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Simulating Cloud-Aerosol Interactions in Cumuli: A New Treatment in WRF-Chem

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Berg et al., 2014: A new WRF-Chem treatment for studying regional scale impacts of cloud-aerosol interactions in parameterized cumuli. Submitted to *Geophysical Model Development*

ASR Atmospheric System Research

Motivation

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- Cloud-aerosol interactions are still a large source of uncertainty in climate simulations
- High-resolution simulations accounting for cloud-aerosol interactions are a commonly used tool
  - No need for parameterized convection
  - Limited in both space and time
- Long-term simulations are needed to understand the impacts on climate
  - Convection must be **parameterized**
  - **Most parameterizations are lacking cloud-aerosol interactions—including WRF-Chem and CAM5**
- New parameterizations are coming online
  - Conversion of cloud water to rainwater and evaporation of rain (Grell and Freitas 2013)
  - Aerosol activation in the Zhang-McFarlane parameterization (Lim et al. 2013)

No treatment of aqueous chemistry!

Modifications to WRF-Chem: Coupling Chemistry and the Kain-Fritsch Scheme

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Modifications to Kain-Fritsch Cumulus

- Used Cumulus Potential (CuP) approach to improve the simulation of shallow cumuli (Berg and Stull 2005; Berg et al. 2013)
- Cloud fraction of both active and passive clouds

Modifications to WRF-Chem chemistry packages

- Aerosol activation
- Transport
- Aqueous chemistry
- Wet removal

Goal is to demonstrate the behavior of the parameterization

Missing links

- Feedback to radiation—second indirect effects not yet implemented
- Feedback on precipitation and cloud lifecycle (aerosols do not affect initiation of rain yet)

Case Study: Conditions on 25 June 2007

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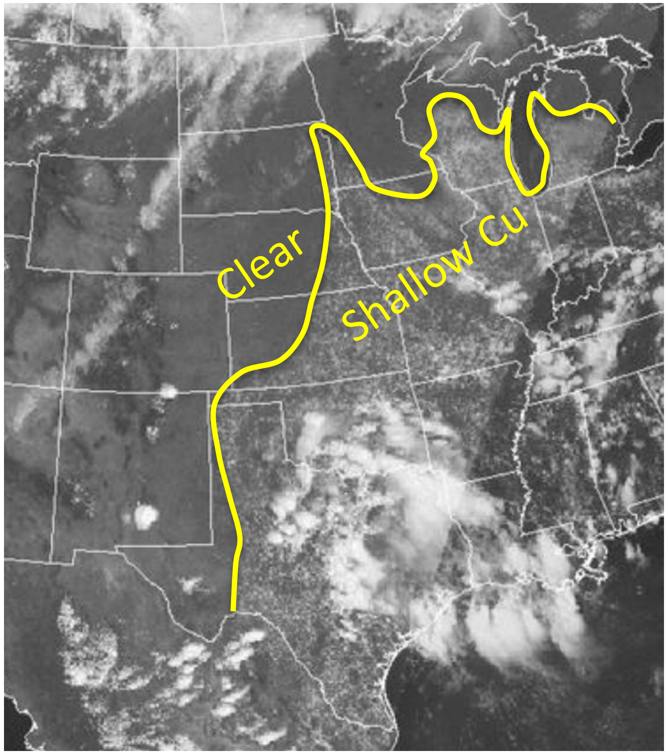
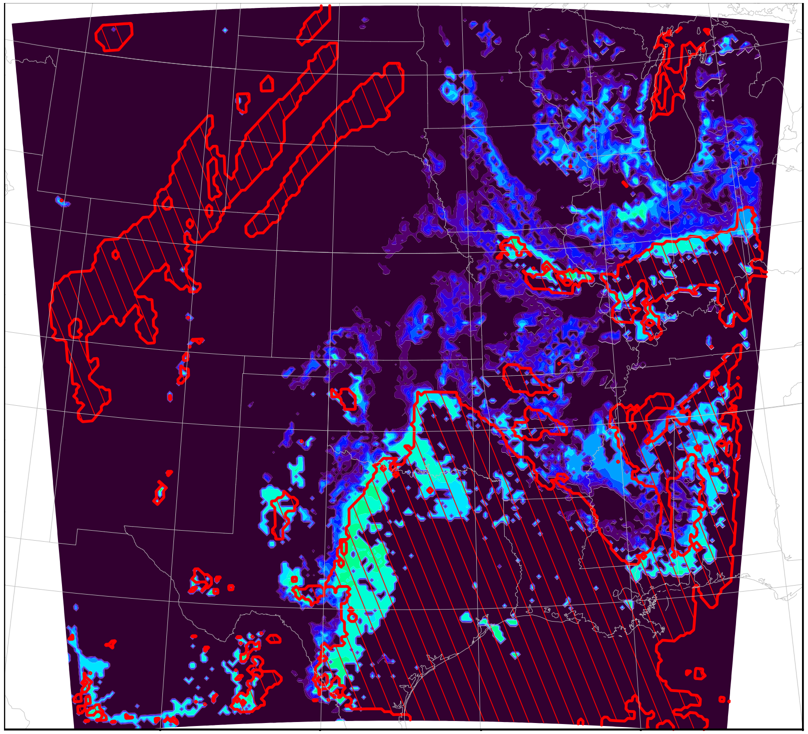


GOES visible satellite image valid at 20:15 UTC, 25 June 2007



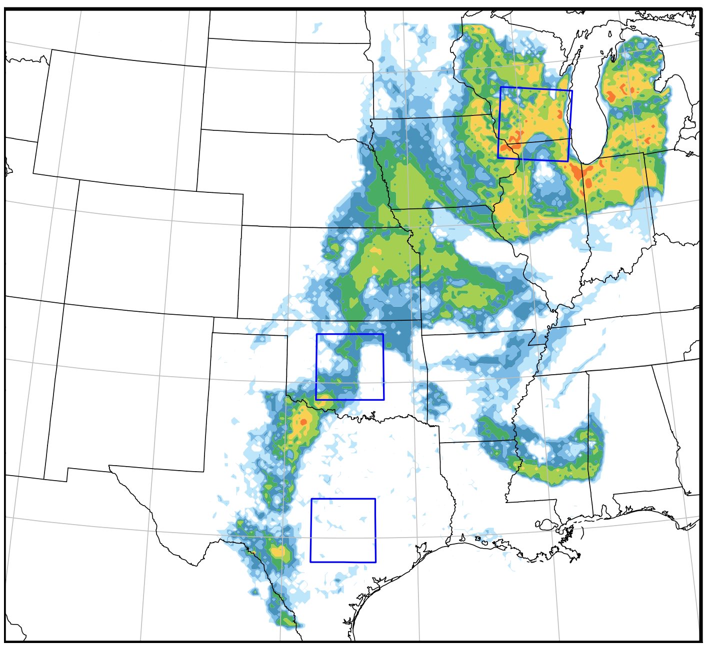
Simulated cloud fraction associated with KF-CuP (colors) and grid resolved clouds (hashed)

Impact of Both Shallow and Deep Convection

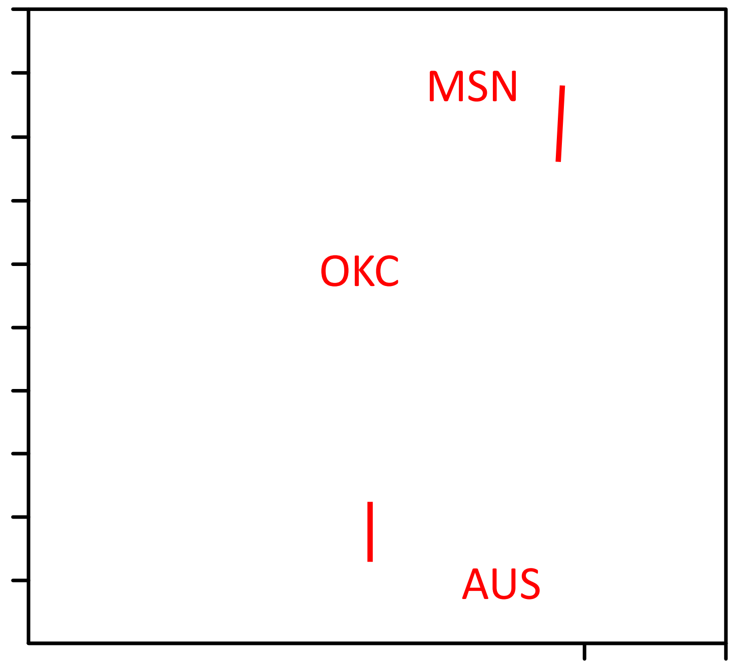
- Three analysis boxes have been selected
  - **MSN**: Shallow clouds
  - **AUS**: Deep clouds
  - **OKC**: Mixture of deep and shallow clouds

Focus: Black Carbon (BC) and Sulfate

Shallow



Deep

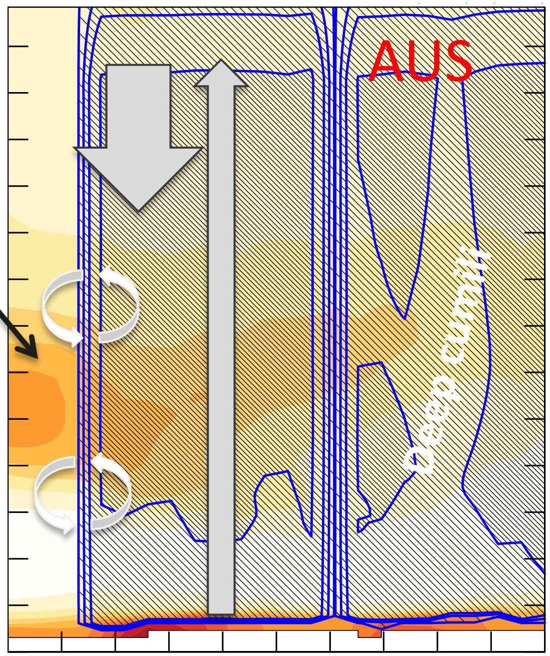


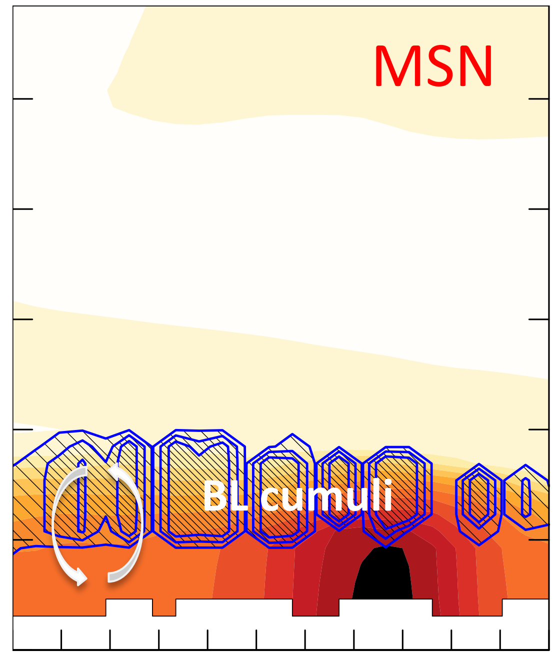
12-20 UTC on 25 June 2007

Vertical Cross Section: BC

- Important processes: transport, wet & dry removal
- Cumulus leads to increased vertical transport, entrainment/detrainment, and compensating subsidence & downdrafts

BC from distant wildfires





BC in boundary layer

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Vertical Cross Section: ΔBC

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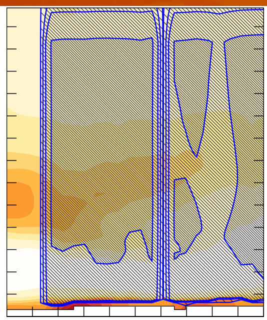
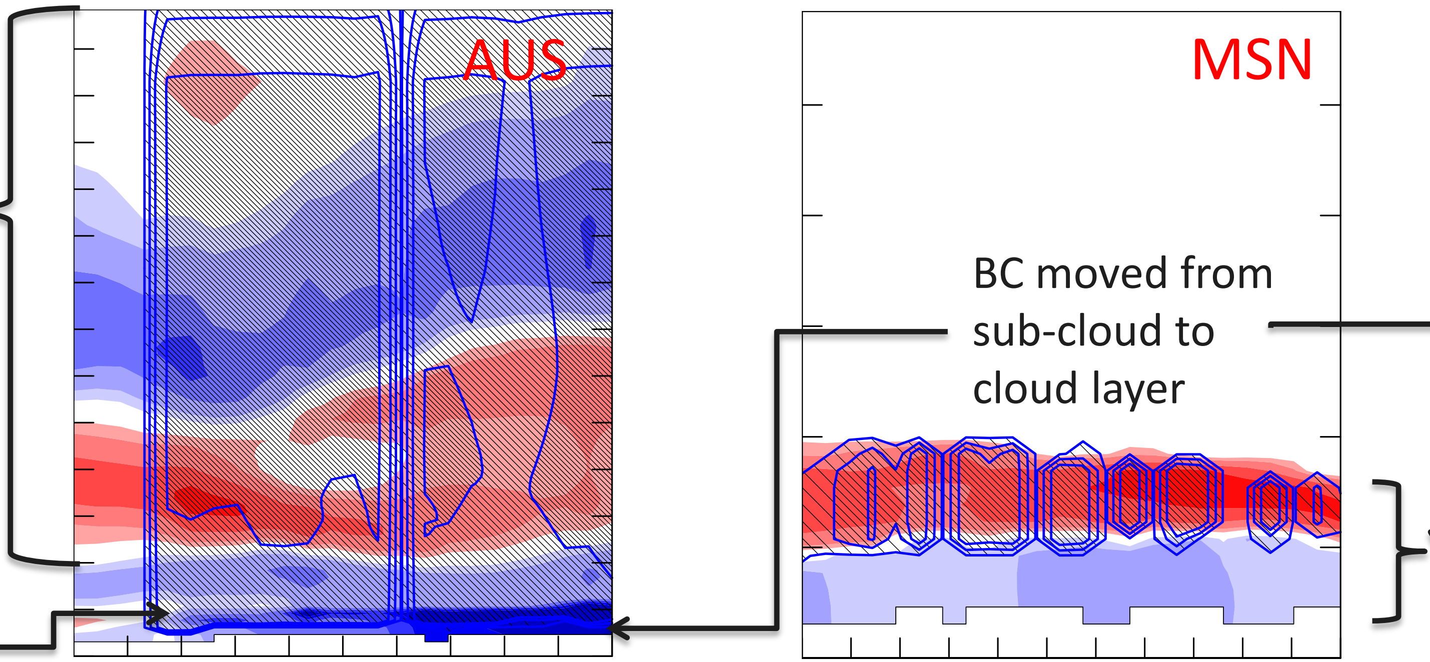


- Convective clouds lead to changes in the vertical structure BC

Convection induced subsidence shifts elevated layers down

Wet removal



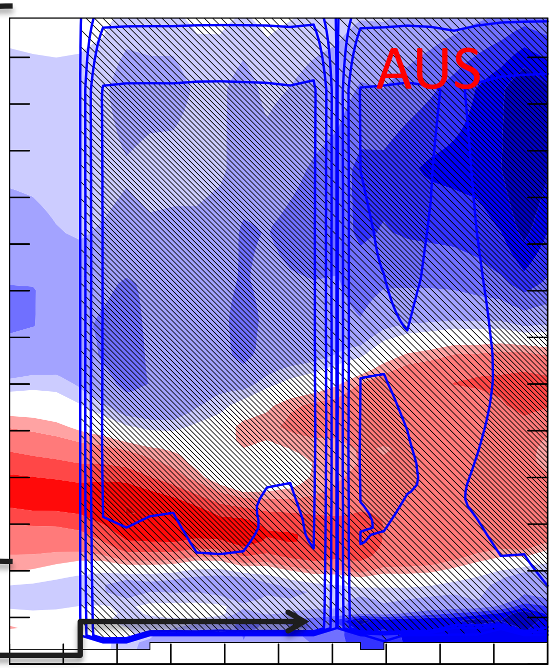
$\Delta BC=(BC_{Cumulus}-BC_{Control})/BC_{Control}$

No wet removal in MSN box

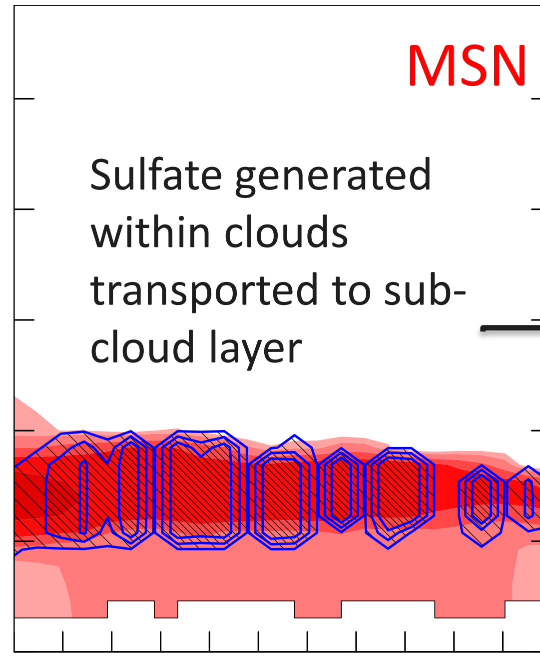
Vertical Cross Section: ΔSulfate

- Convective clouds lead to changes in vertical structure of sulfate loading
  - If no precipitation—increase in sulfate loading due to cloud chemistry

Convection induced subsidence shifts elevated layers down



Wet removal



Sulfate generated within clouds transported to sub-cloud layer

$$\Delta Sulfate=(Sulfate_{Cumulus}-Sulfate_{Control})/Sulfate_{Control}$$

Changes in Mass Loading Near AUS: Dominated by Deep Convection

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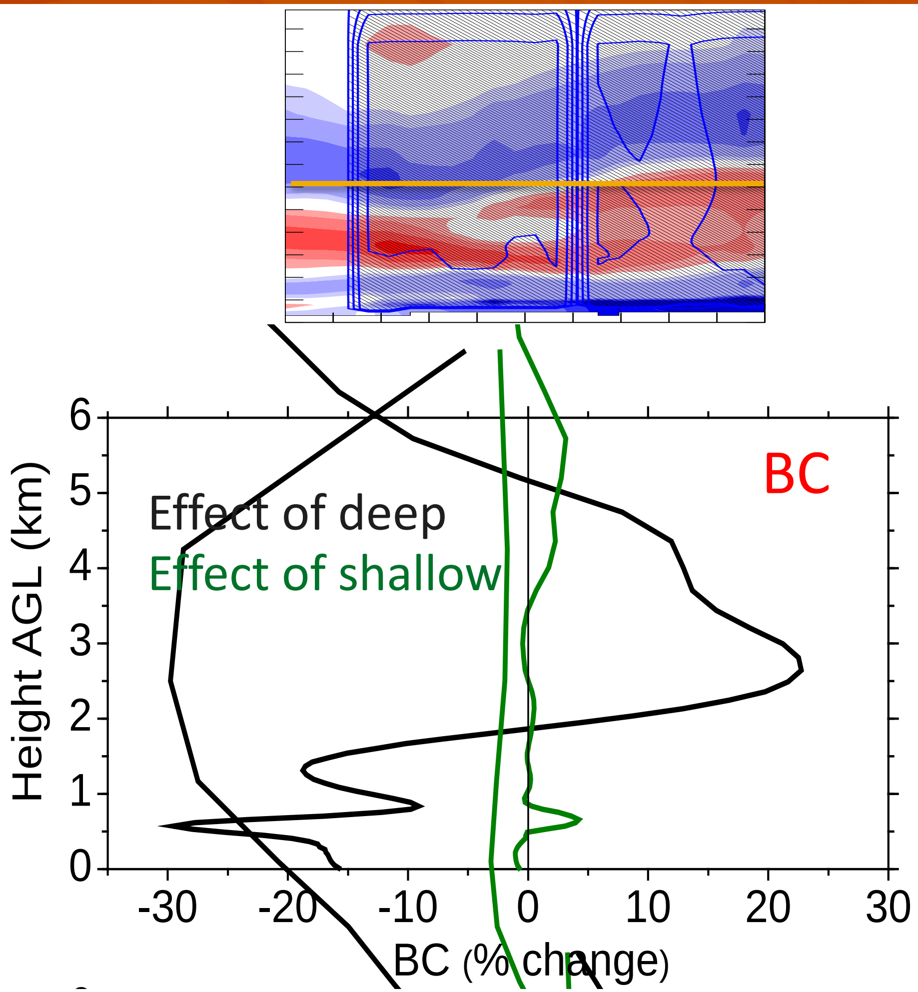

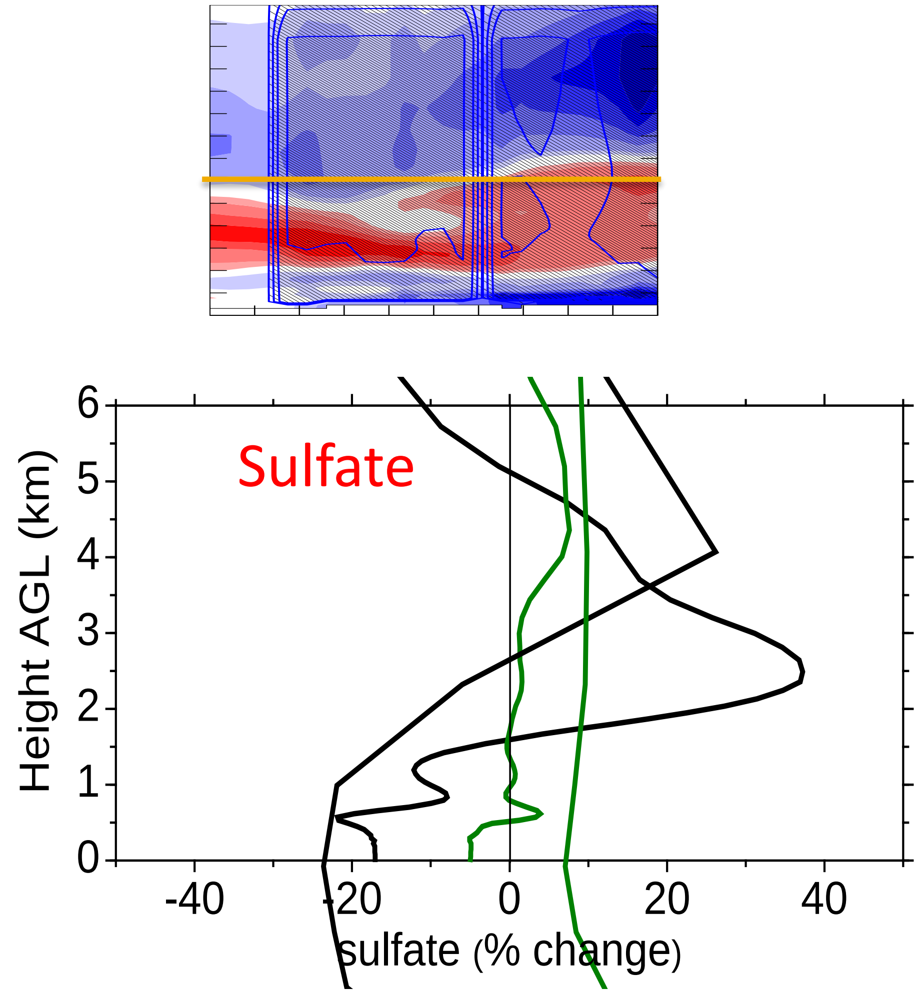

Changes in Mass Loading Near MSN: Dominated by Shallow Convection

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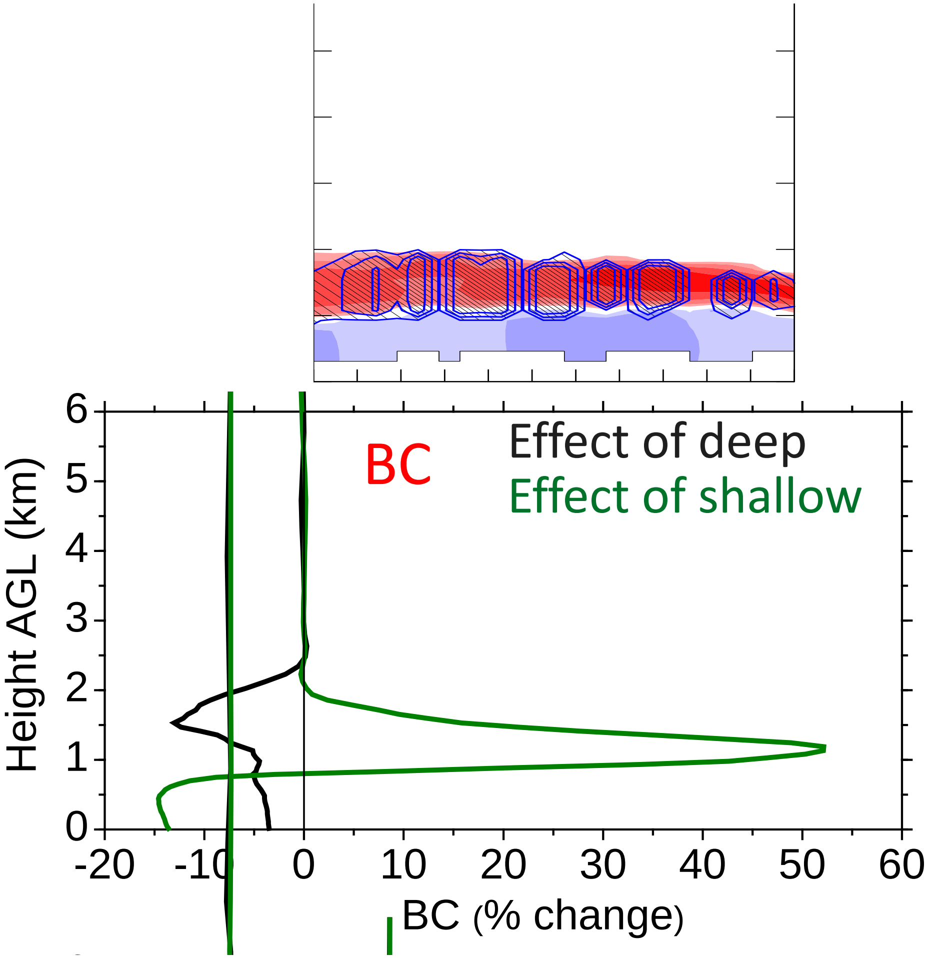

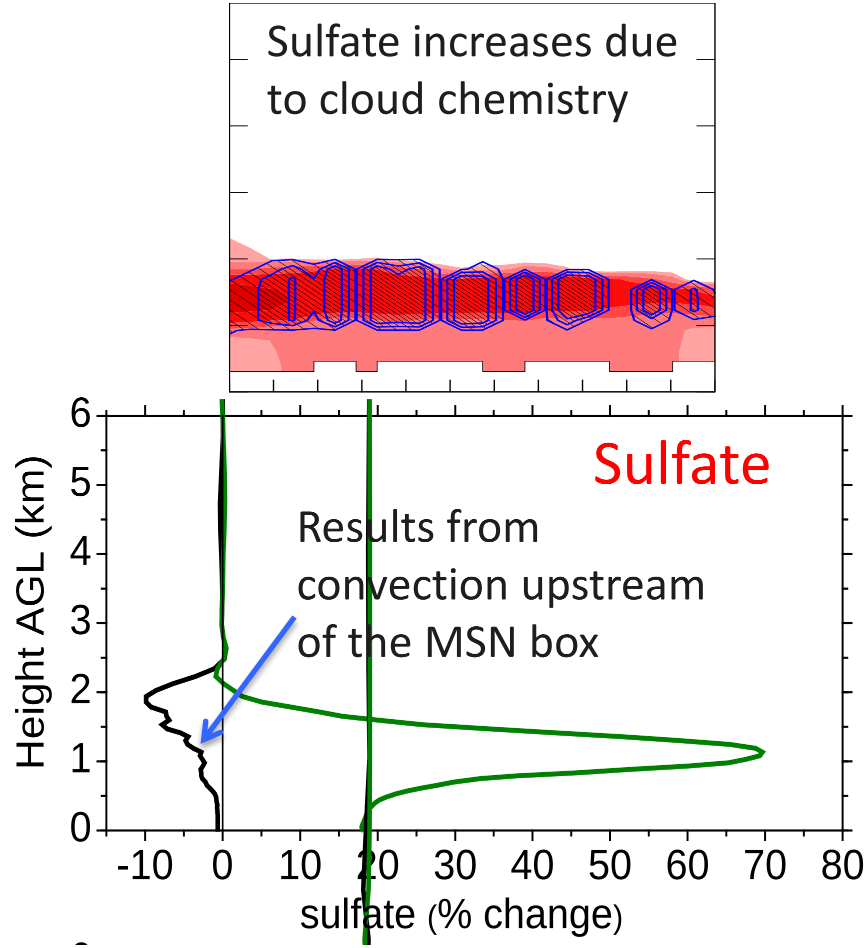

- Conditions near MSN dominated by shallow convection, but impact of deep convection is not negligible.

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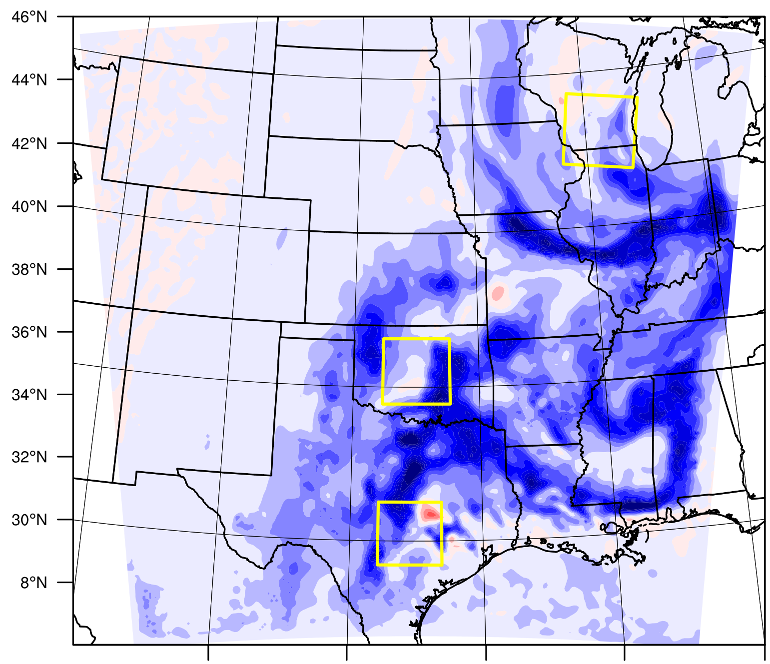
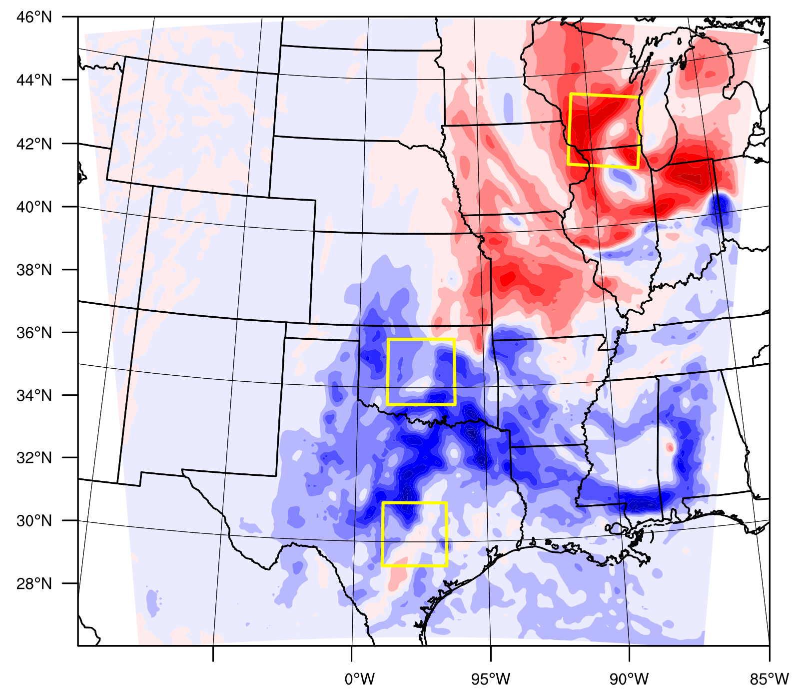
Column integrated mass loading

- BC: Generally decreases due primarily to wet removal
- Sulfate: Can increase or decrease depending on precipitation

BC



Sulfate



Summary and Next Steps

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- New parameterizations have been introduced to improve the representation of cloud-aerosol interactions in **parameterized** clouds.
  - Includes changes to both cumulus parameterization and chemistry modules
- Convective clouds are shown to have an important impact on the horizontal and vertical distribution of aerosol
- Aqueous chemistry has significant effects on aerosol vertical distribution
- Additional work has been completed evaluating aerosol chemistry and indirect effects
  - Comparison with CHAPS data
  - Not included here to save time (but in submission to GMD)
- Future work
  - Finish coupling with radiation
  - Add to the released version of WRF-Chem

Acknowledgements: This work has been supported by the US Department of Energy's Atmospheric System Research Program

ASR Atmospheric System Research

Session 1, Poster 213

Backup slides

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Test Case: CHAPS

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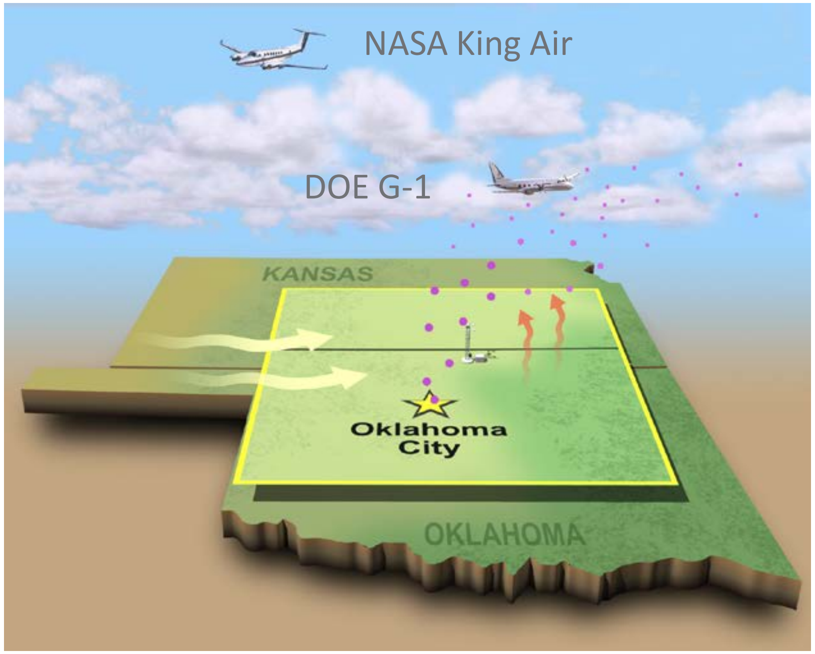
- Based on the Cumulus Humilis Aerosol Processing Study (CHAPS; Berg et al. 2009)
  - Conducted during June 2007
  - Two aircraft: DOE G-1, NASA King Air
- G-1
  - In situ measurements of aerosol optical and chemical properties
  - Two inlets: isokinetic and counter flow virtual impactor
- King Air
  - HSRL Lidar, aerosol back-scatter, extinction



OVERVIEW OF THE CUMULUS HUMILIS AEROSOL PROCESSING STUDY

BY LARRY K. BERG, CARL M. BERKOWITZ, JOHN A. OGREN, CHRIS A. HOSTETLER, RICHARD A. FERRARE, MANVENDRA K. DUBEY, ELISABETH ANDREWS, RICHARD L. COULTER, JOHNATHAN W. HAIR, JOHN M. HUBBE, YIN-NAN LEE, CLAUDIO MAZZOLENI*, JASON OLFERT+, AND STEPHEN R. SPRINGSTON

Case study: 25 June, 2007

Modifications to WRF-Chem: Coupling Chemistry and the Kain-Fritsch Scheme

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- WRF-Chem has been modified to account for cloud-aerosol interactions—including aqueous chemistry

KF scheme has been modified to improve treatment of shallow clouds using the Cumulus Potential (CuP) approach (Berg et al. 2013)

Simulated Cloud Fraction

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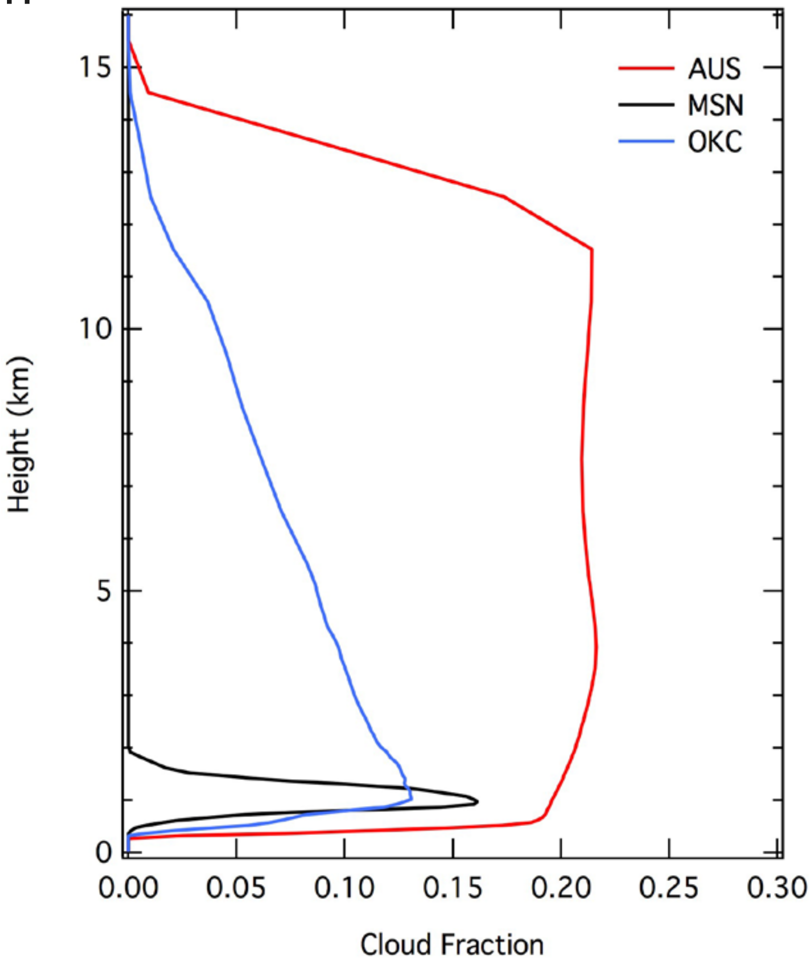
- Differences in cloud fraction between the three boxes



Vertical Cross Section: Sulfate

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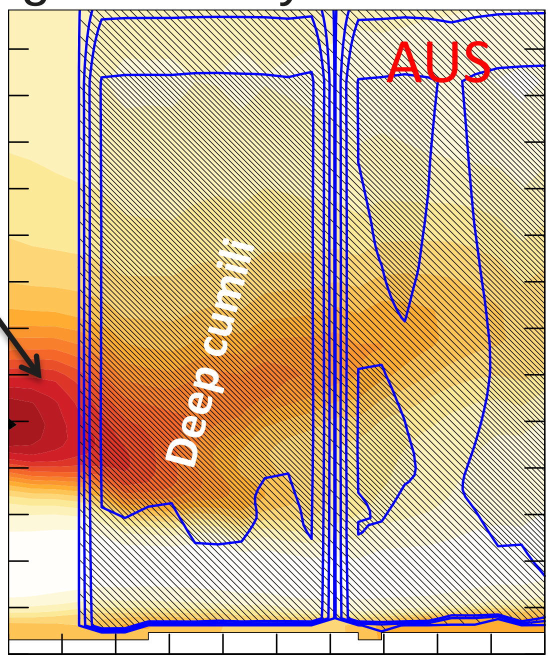
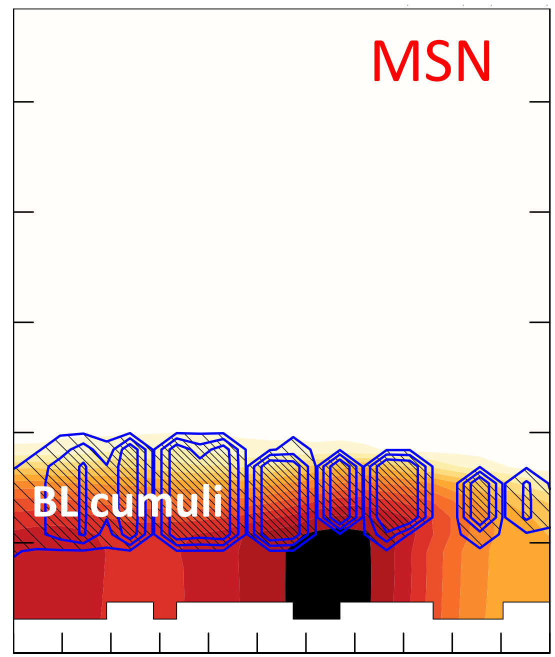
- Important processes: transport, wet & dry removal, and aqueous chemistry
- Loading looks very similar to BC

Sulfate from distant wildfires





Sulfate in boundary layer

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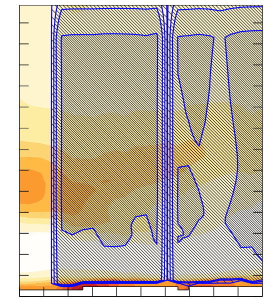
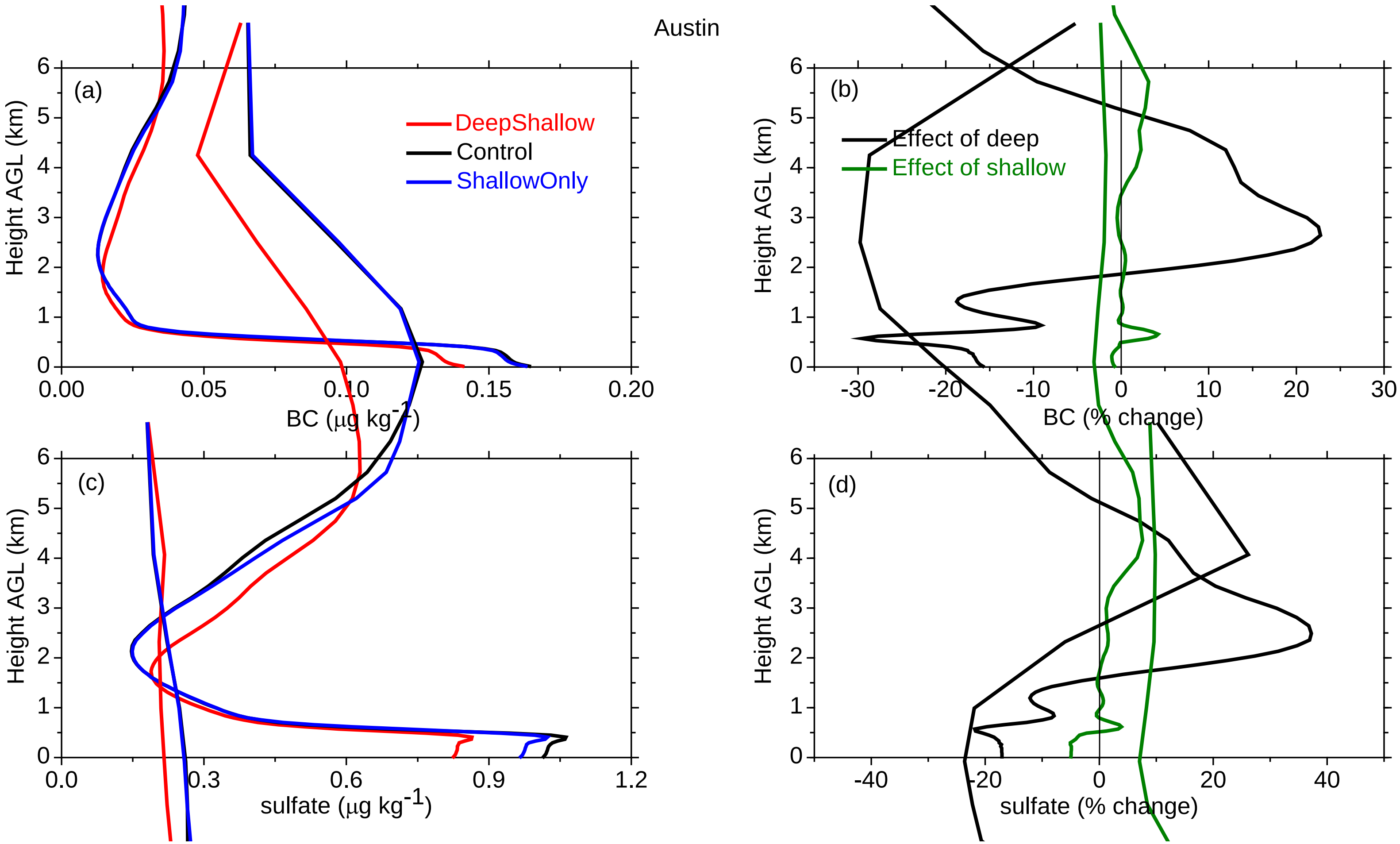
Changes in Mass Loading Near AUS

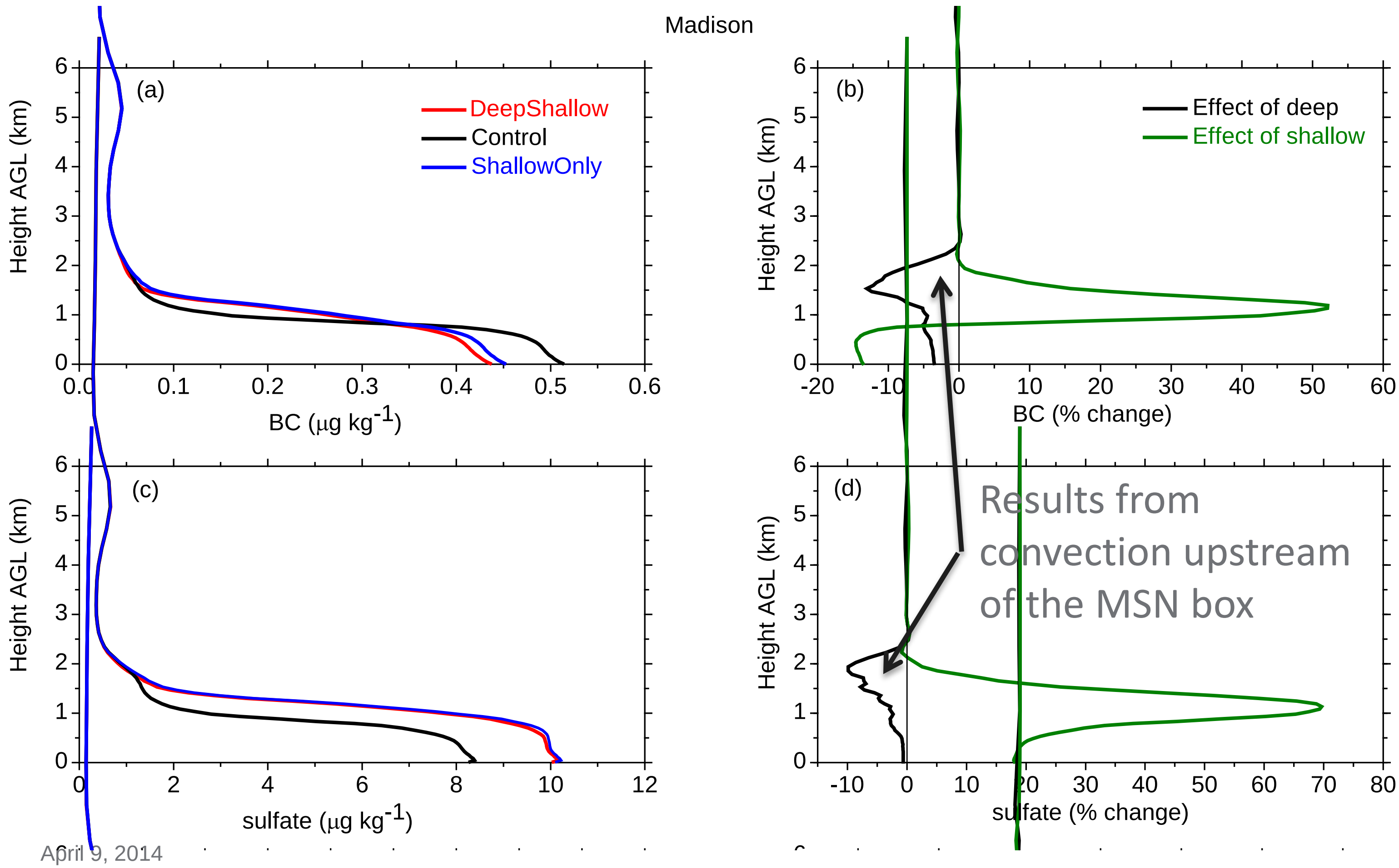


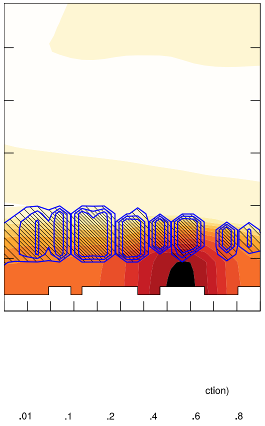
- Conditions in AUS box dominated by deep convection



Changes in Mass Loading Near MSN

- Conditions near MSN dominated by shallow convection, but impact of deep convection is not negligible.





Changes in Mass Loading Near OKC

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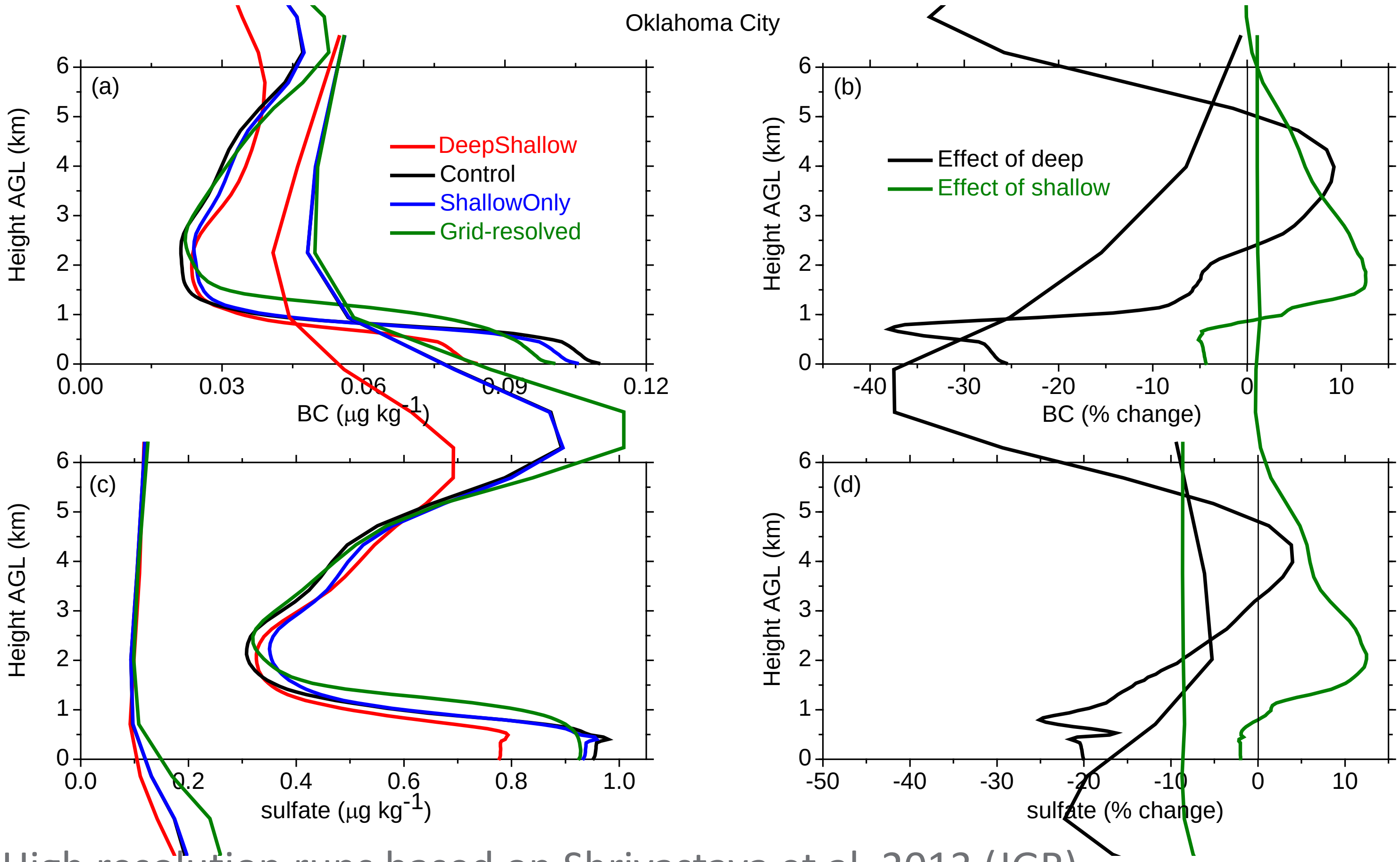
- Balance between both deep and shallow convection
- Grid-resolved simulations had less deep convection



High resolution runs based on Shrivastava et al. 2013 (JGR)

2-Line Header for New PNNL PowerPoint Presentation Template