ANALYZING LEAF CLUMPING EFFECT OF INDIVIDUAL TREES BASED ON MODELED REALISTIC STRUCTURE

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ABSTRACT

The clumping index (CI) describing the spatial pattern and distribution of leaves in vegetation canopy, is a key parameter for accurate retrieval of leaf area index (LAI). In this study, we focused on the individual tree-level CI (i.e., total CI) and decomposed it into the crown shape-related CI and crown internal structure-related CI. Using the simulation datasets from OnyxTree realistic structure software, we calculated all the above-mentioned CI for tree crowns with LAI values from three tree species. We also analyzed the angular effect of these CI. Results showed that the crown shape-related CI generally dominated the clumping effect of leaves although it varied with zenith angle. Nevertheless, the internal structure-related CI was hard to be neglected, especially for the case of *Platanus* with high LAI. Our results also demonstrated that the role of each kind of CI depended on the tree species.

Index Terms— clumping index, leaf area index, individual trees

1. INTRODUCTION

Clumping index (CI) quantifying the spatial distribution pattern of vegetation leaves, is critical to accurately retrieve the leaf area index (LAI) from remote sensing data and indirect ground-based measurements. If the distribution is random, CI is unity. If the distribution more clumped than random, CI is smaller than unity. [1].

Vegetation canopy generally composes of complex structures with five scales: shoots, branches, whorls, crowns and trees. These structures confine the spatial distribution of leaves [2]. Traditionally, people mostly concentrate on canopy scale (from dozens of meters to kilometers), with little consideration on individual tree-level [1]. Unmanned aerial vehicles (UAVs) provide the opportunities for obtaining ultra-high resolution image data from commercial cameras and unprecedented 3D point cloud data from light airborne laser scanning (ALS) [3]. A growing number of studies focus on the retrieval of the structure parameters on individual tree-level. CI is one of the most important parameters [4-6].

With regard to the CI retrieval of individual trees, some studies assumed leaves were randomly distributed, which conflicted with the fact that most natural canopies are clumped [4], others used traditional method proposed based on canopy scale [5] which existed scale effect [6-8]. At canopy scale, CI is majorly due to the big gaps between crowns. However, at individual tree scale, CI is caused by the grow mechanism of leaves and the heterogeneous path lengths that light transfers through the crowns [9-10]. How and what degree do these factors affect, there is a lack of corresponding researches.

By decomposing total CI into crown shape-related CI and crown internal structure-related CI, and based on the simulation datasets, this study proposes a method to analyzing leaf clumping effect of individual trees.

2. METHOD

We decomposed the individual tree-level CI (CI_t) into the crown shape-related CI (CI_s) and crown internal structure-related CI (CI_i). The illustration of these CI is shown in Fig. 1 and the calculation workflow of these CI is illustrated in Fig.2.

2.1. The calculation of CI_t

The method to calculate CI_t is as follows.

Using Markov chain, Nilson firstly brought a parameter into Beer-law to describe the way leaves distributed in canopy [11]. Later, the parameter was defined as CI [12].

$$P(\theta) = e^{-CI \cdot LAI \cdot G(\theta)/\cos\theta} \quad (1)$$

where $P(\theta)$ is gap fraction at observation zenith angle θ, $G(\theta)$ is a parameter to describe canopy structure and LAI is true LAI. The multiply of CI and LAI is effective LAI (LAI_e) [12].

According formula 1 and with the knowledge of θ, $P(\theta)$ and $G(\theta)$, it is not difficult to get LAI_e^{si} ,which is influenced by the total clumping effect of the individual tree. The ratio of LAI_e^{si} to LAI is CI_t.

$$CI_t = LAI_e^{si} / LAI \quad (2)$$

2.2. The calculation of CI_s

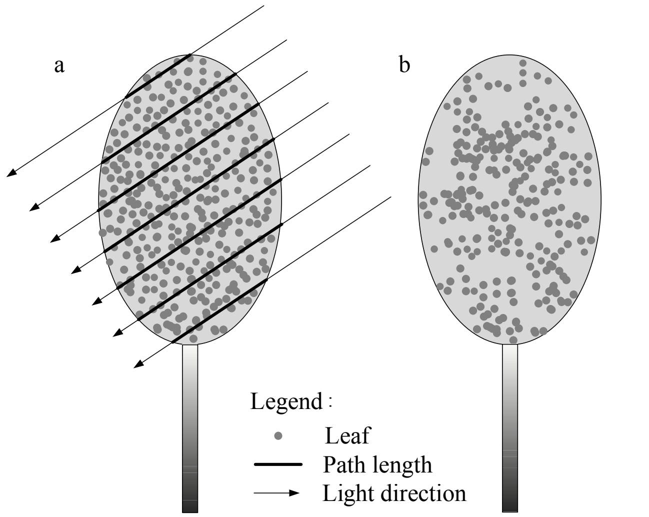

Fig.1 Illustration of the individual tree-level clumping effect. (a) clumping effect caused by crown shape, (b) clumping effect caused by leaves generation inside crown.

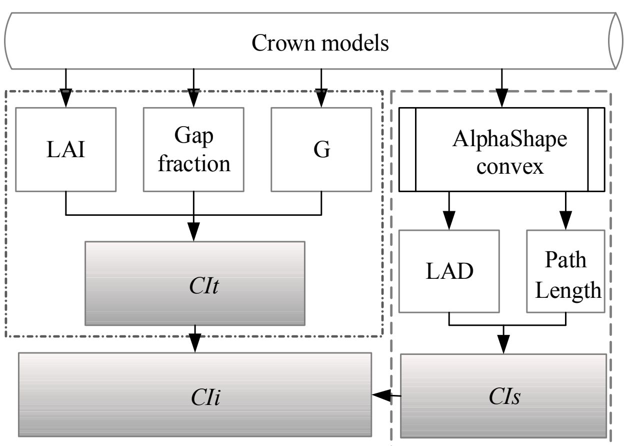

Fig.2 Technical roadmap of the CI calculation

As for the calculation of the shape CI (CI_s), the modified form of formula 1 is

$$P(\theta) = e^{-\rho \cdot l \cdot G(\theta)/\cos\theta} \tag{3}$$

where ρ is leaf area density, l is path length that light transfer through the crown. Caused by the shape of the crown, l is not a constant. As a result of it, $P(\theta)$ is the integral of l [7].

$$P_s(\theta) = \int_0^1 e^{-G(\theta)\cdot\rho\cdot l_{\max}\cdot l_r} \cdot p_{lr}\left(l_r\right) dl_r \tag{4}$$

where l_{max} is the maximum path length, $p_{lr}(l_r)$ is the relative path length distribution function and be normalized from zero to one.

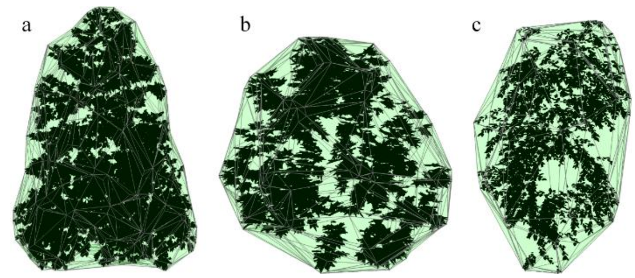

Fig.3 Crown models and their concave envelopes: a.white oak, b. Platanus, c. Betula Pendula.

Table 1 Related parameters of three modeled crowns.

	White oak	*Platanus*	*Butula Pendula*
Canopy height	6 m	1.5 m	1.6 m
Leaf type	Ovate lobed	Palmate lobed	Ovate
Leaf size	Medium	Large	Miniature
Leaf density	5 cm	5 cm	1cm
LAI	7.29	3.38	1.87

Note: Leaf density is the ratio of the length of the leafy branches to the length of the total branches.

Expect the knowledge mentioned above and the assumption that leaves randomly distribute in the crown of the same shape, l_{max},, ρ and $p_{lr}(l_r)$ are also needed to calculate LAI_e^s, which is only influenced by the shape of the crown. And the ratio of LAI_e^s to LAI is CI_s.

$$CI_s = LAI_e^s / LAI \tag{5}$$

2.3. The calculation of CI_i

Suppose the interior clumping effect and the shape clumping effect are independent of each other. The interior CI (CI_i) is the ratio of CI_t to CI_s.

$$CI_i = CI_t / CI_s \tag{6}$$

3. DATA RESOURCES

White oak, *Platanus* and *Betula Pendula* crowns with leaves only (Fig.3) and ten levels LAI were modeled by OnyxTree (http://www.onyxtree.com). The parameters of the three modeled crowns in Fig.3 are shown in Table 1. Different levels LAI are produced by subtract the number of leaves randomly. The concave envelopes of the crowns were calculated by AlphaShape algorithm [13].

$P(\theta)$, LAI, $G(\theta)$, ρ and $p_{lr}(l_r)$ were defined as the ratio of the projection gap area to the projection concave envelope

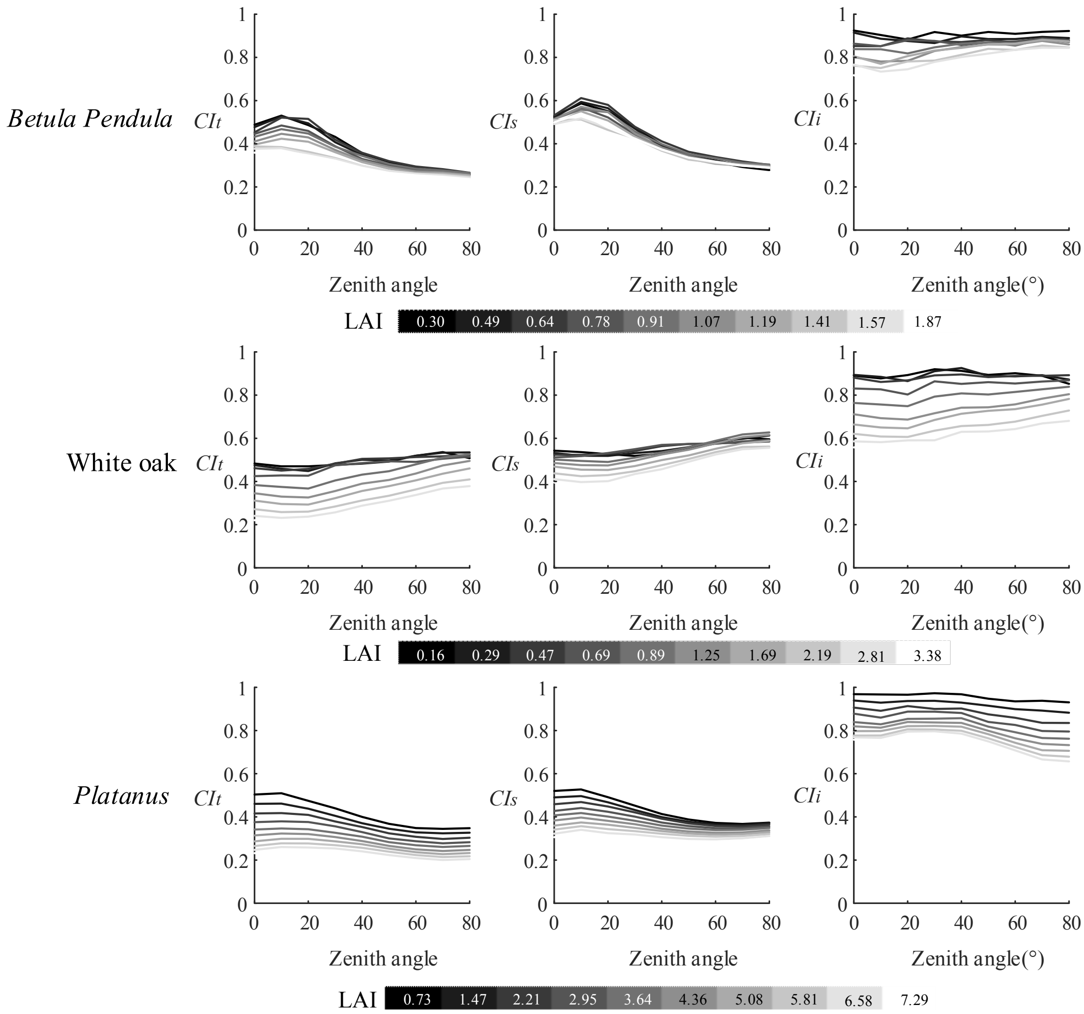

Fig.4 The CI of different crowns at different observational zenith angles and different LAI levels.

area in the direction θ, the ratio of the total one-side leaves area to the vertical projection area of the concave envelope, the mean projection of unit leaf area in the direction θ, the ratio of the total one-side leaves area to the volume of the concave envelope and the relative chord length distribution of the concave envelope in the direction θ respectively.

4. RESULT AND DISCUSSION

Fig.4 illustrates the CI changes with θ and LAI.

Generally, CI_t, CI_s and CI_i decrease slightly with the increase of θ, which is different with the canopy scale at which CI increases dramatically with the increment of θ, which can be explained that light might transfer through more than one crowns with large θ and the forest is more similar to a continuous canopy. Meanwhile, CI_t, CI_s and CI_i decline with the rise of LAI and vary with species due to the various crown shapes and grow mechanisms. As it is illustrated in Fig.3 white oak has multiple horizontal stratification structures and *Platanus* has more cluster structures which lead leaves to be confined in these structures. At canopy scale， CI also decreases with increasing LAI especially at low θ [14].

Obviously, CI_s dominants the change of CI_t, and meanwhile CI_i is larger than CI_s (Fig.4), which means at individual tree-level, clumping effect majorly depends on crown shape especially at low LAI. On account of the various crown shapes, the CI_s curve of *Betula Pendula* and *Platanus* are similar and different with white oak (Fig.4 column 2). There is a convenient approach to discriminate crown shapes through a factor $h/2R$ where h is crown height and R is horizontal radius. Although the crown height of *Betula Pendula* is lower than *Platanus*, the factors of them can be similar and both larger than unity (Fig.3). However, the factor of white oak is approximately unity. In spite of the strong influence the crown shape has, crown interior clumping effect cannot be neglected when LAI has large value, especially when *Platanus* with LAI of 3.38.

Contrasting the value of CI between individual tree-level and canopy level, CI_t is less than 0.5 and the general value at canopy scale [15-16], which means the clumping effect at individual tree-level is stronger than canopy scale. However, CI_i is approximately equal to the general value at canopy scale which reflects the self-similarity from individual tree-level to canopy level to some extent.

5. CONCLUSION

Decomposing the individual tree-level CI_t into CI_s and CI_i, this paper proposes a method to distinguish and calculate them.

At individual tree-level, the crown shape dominates the clumping effect. The interior clumping effect cannot be neglected in some specific circumstances, for instance, the interior CI of *Platanus* with large LAI can reach 0.6.

Based on modeled realistic structure, this paper does not have in-situ experiment data. And in practice, the branches also have influence on the calculation of CI. And accurate $G(\theta)$ is usually difficult to measure. Assumption that $G(\theta)$ equals 0.5 at 57° observation zenith angle or spherical distribution of the leaf inclination angle are often made [17]. Nevertheless, this paper has make a progress on the understanding of the mechanism of the clumping effect on individual tree-level. It can provide some guidance when people investigate individual tree-level CI.

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