The Data You Know (or Thought You Knew)

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CAMEE Table Talk
Wildland Fire Series: Part II
The University of Texas at San Antonio
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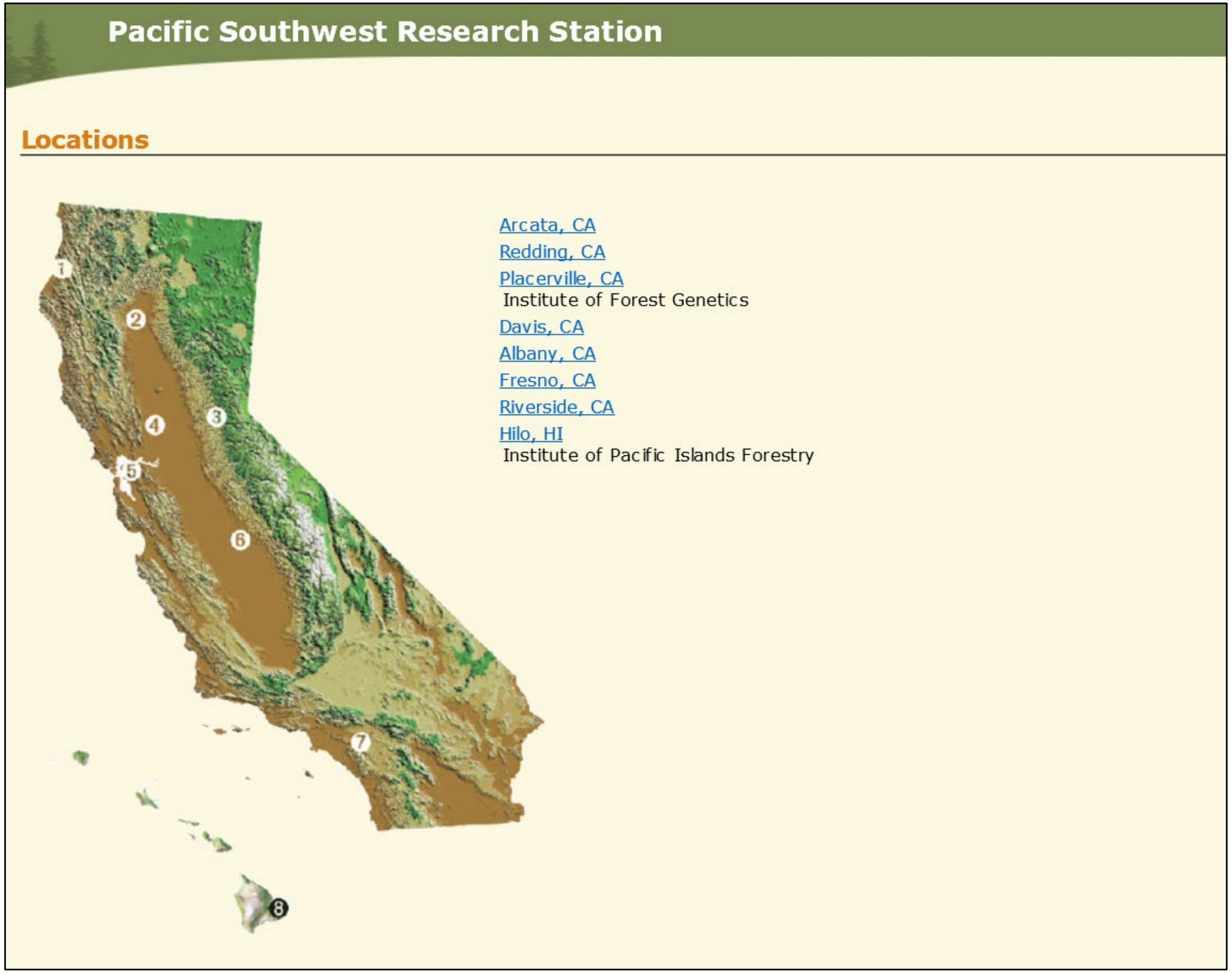
United States Department of Agriculture

Forest Service

Research Offices and Laboratories

Riverside FL is 1 of 3 FS Fire Labs established in 1959 (SFFL), 1961 (NFFL) and 1963 (RFL) to address wildland fire. NIST has BFRL in MD.



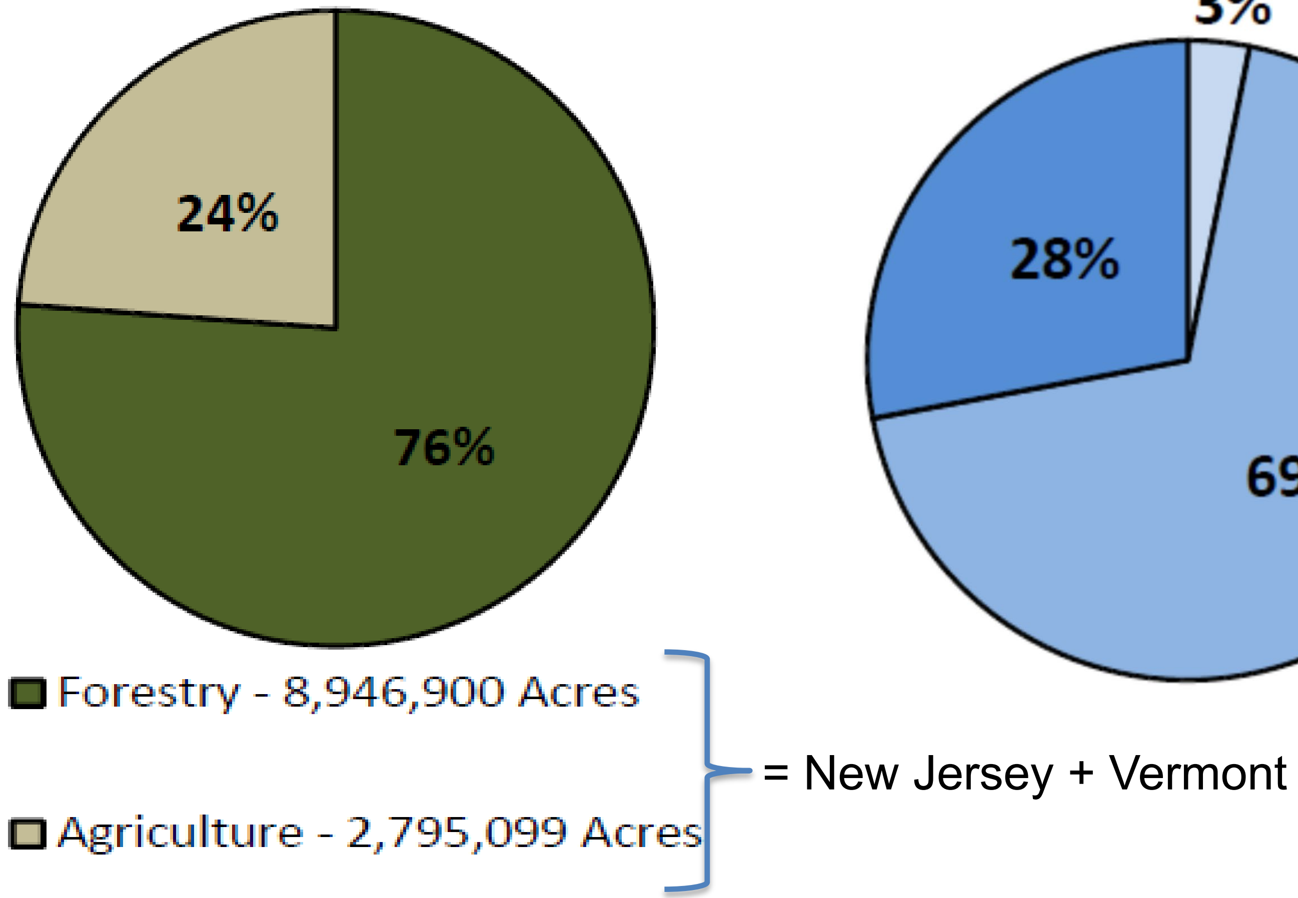
Talk Outline

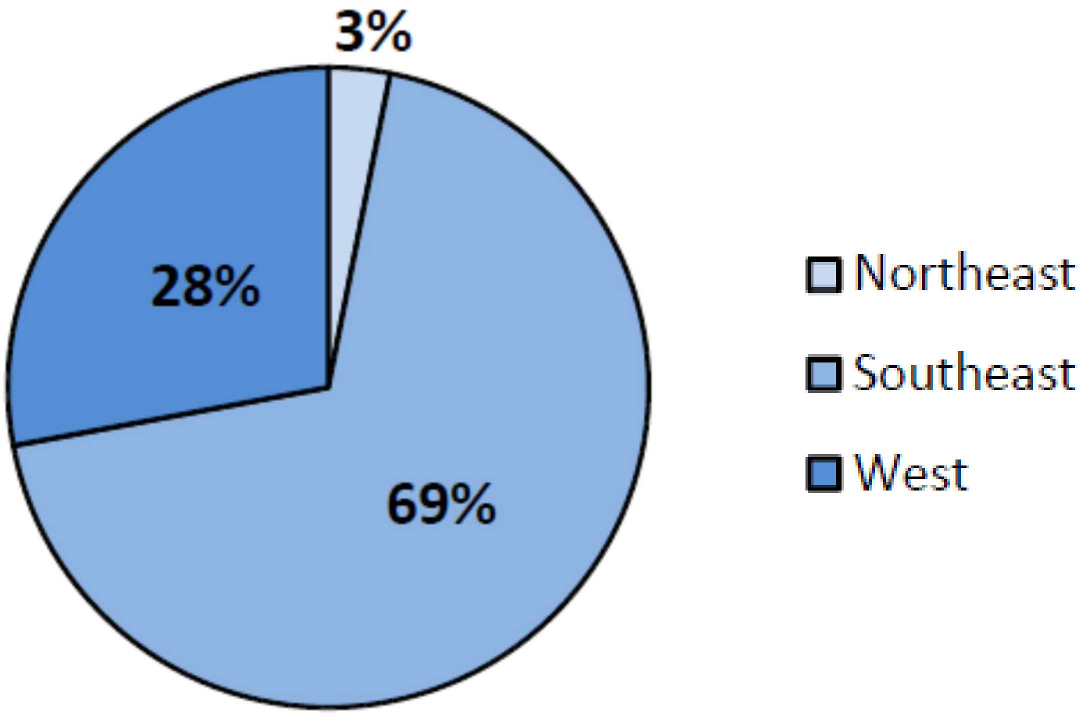
- What is prescribed burning and what do we study?
- Data types / Measurement scales
- What do you Mean by that?
- Some examples
  - Fire behavior
  - Fire effects
  - Smoke

What is Prescribed Burning?

- Fire has been used worldwide by humans for millennia (TEK) – Stephen Pyne “World of Fire”
- The planned application of wildland fire to accomplish specific land management objectives

2015 National Prescribed Fire Use





Source: Melvin, Mark A. 2015. “2015 National Prescribed Fire Use Survey Report.” Technical Report 02–15. Coalition of Prescribed Fire Councils, Inc.

And What Do We Study?

- Objectives:
  - reduce fire hazard by removing fuels
  - improve ecosystem health, mimic natural fire, improve wildlife habitat
  - manage smoke exposure compared to wildfire
- Planning:
  - fire characteristics, smoke transport, meteorology, cost/benefits, social acceptance

And What Do We Study?

- Measurements:
  - Quantity and distribution of woody fuels
  - Effects on plants, animals, soil, water, air
  - Smoke quantity and composition
  - Fire spread patterns, interactions
  - Macro and micrometeorology
  - Economics, social science

Measurement Scales

- Nominal = named data (town, species, color, chemical)
- Ordinal = named and ordered (ranking, scoring)
- Interval = numerical, ordered, difference is measurable and same (temperature in C or F, time)
- Ratio = numerical, ordered, difference is measurable and same, true 0 means no negative values (mass, length)

Data Types

- Fire behavior – velocity, heat flux, temperature, buoyancy, emissivity, reaction rate
- Fuel – mass/area, mass/volume, size, composition, arrangement
- Fire effects – plant species composition, heat transfer, soil composition, growth, mortality, frequency, size
- Weather – wind speed/direction, relative humidity, temperature, fluxes, lapse rates
- Topography

What do you Mean by that?

- Arithmetic – most familiar, all real numbers
- Geometric – for proportions, > 0, log-normal distribution
- Harmonic – for rates, > 0

$$A_n \geq G_n \geq H_n$$

How Confident Are You?

- Arithmetic – standard deviation
- Geometric – geometric standard deviation
- Harmonic – harmonic standard deviation
- General form of confidence interval
  - Estimated mean ± confidence statistic × standard error of mean
  - Use multiple comparison procedures to compare means to control error rate

	Mean	Standard deviation	Confidence interval
Arithmetic	$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$	$s_a = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n}}$	$\bar{x} \pm t_{1-\alpha/2,n-1}\left(\frac{s_a}{\sqrt{n}}\right)$
Geometric	$\bar{x}_g = \sqrt[n]{\prod_{i=1}^{n} x_i}$	$s_g = \mathrm{e}^{\sqrt{\frac{\sum_{i-1}^{n}\left(\ln \frac{x_i}{\bar{x}_g}\right)^2}{n}}}$	$e^{\bar{x}_g \pm t_{1-\alpha/2,n-1}\left(\frac{s_g}{\sqrt{n}}\right)}$
Harmonic	$\bar{x}_h = \frac{1}{n}\sum_{i=1}^{n}(1/x_i)$	$s_h = \sqrt{\frac{\sum_{i=1}^{n}\left(\frac{1}{x_i} - \bar{x}_h\right)^2}{n\bar{x}_h^4}}$	$\bar{x}_h \pm t_{1-\alpha/2,n-1}\bar{x}_h^2 \frac{s_h}{\sqrt{n-1}}$

Example 1 – Fire spread rate

- Important fire behavior variable
- Is a velocity (rate)
- Harmonic mean should be used (F.M. Fujioka, *For. Sci.* 31 (1985) 21–29)

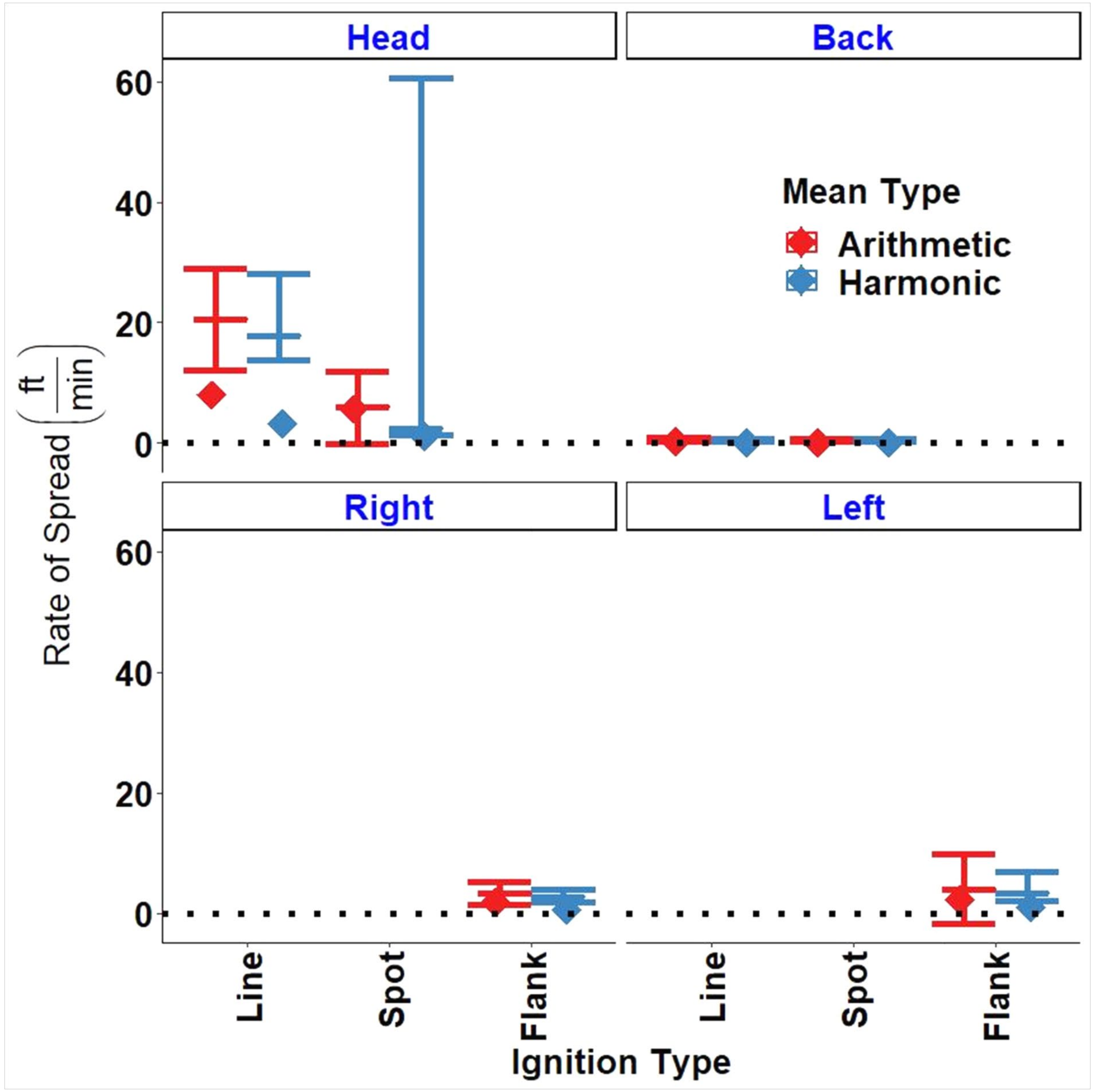
The Data (ft/min)

Line fire		Spot fire		Flank fire	
Heading	Backing	Heading	Backing	Left	Right
24.2	0.5	16.4		6.6	2.1
9.7	0.6	2.3	0.3		5.4
14.8	0.3	2.5	0.6		3.2
21.7		0.7	0.6		1.7
32.9	0.5	6.6	0.5	2.1	1.7
20.0	1.2	6.8		3.3	5.6

Source: Johansen, R. W. 1987. "Ignition Patterns & Prescribed Fire Behavior in Southern Pine Stands." Georgia Forest Research Paper 72. Macon, GA: Georgia Forestry Commission. http://www.treesearch.fs.fed.us/pubs/36482.

Example 1 – Fire spread rate

- Harmonic mean, s.d. smaller
- Harmonic CI generally smaller
- Arithmetic CI crosses 0



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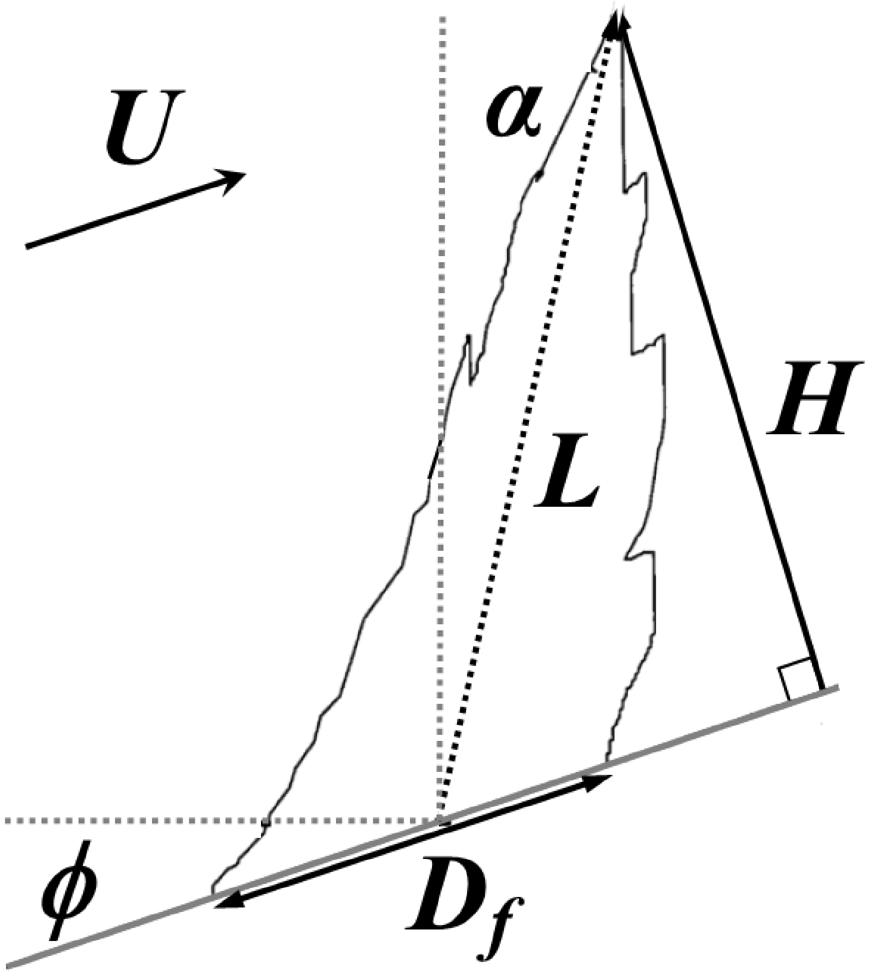
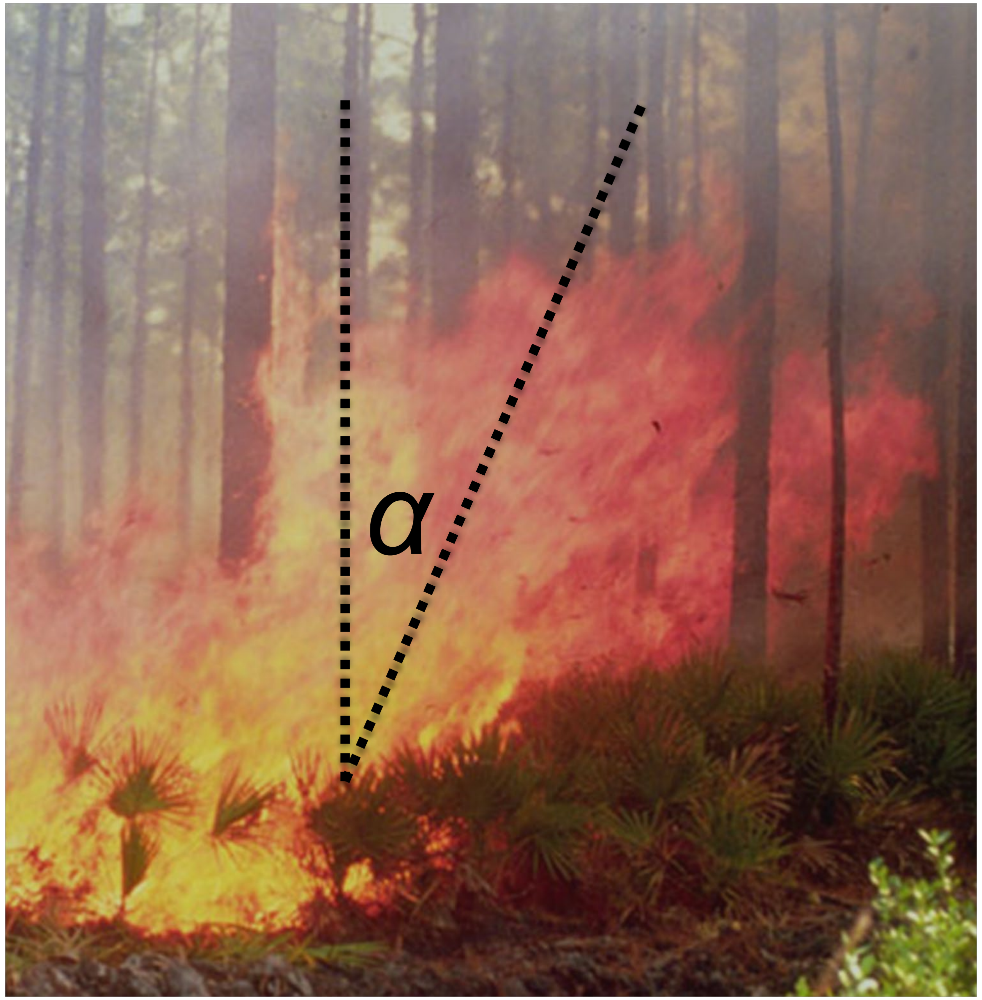
Example 2 – Flame angle

- Important fire behavior variable
- Heats unburned fuels
- Affected by air flow and heat release rate
- Is a circular variable [0, 2Π]



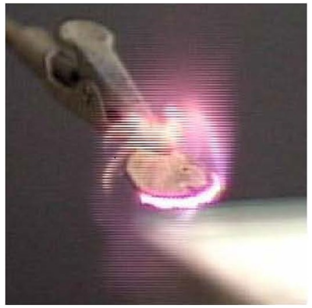


Circular statistic	
Mean	$\bar{\alpha} = \begin{cases} \tan^{-1}(S/C) & S>0, C>0 \\ \tan^{-1}(S/C)+\pi & C<0 \\ \tan^{-1}(S/C)+2\pi & S<0, C>0 \end{cases}$ $C=\sum_{i=1}^{n}\cos\alpha_i$ $S=\sum_{i=1}^{n}\sin\alpha_i$ $R=\sqrt{C^2+S^2}, R\geq 0$
Mean Resultant Length	$\bar{R} = R/n$
Circular standard deviation	$v=\sqrt{-2\log\bar{R}}$
Circular dispersion	$\hat{\delta}=1-(1/n)\sum_{i=1}^{n}\cos 2(\alpha_i-\bar{\alpha})\Big/2\bar{R}^2$
Confidence interval (n≥25)	$\bar{\alpha}\pm\sin^{-1}\left(z_{1-\theta/2}\sqrt{\hat{\delta}/n}\right)$

The Data (°)

Size	n	$\dot{m}_g$ (g s^{-1})		L (m)	
Leaf	233	0.006	0.063	0.015	0.085
Shrub	12	9.1	68.0	0.69	4.82
Bed	12	0.7	50.6	0.55	2.80

Leaf



Shrub

Fuel Bed

Source: Weise, David R., Thomas H. Fletcher, Wesley Cole, Shankar Mahalingam, Xiangyang Zhou, Lulu Sun, and Jing Li. 2018. "Fire Behavior in Chaparral: Evaluating Flame Models with Laboratory Data." *Combustion and Flame* 191: 500–512. 10.1016/j.combustflame.2018.02.012 , https://www.fs.usda.gov/treesearch/pubs/56641 .

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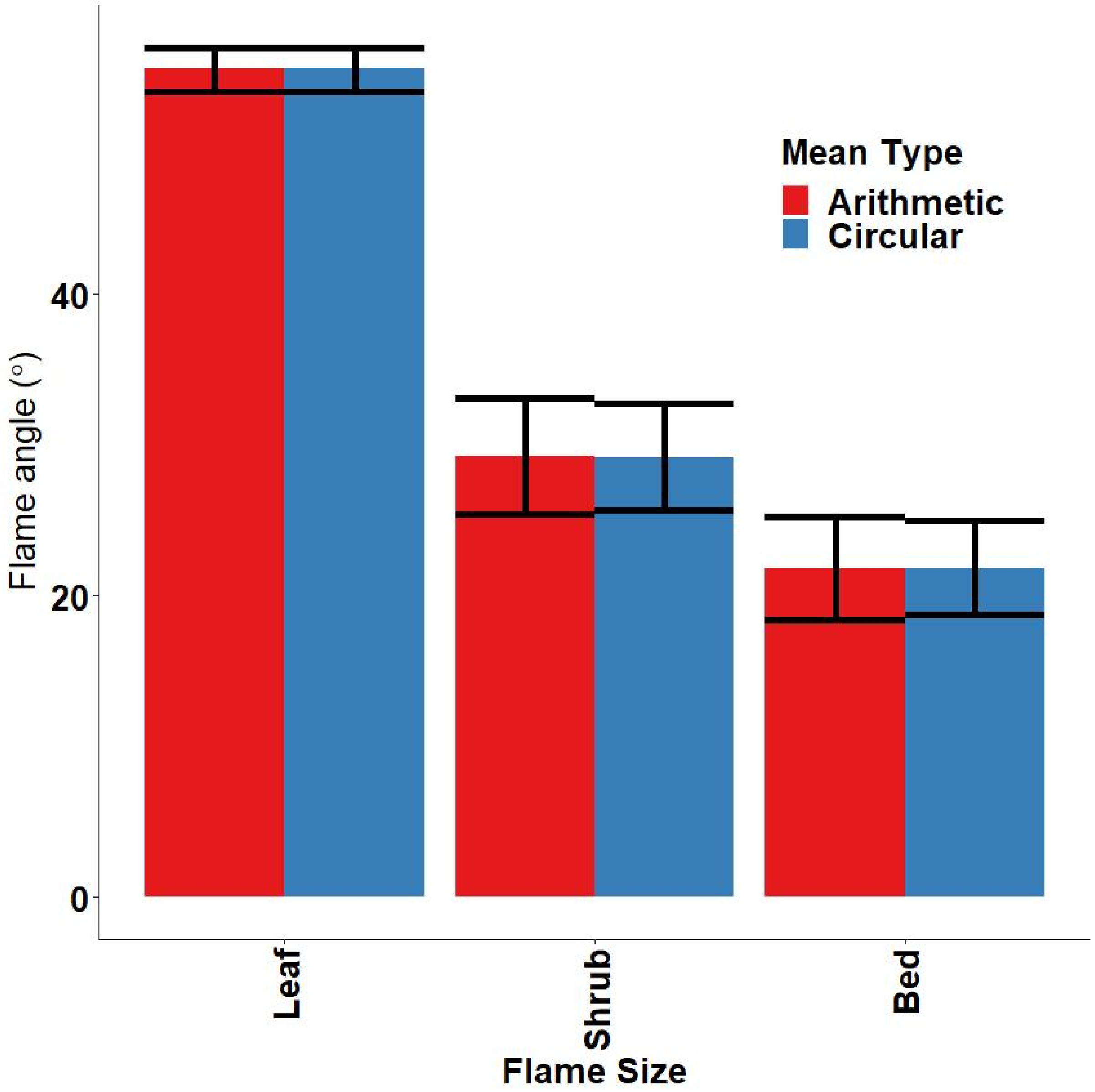
Example 2 – Flame angle

- Arithmetic and circular means equal
- Circular CI are smaller
- Multiple comparison test to determine differences

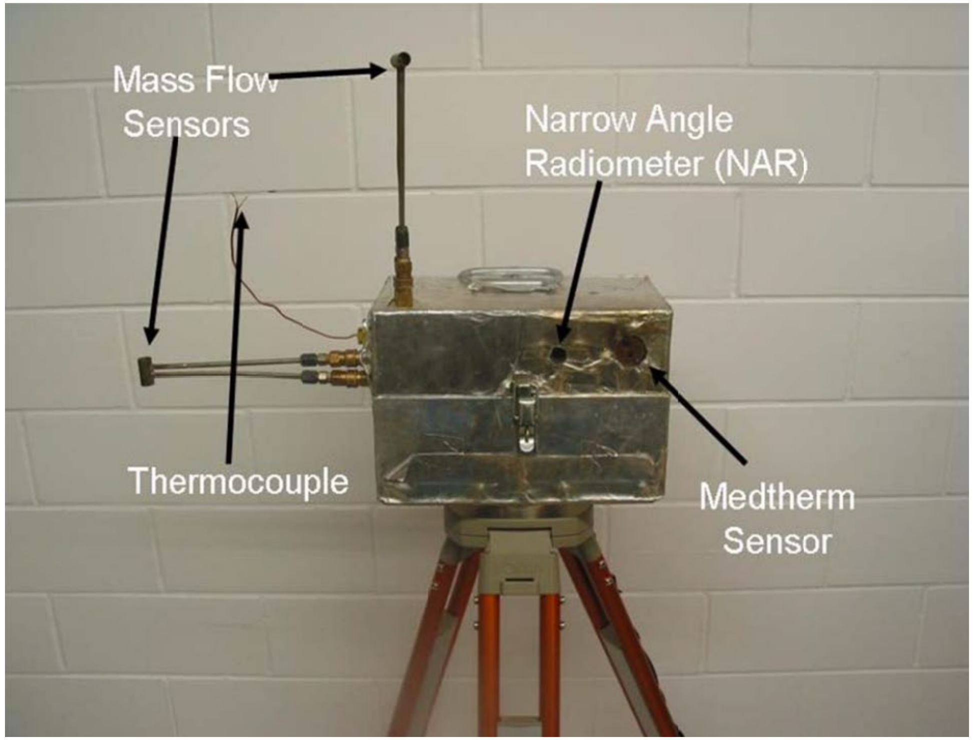


Example 3 – Heat flux

- Important fire behavior variable
- Is a rate $(kJ\ s^{-1}m^{-2})$
- Harmonic mean should be used

The Data

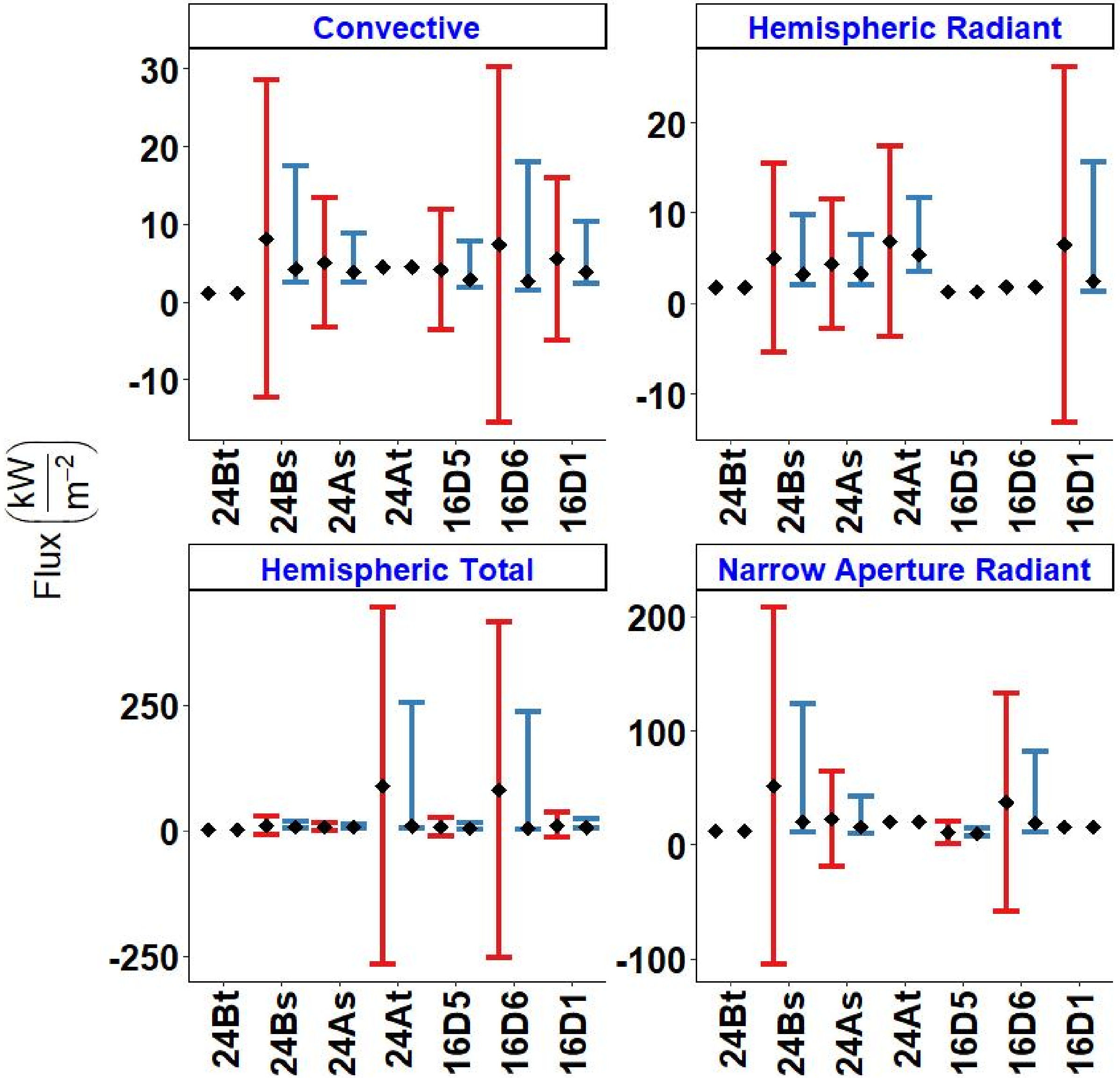
- 7 experimental fires (0.1 ha) at Ft. Jackson, SC
- Deployed Fire Behavior Packages to measure fluxes and velocities



Source: Weise, David R., Thomas H. Fletcher, Timothy J. Johnson, WeiMin Hao, Mark A. Dietenberger, Marko Princevac, Bret W. Butler, et al. 2021. “Fundamental Measurements and Modeling of Prescribed Fire Behavior in the Naturally Heterogeneous Fuel Beds of Southern Pine Forests.” Final Report RC-2640. Albany, CA: USDA Forest Service, Pacific Southwest Research Station.

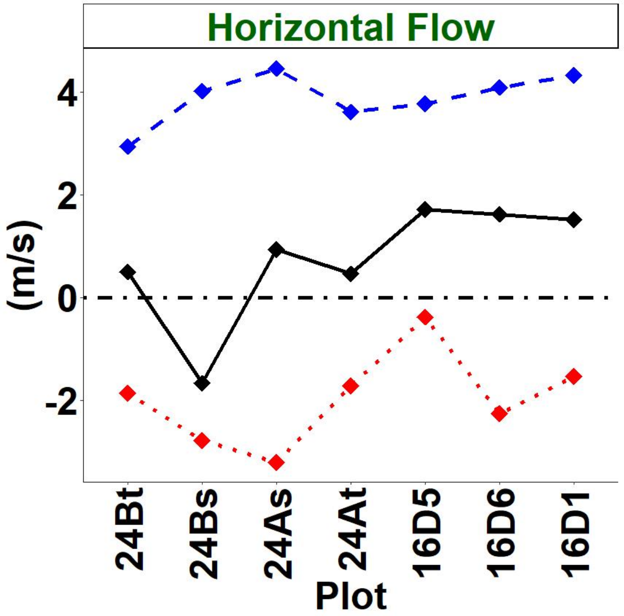
Example 3 – Heat flux

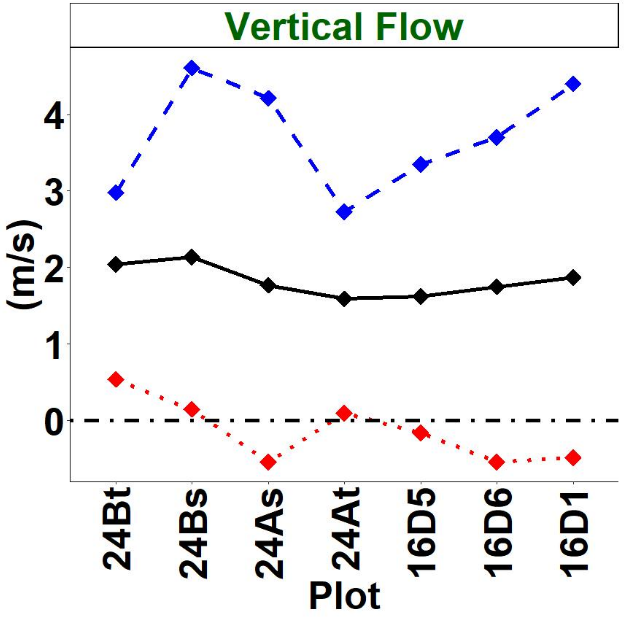
- Arithmetic (red) > harmonic (blue)
- Harmonic CI are smaller
- Arithmetic CIs include negative fluxes

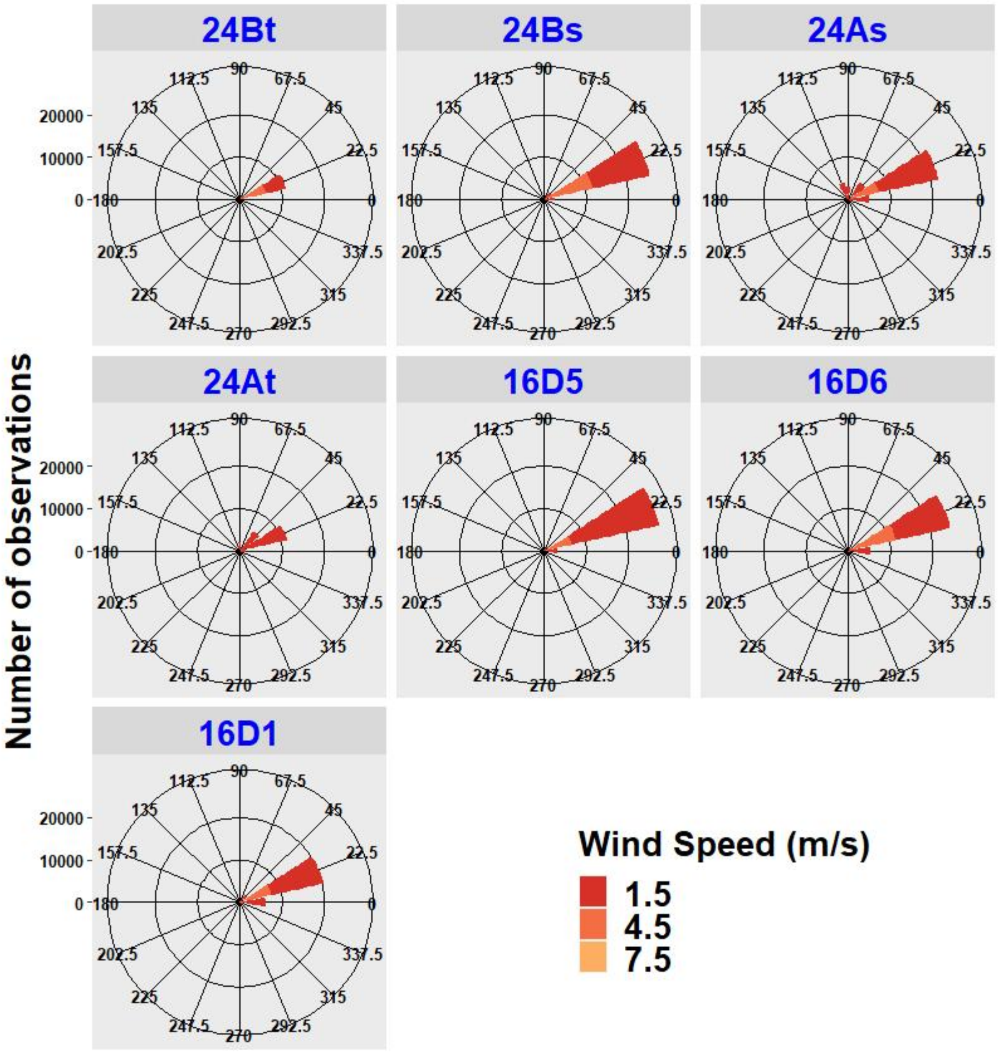


Example 3 – Convective flux

- H & V flow converted to direction and velocity
- Oriented direction into sensor face
- Wind rose common graph for wind and flow direction





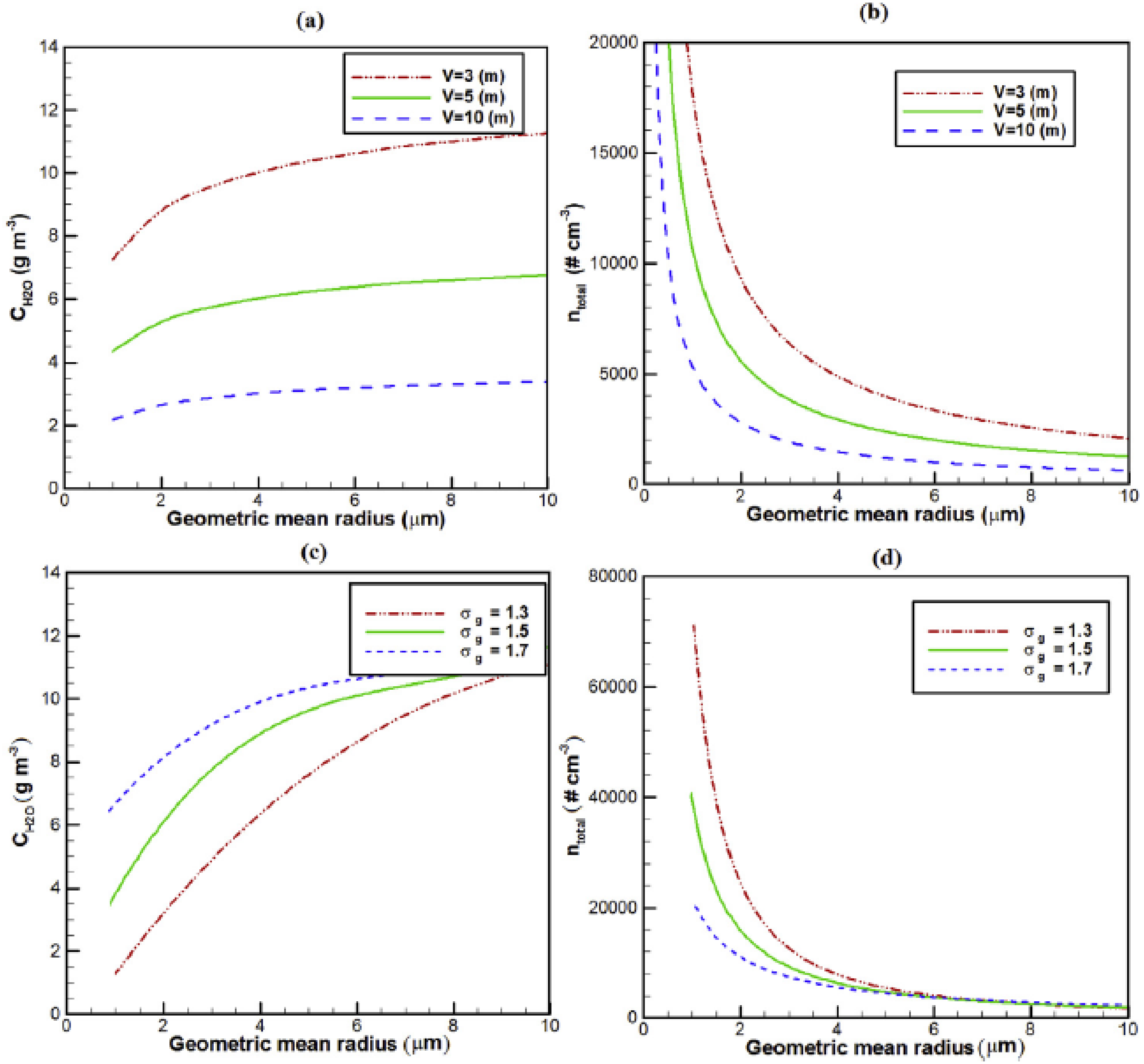


Example 4 – "Super" fog

- Important visibility issue
- Smoke particles enhance fog formation
- Lab study
- Particle size distributions

The Study

- Developed theoretical model for visibility
- PSD assumes log-normal so geometric mean and s.d. appropriate



Source: Bartolome, Christian, Marko Princevac, David R. Weise, Shankar Mahalingam, Masoud Ghasemian, Akula Venkatram, Henry Vu, and Guillermo Aguilar. 2019. “Laboratory and Numerical Modeling of the Formation of Superfog from Wildland Fires.” *Fire Safety Journal* 106 (June): 94–104. 10.1016/j.firesaf.2019.04.009 https://www.fs.usda.gov/treesearch/pubs/58446

Example 5 – Smoke composition and MCE

- Composition of smoke affects human and planetary health
- Prescribed fire smoke regulated
- Hundreds of compounds are present in smoke
- Composition affected by combustion efficiency
- Recent work proposes that compositional data approach be used

Photo credit: Joey Chong, USDA Forest Service

USDA United States Department of Agriculture | Forest Service

Smoke and Combustion Efficiency

- Conservation of mass

$$4C_6H_9O_4 + 25O_2 + \left[(0.322M)H_2O + 94N_2\right] \rightarrow$$
$$18H_2O + 24CO_2 + \left[(0.322M)H_2O + 94N_2\right] + energy$$

- Incomplete combustion

$$T = CO_2 + CO + \text{other gases} + PM + \text{char} + \text{ash}$$

- CO ↑ means other Δ
- Modified Combustion Efficiency not independent

$$\frac{T}{CO + CO_2} = MCE + \frac{CO + PM + \text{other gases} + \text{char} + \text{ash}}{CO + CO_2}$$

Source: Weise, D.R., J. Palarea-Albaladejo, T.J. Johnson, and H. Jung. 2020. "Analyzing Wildland Fire Smoke Emissions Data Using Compositional Data Techniques." *Journal of Geophysical Research: Atmospheres* 125 (6): e2019JD032128. 10.1029/2019JD032128, https://www.fs.usda.gov/treesearch/pubs/60808

Methods

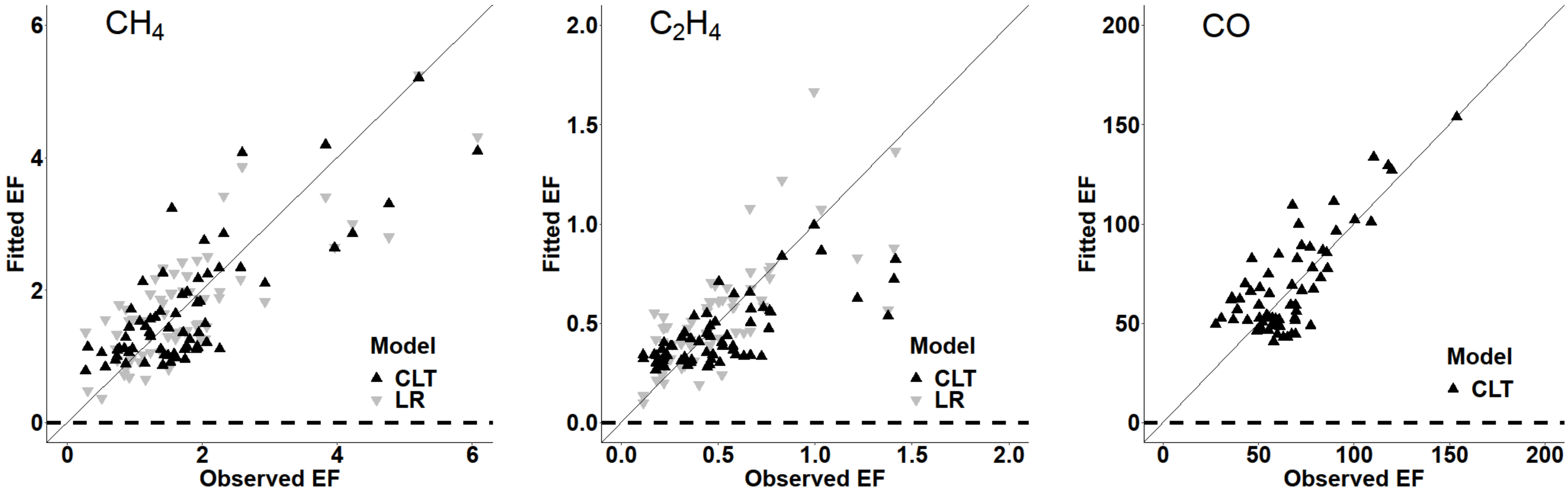
- 18 gases from 65 fires
- Close data

- Compositional linear trend
- Linear regression EF = MCE
- Compare fits

$$\mathbf{x_i} = \left[x_1, x_2, \ldots, x_{18} \right]_i$$

$$\mathcal{C}(\mathbf{x})_i = \frac{\left[x_1, x_2, \ldots, x_{18} \right]}{\sum_{j=1}^{18} x_j}$$

Results – CLT vs LR



Summary

- Smoke emissions data are inherently multivariate
- MCE is NOT an independent variable!
- Linear regression on untransformed data can produce predictions beyond domain of data (negative values)
- Measured values are relative
- Compositional data analysis is mature field of statistics
- Compositional data analysis provides tools and methods similar to “familiar” statistical techniques

Summary

- Data associated with wildland fire come in many forms
- Different statistics developed for different data types
- Learn statistics in order to use appropriate methods to produce scientifically defensible results
- Make friends with a good statistician


Pau!
Contact: david.weise@usda.gov