# Study Plan (SI-1647):

# Enhanced smoke and related measurements at Eglin Air Force Base

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## Contents

# 1 Introduction

In 2008 and 2009 we monitored several prescribed burns (PB) at Ft. Benning, measured plume height and smoke ($PM_{2.5}$ and CO) concentrations downwind of the plume, and used these data to assess the performance of Daysmoke, a smoke dispersion model,. During our model evaluation cycles, we identified a few additional pieces of data we would like to have for more rigorous assessment of Daysmoke's performance. This study plan is prepared for the purpose of collecting these data that we believe are necessary for a more complete evaluation of the model. These data elements are wind speed/direction, fuel consumption, plume height, on-site calibration factors for real-time instruments, and ground-level and aerial smoke concentrations. Below, it will be explained how each one of these data elements would help better understand the skills and limitations of the Daysmoke model.

In our evaluations so far, Daysmoke was found to be very sensitive to the input wind speeds and directions. The errors in winds predicted by the meteorological models (MM5 and WRF), especially error in wind direction, are believed to significantly affect the plume transport by Daysmoke. Therefore, in our 2011 field study, we would like to measure the vertical profile of the winds, evaluate the uncertainty in the winds predicted by the meteorological models, and assess the impact of these uncertainties on Daysmoke predictions.

Emission inputs are critical to Daysmoke performance. While we have a certain level of confidence in emission factors, the fuel loads and fuel consumptions are more uncertain. As part of the Prescribed Fire Combustion and Atmospheric Research Experiment (Rx-CADRE) at Eglin Air Force Base (AFB) in February 2011[*], fuel load and fuel consumption data will be collected. By conducting our field study at Eglin AFB, during Rx-CADRE, we would like to benefit from these data, especially fuel consumption data, for more accurate emissions inputs to Daysmoke. Due to the coastal location of Eglin AFB, new challenges are likely, both from a sampling and modeling perspectives. Typically, burns are conducted under offshore winds at Eglin so that the smoke plume is blown to the Gulf of Mexico. For the ground-based mobile units, this might limit the sampling distances downwind from the burn plots. Also, the land/sea breeze effects might complicate the modeling. However, during the month of February, when the study is planned at Eglin, the effect of the land/sea breeze should be relatively small.

The number of updraft cores is an important parameter of Daysmoke that needs to be set by the user. The resulting plume height is very sensitive to the number of updraft cores. Therefore, plume height measurements are very useful in making an adequate selection for this important Daysmoke parameter. A ceilometer was purchased by the Forest Service for the purpose of measuring plume height. However, this ceilometer was not

[*] The Rx-CADRE study at Eglin AFB is scheduled for February 4-13, 2011. There will be a total of 2 to 3 burns.

used in all prior burns; we would like to use it in all the burns we will monitor during our 2011 field campaign.

The calibration of real-time instruments used on mobile platforms has been a source of uncertainty in our prior measurements. The calibration factors employed were derived from other studies which may not accurately characterize the smoke conditions of monitored burns. Measurements with stationary but more precise instruments side-by-side with real-time instruments can be useful for deriving burn specific calibration factors. In our 2011 study, we would like to set up a stationary site to calibrate the instruments used on mobile platforms. If this site is set up in the short range (~1 km), downwind from the burn unit, it can also provide useful data for evaluation of Daysmoke.

The last data element we would like to have is smoke measurements on the ground and aloft. So far we evaluated the Daysmoke model only with ground-based measurements. By adding a balloon-lofted and tether-maneuvered instrument package, we can collect smoke concentration data that would allow the evaluation of Daysmoke aloft. This would be a major contribution to model evaluation considering that the only above ground evaluation possible so far was qualitative evaluation using lidar and ceilometer measurements. The smoke concentration data aloft will enable quantitative evaluation of the model above ground for the first time.

In the rest of this document we will discuss how we intend to collect these data elements which we would like to have for more rigorous evaluation of the Daysmoke PB plume dispersion model. Two of the data elements, wind speed/direction and fuel consumption, are expected to provide more accurate inputs to the model. One element, plume height, will be used in setting an important parameter of the model. The remaining two elements, on-site calibration data and concentration data on the ground and aloft will be used in evaluating the model outputs.

# 2 Objectives

This study is part of a larger project which aims to develop a simulation framework that can accurately predict the impacts of prescribed burns (PB) on regional air quality. One of the models in this framework is Daysmoke, a plume model developed by the Forest Service specifically for tracking the dispersion of PB plumes. The goal of this study is to collect data that have been identified during prior years of this project as most important elements for a more rigorous evaluation of the Daysmoke model.

Specific objectives of this study are to (1) provide Daysmoke with more accurate inputs, namely wind speed/direction and emissions; (2) set an important model parameter, namely the number of updraft cores; (3) calibrate the real-time instruments on site for more accurate smoke measurements; and (4) collect smoke concentration data, both on the ground and aloft, for more robust evaluation of Daysmoke outputs. The field study will be followed by a re-evaluation of the model with the collected data.

A doppler sodar and an anemometer mounted on a balloon-lofted and tether-maneuvered aerostat will periodically provide vertical profiles of wind speed and direction near the fire. These data will be used as direct inputs to Daysmoke; they will also be used to evaluate the vertical "soundings" provided by the Weather Research and Forecasting (WRF) model, which is the meteorological modeling component of the simulation framework being developed.

To provide more accurate emissions inputs to Daysmoke, fuel loading and fuel consumption data will be collected. Each fuelbed type in a burn unit will be sampled before and following the burn for fuels, which include trees, shrubs, grasses, small woody fuels, and litter. For a burn unit average, Fuel Characteristic Classification System (FCCS) fuelbeds will be built to represent the fuelbed types. This technique will also be compared to the previously used photo-series method. The consumption model Consume (Version 3.0) will be used to predict unit average consumption and emissions based on the area coverage of each fuelbed type.

A ceilometer will be used to measure the height of the smoke plume. These measurements will be used to determine the appropriate number of updraft cores, which is an important parameter of the Daysmoke model.

During the study, ground-based measurements will be made using stationary and mobile platforms. The objective of the mobile platforms is to capture downwind concentrations of $PM_{2.5}$ as well as its composition. The objective of the stationary site is to provide $PM_{2.5}$ measurements by non-portable instruments using the federal reference method. These measurements will be used for calibration of mobile instruments. In addition, CO, $CO_2$ measurements at the stationary site will provide essential combustion information.

Aerial measurements will be made using a tethered balloon lofting the same or similar mobile instruments used on the ground. The objective of the aerial measurements is to provide $PM_{2.5}$ and other burn-related data for use in Daysmoke evaluations.

# 3 Methods and analysis

This section describes the data to be collected, our sampling design, and instrumentation. Dr. Roby Greenwald of Emory University will be setting up a ground-based network with significant improvements over the prior year networks. Dr. Brian Gullett of the US Environmental Protection Agency (EPA) will conduct aerial sampling with a balloon-lofted and tether-maneuvered aerostat. Dr. Roger Ottmar of the US Forest Service (FS), who is the principal investigator of Rx-CADRE, will sample the fuelbeds while Dr. Scott Goodrick of USFS will characterize the fuels using the photo-series approach for comparison. Dr. Warren Heilman of USFS will measure vertical wind profiles using a Doppler sodar. Dr. Yongqiang Liu of the Forest Service will operate a ceilometer to measure plume height.

Post-sampling activities will include data analysis and interpretation, as well as model evaluation and preparation of the reports for the monitored burns. This section also describes how each data element will be used in model evaluation. Dr. Gary Achtemeier and Dr. Talat Odman of Georgia Tech will evaluate the model using the collected data. Applying the Daysmoke model to the monitored burns and comparing its PM2.5 predictions with measured PM2.5 will enable a final assessment of the model's predictive skills and a determination of its potential limitations.

## *3.1 Wind measurements*

Our prior evaluations of the Daysmoke model identified a significant uncertainty in wind speeds and directions that our previous experimental design did not address. Therefore, we would like to measure the vertical profile of the winds. The measured wind speeds and directions will be directly input to Daysmoke, whenever possible, instead of the winds predicted by WRF. The measured winds will also be compared to WRF winds to determine the level of uncertainty introduced to Daysmoke by using predicted wind fields. Our analyses during the first two years of the project suggest that Daysmoke can be sensitive to wind direction shifts from 2-5 degrees – well within the expected range of WRF modeling errors. Since the smoke impact prediction system is planned to operate with predicted winds, a more accurate wind model may be necessary in the future.

### 3.1.1 Remotely sensed wind measurements

We plan to use the USFS Doppler sodar to obtain vertical wind profiles in the lowest 500 m of the atmosphere. The sodar will provide wind speed and direction from 100-500 m with 10 m height resolution. We plan to compare WRF winds from 100-500 m with the Doppler sodar winds, which will be assumed to be ground-truth. If there is a difference between the modeled and observed winds that is considered to compromise the comparisons between Daysmoke and ground-truth PM2.5 measurements, then we will substitute the Doppler sodar winds into the WRF soundings. We will compare Daysmoke/PM2.5 measurements for Daysmoke run with WRF only and WRF/Doppler sodar winds. The purpose is to see whether small differences between WRF winds and Doppler sodar winds lead to improvements in Daysmoke/PM2.5 comparisons.

REMTECH Doppler sodar system consists of one sole antenna (phased array type of transducer elements), one computer, one transceiver, one power amplifier, cables and a small mount for the antenna. The system allows for full control of the antenna beams: four of the electronically steered beams are tilted (30° or 15°) from vertical and turned 90° from each other to provide the horizontal component of wind velocity. The last beam is pointed vertically and provides that component of the wind. The system software controls the sequence and rate of operation for each beam.

Linux OS based software provides a signature to the transmitted pulse. The basic coding consists of transmitting 9 (up to 15 optional) frequencies in the pulse. Upon reception, this coded pulse is easily detected from noise and fixed echoes within the backscattered signal. This is particularly useful for turbulence studies since it allows quicker detection for full analysis on the noise spectrum. The frequency transfer function (in phase and amplitude) between the "active antenna" and the "reference antenna" (made of 4 transducers at the 4 antenna corners) allows a very efficient noise subtraction (especially for a fixed noise source such as an air conditioner, an aspirated shield on a meteorological tower close to the sodar). The final acoustic frequency power spectrum can be cleaned by more than 15dB's decrease of the jamming source in the considered frequency zone.

USFS Doppler sodar has 52 transducer elements. Its nominal central operating frequency is 3500 Hertz (9 frequencies are emitted on each tilted beam during one "beep"). The size of the antenna is 0.4×0.4 m. Its maximum range is 1,000 m with an average range in typical conditions of 200−600 m.

### 3.1.2 Aerial wind measurements

As a supplemental means of wind measurements, we plan to take advantage of the US EPA aerostat. The aerostat will be operated near the burn unit and it will have vertical as well as some horizontal mobility. Therefore, it can be used to measure wind speed and direction at different positions than the Doppler sodar. We plan to use the wind speed and direction measurements from the aerostat for model evaluation in the same way as those measured by the Doppler sodar.

A 3D sonic anemometer will be affixed to the Flyer instrument pack sufficiently beyond the boundary layer of the aerostat balloon. The anemometer will be an R. M. Young Model 81000 3 axis ultrasonic anemometer (Figure 1). It will be equipped with an inertial measurement unit (MTi-G) for correction of the aerostat pitch and yaw movement. The 3D anemometer measures three dimensional wind velocity based on the transit time of ultrasonic acoustic signals. Inertial and barometric position and velocity data are provided by the altitude and heading reference system (AHRS) and navigation processor aboard the XSENS Model MTi-G. Thus, the Mti-G analyzes and corrects for position, motion, and orientation of the aerostat. While wind velocity downwind of the burn will be measured continuously at a frequency of 1 hz, validation of the Daysmoke model requires time averaged data, typically every 10 to 15 minutes. The sonic anemometer will be kept at the center of the plume most of the time but some vertical transects will also be attempted.

**Figure 1.** 3D sonic anemometer.

## 3.2 Fuel load and consumption measurements

One of the goals of this study is to have access to fuel loading data that does not rely on photo series and fuel consumption data that does not completely rely on estimates from the model CONSUME. As part of Rx-CADRE, Dr. Roger Ottmar of USFS will conduct a field study at Eglin AFB in February 2011 to collect fuel loading data in advance of the burn and post-fire consumption field data. The overall objective of that study is to measure the fuelbed component characteristics and fuel consumption for each of the Rx-CADRE prescribed burns. The questions to be answered are: (1) How much fuel exists for the tree, shrub, grass, small woody, and litter categories for each unit? (2) How much of each fuelbed category is consumed during the fire? A detailed plan for Rx-CADRE fuel loading and fuel consumption measurements is appended to this study plan.

The fuel loading and fuel consumption measurements are expected to provide better inputs for the emissions modeling components of our smoke impact prediction system. In particular, the sampled fuelbeds will be compared to fuelbeds estimated from photo-series. This comparison will give us an idea about the error introduced through the Fuel Characteristic Classification System (FCCS). Similarly, the consumption measurements will be compared to the consumptions estimated by the model Consume for each fuelbed type. These comparisons will allow us to determine the level of uncertainty in the emissions inputs to Daysmoke. The level of uncertainty in emissions factors (mass of gas or particle emissions per unit mass of fuel consumed) is expected to be available through SERDP project SI-1649.

We would also like to get a better picture of ignition progression. For aerial burns, and hand-lit burns, the sequence and GPS coordinates of ignition points will be tracked. Because Daysmoke has proven to be sensitive to the location and timing of smoke production in prior evaluations, this data will allow us to determine exactly where the igniters were and when. The data will be processed through an experimental fire spread model, Rabbit Rules that can provide temporal and spatial detail in relative emissions production.

## 3.3 Plume height measurements

The number of updraft cores is an important parameter of Daysmoke that needs to be set by the user. The modeled plume height is very sensitive to the number of updraft cores. Using prior years' data, we have developed certain criteria for setting the number of updraft cores. However, these criteria are not fully tested and more plume height measurements are needed to verify their veracity. First, a number of updraft cores will be assigned to each burn based on the earlier developed criteria. Then, the plume height estimated by Daysmoke for that number of updraft cores will be compared to the measured plume height. If there is a difference significant enough to affect the comparison of modeled and measured PM2.5 concentrations, plume height measurements will be used in making a more adequate selection for the number of updraft cores. When an agreement is reached between the Daysmoke estimated and measured plume heights, the criteria for setting the number of updraft cores will be reviewed and revised as necessary. In prior years, USFS lidar support has proven to be very helpful for determining the actual plume height.

Smoke plume rise will be measured using a CL31 Ceilometer (Figure 2). This device employs laser LIDAR (Light Detection and Ranging) technology. It emits short, powerful laser pulses in a vertical or slant direction. The directly backscattered light caused by haze is measured as the laser pulses traverse the sky. This is an elastic backscatter system and the return signal is measured at the same wavelength as the transmitted beam. As many as three smoke layers can be detected with the height up to 7.5 km. The detection frequency is 2 second. This device was used to measure nearly 20 prescribed burns in the past two years. Figure 3 shows the measured smoke plume structure for a prescribed burn at Ft Benning on April 9, 2009.

During the measurements at Eglin AFB in 2011, the CL31 Ceilometer will be mounted in a mobile or on a leveled plate on the ground. The instrument will be set up before the start of the burn at a certain distance from a burn in the downwind. The distance ranges between 1 and 5 miles, depending on burn intensity and wind speed. The collected data are vertical distribution and temporal variations of backscatter light intensity. They provide smoke plume properties of plume rise and vertical profile of smoke intensity.

**Figure 2.** CL31 Ceilometer with smoke plume from a prescribed burn.

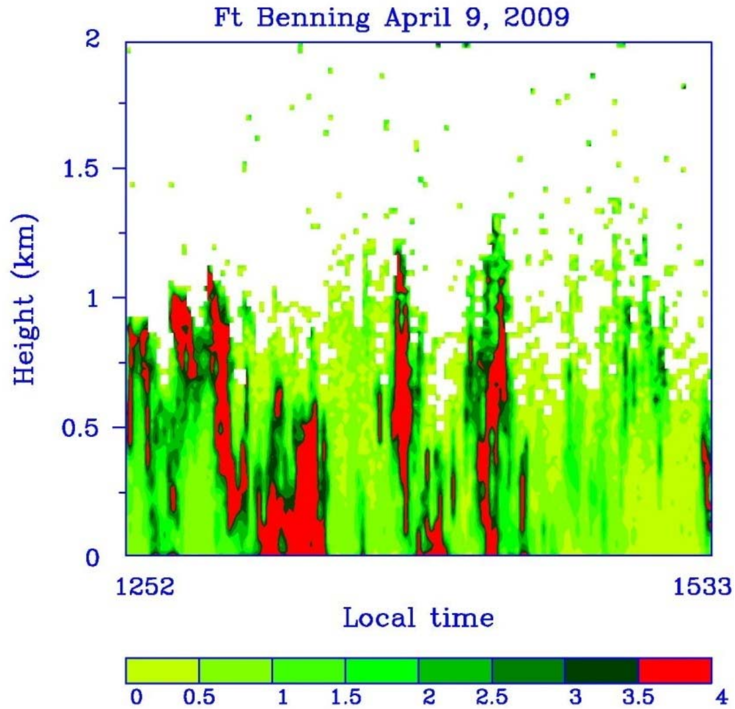


**Figure 3.** Time-height section of backscattered light of CL31 Ceilometer measurement for the prescribed burn at Ft Benning on April 9, 2009.

## 3.4 Smoke concentration measurements

The smoke concentration measurements, especially PM2.5 measurements are compared in evaluating the Daysmoke predictions. Due to the turbulent nature of the atmosphere, the measurements are time-averaged before comparison. The model predictions at the same location as the measurements are also time averaged and compared to time-averaged measurements. Typically a 15-minute or 30-minute time averaging is used. An averaging in space, within a certain radius of the measurements, is also being considered. In prior years, PM2.5 concentrations were only collected at the ground level. In 2011, we would like to measure PM2.5 concentrations aloft.

We will coordinate the ground-level sampling with the US EPA aerostat-based measurements aloft of $PM_{2.5}$, CO, and $CO_2$ concentrations. These data will enable the evaluation of the vertical smoke distribution predicted by Daysmoke. In the smoke impact prediction system that we are developing, Daysmoke provides the vertical distribution of smoke for input into the Community Multiscale Air Quality (CMAQ) model, which is the regional scale air quality modeling component. Simultaneous measurements of $PM_{2.5}$, $CO_2$, and CO will allow further characterization of the plume, including evaluation of emission factors using the carbon balance method.

Our experience in prior year field studies have shown that stationary but more precise PM mass measurements can be helpful for calibrating the less accurate instruments on mobile platforms. We will operate a Tamper Element Oscillating Microbalance (TEOM) at a stationary site in the short range (~ 1km) side-by-side with a sample of the real-time $PM_{2.5}$ instruments which will be used on mobile platforms. These real-time particle counters will be operated on two trucks chasing the PB plume in the mid (3-5 km) to long ranges (7-10 km) for real-time $PM_{2.5}$ mass sampling as well as on the balloon lofted and tether maneuvered aerostat.

The stationary site will also include measurements of the gas-phase combustion products CO and $CO_2$. These measurements will be used in detecting the transition of the burn from flaming phase to smoldering phase. These data will enable us to better estimate the emissions being input to Daysmoke and determine how each phase contributes to the smoke concentrations downwind.

### 3.4.1 *Ground-Based* Gas and PM *Sampling*

We will operate instrumentation to measure the concentration, size distribution and carbon speciation (elemental carbon and organic carbon as primary and secondary) of ambient particulate matter (PM) at both a stationary site and on two mobile platforms in the field. One mobile platform will be operated at a downwind distance of 3-5 km while the other will be 7-10 km downwind. The stationary site is necessary for non-portable instruments (specifically, the TEOM and CO and $CO_2$ instruments described below). These instruments are required for the proper calibration and interpretation of mobile instruments as well as for determining the amount of biomass being combusted. The mobile platforms are required for determining spatial dispersion of the prescribed burn plumes both in the lateral and downwind directions. The instrumentation packages for the mobile platforms were developed by Dr. Roby Greenwald at Emory University, and a similar mobile platform is currently being used to measure in-vehicle pollutant exposures as part of the Atlanta Commuters Exposure (ACE) Study[*]. The measurements will include both real-time data from continuously-operating devices as well as time-integrated data from high flow-rate filters. In order to account for the influence of method artifacts, all filter-based measurements will include analysis of both laboratory and field blanks.

The stationary site for PM measurements will be located ~1 km downwind from the burns. The US Forest Service Doppler sodar and Lidar Ceilometer will be positioned at the same location to measure vertical wind profiles and plume heights, respectively. One of the objectives is to duplicate some of the instruments on the mobile platform at the stationary site so that they can be compared with higher precision non-portable instruments for calibration and interpretation. The stationary site will be powered using a Honda Model EU3000IS 3000 Watt gasoline generator. The generator will be placed 100 ft from the stationary site in the downwind direction. The mobile instrumentation

[*] The ACE Study is a Center for Disease Control (CDC) funded program to assess the health effects on automobile commuters of exposure to motor-vehicle emissions on Atlanta's highways.

packages will be mounted on two trucks that will continuously sample in the intermediate (3-5 km) and long (7-10 km) ranges downwind from the burns. During active sampling periods, the mobile platform vehicles will be parked on the upwind sides of the service road with the engine turned off.

#### 3.4.1.1 Continuous measurements

$PM_{2.5}$ *mass.* Continuous measurements of $PM_{2.5}$ concentrations will be performed at the stationary site using the Tapered Element Oscillating Microbalance or TEOM (Thermo Scientific). This device calculates particle mass as a function the resonant frequency of an oscillating filter element and is a U.S. EPA recognized instrument for continuous measurement of $PM_{2.5}$ mass. On the stationary platform and both mobile platforms, particle mass will be measured using an AeroTrak handheld particle counter (TSI Inc., Model 9306). The AeroTrak measures the light scattered by aerosols as they intercept a laser diode to count the number of particles in six size ranges in real-time. The largest size range will be configured to correspond to particles larger than 2.5 µm. The measured number concentration for each channel will be converted to a volume concentration by assuming particles are spherical with diameter equal to the log-midpoint of each channel. The volume concentration of particles smaller than 2.5 µm will be converted to a mass concentration using a “synthetic density” factor derived from calibration with the TEOM. The synthetic density will be estimated from simultaneous operation of the TEOM and the stationary platform AeroTrak and will be independently estimated during all phases of the burn (pre-burn, flaming phase, and smoldering phase). The measurement range of the AeroTrak is 0-70 particles/cm$^3$ with a resolution of 1 particle/cm$^3$. This measurement range in terms of $PM_{2.5}$ mass is variable depending on particle size and synthetic density, but is generally in the range 0-70 µg/m$^3$.

*Particle number concentration.* The real-time number concentration of ambient aerosols will be characterized on the mobile platforms using condensation particle counters (CPC), the TSI P-Trak (TSI Inc., Model 8525). This model of CPC is capable of measuring particles in the size range of 20 to 1000 nm by condensing isopropyl alcohol vapor onto the particles until they have grown large enough to scatter a detectable amount of light from a laser diode. The measurement range of the P-Trak is 0-500,000 particles/cm$^3$ with a resolution of 1 particle/cm$^3$. Although this instrument does not provide information on particle size, the ambient aerosol number concentration is typically dominated by particles in the ultrafine size mode (< 0.1 µm).

*Carbon monoxide.* The concentration of CO will be measured continuously using the ThermoScientific Model 48i. This device measures the CO-specific absorption of infrared light at a wavelength of 4.6 µm. The measurement range of the 48i is 40 ppb to 10,000 ppm with a resolution of 1 ppb and response time of 60 seconds. This instrument will only be installed on the stationary platform.

*Carbon dioxide.* The concentration of $CO_2$ will be measured using the ThermoScientific Model 410i. This device uses the non-dispersive infrared (NDIR) method to measure the absorption of infrared light by $CO_2$ gas with excellent sensitivity. The measurement range of the 410i is 200 ppb to 10,000 ppm with a resolution of 10 ppb and response time of 90 seconds. The $CO_2$ concentration is very closely related to the amount of biomass that is combusted, and precise $CO_2$ measurements will be essential to calculating emission factors. This instrument will only be installed on the stationary platform.

#### 3.4.1.2 Time-integrated measurements

*Coarse and fine mode mass.* The mass concentration of coarse mode (> 2.5 µm) and fine mode (< 2.5 µm) particles will be measured on both mobile platforms using a Harvard Compact Cascade Impactor operated at a flow rate of 30 L/min. For this study, this impactor will use a single impaction stage with an aerodynamic cutpoint of 2.5 µm; hence particles collected on the impaction plate will be greater than 2.5 µm in aerodynamic diameter while those collected on the after-filter will be smaller than 2.5 µm. The impaction filter is a Polyurethane Foam (PUF) substrate with dimensions of 1×7 cm while the after filter is a 47 mm Teflon filter. Flow rate spot checks will be performed at the beginning and end of each sampling period. Gravimetric measurement of particle mass will be conducted in a dedicated clean room facility at Georgia Tech. The clean room temperature is maintained at 25°C and the relative humidity is maintained at 20%. Both Teflon and PUF filters will be equilibrated to the clean room environmental conditions for 48 hours prior to weighing. Each filter will be weighed three times. The clean room microbalance has a precision of ±5 µg.

*Analysis of elemental and organic carbon.* Additional time-integrated characterization of $PM_{2.5}$ elemental and organic carbon (EC-OC) content will be performed using two parallel filter samples on both mobile platforms. Each sample line will be operated at a flow rate of 30 L/min and will be equipped with a 2.5 µm cutpoint impactor upstream of the filters to remove coarse-mode particles. One sample line will be equipped with a 47 mm Teflon filter followed by a 25 mm quartz fiber filter while the other sample line will only contain a quartz fiber filter. Flow rate spot checks will be performed at the beginning and end of each sampling period. EC-OC analysis will be performed using the Thermal-Optical Transmittance (TOT) method. The TOT method is a two-step thermal evolution process. In the first step, the filter is heated in an oxygen-free helium atmosphere to vaporize organic compounds; in the second step, the filter is heated in the presence of oxygen in order to oxidize elemental carbon. Throughout this process, the optical transmittance of the filter is monitored to provide a measure of the amount of organic carbon incidentally charred during the oxygen-free heating step. Each filter will be split using a semi-circular punch resulting in two halves each with an area of 1 $cm^3$. Filter punches will be analyzed independently, and the mean of both analyses will be used for data analysis. The sampling artifact produced by the adsorption of volatile and semi-volatile organic compounds onto quartz fiber filters will be assessed by subtracting the OC content of the quartz filter which follows the Teflon filter from the stand-alone quartz filter.

*Analysis of water-soluble organic carbon and ion speciation.* The Teflon filter placed upstream of the quartz filter used for OC artifact analysis will be used to produce a duplicate gravimetric measurement of $PM_{2.5}$ mass (as described above) as well as an aqueous extract of water-soluble compounds. The extract will be produced by immersing the filter in 30 mL of ultrapure water and sonicating in an ultrasonic bath for 20 minutes at a temperature of 30°C. A 20 mL aliquot of this extract will be analyzed for water-soluble organic carbon (WSOC) content using a Sievers Model 900 Portable Total Organic Carbon (TOC) analyzer. The TOC analyzer that will be used for this study employs the UV/Chemical Oxidation method to oxidize all organic carbon in the aqueous extract to $CO_2$, which is then detected using a conductivity cell. The ratio of WSOC to EC is useful for parameterizing secondary organic aerosol content. In addition, two separate 200 µL aliquots will be analyzed for ion content using a Dionex ICS-2000 ion chromatograph. One aliquot will be analyzed for anions including acetate, formate, chloride, nitrite, nitrate, sulfate and phosphate while the other will be analyzed for cations including sodium, ammonium, potassium, magnesium, and calcium.

*Filter handling procedures.* PUF filters will be immersed in ultrapure water and sonicated for 20 minutes. The water will be changed, and this process will be repeated. PUF filters will then be dried under a laminar flow hood. Teflon filters will have 50 mL of ultrapure water drawn through the filter membrane and will then be dried under a laminar flow hood. Quartz filters will be similarly treated, but will in addition be baked in a mufflered furnace for 16 hours at a temperature of 550°C. A PLAS Labs Model 800 glove box will be installed at the stationary site for purposes of filter loading and unloading. Given the limited number of filter samples required for this study, it will be feasible to produce and analyze a field blank for each filter sample. Field blanks will be prepared in an identical fashion to filter samples, transported to the field, loaded into filter holders, and then immediately removed. In addition, for each filter substrate preparation procedure, two laboratory blanks will be produced. Lab blanks will be prepared in an identical fashion, but will not be transported to the field.

### 3.4.2 Aerostat-Based Sampling

Aerial sampling will use a balloon-lofted instrument package called the "Flyer." The Flyer is lofted with a helium-filled balloon and maneuvered by one or two tethers (Figure 4) connected to all-terrain-vehicles (ATVs). The Flyer collects batch gas and particle samples from ambient air or plumes. The Flyer (Figure 5) is typically comprised of multiple instruments powered by rechargeable 12-24 V Li-ion and AA batteries. The Flyer can make continuous measurements of CO, $CO_2$, PM, and black carbon with batch sampling of total $PM_{2.5}$ or $PM_{10}$, metals, volatile organic compounds, and semi-volatile organic compounds. Emission factors can be determined by use of C measurements (e.g., $CO_2$, CO, and PM) and the carbon balance method.

Primary measurements from the Flyer will real-time PM, black carbon, CO and $CO_2$ to ensure that the spatial and temporal parameters satisfy the data needs for Daysmoke evaluation. Field sampling will be coordinated with the installation, the burn boss, and the other sampling teams, particularly those teams that are measuring similar analytes and plume attributes. In general, the Flyer will be as close to the burns as is safely possible in order to minimize the sampling times required to exceed the method detection limits.

Likely sampling distances from the flame front are 100 m to 500 m at an altitude of less than 325 m (to stay below the 1000 ft ceiling required by Eglin AFB).

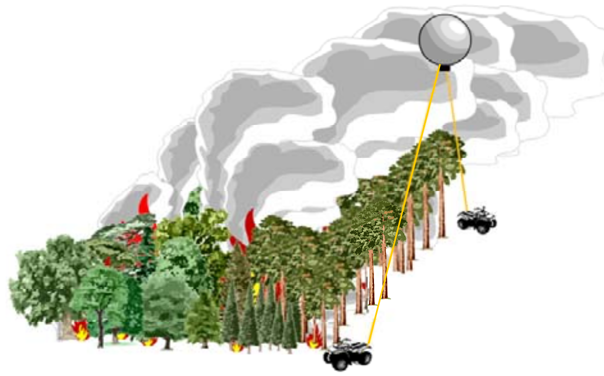

**Figure 4.** Sampling design to be used by the US EPA aerostat.

The aerostat is a Kingfisher (K13N) 13×10.3 foot-diameter (3.96×3.14 m-diameter) helium balloon which lofts approximately 25 lb (11 kg). The balloon is tethered using Spectra line (1,000 or 2,000 ft length, 2.5 mm diameter) to a pair of ATVs equipped with electrically powered winches. The combination of one or two ATVs and tethers permit the positioning of the balloon, and therefore the Flyer, at a specific location and height downwind of burns.

**Figure 5.** The balloon and the instrument package in operation.

The Flyer (Figure 6) will be configured for this project with a continuous mass particle counter, a $PM_{2.5}$ sampler, a summa canister and/or electrochemical cell for CO, and a $CO_2$ CEM. Additional sampling instruments may be included to assist emission factor determination. CEM data and flow rate will be logged to an on-board HOBO or LabView data logger which also measures temperature plus relative humidity.

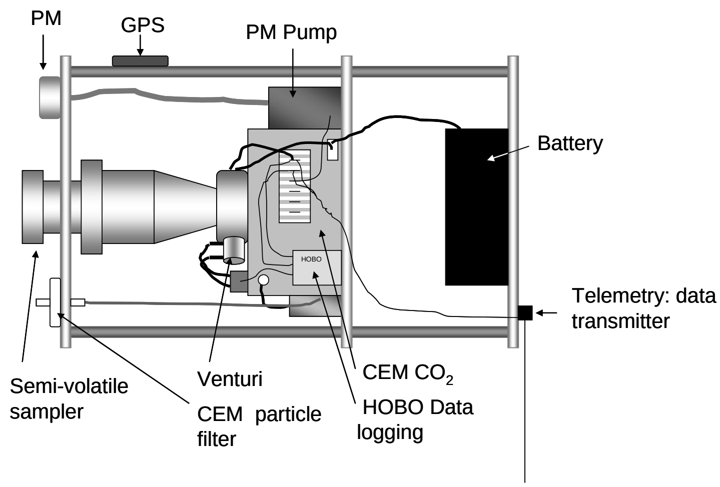


**Figure 6.** Aerial instrument package (not all instruments are shown).

### 3.4.2.1 $CO_2$ Measurements

$CO_2$ is continuously measured in accordance with EPA Method 3A using non-dispersive infrared (NDIR) instrument (LI-820 model, LI-COR Biosciences, USA). This unit is configured with an optional 14 cm optical bench, giving it an analytical range of 0-20,000 ppm with an accuracy specification of less than 2.5% of reading. The LI-820 calibration range is set to 0-4,500 ppm. A particulate filter precedes the optical lens. The LI-820 is equipped with a programmable trigger circuit which activates collection of all samples at a user-set $CO_2$ concentration above background levels, indicating that the Flyer is within the emission plume. This trigger conserves batteries and avoids dilution of the sample with ambient air. The $CO_2$ level also can trigger a PM sampler comprised of a 47 mm tared Teflon filter (pore size of 2.0 μm) and a Leland Legacy sample pump (SKC Inc., USA) with a constant airflow of 13 L/min. An internal flow sensor on the Leland pump measures flow directly and acts as a secondary standard to constantly maintain the set flow. PM is measured gravimetrically using pre-tared filters transported in sealed petri dishes.

### 3.4.2.2 CO Measurements

Summa canisters (6 L capacity) and an electrochemical cell will be used for collection of CO. Summa canisters are outfitted with an electronic valve that is opened at an operator-set threshold $CO_2$ concentration which provides sampling durations on the order of minutes. Analyses will be via GC, utilizing EPA method 25C, in which an aliquot of the collected Summa canister sample was injected into a sample loop equipped GC/FID. CO data will be background-corrected by subtracting the ambient air contribution to the sample. The batch summa canister CO values can be complemented by continuous CO measurements. The electrochemical cell (Model RCO1000, Transducer Technology Division, Newark CA) is supplied with a standard range of 0-1,000 ppm, but will be calibrated at 0-100 ppm (±2 ppm) for anticipated CO levels. From 0 ppm to 90% of full scale takes 20 seconds. For sampling periods in the order of minutes or longer, this lag should not compromise the data.

#### 3.4.2.3 Telemetry and Positioning

The Flyer also has a Geko 301 (Garmin, USA) global position system (GPS) for location and height above sea level, saving data every 10 seconds (adjustable). A wireless telemetry and data recorder system (Seagull Sea Pro 900. Eagle Tree Systems, LLC) on the Flyer transmits signals to the ground crew. This 9 V system transmits (for example) $CO_2$ concentrations (as a voltage), flowrate (as a voltage), ambient temperature, and battery output to the aerostat crew to aid in positioning the aerostat within the plume, monitoring volumetric sampling rate to determine whether a filter change was necessary, and conveying residual battery capacity. These data, together with the telemetry's GPS data, can be saved every millisecond and used as a secondary data logger.

#### 3.4.2.4 Particle Measurements

An Aerocet-531 mass particle counter will be used to measure and record PM2.5 mass in real time. The light source of the particle counter is a laser diode powered by a 6V self-contained battery. The device weighs 0.88 kg.

In addition, PM2.5 will be sampled using a 47 mm tared Teflon filter with a pore size of 2.0 µm via a Leland Legacy Sample pump (SKC Inc., USA) with a constant airflow of 10 L/min. The pump is controlled by the CEM CO2 trigger circuit. The Leland Legacy Sample pump will be calibrated with a Gilibrator Air Flow Calibration System (Sensidyne LP, USA). PM2.5 will be measured gravimetrically following the procedures described in 40 CFR Part 50 (1987). The particulate matter collected on teflon filters can also be used to determine metal concentrations through analysis by energy dispersive x-ray fluorescence spectrometry (ED-XRF) according to U.S. EPA Compendium Method I0-3.3 (1999).

Black carbon (BC) concentrations will be measured with a Magee Scientific MicroAethalometer (AE-51), which is a small, portable, hand-held instrument capable of measuring, BC as defined by the manufacturer. This instrument determines the BC concentration at 880 nm by absorption. The AE-51 has the physical dimensions of 117mm × 66mm × 38mm, and weighs approximately 250g, thus currently making it the only commercially available, lightweight measurement device for BC. The instrument is capable of sampling in increments of 1, 60, or 300 seconds from 0-1mg BC/m3, although it is designed for ambient measurements specifically.

# 4 Quality Assurance

Sodar measurements will be compared with available tower measurements to assess the quality of near-surface sodar measured winds. Upper level sodar wind measurements will be compared with radiosonde measurements, if available, and/or measurements from a WLS70 Doppler Wind Lidar system.* Sample data obtained from the sodar are shown in Figure 7. These sodar measurements were taken in New Jersey earlier this year (2010) during the Joint Fire Science Program (JFSP) burn experiment. The lower level sodar measurements matched up really well with the 30 m tower wind measurements made at the site over the duration of the monitoring period.

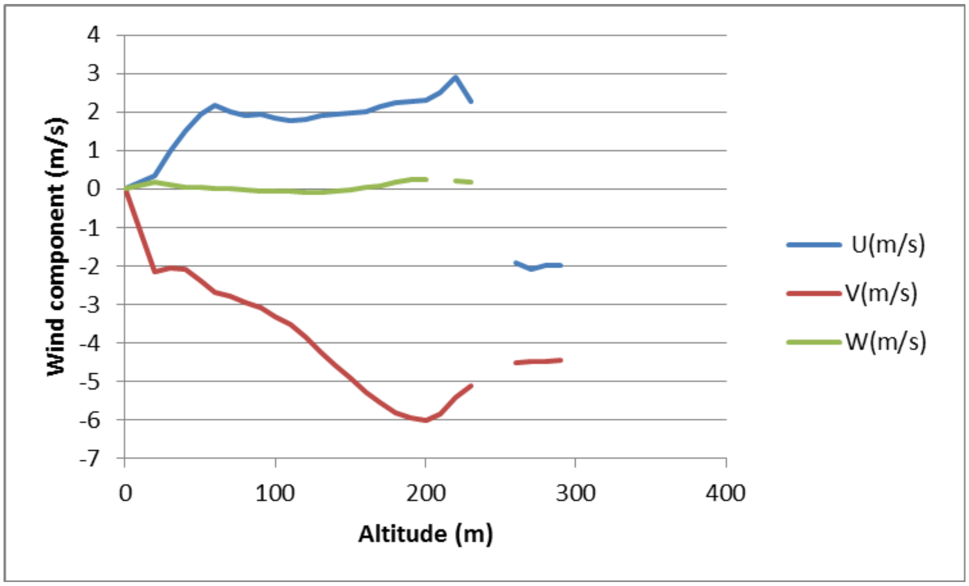


**Figure 7.** Sample wind profiles obtained with the Doppler sodar

The Ceilometer CL31 manufactured by Vaisala will be used to detect smoke plume rise and vertical profile. The quality assurance for the measurements is threefold. (1) Comparisons of atmospheric particles and clouds have been made by many other institutions. One comparison provided by Vaisala indicates a correlation coefficient of 0.83 between the particulate matter detection between CL31 Ceileometer and the ground measurement. (2) Comparisons with more sophisticated instruments like the Doppler sodar will be conducted during the experiment. (3) The following guidance and procedure will be used to assure normal operation of CL31 during the measurement: (i) At least two operators will be at the scene, (ii) arriving at least one day before the burn date to prepare for the measurements. (iii) CL31 will be placed at the best possible site for measurement, (iv) The instrument will be set up and shut down strictly following the steps showed in a note. (iv) The operation and data collection and storing of the instrument will be continuously monitored and changes will be made as needed. (vi) Finally, all data will be backed up before shutting down the instrument.

All ground-based instrumentation will undergo routine maintenance and calibration immediately prior to transport to the field. The Thermo 48i and 410i instruments for CO

* Dr. Craig Clements of San Jose State University is planning to bring a WLS70 Doppler Wind Lidar system to the Rx-CADRE burns.

and $CO_2$ measurement will be calibrated at Georgia Tech following the manufacturer's recommended procedures. These instruments as well as the TEOM will be operated for a period of three days in co-location with identical instruments in the ambient air quality laboratory in the Environmental Science & Technology Building at Georgia Tech. Following transport to the field, instrumental flow rates will be verified using a BIOS Definer dry calibrator. These instruments will be zeroed in the field, and in addition, the TEOM will be field checked using calibration weights on the microbalance. All handheld instruments will be zeroed, have their flow rates verified, and operated simultaneously at a co-location prior to burn ignition to verify agreement between instruments. The flow rates of all filter-based measurements will be verified at the beginning and end of each sampling period. A field blank will be produced for each filter sample, and in addition, multiple laboratory blanks will be produced for each filter preparation procedure.

All laboratory equipment involved in the analysis of filter samples will undergo recommended maintenance and calibration procedures. The environmental controls of the clean room facility at Georgia Tech will be verified during the 48-hour equilibration period and during gravimetric analysis of filter weights. Microbalance performance will be verified using standard weights. Each filter will be weighed three times with each measurement separated by at least twenty minutes. Performance of the TOT instrument for EC-OC analysis will be verified by applying known concentrations of sucrose to filter blanks. The TOC analyzer will be zeroed prior to use, and its performance will be verified by the injection of multiple calibration standards. Sample aqueous extracts for TOC analysis will be divided into two aliquots and analyzed separately. Similarly, ion chromatography analysis will be performed on two aliquots of each sample, and calibration curves will be generated using standard solutions that are analyzed on the same day as samples.

Prior to the onset of measurements, a Quality Assurance Project Plan (QAPP) will be written for the US EPA effort to ensure that planned measurements with the aerostat (both wind and smoke concentration) will meet the data quality objectives. This will ensure that the operation of the instruments, sampling procedures, analytical data, and calculations are consistent with level of quality necessary to meet the data quality objectives and intended use of the data.

# 5 Appendix: Fuel Characertistics, Loading and Fuel Consumption for the Rx-CADRE Fires — 2011

# Study Plan

## Fuel Characertistics, Loading and Fuel Consumption for the RxCADRE Fires—2011

**Jackson Guard**
**Eglin Air Force Base**
**Niceville, Florida**

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December 31, 2011

INTRODUCTION

The Fire Science Caucus is a self-directed team that meets periodically to discuss fire behavior research, knowledge gaps, and to outline a strategic direction for the continued advancement of fire science. The caucus demonstrated its capacity for collaborative research by pooling resources and combining efforts in a field campaign to advance fire behavior and fire effects model development and validation on 6 prescribed burns in southern pine fuelbed types in 2008. The project was called the Prescribed Fire Combustion and Atmospheric Research Experiment (Rx-CADRE)

Rx-CADRE field campaign phase II will be conducted in February, 2011 on three prescribed fires to be conducted in southern pine fuelbed types at Eglin Air Force Base, Niceville, Florida in February, 2011. The objectives will be to: (1) characterize fuels, fuel loading, and fuel consumption for participating scientists and for evaluating FCCS, Consume, and FOFEM ; (2) close the heat budget on prescribed burns of varying size by comparing multiple methods of heat release; (3) evaluate the effects of scale on remote sensing of the heat environment using a variety of manned and unmanned vehicles, 4) test and evaluate next generation models of fire behavior using coupled fire–atmospheric measurement; (5) assess the mechanisms of mortality of oaks and pines within the units, relating mortality to fine scale fuel structure and loading; and (6) provide demonstration and proof of concept for collaborative fire research and data sharing. Teams will collect data on pre-burn fuel characertistics including fuel loads, post-burn consumption, fuel moisture, ambient weather, *in situ* convective dynamics, plume dynamics, radiant heat release (both from *in situ* and remote sensors), *in situ* fire behavior, and selected fire effects. This study plan addresses the Rx-CADRE field campaign objective 1.

Information on the fuels and consumption of those fuels for each research prescribed fire are required if a relationship between fuels and consumption are to be related to fire behavior, fire effects including smoke emissions and tree mortality, and heat release. Therefore, fuelbed characteristics and fuel moisture content will be measured for each fuelbed component prior to each research burn. Fuels remaining for each fuelbed category following the fire will be measured to determined ful consumption. This data will provide fuelbed characteristics and consumption information for other science disciplines studying the burns as well as data to evaluate consumption modeling software such as Consume and FOFEM. This is one of 6 study plans that will be prepared for the upcoming RxCADRE collaborative prescribed fire research burn project.

## OBJECTIVES

The overall objective of this study is to measure the pre-fire loads, characteristics, and fuel moisture content of each fuelbed component before all RxCADRE research prescribed burns. Fuel consumption will be determined by measuring remaining fuels by fuelbed component. There are three questions to guide the research.

1. What are the fuel characteristics of loading, percent cover, depth, density, and other characteristics that are important for driving fuel consumption and heat release?

2. What are the fuel moisture contents prior to burning for each of the fuelbed components including tree needles and leaves, shrub leaves and stems, live and dead grass, downed woody material, litter, and duff?

3. How much fuel consumed in each fuelbed category during the fire?

The research proposed here will address these questions and provide RxCADRE scientists with the fuels information for evaluating heat release, fire behavior, emissions, and other fire effects. The data will also be used to evaluate fuel consumption models and will be available for entry into the national fuel consumption validation data set sponsored by the Joint Fire Science Program. Since limited funding is available, fuels data collection methods will be designed to efficiently collected data to maximize use by the majority of the scientists participating.

## STUDY AREA

The study area will be located on Eglin Air Force Base near Niceville, Florida. The units selected for burning will be 608A, 703C, and 907D. The selected sites will be top priority for burning in February, 2011.

## METHODS AND ANALYSIS

RxCADRE scientists agreed to concentrate monitoring on one to three 40 $m^2$ plots in each prescribed fire area that were established from a previous study. Since the 40 $m^2$ research plots are relatively small and a majority of the research will be concentrated within these plots, fuels will be measured destructively outside the 40 $m^2$ plot area and non-destructively measured or estimated at specific 4m x 5m plots within the 40 $m^2$ plot. Thirty-six destructively measured 1 $m^2$ plots will be located 10 meters from the research area, parallel to the boundary. Each plot will be 5 meters apart. The non-destructive plots will be located within the 40 $m^2$ plot. Figure 1 shows the fuels study plot layout.

**Destructive clipped plots**

Eighteen pre-fire plots will be measured for percent cover, height or depth of the grasses, shrubs, litter. In addition cones will be counted. All biomass will be clipped or gathered and sorted by litter (all undecomposed dead plant material including needles, leaves, etc.), duff (fermentation and humus layers, or F- and H-layers, respectively) and understory vegetation biomass including herbaceous vegetation (grass and herbs), woody vegetation (shrubs and maybe seedlings), palmetto, and small woody fuels (1-, 10, 100-hour size class). The material will be oven dried at 70C to determine mass. Day-of-burn 5 fuel moisture samples will be collected for shrub leaves, grasses, down woody material, litter, and duff. Fuels remaining in the 18 post-fire plots will be collected to determine fuel consumption.

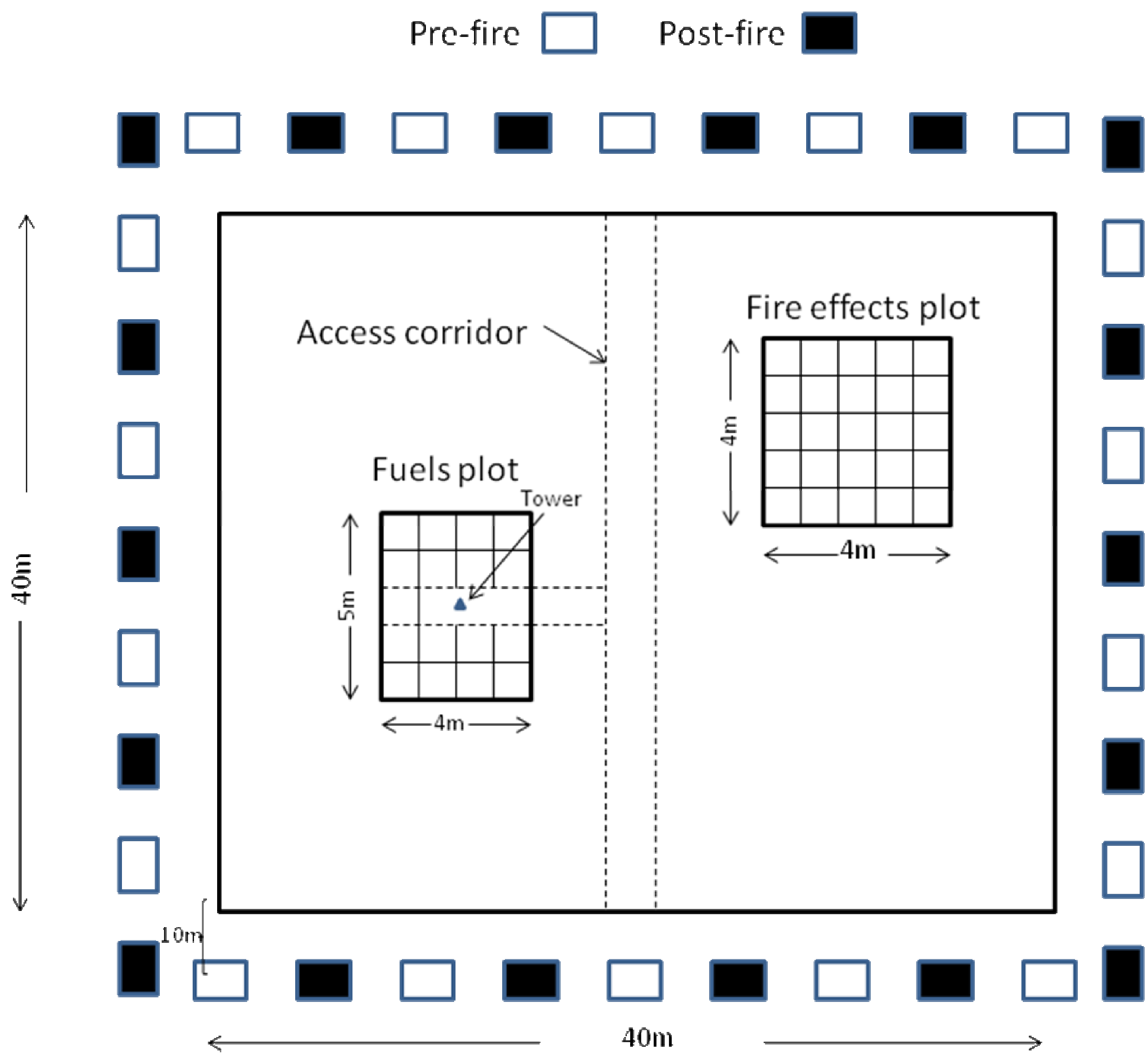


**Figure 1. Fuel plot.**

**Non-destructive plots**

A 4m x 5m non-destructive plot will be positioned in each 40 $m^2$ research plot area. In addition, up to 4 other areas within each prescribed fire research area will be assessed non-destructively for fuel characteristics. These sites will be co-located with sites instrumented with Dickinson towers.

Ocular estimations of percent cover and loading of the grass and shrub fuelbed categories will be made before the research burns based on clip plot results. In addition, measurements of litter depth and fine fuel and cone counts will be made. Following the research burns, four 1 $m^2$ clipped plots will be placed in each of the 4m x 5m plots and destructively sampled for remaining shrub, grass, woody, cones, and litter biomass. The destructive clipped plots and 4m x 5m plots will be used to determine fuel consumed by fuelbed category.

**Overstory Characterization**

The tree overstory has been measured at each of the 40 $m^2$ sample areas from a previous study, thus, no measurements of the tree strata will occur.

**Day-of-Burn Fuel Moistures**

Prior to each prescribed burn, three to ten fuel moisture samples will be collected representing each of the dominant litter and duff material types found at each unit. These will include longleaf pine, evergreen hardwood, loose hardwood, and sand pine. Each sample will be comprised of several handfuls of material from various points in a relatively small area or along a continual transect while moving through the unit. When taking duff samples, if there is a clear differentiation between the F- and H-layers, then the samples were collected separately. Moisture samples will also be collected for 10-hour, 100-hour, and 1000-hour diameter class woody fuels. Wet weights will be measured within 24 hours of sampling. Samples will be later dried for 48 hours at a minimum of 158º F and reweighed.

## DATA ANALYSIS

The data analysis will be restricted to descriptive statistics (generally, treatment averages, with the assumption the data fit a normal distribution) calculated for each of the research blocks and plots within the blocks.