A New Treatment for Studying Regional Scale Impacts of Cloud-Aerosol Interactions in Parameterized Cumuli

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Motivation

To date, the treatment of cloud-aerosol interactions has been largely limited to grid-resolved clouds. We demonstrate in WRF-Chem a methodology to include the treatment of processes important for treating aerosol within sub-grid convective clouds, including: fractional coverage of active and passive clouds, vertical transport, activation and suspension, wet removal, and aqueous chemistry. **The modified version of WRF-Chem provides a new tool for studying the regional scale impacts of cloud-aerosol interactions.**

Modifications to the Parameterizations

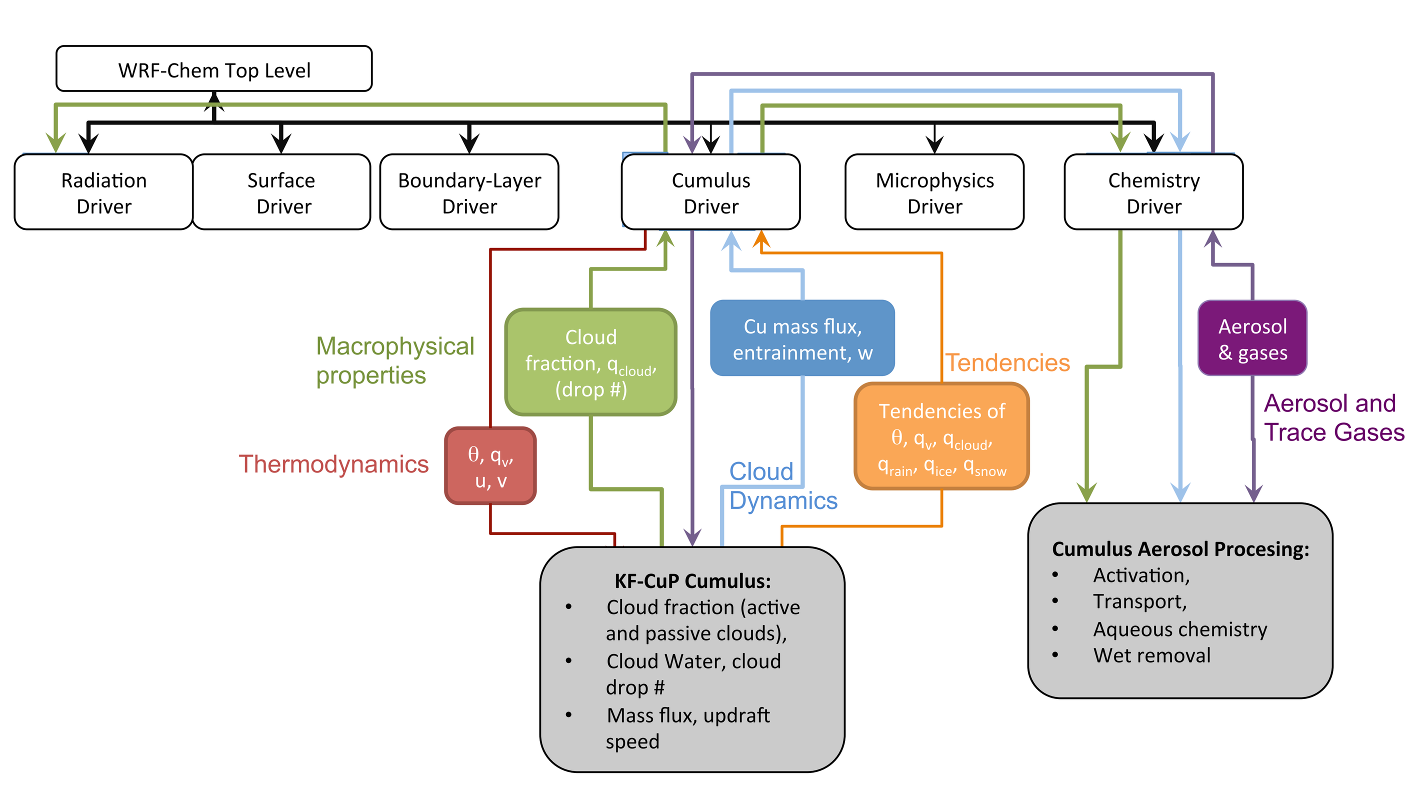
Accounting for Shallow Clouds

The Kain-Frisch (Kain and Fritsch, 1990) parameterization has been modified to better simulate shallow cumuli. These changes include improved treatment of the convective trigger, using the Cumulus Potential (CuP) scheme (Berg et al. 2013) and the cloud fractional area.

Accounting for Cloud-Aerosol Interactions

A number of modifications to WRF-Chem have been implemented in this study to specifically address cloud-aerosol interactions in sub-grid convective clouds, and are shown in the figure below. These modifications include calculations for:

- Cloud droplet number mixing ratio in the KF-CuP cumulus module.
- Cloud microphysical (conversion rates, cloud water and ice mixing ratios) and cloud macrophysical properties (updraft fractional area, updraft and downdraft mass fluxes, and entrainment).
- Vertical transport, activation/resuspension, aqueous chemistry, and wet removal of aerosols and trace gases in a new KF-CuP aerosol/gas processing module.

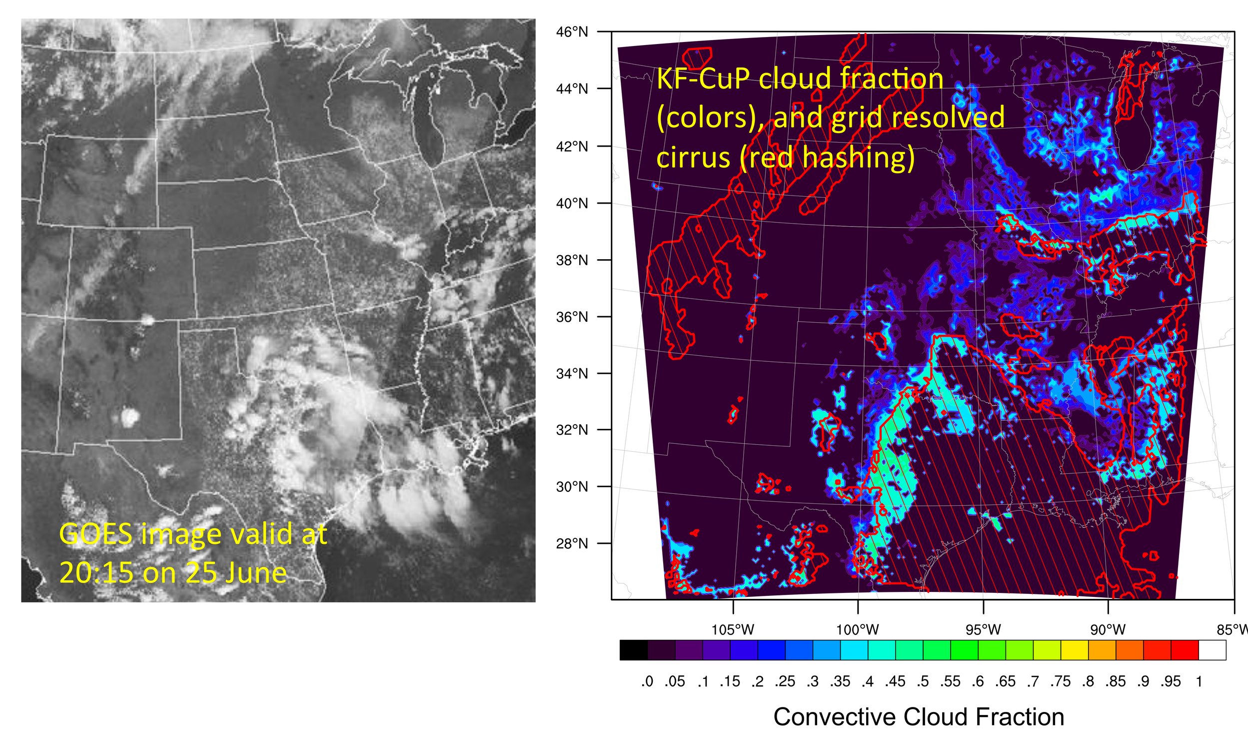


Information flow with the new schemes. Gray boxes indicate new (aerosol processing) or modified (cumulus physics) parameterizations applied in WRF-CHEM.

Case Study: 25 June 2007

The case study was based on the Cumulus Humilis Aerosol Processing Study (CHAPS; Berg et al. 2009) and high-resolution simulations of Shrivastava et al (2013).

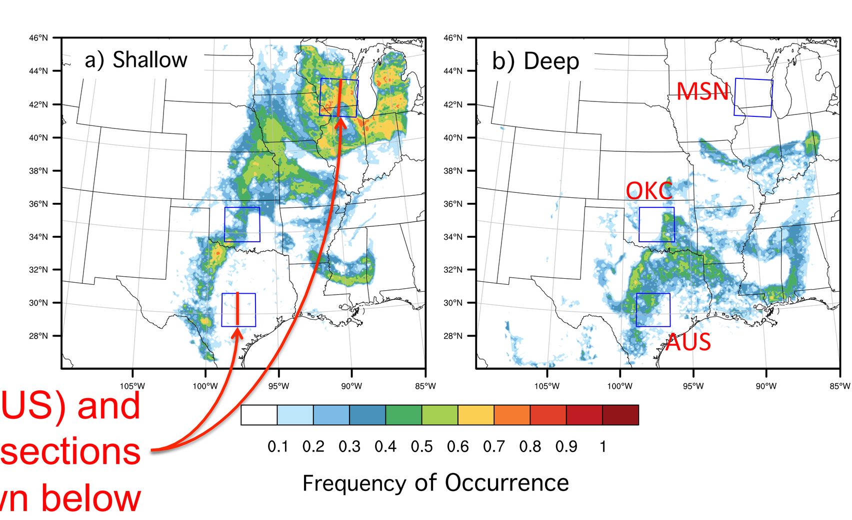
Observed and Simulated Cloud Cover



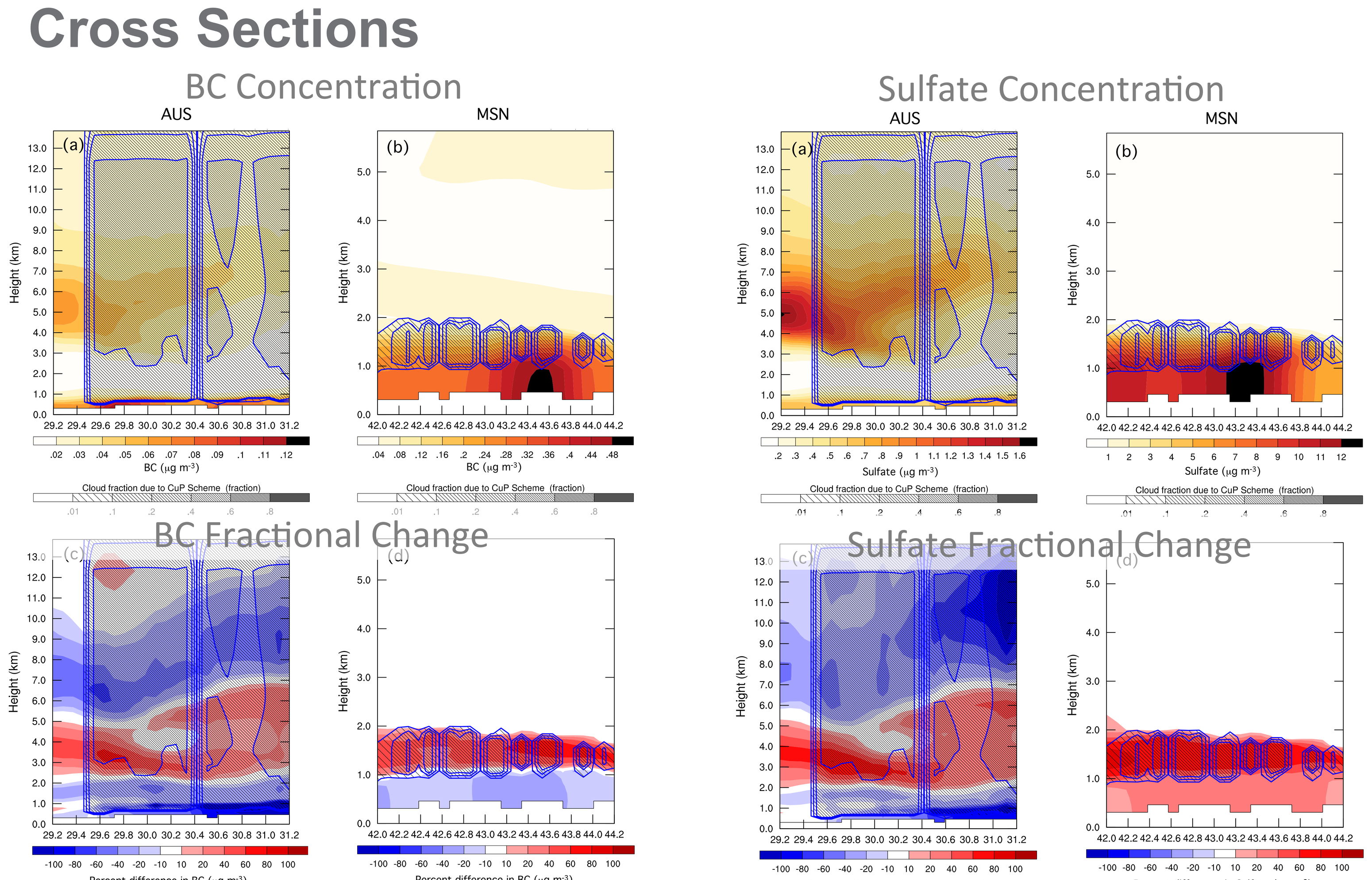
Regions of Shallow and Deep Convection

Shallow and deep cumulative cloud frequency from 12:00-20:00 UTC on 25 June

Location of Austin (AUS) and Madison (MSN) cross sections shown below



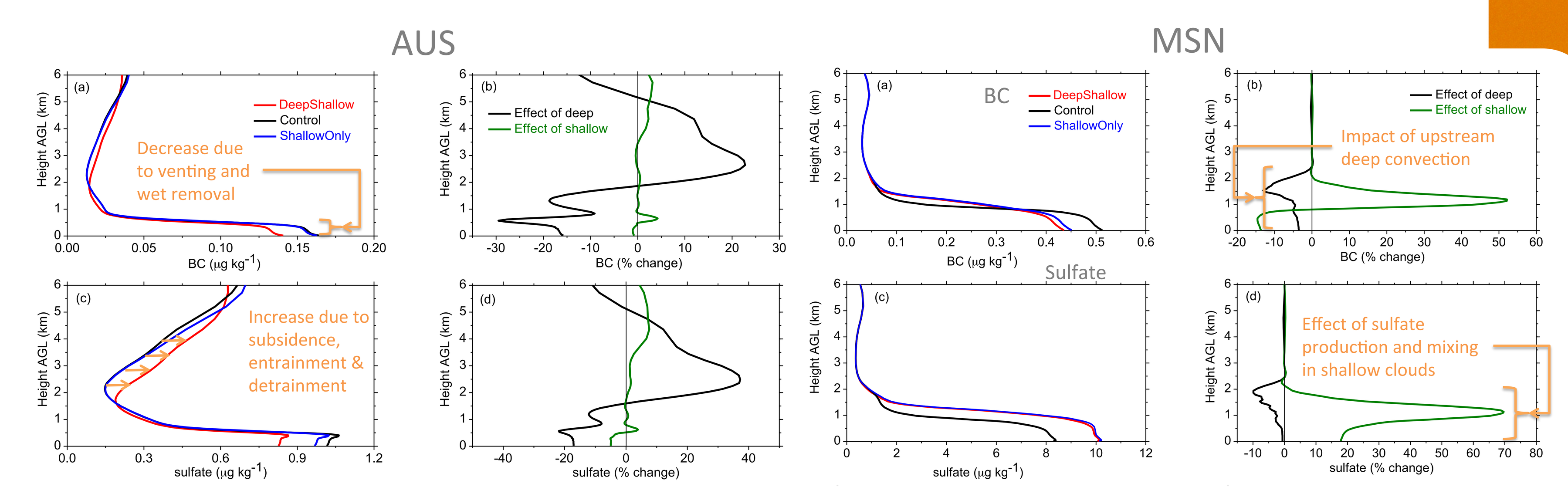
Cumulus Effects on BC and Sulfate-Vertical Cross Sections



Vertical north-south cross sections of BC and sulfate. Color shading shows concentration (top) and percentage change between simulations with/without the new parameterization (bottom). Stippling shows convective cloud fraction.

Cumulus Effects on BC and Sulfate-Vertical Profiles

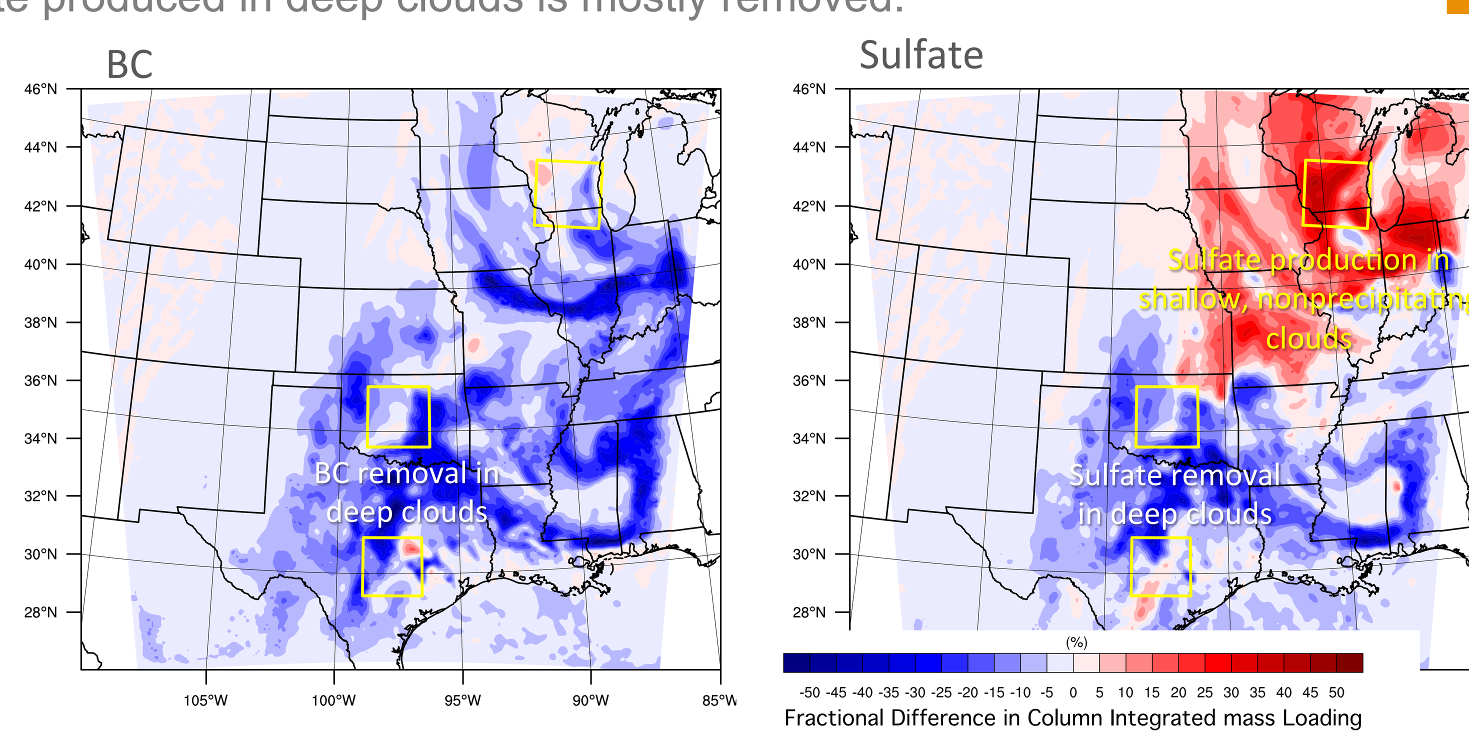
Vertical profiles of BC and sulfate from different simulations (horizontally average over the AUS and MSN boxes) highlights the impacts of deep and shallow convection.



Simulated mass loading, and fractional change for both deep and shallow clouds on BC and sulfate simulated using the full parameterization (red), shallow clouds only (blue), and control (black) for the AUS and MSN boxes valid at 20:00 UTC.

Cumulus Effects on BC and Sulfate Column Burdens

The changes in column burdens show the impact of BC and sulfate wet removal in deep cloud and sulfate production in shallow clouds. Note that sulfate produced in deep clouds is mostly removed.



Conclusions and Future Work

A new treatment of cloud-aerosol interactions within parameterized shallow and deep convection has been implemented in WRF-Chem with the goal of improving regional scale simulations of the aerosol lifecycle and cloud-aerosol interactions. Results show that:

- WRF-Chem simulations behave in a manner consistent with expectations.
- Both deep and shallow convective clouds have an important impact on the horizontal and vertical distribution of aerosol loading.
- For shallow convective clouds in the Madison area, enhanced mixing leads to a deepening of the layer containing BC and decreased amounts of BC near the surface.
- For deep convective clouds in the Austin area, there was a decrease in BC and sulfate in the sub-cloud layer due to vertical transport. There were also significant changes in the aerosol loading aloft that were the result of the impacts of transport (by updrafts, downdrafts, and entrainment) and wet removal.

The new parameterizations will be tested using data from a number of different ARM campaigns including TCAP and GoAmazon.

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