Mapping Vegetation Structure in the Pinaleño Mountains Using Lidar

August 2009

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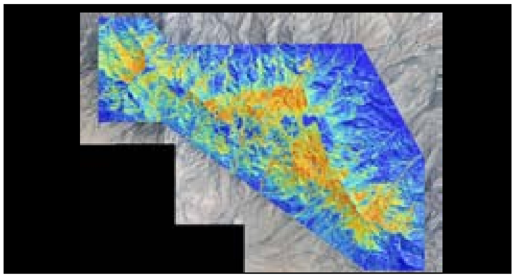

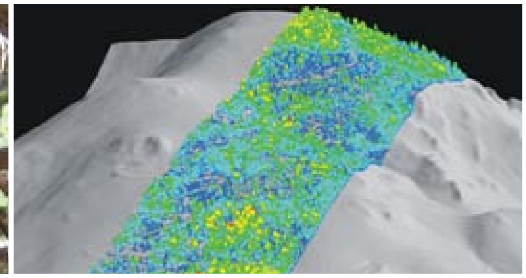

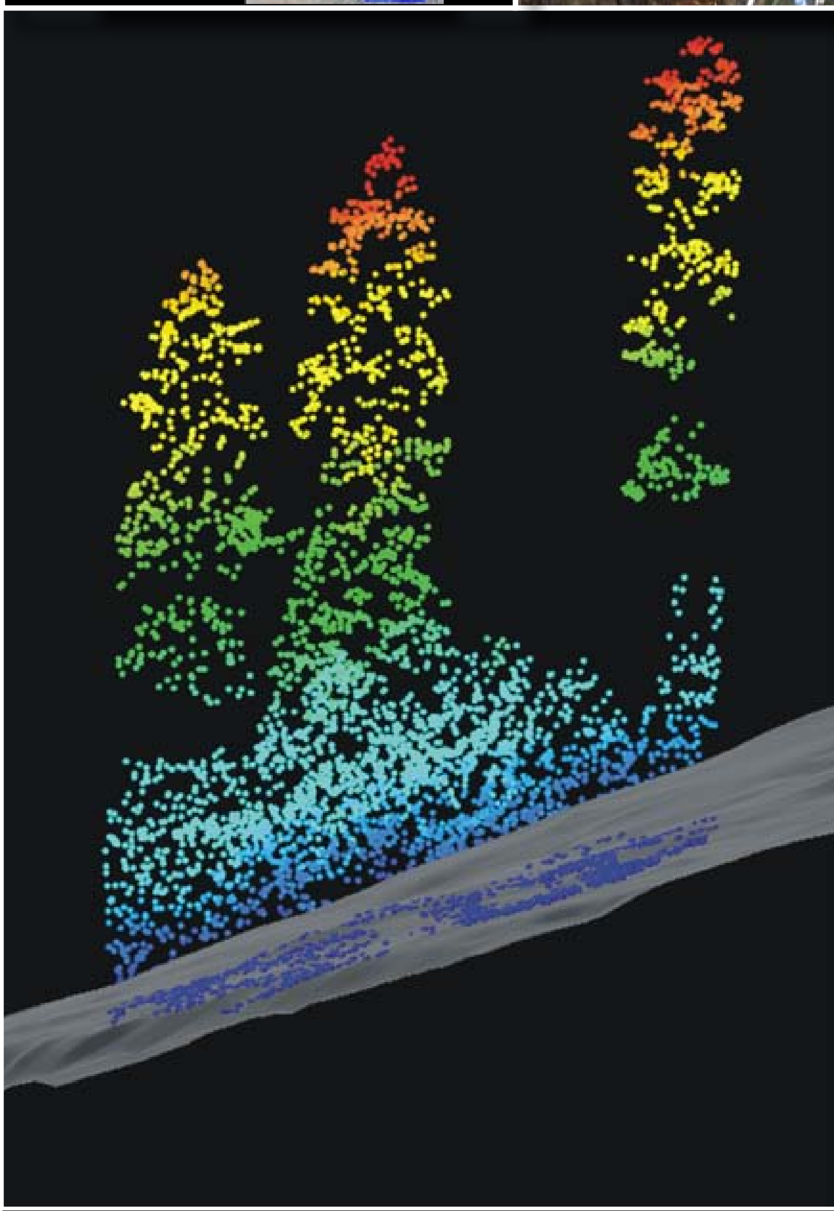

United States Department of Agriculture

Forest Service

Geospatial Management Office

Remote Sensing Applications Center

Abstract

The Pinaleño Mountains, an isolated sky island in southeastern Arizona, contains the southernmost expanse of a spruce/fir forest type in North America as well as one of the most extensive mixed-conifer forests this far south. The high-elevation ecosystems support the only habitat for the Mount Graham red squirrel *(Tamiasciurus hudsonicus grahamenis)* (MGRS), a federally listed endangered species. Changes in forest composition and structure, along with several recent large and severe wildfires and devastating insect outbreaks, have greatly altered the habitat for the MGRS. The risk of additional wildfires and insect outbreaks has led the forest to begin a restoration effort, attempting to balance fuel reduction with habitat conservation. As part of this restoration effort, the Coronado National Forest is pursuing airborne lidar technology as a potentially cost-effective way to provide current and detailed information on forest structure. The derived information will be used to plan, implement, and monitor ecosystem restoration and assist in creating a MGRS habitat model.

Airborne lidar data were collected in late September 2008 over 85,518 acres, covering the forested portion of the Pinaleño Mountains. Once the lidar data were delivered to the U.S. Department of Agriculture Forest Service (USFS) in February 2009, a quality assessment was done to ensure that data met the criteria for optimal forest mapping based on the technical specification completed in April 2008 as a part of this project (Laes and others 2008). This quality assessment used an assemblage of software, including the Fusion catalog function developed by the USFS, ArcGIS, and finally the U.S. Geological Survey (USGS) consistency software program. This report describes this process.

Once the lidar data passed the technical-specification qualification, numerous base raster GIS layers containing forest-canopy, structure, and fuel-related information extracted from the lidar point cloud were developed. These lidar-derived raster data layers included a number of models depicting the forest floor and fuel beds, canopy surface and height, canopy volume and outer surface area, and bare earth. Field data collected during the summer of 2009 will help establish statistical relationships between the conditions on the ground and the lidar raster GIS data. These relationships will be used to model forest structure and improve the understanding of current forest conditions within the Pinaleño Mountains. The appendices in this report details the steps and scripts to facilitate lidar data processing and contain a complete list of output files, descriptions of the data-processing flow, and visuals of the lidar-derived models. The final phase of the project—establishing the statistical relationships between the field and lidar-derived layers—will be completed in 2010.

Key Words
Pinaleño Mountains, lidar, lidar acquisition, lidar quality assessment/quality control, automated processing, fusion, Mount Graham red squirrel

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*Note: Appendices may be in a separate file.

Background

Conducting forest inventory in remote, steep, and rugged areas can be cost prohibitive and may compromise field-crew safety. The Coronado National Forest acquired airborne lidar data to investigate its ability to derive forest-structure, fuel, and biomass information in a safer, more-practical, and cost-effective way. The derived forest information will be used to implement and monitor ecosystem restoration, develop forest-health monitoring tools such as Douglas-fir beetle-risk factors, assist in creating a Mount Graham red squirrel *(Tamiasciurus hudsonicus grahamenis)* (MGRS) habitat model and monitor treatments; and piece together likely presettlement forest characteristics, based on such data as historical aspen clones, remaining patches of old growth, and other forest demographics.

Phase one of this project compiled the technical specifications for lidar data acquisition (Laes and others 2008); secured the necessary funds from the U.S. Department of Agriculture southwestern regional office, the Coronado National Forest (USFS), forest health monitoring-interior west office, and the USFS Remote Sensing Steering Committee; and evaluated the submitted responses to the request for quotations (RFQ). The RFQ was posted in early July of 2008, and the contract was awarded in August. The data collection was complete by the end of September and delivered to the Forest Service in February of 2009.

Figure 1—A view toward the southwest from the Pinaleño Mountains.

Objectives

This report documents the second phase of the Pinaleño Mountains lidar project. The objectives of phase two were the following:

1. Assure that the lidar data delivered by the vendor complied with the contract specifications;
2. Develop and document a quality assessment for lidar data coming from a vendor; and
3. Develop the raster GIS layers containing forest-canopy, structure, and fuel related information extracted from the lidar point cloud.

The next project phase will use field data collected during the summer of 2009 to establish statistical relationships between the conditions on the ground and the lidar data. These relationships will aid in modeling forest structure based on some of the derived raster layers (grids). Other raster layers can be employed immediately to improve the understanding of current forest conditions within the Pinaleño Mountains (figure 1).

This report describes the lidar data, the quality assessment performed after data delivery, and the initial data-processing steps. During this time, information was extracted from the lidar point cloud and transformed into raster layers (in ESRI grid format). Each of these grids contains a specific data derivative or parameter that can form the basis for future modeling. To make this report as concise as possible, familiarity with lidar terminology is assumed. A lidar tutorial is available at the following site: http://www.fs.fed.us/eng/rsac/lidar/

Appendices to the report contain all the steps and the DOS batch scripts used in the lidar data processing, a list of output file names, a brief description of the data-processing flow, and a data dictionary with visuals of various grids created for the entire project area. The scripting supplement may be useful for those trying to process lidar data in an automated way while the data dictionary will help during future modeling.

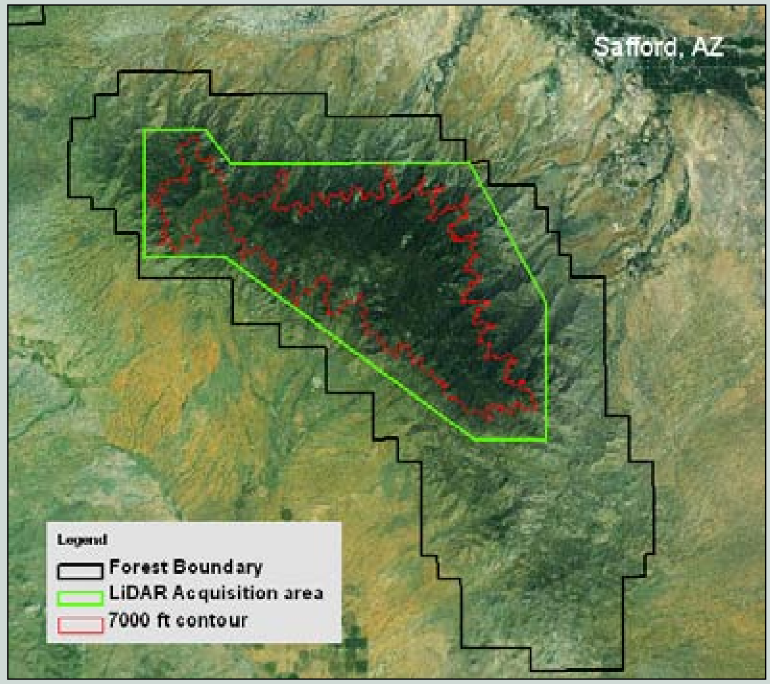


Figure 2—On the left, the location of the project area in the Pinaleño Mountains; on the right, the project area within the bounderies of the Coronado National Forest.

Project Study Area

The project study area covers approximately 85,500 acres (34,600 hectares) in the mixed-conifer zone above 7,000 feet (2,133 meters) within the Pinaleño Mountains, located southwest of Safford, Arizona (figure 2). The Pinaleño range is an isolated Madrean sky island and contains the southernmost expanse of a spruce/fir forest in North America as well as one of the most extensive mixed-conifer forests this far south. The high-elevation ecosystems have been isolated for the last 11,000 years and support the only habitat for the Mount Graham red squirrel (figure 3), a federally listed endangered species. The range has experienced similar post–Euro-American settlement changes in forest composition and structure to other southwestern mixed-conifer forests. The presettlement and pre–fire-suppression forests were more open with less forest-floor fuel, favoring more-frequent, but less-intense, fires (Covington and Moore 1994). Recent changes have led to several large and uncharacteristically severe wildfires and a series of devastating insect outbreaks. Particularly hard hit have been the spruce and fir trees, with mortality estimates of more than 80 percent. This was the primary habitat for the MGRS. The remaining habitat is now reduced primarily to the transitional zone between the spruce/fir and mixed-conifer forest, sometimes referred to as wet mixed-conifer forest (Wood and others 2007).

Figure 3—Mount Graham red squirrel *(T. hudsonicus grahamensis)* in its natural habitat.

Lidar Data

Definition of Lidar

Lidar is an acronym for light detection and ranging. Lidar systems measure distances using the same principle as a laser rangefinder. The travel time of each laser pulse to an object and back is divided by two and multiplied by the speed of light (299,792,458 meters per second) to calculate the precise distance, and the accuracy is dependent on the timing device. An airborne topographic lidar system scans, receives, and georeferences multiple pulse returns (echoes) from the ground, treetops, rooftop, and other objects tens of thousands of times per second. The system uses an IMU (inertial measurement unit) and a GPS (global positioning system) to record the geolocation of each lidar return in three dimensions (Wehr and Lohr 1999; Baltsavias 1999).

Acquisition Specifications and Timeline

After an evaluation of the responses to a competitive bidding process, the contract for the discrete-return lidar-data acquisition over the Pinaleño Mountains was awarded in mid-August of 2008 for $105,013. The vendor, Watershed Sciences, completed the leaf-on data collection between September 22 and September 27, 2008, according to the mission specification in table 1, covering an area of 85,518 acres (figure 4).

Description of Deliverables

A portable hard drive with 91 gigabytes of data arrived at the Remote Sensing Applications Center (RSAC) during the first week of February 2009, nearly two months later than the date in the contract agreement. The disk contained all the requested data files. The lidar point data were organized in 236 tiles in the common binary lidar-exchange

Table 1—Pinaleño Mountains lidar-acquisition specifications

Acquisition dates	September 22–27, 2008; Leaf-on
Aircraft	Cessna Caravan
Lidar scanner	Leica ALS50 Phase 2
Pulse rate	70 to 90 kHz
Scan rate	52.2 Hz
Maximum returns per pulse	4
Scan angle	+/-15 degrees
Beam divergence	19–29 cm
Flight above ground level	800–1300 m
Flight line configuration	Opposing adjacent parallel lines
Flight line overlap	50% sidelap
Average lidar pulse-return spacing	7.36 points/m^2
Average ground-point density	0.98 points/m^2
Acquisition area	85,518 acres
Total numbers of returns	2,892,925,979

The projection information for the spatial data is UTM zone 12 NAD83 and NADV88 geoid03. Both horizontal and vertical units are in meters.

Figure 4—The Cessna Caravan and Leica ALS50 Phase 2 instrument that were used in lidar acquisition.

format or LAS. One LAS point tile corresponds to a 1/25th section of a 3.75-minute digital orthophoto quarter quadrangle (DOQQ). The bare-earth models were in ESRI grid format with a 1-meter spatial resolution. Because of the resolution and the size of the project area, the bare-earth model (as well as all other files at 1-meter spatial resolution) was divided into three sections split along north/south DOQQ lines corresponding with U.S. Geological Survey (USGS) 1, 8, and 7 7.5-minute quadrangle boundaries (figure 5).

Other deliverables included points classified as "ground," provided as separate ASCII files; a report describing the GPS geolocational procedures, including information related to the RTK (real-time kinematic) ground-control point collection; and shape files depicting the tile boundaries and the flight-line trajectories.

Lidar Processing

Figure 6 shows a flowchart where the major processing steps are grouped by color. All but one of the analysis procedures, described later in this report, start from yellow boxes, which represent the data deliverables. The field plot data, collected during the summer of 2009, were not provided by watershed sciences. The volume and outer-surface-area calculations were based on a canopy-height model, not a deliverable. The grey boxes with red text list the script that was used during processing. These batch files are detailed in appendix 1. Green boxes represent output grids.

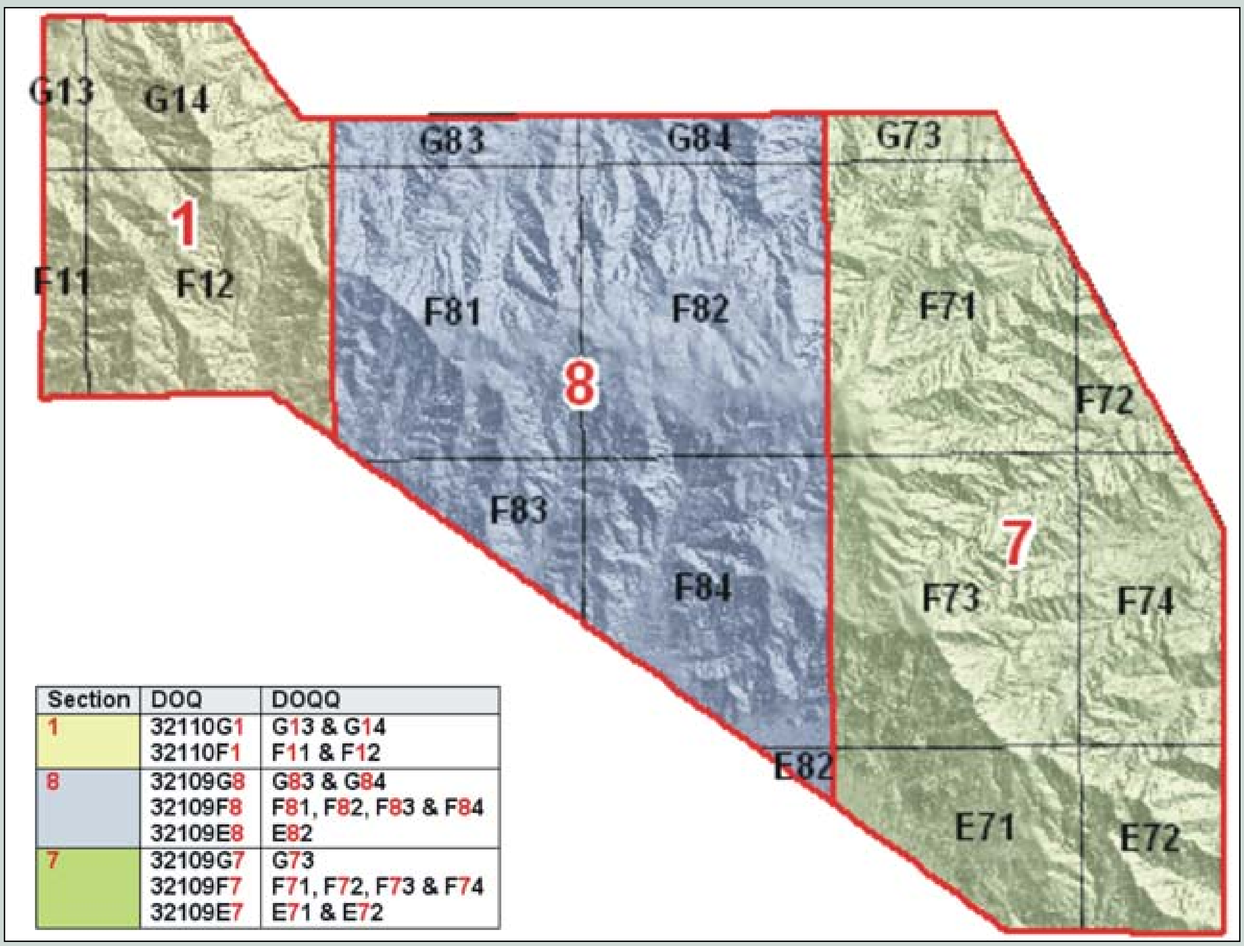


Figure 5—The three sections of the ArcGIS grids that Watershed Sciences delivered for the project area.

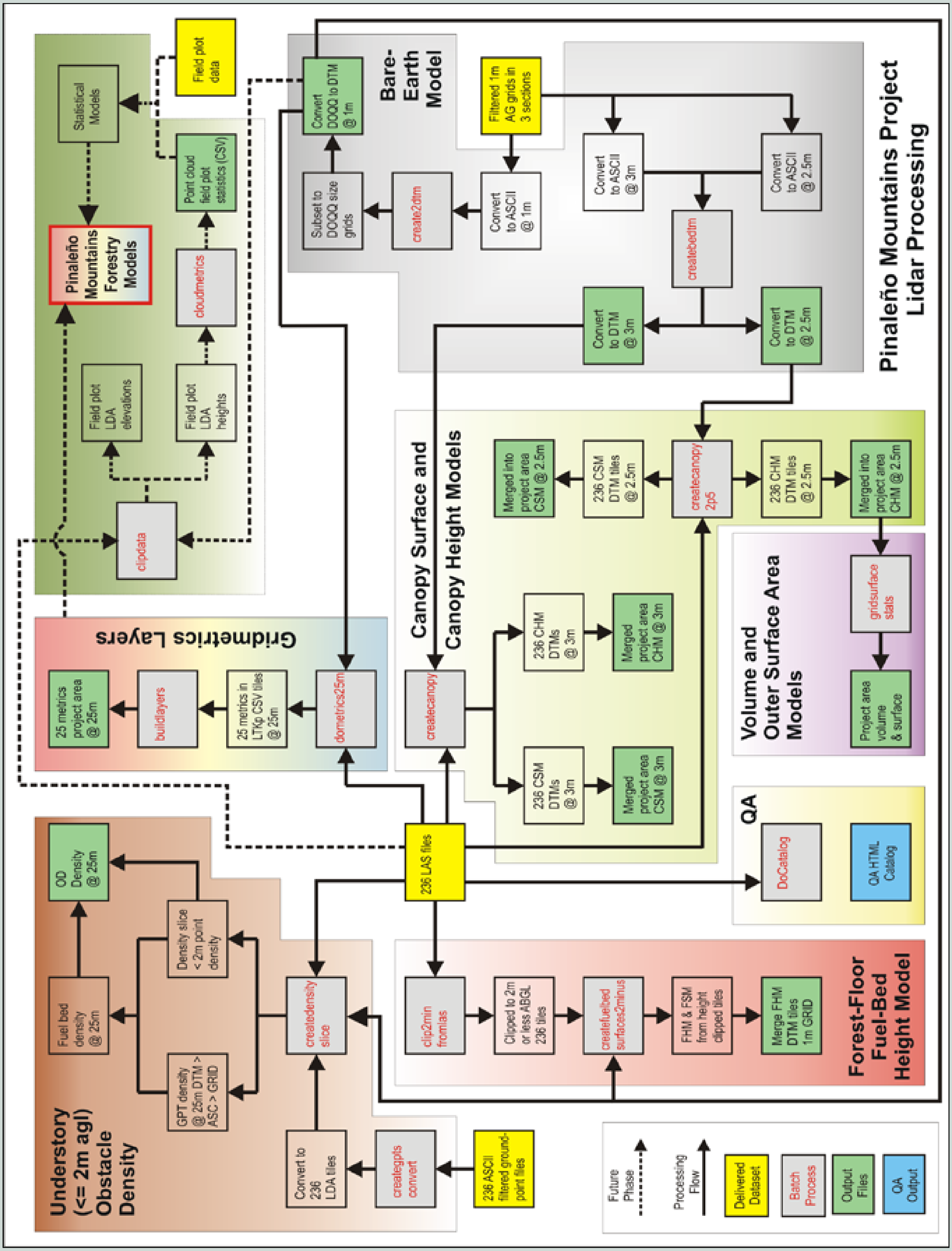


Figure 6—A Lidar-processing flowchart developed for the project.

Quality Assessment of the Deliverables

First, the delivery of all the requested files and documentation was verified. The data were then checked for compliance with the technical specifications of the contract and quality control with an assemblage of software:

1. The Fusion catalog function; Fusion is a software package developed by Bob McGaughey of the Forest Service, Pacific Northwest Research Station, in Seattle specifically to analyze lidar data;
2. Visual inspection of the bare-earth model, the highest-hit model, and the flight-line trajectories with ArcGIS; and
3. Output from the USGS consistency software code: a combination of unpublished ARC workstation AMLs (arc macro language) and Python scripts developed by Ralph Haugerud of the USGS in Seattle.

Table 2 shows which software was used to check different specifications in the lidar-acquisition contract.

Table 2—Lidar data quality assurance checklist

Requested Specifications	Procedure
All requested files delivered?	Windows Explorer
File formats	Windows Explorer
Coverage of the area	Fusion catalog function
Pulse density (first-return density)	Fusion catalog function USGS consistency function
Half minimum-pulse-density area at 30 m	Fusion catalog function
Scan angle	Export random selected LAS files to MS-Access database (from Fusion) and run summary queries on scan-angle field. Fusion can color the data points with the value of the scan angles. The LDV histogram will show the maximum angle.
Data acquisition gaps	Fusion catalog function and visual inspection of the delivered grids USGS consistency function.
Opposing adjacent flight lines	ArcGIS shape file: the difference between the from-*X* and to-*X* coordinate fields was used to visualize the general direction.
Absolute accuracy	Vendor RTK surveying
Bare-earth grid interpolation	Visual inspection in ArcGIS of bare-earth grid for smoothness and indications of areas with few points (DEM looks facetted). Comparison of bare-earth surface to highest-hit surface.
Bare-earth building and vegetation removal	Comparison of bare-earth DTM to ground points in PDQ viewer. The text files with the *XYZ* ground points need to be converted to the Fusion LDA format first.
Point cloud outlier removal	Fusion catalog function Fusion PDQ viewer
Relative accuracy	USGS Consistency by comparing elevation results in flat areas of the bare-earth model from overlapping adjacent flight lines.
50% sidelap (or 100% overlap)	USGS consistency function
Accuracy error as function of increasing slope	USGS consistency function

The Fusion Catalog Function

The function produces an HTML file containing the following:

- A summary table of the lidar data listed by tile: elevation range in each tile, *XY* coordinates of each tile, total return count, return count by return number, and return density;
- The nominal coverage based on the geographic extent of the data tiles;
- Outlier analysis based on a user-defined range (mean elevation ± *(n)* std. dev.);
- The first-return density image, which is an approximation of the requested pulse density based on user-specified cell size and color coding; and
- A first-return intensity image (with or without tile boundaries).

All of the catalog output images include a world file and can be visualized in ArcGIS. The output file sizes in either a BMP and/or JPEG format depend on the user-defined cell size.

Figure 7 shows the results of the first-return density images with a 30-meter cell size. This size was used to verify the specification that no 30-by-30-meter cell should produce less than 1.5 pulses per square meter. The red cells in the southeastern section of the left part of figure 7, indicating that the first return density is less than half the contractual pulse density, coincide with a dropped flight line.

Visual Inspection of the Delivered Surface Models

Unlike the software-based catalog and consistency assessments, the results of the visual inspection are not readily quantifiable. The three sections of both the 1-meter bare-earth and highest-hit surfaces were merged into corresponding 2-meter grids covering the entire study area. Hill-shades of these two grids were combined with a derived height model—obtained by subtracting the bare-earth model from the highest-hit one—and a 4-band National Agriculture Imagery Program (NAIP) mosaic to evaluate the data visually. Investigators systematically panned through the data at a constant

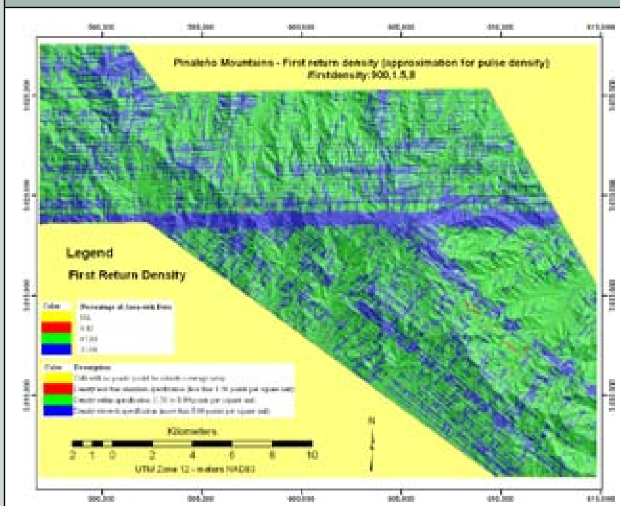
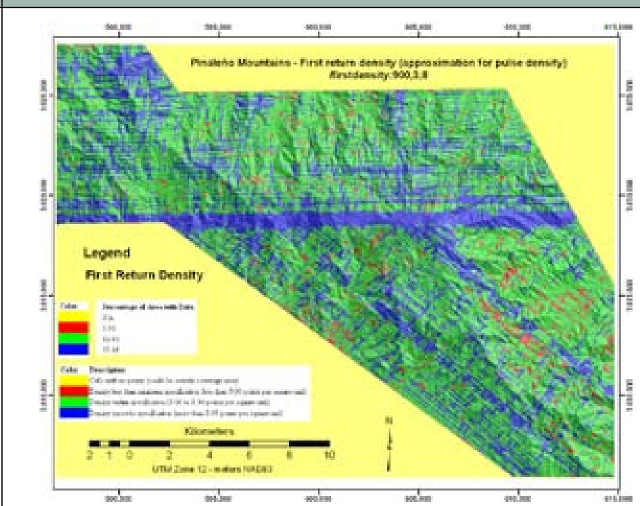
Half minimum pulse density: 1.5 pulses per square meter at 30 m cells	**Minimum pulse density: 3 pulses per square meter at 30 cells**
	
/firstdensity:900,1.5,8	**/firstdensity:900,3,8**
Percent area with data coverage below minimum pulse density: 0.43%	**Percent area with data coverage below minimum pulse density: 5.95%**
Percent area with data coverage at or above minimum pulse density: 99.57%	**Percent area with data coverage at or above minimum pulse density: 94.057%**

Figure 7—A composite image of the Fusion catalog pulse density comparison. Red indicates cells with less than the specified pulse density. The function was run at two resolutions: 1.5 pulses per square meter, shown on the left, and 3 pulses per square meter depicted on the right.

scale of 1:3,000 looking for visible triangular facetted areas (indicative of few ground points), outliers, data gaps, and remnants of vegetation and buildings.

Outliers in the delivered models occurred mainly along steep, near-vertical cliff edges. They were most likely due to the algorithm used to filter out nonground returns. A few areas in the images may potentially still contain vegetation or building remnants, but neither of these should have a major impact on future analysis.

Output from the USGS Consistency Code

This analysis generates estimates of the internal reproducibility of the lidar survey. Consistency duplicates some of the Fusion catalog analyses but adds others, such as checking for flight-line overlap, relative vertical and horizontal accuracy between flight lines, ratio of first returns to ground returns, and changing accuracy information with increasing slope.

Of the 18 AMLs and 25 Python scripts making up this code, three AMLs needed modification to reflect the acquisition specification of the data and the local computer environment (drive and folder settings). Because of the large amount of data and the processing time required by this analysis, not every tile needed to be analyzed. One of the AMLs allows the user to specify a tile-skipping factor. To speed up the analysis even more and resolve computer memory issues, the data tiles were divided into seven folders (figure 8). The analyses for the seven folders were run simultaneously. The details and explanation of the code appear in the documentation for the consistency program (Haugerud, unpublished report).

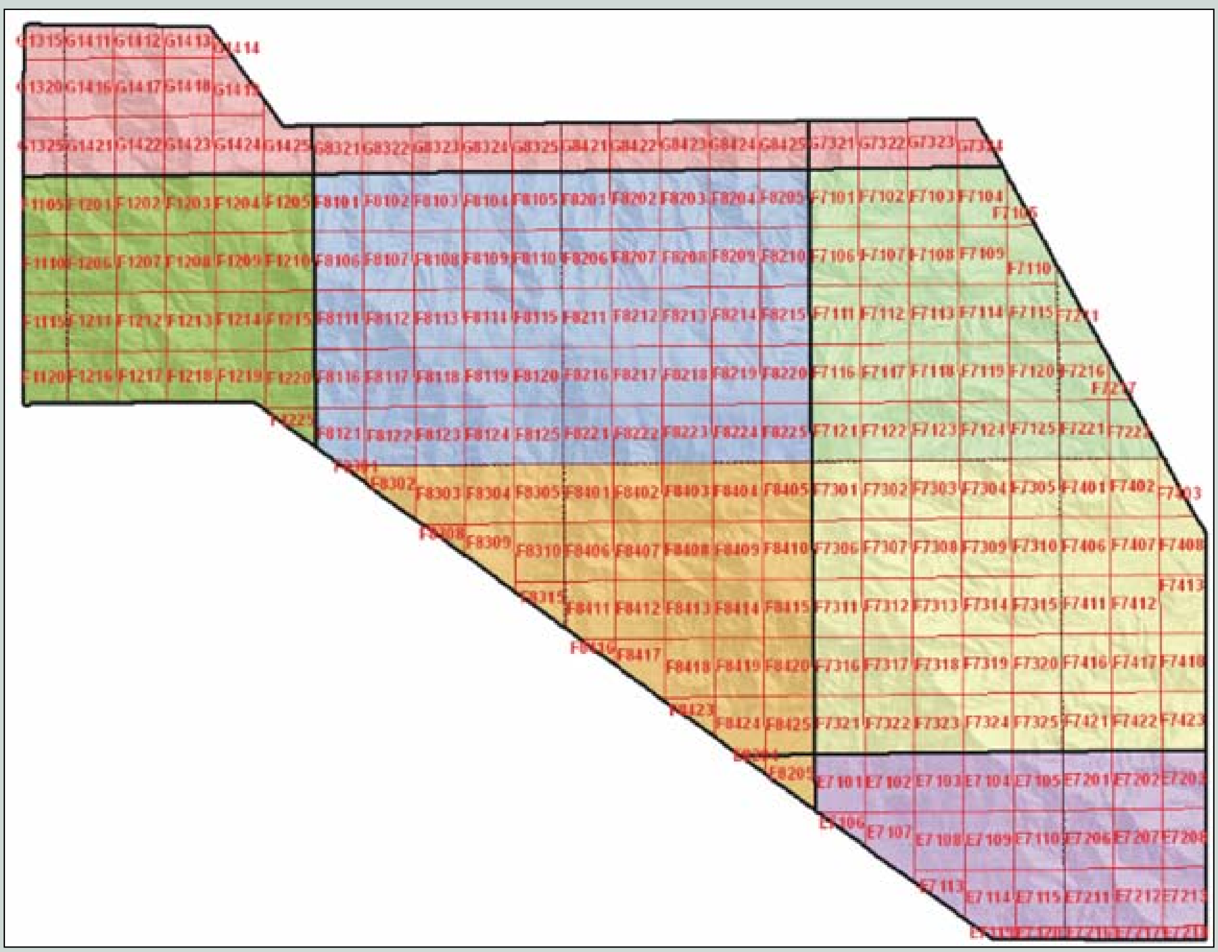


Figure 8—A geographic representation of the grouping of the data tiles into seven separate folders used for consistency analysis.

The program involves a two-step process that first analyzes the selected tiles and then produces a report in HTML format for the larger area (in this case, areas corresponding to the subset of the project area in each of the seven folders). The analysis is the more time-consuming step. It took nearly five days of continuous computer time to analyze about 50 percent of the tiles. The analysis generates a maplike graph that visualizes the pulse density (for ground returns, first returns, and their ratio) and flight line overlap of each tile in an HTML file. The relative accuracies are determined by comparing *Z* values to *XY* values from ground returns in flat areas. Returns from these areas in adjacent overlapping flight lines, flagged by analyzing slope and curvature, were separated by flight line and compared. The results were summarized at the folder level in the HTML file, one for each folder, and contain links to the HTML files created for each of the tiles.

Organizing the lidar tiles allows them to be analyzed more quickly, but unfortunately it does not produce a comprehensive relative accuracy for the entire project area. The quality control performed by Watershed Sciences, using 1,654 RTK ground-control points measured during the time of data acquisition, lists the absolute vertical accuracy at 6.9 centimeters (at 2σ) (Watershed Sciences 2009). The absolute horizontal accuracy depends on the resolution of the GPS base stations and is designed to be within 15 centimeters at 1σ. Because no easily recognizable and measurable features in open terrain exist on the hard surfaces selected for the RTK survey points, the horizontal accuracy is difficult to analyze and is not routinely part of Watershed Sciences's quality control.

Relative accuracy results, indicating flight line to flight line accuracy, are an output of the consistency analysis, listed in table 3. The vertical accuracy, reflected by the P1 values, reveals that the contractual absolute parameters (≥ 15 centimeters vertical on horizontal surfaces) were met. The P2 values reported from the consistency analysis are the only indication of horizontal accuracy, and they are above the 15-centimeter contract specifications. The terrain in the project area has few hard, flat surfaces and even fewer ones with easily recognizable features in open terrain that can be readily identified in overlapping flight lines from which *XY* values of the returns can be compared. This makes it extremely difficult to characterize the returns from two different flight passes as really representing the same location so quality assessment became even more problematic. A well-defined survey design and verifying the base-station instrumentation produce the best quality control possible under these conditions. Although the P2 values are above the contract specs, it is difficult to decide whether they represent real horizontal-accuracy problems, or whether they reflect an inability to determine if the points of comparison really coincide with the ground, or both.

Conclusion of Quality Assessment

Four weeks of intense scrutiny of the data, produced a few minor infractions in the 50 percent sidelap criteria and

Table 3—Summary of relative accuracy for each of the seven folders

Folder group	Number of tiles analyzed	Summary of Estimates of global accuracy and completeness		
		P1 (cm) rms *Z* error flat ground	P2 (cm) rms *XY* error	n=number of points
G187	15	3.2	36.0	34,632
E7-12	13	3.8	31.0	22,912
F1-12	13	3.4	38.7	11,471
F7-12	15	4.2	35.9	34,988
F7-34	20	3.4	34.1	48,583
F8-12	24	4.3	30.0	29,252
F8-34 (includes E8-2)	17	3.7	32.3	28,464
The folders are colored to match their geographic location in figure 8.				

Table 4—Example of the completeness output for tiles within folder F8-12

Tile	Data_ Area	Dlc_ Area	Percent Double	Pulse/ M2	Blunders/ 1,000,000	rmse1n	a951n	rmseg	a95g
F8101	1.623	0	99.998	6.421567	0	0	0	0.339	0.556
F8103	1.623	0	99.998	7.301508	0	0	0	0.337	0.516
F8105	1.623	0	99.992	5.932661	0	0	0	0.348	0.496
F8107	1.623	0	99.993	9.638238	0	0	0	0.361	0.564
F8109	1.623	0	99.997	6.735713	0	0	0	0.549	0.659
F8111	1.624	0	99.999	7.878493	0	0	0	0.366	0.655
F8113	1.624	0	99.963	7.206454	0	0.027	0.004	0.286	0.392
F8115	1.624	0	99.933	7.994095	0	0.039	0.07	1.268	0.791
F8117	1.624	0	99.998	11.0791	0	0	0	0.457	0.832
F8119	1.624	0	99.794	19.31227	0	0.062	0.102	0.266	0.391
F8121	1.478	0	99.996	8.16995	0	0.019	0.019	0.204	0.339
F8123	1.624	0	99.626	11.84933	0	0	0	0.445	0.715
F8125	1.624	0	99.998	9.967041	0	0	0	0.364	0.674
F8202	1.623	0	99.642	6.139299	0	0	0	0.595	0.671
F8204	1.623	0	98.845	8.642747	0	0	0	0.488	0.734
F8206	1.623	0	99.517	7.357137	0	0	0	0.722	0.806
F8208	1.623	0	99.783	8.688858	0	0	0	0.708	0.761
F8210	1.623	0	99.803	10.10022	0	0	0	0.649	0.71
F8212	1.624	0	99.958	9.897661	0	0	0	0.156	0.268
F8214	1.624	0	99.951	13.77929	0	0	0	0.205	0.307
F8216	1.624	0	99.299	14.93763	0	0	0	0.403	0.559
F8218	1.624	0	99.998	14.95608	0	0.098	0.128	0.138	0.221
F8222	1.624	0	98.975	8.958092	0	0.021	0.039	0.615	0.712
F8224	1.624	0	98.43	8.369454	0	0.042	0.077	0.237	0.277

also a few 30-by-30 meter cells with less than half the minimum specified density of 1.5 pulses per square meter. Most of these problems are explained by the steep and very rugged terrain. Turbulence resulting from warmer air temperatures starting daily around noon (typical for the mountainous terrain, the locale, and the time of the year) made flying during the afternoon more difficult. Since these problems were not due to poor mission planning and did not unduly affect further analysis, no objections were raised with the contractor. Other lidar acquisitions contracted by the Forest Service indicate that the "no 30-by-30-meter results at half the minimum pulse density" specification may be too strict, given the current technology mounted in a plane and data collection over mountainous terrain (McGaughey, personal communication).

The contractor delivered all the required files and documentation, most at the contractual specifications and some exceeding them (such as accuracy and pulse density). The requested density of three pulses per square meter was not met in 5.95 percent of the area when measured with 30-by-30-meter cells. Most of the errors occurred along a dropped flight line. The average pulse density for the entire project area was 7.36 points/m2. However, this density was uneven, obviously affecting the analysis of some of the derived raster parameters, particularly those that might provide insight into surface fuels (table 4).

Development of Project-Area Grids from the Lidar Point Data

All of the analysis on the point data was done with the Fusion software developed by the Pacific Northwest Research Station of the USFS (McGaughey and others 2004). Detailed syntax explanations are located in the Fusion manual (McGaughey 2009).

Bare-Earth Models

The bare-earth model was generated by Watershed Sciences and delivered in ArcGIS grid format. The grids were converted to the Fusion Plans DTM format before analysis could begin. A bare-earth model represents the topographic elevation of the area after all the vegetation and buildings have been removed (Kraus and Pfeifer 1998). Haugerud (unpublished report) mentions that, on average, about one in three pulses will hit the surface under forest conditions that are not too dense. According to Watershed Sciences, the ground-point density was on average one pulse per square meter, allowing a 1-meter bare-earth model. The delivered grids were converted to a 1-meter and 3-meter Fusion-ready DTM surface. The 1-meter DTMs were used to normalize the point cloud during gridmetric calculations. Both the 1-meter bare-earth model and those DTMs covering the area in three sections were too large for Fusion's memory. To complete the gridmetrics calculations, the 1-meter bare-earth model was clipped into smaller DOQQ sections. The bare-earth model can be used for watershed delineations, soil-erosion studies, and any other type of project that requires digital elevation models (figure 9).

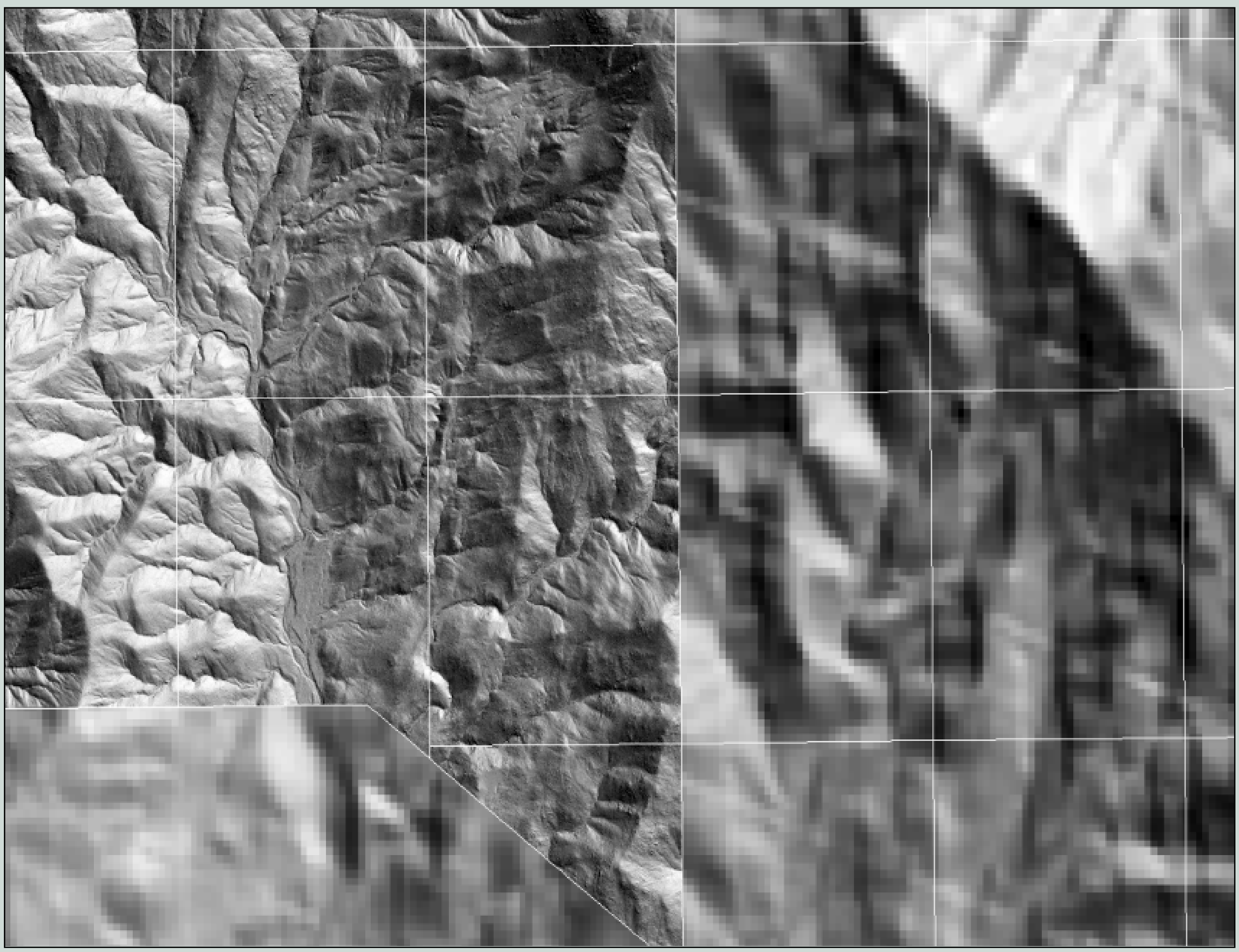


Figure 9—A powerful visual comparison between the 1-meter lidar-derived bare-earth model *(on the left)* and a 30-meter USGS digital elevation model *(on the right)*. The white grid indicates the lidar tile boundaries.

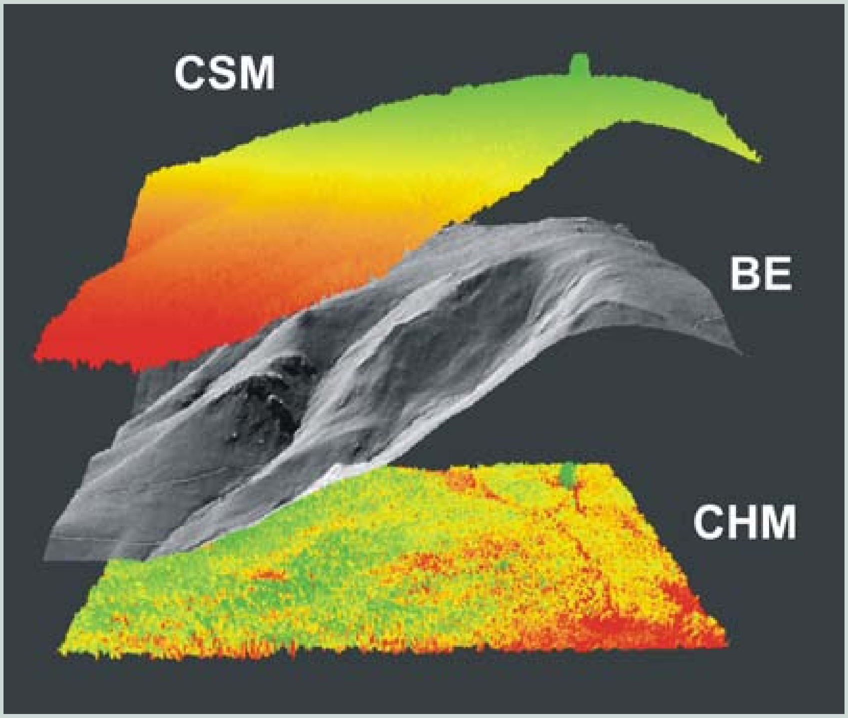


Figure 10—A three-layer offset of a canopy surface model (CSM), bare-earth model (BE), and canopy height model (CHM) derived from data tile F8219.

Canopy Models

A canopy model is derived by creating a surface from the highest returns within a cell. These are usually the first returns. This model includes the upper surface of the trees as well as buildings if the returns from structures are not eliminated from the point cloud or the structures are obscured by taller trees. When the absolute values of the returns are used, a canopy surface model (CSM) is created. The CSM is an elevation model where tree heights (as well as other objects such as buildings) are superimposed on the topographic depiction. To derive heights of trees, called the canopy height model (CHM), a more meaningful metric from a forestry point of view, the CSM needs to be normalized to the topographic elevation by subtracting the interpolated bare-earth model (figure 10). Besides the quality of the lidar data, a good, reliable bare-earth model determines the quality of the CHM.

By using the CSM, inferences about tree height can be made for the entire project area without time-consuming field measurements and dealing with difficult-to-access terrain (figure 11). Lidar data have the tendency to underestimate actual tree height. How much that happens depends on the accuracy of the data, the pulse density, and the quality of the bare-earth model as well as a tree species—more specifically the shape of the top of the tree. Based on information from the field plots, adjustments can be made if necessary (figure 12 and 13). The CHM is generated at 2.5-and 3-meter spatial resolution.

Canopy Surfaces and Volume Models

The 2.5-meter CHM was used as input to create canopy-volume and surface-area layers (figure 14). All these layers are derived at a multiple cell size of the original CHM. Past studies have indicated that the canopy complexity or surface ruggedness can be correlated with the developmental stage of the forest (Parker and Russ 2004; Kane and others 2008).

An overall indication of the canopy density can be derived from the volume models (figure 15). When all the cells have a relatively high value for the canopy height, the surface filled volume (SFV) will be high. After beetle infestations or severe fires, when the forest is characterized by standing snags, logs, and open canopy, the surface potential volume (SPV) can still be high because of the presence of a few taller snags, but the SFV will be low because many cells will have low canopy heights. The canopy SFV, together with cover and CHMs, can be used to create disturbance models. After field data are acquired and processed, these volume layers may be explored for their potential relationship to stand density.

Gridmetrics

Several research studies have shown that statistical modeling of lidar data can be used with forestry plot data to derive canopy structural information at the plot and stand level (Means and others 1999; Naesset and others 2004; Heurich and Thoma 2008; Hudak and others 2008). Fusion's gridmetrics function computes a series of descriptive statistics for a lidar data set based on the returns within a user-defined grid cell. The resulting parameters are the same as those calculated by cloudmetrics, the function used to process returns from the lidar point data corresponding to the field plot locations. The gridmetrics function converts the statistical output to a grid. Besides statistics, each grid contains implicit spatial information, making it possible to derive forest canopy data over the entire project area. This results when the models derived from building relationships between plot data and their corresponding lidar point cloud are applied to the gridmetric-derived rasters.

Except for the cover calculations, all the outputs from this analysis (table 5) are height related and derive statistical information from the point data at 2 meters above the ground and summarize it on a 25-meter raster grid. Returns

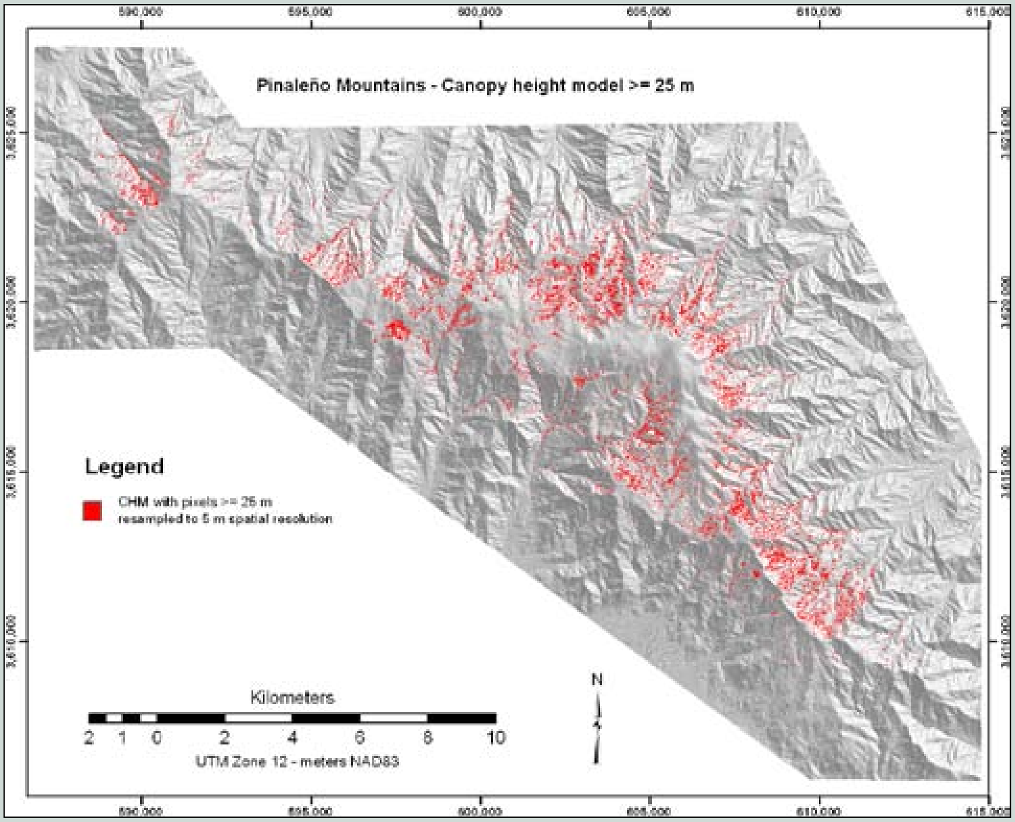


Figure 11—A canopy height model, the pixels with a value ≥ 25 m are shown in red.

Figure 12—An old-growth stand near Riggs Lake: note that only a few areas on the ground show gaps in the canopy through which the sun illuminates the forest floor; also note the absence of a thick understory.

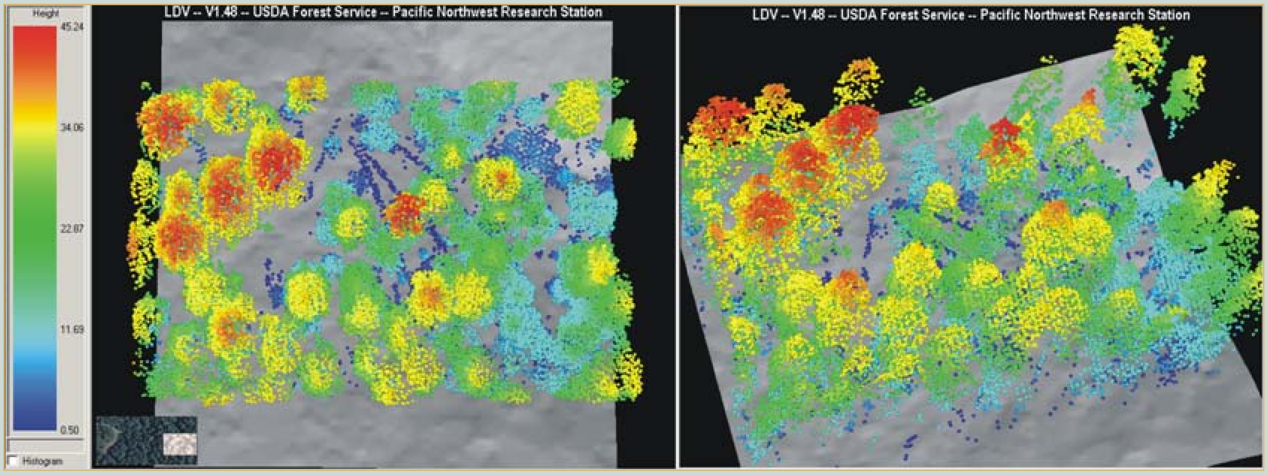


Figure 13—A point cloud representation of old-growth trees in the Riggs Lake area. The overhead view on the left contains a small inset image to locate the coincident tree stand on the ground. The same area appears obliquely in the data cloud on the right.

Table 5—Grids created with gridmetrics

Description	Output Gridmetrics
Descriptive statistical height information	Pulsecnt, minht, maxht, aveht, modeht, stdevht, varianht, cvht, skewht, kurtht, aadht
Percentile height distribution of returns	p05ht, p10ht, p20ht, p25ht, p30ht, p40ht, p50ht, p60ht, p70ht, p75ht, p80ht, p90ht, p95ht
Cover (figure 16)	(# of 1st returns > height break) / (total number of 1st returns)
[*]E (elevation relief ratio)	Derived from gridmetrics: E = (aveht - minht) / (maxht - minht)
[*]Parker and Russ 2004	

lower than 2 meters above the ground are eliminated from the analysis to separate ground points—the effects of boulders, shrubs, and logs—from canopy returns (Naesset 2002; Naesset 2004). Canopy cover is calculated at 3 meters above the ground according to the proportion of first returns above 3 meters in a cell (Strunk and others 2008).

The 25-meter output cell size of the grids was chosen because it is close to the 0.05-hectarefield plot size, which is large enough to summarize forest conditions, not the individual trees (figure 16). Minimum height values should be around the understory cutoff of 2 meters. Higher values indicate canopy too dense for the laser pulse to penetrate to the understory or no returns between 2 meters above the ground surface and the minimum value were measured. Either the 90th or 95th percentile height raster is a good indicator of canopy height.

Fuel-Bed Obstacle Density

Obstacle density is a concept that Seielstad and Queen (2003) borrowed from aerodynamic roughness literature to describe nonground lidar returns in the forest fuel bed (≥ 2 meters above the ground). It is defined as the number of nonground points within the fuel bed per square meter, normalized by the total number of ground and fuel returns.

The densities of the returns are calculated with Fusion's densitymetrics functions. Before the densities can be determined, the delivered ground-point ASCII tiles have to be converted to Fusion's LDA format, a binary format similar to LAS, but without all its required headers and placeholders. After calculating the densitymetrics of the ground points and the part of the data lower than 2 meters above ground, ArcGIS derives the understory fuel-bed densities by subtracting the ground-point density from the less-than-2-meter data. Normalizing the fuel-bed densities to all the returns in the under-2-meter data, including the ground points, generates the obstacle density.

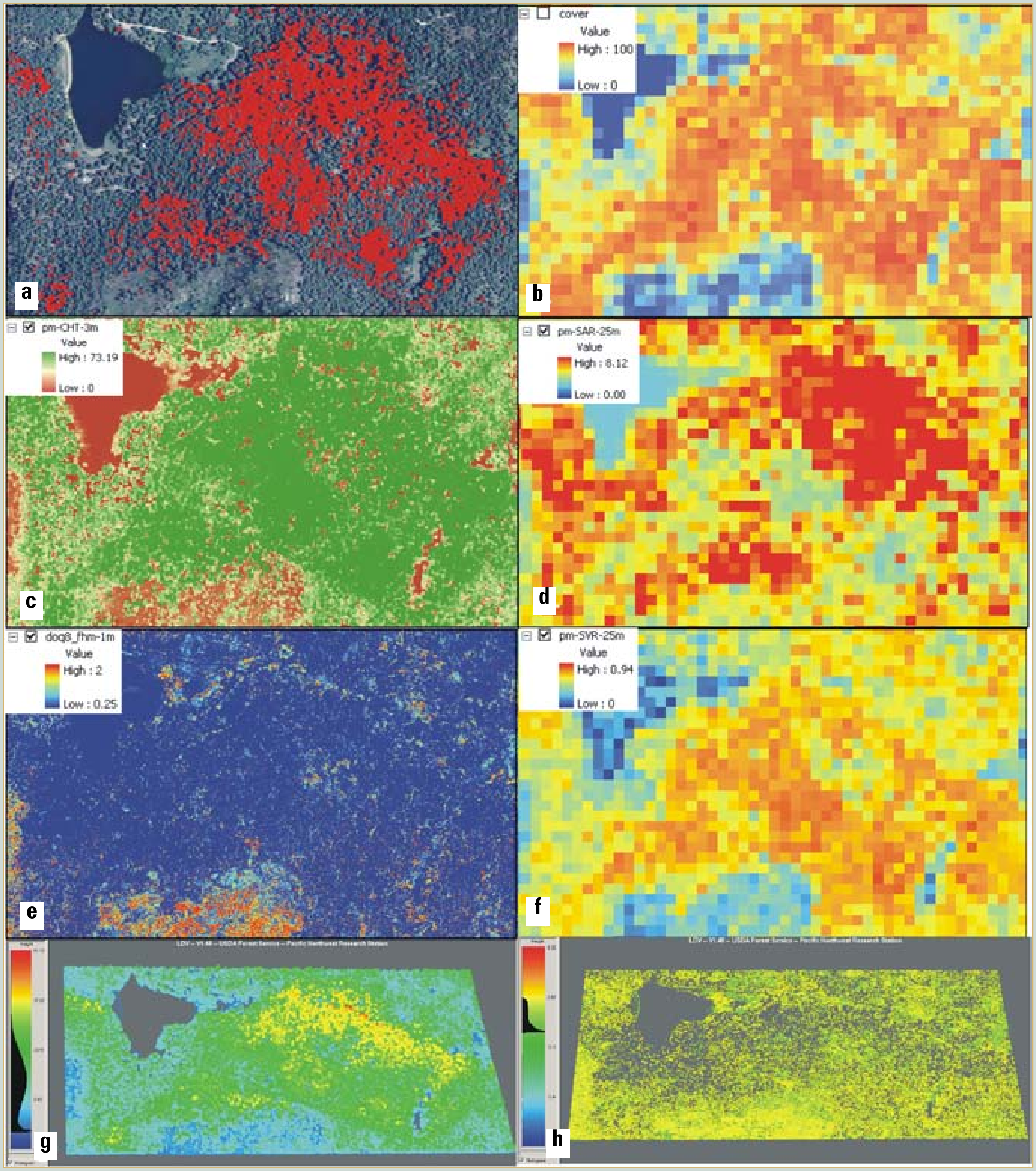


Figure 14—Old-growth stand southeast of Riggs Lake: *a)* **1-meter NAIP with CHM ≥ 25 m in red;** ***b)*** **canopy cover calculation at 25 m;** ***c)*** **CHM calculated at 2.5 m;** ***d)*** **surface area ratio;** ***e)*** **forest floor visualization at 1 m;** ***f)*** **filled volume (surface volume ratio) at 25 m;** ***g)*** **point-cloud visualization of canopy height;** ***h)*** **understory vegetation/litter < 2 m visualization.**

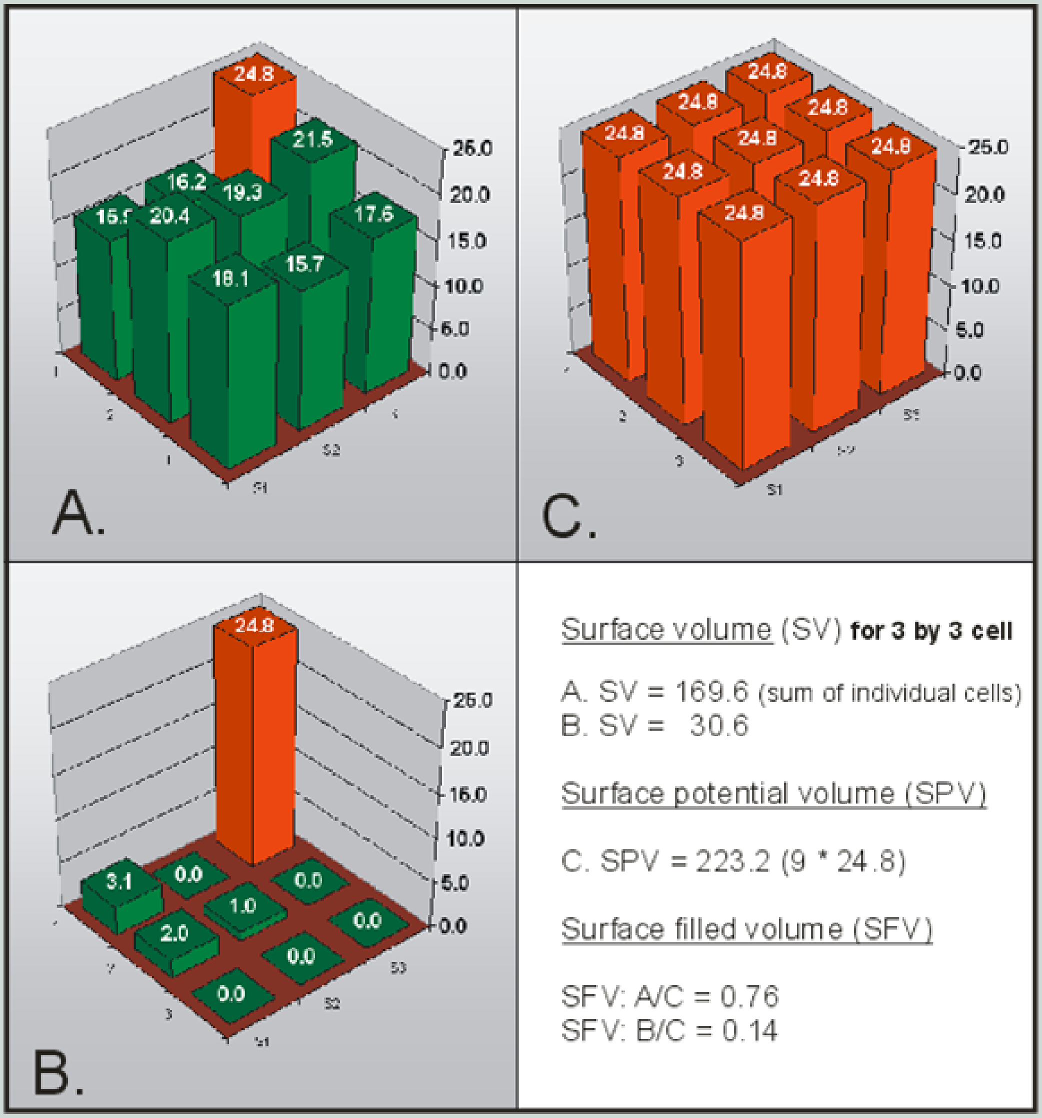


Figure 15—Canopy volume calculation for hypothetical canopy-height values in a 3-by-3 neighborhood.

Forest-Understory Fuel-Bed Visualization

Comparing differences in return densities in the understory fuel bed to the densities of the ground returns in the same location provide information on the presence of material like logs littering the forest floor. The densities were calculated on a grid with 25-meter cells. Visualizing this litter as a height model becomes possible after removing the overstory from the point data. In areas without canopy cover, logs on the forest floor appear in the CHM by restricting the color ramp to the 2-meters-above-ground height.

To visualize this material under canopy cover, a fuel-bed height model was created after Fusion's Clipdata command extracted the points below 2 meters from the LAS. The principle is the same as the one used to create the CHM. To make the size of the understory material close to realistic, a 1-meter cell size was used, the smallest one possible based on the spatial resolution of the bare-earth model. Because an output raster for the entire project area would be too large for most computers to handle, it was subdivided into three sections following the same north/south DOQQ boundaries as the bare-earth model.

Figure 17 shows examples where forest conditions are characterized by the closed and dense canopy of the Riggs Lake old-growth stands. Compared to the conditions in figure 18, where the canopy opened up after the 2004 Nuttall fire, the forest floor here is covered by many logs easily visible between the still-standing snags without removing the canopy.

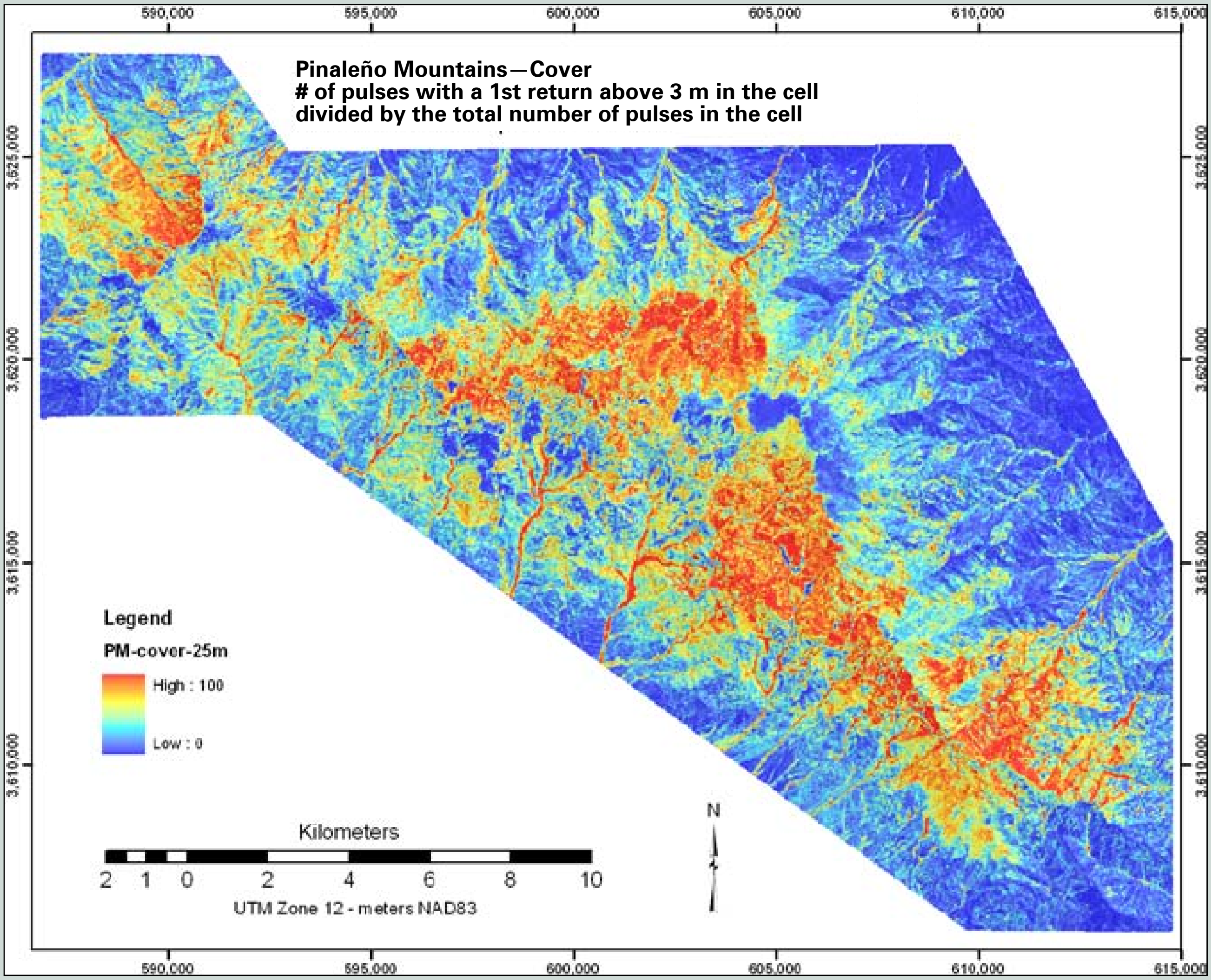


Figure 16—The vegetation cover calculation produced by Fusion's gridmetrics function.

Lidar Preparation for Field Data Measurements

Field plot maps for accessible locations were produced using ArcMap 9.2 and a software extension called Mapbooks. Combining these two programs allows the user to make an indexed book of maps with spatially referenced points, plots, imagery, and, in this case, lidar tiles. The field maps were generated at 1:2,400 and 1:6,000 scales. The lidar plot-data clouds were interactively subset using Fusion to a circle representing a half hectare (39.89-meter radius). This puts the field plot to be measured into context and represents it as a 20th of a hectare (12.62 m radius) (figure 19). Each subset was referenced to the plot center points and printed on the reverse side of the plot map. The planned field protocol is described by Wilcox and others (2009).

The details of the way the mapbooks were created are available in appendix 4. The points, representing the return heights of all the 0.05-hectare plots, were subset from the tiles using a batch script. Cloudmetrics, representing the same statistical and height information calculated by gridmetrics, were derived for each of the field plots. After the field season, when the usable plots are known and their locations have been adjusted based on the GPS measurements, the plots will need to be subset again. The cloudmetrics resulting from those new data sets will become the basis for building relationships between the field and the lidar data.

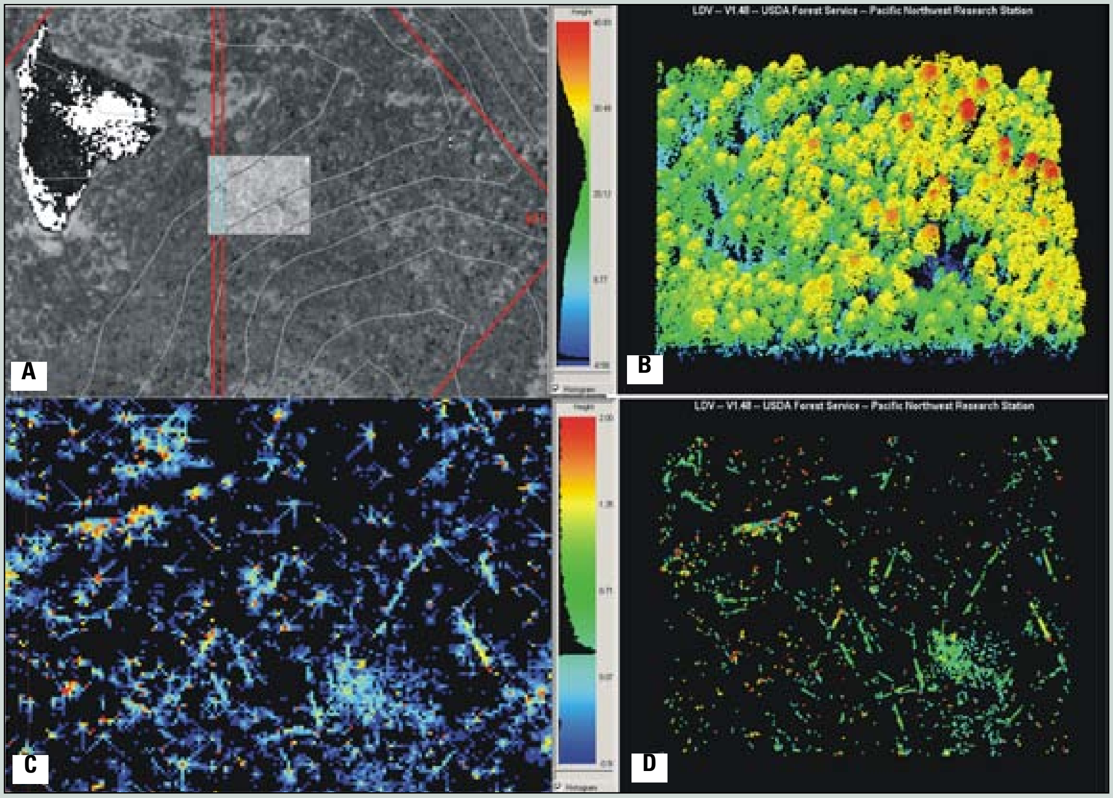


Figure 17—A visualization of the elements of the forest floor under a dense canopy: *A)* the location near Riggs Lake; *B)* an oblique view of the complete lidar point cloud; *C)* ArcGIS grid of the point cloud with the data restricted to 2 m above the ground and omitting anything at 0.25 m above the ground; *D)* lidar data cloud that was the source of image *C*.

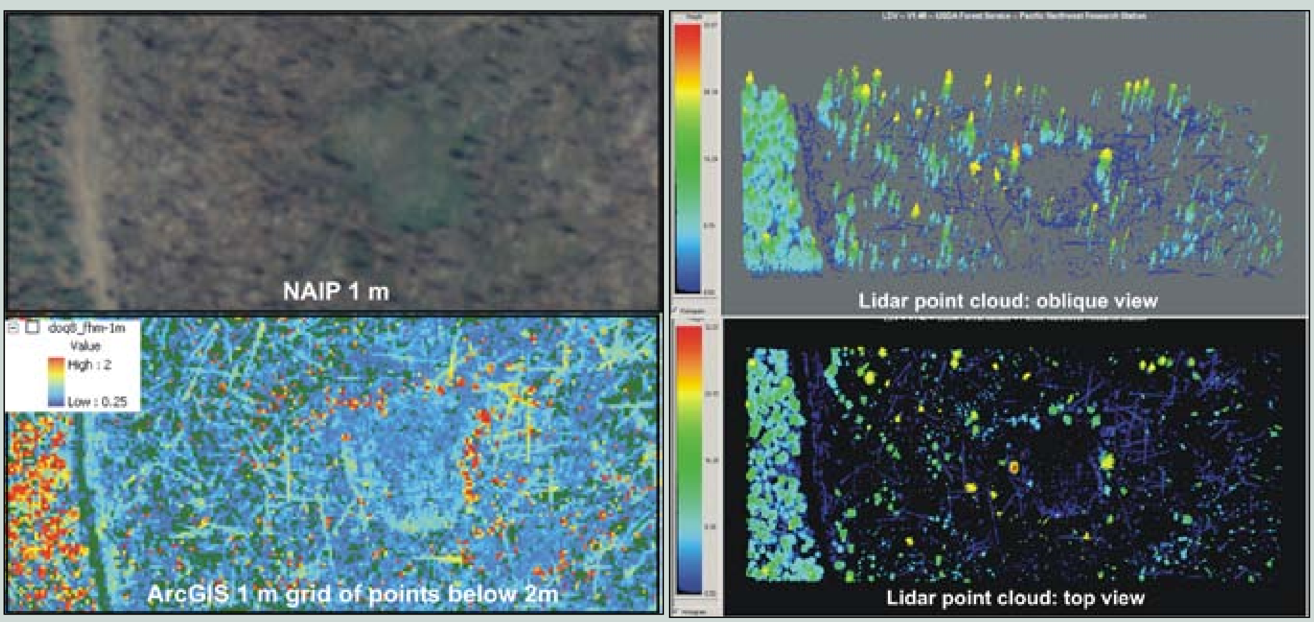


Figure 18—A collection of graphics visualizing forest-floor woody debris in an area with an open tree canopy.

Data-Processing Hardware and Timeline Summaries

Most of the analysis in this report was performed using an IBM class dual processor IV workstation (two Intel Xeon CPUs 5140, running at 2.33 GHZ) with 3 GB of RAM, a 500-GB primary hard drive and a 1.5 TB secondary one. The operating system was Windows XP Professional (version 2002) with service pack two and Forest Service image version 6.1e (version 1.2.6). The two main software packages used during this analysis were Fusion (version 2.7) and ArcGIS (version 9.3).

Table 6 shows the timeline of phases one and two of this project. Most of the processing time figures represent how long it takes to run the different analyses. The time to write or modify the scripts is generally small compared to processing.

Conclusions

This phase two report complements the phase one briefing stating the acquisition contracting specifications (Laes and others 2008). Phase two included quality assessment and the automated processing steps to transform information in the point data to more accessible raster layers. It also answered a few more unknowns related to expected time frames.

The raster parameters derived during this phase of the project, combined with the yet-to-be-modeled relationship between the processed field data and their corresponding lidar point cloud, will form the basis for extracting projectwide information about forest structure—DBH (diameter at breast height), basal area, and size classes—along with biomass and parameters to populate fuel models.

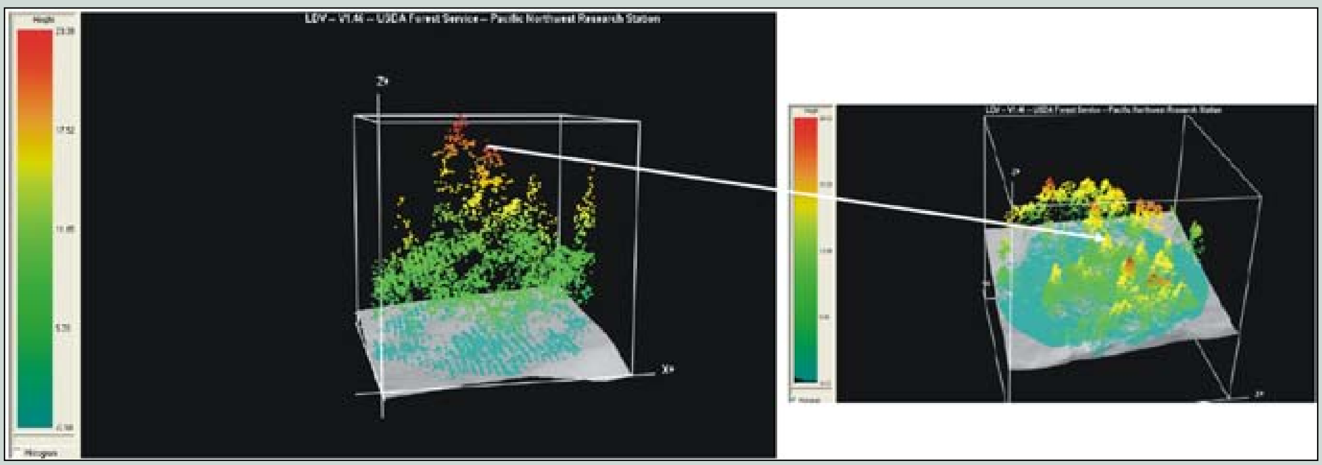


Figure 19—Plot G12 is utilized to relate data clouds of two sizes spatially to trees on the ground. The cloud on the left is the size of a field plot: 0.05 hectares or 0.123 acres. The larger subset of the data cloud on the right—0.5 hectares and 1.23 acres—helps field personnel relate to the smaller data cloud.

Table 6—Timeline summary for the Pinaleño Mountains lidar project

Project phase	Topic	Duration (weeks)	Timeline
Phase 1	Lidar acquisition specification	12	February–June 2008
	Project coordination, workshop, and conference calls	1	January–September 2008
	RFQ bid posting		July 2008
	RFQ info compilation	1	July 2008
	RFQ evaluation	3	August 2008
	Field-data protocol development and testing	2	Summer 2008
	Data acquisition	1	End of September 2008
	Data delivery		Early February 2009 (expected by December 2008)
Phase 2	QA/QC	4	Early March 2009
	Project Coordination and conference calls	1	Early March–August 2009
	Data analysis and methods development	6	Mid April 2009
	Aspen delineation (Including write up)	3	April–May 2009
	Creation of field data sheets	1	April–May 2009
	Report writing (draft and editing)	7 (5 + 2)	May 2009
	Field data-protocol development	2	Spring 2009
	Field data collection (CNF)	12	Summer 2009
	Workshop preparation	6	June-July-August 2009
	Workshop	0.5	17- 19 August 2009
Phase 3 (TBD)	Post-processing of field data		
	Statistical model generation		
	Model application		
	Field check the models		

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Appendices may be in a separate file

* Appendix 1: Batch Files

Introduction

This appendix is a supplement to "Mapping Vegetation Structure in the Pinaleño Mountains Using Lidar," which documents the methodology of phase two of the project. This supplement contains the batch scripts developed to facilitate and automate lidar processing from the Fusion DOS command line. The scripts appear in smaller type and within an outlined area.

A few prerequisites must be met to run the DOS batch files without editing:

- The path to the Fusion executable (fusion.exe) has to be set in the environment variables. This procedure is explained in the Fusion manual (McGaughey 2009) and requires administrative privileges on Forest Service imaged workstations.

- A full understanding of the Fusion command syntax described in the manual is advised.

- Either the folders have to be organized as described here or the batch files must be edited to match computer drive paths. The listed directory structure can be created in Windows or from the DOS prompt before the scripts are run, or their creation can be incorporated into the batch files.

These batch files are structured to run from the processing folder in the DOS prompt window unless noted otherwise:
\processing

Start to run the scripts by typing the file name at the DOS prompt, followed by the Enter key, or by right-clicking on the file from Window Explorer and selecting Open (doing this by accident can have time-consuming consequences, especially for the catalog file, where an existing catalog.html file gets wiped clean). The advantage of starting script execution from a DOS window is that the DOS prompt remains open after the run has been completed and any error messages can be checked.

Important note: When editing a batch file, do not open it by right-clicking or double-left-clicking on the file name. This initializes the run and overwrites previous outputs if they exist. To view the content of a batch script or edit it, right-click and select Edit from Windows Explorer or open the file from within a text editor.

The scripts starting with "Create…." are used to queue (cycle through) all the files, in this case lidar tiles, and move around the folders. They call up a "Do…" script that contains the Fusion analysis. After all the tiles have been processed, the "Create…" script may contain additional functions to merge the processed tiles and export them into ASCII files, which can be imported into ArcGIS.
Example: "**Create**Canopysurface.bat," which calls "**Do**Canopy.bat."

The reason for the "Do…" vprefix before the Fusion descriptor is that the batch files cannot have the same name as existing Fusion executables.

Avoid spaces in the folder and file names. Neither DOS nor ArcGIS handles them well. DOS can recognize spaces if quotation marks are used.
Example: canopymodel /outlier:-5,75 "/ground: E:\Products\BareEarth\pm-be-3m.dtm"

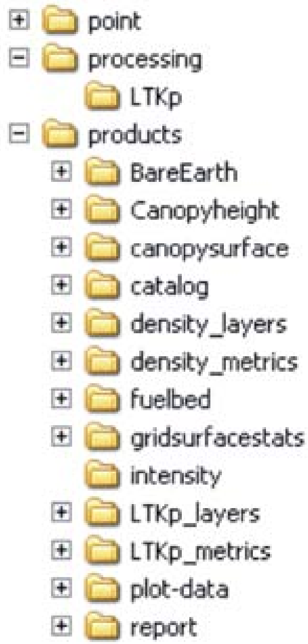
Projection information for all the grids and point files:

- UTM zone 12
- Horizontal units: meters
- Vertical units: meters
- Horizontal datum: NAD 83
- Vertical datum: NAVD88, Geoid03

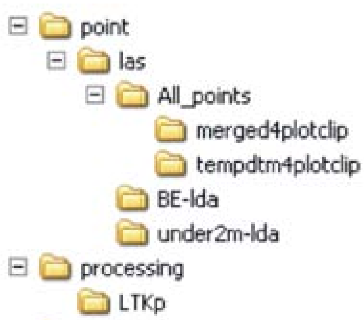
*Main document is in separate file.

Folder Structure

The basic file structure has three main folders: point, processing, and products:

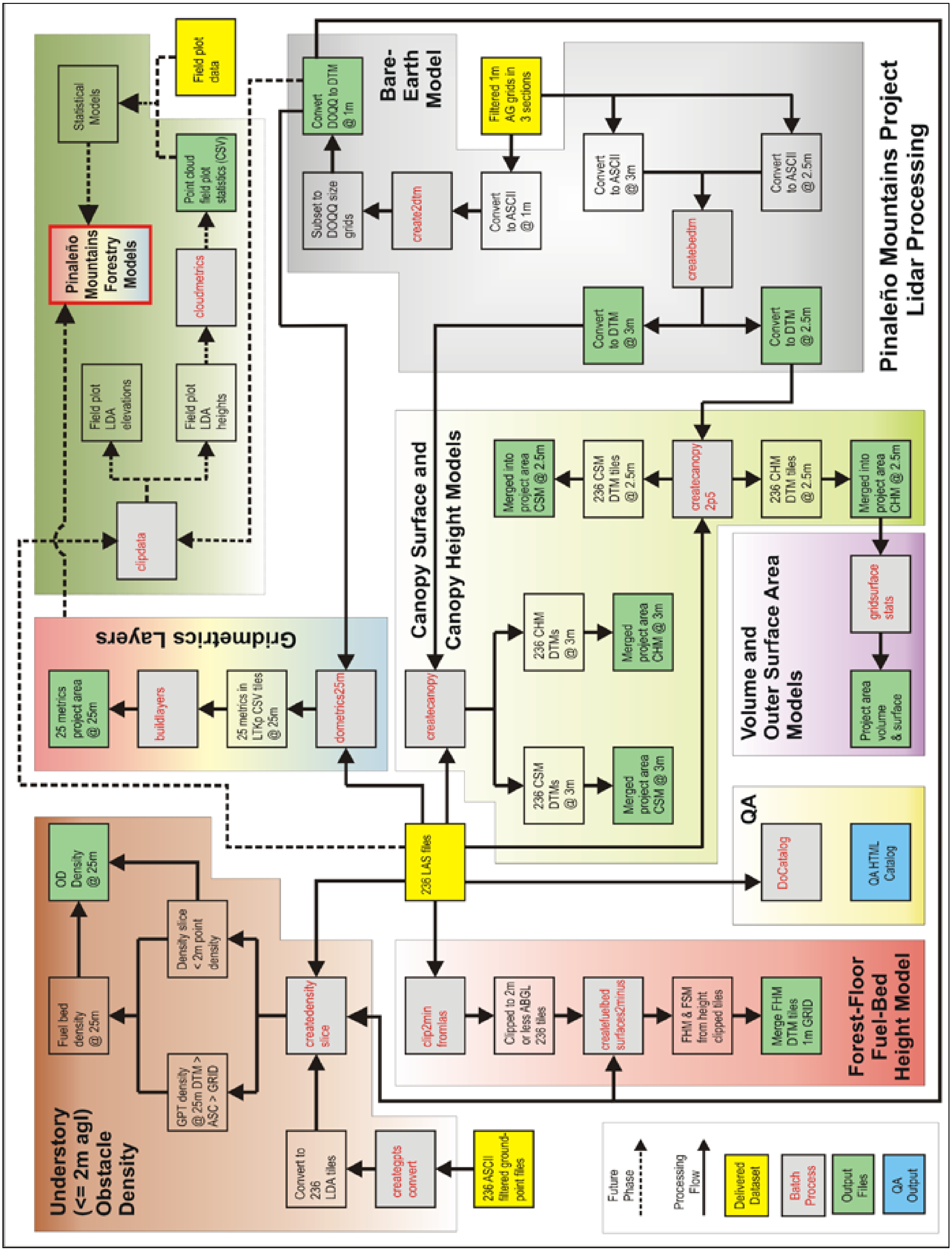


Details of each folder are listed below



- products
  - BareEarth
    - 3sections
    - be_2m
    - be_2masp
    - be_2mhs
    - be_2msl
    - be_2mslperc
    - DOQQ
    - info
    - temp
  - Canopyheight
    - 2p5m-dtm
    - 3m-dtm
    - chm_ge25
    - e
    - HH-derivatives
    - info
    - large5m
    - pm-cht-2p5m
    - pm-cht-3m
    - pm-cht-25m
    - prep-layers
  - canopysurface
    - 2p5m-dtm
    - 3m-dtm
    - HighestHit
    - info
    - pm-csm-3m
  - catalog
    - catalog1
    - catalog2
    - catalog-all
    - density
    - intensity
    - catalog-all.zip
  - density_layers
    - info
    - od
    - pm_d2min-25m
    - pm-dfuel-25m
    - pm-dgpts-25m
    - pm-od-25m
    - pm-od-25mnd
  - density_metrics
    - allslices
    - groundpts
    - under2m
  - fuelbed
  - gridsurfacestats
    - 25m
    - 30m
    - info
  - intensity
  - LTKp_layers
    - aadht
    - aveht
    - cover
    - cvht
    - info
    - kurtht
    - maxht
    - minht
    - modeht
    - p05ht
    - p10ht
    - p20ht
    - p25ht
    - p30ht
    - p40ht
    - p50ht
    - p60ht
    - p70ht
    - p75ht
    - p80ht
    - p90ht
    - p95ht
    - pm-ppbiomass
    - pulsecnt
    - skewht
    - stdevht
    - under2m
    - varianht
  - LTKp_metrics
    - from-3mBE
    - under2m
  - plot-data
    - field sheet examples
    - lidarcloud-0p05ha
      - elevation
      - height
    - Mapbooks
    - notes
    - protocol
    - samplegrid
  - report

Analysis Flowchart



Quality Control

Catalog function:

The outputs from the catalog include the following, depending on what outputs are requested:

- A summary CSV file
  Example: E:\products\catalog\catalog-all\PM_catalog-all.csv

- A summary HTML file
  Example: \products\catalog\catalog-all\PM_catalog-all.html

- An image of the area covered by the tile boundaries

- A pulse density image color coded according to contract specifications

- An intensity image (the catalog function can be executed with different parameters to stretch the color ramp or change the spatial resolution)

- A flag for tiles that contain lidar point outliers

- A log file (this one includes time stamps to calculate elapsed processing time)

When the **/**index switch is included, executing the catalog function generates index files for each tile. That slows down the execution of the first-time run but speeds up further analysis significantly.

DoCatalog.bat

```
rem create an output folder (\products\catalog\catalog-all)
rem when this file is run the first time, it will create index files which can take many hours
rem for additional run, take out the /index switch and any other part that does not need to be redone

rem create output folders if they do not exist
rem md \products\catalog
rem md \products\catalog\catalog-all

cd \point\las\All_points

rem Check for minimum density, draw the tiles on the intensity bmp
catalog /log:PM-catlog /index /image /drawtiles /coverage /countreturns /density:900,3,8 /firstdensity:900,3,8 /
    intensity:900,10,210 /bmp  /outlier:2 *.las \products\catalog\catalog-all\PM_catalog-all

cd \processing
```

Processing time: The first run took just over 10 hours; subsequent runs to generate output from the catalog batch, when the index files existed—and the index switch was remarked out of the script—took about an hour and a half to run.

Note: Processing time for additional runs depends on CPU processing speed and the numbers of switches or output products requested.

The catalog function does not check for the following:

- Opposing flight lines; the \Deliverables\Vectors\Flightlines.shp was modified to check this.
- Scan angle; a few randomly selected LAS tiles were exported to an Access database. Within Access, the scan angles are summarized with a query.
- Fifty percent flight-line sidelap: this was checked with the USGS consistency code.

Intensity images can also be created with the gridmetrics function, which uses a different algorithm; the results look very noisy (salt and peppery).

Lidar Processing

Each of the following sections describes briefly the procedures and lists the scripts that were used. Processing times of more than one day usually represent 24 hours of uninterrupted computer time (not person times).

Bare-Earth Models at 1, 2.5, and 3-meter Spatial Resolution

Bare-Earth Models for the Entire Project Area at 1, 2.5, and 3 Meters:

These scripts converted the ASCII files created after exporting the bare-earth models delivered by Watershed Sciences from the ArcGIS grid format (Toolbox > conversion tools > From Raster > Raster to ASCII). After converting the three sections covering the project area from ASCII to DTM format, the DTMs were merged into a single 1 m and a 3 m bare-earth model. The 3 m resolution layer was created because the file size of the 1 m model was too large for some of the Fusion follow-up analysis.

Batchfiles: CreateBeDtm.bat and Do2Dtm.bat

The bare-earth models are stored under \products\bareearth

CreateBeDtm.bat (calls the Do2Dtm.bat)

```
cd \products\bareearth\3sections\3sections-grids\3sections-asc

dir /b *.asc>filelist.txt

rem Convert the 3 ‘section’ ascii files to dtm

for /F “eol=; tokens=1* delims=,. “ %%i in (filelist.txt) do call \processing\Do2DTM %%i

rem merge the dtms into a 1m bare earth model and a 3 m bare earth model

cd \products\BareEarth\3sections\3sections-dtm

mergedtm /overlap:new /verbose /disk \products\BareEarth\pm-be-1m.dtm *.dtm
mergedtm /overlap:new /verbose /disk /cellsize:2.5 \products\BareEarth\pm-be-2p5m.dtm *.dtm
mergedtm /overlap:new /verbose /disk /cellsize:3 \products\BareEarth\pm-be-3m.dtm *.dtm
```

Do2Dtm.bat

```
rem converts the ascii files generated by arcgis to fusion dtms
ASCII2DTM \products\BareEarth\3sections\3sections-dtm%\1.DTM M M 1 12 2 2 %1.ASC
```

DOQQ-Sized Bare-Earth Model at 1 Meter

These subsets were created for the LTKp gridmetrics calculations (see that section). The LTKp processor is designed to keep multiple grids in memory but the projectwide grid files, and those that divided the area into three sections were still too large for Fusion and the processing computer. Before the DOQQ-sized DTMs could be created, the ArcGIS grids needed to be clipped to the DOQQ limits (ArcToolbox > Data Management tools > Raster > Raster Processing > Clip). After the DOQQ bare-earth models were subset, they needed to be converted to ASCII files.

To generate the DOQQ-sized 1 m DTM bare-earth models, run

\products\BareEarth\DOQQ\doqq-asc\create2dtm.bat (calls Do2Dtm.bat)

```
cd \products\BareEarth\DOQQ\doqq-asc

dir /b *.asc>filelist.txt

for /F "eol=; tokens=1* delims=,. " %%i in (filelist.txt) do call \products\BareEarth\DOQQ\doqq-asc\Do2DTM %%i
```

\products\BareEarth\DOQQ\doqq-asc\Do2DTM.bat

```
ASCII2DTM \products\BareEarth\DOQQ\doqq-dtm\%1.DTM M M 1 12 2 2 \products\BareEarth\DOQQ\doqq-asc\%1.ASC
```

The output is stored under \products\bareearth\3sections

Processing time: about 1 day

Canopy Models at 3 -MeterSpatial Resolution

These scripts produce the canopy surface model (CSM) and canopy height model (CHM). The difference between the two is that the CHM is normalized to the bare-earth model and represents heights above ground instead of elevations as the CSM does.

CSM is stored under \products\canopysurface
CHM is stored under \products\canopyheight

CreateCanopysurface.bat (Calls docanopy.bat)

```
cd \POINT\LAS\ALL_POINTS

rem dir /b *.las>filelist.txt

rem loop through all LAS files in folder and do processing
for /F "eol=; tokens=1* delims=,. " %%i in (filelist.txt) do call \processing\docanopy %%i

cd \products\canopyheight\3m-dtm
mergedtm /overlap:new \products\canopyheight\PM-CHT-3m.dtm *.dtm
cd \products\canopyheight\
dtm2ascii PM-CHT-3m.dtm \products\canopyheight\pm-cht-3m.asc

cd \products\canopysurface\3m-dtm
mergedtm /overlap:new \products\canopysurface\PM-CSM-3m.dtm *.dtm
cd \products\canopysurface\
dtm2ascii PM-CSM-3m.dtm \products\canopysurface\pm-CSM-3m.asc

cd \processing
```

docanopy.bat

```
rem Canopy surface model
canopymodel \Products\CanopySurface\3m-dtm\%1_CSM.dtm 3 m m 1 12 2 2 %1.las

rem canopy height
canopymodel /outlier:-5,75 “/ground:E:\Products\BareEarth\pm-be-3m.dtm”

\Products\CanopyHeight\3m-dtm\%1_CHT.dtm 3 m m 1 12 2 2 %1.las
```

Processing time: 2 days

Canopy Models at 2.5-Meter Spatial Resolution

This is necessary to generate the gridsurfacestat models—surface area and surface volume calculations—with the same cell size as the gridmetrics output models (i.e., 25 m)

CreateCanopysurface2p5.bat (Calls docanopy2p5.bat)

```
cd \POINT\LAS\ALL_POINTS

rem loop through all LAS files in folder and do processing
for /F “eol=; tokens=1* delims=,. “ %%i in (filelist.txt) do call \processing\docanopy2p5 %%i

rem merge canopy products
cd \products\canopyheight\2p5m-dtm
mergedtm /overlap:new \products\canopyheight\PM-CHT-2p5m.dtm *.dtm
cd \products\canopyheight\
dtm2ascii PM-CHT-2p5m.dtm pm-cht-2p5m.asc

rem merge canopy products
cd \products\canopysurface\2p5m-dtm
rem mergedtm /overlap:new \products\canopysurface\PM-CST-2p5m.dtm *.dtm
cd \products\canopysurface\
dtm2ascii PM-CSM-2p5m.dtm pm-CSM-2p5m.asc

cd \processing
```

docanopy2p5.bat

```
rem CSM @ 2.5m
rem Canopy surface model
canopymodel \Products\CanopySurface\2p5m-dtm\%1_CSM.dtm 2.5 m m 1 12 2 2 %1.las

rem CHM @ 2.5m
rem the 2.5 m is needed to create surface and volume derive models at the same 25m cell size
rem canopymodel /outlier:-5,75 “/ground:E:\Products\BareEarth\pm-be-2p5m.dtm”
\Products\CanopyHeight\2p5m-dtm\%1_CHT.dtm 2.5 m m 1 12 2 2 %1.las
```

Volume and Surface Models Derived from 2.5-Meter Canopy Height Model (CHM) at 25-Meter Spatial Resolution

Fusion command required to create the surface volumes and surfaces is not yet part of the released version of Fusion. It will be available after V. Kane's (University of Washington) publications to fulfill the requirements for his PhD are accepted.

This computation is based on the 2.5 meter CHM, from which it creates a multiple neighborhood (which is set at 10).

This analysis calculates volumes in the following way:

- Assigning the maximum height within the 10-by-10-block neighborhood to all the cells (potential volume under the surface at 25m)
- Assigning the sum of the 10-by-10 CHM to the 25 m block (the volume under the canopy surface)
- Calculating the ratio of the volume to the potential volume (the filled volume)

This analysis also calculates the

- Top of surface area
- Surface area ratio (top of surface area / by planimetric surface area)

These metrics provide indications of the overall canopy structure and complexity;

CreateGridSurfaceStats25.bat and Do2Ascii.bat

CreateGridSurfaceStats25.bat

```
gridsurfacestats /verbose \products\Canopyheight\pm-cht-2p5m.dtm \products\gridsurfacestats\25m\pm-area25.dtm 10
gridsurfacestats /verbose /area \products\Canopyheight\pm-cht-2p5m.dtm \products\gridsurfacestats\25m\
    pm-area25.dtm 10

cd \products\gridsurfacestats\25m

dir /b *.dtm>filelist.txt

for /F "eol=; tokens=1* delims=,. " %%i in (filelist.txt) do call \processing\Do2ASCII %%i
```

Do2Ascii.bat

```
DTM2ASCII %1.DTM %1.ASC
```

Store under created output \products\gridsurfacestats\

ASCII File (and DTMs)	Cell Size (meters)	ArcGIS Grids	Remarks
pm-area25_max_height	25	pm-maxht-25 m	Maximum height in the 10-by-10 block from the CHM
pm-area25_potential_ volume	25	pm-potvol-25 m	Maximum potential volume under the canopy height surface using the maximum height in the cell
pm-area25_surface_ volume	25	pm-sv-25 m	Volume under the canopy height surface computed from the CHM
pm-area25_surface_ volume_ratio	25	pm-svr-25 m	Filled volume pm-sv / pm-potvol Ratio of the volume under the canopy height surface divided by the volume under the surface defined by the maximum height in the cell
pm-area25_surface_area (only created with /area switch)	25	pm-sa-25 m	Area of the canopy height surface Indicative of the outer surface ruggedness
pm-area25_surface_area_ ratio	25	pm-sar-25 m	Pm-sa / 900 m^2 Ratio of the area of the canopy height surface divided by the cell area. Canopy roughness or rumple index (Parker and others 2004)

Articles:
Jenness (2004)
Parker and Russ (2004)
Parker and others(2004)
Kane and others (2008)

Processing time from start of batch file to ArcGIS grids: approximate 1 hour

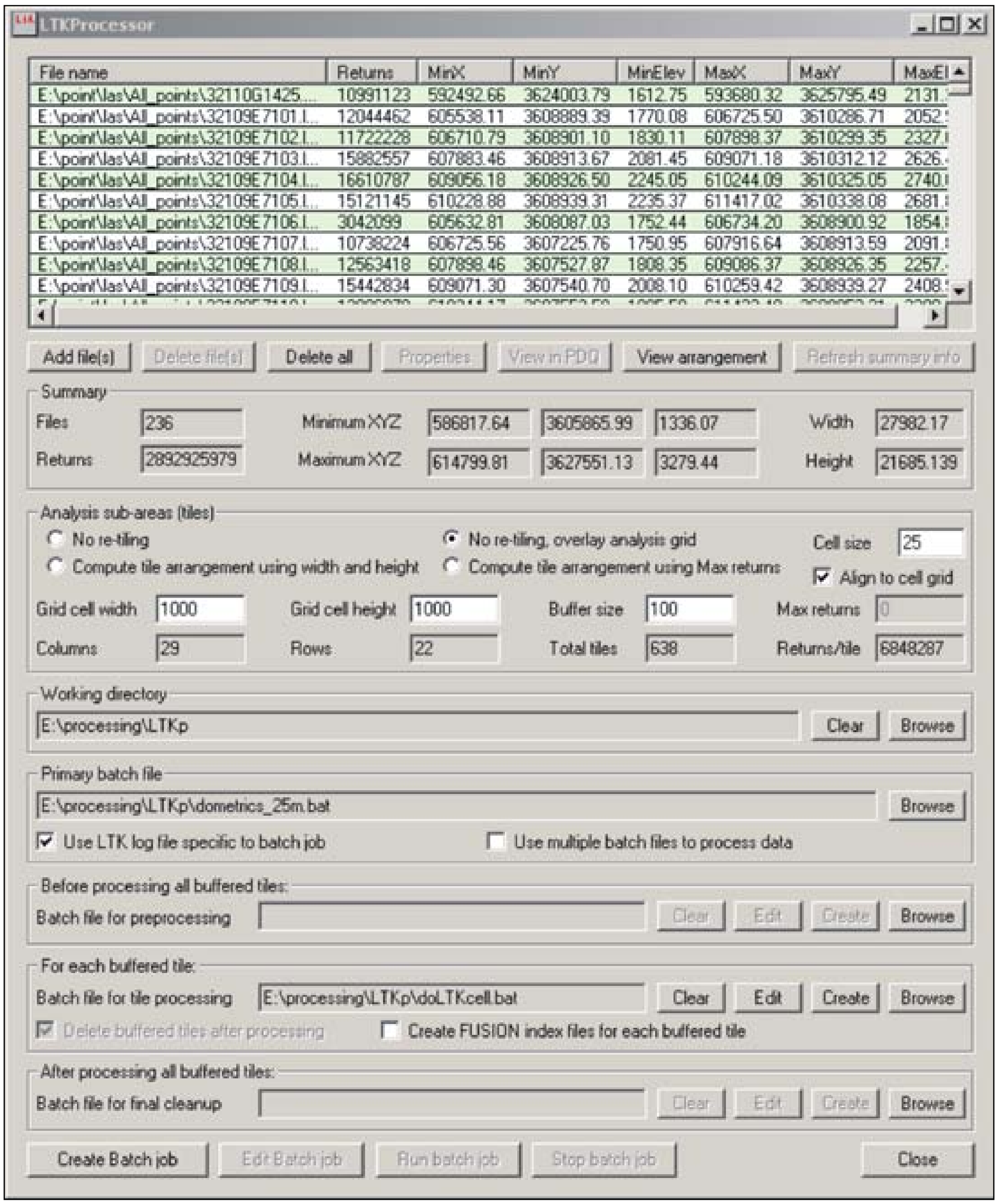
Gridmetrics Models at 25-meter Spatial Resolution

The gridmetrics function requires the input of the 1 m bare-earth model. Using the function on the delivered tiles produces edge effects along their sides. This occurs because the tiles are generated in geographic coordinates. After projecting the tiles, slivers with no data remain along the edges. Grid cells overlapping these cells should be calculated based on the returns from the partial cells spanning the two adjacent tiles. When the statistics are calculated on cells containing partial data from either tile only, the edge effects become visible after merging the grids to the project area. These effects can be avoided by virtually reducing the original lidar tiles into smaller ones than the originals while also defining a buffer around the new smaller virtual tiles. The buffer and the gridcell width/height (i.e., the size of the new virtual tile) should be multiples of the chosen cell size. Fusion's LTKp tool helps write the script for this process. These batch files are stored under \processing\LTKp

The gridmetrics are calculated at 2 m above the ground because they are designed to look at the forest canopy structure. The only exception is the canopy cover, which is calculated at 3 m above the ground. A larger cell size than the CHM is required because these metrics relate to forest structure. At smaller cell sizes, there might not be enough points to derive valid statistical information. The statistics characterize the presence of a tree, not the forest or vegetation cover. When the cell size is too small, the distribution of cover values tends to be bimodal with values near 0 and 100 percent and few values between. The cell size should be larger than individual tree crowns, especially for cover calculations (McGaughey 2009).

The cell size of 25 m was selected since it is close to the plot size of the field data acquisition (0.05 ha). The field data (to be acquired during the summer of 2009) will be used to establish forest relationships with the lidar data. All the gridmetrics are calculated at 2 m above the ground.

dometrics_25m.bat and doLTKcell.bat



dometrics_25m.bat (calls doLTKcell.bat)

```
@ECHO OFF
REM LTKProcessor -- Version 1.20
REM Batch file created by LTKProcessor on 03/30/09 at 15:21:23

REM Data processing extent--LL(586800.00,3605850.00) UR(614800.00,3627575.00)
REM Analysis tile grid is 29 columns by 22 rows
REM Analysis cell size is: 25.000000

REM set working drive and directory
E:
CD E:\processing\LTKp

ECHO Processing analysis tile for column:     1 row:     1 (TILE_C00001_R00001)
ECHO Tile 1 of 638
CALL “E:\processing\LTKp\doLTKcell.bat” TILE_C00001_R00001 586800.0000 3605850.0000 587800.0000
    3606850.0000 586800.0000 3605850.0000 587900.0000 3606950.0000 “E:\processing\LTKp\LTKP_filelist.txt”
    100.0000 1000.0000 1000.0000

ECHO Processing analysis tile for column:     1 row:     2 (TILE_C00001_R00002)
ECHO Tile 2 of 638
CALL “E:\processing\LTKp\doLTKcell.bat” TILE_C00001_R00002 586800.0000 3606850.0000 587800.0000
    3607850.0000 586800.0000 3606750.0000 587900.0000 3607950.0000 “E:\processing\LTKp\LTKP_filelist.txt”
    100.0000 1000.0000 1000.0000

ECHO Processing analysis tile for column:     1 row:     3 (TILE_C00001_R00003)
ECHO Tile 3 of 638
CALL “E:\processing\LTKp\doLTKcell.bat” TILE_C00001_R00003 586800.0000 3607850.0000 587800.0000
    3608850.0000 586800.0000 3607750.0000 587900.0000 3608950.0000 “E:\processing\LTKp\LTKP_filelist.txt”
    100.0000 1000.0000 1000.0000
                    .
                    .
                    .
ECHO Processing analysis tile for column:    29 row:    21 (TILE_C00029_R00021)
ECHO Tile 637 of 638
CALL “E:\processing\LTKp\doLTKcell.bat” TILE_C00029_R00021 614800.0000 3625850.0000 615800.0000
    3626850.0000 614700.0000 3625750.0000 614799.8100 3626950.0000 “E:\processing\LTKp\LTKP_filelist.txt”
    100.0000 1000.0000 1000.0000

ECHO Processing analysis tile for column:    29 row:    22 (TILE_C00029_R00022)
ECHO Tile 638 of 638
CALL “E:\processing\LTKp\doLTKcell.bat” TILE_C00029_R00022 614800.0000 3626850.0000 615800.0000
    3627850.0000 614700.0000 3626750.0000 614799.8100 3627551.1300 “E:\processing\LTKp\LTKP_filelist.txt”
    100.0000 1000.0000 1000.0000

@ECHO ON
```

doLTKcell.bat

```
REM Tile processing batch file created by LTKProcessor on 03/26/09 at 11:19:37

REM Expected command line parameters:
REM   %1    Name of the buffered tile containing LIDAR data
REM   %2    Minimum X value for the unbuffered tile
REM   %3    Minimum Y value for the unbuffered tile
REM   %4    Maximum X value for the unbuffered tile
REM   %5    Maximum Y value for the unbuffered tile
REM   %6    Minimum X value for the buffered tile
REM   %7    Minimum Y value for the buffered tile
REM   %8    Maximum X value for the buffered tile
REM   %9    Maximum Y value for the buffered tile
REM The buffered tile file name looks like this: TILE_C00001_R00002. The row and column numbers
REM specify the tile location with the origin of the row and column coodinate system in the lower left

REM Initially, the values for %2, %3, %4, %5 can be used to clip data products produced using the buffered tile

REM Insert commands that use the original tile corners before the the block of SHIFT commands



REM ------------------------------------------------------
REM After the 4 SHIFT commands, variables %6, %7, %8, %9 contain the following values:

REM   %6    Name of the text file containing a list of all data files
REM   %7    Buffer size
REM   %8    Width of the unbuffered analysis tile
REM   %9    Height of the unbuffered analysis tile

REM SHIFT command moves command line parameters one position. For example, %10 moves to %9.
REM This is necessary because DOS cannot directly reference more than 9 command line parameters
REM since %10 would be interpreted as %1.

REM Shift last four variables (%10-%14) into positions %6-%9
SHIFT /6
SHIFT /6
SHIFT /6
SHIFT /6

REM Insert commands that use the buffer width and all data files after the block of SHIFT commands

gridmetrics /minht:2 /verbose /gridxy:%2,%3,%4,%5 /buffer:%7 /outlier:-2,100 \products\bareearth\be*.dtm 3 25 \
   products\LTKp_metrics\%1_metrics.csv %6
```

The output from this process produces a CSV file for each of the virtual tiles with 31 columns. The outputs are generated at a 25 m cell size and are stored at \products\LTKp_metrics

The following scripts extract the columns from the CSV files to grids:

Buildlayers.bat (calls extractmetric.bat)

```
rem extract metrics from CSV files and merge into a single coverage
rem 2plus refers to minimum height
rem 25m = cellsize
rem above3 = height break for cover calculation
rem this bat file is run from dos e:\processing\LTKp\
rem it calls extractmetric.bat which in his turns calls doextractmetric.bat
rem the 3 variables after 'extracmetric' on the lines below are the %1 %2 and %3 user needed inputs

cd \processing\ltkp

call extractmetric 5 pulsecnt_25m 1
call extractmetric 6 minht_2plus_25m 1
call extractmetric 7 maxht_2plus_25m 1
call extractmetric 8 aveht_2plus_25m 1
call extractmetric 9 modeht_2plus_25m 1
call extractmetric 10 stddevht_2plus_25m 1
call extractmetric 11 varianceht_2plus_25m 1
call extractmetric 12 CVht_2plus_25m 1
call extractmetric 13 skewnessht_2plus_25m 1
call extractmetric 14 kurtosisht_2plus_25m 1
call extractmetric 15 AADht_2plus_25m 1
call extractmetric 16 P05ht_2plus_25m 1
call extractmetric 17 P10ht_2plus_25m 1
call extractmetric 18 P20ht_2plus_25m 1
call extractmetric 19 P25ht_2plus_25m 1
call extractmetric 20 P30ht_2plus_25m 1
call extractmetric 21 P40ht_2plus_25m 1
call extractmetric 22 P50ht_2plus_25m 1
call extractmetric 23 P60ht_2plus_25m 1
call extractmetric 24 P70ht_2plus_25m 1
call extractmetric 25 P75ht_2plus_25m 1
call extractmetric 26 P80ht_2plus_25m 1
call extractmetric 27 P90ht_2plus_25m 1
call extractmetric 28 P95ht_2plus_25m 1
call extractmetric 29 cover_above3_25m 100
```

Extracmetric.bat (calls DoExtractmetric.bat)

```
@echo off
REM extract a specific metric from CSV files produced by Gridmetrics

if "%1"=="" goto syntax
if "%2"=="" goto syntax
if "%3"=="" goto syntax
goto process

:syntax
echo extractmetric column name multiplier
echo column is the column number in the GridMetrics CSV output
echo name is the name used for the merged output DTM file (don't include the .dtm extension)
echo multiplier used for each cell value (use 100 for cover col 29, 1 for all else)

goto end

:process
@echo on
```

```
REM do the extraction from each tile
REM cd \products\LTKp_metrics
cd \products\LTKp_metrics\under2m

dir /b *.csv > csvlist.txt

rem loop through all CSV files in folder and do processing
for /F "eol=; tokens=1* delims=,. " %%i in (csvlist.txt) do call \processing\LTKp\doextractmetric %%i %1 %3

rem merge tiles...ASCII raster format
REM cd \products\LTKp_layers
cd \products\LTKp_layers\under2m
mergeraster /overlap:new %2.asc *_tile.asc

rem convert ASCII raster file to DTM
ascii2dtm  %2.dtm m m 1 12 2 2 %2.asc

rem delete tiles
del *_tile.asc

cd \processing\LTKp

:end
@echo on
```

DoExtractmetric.bat

```
rem extract cover values from CSV files to ASCII raster, then convert to DTM format

REM CSV2Grid /multiplier:%3 %1.csv %2 \Products\LTKp_layers\%1_tile.asc
CSV2Grid /multiplier:%3 %1.csv %2 \Products\LTKp_layers\under2m\%1_tile.asc
```

The 25 m grids for the entire project area are stored under \products\LTKp_layers

Here are the created grids:

CSV Column Number	Gridmetric	ASCII Files	Cell Size (meters)	ArcGIS Grid	Explanation (also Fusion manual)
1	Row				
2	Column				
3	Return count above 2m				
4	First-return count above 3m				
5	Total first-return count	pulsecnt_25 m	25	pulsecnt	Number of first returns (pulses) in cell.
6	Minimum	minht_2plus_25 m	25	minht	Minimum height of all returns located 2 m or more above the ground. Values in this grid should be close to 2 m. When they are higher, it indicates there were no bare-earth returns or the vegetation cover is very dense, preventing the laser pulse from penetrating to the ground.
7	Maximum	maxht_2plus_25 m	25	maxht	Maximum height of all returns located 2 m or more above the ground.
8	Mean	aveht_2plus_25 m	25	aveht	Average height of all returns 2 m or more above the ground.
9	Mode	modeht_2plus_25 m	25	modeht	Mode value of all returns for all returns 2 m or more above the ground.
10	Standard Deviation	stddevht_2plus_25 m	25	stdevht	Standard deviation of height for all returns 2 m or more above the ground.
11	Variance	varianceht_2plus_ 25 m	25	varianht	Variance of height for all returns 2 m or more above the ground.
12	Coefficient of variation	CVht_2plus_25 m	25	cvht	Coefficient of variation of height for all returns 2 m or more above the ground.
13	Skewness	skewnessht_2plus_ 25 m	25	skewht	Skewness of the distribution of heights for all returns 2 m or more above the ground. Negative skewness values indicate that the distribution of height values in the cell is shifted to the right of the mean and the mean<median<mode. Positive skewed values reflects a shift to the left of the mean.
14	Kurtosis	kurtosisht_2plus_25 m	25	kurtht	Kurtosis of the distribution of heights for all returns 2 m or more above the ground.

CSV Column Number	Gridmetric	ASCII Files	Cell Size (meters)	ArcGIS Grid	Explanation (also Fusion manual)
15	AAD	AADht_2plus_25 m	25	aadht	Average absolute deviation of the heights for all returns 2 m or more above the ground
16	P05	P05ht_2plus_25 m	25	p05ht	*Xth* percentile height value for all returns 2 m or more above the ground Percentile heights are interpreted as follows: *X*% of the returns are below the height, (100 – *X*)% are above
17	P10	P10ht_2plus_25 m	25	p10ht	
18	P20	P20ht_2plus_25 m	25	p20ht	
19	P25	P25ht_2plus_25 m	25	p25ht	
20	P30	P30ht_2plus_25 m	25	p30ht	
21	P40	P40ht_2plus_25 m	25	p40ht	
22	P50	P50ht_2plus_25 m	25	p50ht	
23	P60	P60ht_2plus_25 m	25	p60ht	
24	P70	P70ht_2plus_25 m	25	p70ht	
25	P75	P75ht_2plus_25 m	25	p75ht	
26	P80	P80ht_2plus_25 m	25	p80ht	
27	P90	P90ht_2plus_25 m	25	p90ht	
28	P95	P95ht_2plus_25 m	25	p95ht	
29	Density (decimal percent cover)	cover_above3_25 m	25	cover	Proportion of the first returns occurring 3 m or higher above the ground or the number of pulses with a first return above 3 m in the cell divided by the total number of pulses in the cell.
30	Center *X*				
31	Center *Y*				

Articles:

Heurich and Thoma 2008

Hudak and others 2008

Means and others 2000

Processing time: 4 to 5 days

- Prep work to clip the 1 m bare-earth grids into smaller chunks and convert them to DTMs: 2 hours
- Running the LTKp batch files and extracting the grids: 3 to 4 days
- Importing the ASCII files into ArcGIS: 2 hours
- Generating gridmetrics derivatives: E ratio (stored under Canopyheight): 10 minutes

Obstacle Density at 25 Meter Spatial Resolution

Preparation Work: Ground Point Conversion to LDA Files

The *XYZ* text files with the ground point returns are only used during the understory obstacle-density calculations. This batch file is run within the delivered folder.

CreateGptsConvert.bat (calls DoGptsConvert.bat)

```
dir /b *.asc>asclist.txt

for /F "eol=; tokens=1* delims=,. " %%i in (asclist.txt) do doGptsConvert.bat %%i

rem move the lda files to the working point directory
move *.lda  \point\las\BE-lda
```

DoGptsConvert.bat

```
asciiimport PM_bepts.importparam %1.asc %1_ground_pts.lda
```

The PM_bepts.importparam can be created by importing one of the ASCII files through the Fusion Windows interface: Tools> Dataconversion>import generic ASCII lidar data.

Density Metrics at 25 Meter Cell Size:

Extract the returns representing the understory (2 m or less above the ground) from the LAS files. This slice contains both the ground points and the understory returns, which are calculated by subtracting the ground densities from the below-2 m densities. The scripts to extract and process the below-2 m data from the LAS tiles as well as calculate ground point densities are these:

CreateDensityMetrics.bat, DoDensityMetrics.bat and DoDensitymetrics-gpts.bat.
The output is stored in:
\products\density_metrics\groundpts
\products\density_metrics\under2m

After calculating the densities for the below-2 m and the ground point tiles, merge the tile-sized DTMs to create area wide project grids (which show edge effects) and export them to ASCII files. These files can be imported into ArcGIS.

The project-size ASCII files and grid are stored in \prodcuts\density_layers

CreateDensitySlice.bat (calls DoDensitySlice.bat and DoDensitySlice-gpts.bat)

```
cd \POINT\LAS\ALL_POINTS

rem create a filelist
dir /b *.las>filelist.txt

rem loop through all LAS files in folder and do processing
for /F "eol=; tokens=1* delims=,. " %%i in (filelist.txt) do call \processing\dodensityslice %%i
```

```
cd \POINT\LAS\BE-lda

rem create a filelist from lda files converted from *.txt
dir /b *.lda>filelist.txt

for /F "eol=; tokens=1* delims=,. " %%i in (filelist.txt) do call \processing\dodensityslice-gpts %%i

cd \products\density_metrics\under2m
mergedtm /overlap:new \products\density_layers\PM-density-2min-25m.dtm *_total_returns.dtm
dtm2ascii \products\density_layers\PM-density-2min-25m.dtm \products\density_layers\PM-density-2min-25m.asc

cd \products\density_metrics\groundpts
mergedtm /overlap:new \products\density_layers\PM-density-gpts-25m.dtm *_total_returns.dtm
dtm2ascii \products\density_layers\PM-density-gpts-25m.dtm  \products\density_layers\PM-density-gpts-25m.asc

cd \processing
```

DoDensityMetrics.bat

```
rem density metrics for understory (<= 2m above groundsurface) will be first slice
rem the metrics are calculated in 2m height slices (intervals) with maximum height @50m at 25m cellsize
densitymetrics /maxsliceht:50 /outlier:-1,50 \Products\BareEarth\pm-be-3m.dtm 25 2 \Products\density_metrics\
    allslices\%1_density %1.las

rem create densitymetrics from all points for understory only (this creates a separate CSV file with the return count for
    this slice)
densitymetrics /maxsliceht:2 /outlier:-1,2 \Products\BareEarth\pm-be-3m.dtm 25 2 \Products\density_metrics\
    under2m\%1_density  %1.las
```

This batch file creates densitymetrics for all tiles in 2 m intervals up to 50 m above the ground. These densities were calculated for all the lidar tiles but were not processed any further.

DoDensityMetrcis-gpts.bat

```
REM density metrics for groundpoints (to be used for obstacle density calculation)
REM when this density is subtracted from the 2m above groundsurface slice (under 2m), the returns of the fuelbed are
    determined)
REM these densities are used to calculate the obstacle density in the fuelbed (understory)
REM (Seielstad and Queen, JOF, 2003)

densitymetrics /maxsliceht:2 /outlier:-1,2 \Products\BareEarth\pm-be-3m.dtm 25 2 \Products\density_metrics\
    groundpts\%1_density  %1.lda
```

Article:

Seielstad and Queen 2003

Notes

1. The obstacle-density ratio is created in ArcGIS by generating the density for the fuel bed (below-2 m densities—ground-point densities) and normalizing the returns to the sum of the fuel bed and ground-point returns. The expected values range between 0 and 1. In this project, the values were much higher along the tile edges because of the edge effects. These values were replaced with NoData.

2. The output from the DoDensityMetrics.bat is stored in the \products\density_metrics folder. The merged DTMs, converted ASCII files, and ArcGIS grids are stored in the density_layers folder.

Processing time: 2 days

Fuel-Bed Visualization under Canopy at 1-Meter Spatial Resolution

The downed logs in open terrain were visualized by restricting the height of the CHM to 2 m above the ground. To visualize the logs and other material in the understory (lower than 2 m above the ground) these returns had to be extracted from the return point cloud before being rasterized. Clipping the all_points LAS tiles with the Clipdata command accomplished this task.

Prep Work: Extracting the 2-Meters Above Ground from the LAS Point Data Tiles

Clipdata is generally used to spatially subset lidar point data, but since it has a maximum height switch, it can also extract a height interval from the point data. This script is different from the previous ones because each line has the spatial extent for each of the included tiles. Those coordinate values were extracted from the CSV file created by the catalog function during quality assessment. Every single line of the script was concatenated in Excel and saved to a text file: Clip2minfromlas.bat.

The output files are stored in the \point\las\under2m-lda\ folder

Clip2minfromlas.bat

```
clipdata /shape:0 /dtm:pm-be-3m.dtm /zmax:2 /index 32109E7101.las \point\las\under2m-lda\32109E7101min2
    605538.11 3608889.39 606725.5 3610286.71
clipdata /shape:0 /dtm:pm-be-3m.dtm /zmax:2 /index 32109E7102.las \point\las\under2m-lda\32109E7102min2
    606710.79 3608901.1 607898.37 3610299.35
                        .
                        .
                        .
clipdata /shape:0 /dtm:pm-be-3m.dtm /zmax:2 /index 32110G1424.las \point\las\under2m-lda\32110G1424min2
    591325.55 3623992.97 592509.31 3625389.46
clipdata /shape:0 /dtm:pm-be-3m.dtm /zmax:2 /index 32110G1425.las \point\las\under2m-lda\32110G1425min2
    592492.66 3624003.79 593680.32 3625795.49
```

Creation of Surface Models for the Understory Fuel Bed

The scripts to process the data are basically the same as those to generate the CSM and CHM, but to keep the output at 1 m spatial resolution, the project area needed to be divided into smaller sections. The same three sections as the original delivered bare-earth grids were created.

CreateFuelbedSurface2minus.bat and DoFuel bed.bat

The output is stored in \products\fuelbed

CreateFuelbedSurface2minus.bat (calls DoFuelbed.bat)

```
rem this batchfile was recreated from individual pieces
rem the original process was not from this batch file
rem if problems occur, check the file directory structure syntax, space and forward slashes or back slashes
rem the final folder structure and overall file-naming convention was changed after the dtms were created from the
    under2m.lda files
rem before the FHM and FSM can be ceated at 1 m cell size, the under2m points have to be subset from the las
    pointcloud
rem the batch file to do this is stored at \point\las\All_points\clip2minfromlas.bat (explanation of how this was created see
    readme worksheet in \point\las\All_points \fileXY.xls)

rem**********************************************************************************
rem PART 1: process the individual point tiles to create FSM and FHM dtm for each point tile
rem**********************************************************************************

cd \POINT\LAS\under2m-lda

dir /b *.lda>filelist.txt

rem loop through all LAS files in folder and do processing
for /F “eol=; tokens=1* delims=,. “ %%i in (filelist.txt) do call \processing\DoFuelbed %%i

rem**********************************************************************************
rem PART 2: FSM
rem**********************************************************************************

rem merge fuelbed surface products
cd \products\fuelbed\Fuelbed-FSM\tiled-dtm

rem the following lines takes a long time to run and depending on computer memory might crash
mergedtm /disk /overlap:new \products\fuelbed\Fuelbed-FSM\PM-FSM-1m.dtm *.dtm

rem the following 3 lines create smaller files but divide the project area in 3 ‘sections’
rem the ‘DOQ#’ part of the file name is specific to Pinaleños project

mergedtm /overlap:new \products\fuelbed\fuelbed-FSM\DOQ1min2_FSM-1m.dtm ??????1*.dtm
mergedtm /overlap:new \products\fuelbed\fuelbed-FSM\DOQ8min2_FSM-1m.dtm ??????8*.dtm
mergedtm /overlap:new \products\fuelbed\fuelbed-FSM\DOQ7min2_FSM-1m.dtm ??????7*.dtm

cd \products\fuelbed\Fuelbed-FSM

dir /b doq?*.dtm>filelist.txt

rem convert fuelbed surface model (FSM) dtms to ascii which can be imported into arcgis

for /F “eol=; tokens=1* delims=,. “ %%i in (filelist.txt) do call Do2ascii %%i
```

```
rem************************************************************************************
rem PART 3: FHM
rem************************************************************************************

rem merge fuelbed height products
cd \products\fuelbed\Fuelbed-FHM\tiled-dtm

rem the following processing line takes a long time to run and depending on computer memory might crash
mergedtm /disk /overlap:new \products\fuelbed\Fuelbed-FHM\PM-FHM-1m.dtm *.dtm

rem the following 3 lines create smaller files but divide the project area in 3 'sections'
mergedtm /overlap:new \products\fuelbed\fuelbed-FHM\DOQ1min2_FHM-1m.dtm ??????1*.dtm
mergedtm /overlap:new \products\fuelbed\fuelbed-FHM\DOQ8min2_FHM-1m.dtm ??????8*.dtm
mergedtm /overlap:new \products\fuelbed\fuelbed-FHM\DOQ7min2_FHM-1m.dtm ??????7*.dtm

cd \products\fuelbed\Fuelbed-FHM

dir /b doq?*.dtm>filelist.txt

rem convert fuelbed height model (FHM) dtms to ascii which can be imported into arcgis

for /F "eol=; tokens=1* delims=,. " %%i in (filelist.txt) do call Do2ascii %%i

cd \processing
```

DoFuelbed.bat

```
rem FSM and FHM are created at 1 meter, larger cell sizes would overestimate the size of the logs (1m cells overestimates them already)

rem FuelBed surface model (FSM) 2meters above groundsurface

canopymodel \Products\fuelbed\fuelbed-FSM\tiled-dtm\%1_FSM.dtm 1 m m 1 12 2 2 %1.lda



rem FuelBed Height (FHM) 2 meters above groundsurface

canopymodel /outlier:-5,2 "/ground:E:\Products\BareEarth\pm-be-3m.dtm" \Products\fuelbed\fuelbed-FHM\tiled-dtm\%1_FHM.dtm 1 m m 1 12 2 2 %1.lda
```

Note: The 3 sections of the fuel bed output are at 1 m spatial resolution while the "CWD-2 m" is at 2m. The 2m grids were created to generate a single grid for the entire project. The CWD layer was created directly from the highest-hit and bare-earth deliverables before any Fusion processing. Creating a CWD layer at 1 m is possible by dividing the project-data deliverables into three separate sections. For visualization purposes, the 2 m grids work OK. For deriving metrics, they overestimate the size of logs and other understory material. The 1 m fuel bed grids show the understory material in both open terrain and areas where canopy cover obscures what is close to the ground.

Processing time: 2 days

Subsets of the Field Plots from the LAS Files

Data preparation:

- Intersecting the buffer plot centers with the boundaries of the LAS tiles and the DOQQs
- Merging the LAS tiles and bare-earth DOQQs when the plots overlap boundaries

Processing notes:

- The 1m bare-earth model covering the project area in three sections was too large for the Clipdata command.
- The exact location of the plots will be adjusted after the field season based on the GPS measurements. The location of some of the plots may need changing to accommodate field conditions described in the field protocol (Wilcox and others 2009). Subsetting the plots from the lidar tiles needs to be repeated after the final plot-center locations are available.

The plots were subset twice with two separate batch files: once keeping the elevations of the lidar points and once normalizing the elevations to the bare ground and converting the lidar points to the height measurements.

The batch file to calculate the height of the lidar points looks like this (output files have the plotID and an E in the file name):

clipplotelevations.bat

```
clipdata /shape:1  /index 32110G1423.las B5-E 590925.66 3624184.72 590950.9 3624209.96
clipdata /shape:1  /index 32110F1203.las C5-E 590925.67 3623184.7 590950.91 3623209.94
clipdata /shape:1  /index 32110F1204.las C55-E 591425.66 3623684.71 591450.9 3623709.95
clipdata /shape:1  /index 32109F8210.las D19-E 604925.42 3622184.54 604950.66 3622209.78
                                        .
                                        .
                                        .
clipdata /shape:1  /index F7111-F8215.lda F69-E 605425.43 3620684.49 605450.67 3620709.73
clipdata /shape:1  /index F7116-F8220.lda G69-E 605425.45 3619684.46 605450.69 3619709.7
clipdata /shape:1  /index F7116-F8220.lda H69-E 605425.47 3618684.43 605450.71 3618709.67
```

The batch file to calculate the height of the lidar points looks like this (output files have the plotID and an H in the file name):

clipplotheights.bat

```
clipdata /shape:1 /dtm:be_G14.dtm /height /index 32110G1423.las B5-H 590925.66 3624184.72 590950.9 3624209.96
clipdata /shape:1 /dtm:be_F12.dtm /height /index 32110F1203.las C5-H 590925.67 3623184.7 590950.91 3623209.94
clipdata /shape:1 /dtm:be_F12.dtm /height /index 32110F1204.las C55-H 591425.66 3623684.71 591450.9
   3623709.95
clipdata /shape:1 /dtm:be_F82.dtm /height /index 32109F8210.las D19-H 604925.42 3622184.54 604950.66
   3622209.78
                                        .
                                        .
                                        .
clipdata /shape:1 /dtm:beF82-F71.dtm /height /index F7111-F8215.lda F69-H 605425.43 3620684.49 605450.67
   3620709.73
clipdata /shape:1 /dtm:beF82-F71.dtm /height /index F7116-F8220.lda G69-H 605425.45 3619684.46 605450.69
   3619709.7
clipdata /shape:1 /dtm:beF82-F71.dtm /height /index F7116-F8220.lda H69-H 605425.47 3618684.43 605450.71
   3618709.67
```

The output files from the height subsets are used to calculate the cloudmetrics. These metrics are figured at the canopy level only, including the data points 2 m above the ground (indicated by the /htmin switch), just line the gridmetrics ones. An estimate of the canopy cover is included by using the /above switch. The statistics are written to a single CSV file in the \products\plot-data\lidarcloud-0p05ha\height folder.

Docloudmetrics.bat

```
cloudmetrics /htmin:2 /above:3 /new \products\plot-data\lidarcloud-0p05ha\height\*.lda \products\plot-data\lidarcloud-0p05ha\height\plotH-metrics.csv
```

Processing time: 1 day

Appendix 2: Lidar-Processing Output Files

List of commonly used project file extensions

File type	Description	Notes
.tif (also .tfw)	Image file format viewable in Fusion, ArcGIS, and Erdas Imagine	
.bmp (also .bmpw)	Image file format viewable in Fusion, ArcGIS, and Erdas Imagine	
.jp2, jpg (also .j2w and .jpgw)	Compressed image file format viewable in Fusion, ArcGIS, and Erdas Imagine	
.img (also .ige)	Image file format viewable in ArcGIS and Erdas Imagine	
.aux	File created by ArcGIS when displaying images or grids	Can be deleted, ArcGIS will recreate
.rrd	Pyramid file created by ArcGIS or Erdas Imagine when displaying images or grids	Speeds display of imagery, can be deleted and recreated
.sbx, .shp, .shx, .dbf, .prj, .sbn,	Files that comprise an ArcGIS shapefile	.shp, .sbx, and .dbf mandatory, others are optional
.las, .lda	Binary lidar point data files viewable in Fusion, not viewable in ArcGIS or Erdas Imagine.	LAS-files can be opened as a table in ArcMap with LAS-reader http://geocue.com/utilities/lasreader.html
.ldx, .ldi	Lidar data index files created by Fusion for use with .las and .lda files	
.dtm	Binary digital terrain models created by Fusion, not viewable in ArcGIS or Erdas Imagine	
.adf	Files that comprise an ArcGIS grid	
.asc	Text file in ESRI gridformat	Used for moving .dtm or .csv files generated in Fusion to grids in ArcGIS or vice versa
.csv	Comma separated values; textfile in tabular format in which each value is separated by a comma	Used to generate fusion grids that have cells with negative values. dtm's can't store negative values

Quality Assessment

Topic	Content	Cell Size (meters)	Folder
Catalog-all.html	Summary of Fusion QA		products\catalog\catalog-all
Catalog-all.csv	Per tile listing of minXYZ, maxXYZ, count by return number, point density and number of points		\products\catalog\catalog-all
First-return density images	PM_first_return_density-900-3p0-8.bmp (renamed output from catalog10.bat)	30.0	\products\catalog\density
	PM_first_return_density-900-1p5-8.bmp (renamed output from catalog14.bat)		
Intensity images	PM_catalog5_intensity-2p5m.bmp	2.5	\products\catalog\intensity
	PM_catalog4_intensity-3m.bmp	3.0	
	PM_catalog3_intensity-4m.bmp	4.0	
	PM_catalog13_intensity-30m.jpg	30.0	

Lidar Processing

Bare-Earth Models at 1 Meter and 2 Meter (ArcGIS Grids Only), 2.5-Meter and 3-Meter cells

Input: Bare-earth delivered models to be converted to Fusion DTM format

Output: \products\BareEarth

Format	Deliverable/ Additional Processing	Spatial Resolution	Spatial Extent	File Name: File Size (File Type)
ArcGIS grids	Deliverable	1 m	3 sections	:\products\BareEarth\3sections\3sections-grids\ be_32109f7: 704 MB (float) be_32109f8: 751 MB (float) be_32110f1: 274 MB (float)
	Hill shade	1 m	Project area	:\products\BareEarth Be_2mhs: (signed integer)
	Arctool> Data management tools> Raster> Raster processing> Clip (Created DOQQ polygon shape files to clip the grids)	1 m	DOQQ subsets	\products\BareEarth\DOQQ\doqq-grids\ be_g84-1m (float) be_g83-1m (float) be_g73-1m (float) be_g14-1m (float) be_g13-1m (float) be_e71-1m (float) be_f84-1m (float) be_f83-1m (float) be_f82-1m (float) be_f81-1m (float) be_e72-1m (float) be_f74-1m (float) be_f73-1m (float) be_f72-1m (float) be_f71-1m (float) be_e82-1m (float) be_f12-1m (float) be_f11-1m (float)
	Merge grid	2 m	Project area	\products\BareEarth\ be_2m (float)
	Slope	2 m	Project area	\products\BareEarth\ be_2msl (float)
	Aspect	2 m	Project area	\products\BareEarth\ be_2masp

Format	Deliverable/ Additional Processing	Spatial Resolution	Spatial Extent	File Name: File Size (File Type)
DTM grids (Fusion)	Grid2ASCII and Ascii2dtm (createbedtm.bat and do2dtm.bat)	1 m	3 sections	\products\ BareEarth\3sections\3sections-dtm\ be_32109f7.dtm: 1.36GB be_32109f8.dtm 1.44GB be_32110f1.dtm 528 MB
	Mergedtm (part of the createbedtm. bat)	1 m 2.5 m 3 m	Project area	\products\BareEarth\ pm-be-1m.dtm: 4.52 GB pm-be-2p5m.dtm: 740 MB pm-be-3m.dtm: 514 MB
	Grid2ASCII & Ascii2dtm Used in Fusion LTKp processor during the gridmetrics calculations (needed because the 1m project area or section grids were too large to keep in memory; intermediary *.asc files were created as well)	1 m	DOQQ	\products\BareEarth\DOQQ\doqq-dtm\ be_g84-1m.dtm be_g83-1m.dtm be_g73-1m.dtm be_g14-1m.dtm be_g13-1m.dtm be_e71-1m.dtm be_f84-1m.dtm be_f83-1m.dtm be_f82-1m.dtm be_f81-1m.dtm be_e72-1m.dtm be_f74-1m.dtm be_f73-1m.dtm be_f72-1m.dtm be_f71-1m.dtm be_e82-1m.dtm be_f12-1m.dtm be_f11-1m.dtm

Note: If a 1 m project-area bare-earth model is needed in ArcGIS, the following procedure can be applied:

- Multiply the three section grids by 100 (i.e., convert to cm);
- Convert the three sections to an integer grid;
- Merge the three grids into a single one;
- Divide by 100 (convert back to m).

Canopy Models and Highest Hit at 2-Meter, 2.5-Meter and 3-Meter Cells

The project-area grids at 2 m resolution were generated from the bare-earth and highest-hit grids. The 2 m CHM was used to visualize the downed logs in open terrain.

The CHM and CSM models generated by Fusion are at 2.5 m and 3 m. The 2.5 m CHM model was used for further processing with gridssurfacestats, which creates an output at a multiple of the input CHM.

Input: \point\las\All_points
Tiles las files (CSM and CHM)
\products\BareEarth\3sections\3sections-dtm
BE model in dtm format at 1m resolution (CHM)

Output: \products\canopysurface
\products\Canopyheight

Format	Deliverable/ Additional Processing	Spatial Resolution	Spatial Extent	File Name
ArcGIS	Deliverable (highest hit)	1 m	3 sections	HH_32109f7: 704 MB HH_32109f8: 751 MB HH_32110f1: 274 MB
	Merge grid	2 m	Project area	HH_2m
	HH—BE	2 m	Project area	chm_2m
	Restrict height range of CHM between 0 and 2m to display the logs in uncovered terrain	2 m	Project area	cwd_2m
	CHM above 25 m (displays the tallest trees, most likely old growth)	2 m	Project area	chm_ge25
DTM grids (Fusion)	CSM (combination of createcanopysurfaces.bat and docanopy.bat)	3 m	LAS tile based	\products\canopysurface\3m-dtm\ Tile#_CSM-3m.dtm (236)
			Project area	\products\canopysurface PM-CSM-3m.dtm
		2.5 m	LAS tile based	\products\Canopyheight\2p5m-dtm\ Tile#_CSM-2p5m.dtm (236)
			Project area	
	CHMI (combination of createcanopysurfaces.bat and docanopy.bat) but normalized to the bare-earth model	3 m	LAS tile based	\products\Canopyheight\3m-dtm\ Tile#_CHM.dtm (236)
			Project area	\products\Canopyheight\ PM-CHM-3m.dtm
		2.5 m	LAS tile based	products\Canopyheight\2p5m-dtm\ Tile#_CHM.dtm (236)
			Project area	\products\Canopyheight\ PM-CHT-2p5m.dtm
ArcGIS	Import ASCII into arcGIS	2.5 m	Project area	PM-CHT-2p5m PM-CHT-3m
		3 m	Project area	PM-CST-2p5m PM-CST-3m

Volume and Surface Models Derived from 3-Meter CHM at 25-Meter Cells

(Fusion's "GridSurfaceStats" is not part of the released version of the program as of April 2009. It was developed cooperatively by Van Kane and Bob McGaughey and will be part of the public version after Kane fulfils the requirements for his PhD at the University of Washington expected for later 2009.

Input: \products\Canopyheight\PM-CHT-2p5m.dtm

Output: \products\gridsurfacestats\25m\

Format	Additional Processing	Spatial Resolution	Spatial Extent	File Name
DTM grids and *.asc files	CreateGridsurfaceStats25.bat (creates the *.dtms and converts them to *. asc files)	25 m (a multiple of the input 2.5 m CHM)	Project area	\products\gridsurfacestats\25m Pm-area25_max_height Pm-area25_pote12l_volume Pm-area25_surface_Area (only created with /area switch) Pm-area25_surface_Area_ratio Pm-area25_surface_volume Pm-area25_surface_volume_ratio
ArcGIS	Import ASC grids into ArcGIS	25 m	Project area	\products\gridsurfacestats\25m pm-maxht-25m pm-potvol-25m pm-sa-25m pm-sar-25m pm-sv-25m pm-svr-25m

The first set of grids were created at 30 m and is stored under \products\gridsurfacestats\30m

Gridmetrics Models at 25-Meter Cells

Step 1 input:	\products\BareEarth\DOQQ\doqq-dtm 1m Bare earth dtm models at doqq size \point\las\All_points\ LAS tiles
Step 1 output:	\products\LTKp_metrics 1 CSV file for each LTKp tile at size defined in batch file (becomes input for step 2)
Step 2 output:	\products\LTKp_layers A project-size DTM grid for each column extracted from the CSV file An ASCII file and an ArcInfo raster after converting the DTM

Format	Deliverable/ Additional Processing	Spatial Resolution	Spatial Extent	File Name
DTM grids	Combination of dometrics_25m.bat and doLTKpcell.bat on retiled LAS files in LTKp processor to extract gridmetrics for points higher than 2 m above ground surface to a CSV file	25 m	LTKp grid CSV files (100 m by 1000 m with 100 m buffer) (saved in LTKp_ metrics folder)	\products\LTKp_metrics\ Tile#.scv
	Buildlayers.bat, extracmetric.bat and doextracmetric.bat from DOS window to extract the gridmetric from the CSV file, create an LTKP tile ASCII file, merge all the ASCII tiles into a project-area ASCII file, convert those to a dtm and delete the LTKp tile ASCII files	25m	Project area (saved in LTKp_ layers folder as *.dtm and *.asc)	products\LTKp_layers\ *.dtm & *.asc aadht_2plus_25m aveht_2plus_25m cover_2plus_25m cvht_2plus_25m kurtht_2plus_25m maxht_2plus_25m minht_2plus_25m modeht_2plus_25m p05ht_2plus_25m p10ht_2plus_25m p20ht_2plus_25m p25ht_2plus_25m p30ht_2plus_25m p40ht_2plus_25m p50ht_2plus_25m p60ht_2plus_25m p70ht_2plus_25m p75ht_2plus_25m p80ht_2plus_25m p90ht_2plus_25m p95ht_2plus_25m pulsecnt_2plus_25m skewht_2plus_25m stdevht_2plus_25m varianht_2plus_25m

Format	Deliverable/ Additional Processing	Spatial Resolution	Spatial Extent	File Name
ArcGIS	ASCII2grid (Toolbox>conversion tools>From Raster>Raster to ASCII).	25 m	Project area	products\LTKp_layers\ aadht aveht cover cvht kurtht maxht minht modeht p05ht p10ht p20ht p25ht p30ht p40ht p50ht p60ht p70ht p75ht p80ht p90ht p95ht pulsecnt skewht stdevht varianht
ArcGIS	*Raster calculator: E = (aveht - minht) / (maxht - minht)	25 m	Project area	\products\Canopyheight E

*Parker and others 2004

Obstacle Density at 25-Meter Cells

Data prep: \point\las\BE-lda
convert text files with filtered ground point to LDA format

Input: \point\las\All_points
las tiles
\products\BareEarth\ pm-be-3m.dtm
3m bare earth dtm
\point\las\BE-lda
Filtered ground points in LDA format

Output 1: \products\density_metrics\ under2m
dtm for each defined slice interval (2m in our project) for each LAS tile
Density of the ground points for each LDA tile

Output 2: \products\density_layers\
Project area DTMs, ASCII and ArcGIS grids after merging the DTM from output1

Format	Deliverable/ Additional Processing	Spatial Resolution	Spatial Extent	File Name
Fusion Convert asc to lda	CreateGptsConvert.bat & DoGptsConvert.bat	Point file	236 tiles	:\point\las\BE-lda\ tile#_ground_pts.lda
Fusion DTM and ASCII \density_layers\	CreateDensityMetrics.bat & DoDensityMetrics.bat DoDensitymetric-gpts.bat Mergedtm and dtm2Ascii	25 m	Project area	PM-density-2min-25m
		25 m	Project area	PM-density-gpts-25m
ArcGIS grid \density_layers\	Import ASCII into ArcGIS (Toolbox>conversion tools>From Raster>Raster to ASCII).	25 m	Project area	pm_d2min-25m
	Import ASCII into ArcGIS (Toolbox>conversion tools>From Raster>Raster to ASCII).	25 m	Project area	pm-dgpts-25m
	pm-dfuel-25m = (pm_d2min-25m – pm-dgpts-25m)	25 m	Project area	pm-dfuel-25m
	pm-od-25m = (pm-dfuel-25m / pm_d2min-25m)	25 m	Project area	pm-od-25m
	Minimizing the tile edge affects by setting values less than 0 to NoData pm-od-25mnd = con(pm-od-25m < 0, pm-od-25m, setnull(pm-od-25m))	25 m	Project area	pm-od-25mnd

Fuel Bed at 1-Meter Cells

Data prep: \point\las\under2m-lda
Subset (clip) the LAS tiles so they contain only returns 2m above the ground or less.

Input: \point\las\under2m-lda
the <2m agl clipped LDA tiles
bare-earth model at 1m in three DOQQ sections

Output: \products\fuel-bed\fuelbed-FSM
1m fuelbed surface model in three sections
\products\fuel-bed\fuelbed-FHM
1m fuelbed height model in three sections

Format	Deliverable/ Additional Processing	Spatial Resolution	Spatial Extend	File Name
LDA height subsets by tile	Clip the LAS tiles to the point cloud 2m above ground (clip2minfromlas.bat) (used to look at understory info)	Point files	236 LDA tiles	\point\las\under2m-lda\ *tile#min2.lda
DTM	FSM CreateFuelbedSurface2minus.bat and DoFuelbed.bat	1 m	Project area	PM-FSM-1m.dtm
		1 m	3 sections	DOQ1min2_FSM-1m.dtm DOQ8min2_FSM-1m.dtm DOQ7min2_FSM-1m.dtm
	FHM CreateFuelbedSurface2minus.bat and DoFuelbed.bat	1 m	Project area	PM-FHM-1m.dtm
		1 m	3 sections	DOQ1min2_FHM-1m.dtm DOQ8min2_FHM-1m.dtm DOQ7min2_FHM-1m.dtm
ArcGIS	FHM (Toolbox>conversion tools>From Raster>Raster to ASCII). The FSM was not converted.	1 m	3 sections	\products\fuelbed\ fuelbed-FHM\ DOQ1min2_FHM-1m. DOQ8min2_FHM-1m DOQ7min2_FHM-1m

Field Plot Lidar Data Clipping from LAS Tiles

Data prep: \products\plot-data\samplegrid\samplegrid_utmnad83-v2_Buffe.shp
buffering the plotcenter coordinate (12.62m radius buffer or 0.05 ha plot)
\products\plot-data\samplegrid\plots_tiles_Intersect.shp
\point\las\All_points
Merging LAS tiles and bare-earth DOQQ for 0.05ha plot, overlapping two LAS tiles or DOQQs.
LAS tiles: \point\las\All_points\merged4plotclip
(They need to be moved to the \point\las\All_points folder before running the batch file.)
DOQQs: \point\las\All_points\tempdtm4plotclip these with all the DOQQs; there need to be moved to the \point\las\All_points\merged4plotclip.
\products\plot-data\samplegrid\plot-tile-intersections.xls
The spreadsheet generated from the intersection of the buffered plots with the LAS tiles and the DOQQ bare-earth boundaries

Input: \point\las\All_points
The LAS tiles, the DOQQs 1m bare-earth models (merged where required)

Output: Lidar point data representing the elevation values (plotid-E.lda) copied to \products\plot-data\lidarcloud-0p05ha\elevation

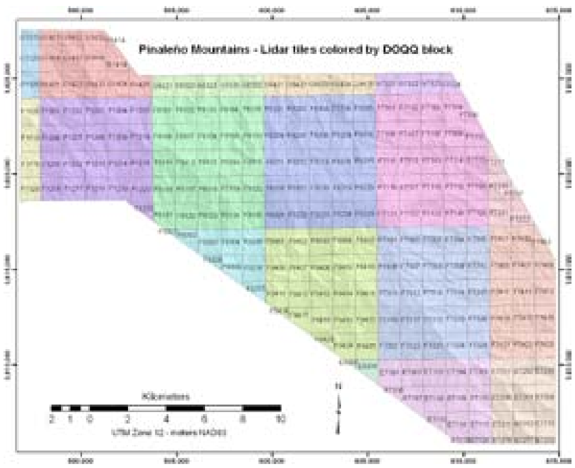
Lidar point data representing the normalized heights of the data points (plotid-H.lda) copied to \products\plot-data\lidarcloud-0p05ha\height

Cloudmetrics for the height data:
E:\products\plot-data\lidarcloud-0p05ha\height\plotH-metrics.csv

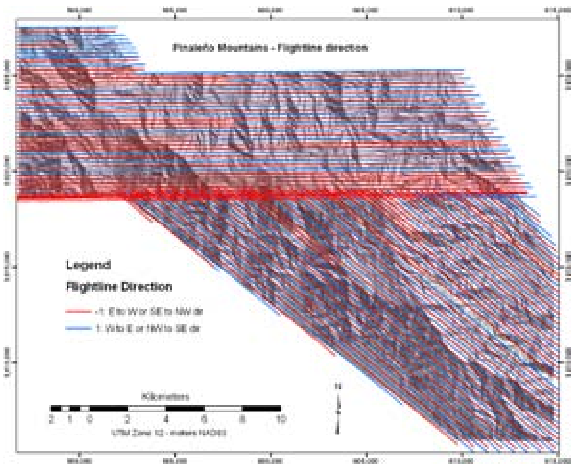
Appendix 3: Pinaleño Mountains Lidar-Project Data Dictionary

Quality Control and General Information

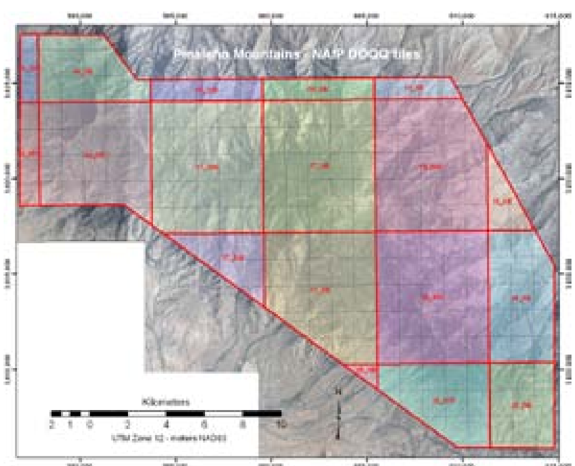
LAS Tiles Colored According to DOQQ



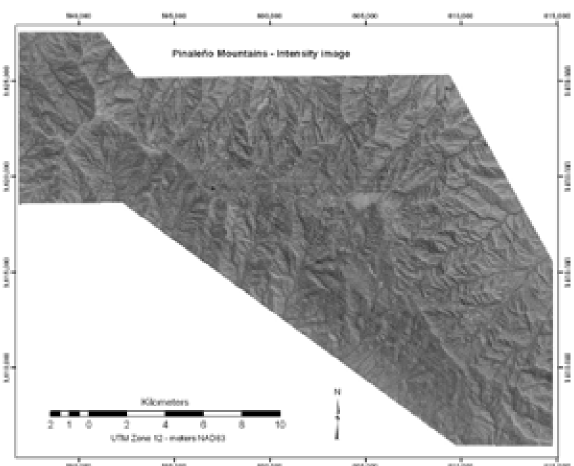
Flight-Line Direction



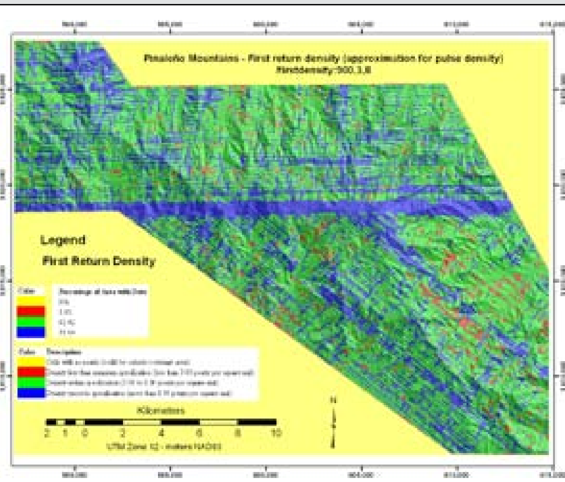
NAIP DOQQs



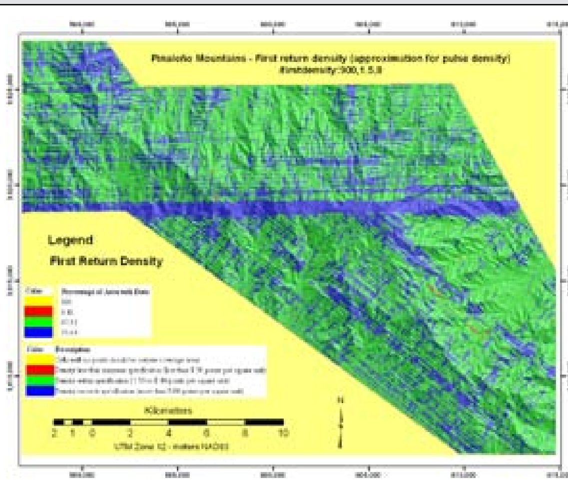
Intensity Image



First-Return Density at Minimum Density

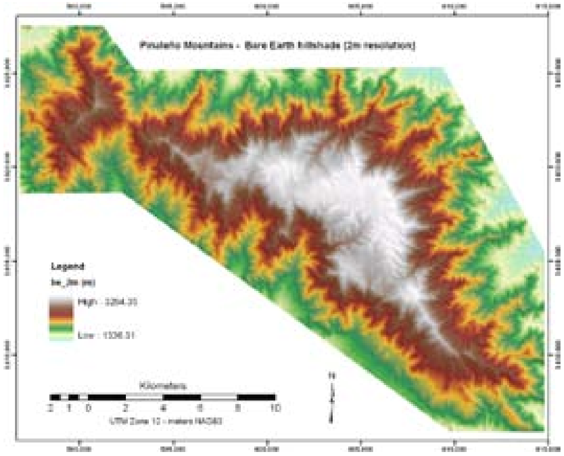


First-Return Density at Half Minimum

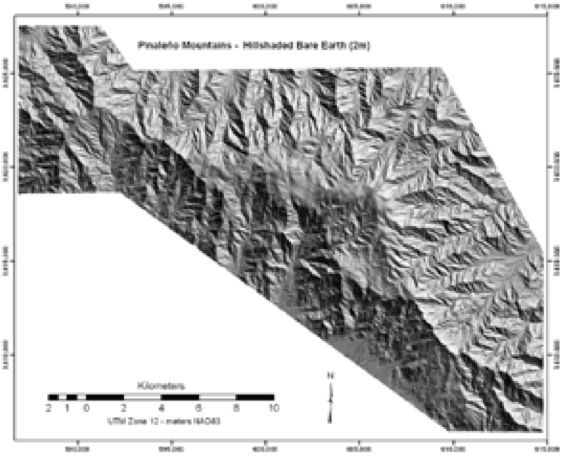


Bare Earth Grids

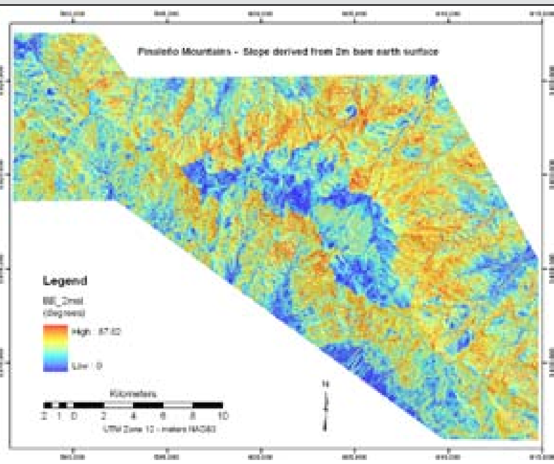
Bare Earth (elevation)



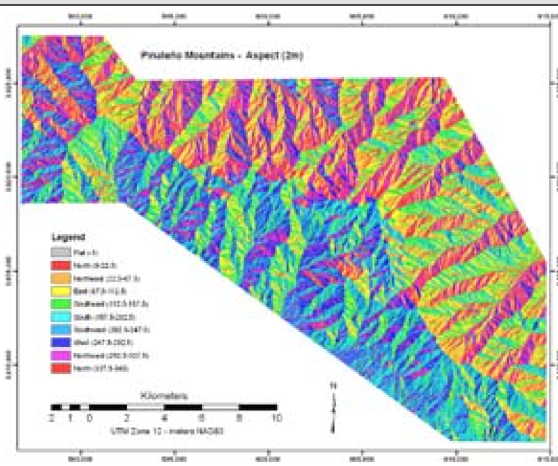
Bare Earth Hill Shade



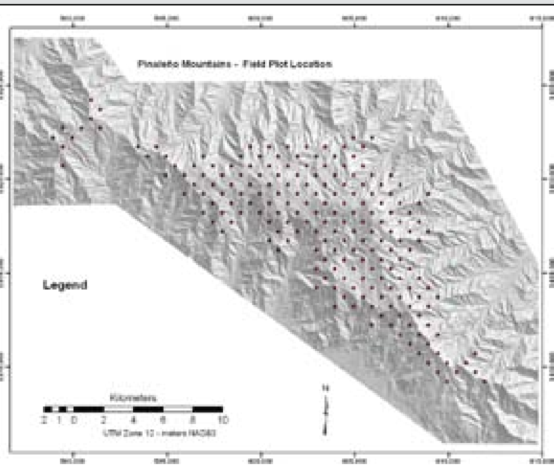
Slope



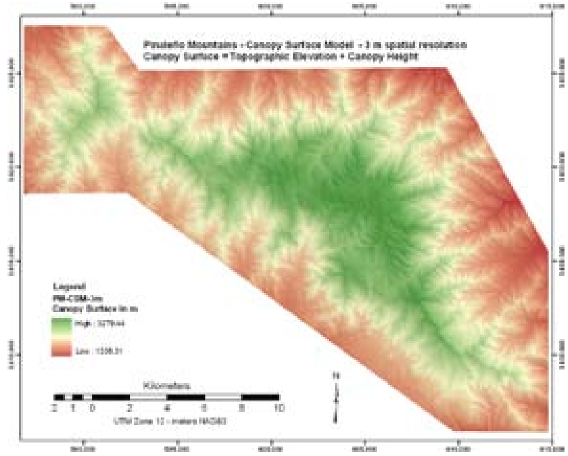
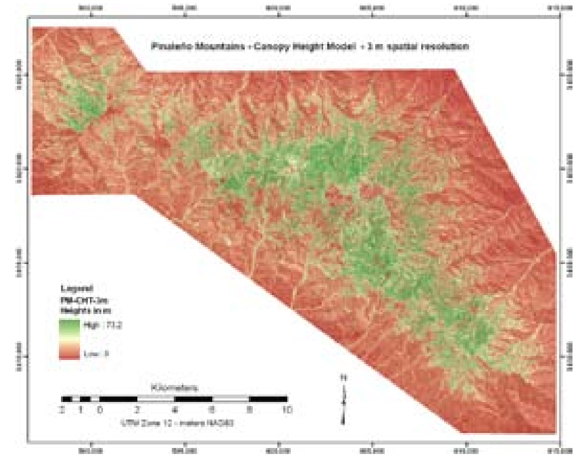
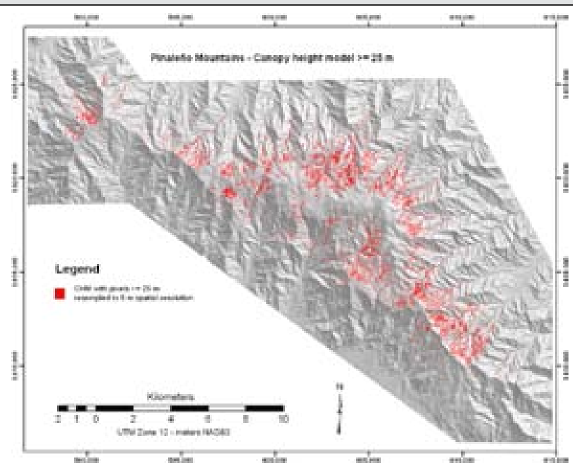
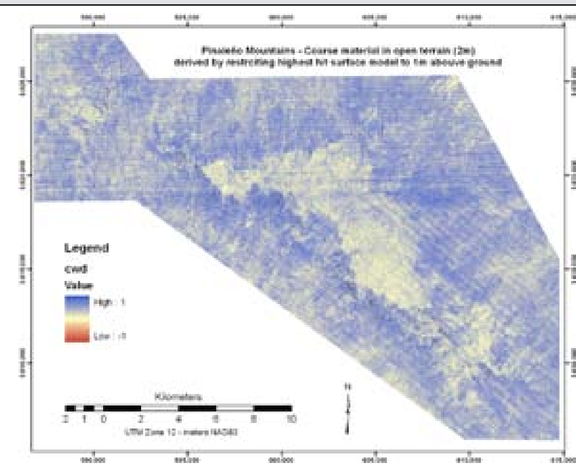
Aspect



Field Plot Locations



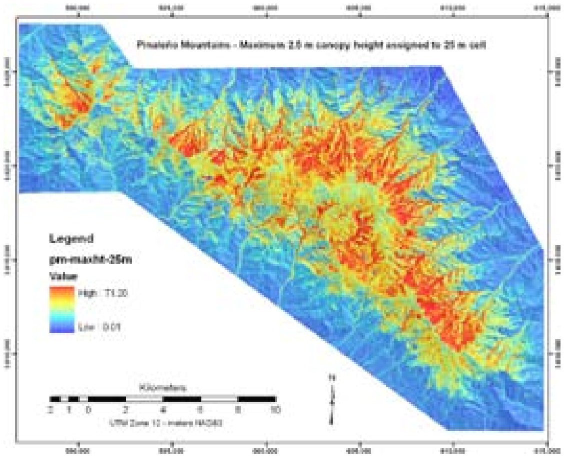
Canopy Surface and Height Models

Canopy Height Model at 3 m (elevation in meters)	Canopy Surface Model at 3 m (height in meters)
	
Canopy Height Model ≥ 25 m at 5 m Cell Size	**Coarse Woody Material at 2 m**
	

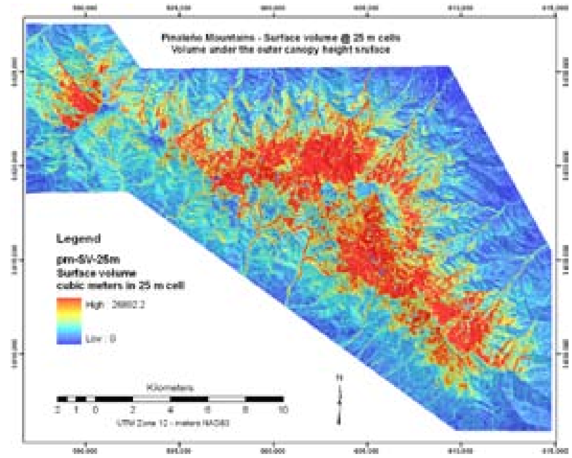
* There is also a canopy surface model and canopy height model at 2.5 m spatial resolution

Surface and Volume Models Derived from 2.5-meter Canopy-Height Model

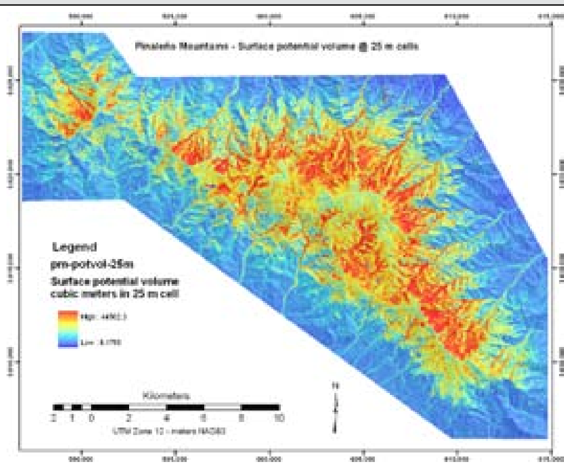
Canopy Max. Height at 25 m



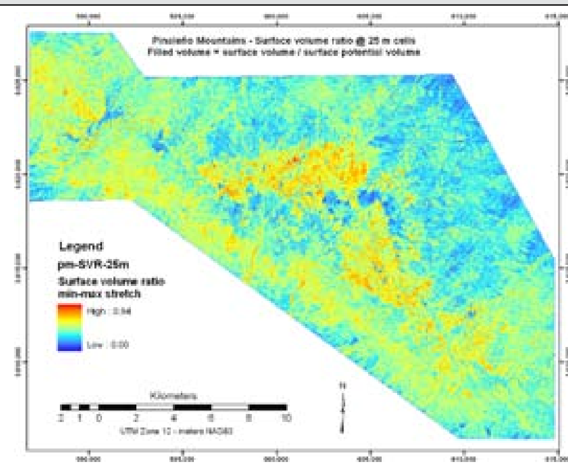
Surface Volume at 25 m



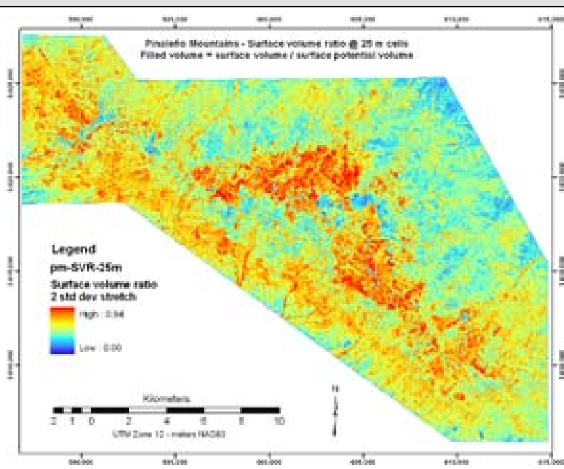
Potential Volume at 25 m



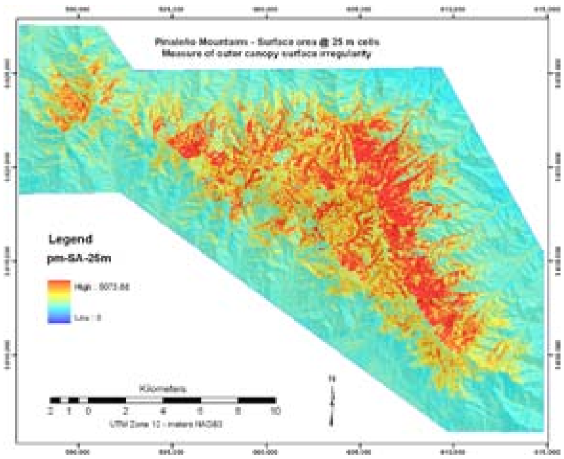
Filled Volume at 25 m (min.-max. stretch)



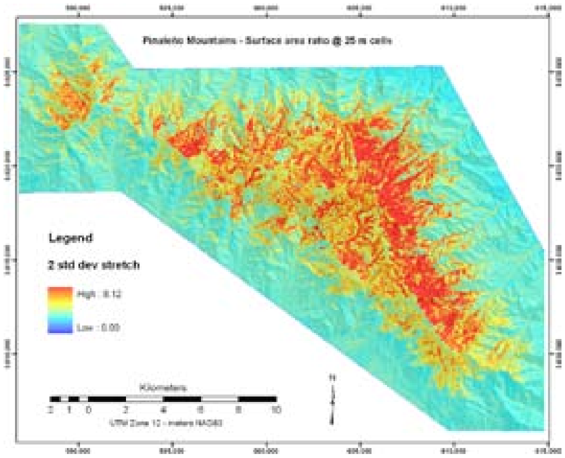
Filled Volume at 25 m (2std stretch)



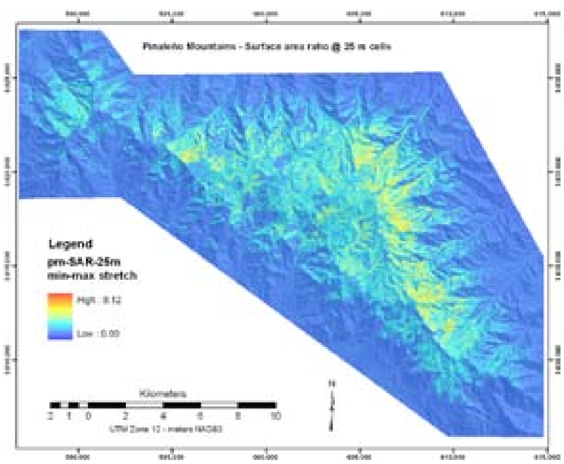
Surface Area at 25 m



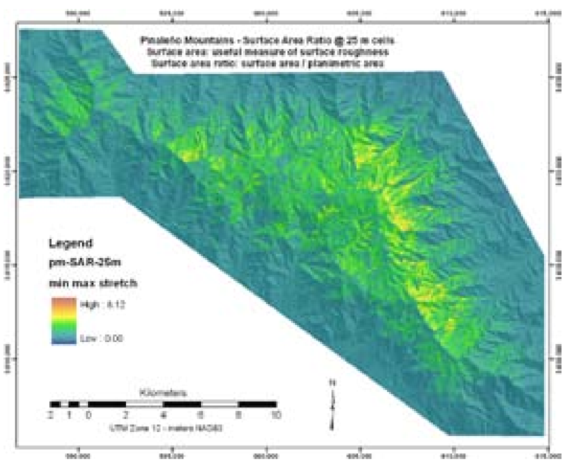
Surface Area Ratio at 25 m (2 std. dev. stretch)



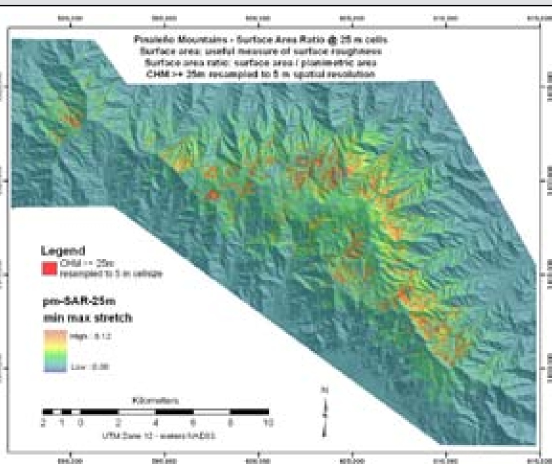
Surface Area Ratio at 25 m (min.-max. stretch)



Surface Area Ratio at 25 m (min.-max. stretch) (eliminating reds)

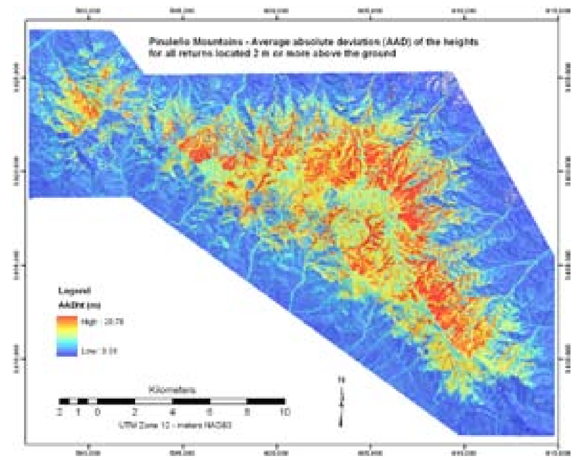


Surface Area Ratio at 25 m (min.-max. stretch with ≥ 25 m trees)

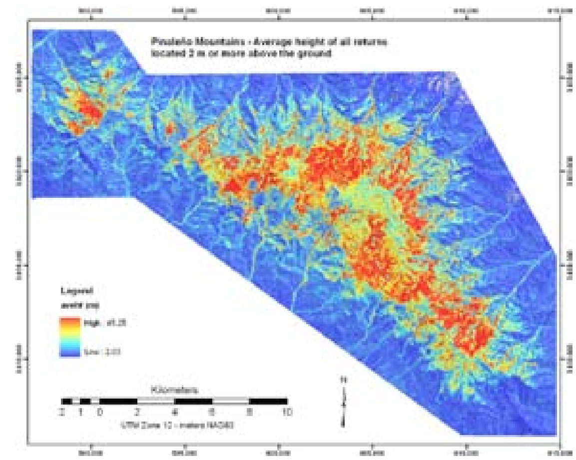


Gridmetrics

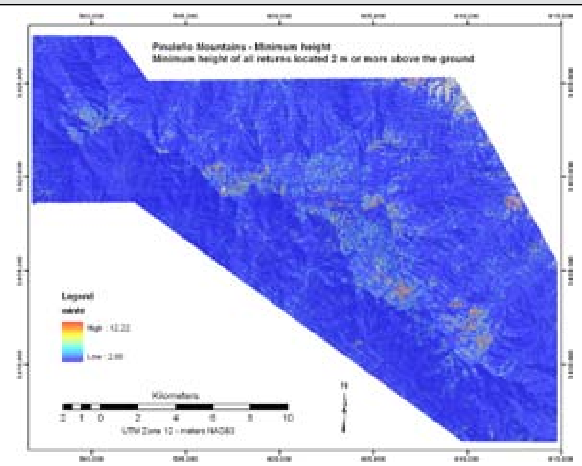
AAdht at 25 m



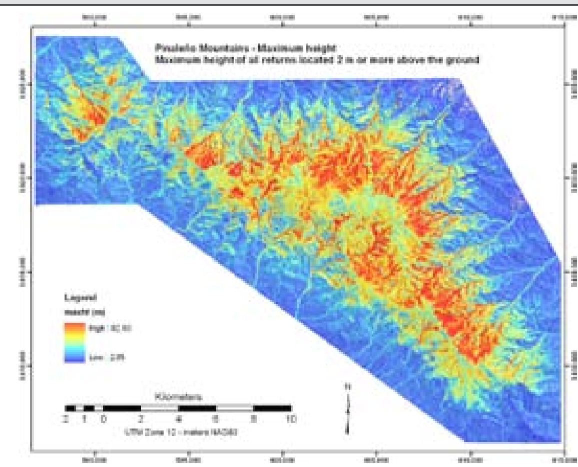
Aveht at 25 m



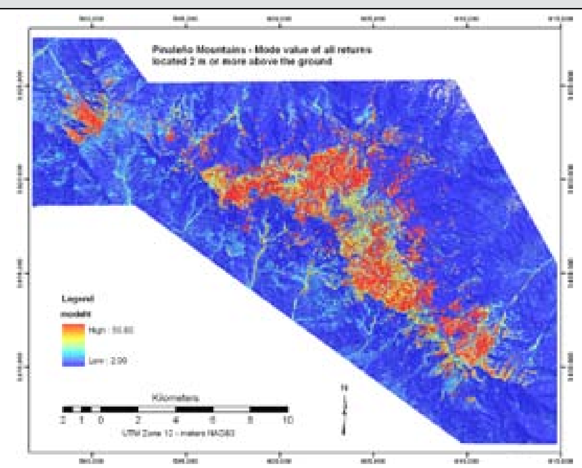
Minht at 25 m



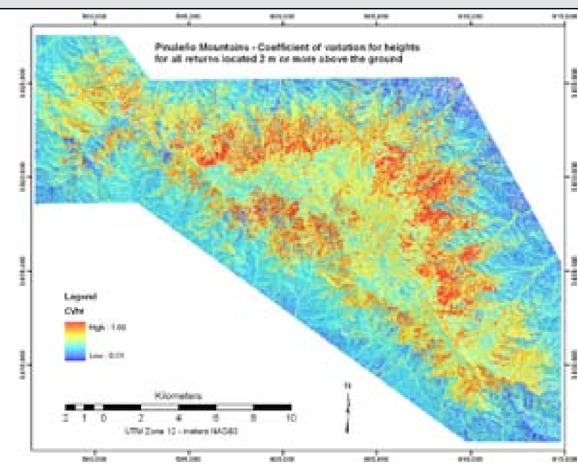
Maxht at 25 m



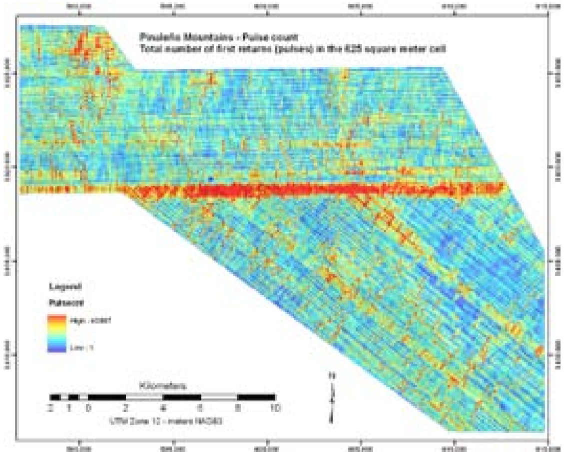
Modeht at 25 m



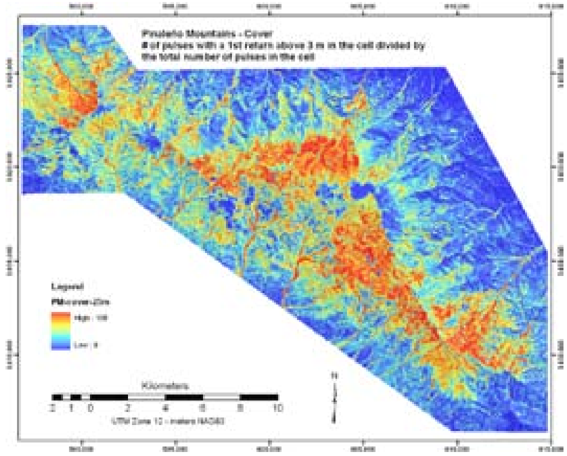
Cvht at 25 m



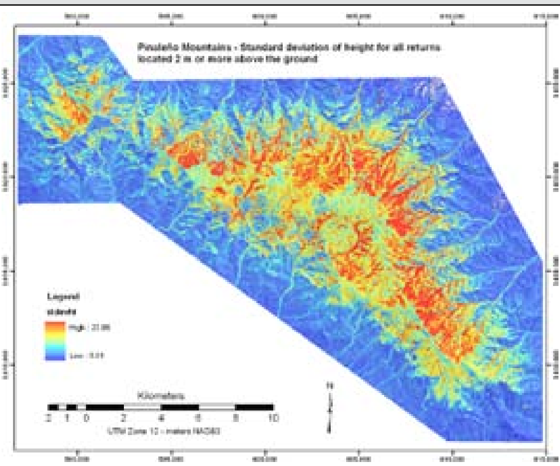
Pulse Count at 25 m



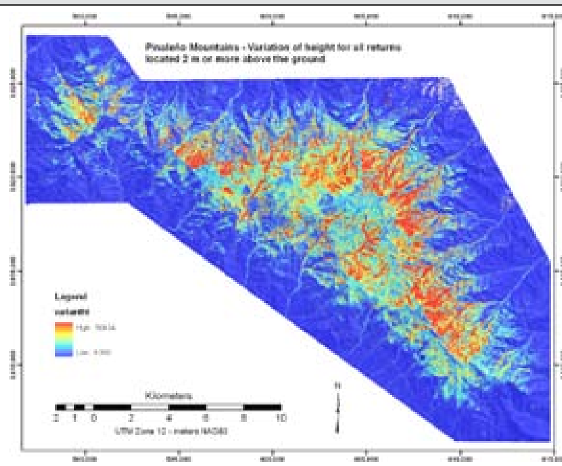
Cover at 25 m



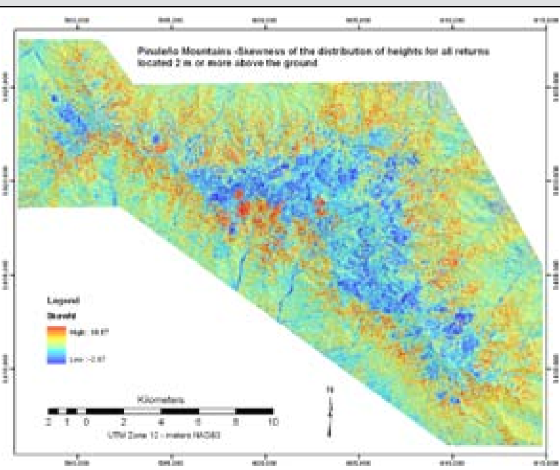
20th Standard Deviation at 25 m



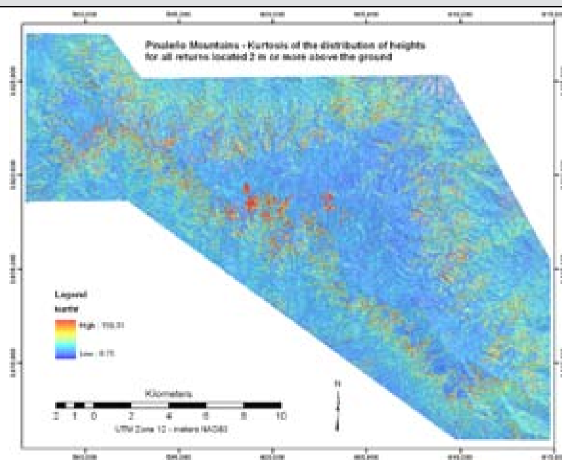
Variance at 25 m



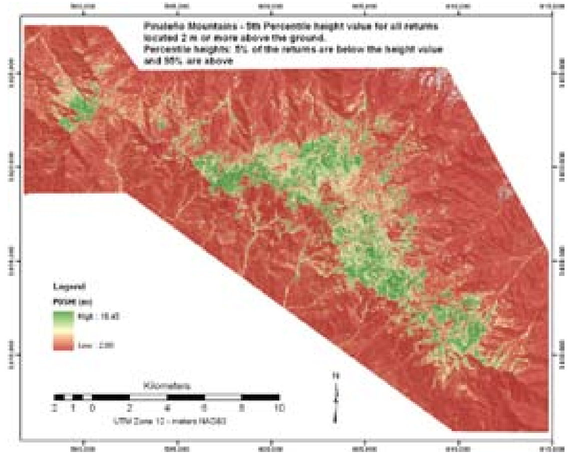
Skewness at 25 m



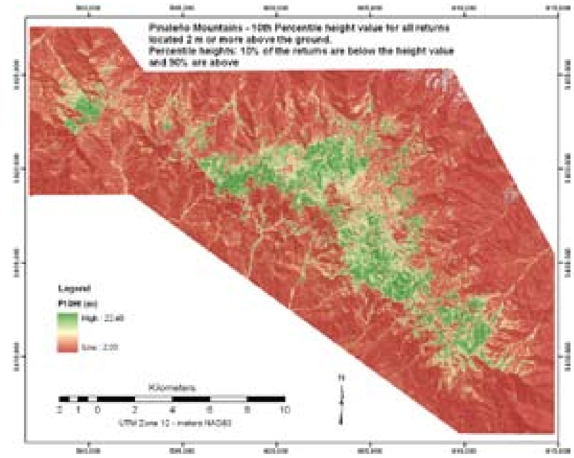
Kurtosis at 25 m



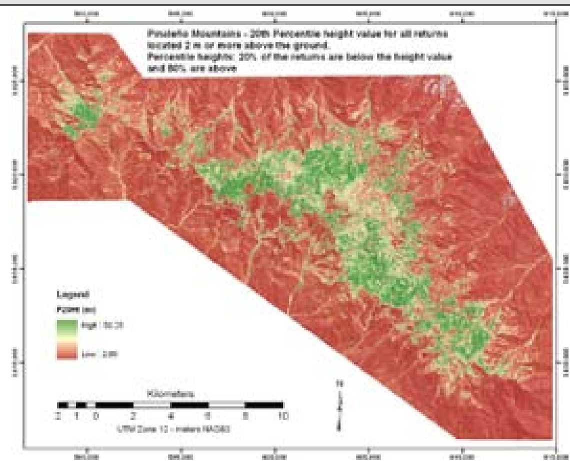
5th Percentile Height at 25 m



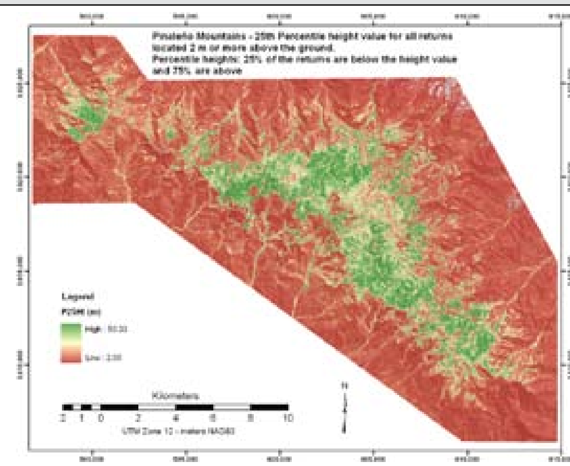
10th Percentile Height at 25 m



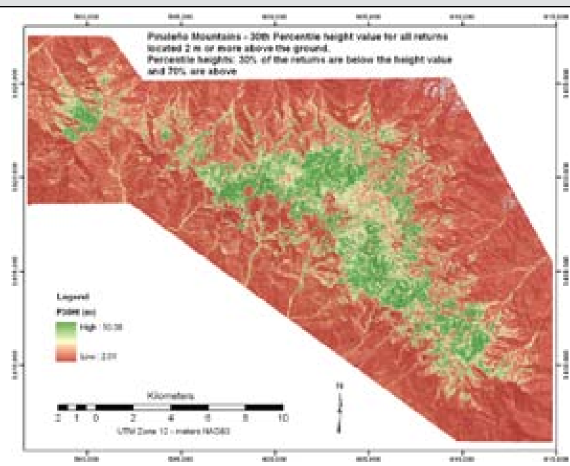
20th Percentile Height at 25 m



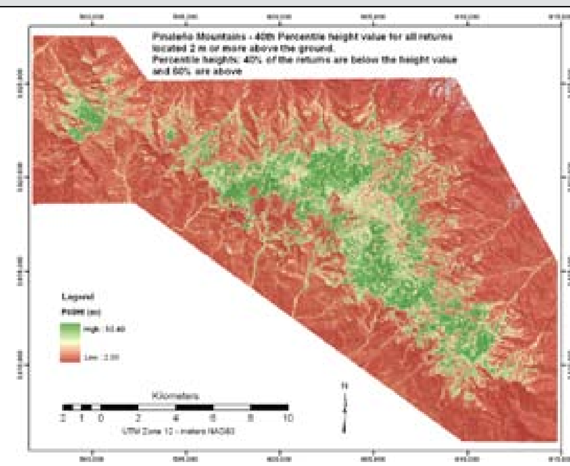
25th Percentile Height at 25 m

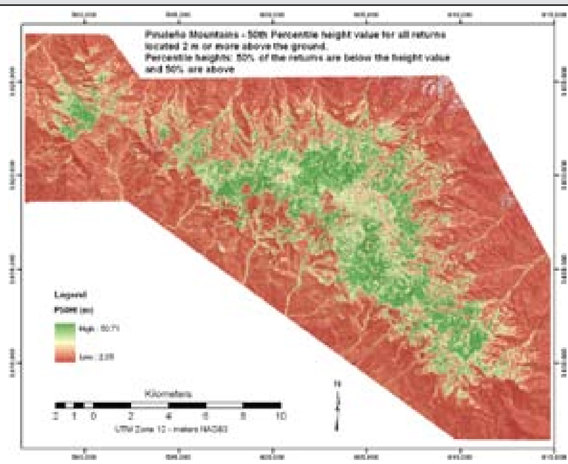
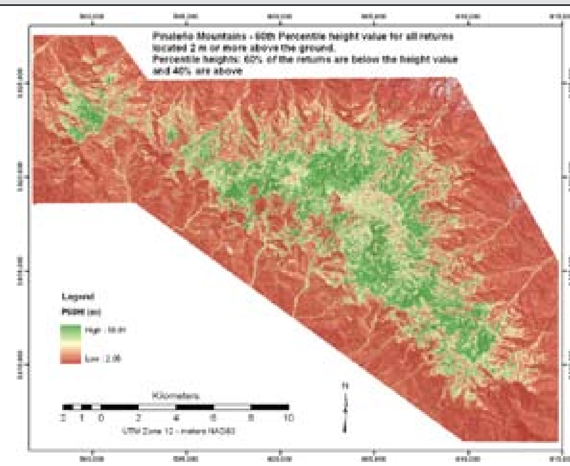
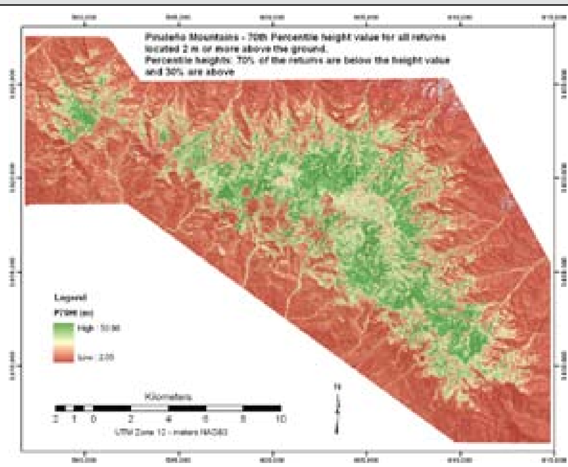
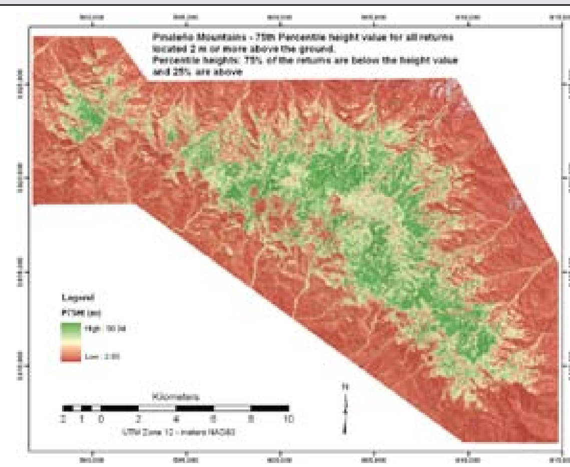
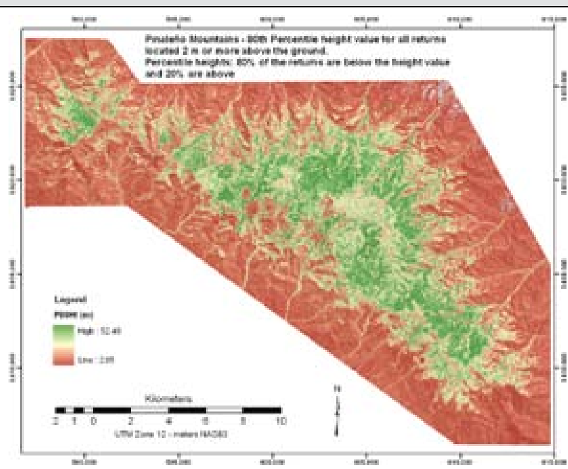
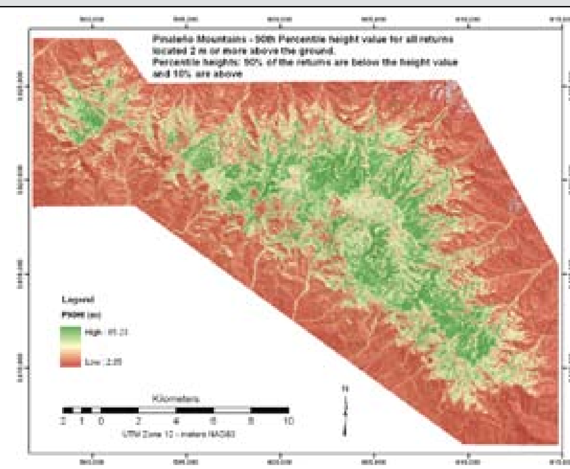


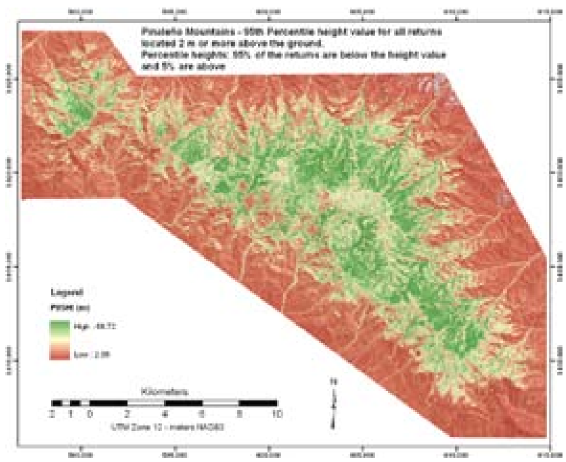
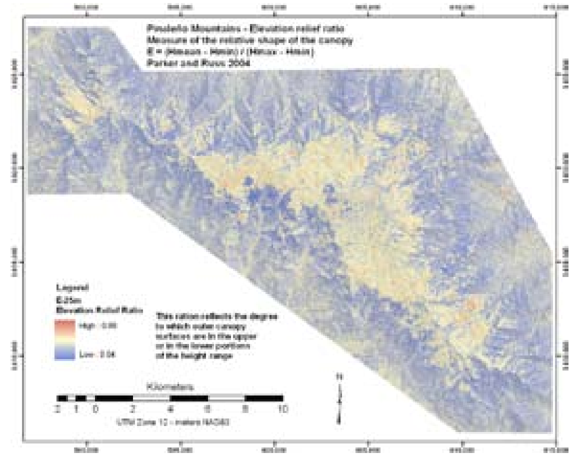
30th Percentile Height at 25 m



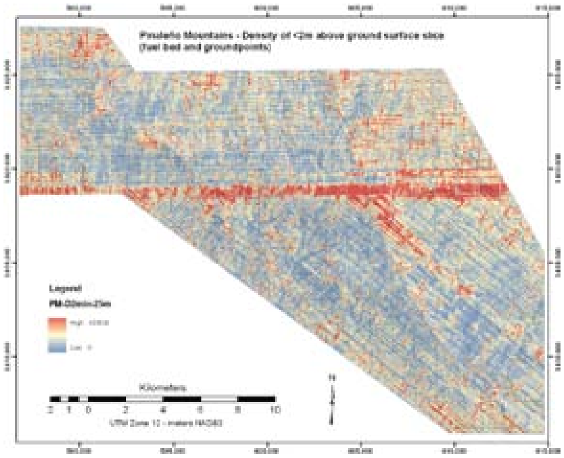
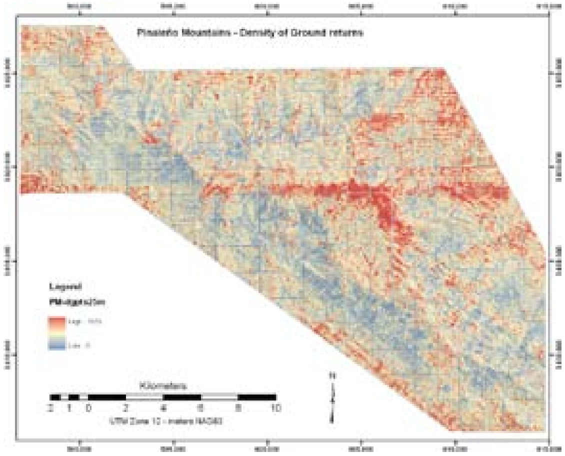
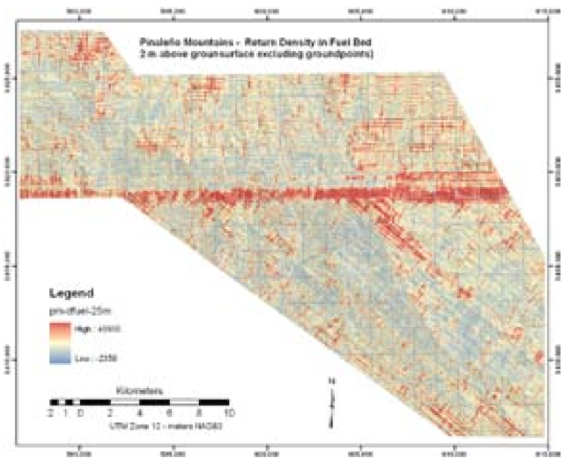
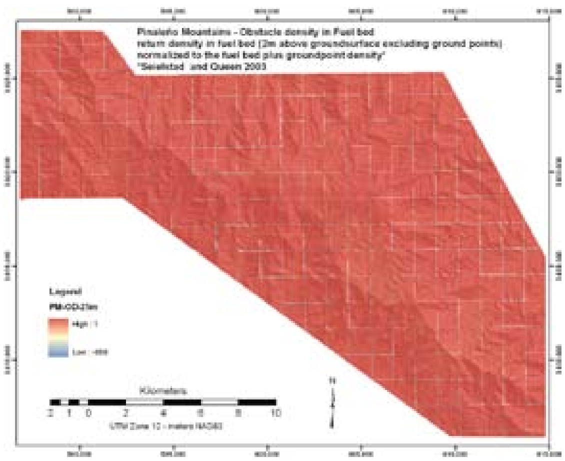
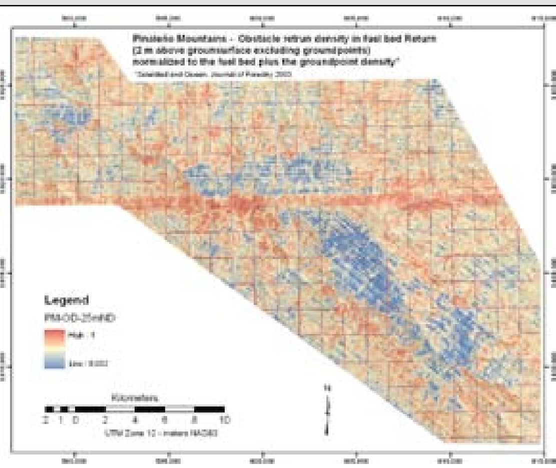
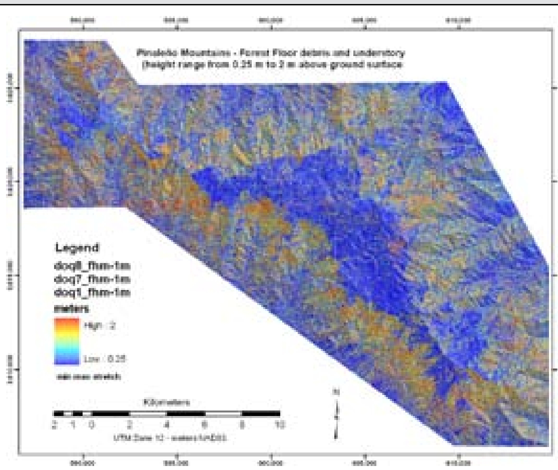
40th Percentile Height at 25 m



50th percentile Height at 25 m	60th Percentile Height at 25 m
	
70th Percentile Height at 25 m	**75th Percentile Height at 25 m**
	
80th Percentile Height at 25 m	**90th Percentile Height at 25 m**
	

95th Percentile Height at 25 m	ERR: Elevation Relief Ratio
	

Obstacle Density and Fuel-Bed Visualization of Forest Floor and Understory

PM_d2min-25 m (return density below 2 m)	Pm-dgpts-25 m (ground points density)
	
Pm-dfuel-25 m (dbelow 2 m—dgtps)	**Pm-od-25 m (dfuel / dmin2 m)**
	
Pm-od-25mnd (dfuel / dmin2 m NoData)	**DOQ8_fhm-1 m , doq7_fhm-1 m DOQ1_fhm-1 m at 1 m**
	

Appendix 4: Field Maps and Plot Lidar Data Clouds

- Making Mapbooks in ArcMap 9.2
- Lidar data clouds for relating field data

Field Maps and Mapbooks

Brief Description: As a supplemental step to field protocol, field maps were produced for the Pinaleños study area based on predetermined plot center points. A series of two-sided maps were produced at scales of 1:2,400 and 1:6,000. These maps were initially created in ArcMap 9.2, using a script named DSMapbooks. You can find the script at this URL: http://edndoc.esri.com/arcobjects/9.0/Samples/Cartography/Map_Production/DSMapBook/DSMAPBOOK.htm. The Mapbooks script enables the user to produce a map index series based on a polygon shape file (figure 1). The extension permits dynamic labeling for each plot-location map. This labeling also allows geographic elements like elevation, slope, and canopy-cover percentage to be indexed to the plot locations.

In addition, lidar data clouds were added to the mapbooks on the reverse side and were subset to the 20th hectare plot locations and to a half hectare for visual reference. The data clouds were added to the mapbooks to relate field measurements to the lidar data clouds. These data clouds were produced using Fusion software, which allows the user to subset and screen-capture them (figure 2). The data clouds were then placed in PowerPoint slides to be added to an Adobe PDF binder of both the mapbooks and the lidar data cloud to compose a two sided map in a single PDF (figure 3).

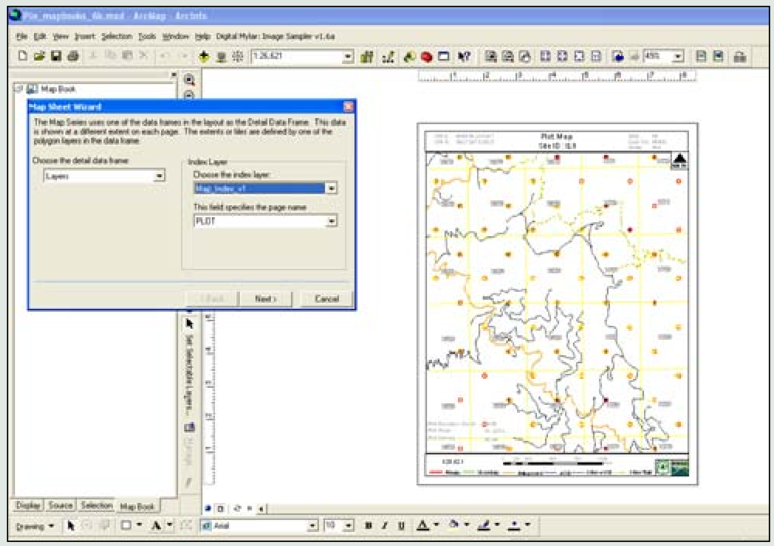


Figure 1—The interface for importing a polygon shape file to produce a set of indexed maps using DSMapbooks.

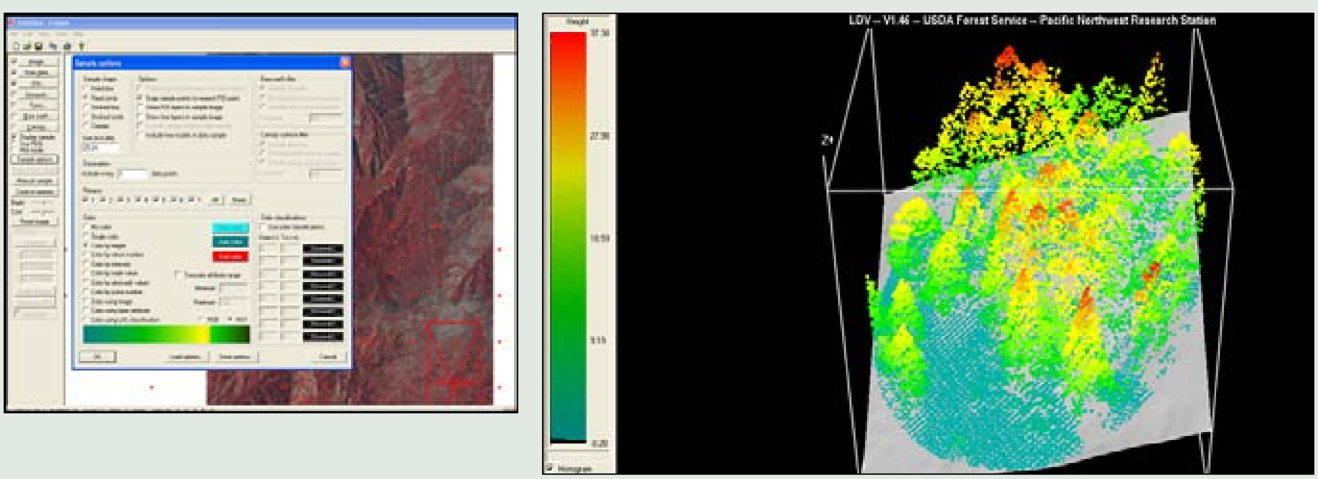


Figure 2—On the left, the Fusion interface; on the right, a lidar data cloud.

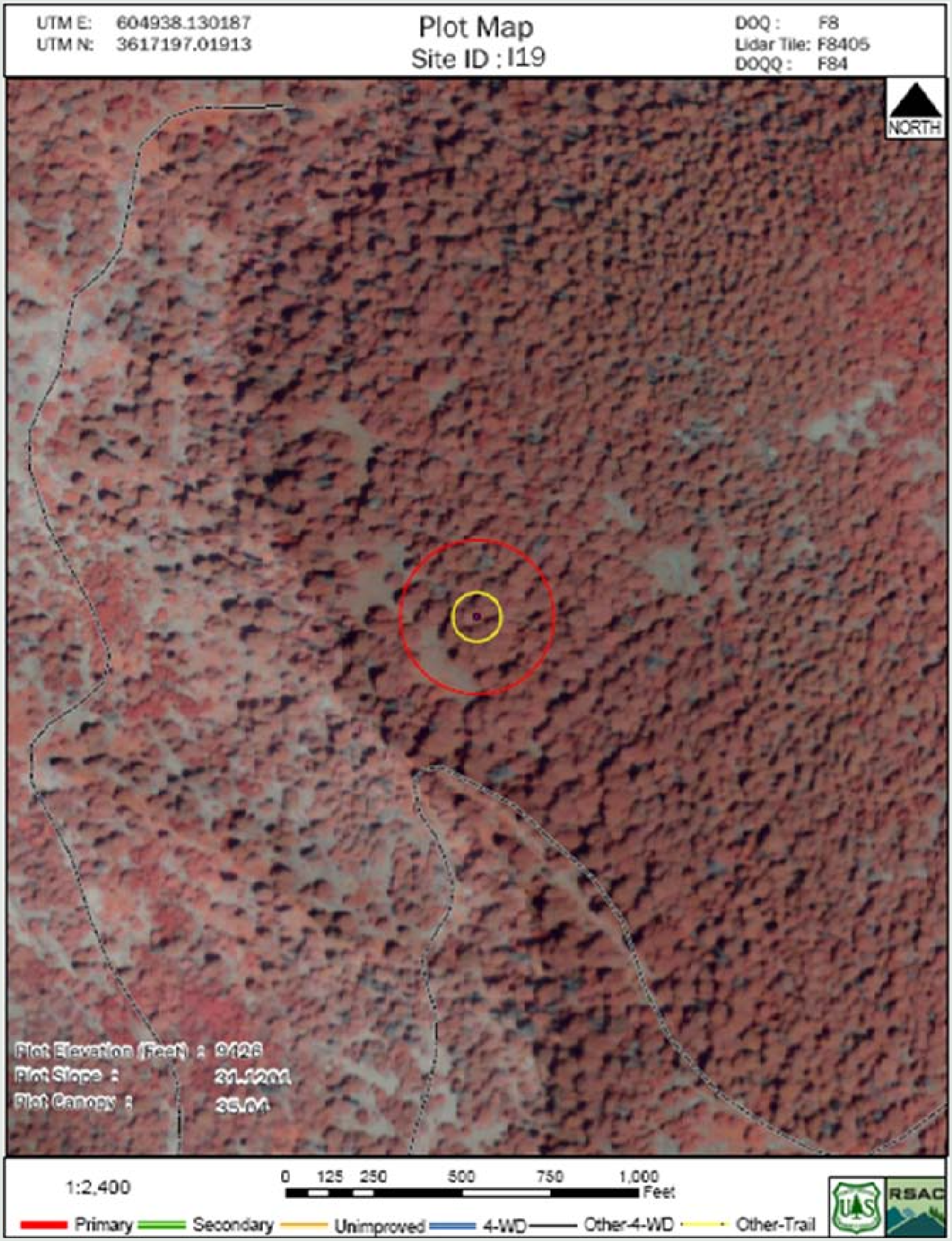


Figure 3A—An example of the front page of a field map produced with DSMapbooks with a representation of the plots in the center.

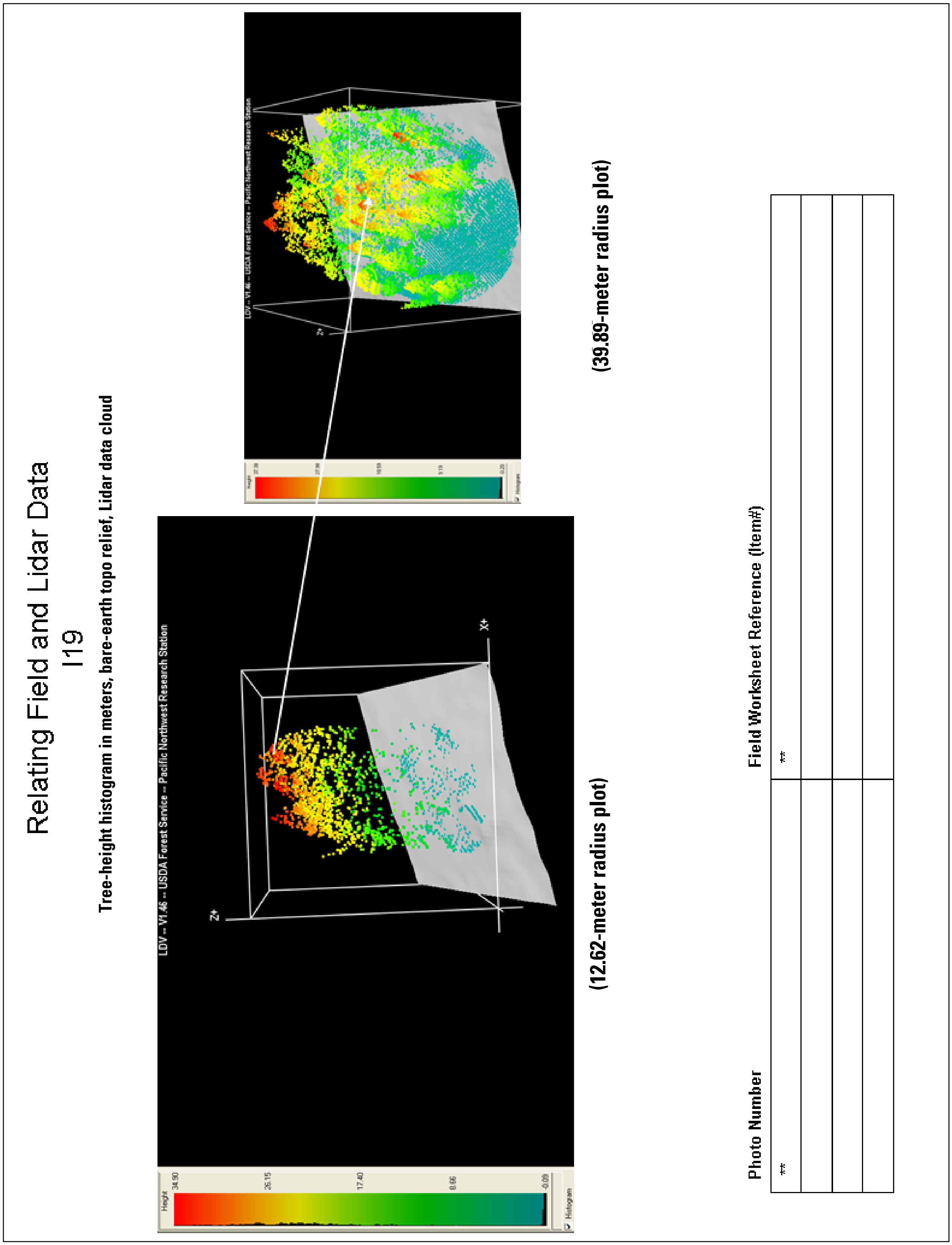


Figure 3B—The reverse side of the field map from figure 3A and the coincident lidar data cloud of the plots.

Process: The geospatial layers used in the field maps and their composition are described in this section.

- As a starting point for the mapbooks, an original plot center-point shape file was buffered to represent the size of the field plots, in this case a 20th-hectare circular plot. An additional, larger circular buffer was made to represent subsequent lidar data-cloud radius plots. These data clouds were imaged on the reverse side of the maps to relate field findings to lidar data.

- The maps it was determined that color-infrared (CIR) imagery should be used as the backdrop for the front of the field maps. Imagery of the study area was acquired at the time of the lidar data collection and delivered as 1-meter spatial-resolution and 4 band .tif images, with an available CIR band. This imagery was the primary backdrop in the mapbooks and required some preprocessing through an ERDAS Imagine model (figure 4). The model separates the three desired bands—4, 3, and 2—from the original 4-band image, then restacks the bands into a representative CIR 3-band image.

- The imagery was then added to the mapbooks and given a 25 percent display transparency. To reveal the 1-meter spatial-resolution hill shade relief produced for the area from the raw lidar data. This layer added visual topography to the photos and plot locations that formerly was not possible.

- In addition to visual enhancement, dynamic topographic elements were added, in this case as text tables, to the front page of the mapbooks by producing zonal statistics based on the 20th-hectare plot radius polygon file and lidar-derived elevation, slope, and canopy-cover percentage layers (figure 5). To add dynamic elements to the set of maps, ArcTools spatial Analyst processed the zonal statistics on these layers (figure 6).

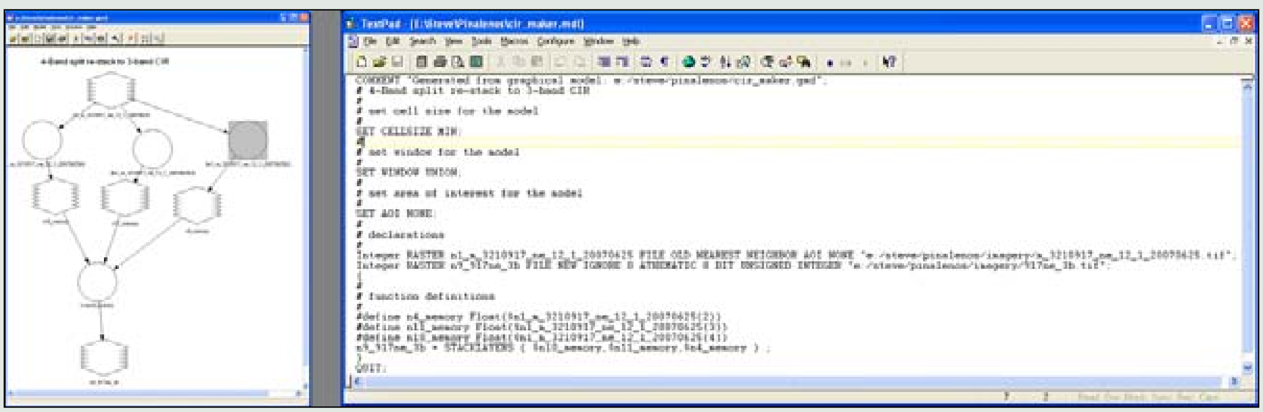


Figure 4—The ERDAS graphical model and script used to produce 3-band CIR imagery from the original 4-band imagery.

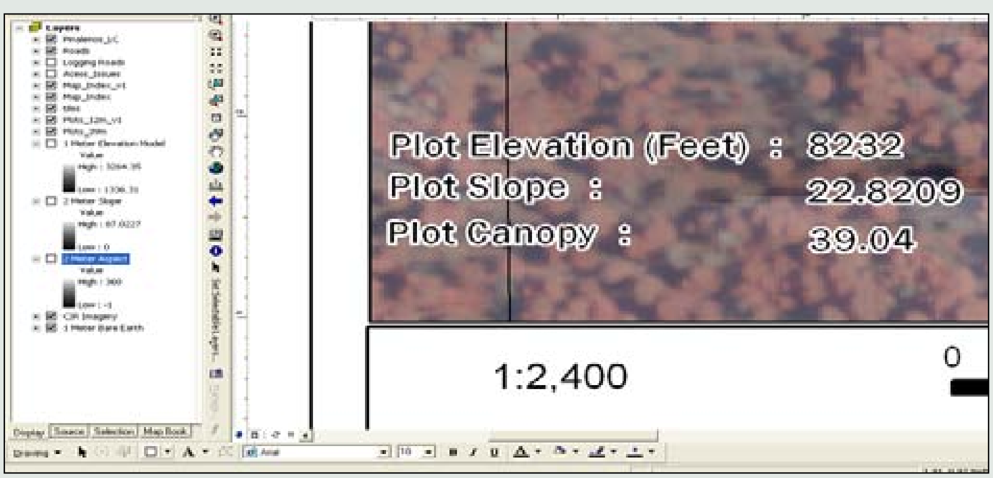


Figure 5—An example of dynamic reference on the front of the field maps to elevation, slope, and canopy cover to a sample plot.

- Additional GIS vector layers such as roads and trails were added to the mapbooks, and they were exported to PDF files (figure 7).

- Using Fusion software, lidar data clouds were screen-captured for use in the maps and added to PowerPoint slides. A toolbar was made, and a macro was written to place them graphically inside the PowerPoint at the correct size (figure 8). Adobe then combined the plot maps and the lidar data clouds into a single PDF binder (figure 9).

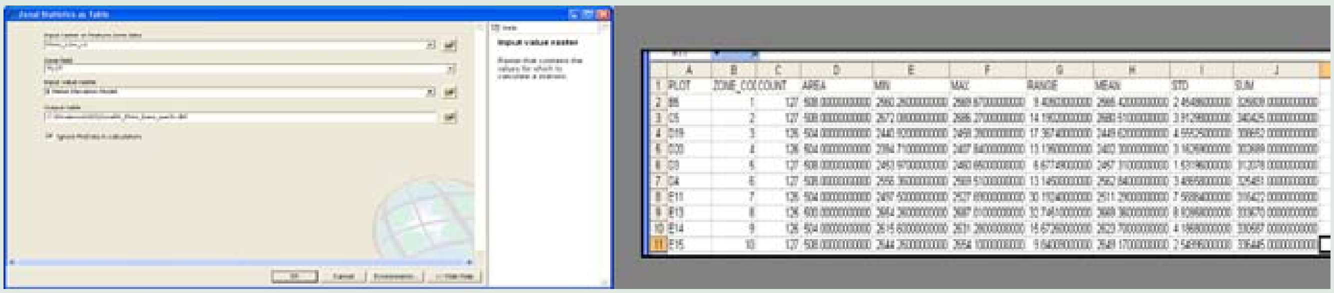


Figure 6—An example of ArcTools Spatial Analyst which produced the zonal statistics. These statistics are operating behind the scenes to dynamically label items portrayed in figure 5.

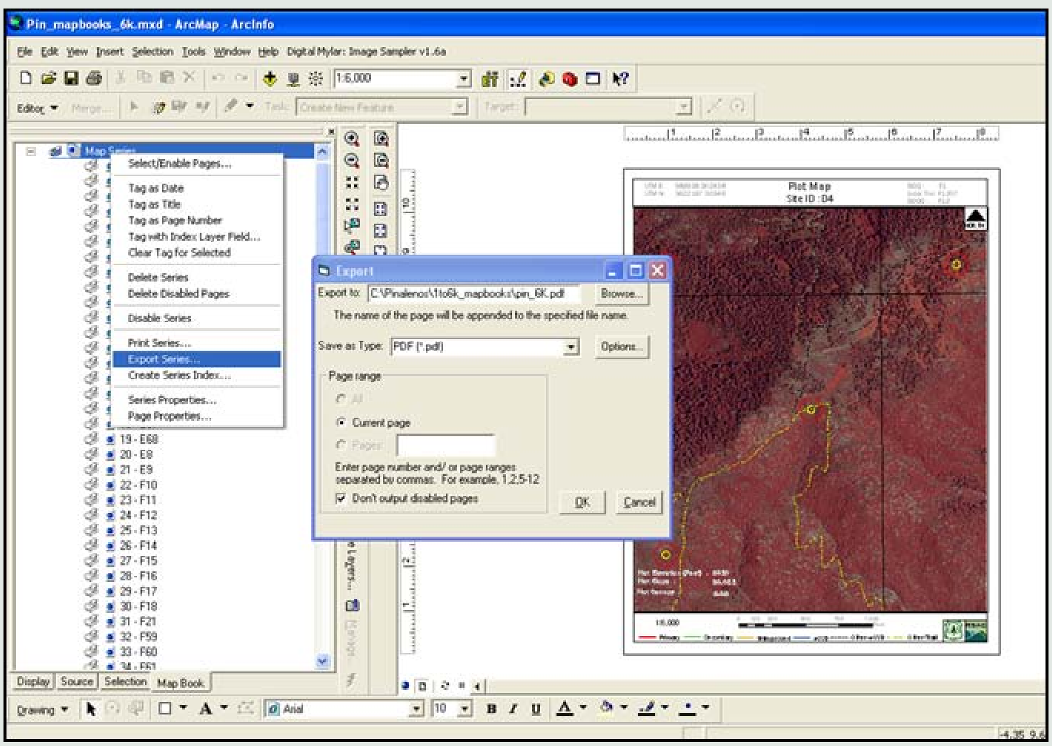


Figure 7—Exporting a mapbook series to .pdf files inside of ArcMap.

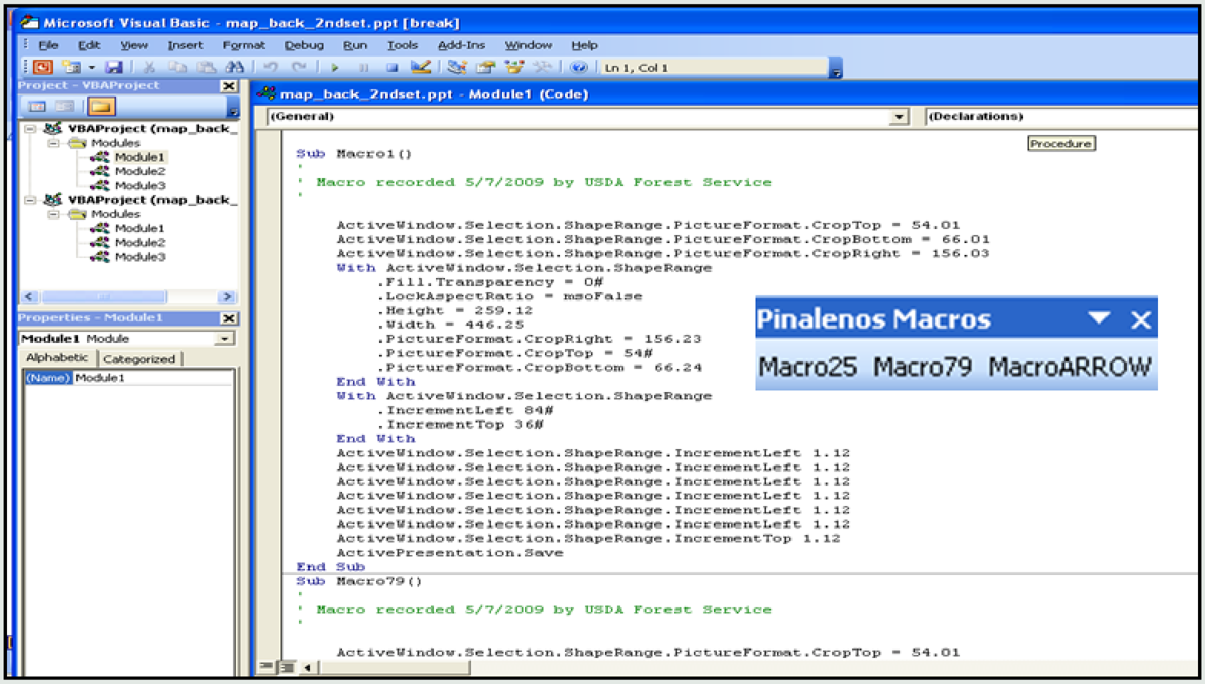


Figure 8— These macros were developed for sizing the pages of lidar data-cloud screen captures.

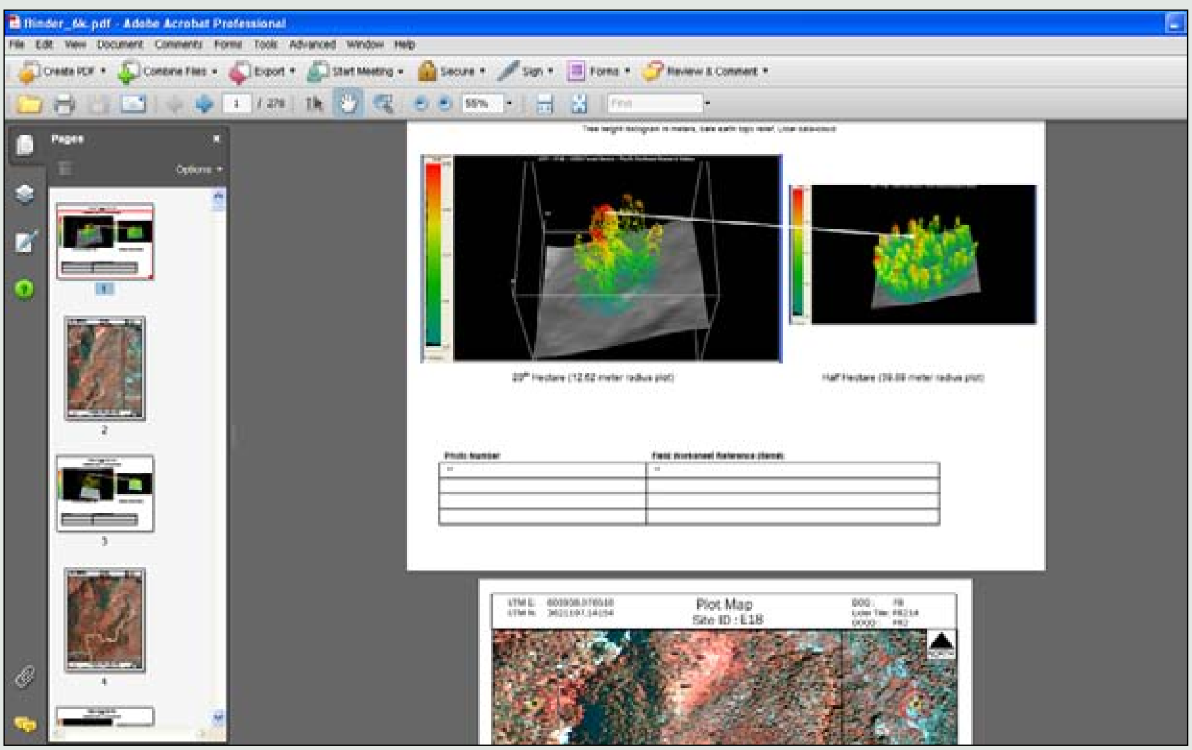


Figure 9—The Adobe .pdf binder produced for the two-sided field maps.

Plot Lidar Data Clouds Subsets

The lidar returns in the 0.05-hectare field plots were subset twice with two separate batch files:

- The first kept the elevations of the lidar points
- The second normalized the elevations to the bare ground (using the 1 m bare-earth DOQQs) by converting the lidar points to height measurements.

Before the scripts could be generated, the plot centers were buffered in ArcGIS with 12.62 m-radius buffer. The plots, now representing circles, were intersected with the LAS tile index and the DOQQ boundaries to find out which ones intersected more than one LAS tile or DOQQ. Where this occurred, the LAS tiles and the DOQQs were merged into a single input file. Twelve plots (G16, H16, I16, I18, I19, I20, I62, O72, O73, F69, G69 and H69) required merging LAS tiles, and seven needed DOQQ DTMs combined before the batch script could be generated. The merged LAS files and all the DOQQ files need to be copied to the \point\las\all_points\ folder for the batch file to work (or the spreadsheet can be edited to point to the right folders).

The batch files were prepared in an Excel spreadsheet (plot-tile-intersections.xls). The information to build the spreadsheet was extracted from the table created by intersecting the buffered plots with the tiles and DOQQ boundaries. The resulting dbf table was further manipulated in Excel.

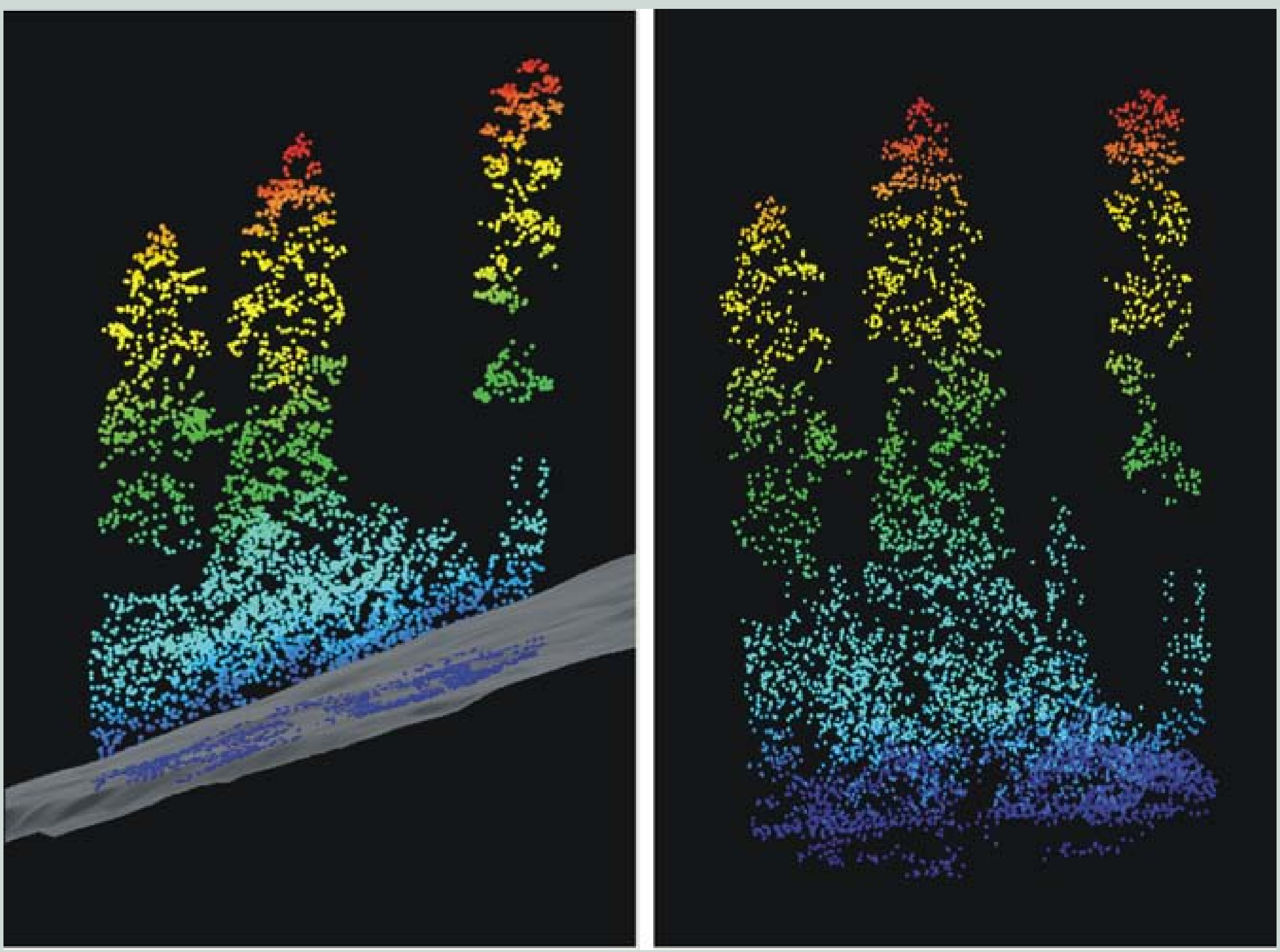


Figure 10—An example of the point cloud for plot J69, showing elevation values on the left and height values on the right.

The required min*X*, min*Y*, max*X,* max*Y* were calculated from the *XY* coordinates *(X-12.62, Y-12.62, X+12.62, Y+12.62)*. Where the plots overlapped 2 tiles or a DOQQ boundary, the necessary substitutions reflecting the file names of the merged input files were made. Finally, the required syntax switches were added for each line. The final batch file was generated by concatenating the individual columns into a single one that was copied by a text editor.

The plot data representing point elevations are identified by the *E* in the file name: example, J69-E.lda. Those that are normalized to heights have the leeter *H* in the filename: J69-H.lda. The files represented by heights are used to calculate the cloudmetrics for each plot. The results for plot J69 appear in figure 10.

Unlike the other batch files, which are relatively fast to make and slow to run, creating the one to subset the lidar points corresponding to the field plot locations takes more time but runs very fast. After double-checking that the required number of files were created (597) for each of the runs, the content of the LDA files was checked by dropping them into Fusion's PDQ viewer. To make sure the subsets coincided with the locations of the plots, the intensity image for the entire project area was loaded into Fusion, and the shape file with the plot ceters was superimposed on it (figure 11). The resulting file was loaded as a point of interest (POI), (figure and the LDA files for all the plots). The POI locations and LDA locations should overlap (figure 12)

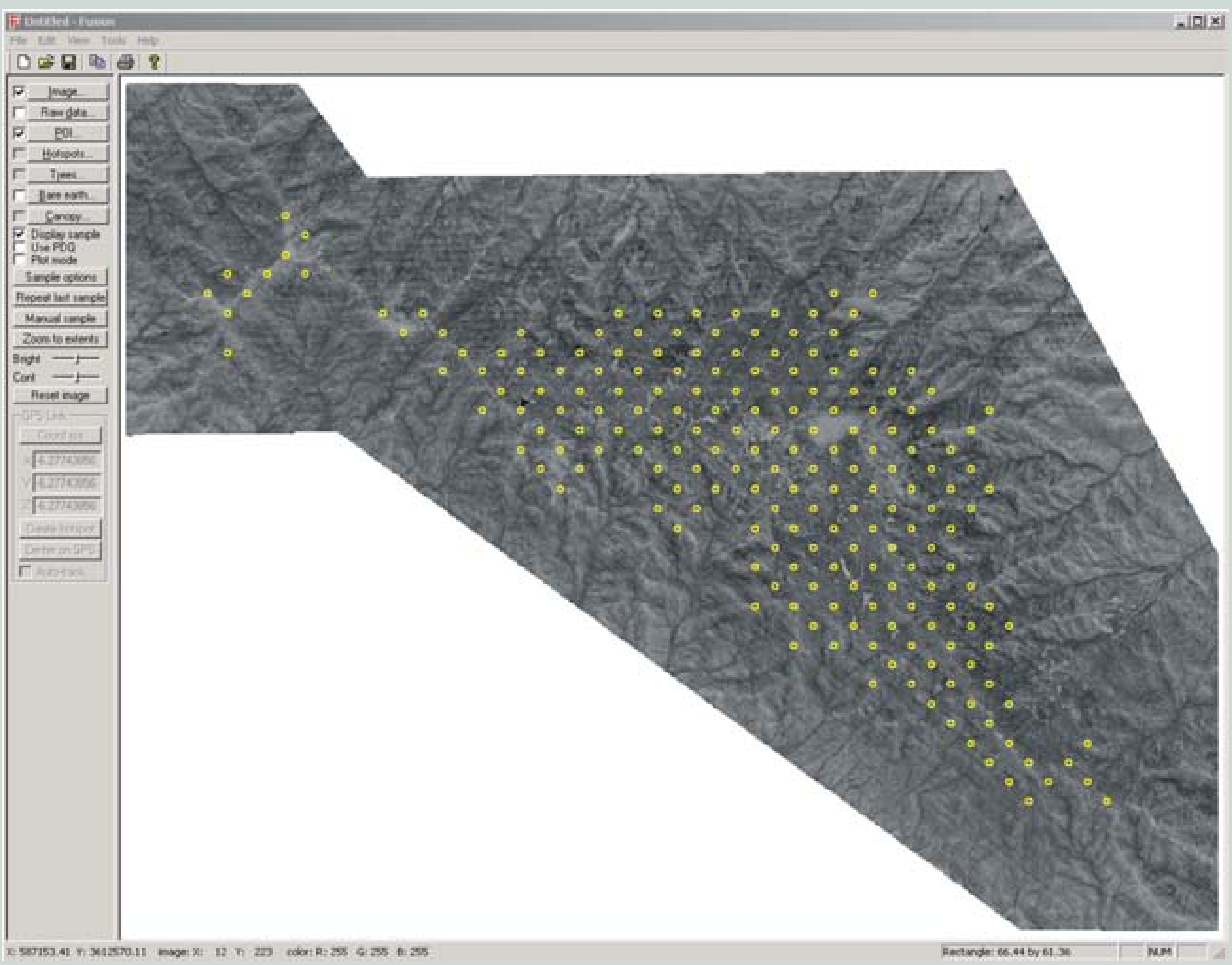


Figure 11—A Fusion display of the intensity map with the field plot locations depicted by a shape file.

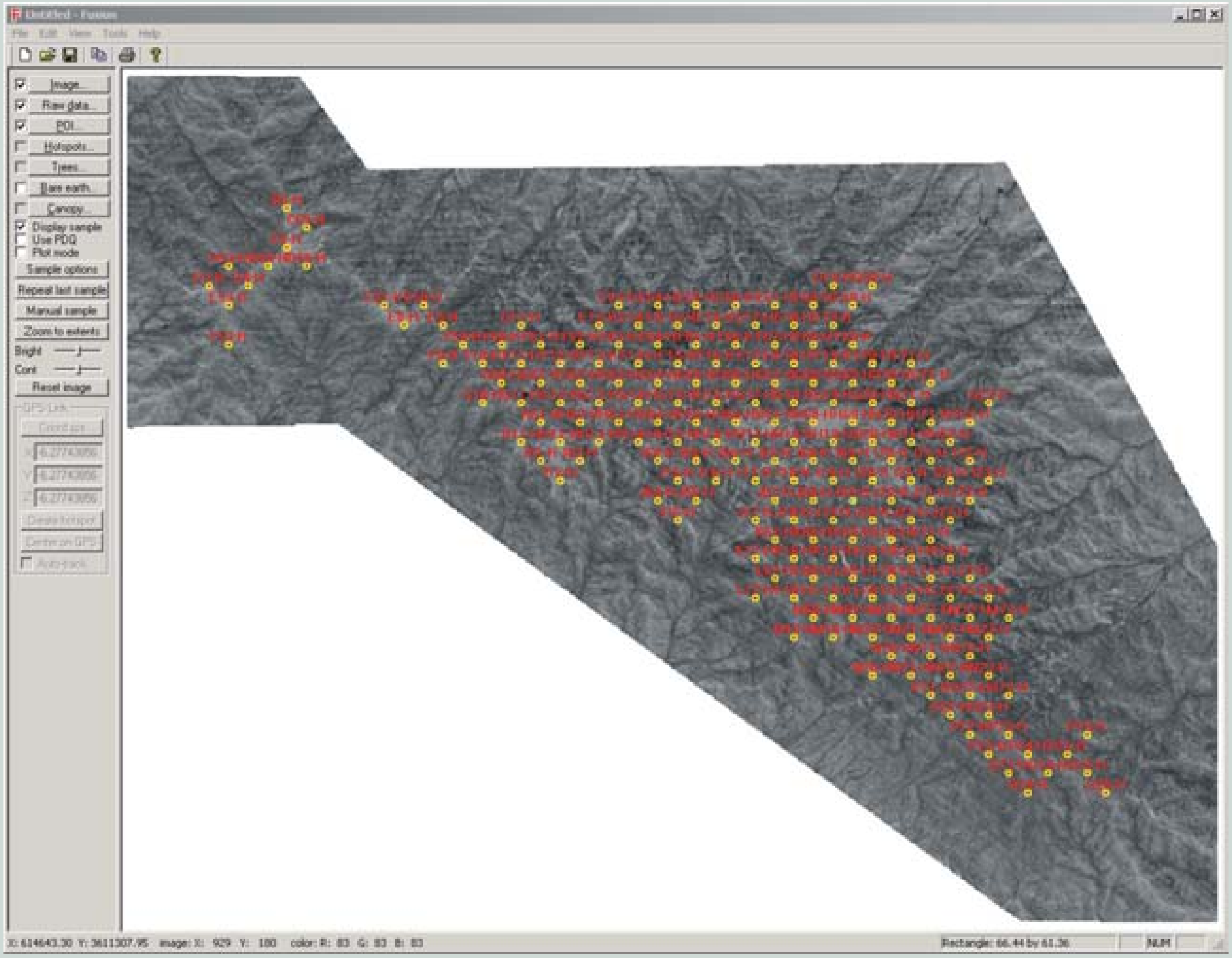


Figure 12— A Fusion display of the intensity map with the field plot locations labeled in preparation for point-cloud extraction for each plot.

Appendix 5: Abbreviations

Aadht	Average absolute deviation height
AML	Arc macro language
Asc	ASCII file
ASCII	American standard code for information interchange
Aveht	Average height
BAT	Batch file extension
BE	Bare earth
CHM	Canopy height model
CIR	Color infrared
cm	Centimeter
CPU	Central processing unit
CSM	Canopy surface model
CSV	Comma-separated-values file format
Cvht	Coefficient of variation height
CWD	Coarse woody debris
CWM	Coarse woody material
DBH	Diameter at breast height
DOQQ	Digital ortho quarter quadrangle
DTM	Digital terrain model or Plans file extension
FHM	Fuel-bed height model
FSM	Fuel-bed surface model
GB	Gigabytes
Ge	Greater than
GIS	Geographic information system
GPS	Global positioning system
Ha	Hectare
HH	Highest hit
HTML	Hypertext markup manguage
IMU	Inertial measurement unit
kHz	Kilohertz
Kurtht	Kurtosis height
LAS	File extension for lidar files
LDA	Fusion binary lidar format for point data
m	Meter
Maxht	Maximum height
MGIO	Mount Graham International Observatory
MGRS	Mount Graham red squirrel
Minht	Minimum height
Modeht	Mode height
NAD	North American datum
NAIP	National Agricultural Imagery Program
NAVD	North American vertical datum
ND	No data
NS	North/South
OD	Obstacle density
P	Percentile
PM	Pinaleño Mountains
PNWRS	Pacific Northwest Research Station
Potvol	Potential volume
QA	Quality assessment
QC	Quality control
RAM	Random access memory

REM	DOS batch file comment line that gets ignored during execution
RFQ	Request for proposal
RTK	Real time kinematic
SA	Surface area
SAR	Surface area ratio
SFV	Surface filled volume
Skewht	Skewness height
SPV	Surface potential volume
Stdevht	Standard deviation height
SV	Surface volume
SVR	Surface volume ratio (SA/potvol = filled volume)
TB	Terabytes
TBD	To be determined
Tile#	Tile-ID
USFS	United States Forest Service
USGS	United States Geological Survey
UTM	Universal transverse mercator
Varianht	Variance height