Emission Testing of Rocket Stoves

Tami C. Bond (NOAA-PMEL, Seattle, WA, USA),
Ken Goyer, Larry Winiarski, and Dean Still
(Aprovecho Research Center, Eugene, OR USA)

ETHOS Meeting
Seattle, Washington, USA
January 12, 2002

Importance of Particulate Matter

Particulate matter (PM) has negative effects on:

- Human health (respiratory ailments, increased hospital admissions)
- Regional air quality (visibility)
- Agriculture (haze decreases sunlight available for crops)
- Climate (reduces input of sunlight, may heat atmosphere)

How do stoves play into each of these pictures?

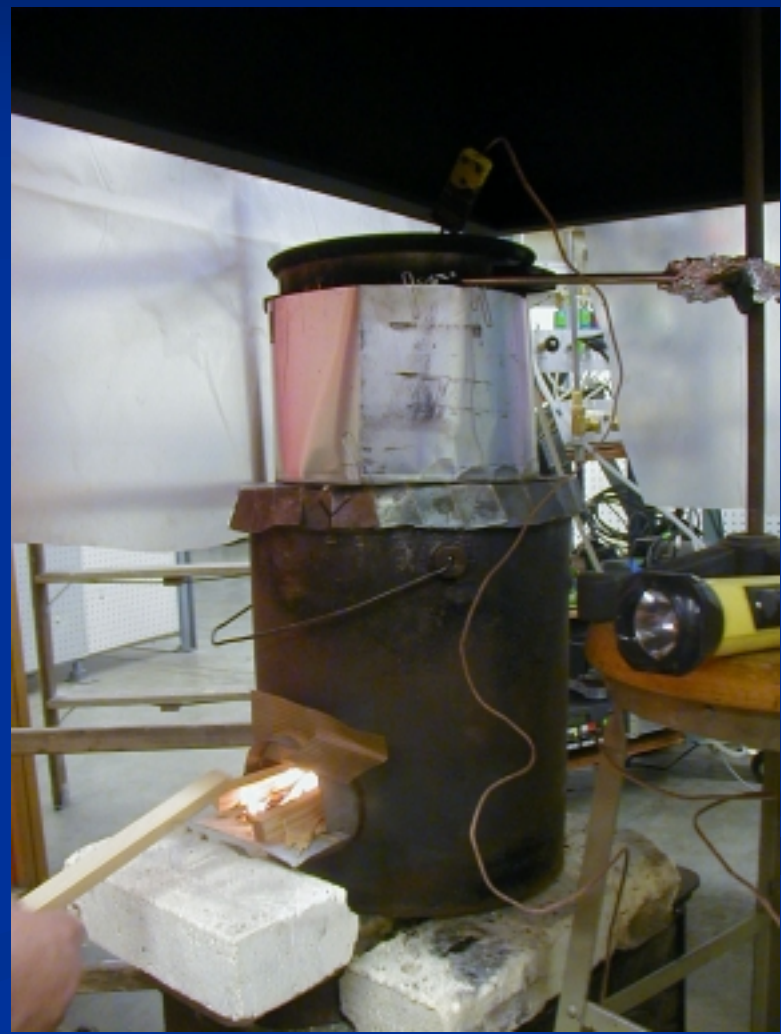
Do ‘improved stoves’ really improve emissions?

Stove #1: “Bricket Rocket”

- Made by Aprovecho with Rocket design
- 6 bricks in hexagon
- Ken Goyer’s vernacular firebrick recipe
- Pot skirt

Stove #2: “Bucket Rocket”

- Made by Aprovecho with Rocket design
- Cylindrical, insulated
- Pot skirt



Testing so far

Wood: Dry Douglas fir, about 1 cm square cross-section

First round: *December 19*

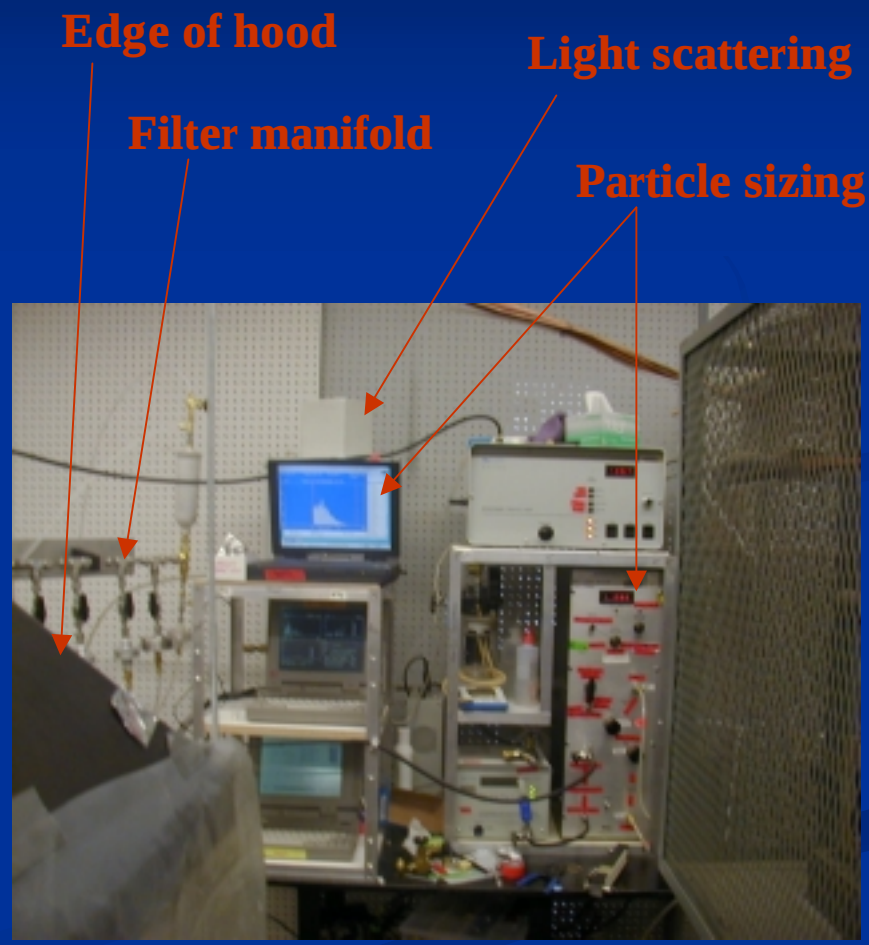
- Fire tended by Larry and Ken: attention to burning
- 4 kg water boiled, simmered for 30 minutes

Second round: *December 28*

- Fire tended by Tami while watching measurement equipment. Less attention to fire, as if rolling tortillas, chasing children, etc.
- 1.5 kg water boiled, simmered for 30 minutes

Testing Setup

- Exhaust hood with light draft (0.08 m/s)
- Exhaust withdrawn from duct above hood with diluting probe



Measured emissions

- Carbon monoxide
- Particulate mass (submicron)
- “Elemental” and “organic” carbon (Carbon analyzer)
- Light absorption (PSAP, IP)
- Light scattering (3-λ nephelometer)
- Size distributions (SMPS, APS)
- Waiting for analysis:
  Ions (IC), Trace metals (XRF)

Efficiency Comparison

Stove	12/19 (Larry/Ken)	12/28 (Tami solo)
Bricket Rocket	27%	22% *
Bucket Rocket	28%	29%
Open Fire	21%	23%

Did not count heating of pot. Assumed heating value of wood 20 MJ/kg (8600 Btu/lb)

* Tried large piece of wood (3 cm diameter), which probably contributed to low efficiency

Emission Comparison (g/kg fuel)

Stove	Particulate Mass	CO
Bricket Rocket	3.4 (2.9, 3.8)	38 (48, 28)
Bucket Rocket	4.0 (3.2, 4.9)	40 (46, 34)
Open Fire	6.1 (6.8, 5.5)	62 (76, 50)

Emission Comparison (g/MJ delivered)

Stove	Particulate Mass	CO
Bricket Rocket	0.7 (0.5, 0.9)	7.5 (8.8, 6.2)
Bucket Rocket	0.7 (0.6, 0.9)	7.1 (8.2, 6.1)
Open Fire	1.4 (1.6, 1.2)	15 (18, 11)

Comparison with other studies

Investigator	Stove	Mass (g/kg)	CO (g/kg)
These measurements	Bricket Rocket Bucket Rocket Open Fire	3.4 4.0 6.8	29 31 48
Smith/China	Traditional (4) Improved (2)	2.8 (1.5-4.2) 4.4 (4.1-4.6)	57 (23-95) 82 (65-98)
Smith/India	Traditional (2) Improved (8) Open fire (2)	1.0 (1.0-1.0) 2.8 (1.2-4.0) 1.5 (0.9-2.1)	58 (50-67) 89 (64-140) 62 (60-65)
Ballard-Tremeer	Open fire (2) Stoves (3)	0.9 (0.8-1.1) 1.1 (0.6-1.5)	19 (19-19) 42 (22-66)
Joshi	Stoves (3)	2.2 (1.9-2.8)	37 (17-62)
Venkataraman	Stoves (4)	1.2 (0.8-1.8)	11 (11-12)
Oanh	Stove (1)	0.05	--

Other emission characteristics

	Bricket	Bucket	Open
Particles (N/kg)	4.2×10^{14}	2.9×10^{14}	8.5×10^{14}
Absorption (m^2/kg)	17	18	22
Single-scatter albedo *	0.22	0.26	0.34
EC fraction of carbon	0.60	0.46	0.33

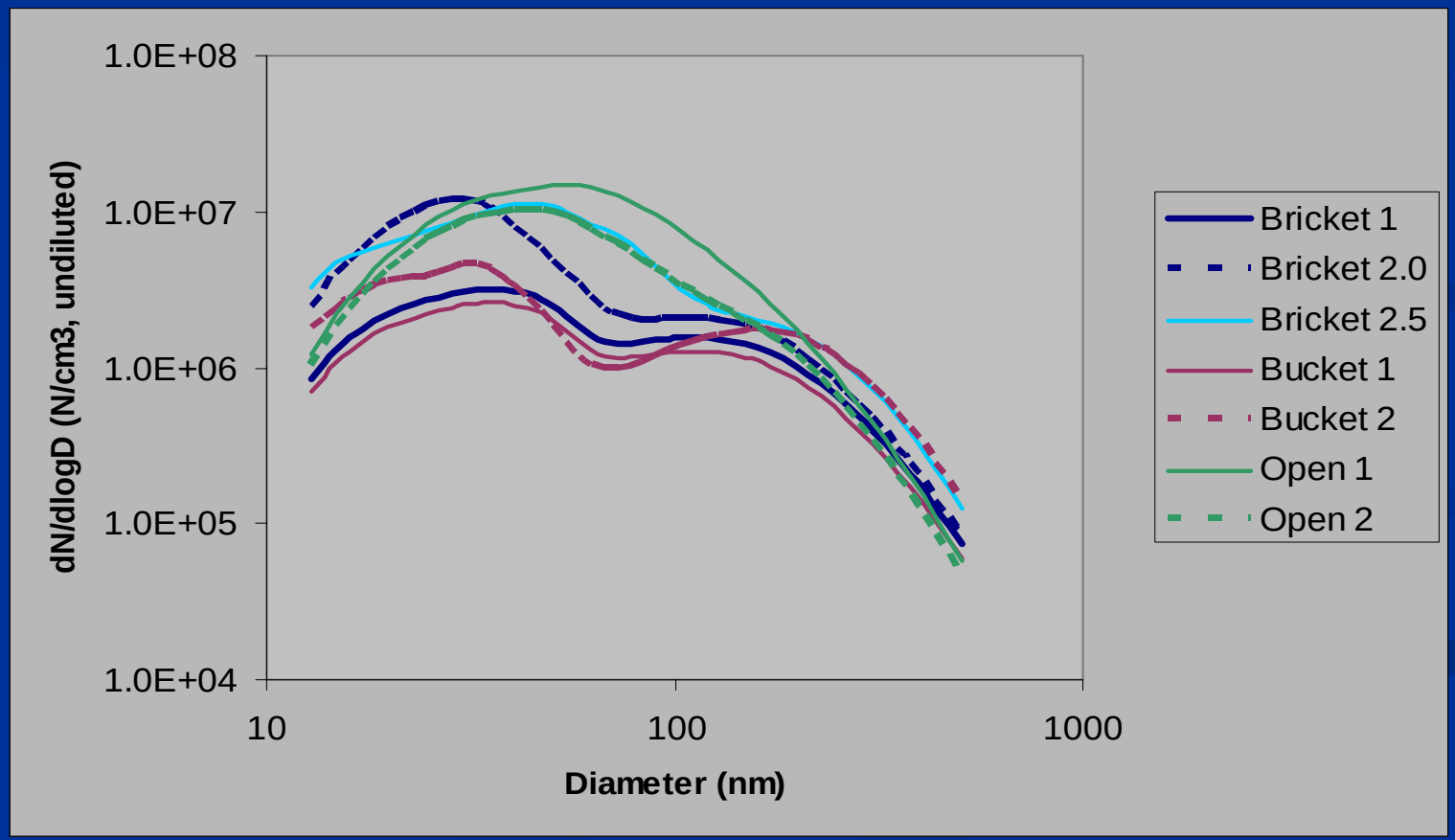
- Single-scatter albedo goes from 0 to 1; low single-scatter albedo indicates more absorption.
- The open fire produces *more* particles that are *less black*.

Why size distributions?

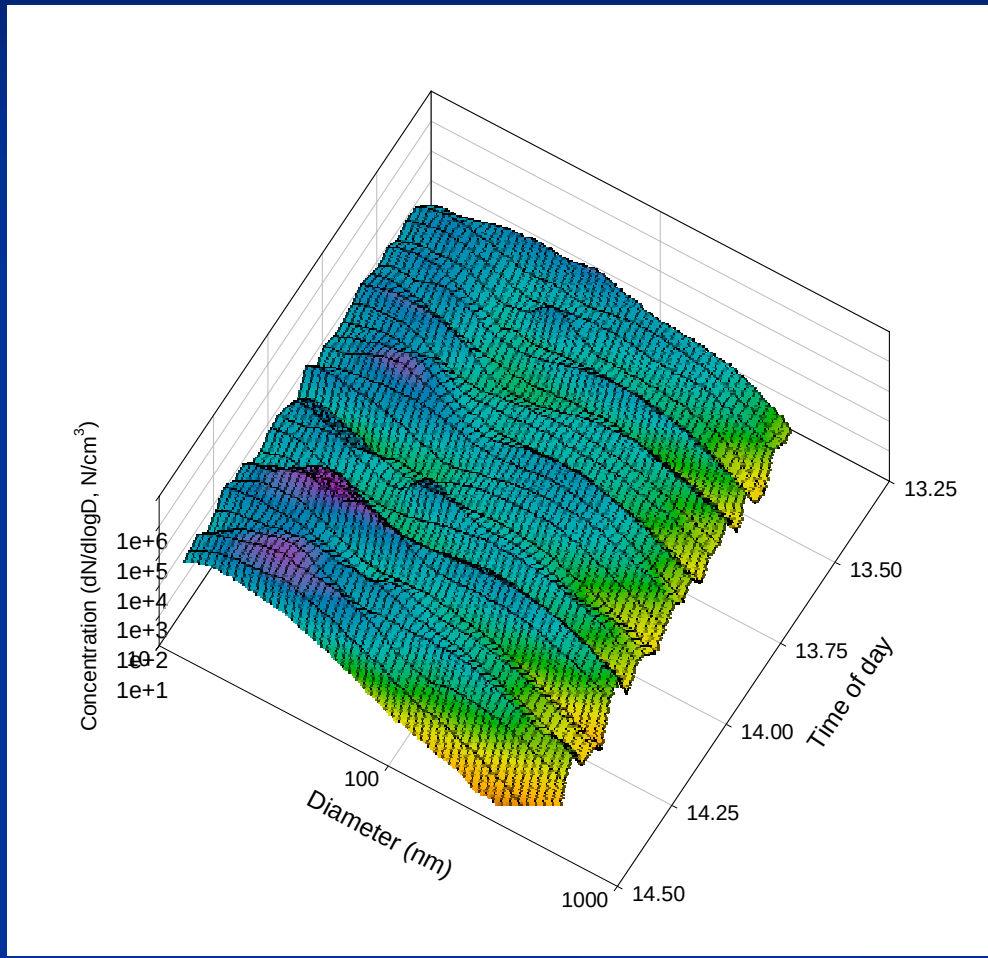
- For stovers, perhaps of only passing interest at this point
- Particle size:
  - Indicates formation mechanisms
  - Affects atmospheric processing & lifetime
  - Affects fraction of particles deposited in lung

Size distributions

For the two Rockets, there are two modes: one small (~30 nm) and one larger (~200 nm). The open fire has less well-defined modes. The Rocket looks more like the open fire when I used larger wood (Bricket 2.5).



Real-time size distributions

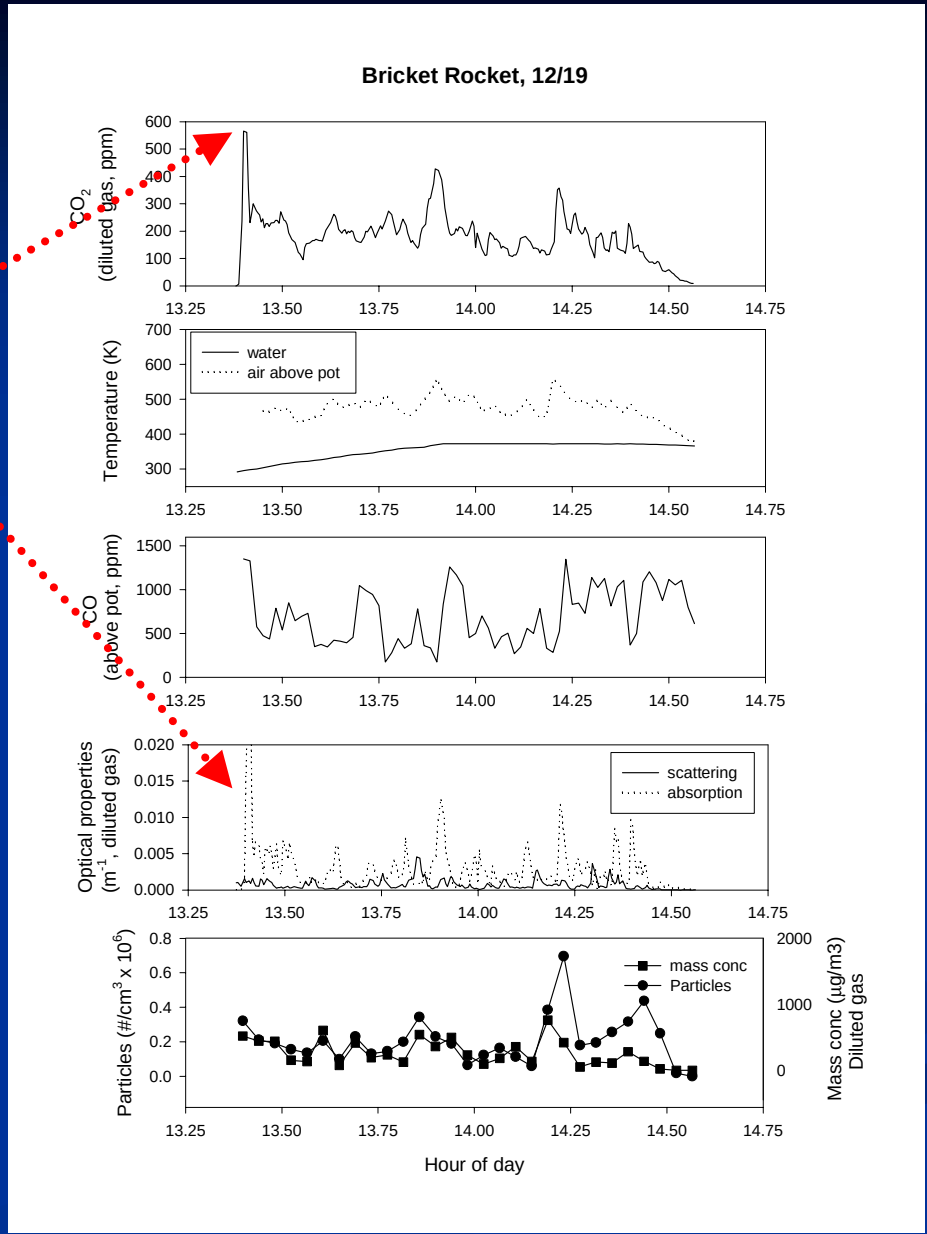


What's the good of real-time data?

- Identify situations that produce high emissions
- Rapid feedback in stove design
- Understand nature and magnitude of variability
- Validate models?

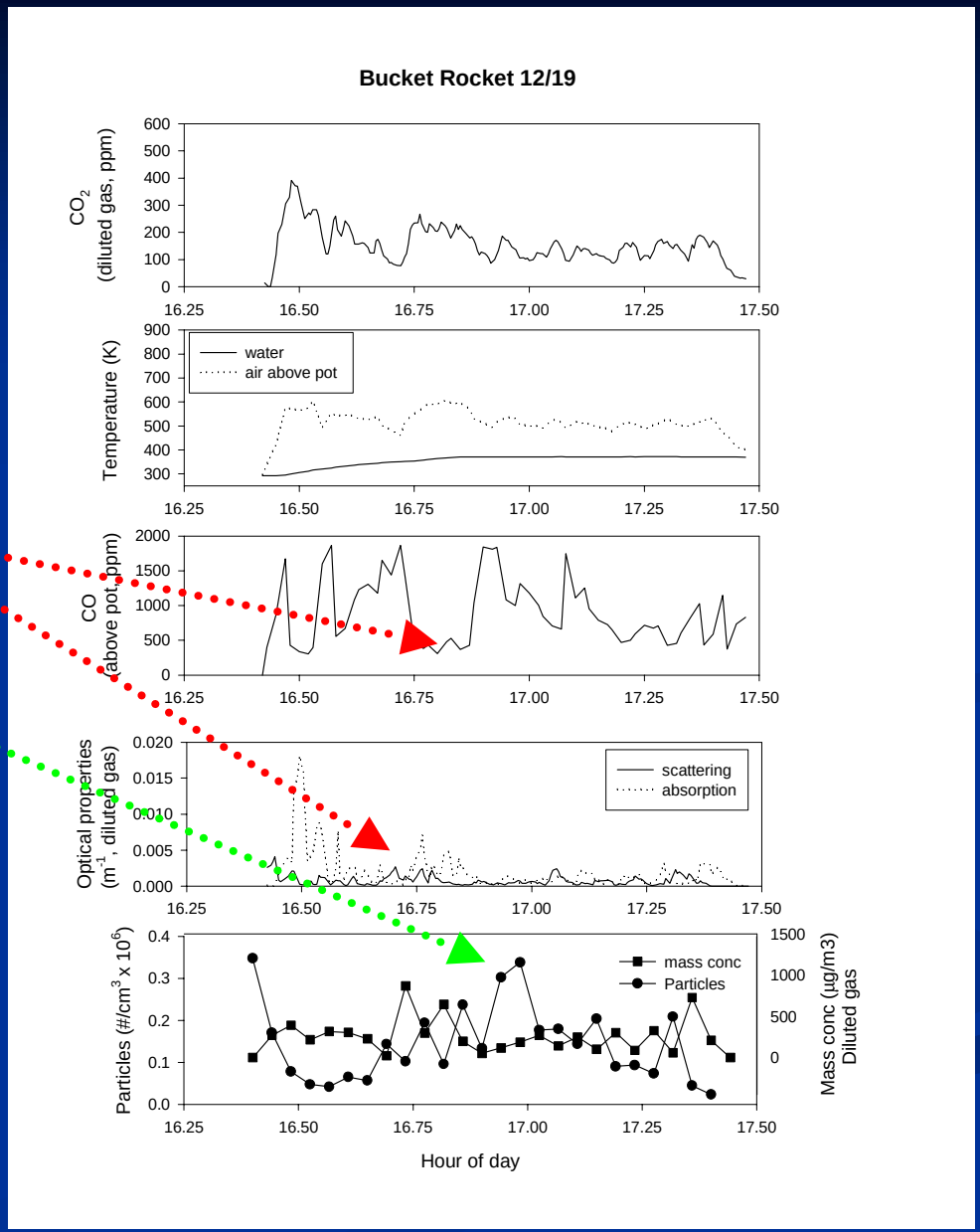
Real-time data Bricket Rocket

- Spike of CO & absorption at start-up
- We frequently saw absorption spikes when wood was added.
- Highly variable: for CO, standard deviation is 85% of the mean (1-min avgs)



Real-time data Bucket Rocket

- Spike at start-up
- Absorption less spiky than Bricket Rocket
- Sometimes CO is low when absorption is high
- Number of particles not always correlated with mass



Conclusions

- Both Rocket stoves improved over an open fire
  - Higher efficiencies
  - Emissions of CO & particles reduced by ~50%
- Combustion variable for all fires
- Particles quite black