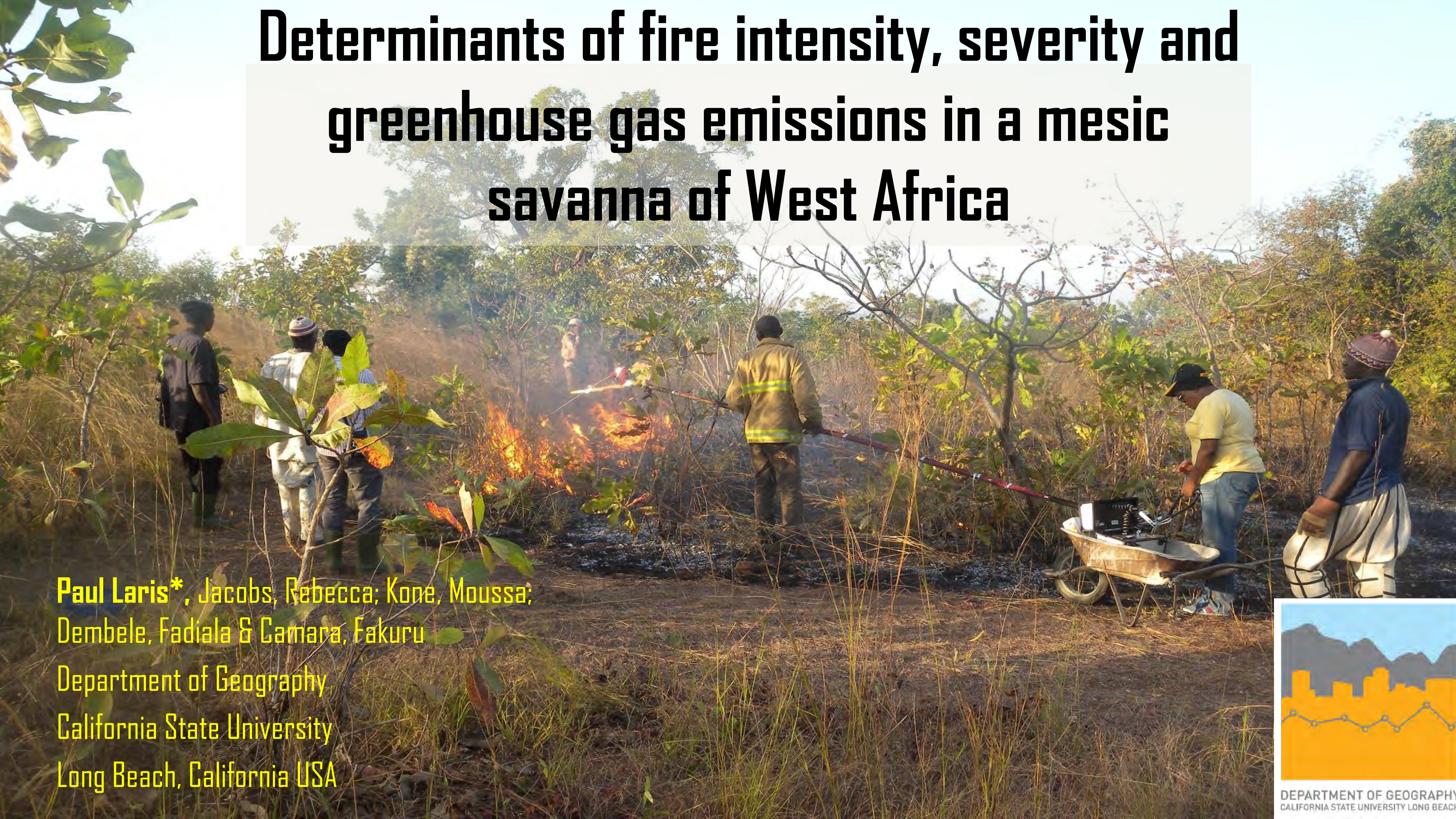


Determinants of fire intensity, severity and greenhouse gas emissions in a mesic savanna of West Africa

Paul Laris*, Jacobs, Rebecca; Kone, Moussa; Dembele, Fadiala & Camara, Fakuru

Department of Geography

California State University

Long Beach, California USA

DEPARTMENT OF GEOGRAPHY
CALIFORNIA STATE UNIVERSITY LONG BEACH


Savanna fires have two impacts on atmospheric concentrations of GHGs:
(i) Reduction of tree cover; and
(ii) Direct emissions of gases.

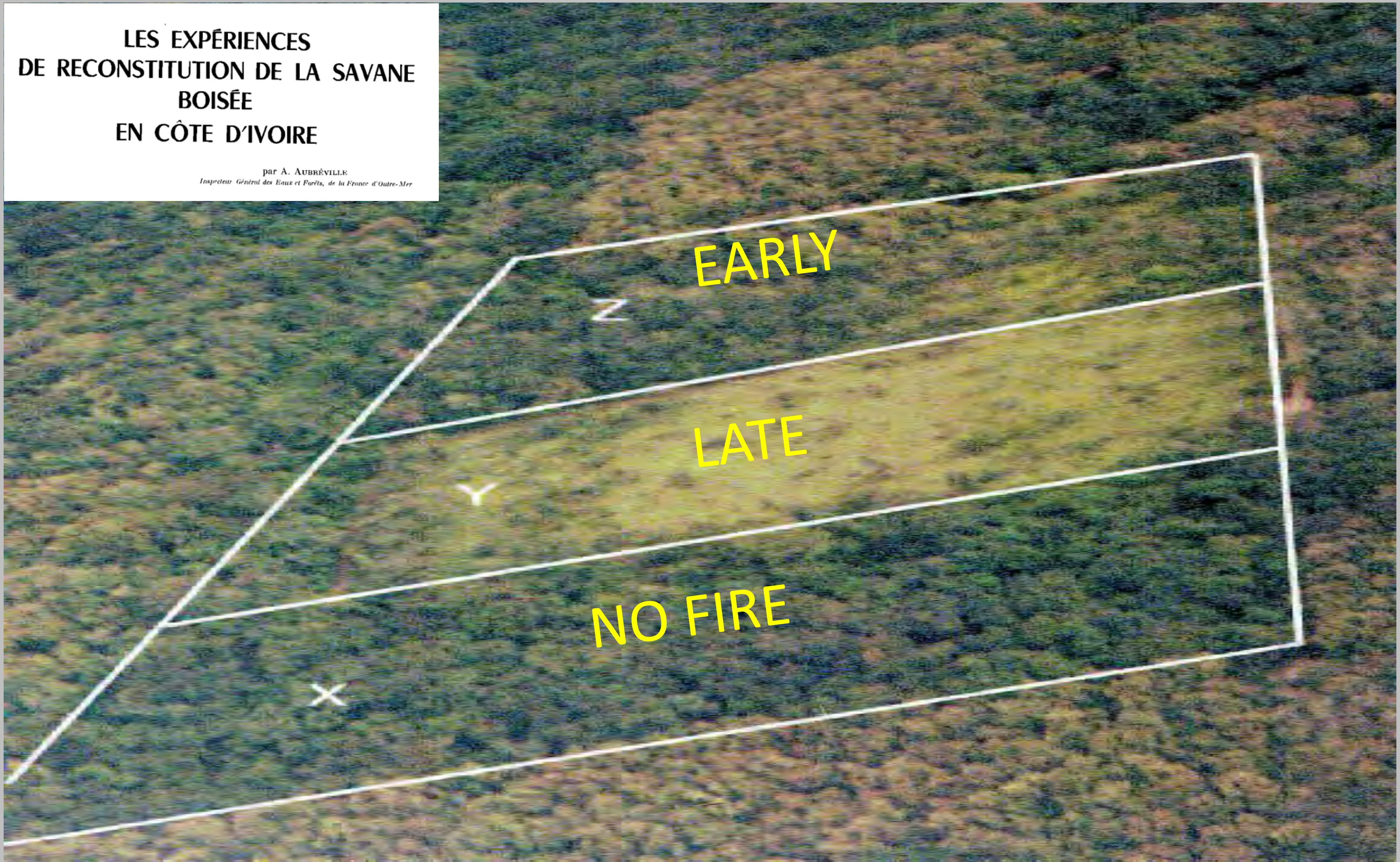
First Law of Savanna Fire Ecology

Fire regime determines vegetation (tree) cover in a *Mesic** savanna

Corollary: **Late** fires are thought to be more intense than **early** fires and thus more damaging to trees (especially juveniles).

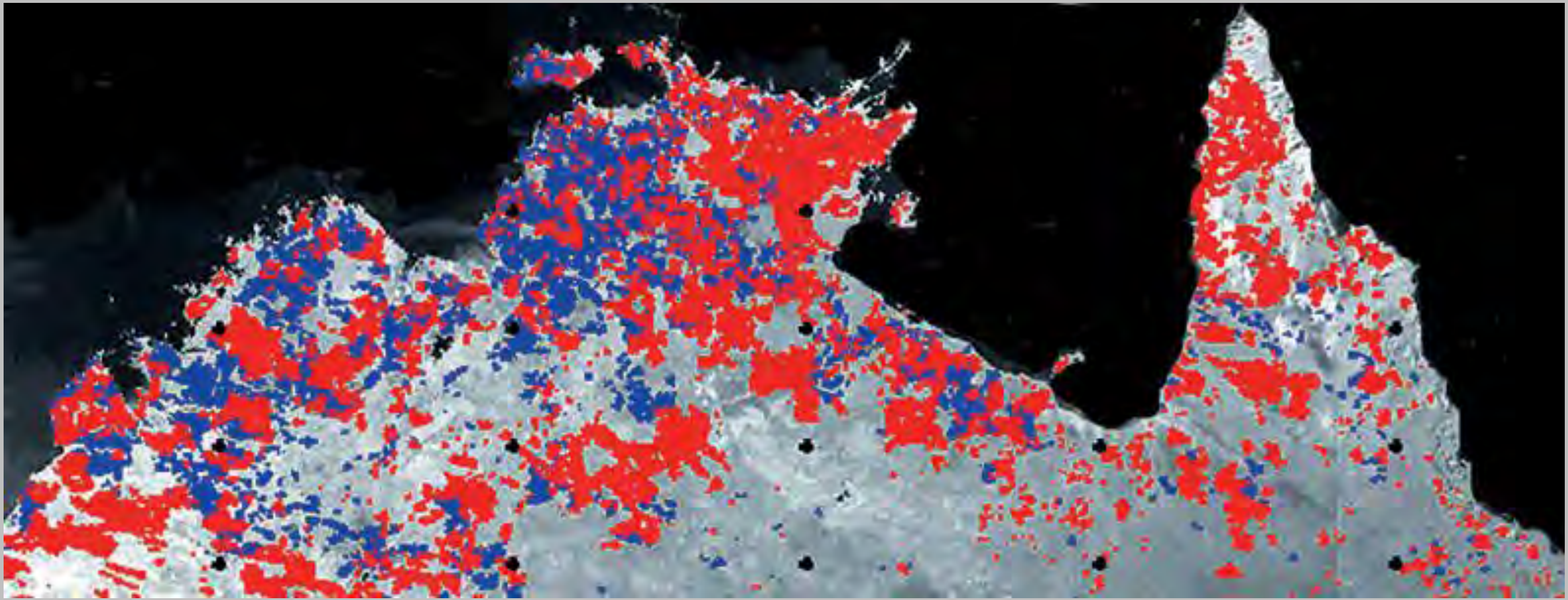
* Over 750 mm annual precipitation

Aubréville's burning experiments: timing is key to tree survival and growth



Representing fire: the Early/Late dichotomy

A dominant view of savanna fires



The Australian Fire Regime: Blue - fires before June 30;
Red - fires begin July 1st.   Source: WA DLI

The predominant view of fire is Early/Late: IPCC…key emission factors decrease by season

Direct measurements of the seasonality of emission factors from savanna fires in northern Australia

C. P. Meyer,[1] G. D. Cook,[2] F. Reisen,[1] T. E. L. Smith,[3] M. Tattaris,[3] J. Russell-Smith,[4] S. W. Maier,[4] C. P. Yates,[4] and M. J. Wooster[3,5]

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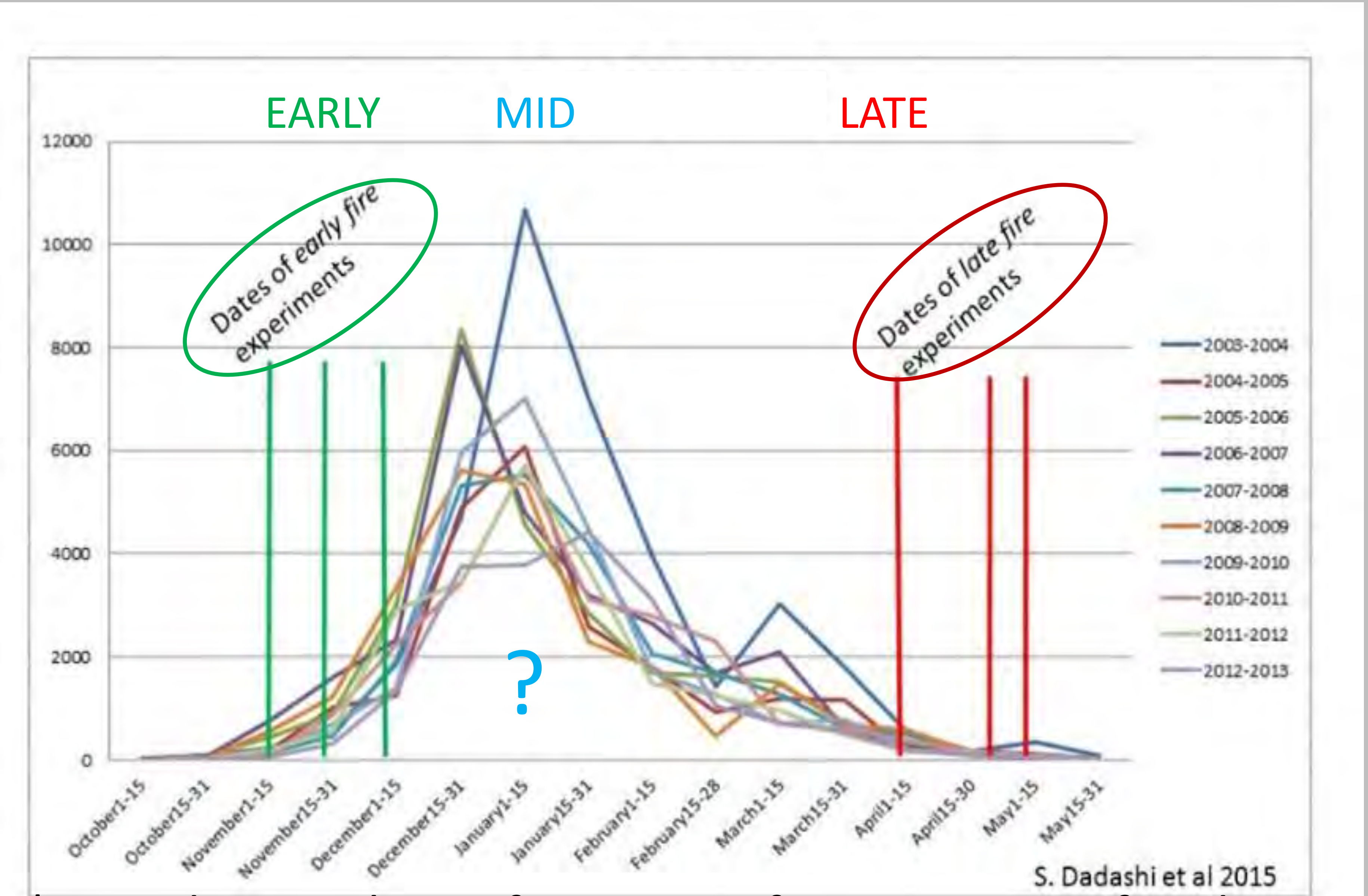
Since the emission factor for CH_4 can decrease by 50–75% as the burning season progresses, it is strongly suggested that each inventory agency collect seasonal data on the fraction of savanna area burned, the aboveground biomass density, and the fraction of aboveground biomass burned in each savanna ecosystem from the early dry season to the late dry season.

IPCC (chap. 4, §A.1.1.3, p. 4.87)

Fire Season* and Historic Experiment Dates



* Based on analysis of 10 years of MODIS active fire data

QUESTION: How does fire timing—EARLY—MIDDLE—LATE impact, intensity, severity and GHG emissions from savanna fires?

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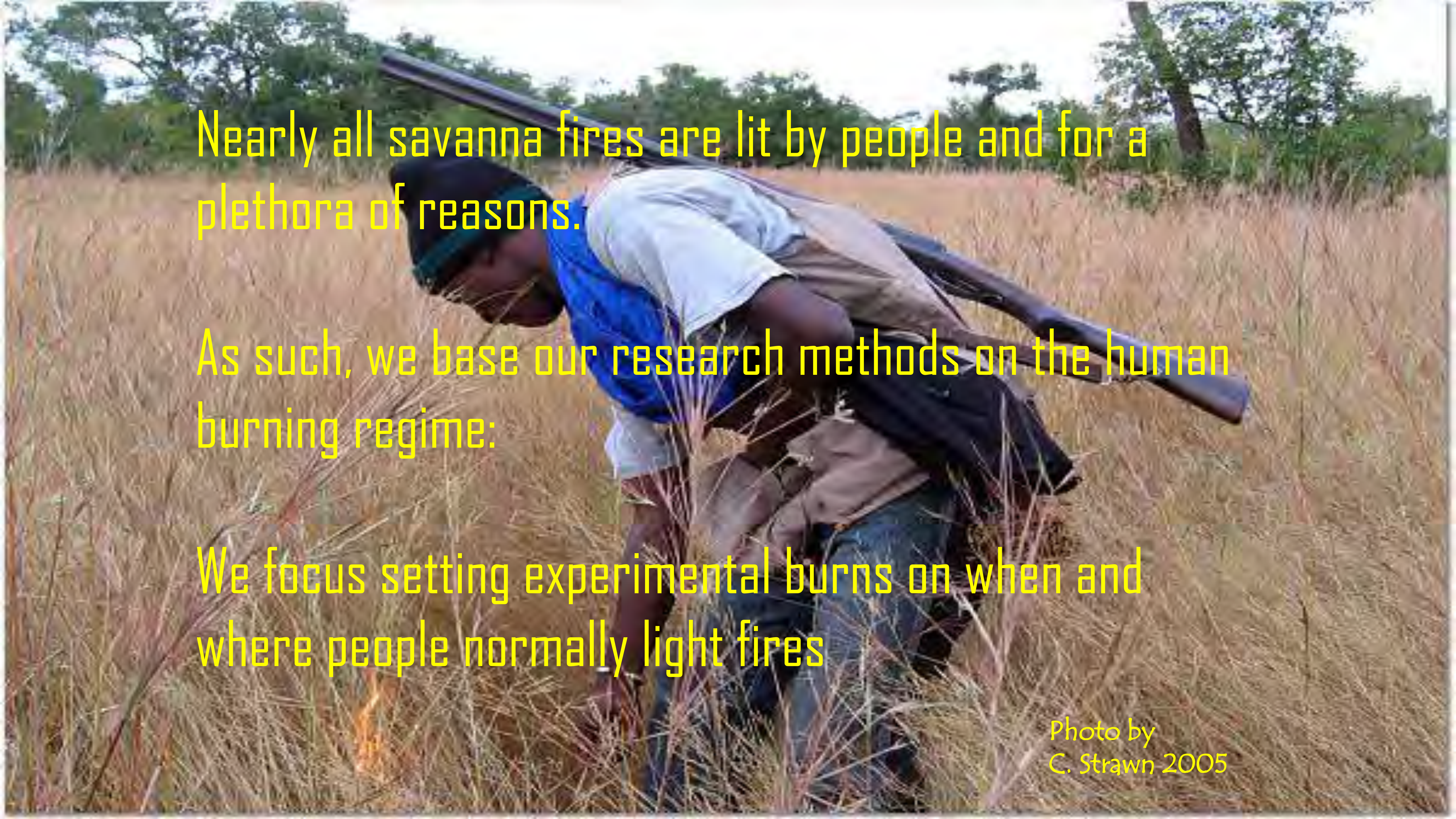

Nearly all savanna fires are lit by people and for a plethora of reasons.
As such, we base our research methods on the human burning regime:
We focus setting experimental burns on when and where people normally light fires
Photo by
C. Strawn 2005

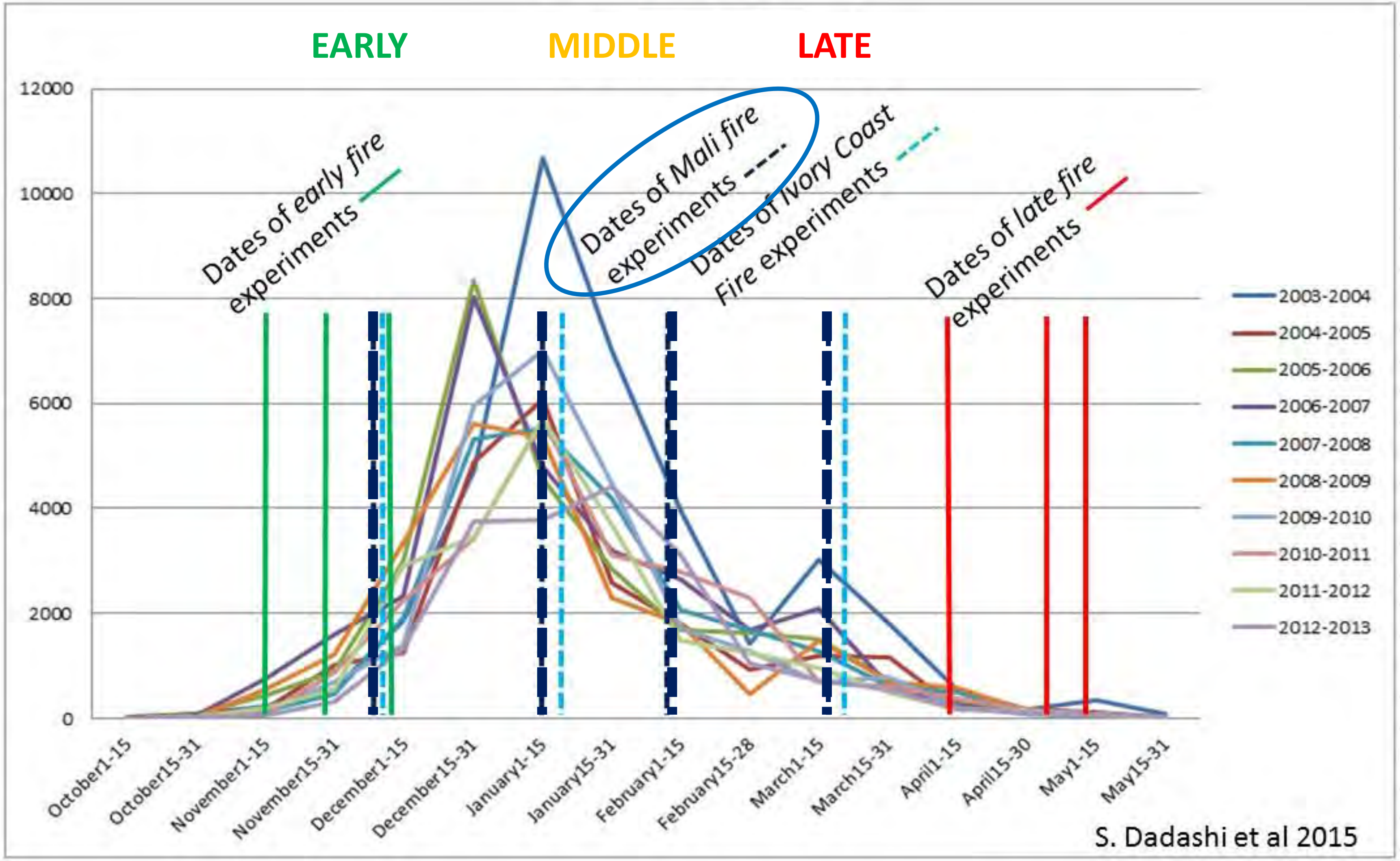
What kind of fires do people intentionally set in Mali?

Interview results find that:

- Most fires are set in **early to mid** fire season (Late December Peak)
- People overwhelmingly set **back-fires** when they purposefully and systematically set fires
- Afternoon is the preferred time for setting fires because winds are dropping and humidity rising, thus, fires are easier to control and **tend to burn themselves out** at night.
- People set fires to grasses purposefully when they are still slightly moist, but **just dry enough** to burn.

Laris et al 2002, 2011, 2016

Dates of our fire experiments and annual fire timing and frequency (historical burning experiment dates shown for comparison)



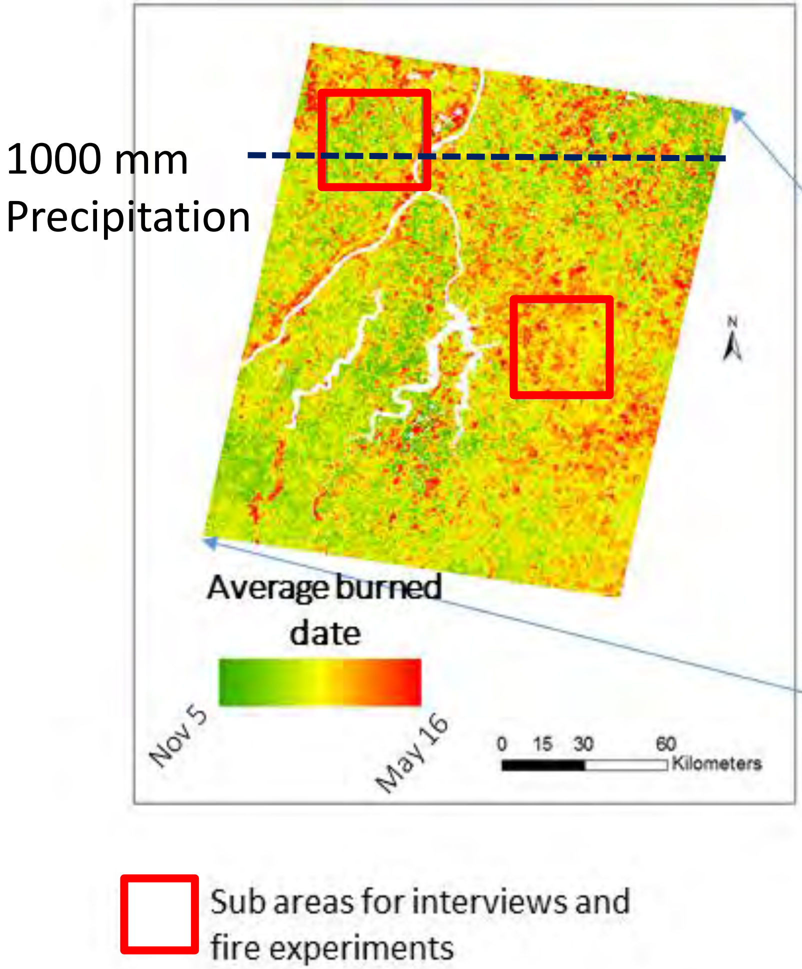
3 Savanna fire emission study approaches

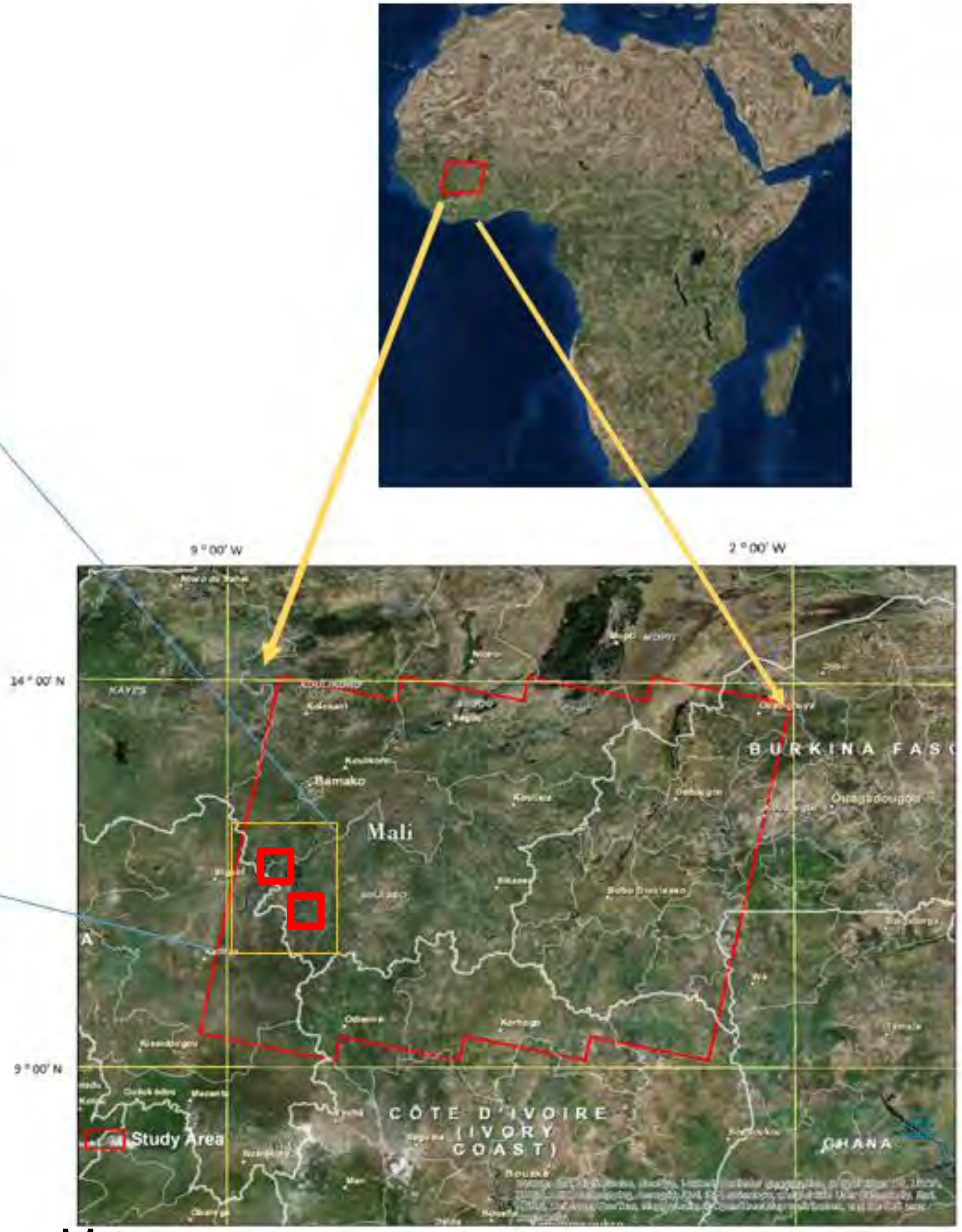
1. Laboratory burning of fuels (fewer smaller samples, less reality, but controlled)
2. Airborne sampling of smoke above fire (fewer, larger samples, low heterogeneity, far from source, large fires required…most common method)
3. Field sampling (more and smaller samples, high heterogeneity)
   (i) Canister samples of gases analyzed in laboratory
   (ii) Direct measuring with emissions sampling device

Our Study Approach

- Conduct 150+ experimental fires on 10 x 10 m plots
- Record data on biomass type and weight, weather conditions, fire speed, time of day, scorch height and % biomass consumed and calculate fire intensity.
- Both **head and back** fires
- Measure emissions from fires for **CO, CO_2, CH_4**

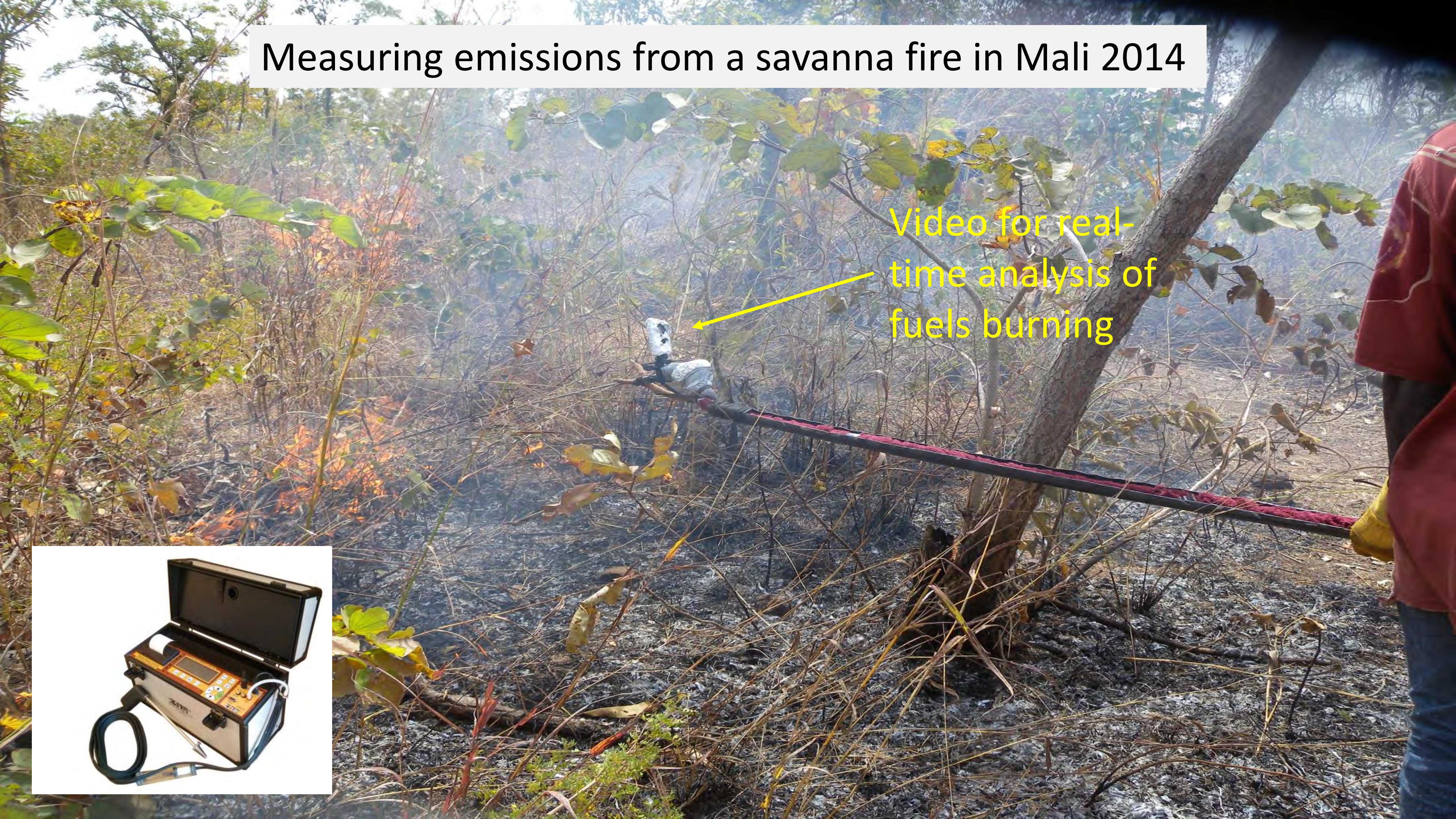
2 Study areas in Mali





Dry (fire) season from November-May

Measuring emissions from a savanna fire in Mali 2014



Collecting gas in canisters: early fire
Mali 2015


RESULTS: What do field observations tell us?

RESULTS: Fire-line Intensity Values

Intensity ranged from 24.69 to 1395.36 kWm^{-1} for all plots*

Major distinction between head and back fire intensity values

- Mean head fire Intensity was 336.26 kWm^{-1}.
- Mean back fire Intensity was 124.24 kWm^{-1}.

Type of fire	n	Mean	Minimum	Maximum
Head	40	336.26	48.52	1395.36
Back	43	124.24	24.69	476.94

* Intensity values might be slightly lower given the small size of the plots burned and time it takes to develop the burning fire front.

RESULTS Fire Intensity by Season: Correlates for back fires but *not* head fires

Back fires

Correlation between season and intensity

Table 1. Subset of correlation matrix with **Head** fires in gold and **Back** fires in blue. Darker shades indicate significance of 0.05 or less.

		Season	Day Timing	Biomass Dry (t/ha)	Wind Speed (m/s)	Grass Biomass %	Humidity	Ambient Temp	Grass by Ht	Annual Perenial	Biom Load (t/ha)	Flame Height (m)	Visual Efficiency	Biomass Consumed %	Fire Speed (m/s)	Intensity
Season	Pearson Correlation	1	0.001	0.041	-0.071	-0.174	-.570**	.356*	0.066	0.069	-0.004	.371*	.498**	0.253	.573**	.488**
	Sig. (2-tailed)		0.996	0.792	0.653	0.264	0.000	0.019	0.674	0.662	0.978	0.014	0.001	0.102	0.000	0.001
	N	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43
Intensity	Pearson Correlation	0.089	0.005	.668**	0.222	0.243	-0.131	0.128	-0.162	-0.134	.555**	.420**	.367*	0.231	.871**	1
	Sig. (2-tailed)	0.584	0.978	0.000	0.169	0.131	0.420	0.432	0.319	0.408	0.000	0.007	0.020	0.152	0.000	
	N	40	40	40	40	40	40	40	40	40	40	40	40	40	40	43

Head fires

No correlation between season and intensity

Indeed, **head fire intensity is not explained** by any common variables to do with weather, season or grass type. Head fire intensity is *unpredictable* (**Trollope** found this as well long ago).

R. Jacobs

Back fire regression model statistics: Season and grass biomass % best explain fire intensity

Model	R	R^2_{adj}	F	Sig F	Valid	Explanatory Variable
Enter	.652	.290	3.143	.009	Yes	Season
Backward	.560	.279	9.137	.001	Yes	Season, Grass Biomass %
Forward	.560	.279	9.137	.001	Yes	Season, Grass Biomass %

Note that "grass biomass %" is the value for the percentage of all biomass consumed that is **grasses as opposed to leaf** matter.

Digging Deeper:
2 Methods of fire research

Type A. Fire timing *a function of land manager practice* (fires set to grasses at moment they are dry enough to burn)

Type B. Fire timing ***not*** a function of land managers (fires set to all vegetation types for all seasons—random)

Fire type and grass type:

- With head fires there is **no correlation** between fire intensity and seasonality for either type A or type B
- With back fires there is **no correlation** between fire intensity and seasonality for type **A—fires set by land managers according to grass type**
- With back fires there is a **correlation** between fire intensity and seasonality for type **B—fires set for all grasses and all seasons (random fires)**

Thus for back fires, ***season does matter*** when grasses are set on fire at different times of year or randomly (i.e., different levels of dryness) not when they are set systematically by people at a point when grasses are just dry.

Emissions (Modified Combustion Efficiency)

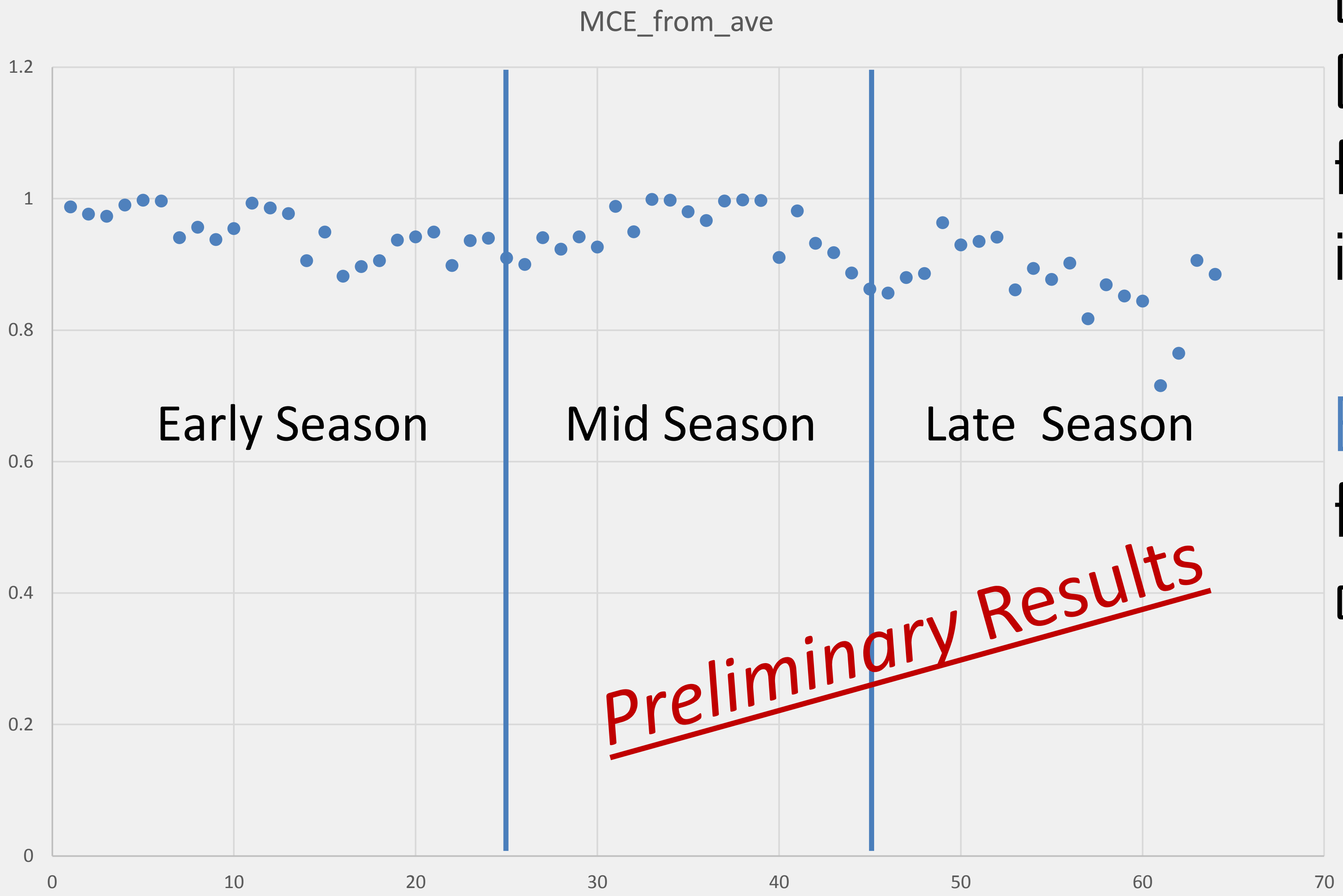
$MCE = CO_2 / (CO + CO_2)$

MCE is a good measure of combustion efficiency

Preliminary Results

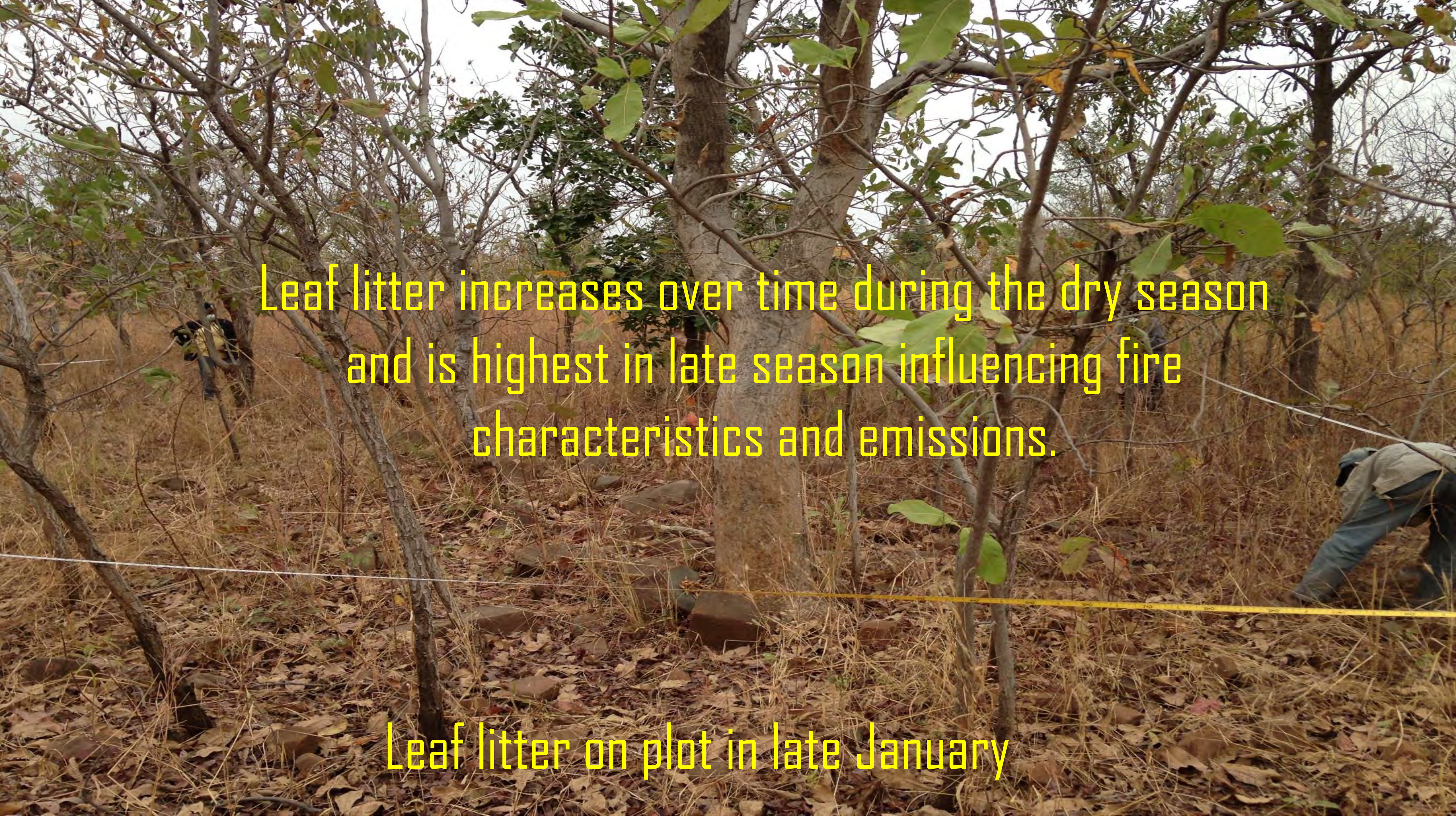
	Mean (field)	Mean (canisters)
• Early Season	0.952	0.90
• Mid Season	0.962	0.92
• Late Season	0.872	*Why lowest?*
• Average	0.93	0.91

MCE by Season (field)

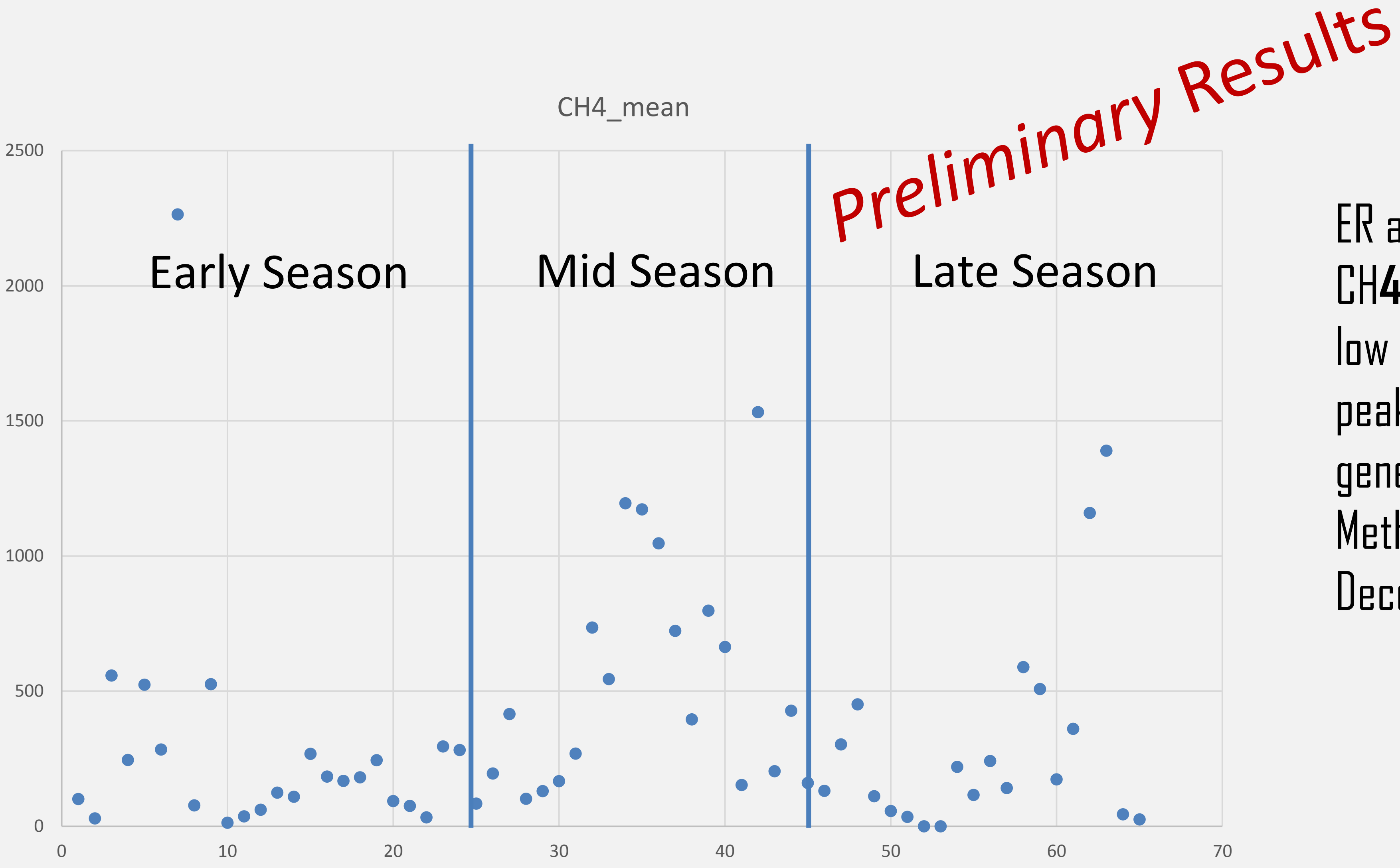


Head Fires: Fire season correlates negatively with MCE. CO emissions rise later in the fire season. Also as fire intensity increases, MCE declines.

Back fires: Similarly MCE declines from early to late season, No correlation with intensity.

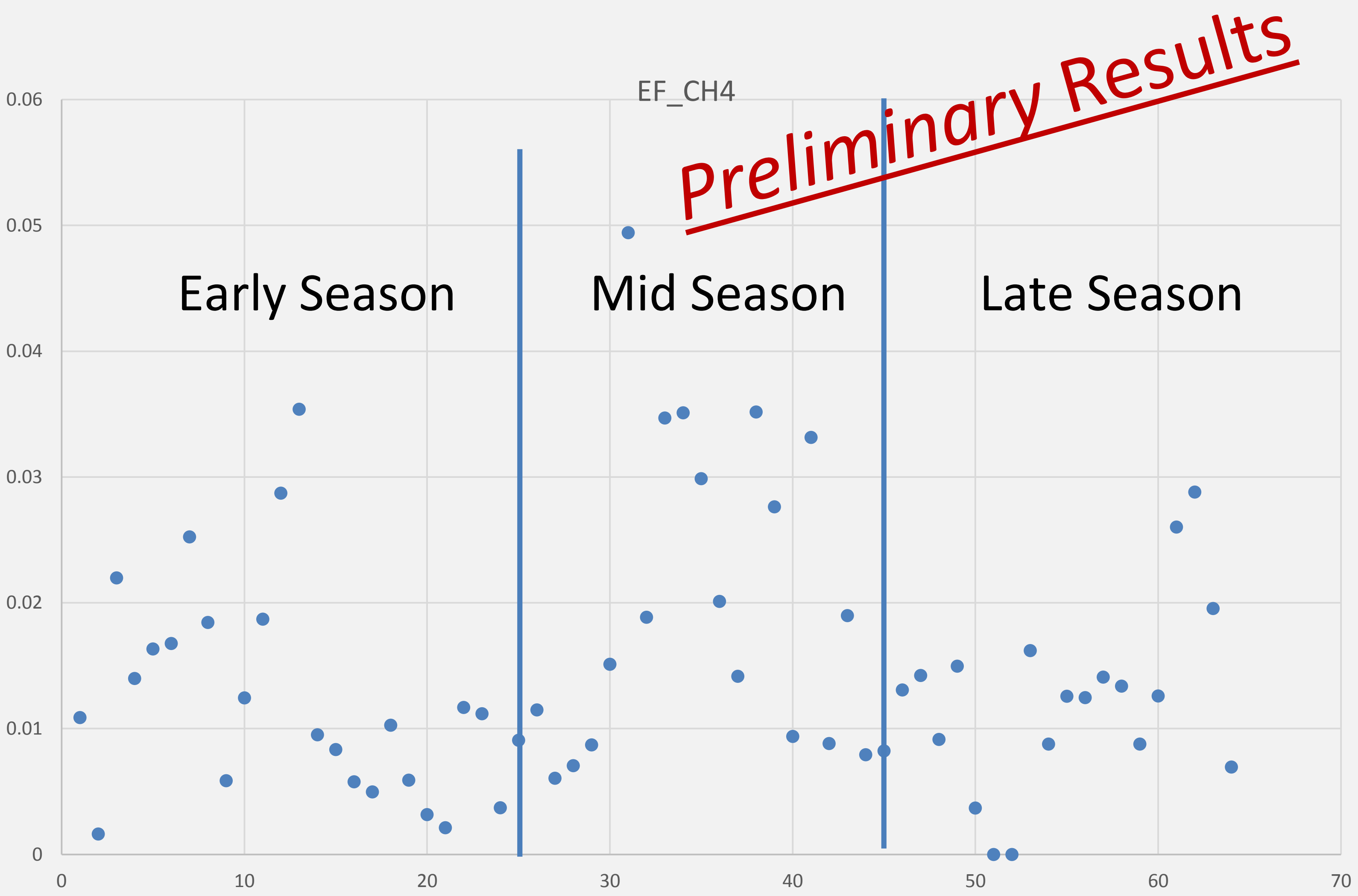

Leaf litter increases over time during the dry season
and is highest in late season influencing fire
characteristics and emissions.
Leaf litter on plot in late January

Methane Emission by Season (ppm)



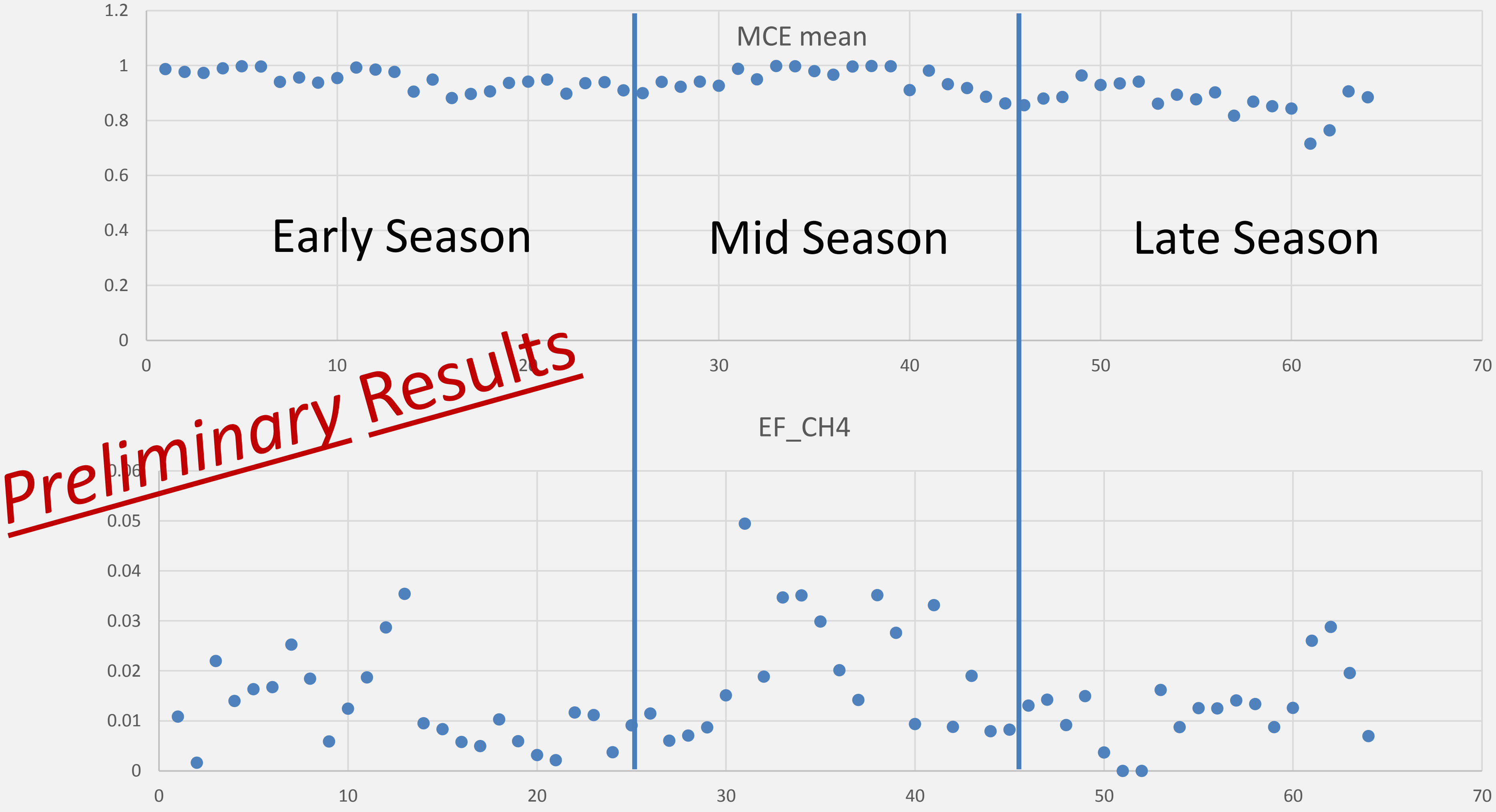
ER and measured amounts of CH_4 have high variation with low mean in early season and peak mean in mid-season; generally higher amounts of Methane were measured after December

Methane Emission by Season (Emission Ratio)



We found no relationship between methane emissions or emission ratio by fire season or fire type. We suspect this has to do with the fact our data has **not yet been broken out by fire regime—the human regime** involves burning grasses when they have some moisture, while the seasonal burning regime would result in biomass being dryer as the fire season progresses.

MCE & Methane Emissions by Season



The usually a strong inverse relationship between methane and MCE is reversed as methane is highest in mid season and not late season.

This runs counter to the notion that as the season progresses combustion is more complete (MCE rises) and thus Methane is expected to decrease.

Observation indicates that methane peaks when burning green leaves on small trees and shrubs (by late season, most leaves have fallen off small trees.

Conclusions: How does the human practice influence fire intensity and emissions in Mali?

Our results suggest that:

- Intentionally lit fires **have lower intensity**, more backfires lit in afternoon (lower temperature, lower wind and higher humidity)
- By setting fires *early* according to grass type **intensity does not vary significantly by season** for the human regime (it does for random one).
- **MCE decreases by season due likely to leaf litter** accumulation and possibly burning taller annuals later when they still have moisture (even as biomass consumed increases by season)
- **Methane emissions appear to peak** in **mid-season** but with great variation

Summary of Key Points and Research Needs

- **Fire direction** and **fuel type** (grass species and leaf litter %) are major unknowns in much of the data sets for Africa. Yet these factors appear to matter!
- **Break the early/late dichotomy**, need studies from all seasons especially those when people light fires.
- **Human fire practices influence fire intensity and MCE** and thus may influence **Methane emissions**.
- **To Do:** Separate analysis of human vs random fire regime may reveal how human practices effect methane emissions.

Thanks to all of those people in Mali and elsewhere who made the research possible

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plaris@csulb.edu