

# Application of Ground-Based LIDAR for Fine-Scale Forest Fuel Modeling

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**Abstract**—Frequent (1 to 5 year) low intensity fire regimes of longleaf pine (*Pinus palustris*) savannas of the Southeastern United States create a continuous fuelbed of understory grasses, forbs, flammable pine needle litter, with interstitial hardwood shrubs. Measuring the spatial heterogeneity of these fine-fuels can be difficult, requiring intensive field sampling. Ground-based LIDAR (Light Detection and Ranging) may prove useful in this aspect, collecting accurate three-dimensional point-clouds of objects at the sub-centimeter level. Here we present the methods and discuss the applicability of using a ground-based LIDAR system, the Mobile Terrestrial Laser Scanner (MTLS), to measure variation in fuelbed structure. The MTLS consists of Optech's ILRIS 3<sub>6</sub>D ground based laser scanner mounted on a lift atop a mobile platform, which increases its versatility in capturing details about the terrain at multiple angles, vertically and horizontally. We recorded sub-meter, spatially explicit fuel characteristics using the MTLS and manual point-intercept sampling techniques in multiple plots within a longleaf pine woodland. The LIDAR data required additional processing to make it comparable to the field data. This process involved merging individual scans of a plot taken at different angles and cropping out the areas of interest from the point clouds. Preliminary results illustrate that the fuelbeds can be classified into distinct categories with distinct characteristics, such as bulk density. The MTLS may be applicable for measuring spatially explicit plot-to-stand level fuel structure, continuity, and volume. Coupling MTLS derived fuel maps with fire behavior, through thermal imagery and modeling, combine to produce a promising strategy to connect fuels and fire at much finer scales than attempted before. This approach is particularly well suited to pine savannas with high frequency, low intensity fire regimes and other fuel types with fuel heights <10 m.

## Objectives

Our purpose was to introduce a new approach to measuring fine-scale fuelbed structure in forested ecosystems. Our first objective was to provide a detailed background of the technology used; the Mobile Terrestrial Laser Scanner (MTLS), a ground-based LIght Detection and Ranging (LIDAR) system. Our second objective was to present the field data collection procedures and beginning stages of the data processing methodology. Our third objective was to provide a brief discussion of the possible applicability of the MTLS in forest fuel, fire behavior, and fire effects modeling.

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## Introduction

The frequent (1 to 5 year) low intensity fire regimes of longleaf pine (*Pinus palustris*) savannas of the Southeastern United States create a relatively continuous fuelbed of understory grasses, forbs, flammable pine needle litter, with scattered hardwood shrubs. Although this understory fuelbed is often considered homogenous within a stand, considerable heterogeneity exists at fine spatial scales (sub-meter; see table 1). Understanding the variation in these fine fuels is important for linking fuel, fire behavior, and fire effects modeling. Capturing the heterogeneity in fine-fuels can be difficult, requiring intensive field sampling. A LIDAR (LIght Detection and Ranging) system with three-dimensional (3D) capabilities and high accuracy information may provide critical spatial information needed to assess these fuel characteristics.

**Table 1**—Results from cluster analysis identifying discrete categories of 'fuel cells' at sub-meter scales. Heights are in centimeters.

Cluster no.	% of fuelbed	Mean fuelbed height	Mean litter height	Description of fuel cells
2	40	20	11	Wiregrass with perched pine litter
4	25	52	10	Shrub, wiregrass, and perched litter
3	13	11	6	Pine litter in interstitial space between wiregrass
5	10	29	5	Shrubs with oak litter
8	6	53	25	Other graminoids with perched pine
1	5	4	3	Oak and pine litter on mineral soil

Airborne LIDAR has been used extensively for measuring multidimensional forest metrics, namely tree canopy height, canopy density, tree volume/biomass (Hall and others 2005; Lefsky and others 1999; Nelson and others 1988) as well as understanding the spatial structure of a forest (Drake and Weishampel 2000) over large landscapes. Airborne LIDAR has not, however, been able to measure forest metrics related to understory vegetation at the sub-meter scale. Ground-based LIDAR could be used as a potential tool to address this problem.

Ground-based LIDAR is a new tool that brings the elements of airborne LIDAR to a finer-scale, collecting 3D point-clouds of objects at the sub-centimeter level. A complete description on the technology can be found in Lichti and others (2002) and Fröhlich and Mettenleiter (2004). In this study, we present the methods and discuss the applicability of using a ground-based LIDAR system, the Mobile Terrestrial Laser Scanner (MTLS), for measuring small-scale spatial variation in fuelbed structure. The MTLS consists of Optech's ILRIS 3<sub>6</sub>D (Intelligent Laser Ranging and Imaging System) ground based laser scanner that is mounted on a lift atop a mobile platform (fig. 1), increasing its versatility in capturing details about the terrain at multiple angles. The ILRIS uses a 1,500 nm wavelength laser with a pulse frequency of 2,500 points per second, recording first or last returns of each laser pulse (user defined). The field of view is 40° in both horizontal as well as vertical plane. It has a range of 5 m to 1,500 m (at 80 percent reflectivity). The ILRIS has a pan-tilt base providing it a 360° rotation in the horizontal plane and about ± 40° in the vertical plane. The lift makes possible the vertical



**Figure 1**—A ground-based LIDAR system: The MTLS (Mobile Terrestrial Laser Scanner) is used to mobilize Optech's ILRIS 3<sub>6</sub>D (yellow instrument) for collecting high-resolution 3D point-cloud laser data.

movement of the scanner up to a height of about 9 m. Mean point spacing of the laser data is user defined, typically ranging from 1 mm to a few cm. The ILRIS collects: (1) x, y, z values with respect to the position of the laser sensor; (2) intensity values of the return; (3) true color RGB values for each point obtained from an integrated and calibrated digital camera within the instrument.

The strength of the ground-based unit lies in its ability to produce accurate high-resolution data. This is not possible using airborne LIDAR, which covers large areas, while producing data at an average resolution of about 0.5 m horizontally. The MTLS, on the other hand, is a static, stop and scan laser scanner that covers limited area, but captures data at an average spot spacing at a sub-cm level. The MTLS, with its high-density point data, provides a useful tool for characterizing the fuelbed, particularly highly accurate fuel volumes.

As a newly developed instrument, there are few published examples of the application of ground-based LIDAR in forestry (but see Hopkinson and others 2004; Watt and Donoghue 2005). We know of no published work on the use of ground-based LIDAR to measure understory vegetation traits. This research provides a unique opportunity to develop an approach to accurately measure spatially explicit sub-meter vegetation characteristics.

## Study Areas

### *Ichauway Preserve*

A portion of the research was performed at Ichauway, an 11,000 ha reserve of the Jones Ecological Research Center in southwestern Georgia, USA. Ichauway is located within the Plains and Wiregrass Plains subsections of the Lower Coastal Plain and Flatwoods section (McNab and Avers 1994). Ichauway has an extensive tract of second-growth longleaf pine and has been managed with low intensity, dormant-season prescribed fires for at least 70 years, at a frequency of 1 to 3 years. The specific study site used had a 1 year rough.

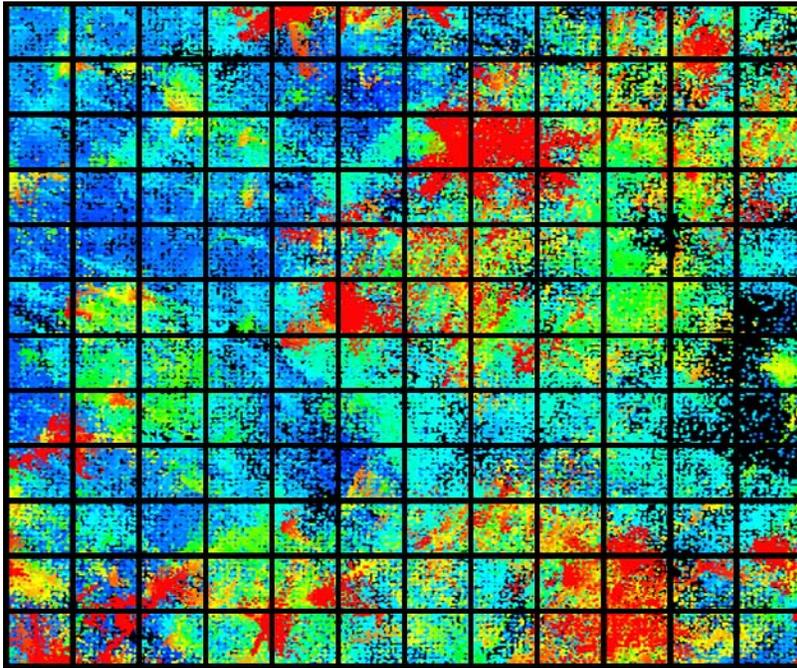
### *Ordway-Swisher Biological Station*

A portion of the research was also performed at the Ordway-Swisher Biological Station, a 3,800 ha reserve in north-central Florida, USA. It is managed by the University of Florida's Department of Wildlife Ecology and Conservation. Ordway has a large amount of second-growth longleaf pine as well and has been intensively managed for the past two decades with prescribed fire. The current fire frequency is 2 to 5 years, with some areas reaching more than 10 years. The specific study site used had a 2 year rough.

## Field and Ground-LIDAR Data Collection

In early spring 2007, a total of 30 georeferenced 4 m x 4 m plots were set up throughout the forest matrix with a goal to capture fine-scale (< m) variation in fuelbed characteristics in relation to overstory structure (that is, within forest gaps, along gap edges, and so forth). The 4 m x 4 m area was chosen because it was a large enough area to capture heterogeneity at sub-meter scales, but small enough to support intensive sampling with minimal impact to the vegetation. Spatially explicit point-intercept sampling data were recorded for each plot using a graduated dowel rod. We used 0.33 m spacing between traditional point-intercept samples, including sampling along the edge of the plot, totaling 169 sample points within each plot (fig. 2). A ladder was suspended horizontally across each plot using make-shift saw-horses at each end to sample the interior of the plot, taking care not to disturb the vegetation. The spatially explicit arrangement and sampling intensity were performed to capture the spatial variation of the fuelbed found within this small (16 m<sup>2</sup>) area and to relate to the cm-level 3D laser data collected from the ground-based LIDAR. At each sample point, fuelbed and litter depth (or height), as well as presence/absence of fuel and vegetation types, were recorded.

Within 2 weeks of field data collection, the MTLs collected ground-LIDAR data on all 30 plots. Prior to data collection, reference targets (consisting of a Styrofoam ball on top of a metal rod, fig. 3) were placed at all four corners of the plot. A double reference target (two Styrofoam balls on one metal rod) was used at the northwest corner of each plot to orient the plot for data processing. An additional one to four reference targets were placed just outside the 4 m plots to align lidar volume estimations with biomass clip plots. Biomass reference targets were placed in relatively homogeneous fuel types, with a circular area of 0.3 m<sup>2</sup>. The MTLs was restricted to mapped roads



**Figure 2**—Example of the spatial grid pattern of field data points and corresponding LIDAR heights (color gradients) within the 4 m x 4 m plot (2D aerial view). Point-intercept data on fuel traits were collected every 0.33 m (cross sections of the grid) throughout the plot.



**Figure 3**—Example of a 4 m x 4 m plot, with reference targets set up for ground-LIDAR acquisition and subsequent data processing.

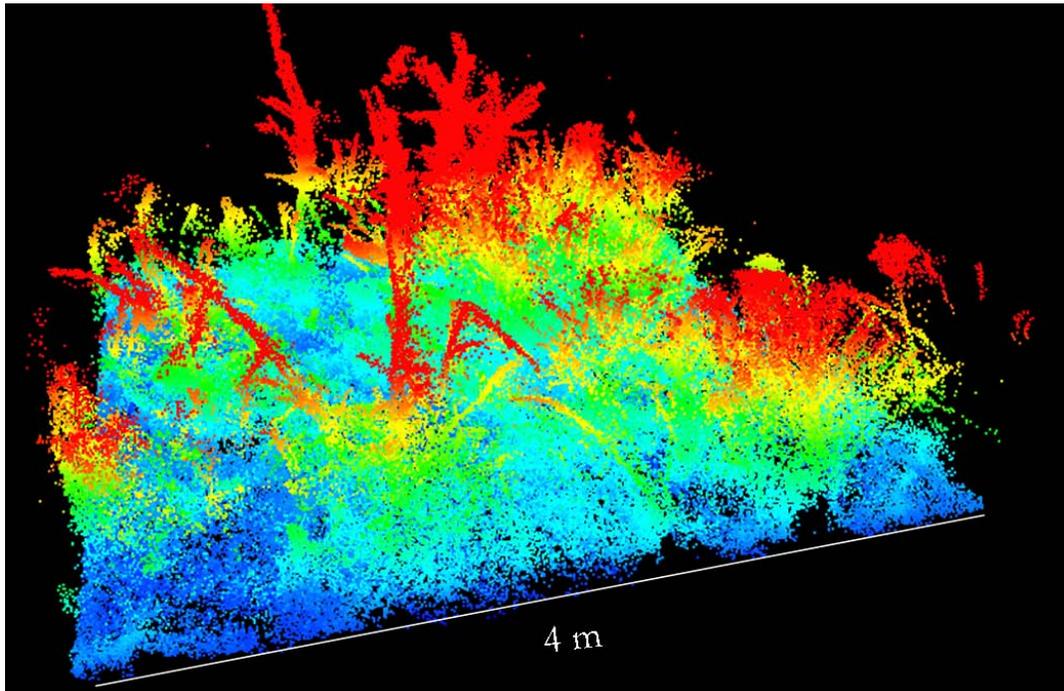
and trails, as well as a buffer of 6 to 10 m around each plot, to reduce site degradation and vegetation disturbance. The ILRIS was lifted to an appropriate height at each plot (6 to 7 m), with a goal to capture as much of an aerial view as possible, without bole or canopy obstruction. The ability to vary the height and angle of the ILRIS (hence, using the MTLs) allows significant reduction in shadowing effects within the fuelbed that may be found when using the ILRIS on a tripod. The ILRIS was set to a downward angle tilt of  $25^\circ$  (from horizontal). A true color digital photograph was taken by the ILRIS for each plot, and used in the field to delineate the focus area. This eliminates any unnecessary data collection, enhancing efficiency in the field and reducing file storage size. First-return laser pulses were recorded with 5 mm mean point spacing. One scan was taken on opposite sides of the plot to further reduce shadowing effects and ensure more accurate and complete sub-cm-scale data for both the 4 m and biomass plots. These two scans were merged in the processing stage to a single spatial coherent data set. Data collection with the MTLs took approximately 20 minutes per plot.

After laser data collection, the biomass plots were analyzed with traditional field methods. The biomass reference targets were used as the center of a 40 cm diameter circular area (area of  $0.3 \text{ m}^2$ ). First, 20 random point-intercept samples were taken throughout the plot. The same fuelbed traits were measured as described above. All vegetation was removed from the plot, separated into perched litter, fine fuels (grasses, forbs, ground litter), woody vegetation, pine cones, and other woody debris, and subsequently dry weighed.

## Data Processing

Initially, data processing involved converting the collected laser data from binary to ASCII format (that is, parsing). This raw data includes a four column text file containing x, y, z coordinates and laser return intensity values for each of the sampled laser points. Of the two scans taken per plot, the first was horizontally rectified by compensating for the original scanning geometry, where the instrument had a downward tilt of  $25^\circ$  with respect to horizontal. Then common points (reference targets) between the two scans were identified and their coordinates were used to compute the parameters of a 3D conformal transformation with a unit scale factor (Wolf and Ghilani 1997). The conformal transformation was then applied to the second scan to bring it to the same coordinate frame of the first scan, combining them into a single spatially coherent data set. The merged data set was then rotated about the z axis to orient the point cloud in cardinal space. A constant value offset was added to the height values in order to set the ground points to a value of zero. The digital image and the double reference target for the NW corner of the plot were especially helpful in this merging process and in orienting the plot in cardinal space. The 4 m x 4 m plot area (fig. 4) and biomass plot areas were clipped from the resulting merged scans using the reference targets. Roughly 600,000 to 700,000 sample laser points were found within each 4 m x 4 m plot. Point-densities, volume estimates, and height distributions were calculated for each biomass plot and each 4 m x 4 m plot.

Total volume ( $\text{cm}^3$ ) was calculated in each plot by determining the presence/absence of laser points within each  $\text{cm}^3$  space. The process involved using a 1  $\text{cm}^3$  3D window to move through each plot's point cloud in the x, y, and z direction, respectively. Every time a point (or points) was found in the 3D window, 1  $\text{cm}^3$  of volume was added to the volume counter for that plot.



**Figure 4**—Example output 3D ground-LIDAR point-cloud of a 4 m x 4 m plot. (This is not the same plot as fig. 3.) Color gradients represent fuelbed height variation.

## Applicability: Fuel Analysis and Modeling

We used cluster analysis to categorize variation across the fuelbed (table 1). These distinct clusters of fuels at these fine scales are termed ‘fuel cells.’ The distribution and arrangement of these fuel cells represent within-fuelbed variation, each with distinct bulk density, height, and composition. These categorized fuel cells may be used to classify the laser data into fuel types and then used to project fuel types across a similar dataset. Ultimately, these fuel cells may produce fine-scale burn heterogeneity, which may be important to managing prescribed fire effects.

With this new approach to measuring fine-scale fuels, future work will explore several aspects of fuelbed assessment that have been difficult to measure and understand thus far. We plan to use geostatistical techniques (for example, variogram analysis, model fitting, and so forth) to assess fuelbed variability across spatial scales, utilizing both the laser and field data. For instance, we can gain insight into how fuel depth varies with fuel type across the fuel bed. As fuel structure is apparent within the laser data outputs (fig. 4), it may be possible to run a pattern recognition analysis (with both field and laser data) to ultimately train the model to recognize certain fuel types across the fuelbed. With respect to fine-fuels, we are currently using ground-based LIDAR to accurately estimate fuel volumes, then relate this to field biomass, for more precise fuel volume measurements in bulk density calculations. We also hope to better understand bulk density estimates of particular fuels, such as common shrubs and grasses, utilizing the volumetric measurements ( $\text{cm}^3$ ) extracted from the laser data. For instance, the volume estimates can be segregated in particular horizontal plains of data (such as every 10 cm) within the understory or for just one plant and related to leaf

area. Such detailed information is critical for improving our understanding of the physical structure of fuelbeds that influence fire behavior, such as surface area to volume ratios, packing ratio, and fuel arrangement (such as horizontal continuity, patchiness). Furthermore, fine-scale variation in fuels, as measured by ground-based LIDAR, may provide insight to variation found within the plots that may be attributed to the forest structure (for example, forest gaps, edges), or spatial arrangement of the adult pines near the plot.

In a linked study, we are investigating how fine-scale variation in fuels may drive fire behavior and second order fire effects. We are using time-elapsd thermal imagery within these plots (as they burn) to assess fine-scale fire intensity, with a goal to relate the output thermal signatures to the fuel structure captured with both field and laser data. This imagery was recorded atop a custom telescoping lift above each plot. The results showed that fuel and fire behavior heterogeneity at this fine-scale varied together (spatial autocorrelation). Understanding fine-scale fuel heterogeneity and fire behavior will aid in better understanding the varying fire intensity effects on pine seedling and young oak demographics, which have been complex and difficult to study (Rebertus and others 1989).

## Conclusions

Here, we introduce a novel approach to assessing fine-scale fuels and a preliminary description and assessment of some of the data collected and possible research applications. As this research progresses, we hope to learn more about the complexities of the fuelbed and its influence on fire behavior and secondary fire effects.

The variation in longleaf pine fuelbeds captured using this new technique is complex in physical structure. These structures (within fuelbed heterogeneity) may affect fine-scale fire behavior and subsequent plant response, especially related to pine seedling and young oak interactions. Ground-based LIDAR is a new tool that may be used to measure and analyze these vegetative features at multiple spatial scales and more accurately quantify important fuelbed properties, such as bulk density, packing ratios, and continuity.

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