Stove Testing Recommendations

...a contribution to a continuing discussion

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and dozens of interested & affected parties

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Outline

- Two scenarios defined
- Emission testing
  - History
  - Variability
  - Extraction methods
  - Use of optical methods to estimate particle mass
  - Choice of measurements
- Some ideas & open discussion

Why standardize?

- Consensus
  - agreement on important factors
- Comparability
  - assembling worldwide database
  - trading knowledge
- Capacity-building
  - recommendations to funding agencies
  - make affordable through bulk discounts

Thermal Performance

- Discussion elsewhere
- Efficiency testing (water-boiling)
  - Define pot size and shape; water quantity; simmering time
- As-used testing
- Performance testing (time to boil)

Why measure emissions?

??

Why measure emissions?

- Technology comparison
- Design feedback
- Assist in prediction
  - indoor air quality (IAQ)
  - regional air quality (RAQ)
  - global atmosphere
- Source profiling
  - identify contribution of specific sources to regional pollution

Caveat!!! on emission recommendations

- Lots of previous work on this issue
  - Kirk Smith's protocol– extensive database
  - Grant Ballard-Tremeer– analyzed chamber method
  - Many other stove researchers
  - U. S. EPA has been trying to understand sampling issues for years
- We are not going to figure it out today!

Testing scenario #1: Stove-Design Lab

- Focusing on:
  - *Evaluating* design choices
  - *Demonstrating* stove improvements-- possibly for obtaining dissemination funding
- Requirements:
  - Several emission parameters
  - Easy to maintain and calibrate (standard equipment)
  - Accuracy ~5-10%
  - Reasonably-priced replacement parts

Testing scenario #2: In-field monitoring

- Focusing on:
  - *Rapid feedback* to stove artisans
  - *Widespread* data measurements
- Requirements:
  - Minimum number of emission parameters for characterization
  - Real-time data or immediate analysis
  - Portable; low energy requirements
  - Robust, cheap replacement parts (just like a Stove)
  - Accuracy ~25%

Emission testing history (cooking stoves)

Group	Stoves/Fuels	Species	Extraction
Smith	Many stoves Wood, coal, crop res.	CO, CH_4, N_2O, NMVOC, TSP	Hood
Ballard-Tremeer	Five stoves Wood	CO, TSP	Hood
Oanh	Charcoal, briquette, wood; bucket, open fire	TSP, PAH	Hood + EPA method 5
Venkata-raman	Wood, dungcake, biofuel briquette Traditional stoves	CO, particles, PAH, size dist w/impactor	Hood + dilution plenum
Joshi	Metal cookstoves	CO, TSP	Chamber

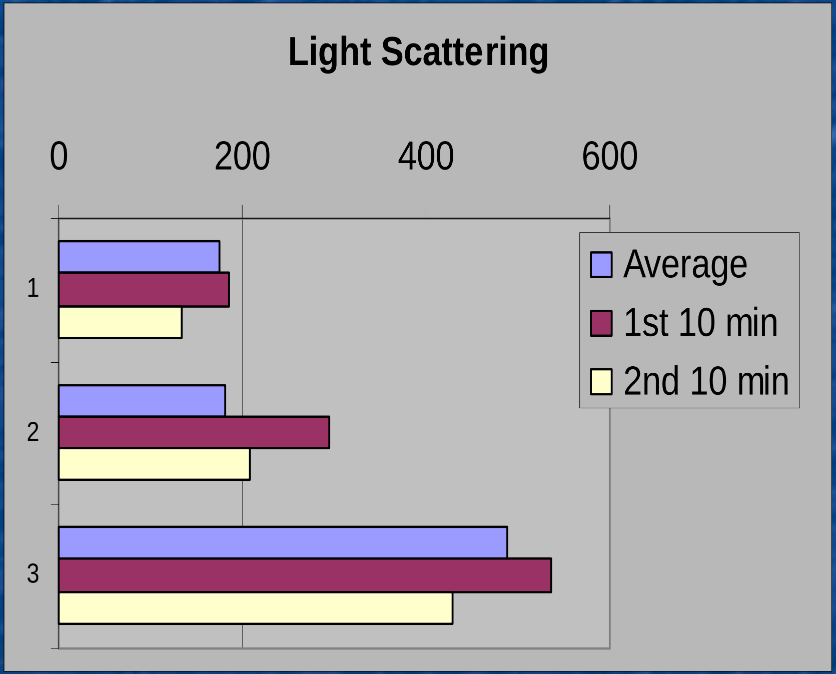
Emission testing history (heating stoves & fireplaces)

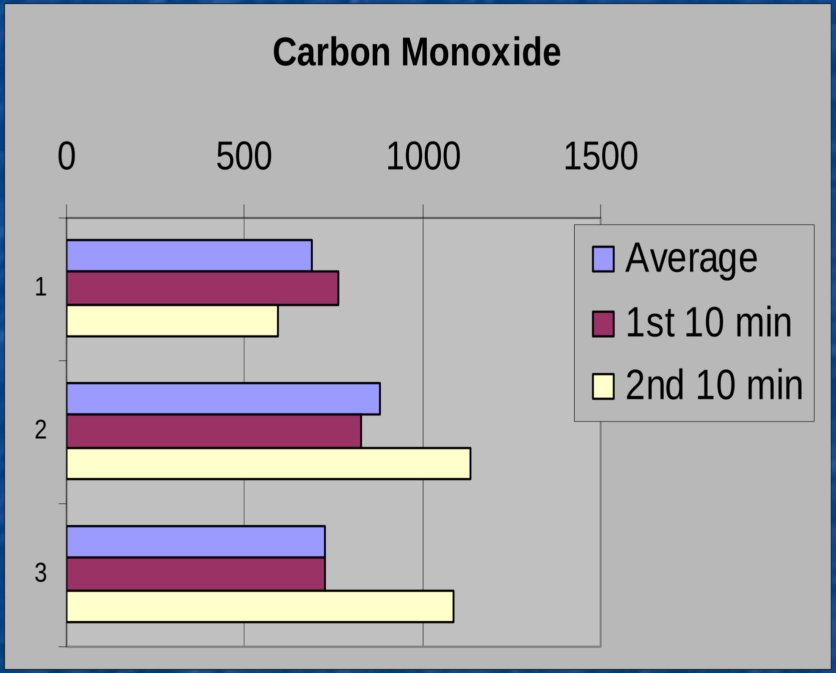
Group	**Extraction method**
EPA Method 5G	Hood
EPA Method 5H	Direct from flue
OMNI	Hood; “Condar’s sampler”
Early 1980s work	Several; dilution tunnels examined
Cal Tech	Hood + dilution plenum

Real-time?

- Real-time measurements
  - Advantages: immediate feedback; replacement parts limited
  - Disadvantages: requires datalogging; introduces errors due to summing data
- Samples taken over partial test
  - Advantages: quick
  - Disadvantages: combustion variability
- Samples taken over entire test
  - Advantages: average result, no worries about variability
  - Disadvantages: replacement of sampling media (bags, filters); no feedback on individual conditions

Partial-burn measurements are not enough!





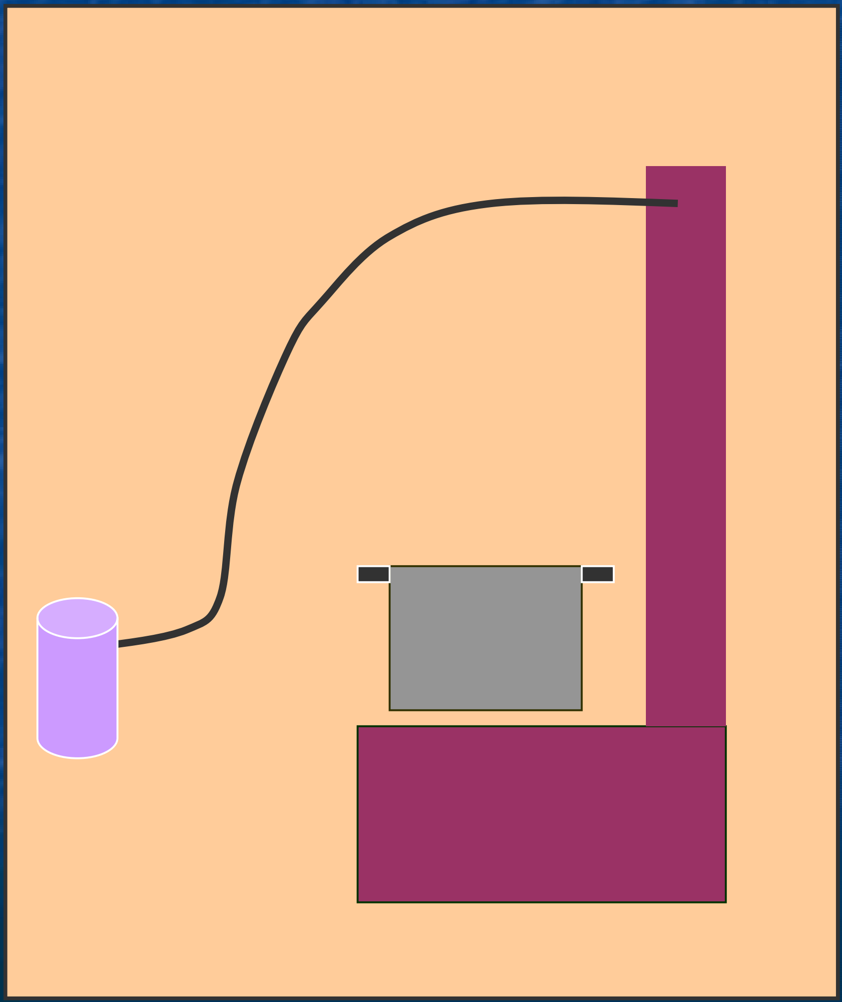
Average error is about 20% (up or down) and can be as high as 60%.

The dilution question

- Gases become particles as gases cool
  - ...just like water condensation
  - Flue sampling measures lower PM than sampling in diluted gas
- Most important when there are lots of semi-volatile compounds
  - ...like in wood exhaust
- Contentious issue!

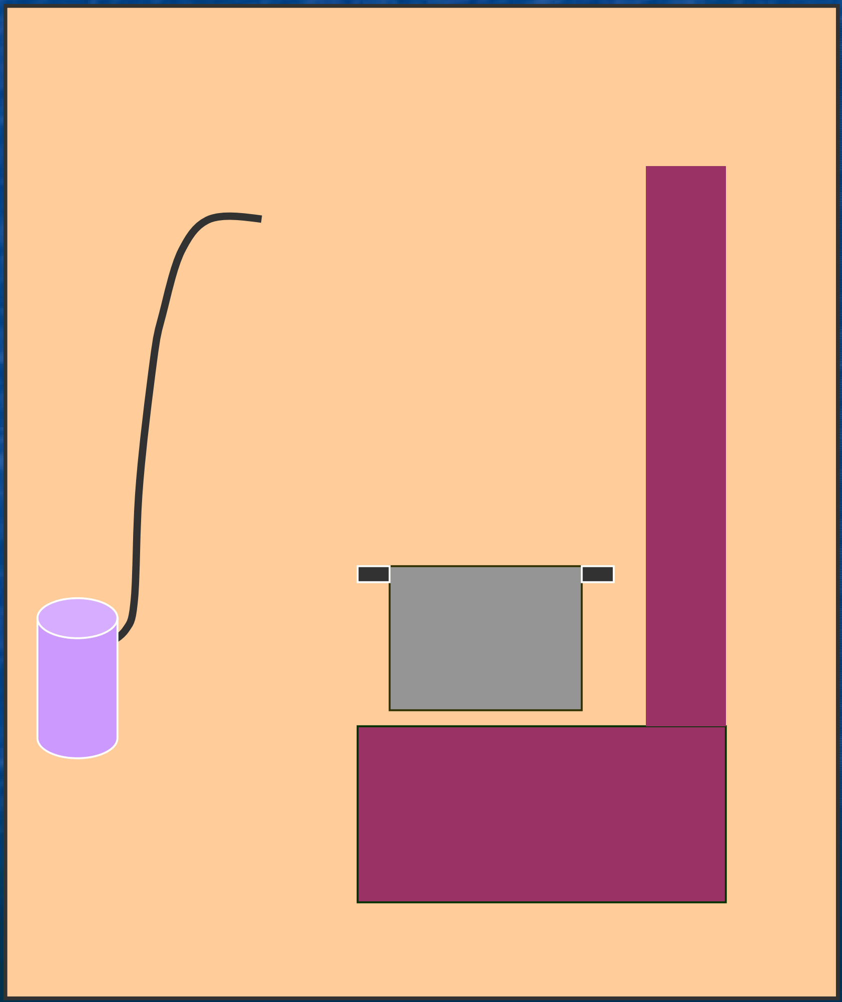
Ways to extract #1

- Directly from exhaust gas
  - sample is hot
  - not representative of cooled emissions
  - doesn't work for fires without chimneys
  - not recommended



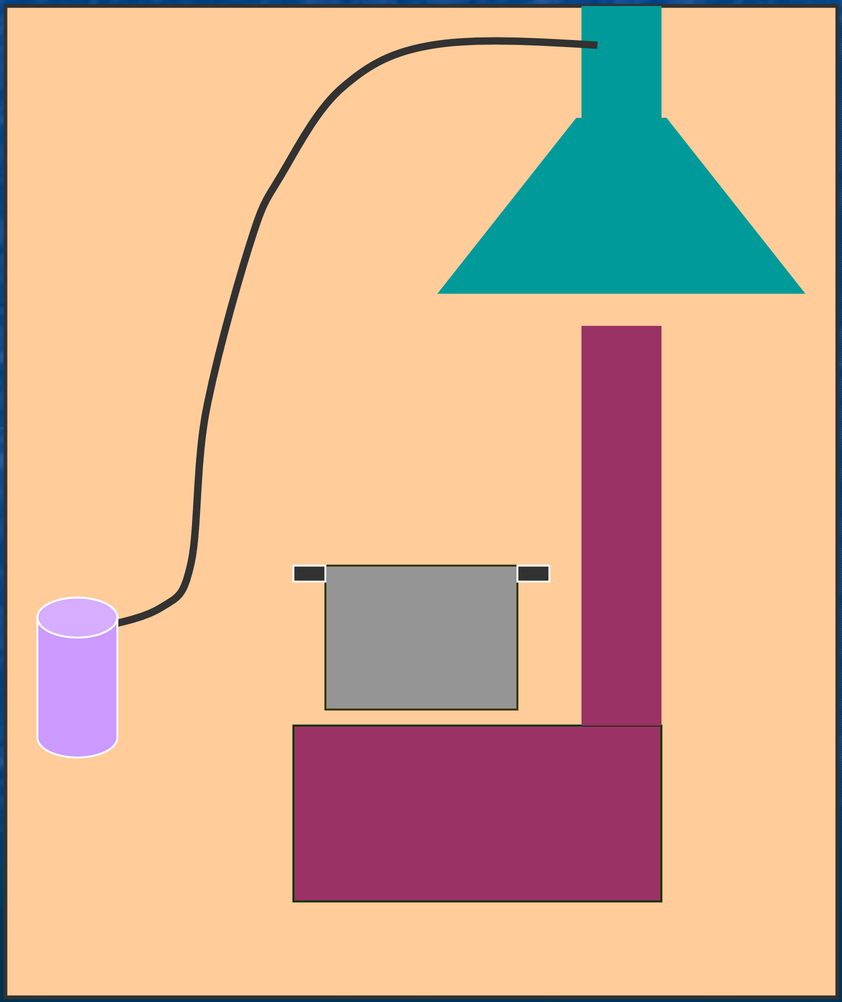
Ways to extract #2

- From known-volume chamber
  - representative of dilution to room
  - doesn’t work for stoves with chimneys
  - uncertainty due to variable air exchange rates
  - needs further examination



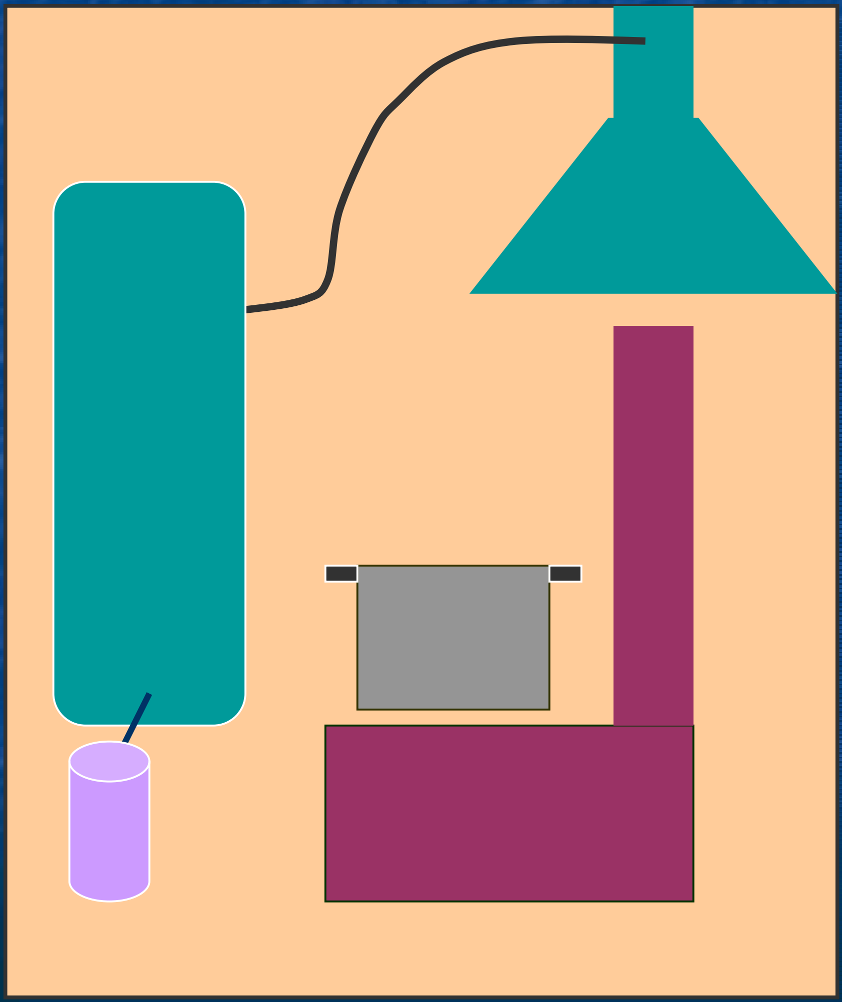
Ways to extract #3

- From collecting hood
  - many people have used this
  - may not represent dilution into atmosphere or room
  - requires bulky hood & exhaust fan
  - adds height to measurement setup



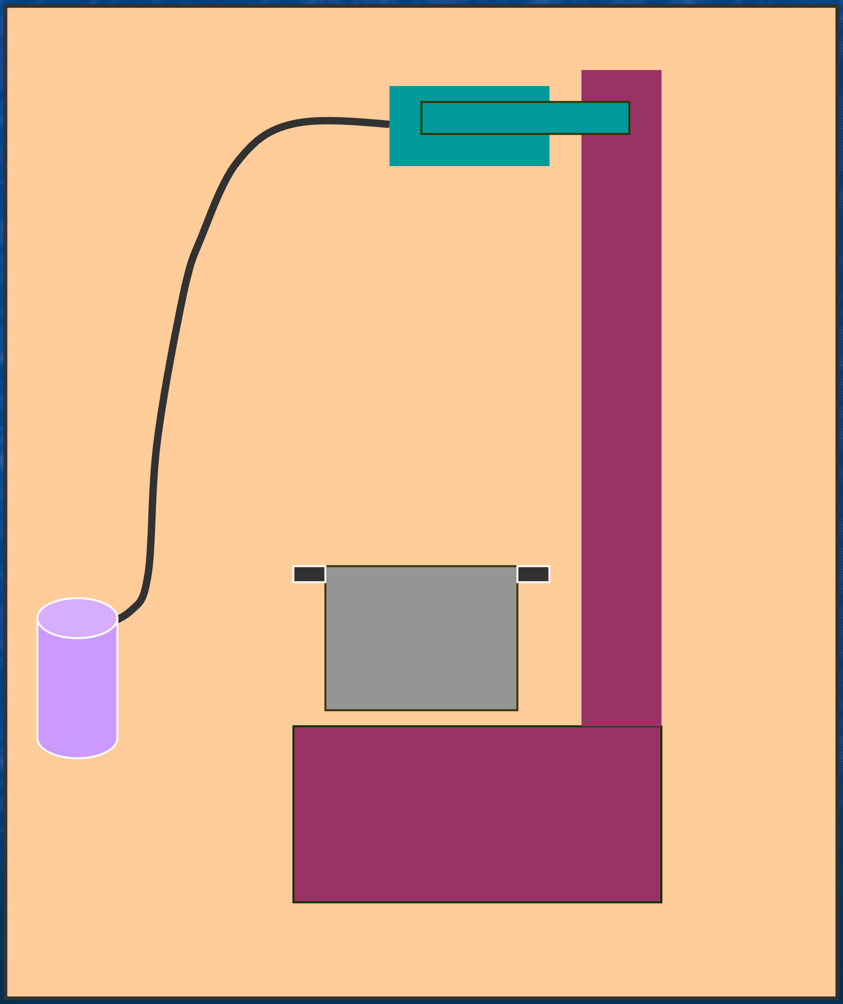
Ways to extract #4

- From collecting hood with dilution plenum
  - may be most representative of actual dilution
  - requires bulky hood & exhaust fan & large plenum



Ways to extract #5

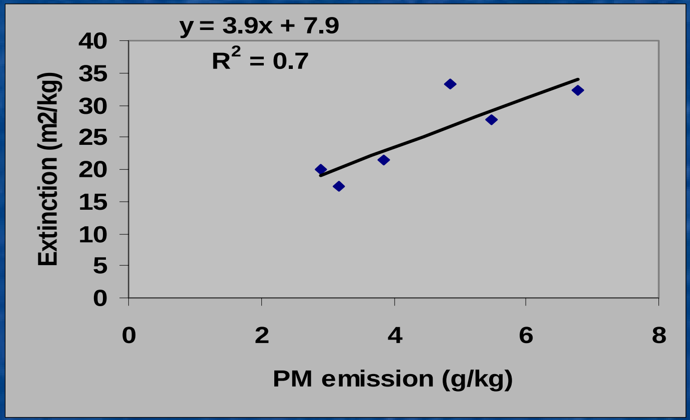
- Dilute part of exhaust
  - use small fan
  - somewhat representative of actual dilution
  - need controlled flows to keep dilution constant

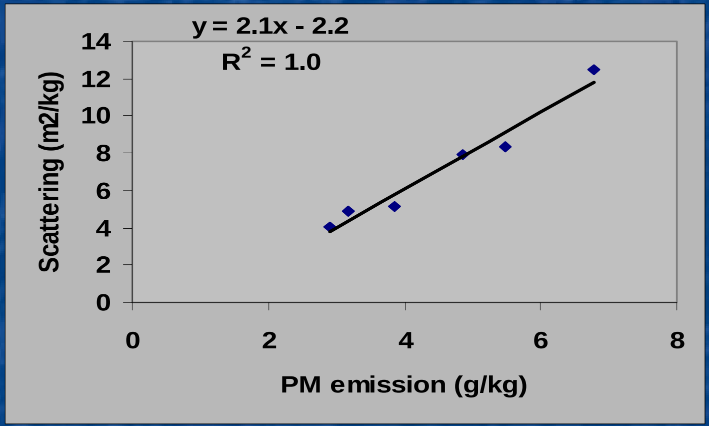


How useful are optical methods?

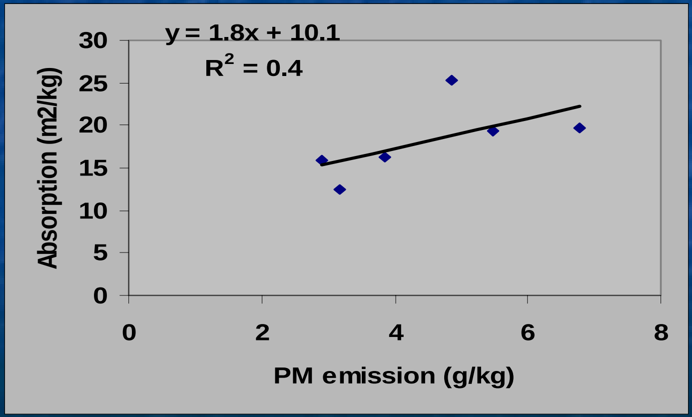
- From diesel tests, we know that "opacity" can be poorly correlated with mass emissions.
- Do any optical properties correlate with mass?
  - Extinction (opacity)= scattering + absorption
  - Light *scattering* is supposed to be best

Correlations with optical properties

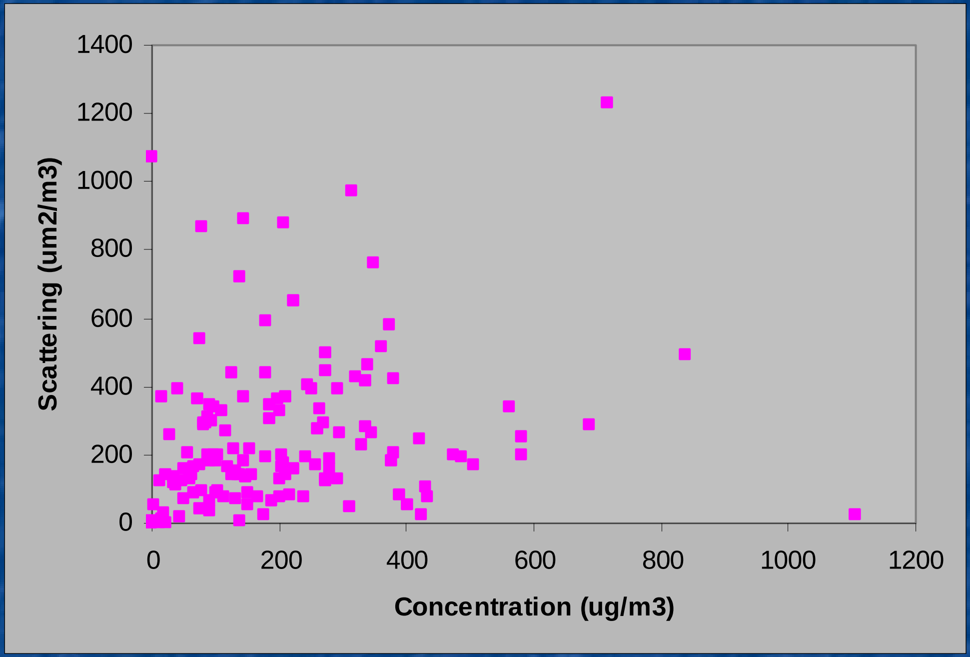




- Scattering has best correlation with mass
- Extinction is worse correlation, because absorbing properties change



Relationship between mass & scattering in real-time



Mass estimated from particle-size data
Correlation coefficient = 0.23 – not very good!

Gases we could measure...

Compound	**Reasons to measure**
CO_2 (carbon dioxide)	Relate other measurements to total fuel burned GCC: Greenhouse gas
CO (carbon monoxide)	IAQ: health effects RAQ: EPA 'criteria pollutant' GCC: affects oxidizing capability of atmosphere
NOx (nitrogen oxide)	RAQ: ozone formation
SO_2 (sulfur dioxide)	RAQ: Precursor to acid rain GCC: Precursor to sulfate aerosols
UHC (unburned hydrocarbons)	RAQ: Ozone precursor (→GCC: radiative forcing)
CH_4 (methane)	RAQ: Ozone precursor GCC: Greenhouse gas
NMVOC (non-methane volatile organic comp.)	Health effects? RAQ: Ozone precursors (→GCC: radiative forcing)

...and should measure

Compound	In-field	Testing Lab	Comments
CO_2	Yes	Yes	Makes it easy to relate all emissions to fuel burned
CO	Yes	Yes	Really important for all impacts
NO_x	No	??	Usually have low emissions because of low temperatures
SO_2	No	Probably not	If estimates are wanted, may be easier to correlate with fuel sulfur content
UHC	No	Probably	Helps in understanding of incomplete combustion
CH_4	No	Limited	With help from outside lab
NMVOC	No	Limited	With help

Particle components we could measure…

Compound	Reasons to measure
Total mass (size range?)	IAQ: Health effects RAQ: Visibility, health effects due to outdoor air
“EC” (elemental carbon) and “OC” (organic carbon)	RAQ and GCC: Affects radiative transfer May be indicator for health effects
PAH	IAQ: Health effects
Trace metals	Tracers for source apportionment; health effects
Specific organic compounds	Tracers for source apportionment; health effects
Ionic compounds	RAQ: Acid rain GCC: Modeling input

…and should measure

Compound	In-field	Testing Lab	Comments
Total mass	Yes	Yes	One of the most basic measurements
EC/OC	No	Yes	Or some method of absorption; simplest test of smoke composition
PAH	Yes	Limited	Perhaps only if used for epidemiological studies
Trace metals	No	No	Emissions quite low
Specific organic compounds	No	Limited	For tracer purposes; if outside organization will provide analysis
Ionic compounds	No	Limited	For tracer purposes; if outside organization will provide analysis

Ideas: In-field

- All real-time, or as close as possible
- Sampling possibilities:
  - Hood method?
  - Diluting probe?
- CO_2, CO, PM, draft

Ideas: Testing lab

- Hood measurements
- Real-time: CO_2, CO, PM, light absorption, UHC
- Limited basis:
  - bag samples for CH_4, NMVOC– need Tedlar bags, pump, flowmeter
  - filter samples for PAH– need filters, filter holders, pump, flowmeter
- Very limited basis:
  - filter samples for specific organic and ionic compounds– need filters, filter holders, pump, flowmeter

Conclusions (do we have any?)

- Difficult to decide on extraction approach (and prove its validity)
- Real-time data for most variables of interest
- Decision on specific measurements probably easier
  - All agree on CO and PM!