THE IMPACT OF SENSOR CHARACTERISTICS FOR OBTAINING ACCURATE GROUND-BASED MEASUREMENTS OF LAI

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ABSTRACT

Calibration and validation of LAI products require accurate ground-based measurements. Many indirect ground-based sensors such as digital hemispherical photography (DHP), ceptometers, and terrestrial laser scanners (TLS) are used interchangeably to estimate reference values. However these sensors have biases in regards to the true LAI value, which can never be known in the field. Results from three representative woody ecosystems in Eastern Australia are presented from real field measurements. Significant differences were found between methods at the individual measurement and plot scale. Furthermore, one of the sites in South East Australia was measured and modeled in a 3D deterministic model. In this digital environment where the truth is known, sensors can be simulated to determine their bias.

Index Terms— LAI, ground-based, forest, simulations

1. INTRODUCTION

Ground-based measurements of leaf area index (LAI) are integral to the calibration and validation of regional and global LAI products. A large number of direct and indirect ground-based methods can be used to estimate LAI. However, in forested environments instruments that indirectly estimate LAI are suited to deriving representative values to characterise large areas because they are more efficient and cost-effective than direct measures such as destructive harvesting [5]. Presently there is no consensus in the scientific community as to the best ground-based method to derive LAI [4]. Indirect instruments such as high resolution (HR, > 10 megapixels) and low resolution (LR) digital hemispherical photography (DHP), the LAI-2200 (LiCOR), terrestrial laser scanners (TLS), and ceptometers have been successfully utilised to derive LAI in a range of environments. These instruments vary based on the active or passive nature of the sensor, operating wavelength, resolution or point density, and field-of-view (FOV) to name a few. These differences have the potential to cause large discrepancies in derived LAI values.

Numerous ground-based comparison studies have been conducted to calibrate and better understand the accuracy of indirect measurements to derive LAI. However, the majority of these studies have been conducted in the Northern Hemisphere. Australian vegetation presents unique characteristics such as erectophile leaf angle distribution and crown structural configuration. LAI comparison studies on woody ecosystems within Australia have identified discrepancies between direct and indirect measurements, where indirect methods have produced both over- and under-estimates of LAI when compared with direct methods. This can lead to implications when validating LAI products if there is no direct measure to calibrate the instruments for each woody environment. 3D models of woody ecosystems using Monte Carlo ray tracing (MCRT) have been used to simulate DHP and TLS measurements that can be compared to values derived from the modeled structural data [1, 2].

The objective of this investigation using real field-derived results of representative Australian woody ecosystems is to determine if there are any significant differences (0.5 or maximum 20% LAI [3]) between instruments for deriving accurate ground-based measurements of LAI. In addition, to quantify which sensor characteristics contribute to higher errors in LAI estimations using a 3D MCRT model.

2. STUDY AREAS

Three study areas, Rushworth (RW); Watts Creek (WC); and Robson Creek (RC) were chosen for this investigation. All three areas are representative of different woody ecosystems found within Australia.

RW (36°45'S, 144°58'E) is representative of a dry sclerophyll forest and is located within a box-ironbark forest in Victoria, Australia. Typical tree heights range from 15-25 m with sparse understory vegetation present.

WC (37°41'S, 145°41'E) is located on the slopes of Mount Donna Buang, Victoria, Australia. The area largely comprises a mature open forest of Mountain Ash (*Eucalyptus regnans*). Typical tree heights of the dominant species range between 30-70 m with large amounts of mid- and understory vegetation present.

RC (17°07'S, 145°38'E) is located in the Wet Tropics World Heritage Area Queensland, Australia. The forest present (forest type is Simple Notophyll Vine Forest) has one of the highest rates of biodiversity in Australia. The canopy height ranges from around 26 m to 40 m.

3. METHOD

3.1. Field measurements

Across the three study sites a combination of six different instruments were used to indirectly measure LAI. These were the LAI-2200, two HR cameras (Nikon D90 DSLR camera with a Sigma EX 180° 4.5mm circular fisheye lens and a Canon EOS 50D DSLR camera with a Sigma 8mm EX 180° fisheye lens), a LR camera (CI-110, CID Inc.), a phased-based TLS (Trimble CX) and a time-of-flight (ToF) TLS (Riegl Vz 400). Measurements were collected for RW and WC in April and May, 2012, and RC in September, 2012. The instrument type and sampling design employed varied across the sites due to field and resourcing constraints. For direct comparison of instruments, each instrument was measured at the same location at approximately the same time. It must be noted that the measurements were collected following best practice procedures as outlined in various protocols and operating guides. Plots consisted of between 10-17 measurements aggregated to produce one LAI value.

Both the HR and LR DHP images were analysed using CanEye v6.3.9 (INRA, France). The LAI results presented in this paper were derived using Miller's method [7]. Miller estimates LAI from gap fraction (GF - the proportion of sky to vegetation) in all directions. GF from TLS was determined by the proportion of returns to total emitted points. GF from the LAI-2200 was determined by the ratio of light measured under the canopy to light over the canopy. Since no distinction is made between foliage and non-foliage elements (e.g., tree stems and branches are not distinguished from green vegetation) in any of the instruments, the variable derived is plant area index (PAI). However, for consistency in nomenclature it will be referred to as LAI. LAI values for individual points were determined using GF over the range of view zenith angles sampled [7].

3.2 3D MCRT model

A non-spatially explicit deterministic 3D model of RW was constructed using representative tree models as objects and field derived measurements for parameterization. Simulations of DHP, LAI-2200, and TLS were made in the 3D model through the MCRT model. The model was parameterized to simulate the configuration of each of the instruments, giving as output simulated measurements, which in turn can be used to estimate canopy LAI.

4. RESULTS AND DISCUSSION

LAI results derived from the all instruments from fieldwork, with the exception of the phase-based TLS, were found to be in agreement with published LAI values for similar woody environments within Australia in all three study sites. Figure 1 presents results obtained from the comparison of indirect field measurements with different instruments.

Figure 1a compares the LAI results of the HR camera plotted against the LR camera. Figure 1b depicts the measured GF from each of the five instruments at one measurement location in RW over the 0-75° range of zenith angles.

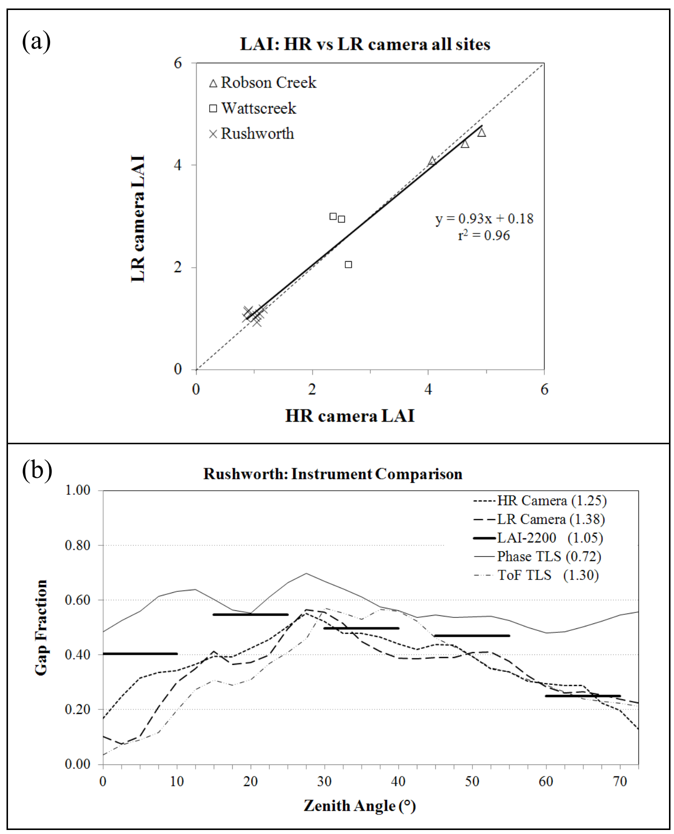

Figure 1. (a) LAI results comparing the HR and LR cameras for plots measured at each of the study sites: 8 plots for RW, 3 for WC, and 3 for RC. (b) GF over the range of view zenith angles (0-75°) for five instruments measured at one point in RW. The HR camera used was the

Nikon D90 DSLR. The LAI value for each instrument is in brackets next to the instrument type in the key.

In figure 1a, the R^2 values were poor for the plots measured with HR and LR DHP at each site when treated separately (results not shown). However, when the sites are included together which provided a wide range of LAI values for comparison, the R^2 value increased near to 1. This indicates a strong relationship for both instruments across and range of LAI from 0.9 to 5.0. There was a tendency for the LR camera to slightly overestimate LAI when compared with the HR camera. This finding can be partially explained by the LR camera being less suited to distinguish sky gaps at higher zenith angles, where the LAI formula used is weighted more heavily towards the higher zenith angles.

In figure 1b the GF of all instruments is quite variable over the first 30 degrees of zenith angles, which is consistent with [6]. The GF lines for the HR camera, the ToF TLS and the LR camera match closely over the entire range of zenith angles, which is reflected in the LAI value of each instrument as maximum difference is 0.13. The largest difference in GF and subsequently LAI was by the phase-based TLS. This was determined to be the only outlier (both statistically and as recognised by the Global Climate Observing System (GCOS) [3]). There are a number of potential reasons for this which are described in-depth in [8]. Lastly, by creating a representative 3D model, it is possible to determine which instrument is able to produce the most accurate GF and subsequently LAI value.

5. CONCLUSION

This investigation presented results from a comparison of indirect instruments to derive accurate ground-based measurements of LAI in three representative Australian woody ecosystems. The HR and LR hemispherical cameras, LAI-2200, and ToF TLS for measuring GF within RW were comparable over a wide FOV with the exception of the phase-based TLS. Significant differences, both statistically and as recognised by GCOS, were found for real field-derived LAI results between instruments at the individual point and plot levels across a number of study sites. Although significant differences were found for individual plot-based estimates of LAI between the HR and LR hemispherical cameras, results indicate that the instruments perform similarly over a variety of woody ecosystems covering a range of LAI values from 0.9 to 5.0.

6. REFERENCES

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