JULY 24, 2013

Technical Data Report

University of Washington Pack Forest LiDAR Survey

Prepared For:

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UNIVERSITY OF WASHINGTON
SCHOOL OF ENVIRONMENTAL AND FOREST SCIENCES
CENTER FOR SUSTAINABLE FORESTRY
AT PACK FOREST

Applied Remote Sensing and Analysis

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Overview

WSI has collected Light Detection and Ranging (LiDAR) data for the University of Washington. The data set contains the Pack Forest Study Area. The data were collected on July 3, 2013 and delivered to the client on July 24, 2013.

Project Overview	
Study Area	University of Washington Pack Forest
AOI Acres	4,353
TAF Acres	5,287
Acquisition Date	7/03/2013
Delivery Date	7/24/2013

Project Extent

The study area is located in Pierce County, Washington near the city of Eatonville. The primary purpose of the data set is to support forest inventory analysis and the creation of map baselayers.

The area of interest (AOI) is 4,353 acres. The total area flown (TAF) equaled 5,287 acres, and was calculated by buffering the AOI by 100 meters.

PROJECTION
Universal Transverse Mercator (UTM) 10

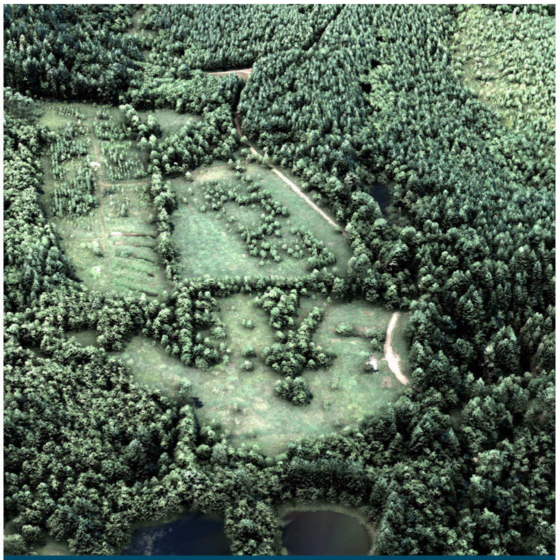
DATUM
Horizontal:
North American Datum of 1983 (NAD83) 2011
Vertical:
North American Vertical Datum 1988, GEOID 12A

UNITS
Meters

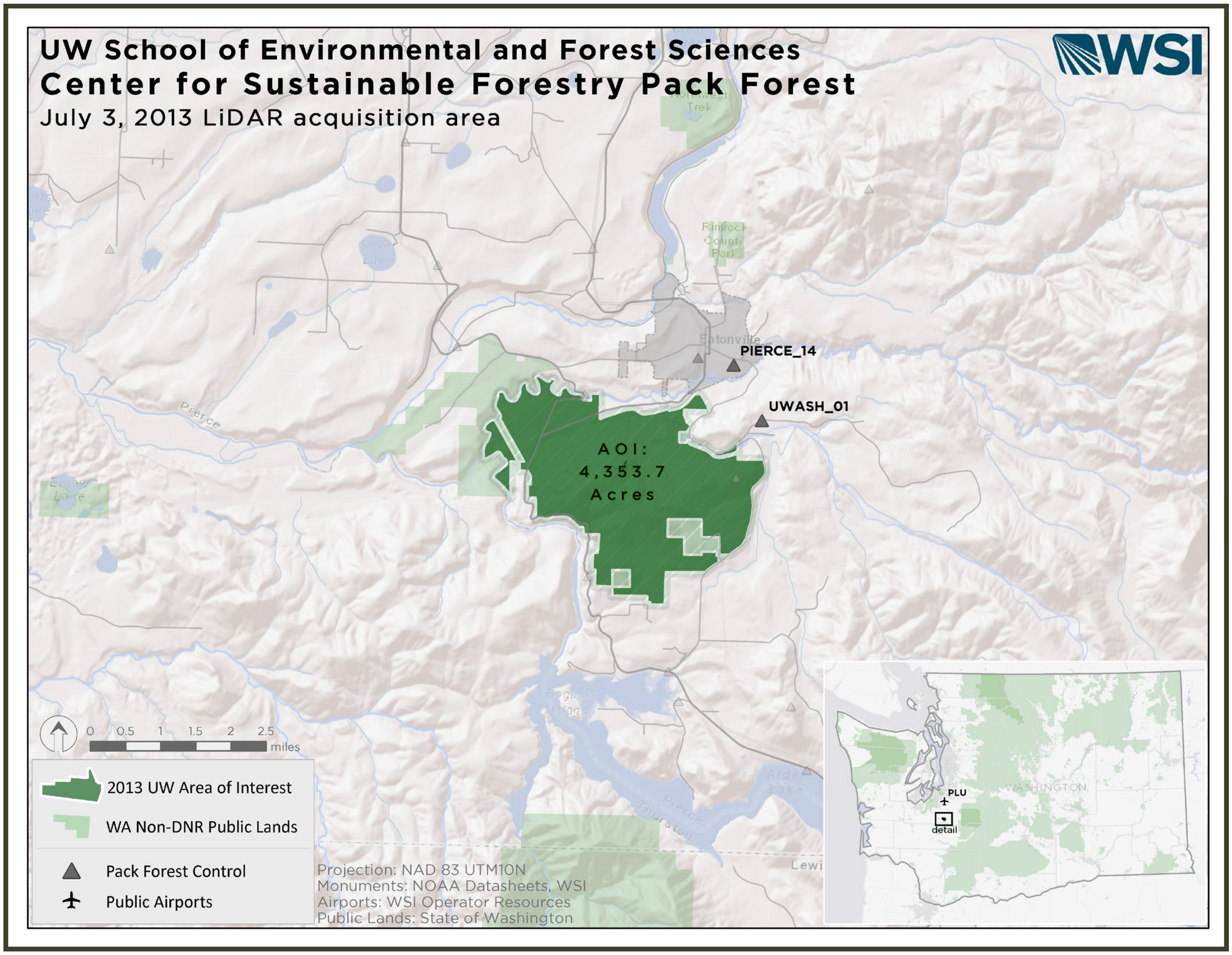
Deliverables

The following data have been provided to the University of Washington Pack Forest on an external drive from WSI:

- Classified LiDAR points (*.las)- Ground & Default. Point files include the following fields:
  - X, Y. Z
  - Return Intensity
  - Return number
  - Point classification
  - Scan angle
  - GPS time
- Raster Datasets:
  - Bare Earth DEM (1-meter resolution)
  - Intensity Rasters (0.5-meter resolution)
- Vector Datasets: ESRI shapefiles of the following data
  - Total Area Flown (TAF)
  - Tiling scheme for deliverable products
  - Flightlines
  - Location of RTK checkpoints
  - Location of GPS monuments occupied
- Six inch Orthophotos
- Technical Data Report



LiDAR point cloud with RGB extracted from orthophotos. Alder Cutoff Rd E.



University of Washington Forest Inventory LiDAR Survey			
Area of Interest	Total Area Flown	Acquisition Date	Delivery Date
4,353 acres	5,287 acres	7/03/2013	7/24/2013

Acquisition

For the survey of the Pack Forest Study Area, WSI employed a Cessna Grand Caravan 208-B fixed-wing aircraft with a crew of two airborne field professionals. LiDAR acquisition from the aircraft was accomplished with an onboard high performance laser scanning system, the Leica ALS60. A third crew member equipped with GPS receiver was stationed on the ground within the study area for the duration of each flight.

R7 unit set up over base station “UWASH_01”

Planning

Flightlines were developed using ALTM-NAV Planner (v.3.0) software. Careful planning of the pulse rate, flight altitude, and ground speed ensured that data quality and coverage conditions were met while optimizing flight paths and ensuring a data density of eight pulses per square meter, as requested by the University of Washington.

The mission planning conducted at WSI was designed to optimize flight efficiency while meeting or exceeding project accuracy and resolution specifications. In this process, known factors were prepared for, such as GPS constellation availability, photography and acquisition windows, and resource allocation. In addition, a variety of logistical barriers were anticipated, namely private property access and acquisition personnel logistics. Finally, weather hazards and conditions affecting flight were continuously monitored due to their impact on the daily success of airborne and ground operations.

Monument cap “UWASH_01”

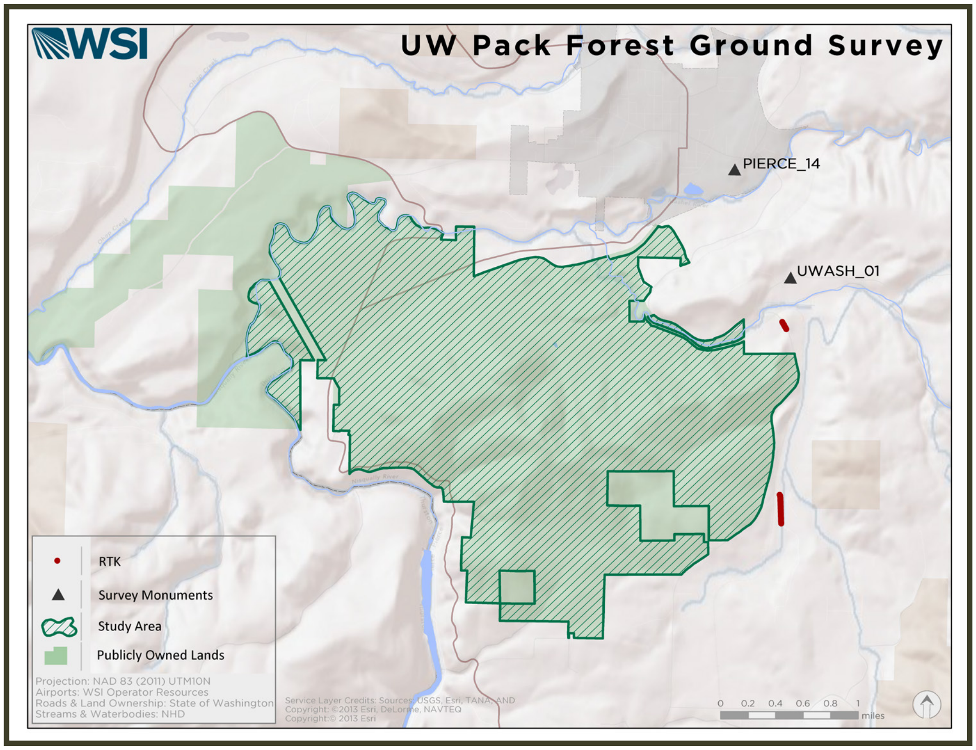
Ground Survey

Ground check points (GCPs) were collected for every mission, which included establishing and occupying survey control, collecting static positional data, and collecting ground check points using GPS real-time kinematic (RTK) survey with a roving radio relayed unit. Using the Continuous Operation Reference System (CORS), WSI tied to a network of points with orthometric heights determined by differential leveling.

Monumentation

Whenever possible, existing and established survey benchmarks served as control points during LiDAR acquisition. Where available, First Order National Geodetic Survey (NGS) High Accuracy Reference Network (HARN) published monuments with NAVD88 were used. In the absence of NGS benchmarks, WSI produced our own monuments. For the Pack Forest survey, one monument was established (UWASH_01) and one monument was used which was established by WSI during a previous survey (PIERCE_14). Every effort is made to keep monuments established by WSI within the public right of way or on public lands. If monuments are required on private property, consent from the owner is required. All monumentation is done with 5/8” X 30” rebar topped with a 2” diameter aluminum cap stamped “Watershed, Sciences, Inc. Control.”

During the project, GPS files were submitted to OPUS and OPUS Projects, where daily session networks were adjusted. Upon completion of the project, a total network adjustment was performed. The final monument positions are provided below in decimal degrees with geodetic positions and ellipsoid elevations. Please see Appendix A for PLS certification.



Monument "PIERCE_14"

List of Monuments

PID	Latitude	Longitude	Ellipsoid Height
UWASH_01	46 51 07.50192	-122 14 57.13452	356.141
PIERCE_14	46 51 48.18290	-122 15 28.94829	237.688

Monument Accuracy

FGDC-STD-007.2-1998 Rating	
St. Dev. Northing, Easting	0.010 m
St. Dev. Z	0.050 m

Receiver Equipment Specifications

Receiver Model	Antenna	OPUS Antenna ID	Use
Trimble R7 GNSS	Zephyr GNSS Geodetic Model 2	TRM55972.00	Static
Trimble R8	Integrated Antenna R8 Model 2	TRM_R8_Model 2	Static & RTK

A WSI Ground Professional collects GCP points with a roving R8 unit.

Static Positional Data

During each LiDAR mission, a ground-based technician was deployed, outfitted with two Trimble Base Stations (R7) and one RTK Rover (R8).

All static control points were observed for a minimum of one two-hour session and one four-hour session. At the beginning of every session the tripod and antenna were reset, resulting in two independent instrument heights and data files. A fixed height tripod was used. Data were collected at a recording frequency of one hertz using a 10 degree mask on the antenna.

GPS data were uploaded to WSI servers for WSI PLS QA/QC and oversight. OPUS processing triangulated the monument position using three CORS stations, resulting in a fully adjusted position. After multiple sessions of data collection at each monument, accuracy was calculated. Blue Marble Geographics Calculator 2013 software was used to convert the geodetic positions from the OPUS reports.

RTK

A Trimble R7 base unit was set up over an appropriate monument to broadcast a kinematic correction to a roving R8 unit. This RTK survey allows for precise location measurement ($\sigma \leq 2.0$ cm). All RTK measurements were made during periods with a Position Dilution of Precision (PDOP) of ≤ 3.0 and in view of at least six satellites by the stationary reference and roving receiver. For RTK data, the collector

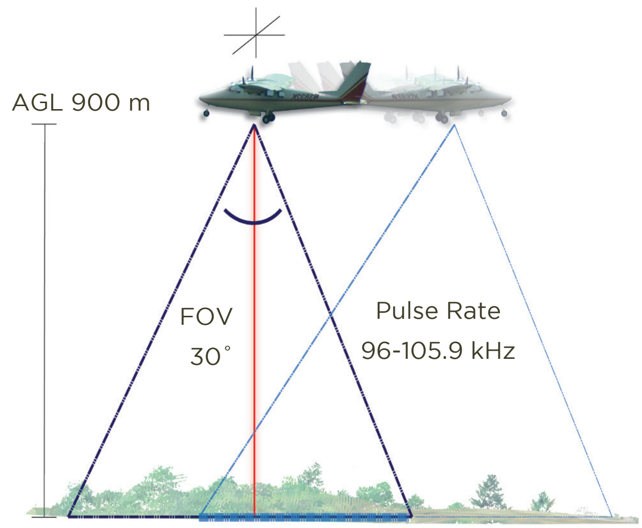
WSI collected 100 RTK points and utilized two monuments for the Pack Forest study area

GPS Specifications	
GPS Satellite Constellation	≥ 6
GPS PDOP	≤ 3.0
GPS Baselines	≤ 13 nm

GPS Specifications	Survey Control Monuments	Ground Check Points (GCPs)
Accuracy	RMSExy ≤ 1.5 cm (0.6 in)	RMSExyz ≤ 1.5 cm (0.6 in)
	RMSEz ≤ 2.0 cm (0.8 in)	Deviation from monument coordinates
Resolution	Minimum of one per 13 nautical mile spacing	≥ 25 per cluster
	Minimum independent occupation of 4 hrs. & 2 hrs.	100 Total
Equipment	Trimble R7	Trimble R7
	R8 GNSS	R8 GNSS

began recording after remaining stationary for five seconds, then calculated the pseudorange position from at least three one-second epochs with the relative error less than 1.5 cm horizontal and 2.0 cm vertical. RTK positions were collected on bare earth locations such as paved gravel or stable dirt roads, and other locations where the ground was clearly visible (and was likely to remain visible) from the sky during the data acquisition and RTK measurement periods. In order to facilitate comparisons with LiDAR data, RTK measurements were not taken on highly reflective surfaces such as center line stripes or lane markings on roads.

In order to obtain statistical viability, ground data are gathered in clusters of at least 25 points. More emphasis is placed on high dispersal of ground data than quantity. The planned locations for these control points were determined prior to field deployment, and the suitability of these locations was verified on site. The distribution of RTK points depended on ground access constraints, and may not be equitably distributed throughout the study area.



Airborne Survey

LiDAR Survey

All data for the University of Washington Pack Forest project area was flown on July 3, 2013, utilizing a Leica ALS60 sensor mounted in a Cessna 208-B Grand Caravan aircraft.

The LiDAR system was set to acquire ≥96,000 laser pulses per second (i.e. 96 kHz pulse rate) and flown at 900 meters above ground level (AGL), capturing a scan angle of 15 degrees from nadir, or 30 degree field of view (FOV). These settings and flight parameters are developed to yield points with an average native density of ≥8 over terrestrial surfaces. The native pulse density is the number of pulses emitted by the LiDAR system. Some types of surfaces (e.g., dense vegetation or water) may return fewer pulses than the laser originally emitted. Therefore, the delivered density can be less than the native density and lightly variable according to distributions of terrain, land cover, and water bodies.

The study area was surveyed with opposing flight line side-lap of ≥60% (≥100% overlap) to reduce laser shadowing and increase surface laser painting. The system allows up to four range measurements per

LiDAR Survey Specifications	
Aircraft	Cessna 208-B Grand Caravan
Sensor	Leica ALS60
Altitude	900 m AGL
Swath Width	482 m
Coverage	60% Sidelap, 100% Overlap
Targeted Pulse Density	≥ 8 pulses/m^2
Field of View	30˚
Mirror Scan Rate	61.1 Hz

pulse, and all discernible laser returns were processed for the output data set.

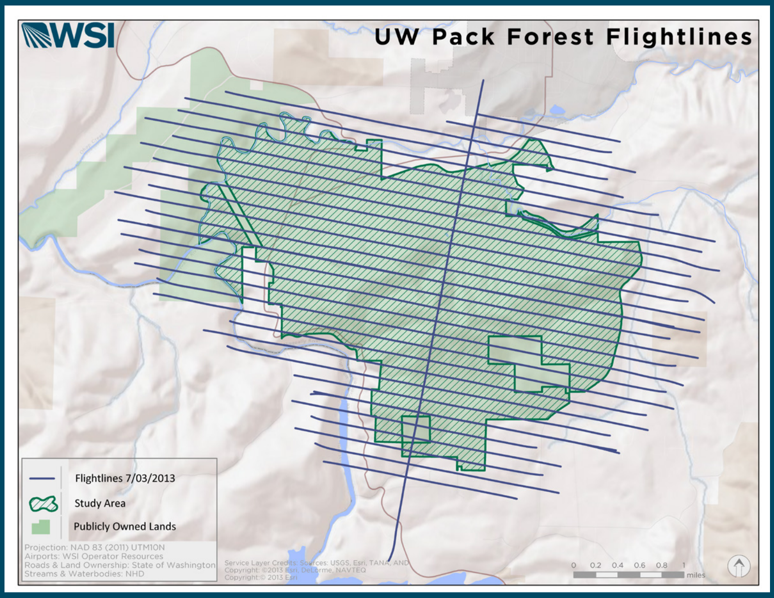
The LiDAR sensor operators constantly monitored the data collection settings during acquisition of the data, including pulse rate, power setting, scan rate, gain, field of view, and pulse mode. For each flight, the crew performed airborne calibration maneuvers designed to improve the calibration results during the data processing stage. They were also in constant communication with the ground crew to ensure proper ground GPS coverage for data quality. The LiDAR coverage was completed with no data gaps or voids, barring non-reflective surfaces (e.g., open water, wet asphalt). All necessary measures were taken to acquire data under conditions (e.g., minimum cloud decks) and in a manner (e.g., adherence to flight plans) that prevented the possibility of data gaps. All WSI LiDAR systems are calibrated per the manufacturer and our own specifications, and tested by WSI for internal consistency for every mission using proprietary methods.

Leica sensor ALS 6106 installed in the aircraft

To solve for laser point position, an accurate description of aircraft position and attitude is vital. Aircraft position is described as x, y, and z and was measured twice per second (two hertz) by an onboard differential GPS unit. Aircraft attitude is described as pitch, roll, and yaw (heading) and was measured 200 times per second (200 hertz) from an onboard inertial measurement unit (IMU).

Weather conditions were constantly assessed in flight, as adverse conditions not only affect data quality, but can prove unsafe for flying.

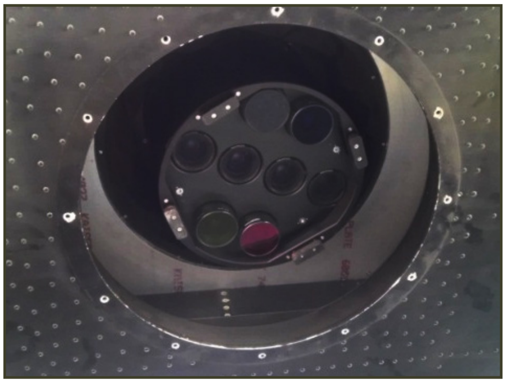
Pack Forest survey flightlines and date flown



Photography

The photography survey utilized an UltraCam Eagle 260 megapixel camera mounted in a Cessna 208-B Grand Caravan. The UltraCam-Eagle is a large format digital aerial camera manufactured by the Microsoft Corporation. The system is gyro-stabilized and simultaneously collects panchromatic and multispectral (RGB, NIR) imagery. Panchromatic lenses collect high resolution imagery by illuminating nine CCD (charged coupled device) arrays, writing nine raw image files. RGB and NIR lenses collect lower resolution imagery, written as four individual raw image files. Level 02 images are created by stitching together raw image data from the nine panchromatic CCDs, and ultimately combined with the multispectral image data to yield Level 03 pan-sharpened tiffs.

UltraCam Eagle Manufacture Specifications	
Focal length	80mm
Data format	RGBNIR
Pixel size	5.2 µm
Image size	20,010 X 13,080 pixels
Frame rate	>1.8 s
FOV	66° X 46°
GSD at 1000 m	6.5 cm
Image width at 800 m	1,040 m



Left: UltraCam Eagle lens configuration as viewed from the Cessna Caravan.

Above: A Cessna Grand Caravan 208B was employed in the collection of all orthoimagery.

Below: UltraCam Eagle installed in the aircraft.

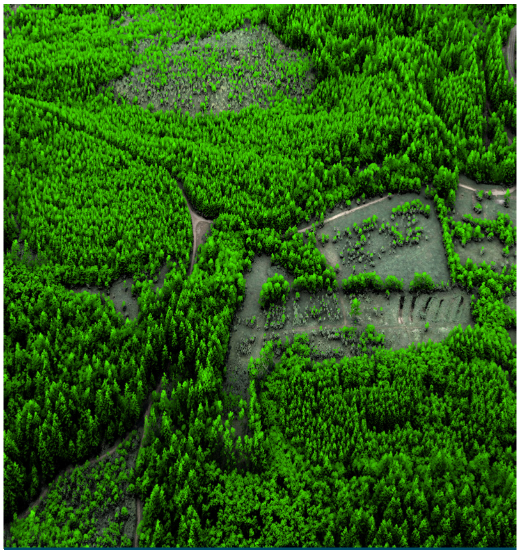
Digital Orthophotography Survey Specifications	
Aircraft	Cessna 208-B Grand Caravan
Sensor	UltraCam Eagle
Altitude	1,846 m AGL
GPS Satelite Constellation	6
GPS PDOP	3.0
GPS Baselines	≤ 13nm
Image	8-bit GeoTIFF
Along Track Overlap	60%
Spectral Bands	Red, Green, Blue, NIR
Resolution	6 in. pixel size

Processing

This section describes the processing methodologies for all data acquired by WSI for the Pack Forest project. All of our methodologies and deliverables are compliant with Federal and industry specifications and guidelines (USGS v.13, FGDC NSSDA, and ASPRS)

LiDAR

Once the LiDAR data arrived in the laboratory, WSI employed a suite of automated and manual techniques for processing tasks. Processing tasks included: GPS, kinematic corrections, calculation of laser point position, relative accuracy testing and calibrations, classification of ground and non-ground points, and assessments of statistical absolute accuracy. The general workflow for calibration of the LiDAR data was as follows:



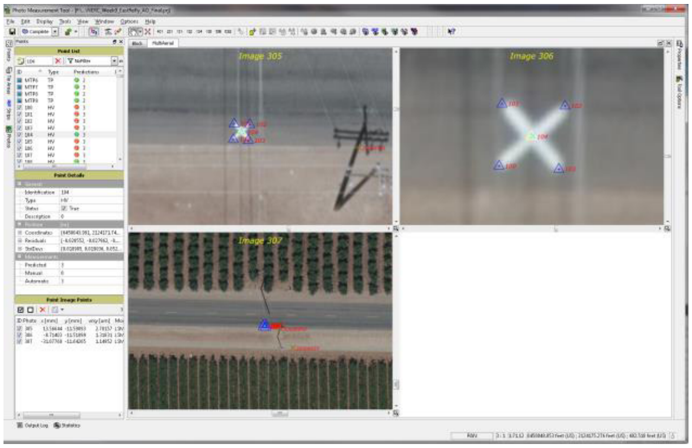
LiDAR point cloud image along Lathrop Drive.

LiDAR Processing Step	Software Used
Resolve GPS kinematic corrections for aircraft position data using kinematic aircraft GPS (Collected at two hertz) and static ground GPS (one hertz) data collected over geodetic controls.	IPAS TC v. 3.2, Trimble Business Center v. 3.02
Develop a smoothed best estimate of trajectory (SBET) file that blends post-processed aircraft position with attitude data. Sensor heading, position, and attitude are calculated throughout the survey.	IPAS TC v. 3.2
Calculate laser point position by associating SBET information to each laser point return time, with offsets relative to scan angle, intensity, etc. included. This process creates the raw laser point cloud data for the entire survey in *.las (ASPRS v. 1.2) format, in which each point maintains the corresponding scan angle, return number (echo), intensity, and x, y, z information. These data were converted to orthometric elevation (NAVD88) by applying a Geoid 03 correction.	Leica ALSPP 2.75 Build #9
Import raw laser points into subset bins (less than 500 MB, to accommodate file size constraints in processing software). Filter for noise and perform manual relative accuracy calibration.	TerraScan v. 13, Custom WSI software
Classify ground points and test relative accuracy using ground classified points per each flight line. Perform automated line-to-line calibrations for system attitude parameters (pitch, roll, heading), mirror flex (scale) and GPS/IMU drift. Calibrations are performed on ground classified points from paired flight lines. Every flight line is used for relative accuracy calibration.	TerraMatch v. 13, TerraScan v. 13, Custom WSI software
Assess fundamental vertical accuracy via direct comparisons of ground classified points to ground RTK survey data	TerraScan v. 13

Orthophotos

Digital orthophotos were collected using a 260 megapixel ultra large format digital aerial camera. Image radiometric values were calibrated to specific gain and exposure settings associated with each capture using Microsoft's UltraMap software suite. The calibrated images were saved in TIFF format for input to subsequent processes. Photo position and orientation were calculated by linking the time of image capture, the corresponding aircraft position and attitude, and the smoothed best estimate of trajectory (SBET) data in POSPAC. Within the Inpho software suite, automated aerial triangulation was performed to tie images together and align with ground control. Adjusted images were then draped upon a ground model and orthorectified. Individual orthorectified tiffs were blended together to remove seams and corrected for any remaining radiometric differences between images using Inpho's OrthoVista. The processing workflow for orthophotos is as follows:

Orthophoto Processing Step	Software Used
Resolve GPS kinematic corrections for aircraft position data using kinematic aircraft GPS (collected at two hertz) and static ground GPS (one hertz) data collected over geodetic controls.	Pos Pac MMS v. 6.1
Develop a smoothed best estimate of trajectory (SBET) file that blends post-processed aircraft position with attitude data. Sensor heading, position, and attitude will be calculated throughout the survey.	Pos Pac MMS v. 6.1
Create an exterior orientation (EO) files for each photo image with omega, phi, and kappa.	POS-EO and Pos Pac MMS v. 6.1
Convert "Level 00" raw imagery into geometrically corrected "Level 02" image files.	UltraMap Raw Data Center v. 3.0
Apply radiometric adjustments to "Level 02" image files to create "Level 03" Pan-sharpened tiffs.	UltraMap Radiometry v. 3.0
Apply EO to photos, measure ground control points, and perform aerial triangulation.	Inpho Match-AT v. 5.5
Import DEM, orthorectify, and clip triangulated photos to specified area of interest.	Inpho OrthoMaster v. 5.5
Mosaic orthorectified imagery, blending seams between individual photos and correcting for radiometric differences between photos.	Inpho Orthovista v. 5.5



Left: Inpho's MultiPhoto measurement tool. Air target GCP is measured for use as orthophoto ground control.

Results

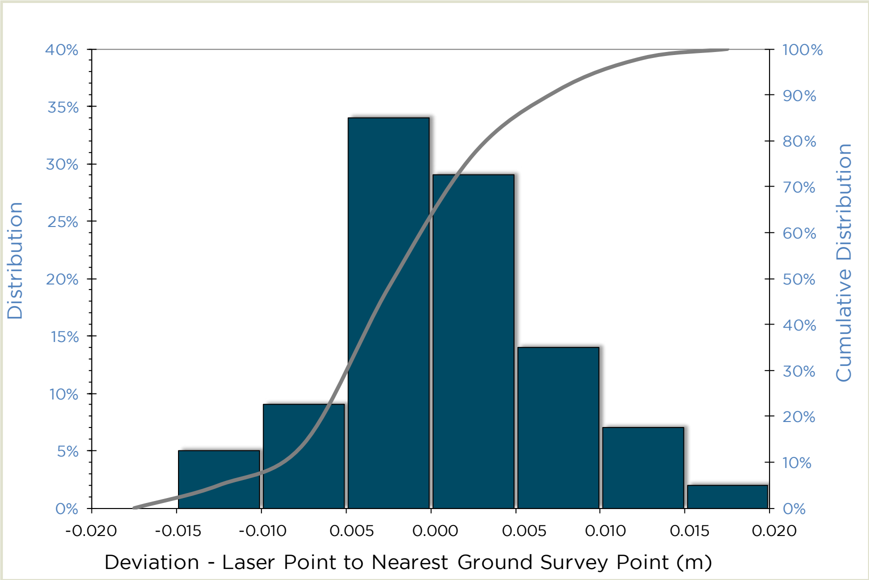
Accuracy Assessment

Vertical Accuracy

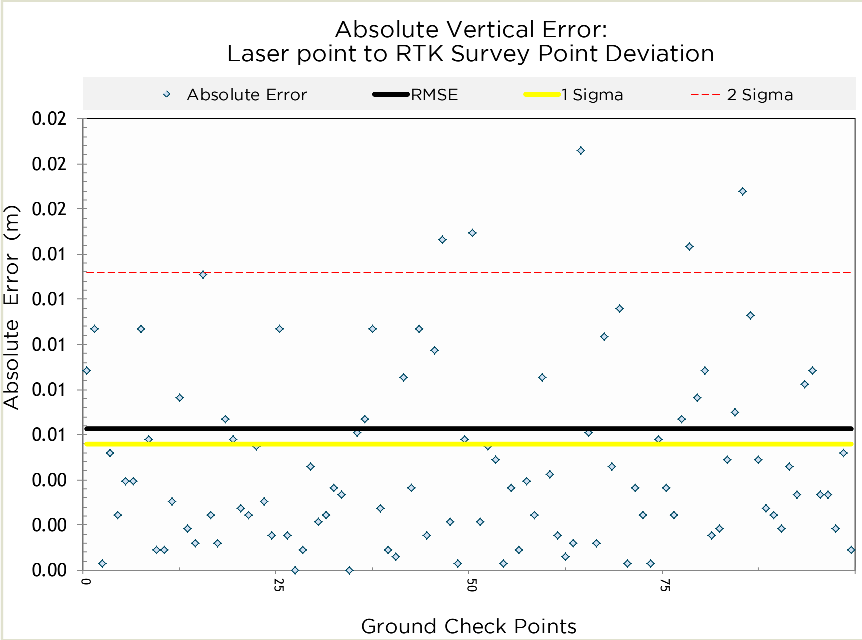
Vertical absolute accuracy was primarily assessed from ground check points on open, bare earth surfaces with level slope. These check points enabled an effective assessment of swath-to-swath reproducibility and fundamental vertical accuracy.

For this project, no independent survey data were collected, nor were reserved points collected for testing. As such, vertical accuracy statistics are reported as "Compiled to Meet," in accordance with the ASPRS Guidelines for Vertical Accuracy Reporting for LiDAR Data v. 1.0 (ASPRS, 2004).

The absolute vertical accuracy (RMSE) for the Pack Forest study area is 0.6 cm and was calculated with an RTK sample size of 100 ground check points (GCPs) spread throughout the study area.



Vertical Accuracy Statistics	WSI Results (meters)
Sample Size	100 GCPs
RMSE	0.006
1 Sigma	0.006
2 Sigma	0.013
Average Magnitude of Deviation	0.001

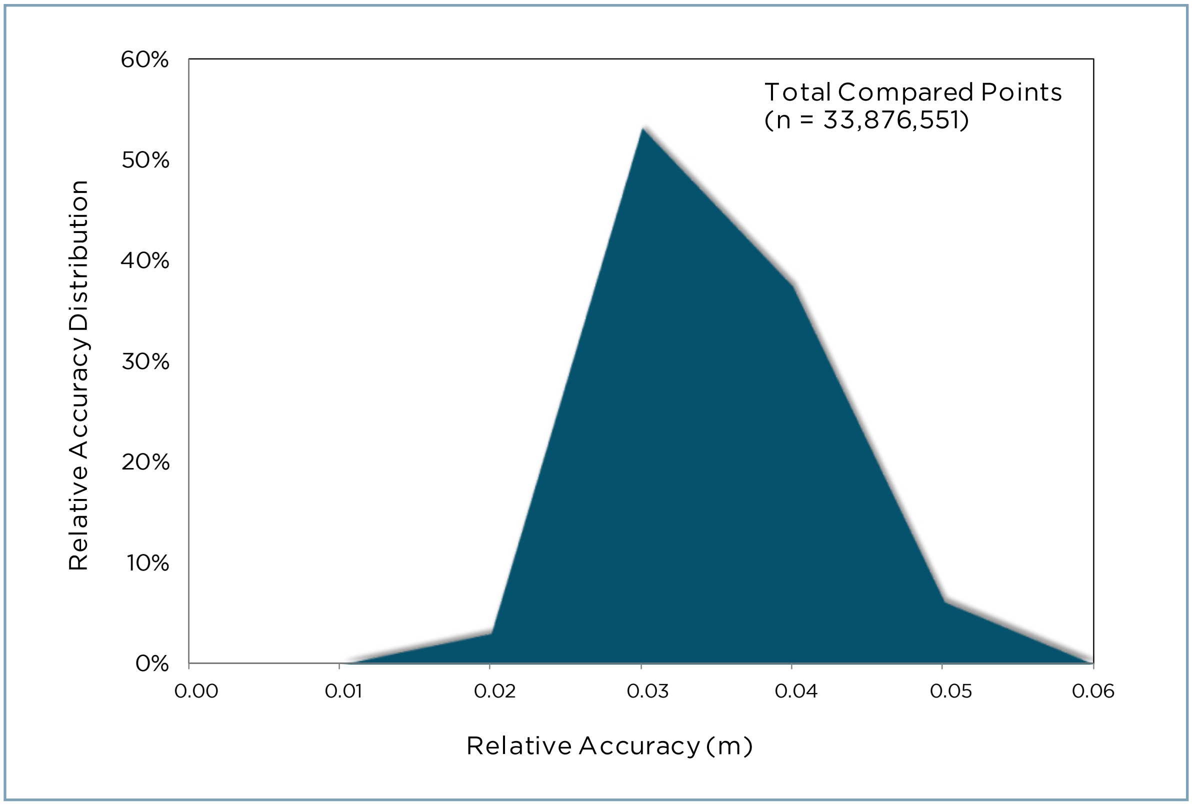


Relative Accuracy

Relative accuracy refers to the internal consistency of the data set and is measured as the divergence between points from different flightlines within an overlapping area. Divergence is most apparent when flightlines are opposing. When the LiDAR system is well calibrated, the line to line divergence is low (<10 cm). Internal consistency is affected by system attitude offsets (pitch, roll, and heading), mirror flex (scale), and GPS/IMU drift.

Relative accuracy statistics are based on the comparison of 32 flightlines and over 33 million points. Relative accuracy is reported for the entire study area.

Relative Accuracy Statistics	WSI Results (meters)
Average	0.040
Median	0.040
1 Sigma	0.041
2 Sigma	0.048
Survey Points	33,876,551
Flightlines	32



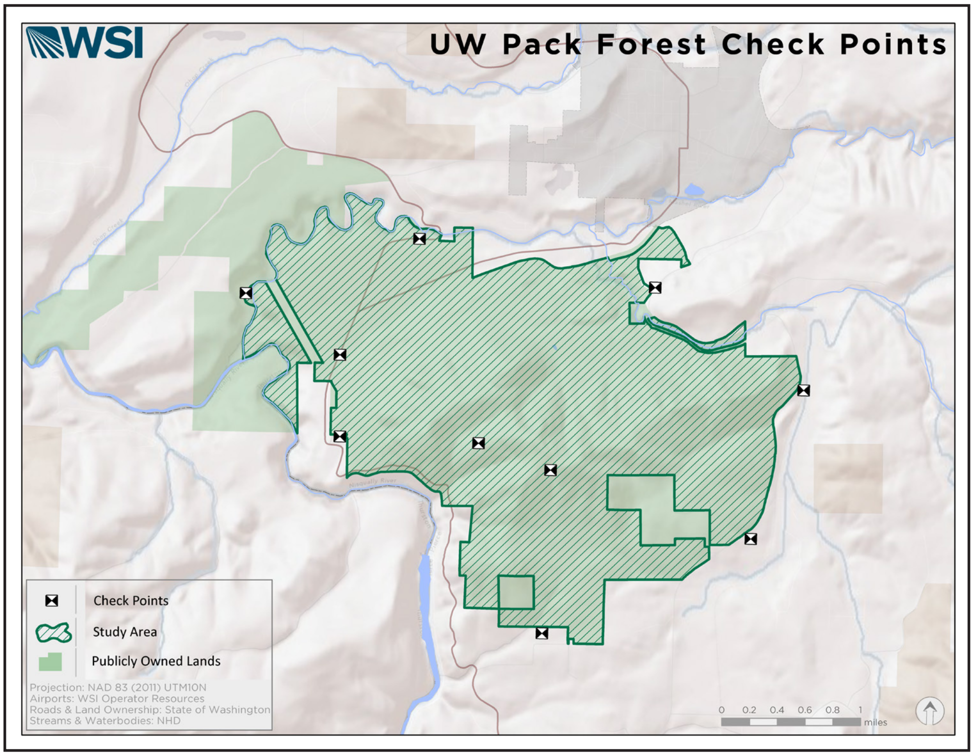
Orthophoto Accuracy

To assess the spatial accuracy of the orthophotographs, artificial check points were established. Ten check points, distributed evenly across the total acquired area, were generated on surface features such as painted road lines and fixed high-contrast objects on the ground surface. They were then compared against check points identified from the LiDAR intensity images. The accuracy of the final mosaic was calculated in relation to the LiDAR-derived check points and is listed below.

Above: Example of co-registration of color images with LiDAR intensity images.

Orthophoto horizontal accuracy results

Orthophoto Horizontal Accuracy (n=10)	WSI Achieved (m)	WSI Achieved (ft.)
RMSE	0.030	0.097
1 Sigma	0.186	0.610
2 Sigma	0.232	0.761



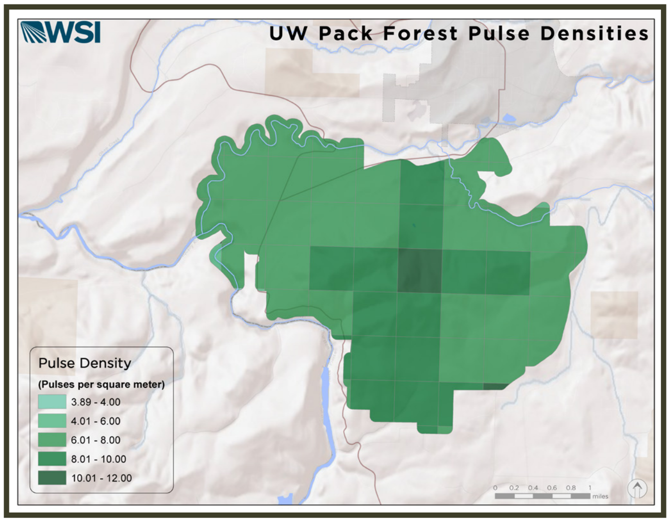
Right: Artificially-generated check point locations within the study area.

Density Results

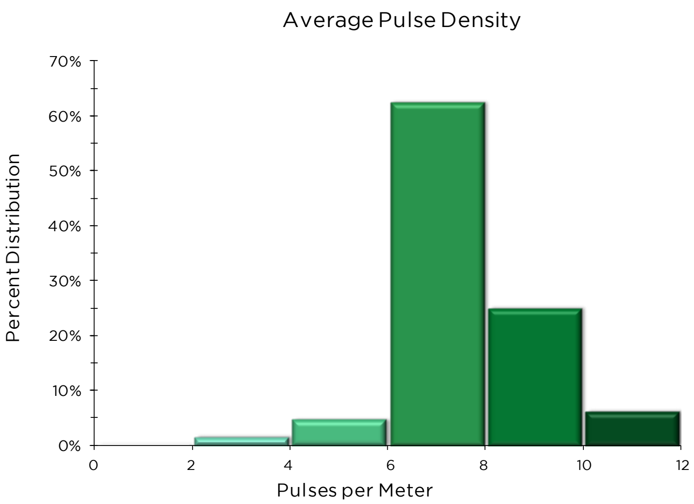
The native pulse density is the number of pulses emitted by the LiDAR system. The pulse density resolution specification for the Pack Forest survey area was a minimum mean of eight pulses per square meter (ppsm); WSI achieved 8 ppsm.

Images below show ground and pulse densities for the entire study area. Density histograms have been calculated based on first return laser point density and ground-classified laser point density.

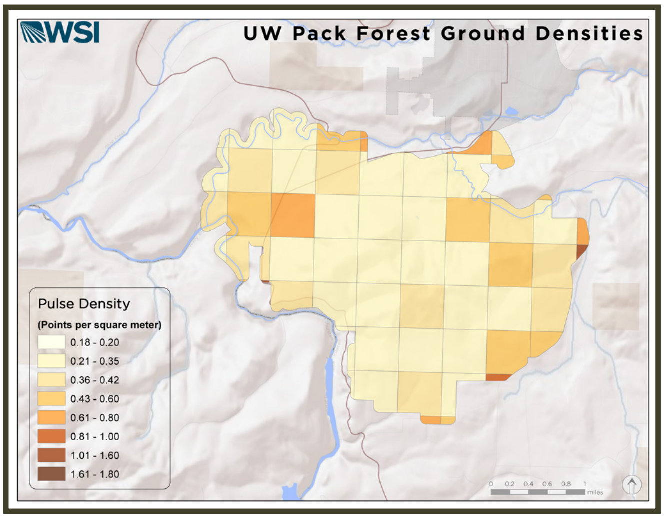
Pulse Density Map



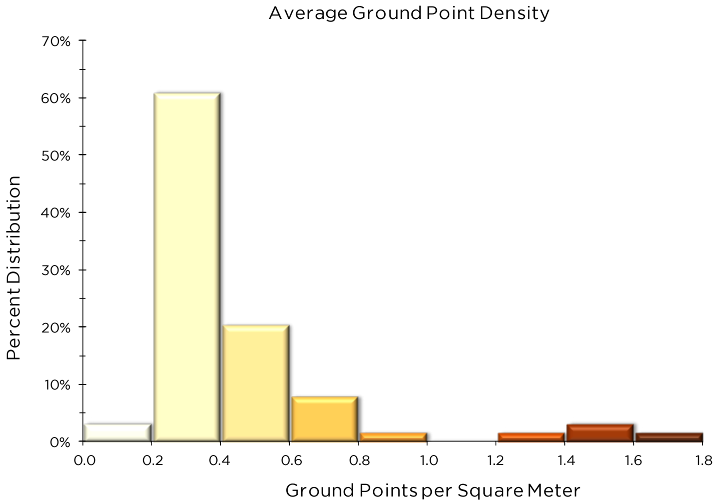
Pulse Density Chart



Ground Density Map



Ground Density Chart

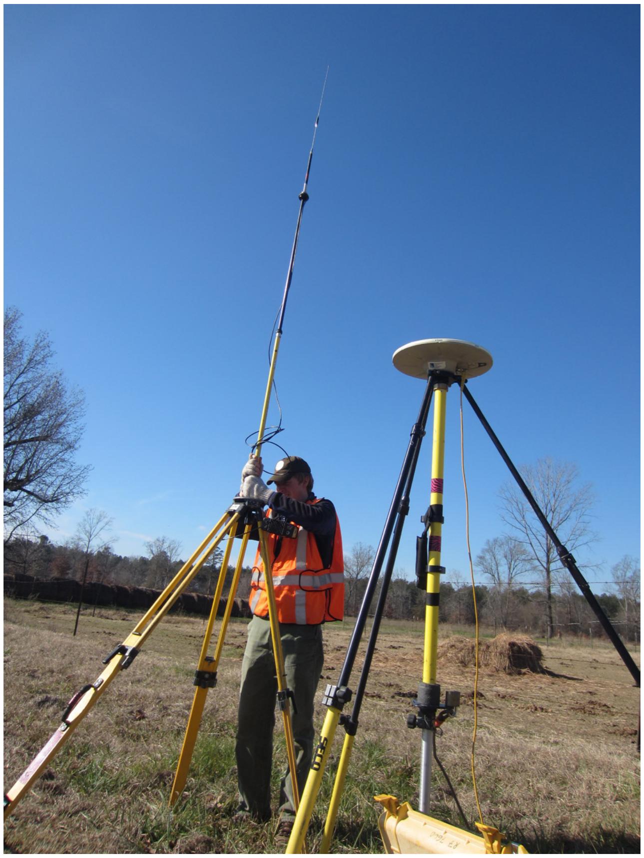


Best Practices

WSI Standards

WSI has high standards and adheres to best practices in all efforts. In the field, rigorous quality control methods include deployment of base stations at pre-surveyed level one monuments and collecting RTK, and efficient planning to reduce flight times and mobilizations.

In the laboratory, quality checks are built in throughout processing steps, and automated methodology allows for rapid data processing. There is no off-shoring, which allows for in-house project control for all data collection and processing. WSI's innovation and adaptive culture rises to technical challenges and the needs of clients like the University of Washington.



Appendix A: PLS Certification

Watershed Sciences provided LiDAR services for the University of Washington Pack Forest study area as described in this report.

I, Mathew Boyd, have reviewed the attached report for completeness and hereby state that it is a complete and accurate report of this project.

Mathew Boyd
Principal
Watershed Sciences, Inc.

I, Christopher W. Yotter-Brown, being first dully sworn, say that as described in the Ground Survey subsection of the Acquisition section of this report was completed by me or under my direct supervision and was completed using commonly accepted standard practices. Accuracy statistics shown in the Accuracy Section have been reviewed by me to meet National Standard for Spatial Data Accuracy.

7/23/2013

CHRISTOPHER W. YOTTER-BROWN
STATE OF WASHINGTON
46328
REGISTERED
PROFESSIONAL LAND SURVEYOR

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Renews: 12/21/2014

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