# Simulating Aerosols Entrained into Fair Weather Cumulus during CHAPS

J.D. Fast, M. Shrivastava, E.G. Chapman, and L.K. Berg, Pacific Northwest National Laboratory
R. Ferrare, and C. Hostetler, NASA Langley Research Center

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

Motivation

The Cumulus Humulis Aerosol Processing Study (CHAPS) was conducted in June 2007 to provide concurrent observations of chemical composition of activated and non-activated aerosols, scattering and extinction profiles, and aerosol and droplet size spectra in the vicinity of Oklahoma City [*Berg et al.*, GRL, 2011].
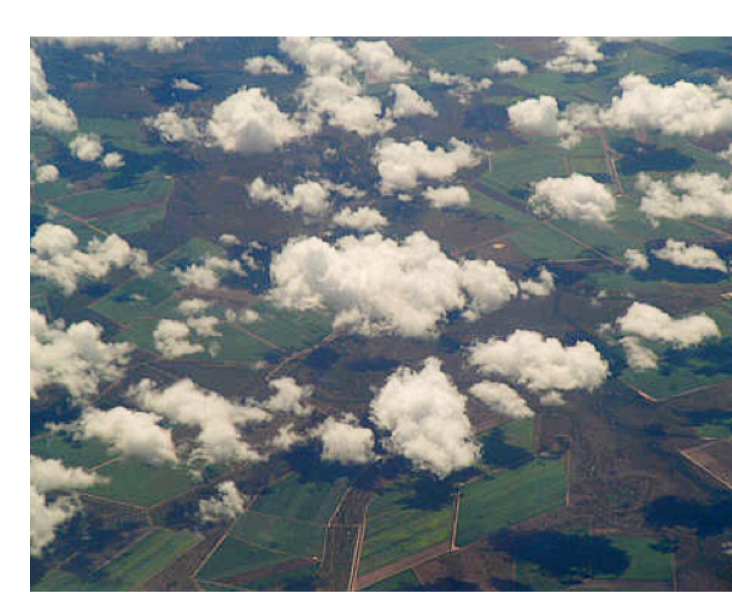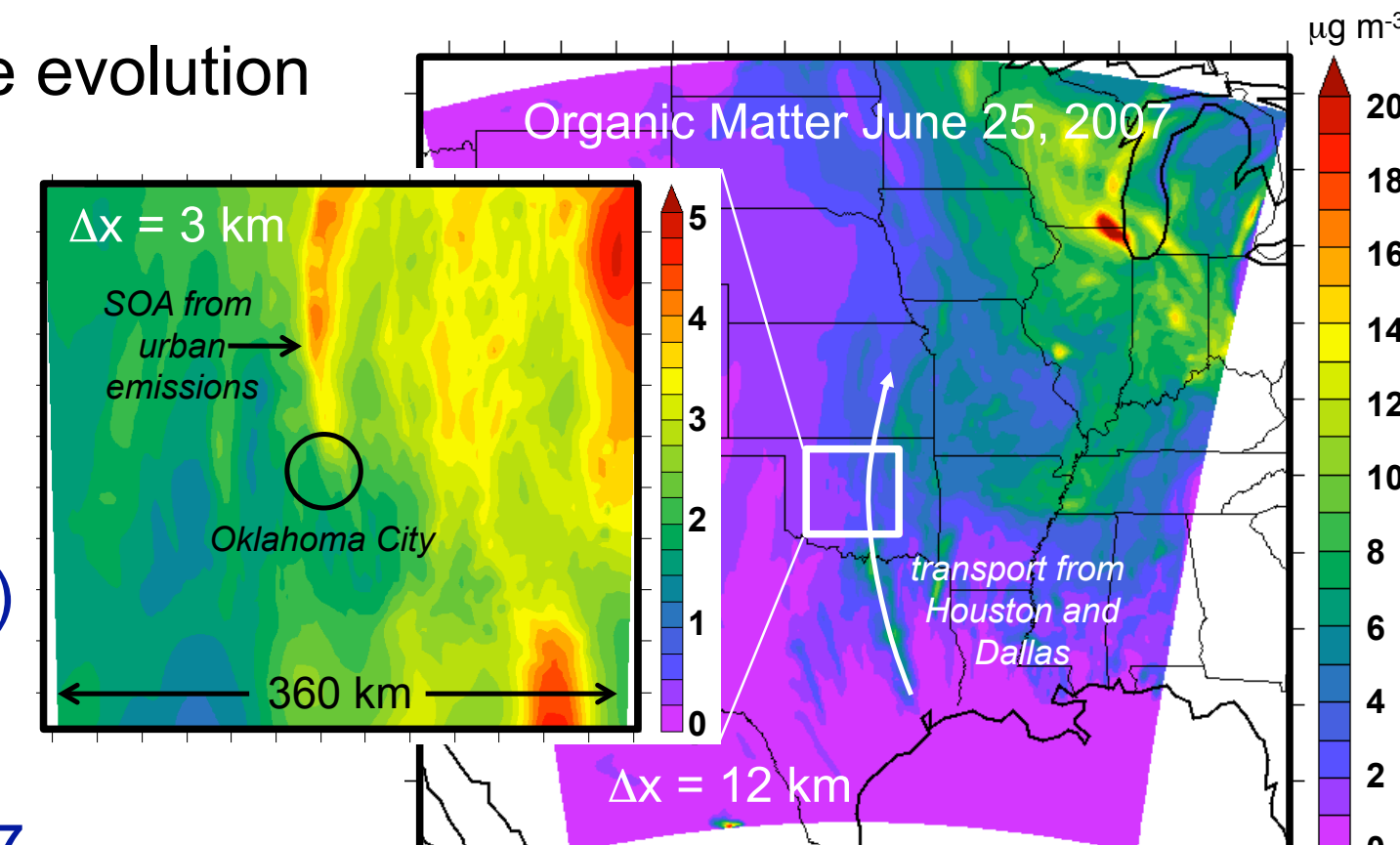
- ► Even moderately sized cities can have a measureable impact on the optical properties of shallow cumuli
- ► Statistically significant changes in CDNC, r_{eff}, and dispersion of cloud drop size distribution found to be a function both updraft draft strength and pollutant loading
- ► Both cloud dynamics and aerosol loading need to be considered when investigating aerosol indirect effects

We are currently investigating whether regional-scale models are capable of simulating these effects and testing improved approaches of treating aerosol processing in sub-grid scale shallow clouds.

Approach

Use the WRF-Chem model to simulate the evolution of aerosols, clouds, and their interactions.

- ► **Boundary Layer:** YSU
- ► **Surface Layer:** Noah
- ► **Microphysics:** Morrison
- ► **Cumulus:** Betts-Miller-Janic
- ► **Radiation:** Goddard (SW), RRTM (LW)
- ► **Photochemistry:** SAPRC99
- ► **Aerosols:** MOSAIC + VBS SOA
- ► **Simulation Period:** June 18 – 27, 2007
- ► **Boundary conditions:** GFS and MOZART model

Organic Matter June 25, 2007
$\Delta x = 3$ km
SOA from urban emissions
Oklahoma City
360 km
Transport from Houston and Dallas
$\Delta x = 12$ km

Step 1 (this work)

Perform simulation of aerosols and clouds <u>without</u> cloud-aerosol interactions and wet removal
- ► Are the simulated aerosol properties qualitatively similar to observed interstitial aerosols ?
- ► Are the simulated boundary layer properties and clouds statistically similar to observed conditions ?

yes ↓ *no* → *revise model setup*

Step 2 (next phase)

Perform simulation <u>with</u> cloud-aerosol interactions and wet removal
- ► How sensitive are activated aerosols to assumptions of hygroscopicity for aerosol compositions ?
- ► Are the simulated in-cloud aerosols statistically similar to aerosols sampled within cumulus clouds ?

yes ↓ *no* → *revise model setup*

Step 3

Perform simulation that also includes shallow cumulus parameterization, CuP, with chemistry
- ► What is the relative role of processing of aerosols within clouds between simulations with resolved and parameterized shallow cumulus clouds ?
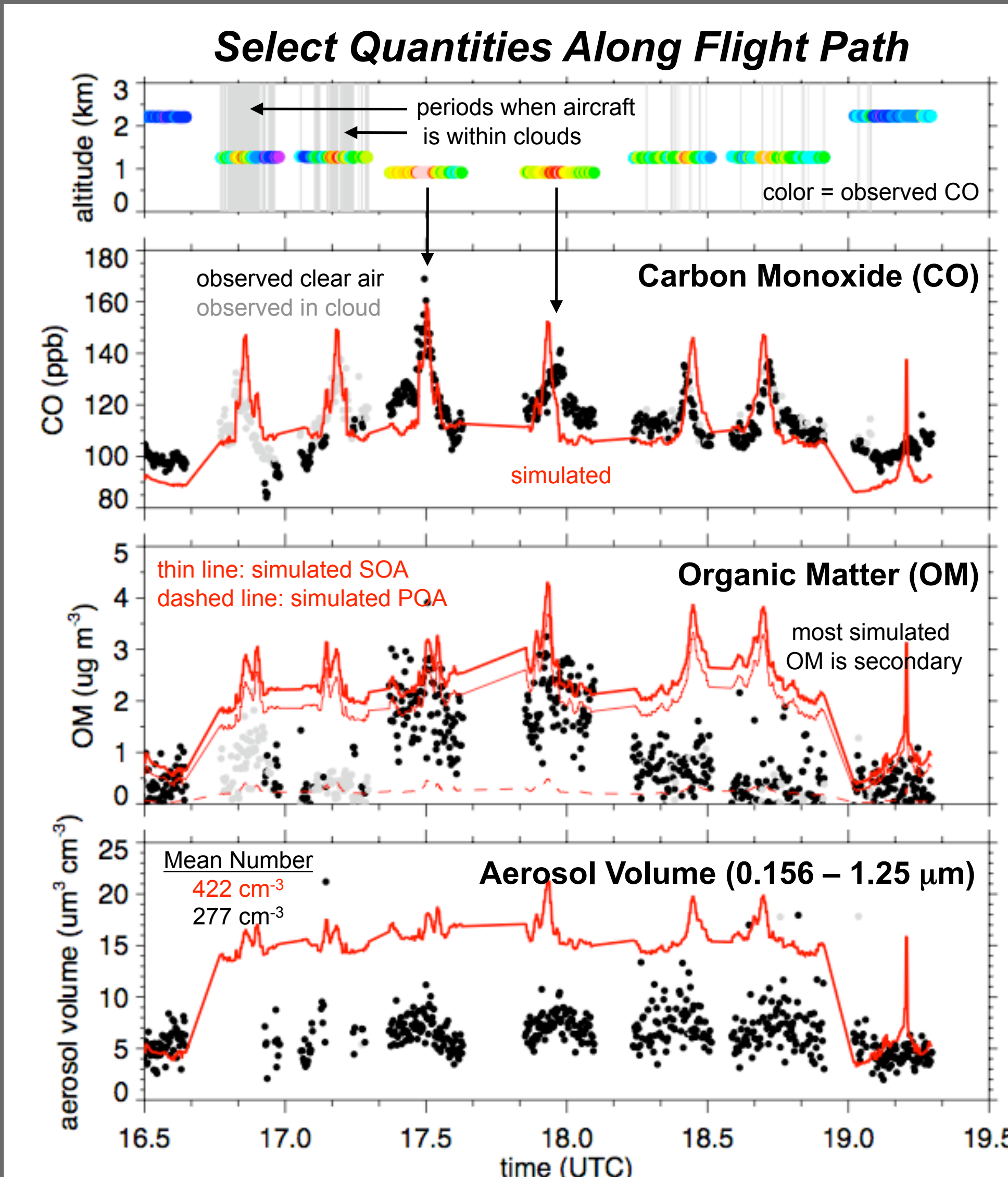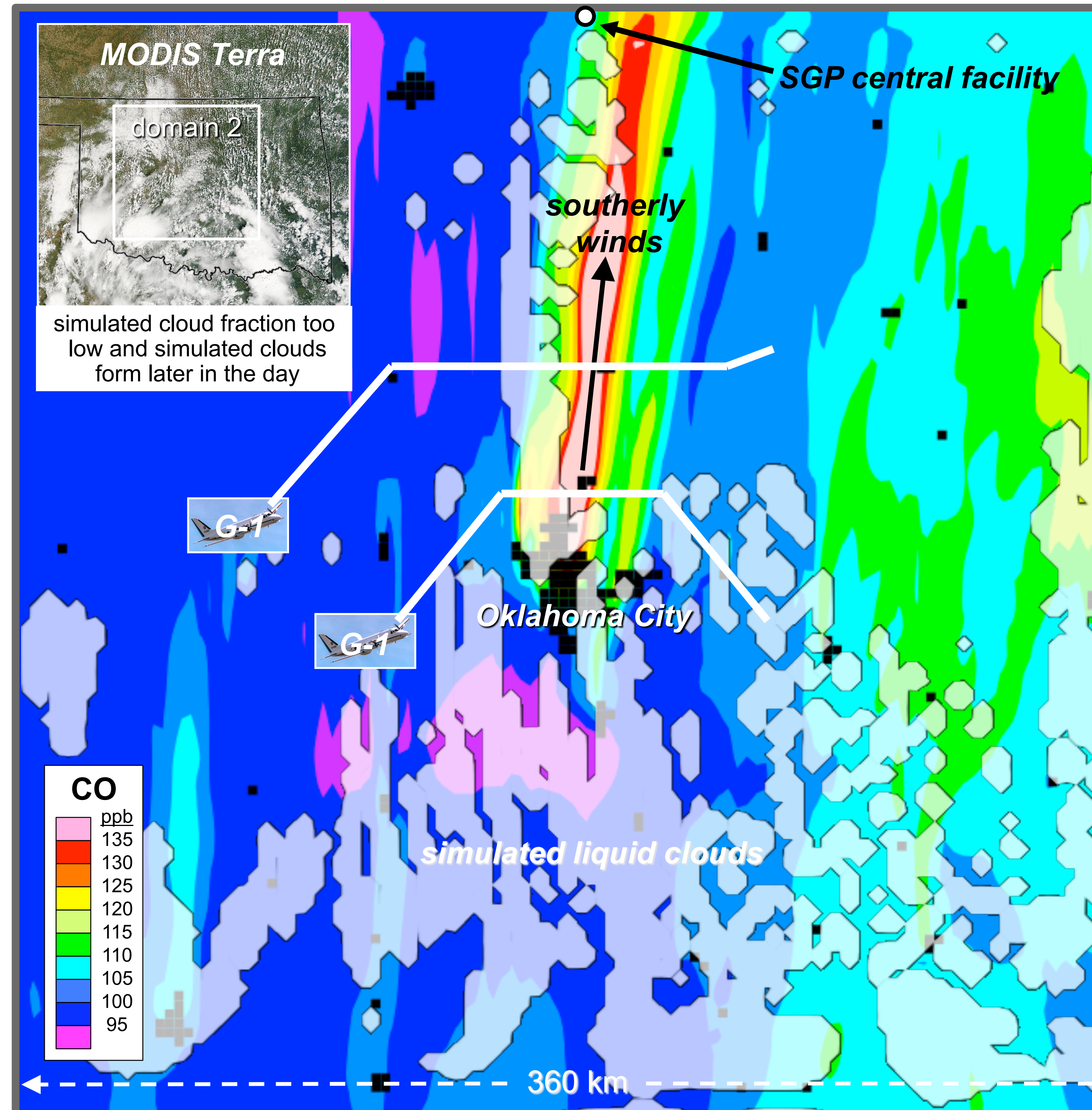- ► Is cloud fraction simulated better with CuP ?

yes ↓ *no* → *revise model setup*

Step 4

Assess the impact of aerosol processing within cumulus over the entire regional (central U.S.) domain
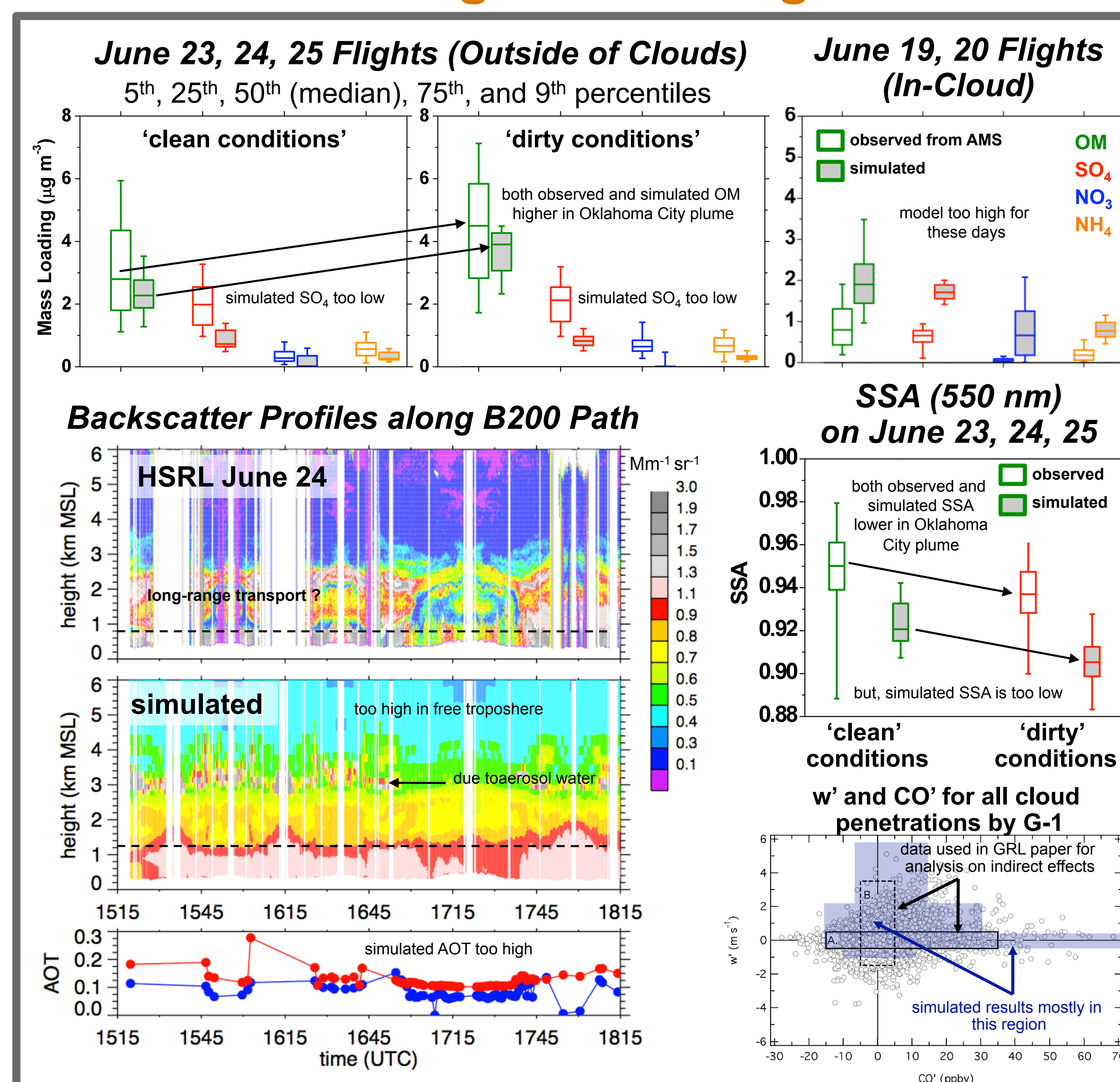- ► To what extent do shallow clouds affect aerosol properties over the region ?
- ► Does including the effect of subgrid scale clouds significantly affect regional aerosol radiative forcing?

Results – G-1 Flight on June 25, 2007

MODIS Terra
domain 2
simulated cloud fraction too low and simulated clouds form later in the day
SGP central facility
southerly winds
Oklahoma City
simulated liquid clouds

CO
ppb
135
130
125
120
115
110
105
100
95

360 km

Select Quantities Along Flight Path

altitude (km)
periods when aircraft is within clouds
color = observed CO

Carbon Monoxide (CO)
CO (ppb)
observed clear air
observed in cloud
simulated

Organic Matter (OM)
OM (ug m⁻³)
thin line: simulated SOA
dashed line: simulated PQA
most simulated OM is secondary

Aerosol Volume (0.156 – 1.25 µm)
aerosol volume (µm³ cm⁻³)
Mean Number
422 cm⁻³
277 cm⁻³
time (UTC)

- ► CO plume downwind of Oklahoma City well simulated by the model
- ► Simulated OM is too high (and other species for some transects); OM simulated better on June 23 and 24
- ► Over-prediction of aerosols may be due to omitting wet removal in this simulation and/or boundary conditions of aerosol concentrations that are too high
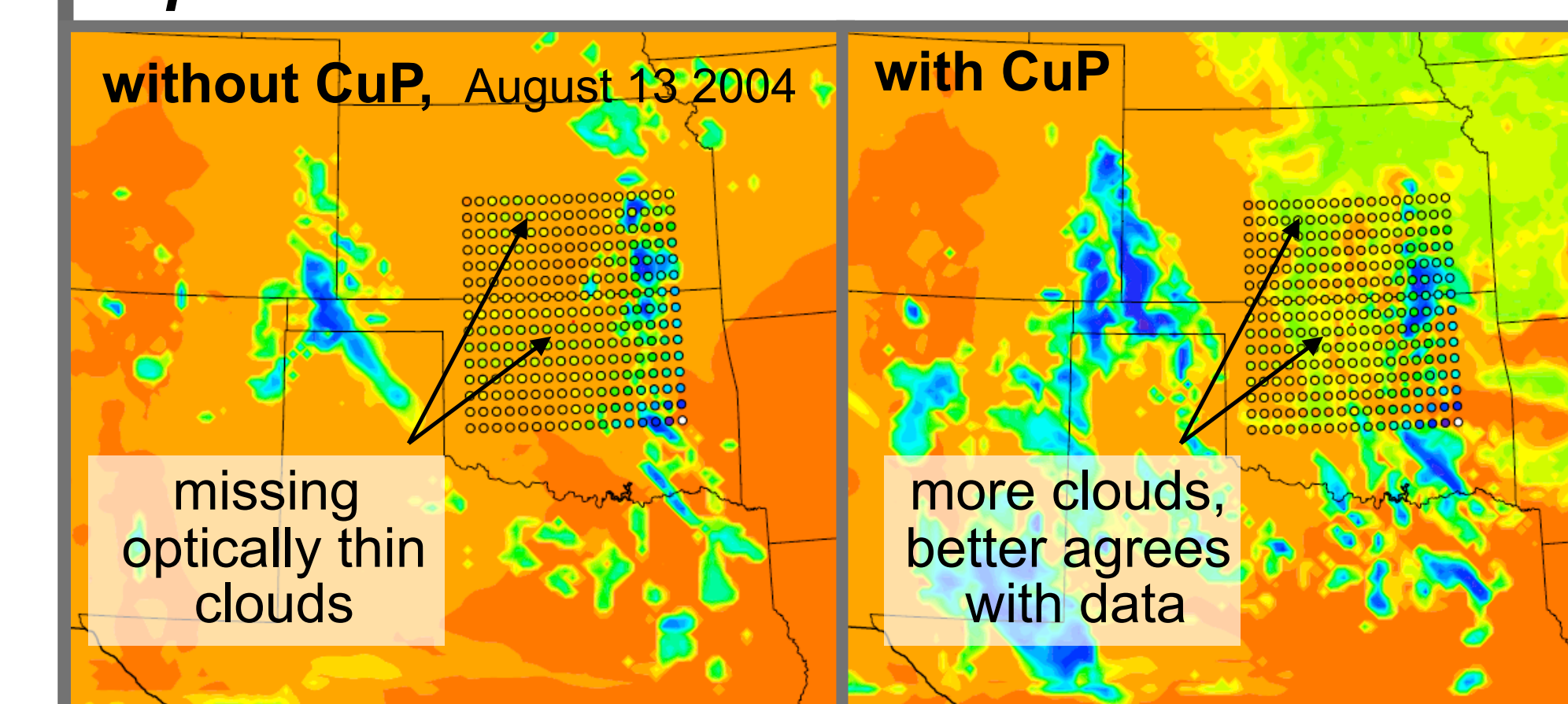
Results Along Aircraft Flight Paths

June 23, 24, 25 Flights (Outside of Clouds)
5th, 25th, 50th (median), 75th, and 9th percentiles

Mass Loading (µg m⁻³)
'clean conditions'
both observed and simulated OM higher in Oklahoma City plume
simulated SO₄ too low
'dirty conditions'
simulated SO₄ too low

June 19, 20 Flights (In-Cloud)
observed from AMS
simulated
OM
SO₄
NO₃
NH₄
model too high for these days

Backscatter Profiles along B200 Path
Mm⁻¹ sr⁻¹
HSRL June 24
height (km MSL)
long-range transport ?
simulated
too high in free troposphere
due to aerosol water
time (UTC)
AOT
simulated AOT too high

SSA (550 nm) on June 23, 24, 25
SSA
both observed and simulated SSA lower in Oklahoma City plume
observed
simulated
but, simulated SSA is too low
'clean' conditions
'dirty' conditions

w' and CO' for all cloud penetrations by G-1
data used in GRL paper for analysis on indirect effects
simulated results mostly in this region
CO' (ppbv)

Next Steps

- ► Although some aspects of simulated aerosol mass, composition, and optical properties are consistent with the aircraft data, there is room for **improvement**
- ► Additional testing of **boundary layer** and **microphysics** quantities is needed to ensure that meteorological conditions are simulated as well as possible
- ► Utilize **ACRF SGP** data (continuous profiles) as well as regional **operational** measurements (e.g. precipitation)
- ► Then, we can assess aerosol-cloud interactions coupled with a shallow convection parameterization (CuP)

Impact of CuP on Downward Shortwave Radiation

without CuP, August 13 2004
missing optically thin clouds

with CuP
more clouds, better agrees with data

- ► How will more extensive cloudiness simulated by CuP affect aerosols and radiative forcing in the region ?

Acknowledgements

U.S. DEPARTMENT OF **ENERGY**

www.pnl.gov