FRESH OFF THE FIRE

A look into the particle density, dynamic shape factor, & refractive index of aerosol particles from wildfire emissions — GABE RODRIGUEZ

MOTIVATION

Biomass Burning (BB) / Wildfires

- The combustion of organic matter.

Impacts of Biomass Burning

- Due to higher average temperatures, early snow melt, changing precipitation patterns, and impacts of drought, wildfire activity has increased.
- BB emits smoke comprised of gaseous and aerosol components such as black carbon (BC) and organic carbon, both causing critical climate and health impacts.
- According to the EPA,
  - Health impacts include possible heart/lung disease, nonfatal heart attacks, decreased lung function.
  - Environmental impacts include haze, changing nutrient balance in coastal waters and river basins, etc.

WHAT IS FIREX?

Fire Influence on Regional & Global Environments Experiment (FIREX)

- FIREX is a five-year research effort that seeks to identify the mysteries of biomass burning. This research effort began in fall of 2015.

Fire Lab Experiments

- Fire chamber experiments were conducted in Missoula, MT to study the photochemical evolution of biomass burning aerosols. Working with Aerodyne Research, we conducted a total of 16 chamber experiments with different fuels, oxidants, and environmental conditions with several instruments that computed number and mass concentrations and composition.

MY PROJECT OBJECTIVE

Objective

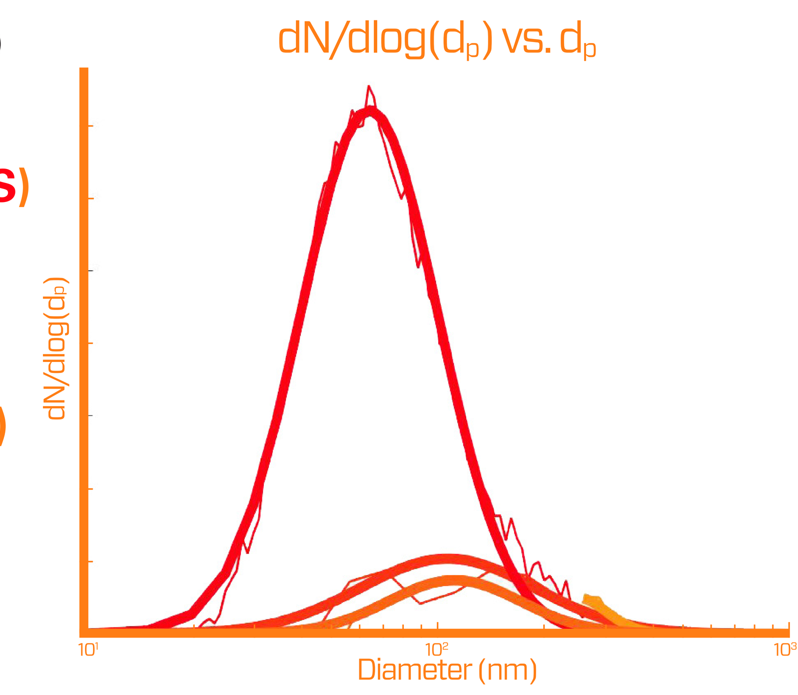
- To understand the size- and composition-resolved emissions of biomass burning

Why?

- The impacts on health and climate are dependent on particle size and composition.

How?

- We conducted data of size (N) and mass (M) concentrations vs. particle diameter with the following instruments:
  - **Scanning Mobility Particle Sizer (SMPS)**
    - $dN/dlog(d_p)$ vs. mobility diameter (d_m)
  - **Aerosol Mass Spectrometer (AMS)**
    - $dM/dlog(d_p)$ vs. vacuum aerodynamic diameter (d_{va})
  - **Single Particle Soot Photometer (SP2)**
    - $dN/dlog(d_p)$ of BC vs. volume equivalent diameter (d_{ve})
  - **Optical Particle Sizer (OPC)**
    - $dN/dlog(d_p)$ vs. "scattered light" diameter (d_{scat})



DYNAMIC SHAPE FACTOR (χ)

Dynamic Shape Factor (χ)

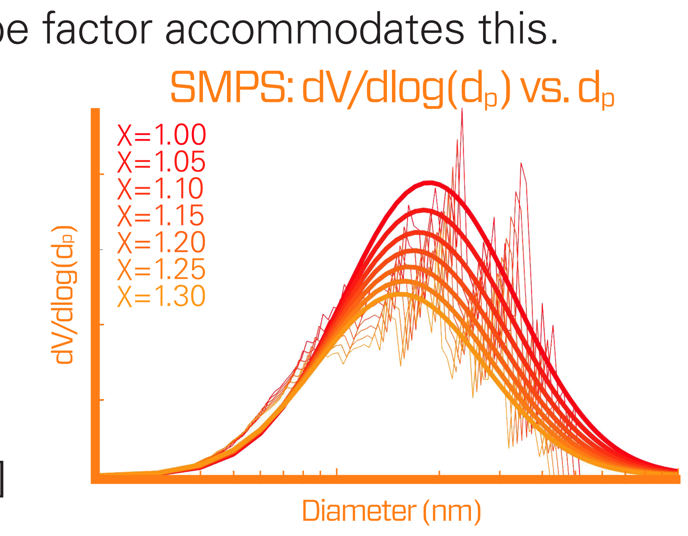
- All particles are non-spherical. The dynamic shape factor accommodates this. $\chi = 1$ is spherical, while a $\chi > 1$ is non-spherical.

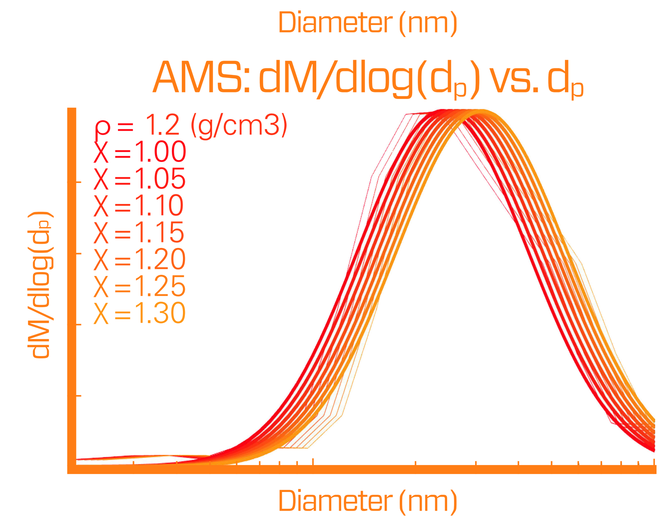
SMPS: $d_m \rightarrow d_{ve}$ Conversion

- SMPS measures the diameters of particles using a combination of timing, drag force, and coulombic force.
  - $d_{ve} = d_m \frac{C_c(d_{ve})}{C_c(d_m)} \frac{1}{\chi}$
  - **Cunningham Slip Correction Factor (C_c)**
    - $C_c(d') = 1 + \frac{\lambda}{d'}[2.34 + 1.05 * \exp(-0.39\frac{d'}{\lambda})]$
      - Mean Free Path (λ)
        - $\lambda = 0.73$ nm (at 89 kPa)

AMS: $d_{va} \rightarrow d_{ve}$ Conversion

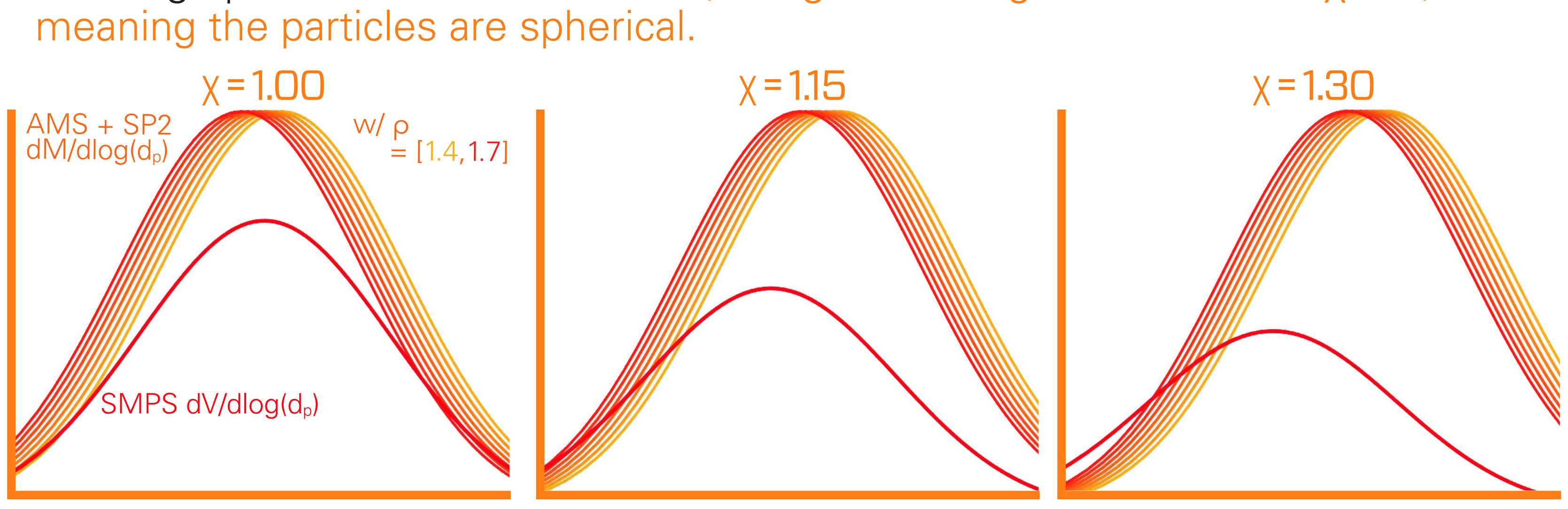
- AMS measures diameters by throttling particles through an aerodynamic lens and recording its time of flight. Different times = different diameters.
  - $d_{ve} = d_{va} * \chi \frac{\rho_0}{\rho_p}$
    - ρ_0 = density of water (1 g/cm^3)
    - ρ_p = density of aerosol particle (unknown)





Result

- The goal is align the SMPS dV/dlog(dp) curve with the sum of AMS and SP2 dM/dlog(dp) curves. As can be seen, the greatest alignment is when $\chi = 1$, meaning the particles are spherical.



PARTICLE DENSITY (ρ)

Method #1: Calculating ρ_{org} through O:C & H:C ratios

- Calculate density of organic aerosol using this equation:
  - $\rho_{org} = \frac{12.0 + 1.0\,(H:C) + 16.0\,(O:C)}{7.0 + 5.0\,(H:C) + 4.15\,(O:C)}$
    - H:C = Hydrogen-Carbon mole ratio
    - O:C = Oxygen-Carbon mole ratio

Method #2: Calculating ρ_{org} through maximums of AMS $dM/dlog(d_{p,va})$ & SMPS $dV/dlog(d_{p,ve})$ curve

- Rearrange the $d_{va} \rightarrow d_{ve}$ equation to solve density. Use diameter where max is found.
  - $\rho_p = \rho_0 \frac{d_{va}}{d_{ve}}$ (assume $\chi = 1$)

Method #3: Iterative Process to find the closest match between SMPS & AMS + SP2

- Multiply SMPS dV/dlog(dp) by different densities and compare errors.

Results

- The three points tested were (a) after aerosols within the chamber were well mixed, (b) before photochemistry (exposure to UV light) was simulated, and (c) after photochemistry was simulated.
- While each method produced varying results, each show a noticeable increase in density.

METHOD #1

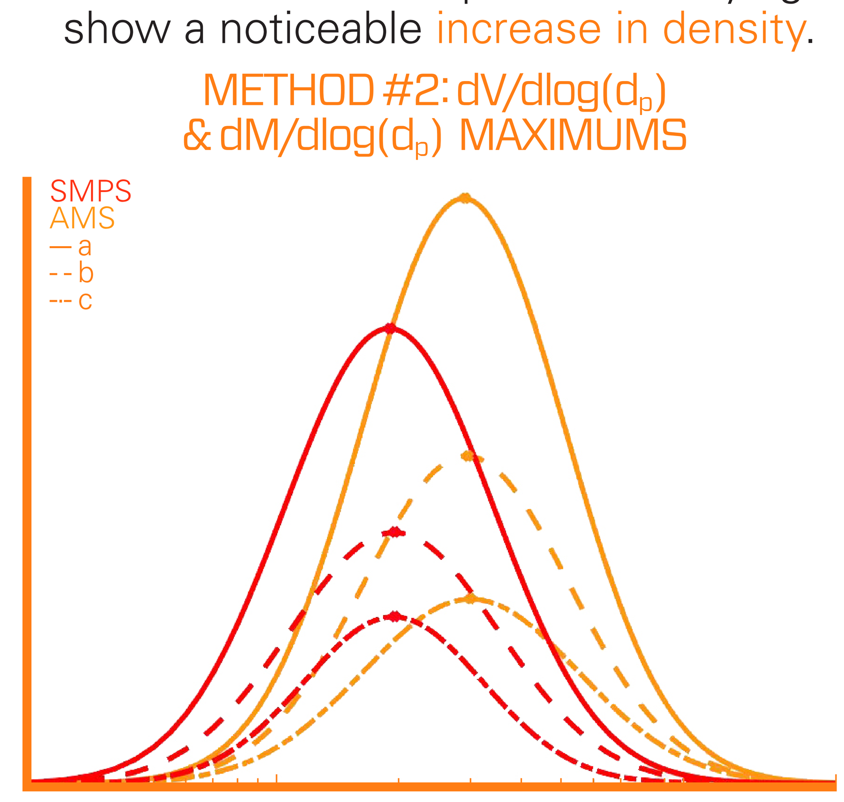
- (a) $\rho_{org} = 1.101 \pm 0.049$ g/cm^3; $\rho_p = 1.221 \pm 0.071$ g/cm^3
- (b) $\rho_{org} = 1.113 \pm 0.049$ g/cm^3; $\rho_p = 1.235 \pm 0.071$ g/cm^3
- (c) $\rho_{org} = 1.157 \pm 0.048$ g/cm^3; $\rho_p = 1.273 \pm 0.049$ g/cm^3

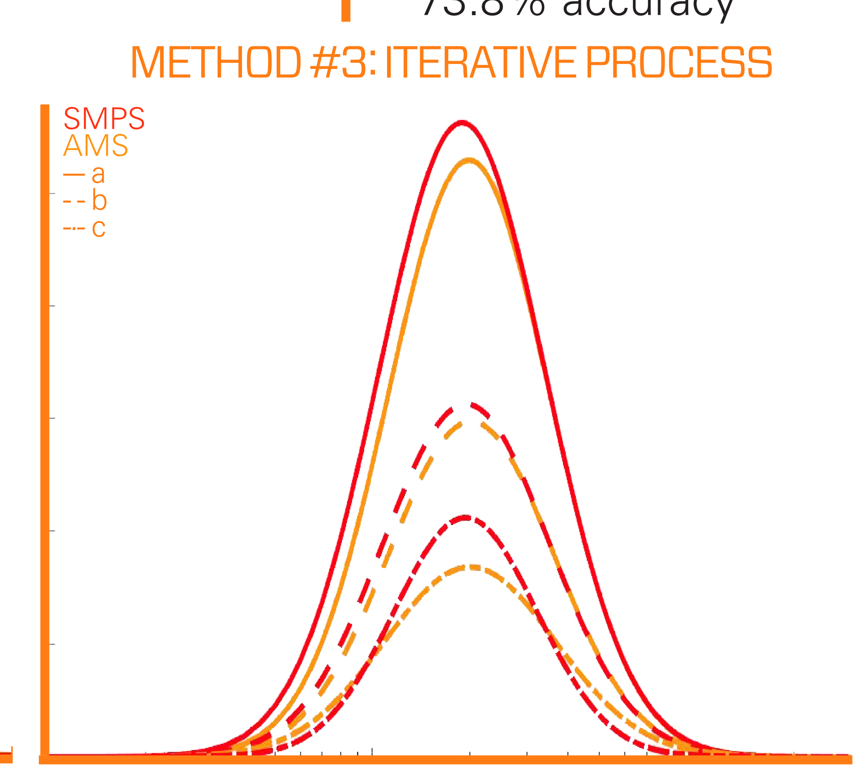
METHOD #2

- (a) $\rho_{org} = 1.465 \pm 0.308$ g/cm^3; $\rho_p = 1.539 \pm 0.221$ g/cm^3
- (b) $\rho_{org} = 1.526 \pm 0.423$ g/cm^3; $\rho_p = 1.583 \pm 0.311$ g/cm^3
- (c) $\rho_{org} = 1.711 \pm 0.340$ g/cm^3; $\rho_p = 1.715 \pm 0.274$ g/cm^3

METHOD #3

- (a) $\rho_p = 1.448$ g/cm^3; 94.0% accuracy
- (b) $\rho_p = 1.459$ g/cm^3; 95.5% accuracy
- (c) $\rho_p = 1.491$ g/cm^3; 73.8% accuracy

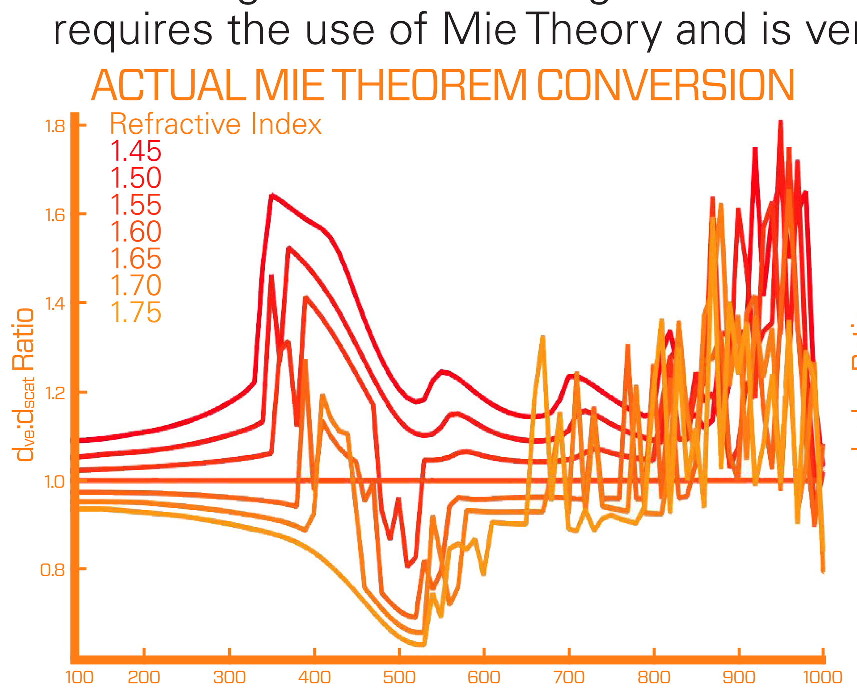


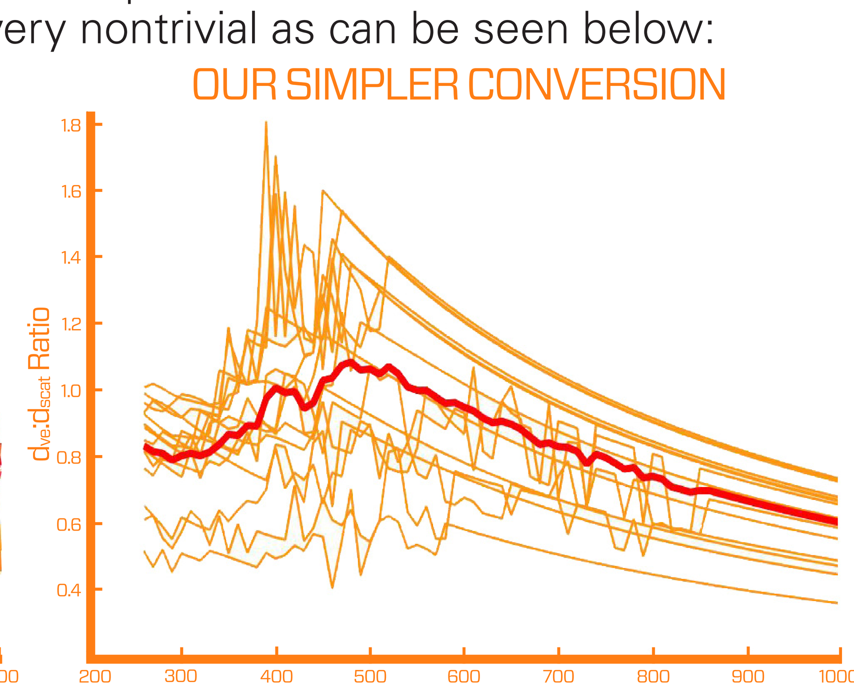


REFRACTIVE INDEX

OPC: $d_{scat} \rightarrow d_{ve}$ Conversion

- OPC measures particle diameters by shining a laser onto each particle and correlating the amount of light scattered to a particular diameter. The conversion requires the use of Mie Theory and is very nontrivial as can be seen below:





- Due to uncertainty in calculations, we instead calculated the ratios needed to convert d_{scat} to d_{ve} and compared those values with our generated graphs. More information on how to properly convert is still needed, however.

LIMITATIONS

Collection Efficiency

- The AMS instrument does not detect all particles that pass through it — especially black carbon. A collection efficiency <100% means less accurate data, and we did not obtain the corrected data in the time of the project.

Fitting Uncertainty

- Nearly all data was averaged and fitted to a Gaussian function, by finding the minimum error from the original data, meaning inevitable uncertainty.

Calculation Ambiguity

- Certain calculation methods are still unclear, and many assumptions were made in the process (especially in OPC and AMS data).

REFERENCES

- DeCarlo et al., ES&T, 2004, 46 (2) 1206-1222.
- Kuwata, Zorn, Martin, ES&T, 2012, 46 (2), 787-794.
- Westerling et al., Science, 2006, 313 (940), 940-950.

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