Retrieval of Vegetation Structure and Carbon Balance Parameters Using Ground-Based Lidar and Scaling to Airborne and Spaceborne Lidar Sensors

A. Strahler,[1] W. Ni-Meister,[2] C. Woodcock,[1] X. Li,[1,3] D. Jupp,[4] D. Culvenor[4]

[1]Boston University [2]Hunter College of CUNY [3]Beijing Normal University [4]CSIRO Australia

Overview

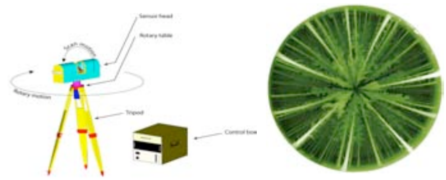
This research will use ground-based, upward-scanning hemispherical lidar to retrieve forest canopy structural information, including tree height, mean tree diameter, basal area, stem count density, crown diameter, woody biomass, and green biomass, and link this information to airborne and spaceborne 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.

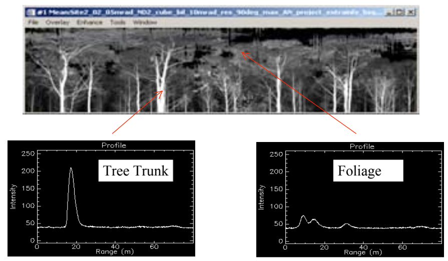
Lidar waveforms and vegetation structure will be linked for these three sensors through the hybrid geometric-optical radiative-transfer (GORT) model, which uses basic vegetation structure parameters and principles of geometric optics, coupled with radiative transfer theory, to model scattering and absorption of light by collections of individual plant crowns. Use of a common model for lidar waveforms at ground, airborne, and spaceborne levels will facilitate integration and scaling of the data to provide large-area maps and inventories of vegetation structure and carbon stocks.

Our research plan includes acquisition of Echidna® under-canopy hemispherical lidar scans at North American test sites where LVIS and GLAS data have been or are being acquired; analysis and modeling of spatially coincident lidar waveforms acquired by the three sensor systems; linking of the three data sources using the GORT model; and mapping of vegetation structure and carbon-balance parameters at LVIS and GLAS resolutions based on Echidna® measurements.

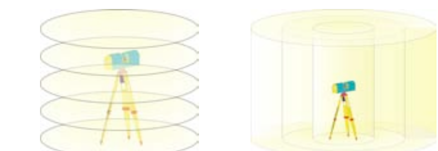
A proper Auzzie echidna.



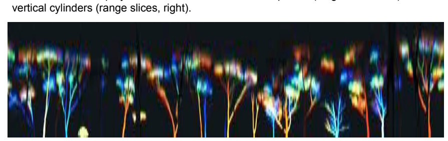
Echidna® scans the full hemisphere using its scan mirror and the instrument's rotary motion. On the right, Echidna® data are presented as a polar projection, resembling a fish-eye photo.



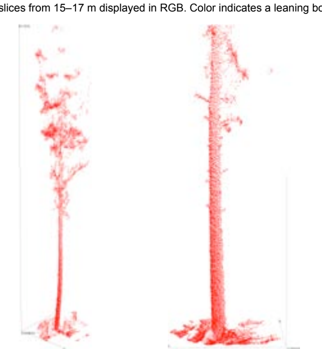
The intensity and shape of the lidar return distinguishes trunks from foliage and determines their distance from the instrument.



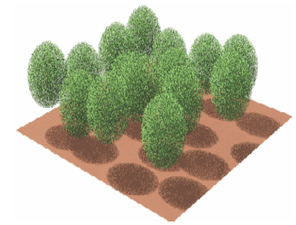
The scan can be reprojected into a series of horizontal planes (height slices, left) or vertical cylinders (range slices, right).



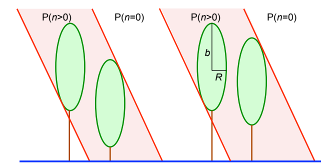
Three range slices from 15–17 m displayed in RGB. Color indicates a leaning bole.



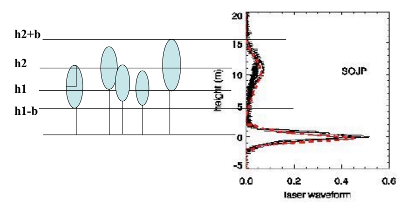
An individual tree (*Pinus radiata*) reconstructed from Echidna® data. Left, whole tree. Right, zoomed in to show fine detail (3 mr scan).



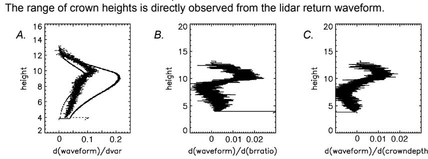
The GORT model uses spheroids filled with scattering and attenuating elements as tree crowns.



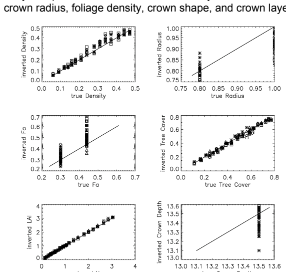
A Boolean model determines the probability that a ray passes through n = 0, 1, 2, ... crowns. Crown shape is determined by the ratio of half-height (b) to radius (R).



A lidar waveform from SLICER acquired at the Southern Old Jack Pine site, BOREAS. The range of crown heights is directly observed from the lidar return waveform.



Sensitivity of lidar waveforms to vegetation geometry parameters. *A.* Three curves (L to R): foliage area volume density, crown radius, tree count density. *B.* Crown shape (*b/R* ratio). *C.* Crown layer depth. Parameter retrieval accuracy decreases in the order tree count density, crown radius, foliage density, crown shape, and crown layer depth.



Early results of BSI inversion at the BOREAS OJP site. Crown count density, tree cover, and true LAI are retrieved well. Crown radius, crown depth, and foliage area are only known at the stand level.

GORT Model

The Geometric Optical-Radiative Transfer (GORT) model will be the principal tool used to link Echidna® undercanopy lidar scans with airborne and spaceborne lidar scans of LVIS and GLAS. The GORT model was developed to describe the effects of three-dimensional canopy structure on the radiation environment and to characterize the heterogeneous radiation environment in natural vegetation at the forest stand scale (Li et al., 1995).

Merging theory from geometric optics and radiative transfer, the GORT model treats vegetation canopies as assemblages of randomly distributed tree crowns of ellipsoidal shape. The tree crowns are filled with leaves that absorb and scatter radiation passing through the crown. Principles of radiative transfer are used in describing the multiple scattering of leaves inside crowns and the multiple scattering among crowns and the ground surface. The GORT model was extended by Ni et al. (1997) to include the vertical canopy gap probability profile.

For this study, we will use a physical approach to link canopy lidar energy returns with aboveground biomass. GORT will be the key bridge to those links and Echidna® will provide ground-based parameters to calibrate GORT. The primary driving parameters for GORT are tree density (stems per hectare), tree size and shape, foliage density, and the upper and lower bounds of tree height.

In order to retrieve vegetation structure parameters, we invert the GORT model to retrieve the tree density (possibly constrained by Echidna® tree counts), size of crowns, and foliage area volume density within crowns using lidar data first and calculate the actual foliage profile from the retrieved tree structure parameters.

Inversions will use the Bayesian Stochastic Inversion (BSI) approach (Box and Tiao, 1973). It gives an estimate of optimal model parameter values and estimates uncertainties through parameter multidimensional posterior probability density function (PPD) and covariances. This will allow us to place the error bounds on point biomass measurements and extend these to spatial uncertainties using spatial statistics.

Contacts: alan@bu.edu, wnimeist@hunter.cuny.edu.