SunScan and HemiView LAI Models Compared

Introduction

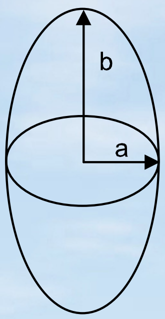
Measuring the leaf area index has always been problematic using non-destructive methods.

SunScan and HemiView use different models for calculating Leaf Area Index (LAI), because the information that the two systems measure is different.

This application note compares the two LAI models and gives guidance on which to use.
The integration of HemiView and BF5 radiation measurements is described, and we give advice on how to choose between HemiView or SunScan systems.

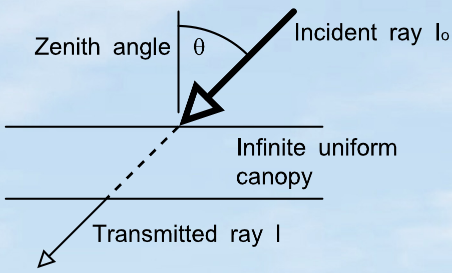
Background

Campbell (1986) derived a straightforward value for the extinction coefficient for an infinite uniform canopy of randomly oriented leaf elements, of given LAI and an ellipsoidal leaf angle distribution. This allowed the leaf angle distribution to be described by a single parameter, the Ellipsoidal Leaf Angle Distribution Parameter or ELADP. In this model, the leaf elements are distributed in the same proportions as the surface of an ellipsoid of revolution, where ELADP is the ratio of the horizontal to vertical axes of the ellipsoid. To imagine this, think of an ellipsoid with total surface area L, then break it up into leaf shaped elements scattered randomly through the canopy over unit surface area, without changing their orientation.



ELADP = a / b

$\tau = I / I_0$



For a canopy of LAI L and ELADP x, the extinction coefficient for a light ray passing through the canopy at zenith angle θ is given by the equation:

$$K(x,\theta) := \frac{\sqrt{x^2 + \tan(\theta)^2}}{x + 1.702\cdot(x + 1.12)^{-0.708}}$$

Where:
x is the ELADP

θ is the zenith angle of the direct beam

The probability of the light ray passing through the canopy, and hence the gap fraction in that direction, is then given by Beer's law:

$$\tau(x,\theta) := \exp(-K(x,\theta)\cdot L)$$

Where: τ is the gap fraction.

L is the Leaf Area Index.

$K(x,\theta)$ is the extinction coefficient.

If the gap fraction is known, for example from hemispherical photography or light interception measurements, then the equations can be inverted to give an estimate of LAI. If gap fraction is known at a number of different zenith angles, an estimate for ELADP can be made as well as for LAI.

Inversions of this type are used for the LAI calculations in HemiView, and in the SunScan canopy analysis system. A further point to note is that this model is completely independent of scale, so that the actual thickness of the canopy does not make any difference, only the total LAI of the whole canopy matters.

SunScan Model for Leaf Area Index

For SunScan, we measure the Direct and Diffuse above the canopy (ideally with a BF5), and the total amount of light below the canopy. We assume the sun is up there in the sky.
The extinction of the direct beam is fairly easy to calculate from Campbell's equation. For this we need to know the angle of the incoming light, and the leaf angle distribution, which is an input in SunScan.
The extinction of the diffuse light is different, because it is the integrated value of lots of direct beams from the whole sky hemisphere.
The third thing the SunScan model does is to estimate the effects of reflection off leaf surfaces. This is because we're not just looking at rays of light which do or don't get through, but measuring the actual light intensity below the canopy, so there will also be a contribution from all those rays of light which hit a leaf, and are then partially reflected from it. This is where the SunScan layered model with its calculations of the contribution from leaf reflectance is distinctive.

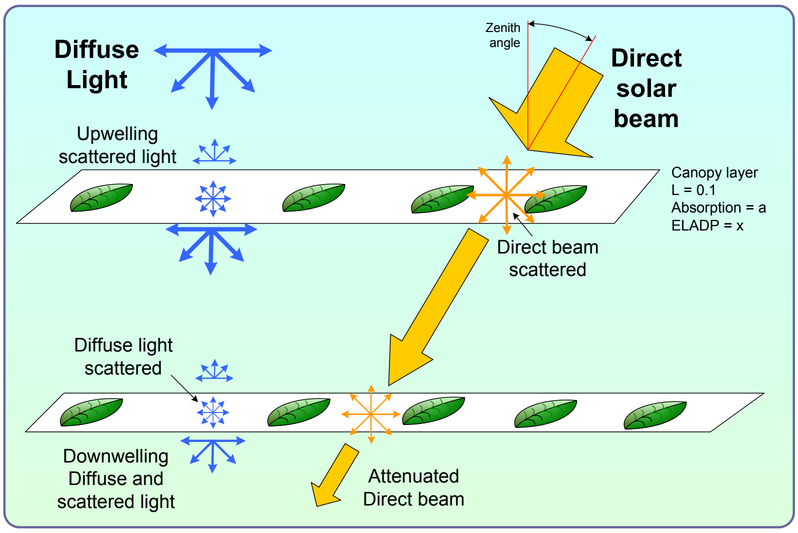


Figure 1 The canopy light scattering model used in SunScan

See also SunScan Canopy Analysis System User Manual available at www.delta-t.co.uk.

HemiView Model for Leaf Area Index

For HemiView, the measurement is in some ways simpler. Firstly, we assume there is no sun visible, and hemiphotos have to be taken in uniform sky conditions to make it work properly. Secondly, because of the way the image is thresholded, what we measure is the penetration or interception of a ray of light through the canopy, for all possible directions on the sky hemisphere. So we're unaffected by reflected light.
The diffuse sky distribution is irrelevant, as long as the image can be thresholded properly.
This makes the calculation simpler, because it doesn't involve light intensities or reflection, just penetration or absorption. And because we have a measure of this at all possible angles, it's possible to estimate the leaf angle distribution as well as the LAI (all based on the assumption of canopy uniformity of course, as is the SunScan model). So the leaf angle distribution (ELADP) is an output in HemiView.

HemiView Radiation calculations

The HemiView LAI calculation makes no assumptions about light intensities - these are only used for the part of HemiView which estimates radiation intensities above and below the canopy. The principle behind the radiation calculations is the assumption that the canopy structure recorded in the hemiphoto remains relatively constant. By applying whatever above-canopy light conditions we like, we can then calculate the corresponding below-canopy light conditions. So a single hemiphoto could be used to estimate below-canopy light levels over a whole year, or as long a period as the canopy stays the same. HemiView includes a simple light model for predicting Direct & Diffuse radiation, based on clear-sky conditions. But HemiView doesn't go

as far as including leaf reflectance in its radiation calculations - in this respect SunScan is a little more advanced.
See the HemiView User Manual and HemiView software SR2.1 online Help at www.delta-t.co.uk.

Use with real forest canopies

Real forest canopies, especially with mixed species, can deviate very significantly from the LAI model's assumption of a uniform canopy structure, because they are highly clumped and variable. This means the LAI models don't work well, either in measuring LAI from interception, or in predicting interception from actual LAI. You can think of the HemiView LAI as an ***effective LAI***, i.e. the LAI of a uniform canopy which gives the same light interception as your canopy, but this will not necessarily agree with physical LAI measurements.

Canopy growth is driven by radiation interception. It makes more sense if you are interested in radiation interception, to use the radiation interception parts of HemiView directly, which work on the actual canopy visible, with all its non-homogeneity, and calculate interception directly without needing any assumptions about structure.

In this situation, you can improve on the simple HemiView light models by using HemiView to **measure** the gap fraction and the BF5 Sunshine Sensor to **measure** the actual Diffuse and Global radiation above the canopy.

HemiView use with a BF5 Sunshine Sensor.

A hemispherical image is a snapshot of the actual canopy geometry. It can provide direct measurement of many canopy structure parameters. This can be combined with information about incident Direct and Diffuse light from elsewhere (e.g. a weather station, global radiation model, or actual measurement using BF5 Sunshine Sensor) to predict the light variations below the canopy at any instant or integrated over longer periods. One reason this is good is that it does not use or depend on an LAI model

How to integrate BF5 results with HemiView

Two approaches can be used. It depends on what you are trying to do.

A. To match the HemiView solar model to your local climate

This is relevant for long term integrated measurements.

See also p 31 of the HemiView User manual v2.1.
In HemiView the solar model requires values to be set for the transmissivity of the atmosphere and the proportion of the global radiation which is diffuse radiation.

1. Take a long run of BF5 data from a position above the canopy.
2. Integrate this to give monthly totals of the Direct and Diffuse radaiton.
3. Calculate the equivalent values using HemiView.
   Direct values are given in the **Total** row at the bottom of the **DirAb** worksheet.
   Calculate the Diffuse radiation integrals by multiplying the **DifAb** value in the **Values** worksheet by the appropriate **Month** value in the **DifMonth** worksheet.
4. Adjust the values of **Transmissivity** and **Diffuse Proportion**, by a process of trial and error, to give the best fit between you measured irradiance integral and the computed value form HemiView.
   You may find that a single solar model setting may not give a good fit for the whole year. In this case it may be appropriate to use several sets of solar modal settings that work well at different times of the year, and to use their outputs for those times.

Having done this "calibration" you are now in a position to make predictions using HemiView and its solar model(s) with a greater degree of confidence.

B. Use a BF5 to measure the actual radiation above the canopy and HemiView solely to calculate the Gap Fraction

For long term Integrals

1. Analyse BF5 data to give
   monthly integrals of Diffuse radiation and
   monthly, by hour of day, integrals of Direct radiation
2. Multiply these by the **Site Factor** calculations (for Diffuse)
   and by the **Gap Fraction** (for Direct).
3. Add together to obtain the radiation transmitted through the canopy

Diffuse radiation below canopy = Diffuse above (from BF5) x **ISF** (from HemiView)
Direct radiation below canopy = Direct above (table from BF5) x **Gap Fraction** (**SunGap** sheet from HemiView).

For Sunfleck analysis or short timescales

Use the **TimSer** worksheet to give **solar visibility on the solar path for the day of interest,** at the same intervals as your BF5 data.

Radiation below the canopy = Direct above (from BF5) x **SunVis** column in the **TimSer** worksheet.

Warning: see the note below on Equation of Time.

The details of these calculations are in the **HemiView Help** file under **Appendices, Calculations Theory.** The general principle is to follow the calculations, replacing the calculated radiation form the solar model with the actual measured radiation from the BF5.

Equation of Time

HemiView works with solar time. That is, the sun being due south defines midday (12:00).

Owing to the eccentricity of the earth's orbit around the sun, Solar Time can deviate from clock time by up to 20 minutes at some times of the year. Adjustments must be made for this if the time series measurements are resolved to time intervals of less than an hour.

HemiView months are also not aligned with calendar months – see "Month Divisions" in the Help file for details.

When to use HemiView and when to use SunScan

The **SunScan** system measures the actual light levels above and below the canopy at an instant in time. These can be combined with a theoretical model of the canopy structure, to predict canopy parameters. Repeated measurements can easily be taken to give integrals in time and space.

SunScan *measures* PAR radiation levels and uses these measurements to ***predict*** LAI.

HemiView *measures* canopy geometry to calculate LAI, and can ***predict*** PAR or Energy radiation levels above and below the canopy.

Which System?

- HemiView complements Sunscan by providing detailed assessment of geometric effects
- BF5 complements HemiView by providing rapid direct measures of solar radiation

Agricultural crops tend by nature to be uniform and low. These characteristics match the assumptions in the **SunScan** models, making **SunScan** the ideal choice in these types of canopies. It is more difficult to obtain incident light readings above very high canopies, and the canopy structure predictions made by **SunScan** become less accurate for highly variable canopies such as forests.

In contrast, **HemiView** deals very effectively with canopy variability, and it is easy to use in taller canopies, making this the ideal choice for work in forests, particularly if used with a BF5 Sunshine sensor. It is more difficult to obtain good images in low canopies, and rapidly changing structure makes light predictions less accurate in fast growing crops.

In summary, **SunScan** is recommended for low, regular, uniform canopies and **HemiView** (ideally with a BF5) in high, variable canopies. Both systems can however give useful information in a wide range of canopy types.

	HemiView System	**SunScan System**
Technique	System for obtaining photos and analysing hemispherical images of plant canopies	System for measuring incident and intercepted light which can be used to calculate canopy parameters
System contents	Hardware includes camera, self-levelling mount and accessories for taking and digitizing hemispherical photographs. The image files are analysed using HemiView Analysis Software.	The SunScan Probe, SunData Software, Beam Fraction Sensor and Data Terminal provide a system for measuring and recording PAR levels and LAI readings in the field.
Canopy types	Very suitable for high, irregular canopies such as forests	For LAI, best suited to low, regular canopies such as agricultural crops. Works well with any canopy for measurement of PAR interception
Light conditions	Requires uniform light conditions (dawn, dusk or overcast sky)	Works under all light conditions but best in bright daylight
Solar radiation	Indirectly calculates solar radiation, from canopy geometry	Directly measures solar radiation - incident and transmitted PAR, also direct and diffuse fractions of incident light above the canopy
Leaf Area Index (LAI)	Derived by analysis of scanned image	Real-time measurement and display in the field
Analysis	Incorporates advanced models to calculate radiation indices, canopy indices, suntrack overlay, direct and diffuse site factors.	Uses new model of the interception of light by a random canopy. Variables include direct and diffuse incident light, solar zenith angle, leaf angle distribution, leaf absorption and transmitted light

Delta-T Devices Ltd

130 Low Road, Burwell, Cambridge CB25 0EJ, England
Tel: +44 (0) 1638 742922

sales@delta-t.co.uk **www.delta-t.co.uk**

Delta-T Devices