Final Report, Joint Fire Sciences Program Project No. 03-2-3-18

Title: Using Lidar to identify sediment and forest structure change in the Hayman burn, Colorado

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This report for JFSP Project 03-2-3-18 addresses findings of a research project testing the use of Lidar for change detection before and after the Hayman fire. The grant funds provided valuable support for examining Lidar technology as a tool for measuring bare earth and forest vertical characteristics, and for determining if quantification of vertical change in the soil surface and vegetation is possible using this technology, and if so, how effective this technology may be in future quantifications of vertical change of bare earth and vegetation.

The project abstract is reproduced here as an outline and summary of the work. Project background, objectives, and justification are appended at the end of the report.

Project Abstract: "Small-footprint multiple-return Lidar data collected in the Cheesman Lake property prior to the 2002 Hayman fire in Colorado provides an excellent opportunity to evaluate Lidar as a tool to predict and analyze fire effects on both soil erosion and overstory structure. Remeasuring this area and applying change detection techniques will allow analysis at a high resolution not possible before. Our primary objectives focus on the use of change detection techniques with pre-and post-fire small-footprint multiple-return Lidar data to: (1) evaluate the effectiveness of change detection to identify and quantify areas of erosion or deposition caused by post-fire rain events and rehab activities; (2) identify and quantify areas of biomass loss or forest structure change due to the Hayman fire; and (3) examine effects of pre-fire fuels and vegetation structure derived from Lidar data on patterns of burn severity. The proposed study will use existing Lidar and field data and post-fire Lidar data in the same area."

Project Accomplishments

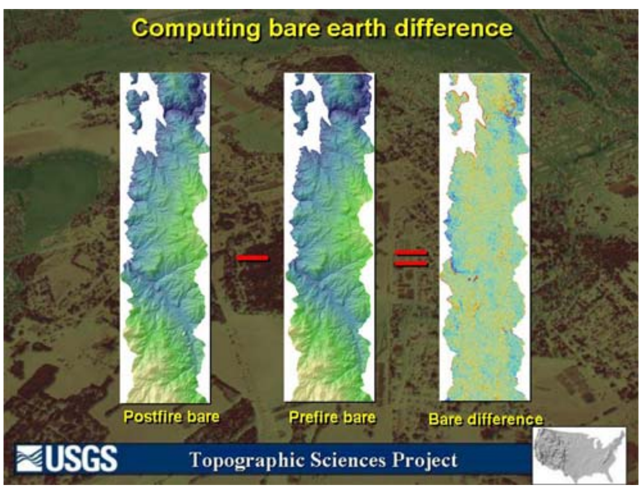
The goal of the project was to determine if small-footprint Light Detection and Ranging (Lidar) could be used in a change detection capacity to locate and quantify areas of significant topographic and vegetative change. In particular we were looking to quantify the amount of sediment that had been moved due to post-fire erosion, as well as quantifying amount of biomass burned up in the fire itself.

Change detection techniques have used traditional optical remote sensing, but very little research has been done to analyze vertical change using Lidar. We wanted to locate and quantify the areas of significant change between pre- and post-fire Hayman Lidar datasets. Because there is vertical error inherent in the Lidar system, we needed to make sure we were only detecting areas of significant topographic change. By 'significant topographic change', we mean areas where the vertical change was outside the range that could be caused just by sensor error alone. In our case significant change was that over 30 centimeters (15 cm vertical error pre and post data), because the vertical error quoted to us by the vendor was 15 cm RMSE.

To accomplish these tasks, we started with a Lidar dataset that was collected over the Cheesman Lake area before the Hayman fire for a separate research effort. We then wanted to fly a post-fire dataset over the same area after the fire, process both datasets to bare earth, 'difference' the two datasets, and use statistical analyses to locate the areas of significant elevational change. We then wanted to difference the first reflective surface (topmost portion of the canopy) from the bare earth to create a vegetation height model, and then apply this same kind of differencing to locate the trees whose foliage had been consumed in the fire.

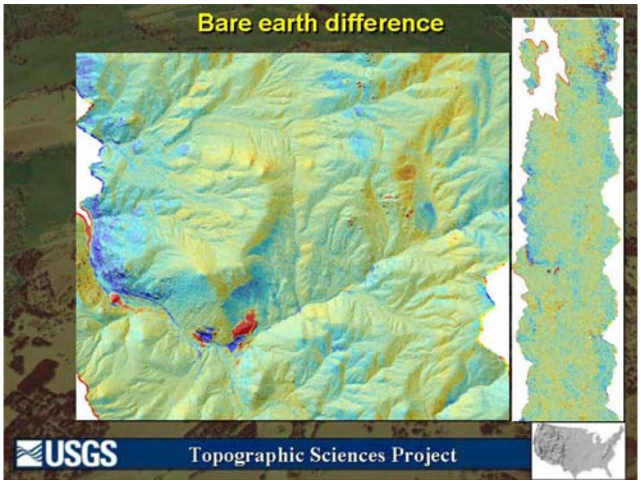
The pre-fire research dataset was collected using a custom system developed by EagleScan. EagleScan was bought by 3Di, which was then bought by Spectrum mapping. Our objective was to use the same sensor and resolution to minimize the variables that we would have to be aware of in creating our change detection project. Spectrum mapping could not get the original DATIS II sensor working properly, so they offered to collect new data using their own sensor, but as compensation they provided color digital photo imagery free of charge.

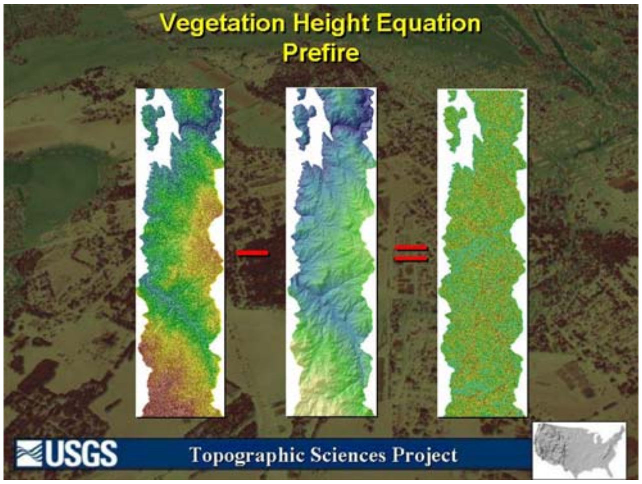
Geographic Analysis



The pre- and post-fire datasets were both processed using the same algorithm with the same variables in the same software. We used TerraScan to process the approximately 39 million Lidar points for each dataset. Computing bare earth difference was relatively straightforward once the datasets were co-registered and the post fire data was masked to have the same cell extent as the prefire. Simple map algebra allowed us to subtract the postfire from the prefire to create a bare earth difference grid. We subtracted postfire from prefire so that negative values depicted a loss, while positive values depicted a gain in elevation.

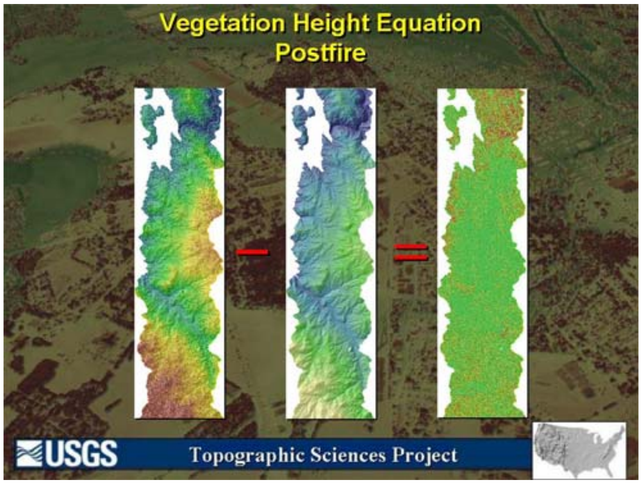
There are several obvious changes in the bare earth difference image (upper right illustration on next page), and some not so obvious. There are small boulders that were filtered out of prefire, but not the postfire dataset- hence the small red dots. There are some textural differences, but over the large area significant differences are visually apparent. Overlaying imagery on top of the bare earth difference grid showed us that our significant change is in fact real – man-made earth moving and a damming of the creek to trap sediment before it enters the reservoir. Sharp gullies can also be seen.

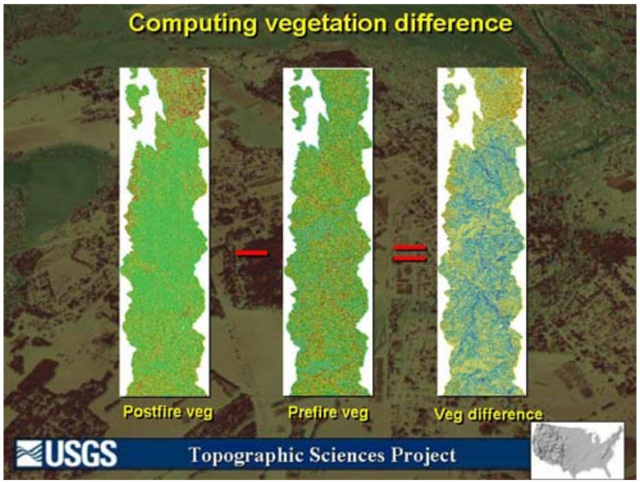




To compute vegetation height, we performed similar analyses (left). We created a surface of the first return, or the first reflective surface, which best models the top of the vegetative canopy. Subtracting the first reflective surface from the bare earth model gave tree heights as if on a flat surface, in essence the height of individual trees and shrubs.

We performed this for both the prefire and the postfire datasets. The postfire showed much less vertical vegetation within the burn footprint (right). Some of these trees, while showing up in the imagery, were actually dead but had enough needles at the time of the flight to return a high canopy height.





To calculate the vegetation lost, we simply subtracted the postfire veg height grid from the prefire veg height grid to show how much height was lost (left). The red color on the north side of the Platte (upper end of each insert) did not burn in the Hayman fire, and the apparent increase in height may have resulted from tree growth occurring between the two flights, though it could also be part of the error issues that we will now discuss.

Statistical analysis

One of the confounding factors in *quantifying* the amount of change results from the fact that the resolution error between the datasets is not a uniform 15 cm across the entire dataset. Errors increased due to confounding factors, particularly related to slope. The areas of high variance in the bare earth difference are also areas of high percent slope. This is where our original goals and our lessons learned diverge.

Elevation values of the pre- and post-fire bare earth models were compared with survey-grade ground truth points collected by Denver Water throughout the study area. A total of 23 points on slopes of 0-60 degrees were used to compare elevations to ground data.

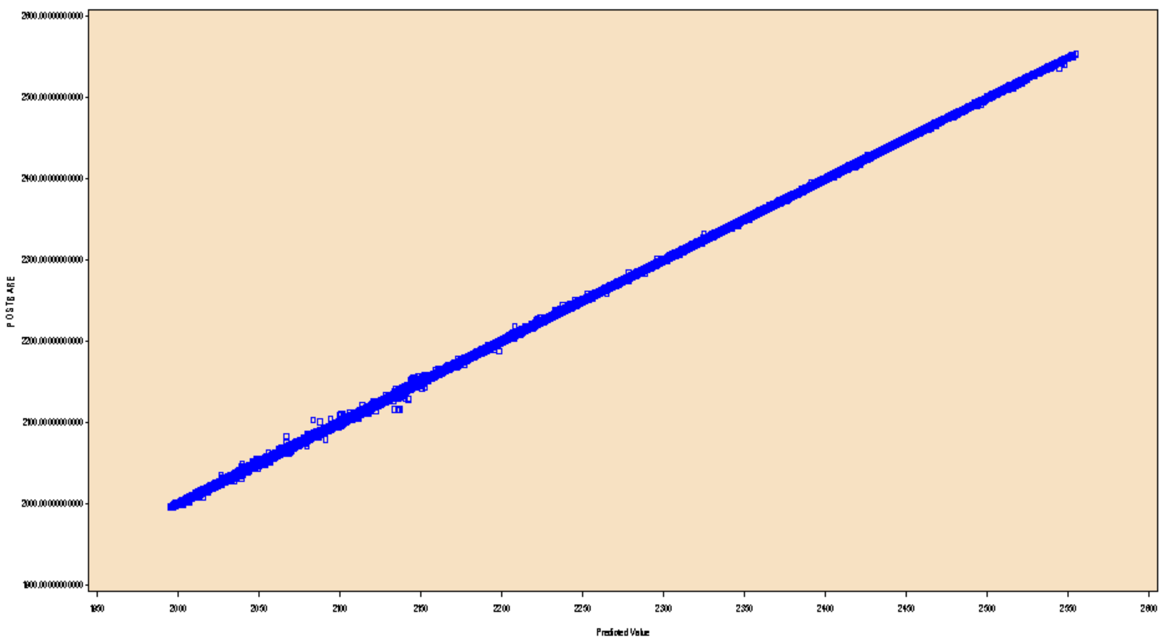
Variable	Mean	Std Dev	Std Error	Variance	N	Minimum
Post-Pre	0.8417391	1.5733105	0.3280579	2.4753059	23	-0.2600000
Post-Surv	0.5325900	0.8557210	0.1784302	0.7322585	23	-0.1799610
Prebare-Su	-0.3091493	1.4118907	0.2943996	1.9934352	23	-6.4301000

Variable	Maximum	Coeff of Variation	Skewness	Pr > |t|
Post-Pre	7.2600000	186.9118879	3.5760568	0.0176
Post-Surv	4.2199400	160.6716305	3.9326934	0.0068
Prebare-Su	1.2698900	-456.7019240	-3.9403291	0.3051

A random sample of 100,000 points was taken in the study area, for which prefire bare earth, postfire bare earth, prefire vegetation height, postfire vegetation height, slope, aspect, and pre and postfire intensity values were computed for each point. Over the entire dataset, the pre and post elevations showed a perfect relationship (top of next page) with a RMSE of 60 cm.

Source	DF	Squares	Square	F Value	Pr > F
Model	1	841707412	841707412	2.335E9	<.0001
Error	99043	35710	0.36055		
Corrected Total	99044	841743122			

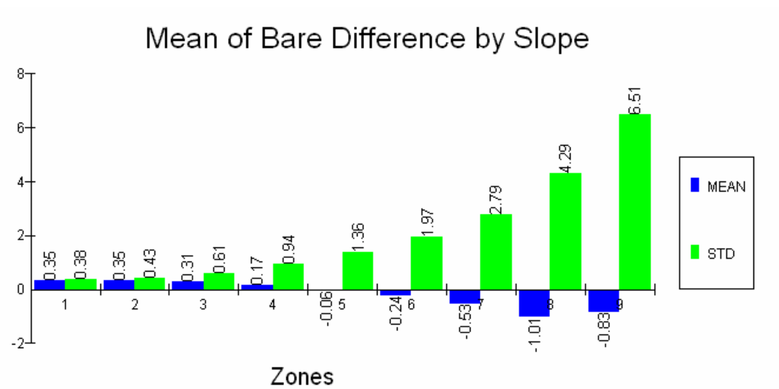
Root MSE	0.60046	R-Square	1.0000
Dependent Mean	2220.52296	Adj R-Sq	1.0000
Coeff Var	0.02704		



When we analyzed the bare earth elevation fit by slope class in 10-degree increments, the RMSE increased with slope.

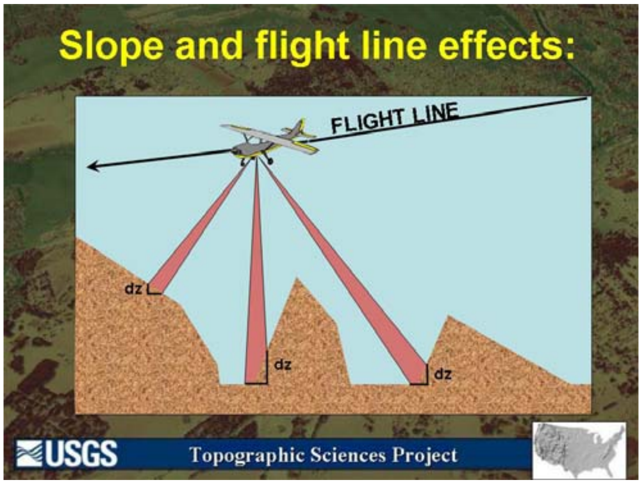
Slope Class	RMSE	R-Square
0-10	.36401	1.000
10-20	.42017	1.000
20-30	.60217	1.000
30-40	1.01404	.9999
40-50	1.38597	.9998
50-60	1.91867	.9997
60-70	2.70075	.9993
70-80	3.97229	.9984
80-90	10.04103	.9883

The slope effect influenced the errors in our datasets more than 15 cm each. This is because the vendor quotes 15 cm vertical error on flat surfaces, and does not incorporate slope into their accuracy assessment. We also did this assessment for aspect, but it was not significantly different.



Because of laser beam divergence – in our case the beam footprint on flat ground is about 0.5 m – the beam does not just hit a point on the ground, but rather a 3-

dimensional area. We usually represent such data as an xyz point with error 15cm, when in fact the error will increase based on two factors – the slope of the target, and the trajectory of the aircraft.



As the plane moves along the flight line, we noticed the vertical error changed. Even though we kept the angles of the beams constant, the varying slope and the movement of the aircraft cause the errors to be different across the board. Similarly, if we were to vary the flight line, the errors would be different as well. So, when attempting a change detection using two datasets with differing flight paths, we have extremely varying and unknown compounding errors. This is because differences in GPS geometries and IMU accuracies over multiple dates will affect the accuracy of the coordinates on the ground. This could help explain the positive difference in elevations between the postfire and surveyed points, and the negative difference in elevations between the prefire and surveyed points.

Conclusions and implications for management

Intuitively, one would believe that computing topographic change detection using high-resolution Lidar data would be straightforward, and in essence it is. But serious difficulties emerge when a point on the ground is measured twice from different positions of the sensor above. The problem arises when attempting to quantify the amount of change, in this case the volume of sediment moved or biomass lost due to the fire and post-fire erosion. While we can easily identify the areas *where* this change has occurred, the error bounds we must put on the variation in actual elevation makes it difficult, if not misleading to quantify volumes of material changed. The implications for management from this project highlight the need to ask for more ancillary information and to develop models to estimate the amount of volume transported using this information as well as soils and precipitation information. Directly measuring vertical change using only Lidar will provide errors that make quantifications meaningless in areas with steep slopes.

Deliverables:

Proposed	**Delivered**	**Status**
Journal Publication	Using Lidar to identify sediment and forest structure change in the Hayman burn, Colorado	In Review
Non-peer reviewed published	Cover of June PE&RS http://www.asprs.org/publications/pers/2006journal/june/index.html	Completed

Presentations	Six presentations at conferences on results, plus several more continuing	Continuing
Poster Presentation	"Using Lidar to identify sediment and forest structure change in the Hayman burn, Colorado" ASPRS Pecora conference, October, 2005, Sioux Falls, SD	Completed

APPENDED PROJECT BACKGROUND, OBJECTIVES, AND JUSTIFICATION

Project Background

The 2002 Hayman fire is the largest fire in Colorado's recorded history, covering 55,850 ha (138,000 acres). This fire 35 miles southwest of Denver and several fires before it in the South Platte Basin and elsewhere in the Colorado Front Range confirmed the concerns of researchers and managers about forest condition in the wildland and urban interface areas of the ponderosa pine zone. These warnings are supported by research at Cheesman Lake, located in the center of the Hayman fire perimeter, where extensive field studies indicated a much more open historical forest landscape condition (Kaufmann et al. 2000, 2001). These studies have been invaluable for assessing the health of the forests in the South Platte Basin and other parts of the Front Range and developing guidelines for restoration and wildfire mitigation activities.

While field studies are important, they also are very expensive and labor intensive. Remote sensing has often been used as a supplement to field studies, because the data cover large areas and are usually more cost effective than field surveys (Martin and Aber, 1997). A relatively new remote sensing technology, Light Detection and Ranging, or Lidar, has strong potential to provide information about forest systems. Lidar analysis integrates remote sensing, Geographic Information System (GIS), and Global Positioning System (GPS). Lidar systems use an active sensor that generates its own energy by emitting a pulse of laser light ("posting") at a target. The distance, or range of the target, is recorded in three dimensions (X, Y, and Z), determined from reflected signals from the target. There are many types of Lidar sensors, with varying footprint sizes, posting densities, and amount of information the sensor is able to record. Some sensors record the first return from an object, first and last return, multiple returns, or completely digitize the return signal. Some sensors such as multiple-return Lidar systems record more than one return per laser pulse, providing information within vegetation layers and for the bare ground below. While there have been several studies using large-footprint waveform return Lidar in forest systems with promising results (Dubayah et al., 2000; Lefsky et al., 2002; Means et al., 1999; Lefsky et al., 1999; Blair and Hofton, 1999; Drake and Weishampel, 1998; Harding et al., 1994), there have been few forest studies using small-footprint multiple-return Lidar (Means, 2000). Recent work in our laboratory (Stoker 2002) demonstrated, however, that Lidar has outstanding potential for characterizing the crown structure, height, and diameter of individual trees. We propose to utilize this potential for assessing post-fire erosion and forest structure changes resulting from the Hayman wildfire.

Change detection using remotely sensed data involves comparing the changes in value between two or more different dates of imagery over the same area. Change detection in remote sensing has typically been used to detect areas of land use or land cover change. Because the technology itself is so new, change detection involving Lidar is proven but relatively unexplored. Lidar has been used for studying change in urban areas (Murakami et al., 1999), and beaches and dunes (Krabill et al., 2000). While there are obviously changes to the forest itself after a forest fire, especially in areas of intense fire behavior, there also may be changes to the land surface, such as erosion or depositional events that can occur from a post-fire rainstorm. These erosion and deposition events can have serious consequences on downstream water supply, post-fire vegetation establishment, and property value not only in the fire perimeter, but also downstream.

Objectives

A pre-fire Lidar data set for a key research area at Cheesman Lake near the center of the Hayman burn provides the backbone of the research. 3Di Technologies Inc. of Boulder, CO captured the original data in October 2001 over the east side of the Cheesman Lake property. The original data were collected to analyze the potential for using Lidar data to create an inventory of forest biomass and fuel conditions (Stoker 2002). A second data set collected in late summer 2003 by Spectrum mapping allowed us to use change detection methodologies to address several objectives.

Justification

Severe, large-scale wildfires in the Colorado Front Range have generated intense interest, especially as more people move into the wildland/urban interface. A hundred or more years of logging, grazing, and fire suppression created a landscape that is more prone to these large and life-threatening fires (Kaufmann et al. 2000). Severe flooding and erosion occurred after the 1996 Buffalo Creek and 2000 Hi Meadows fires in the South Platte watershed, an area that supplies most of the water for the Denver metropolitan area. The ability to identify areas that are more prone to flooding and erosion after a fire would allow managers to take proactive steps in mitigating the damage caused by these flood events, and perhaps even help take steps to mitigate effects of a potential wildfire. Presently, erosion potential is estimated during BAER efforts using standard hydrologic models, but evaluation of post-fire erosion is limited by lacking pre-fire data and the general difficulties of estimating locations and volumes of sediment movement. Small-footprint multiple return Lidar data have great potential for producing pre-fire, post-fire, and post-erosion data sets for assessing changes in soil surface metrics. In addition, these data have potential for assessing changes in overstory structure, including biomass. In both cases, Lidar has the advantage of providing three-dimension characteristics not obtained with most remote sensing technologies.

While research using small-footprint multiple return data is limited, especially in Front Range ponderosa pine ecosystems, we have had outstanding success identifying and quantifying individual tree characteristics and ground features in the Colorado Front Range (Stoker 2002). Earlier research using profiling Lidar systems concluded that individual trees could be identified (Leckie, 1990). We recently used a small-footprint multiple-return Lidar system to estimate tree height, crown base height, length of live crown, and diameter at breast height (Stoker 2002). Others also have estimated mean tree heights using small-footprint systems (Magnussen and Boudewyn, 1998; Magnussen et al., 1999; Means et al., 2000; Naesset, 1997a; Young et al., 2000), as well as large-footprint (Lefsky et al, 2002; Means et al., 1999; Lefsky et al., 1999). Naesset and Okland (2002) hypothesize that crown length may be estimated directly from laser data, particularly when crowns of adjacent trees are separated from each other, but also in dense stands where crowns interfere. Stoker (2002) was able to accurately detect length of live crown and crown shape for individual freestanding trees in the Cheesman Lake area. Lefsky et al. (1999) used linear regression to develop equations relating height indices to base area and biomass. Ground features (digital elevations) are readily determined with small-footprint multiple return systems, as indicated by the successful estimation of tree heights that required subtracting out ground elevation beneath tree crowns (Stoker 2002). Collectively, these data illustrate great potential for characterizing both ground surface and above-ground vegetation structure in three dimensions.

A rapid response is important to capture time-critical data when detecting change from remote sensing. Initial Lidar data are already archived at a private firm, and extracting those data before technologies and personnel change is critical. While it is possible that flights could be flown for several years, the first year after the fire is important for determining first-year erosion (the year most erosion is likely to occur) and post-fire vegetation structure before treatments or decay alter the forest throughout the burn area. Collecting these data less in the first post-fire year would provide a baseline for future change detection studies to examine topics such as understory recovery, channel stabilization, and regeneration. Because small-footprint multiple-return Lidar is a relatively new technology, there is an increasing interest in using Lidar for many applications that have not yet been explored.

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