

Development of a Quantitative Accounting Framework for Black Carbon and Brown Carbon from Emissions Inventory to Impacts

Jamie Schauer, UW-Madison (PI)

Mike Bergin, Georgia Tech (Co-PI)

Collaborator: Jerry Liu, Cummins



Framework for Black Carbon and Brown Carbon from Emissions to Impacts
EPA STAR Grant R83503901



Motivation

- Emissions inventories and air quality models of light absorbing carbon require parameterization of the radiative properties of emissions
- Current parameterizations of light absorbing carbon emissions do not address the range of variability within sources or control technologies
- Elemental carbon is not a good surrogate for light absorbing carbon for control strategy development nor assessment of control strategy implementation
 - May be OK if limited to absorption at 880 nm
- The light absorbing capacity of carbonaceous aerosol is not a conservative property from the point of emissions to atmosphere



Project Goals

- Overall Goal
 - Development of a quantitative framework for source-receptor relationships for light absorbing carbon and their associated wavelength dependent light absorptivity
- Key Objectives
 - Deconstruct emissions from sources of light absorbing carbon to elucidate the contribution of different emissions components to wavelength dependent absorption
 - Elucidate how the evolution of emissions in plumes impact wavelength dependent absorption
 - Integrate source apportionment models for aerosol components impacting light adsorption with wavelength dependent light absorption closure calculations



Project Strategy

- Source Testing
- Mie theory calculations for source emissions and deconstructed emissions
- Atmospheric measurements
- Mie theory calculations for atmospheric aerosols and deconstructed aerosols
- Develop a source apportionment framework that can address the optical evolution of aerosols and precursors



Framework for Black Carbon and Brown Carbon from Emissions to Impacts
EPA STAR Grant R83503901



Source Testing

- Examine key sources of light absorbing carbon:
 - Mobile sources
 - Conventional CI and SI and Emerging Technologies
 - Biomass burning
 - Lab and Field Studies
 - Coal combustion
- Examine for each source
 - Role of process variables on emissions
 - Optical properties of the organic carbon
 - Optical properties of the elemental carbon
 - Impact of dilution
 - Impact of thermal stripping of organics
- Develop source specific light absorption closure models for measurement conditions and high dilution conditions



Framework for Black Carbon and Brown Carbon from Emissions to Impacts
EPA STAR Grant R83503901



Atmospheric Measurements

- Use sites where we have conducted source apportionment studies in the past and where historical record and optical measurements
 - Atlanta, Georgia
 - Near Roadway
 - Rural Alabama
 - SOA
 - India
 - Biomass and Trash Burning
 - Low Temperature Coal Combustion

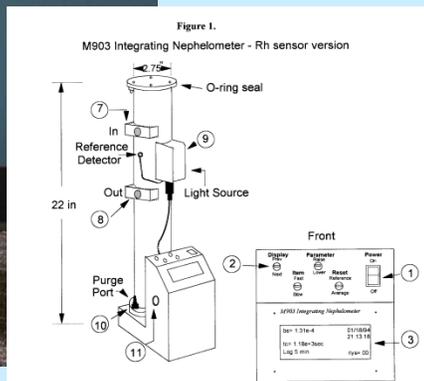
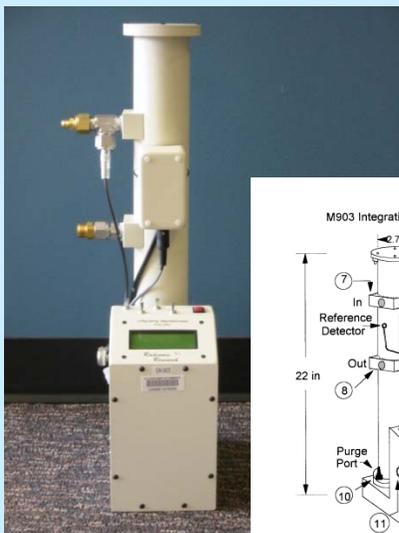


Approach

- Measure the optical properties under controlled conditions
 - Scattering and Absorption (multiple wavelengths)
- Measure physical-chemical properties
 - Size distribution, particle shape, chemical composition
- Segregate components of aerosols
 - Thermal Denuder, WS and Organic solvent atomization
- Correct absorption artifacts and compare optical properties of aerosol components



Methods



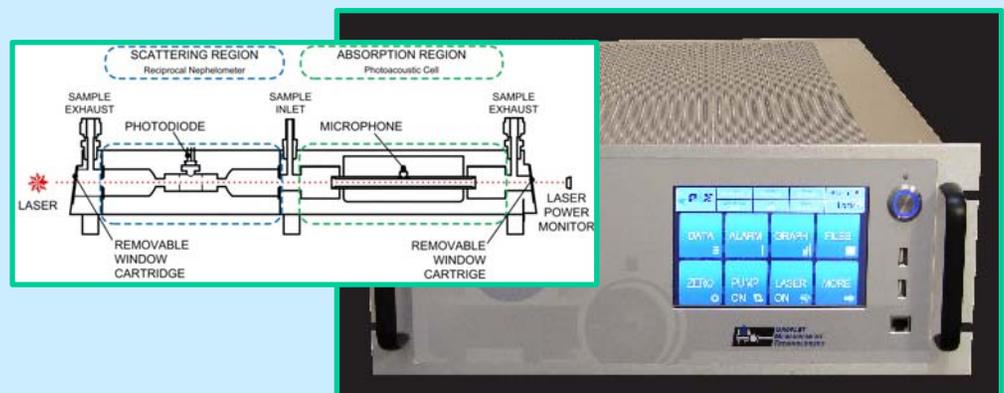
Radiance Research Nephelometer



Magee Scientific AE31 7-channel Aethalometer



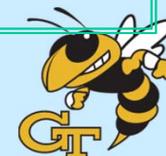
TSI Scanning Mobility Particle Sizer/ Electrostatic classifier



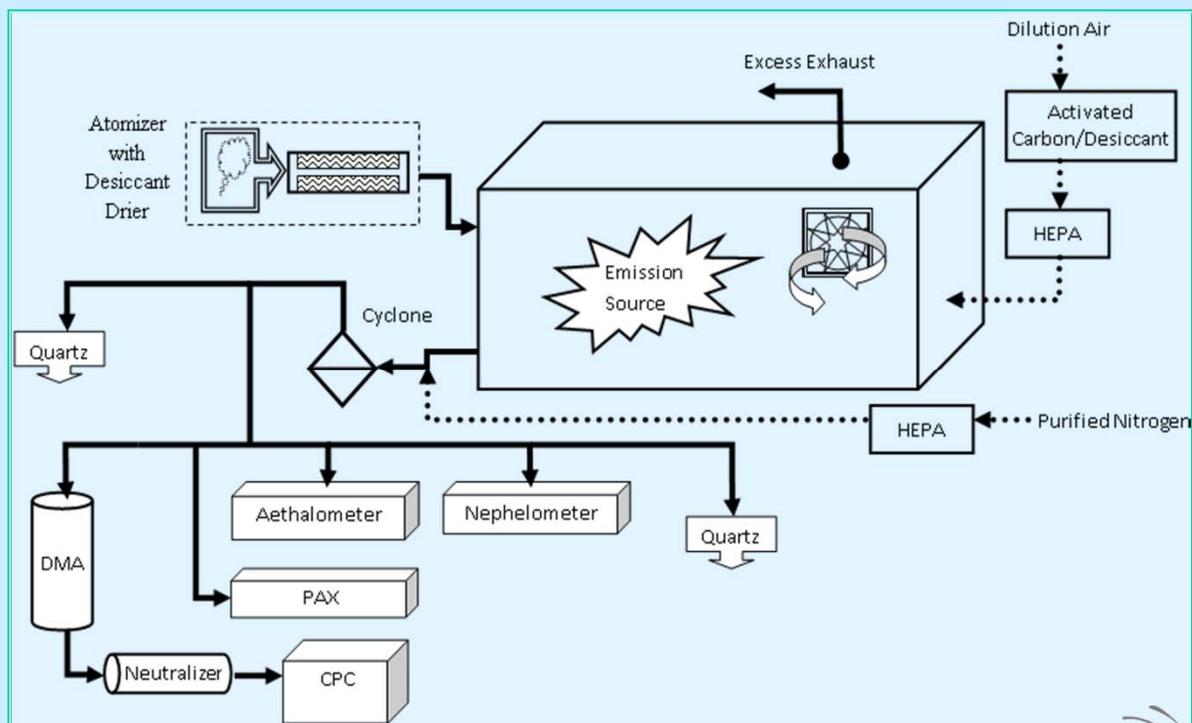
DMT PAX 532: Photoacoustic Extinctionometer



Framework for Black Carbon and Brown Carbon from Emissions to Impacts
EPA STAR Grant R83503901



Methods

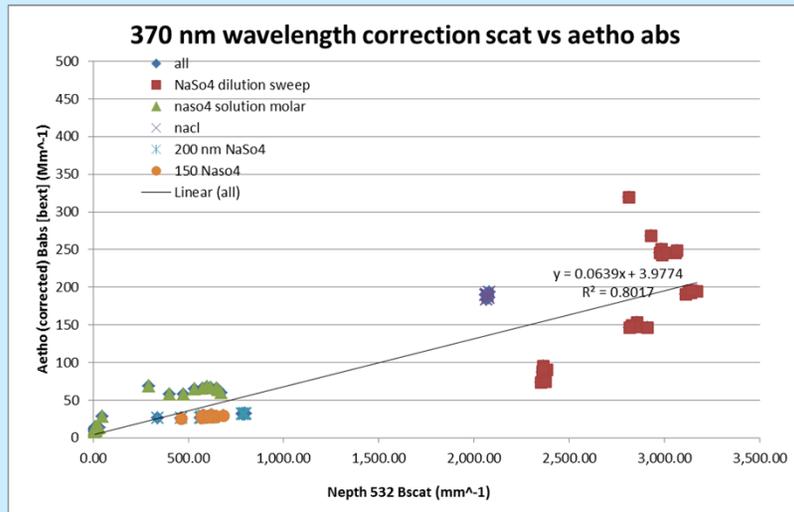


Framework for Black Carbon and Brown Carbon from Emissions to Impacts
EPA STAR Grant R83503901

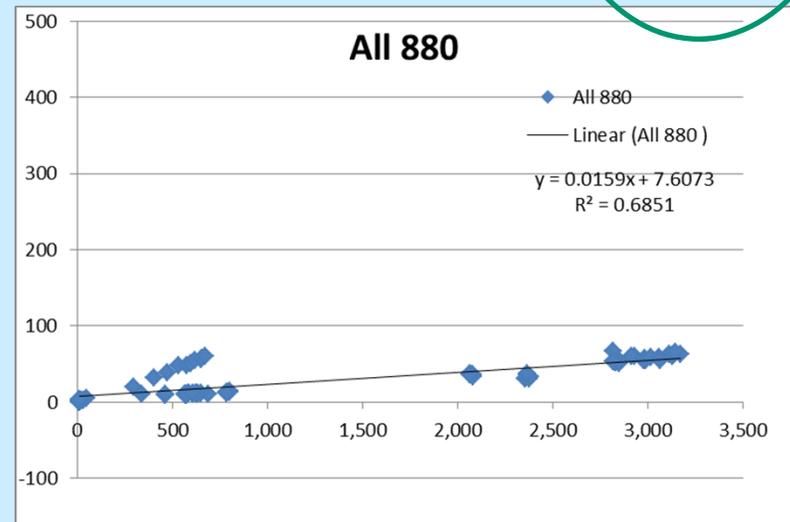
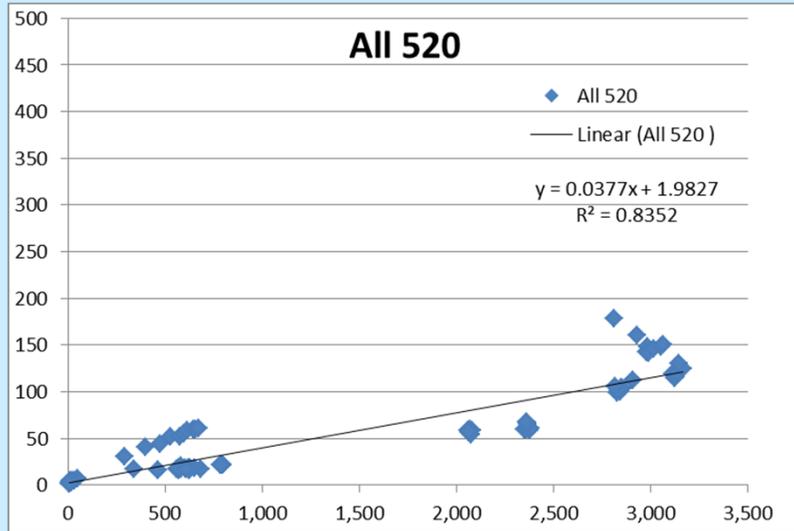


Attenuation by Non-Absorbing Aerosols

Absorption vs Scattering: Scattering Artifact correction

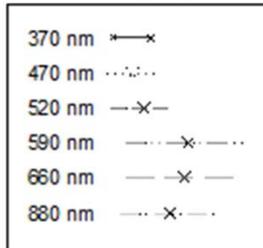
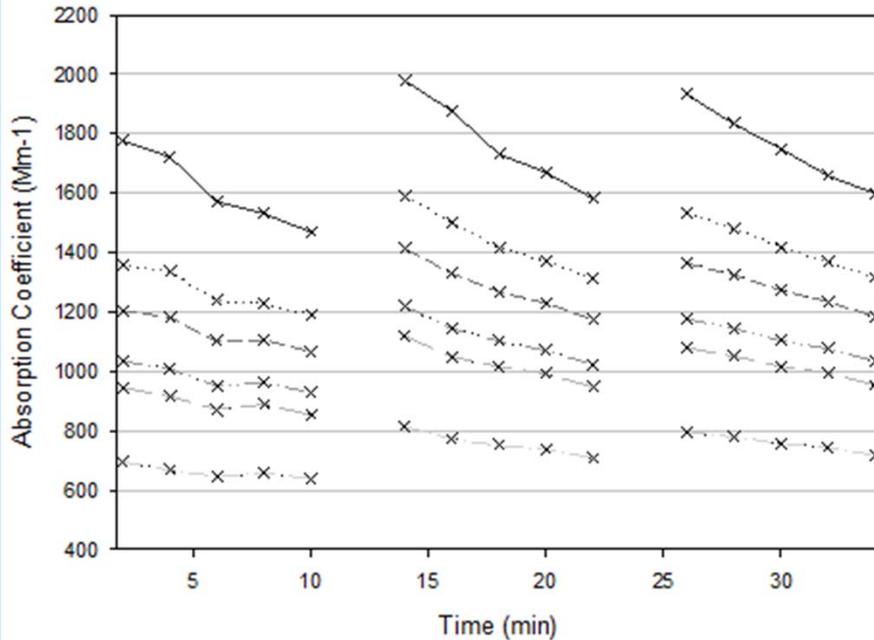


Wavelengths	slope (m)	Intercept (b)	R ²	slope forced through zero (m')
370	0.064	3.977	0.801747	0.066
470	0.049	-0.909	0.816126	0.048
520	0.038	1.983	0.835205	0.039
590	0.030	2.919	0.801001	0.032
660	0.027	3.207	0.84761	0.028
880	0.016	7.607	0.685092	0.019
950	0.013	7.410	0.651662	0.016

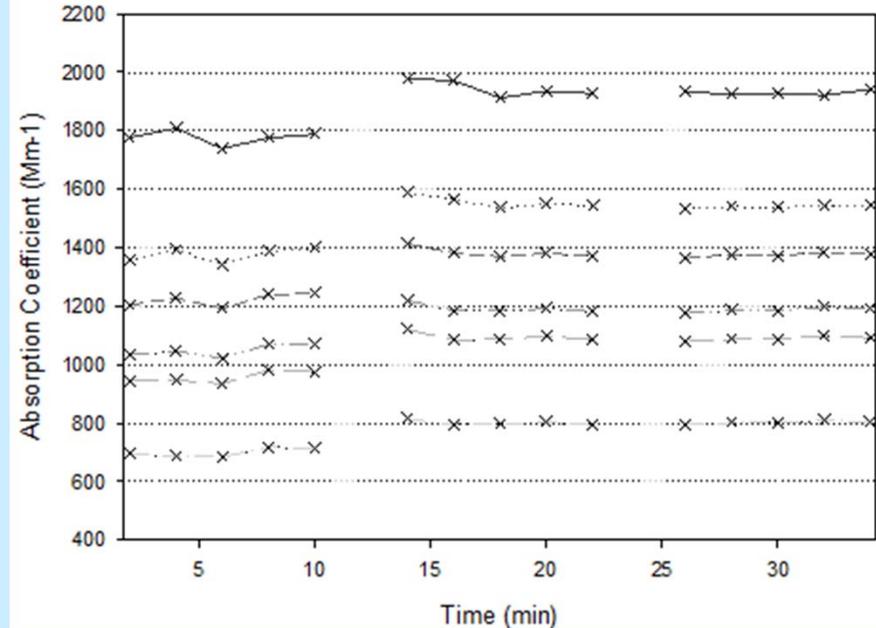


Multiple Wavelength Absorption Correction

Idle Engine Out, TD on, Not Corrected Absorption



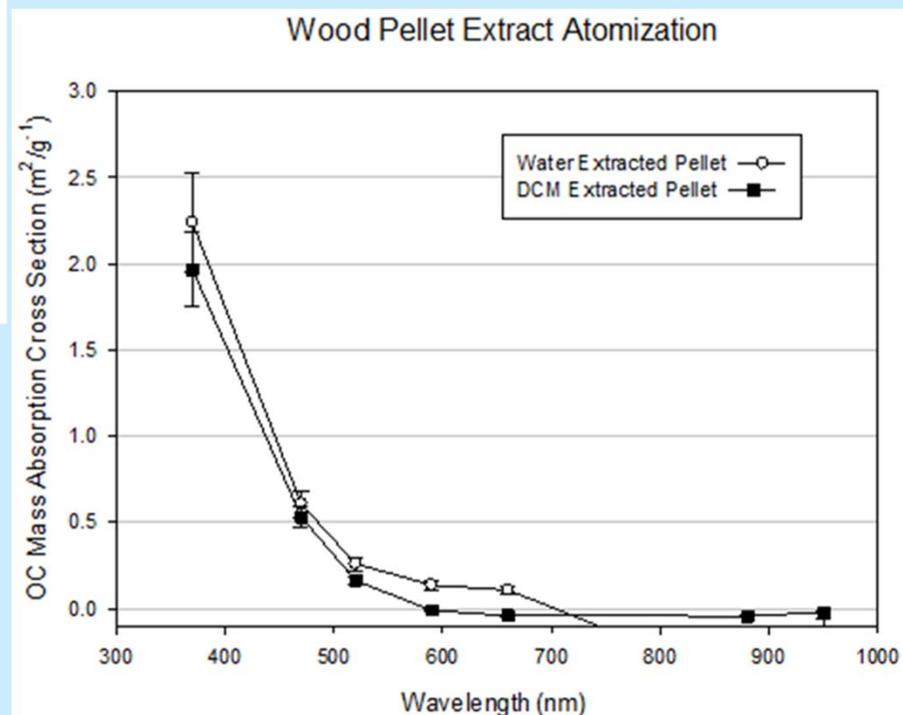
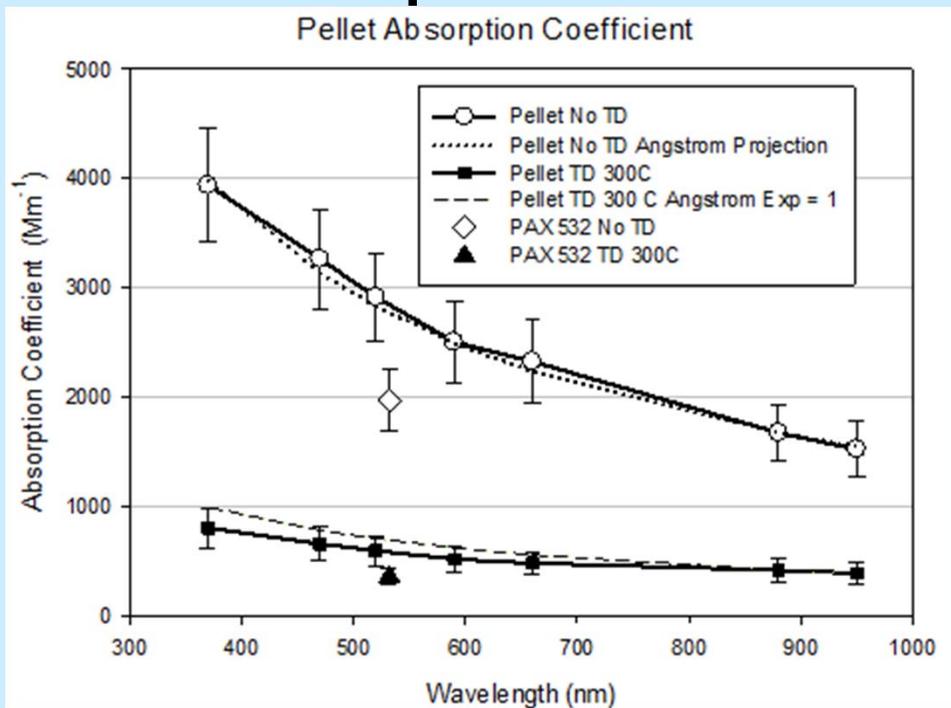
Idle Engine Out, TD on, Corrected Absorption



- Test run at steady-state
- Scattering correction is not significant for engine out emissions
- Loading correction is wavelength specific



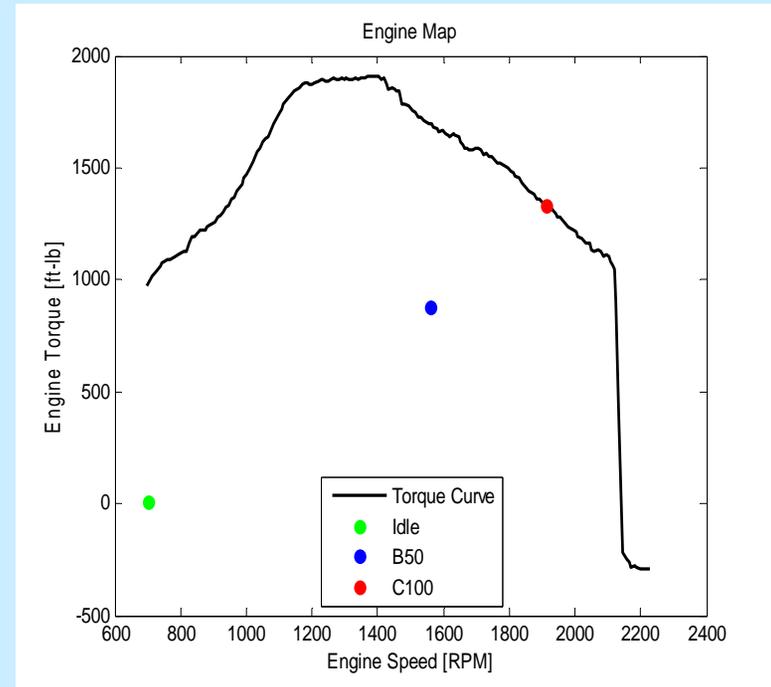
Example of Wood Pellets



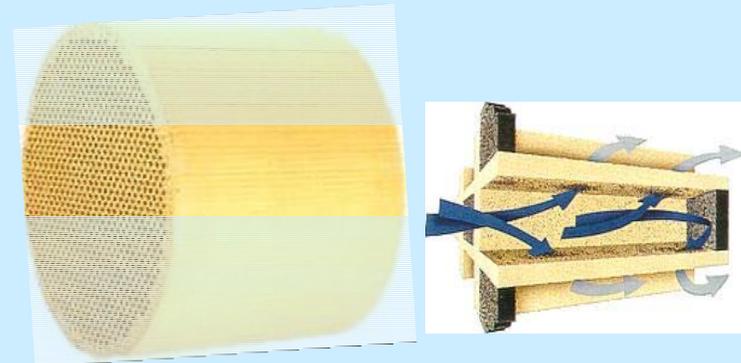
Framework for Black Carbon and Brown Carbon from Emissions to Impacts
EPA STAR Grant R83503901



Experimental Setup



Model	2010, Cummins ISX15 – 500
Emission Certification	EPA 2010, CARB 2010
Type	4-stroke cycle
Cylinder Configuration	In-line 6
Bore and Stroke	137 mm x 169 mm
Compression Ratio	17.2:1
Aspiration	Turbocharged & Charge Air Cooled
Displacement	14.9 L
Rated Power & Rated Speed	373 kW & 1800 RPM
Peak Torque	2508 N-m at 1200 RPM
Fuel System	Cummins XPI
EGR System	Cooled High Pressure



Framework for Black Carbon and Brown Carbon from Emissions to Impacts
EPA STAR Grant R83503901



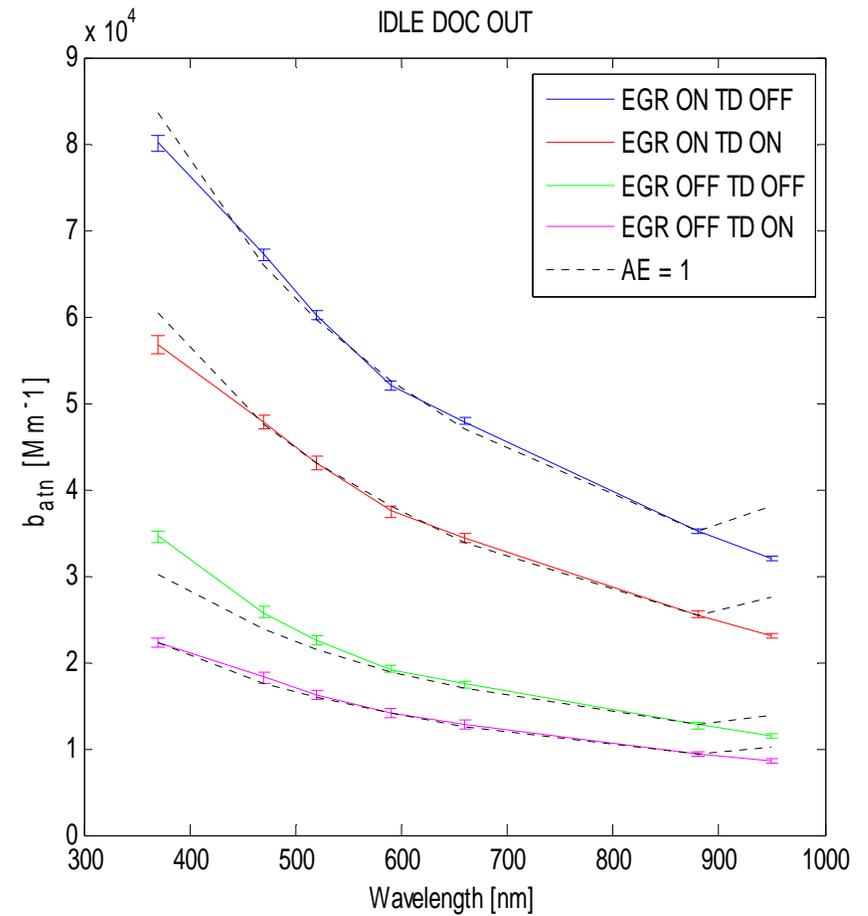
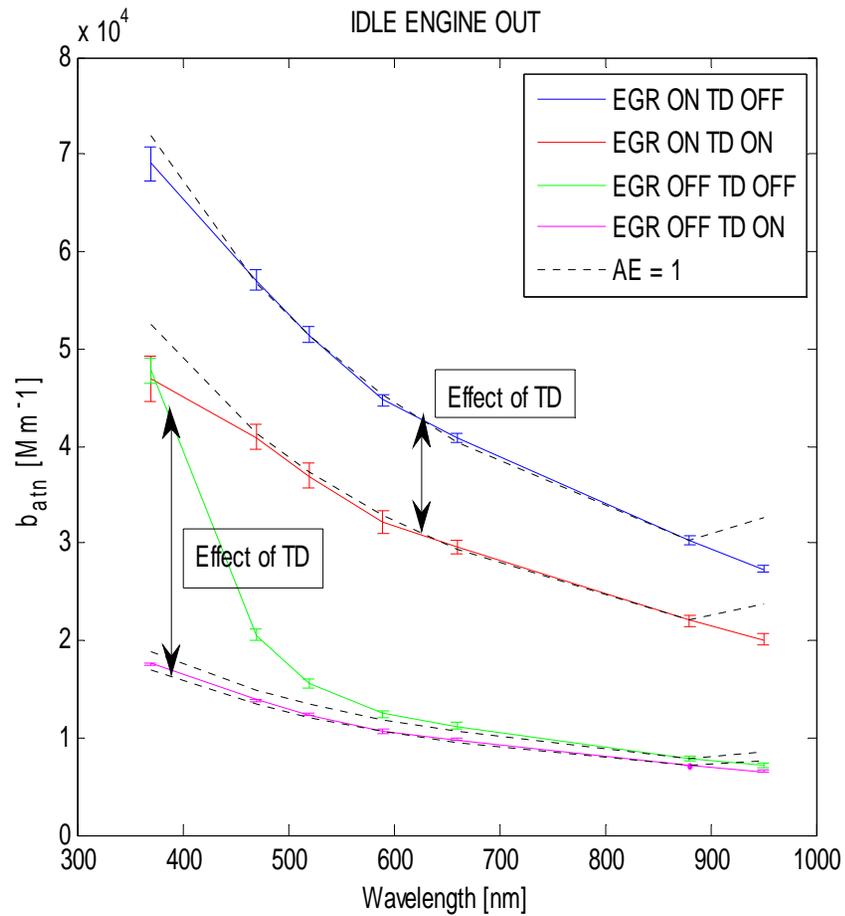
Emissions Testing Lab



Framework for Black Carbon and Brown Carbon from Emissions to Impacts
EPA STAR Grant R83503901



BrC Plots



Framework for Black Carbon and Brown Carbon from Emissions to Impacts
EPA STAR Grant R83503901



Atmospheric Sampling: Objectives

- Conduct field measurements at a variety of sites dominated by various sources of Black Carbon (BC) and Brown Carbon (BrC)
- Determine relative fraction of light absorption by BC and BrC
- Determine sources of BC and BrC
- Develop simple parameterizations for influence of aging on the light absorbing properties of aerosols



Approach: Specifics

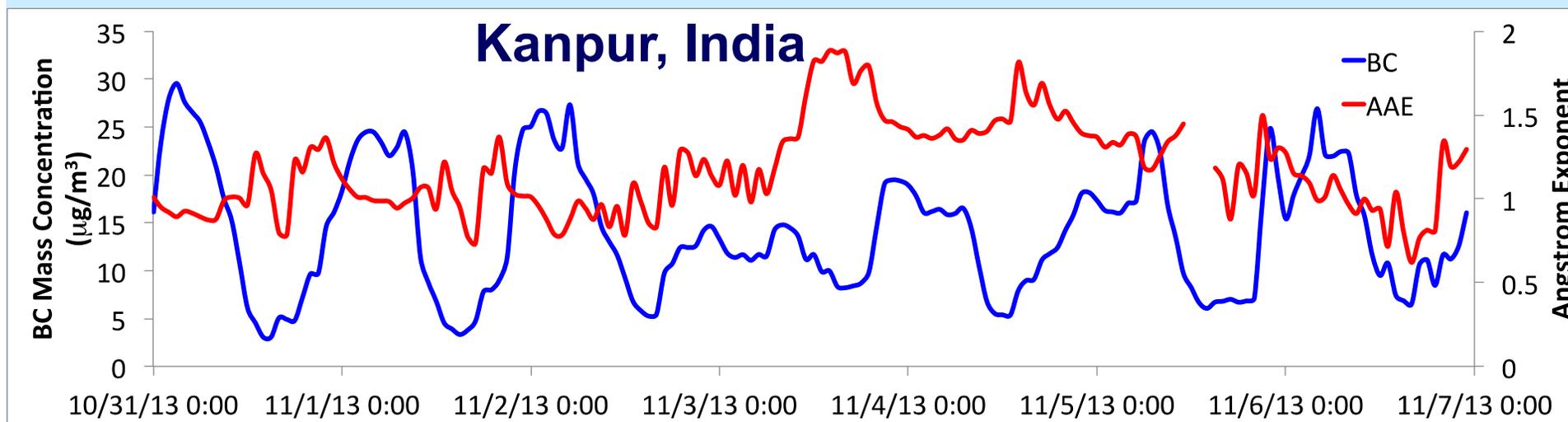
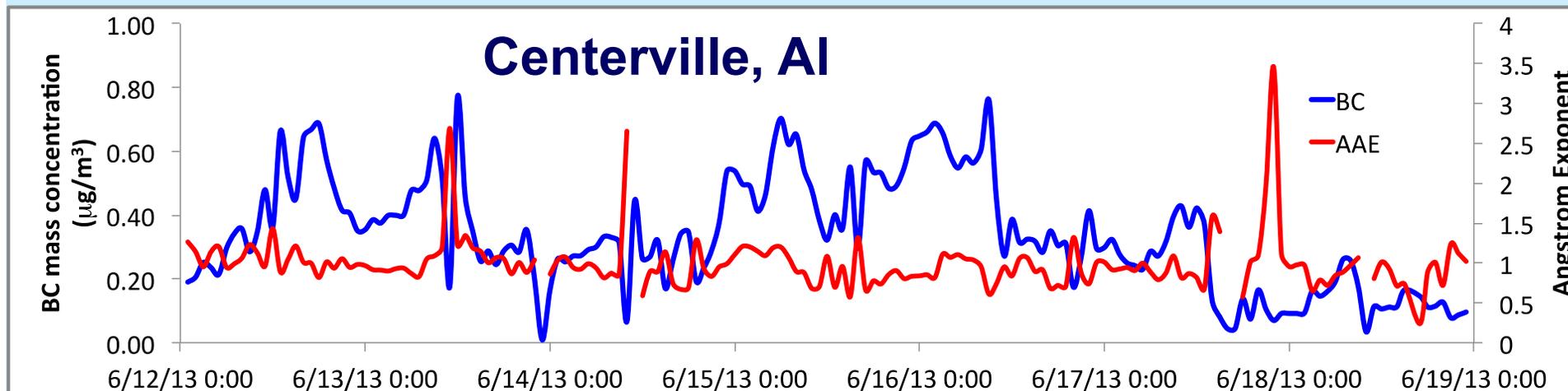
Parameter	Instrument	Dates	Objective
<i>Real-Time Continuous</i>			
$\sigma_{ap}(\lambda)$	Magee Aethalometer, PAX	4-1 Month Periods	Compare with Mie Theory Light Absorption Estimates from MOUDI 1
$\sigma_{sp}(\lambda)$	Radiance Research Nephelometer	--	Compare with Mie Theory Estimates from MOUDI
<i>Time-Integrated Sampling</i>			
EC/OC, Trace Organics, WSOC, $Abs(\lambda)_{solvent}$, $Abs(\lambda)_{water}$	HiVol Filter sampler	4-1 Month Periods	Source apportionment, RI Estimates for Mie Theory, Solvents Extracts for Aerosolization Experiments
EC/OC, WSOC, $Abs(\lambda)_{solvent}$, $Abs(\lambda)_{water}$	MOUDI 1	4-1 Month Periods	Estimation of $\sigma_{ap}(\lambda)$ as function of size for both water and solvent extracts and BC
Mass, Ions	MOUDI 2	4-1 Month Periods	Estimation of $\sigma_{sp}(\lambda)$ as a function of size



Framework for Black Carbon and Brown Carbon from Emissions to Impacts
EPA STAR Grant R83503901



Black Carbon (BC) and Angstrom Absorption Exponent (AAE) in rural US and India



Framework for Black Carbon and Brown Carbon from Emissions to Impacts
EPA STAR Grant R83503901



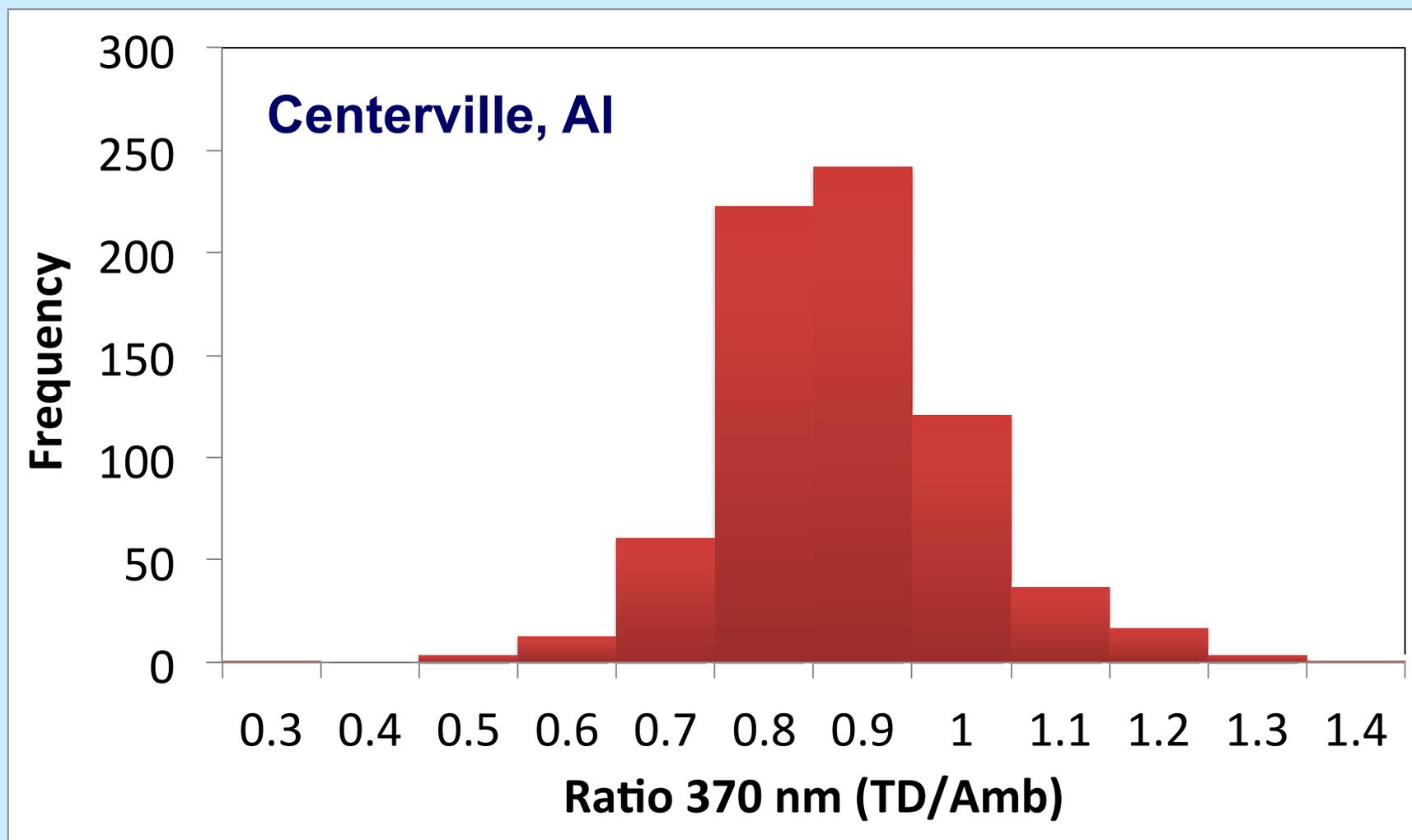
Trash/Refuse Burning: A Source of Brown Carbon



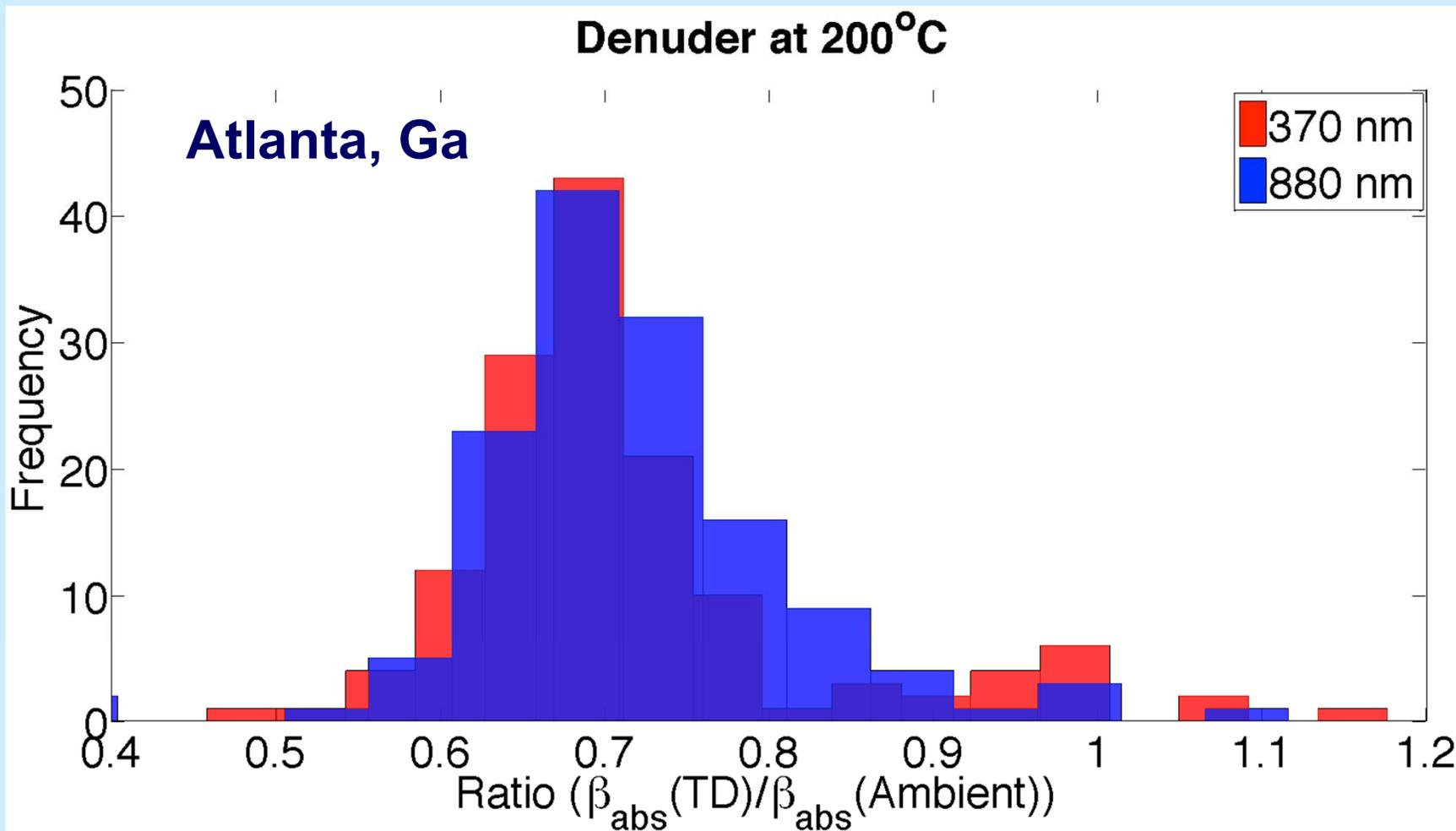
Framework for Black Carbon and Brown Carbon from Emissions to Impacts
EPA STAR Grant R83503901



Ratio of light absorption for denuder (200°C) to ambient air



Ratio of light absorption for denuder (200°C) to ambient air

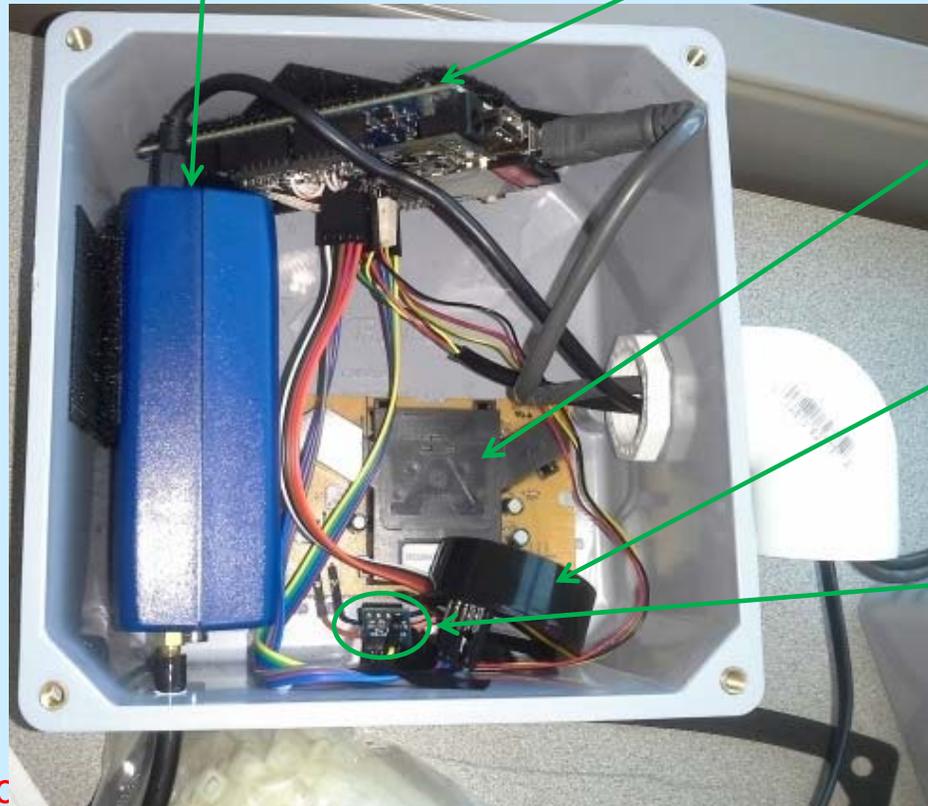


Low Cost Sensor Networks



microAet
h-Black
Carbon

Arduino-
microcontroler



PM
sensor

CO₂
Sensor

T, RH



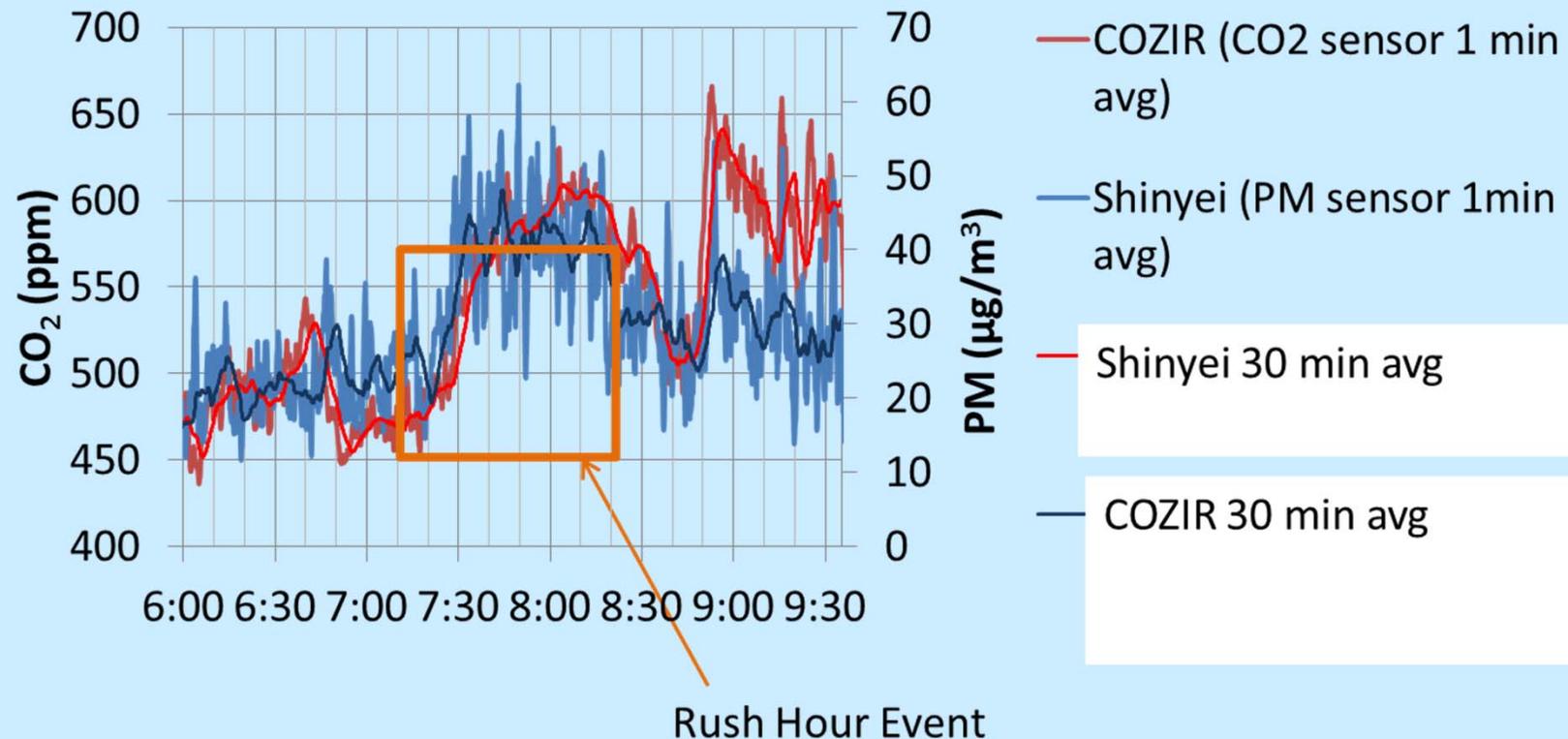
Framework for Black

EPA STAR Grant R83503901

Impacts



Atlanta Freeway PM Emission Factor Estimate



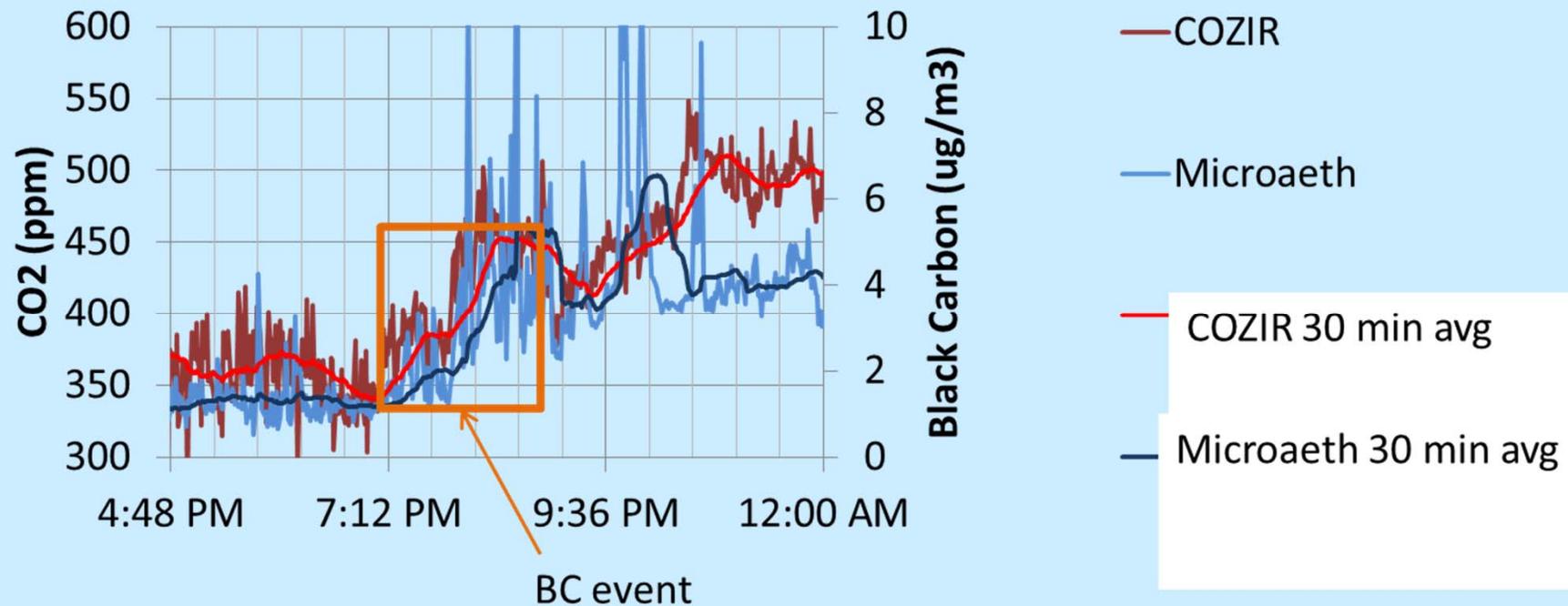
$$\begin{aligned}\text{Rough Emissions Factor} &= \Delta\text{PM}/\Delta\text{CO}_2 \\ &= 0.079\mu\text{g m}^{-3} \text{ PM/ppmCO}_2 \\ &= 0.39 \text{ g PM/kg fuel}\end{aligned}$$



Framework for Black Carbon and Brown Carbon from Emissions to Impacts
EPA STAR Grant R83503901



Atlanta Freeway BC Emission Factor Estimate



$$\begin{aligned}\text{Rough Emissions Factor} &= \Delta BC / \Delta CO_2 \\ &= 0.044 \mu\text{g m}^{-3} \text{ BC/ppmCO}_2 \\ &= 75 \text{ mg BC/kg fuel}\end{aligned}$$



Framework for Black Carbon and Brown Carbon from Emissions to Impacts
EPA STAR Grant R83503901



Ongoing Efforts

- Source Testing
 - Applying methodology to other source of concern: real world biomass, residential coal
- Atmospheric Sampling
 - Water and methanol extractions of size-resolved BC and BrC samples
 - Extraction of hivol samples to determine optical properties and sources of light absorption
- Publications

