Uncertainty in Remote Sensing of Leaf Area Index and Foliage Cover in Australian forests

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1. Background
   - Significance of topic

2. Objectives
   - Aims

3. Methods & Results
   - Part 1 (field study) method and results
   - Part 2 (simulation study) method and prelim results
Vegetation as the boundary layer

Evapotranspiration

CO₂  O₂

Leaf Area Index = Total one-sided leaf area (m²) / Total Area (m²)
Australian Forests

Distribution of Australia’s forests

Remote Sensing Products
Australian forest traits and challenges

Some of the main factors when remotely sensing vegetation:

1. Clumping (at all scales)
2. Leaf Angle (distribution)
3. Impact of woody components
1. **Clumping (at all scales)**

- **Crown architecture** (within-crown clumping)
- **Tree distribution** (between-crown clumping)

**Regular Tree Distribution**

**Clumped Tree Distribution**
2. **Leaf Angle (distribution)**

- **Vertical leaf angle** (Eucalypt)
- **Horizontal leaf angle**
3. **Impact of woody components** (i.e. leaf:woody ratio)

Upward-looking view of a canopy
Remote Sensing of LAI

LAI = f(canopy gaps, clumping, leaf & wood angle, leaf:wood ratio)
Part 1: Product Accuracy Requirements

• Need for accurate ground-based measurements in support of calibration/validation activities

Target Accuracies (*products to match within ground-based estimates*)

± 0.5 LAI or 20% maximum (CEOS, GCOS)

5% (WMO 2013)
Main Research Questions/Themes

Part 1

Are there any significant differences between the ground-based instruments for estimating LAI?

Part 2

How accurately can you estimate LAI using these ground-based instruments?
Part 1: Field-based Investigation

Are there any significant differences between the ground-based instruments for estimating LAI?

Following...

- Best practise guidelines (where they exist)
- Standard approach

Can only estimate uncertainty. **Not** accuracy!
Part 1 – Study sites & Instruments

Instruments

- Terrestrial Laser Scanner
- LAI-2200
- High and Low Resolution Hemispherical Cameras
## Part 1 – Instruments

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Model (Manufacturer)</th>
<th>Angular resolution (degrees)</th>
<th>FOV (degrees) H, V</th>
<th>Wavelength (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAI-2200</td>
<td>LAI-2200 (Li Cor Inc.)</td>
<td>NA</td>
<td>300, 75</td>
<td>&lt;490</td>
</tr>
<tr>
<td>High res DHP</td>
<td>D90 (Nikon)</td>
<td>0.08</td>
<td>360, 90</td>
<td>400-700</td>
</tr>
<tr>
<td>Low res DHP</td>
<td>CI-110 (CID Inc.)</td>
<td>0.26</td>
<td>360, 90</td>
<td>400-700</td>
</tr>
<tr>
<td>TLS</td>
<td>VZ400 (Riegl)</td>
<td>0.06</td>
<td>360, 100</td>
<td>1550</td>
</tr>
</tbody>
</table>
Part 1 – Results

Woodgate et al., (2014) in review
Part 1 – Results

• A total of 67 method-to-method pairwise comparisons were conducted across 11 plots.
• Out of 67 comparisons, 29 had an RMSE ≥ 0.5 LAIₑ.

<table>
<thead>
<tr>
<th></th>
<th>HR-DHP (S)</th>
<th>HR-DHP (AT)</th>
<th>LR-DHP (S)</th>
<th>LR-DHP (AT)</th>
<th>LAI-2200</th>
<th>TLS</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR-DHP (S)</td>
<td>-</td>
<td>11</td>
<td>6</td>
<td>6</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>HR-DHP (AT)</td>
<td>0.58</td>
<td>-</td>
<td>6</td>
<td>6</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>LR-DHP (S)</td>
<td>0.24</td>
<td>0.68</td>
<td>-</td>
<td>6</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>LR-DHP (AT)</td>
<td>0.23</td>
<td>0.51</td>
<td>0.33</td>
<td>-</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>LAI-2200</td>
<td>0.10</td>
<td>0.44</td>
<td>0.27</td>
<td>0.24</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>TLS</td>
<td>0.76</td>
<td>0.97</td>
<td>1.49</td>
<td>1.43</td>
<td>NA</td>
<td>-</td>
</tr>
</tbody>
</table>

Bottom diagonal is the average of plot RMSE’s between instruments.
Top diagonal is the number of plots where these instruments were compared.

Woodgate et al., (2014) in review
Part 1 – Results & Lessons learned

• Large uncertainties exist for these methods for LAI estimates following standard operational protocols for data collection

What are the main causes of the differences?

• DHP = exposure (radiometric sensitivity), lighting and sky background and conditions

• TLS = combination of beam size, range/power, detection threshold, ranging method (phase vs ToF) & wavelength

• LAI-2200 = assumption that all elements are ‘black’ when estimating transmittance
Part 2: Model-based Investigation

How accurately can you estimate LAI using these ground-based instruments?

Aim
Evaluate accuracy using a 3D reconstructed forest stand to simulate the instruments.
Model parameterisation: creating the forest

- Rushworth Forest
Model parameterisation: creating the trees
Model parameterisation: creating the trees

Modelled structure of the trees in OnyxTree (no spectra or leaf template added)

(a) *E. tricarpa*
Height = 18.6 m, DBH = 28.3 cm

(b) *E. macrorhyncha*
Height = 9.6 m, DBH = 12.8 cm

(c) *E. microcarpa*
Height = 21.8 m, DBH = 27.2 cm
Model parameterisation: creating the trees

Library of 51 trees (5 Eucalypt species)
- First of its kind in Australian forests
Validation of the 51 tree models
Part 2 results: Within-crown clumping and Leaf Angle

Crown cover simulations

<table>
<thead>
<tr>
<th>View Angle</th>
<th>Simulated Species</th>
<th>Crown Cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 degree</td>
<td>Planophile (vza = 0)</td>
<td>11.63 m²</td>
</tr>
<tr>
<td></td>
<td>Extremophile (vza = 0)</td>
<td>10.01 m²</td>
</tr>
<tr>
<td></td>
<td>Erectophile (vza = 0)</td>
<td>8.24 m²</td>
</tr>
<tr>
<td>57 degree</td>
<td>Planophile (vza = 1rad)</td>
<td>8.32 m²</td>
</tr>
<tr>
<td></td>
<td>Extremophile (vza = 1rad)</td>
<td>8.43 m²</td>
</tr>
<tr>
<td></td>
<td>Erectophile (vza = 1rad)</td>
<td>8.14 m²</td>
</tr>
</tbody>
</table>
Part 2 results: Within-crown clumping and Leaf Angle

\[
y = 1.01x - 0.14 \\
R^2 = 0.96
\]

\[
y = 1.01x - 0.05 \\
R^2 = 0.97
\]

\[
y = 1.04x + 0.01 \\
R^2 = 0.99
\]

\[
y = 1.03x + 0.00 \\
R^2 = 0.99
\]

0 degree view angle

57 degree view angle
Part 2 results: Within-crown clumping and Leaf Angle

Accounting for the woody components

Projection coefficient of leaves and wood
Part 2: Up-scaling from tree to plot to stand

Ongoing work...
Clumping Simulations

Regular Tree Distribution

Clumped Tree Distribution
Exemplar stem distributions
Part 2: Site scale simulations

Stem density = 230 stems ha$^{-1}$

$LAI = 0.4$, Cover = 10%

Random tree distribution

Top-down view (90 x 90 m)
Part 2: Site scale preliminary results

*Simulated hemi photo*
Part 2: Example site simulations

Openness = 79%
Reference LAI = 0.4

Openness = 65%
Reference LAI = 0.8

Openness = 51%
Reference LAI = 1.2
Questions?
Maybe to include...
Thanks to...

- **Supervisory panel** (Simon Jones, Lola Suarez, Michael Hill)
- **Work colleagues** (esp. CRC-SI 2.07 team – Simon Jones, Andrew Haywood, Lola Suarez, Phil Wilkes, Andrew Mellor, Mariela Soto-Berelov. Lab colleagues – Vaibhav Gupta, Laurie Buxton, Bill Langford, Barbara Rasaiah, James Leversha, Tapasya Arya. Staff – Mark Shortis, Chris Bellman, Lucas Holden)
- **Mentors** (Wu Bingfang, Graeme Kernich)
- **Research collaborators** (John Armston, Mat Disney, Michael Schaefer)
- **Friends and Family**
- ++
Selection of Research Outputs

**Ground based method intercomparison (journal article)**


**Crown-scale modeling (journal article)**


**TLS international collaboration effort (journal article)**


**TERN Greenbook (book chapter)**


**Sampling Design (peer reviewed conference paper)**


**Ground based methods and modelling introduction (peer reviewed conference paper)**