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A Few Small Steps for the Parameterization of Wet Removal: Improved Treatment of Cloud-Aerosol Interactions in WRF-Chem

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Improving Treatment of Shallow Cumuli

The KF-CuP Parameterization

- Replaces trigger function in the standard KF scheme applied in WRF and WRF-Chem
- Increased occurrence of shallow clouds, consistent with observations
- Focused on shallow clouds

Can this framework be used for cloud-aerosol interactions?

Based on Berg et al. 2013, *MWR*

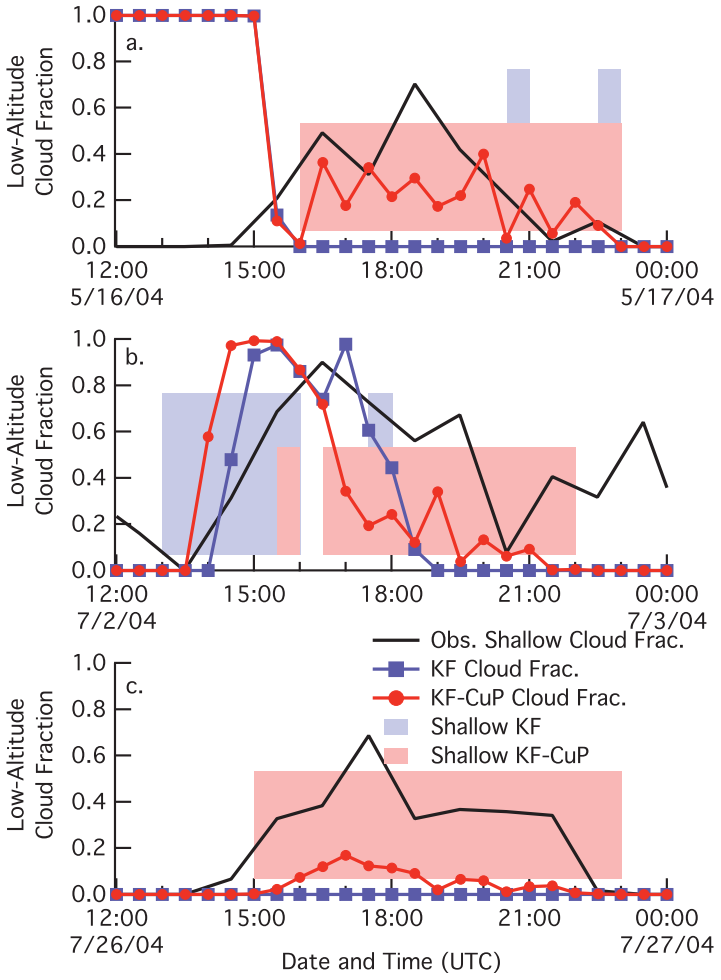
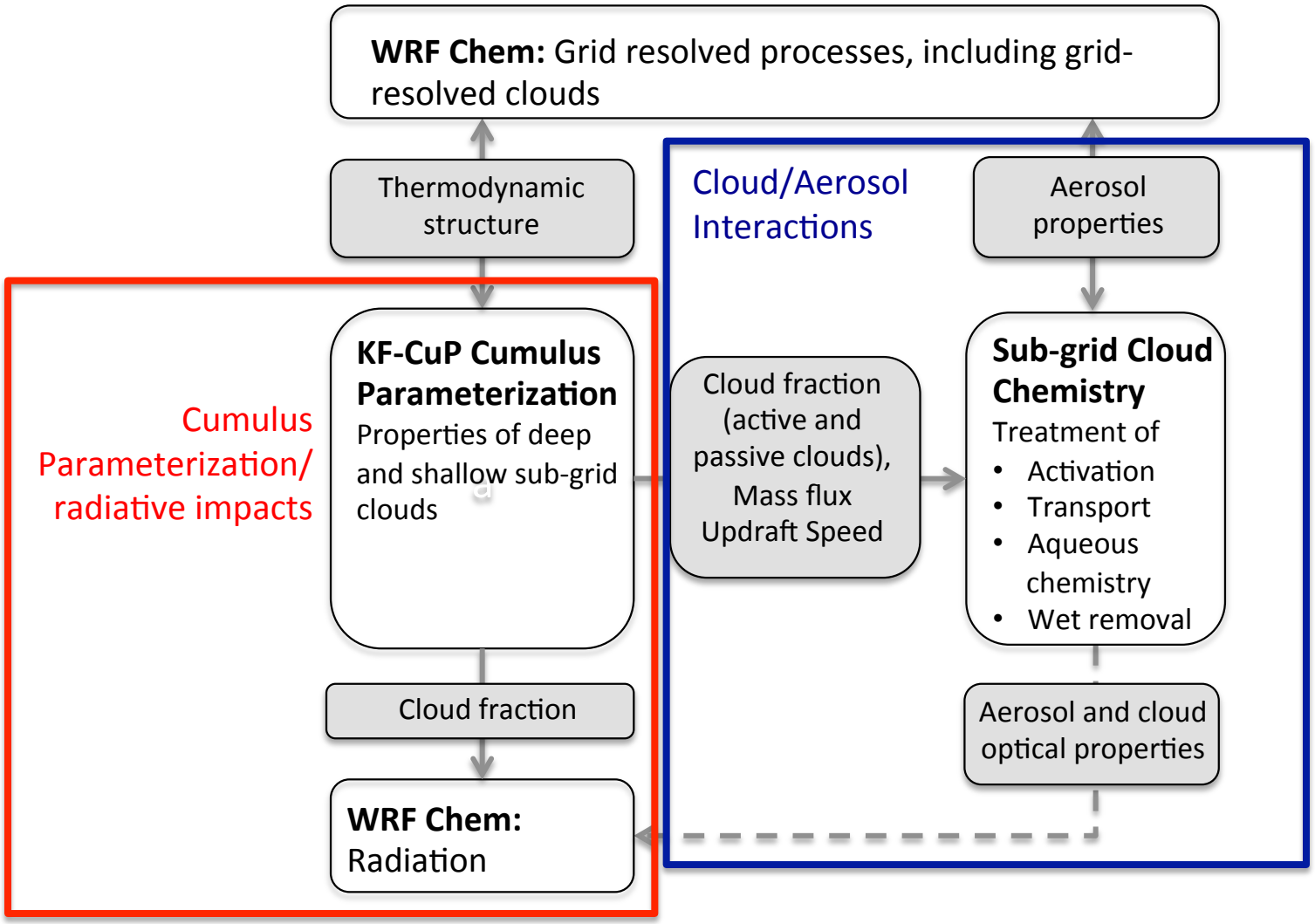


FIG. 6. Observed (black lines) and predicted low-altitude cloud fraction (defined as clouds occurring below 6 km) using the default KF (blue) and KF-CuP (red) for (a) 16 May, (b) 2 Jul, and (c) 26 Jul. Shading indicates periods during which the KF (blue) or KF-CuP (red) shallow convection parameterization is active.

Modifications to WRF-Chem for Sub-Grid Convective Clouds



WRF-Chem Configuration

Physical Process	Parameterization
Surface	Noah land-surface model (Chen et al. 1996)
Boundary layer	Mellor-Yamada-Janjić (Janjić, 1990, 2002)
Cloud microphysics	Morrison two moment (Morrision et al. 2005 and 2009)
Cumulus	Kain-Frisch (with CuP modifications) (Kain and Fritsch 1990; Kain 2004; Berg et al. 2013)
Radiation	CAM (for both shortwave and longwave)
Gas-phase chemistry	SAPRC-99
Aerosol chemistry	MOSAIC for inorganic aerosols; Simplified Volatility Basis Set (VBS) for organic aerosol (Sharavstra et al. 2011)

Note: Standard microphysics is only applied for grid resolved clouds

Experiment	Aerosol Processing
DeepShallow	Aerosol Processing Shallow Cu: On Aerosol Processing Deep Cu: On
ShallowOnly	Aerosol Processing Shallow Cu: On Aerosol Processing Deep Cu: Off
Control	Aerosol Processing Shallow Cu: Off Aerosol Processing Deep Cu: Off

Observed and Simulated Clouds

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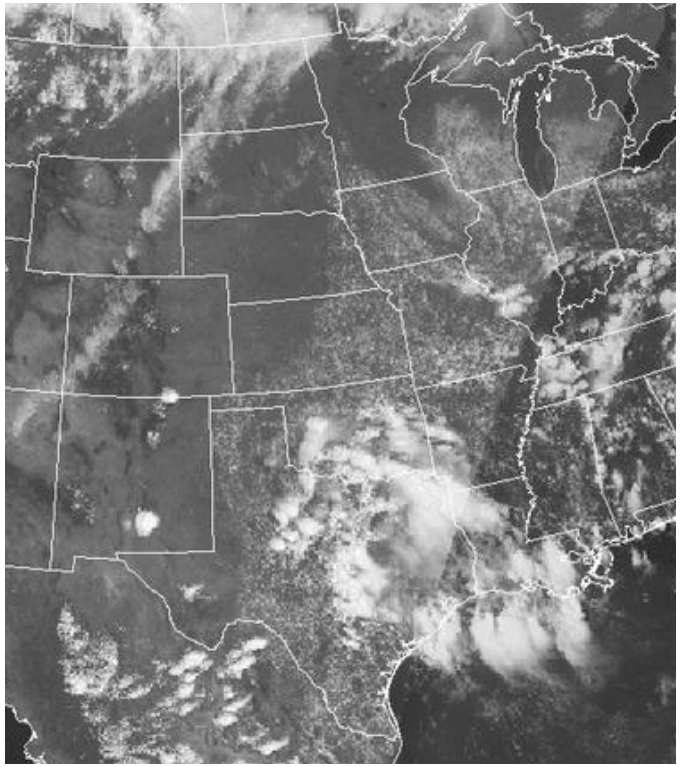
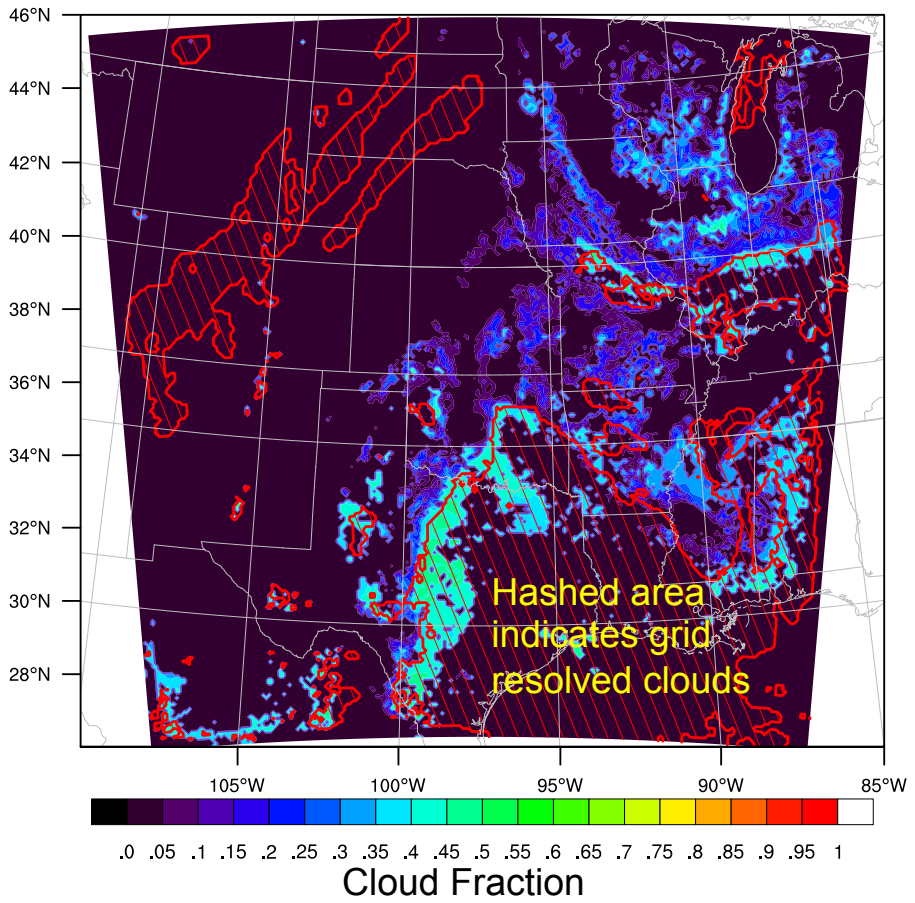
CHAPS* test case selected be consistent with Shrivastava et al. 2013, *JGR*

Sat. Reflectivity



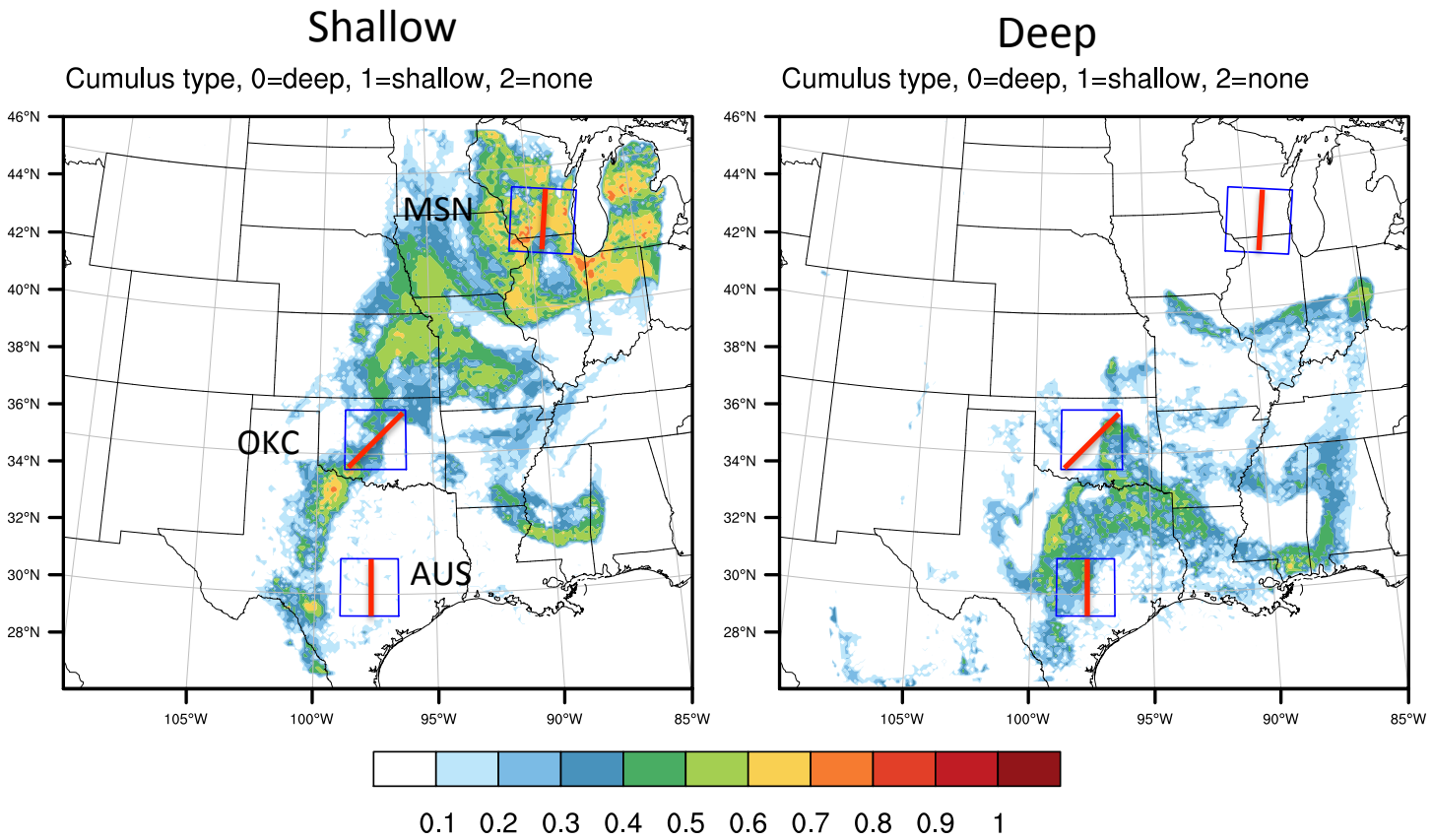
WRF-Chem cloud fraction



Valid at 20:00 UTC, 25 June 2007

CHAPS = Cumulus Humilis Aerosol Processing Study; Berg et al. 2007

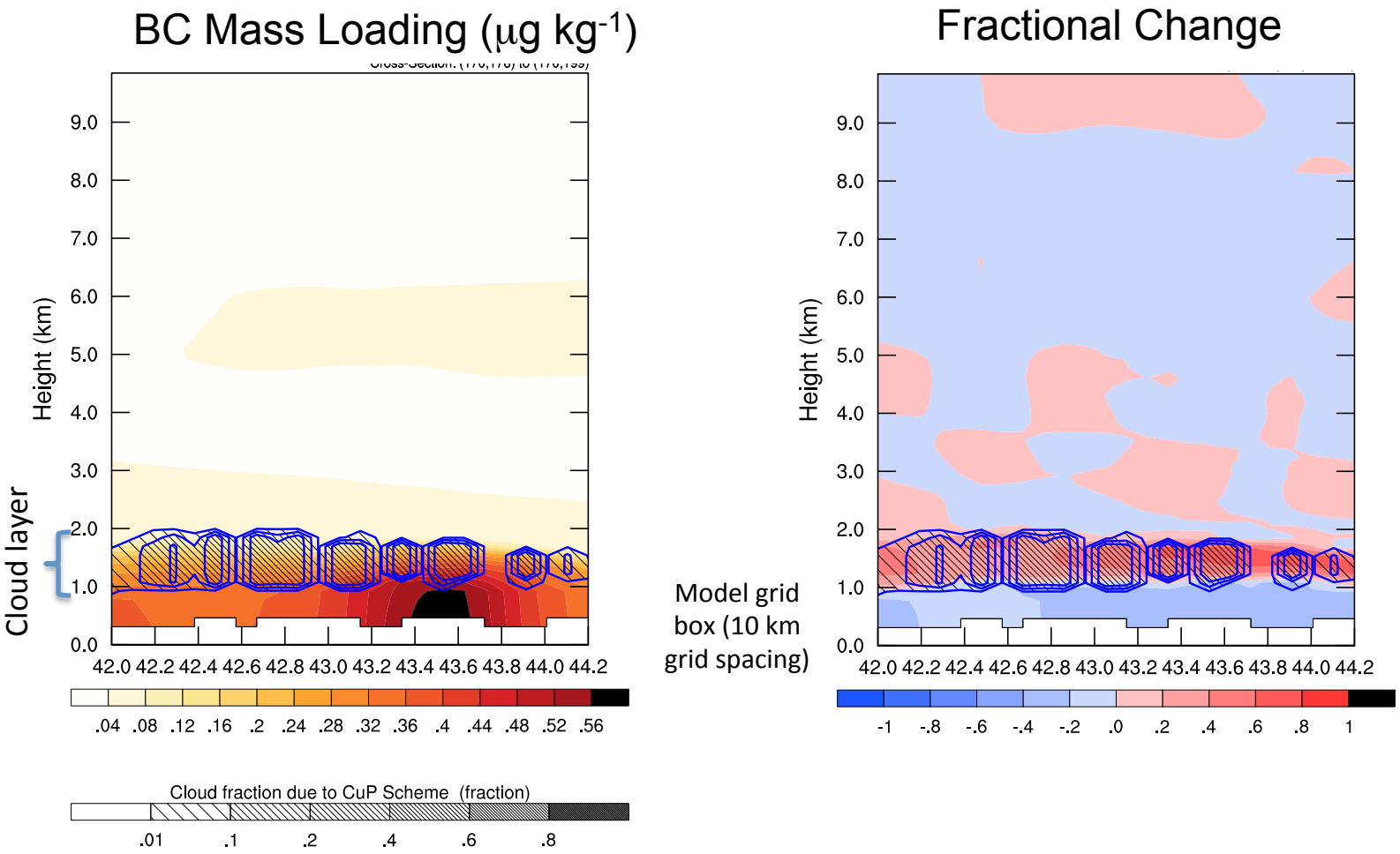
Shallow vs. Deep convection



Frequency of occurrence of shallow and deep convection for the time period 12:00-20:00 UTC on 25 June, 2007

Vertical Cross Section: BC in MSN Box

DeepShallow simulations



- Reduction in BC mass loading in sub-cloud layer, increase in cloud layer

Vertical Cross Section: BC in AUS Box

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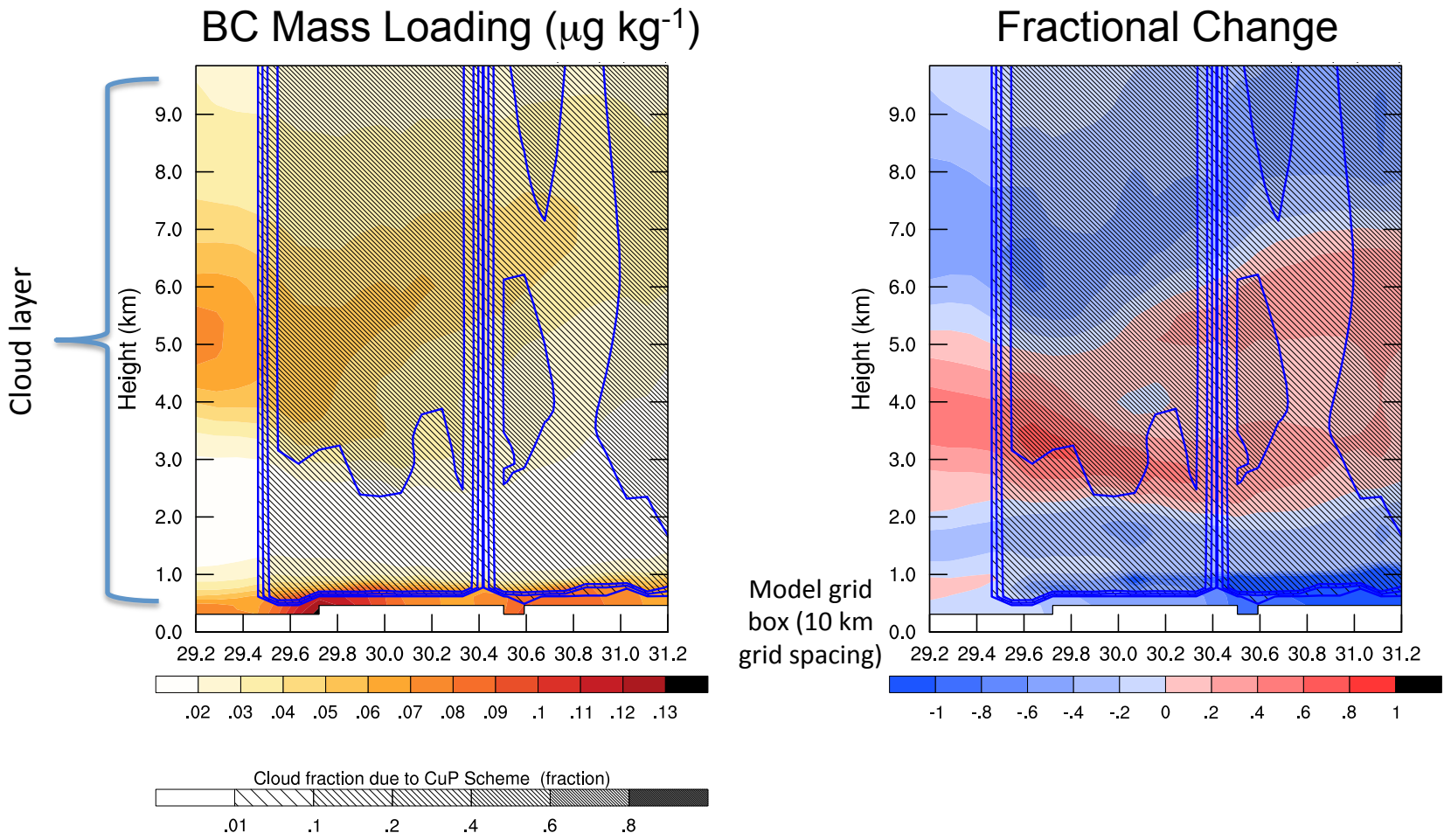
DeepShallow simulations



- Reduction in BC mass loading in sub-cloud layer, wet removal, increase/ decrease aloft associated with compensating subsidence

Vertical Cross Section: BC in OKC Box

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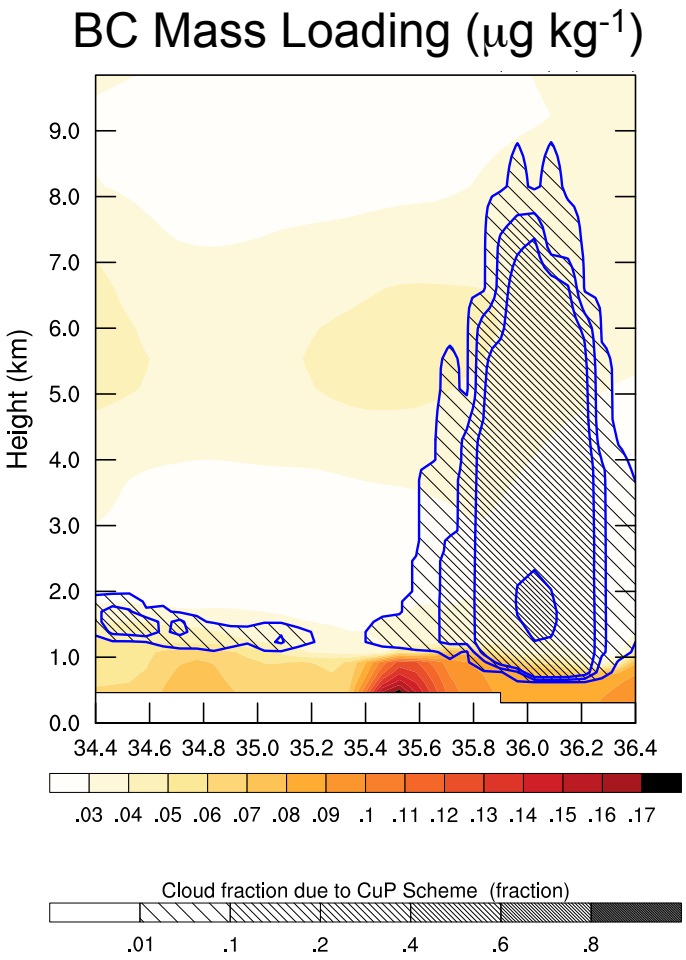
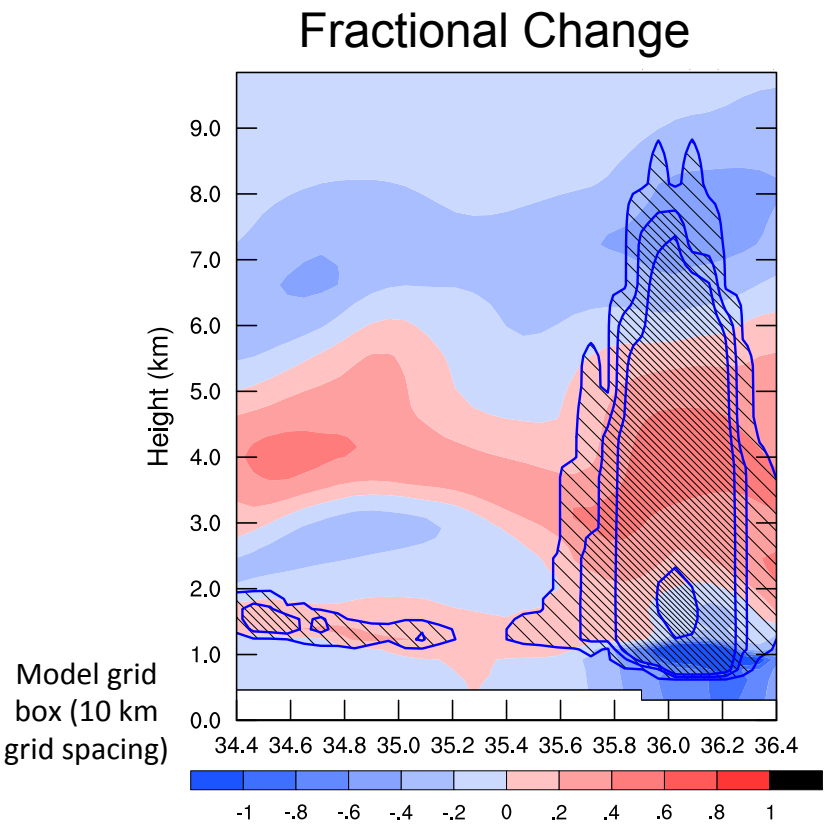
DeepShallow simulations





Model grid box (10 km grid spacing)

- Reduction in BC mass loading in sub-cloud layer, wet removal, increase/ decrease aloft associated with compensating subsidence

Regional scale impacts

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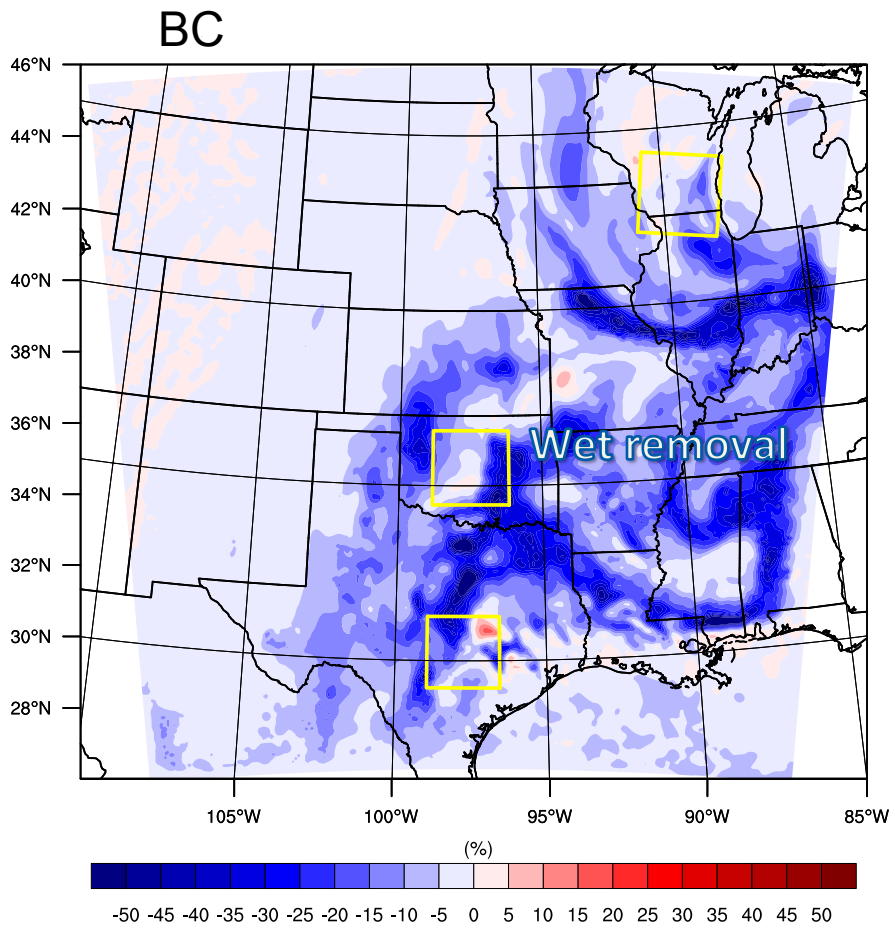
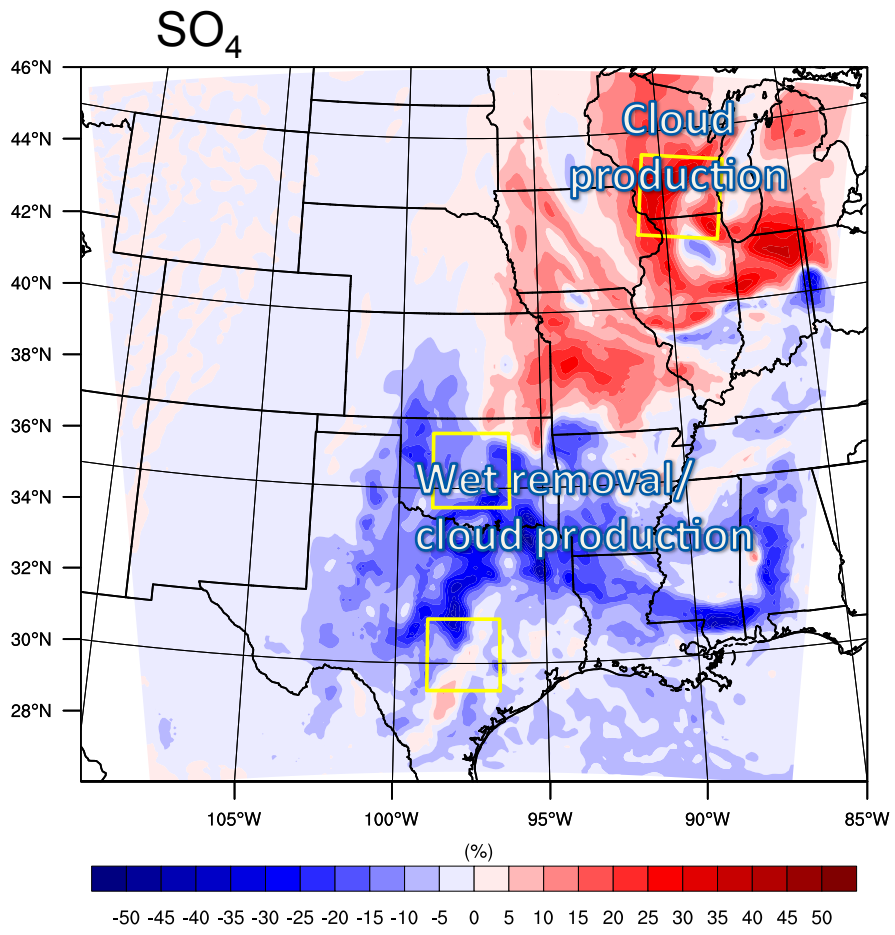
Changes in column integrated mass loading: DeepShallow-Control





Summary and Questions for Discussion

Small steps forward…

- A new treatment for cloud-aerosol interactions for parameterized clouds has been implemented in WRF-Chem
- Results are compared to data collected during CHAPS and high-resolution simulations
- Important impact on the distribution of aerosol, wet removal is significant

But…

- How can we be sure that the results are correct?
  - Limited to nucleation scavenging (aerosol activation) and removal of cloud drops
  - Activation limited to cloud base—no secondary activation
  - No cloud ice
- Data from CHAPS (or other studies including TCAP) are generally not sufficient for studies of wet removal
  - CHAPS and TCAP included CVI, AMS and surface site
  - No measurement of chemical composition in rain drops or wet deposition

What's in the Cloud Drops?

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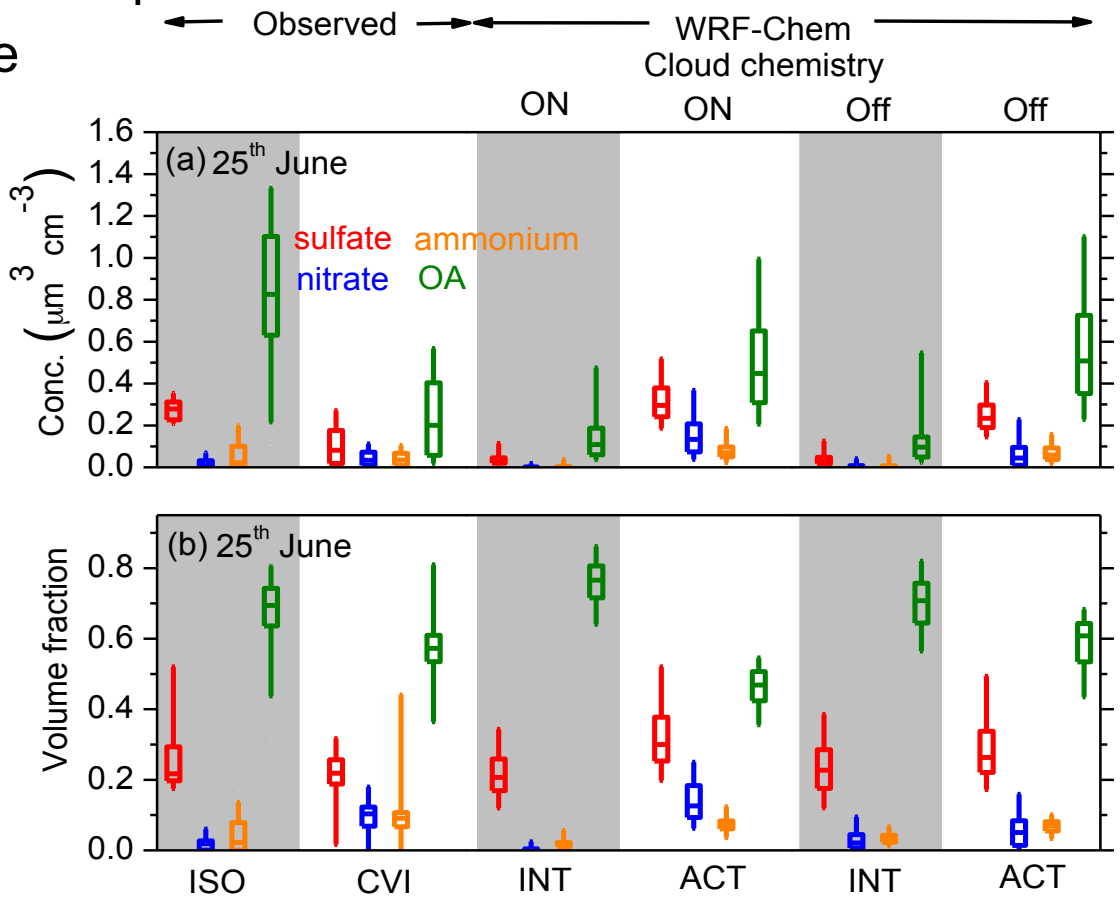
Sampling during CHAPS

- CVI used to separate cloud drops from the sampling stream
- Isokinetic inlet used to sample interstitial aerosol
- AMS used to measure chemical composition

Results

- Enhanced nitrate within the drops
- Enhanced removal of nitrate?

Results based on CHAPS measurements in OKC box



Vertical Cross Section: SO_4 in MSN box

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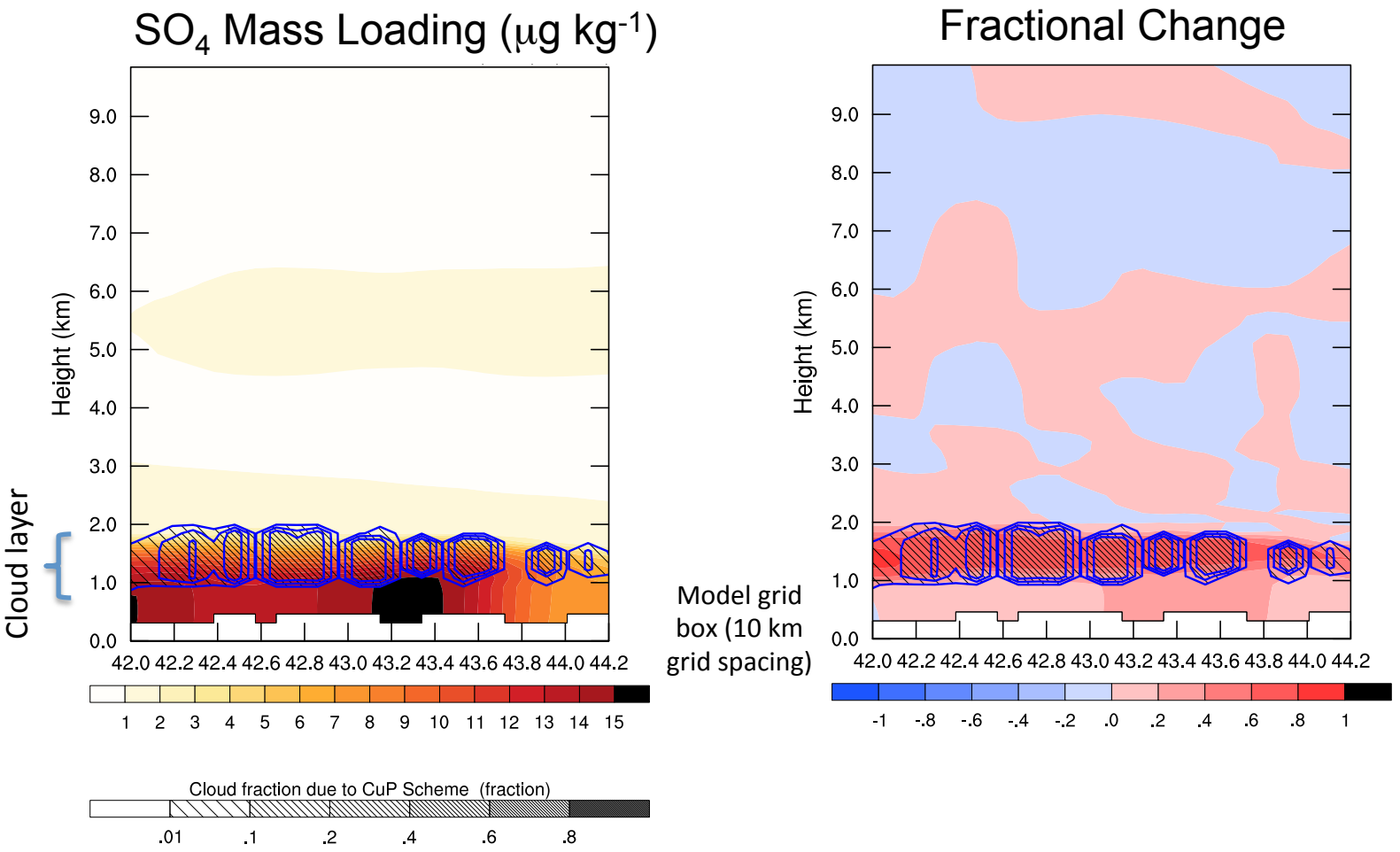
DeepShallow simulations



- Increase of SO_4 mass loading in sub-cloud layer and cloud layer

Vertical Cross Section: SO_4 in AUS Box

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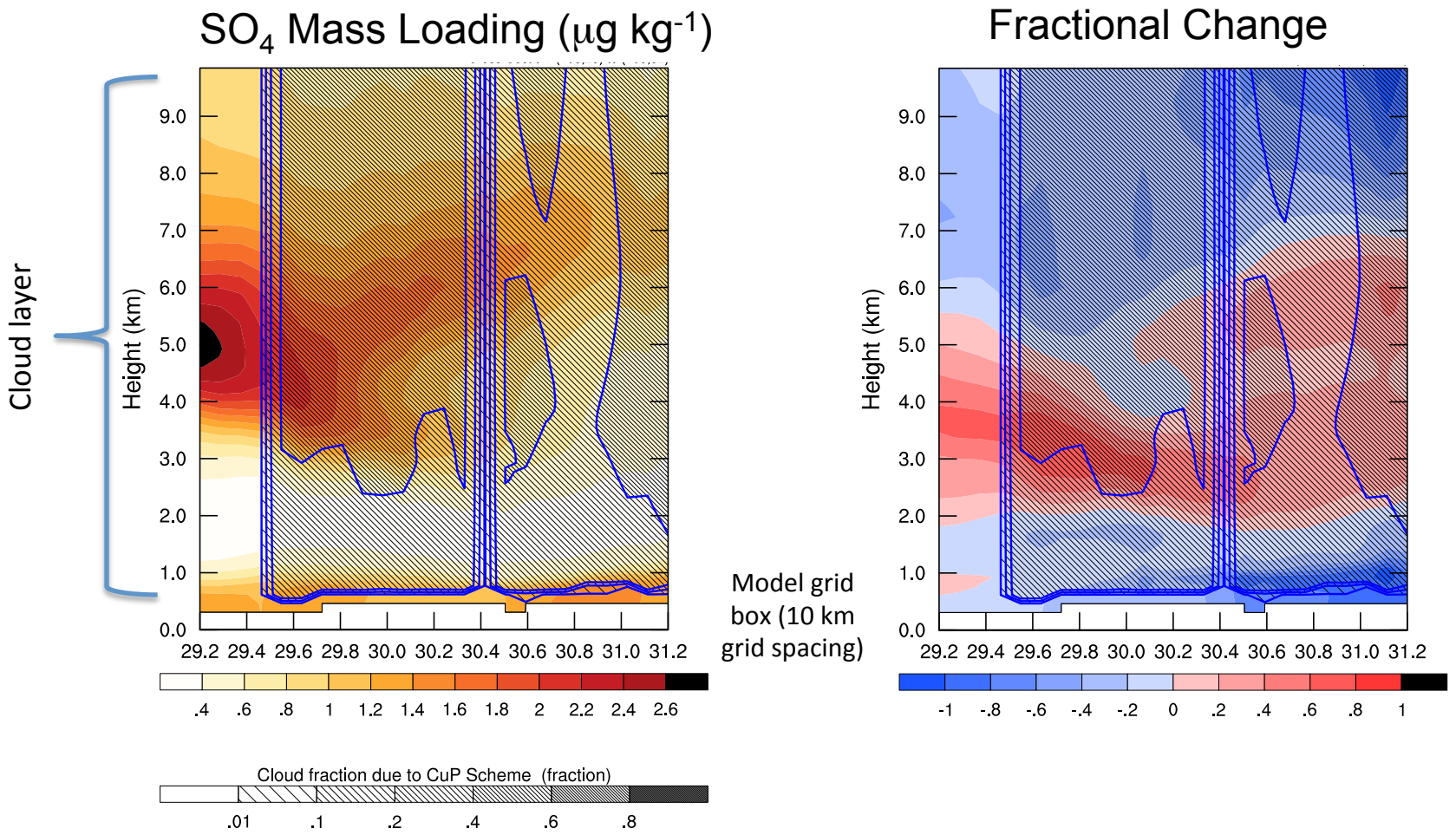

- Reduction in BL mass loading in sub-cloud layer, increase/decrease aloft associated with compensating subsidence, wet removal

Vertical Cross Section: SO_4 in OKC Box

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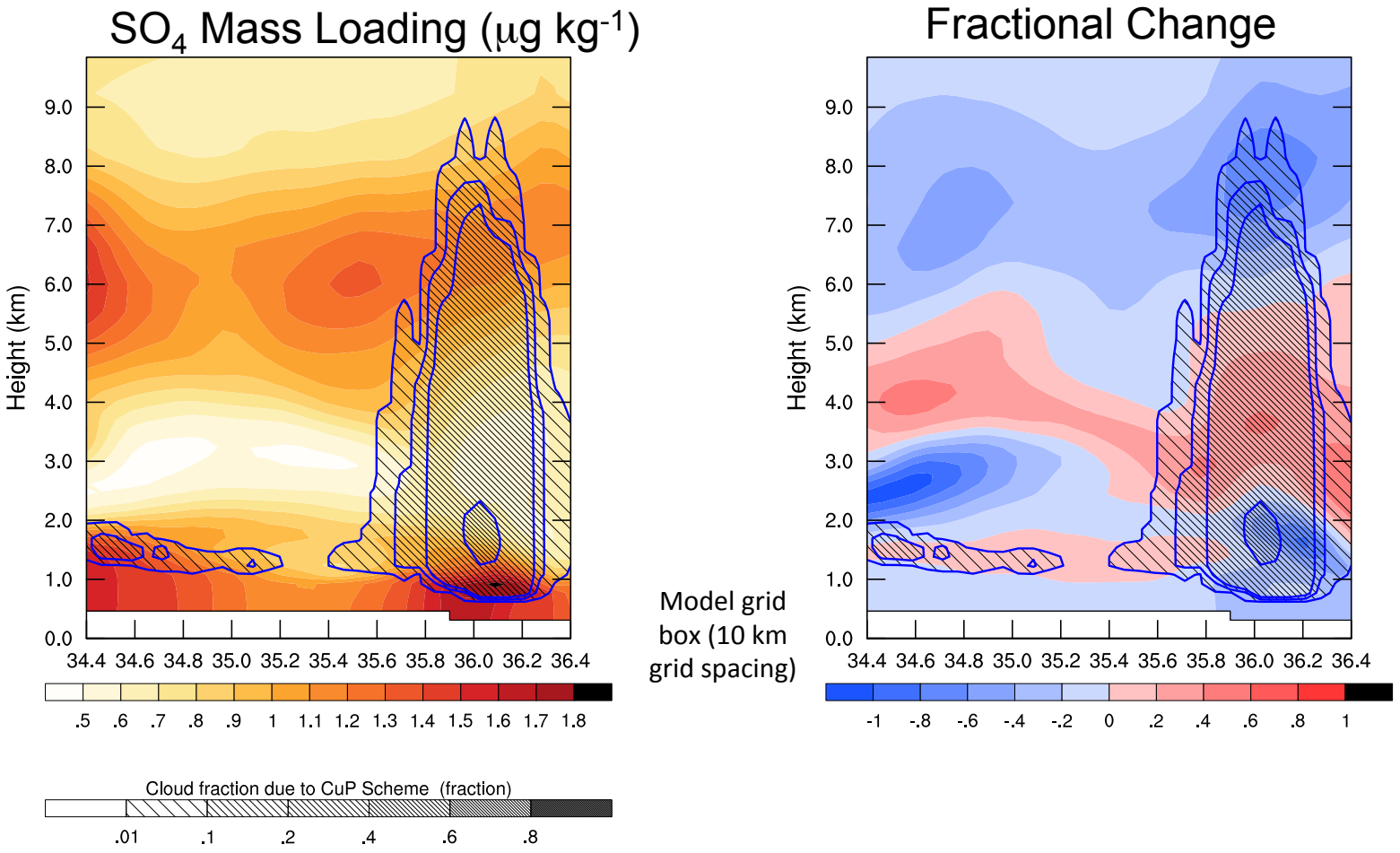
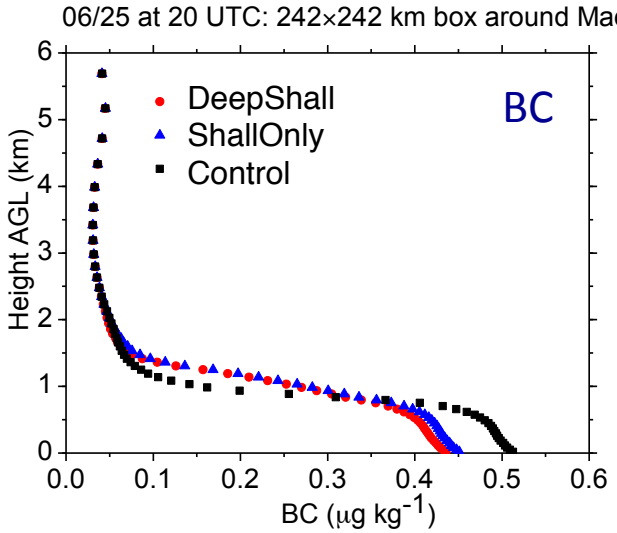
DeepShallow simulations

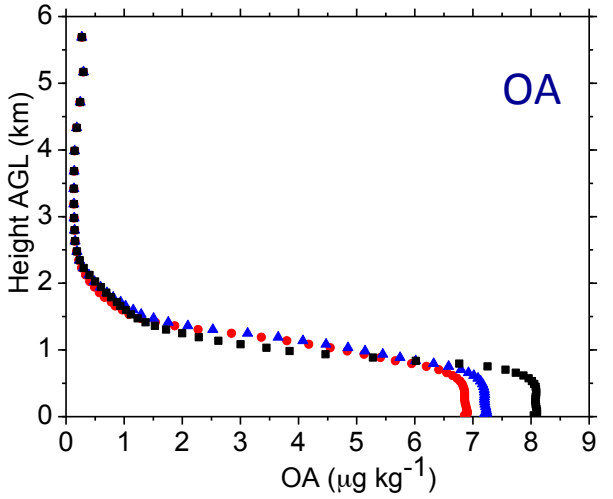


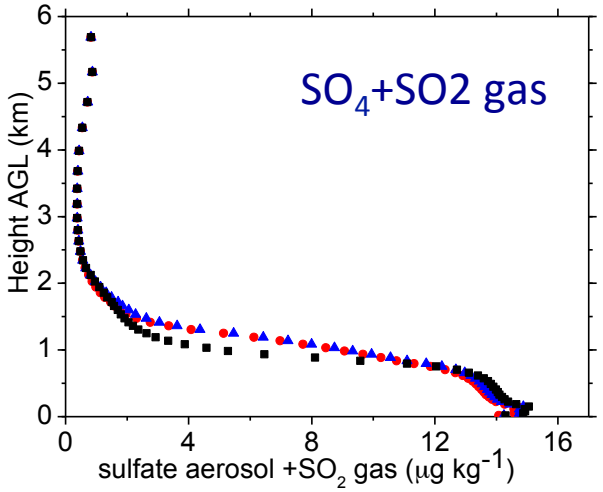
- Reduction in BL mass loading in sub-cloud layer, increase/decrease aloft associated with compensating subsidence, wet removal

Average Mass Loading: MSN Box

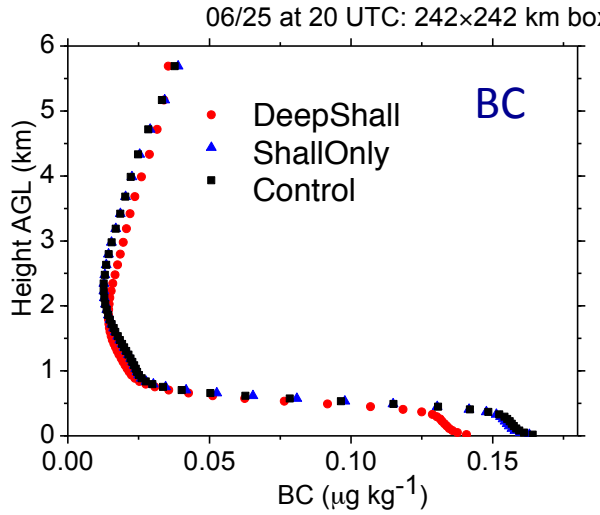


- Reduction in BL loading
- Relatively small difference in DeepShall and ShallOnly

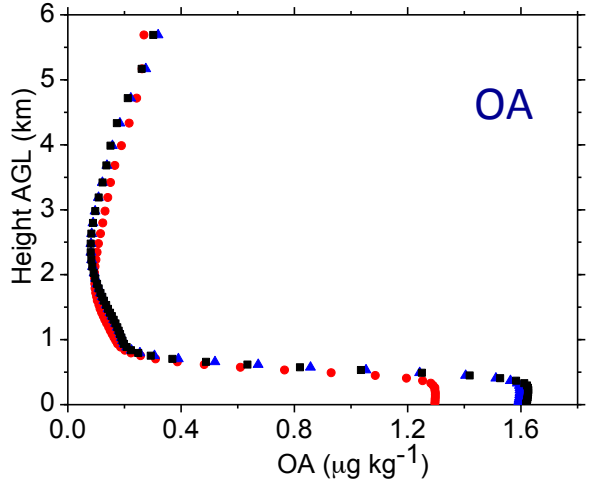


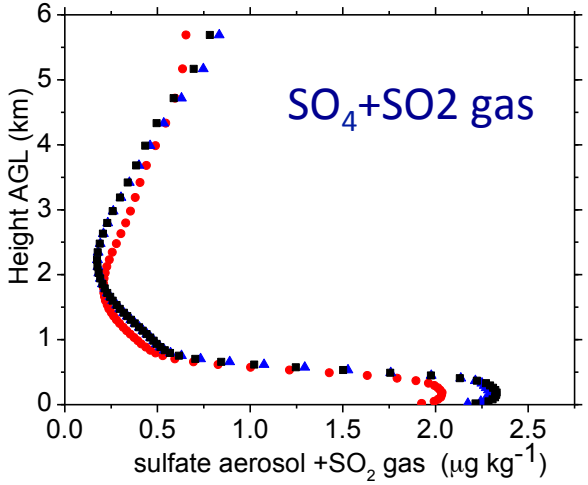


Average Mass Loading: AUS Box



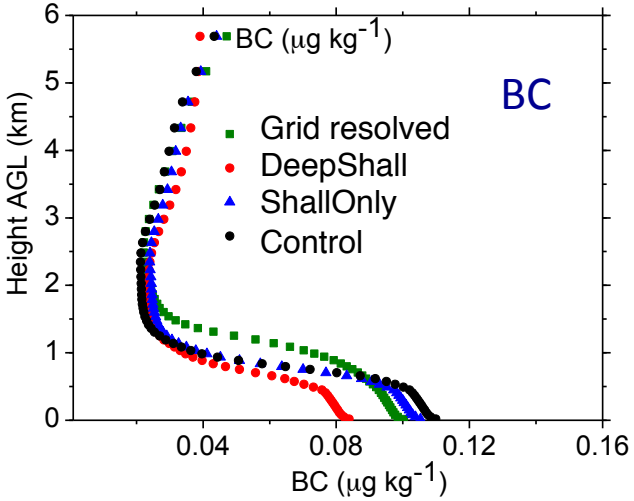
- Reduction in BL loading
- Relatively large difference in DeepShall and ShallOnly





Average Mass Loading: OKC Box

06/25 at 20 UTC: Horizontal average over 242×242 km box
Sum of interstitial and cloud-borne aerosols (size 39-625 nm)



- Reduction in BL loading
- Relatively large difference in DeepShall and ShallOnly
- Too large a reduction in boundary layer using DeepShall?