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AIRBORNE LASER MEASUREMENTS OF FOREST AND RANGE CANOPIES

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ABSTRACT

Quantification of vegetation patterns and properties is needed to determine their role on the landscape and to develop management plans to conserve our natural resources. Vegetation patterns can be mapped from the ground or by using aerial photography or satellite imagery. However, quantifying the physical properties of vegetation patterns with conventional ground-based or remote sensing technology is difficult, time consuming, and often expensive. Digital data from an airborne laser altimeter offer an alternative method to quantify vegetation properties and patterns. In forest areas, canopy structure was measured. Within even-aged pine forests, canopy heights varied from 2 to 6 m. Maximum canopy heights measured with the laser altimeter were significantly correlated to measurements made with ground-based methods. Canopy shape was used to distinguish deciduous and evergreen trees. Vegetation heights, spatial patterns, and canopy cover were measured in rangeland areas with the laser altimeter. Laser-measured canopy properties were significantly related with field measurements made in forest and rangeland areas. These studies demonstrate the potential of airborne laser data to measure canopy patterns and properties for large areas quickly and quantitatively. A rapid method of determining canopy characteristics will provide data on vegetation dynamics and productivity in forest and range areas and can be used for making decisions related to managing our natural resources.
KEYWORDS: laser, remote sensing, forest canopy, topography

INTRODUCTION

Complex patterns of vegetation cover the land surface (Forman and Godron, 1986). Vegetation patterns and associated canopy structure influence the functions of landscape elements. The properties of vegetation and canopy must be quantified in order to understand the roles in the different landscape elements and before management plans can be developed to conserve our natural resources. Vegetation patterns can be mapped from the ground or by using aerial photography or satellite imagery. However, determining the physical properties of canopy architecture and structure (i.e. height, roughness, volume) with conventional ground-based or remote sensing technology is difficult, labor intensive, expensive, and usually very limited for assessing large scale or landscape characteristics. This paper discusses the application of airborne laser altimeter data for nondestructive measurements of canopy structure, properties, and patterns for large areas.

Laser technology is used widely to measure distance. When this technology is adapted for aerial surveys (Jepsky, 1986), rapid and accurate assessment of vertical properties of land surface features can be made. Airborne laser altimeters have been used for mapping sea ice roughness (Ketchum, 1971), topography (Krabill et al., 1984), vegetation characteristics (Schreier et al., 1985; Nelson et al., 1988; Ritchie et al., 1992), water depths (Penny et al., 1989), and gullies (Ritchie and Jackson, 1989). This paper shows the potential of using airborne laser data for providing data for quantifying the properties of the canopy of forest and range vegetation.

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METHODS AND MATERIALS

A laser altimeter mounted in a twin engine airplane was used to measure the vertical features of the landscape surface as defined by any object (i.e., soil, rock, vegetation, man-made structure) reflecting the laser pulse (Ritchie and Jackson, 1989). Altitude of the airplane was between 100 to 300 m and speeds were from 50 to 100 m per second. The laser is a pulsed gallium-arsenide diode laser, transmitting and receiving 4000 pulses per second at a wavelength of 904 nm. Under these operating conditions, the distance from the airplane to the landscape surface is measured at 0.0125 to 0.025 m intervals along the flight path. The timing mechanism in the laser receiver allows a vertical recording accuracy of 0.05 m for a single measurement. Under controlled laboratory conditions, the standard deviation of the laser measurements of a stationary object is between 0.10 and 0.11 m. This standard deviation under controlled laboratory conditions is constant for distances between 50 and 300 m.

Digital data from the laser receiver are recorded with a computer. The gated receiver allows either the first or last return pulse of the laser wave to be recorded. In these studies the first pulse was recorded on a fixed disk along with data from a gyroscope and an accelerometer mounted on the laser platform. The data from the gyroscope and accelerometer are used to correct the laser data for aircraft motion. A video camera, borehole-sighted with the laser, records a visual image of the flight path. Video frames are recorded 60 times per second and each frame is annotated with consecutive numbers and clock time. The video frame number is also recorded simultaneously with the digital laser data to allow precise location of the laser data with the video image.

Landscape surface elevation is calculated for each laser measurement based on known elevations along the flight path. The minimum elevations (maximum laser distance) along a laser flight path are assumed to be ground surface elevation with laser measurements less than this maximum being due to vegetation or man-made structures. In areas of vegetation, the maximum values (ground surface) were determined by calculating a moving maximum elevation for 50 laser measurements. Some manual editing of these maximum elevations is required in areas of dense vegetation cover. Vegetation heights were calculated as the difference between the calculated ground surface and the actual laser measurement.

STUDY AREAS

Landscape surfaces were measured at sites in Mississippi and Arizona. The Mississippi State University School Forest south of Starkville, Mississippi was used to study forest vegetation. The forest is predominately pine (*Pinus spp.*) and is a combination of pine plantations and natural pine stands with some hardwood trees. Thirty-three permanent plots in the forest are inventoried each year to monitor change and study inventory methods. The area is generally flat with elevation ranging from 90 to 120 m. Airborne laser measurements were made at this site in November 1991.

A second study site was located in the USDA-ARS Walnut Gulch Experimental Watershed near Tombstone, Arizona. The gently rolling topography ranges in elevation from 1225 to 1950 m with local relief of 17 to 25 m from ridge top to valley floor (Renard, 1970). This area is representative of the Chihuahuan desert shrub and semidesert grassland (Brown, 1982). Grass dominates the upper third of the watershed while low shrubby vegetation dominates the lower two-thirds of the watershed. Airborne laser measurements were made at this site in August 1991 (Ritchie and Weltz, 1992).

RESULTS AND DISCUSSION

The forest site in Mississippi varied from regeneration to mature natural pine forest intermixed with different aged pine stands and hardwood species. Figures 1, 2, and 3 are examples of laser measured transects of the forest. Figure 1 was extracted by block averaging 8 laser measurements into a single measurement used for these analyses. Figures 2 and 3 were extracted using a block average of 5 laser measurements. Block averaging reduces the volume of data needed for analyzing long transects. Earlier studies have shown that little information was lost by block averaging when making 4000 measurements per second (Ritchie and Jackson, 1989). Ground surface topography was estimated by connecting the minimum values shown in subfigure B (Ritchie et al., 1992). The canopy height was calculated as the difference between the estimated ground surface topography and the actual laser measurements and is shown in subfigure A. The forest shown in fig. 2 is located 2 km east of the site of fig. 1 and 80 m west of the site of fig. 3. These figures show a range

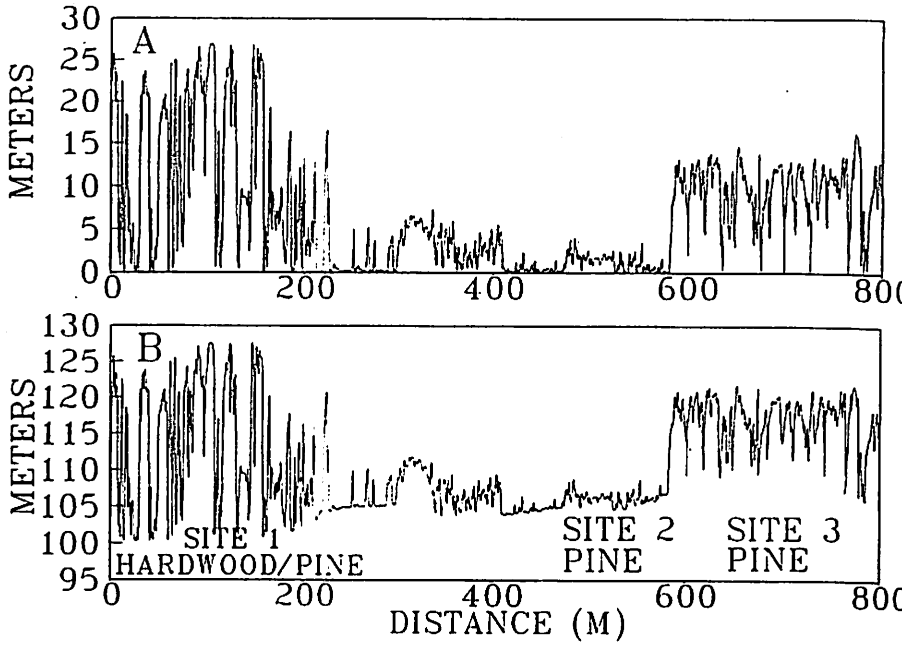

Figure 1. Laser measurements of canopy height (A) and ground topography and canopy structure (B), Starkville, MS.

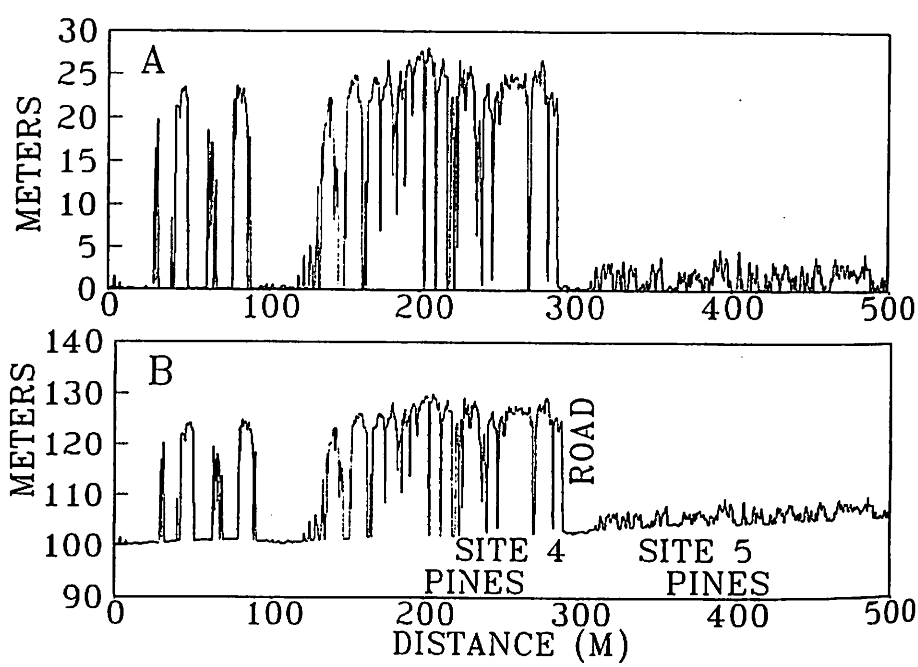

Figure 2. Laser measurements of canopy height (A) and ground topography and canopy structure (B), Starkville, MS.

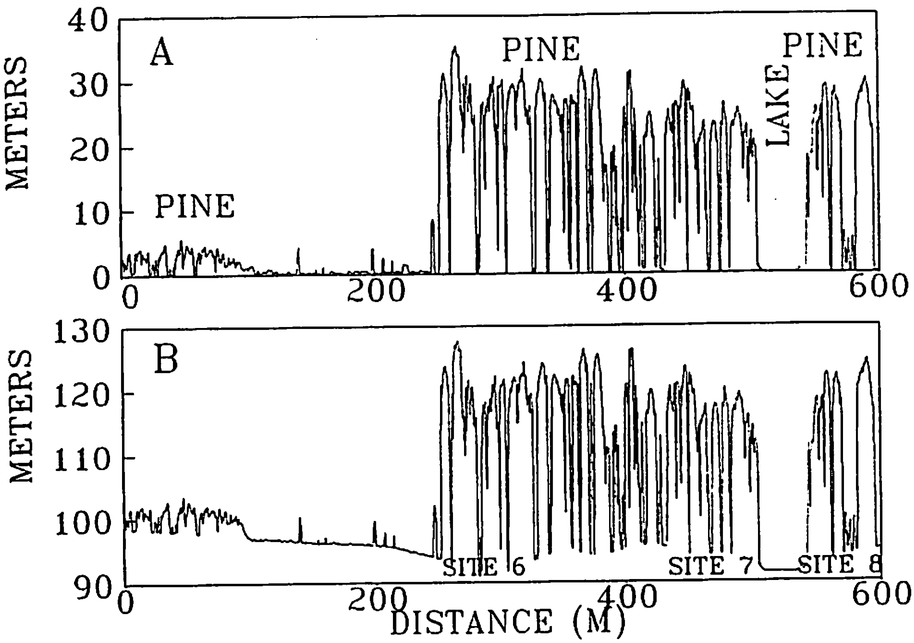

Figure 3. Laser measurements of canopy height (A) and ground topography and canopy structure (B), Starkville, MS.

of vegetation types in the study area.

Eight sites along this flight line were visited in April 1992 and the height of 10 upper canopy trees were measured at each site. The location of these eight sites are shown on figures 1-3. Site 1 was a mixed hardwood/pine stand located along a stream channel. Sites 2 and 5 were young pine stands (<10 yrs. old). Site 5 was commercially thinned. Sites 3 and 4 were older pine stands. Sites 6, 7, and 8 were in different locations in a natural pine forest with site 6 having the highest position, topographically, and sites 7 and 8 being located on each side of an arm of Dorman Lake.

The video imagery taken during the laser flights was used to locate and extract laser data for the 8 sites. Statistical data of laser measurements for vegetation heights for the 8 field sample sites are given in Table 1. This statistical data can be used to evaluate properties of the canopies at the different sites. The young pine stands (sites 2 and 5) were short as indicated by the low means, medians, and maximums of the height data. High coefficients of variation indicate an open canopy which allowed the laser to measure canopy top and ground often. This type of canopy would be expected in a young pine stand where the trees were too small to have a closed canopy.

Site 1 also had a high coefficient of variation. Combining the high coefficient of variation with the high maximum canopy heights (27 m) and mean height less than 50% of the maximum indicates a mature forest with a canopy that allowed significant laser penetration. A high canopy top with a significantly lower mean height occurs in a forest with gaps or in a forest without leaves to reflect the laser. Site 1 was predominately mixed hardwood with a few pine. The laser measurements were made in late November when leaves had fallen from the hardwood trees allowing the laser beam to penetrate the canopy to the ground.

Sites 3 and 4 had low coefficients of variation and means and median values that were at least 70% of the maximum values. Such measurements are associated with a with a canopy cover which reflected most of the laser pulses allowing few to penetrate into the canopy. Sites 3 and 4 were maturing pine stands with closed canopies with few gaps.

Table 1. Statistical data for the laser measurements of vegetation heights for the 8 field sample sites at the Starkville, Mississippi forest site. Comparison data are given for vegetation heights for the total area shown in Figures 1, 2, and 3.

SITE	N*	MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	MEDIAN	MAXIMUM
		--- meters ---		%	--- meters ---	
1	1534	12.51	9.77	78.15	11.59	27.39
2	669	1.42	1.04	73.40	1.48	4.63
3	471	10.03	3.32	33.09	10.86	14.49
4	941	20.63	7.69	37.28	23.50	28.12
5	637	1.29	1.19	92.58	1.00	4.19
6	997	23.91	9.86	41.25	27.01	35.55
7	267	17.27	9.63	55.74	22.62	27.32
8	510	18.15	11.32	62.38	24.21	29.63
Fig 1	6410	6.96	7.14	102.54	4.85	27.39
Fig 2	7580	7.82	10.27	131.24	1.73	28.12
Fig 3	7798	10.16	12.09	118.88	2.10	35.55

*N is the number of laser measurements analyzed.

Sites 6,7, and 8 were in a mature natural pine stand with a developing hardwood understory. The natural spacing of the trees, along with canopy damage, permitted gaps to occur in the canopy. The laser measurements for these sites had high maximums, medians, and coefficients of variation. The high maximums with corresponding high medians indicate a mature forest with a significant canopy cover as opposed to the hardwood site which had high maximums but low medians. The coefficient of variation indicates that a significant number of the laser pulses did penetrate the canopy indicating gaps in these canopies.

Some generalizations can be drawn from these laser measurements of vertical canopy structure. A high coefficient of variation (>70%) indicated an open canopy. A low coefficient of variation (<40%) indicated a relatively closed canopy. Indications of forest maturity, spacing, and gaps in the canopy could also be inferred by considering means, maximums, medians, and coefficients of variation. Research in other forest types will be required to generalize the interpretation of airborne laser measurements to other forest types.

A comparison of field measurements of tree heights with laser measurements is given in Table 2. Both the field and laser measurements are considered site attributes since no attempt was made to measure the same tree. Field measurements were made of trees that were in the upper canopy. Ten trees were measured at each of the eight sites. Since the field measurements were of upper canopy trees, the comparative laser measurements of tree heights were calculated as an average of only the highest 5% of the laser measurements of vegetation heights. A paired-T test indicated no significant difference ($p=0.01$) between field measurements and laser measurements of average tree heights for the 8 sites.

Table 2. Statistical data for field and laser measurements of tree heights at Starkville, MS.

SITE	FIELD DATA* MEAN	FIELD DATA* STANDARD DEVIATION	LASER DATA** MEAN	LASER DATA** STANDARD DEVIATION	LASER DATA** MAXIMUM
		------ meters -----			
1	27.01	2.14	26.88	0.19	27.39
2	3.54	0.31	3.83	0.37	4.63
3	15.24	0.75	14.13	0.22	14.49
4	28.13	1.05	27.56	0.40	28.12
5	5.52	0.46	3.41	0.25	4.19
6	31.15	1.40	34.72	0.49	35.55
7	27.31	1.51	26.24	0.63	27.32
8	28.77	1.49	29.37	0.17	29.63

* Average of 10 measurements
** Average of the highest 5% of the laser measurements

An analysis using the highest 10% of the laser measurements gave similar results. However, when the highest 15% of the laser measurements were used, a paired-T test showed the laser and field measurements to be significantly different (p=0.05). A plot of the data (Fig. 4A) shows the data to be closely clustered around the 1:1 line indicating that tree height can be estimated directly from the laser data. Since tree height is correlated to tree biomass and other properties, laser surveys of forest canopy should allow estimation of other forest properties. More studies are needed to generalize these findings since only limited field measurements (80 trees) were made during this study.

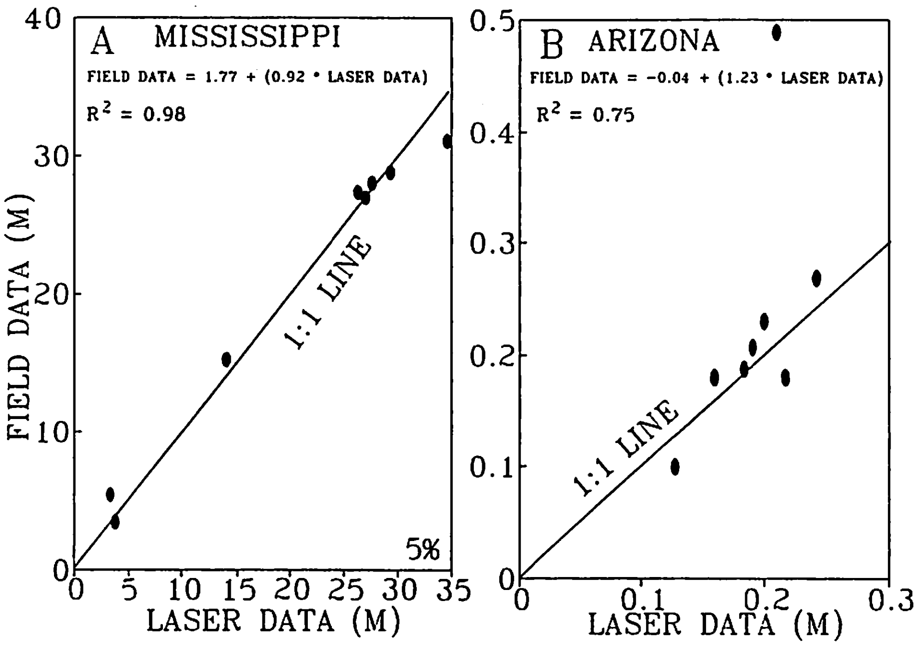

Figure 4. Relationship between laser and field measurements of canopy height at Starkville, Mississippi (A) and at Tombstone, Arizona (B).

A similar study was done on Walnut Gulch Experimental Watershed near Tombstone, Arizona (Fig. 5). The vegetation was shorter and canopy sparse. The 35 m transect shown in figure 5 is from 1 of 8 sites (site 7) on the watershed where extensive ground measurements were made using line transect methods on 30 m lines to determine vegetation properties (Ritchie and Weltz, 1992). The data shown represents one of four laser measurements made at site 7 for comparison with 3 ground measurements made at site 7. The laser profile shows the relatively sparse cover and low height of the vegetation.

A plot of the vegetation height data from the field and laser measurement (Fig. 4B) shows a cluster around a 1:1 line with one outlier. The outlier is probably due to the clumped nature of the vegetation at that site and the inability to locate the ground and laser measurements on the same transect (Weltz et al., 1993). At the other 7 sites, the vegetation was randomly spaced rather than clumped reducing the need for measuring vegetation on the same transects.

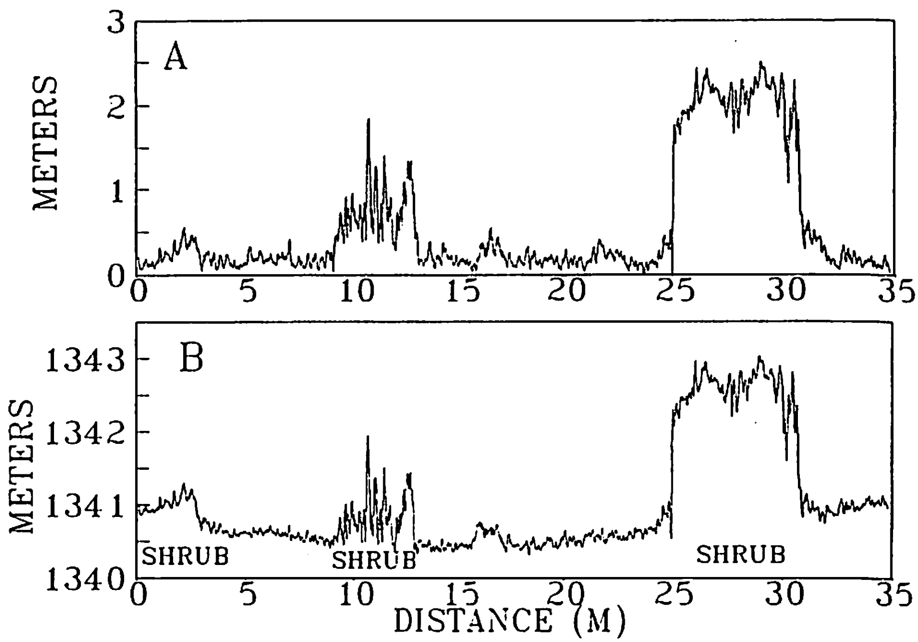

Figure 5. Laser measurements of canopy height (A) and ground topography and canopy structure (B), Tombstone, AZ.

Comparison of canopy cover measured for rangelands in Walnut Gulch Watershed and in the Rio Grande Valley in south Texas (Ritchie et al., 1992) showed a high correlation between cover measured on the ground using line transect techniques and cover estimated from airborne laser measurements.

CONCLUSION

Studies of forest and rangeland vegetation show the potential for using measurements from an airborne laser altimeter to measure vegetation canopy properties. Measurements of canopy heights made with the laser in the forest and rangeland were not significantly different from measurements made on the ground and were clumped around a 1:1 line indicating that the laser data could be used directly to estimate canopy height. Interpretation of the laser measurements allowed inferences to be made about spacing, type, and maturity of trees in the canopy. Percent canopy cover was estimated for rangeland areas. More research is needed, but this study indicated that airborne laser data does provide information about the properties of vegetation canopies on the landscape. Laser technology allows measurements to be made rapidly for large areas and for locations and conditions such as the top of a 30 m tall forest canopy or sparse rangeland or forest canopy conditions. Large scale measurements of canopy properties will assist understanding of the landscape functions and should provide data that will allow better management plans to be made to conserve and improve the productivity of our natural resources.

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