Prescribed Grassland Smoke Plume Observations Using Lidar in the Northern Flint Hills Region

United States Environmental Protection Agency

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Background

Researchers from the **U**nited **S**tates **E**nvironmental **P**rotection **A**gency (USEPA), **K**onza **P**rairie **B**iological **S**tation (KPBS), and Kansas State University conducted a prescribed burn study focusing on smoke plume dynamics and chemistry in the Flint Hills region (KR_X) during March 13-22, 2017. KPBS (39°05' N, 96°35' W) is a 3,487 ha native tallgrass prairie preserve (*http://kpbs.konza.k-state.edu/*). Plumes were observed using Ceilometers (CL-51) and a scanning Mini Micro Pulse Lidar (MiniMPL) for 17 tall Prairie grass plots <300 acres (121 ha), the total area burned ~1500 acres (607 ha). **Potential uses for the data:** characterizing plumes from small fires, evaluating air quality models, and development of plume rise algorithms.

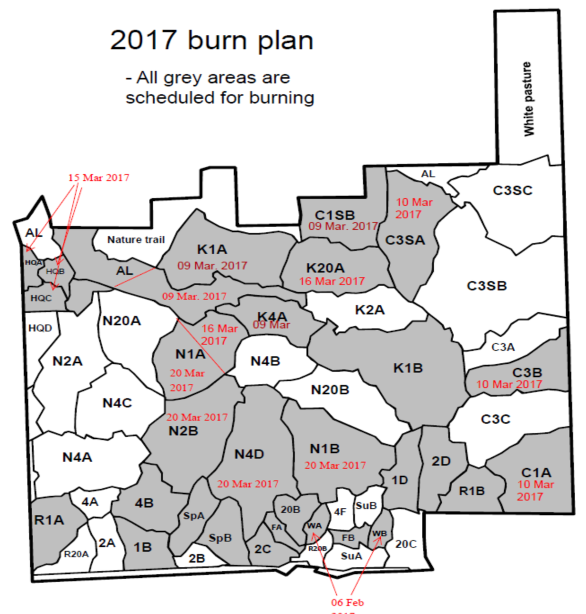


Figure 1. 2017 Burn Plan from KPBS website http://kpbs.konza.k-state.edu/ , indicated in red are the burn dates for each field. The grey areas are all burns planned for 2017.

Table 1. Specific prescribed burns during KRX March 2017

Burn id	Burn Site	Date	Area Burned (acres)	Start time	End time
K1	Nature Trail	15-Mar-17	-	1:34pm	1:58pm
K2	Below Ground plots	15-Mar-17	-	1:34pm	1:58pm
K3	Ramp plots	15-Mar-17	-	1:34pm	1:58pm
K4	HQA	15-Mar-17	31	2:11pm	3:05pm
K5	HQB	15-Mar-17	37	2:41pm	3:28pm
K6	A3	15-Mar-17	13	2:41pm	3:28pm
K7	HQC	15-Mar-17	43	3:47pm	5:30pm
K8	Top half N1A	16-Mar-17	84	10:52am	12:43pm
K9	K20A	16-Mar-17	205	12:55pm	2:30pm
K10	N2B	20-Mar-17	294	10:44am	2:20pm
K11	N4D	20-Mar-17	335	~	2:20pm
K12	N1B	20-Mar-17	299	~	2:20pm
K13	N1A bottom half	20-Mar-17	148	~	2:20pm

Experimental Design

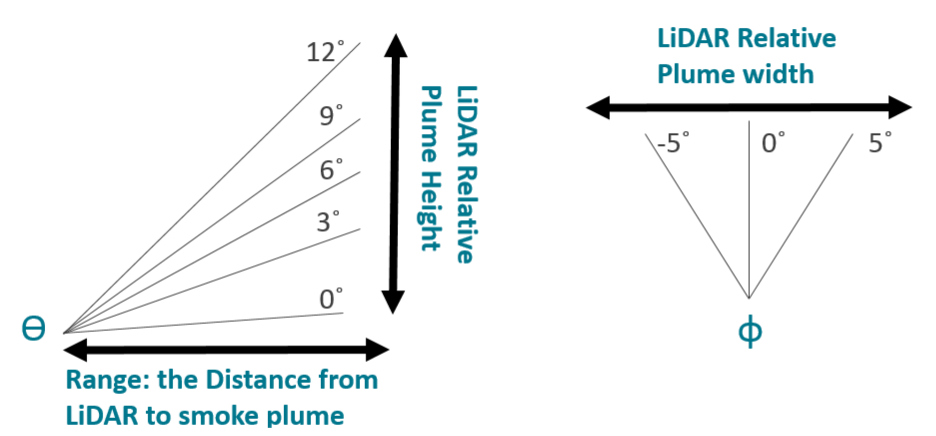
The initial study design: 1. Capture fire smoke plumes and 2. Study the mixed layer height.

To capture smoke plumes we deployed the MiniMPL perpendicular to the mean wind direction ~500 m from the center of the prescribed burn field. The scanning pattern is set between 0-40˚ elevation (ϴ) at 2-10˚ steps and at azimuth (ϕ) of 0-90˚ at 10-45˚ steps. To compare with air quality models, we record a full field scan at least every 15 min using 5-15s averaging bins.
*The mixed layer height (MLH) was measured with the MiniMPL using daily 30 min vertical scans and constant vertical scans from the CL-51 (36 sec averaging bins, for both).

Example MiniMPL Scanning Scenario for a Prescribed burn used March 15, 2017

The elevation angle (ϴ) Plume vertical extent

The azimuth angle (ϕ) Plume horizontal extent



Accumulation time (Averaging BIN)

The MiniMPL takes an observation using light, every 1s, a signal is sent out and received back. To reduce noise the mean or averaging bin of 5-36s are used.

At a deployment distance from the fire of 500 m using 15 s averaging bins with 0-12˚ elevation (ϴ) at 3˚ steps and 3 azimuth angles (ϕ) (-5, 0, 5), where 0˚ = North.

The time of a full field scan is calculated as such:

Field scan time (ρ_T) = 15s * Θ_T (x 5 angles) * ϕ_T (x 3 angles) = 225 s (3.75 min)
This scan scenario allows for 16 field scans per hour.

Konza Prairie Biological Station Prescribed Burn (KR_X)

Lidar Experiment Instrumentation

During KR_X, Lidars are used to investigate prescribed burns in the Flint Hills. Yearly burns are used to maintain the 1.6 million acres of ecosystem and cattle grazing land. Observations assist modeling limitations: steep terrain, small fire sizes, on short time scales, and missed detections.

		Sigma Space Mini MPL 1st GEN	Vaisala CL-51
Performance	Range resolution	30 m	10 m
	Minimum range	150 m	5 m
	Accumulation time	1 sec – 15 min	6-160 s
	Detection range	Up to 10 km	Up to 15 km
	Scanning	Yes	Vertical or 12˚ titled
Optics	Laser wavelength	532 nm	910 nm
	Laser pulse energy	3-4 µJ @ 2500 Hz	6500 Hz
	Detector	Fiber coupled	InGaAs diode
Design	Size (mm)	380 x 305 x 480	834 x 266 x 264
	Weight	13 kg	18.6 kg
	Power requirement	100 W	310 W

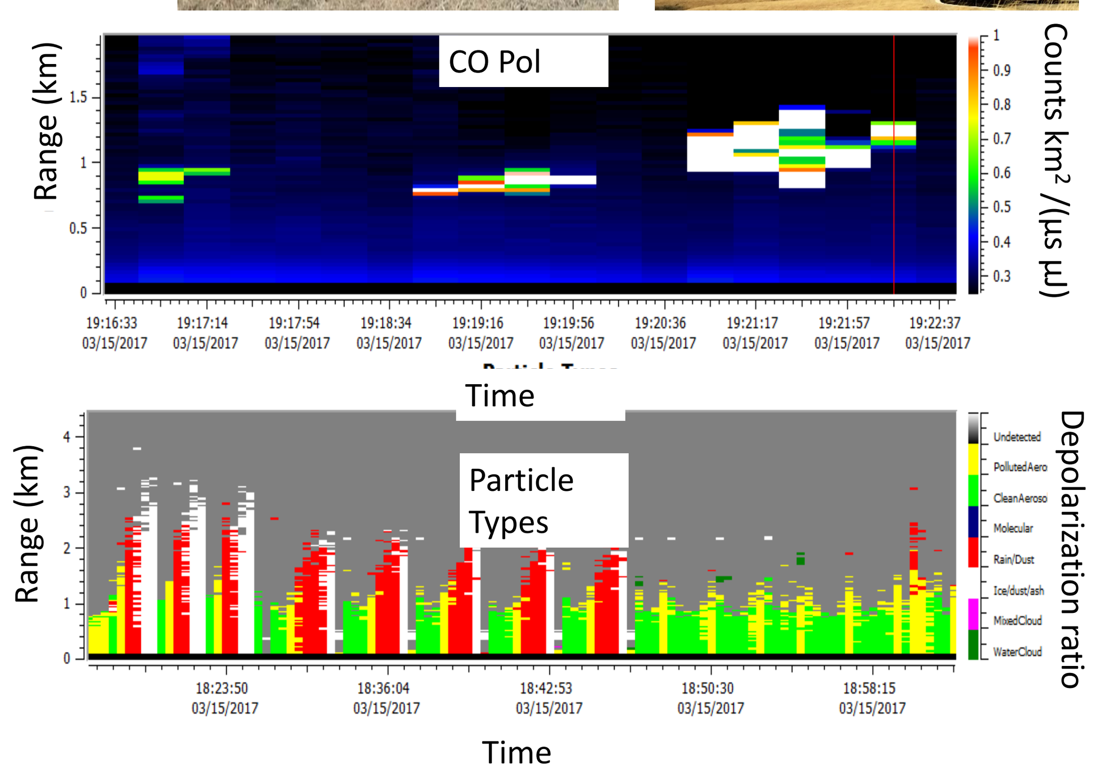
Figure 2. A MiniMPL (left) and a CL-51 ceilometer (right) placed near a burn site. Lidars are placed next to each other scanning vertically to cross validate data and to measure the mixed layer height. The accumulation time for each instrument differs so for comparison a 36s average bin for backscatter data is used.

Determining the Lidar Relative Plume Height

Images of smoke taken from the MiniMPL's location for each prescribed burn

15Mar17 K1-K3 1:34pm | 15Mar17 K4-K5 2:48pm | 15Mar17 K7 4:06 pm

16Mar17 K8 11:31am | 16Mar17 K9 1:15pm | 20Mar17 K10-K13 11:36pm



Visualizing the plume from the MiniMPL

Figure 3. The Relative plume height is interpreted from the MiniMPL backscatter (on March 15). The range indicates distance from Lidar to particle. (Top) particle counts, the lighter the color the higher the intensity of backscatter, with white being off scale.
(Bottom) depolarization ratio, used to determine particle types. Smoke is indicated by yellow and red; white is underdetermined by the software

Max Plume height 461m above surface detected @ 15˚ elevation (ϴ) and azimuth (ϕ) 0˚, range 1.56 km from LiDAR.

CL-51 and MiniMPL MLH comparison

Six minute averaged Lidar mixed layer height (MLH) scans

18 MAR 2017 (Saturday) | **19 MAR 2017 (Sunday)**

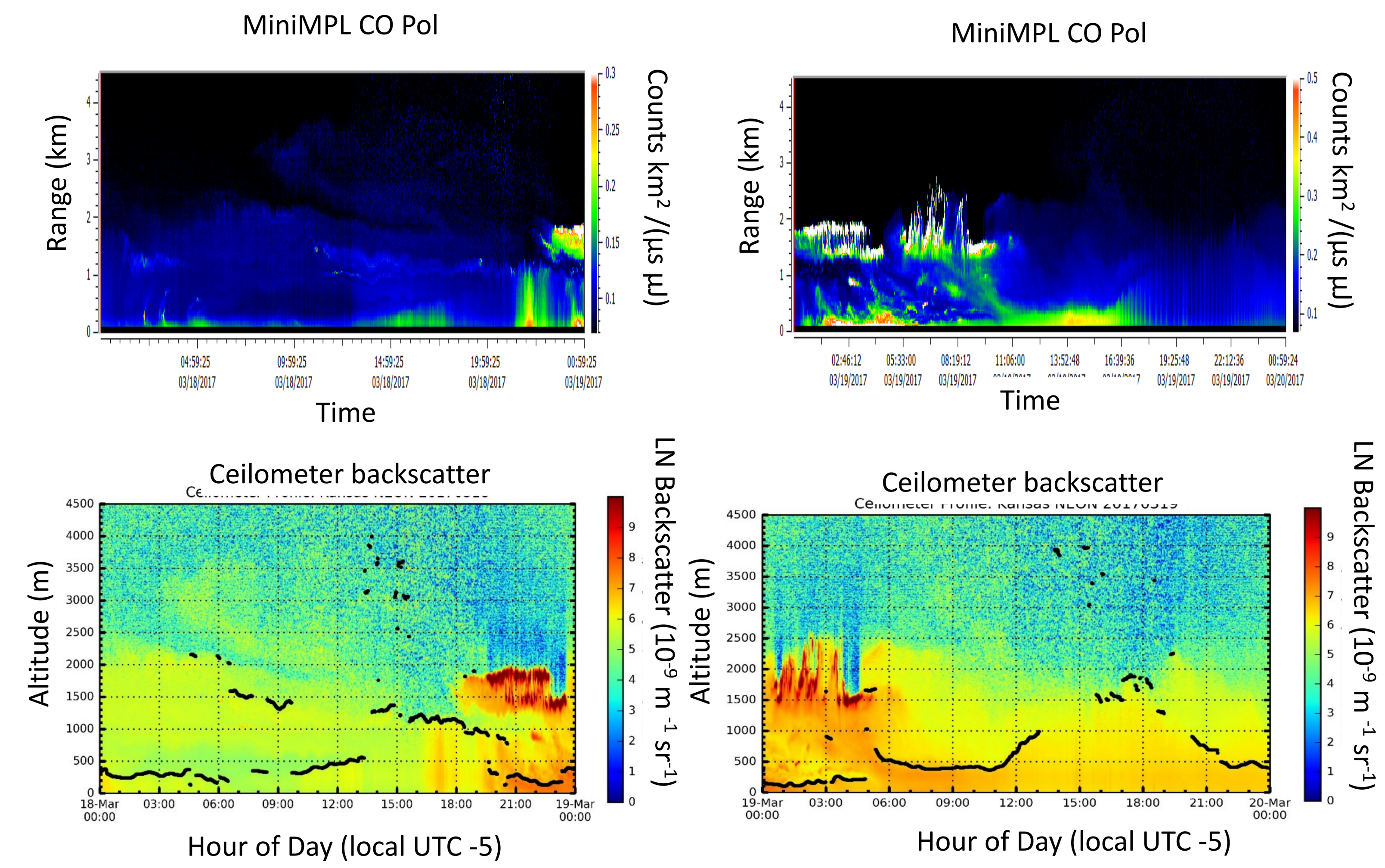


Figure 4. *MiniMPL (top) and a CL-51 ceilometer (bottom) side-by-side* vertical scanning pattern weekend analysis. A 36s averaging bins for the MiniMPL was used to compare with preset CL-51 bins to study the mixed layer height (MLH). Modeling the correct MLH (lower 1-4 km) is critical for improvement of transport chemistry and plume height determination. Both instruments capture very little smoke outside of the relative MLH (CL-51 MLH indicated with black dots) indicating that pollution in the area typically stays in the MLH.

Preliminary Results/Future Work

- Our initial study design was too slow and included scan angles that were too steep. Individual plumes were discernable from only 5-30 minutes, and were often missed by the scanning Lidar.
- Ideally scanning patterns should only extend slightly above the MLH unless weather conditions are supportive or large enough acres burned.
- For this study, a vertical slicing pattern perpendicular to the mean wind flow was the best position for Lidar measurements., with the preferred downwind distance being ~500 m.
- Scanning patterns had to be created "on-the-fly" based on burn orientation and meteorology.
- Preliminary results suggest that plume tops were less than ~0.7 km and remained trapped in the lower mixed layer (~1 km), unless more than 80 acres burned.
- Mixed layer heights estimated with the MiniMPL showed decent agreement with the CL-51, with the MiniMPL ~100 m lower than the CL-51.

With this experiment being the first to use a scanning MiniMPL during a prescribed burn, we propose that with further refinement and field experience, the MiniMPL may be able to provide useful information on near source plume mapping in future studies. These studies would be useful in evaluating mixed layer heights and plume rise for different fuel types in order to improve model parametrization.

Acknowledgements: We would like to recognize the USEPA Region 7 Office for help provided in collecting data. The EPA NEIC office for loaning the MiniMPL and Sigma Space for training on the MiniMPL. Fire burn Manager Patrick O'Neil and KPBS along with the many workers/volunteers. A special thanks to Jim Szykman for providing the ceilometers and backscatter plots.