Forest Laser Scanning Instruments

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With considerable help from:
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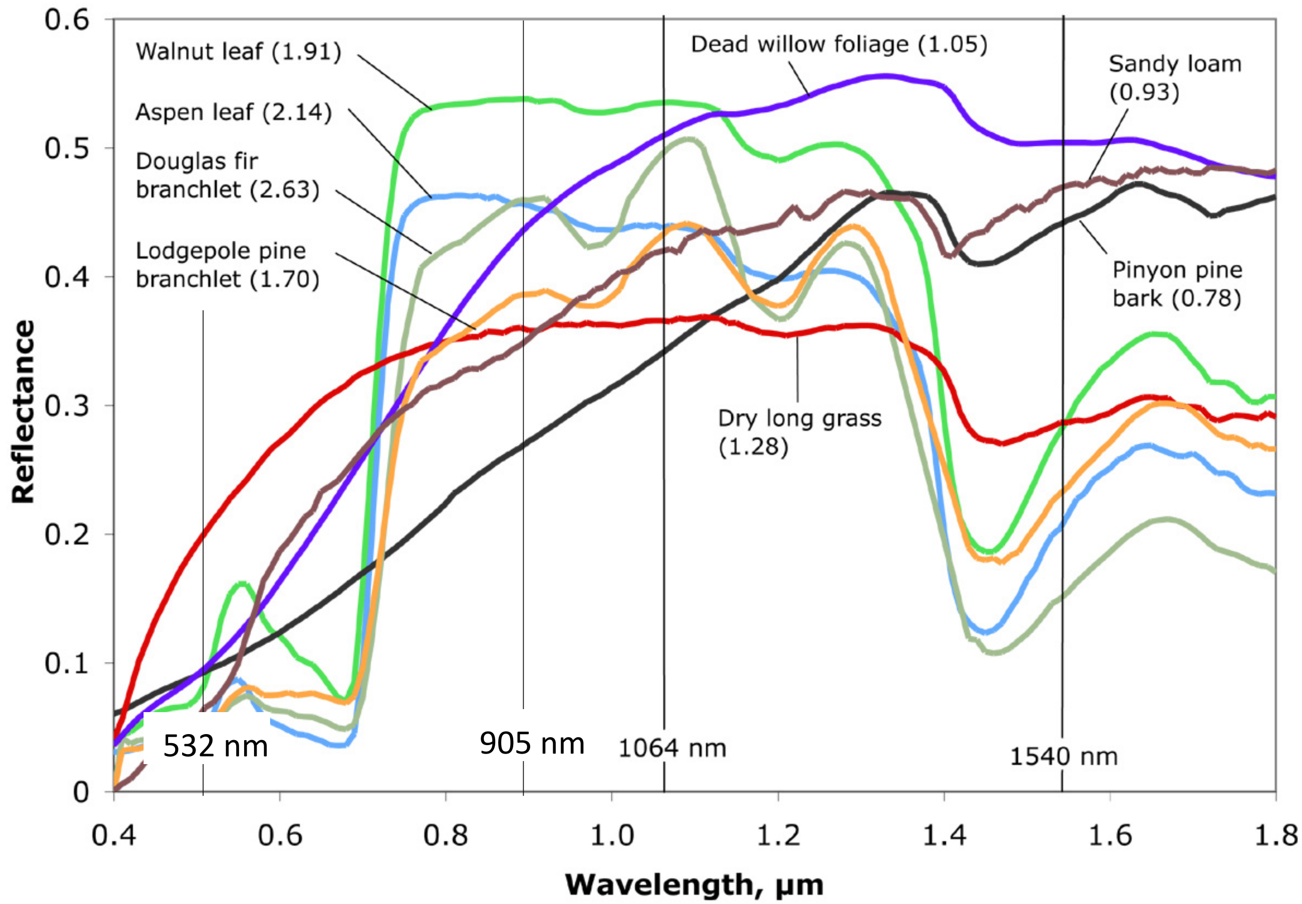
Terrestrial Laser Scanners: Basic Types

- *Discrete Return—Records scattering events as a point cloud*
  - First return; first and last returns; multiple point returns exceeding a threshold
  - Provide *x, y, z* position of scattering point and a measure of intensity—i.e., a point cloud
  - May be pulsed, or continuous wave (first return only)
- *Waveform—Records continuous return intensity with range*
  - Provides pulse vector direction in zenith and azimuth
  - Provides gap probability with range as a function of zenith and azimuth
  - Software/hardware can identify scattering events and produce a cloud of points in *x, y, z* space

Laser Wavelength and Target Response

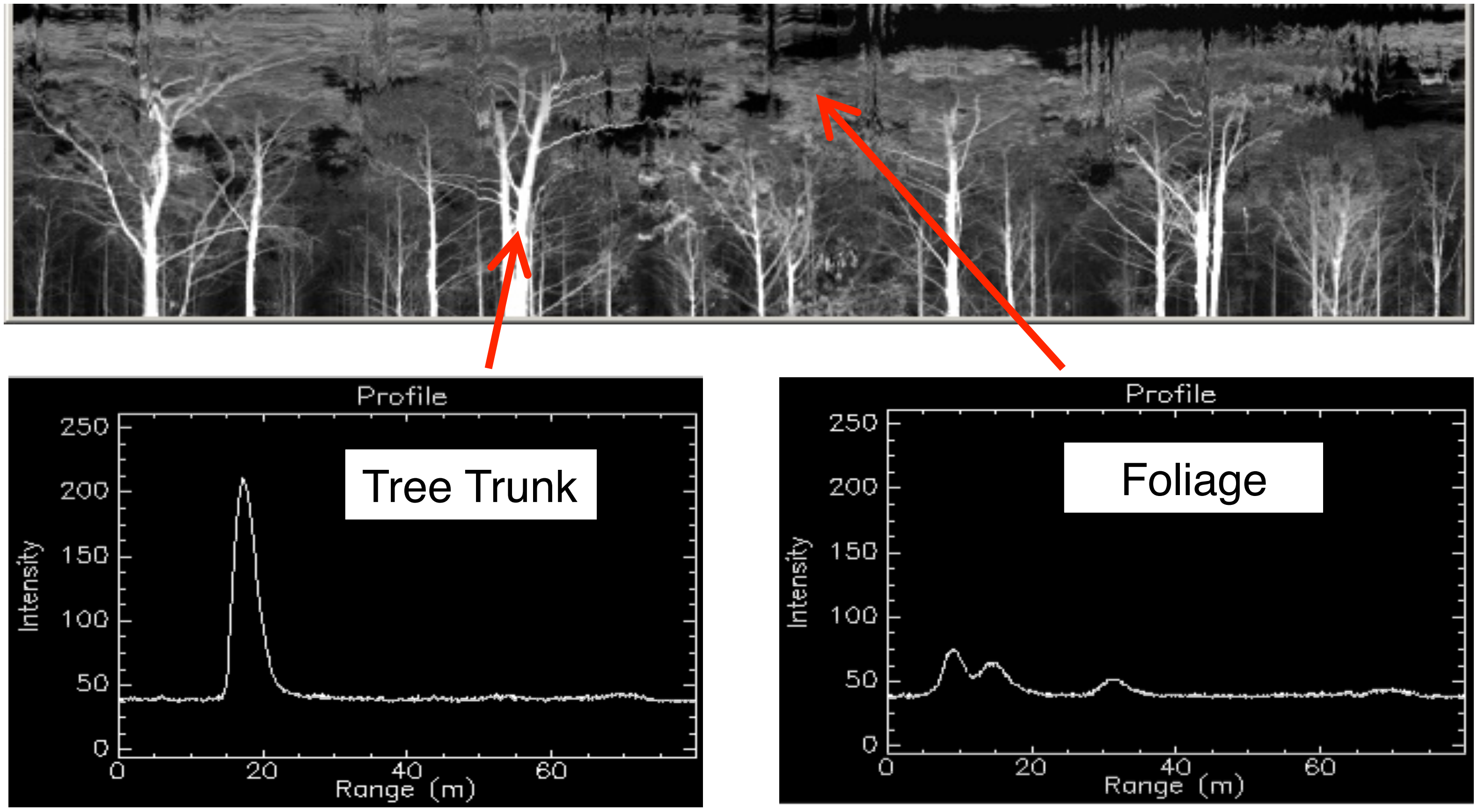
- *Typical TLS Wavelengths: 532, 905, 1064, 1540 nm*
  - Cost and availability of lasers affects choice
  - Eye safety issues are of concern – 1540 nm is very safe
  - Scattering objects have different spectral reflectances



Waveform Scanners

- *Advantages of Waveform TLS*
  - Waveform shape can identify hard hits (branches, trunks) and soft hits (leaves and fine branches)
  - Waveform tracks partial hits along the same path
  - Can provide *apparent reflectance* associated with a scattering event, taking into account prior hits
  - Readily provides gap probability (range, zenith angle), which is used to derive leaf area index and the foliage profile
  - Can also provide a point cloud with multiple attributes at each point
- *Disadvantages*
  - Large data volume, slow data acquisition speed

Hard and Soft Returns in EVI Data



- *Pulse Characteristics*
  - Length: 8 ns (FWHM) (2.4 m), strongly peaked
  - Beam divergence: 5 mrad scanned on 4 mrad centers (standard operation)
  - Digitized every 7.5 cm on return to 140 m range

Discrete Return Scanners

- *Advantages of Discrete Return (Point Cloud) TLS*
  - Well-integrated commercial systems available
  - Rapid data acquisition, large numbers of points
  - Fine resolution, often long distance
  - Software to merge multiple scans readily available
- *Disadvantages*
  - Point finding—not volume scattering—orientation
  - Thresholding may eliminate weaker scattering events
  - Intensity associated with a scattering event may be hard to interpret
  - Apparent reflectance and gap probability may be difficult to obtain
  - Calibration and internal workings may be proprietary and difficult to obtain for application processing

Research Scanners

EVI

SALCA

CBL

DWEL

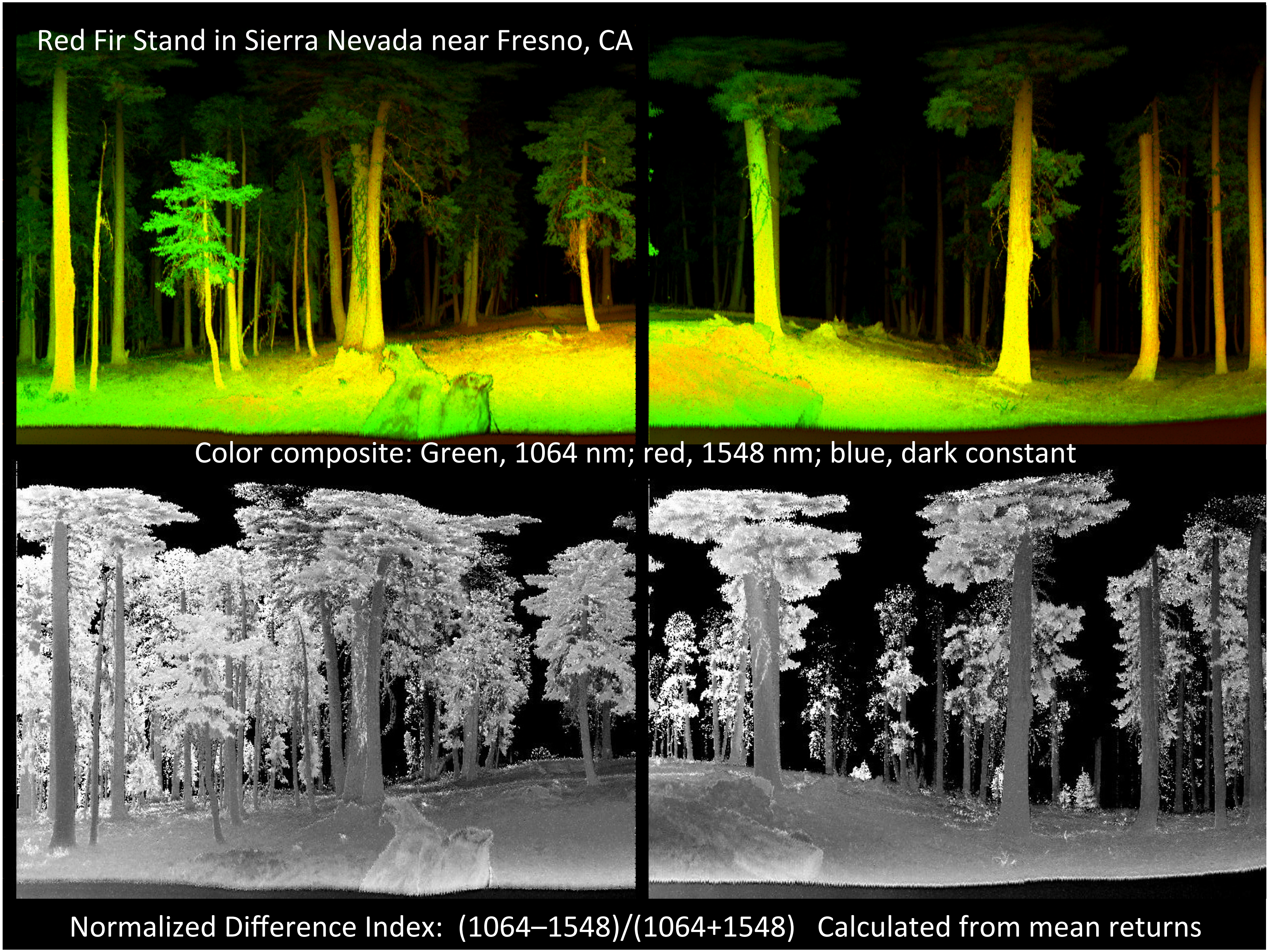
GFI Hyperspectral Lidar

Source:salca-salford.blogspot.co.uk

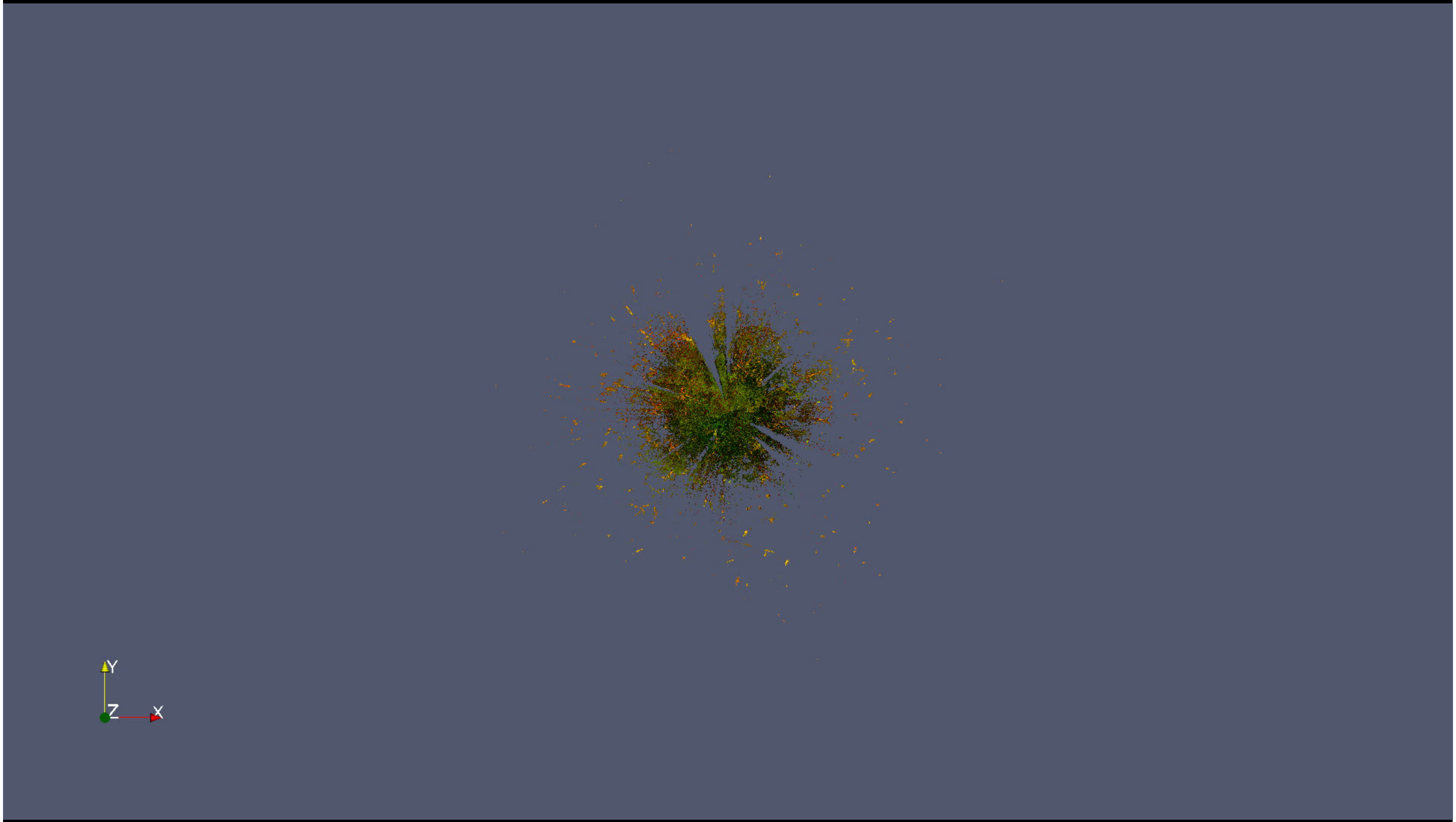
Source:http://www.auscover.org.au/DWEL

Dual Wavelength Scanners: Dual Wavelength Echidna Lidar (DWEL)

- 1064 and 1548 nm simultaneous pulses
- Full waveform recording at 0.5 ns sampling (7.5 cm range sampling)
- 1, 2, 4 mrad scanning and resolution
- Beam divergence 1.25, 2.5, 5.0 mrad
- Exit beam diameter 6 mm
- Pulse length 5 ns FWHM
- Pulse energies 0.6 μJ
- Scanning rate 2kHz
- Weight 22 kg
- Range 100 m @ 10% ρ
- Built by Boston U., funded by NSF
- Second copy currently in use by CSIRO Australia


Red Fir Stand in Sierra Nevada near Fresno, CA
Color composite: Green, 1064 nm; red, 1548 nm; blue, dark constant
Normalized Difference Index: (1064–1548)/(1064+1548) Calculated from mean returns

Harvard Forest Hardwood Stand

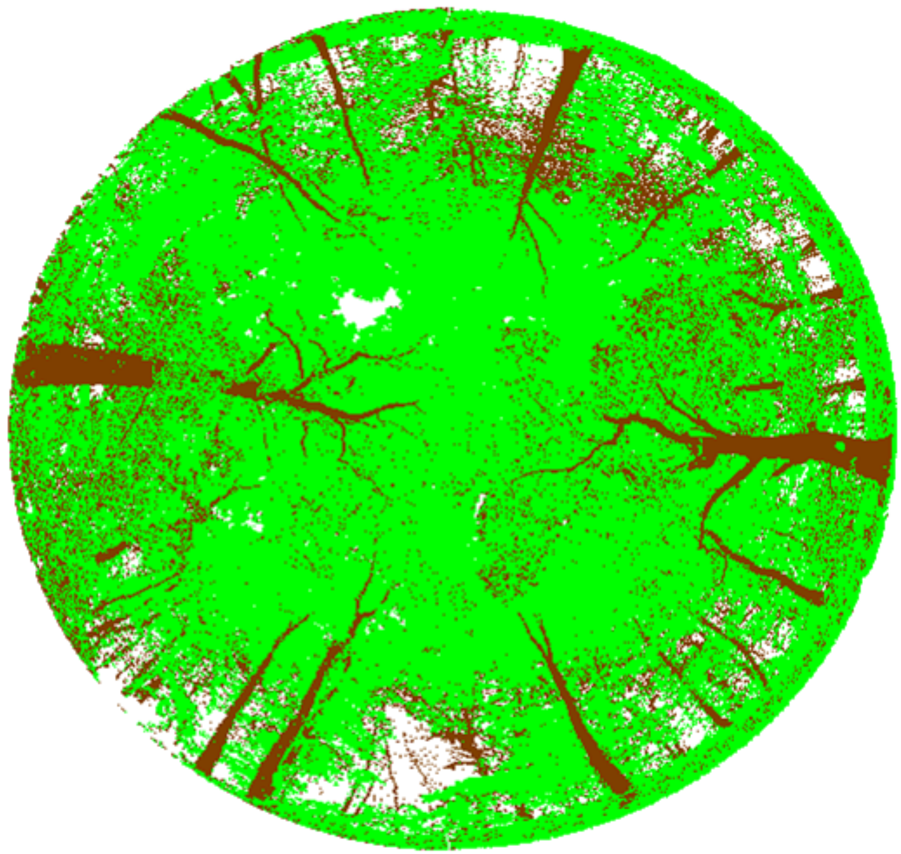


- DWEL False Color and Classified Point Cloud
- Harvard Forest Hardwood Stand
- Single Scan

Dual Wavelength Scanners: SALCA
Salford Advanced Laser Canopy Analyzer

- 1063 and 1546 nm alternating pulses
- Full waveform recording at 15 cm range sampling
- 1, 2, 4 mrad scanning and resolution
- Beam divergence 0.56 mrad
- Exit beam diameters 2/4 mm, 3.6 mm mm
- Pulse lengths 1, 3 ns FWHM
- Pulse energies 0.5, 5.0 μJ
- Scanning rate 5kHz
- Weight 15 kg
- Range 150, 105 m @ 10% ρ
- Built by Salford University, UK, Mark Danson, PI

SALCA Two-Band Ratio



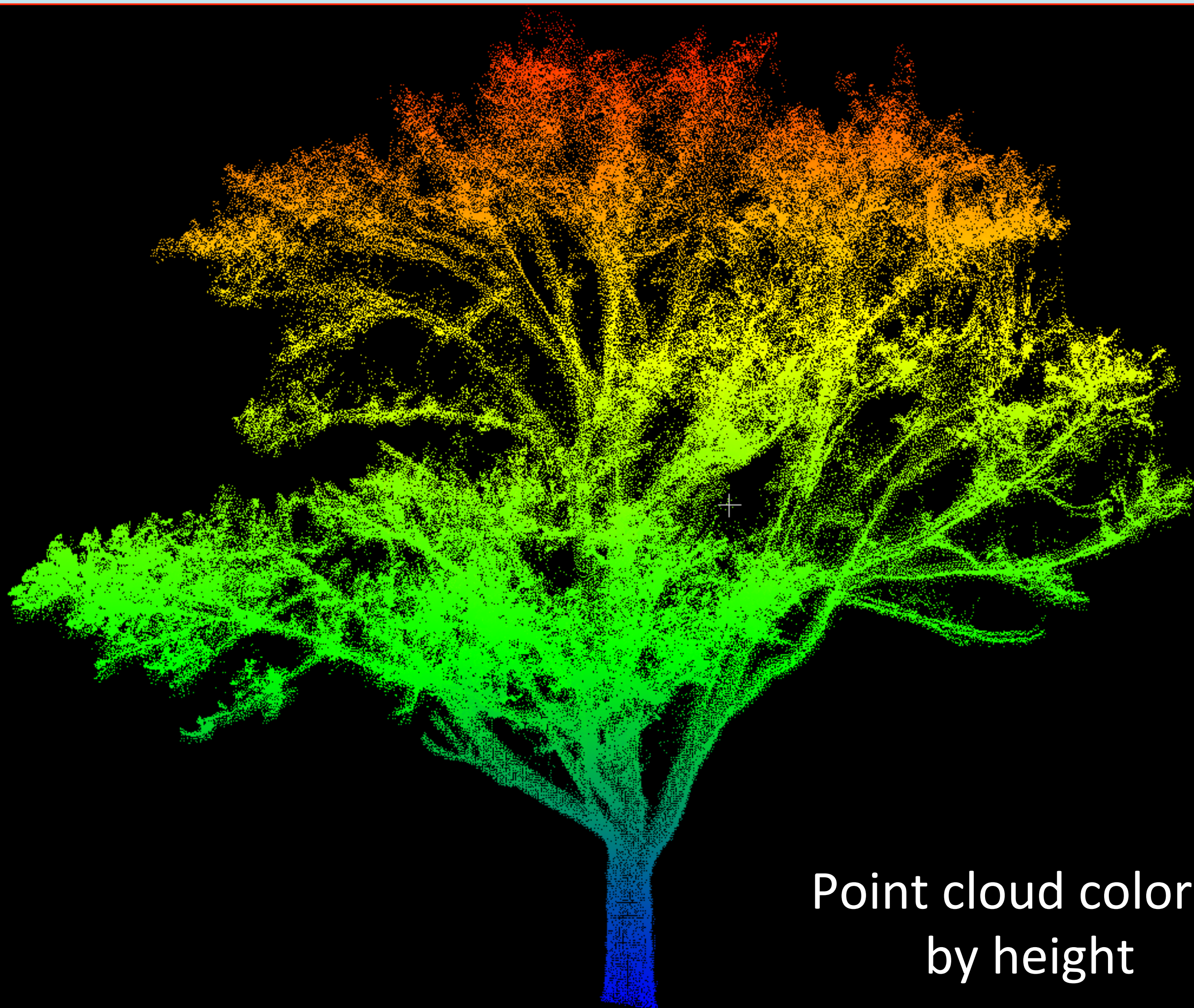
Separation of foliage and wood based on two-band ratio of first return waveform intensity

Compact Biomass Lidar 2 (CBL2)

- Lightweight (3.9 kg)
- Rapid-scanning (33 secs)
- 40 meter range
- 0.25° angular resolution
- 0.86° beam divergence
- First and second return
- 905 nm laser (eye safe)
- Onboard control and data ingest (Beagle Bone)
- Time-of-flight and intensity recorded
- Wireless activation (mobile phones and devices)
- Flexible mount for deployment platforms

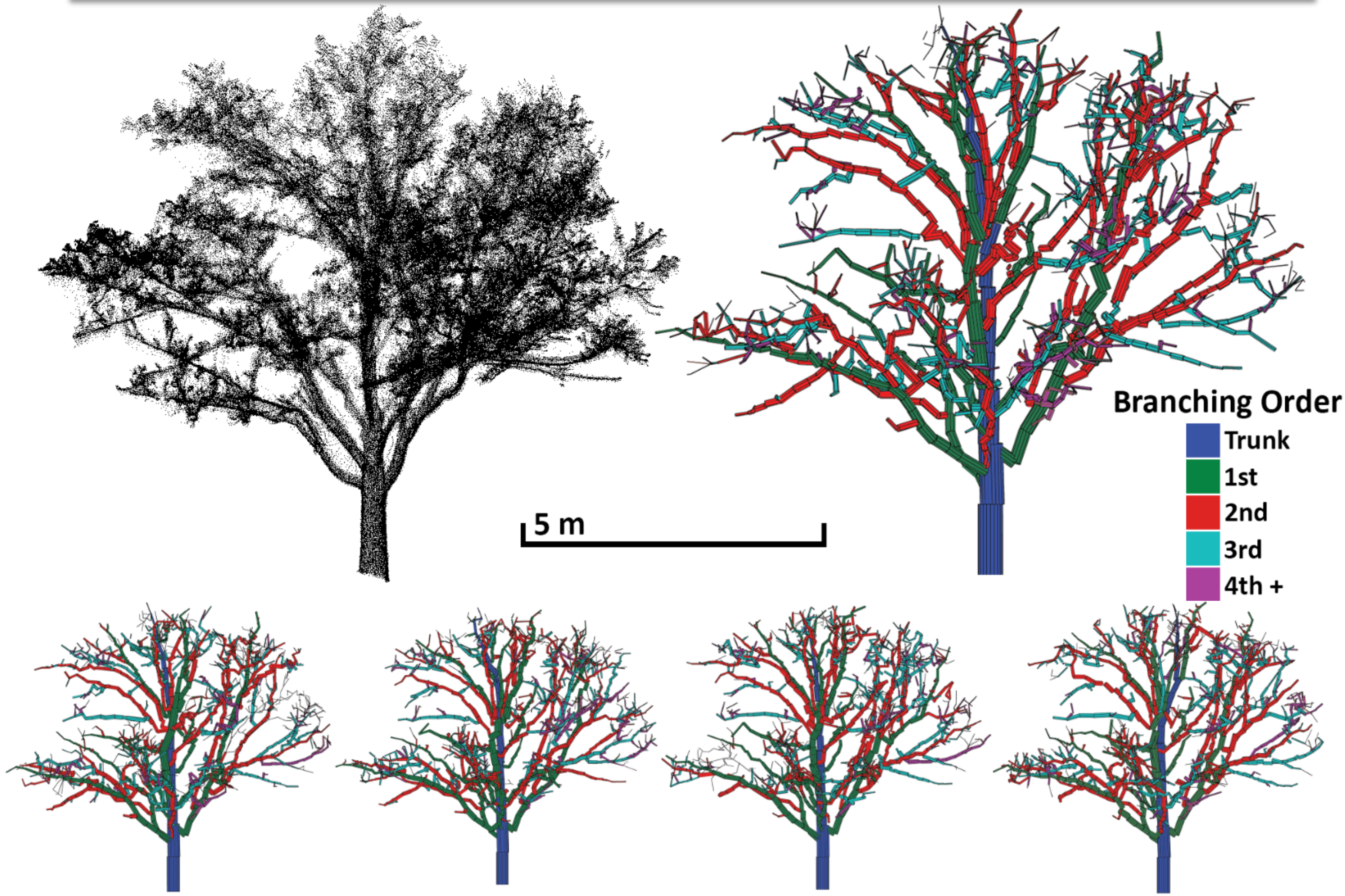
CBL2 in Point Cloud (Harvard Forest, MA, USA)

Norway Maple (Boston, MA, USA) from Four CBL2 Scans



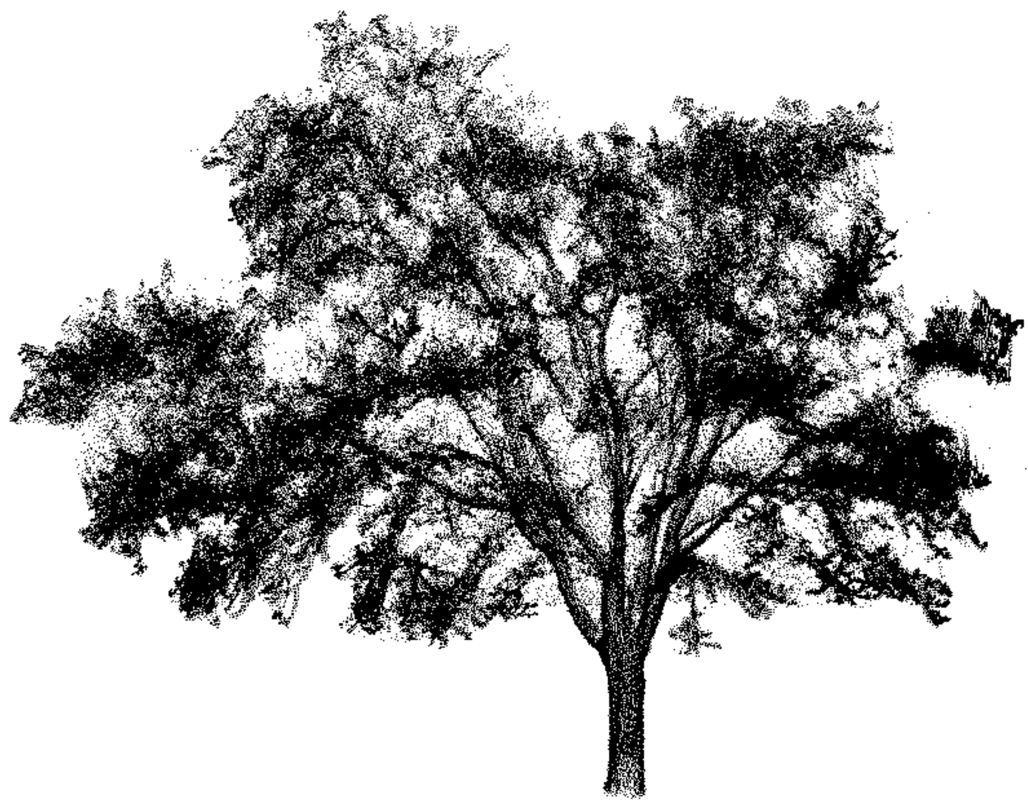
Point cloud colored
by height

Result: Quite Plausible QSMs from CBL2



QSMs with the CBL2

- *Conclusions:*
  - QSM algorithm functions well with CBL2
  - Additional scans add unique information
  - Higher branching orders have larger uncertainties
- *Ongoing work:*
  - Sampling schemes
  - Suitable filtering
  - Parameterization
  - Number of QSMs
  - Validation



Commercial Scanners

LEICAs

RIEGL

OPTECH

TRIMBLE

FARO

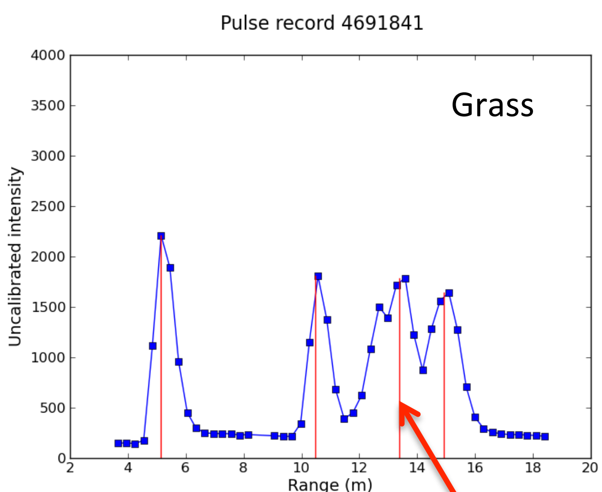
Riegl VZ-400 TLS

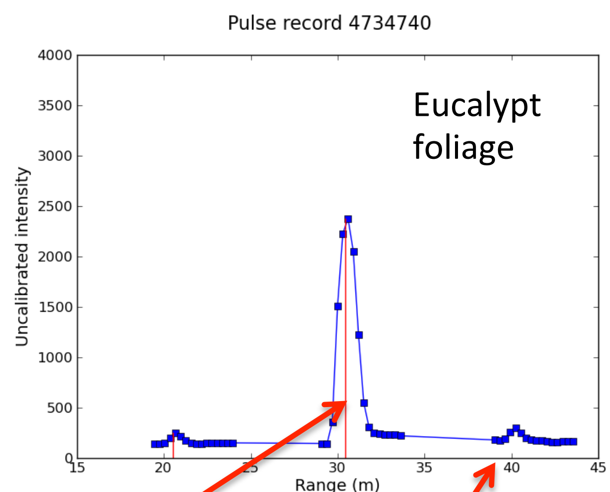
- 1550 nm laser
- Records multiple discrete returns and some waveforms
- Angular resolution 0.04–5 mrad zenith, 0.04–8.7 mrad azimuth
- Beam divergence 0.35 mrad
- Exit beam diameter 7 mm
- Pulse length 3 ns FWHM
- Pulse energy 0.48 μJ
- Effective scanning rate 42, 122 kHz
- Weight 9.6 kg
- Range 200, 120 m @ 10% ρ
- RIEGL Laser Measurement Systems GmbH, Horn, Austria
- Photo: Andy Burt with DSITIA TERN UQ instrument

Wytham Woods Fly-Through

Shows forest plot Wytham Woods, UK, scanned with Riegl VZ-400 with point cloud overlain with coregistered RGB photos

Riegl VZ-400 Waveform Recording





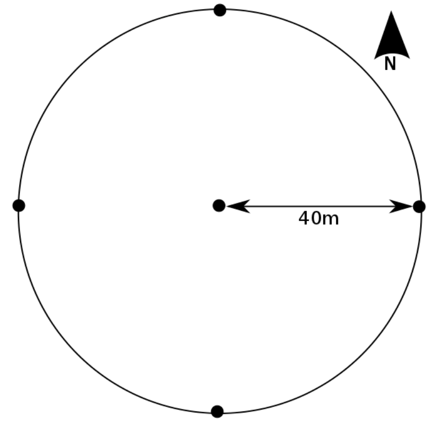
Digitized return echo

Undetected echo

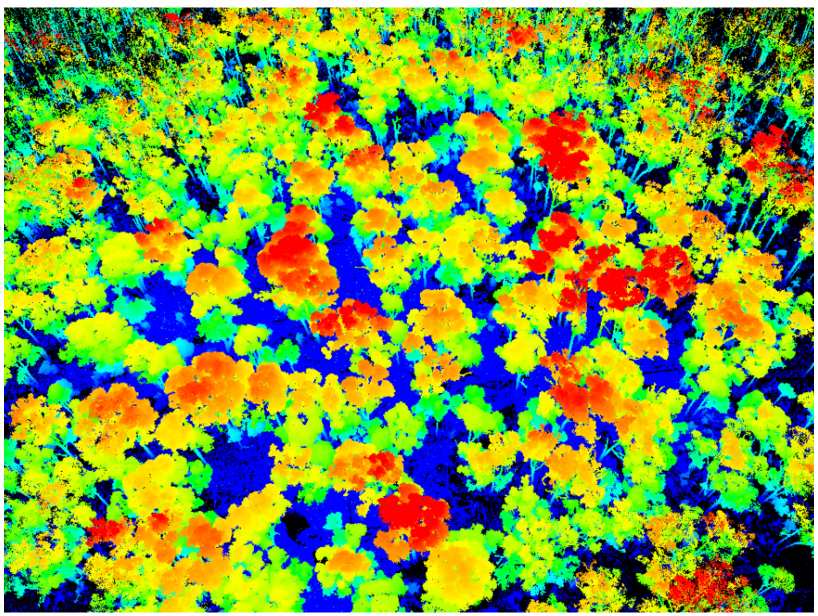
John Armston

Individual Tree Biomass from Scanning and Modeling

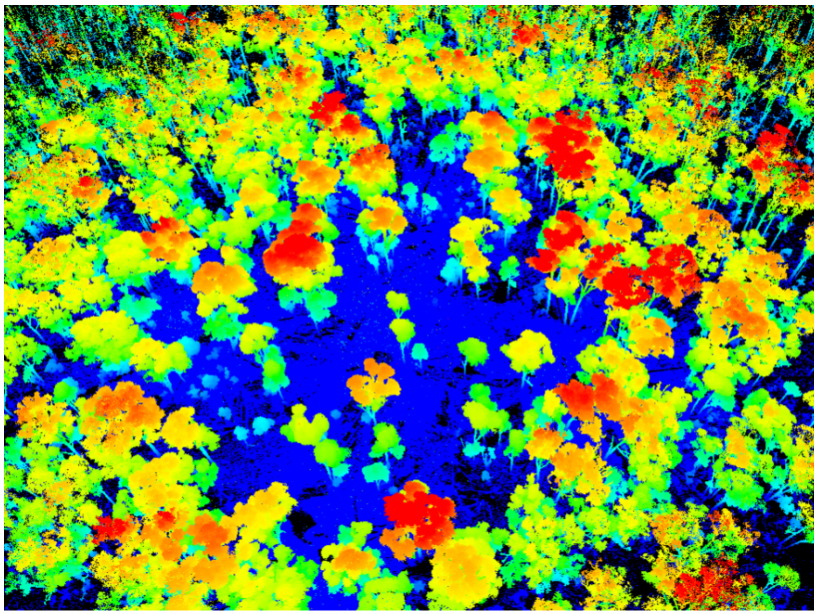
- Destructive Sampling of Open Eucalypt Forest, Victoria
- Scanning with Riegl VZ-400



Pre-harvest



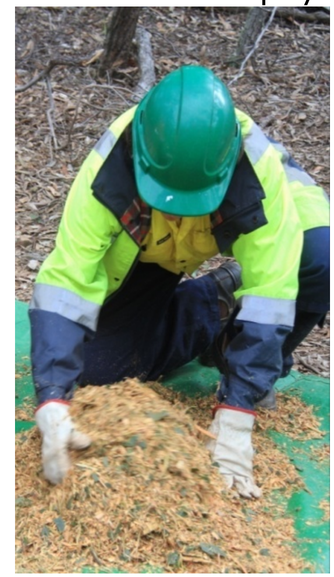
Post-harvest



Calders, K. et al (2015) Nondestructive estimates of above-ground biomass using terrestrial laser scanning. Methods in Ecology and Evolution 6, 198-208.

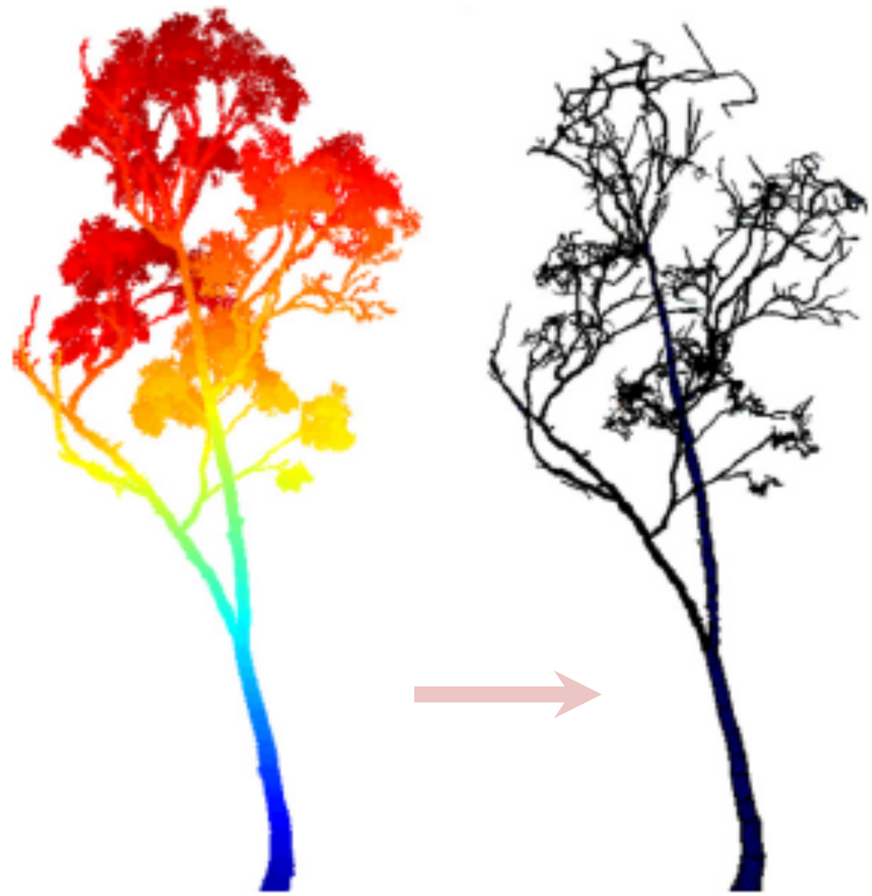
Individual Tree Biomass from Scanning and Modeling

Credit: S. Murphy



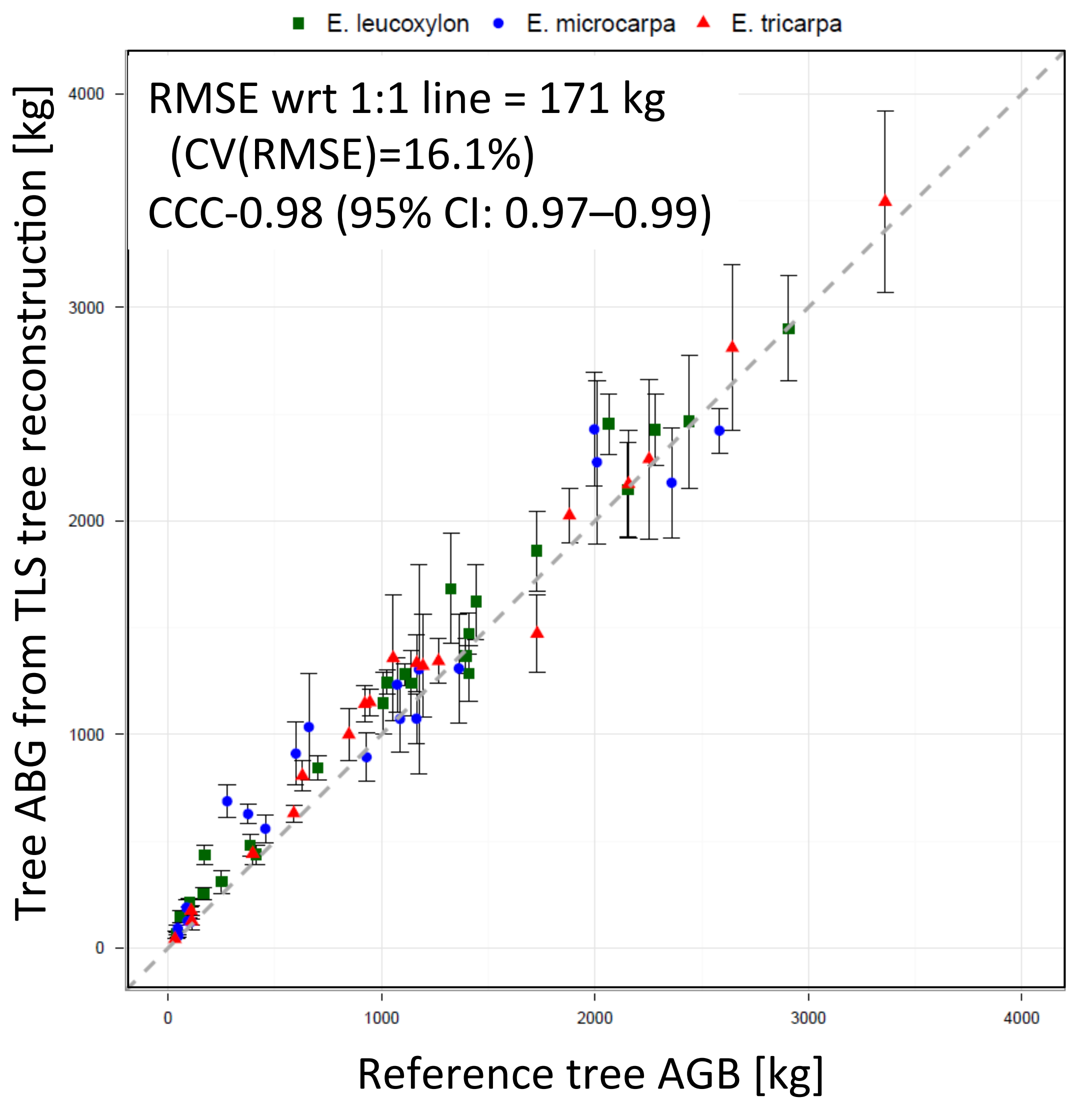
Tree Reconstruction

- *Cylinder Model*
  - Permits easy calculation of volume of segments
  - Two steps: Segmentation and surface reconstruction
  - Two-stage filtering removes stray points
  - Final parameters fitted to TLS scanned tree by visual comparison



Calders, K. et al (2015) Nondestructive estimates of above-ground biomass using terrestrial laser scanning. Methods in Ecology and Evolution 6, 198-208.

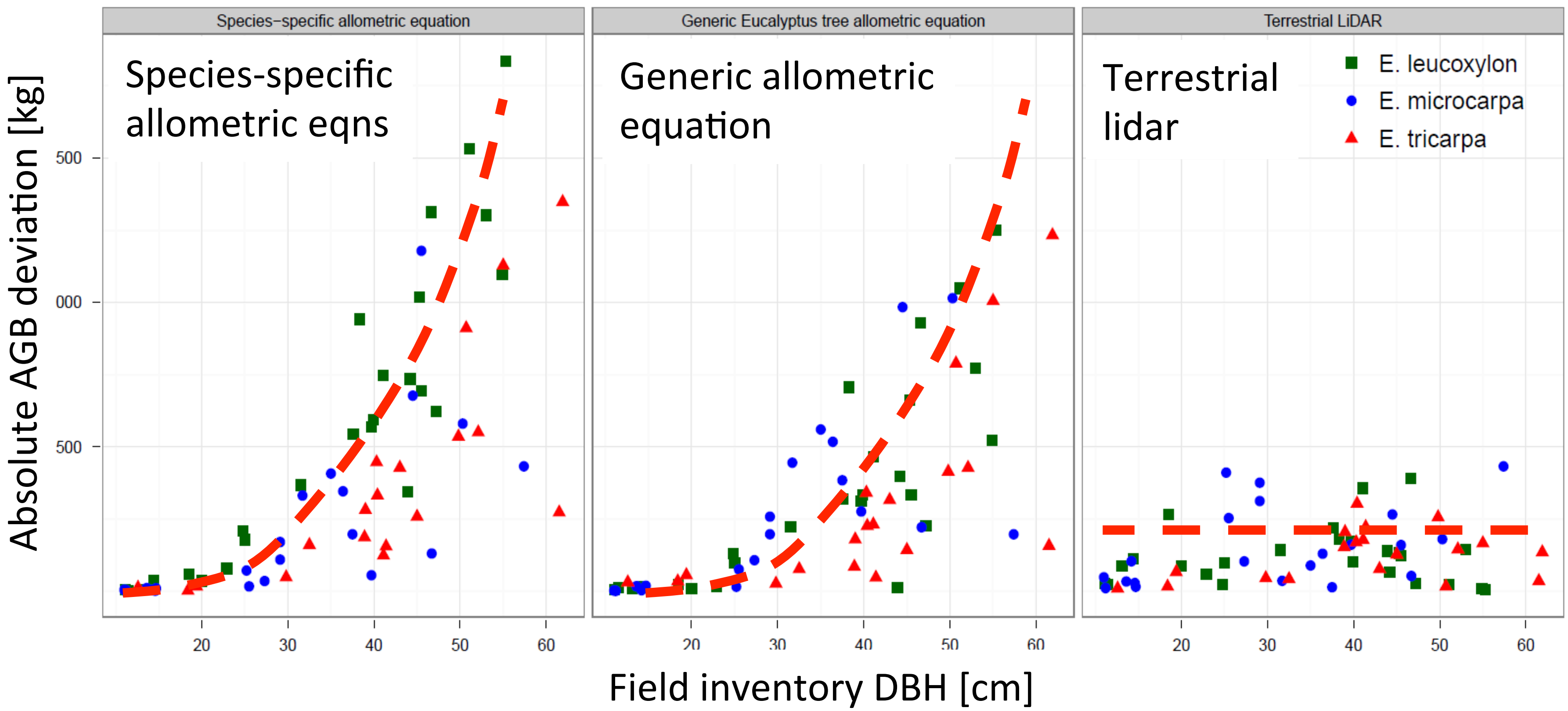
Measured and Modeled Biomass Matches Well



Improvement Compared to Allometry

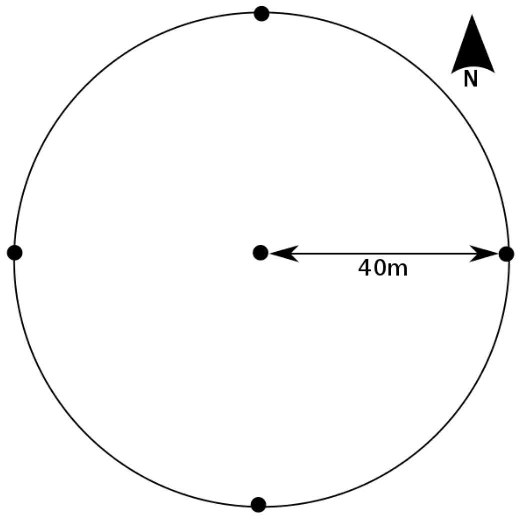
Above Ground Biomass from TLS and Allometry

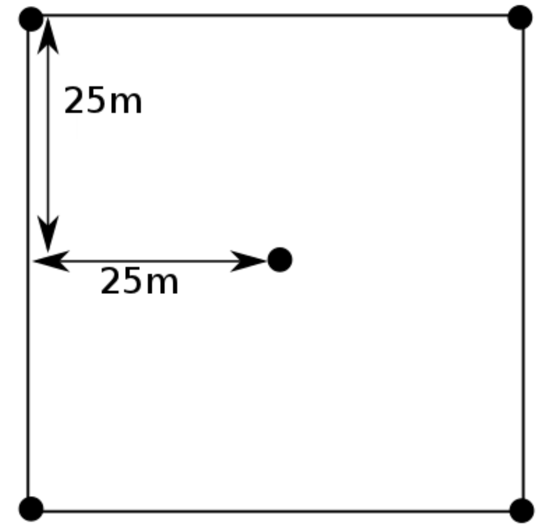
- At plot level:
  - Allometry: Underestimation of 29.9 to 36.6%
    - Deviation from measured AGB increases with DBH
  - TLS: Overestimation of 9.7 %
    - Deviation remains about the same with DBH

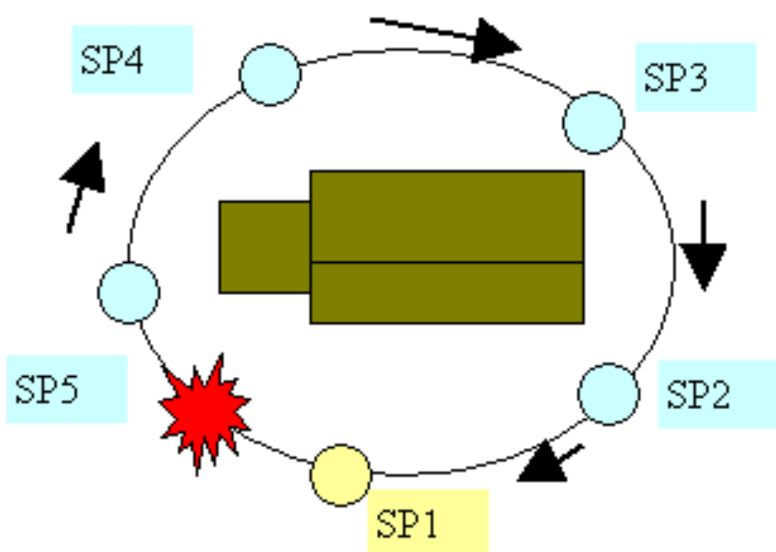


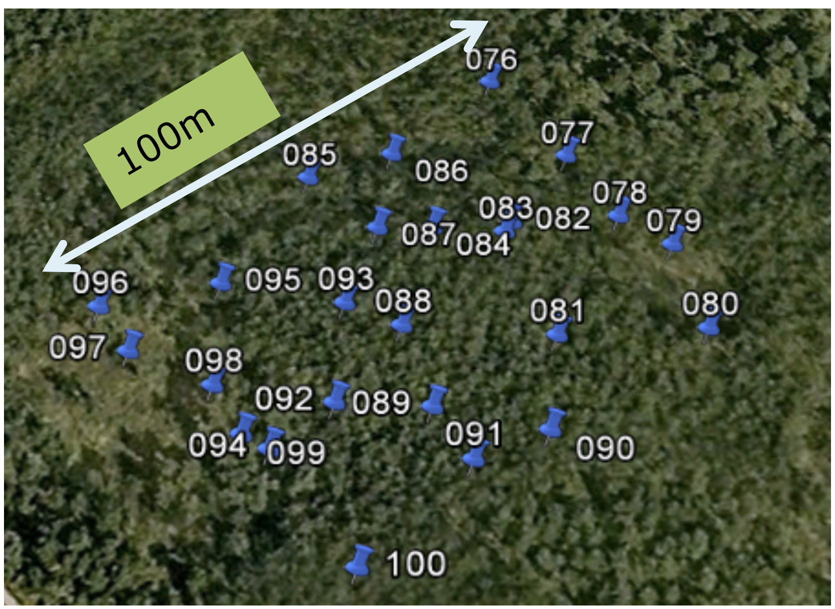
Data Collection

- Occlusion: Data registration to link different positions
- Use of tie points





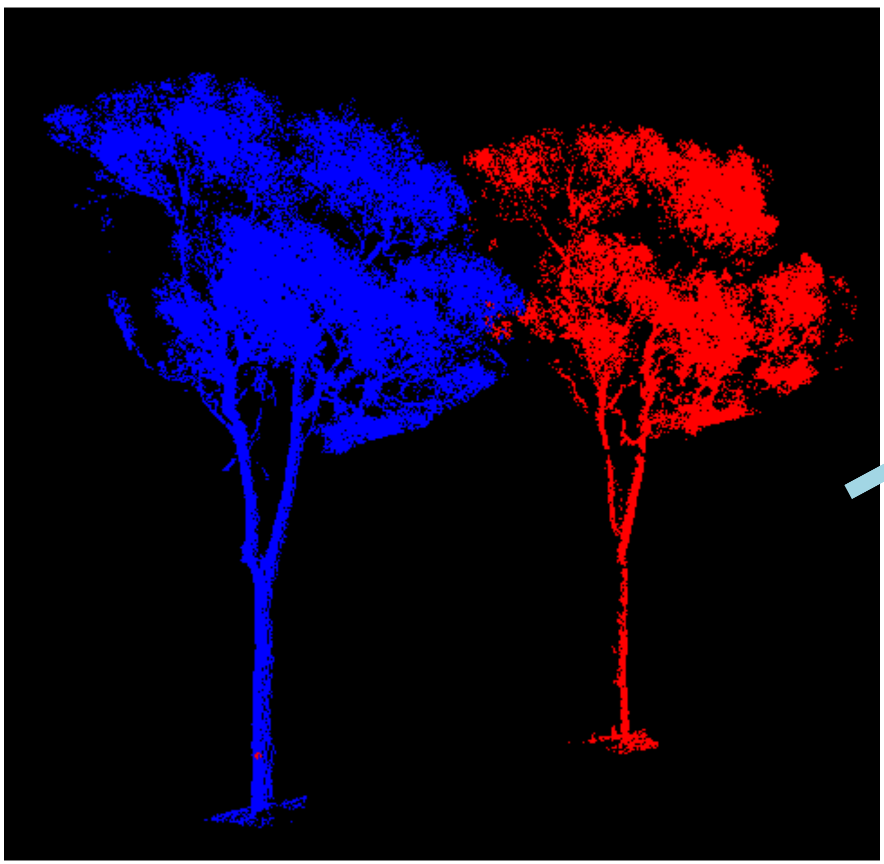


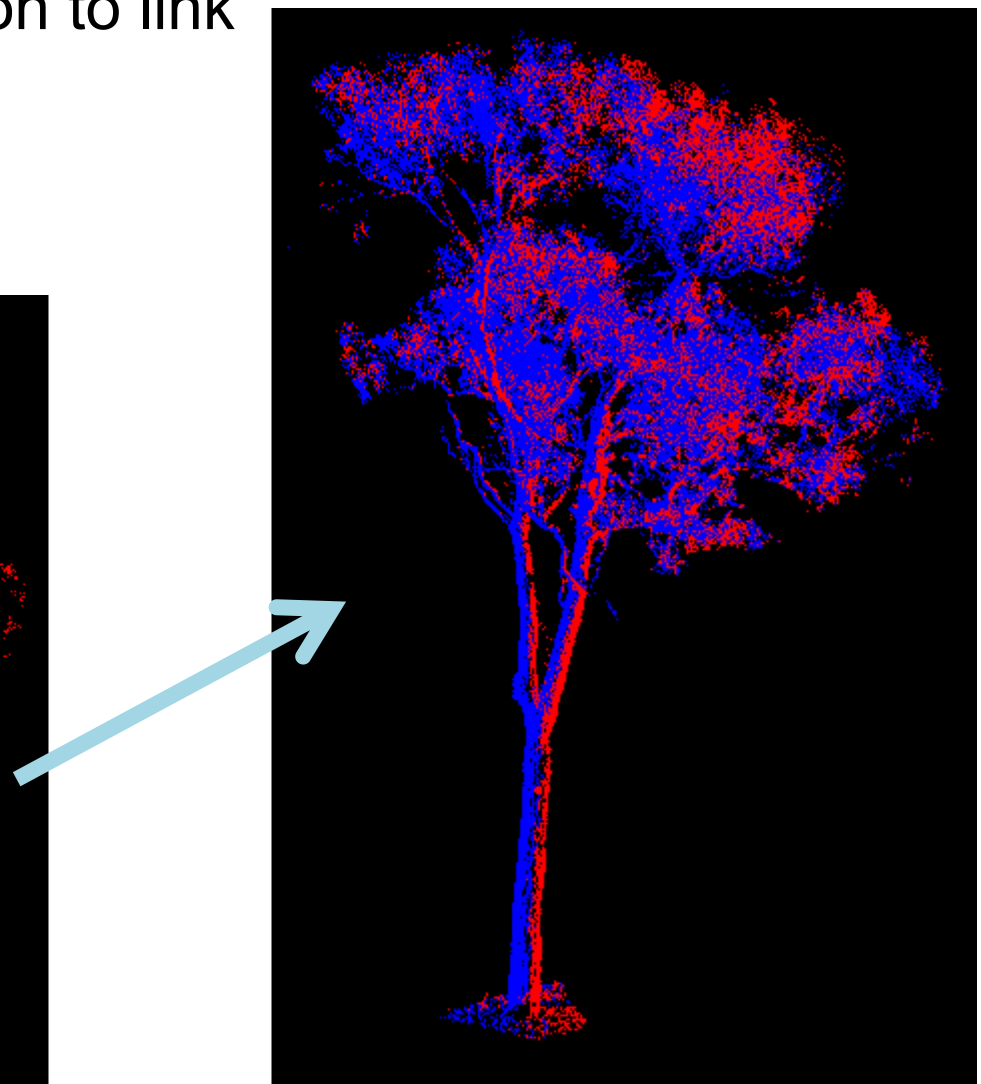


Data Collection: Registration Targets

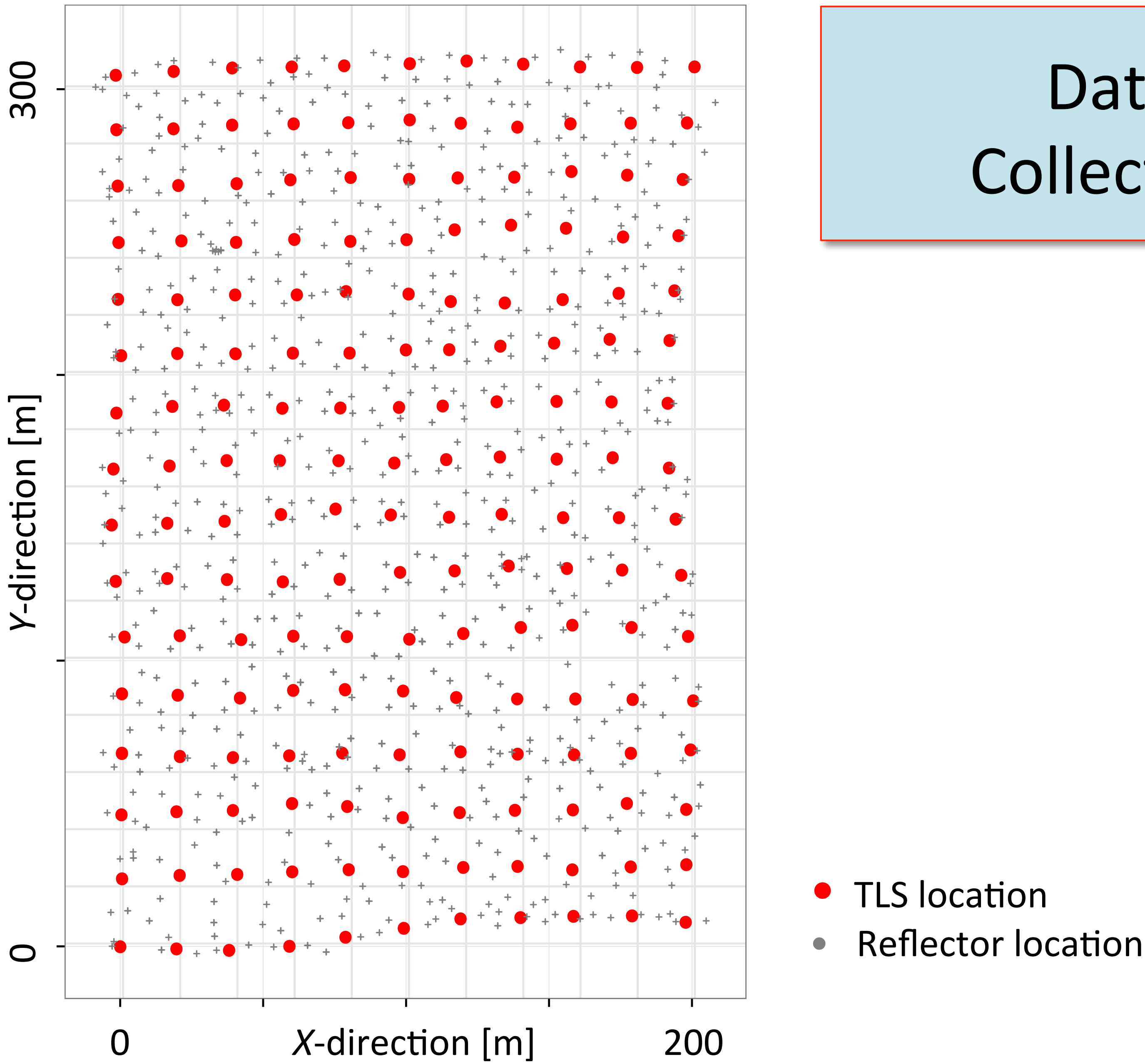
Data Collection

- Occlusion: Data registration to link different positions
- Use of tie points





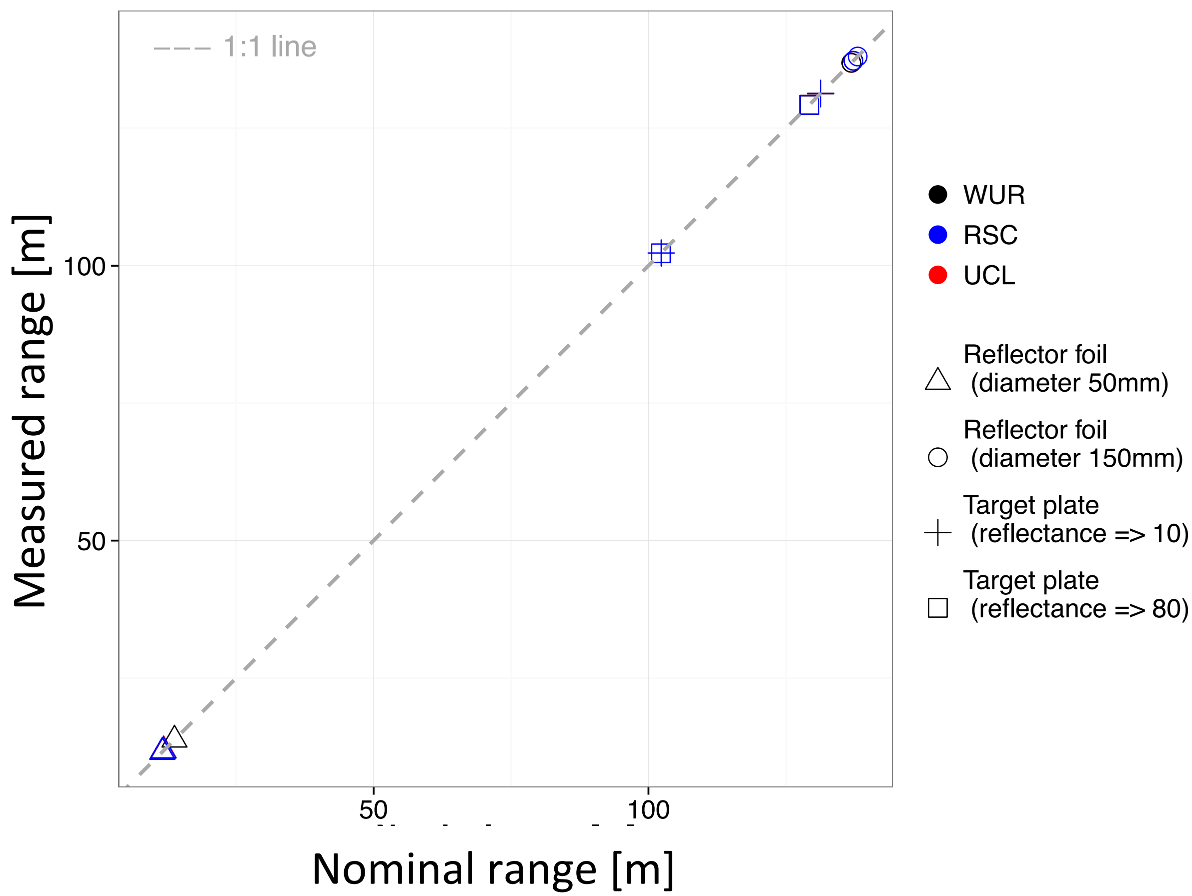
Data Collection



Open Questions / Future Visions

Is plot size (still) a limitation?

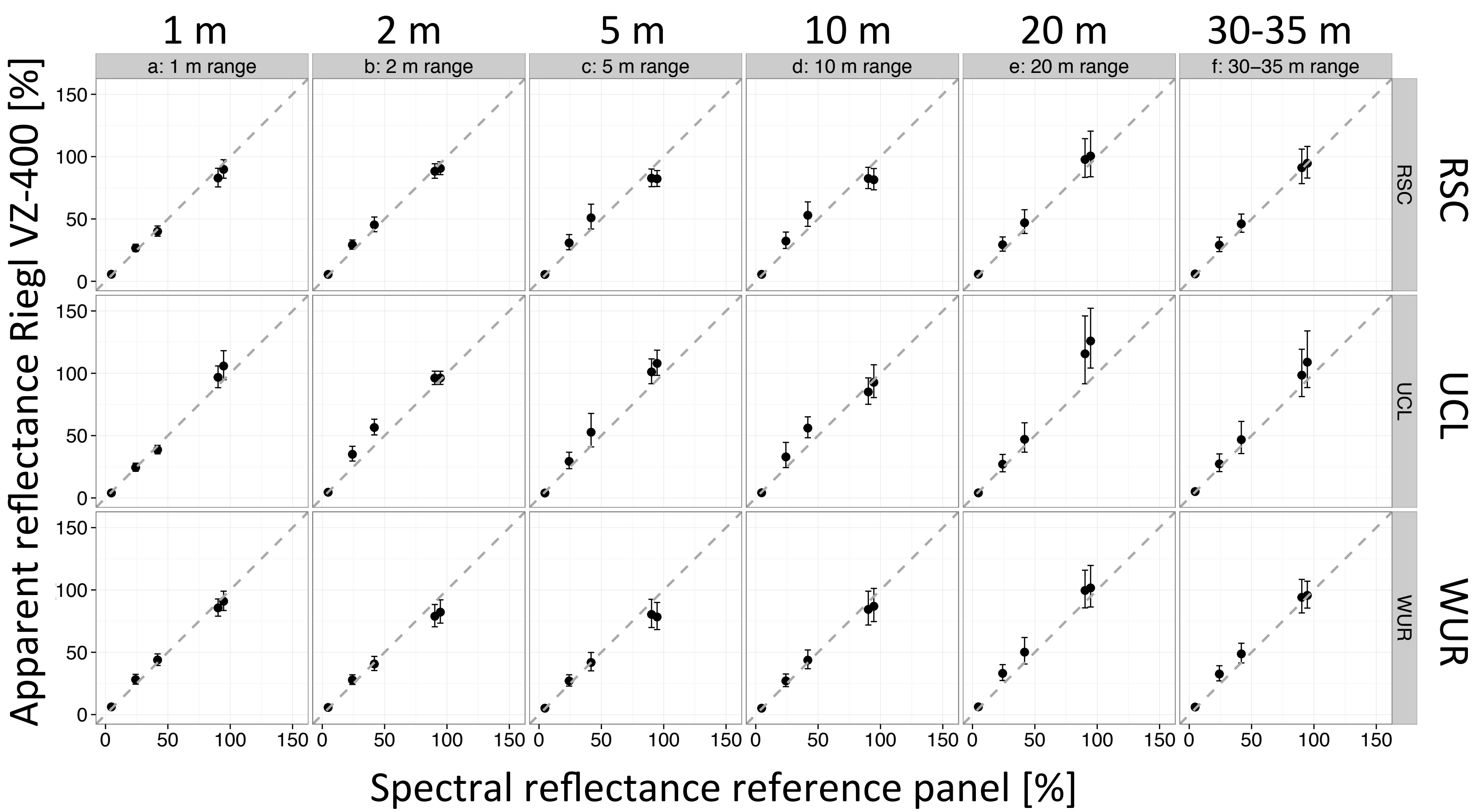
- Use of multiple instruments in one plot
- Need for intercomparison: Range



Open Questions / Future Visions

Is plot size (still) a limitation?

- Use of multiple instruments in one plot:
- Need for intercomparison: Apparent reflectance



Calders, K. et al (submitted) IEEE TGRS

Open Questions / Future Visions

Is plot size (still) a limitation?

- Mobile platforms: ZEBEDEEs

- Rapid scanning of large areas
- Long lasting (5hrs scan time)
- Cost effective
- Simple to use
- Automatic data processing
- Lightweight (3.6 kg total)

- Max range: 30 m (Limitation!)
- Wavelength: 905 nm
- Scan rate: 43 200 points/s
- FOV: 270 x 120 deg
- CLASS I Laser Product

ZEB1

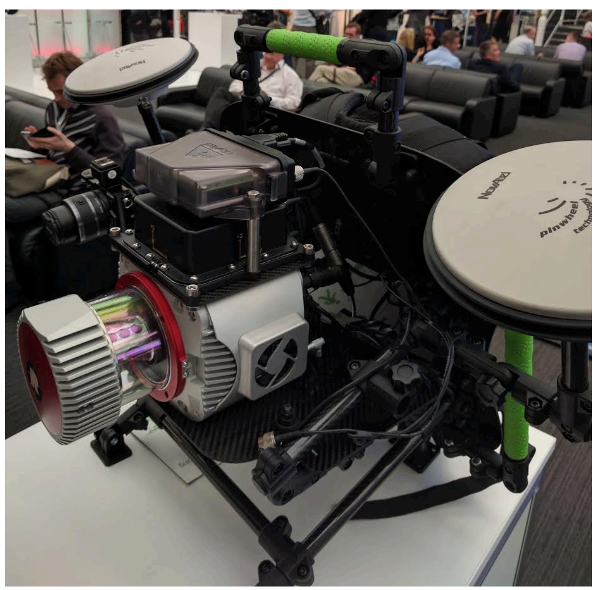
ZEB-REVO

Open Questions / Future Visions

Is plot size (still) a limitation?

- Mobile platforms: ROBIN

- Multi platform: walk / drive / fly
- Weight ~ 10 kg
- Max range: 350m @ 50kHz, 110m @500kHz
- Average point cloud density: 3000 pts per sqm (walk at 5 km/hr)



Source: 3D laser mapping

Open Questions/Future Visions

- *1. Is quantitative structure modeling of trees in a stand from lidar point clouds the best way to estimate aboveground biomass?*
  - Probably yes; allometric equations are intrinsically less accurate
  - Are existing algorithms satisfactory? What improvements are needed?
  - How dependent are algorithms on stand structures, tropical rainforest vs. boreal conifer stand, for example?
  - Can one algorithm fit all stand types by varying parameters?
- *2. What are the key issues affecting the quality of forest point clouds?*
  - *2.A. Interscan registration* – Are the methods up to the task?
    - Targets work well but are a lot of work (Kim). When are targets needed?
    - When can markerless registration work?
    - How do errors in registration propagate through structure models to affect biomass estimates?
  - *2.B. What are the limits on plot size?*
    - Kim: Multiple instruments may speed acquisition if cross calibrated

Open Questions/Future Visions

- *2. What are the key issues affecting the quality of forest point clouds?*
  - *2.C. Occlusion in point clouds* – Controlled by sample density and vegetation density
    - How do we measure occlusion? Is there a minimum occlusion we can strive to achieve by controlling sample layout and scanning resolution?
    - Can novel approaches (towers, trams, tall tripods) and novel scanners (Zebs, ROBIN) (Kim) help reduce occlusion cost-effectively?
    - What about merging airborne lidar (ALS) from UAVs with TLS to fill in points from above?
  - *2. D. Separation of leaf and woody hits* -- How helpful and necessary is this?
    - Spectral separation: Is bi-, multi-, or hyperspectral scanning required? Can leaf and woody hits be readily separated at 1550 nm?
    - Spatial separation: How can spatial context be best used to separate leaf and woody hits?

Open Questions/Future Visions

- *3. What's the best way to get leaf area index and foliage profiles from point clouds?*
  - Are 1/n methods good enough for gap probability with height and zenith angle to give LAI and FP at individual scans?
  - How good are voxel methods for registered point clouds?

Thank You

(Himalayan Cedars from the Oz DWEL courtesy Mick Schaefer)