

Evidence of the First Indirect Effect in Clouds Downwind of a Mid-size North American City

Carl Berkowitz, Larry Berg, James Barnard: Pacific Northwest National Laboratory
Gunnar Senum, Stephen Springston: Brookhaven National Laboratory



Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

The Problem

► Can a mid-size North American City affect microphysics and optics of small to mid-size cumulus clouds?

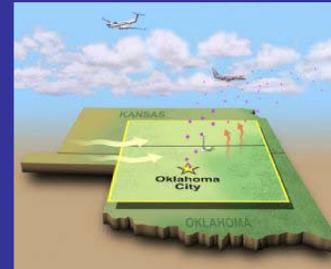
- FWC occur over much of planet
- Most sources of anthropogenic particle (e.g., cities with populations $\sim 10 \times 10^3$) are small relative to a few large anthropogenic sources (e.g., megacities with populations of $\sim 10 \times 10^6$)



The CHAPS Campaign

Time: June 1-30, 2007
Location: Downwind of Oklahoma City, OK

Synoptic Pattern: Record rainfall as a result of a blocking pattern over much of North America.



Key Measurements included:

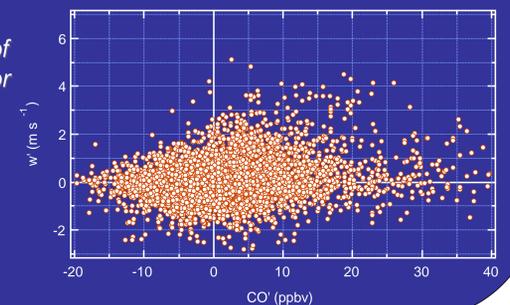
- Cloud microphysics
 - DMT Cloud, Aerosol, and Precipitation Spectrometer (CAPS)
 - Cloud Imaging Probe (CIP): precipitation
 - Cloud Aerosol Spectrometer (CAS): 20 bins, 0.63-60 μm
- CO
 - Vacuum UV Fluorimeter used as proxy to identify plumes associated with an urban source (inside and outside clouds)
- Vertical velocity (w)
 - Gust probe mounted on nose of G-1

Observations and Data Processing

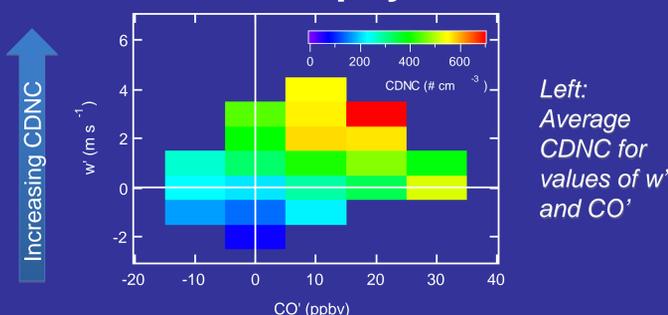
CO and w : removed mean and trend— analysis focused on CO' and w'

- Cloud microphysics
 - Drops greater than 3 μm
 - Cloud droplet number concentration (CDNC),
 - Liquid water content (LWC), and
 - Effective radius (r_{eff})
- Data binned according to CO' and w'
 - Mean CDNC, LWC, r_{eff} found for each bin
 - At least 10 observations/bin

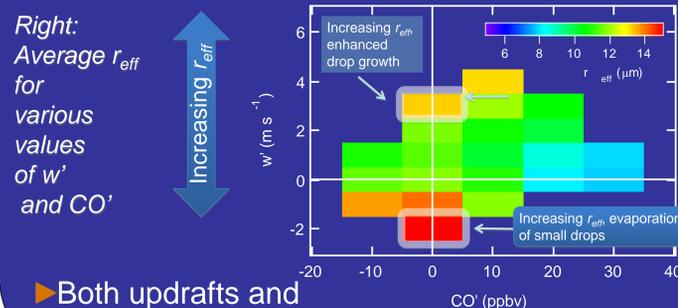
Scatter plot of w' and CO' for all CHAPS cloud penetrations



Microphysics



Left: Average CDNC for values of w' and CO'



Right: Average r_{eff} for various values of w' and CO'

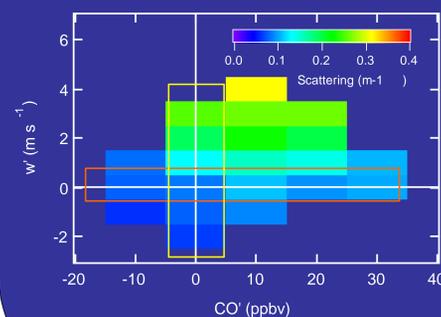
► Both updrafts and aerosol loading are important.

Optics

Total light scattering by cloud drops, $\sigma_{\text{cl d}}$, was not measured so scattering evaluated by:

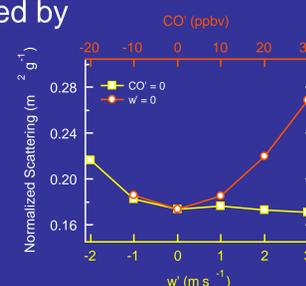
- Mie theory
- Size distribution of cloud drops
- Assume scattering is not affected by properties of CCN

Below: Average LWC for various values of w' and CO'



► Scattering sensitive to LWC

Below: Normalized Scattering, $\sigma_{\text{cl d}} / \text{LWC}$, as a function of CO' and w' only



- Increase associated with increasing CO'
- Decrease associated with decreasing w'

Conclusions and Future Work

- Yes, a mid-size North American City can affect microphysics and optics of FWC ...based on observations that:
 - Aerosol effects were consistent with postulated 1st Indirect Effects
 - Changes in scattering were observed
- Next steps
 - Computation of cloud optical depth
 - Relation of particle composition to these effects?
 - Repeat measurements in simpler synoptic situation
 - Add state-of-the-science measurements of black carbon, absorption
 - Similar instrumentation for a 2012 ARM-supported campaign (proposed)