Aerosol Impacts on MC3E Case Studies - Some Preliminary Results

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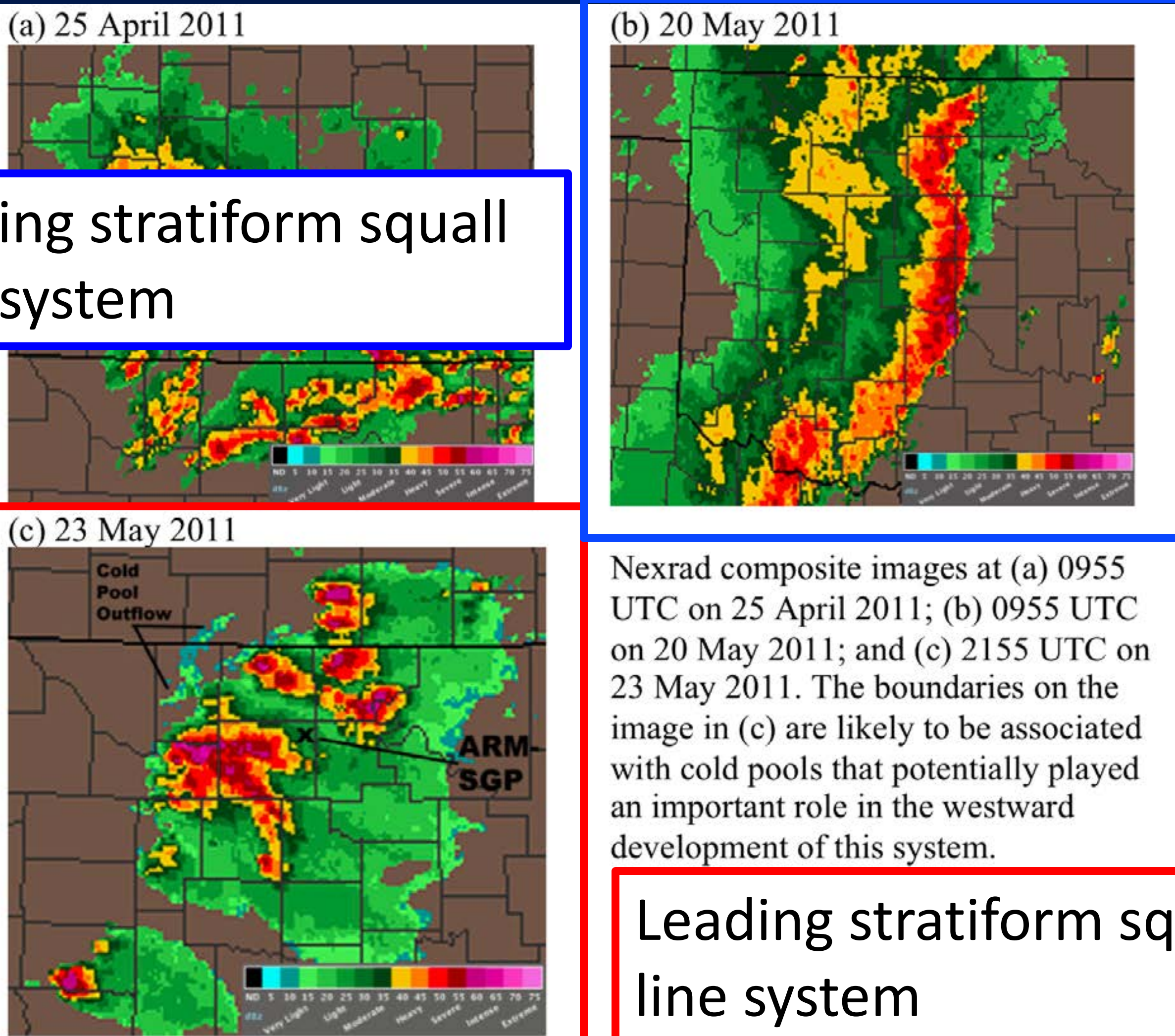
Aerosol Impacts on MCSs

- A number of past studies have investigated AIEs on MCSs (e.g. Lynn et al. 2005a; Wang 2005; Lee et al. 2008; Li et al, 2009; Fan et al 2012; Tao et al 2013)
- More recent studies have examined the impacts of specific aerosol types e.g. dust (e.g. Seigel et al 2013)
- Modeling studies often make use of regionally averaged or “idealized” profiles of aerosol concentrations and types
- MCSs during MC3E
  - range of different aerosol types, concentrations and vertical and horizontal distributions
  - ideal opportunity to assess relative roles of different aerosols on organized deep convection through use of observational and model output

Goals

1. Aerosol impacts on various MCS characteristics:
   - Characteristics of MCS anvils
   - Dynamical features including cold pools and the rear inflow jet (RIJ)
   - Convective-stratiform precipitation partitioning
2. Impacts of the vertical and horizontal distribution of aerosols and aerosol type on MCSs
3. MCS impacts on the vertical and horizontal redistribution of aerosols

MC3E Case Studies



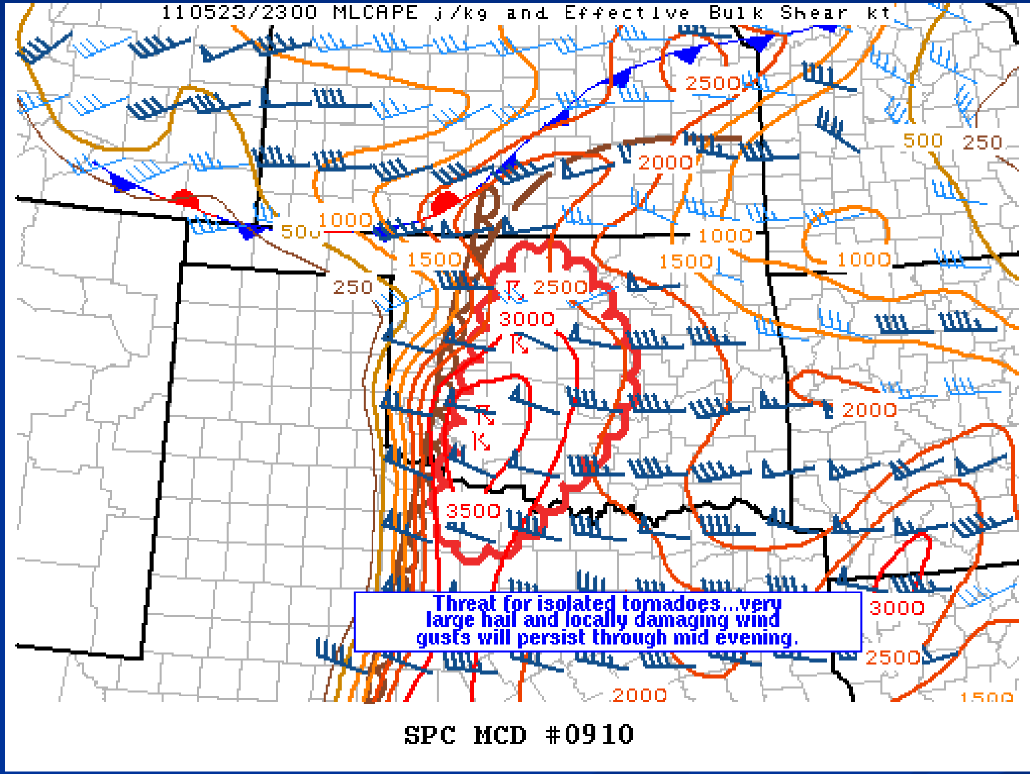
Trailing stratiform squall line system

Nexrad composite images at (a) 0955 UTC on 25 April 2011; (b) 0955 UTC on 20 May 2011; and (c) 2155 UTC on 23 May 2011. The boundaries on the image in (c) are likely to be associated with cold pools that potentially played an important role in the westward development of this system.

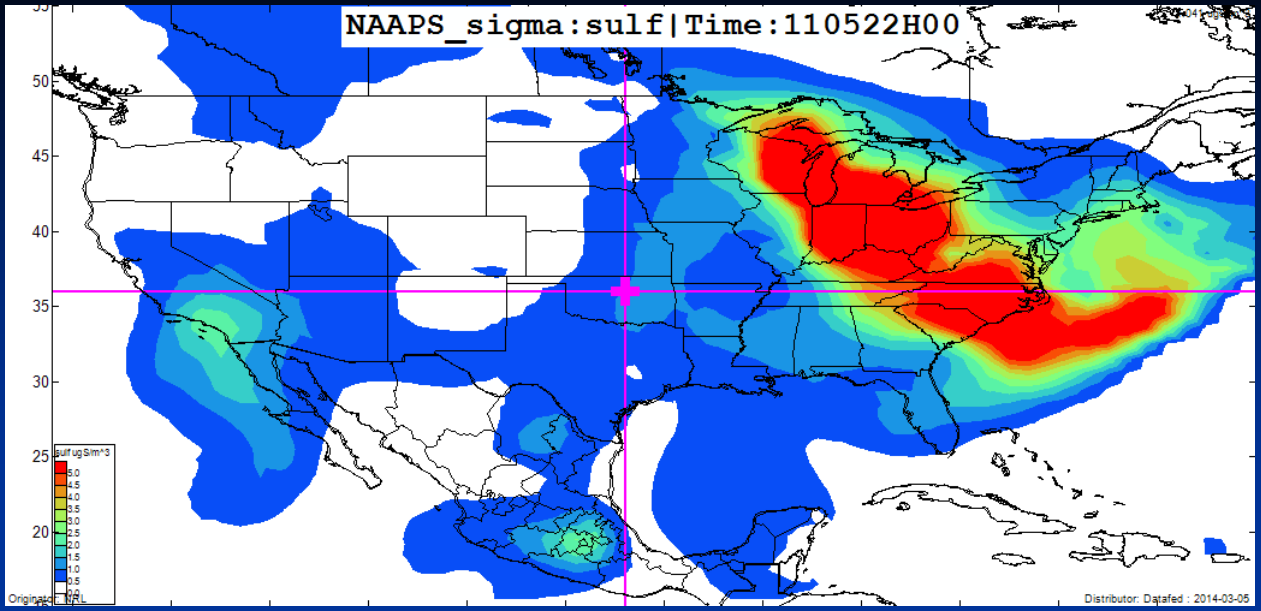
Leading stratiform squall line system

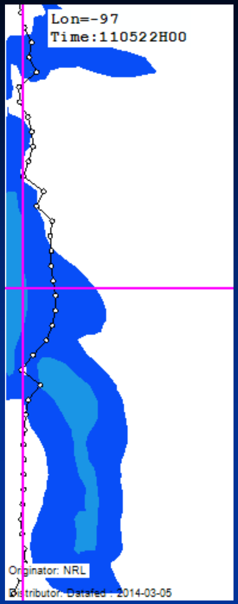
Ingredients for a Convective Outbreak
23 May 2011

- Low level Jet
  - Transport of warm, moist air at low levels
- High CAPE
- Dryline
- Strong Shear

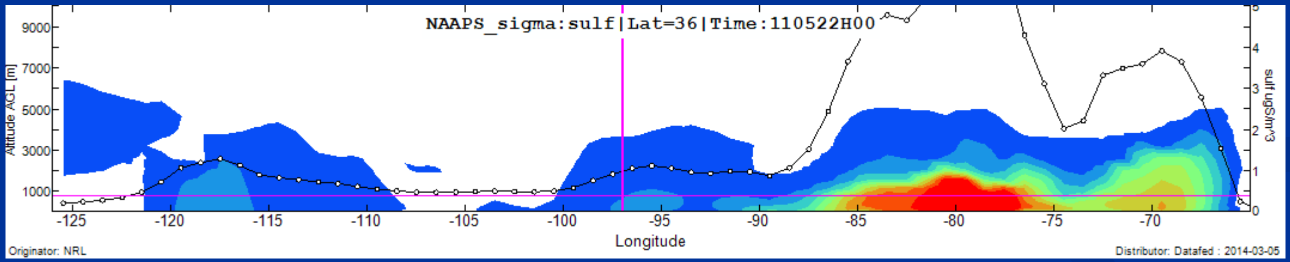


(http://www.spc.noaa.gov/exper/archive/event.php?date=20110522)



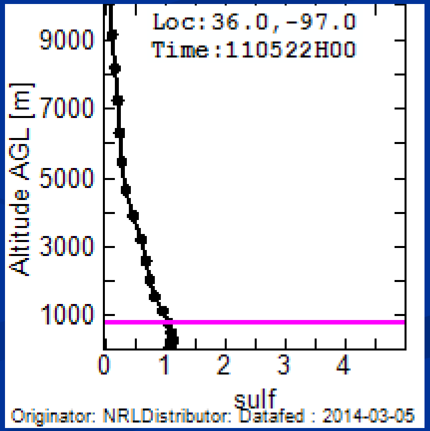


N-S Cross-Section



W-E Cross-Section

Vertical Profile



22 May – Sulfate

- Moderate event over eastern USA
- Low-level presence over SGP

NAAPS Model output

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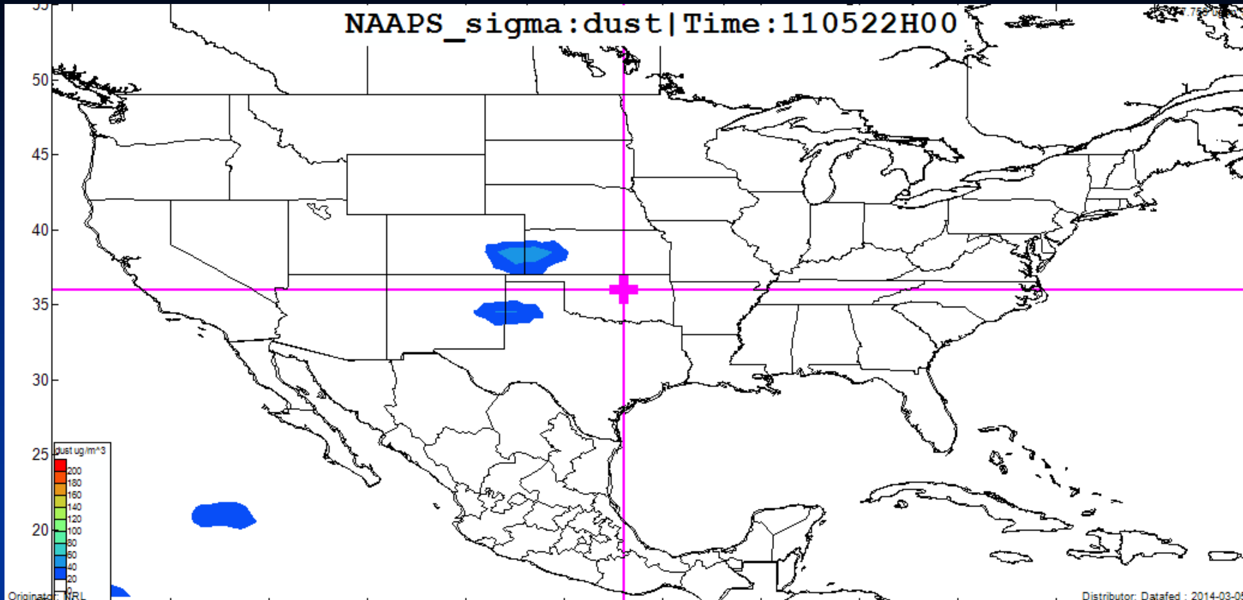

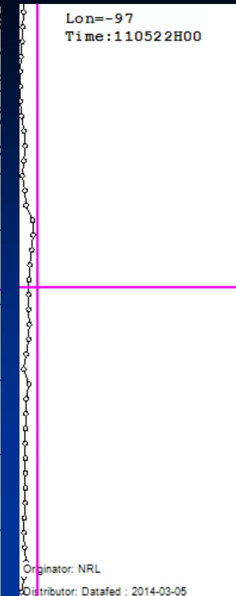

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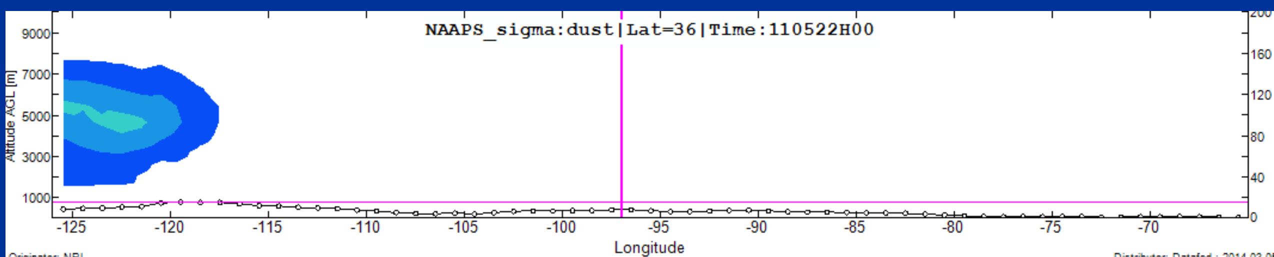
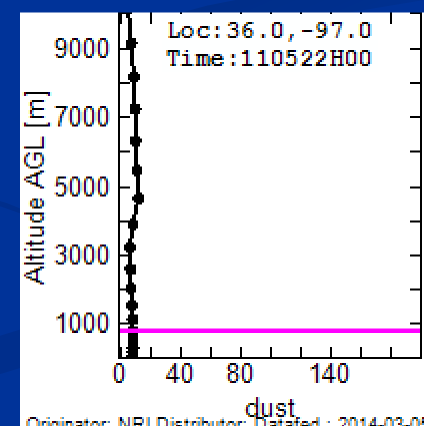


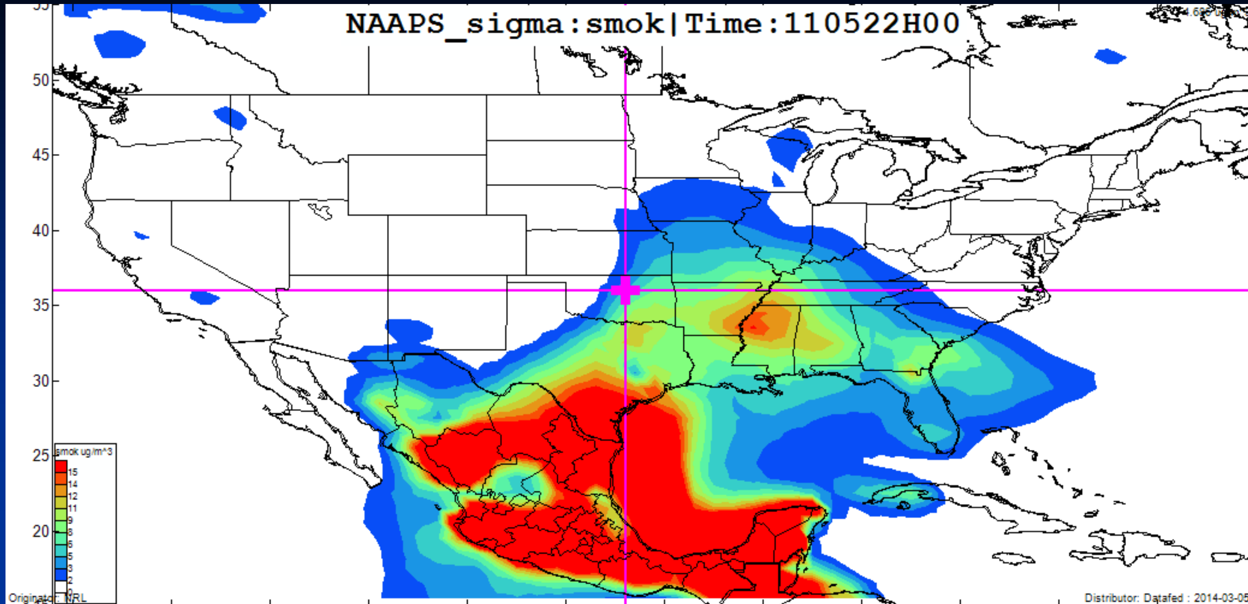
W-E Cross-Section

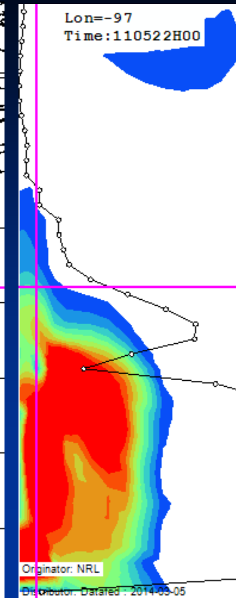
Vertical Profile



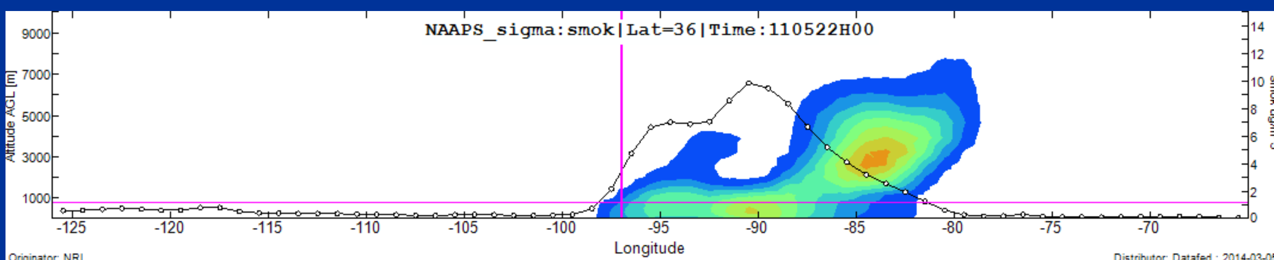
22 May – Dust

- Concentrations relatively low
- Dust present to the west of SGP



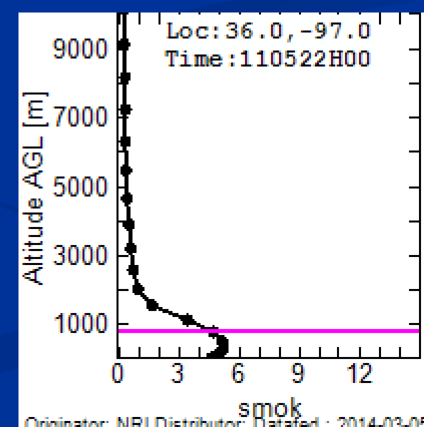


N-S Cross-Section



W-E Cross-Section

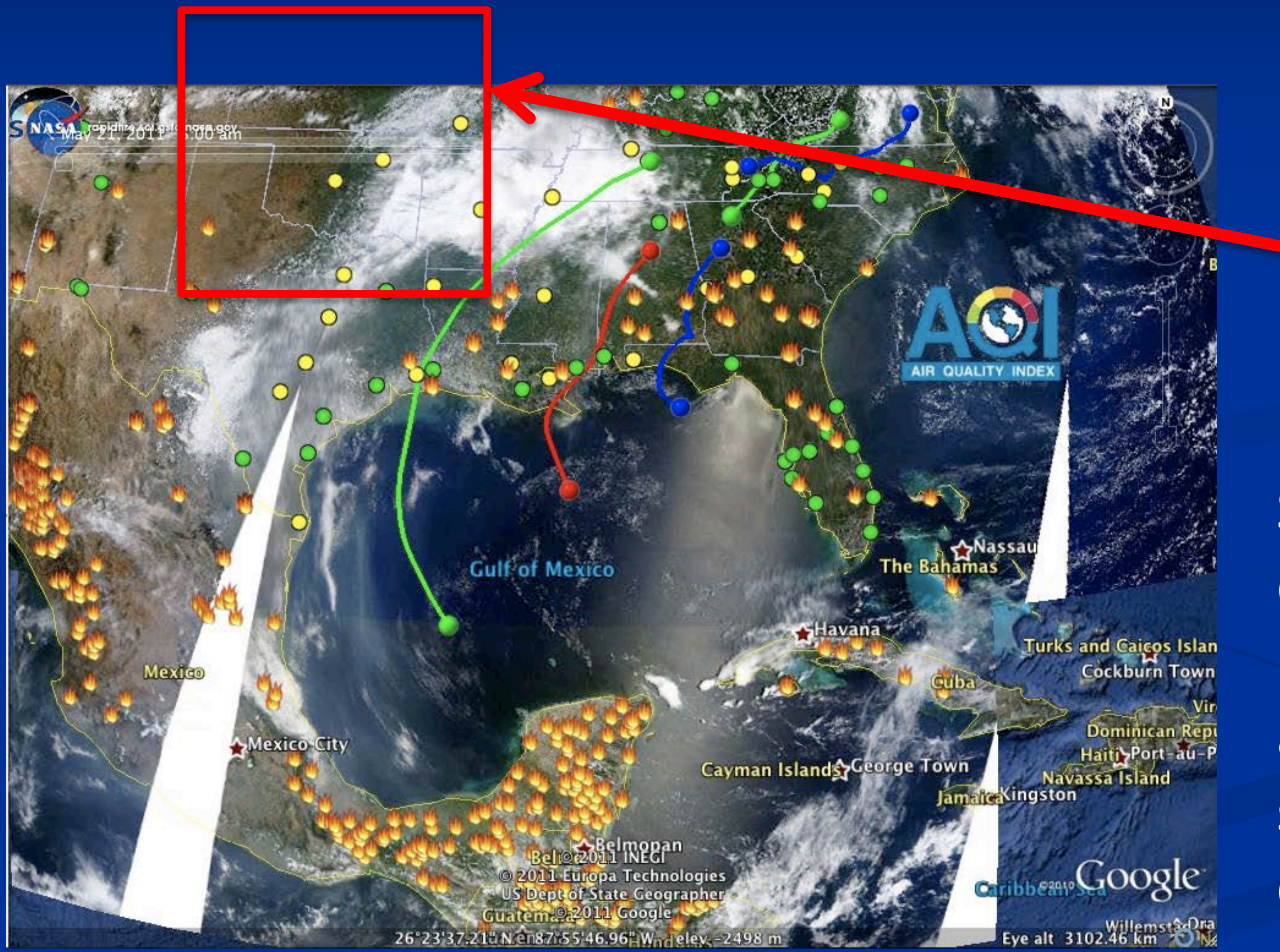
Vertical Profile



22 May – Smoke

- Transport from the southwest
- Higher concentrations at midlevels

Transport of Smoke into Southern Parts of Southern Great Plains



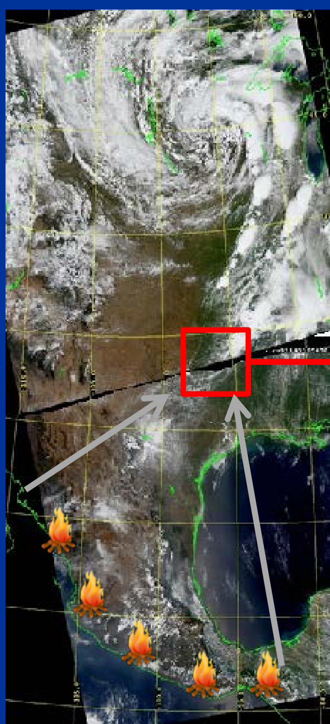
Innermost Grid in Simulation

Southern and eastern parts of inner domain affected by significant concentrations of smoke

http://alg.umbc.edu/usaq/archives/2011_05.html

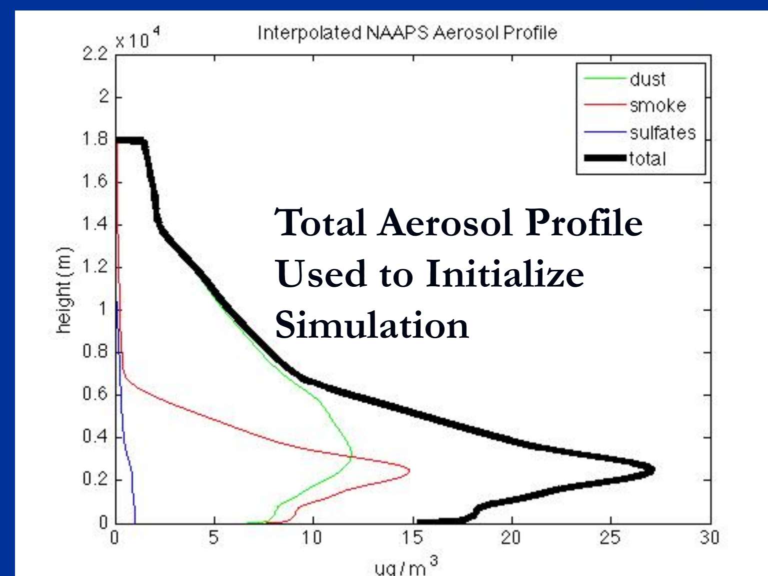
In-Plume Experience

- Understand the effects of smoke plumes on convective systems
- Initialize RAMS with aerosol profile representative of plume transport



NASA Landsat RGB Image.

Mean vertical aerosol profile within box [91.5-95.5W and 31.5-34.5N] from NAAPS Aerosol Model



Cloud Resolving Model

- RAMS model developed at CSU
- 2 Moment bin-emulating bulk microphysics
- Prognostic aerosol scheme (Saleeby and Cotton, 2004)

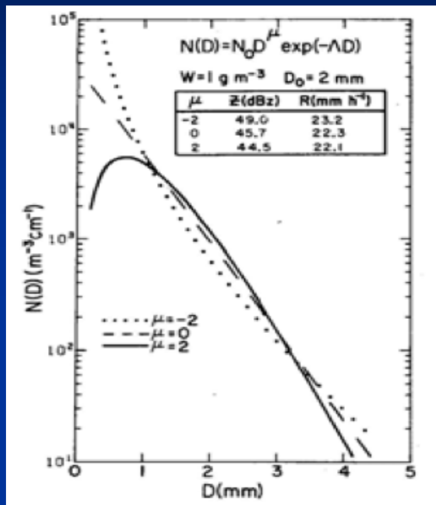
Aerosol Input

$$N_{activated} = N_{available} F_{activation}$$

- Cloud droplets are nucleated from CCN as a function of temperature, w, CCN number concentrations and aerosol mean diameter

RAMS Bin-Emulating Bulk Scheme = Bulk + Bin

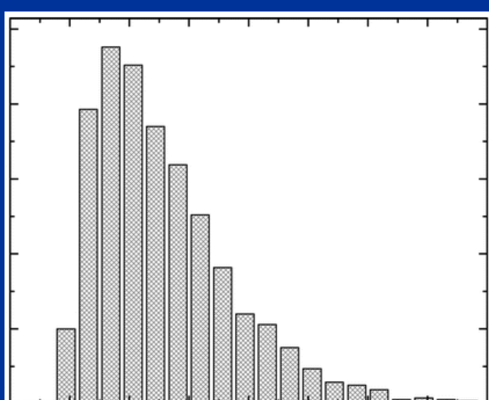
BULK SCHEMES



RAMS MODEL

BIN SCHEMES

N(D)



D(mm)

Recently implemented HUCM bin microphysics (Khain et al 2005)

Bin scheme in an offline parcel model for a wide range of conditions

↓

Generate lookup tables

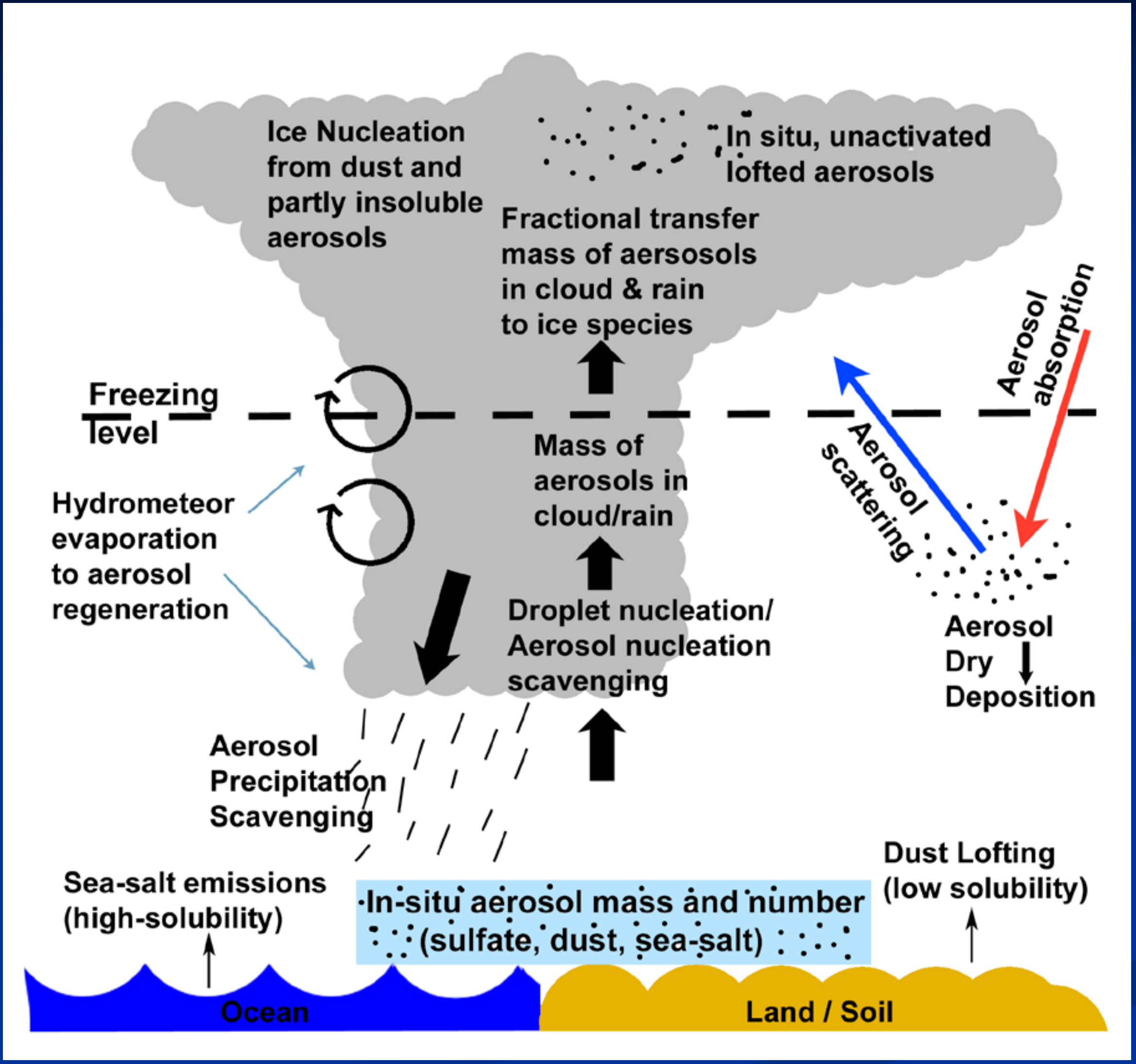
↓

Access lookup tables while running online

Processes:
Nucleation
Diffusion growth
Collision-coalescence
Sedimentation
Melting and riming

RAMS

- Recent extensive modifications to microphysics and aerosol schemes (Saleeby and van den Heever 2013)
- Aerosol scheme
  - Prognostic scheme
  - Sulfate, dust smoke, sea salt and regenerated aerosol (after evaporation)
  - DeMott et al (2010) IN scheme



(after Saleeby and van den Heever 2013)

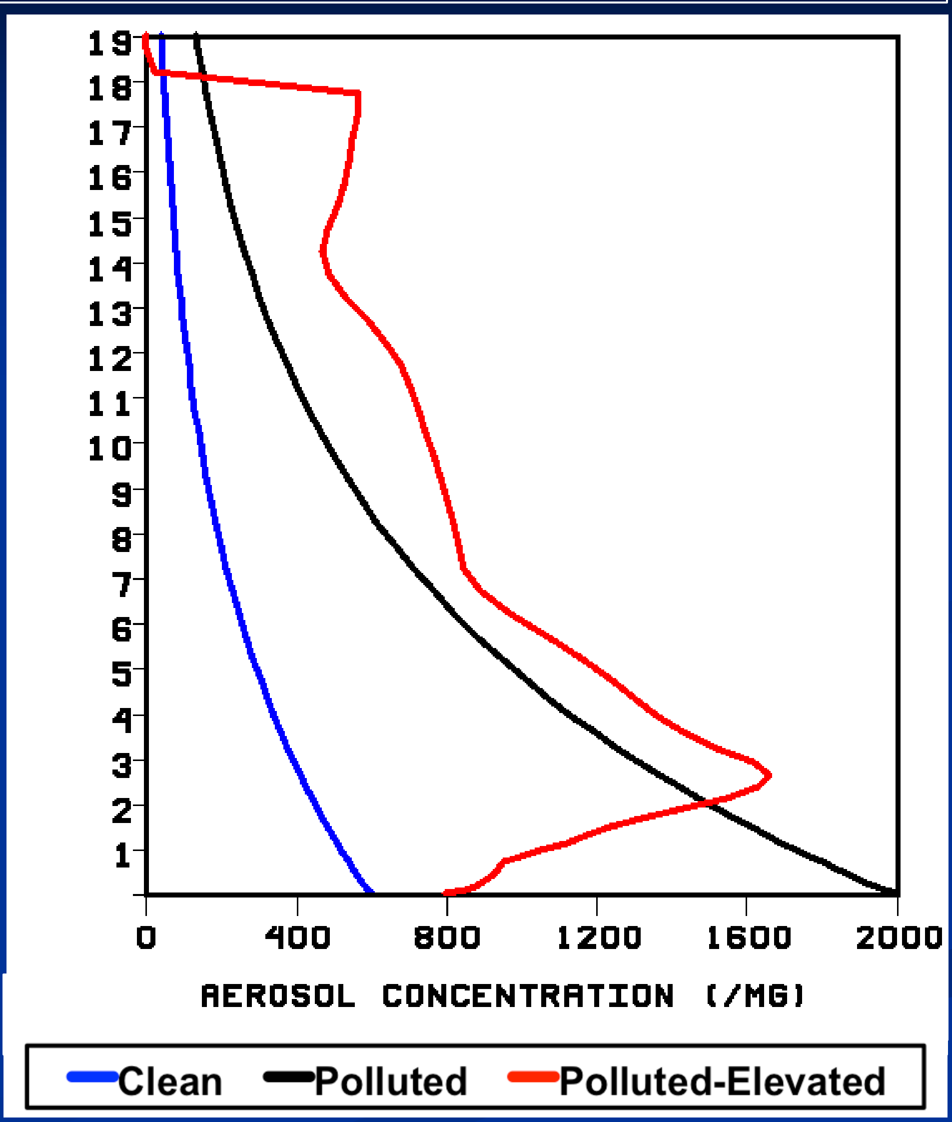
MC3E Case Studies - Model Setup

- Grid 1: dx = 30km (covering most of CONUS)
  Grid 2: dx = 6km (covering Great Plains)
  Grid 3: dx = 2km (covering much of KS & OK)
- Initialized 22 May 0000Z with GFS pressure level data and soil fields.
- On 23 May 1500Z spawned grid-3 from history file
- Ran through 24 May 0800Z
- Analysis performed for Grid 3 – spatially and temporally

Experiment Setup

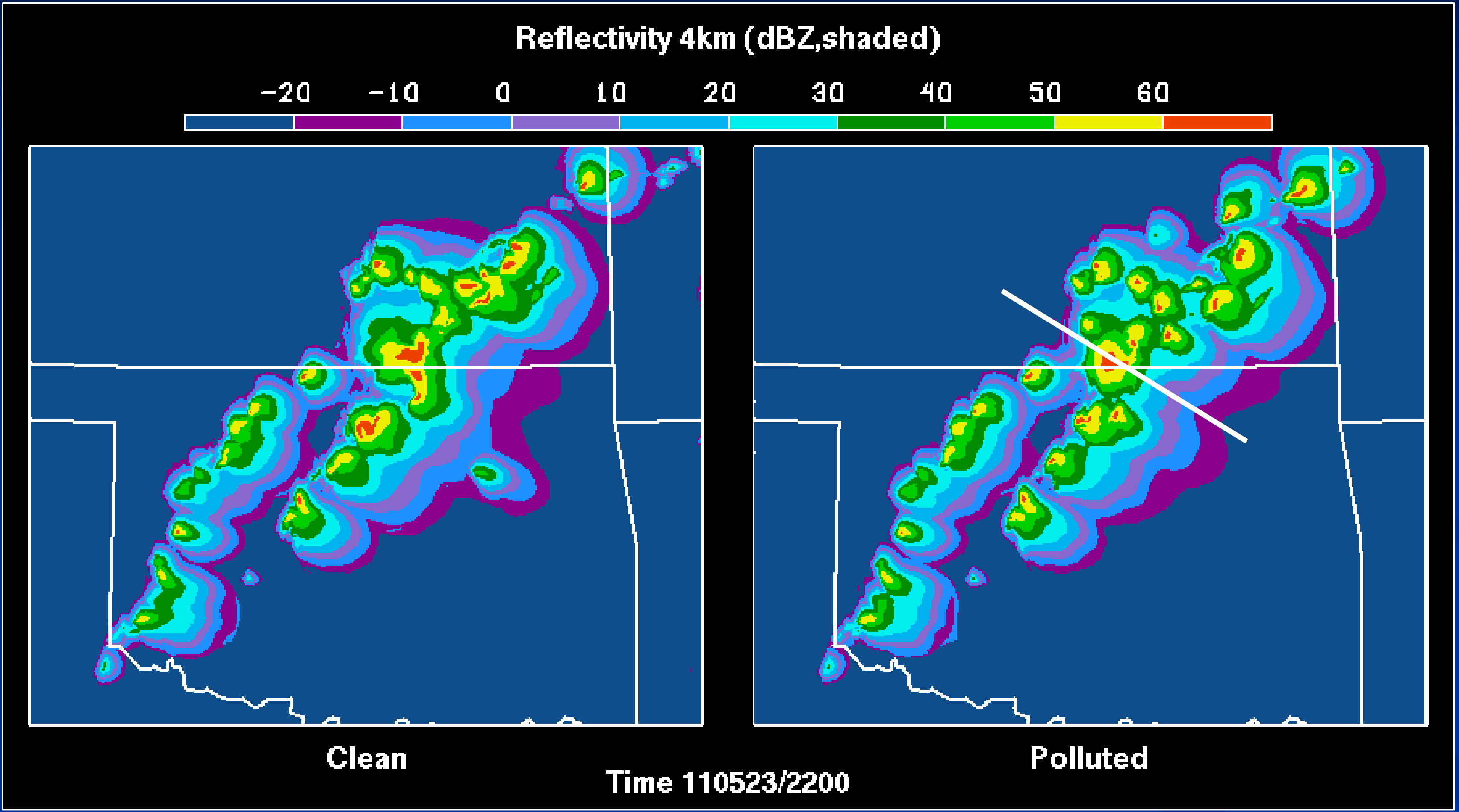
- Runs identical except for initial aerosol field
- Exp1: Clean = 600 mg^{-3} (exponentially decreasing profile with height)
- Exp2: Polluted = 2000 mg^{-3} (exponentially decreasing profile with height)
- Exp3: Same as polluted simulation but aerosols were redistributed vertically to simulate an elevated pollution layer.

Initial aerosol profiles for sensitivity tests



Basic Storm Structure

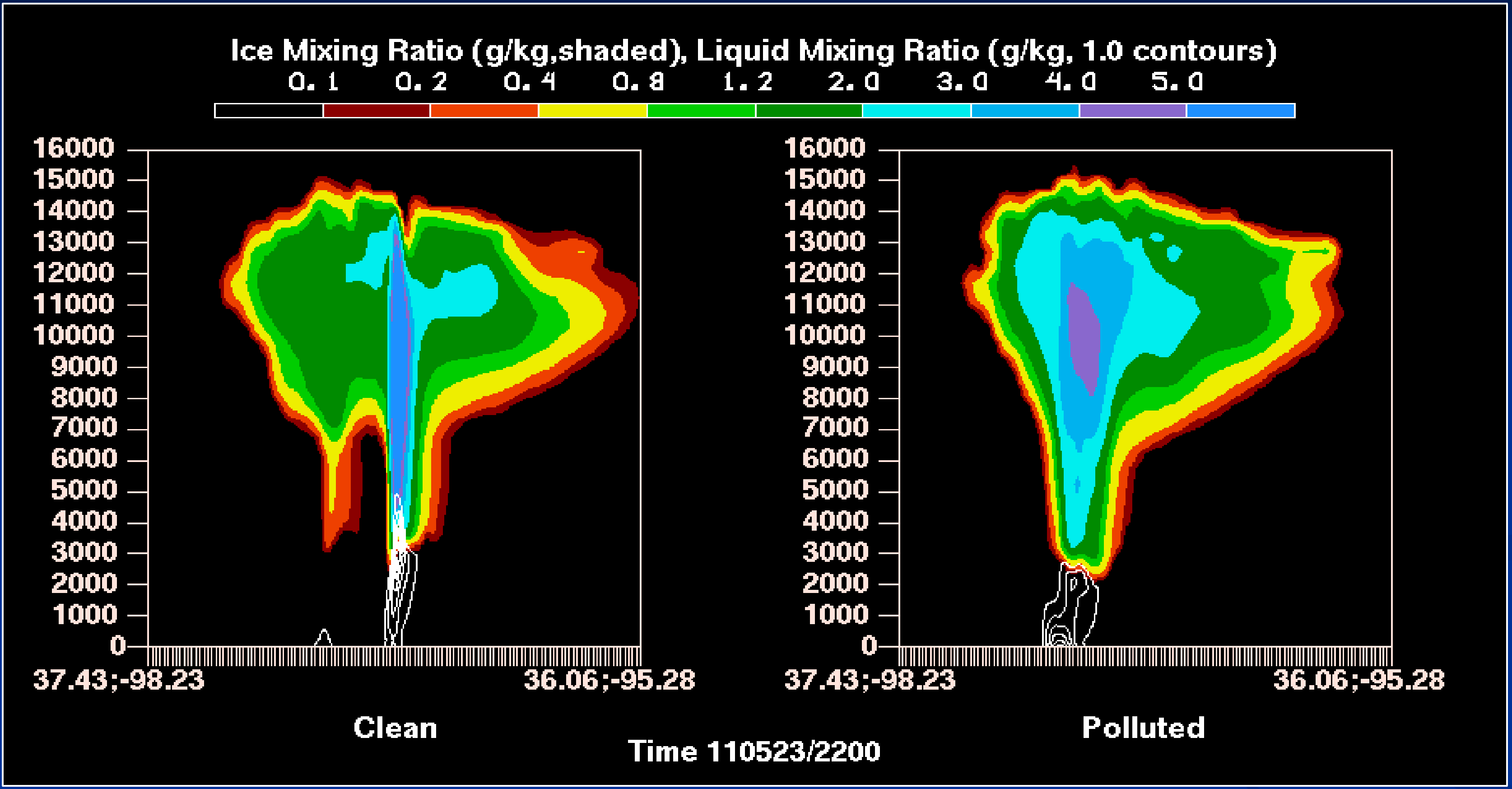
Radar reflectivity at 4km AGL



- Leading stratiform squall line
- No major structural differences between clean and polluted

Storm Structure

Ice (shaded) and liquid water (contours) mixing ratios (g/kg)



- Substantial leading stratiform condensate
- Significantly greater ice mass in the polluted anvils as more cloud water is being lofted to higher levels rather than being rained out

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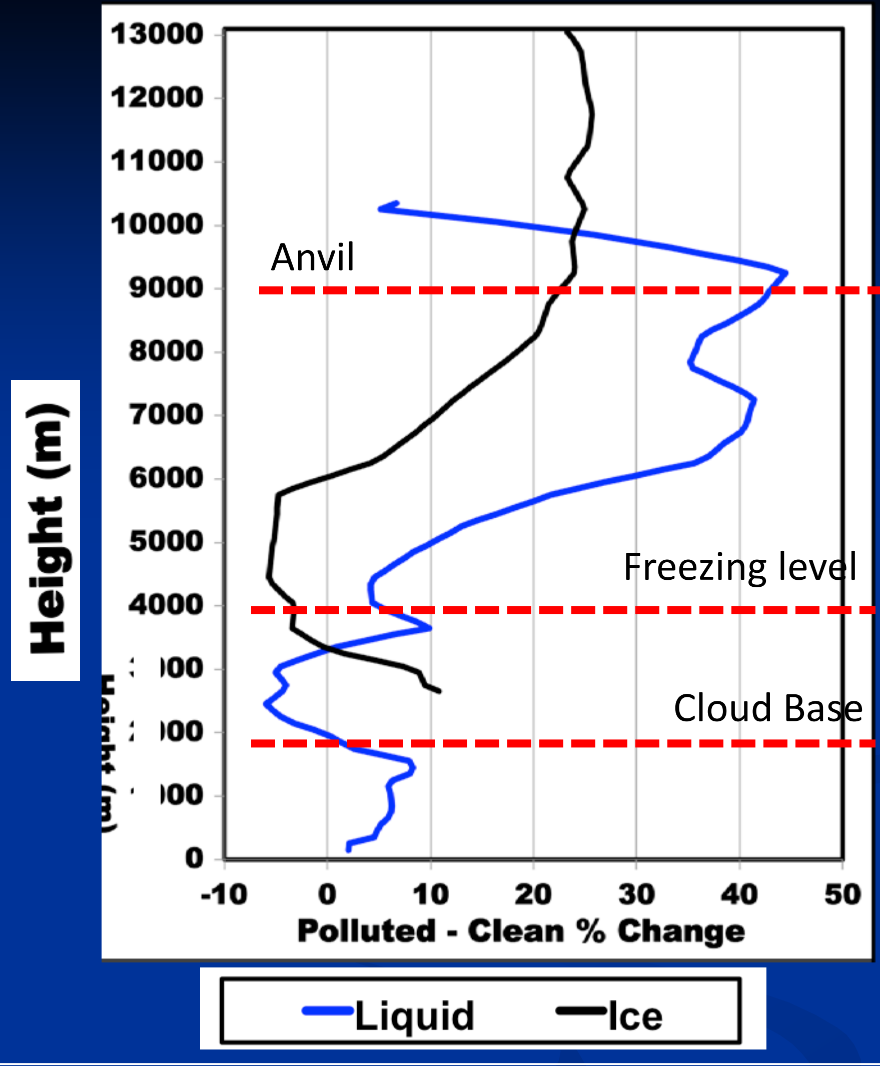
Condensate Profiles

- Greater liquid water mixing ratios between cloud base and anvil base in the polluted scenarios (up to ~40%) due to suppression of warm rain processes
- Greater ice mixing ratios (~20%) from just above the freezing level through the anvil in the polluted cases due to the vertical lofting of greater amounts of available liquid water to these levels



Polluted – Clean differences (%) in the spatially and temporally averaged vertical profiles of liquid water (blue) and ice (gray) mixing ratios

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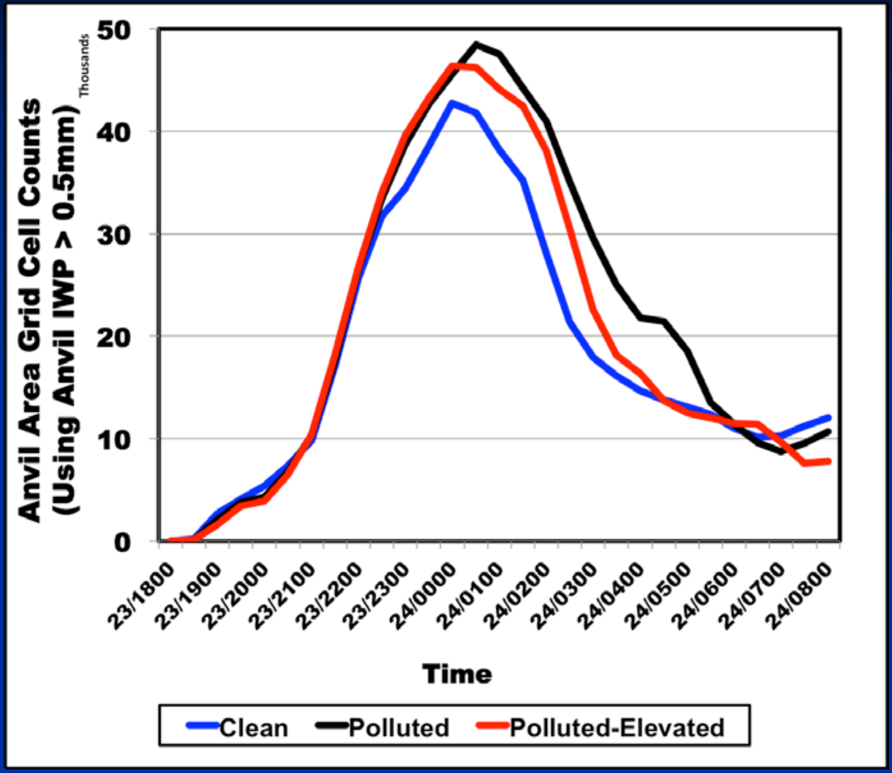
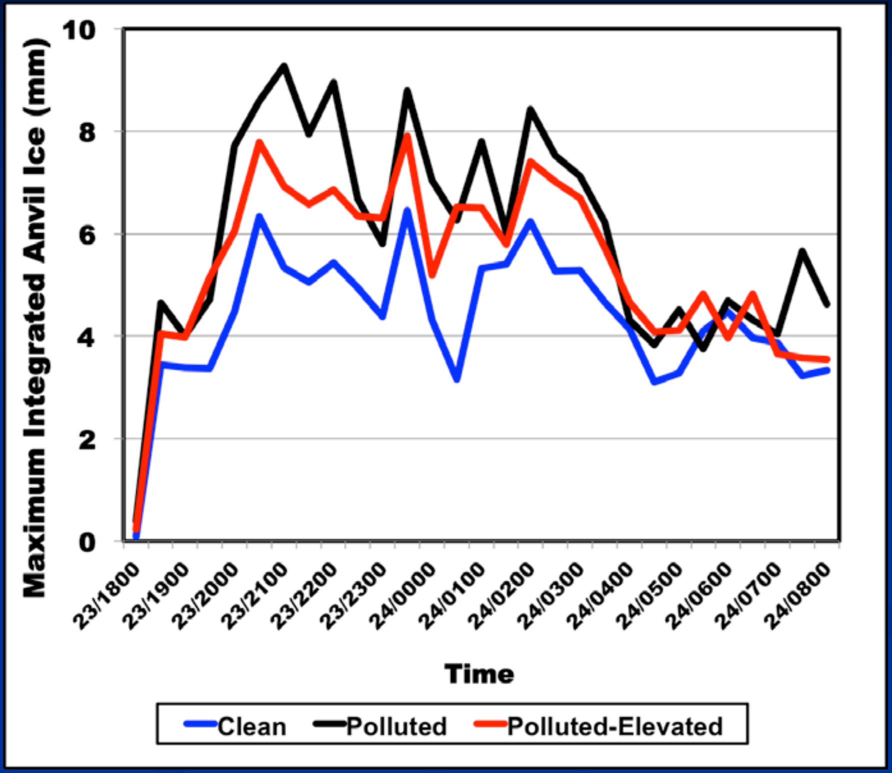
Anvil Characteristics

Time series of (left) anvil area and (right) integrated anvil ice





- We see increased spatial coverage of convective anvils as well as the integrated ice mass in the anvils => thicker anvils covering greater areas; also composed of greater number of smaller ice particles
- POLLUTED-ELEVATED falls between CLEAN and POLLUTED => aerosols are more efficiently ingested when concentrated in the boundary layer.

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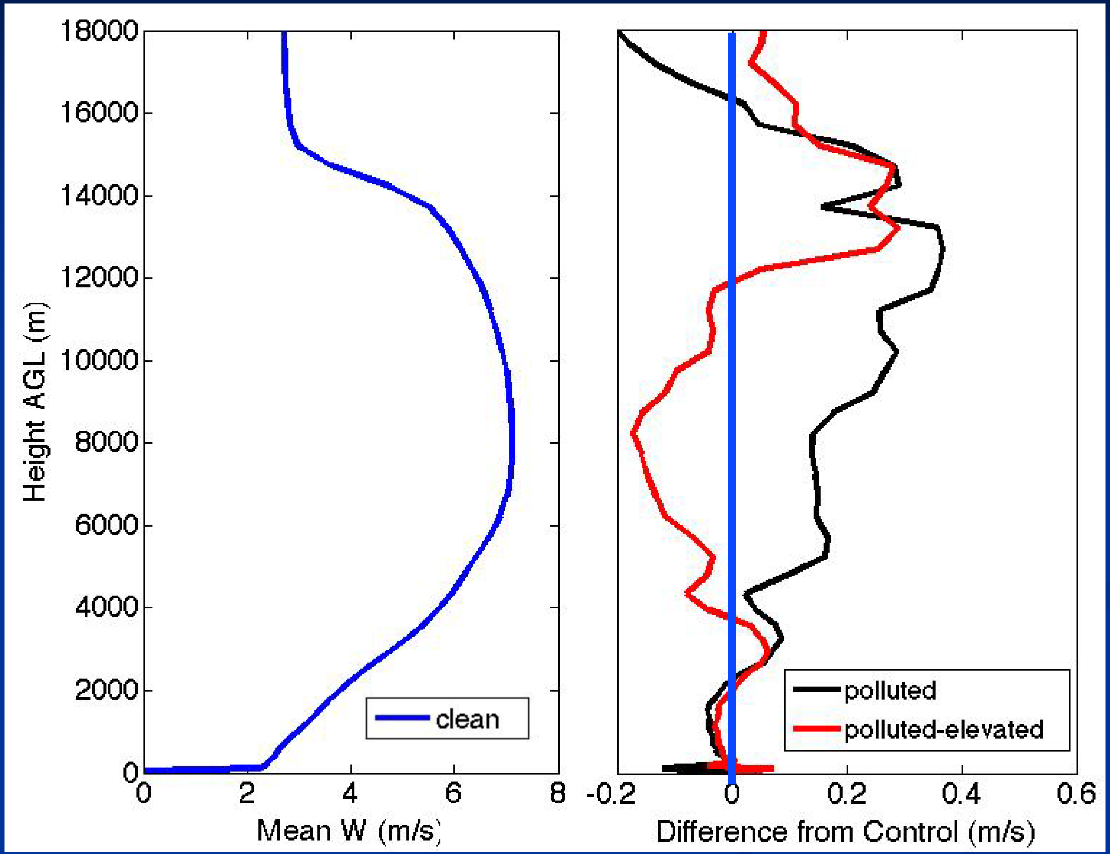
Vertical Velocity

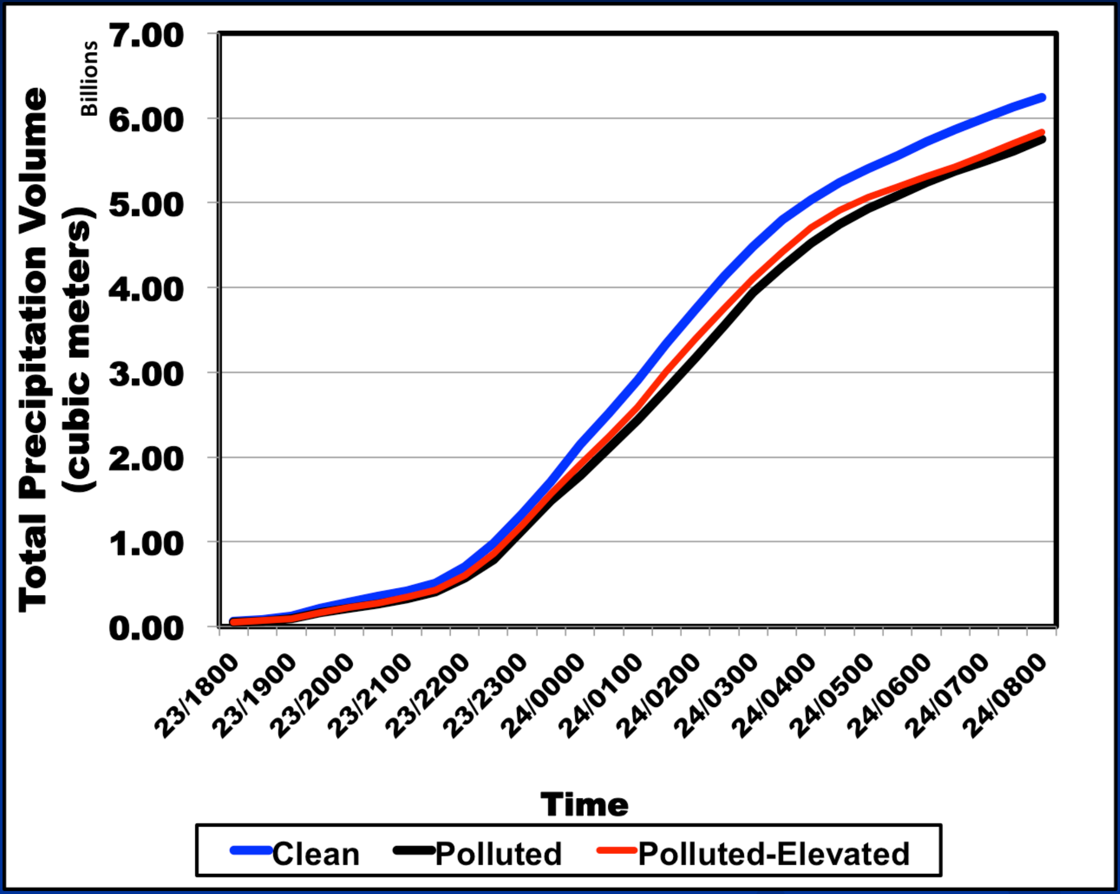
- Increases in vertical velocity in the POLLUTED (~10%) case throughout most of the storm => invigoration effect
- Weakened updrafts in POLLUTED-ELEVATED in the mixed phase regions and above



Vertical profiles of (left) CLEAN mean vertical velocity ($w>2ms^{-1}$); and (right) POLLUTED-CLEAN differences

Accumulated Precipitation

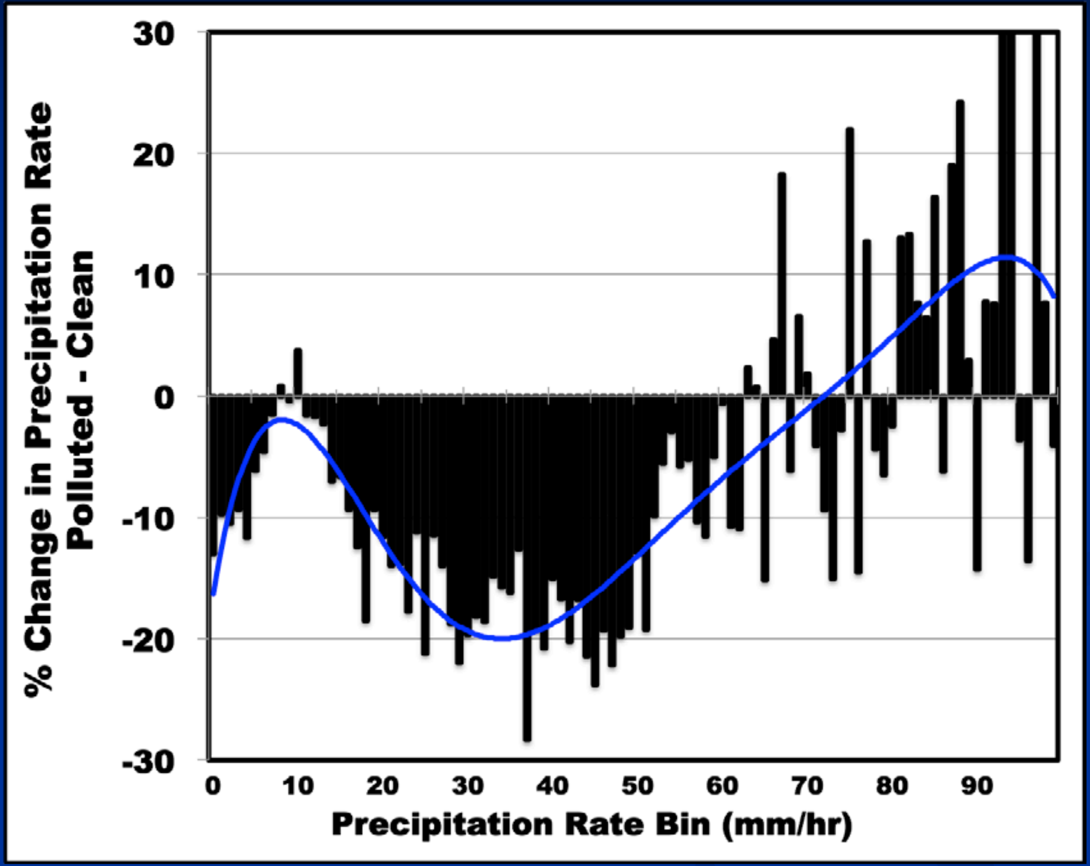
- Increased aerosol loading => substantially more vertically lofted liquid and ice, much of which is deposited in the outflow anvil.
- This process, in combination with a suppressed warm rain process leads to a REDUCTION in total accumulated volume precipitation of ~ 8 %.



Time series of accumulated precipitation

Precipitation Rates

- Increased aerosol loading leads to a decrease in light and moderate precipitation rates and an increase in heavy precipitation rates
- Polluted scenarios
  - reduced stratiform precipitation due to reduced size of anvil hydrometeors
  - shift towards enhanced heavier convective precipitation



Histogram of binned precipitation rates shown as a difference between the POLLUTED and CLEAN simulations

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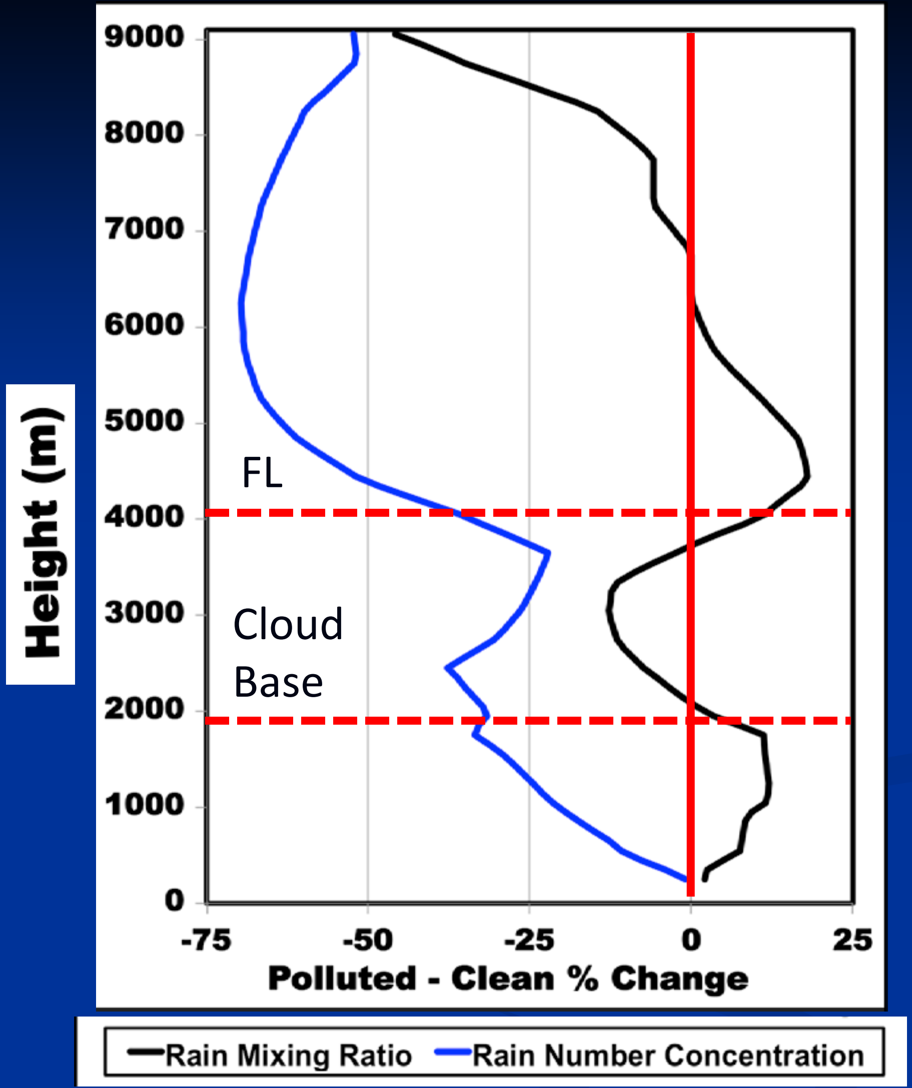
Rain Characteristics

- Fewer but larger raindrops below cloud base in the polluted scenario => reduced evaporation rates
- Rain is more efficiently produced in the CLEAN case in the lower regions of the cloud
- Riming of raindrops is reduced in the polluted case above the freezing level leaving more liquid water in this regions



Vertical profiles of POLLUTED-CLEAN rain mixing ratio (black) and raindrop number concentrations (blue) (%)

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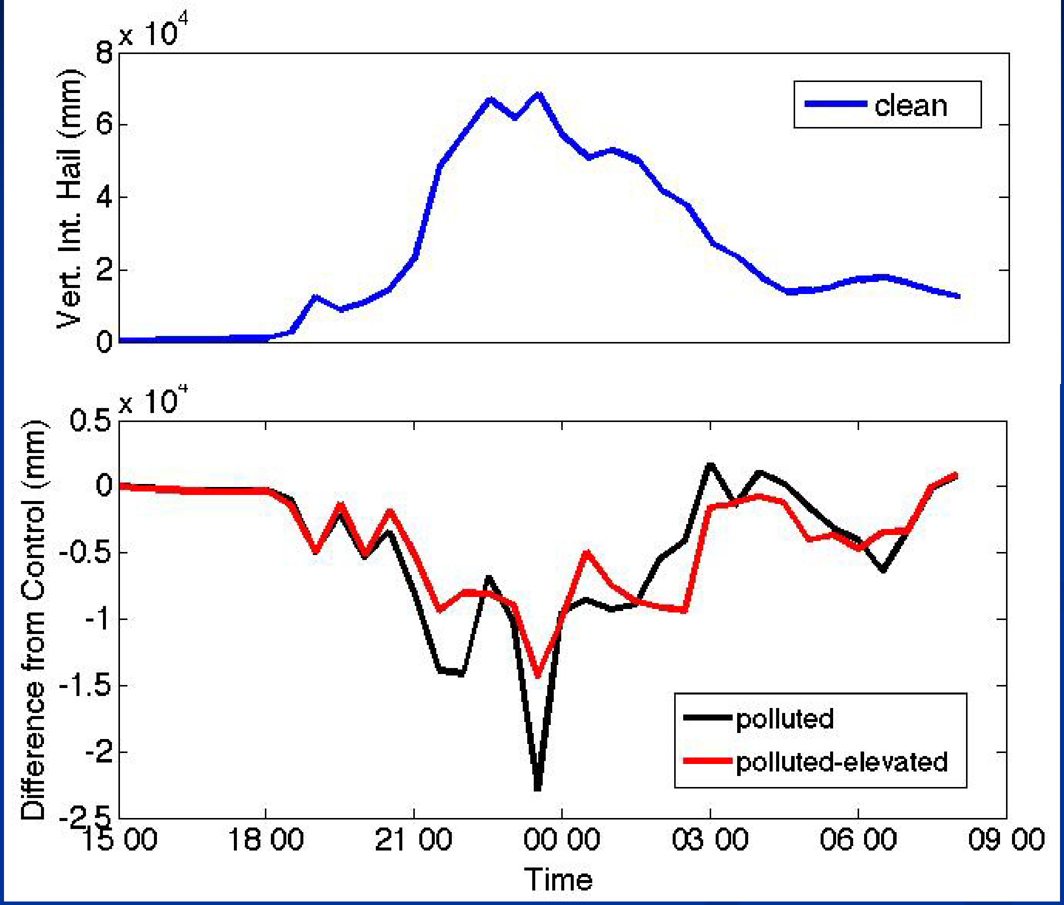
Hail Characteristics

- Increased aerosol concentrations lead to a reduction in the amount of hail produced (~25-35%)
- POLLUTED-ELEVATED once again falls between CLEAN and POLLUTED demonstrating the role of the vertical location of aerosol



Time series of (top) vertically-integrated hail in the CLEAN and (bottom) the POLLUTED-CLEAN differences

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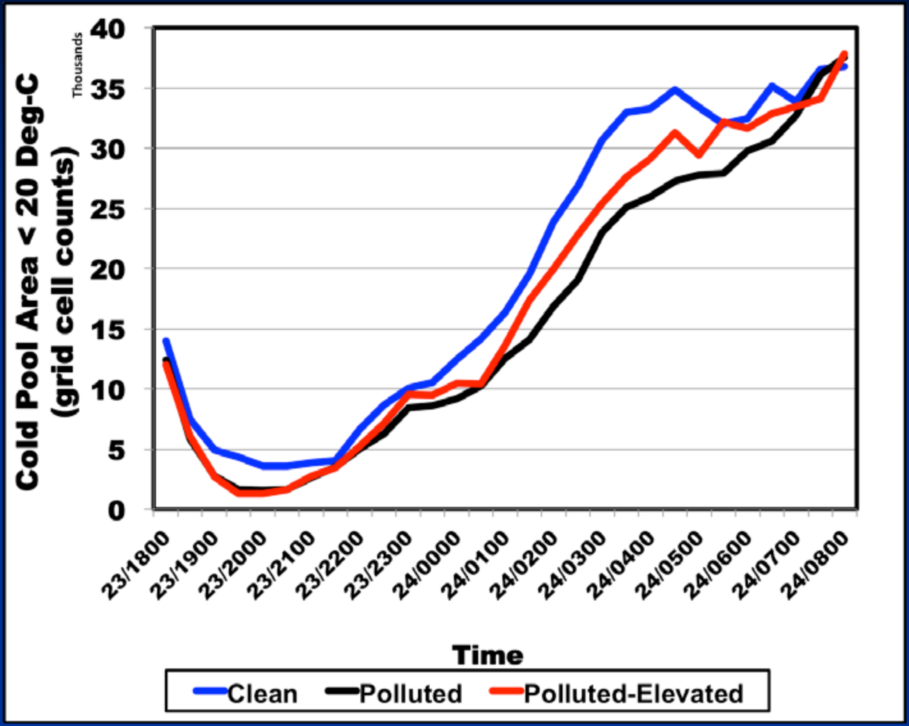
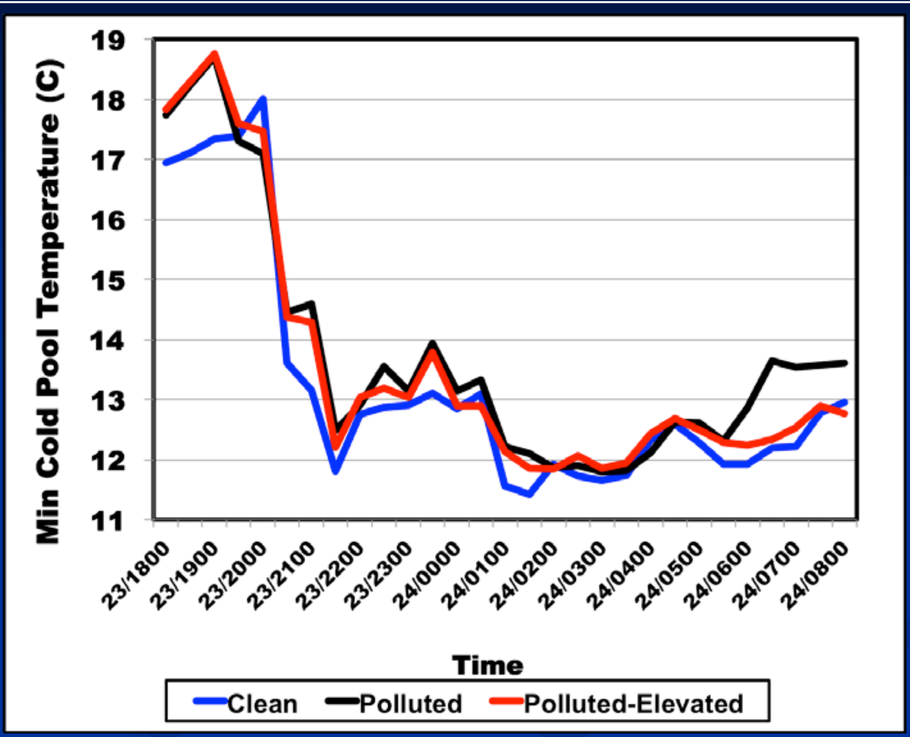
Cold Pools

Time series of (left) cold pool area and (right) minimum cold pool temperature





- An increase in pollution aerosols leads to a decrease in the expanse of the cold pool. Also the minimum cold pool temperature is warmer in the polluted scenarios.
- Under polluted conditions, the warm rain process leads to fewer and larger raindrops, which is less conducive to total sub-cloud evaporative cooling.

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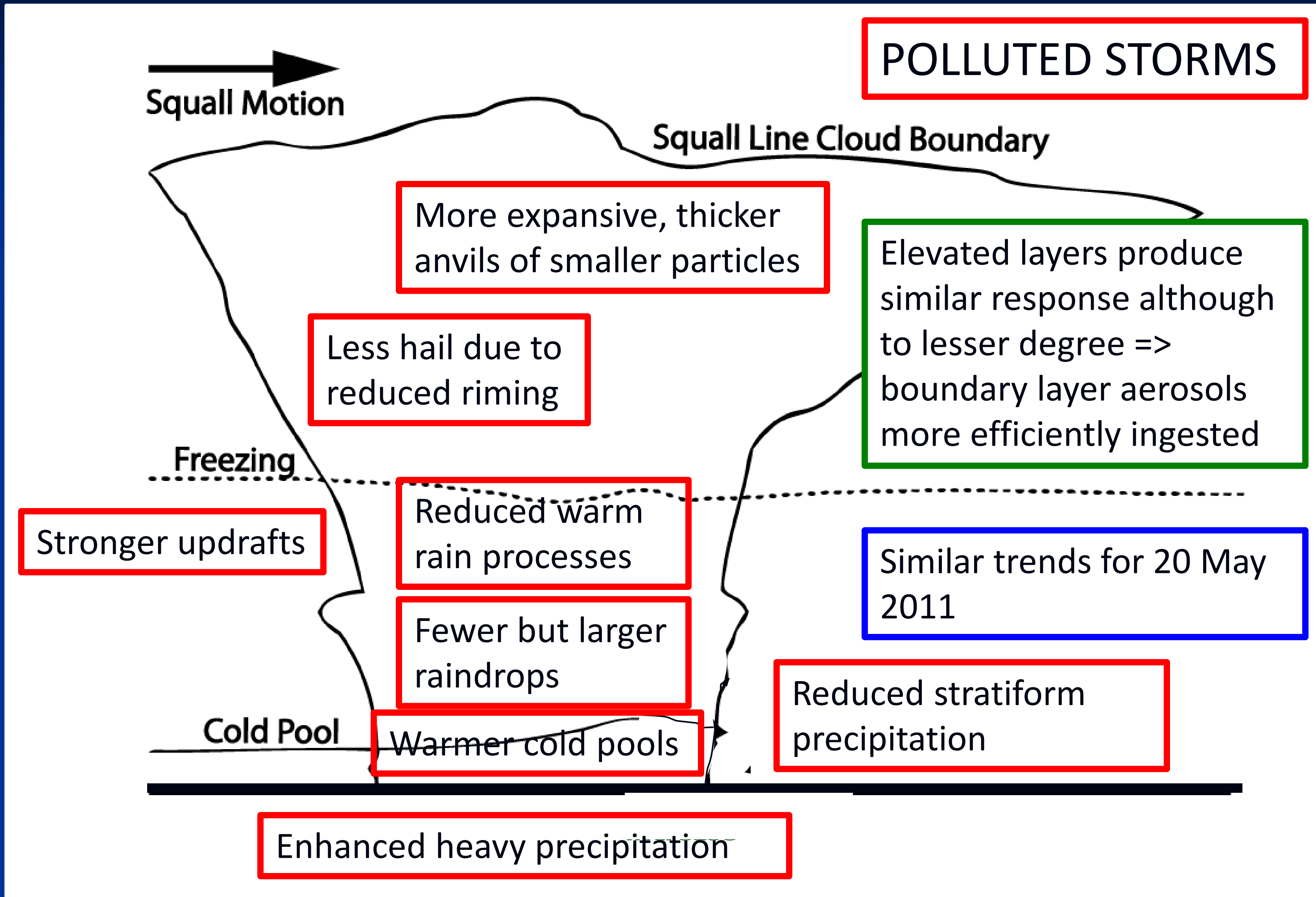
Summary


POLLUTED STORMS
Squall Motion
Squall Line Cloud Boundary
More expansive, thicker anvils of smaller particles
Elevated layers produce similar response although to lesser degree => boundary layer aerosols more efficiently ingested
Less hail due to reduced riming
Freezing
Stronger updrafts
Reduced warm rain processes
Similar trends for 20 May 2011
Fewer but larger raindrops
Reduced stratiform precipitation
Cold Pool
Warmer cold pools
Enhanced heavy precipitation

Path Forward

- Heterogeneous observationally-derived aerosol initialization
- Role of elevated layers
- Dust vs sulfate vs smoke
- Detailed modeling – observational comparisons of microphysical processes and the feedbacks to vertical velocity using SGP data
- Microphysical-dynamical feedbacks on squall line features including RIJ
- Provide modeling data bases