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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

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Motivation

- 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

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)
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

Fraction of time with deep or shallow convection

12-20 UTC on 25 June 2007
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
Vertical Cross Section: $\Delta BC$

Convective clouds lead to changes in the vertical structure $BC$

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

BC moved from sub-cloud to cloud layer

No wet removal in MSN box
Vertical Cross Section: $\Delta$Sulfate

Convective clouds lead to changes in vertical structure of sulfate loading

- If no precipitation—increase in sulfate loading due to cloud chemistry

$\Delta$Sulfate = \frac{(Sulfate_{Cumulus} - Sulfate_{Control})}{Sulfate_{Control}}
Changes in Mass Loading Near AUS: Dominated by Deep Convection

- **BC** (% change)
  - Effect of deep
  - Effect of shallow

- **Sulfate** (% change)
Changes in Mass Loading Near MSN: Dominated by Shallow Convection

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

Column integrated mass loading

- **BC**: Generally decreases due primarily to wet removal
- **Sulfate**: Can increase or decrease depending on precipitation
Summary and Next Steps

- 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

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Test Case: CHAPS

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 backscatter, extinction

OVERVIEW OF THE CUMULUS HUMILIS AEROSOL PROCESSING STUDY

Case study: 25 June, 2007
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)
Differences in cloud fraction between the three boxes

![Graph showing differences in cloud fraction between three boxes: AUS, MSN, OKC. The graph plots cloud fraction against height (km) with three lines representing different boxes.]
Vertical Cross Section: Sulfate

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

Sulfate from distant wildfires

Sulfate in boundary layer
Conditions in AUS box dominated by deep convection

(a) BC (μg kg⁻¹) vs Height AGL (km)

(b) BC (% change) vs Height AGL (km)

(c) Sulfate (μg kg⁻¹) vs Height AGL (km)

(d) Sulfate (% change) vs Height AGL (km)

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

(a) Height AGL (km) vs BC (µg kg⁻¹)

(b) Height AGL (km) vs BC (% change)

(c) Height AGL (km) vs sulfate (µg kg⁻¹)

(d) Height AGL (km) vs sulfate (% change)

Results from convection upstream of the MSN box.
Changes in Mass Loading Near OKC

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

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