Latent Heating, Microphysical and Aerosol Processes of MC3E Mesoscale Convective Systems

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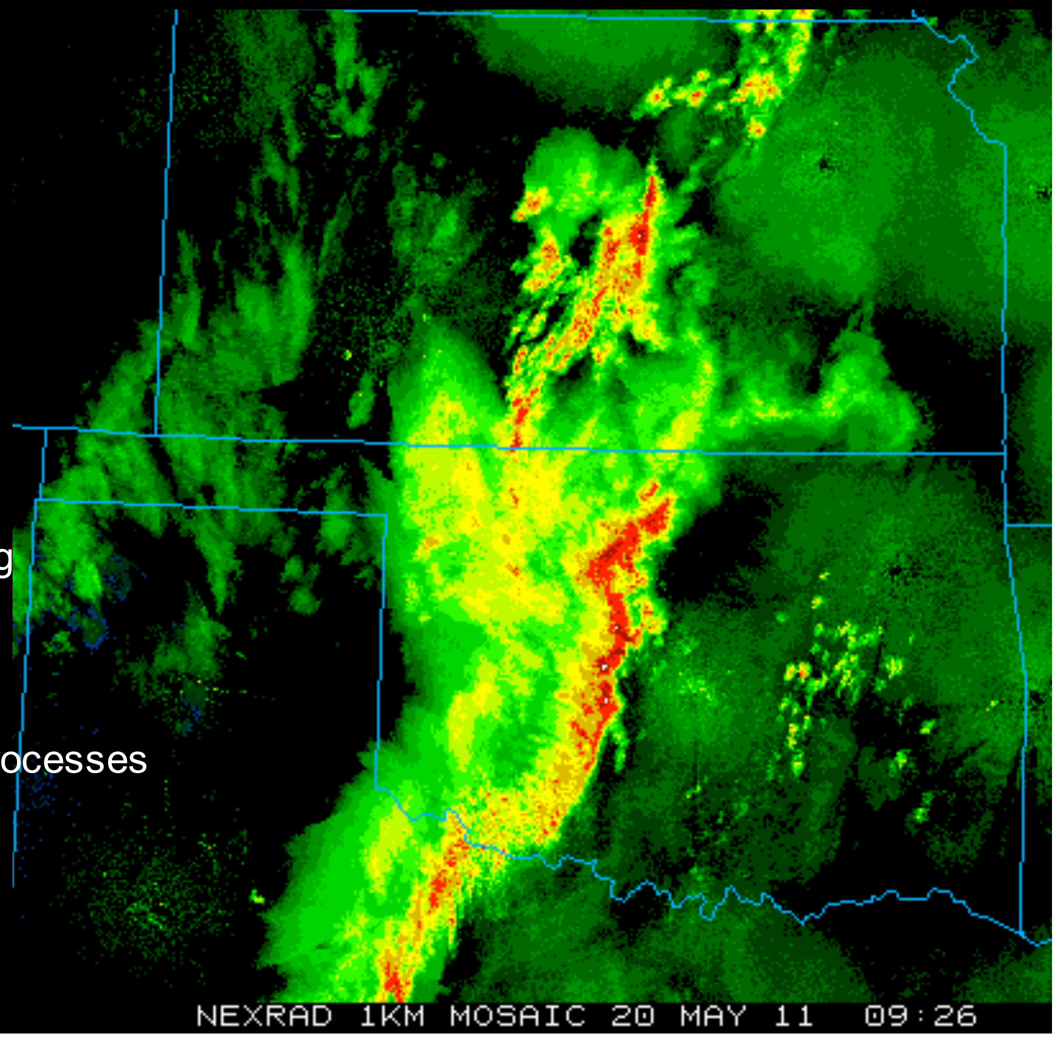
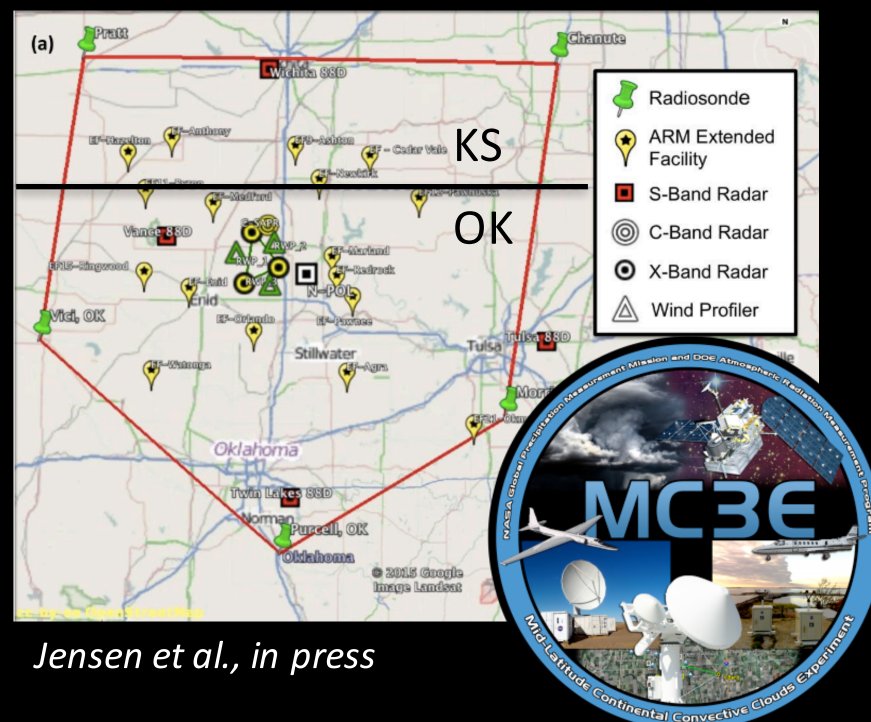
Image from http://www2.mmm.ucar.edu/imagearchive/



MC3E Field Campaign

- Midlatitude Continental Convective Clouds Experiment
  (*Jensen et al.*, in press)
  - Better understand convective cloud processes and lifetimes and how to improve the representation of these processes in models
  - Led by the DOE and NASA
  - April-May 2011
  - Southern Great Plains region



Jensen et al., in press

Overview

MC3E data used to study 4 aspects of aerosol and microphysical processes within mesoscale convective systems (MCSs)

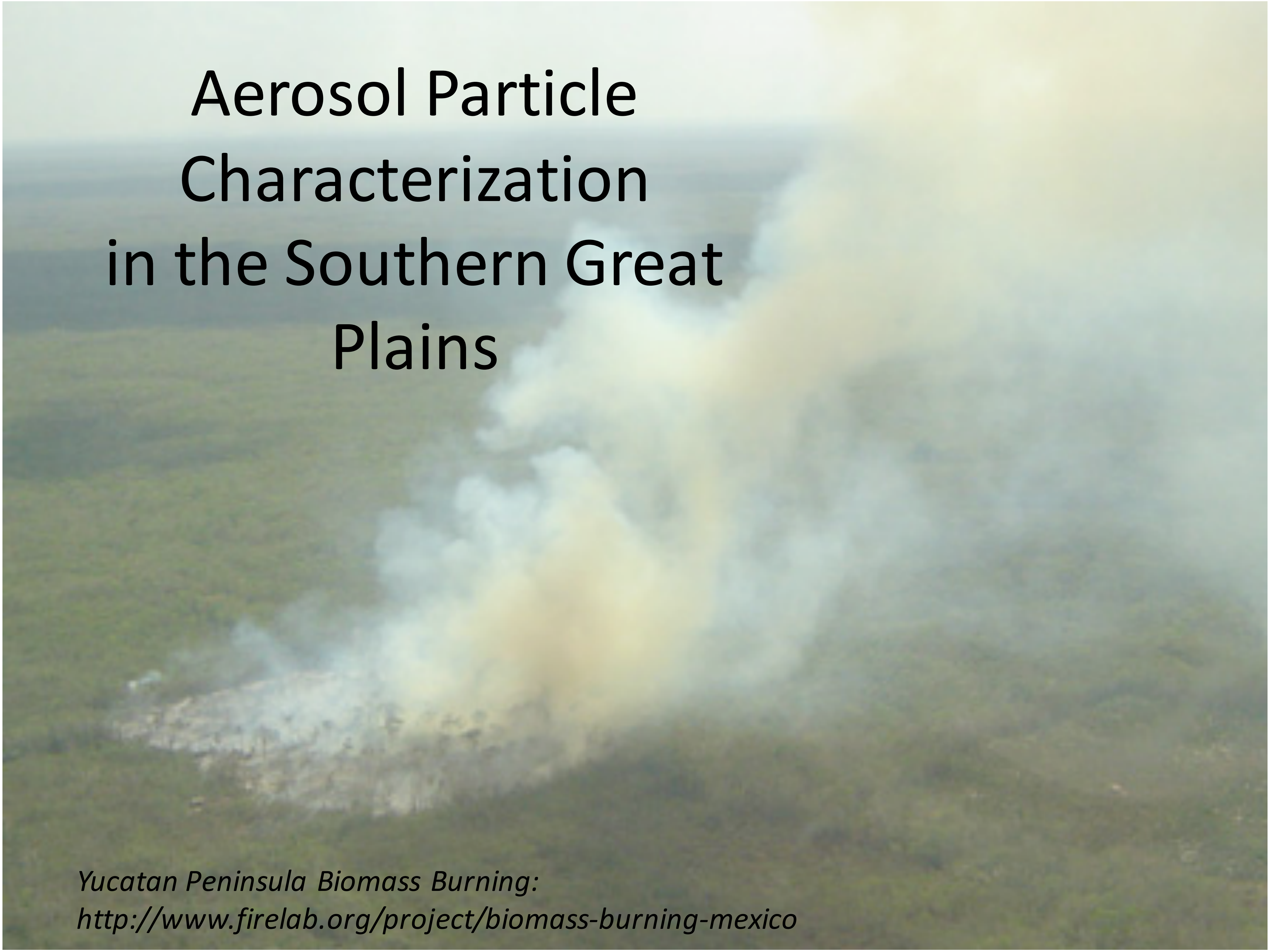
1) Understanding the aerosol environment during MC3E and developing model representations of aerosols

2) Assessing the microphysical contributions to and evolution of latent heating within MCSs

3) Quantifying aerosol effects on MCS microphysical development and anvil characteristics

4) Determining the impacts of vertical variations in CCN on MCS precipitation for these cases

Aerosol Particle Characterization in the Southern Great Plains



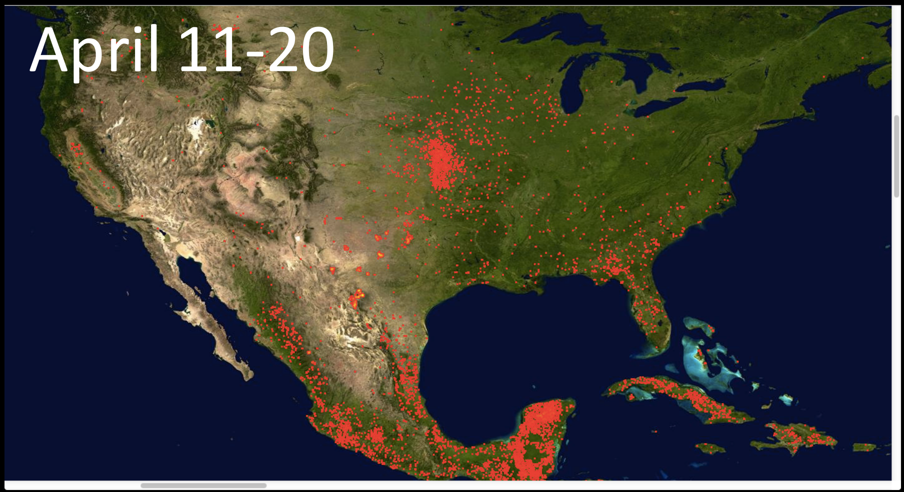
Yucatan Peninsula Biomass Burning:
http://www.firelab.org/project/biomass-burning-mexico

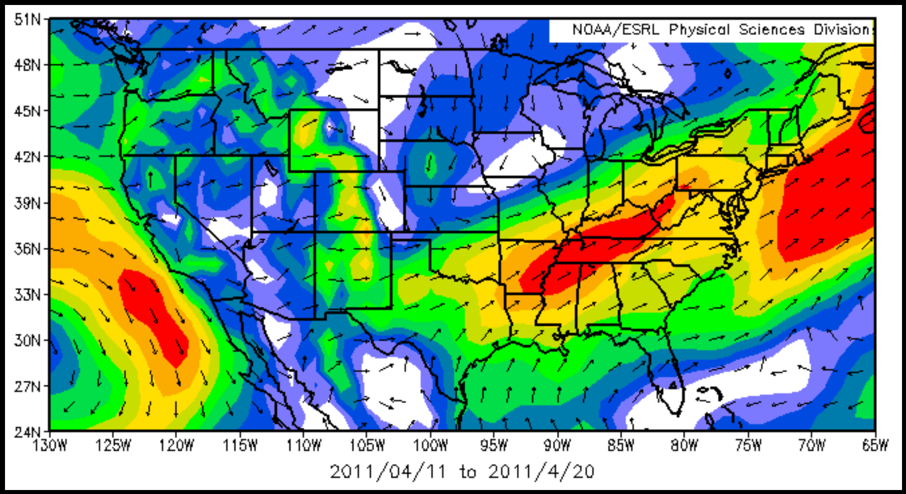
SGP Aerosol Frequently Impacted by Smoke

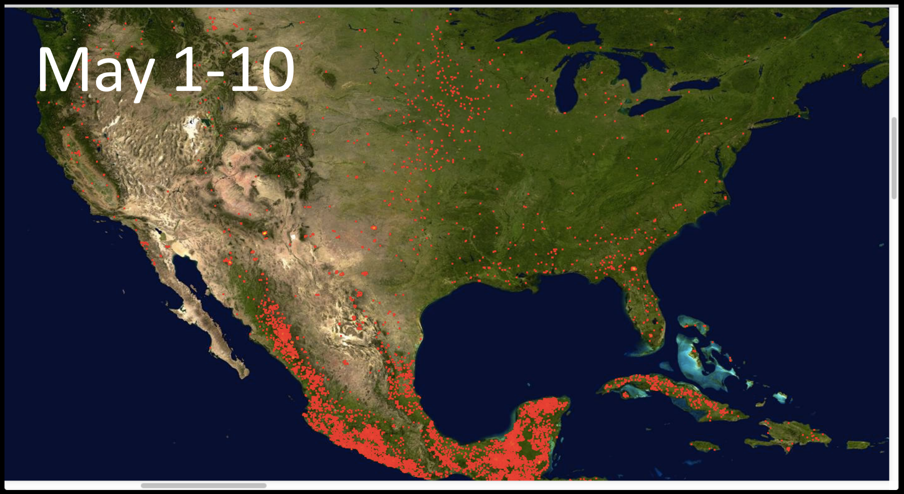
Local burning dominated during April, while transport of biomass burning aerosol from Mexico and Central America were more evident in May

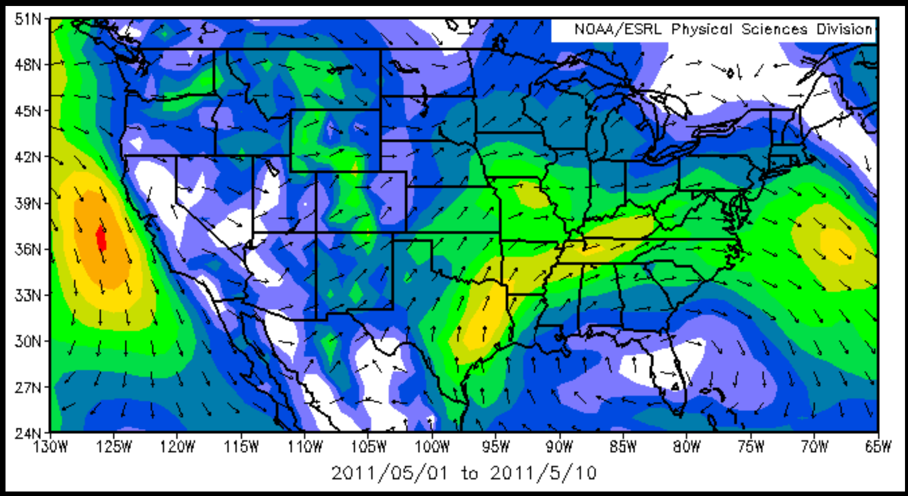
MODIS Fire Counts

850 mb Winds

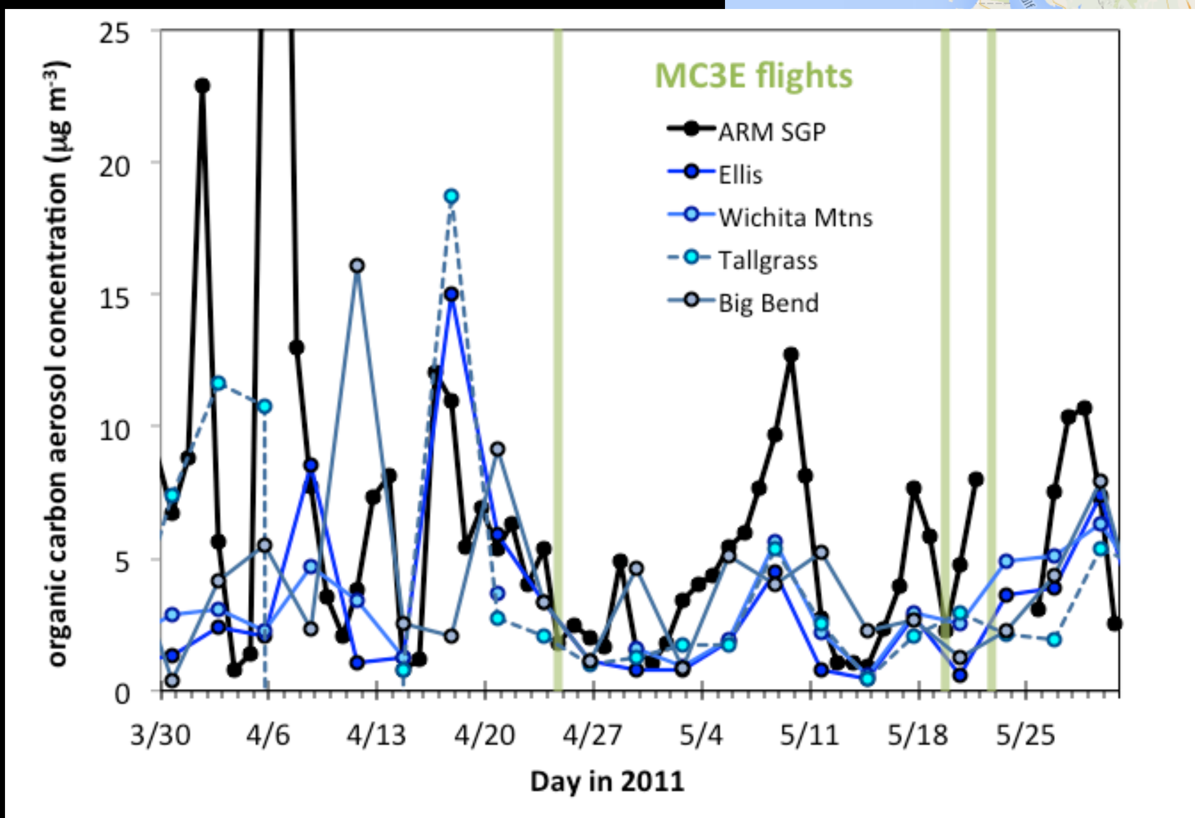








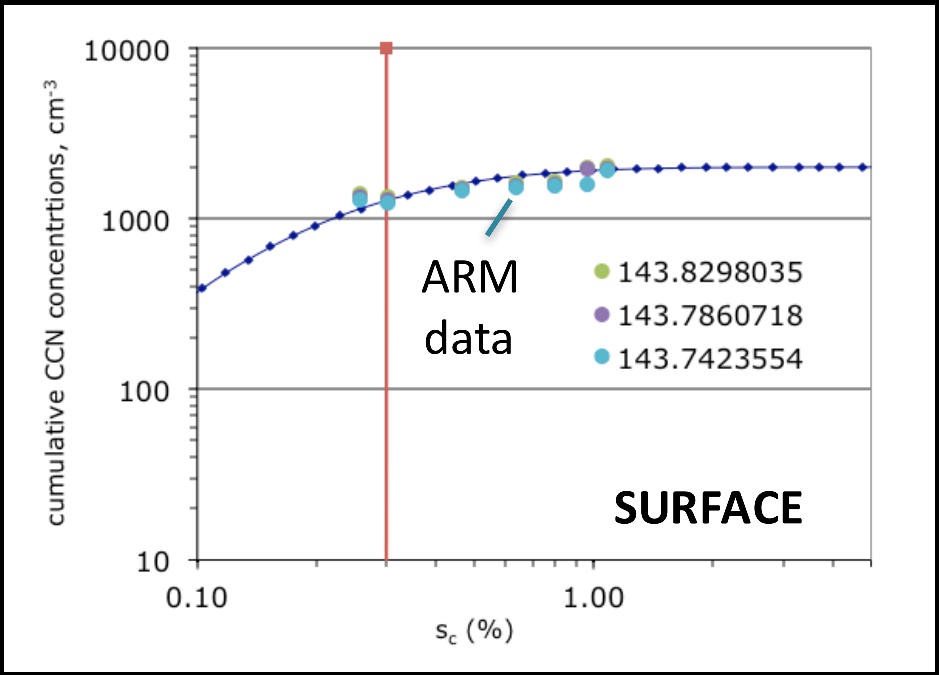
Organic Aerosol Concentrations in the Great Plains



- Peak organic aerosol concentrations in April dominated by local sources
- Periodic events in May representative of biomass burning events

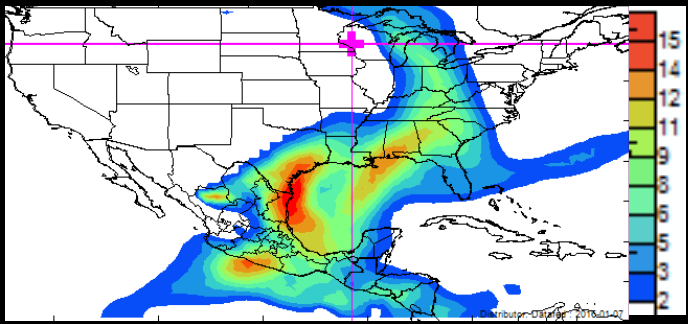
“Background” and Smoke Aerosol

Derived CCN spectrum



Smoke Concentrations (μg m^{-3})

5 km



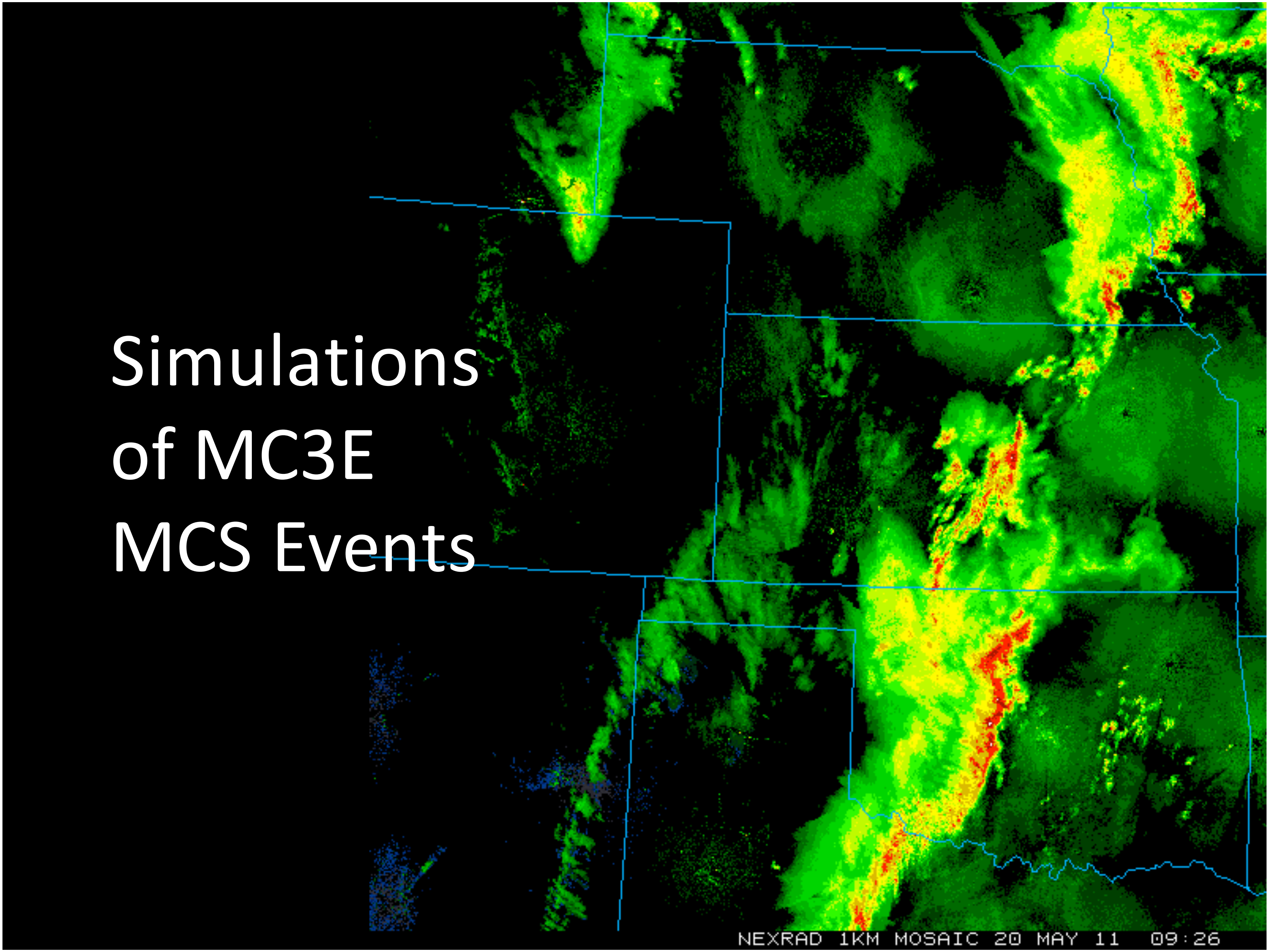
From the Navy Aerosol Analysis and Prediction System (NAAPS Model): May 20 2011 00Z

NAAPS USED TO LINK SURFACE TO VERTICAL LAYERS

$N = 2000\ cm^{-3}$
$D_g = 120$ nm
$\sigma_g = 1.8$
$\varepsilon = 0.2$ (or, $\kappa = 0.15$)

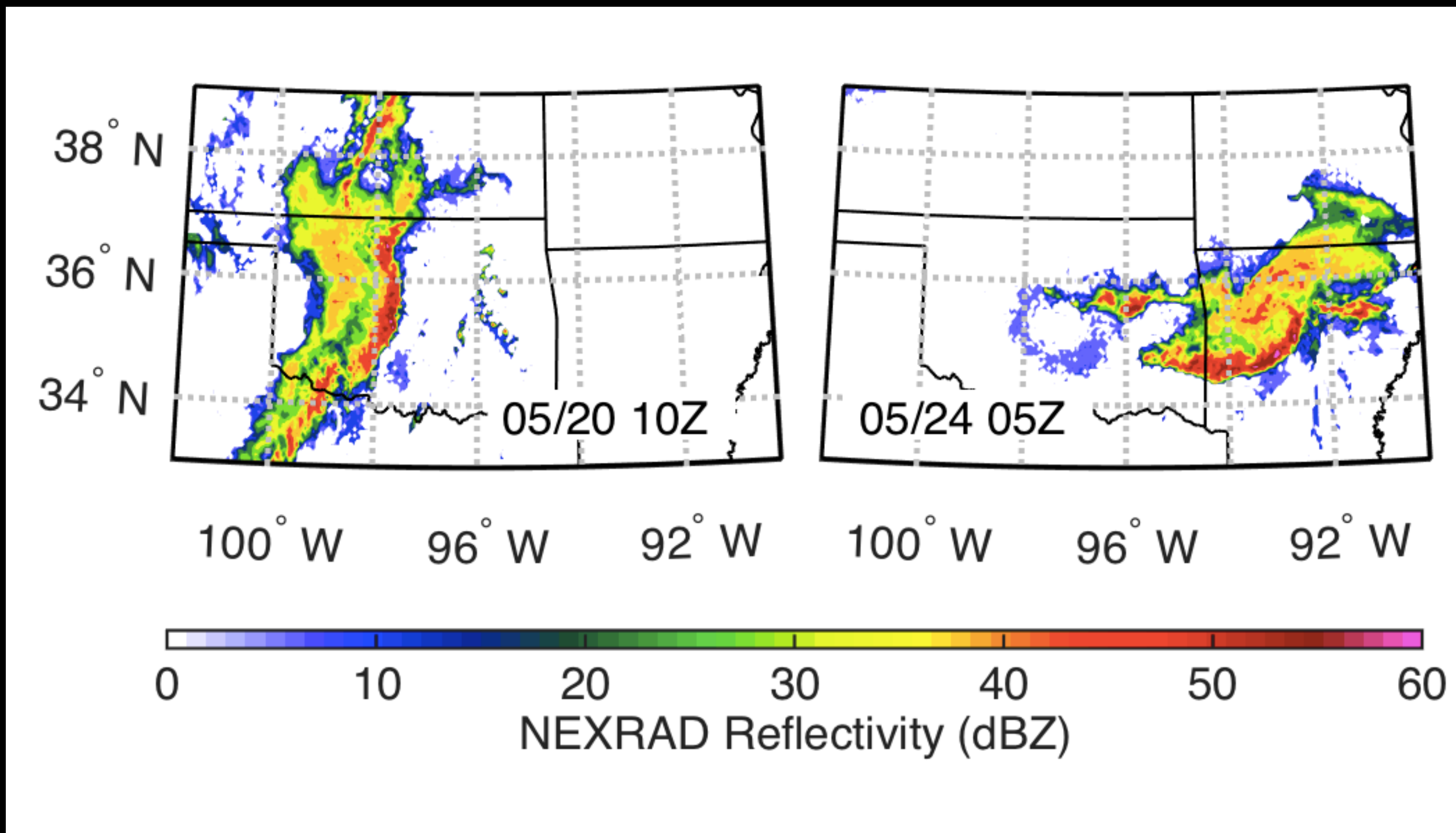
Also matched total aerosol mass and dry scattering coefficient

Simulations of MC3E MCS Events



Two MC3E MCS Events

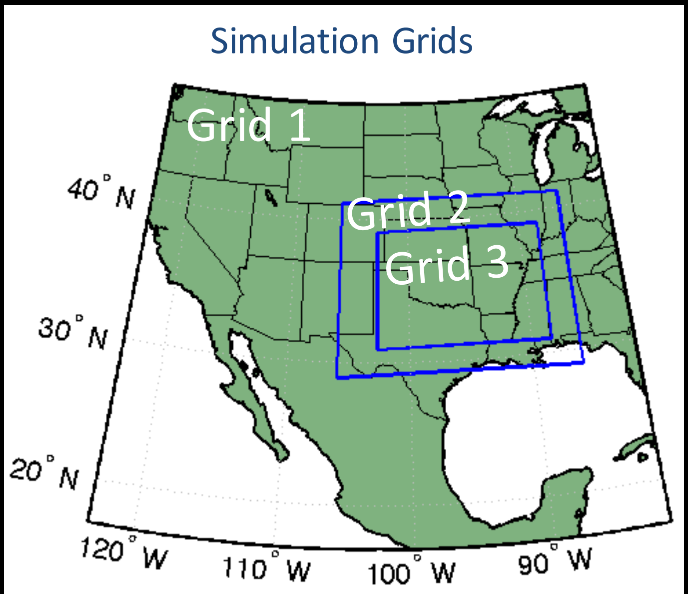
- May 20 MCS
  - "Textbook" Leading Line, Trailing Stratiform MCS
- May 23-24 MCS
  - Asymmetric Leading Line Trailing Stratiform MCS



Simulations

- RAMS (Regional Atmospheric Modeling System)
  (Cotton et al. 2003; Saleeby and van den Heever 2013)
  – Version 6.1
  – 2-moment bin-emulating bulk microphysics
  – 8 hydrometeor types
  – Aerosol parameterization scheme (Saleeby and van den Heever, 2013)
    - CCN and IN initializations based on observations during MC3E
  – Harrington two-stream, hydrometeor-sensitive radiation scheme

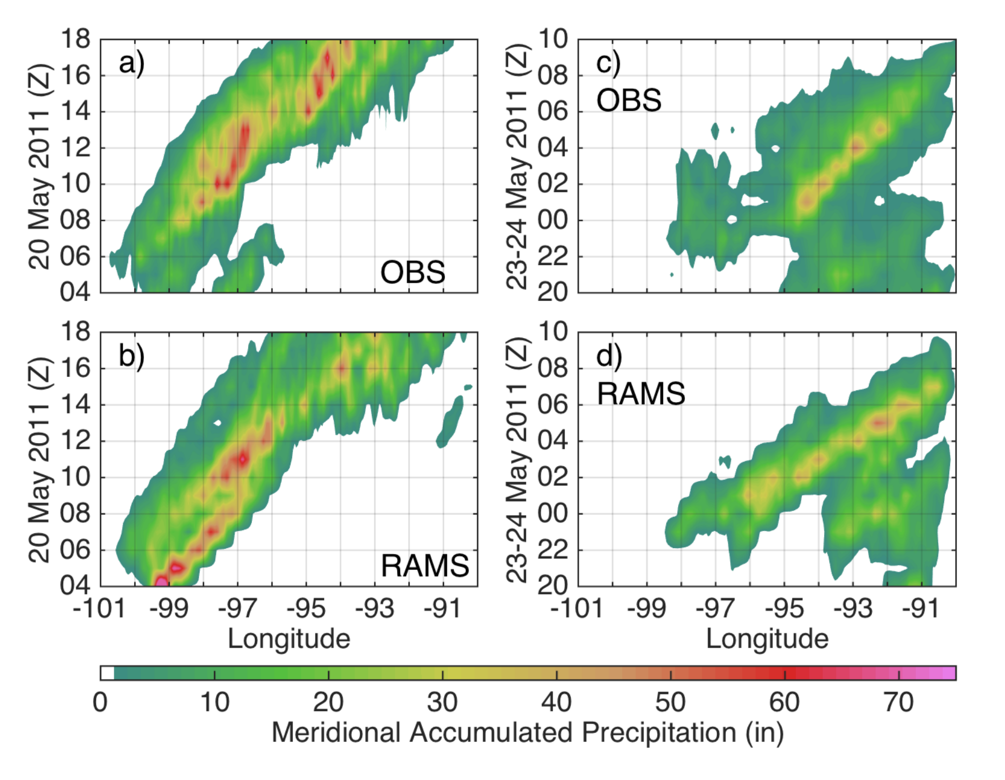
- 3 nested grids
  – Grid 1: $\Delta x = \Delta y = 30km$
  – Grid 2: $\Delta x = \Delta y = 6km$
  – Grid 3: $\Delta x = \Delta y = 1.2km$
  – 60 stretched vertical levels



Model-Observation Comparison

- RAMS simulations compared to observations during MC3E
  - Convective and stratiform areas, convective vertical velocities, radar reflectivity, and precipitation

Precipitation Comparison (Hovmöller)



Observational data from Stage IV

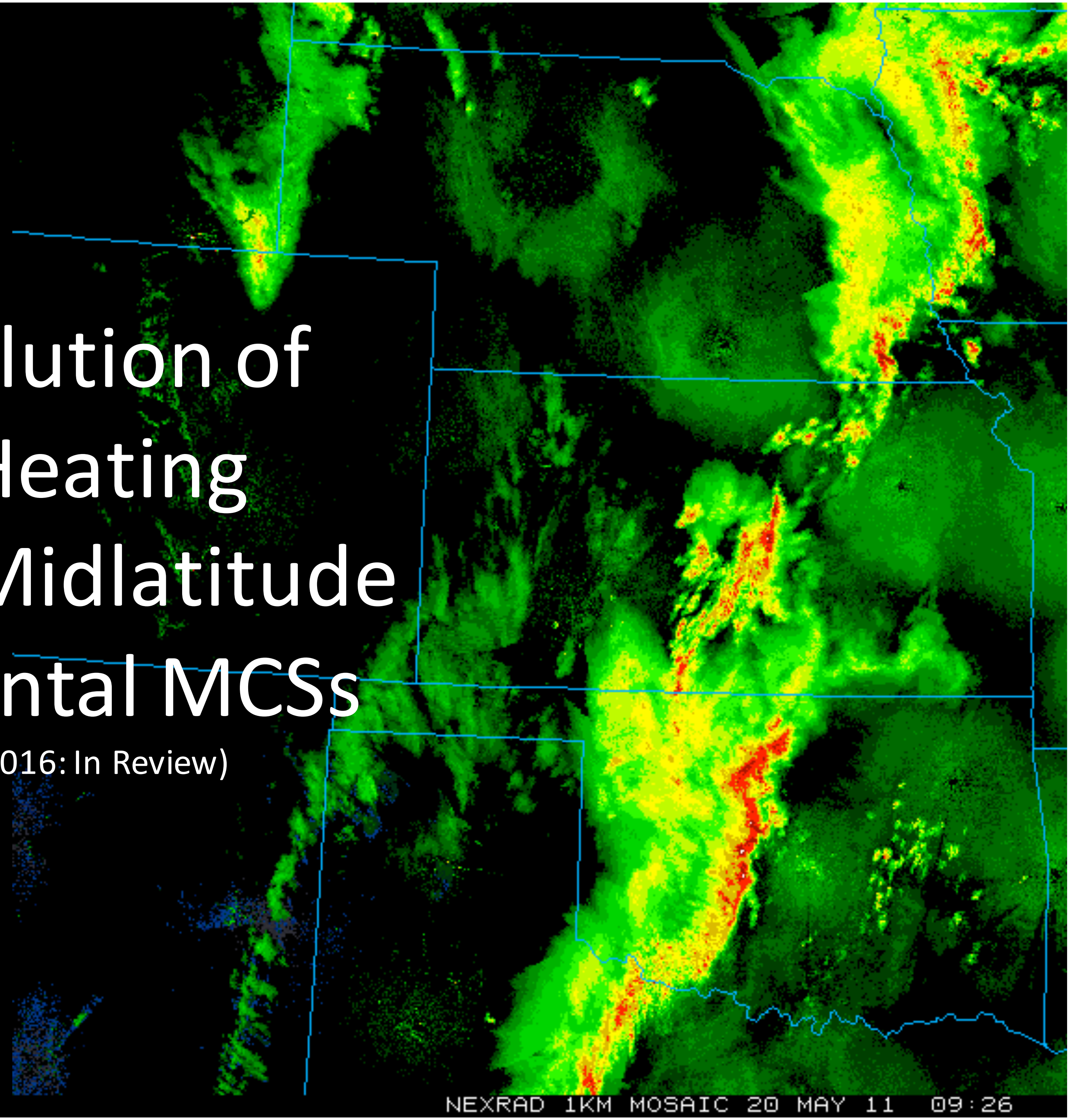
- Total surface accumulated precipitation differences (*RAMS-Obs*):

  May 20: -4%

  May 23-24: +12%
- RAMS spatial and temporal evolution follow observations
- Low stratiform precipitation model bias

The Evolution of Latent Heating within Midlatitude Continental MCSs

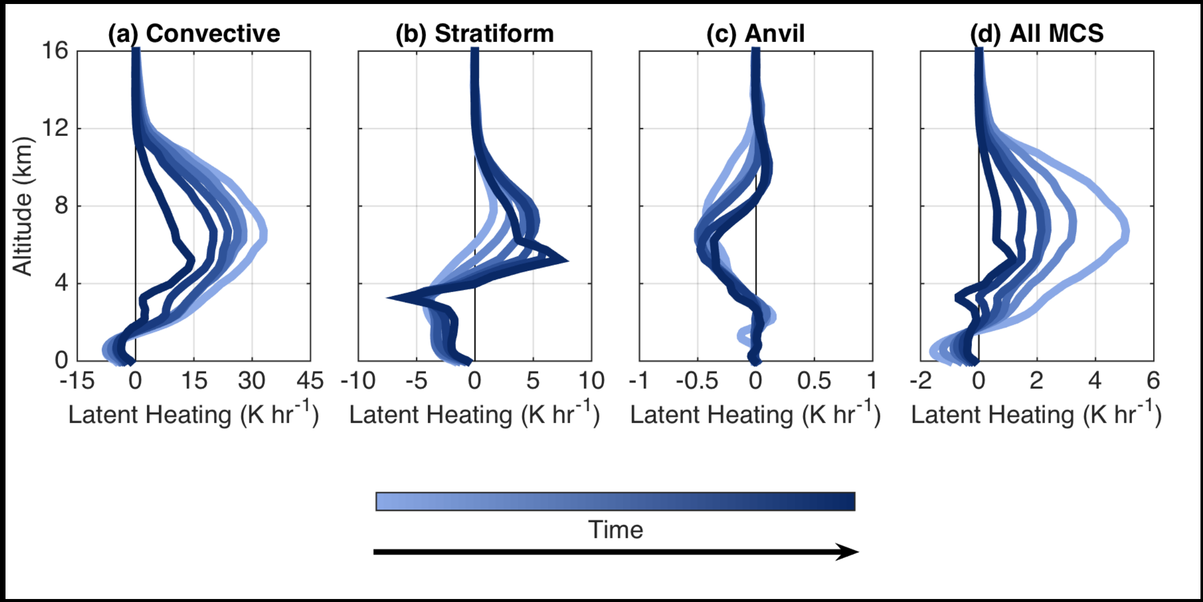
(Marinescu et al., 2016: In Review)



Latent Heating Vertical Profile Evolution

- MCS simulations partitioned into Convective, Stratiform and Anvil regions

- **Convective:**
  ~Linear decrease over time with constant shape



- **Stratiform:**
  Profile shape evolves with time (flow regimes; i.e., front -to-rear ascending flow)

- **Anvil:**
  Relatively small changes in latent heating profile

- Quantified latent heating evolution with MCS lifecycle to assist in developing parameterizations in models that do not resolve cloud process

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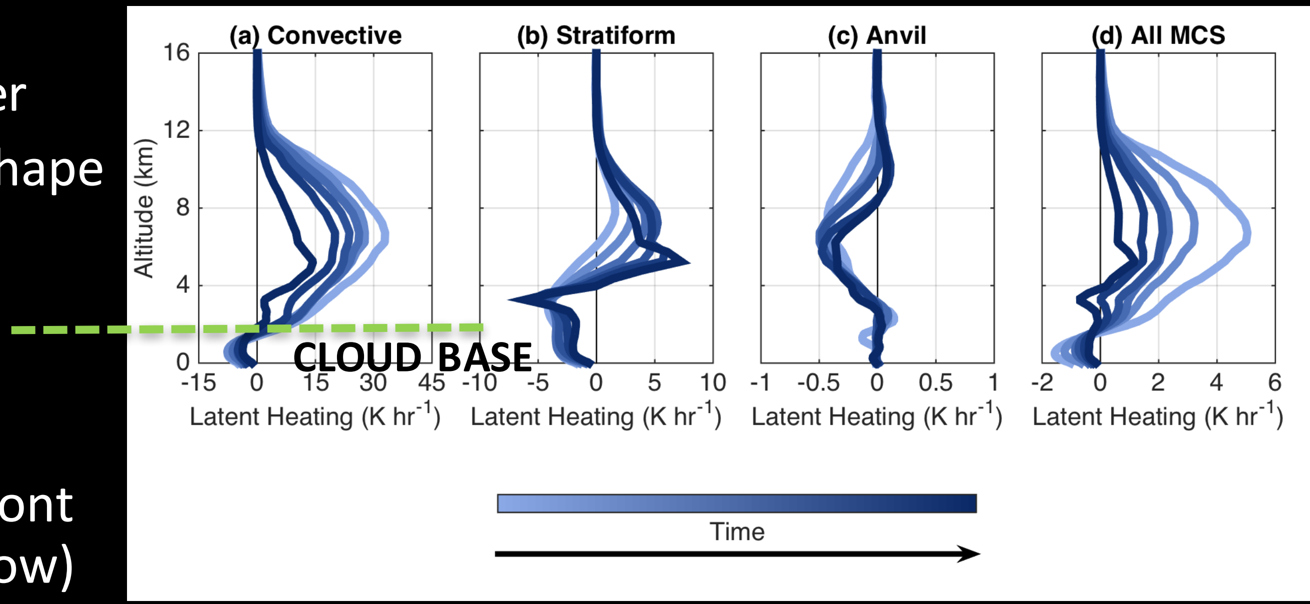

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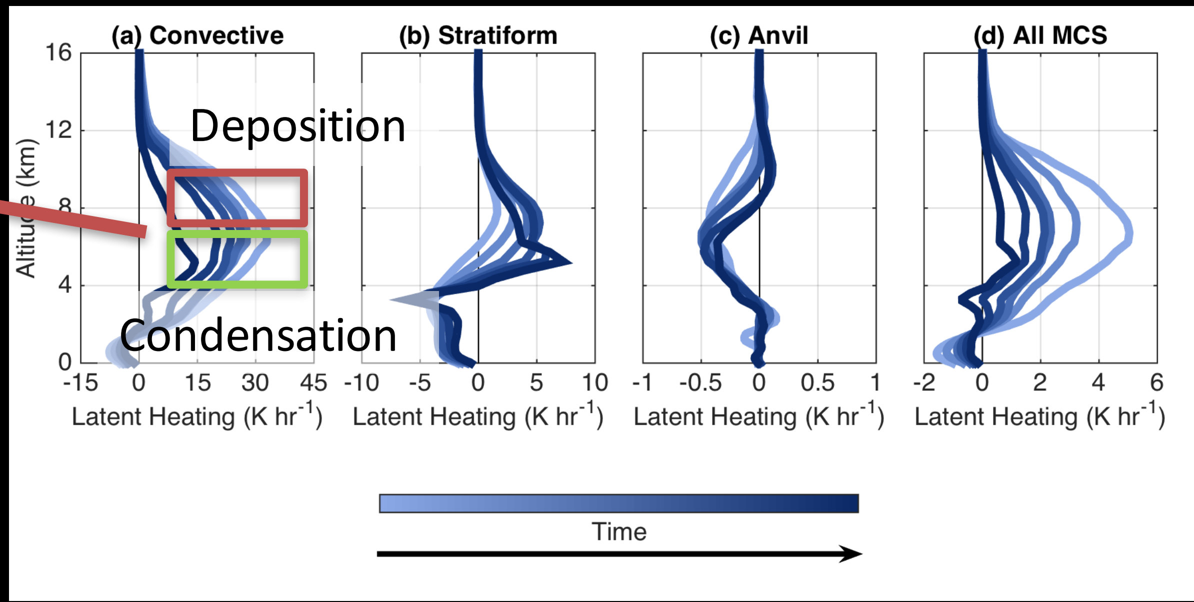

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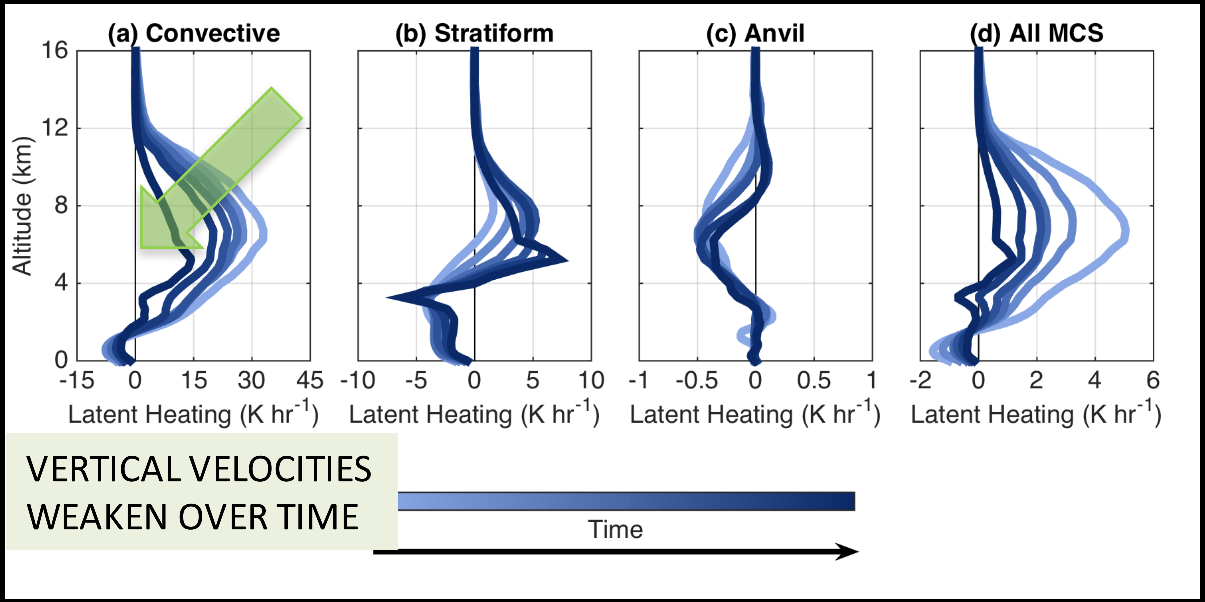

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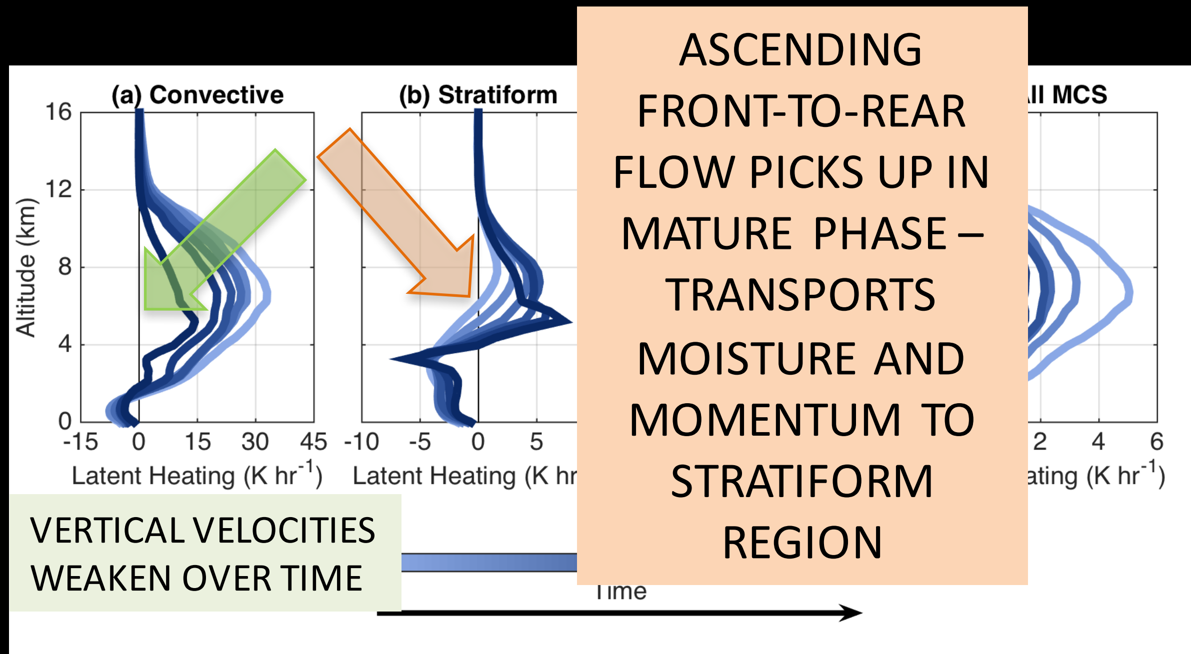

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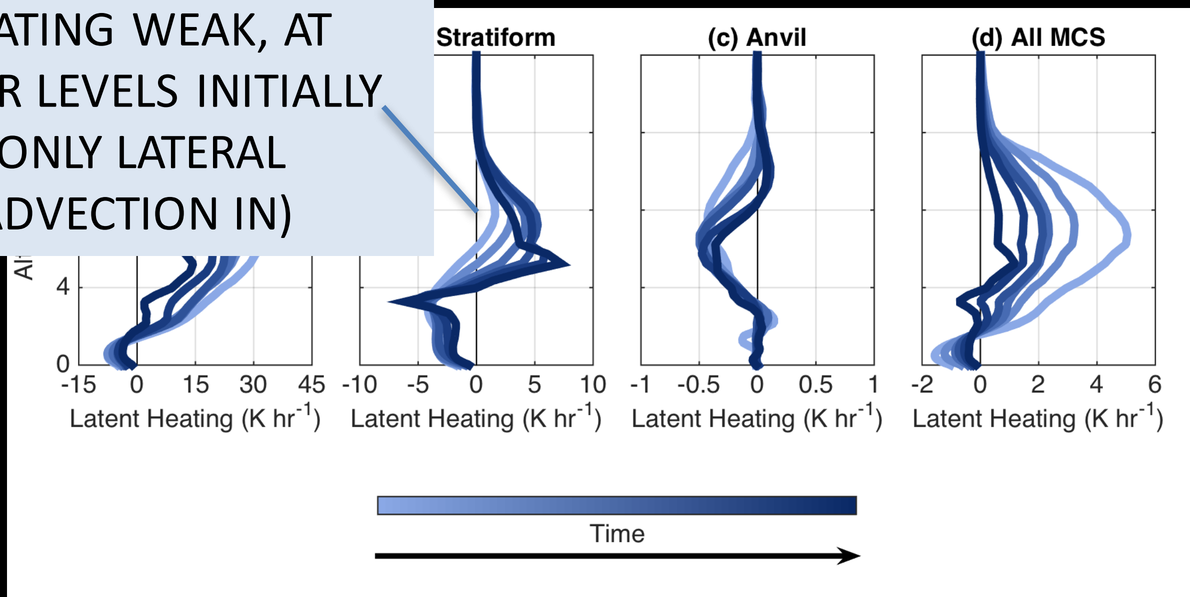
HEATING WEAK, AT UPPER LEVELS INITIALLY (ONLY LATERAL ADVECTION IN)



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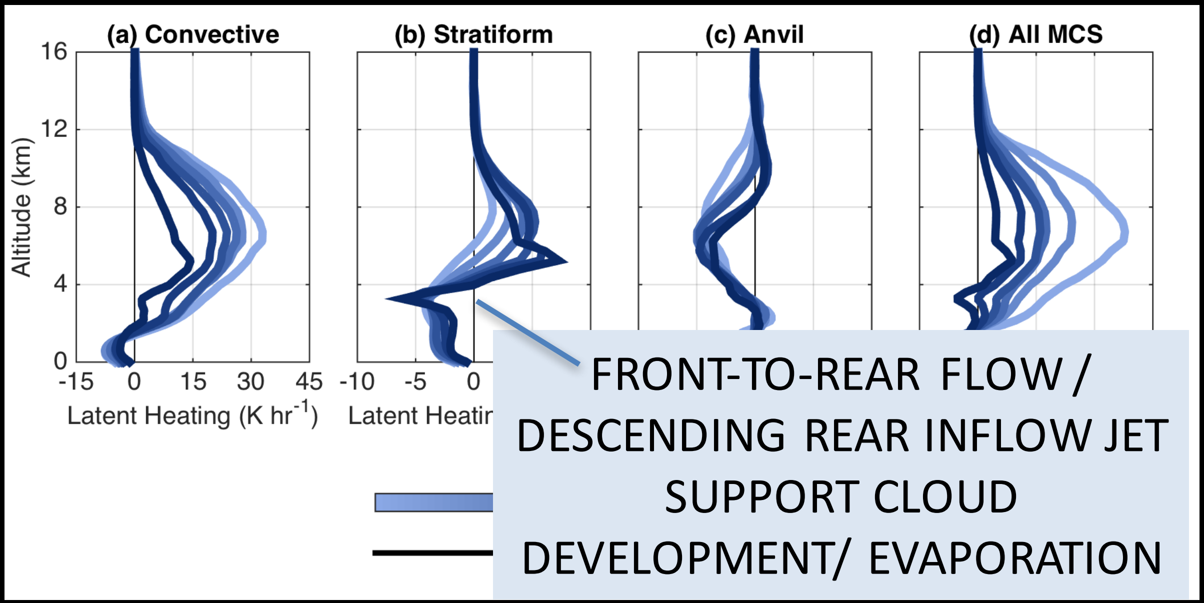

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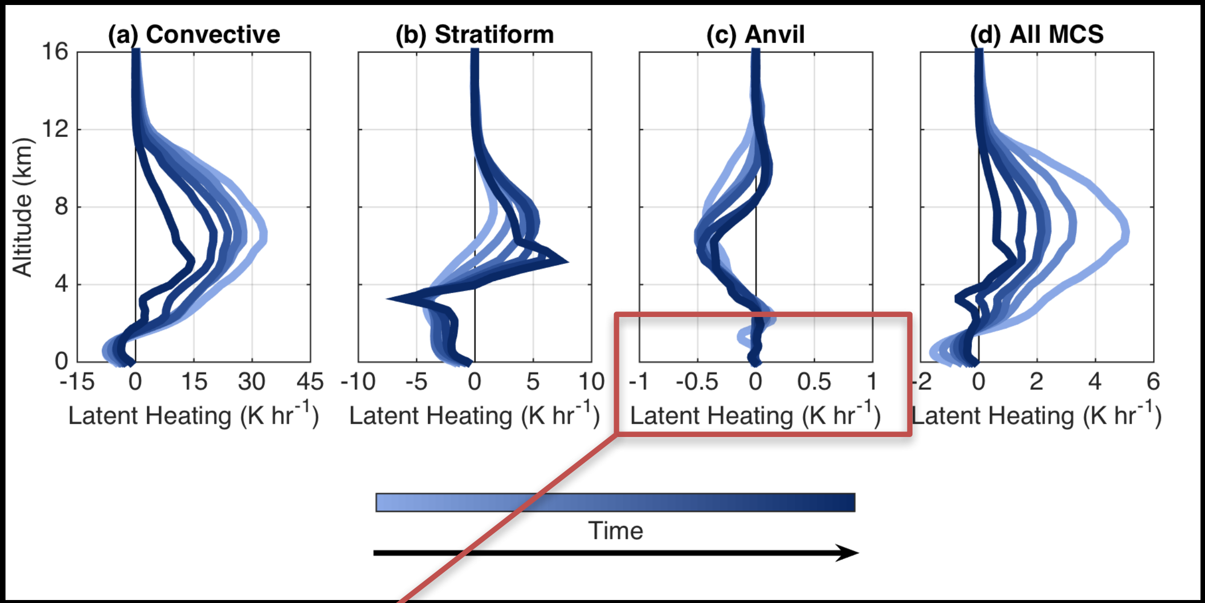

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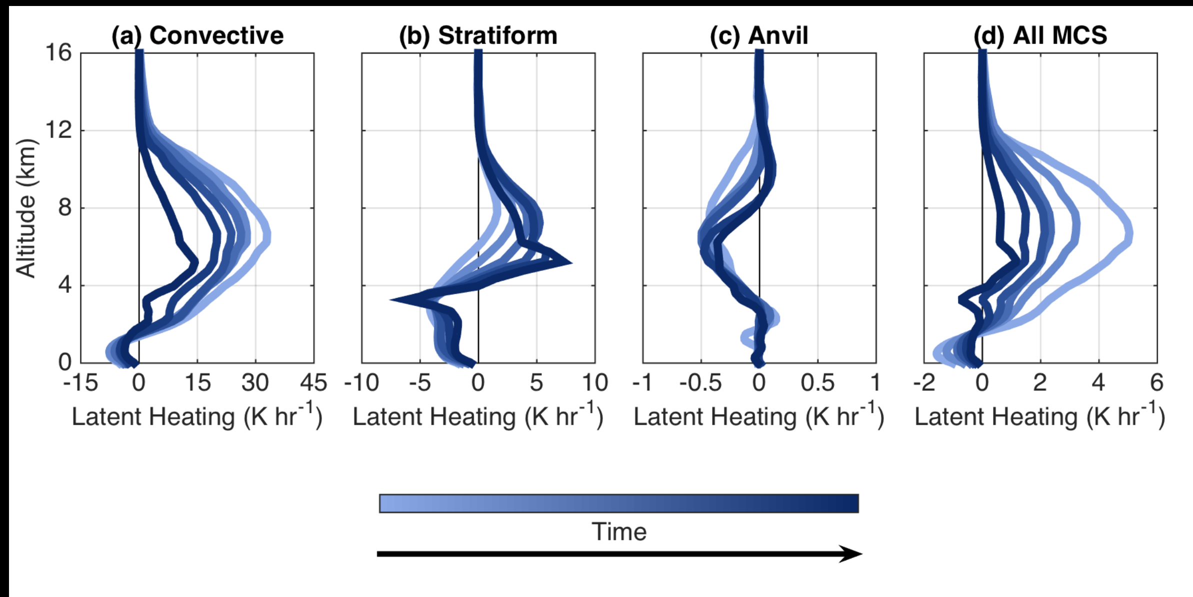

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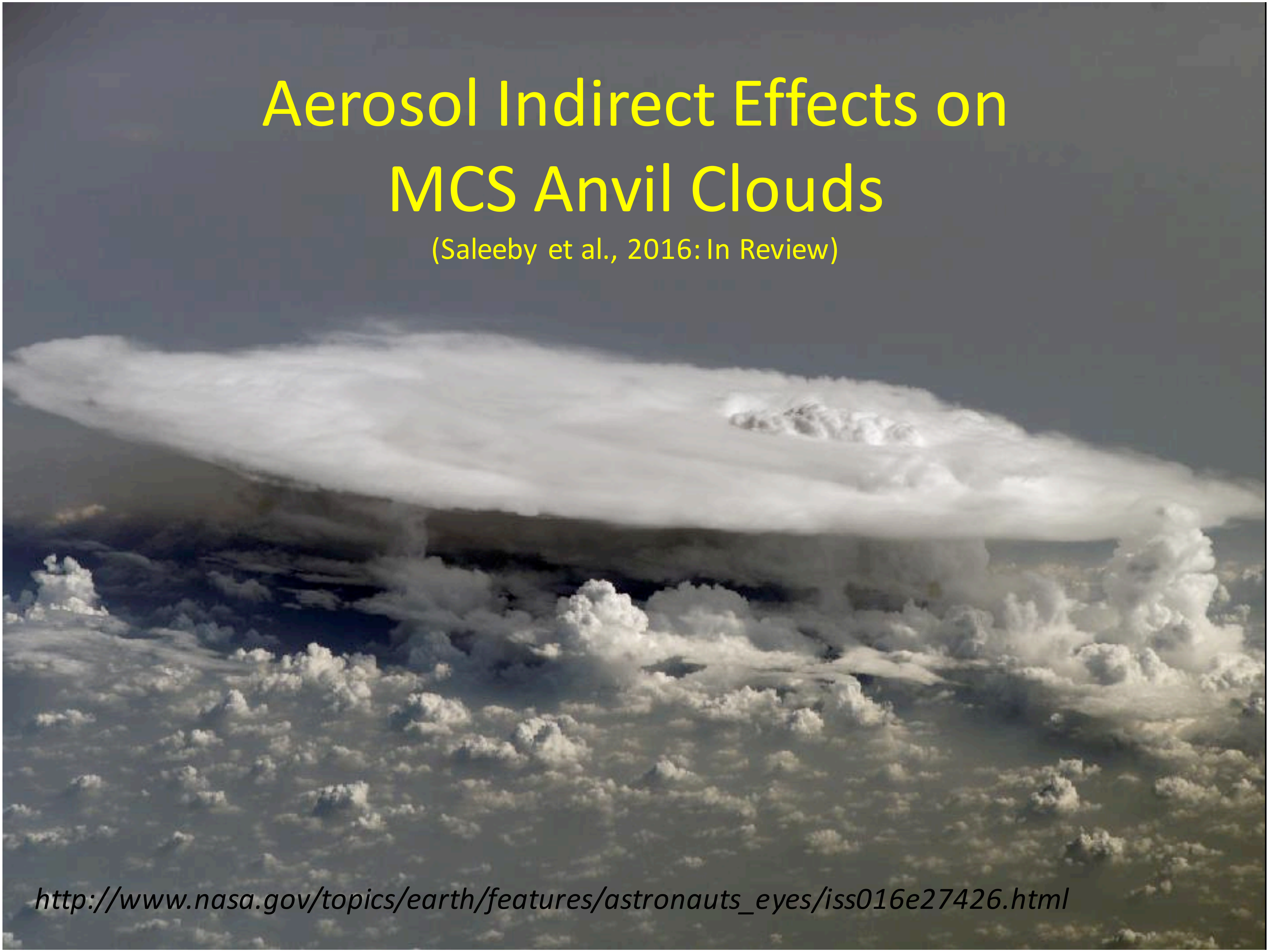
Aerosol Indirect Effects on MCS Anvil Clouds

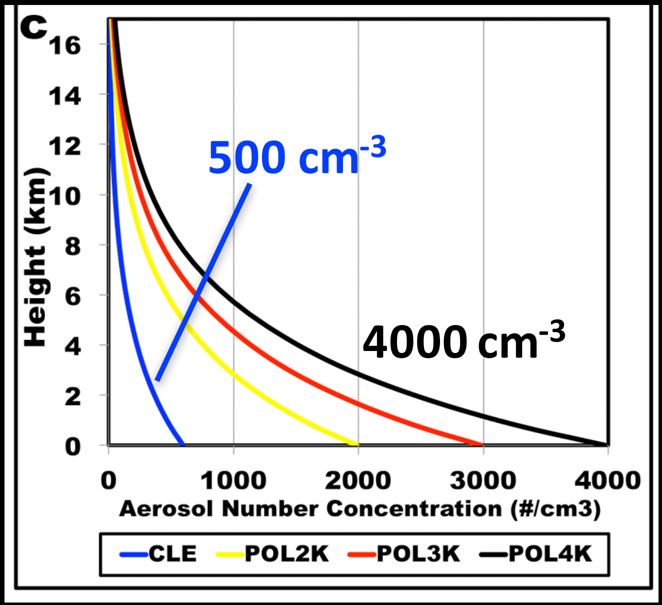
(Saleeby et al., 2016: In Review)



http://www.nasa.gov/topics/earth/features/astronauts_eyes/iss016e27426.html

MCS Anvils and Aerosol Indirect Effects

- High-level cirrus anvil clouds are important to earth's energy budget through their radiative effects. (e.g. Ramanathan and Collins 1991; Fowler and Randall 1994; Stephens 2005)
- Ice water content, ice crystal size, and anvil thickness impact the radiative properties of these clouds. (e.g. Platt and Harshvardhan 1988; Platt 1989)
- To study the impact of aerosol on MCS anvils clouds, sensitivity simulations conducted
- Aerosol profiles guided by MC3E observations
  - UND-Citation data used to constrain IN via DeMott et al. (2010) parameterization
  - Both profiles constrained by ARM-SGP site particle observations at surface



Impacts on Microphysics and Radiation

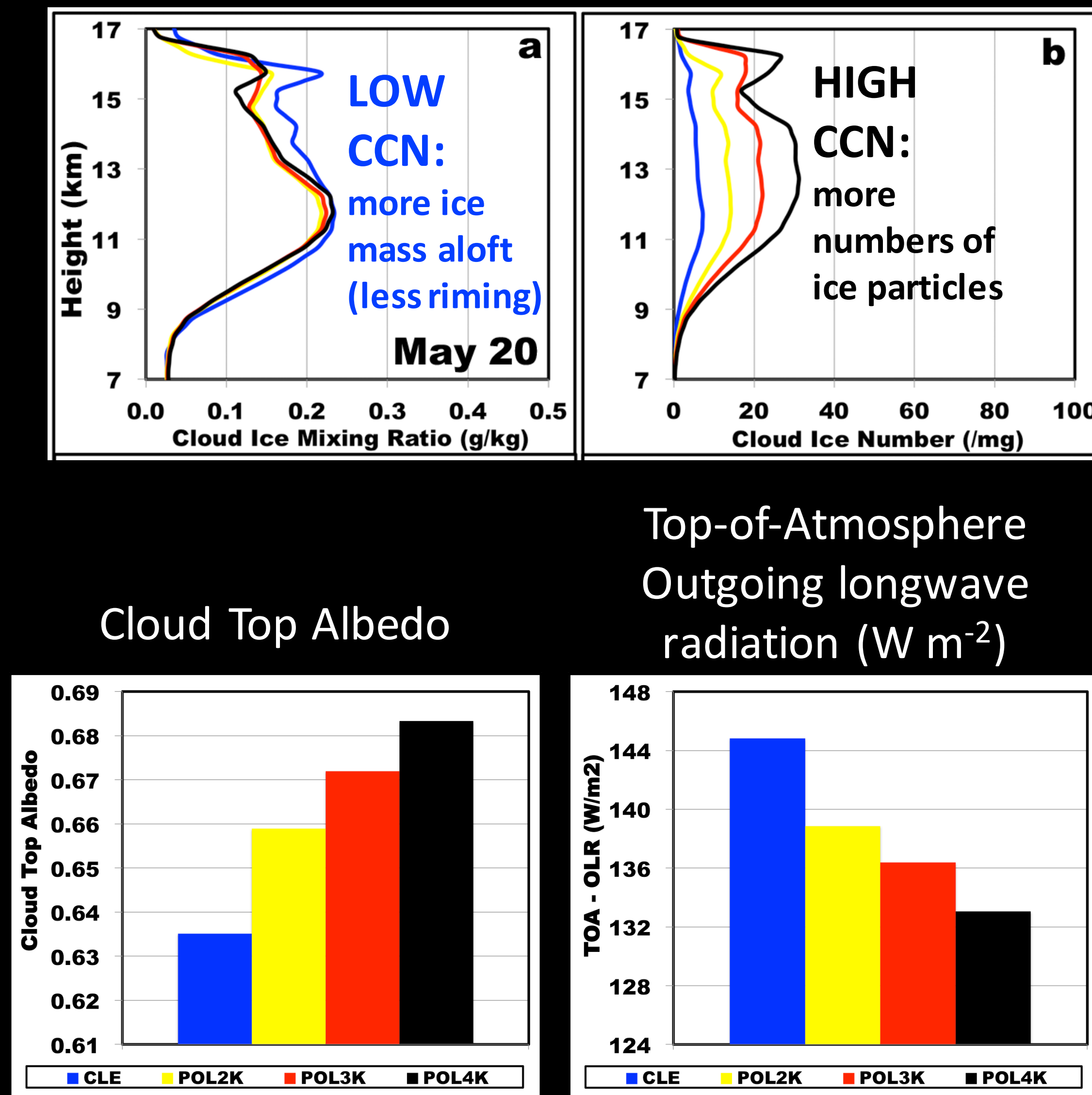
- An increase in aerosol concentration led to:
  - Greater number of smaller ice crystals from homogeneous freezing of more numerous, smaller lofted cloud droplets
  - Reduced mixing ratios of cloud ice in the upper levels due to greater rime collection of the largest cloud droplets at lower altitudes
  - Enhanced albedo from more numerous, smaller ice particles
  - Reduction in outgoing long-wave radiation due to less anvil mass and/or emission at higher altitude

Cloud Ice Mixing Ratio

Cloud Ice # Conc.

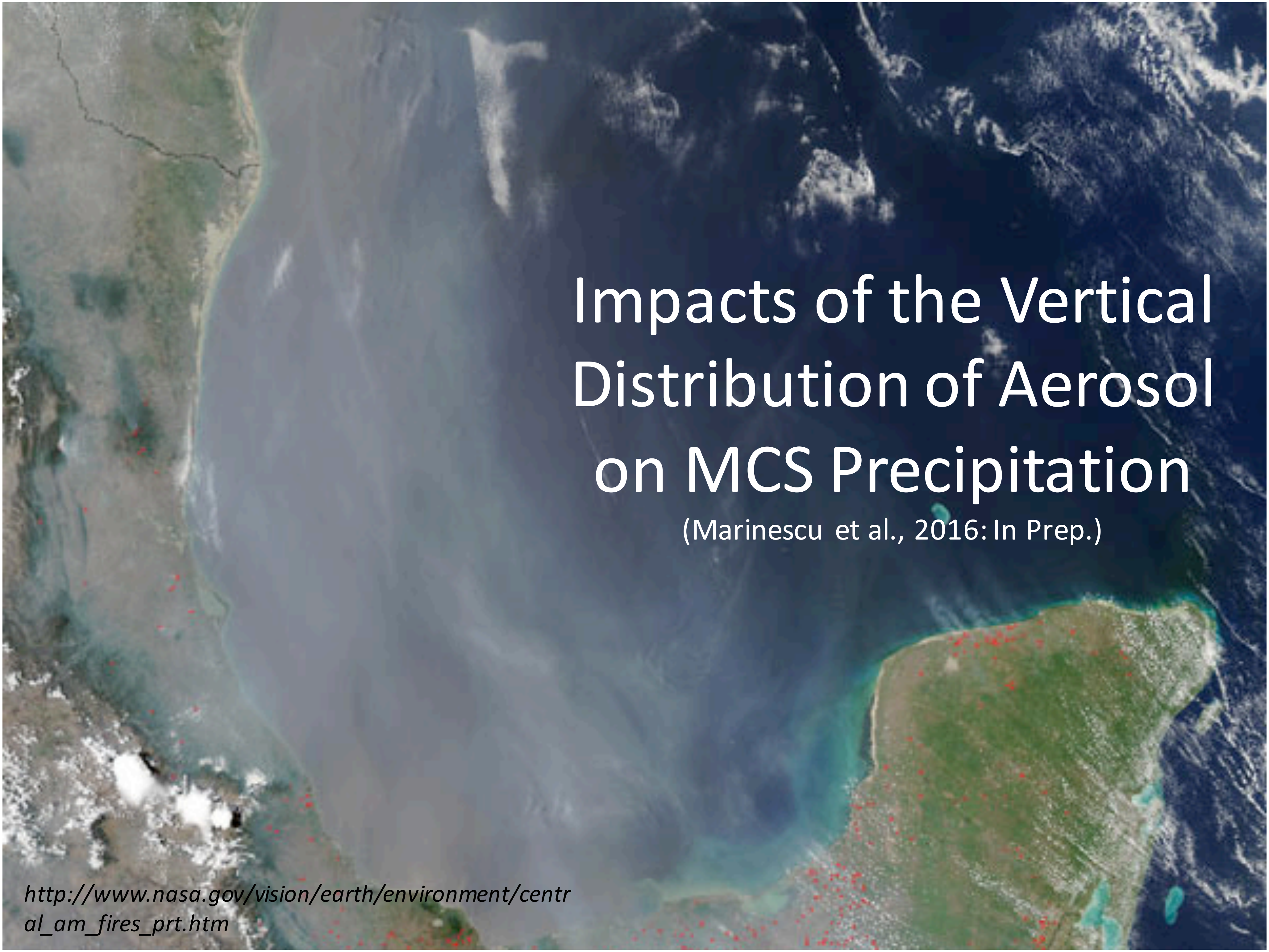
Cloud Top Albedo

Top-of-Atmosphere Outgoing longwave radiation (W m^{-2})



Impacts of the Vertical Distribution of Aerosol on MCS Precipitation

(Marinescu et al., 2016: In Prep.)



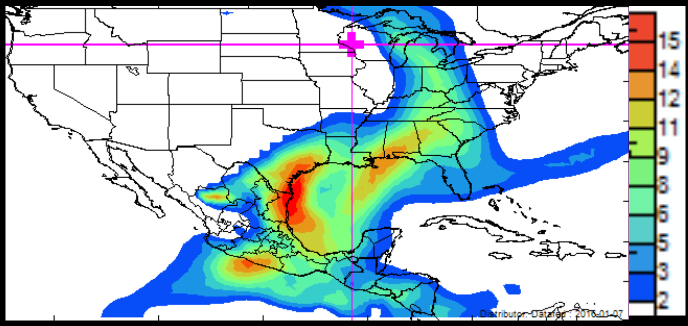
http://www.nasa.gov/vision/earth/environment/central_am_fires_prt.htm

Biomass Burning Particle Transport

- Plumes of aerosol particles that are transported into the southern U.S.
(e.g. Rogers and Bowman, 2001; Wang et al., 2006)
  - Can occur at various altitudes
  (e.g., Peppler et al., 2000)

5 km

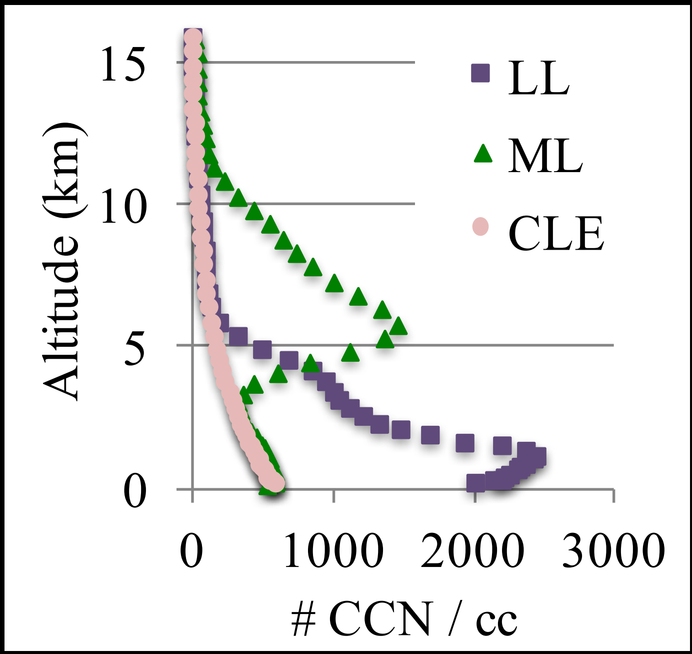
Smoke Concentrations ($\mu g\ m^{-3}$)



From the Navy Aerosol Analysis and Prediction System (NAAPS Model): May 20 2011 00Z

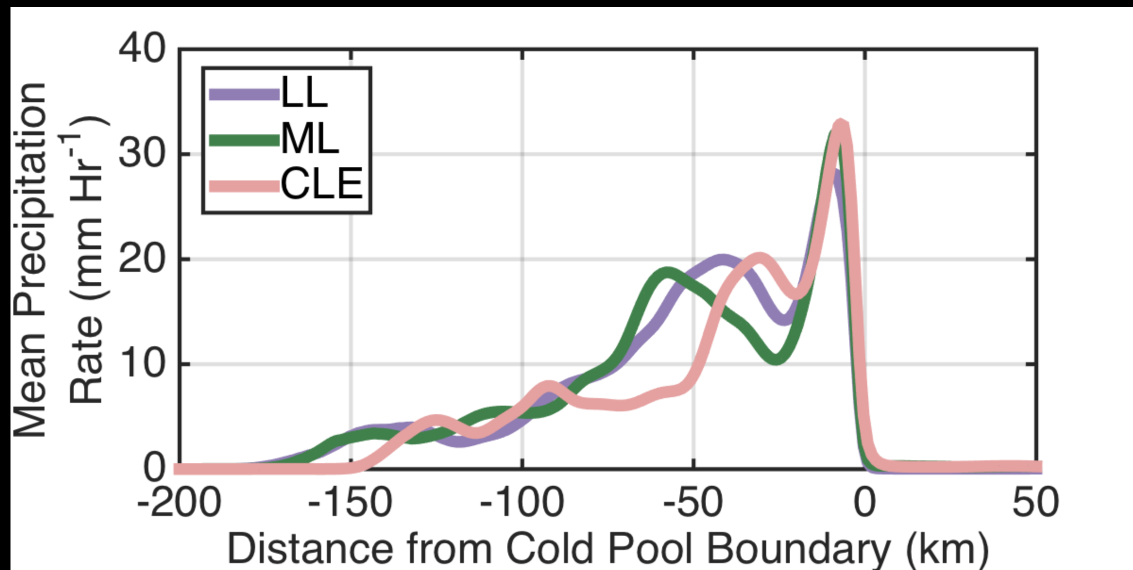
- Simulations are initialized with different aerosol profiles
  - Initialized horizontally homogeneous

- Mid-level (**ML**) vs. Low-level (**LL**) aerosol profile tests
  - Aerosol layer elevation based on NAAPS
  - Total integrated aerosol mass was kept constant
  - Clean (**CLE**) simulation used to assess the impact of **ML** aerosol



Aerosol Impacts on MCS Precipitation

Cross section of MCS precipitation rates during the mature stage (May 20 event)



- Further rearwards, both microphysical and dynamic processes impact precipitation
- May 20 different from May 23/ 24 case
- Demonstrates the importance of environmental factors on aerosol indirect effects
  (e.g., Tao et al., 2007; Fan et al., 2009; Storer et al., 2010)

- Warm rain processes / low-level aerosol play primary roles for intense precipitation near leading edge of cold pool

ML ↑ CLE ↑

Summary

- CCN data used to initialize RAMS simulations and to relate aerosol physical properties to CCN characteristics for modeling

- Simulations were conducted with RAMS of two MCS events that occurred during MC3E (20 May 2011 and 23-24 May 2011)
  - Compared well to observations taken during MC3E, including precipitation, radar reflectivity, vertical velocities and convective/stratiform areas

- The evolution and magnitude of latent heating profiles within MCS regions was quantified

- MCS sensitivity studies to both surface aerosol concentrations and the vertical distribution on aerosol were completed