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AIRBORNE LASER TECHNOLOGY FOR MEASURING RANGELAND CONDITIONS

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Abstract

Land surface and vegetation properties are key for understanding range conditions. Ground-based measurements of these properties are difficult and time-consuming. Profiling and scanning airborne laser altimeter systems provide an alternative method to quickly and easily measure land surface and vegetation features and properties for large land areas. The agreement between airborne laser altimeter and field measurements is good for topographic features, vegetation properties (i.e., height, cover), and surface roughness. This paper presents examples of the applications of profiling and scanning airborne lasers as additional tools in the arsenal of remote sensing tools used to monitor rangeland conditions. Airborne laser measurements of plant canopy properties across the landscape and their effects on aerodynamic roughness allow better understanding of evaporative losses, infiltration, and surface water movement. Laser measurements improve our understanding of the effect of canopy and landscape roughness on rangeland conditions.

Introduction

Topography and land surface features (i.e., vegetation, surface roughness) influence the functions of natural and agricultural landscapes. Measurements of land surface shapes, patterns, and roughness provide data to understand these changes in space and time. Measuring these features and their spatial distribution using conventional ground-based technologies provides limited temporal and spatial data. Applying laser-distancing technology from airborne platforms provides rapid and accurate data of land surface topography, roughness features, and patterns. Airborne laser surveys have been used to measure vegetation properties (Schreier et al. 1985, Nelson 1997, Ritchie et al. 1992, 1993a), erosion features (Ritchie et al. 1993b), topography (Krabill et al. 1984), and aerodynamic roughness (Menenti and Ritchie 1994).

Profiling and scanning airborne laser altimeters have been used to measure land surface features and patterns over rangelands in the western United States (Table 1). This paper summarizes some applications of laser data for measuring features and patterns of the land surface and discusses these applications as a data source for understanding the interactions of land surface roughness, vegetation patterns, hydrological systems, and energy fluxes on rangeland.

Methods

Airborne laser data have been collected over a wide environmental gradient of the western United States (Table 1) by United States Department of Agriculture (USDA), Agriculture Research Service (ARS) Hydrology Laboratory in cooperation with ARS rangeland research locations and National Science Foundation (NSF) Long-term Ecological Research (LTER) research sites in the western United States. Data from profiling airborne laser systems were collected at all sites. Scanning laser data were collected at the Jornada Experimental Range.

The profiling laser altimeter is a pulsed gallium-arsenide diode laser operating at a frequency of 4Hz and a wavelength of 0.904 µm. Nominal altitude of the airplane is 200 m above ground level (AGL) and nominal ground speed is 75 m sec^{-1}. Under these operating conditions, a laser measurement occurs at intervals of 1.875 cm along the flight line. The field-of-view of the laser is 0.6 milliradians which gives a "footprint" on the ground that is approximately 0.06% of the altitude or approximately 12 cm for the nominal 200 m altitude used during these flights. The timing electronics of the laser receiver allow a vertical resolution of 0.05 m for a single measurement. Digital data from the laser receiver are recorded along with data from a gyroscope and an accelerometer mounted on the base of the laser platform. A video camera, borehole-sighted with the laser, records 60 video frames per second and each frame is annotated with consecutive numbers, GPS location and time. Each video frame number is recorded with the digital laser data to allow precise location of the laser data on the landscape with the video and the GPS data.

The scanning laser data were acquired by Airborne Remote Mapping, Inc.[1] for an area in the ARS Jornada Experimental Range. The laser was the Swedish Saab/TopEye system flown on a helicopter platform, using an across-track scanning system with a Z-shaped ground target path. The wavelength of the laser is 1.064 µm. The laser pulses have a frequency of 7 Hz. The maximum scan angle is 20°. The data were collected with X, Y and Z values with X and Y in the UTM reference system and Z as elevation with an average sampling interval of about 2 m between footprints in the across-track direction and about 1.5 m in the along-track direction. The footprint diameter was 0.38 m (Rango et al. 2000).

Results and Discussion

Landscape and vegetation patterns associated with a 100-m laser profile from near the summit of Reynolds Mountain in Reynolds Creek Watershed (N 43°15.6', W 116°45.1'), Boise, Idaho can be observed in Figure 1. Topography, roughness, and gaps between the vegetation elements are shown in Figure 1A. The elevation of the ground surface under the vegetation is estimated by assuming that minimum elevation measurements along the profile represent laser measurements that reached the ground surface. If the topography (oriented roughness) is removed

[1] Trade and Company names are included for the benefit of the reader and do not imply an endorsement of or a preference for the product listed by the U.S. Department of Agriculture.

by calculating the difference between the estimated ground surface and the actual laser measurements, vegetation heights and distribution and surface roughness can be calculated (Fig. 1B). These measurements can be used to estimate vegetation canopy height (Fig. 2). Most of the canopy heights (74.2%) in this profile are less than 0.5 m. Only 12.5% of the height measurements are greater than 1 m. This height data (Fig. 2) can also be used to calculate canopy cover. Using all data, the average vegetation height for this 100-m segment is 0.47 ± 0.73 m. Using measurements greater than 0.5 m, the average vegetation height is 1.77 ± 0.99 m.

Laser profile and ground data were collected from 5 different vegetation types in the Reynolds Creek Watershed. The vegetation sites were Mountain big sagebrush (*Artemisia tridentata* subsp. *vaseyana* [Rydb.] Beetle) (Fig. 1), low sagebrush (*Artemisia arbuscula* Nutt.), Wyoming big sagebrush (*Artemisia tridentata* subsp. *wyomingensis* Beetle & A. L. Young), bitterbush (*Purshia tridentata* [Pursh] DC.), and greasewood (*Sarcobatus vermiculatus* [Hook.] Torr.) (Table 2). The ground data are averages of six, 30-m transects along an approximate 1 km line, using the line intercept method. The laser data are averages of three 1-km transects over the same area. The difference in the average heights between the ground and laser measurement of the transects ranged from 2.0 to 8.7 cm with the laser measured heights always being lower (Fig. 3). There was no statistical difference between the ground and laser height measurements at the 5% level of probability.

Comparison of canopy cover measured by laser and ground techniques (Table 2 and Fig. 4) found the measurements to be significantly different. There was good agreement between the 2 techniques in the Bitterbrush (<4%) and Low sagebrush (<6%) communities. The greatest difference was at the Wyoming big sagebrush community where the laser measure of cover was twice that of the ground measurement. It is difficult to explain either good or bad comparisons. The ground data was an average for six, 30-m transects while the laser data was the average of three 1-km transect. The ground transects were selected to be along one of the laser transect and all 3 of the laser transects were along the same general flight line.

Studies in a South Texas (N 26° 11.5', W 97° 59.2') mesquite stand (Ritchie et al. 1992), a Mississippi (N 33° 15.6', W 88° 52.8') pine forest (Ritchie et al. 1993a), and a desert rangeland in the Walnut Gulch Experimental Watershed (N 31° 44.3', W 110° 01.4') in Arizona (Weltz et al. 1994) have shown that the laser altimeter measurements of vegetation heights and cover were highly correlated with ground measurements made with standard line transect techniques.

Large landscape features can also be quantified to estimate their effects on water flow and quality across the landscape. The valley and channel associated with Reynolds Creek near the outlet of Reynolds Creek Experimental Watershed (Fig. 5) were measured using two seconds of airborne laser data. The profile shows a 140-m cross-section of the valley with the channel with no water. The channel cross-section under the lower dashed line was calculated to be 48.94m^2. Other stages for water flow could be assumed (Fig. 5. upper dashed line) and their cross-sections measured to estimate channel/flood plain capacity. Channel/flood plain roughness can be measured to help calculate resistance to flow and potential flood area at different stages.

Cross-sections of channels and gullies have been measured at sites in Arizona, Oklahoma, and Mississippi (Ritchie et al. 1993b, Ritchie et al. 1995) and used to quantify gully, channel, and flood plain roughness and cross-sections for estimating flow rates. Data on gully, channel, and flood plain cross sections, roughness, and degradation provide valuable data for the design and development of physical structures to control flow, reduce bank erosion, and to calculate flows and extent of floods.

These examples show the application of laser altimeter data for measuring landscape patterns related to roughness and geometry of soil surfaces, gullies, and channels and their associated landscape at small scales. While there is need for data on changes in micro roughness of landscape features, there is also need for data on topography over distances from hundreds of meters to kilometers. An airborne laser altimeter can be used to measure longer topographic profiles quickly and efficiently. At an airplane ground speed of 75 m sec^{-1}, 4.5 km profiles are measured each minute (240,000 laser measurements) with the same detail as shown for short profiles. An example of a topographic profile of a coppice dune area (Fig. 6) at the ARS Jornada Experimental Range (N 32°35.4' W 106°50.6') near Las Cruces, New Mexico, USA is shown in Figure 7 using approximately 25 seconds of the laser altimeter data. Since the purpose was to measure macro topography rather than micro topography, block averaging 12 laser measurements were used, giving an effective laser measurement rate of 333 measurements per second resulting in a "footprint" size of 22.5 cm for this profile. The profile is from an area with mesquite shrubs on top of the dunes and almost no vegetation between the dunes (Ritchie et al. 1998). The insert in Figure 7 is the full resolution laser data (no averaging) showing 1 to 3 m tall dunes with vegetation on them.

The profile shown in Figure 7 illustrates the topographic data that can be collected with the laser profiler. While the length of the profile shown is 1.8 km, profiles can be measured and analyzed for any length. Greater spatial and vertical detail on such profiles can be measured by using smaller block averages or all data points (Fig. 7 Insert). Ease and speed of data collection allow measurement of several profiles over the same area with a minimum of extra survey cost. Such measurements of topography provide data for estimating aerodynamic roughness for understanding water and wind flow across the landscape (Menenti and Ritchie 1994, Menenti et al. 1996).

While profiling lasers provide two-dimensional cross-sections of topographic and vegetation features which allow quantification of the landscape morphology for calculating aerodynamic roughness length and displacement height (De Vries et al. 1997), scanning lasers can provide measurements of three-dimensional shapes and areal distributions of landscape features. Scanning laser data (Fig. 8) of shrub-coppice dune area (same area as Fig. 6) in the desert grasslands of Jornada Experimental Range in southern New Mexico measured the morphological characteristics (height, perimeter, distribution) with acceptable accuracy and precision for a range of uses, including hydrological, biophysical, and aerodynamic applications. Comparable ground-based measurements would be time-consuming if not impossible to collect. Scanning laser data used in conjunction with land cover classification from multispectral aerial videography or spectral scanners provide improved information on both the areal and the vertical variability of these dunes. The use of such systems together is highly synergistic (Rango et al. 2000) and provides data on the spatial distribution of the dunes that is necessary for understanding the patterns of dune development and movement.

Fractal analysis of 100,000 laser measurements (~2 km in distance) for 15 laser transects at the Reynolds Creek Experimental Watershed (3 transects for each of the 5 vegetation types in Table 2) was used to calculate the root-mean-square (RMS) roughness known to display fractal scaling along the cross-sections of self-affine surfaces (Pachepsky et al. 1997, Pachepsky and Ritchie 1998). Root-mean-square roughness is the RMS value of residuals of a linear trend fitted to the sampled points in an interval. The interval is called a 'window'. Construction of the fractal models for a line includes the (a) selection of a property to be calculated on different scales, (b) selection of a procedure to define ranges of scales within which the self-affinity exists, and (c) selection of a method to calculate fractal dimensions for each range of the self-affinity. To define ranges of scales over which self-affinity exists, the linearity measure introduced in fractal modeling by Yokoya et al.

(1989) was calculated.

Results of applying the linearity measure to separate different ranges of fractal scaling on roughness plots are shown in Figure 9. Each vegetation type had a unique fractal pattern. Fractal dimensions between 0.80 and 1.30 correspond to low irregularity. The Low sagebrush, the shortest community, had the lowest fractal dimension indicating a relative uniform ground pattern. The Greasewood and Wyoming Big sagebrush had the higher fractal dimensions indicating more irregularity and clumped patterns. These analyses indicate that separation of different vegetation types may be possible using fractal analysis of laser data.

Conclusions

Airborne laser altimetry can provide rapid quantification of landscape topography, gully and stream cross sections and roughness and vegetation canopy properties for large areas. Land surface roughness due to the physical and biological properties and features can be separated and quantified. These properties and features are integral parts of the landscape and have to be evaluated at large scales to understand the hydrology of natural and agricultural systems. Measurements of these micro and macro surface features contribute to quantification of water retention, infiltration, evaporation, and movement from landscape surfaces and in channels and across flood plains. Channel and gully development, degradation, and roughness can be measured and used to estimate soil loss and explain water quality and flow patterns. Measurements of canopy properties and distribution across the landscape and their effect on water movement and aerodynamic roughness allow better understanding of evaporative loss, infiltration, and surface water movement. Scaling properties of altimetry data provide compact indexes to compare and discriminate landscapes, as well as to summarize roughness properties for further applications. Airborne laser altimeters offer the potential to measure landscape properties over large areas quickly and easily. Such measurements will improve our understanding of the effects of these factors on hydrological systems of natural and agricultural landscapes so that improved management practices and structures can be developed to manage our natural resources better.

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Table 1. Locations of airborne laser altimetry studies by the ARS Hydrology Laboratory

Location	State	Cooperators
Rangelands in the Rio Grande Valley, South Texas	Texas	ARS Integrated Farming and Natural Resources Research Unit, Weslaco, Tex.
Walnut Gulch Experimental Watershed	Arizona	ARS Southwest Watershed Research Center, Tucson, Ariz.
Jornada Experimental Range	New Mexico	ARS Jornada Experimental Range, Las Cruces, NM **and** Jornada Long-term Ecological Research, New Mexico State University, Las Cruces, N.M.
Sevilleta National Wildlife Refugee	New Mexico	Sevilleta Long-term Ecological Research, University of New Mexico, Albuquerque, N.M.
Little Washita Experimental Watershed	Oklahoma	ARS Grazinglands Research Laboratory, El Reno, Okla
Central Plains Experimental Range	Colorado	ARS Rangeland Resources Research Unit, Ft. Collins Colo **and** Shortgrass Steppe Long-term Ecological Research, Colorado State University, Ft. Collins, Colo
High Plains Grasslands Research Station	Wyoming	ARS High Plains Grasslands Research Station, Cheyenne, Wyo
Reynolds Creek Experimental Watershed	Idaho	ARS Northwest Watershed Research Center, Boise, Ida

Table 2. Comparison of ground and laser profiler measurements of cover and height for five plant communities in the Reynolds Creek Watershed.

Site	Plant Name[1]	Plant Cover[2] Ground		Plant Cover[3] Laser	Plant Height[2] Ground	Plant Height[3] Laser
		%		%	cm	cm
Mountain Big Sagebrush	Total Vegetation		(86.3)	76.0[4]	37.5 ± 17.8	34.2 ± 18.4
	ARTRV	56.0		69.7[5]		
	SYOR	4.0				
	Forbs	20.3				
	Grass	6.0				
	Ground		13.7			
Low Sagebrush	Total Vegetation		(54.3)	60.4	19.7 ± 13.2	17.7 ± 15.2
	ARAR	38.0		49.7		
	Forbs - Other	4.3				
	Grass	12.0				
	Ground		45.7			
Wyoming Big Sagebrush	Total Vegetation		(32.3)	79.5	38.1 ± 21.1	32.1 ± 13.9
	ATTRW	23.5		74.0		
	SAVE	2.2				
	Forbs - other	3.9				
	Grass	2.7				
	Ground		67.7			
Bitterbrush	Total Vegetation		(75.9)	79.8	45.5 ± 30.1	36.8 ± 18.3
	ARTTW	25.0		74.4		
	PUTR	15.5				
	Forbs - other	14.2				
	Grass	21.2				
	Ground		24.1			
Greasewood	Total Vegetation		(51.5)	69.1	40.5 ± 22.3	32.35 ± 11.9
	SAVE	16.8		61.8		
	ARTRW	12.8				
	Forbs - other	14.4				
	Grass	7.5				
	Ground		48.5			

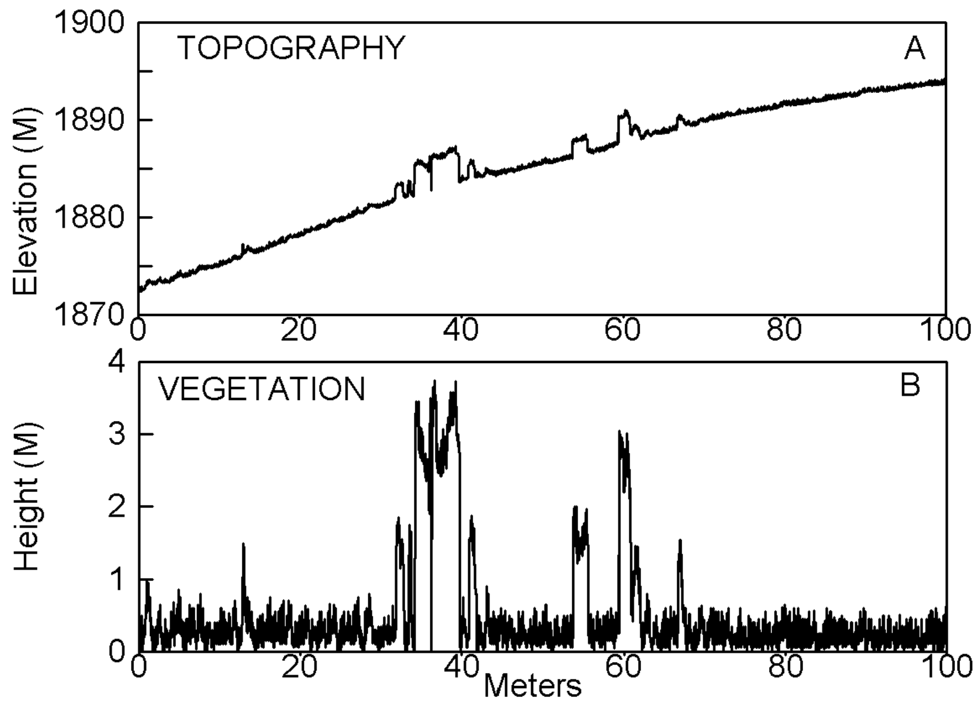
[1] Vegetation
ARTRV -Mountain Big Sagebrush - (*Artemisia tridentata* subsp. *vaseyana* [Rydb.] Beetle)
SYOR -Snow Berry - (*Symphoricarpos oreophilus* A. Gray)
ARAR -Low Sagebrush - (*Artemisia arbuscula* Nutt.)
ATTRW - Wyoming Big Sagebrush - (*Artemisia tridentata* subsp. *wyomingensis* Beetle & A. L. Young)
SAVE - Greasewood - (*Sarcobatus vermiculatus* [Hook.] Torr.)
PUTR - Bitterbrush - (*Purshia tridentata* [Pursh] DC.)

[2] Average of six, 30-m ground transects along an approximate 1-km line

[3] Average of three, 1-km laser transects over approximately the same line as the ground transects

[4] Percent cover for all laser measurements

[5] Percent cover for laser measurements greater than 15 cm above the ground surface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VEGETATION
B
Height (M)
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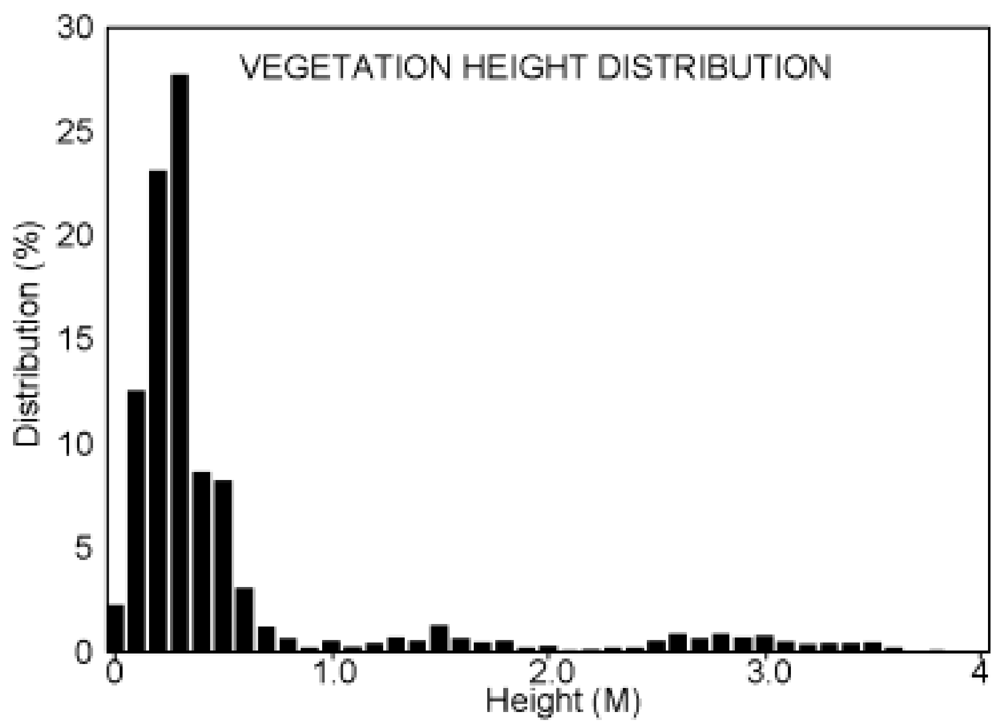
3
2
1
0
Meters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Distribution (%)
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5
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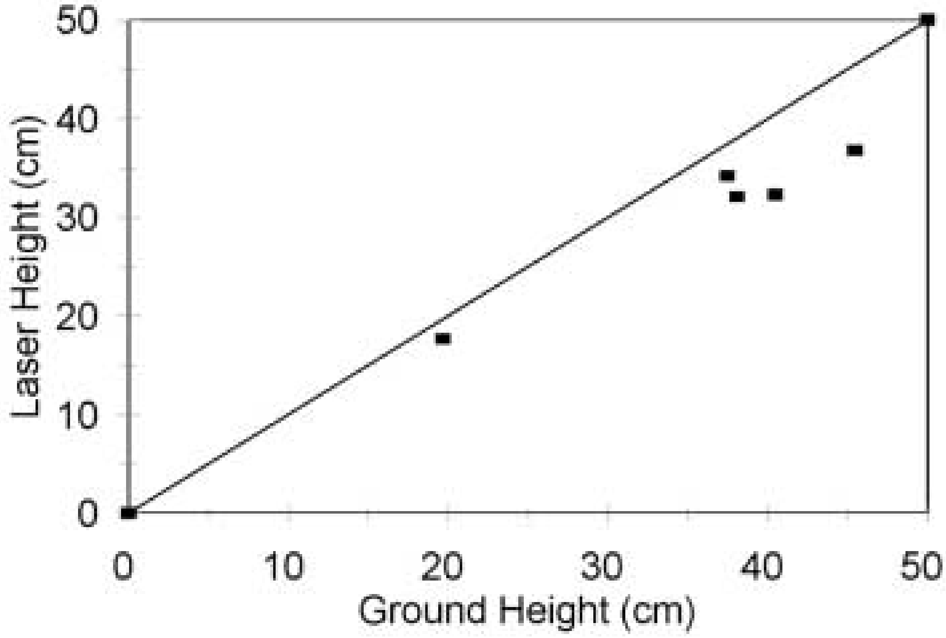
1.0
2.0
3.0
4
Height (M)



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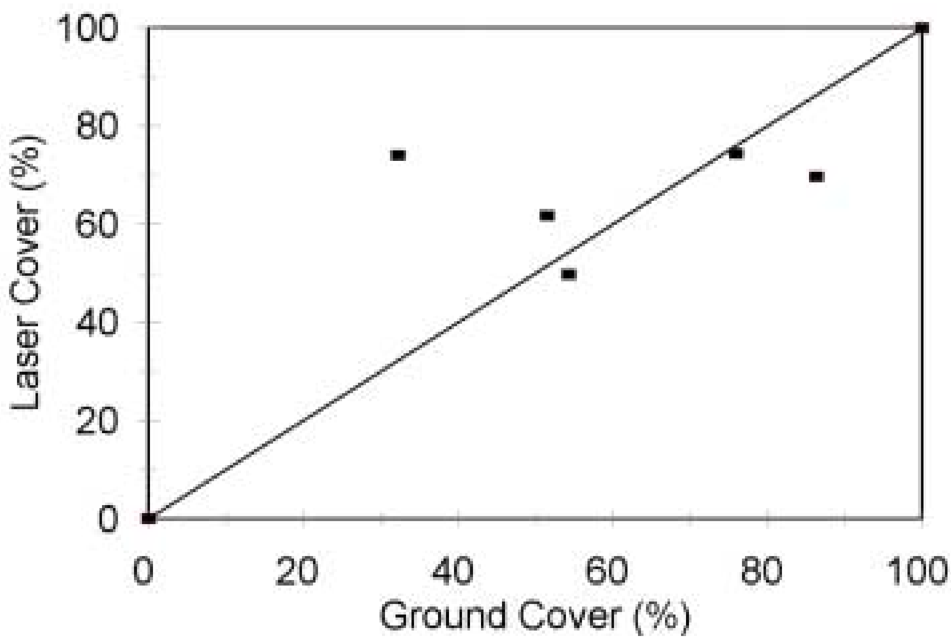
Laser Height (cm)
Ground Height (cm)



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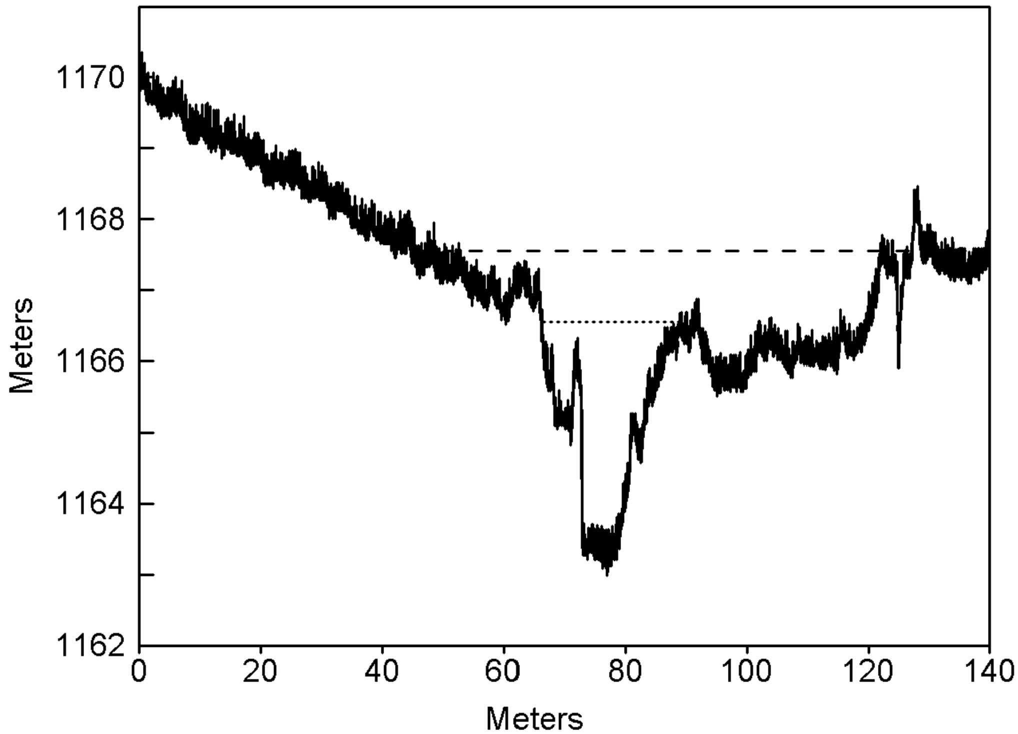
Laser Cover (%)
Ground Cover (%)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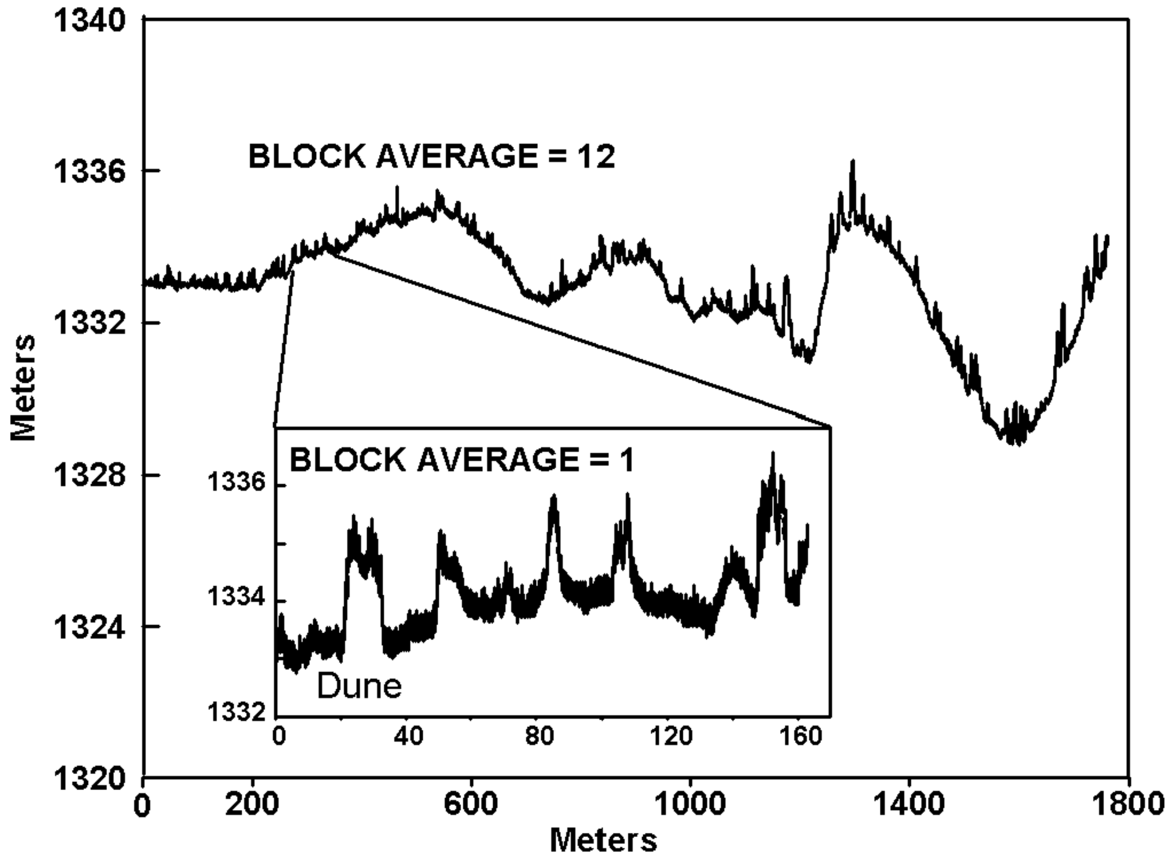

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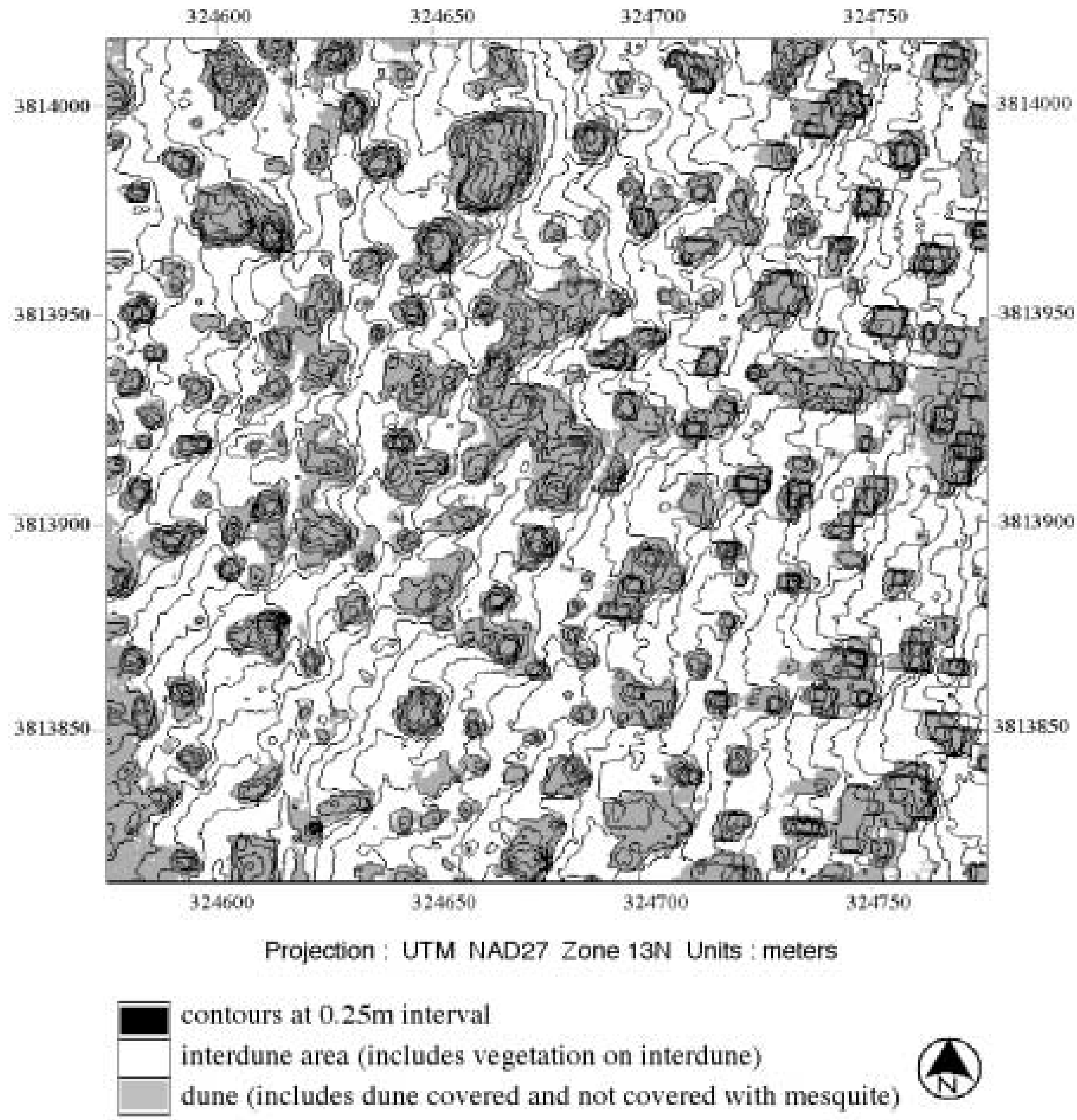
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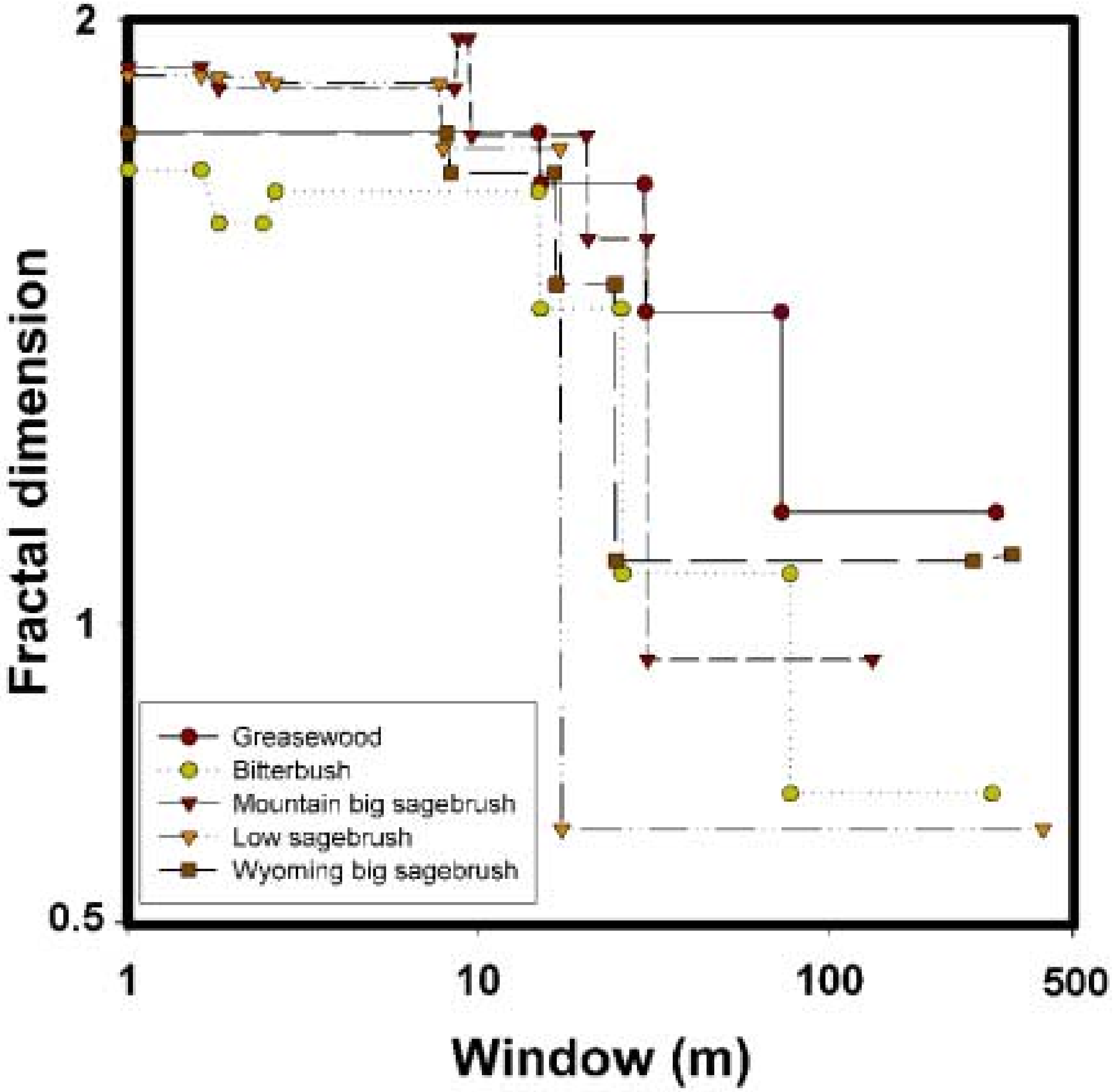
dune (includes dune covered and not covered with mesquite)
N



2
1
0.5
Fractal dimension
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10
100
500
Window (m)
Greasewood
Bitterbush
Mountain big sagebrush
Low sagebrush
Wyoming big sagebrush