GLOBAL LEAF AREA INDEX MAPPING AND ITS REMAINING CHALLENGES

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1. INTRODUCTION

Leaf area index, defined as one half the total (all sided) leaf area per unit ground surface area [1], is a key vegetation structural parameter used in most ecological, hydrological and meteorological models to describe physical and biological processes associated with vegetated surfaces and their interaction with the atmosphere. The accuracy of existing global LAI parameters is not yet satisfactory for many applications, and much effort is still needed to improve these products.

2. LAI ALGORITHM

As part of the GlobCarbon project funded by the European Space Agency, we developed a global LAI algorithm [2]. This algorithm developed based on the 4-Scale geometrical optical model makes use of not only the reflectances but also the angular information at the time of data acquisition for each pixel, including solar zenith angle, view zenith angle, and the difference between sun and satellite azimuth angles. In this way, the variations of the reflectances at the various bands with the angles of sun and satellite, i.e. the bidirectional reflectance distribution functions, are considered. The main characteristics of this algorithm include: (1) the effective LAI is first retrieved based on the reflectances, and a clumping index map is used to convert effective LAI to LAI; and (2) the shortwave infrared (MIR) reflectance is used for forests in order to improve the sensitivity of the algorithm to forest LAI (leaves absorb strongly MIR) but not used for crops where irrigation might affect MIR.

For reliable terrestrial applications of these LAI images, the residual cloud and atmospheric effects in the LAI images are detected and removed using a Locally Adjusted Cubic-spline Capping (LACC) method based on the seasonal trajectory at each pixel [3]. This LAI algorithm has been assessed using data from Canada and USA and also inter-compared with MODIS LAI products [4].

While the core part of our LAI algorithm has remained the same over the years, we have been working towards improvements of the input parameter fields that have a strong influence on LAI estimation. These parameters are clumping index and background reflectance.

3. GLOBAL CLUMPING INDEX MAPPING

The foliage clumping index quantifies the degree of the deviation of leaf spatial distribution in the canopy from the random case, defined as effective LAI divided by LAI. In our LAI algorithm, clumping index is used in the last step to convert effective LAI obtained from the canopy gap fraction retrieved at one observation angle to the true LAI value for each pixel. The clumping index of a vegetation canopy can be measured on the ground using an optical instrument named TRAC, and its measurements for various cover types show distinct ranges of values and correlate well with an angular index obtained from an airborne sensor POLDER. An improved angular index, named Normalized Difference between Hotspot and Darkspot (NDHD) was proposed for retrieving the clumping index using multiple angle remote sensing data [5]. The physical principle underlying the derivation of NDHD is that well structured canopies, consisting of foliage clumps at various levels such as shoots, branches and tree crowns, usually cause large variations in reflectance from the hotspot, where the sun and view angles coincide, to the darkspot, where shadows of these clumps are maximally observed. The more clumped is a canopy, the more shadow it has, and hence the darker is the darkspot. The relative variation from the hotspot to the darkspot minimizes the influence of the leaf optical property and accentuates the canopy structural effect.

Through geometric-optical modeling using 4-Scale, linear relationships between the clumping index and NDHD were derived, and these relationships were used to derive a global clumping index map using POLDER I data at 7 km resolution [6]. The POLDER sensor uses the image array technology that allows for data acquisition for a ground target at up to 13 angles during one overpass, and these multi-angle observations are accumulated monthly in order to obtain a sufficient coverage of the view angle range to retrieve and hotspot and darkspot for each pixel. As POLDER I only operated from 30 October 1995 to 30 June 1996, the published clumping index map [6] had many pixels with missing values because of clouds. Therefore, we have processed POLDER 3 data covering the whole year 2005, and produced an updated clumping index map. This map shows distinct clumping distribution patterns at the global scale. Forested areas generally have low index values (high clumping) while agricultural and grassland have high index values. Analysis of this dataset reveals that 7 km resolution is too coarse to capture the true variability of vegetation structure on the ground and there are also obvious topographical effects in the images, i.e. low clumping index values for mountain ranges. Topographical shadows increase NDHD and therefore have considerable influence on vegetation clumping retrieval.

In our recent work, the first order effects of topographical variation have been removed based on the standard deviation of the digital elevation model at 1 km resolution within each 7 km pixel. We have conducted a preliminary evaluation of the map using existing ground-based measurements using TRAC reported in the literature. There are 39 data points collected in forests, woodlands and savannas in Canada, USA, China, Japan, Zambia, Botswana, Israel, Belgium, Estonia, and Czech Republic; the majority of them were taken in forest stands. When a simple comparison between a ground point and a 7 × 7 km pixel was made for all points, the mean bias error (MBE) was 0.104. However, when we select data points that match with the dominant cover type in the clumping map, the MBE becomes 0.027 for woodlands and savannas (7 sites) and 0.046 for forest stands (17 sites). These small errors give us some confidence in the clumping map. However, the mean values for C4 and other vegetation (including crops and grass) seem to be smaller than their expected typical values [6]. This may be due to shadowing effects on NDHD caused by surface heterogeneity rather than stand structure, indicating a limitation of this coarse resolution dataset. The resolution of this clumping index map is not yet high enough for our LAI mapping at 1 km resolution, and we are experimenting with ways to retrieve clumping from MODIS data.

4. VEGETATION BACKGROUND MAPPING

In our LAI algorithm, the vegetation background is defined as the combination of understorey, moss, litter, soil, etc. in forest stands and simply soil and litter in crops and grassland. The optical properties of the background in our previous algorithm were based on soil types and limited ground based observations. To obtain this information globally using remote sensing data, a field experiment with multi-angle, high resolution airborne observations over modified and natural backgrounds was conducted in 2007 near Sudbury, Ontario, Canada, to test a methodology for the background information retrieval [7]. The experiment showed that it is feasible to retrieve the background information, especially over the crucial low to intermediate canopy density range where the effect of the understory vegetation is the largest. The tested methodology was then applied to background reflectivity mapping over conterminous United States, Canada, Mexico, and Caribbean land masses using space-borne Multi-angle Imaging SpectroRadiometer (MISR) data [8]. Important seasonal development of the forest background vegetation was observed across a wide longitudinal and latitudinal span of the study area. This background information has now been used in our LAI mapping for North America, but much work is still needed to retrieve the background information for other continents.

5. REMAINING CHALLENGES

In our view, the most serious bottleneck for accurate LAI mapping is caused by the errors of the input data to LAI algorithms rather than the form of LAI algorithms produced by various canopy radiation models with various assumptions. With sound observational constraints, the differences among models and algorithms can be rectified one way or the other. We therefore need to make genuine efforts, however tedious they may be, to obtain the observational constraints using information from existing sensors. Two key pieces of information missing from most LAI algorithms are be foliage clumping and background optical properties, and both can be obtained from multi-angle remote sensing. For clumping, the angular variation along the principal solar plane is most useful, and for the background, the angular variation along the perpendicular plane is most useful.

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