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

Manish Shrivastava,[1] Larry K. Berg,[1] Jerome D. Fast,[1] Richard C. Easter,[1] Alexander Laskin,[2] Elaine G. Chapman,[1] William I. Gustafson Jr.,[1] Ying Liu,[1] and Carl M. Berkowitz[1]

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Modeling aerosols and their interactions with shallow cumuli

MANISH SHRIVASTAVA

L.K. BERG, J.D. FAST, R.C. EASTER, A. LASKIN, E.G. CHAPMAN, W.I. GUSTAFSON JR., Y. LIU, C.M. BERKOWITZ

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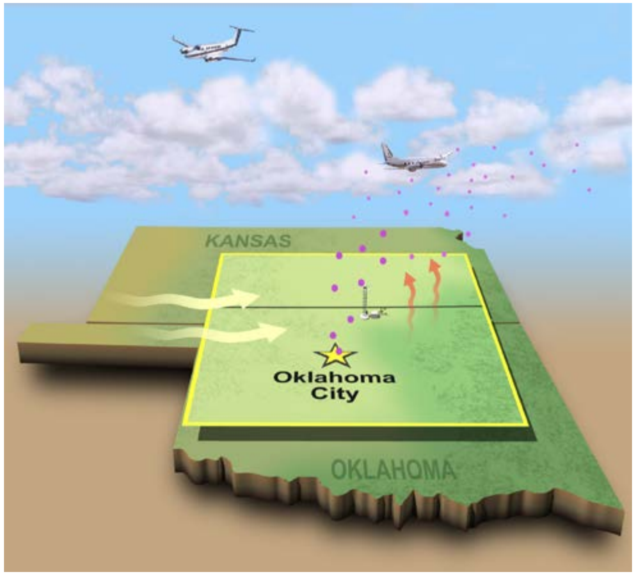
Motivation

- 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

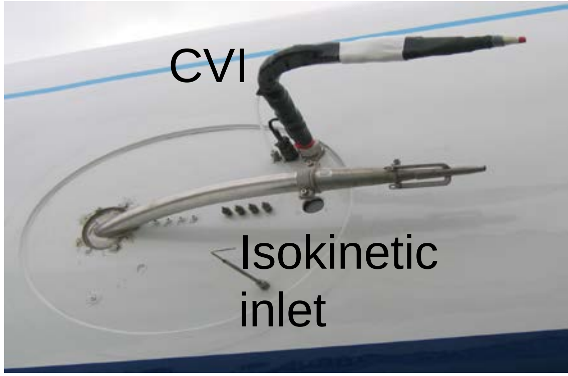
- Cumulus Humilis Aerosol Processing Study (CHAPS), Oklahoma City
  - June 2007
  - Moderately sized city (represents several cities in North America)

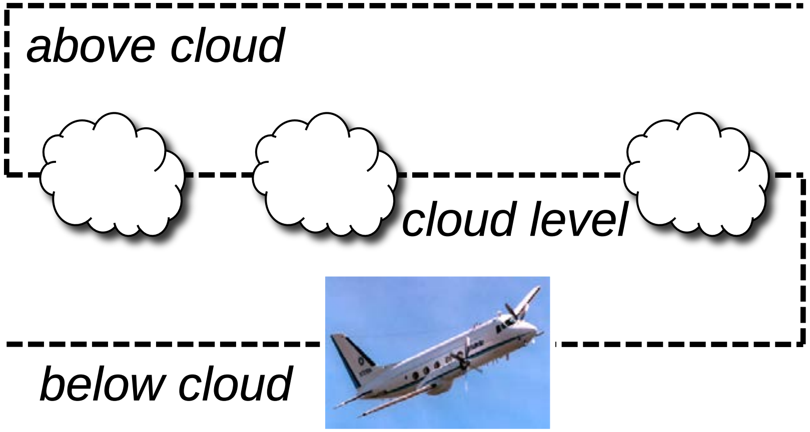


G-1 aircraft instrumentation

- Two inlets
  - Cloud droplets sampled by Counter Flow Virtual Impactor (CVI)
  - Aerosols (D_p<2μm) 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

Dual inlets



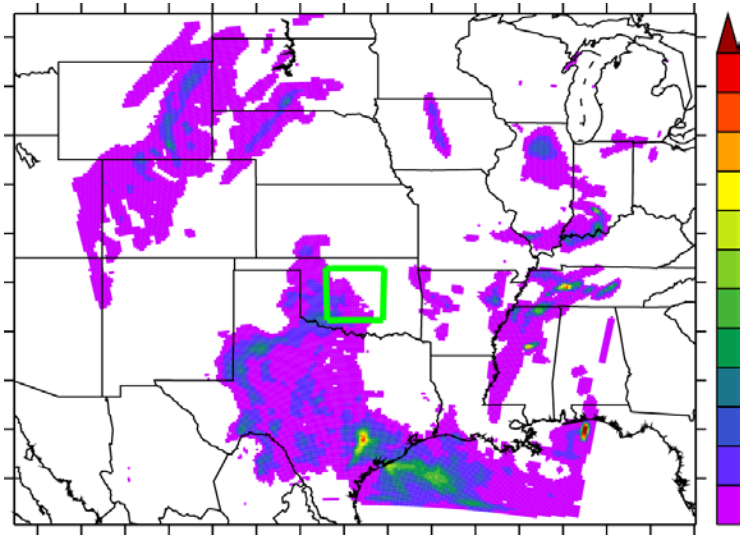


WRF-Chem configuration

- 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

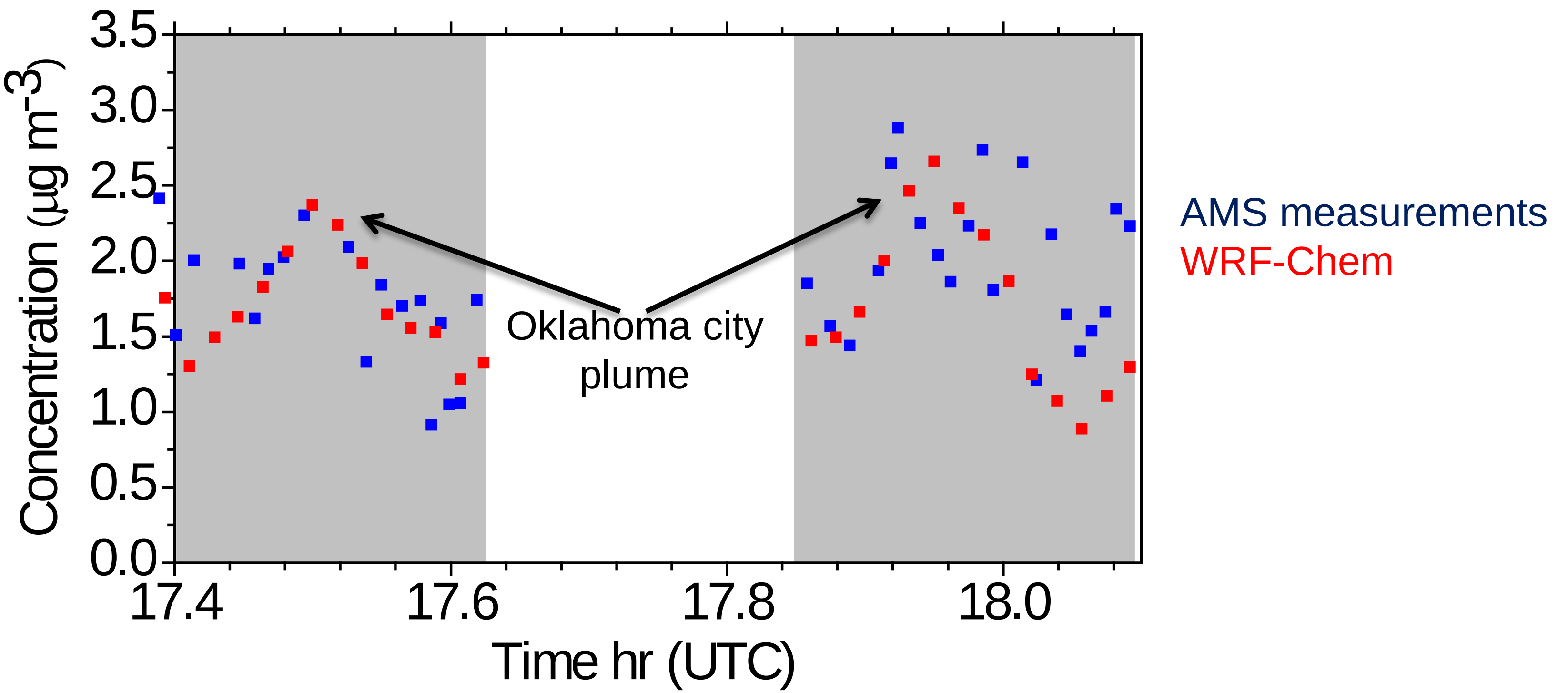
    (Shrivastava et al. 2011)
  - MEGAN for biogenic emissions & literature biogenic SOA yields

WRF-Chem domain



Analyze cloud-aerosol interactions for the green box

Organic aerosol (OA) below clouds on 25th June



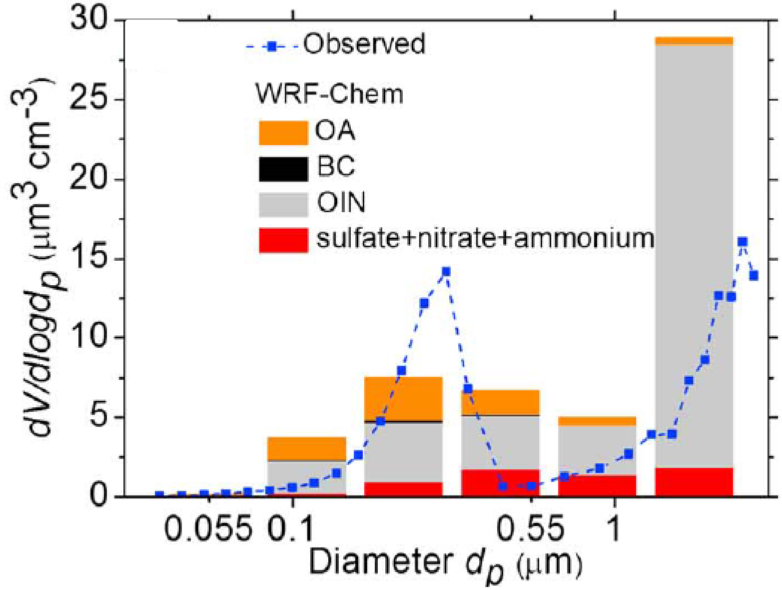
- WRF-Chem qualitatively simulates non-refractory aerosols and trace gases reasonably well within the Oklahoma City plume
- E.g. OA concentrations simulated by WRF-Chem agree with AMS measurements

Aerosol optical property simulations

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

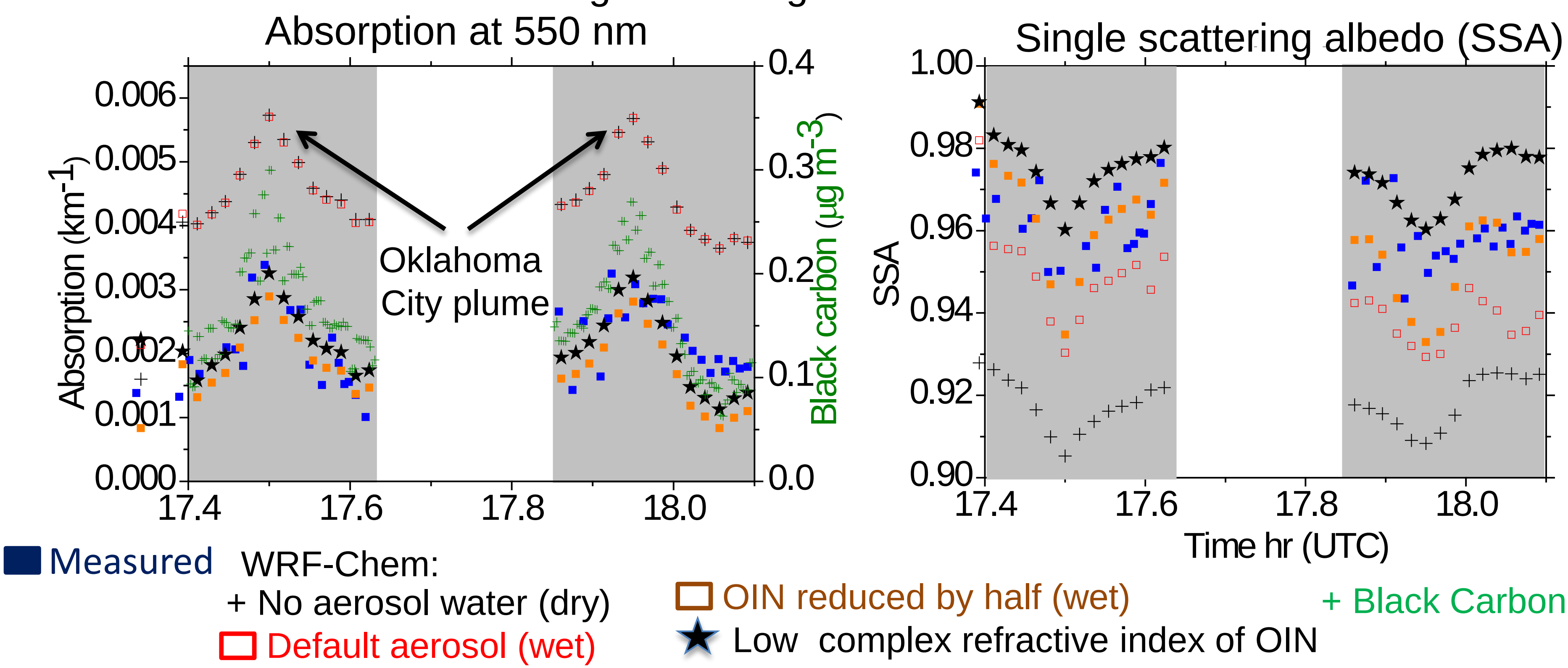
- Uncertainties:
  - Aerosol water content
  - High ambient relative humidity (~80%) during CHAPS → aerosols may retain significant water (sampled at 40% RH)
  - Simulations : Refractory other inorganics (OIN) large contribution to fine aerosols
  - OIN: crustal, dust, or other unspeciated sources (e.g.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

Simulated aerosol volume below cloud: 25th June



Aerosol optical properties in clear sky below clouds

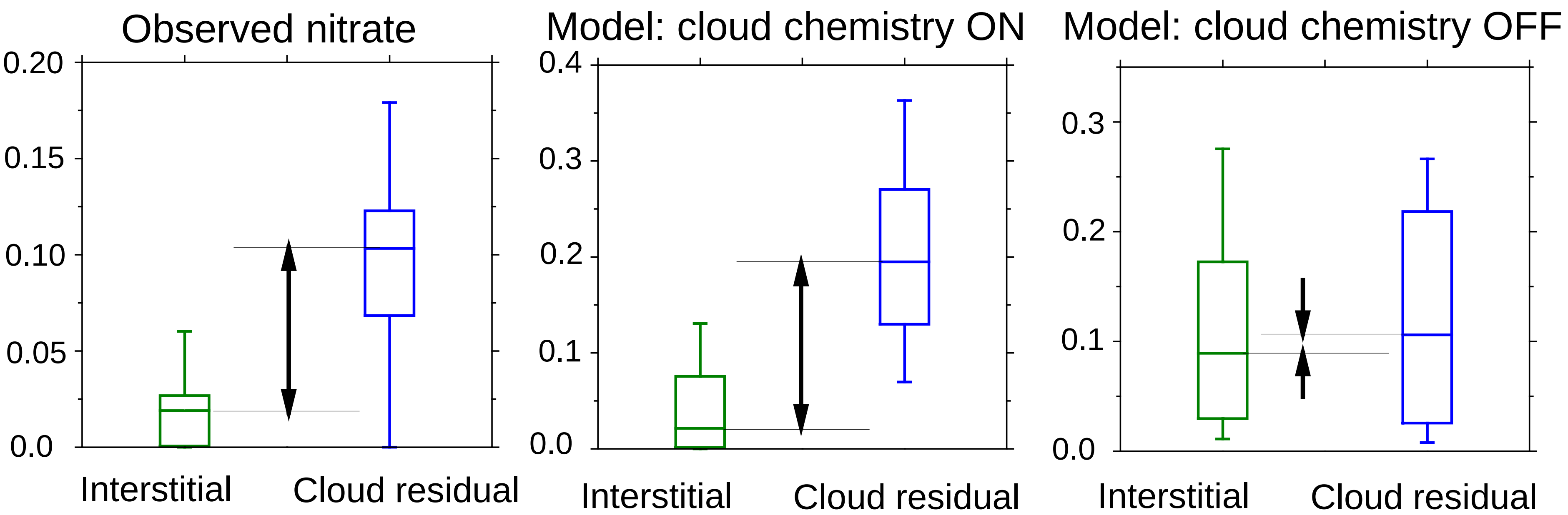
Along aircraft flight: 25th June 2007



- 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

Along aircraft flight: 25th June 2007



- 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 HNO_3 vapor on cloud droplets causes this nitrate enhancement

Aerosol effects on clouds: Effects of vertical velocity and pollutant loading

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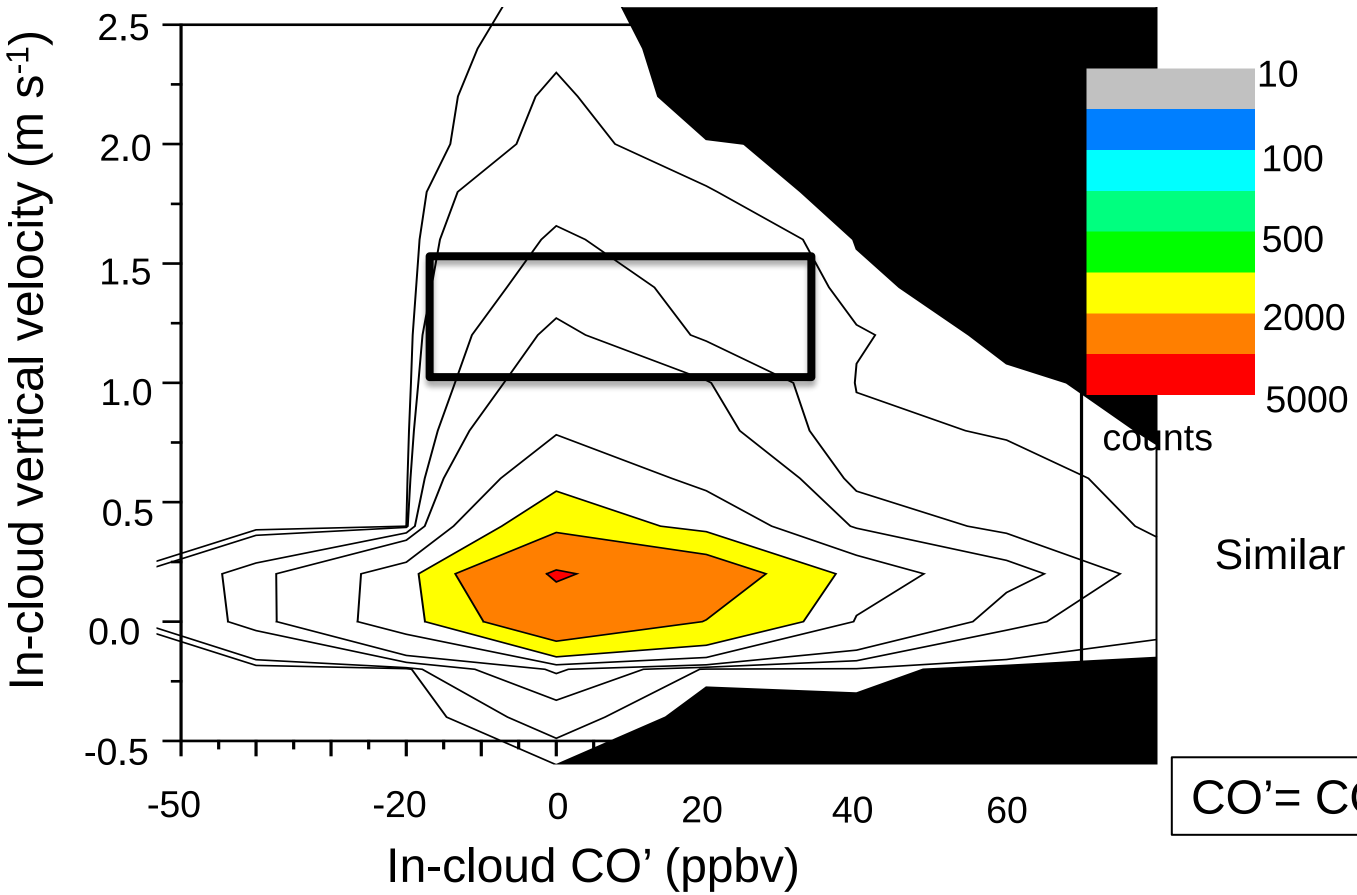
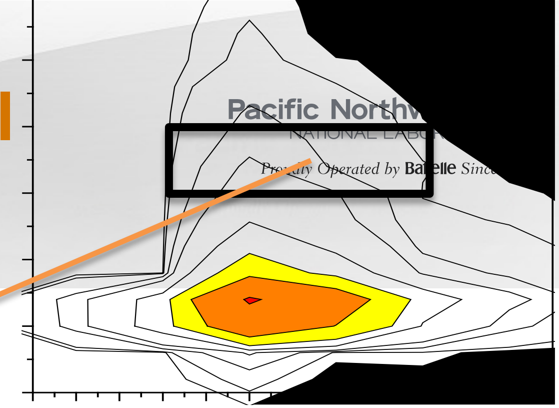


Similar to Berg et al. 2011

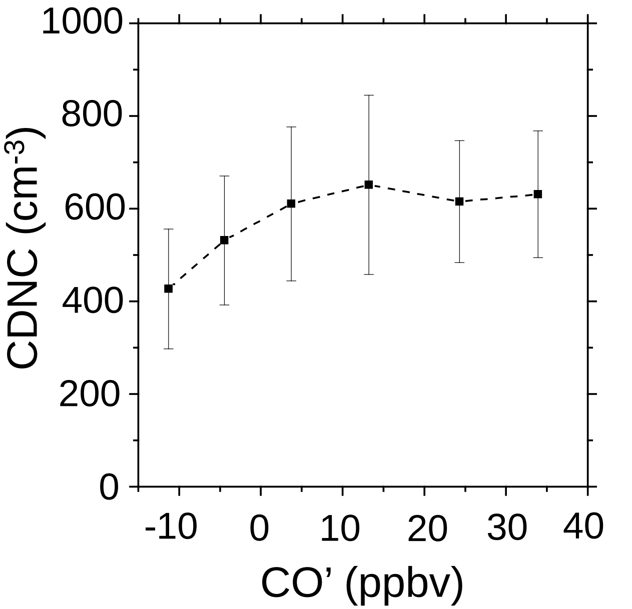
$CO' = CO - CO_{bkg}$

- Both vertical velocity and pollutant loading affect cloud properties
- Box → effect of pollutant loading (CO') for a narrow range of vertical velocity

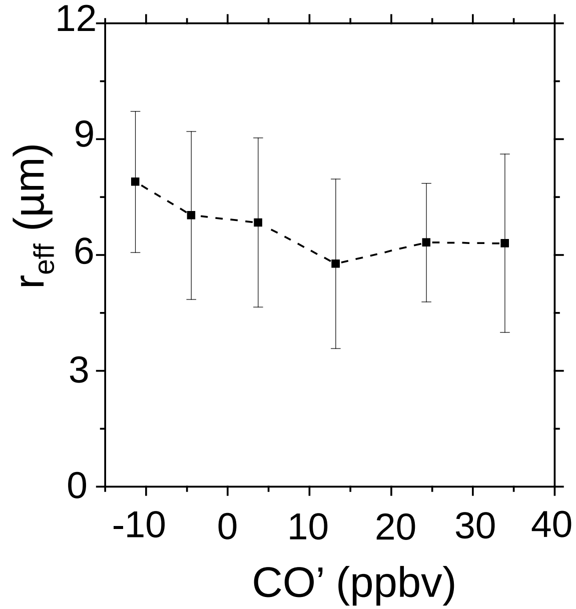
Simulations clearly indicate first aerosol indirect effect



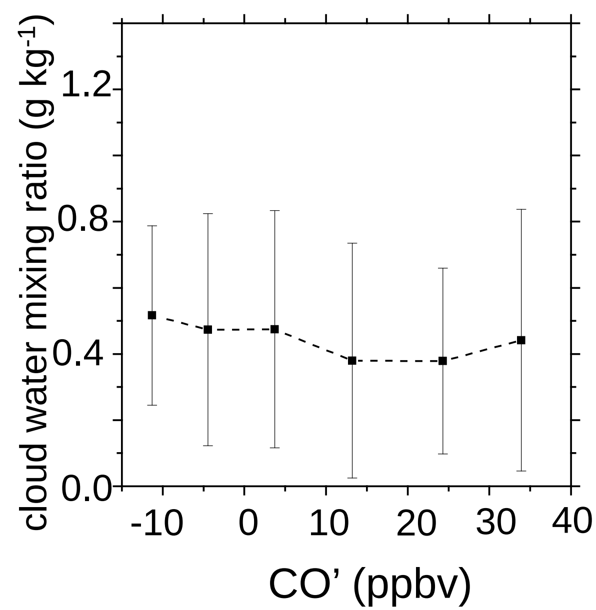
Cloud droplet number (CDNC)



Droplet effective radius (r_{eff})



Cloud water mixing ratio



- CDNC increases and r_{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 HNO_3 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

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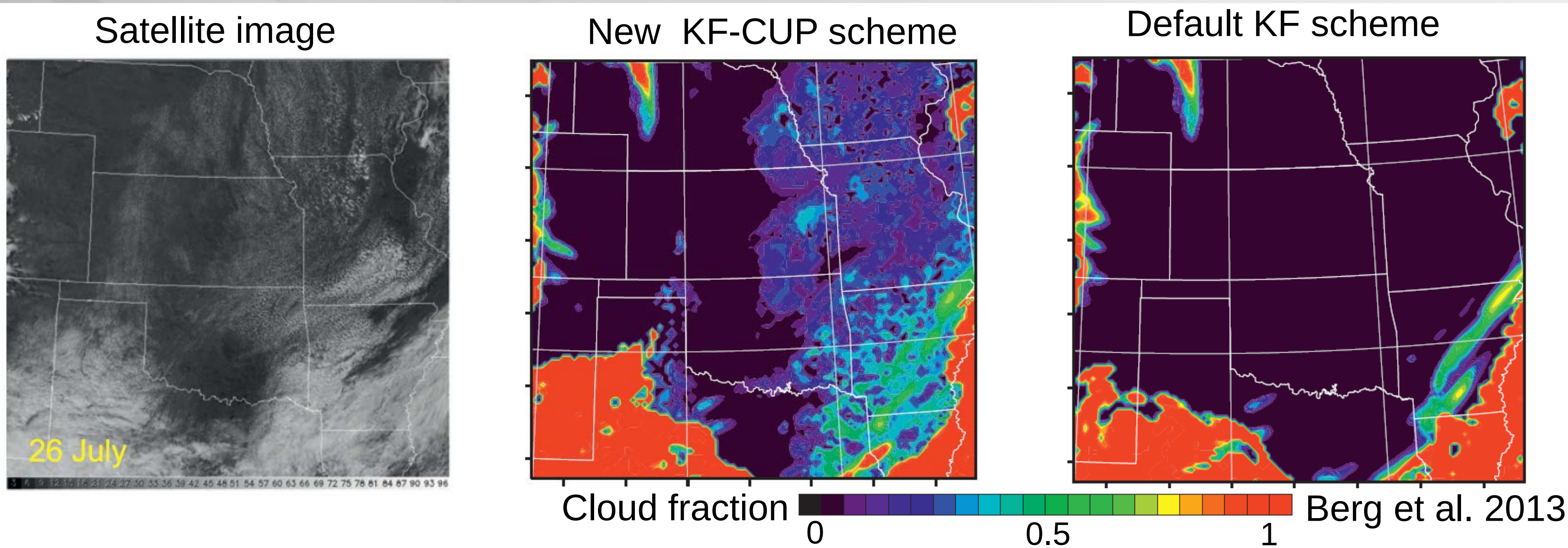

- Coupled cloud-aerosol meteorology simulations at high resolution (small grid spacing) already computationally expensive
- New shallow cumulus parameterization shown to better simulate sub-grid scale shallow cumuli at coarser grid resolution (Berg et al. 2013)
- Ongoing work: coupling aerosols, chemistry 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)