower Levels
850 hPa Wind vectors
850 hPa Relative Humidity Contours (%)



RUC model data

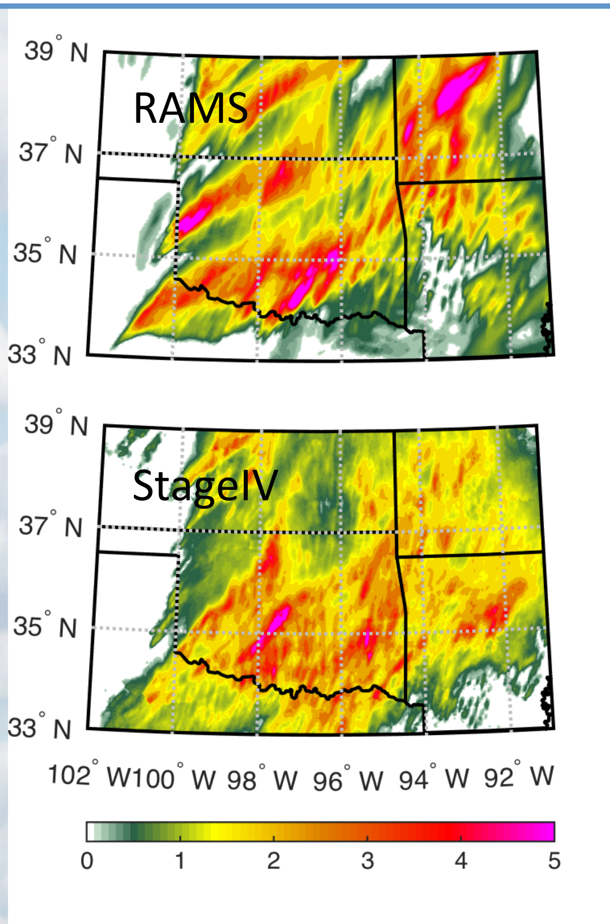
Model Comparisons to Observations

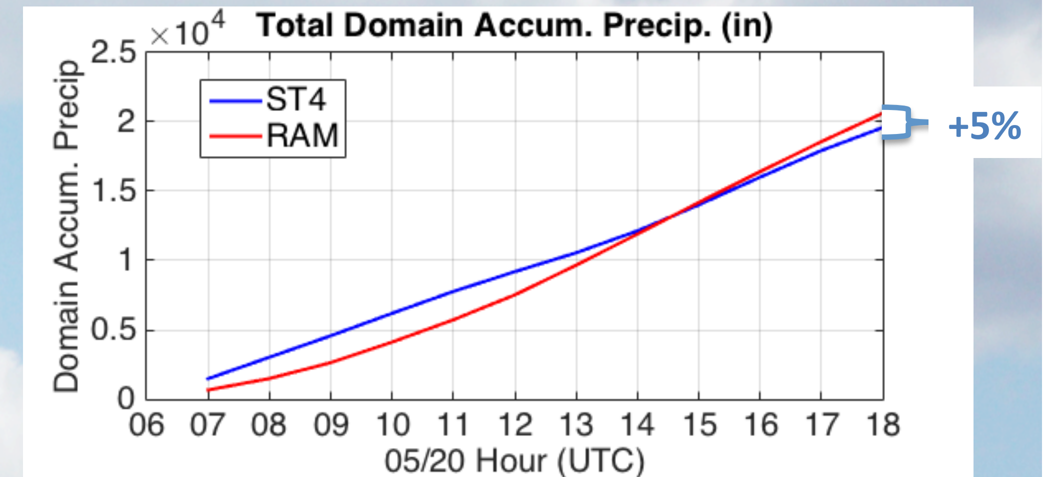
- Convective / Stratiform / Anvil Regions
  - Convective-Stratiform separation is radar reflectivity based, and follows Steiner et al., 1995 and Feng et al., 2011
  - Model data converted to reflectivity using Quickbeam (Haynes et al., 2007)

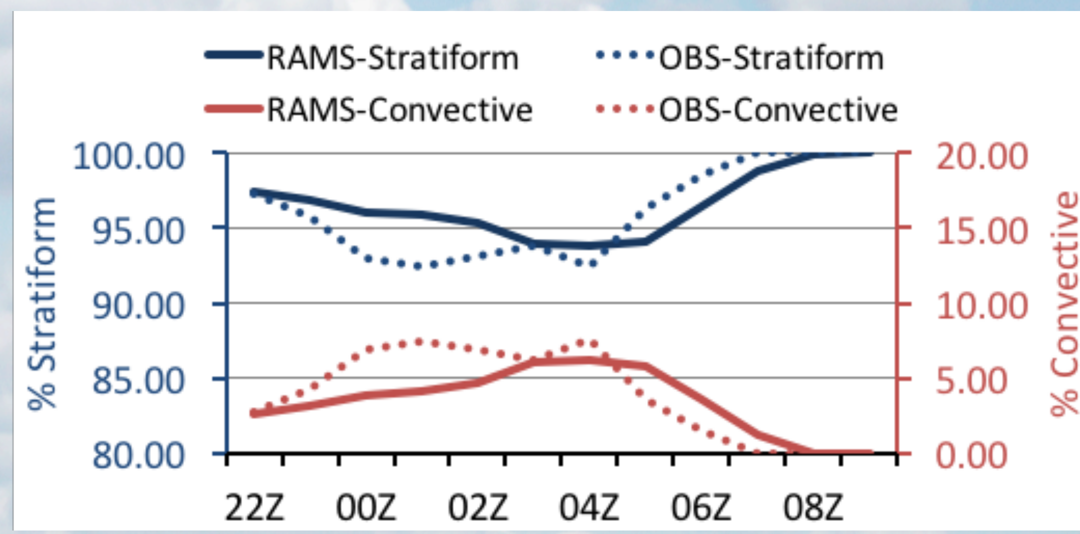


Model Comparisons to Observations

Domain Accumulated Precipitation
Spatial (05/20 06Z-18Z)

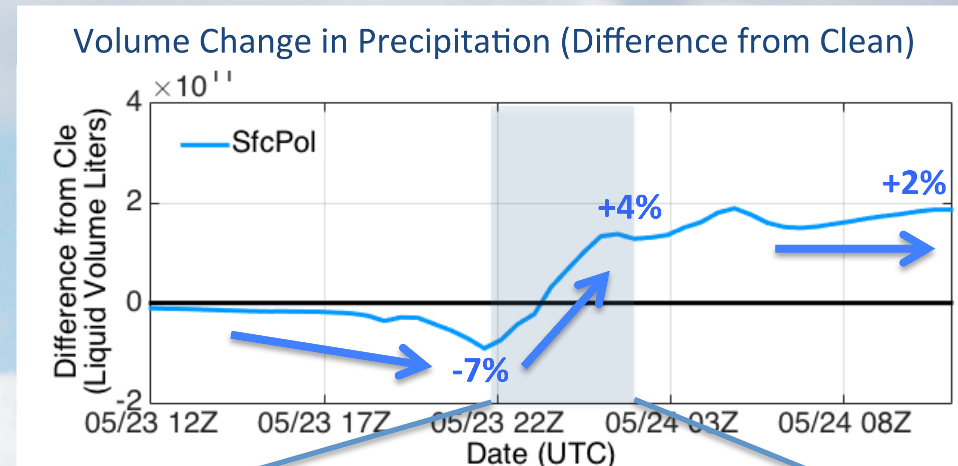


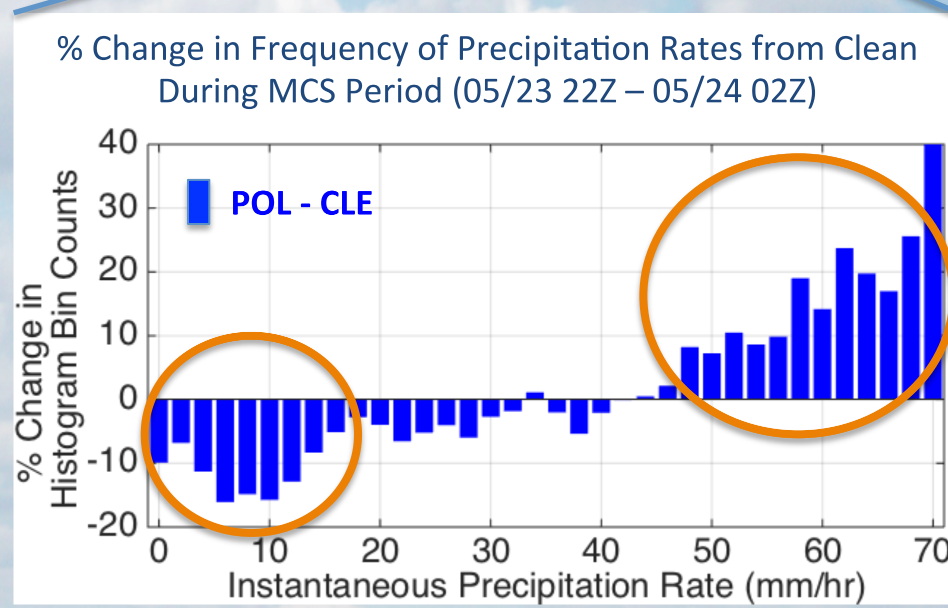




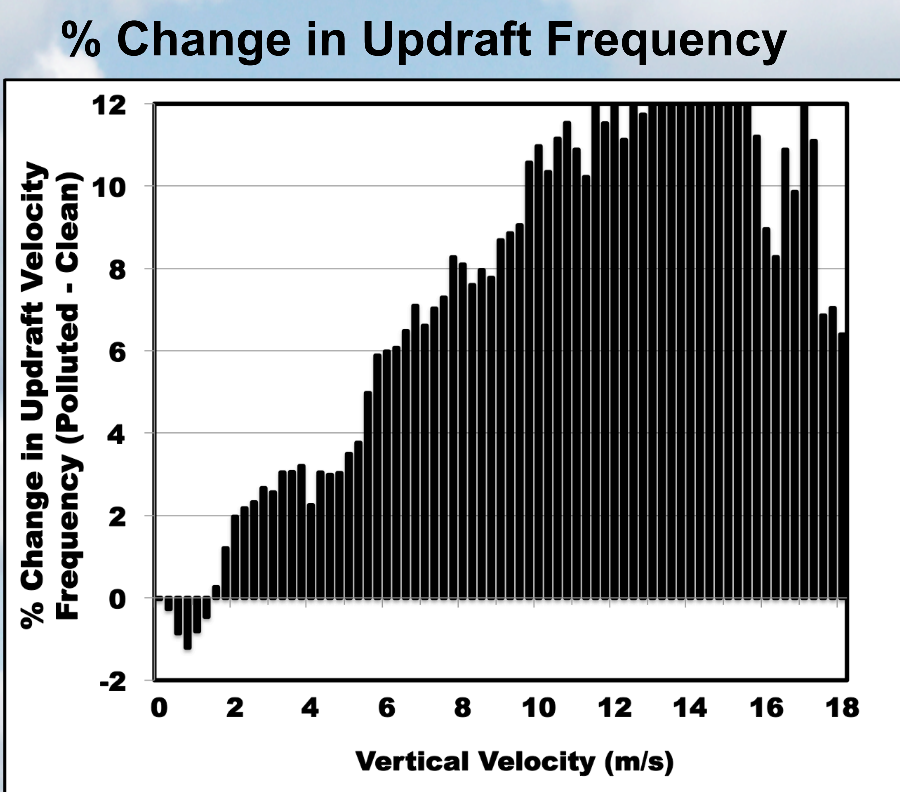
MCS precipitation:
Contrast polluted conditions to clean base run (May 23)

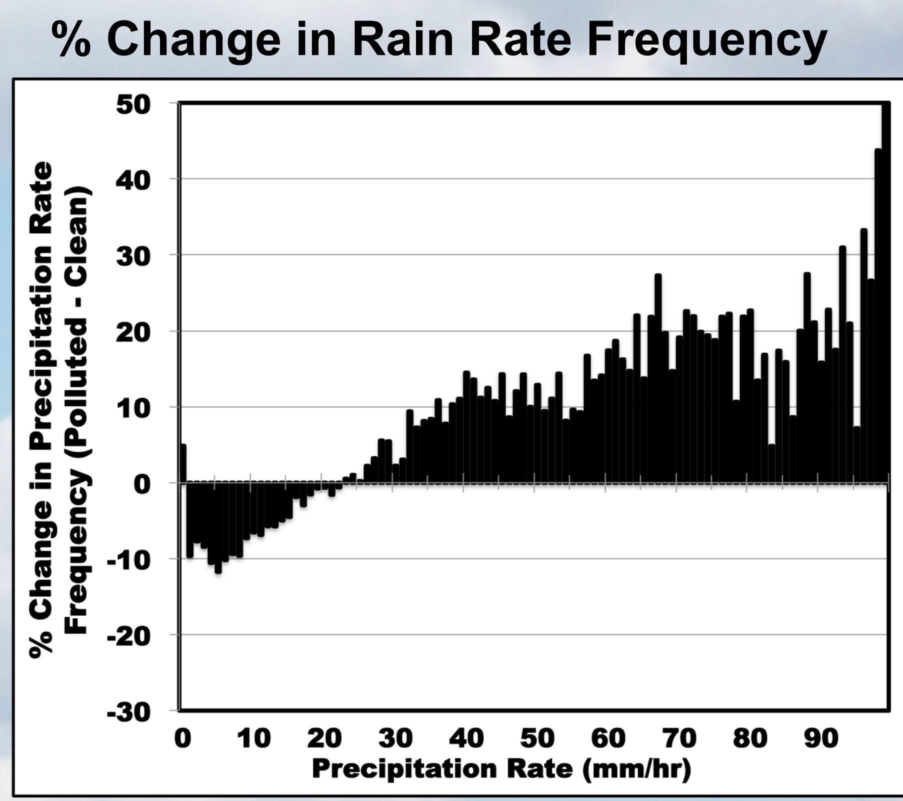
- Initially, precipitation lower, due to lower growth rates via collision-coalescence
- Shifts to enhanced precipitation as storm develops
  - More frequent intense convective precipitation: impacts on flooding?
  - Smaller area of stratiform precipitation
- Only slight increase in MCS total accumulated precipitation
  - SHIFT in precip mode to less stratiform and more convective is key





Updrafts & rain rates (May 20)

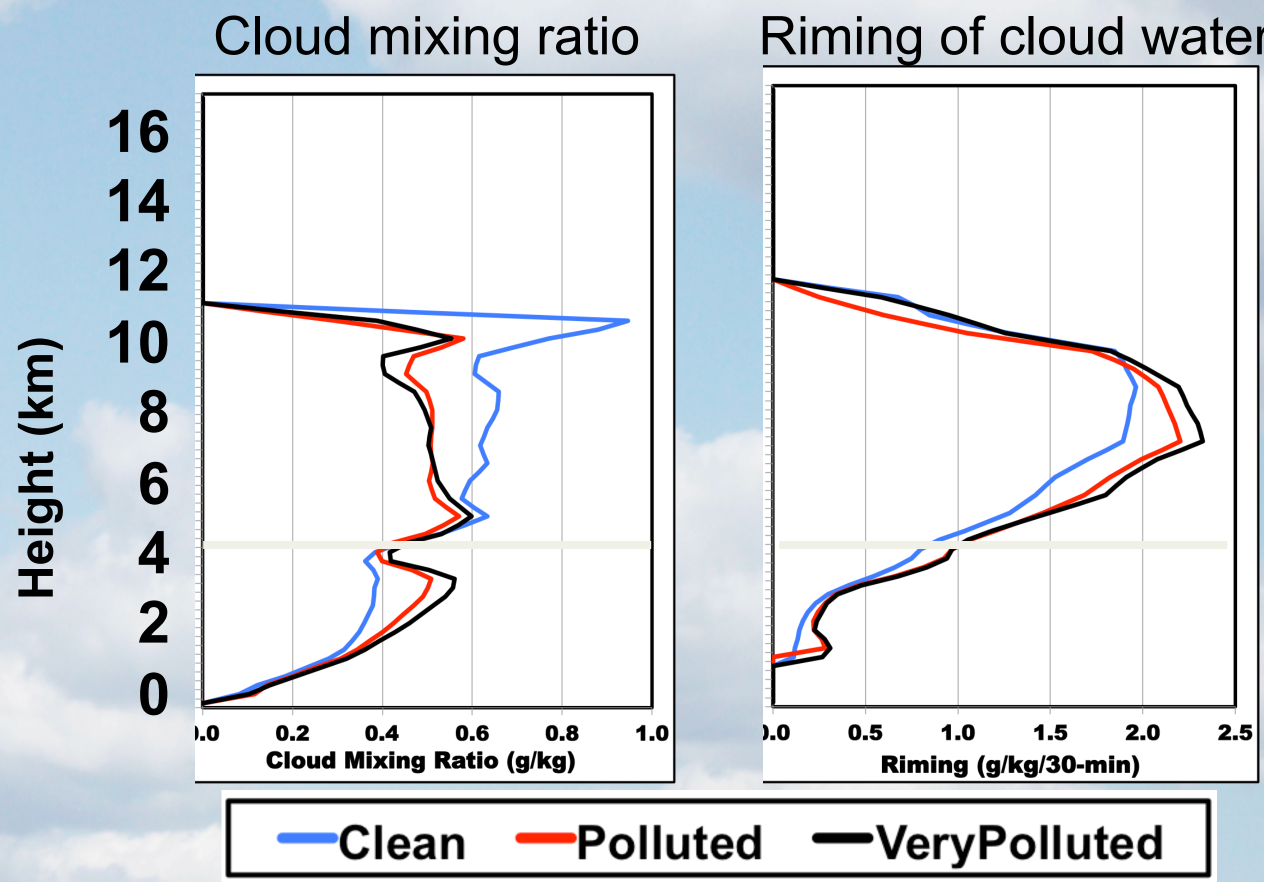




Conclusion: for these MCS,
an increase in aerosol concentration leads to

- an increased frequency of strong updrafts,
- a reduction in stratiform precipitation rates, and
- an increase in more convective precipitation rates.

Cloud Water and Riming Effects



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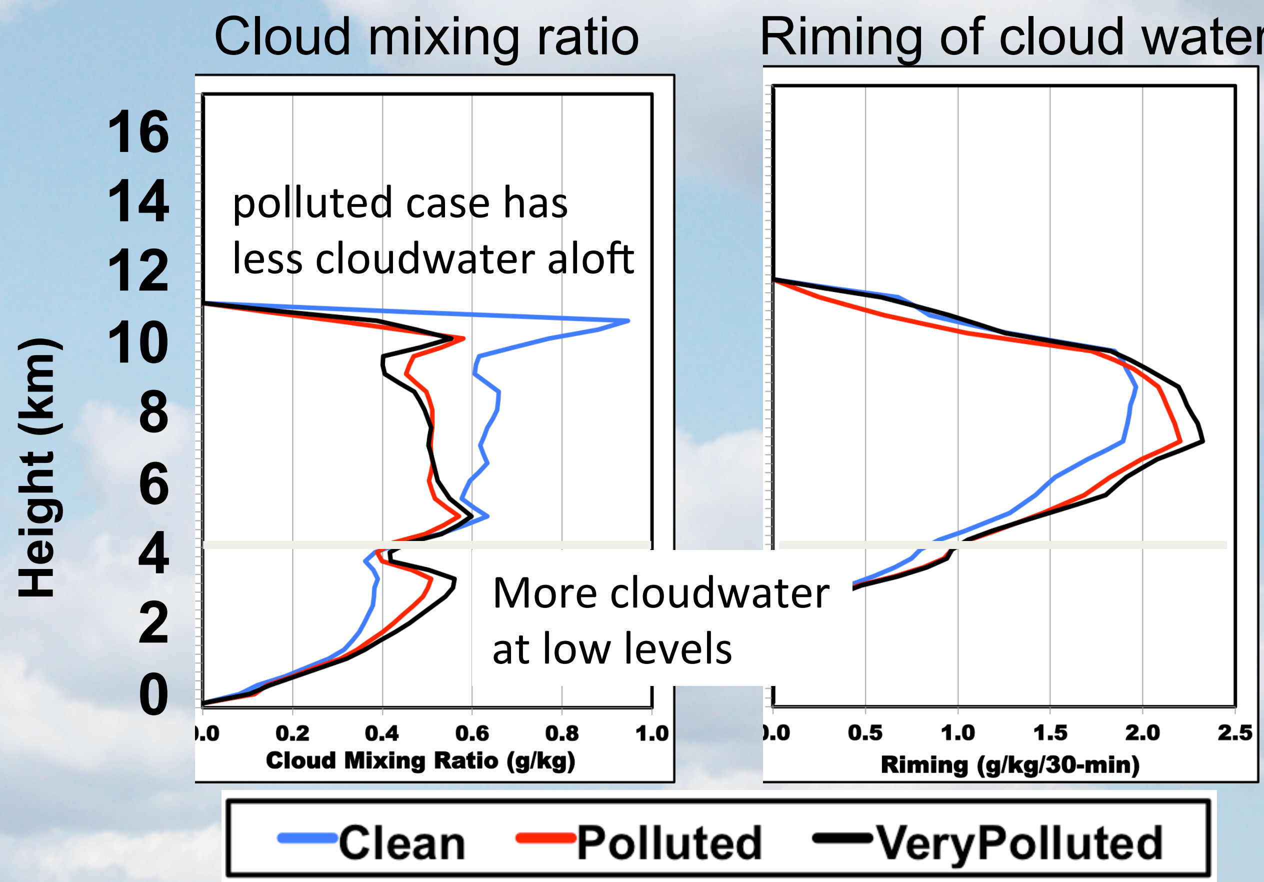

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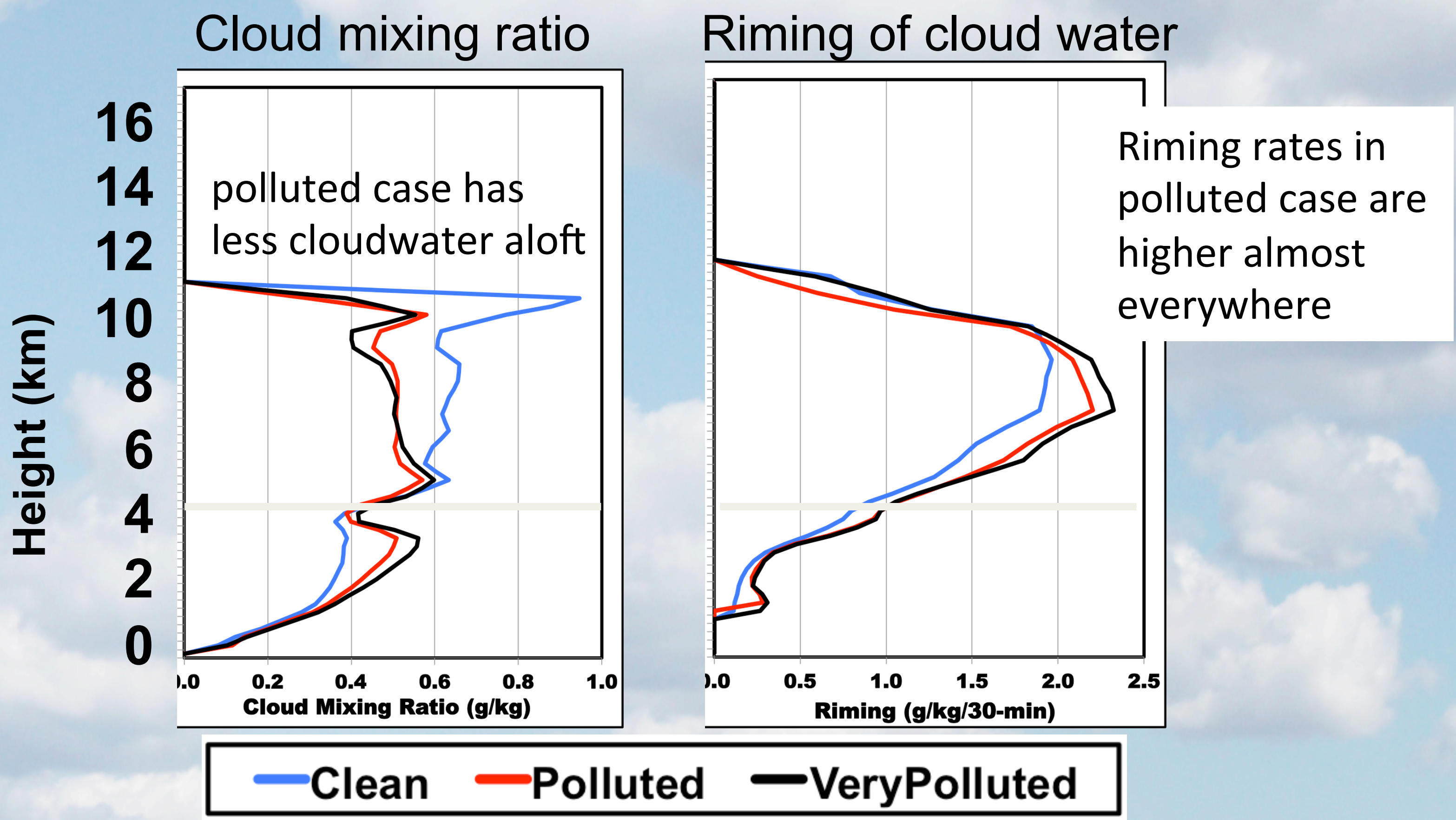
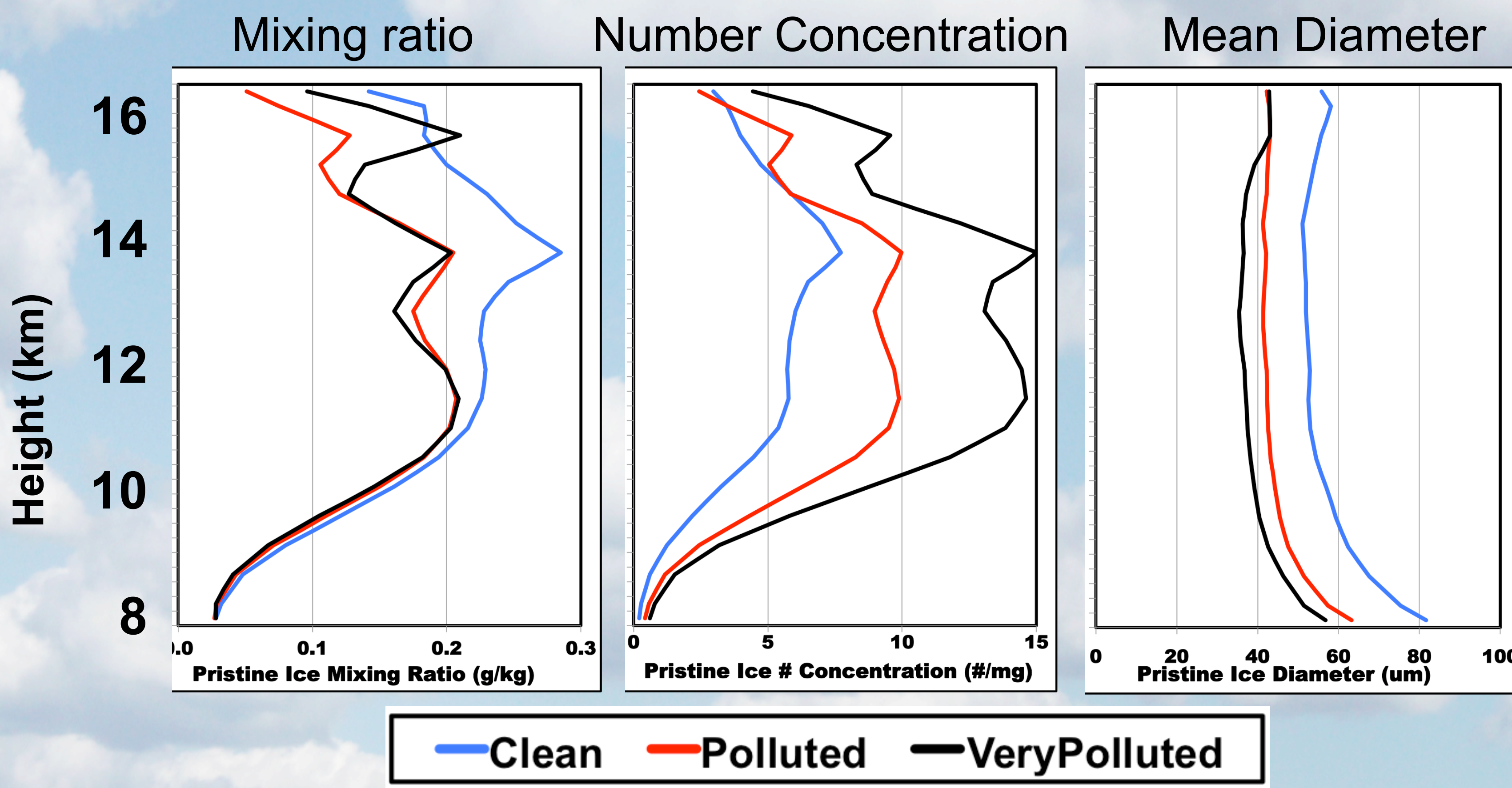


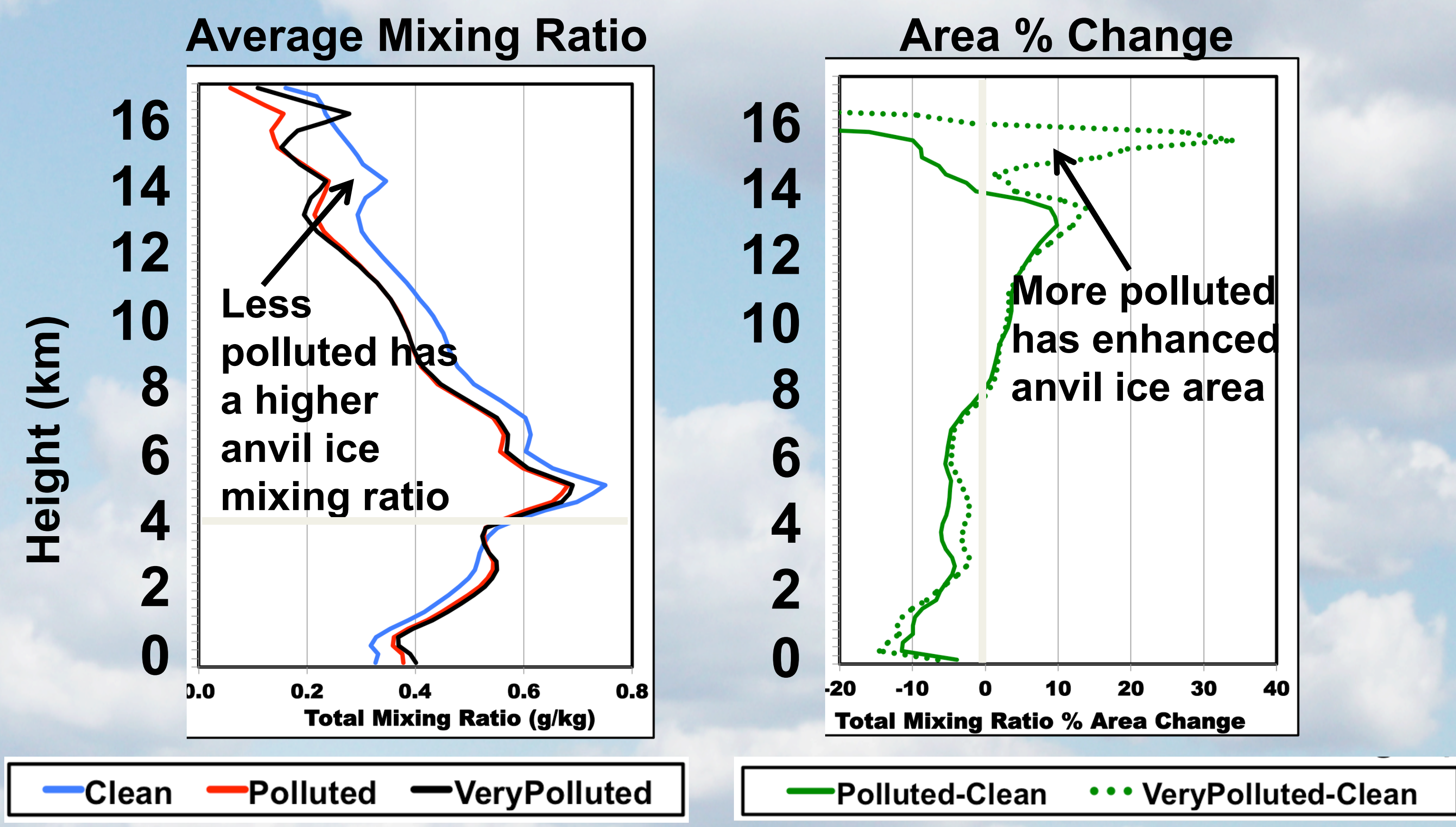
The reduction in cloud mixing ratio aloft is likely due to enhanced riming in the polluted case resulting from more frequent heavy precipitation rates and increased hail (mixing ratio), which is the most prolific rimer.

Cloud Ice



An increase in aerosol concentration leads to a greater number of smaller ice crystals in the mid- to upper levels. The polluted mixing ratio falls below that of the clean case.

Total Hydrometeor Condensate



An increase in aerosol concentration leads to a greater time integrated areal coverage at the anvil level, little change at mid-levels, and a reduction at low levels. Mixing ratio is greater in the polluted cases at low-levels and less further aloft.

Summary and Questions

Enhanced availability of aerosol particles in the boundary layer leads to:

- Higher frequency of occurrence of strong updrafts and convective precipitation rates, and reduced frequency of stratiform precipitation rates
- Greater areal coverage of smaller cloud ice at the upper anvil levels
- Reduced cloud water mixing ratio above the freezing level resulting from increased rates of riming by hail
- Increased scavenging of cloud water and higher precipitation rates in the polluted case may be limiting the amount of total lofted condensate

Still to investigate:

- Elevated aerosol layers with high particle number concentrations – are they efficiently ingested into clouds? What is impact on precipitation and anvil?
- Does availability of INP significantly impact these findings?