Surface Fractal Characterization of Topography and Landcover Using Airborne Laser Swath Mapping

David R Streutker (stredavi@isu.edu) and Nancy F Glenn (glennanc@isu.edu), Department of Geosciences, Idaho State University
ISU Boise Center, 12301 W. Explorer Dr. Boise, ID 83713

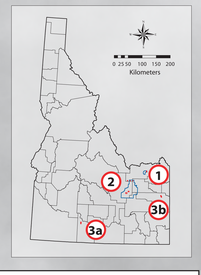
Abstract

High density, small-footprint Airborne Laser Swath Mapping (ALSM, also referred to as LiDAR) data are used to determine the surface fractal dimensionality of various types of topography and landcover throughout southern and eastern Idaho. Surface fractal mapping and classification are used to determine principal length scales found in different types of topography and vegetation. Knowledge of fractal dimensions can assist in determining sampling intervals, error statistics, and vegetation removal when creating digital terrain models (DTMs) or vegetation height maps. Terrain types investigated in this study include semi-arid rangelands, forests, riparian areas, canyons, landslides, and agricultural regions.

Data

LiDAR data were collected for eight locations throughout southern and eastern Idaho during the fall of 2002. Individual datasets were acquired for the U.S. Sheep Experiment Station (USSES, operated by the USDA Agricultural Research Service), a portion of Salmon Falls Creek, Swan Valley, in addition to five datasets in and around the Idaho National Engineering and Environmental Laboratory (INEEL, operated by DOE). The terrain of the INEEL and USSES areas consist primarily of gently rolling rangeland and sagebrush steppe, while the Salmon Falls Creek and Swan Valley areas feature wooded river valleys and canyons bordered by agricultural areas. The Salmon Falls Creek canyon also contains multiple landslides.

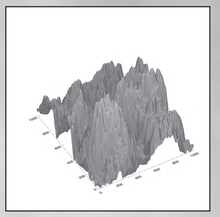
The LiDAR data are small-footprint (diameter of approximately 0.25 m) and irregularly spaced, with an average spacing of nearly 1 m. The individual datasets generally contain several million data points, each of which have both first and last return coordinates. The LiDAR data used for this study consist of the first return pulse data only.

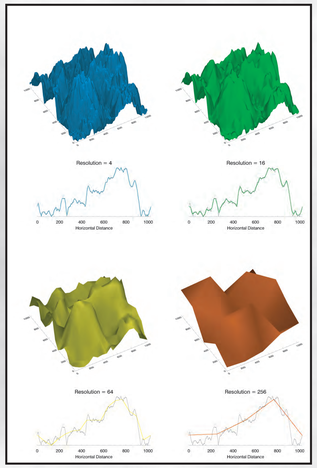


Fractal Dimension

Within traditional Euclidean geometry, spatial dimesions are assumed to be intergers: 0 for a point, 1 for a line, 2 for a plane, or 3 for a volume. In recent decades, however, mathematicians and scientists have begun using fractional, or *fractal,* dimensions to characterize natural phenomena. Topographic surfaces, for instance, are not perfectly planar and have a fractal dimension of between 2 and 3.

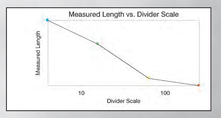
One of the simplest methods of determining the fractal dimension is the divider method. This method consists of measuring a length (such as a coastline) or a surface area (such as that of a mountain) using several different measurement resolutions or divider length scales.





Above is a synthetic elevation data set. At left is the same dataset represented at decreasing levels of resolution. Below each surface are two cross-sections: one at the original resolution and one at the corresponding lower resolution.

In order to determine the fractal dimension, the length or area is calculated for each of the varying resolutions. The resulting measurements are then plotted versus the resolution (divider scale) on a log-log graph. This is shown below:



In a log-log plot, the measured lengths versus divider scales fall along a line. The slope of this line determines the fractal dimension.

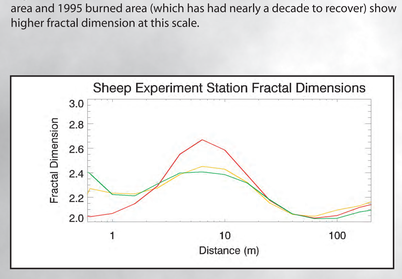
This method is also valid using surface area, as is used in this study. Triplets of LiDAR points are selected randomly, with each triplet forming a triangular plane. The surface area of the plane is calculated, along with the area of its footprint. The surface area is then plotted versus the footprint area, similar to the graph above. Iterating this process many times with many different LiDAR triplets populates the graph over a range of resolutions. The fractal dimension is then calculated from the slope as **D = 2 - b,** where b is the slope of the graph.

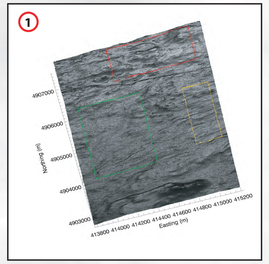
1 USSES

There are two burned areas within the USSES study area, the first of which burned in 1995 and the second in 2002. The region outlined in red on the map below lies within the 2002 burn, while the orange region is within the 1995 burn. The green region denotes an unburned area which is used to compare with the two burned regions.

The graph below shows the fractal dimensions of these three areas over a range of length scales. The highest fractal dimension occurs in the 2002 burned area at a scale of 8-10 m. This is likely due to the hilly terrain within the region. At higher length scales (greater than 50 m), all the regions are quite flat and have a correspondingly low fractal dimension.

What is noteworthy, however, is that the 2002 burned area has a much lower dimension at a length scale near 1 m, which may in fact be due to the lack of vegetation following the burn. (The dominant vegetation in the area is sagebrush, which has a characteristic size of approximately 1 m). The unburned area and 1995 burned area (which has had nearly a decade to recover) show higher fractal dimension at this scale.



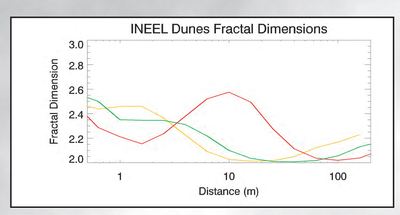


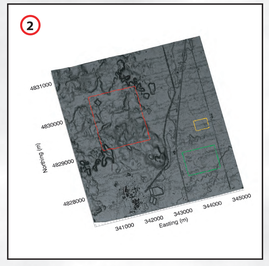
2 INEEL

As with the USSES, there are also two burned areas within the INEEL study area. The first of these burned in 1974, while the second burned in 2002. As above, the region outlined in red on the map below lies within the recent, 2000 burn, while the orange region is within the earlier, 1974 burn. Again, the green region denotes an unburned area which is used to compare with the burned regions.

The graph below shows the fractal dimensions of these three areas over a range of length scales. The highest fractal dimension occurs in the 2000 burned area at a scale of about 10 m. As with the USSES, this is likely due to the hilly terrain within the region.

Just as in the USSES case, the recent (2002) INEEL burned area has a much lower dimension at length scales below 2 m, which again may very well be due to the lack of vegetation following the burn. The unburned area and 1974 burned area (which has had 30 years to recover) show higher fractal dimension at these scales.

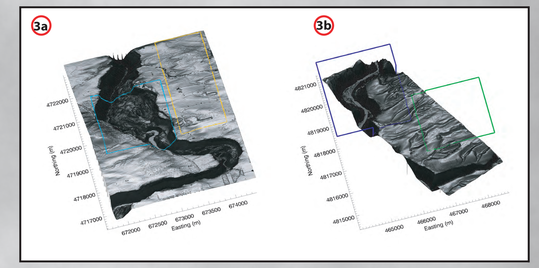




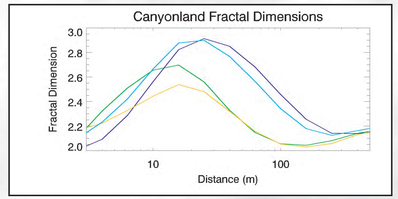
3 Canyonlands

The graph below shows the fractal dimensions of two canyons and two adjacent agricultural areas. The canyon areas are outlined in purple and blue in the two maps below, while the agricultural areas are outlined in orange and green.

As would be expected, the canyons show a very high fractal dimension, peaking at nearly 3 at length scales of 10-20 meters. At higher length scales, the fractal dimension drops to a much lower value. As can be seen in the surface images, the agricultural areas are very flat at a scale of 100-200 m, and have a correspondingly low fractal dimension.



It is also notable how similar the fractal dimensions of the two Swan Valley areas (purple and green) are to the two Salmon Falls Creek areas (blue and orange), even though the two regions are separated by several hundred kilometers. This appears to demonstrate the applicability of using fractal dimensions to characterize similar, though separate, types of topography.



Results

High resolution, small-footprint LiDAR is found to be useful in calculating the fractal dimensions of natural surfaces over a range of length scales. The dense spacing of the LiDAR data points allows for the fractal dimension to be calculated at length scales smaller than was previously feasible with existing topographic datasets, down to a meter or less.

The calculation of the fractal dimension at length scales representative of vegetation (a few meters or less) allows for the characterization of vegetation and canopy cover based on fractal dimension. Using this method in multiple regions in southern and eastern Idaho, it is shown to be possible to differentiate between burned and unburned areas in regions of sagebrush steppe. Further use of this method may allow for the mapping of disparate vegetation types by the calculation of fractal dimension over small areas.

Acknowledgements

The authors would also like to thank Steve Seefeldt of the U.S. Sheep Experiment Station and Ron Rope of the Idaho National Engineering and Environmental Laboratory for their contributions to this study.

This study was made possible by a grant from the National Aeronautics and Space Administration Goddard Space Flight Center. ISU would also like to acknowledge the Idaho Delegation for their assistance in obtaining this grant.