Modeling aerosols and their interactions with shallow cumuli
during the 2007 CHAPS field study


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Effect of aerosols on clouds: large uncertainty in 3D models
Previous studies focused on stratiform or deep convective clouds
Short-lived shallow cumuli common in North America and many places in the world
Sub-grid scale processes difficult to simulate using coarse grid regional models

Cumulus Humilis Aerosol Processing Study (CHAPS), Oklahoma City
- June 2007
- Moderately sized city (represents several cities in North America)
G-1 aircraft instrumentation

- Two inlets
  - Cloud droplets sampled by Counter Flow Virtual Impactor (CVI)
  - Aerosols ($D_p < 2\mu m$) sampled by Isokinetic inlet
- Nearly identical instrumentation on each inlet
- Detailed size and composition
  - PCASP & CAPS probes, SMPS, FIMS - particle and cloud droplet size distributions
  - Nephelometer, PSAP - particle optical properties
  - DMT CCN counter
  - AMS - Aerosol chemical composition
- Trace gases: CO
- Flight pattern:
  - In and out of plume
  - Below, within, and above the cloud layer
WRF-Chem configuration

- Simulation: 18-25 June 2007
- Model physics:
  - 10 km outer and 2 km nested domain
  - Nested domain: 242×242 km around Oklahoma City
  - Morrison 2-moment microphysics
  - Kain-Fritsch (new Eta) cumulus scheme on 10 km outer domain
- Emissions and chemistry:
  - EPA NEI 2005 emissions inventory
  - SAPRC-99 gas chemistry
  - MOSAIC for inorganic aerosols
  - 2-species VBS → Anthropogenic SOA (Shrivastava et al. 2011)
  - MEGAN for biogenic emissions & literature biogenic SOA yields
Organic aerosol (OA) below clouds on 25th June

WRF-Chem qualitatively simulates non-refractory aerosols and trace gases reasonably well within the Oklahoma City plume.

- E.g. OA concentrations simulated by WRF-Chem agree with AMS measurements.
Aerosol optical property simulations

- Simulations assume internal mixture and volume weighted mixing rule for optical calculations

- Uncertainties:
  - Aerosol water content
  - High ambient relative humidity (~80%) during CHAPS → aerosols may retain significant water (sampled at 40% RH)
  - Simulations: Refractory other inorganics (OIN) large contribution to fine aerosols
  - OIN: crustal, dust, or other unspecified sources (e.g. off-road diesel engines), not measured
  - Size distribution, hygroscopicity and complex refractive index of OIN unknown
Aerosol optical properties in clear sky below clouds

Along aircraft flight: 25th June 2007

Absorption increases and SSA decreases within plumes
WRF-Chem simulations reproduce this trend qualitatively
Results sensitive to aerosol water, OIN content and complex refractive index of OIN 

→ need to characterize fine aerosol OIN content and properties
Cloud processing changes aerosol chemical composition: Nitrate

Observations show large enhancement in nitrate content of cloud droplet residuals

- Consistent with previous studies (Sellegri et al. 2003; Hayden et al. 2008)
- Model reproduces the large enhancement of nitrate in cloud drops
- Uptake of HNO₃ vapor on cloud droplets causes this nitrate enhancement
Aerosol effects on clouds: Effects of vertical velocity and pollutant loading

Both vertical velocity and pollutant loading affect cloud properties.

- Box → effect of pollutant loading (CO’) for a narrow range of vertical velocity

Similar to Berg et al. 2011

\[ \text{CO'} = \text{CO} - \text{CO_{bkg}} \]
Simulations clearly indicate first aerosol indirect effect

- CDNC increases and $r_{\text{eff}}$ decreases with increase in pollutant loading
- First Aerosol Indirect Effect consistent with observations (Berg et al. 2011)
Conclusions

- Below cloud optical simulations show increase in light absorption and decrease in SSA within the Oklahoma City plumes as observed.
- Need to routinely measure other inorganic (refractory) part of fine aerosols in addition to non-refractory components.
- Impact of clouds on aerosols:
  - Cloud chemistry changes aerosol composition.
  - Cloud droplets show enhanced nitrate due to uptake of HNO₃ vapor consistent with other studies in different cloud types and air masses.
- Impact of aerosols on clouds:
  - Simulations clearly show First Aerosol Indirect Effect consistent with analysis of observations during CHAPS.
  - Even moderately sized Oklahoma city has measurable impacts on cloud microphysics, and aerosol optical properties.
- WRF-Chem with 2 km grid spacing captures key relationships between aerosol processes and cloud microphysical properties.
Future work

- Coupled cloud-aerosol meteorology simulations at high resolution (small grid spacing) already computationally expensive

- New shallow cumulus parameterization shown to better simulate sub-grid scale shallow cumuli at coarser grid resolution (Berg et al. 2013)

- Ongoing work: coupling aerosols, chemistry and the revised SOA scheme using VBS to the new KF-CUP cumulus parameterization

- Evaluating aerosol-cloud interactions in coarse grid models
Satellite reflectivity (grayscale) vs. simulated cloud fraction (colorbar)