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Methodology comparison for canopy structure parameters extraction from digital hemispherical photography in boreal forests

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Abstract

The retrieval of canopy architectural parameters using off-the-shelf digital cameras with fish-eye lens is investigated. The technique used takes advantage of the sensor's linear response to light of these cameras to improve the estimation of gap fraction using:

(1) the digital numbers of mixed sky-canopy pixels to estimate the within-pixel gap fraction; and
(2) this process is done considering the variation in view zenith angle to take into account the sky radiance distribution and the canopy multiple scattering effects.

The foliage element clumping index is retrieved over a wide range of view zenith angles using:

(1) the accumulated gap size distribution theory developed for the TRAC by Chen and Cihlar (1995a);
(2) the Lang and Xiang (1986) finite-length averaging method; and
(3) a method combining the gap size distribution and the Lang and Xiang finite-length methods.

Using data from Canadian and Russian boreal forests, comparisons of gap fraction, clumping index and plant area index measured with the tracing radiation and architecture of canopies (TRAC) and digital hemispherical photography are presented. Evaluation of the LAI estimated from digital hemispherical photography with allometric LAI of two boreal forest stands suggest that that the clumping index combined method may be more accurate.

Keywords: Leaf area index; Canopy architecture; TRAC; Hemispherical photography

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1. Introduction

The boreal forest covers about one third of the global forested area and can be found in Russia, Canada, Scandinavia and Alaska. This biome type is greatly affected by global warming, as it is limited in its growth, among other reasons, by its short growing season and low solar radiation. To study changes in this biome, remote sensing tools are useful because they provide appropriate spatial extent and access to remote locations. Foliage density, often quantified by the leaf area index (LAI), defined as half the total surface area per unit of horizontal ground area (Chen and Black, 1992a), is a measure that has shown potential for mapping areas using optical space-borne sensors (Running et al., 1989; Myneni et al., 1997; Bicheron and Leroy, 1999; Privette et al., 2002; Chen et al., 2002; Fernandes et al., 2003). However, calibration of global LAI maps requires many more ground truth points than currently available worldwide (e.g. Scurlock et al., 2001; Asner et al., 2003). Fast and accurate extraction of canopy structural parameters is important, as fieldwork is expensive and weather dependant. Several methodologies have been used to measure LAI in vegetation canopies (see Jonckheere et al., 2004; Weiss et al., 2004). Optical sensors are often used to estimate LAI from radiation transmittance through the canopy. The simple, yet effective, Beer-Lambert's law has often been used to model canopy transmittance as:

$$P(\theta) = e^{-G(\theta)\Omega(\theta)L_t/\cos\theta} \quad (1)$$

where θ is the zenith angle, $P(\theta)$ the canopy gap fraction, $G(\theta)$ the projection of unit foliage in the θ direction, which characterizes the foliage angular distribution (e.g. Warren-Wilson and Reeve, 1959; Norman and Campbell, 1989; Welles and Norman, 1991); $\Omega(\theta)$, the (element) 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:

$$L = \gamma_E(L_t - L_W) = L_t\gamma_E(1-\alpha), \quad (2)$$

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 (Fassnacht et al., 1994; Stenberg et al., 1995; Chen et al., 1997). For broadleaf species, $\gamma_E = 1$. In deciduous species, the pre- or post-leaf emergence can be used to separate the woody to the total plant area (Chen, 1996a; Leblanc and Chen, 2001). α is the woody to total area ratio. Values of γ_E and α have been tabulated for several species and plots in the Canadian boreal forest (Chen et al., 1997; Gower et al., 1997).

The product of the clumping index with one of the area indices is referred as an effective measure (Chen, 1996a). The effective PAI, which is the product of the clumping index and the PAI, is the PAI inverted from gap fraction measurements with the assumption of randomly distributed canopy elements.

4. Conclusions

We showed that the plant area index and clumping index can be retrieved using only fish-eye photographs; cutting down the cost of instrumentation needed and the accuracy is expected to increase, as the digital camera technology improves. Considering the combined costs of the LAI-2000 and TRAC, a system with on off-the-shelf digital camera with a fish-eye lens is a low-cost alternative. New digital cameras with better spatial radiometric resolutions are constantly made available for the same price as current cameras. Gap fraction measurements made with TRAC and from digital hemispherical photography are well correlated, with a bias attributed to light scattering effects on the photographs and by TRAC inability to see very small gaps. Different sampling schemes of the canopy may have contributed to the poor agreement for the clumping index retrieved with TRAC and digital hemispherical photography. The LAI estimated from DHP using clumping index from the CC and LX methods with typical values for the needle-to-shoot ratio and the woody-to-total area ratio underestimated the allometric measurements from two boreal forest stands, but the combined method (CLX) gave results closer to the allometric method. This later method should be investigated in more details in order to solve its difficulty in dense area of canopies.

The Microsoft Windows-based programs DHP.exe and TRACWin.exe that were used for the analysis in this paper are available freely from the corresponding author.