Towards a better understanding of *in-situ* canopy measurements used in the derivation and validation of remote sensing leaf area index products.

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Abstract- Remote sensing products, such as the leaf area index, are available from different remote sensing platforms and sensors with different resolutions. There is a clear need for the remote sensing community to acquire a better understanding of the measurement techniques frequently used to acquired these field measurements. Examples of field measurement protocols for the LICOR's LAI-2000, 3rd Wave Engineering's Tracing Radiation and Architecture of Canopy (TRAC), hemispherical photography systems, and portable LIDARs such as the Optech ILRIS 3D are examined. The advantages and disadvantages of these four types of instruments are discussed based on price, durability, usable conditions, and information retrieval. The comparison shows that the hemispherical photography is the best value for the price since it can be used to get almost all parameters that the LAI-2000 and TRAC can measure together while the LIDAR system can acquire the most information of all four systems, but at a very high price that makes it too expensive for widespread used today.

Keywords: LAI, field measurements, validation, forest.

1. INTRODUCTION

Field measurements of Leaf Area Index (LAI) are by scientists for several purposes, including characterization of canopies for water and carbon cycles for stand information, or derivation and validation data for remote sensing products. Measurements protocols have been written in order for users with limited knowledge of the instruments to perform the measurements adequately. However, a better understanding of the instruments may be required when using the instruments in canopy conditions for which they were not designed. The concept of optical LAI retrieval is based on Beer's law:

$$P(\theta) = \exp[-G(\theta)\Omega(\theta)L_t / \cos\theta] \tag{1}$$

where θ is the angle from the zenith, $P(\theta)$ is the canopy gap fraction, $G(\theta)$ is the projection of unit foliage in the θ direction, which characterizes the foliage angular distribution; $\Omega(\theta)$, the clumping index (Nilson, 1971), is a parameter determined by the deviation of the canopy element's spatial distribution from the random case; L_t is the plant area index (PAI), which includes the LAI (L) and the woody area index (L_W) such as the LAI is found with:

$$L = \gamma_E(L_t - L_W) = L_t\gamma_E(1-\alpha), \tag{2}$$

where γ_E quantifies the clumping of needles in shoots, referred as the needle-to-shoot area ratio, and can be measured from sampling of shoots in stands. For broadleaf species, γ_E=1. α is the woody to total area ratio. Eq. 1 can be inverted for *Lt* using Miller's theorem, but it has been shown that retrieval at view zenith angle of 57.3º is possible (see Figure 1) (Leblanc and Chen 2001; Jonckheere et al., 2004).

This paper introduces some key measurements concept that can be applied to four optical instruments used in the retrieval of LAI *in-situ*. The first three have been routinely used by Natural Resources Canada in the last 15 years, namely the LICOR LAI-2000 (Fig. 2a) (Licor, 1991), hemispherical photography systems (Fig. 2b), and the 3rd WAVE ENGINEERING's Tracing Radiation and Architecture of Canopy (TRAC) (Fig. 2c) (see Leblanc et al., 2002). The fourth one described in this study has had limited usage: the OPTECH ILRIS 3D portable LIDAR (Fig. 2d). Advantages and disadvantages of these instruments are examined for different canopy types and structural parameters.

2.0 ACQUISITION CONSIDERATIONS

Non-destructive sampling of LAI is largely based on canopy gap measurements. The instruments assessed here are all optical devices; three are passive sensors that require light to penetrate the canopy while the LIDAR is an active system utilizing a laser as a source of energy being reflected back to the sensor.

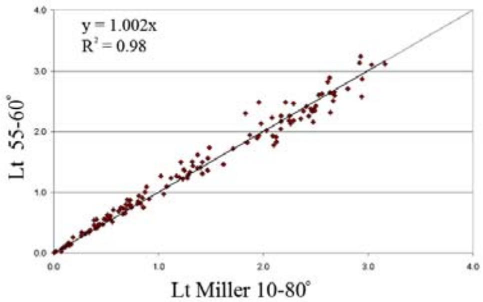

Figure 1: Inversion of Eq. 1 using Miller's in X and near 57.3º (55-60º) in Y from 138 plots from field campaigns in Canada and Russia using digital hemispherical cameras with fish-eye lens. The clumping index used in this figure is that of Chen and Cihlar, 1995.

(a) (b)

(c) (d)

Figure 2: Field instruments assessed in this paper, a) the LAI-2000, b) hemispherical photography systems, c) TRAC, and d) ILRIS 3D.

The LAI-2000 and the hemispherical photography systems are based on similar principals: measurements of gap using a fish-eye device lens covering all, or a large part, of the up-looking hemisphere. Although they have been used under sunlit conditions (e.g. Leblanc and Chen, 2001; Leblanc et al., 2005), it is strongly recommended that they be used under diffused light, as there is usually an assumption of azimuthal isotropy of the light in the analysis. This strong recommendation is costly, as the measurements need to be taken preferably near dawn or dusk. For measurements taken at high latitude during the local summer, this can mean field time late at night or early morning. Measurements can be taken under cloudy conditions, but the clouds should be uniform. This is even more important for the LAI-2000 as the sensor reading is averaged over all azimuth angles, except those blocked by a view cap. The TRAC on the other hand needs strong sunlight to cast discernable shadows and a transect perpendicular to the sun (Chen and Cihlar, 1995). LIDAR systems can be use under any light conditions as long as there is no precipitation. The LIDAR can be used to take similar viewing geometry as a fish-eye device instruments. The ILRIS 3D and the more recent ILRIS 3_6D, have a very narrow laser beam divergence of 0.00974º with an initial beam size of 12 mm and a minimum step size (X and Y axis) of 0.00115º.

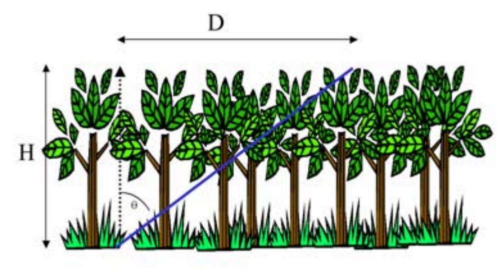

Figure 3. Schematic representation of the acquisition distance at a given zenith angle θ. The distance D, where a gap can be measured at the top of the canopy, is equal to tan(θ)*H.

This means that at the full resolution without overall between points (i.e. step of 0.00974º), a scan line of 40º has about 4100 points. At this beam resolution, the bean size at 10m from the sensor is about 1.9 mm.

The plot size and number of measurements (points or transects) has some general rules, but an understanding of the geometry of the measurements can be used to estimate if the plot design correspond to the desired area to be sampled. At a given view zenith angle θ, the extend from the instrument at which a gap at the top of the canopy can be estimated is found as the height*tan(θ) (see Figure 3). For example, at 57.3º from the zenith, this distance is 1.6 times the height of the canopy. This implies that for a 10m high canopy, a plot may need to be at least 15 m large for measurements taken on a "single side" or 32 m in diameter for full a fish-eye view. This footprint estimate is only for a single point. Figure 4 show the footprint extend corresponding to a 360º fisheye device instruments. The color used represents the five LAI-2000 concentric rings. A simulation of a hemispherical photograph taken from that simulated point is shown in Figure 4. It is not recommended to use a single point, or short transect for TRAC. Many theories used in the retrieval of LAI, especially the clumping factors, requires good sampling for accurate statistical retrieval.

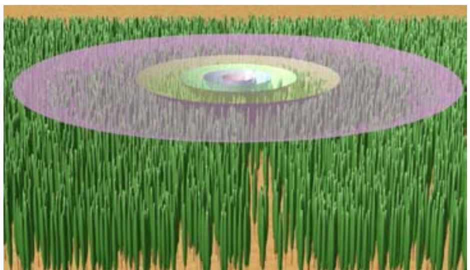

Figure 4. Illustration of the footprint equivalent of a fish-eye device, the different transparent cones correspond to the to the LAI-2000 five rings that are about 30º in zenith angle range.

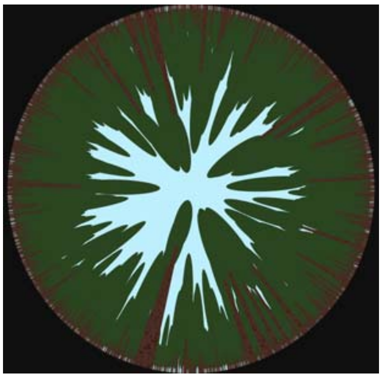

Figure 5. Simulation of a hemispherical photograph taken at the footprint center shown in Fig. 3.

Leblanc et al. (2005) recommended four to six hemispherical photographs as minimum numbers to get reasonable profiles. Similarly, Chen (1996) recommended TRAC transect of at least 60-100 m, depending on foliage and crown grouping.

3.0 STRUCTURAL PARAMETERS

All four instruments can measure gap fraction at different zenith angle. TRAC is limited by the local solar zenith angle available and requires half a day to produce such measurements. The hemispherical photography systems and LAI-2000 measure the gap fraction over a wide range of zenith angle in a single shot while LIDARS can do such measurements in one acquisition, albeit far from being instantaneous. However, with the gap fraction, only the so-called effective LAI or PAI can be retrieved. To get an estimate of LAI, gap size information is needed. In that case, only the LAI-2000 is limited to gap fraction, the other three sensors are able to get gap size distribution (Fig. 7a,7b, and 7c), limited by the instruments ability to discriminate small gaps. The gap and the non-gap size information have been used in retrieving the clumping index (Walter et al., 2003; Leblanc et al., 2005; Fraser et al., 2005) that is used in transforming the so-called effective LAI into LAI. When angular gap fraction is measured, estimation of leaf orientation can be obtained. This information is m ore precise when the gap fraction and clumping index are used.

Figure 6. Paths from different zenith angle through a canopy should go through the same amount of vegetation. When using a small number of segments, the chances of having different foliage density at different VZA are very large.

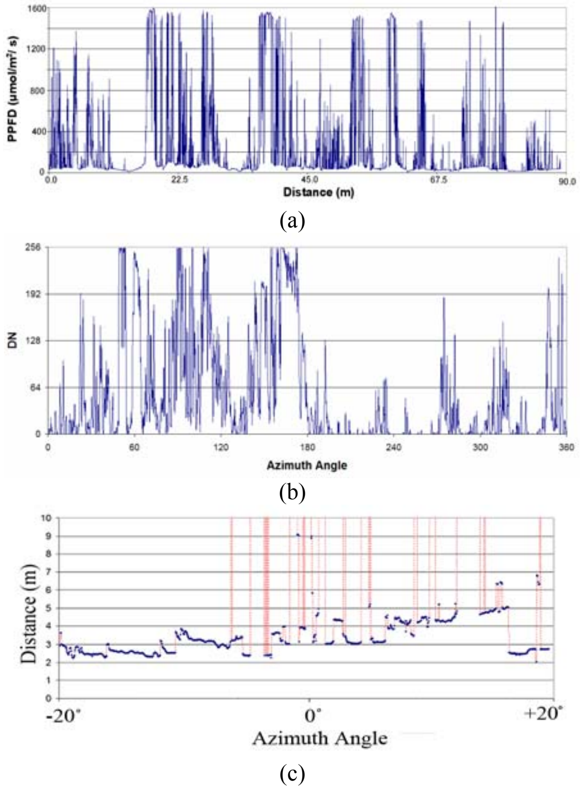

Figure 7. Data profiles taken in a deciduous forest near Ottawa, Canada from a) a 90m TRAC transect (solar zenith angle 23º), b) a 360º digital hemispherical photograph (view zenith angle 57º), and c) a 40º scan line from the ILRIS 3D (view zenith angle near 60º).

Crown closure can be estimated from LAI-2000, hemi-photos and LIDARS, but is difficult to obtain from TRAC measurements, except near the equator where the sun can be found near the zenith at noontime. However, there is one major advantage of the TRAC: it measures directly the amount of solar energy that penetrates through the canopy. Other instruments have to infer that from the gaps and estimation of the incoming solar radiation at the top of the canopy. TRAC generally has a good radiometric resolution with PPDF larger than 1500 $\mu mol/m^2/s$ in Canada (see Fig. 7a) compared to 8-bit, 256 shades of grey for most digital cameras (Fig. 7b). Film cameras can have a larger radiometric range, but the photographs are often digitized in a format that gives the same radiometric of 256 shades of grey.

The LIDAR can give additional information not found in passive sensors: the distance. Each signal returned from canopy elements to the LIDAR has information not only of the presence of that element, but its distance from the sensor (Fig. 7c and 8a). The distribution of the closest element in the canopy from the first signal back, and sometimes the latest signal back, contains additional information that will needs to be investigated for improving LAI retrieval.

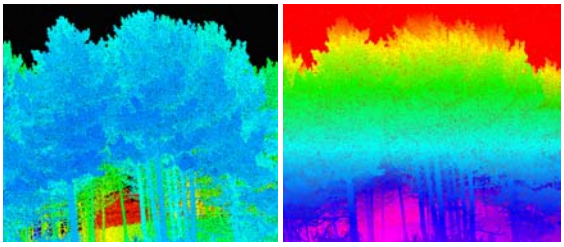

Figure 8: Color coded ILRIS 3D scans of a red pine stand: a) distance from sensor and b) height.

The used of the LIDAR has shown clearly that tree height can be easily found (Fig. 8b) and DBH can easily be estimate when the Understory is not too thick.

4.0 MONETARY CONSIDERATIONS

Although the instruments price is an important issue, the actual information provided by the instruments is also important. The TRAC and LAI-2000 are in a similar price range, $3,000.00 US for TRAC and $5,900.00 US for the LAI-2000. However, the LAI-2000 often requires a second unit used as a reference while only one TRAC is needed. It is now very affordable to buy a good digital camera with a fish-eye lens. Good systems can be bought staring at less than $1,000.00 US and the quality is still improving for the same or lesser amount of money. LIDAR systems are very expensive at the moment; generally well above $100,000.00 US and only slowly decreasing in price. The ILRIS 3D is $ 99,800.00 US without software while the new 3_6D is $ 136,800.00 US. The 3_6D has the advantage of having a motorized platform that can reproduce hemispherical view automatically.

5.0 OTHER CONSIDERATIONS

All four systems presented in this paper are adequate for forested areas, even though TRAC can be very difficult to walk at a steady pace through dense understory. The LAI-2000 is probably the best of the four instruments in respect to its usage in different canopy types. Its size makes it easy to be at near-soil level. TRAC is almost as small, but it not easy to walk the instruments so close to the ground. Fish-eye systems are taller, but they have been used looking downward. However, no validation of that technique with destructive sampling exists. LIDAR systems have not been tested for shrub, agriculture or any low vegetation, but in principle they could be used at the soil should be easy to distinguished from the foliage, so canopy gaps should be measurable.

The instruments have different look direction and associated footprint, making comparison difficult, but feasible. Leblanc et al (2005) showed that when long transect and many photographs are taken, gap fraction and clumping index values can be compared successfully.

6.0 CONCLUSIONS

Considering the time and money spent on field validation of remote sensing products, optimal uses of available instruments should an integral part of the planning process. Only a few considerations were presented here, and they were not explored in details, but they are the basis of a better understanding of the instruments. At the moment, digital hemispherical systems are the best choice for new purchases of optical field instruments based largely on price and measurable parameters, while in the future, LIDARs have a great potential once the price decrease to a critical mass value that would make these tools accessible to a larger audience.

7.0 REFERENCES

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