Retrieval of Vegetation Structural Parameters and 3-D Reconstruction of Forest Canopies for Carbon Inventory Using Ground-Based Echidna® Lidar

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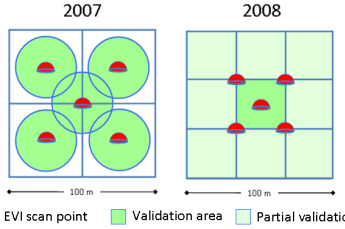
Overview

Our research uses a ground-based, scanning lidar instrument to retrieve forest canopy structural information, including stand height, mean tree diameter, basal area, stem count density, woody biomass, leaf area index, and foliage profile, and links this information to airborne and spaceborne lidars to provide large-area mapping of structural and biomass parameters.

The terrestrial lidar instrument, Echidna®, developed by CSIRO Australia, allows rapid acquisition of vegetation structure data that can be readily integrated with downward-looking airborne lidar, such as LVIS (Laser Vegetation Imaging Sensor), and spaceborne lidar, such as GLAS (Geoscience Laser Altimeter System) on ICESat, to provide large-area maps and inventories of vegetation structure and carbon stocks.

First-generation algorithms for processing Echidna® data focus on retrieving the location, size, and spacing of tree trunks and on the foliage profile of the stand. To the right are some results for lidar scans using the Echidna® Validation Instrument (EVI), an engineering prototype. The results include comparison of stand height, LAI, biomass, DBH, and stem density derived from the EVI with contemporaneous field measurements for New England hardwood/conifer and Sierra Nevada conifer stands.



Sample design. A 1-ha area was sampled at each site (stand). In 2007, the area was divided into 4 subplots, and in 2008 into 9 subplots. We acquired EVI scans and ground stem measurements in validation areas as shown in the diagrams. At each scan point, we also acquired 13 hemispherical photos and LA-2000 measurements to validate LAI retrievals.

A proper Auzzie echidna.

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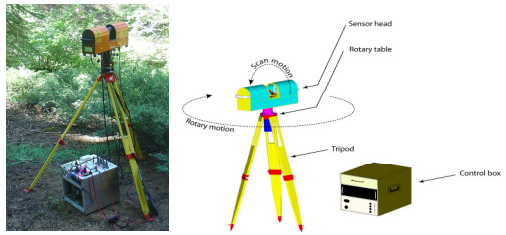
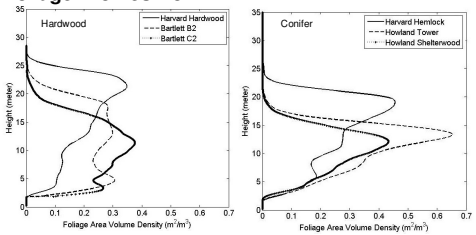
Instrument and Data Characteristics



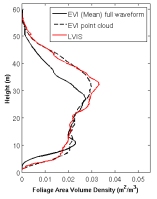
Echidna® ground-based lidar. Lidar pulses strike a rotating mirror at an angle of 45°, providing a scan through zenith angles of ±130° in a vertical circle. As the instrument rotates on its vertical axis, data from all azimuths are acquired.

Examples of EVI data for a hemlock stand at the Harvard Forest in Massachusetts (top image) and a giant sequoia-red fir stand at Sequoia National Forest in California (bottom image). The images are in a *plate carrée* projection that displays the data by azimuth angle (*x*-axis) and zenith angle (*y*-axis).

Foliage Profiles from EVI

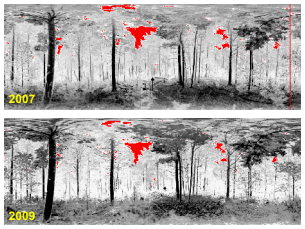


Foliage profiles (leaf area with height) retrieved from EVI scans at 6 sites, 5 scans per site. Among the hardwood sites, Harvard Hardwood is tallest, with an open understory. The Bartlett stands are shorter with more understory. The conifer sites show sharply peaked profiles with little or no understory layer. The curves fit a model of leaf area that increases with conifer crown width until the crowns touch and intersect, when leaf area is at its peak.

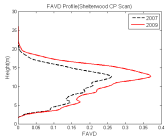


Foliage profiles derived from LVIS for a high-elevation red fir stand in the Sierra Nevada show good agreement with foliage profiles derived from EVI. LVIS profile: mean of all profiles within a 100 m radius; EVI full waveform: mean of 5 profiles, 30 x 30 m square; EVI point cloud: 3-D reconstruction from 5 EVI scans as above. Topographic correction applied.

Detecting Forest Growth and Change with EVI



P_{gap} image at 80 m range
[Pure gap in red]



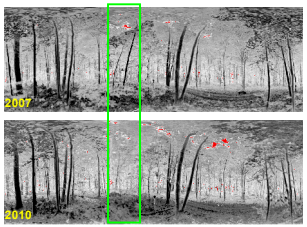
Foliage profiles, 2007 and 2009, for the Howland shelterwood site

Scans of the Howland shelterwood site in 2007 and 2009 show that the Echidna® lidar can detect forest growth. Above are two equal-angle images of gap probability at far range. The gaps between crowns (red color regions) shrank visibly during the two-year interval. Based on ground measurements, mean DBH in the plot increased by 0.3 cm, while EVI found the increase to be 0.5 cm. The stem count density decreased as diameters increased.

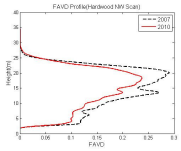
Change in structural parameters, Howland shelterwood and Harvard hardwood sites[1]

Site	Year	Mean DBH (m)		Stem density (tree/ha)		Basal area (m²/ha)		Canopy mean top height (m)	LAI (EVI regression method)
		Field	EVI	Field	EVI	Field	EVI		
Howland Forest Shelterwood Site[1]	2007	0.221 ±0.01	0.210 ±0.01	538 ±19	603 ±55	25.26 ±0.80	27.42 ±1.71	19.17 ±0.79	3.13 ±0.27
	2009	0.224 ±0.01	0.215 ±0.02	524	584 ±28	26.14	29.18 ±1.05	19.20 ±0.59	3.44 ±0.33
Harvard Forest Hardwood Site	2007	0.234 ±0.01	0.215 ±0.01	629 ±39	694 ±118	36.50 ±1.63	31.95 ±4.18	24.80 ±0.37	4.20 ±0.08
	2010	0.240 ±0.01	0.247 ±0.02	623 ±34	651 ±50	37.73 ±1.2	38.94 ±5.49	25.36 ±0.53	3.60 ±0.14

[1] Standard deviations based on five plots or scans at each site. For Howland shelterwood, only a single 50 x 50 m field plot was recorded, so standard deviations are not available.

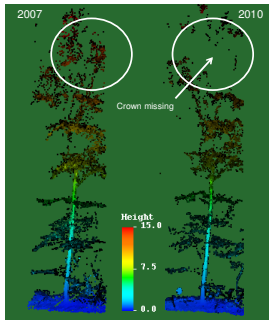


P_{gap} image at 80 m range
[Pure gap in red]



Foliage profiles, 2007 and 2010, for the Harvard hardwood site.

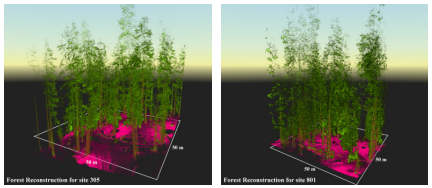
These scans of the Harvard Forest hardwood site in 2007 and 2010 show that the Echidna® lidar can detect a decrease of LAI as well as an increase. The gaps between crowns were visibly larger at the end of the three-year interval. Some small trees were downed (green box) while other trees lost crowns and large branches in the ice storm of December, 2008.



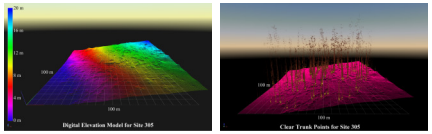
The images show a 3-D point cloud reconstruction of a tree in 2007 and 2010. During the period, the tree lost upper foliage and branches, probably in the ice storm of December 2008.

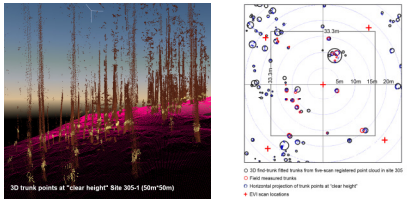
Point Cloud Processing

The peak intensity and its location within each waveform were used to create a point cloud dataset for each of the lidar scans at a site. The point cloud records each scattering event and its apparent reflectance within an *x*-, *y*-, *z*-coordinate space. By carefully locating the position of each scan point and then finding trees and objects viewed by multiple scans, we merged the point clouds to create a 3-D reconstructions of each stand. Scattering events were then classified into trunk, leaf and ground and used in creating the color images below.



These reconstructions, based on merging multiple scans, show a stand of high-elevation red fir (left) and a stand including giant sequoias (right) in the Sequoia National Forest, near Fresno, California. Using a simple classification algorithm based on the shape of the return lidar waveform and its vertical position, each point is classified into trunk (brown), leaf (green), or ground (magenta).





Further processing of the point cloud, shown here for the red fir site, uses the ground points to fit a digital elevation model for the site (upper left), which is then used to identify trunk returns between 01.75 and 2.25 m above the ground. When these are projected onto a stem map, they fit stem locations very well (lower right), with R^2 values for retrieved vs. measured DBH of 0.97. Height and crown size, identified by similar processing techniques, were also retrieved well with R^2 values of 0.98 and 0.81 respectively.

The three-dimensional forest stand reconstructions can be displayed as fly-through videos. The computer display shows these for the two stands above as well as a deciduous forest stand in Massachusetts scanned in 2009.