Modeling crop residue burning experiments and assessing the fire impacts on air quality

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Crop residue burning experiments in summer 2013

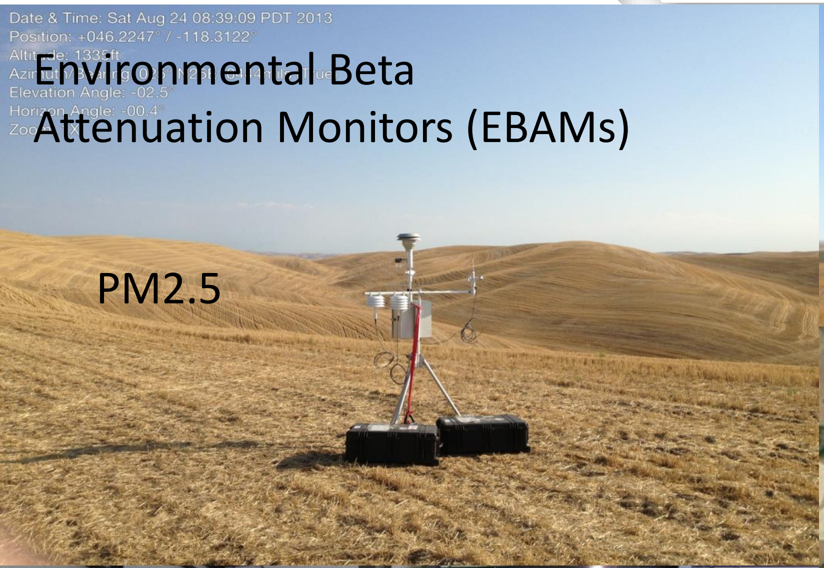
Nez Perce, ID

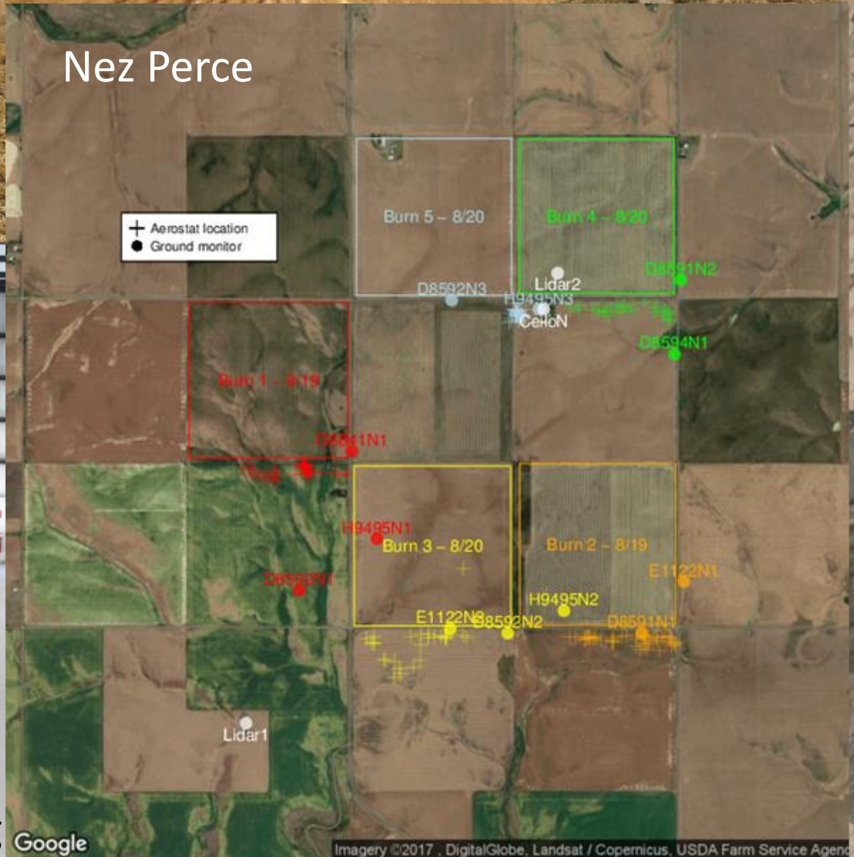
- Aug. 19, Burn 1-2, (Kentucky Bluegrass)
- Aug. 20, Burn 3-5 (Bluegrass, Wheat)

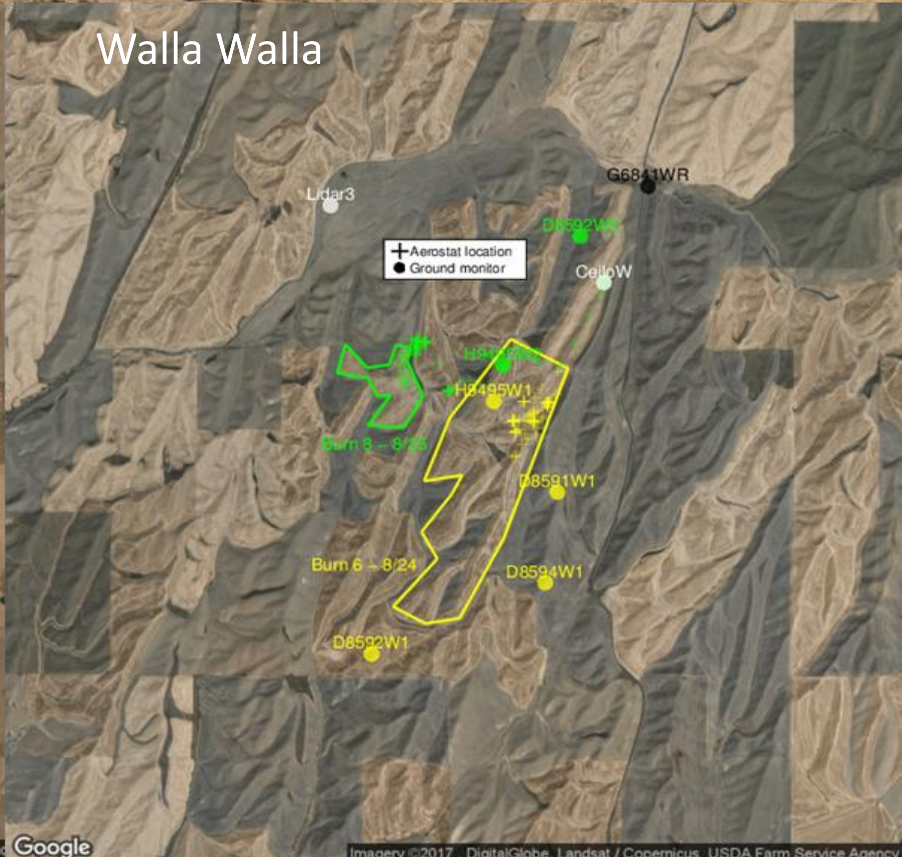
Walla Walla, WA:

- Aug. 24 Burn 6, (7) (Wheat)
- Aug. 25 Burn 8 (Wheat)

Ground / Flight / Aerostat / Remote Sensing

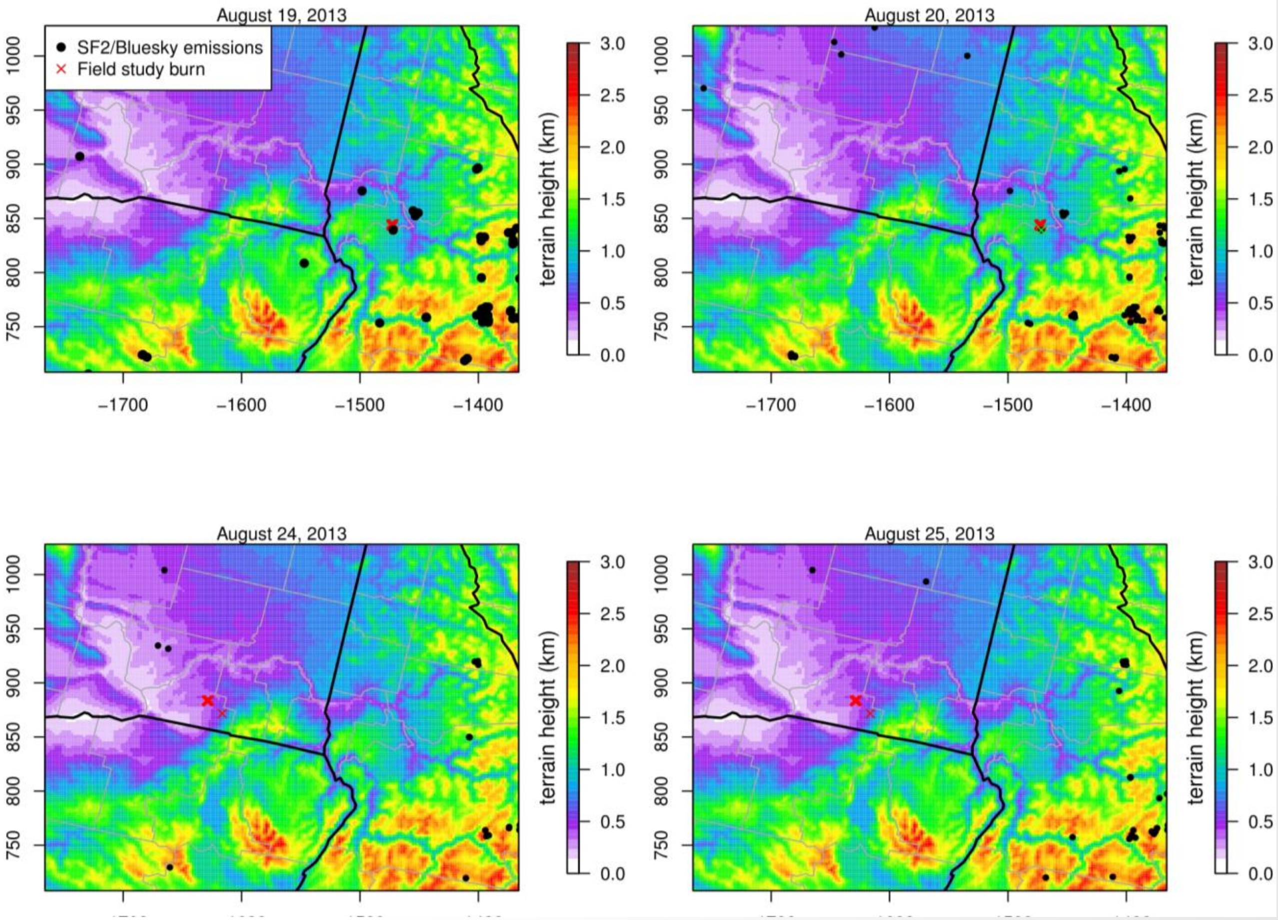






Model configuration and inputs

- CMAQ v5.2
- August 18 to 28, 2013
- 200 × 160 2-km square grid cells
- Meteorological input from WRF
- IC and BC from 2013 CONUS 12 km
- CB6_AE6_nvPOA
- 2011v2 NEI
- BEIS3.6
- Wild and prescribed fire from BlueSky framework



Model domain with the terrain height, location of field study burns in this study (red cross), and location of other fires detected by HMS satellite detect based wildfire emission points (black dot).

Emission estimation – field data based

Approach I – emission input based on field information											
Burn No.	Fuel Type	size (acres)	Fuel load (tons/acre)	combustion completeness	biomass consumed (tons)	Approximate duration (h)	MCE	Emission factor		Total emissions[c] (tons)	
								CO	$PM_{2.5}$	CO	$PM_{2.5}$
1	B	163	1.16	0.9	170	1	0.95	49.4	14.6	8.4	2.5
2	B	163	1.61	0.9	236	1	0.93	68.1	12.4	16.1	2.9
3	W	163	1.65	0.9	242	1	0.95	49.9	9.3	12.1	2.3
4	B	163	2.87	0.9	421	1	0.93	74.2	19	31.2	8.0
5	B	163	1.82	0.9	267	2	0.94	64.7	8.5	17.8	2.4
6	W	237	3.07	0.9	655	2	0.97	34.1	12.6	22.4	8.2
8	W	67	3.39	0.9	204	1	0.97	27	12.2	5.5	2.5

B – Bluegrass W – Wheat

Emission estimation – 2014 NEI method

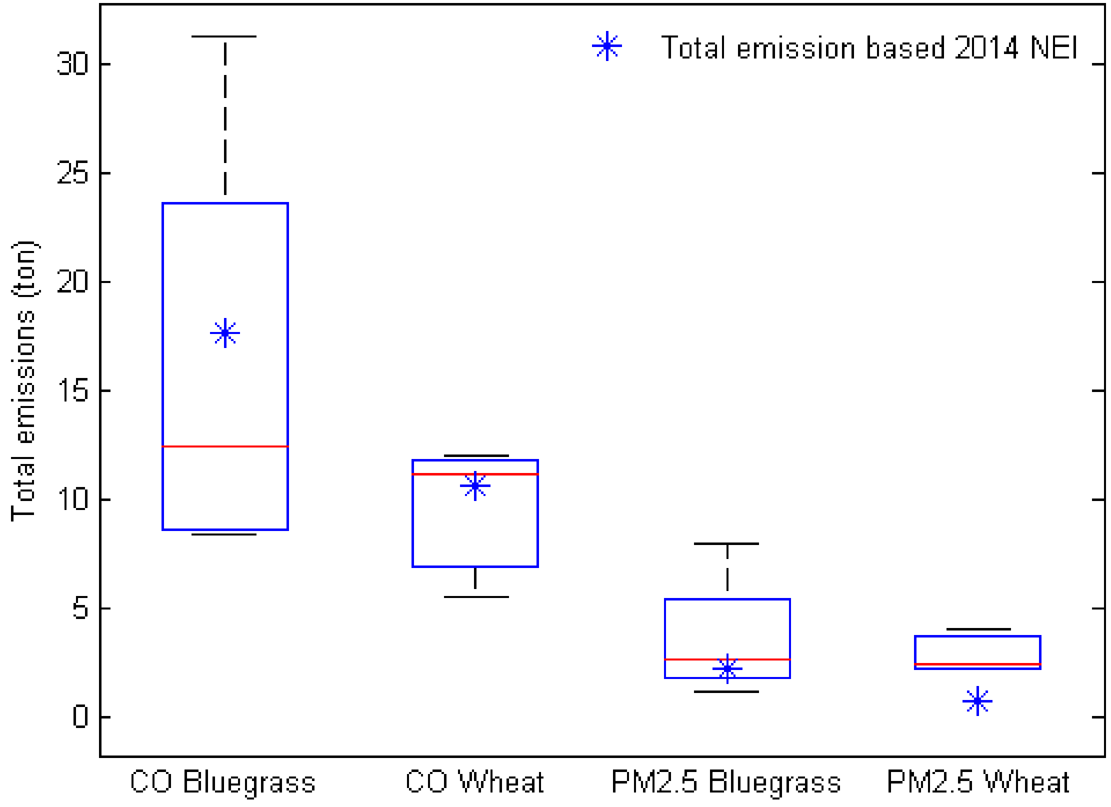
- The Hazard Mapping System (HMS) detected burns for only one of the sampling days and did not distinguish between multiple burns at that location.
- Fire location and timing were based on actual field study information during Aug. 19 – 25 2013.
- Area burned, fuel load and fuel specific (bluegrass and wheat) emission factors were based on default assumptions used in the 2014 NEI (Pouliot et al., 2017).

Approach II – emission input based on 2014 NEI method (Pouliot et al., 2017)

Burn No.	Fuel Type	size (acres)	Fuel load (tons/acre)	combustion completeness	biomass consumed (tons)	Approximate duration (h)	MCE	Emission factor (McCarty, 2011)		Total emissions (tons)	
								CO	$PM_{2.5}$	CO	$PM_{2.5}$
1/2/4/5	B	120	1.9	0.85	194	1	0.95	91.1	11.6	17.6	2.3
3/6/8	W	120	1.9	0.85	194	1	0.97	55.1	4.0	10.7	0.8

Higher fuel consumption and large variation in emission estimation

- **~ 60% higher fuel consumption** than 2014 NEI estimation in this region.
  - Average biomass fuel load is 2.2 tons/acres, 16% higher than the default 1.9 tons/acres in 2014 NEI.
  - Average area burned is 160 acres, 30% higher than the default 120 acres in 2014 NEI.
  - Average combustion completeness is 90%, 5% higher than the default 85% in 2014 NEI.
- Measured CO emission factors lower than default factor in 2014 NEI
- Measured $PM_{2.5}$ emission factors are comparable with default factors in 2014 NEI for bluegrass, but higher for wheat.
- Overall, the total emissions (consequently the emission rates) by 2014 NEI approach are within the interquartile range of the filed data.



$$Emission = fuel\ consumption * emission\ factor$$

Two inputs related to plume-rise simulation

- **Plume-rise height is dependent on Buoyancy Heat Flux (BHF, BTU/s)**

$$BHF\left(\frac{BTU}{s}\right)$$
$$= Area\ Burned\ (acre) \times Fuel\ Loading\ \left(\frac{ton}{acre}\right) \times Heat\ content\ \left(\frac{BTU}{ton}\right) \div Duration\ of\ fire\ (s)$$

Heat Content always assumed to be 1.6×10^{7} BTU/ton in SMOKE.

- **Vertical distribution of emissions based on flaming (or smoldering) phase allocation**

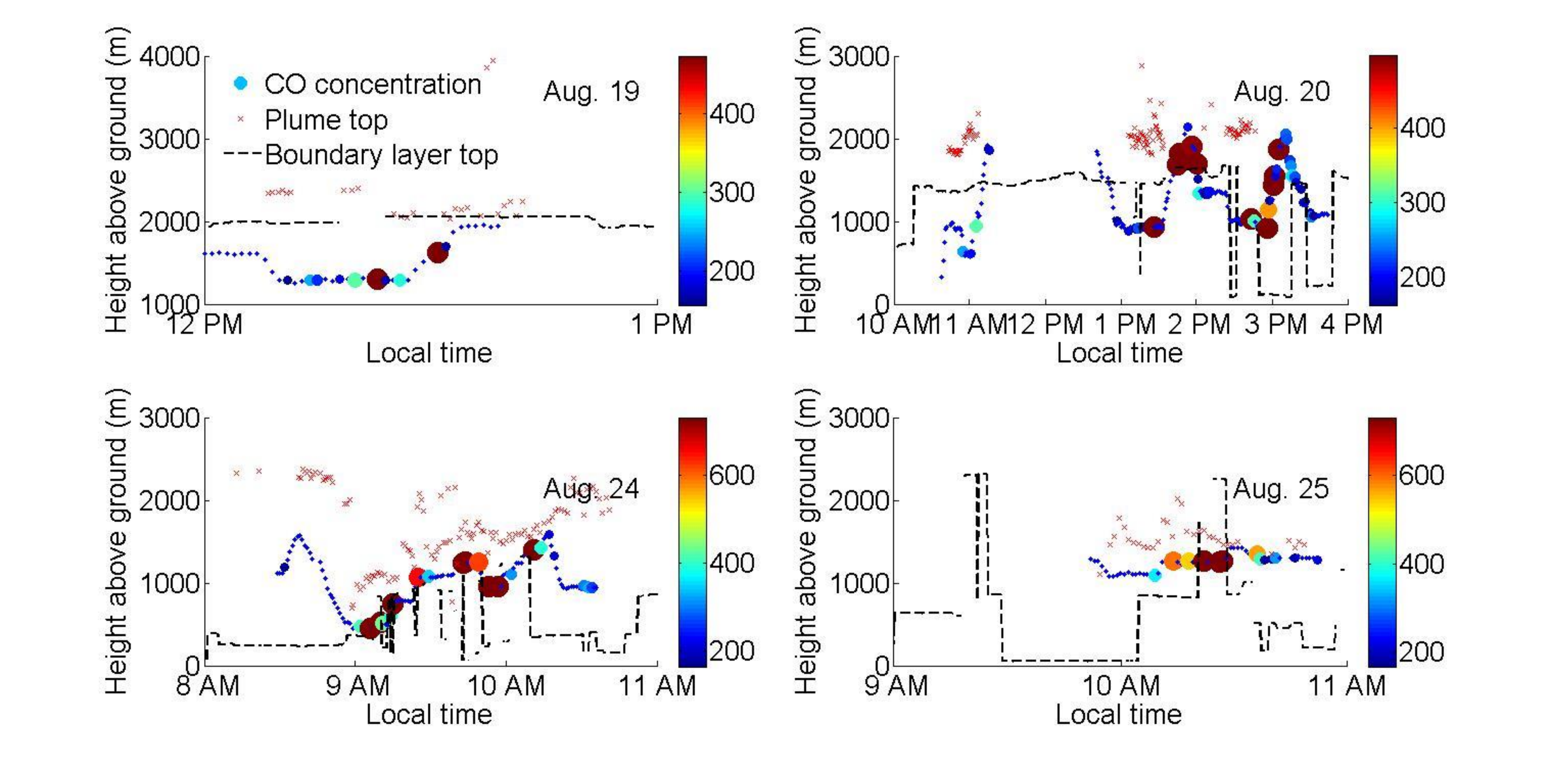
$$Flaming\ \% = Ln(Area\ Burned\ in\ acres) \times 0.0703 + 0.3$$

The Residual smoldering phase is not considered separately but as part of the smoldering phase.

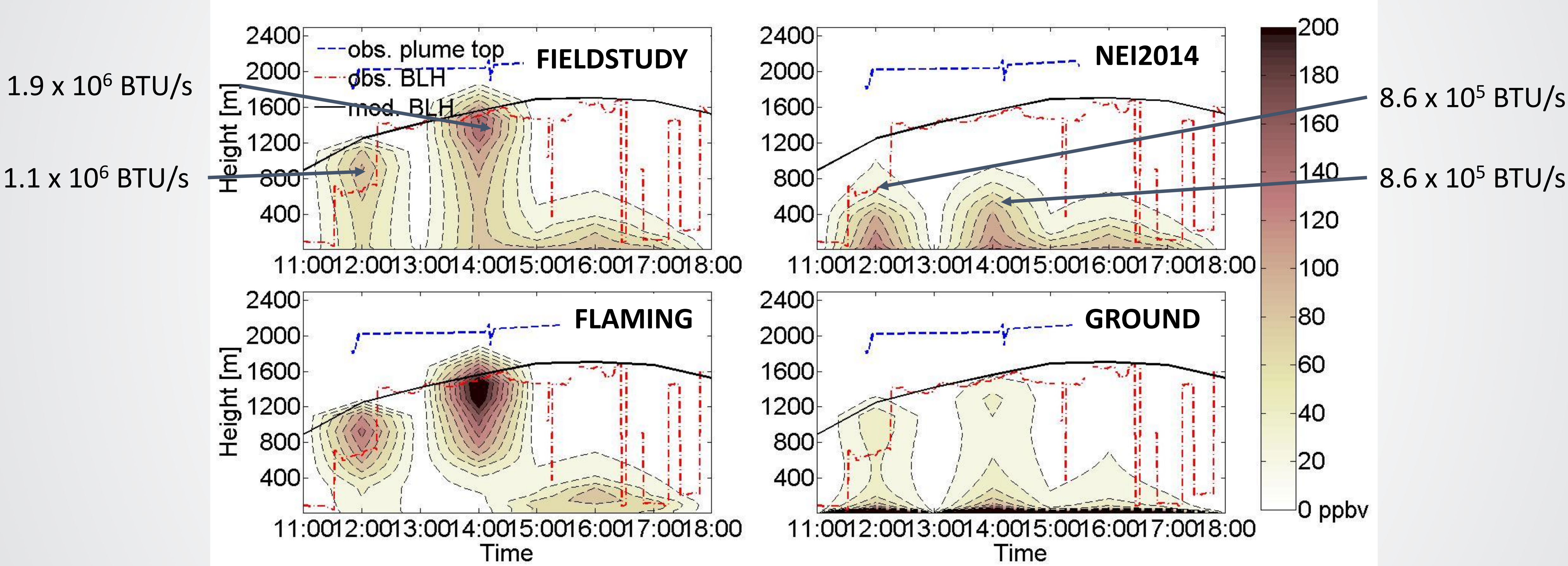
Four sensitivity simulations and one base simulation

- **FIELDSTUDY** – field study specific emissions (approach I)
- **FLAMING** – field study specific emissions (approach I); all emissions allocated to the buoyant plume, i.e. flaming only.
- **NEI2014** – emission estimates based on 2014 NEI approach (approach II)
- **GROUND** – emission estimates based on 2014 NEI approach (approach II); all emissions injected in to the surface layer
- **BASE** – no emissions from the experiment burns are included.

Observed plume top higher than boundary layer top

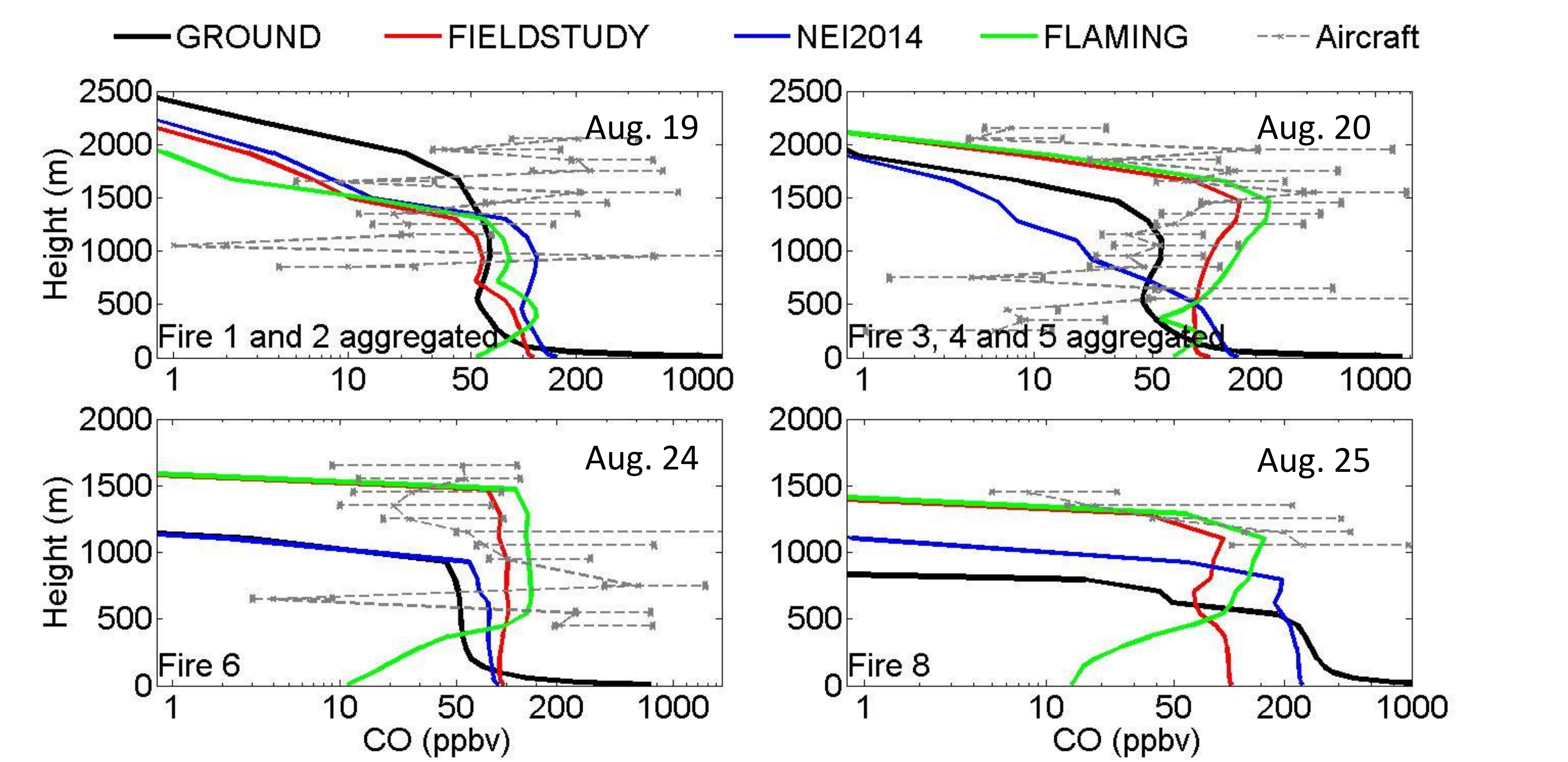


Large uncertainty in BHF leads to significant variation in plume-rise height



Color-filled contours of the simulated CO concentration due to experiment burn emissions at Nez Perce on Aug. 20, superimposed with ceilometer detected boundary layer height, model input boundary layer height, and lidar estimated plume top. The plume edge is the 20 ppbv contour line.

Vertical profile of CO



Depending on emission approaches and emission allocation, the simulated CO surface concentration due to burn experiments ranges between 54 to 157, 12 to 253 ppb (exclude Simulation GROUND).

Impact on surface concentration ($PM_{2.5}$)

Impacts due to different emission estimates (red / blue lines)

- Limited impacts at Nez Perce,
- ~ 80% decrease at Walla Walla

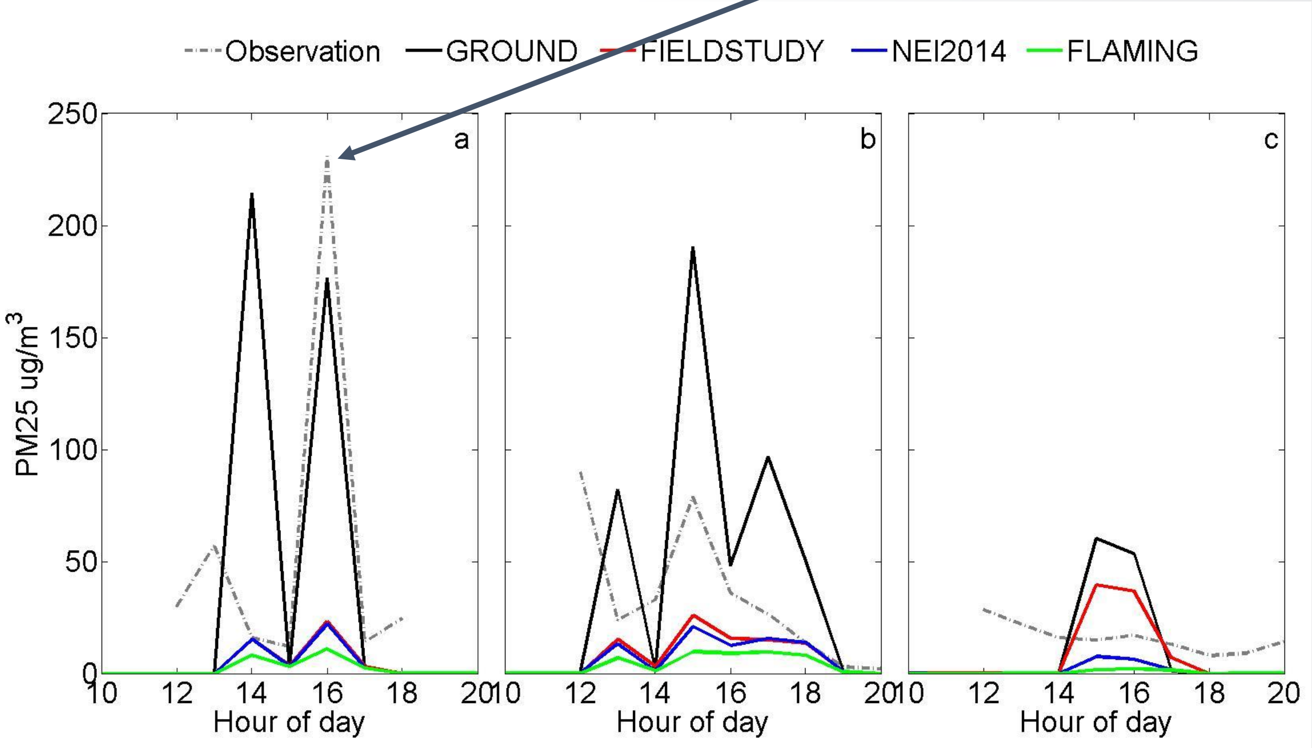
Vertical allocation of emissions (red / green lines)

- 40~60% decrease at Nez Perce
- ~ 90% decrease at Walla Walla

Injecting emissions to the surface layer overestimates the smoke impacts at surface level (black lines)

Depending on emission approaches and emission allocation, the average $PM_{2.5}$ surface concentration due to burn experiments ranges between 8 to 40 ug/m^3 (exclude Simulation GROUND).

EBAMs were set very close to the burning site that the plume hit the instrument inlet directly.



Simulated maximum surface $PM_{2.5}$ concentrations due to fire emissions (lines) and hourly median of EBAMS measurements (dashed line) at Nez Perce on August 19 (a) and 20 (b) and at Walla Walla on August 24 (c).

Conclusion

- Field study average area burned, fuel consumption, and combustion completeness increased biomass consumption by 123 tons (~60% increase) compared to using default values used in 2014 NEI process.

- Buoyancy heat flux estimated directly from measured fuel loading can be 130% to 300% the amount estimated by the current NEI method. The consequent estimated plume rise height increase ranges from 30% to 80%.

- Vertical allocation of emissions directly affects the concentration at the surface. By treating fire emissions solely as flaming related, simulations indicate a 30% to 90% decrease in surface concentration.

- Based on the simulation results, the cropland burns in this study contributed 36 to 164 ppb of CO; 8 to 27 ug/m^3 of $PM_{2.5}$ during the hours of burning.