Leaf Area Index (LAI)

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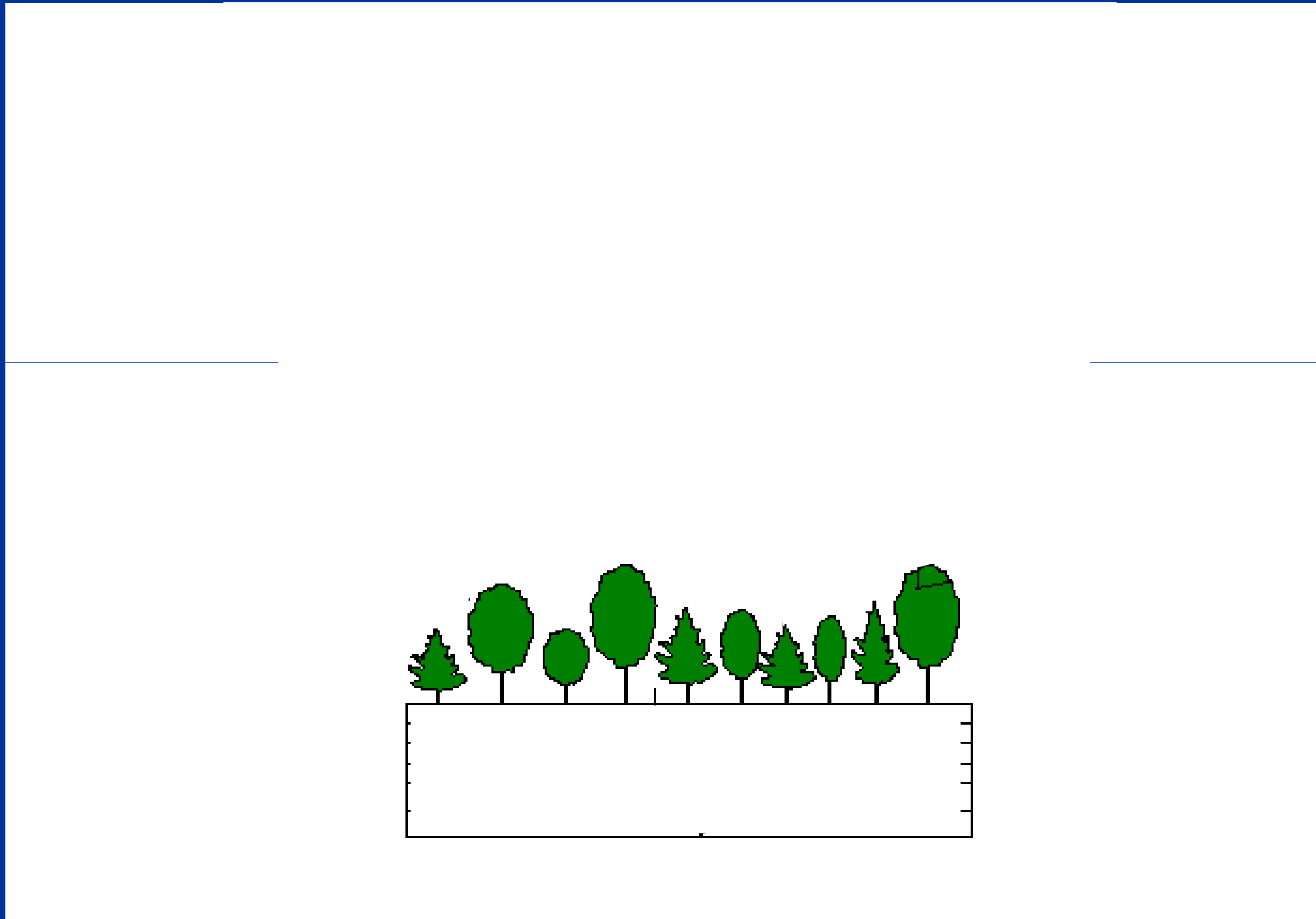
Importance of vegetative canopies

Influence of Canopy

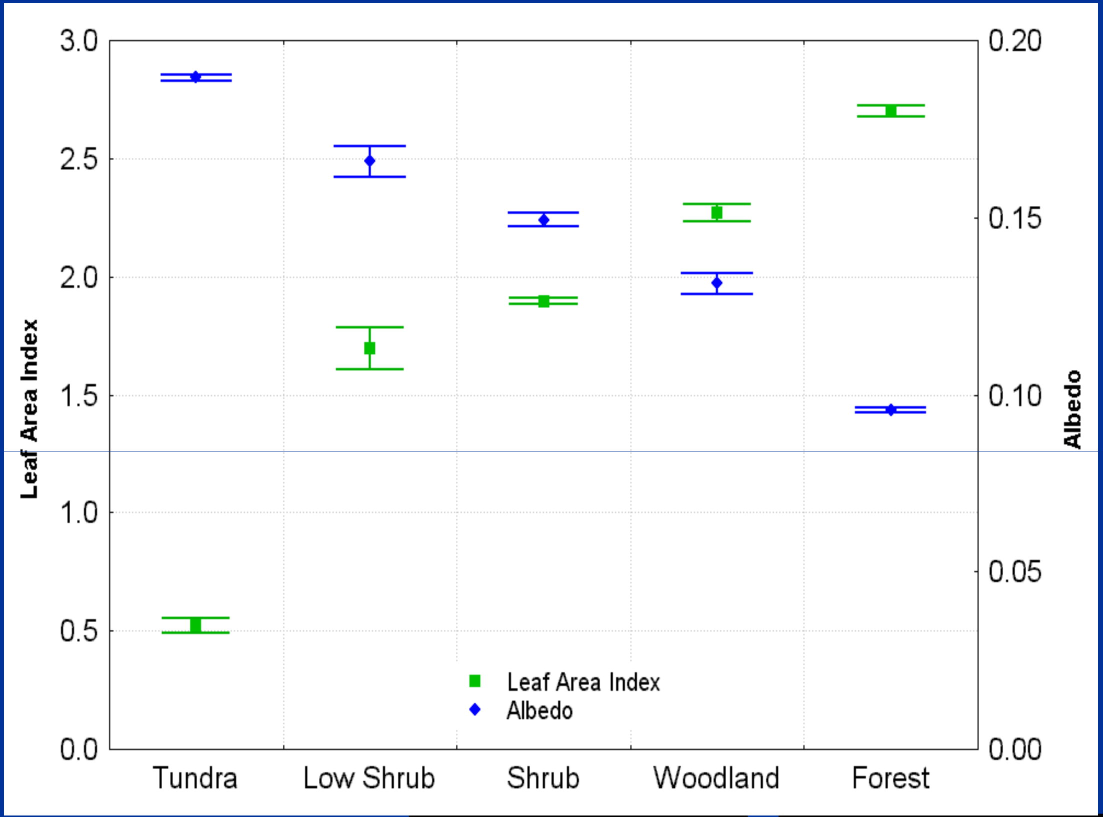
- •Surface roughness
- •Displacement height
- •Albedo
- •Shading – SHF
- •Transpiration (LE)
- •Surface temperatures
- •Water balance



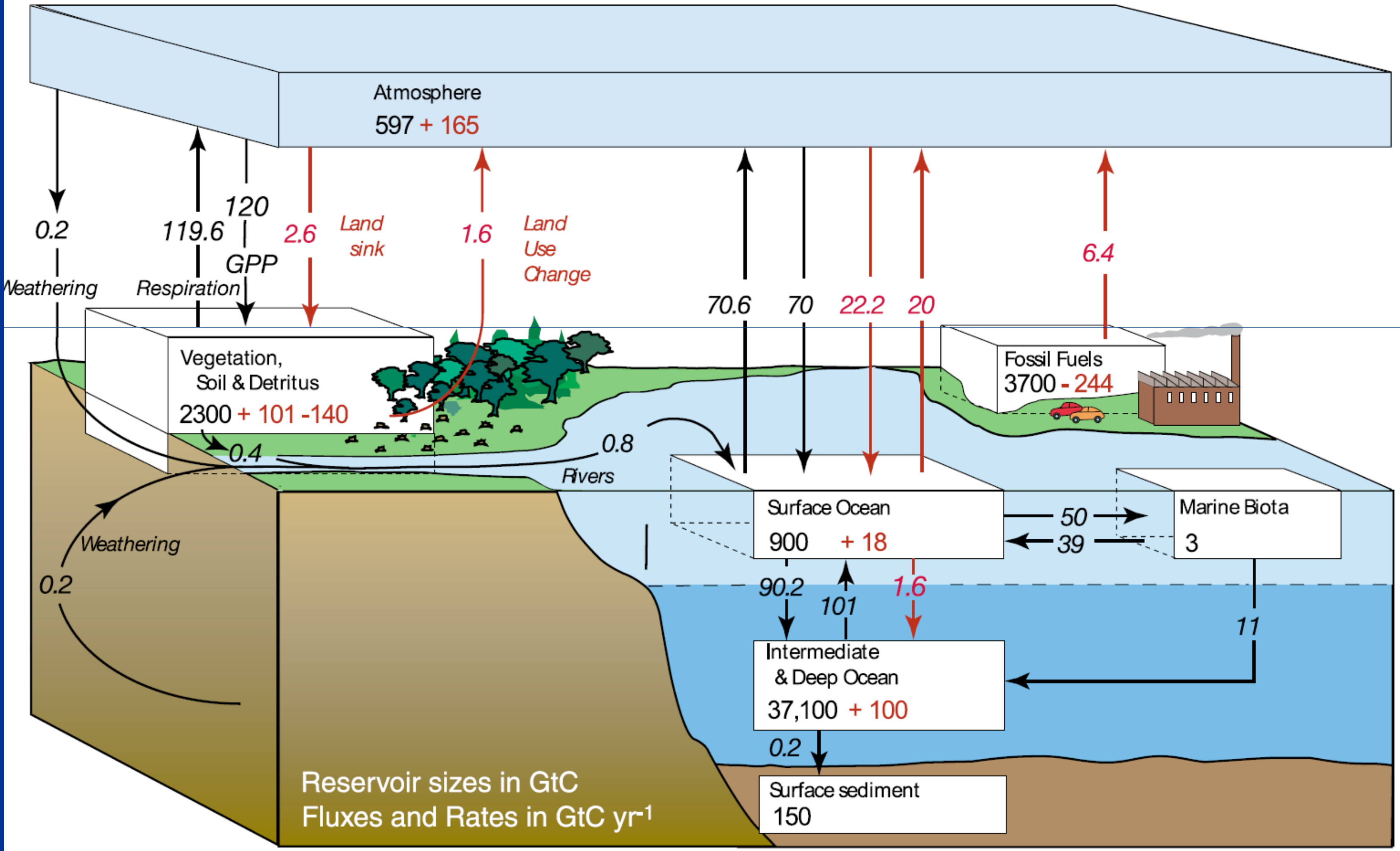
Bonan (2002)

Example Albedo of different vegetation types

•Effect of vegetation type on albedo. Albedo decreases with increasing leaf area. Canopy structure is also important



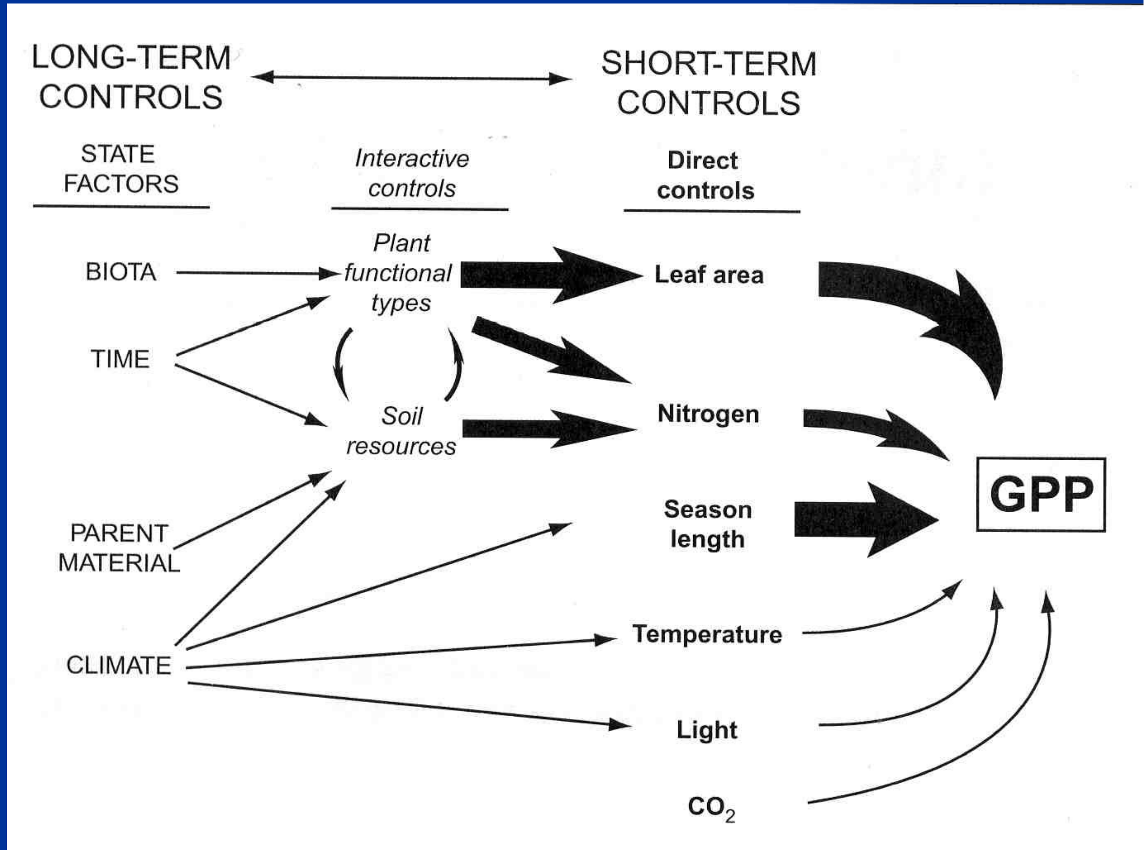
Influence on carbon cycle



IPCC (2007)

Carbon input to ecosystems

- Energy fixed by photosynthesis support plant growth
- Plant organic matter then supports animals and soil microbes
- Photosynthesis describes leaves whereas Gross Primary Production (GPP) describes whole canopy
- Maximum GPP driven by water and nutrients, expressed as LAI
- Constrained by season length
- Single leaf photosynthesis controlled by light, CO_2, temperature, and nitrogen.



Chapin, Matson, Mooney (2002)

LAI HIGHLY VARIABLE

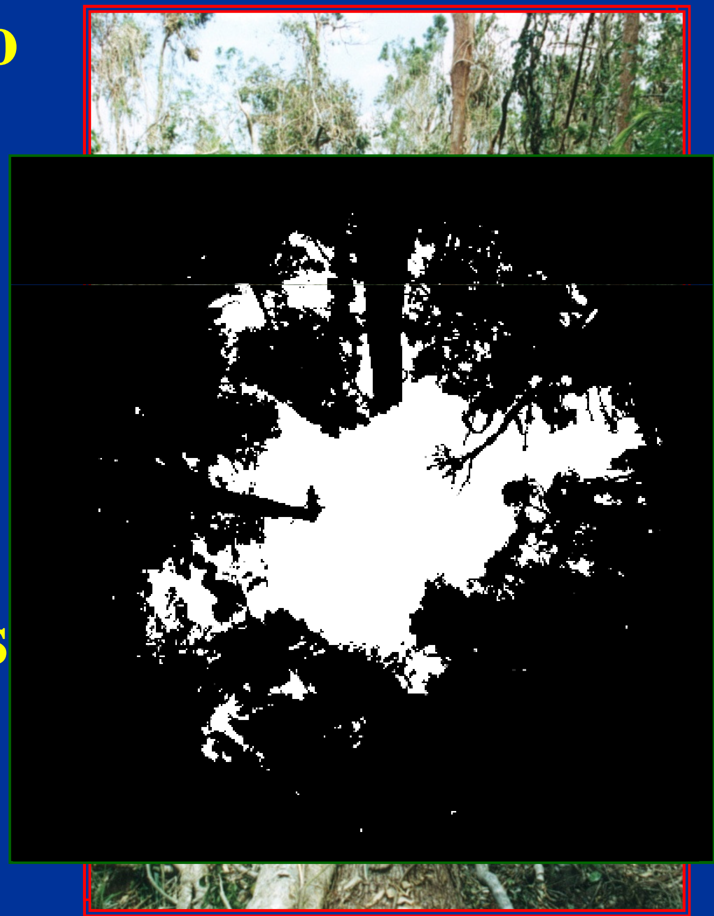
Highly variable crown cover and LAI over one hectare plot

(Three of the 25 canopy fish-eye images taken at litter trap sites in April 2008)

AFTER CYCLONE RONA

Significant damage occurred to the canopy structure.

- **in particular the vines towers were knocked to the ground.**
- **large amounts of debris trees were carried to the fores floor.**
- **Light penetration changed considerably.**



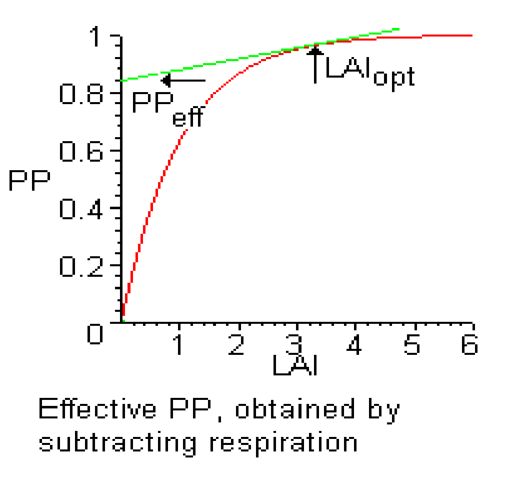
Simple models

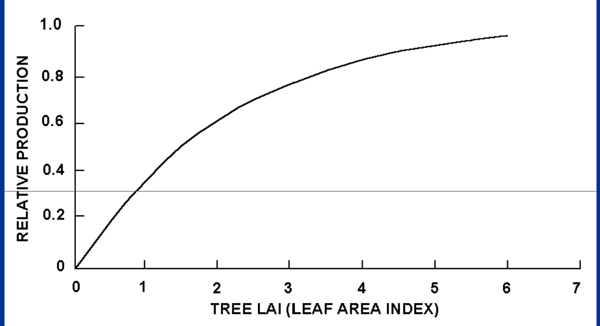
- Productivity function of leaf area

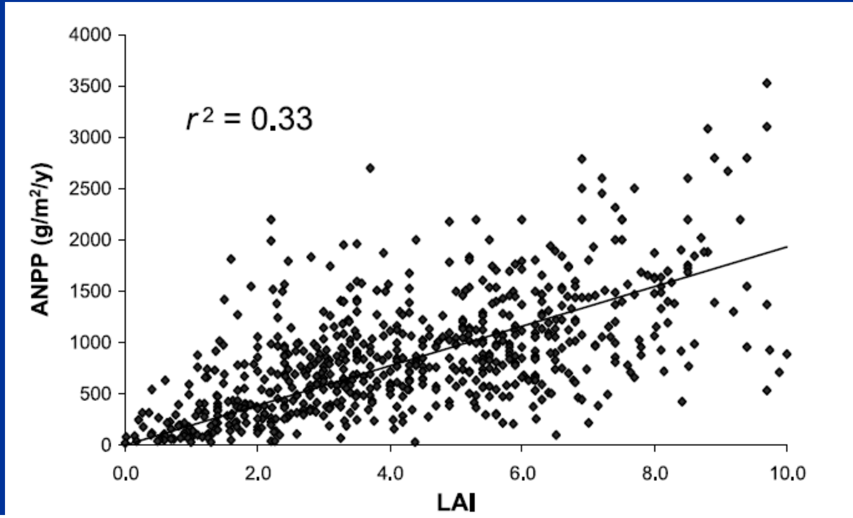
$$P = P_{\max}\left(1 - e^{-c \cdot LAI}\right)$$

where Pmax designates the maximum primary production and c designates a crop-specific growth coefficient

- Models such as Century use this
http://www.nrel.colostate.edu/projects/century/MANUAL/html_manual/fig3-18.gif





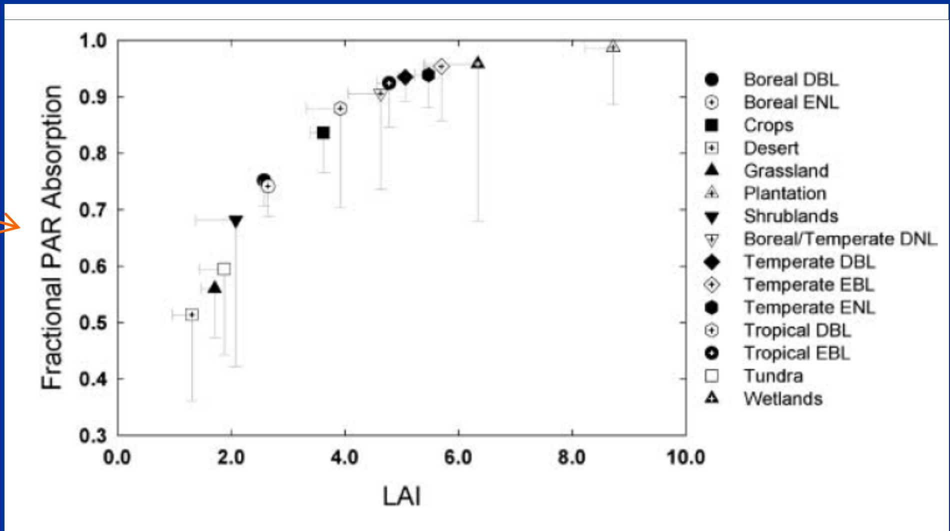


Asner GP, et al. (2003) Global synthesis of leaf area index observations: implications for ecological and remote sensing studies, *Global Ecology & Biogeography,* 12, 191–205.

MODIS GPP

$$GPP\left(kg\ C\ m^{-2}\ day^{-1}\right) = APAR(MJ) \times LUE\left(kg\ C\ MJ^{-1}\right) \times T_{MIN}\ scalar \times VPD\ scalar$$

=fPAR x PAR



Asner GP, et al. (2003) Global synthesis of leaf area index observations: implications for ecological and remote sensing studies, *Global Ecology & Biogeography,* 12, 191–205.

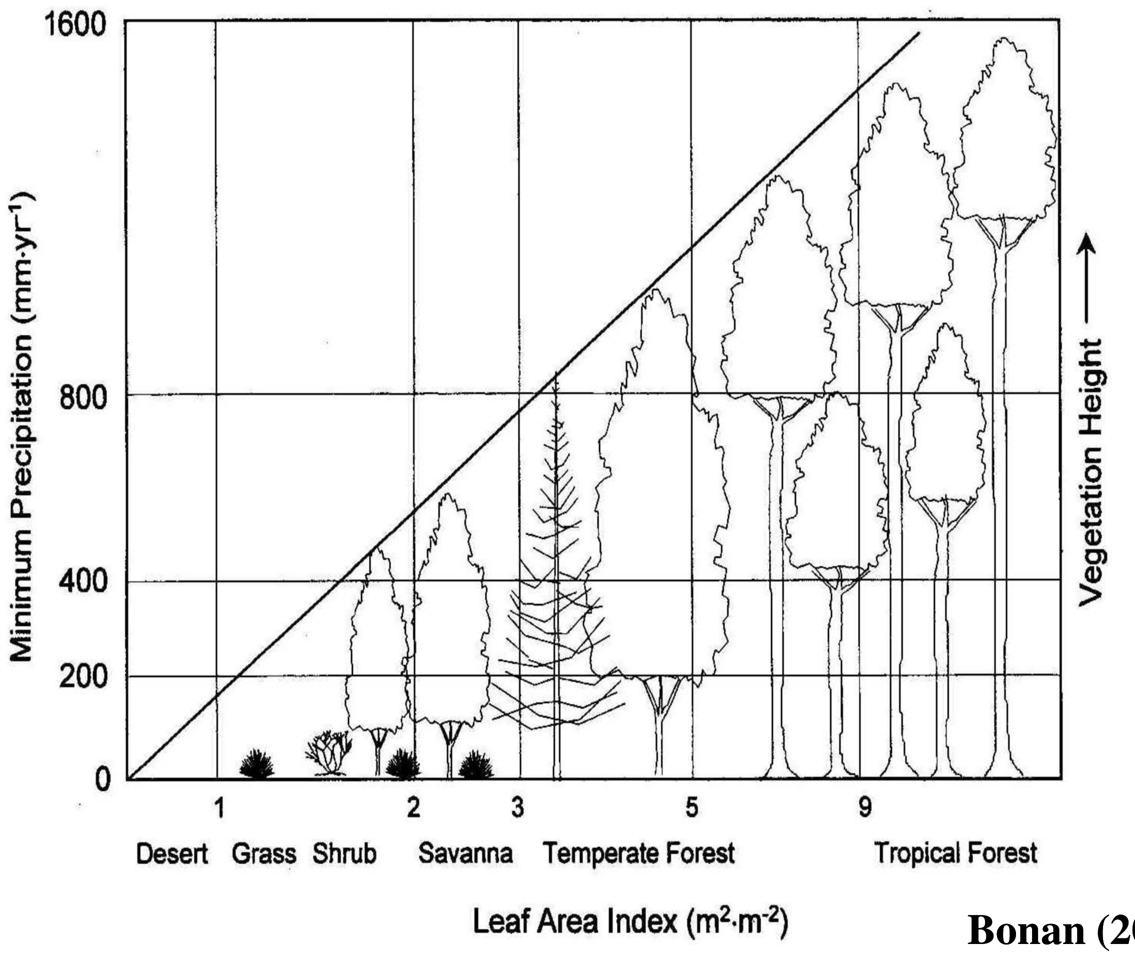
LAI theory and measurement

Reviews:

- M. Weiss, F. Baret, G. J. Smith, I. Jonckheere, P. Coppin, (2004) Review of methods for in situ leaf area index (LAI) determination: Part II. Estimation of LAI, errors and sampling, Agricultural and Forest Meteorology, Volume 121, Issues 1-2, 20 Pages 37-53,
- Inge Jonckheere, Stefan Fleck, Kris Nackaerts, Bart Muys, Pol Coppin, Marie Weiss, Frederic Baret, (2004) Review of methods for in situ leaf area index determination: Part I. Theories, sensors and hemispherical photography, Agricultural and Forest Meteorology, Volume 121, Issues 1-2, 2, Pages 19-35

Plant cover

- Plant cover is distributed over a continuum
- Influenced by rainfall, temperature, light, and nutrients
- Leaf area increases with increasingly favourable conditions



Bonan (2002)

Leaf Area Index Definition

LAI is defined as one half the total green leaf area per unit horizontal ground surface area

Many definitions: half the total area vs. projected area
half the total area (gas) vs. intercepting area (rad)
green vs. non-green
horizontal vs. sloping

LAI is not LAI – Not comparing apples with apples.

Chen and Black (1992a)

Direct Methods

(1) **Destructive sampling**: Measurements on leaves and area accumulation. Vertical distribution possible. Upscaling assumes homogeneity. Gravimetric analysis used.

(2) **Allometry**: relationship between leaf area and the dimensions of canopy components such as Dbh and sapwood area. It requires ***fewer*** destructive sampling and often involves large sampling errors.

(2) **Point contact**: the number of contacts of a thing needle penetrated through a canopy. Proven useful for short vegetation with large leaves, not practical for forests (Warren Wilson, 1960).

(3) **Litterfall** Collection: Frequent collection to avoid leaf decay. Useful for deciduous but not for conifer/evergreen species. Sampling issues.

- Time consuming
- Validation

examples

Ogrady, Chen, Eamus, Hutley (200) Composition, leaf area index and standing biomass of eucalypt open forests near Darwin in the Northern Territory, Australia, Aust. J. Bot. 48: 629-638

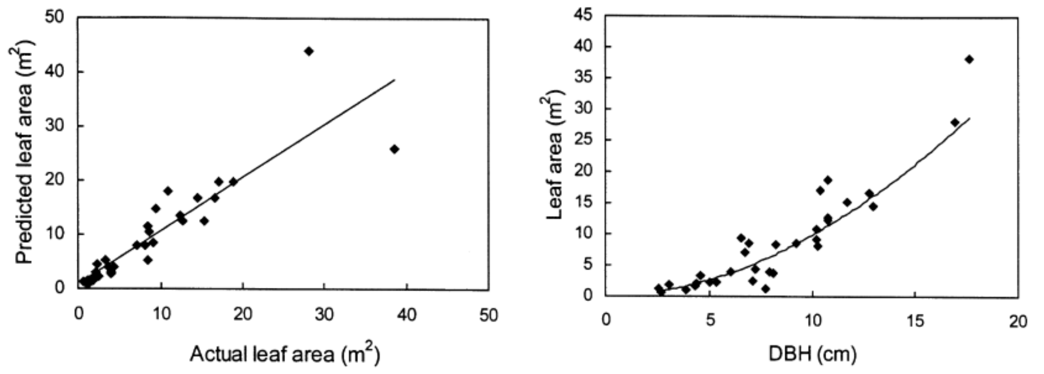


Fig. 1. Relationship for leaf area predicted by using the 'Adelaide technique' and leaf area predicted from fresh leaf weight. There was a strong linear relationship of the form $y = 0.98x + 0.92$, $r^2 = 0.80$ (species pooled).

Fig. 2. Allometric relationships developed from harvesting show the relationship between diameter at 1.3 m (DBH) and leaf area ($y = 0.12x^2 + 0.32x + 1.55$, $r^2 = 0.87$) for 30 harvested trees.

Andrew MH, Noble IR, Lange RT (1979) A non-destructive method for estimating the weight of forage on shrubs. ***Australian Rangelands Journal 1, 225–231.***

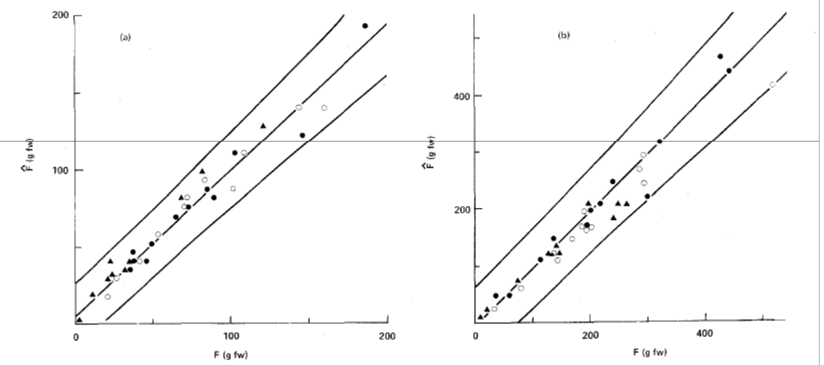


Fig. 2 Calculated ($\hat{F}$) vs. actual (F) forage weights for calibration (●), ungrazed (○) and grazed (▲) shrubs for (a) saltbush and (b) bluebush. The central line is the linear regression through the origin for the calibration data and the outer lines are the corresponding 95% prediction limits.

Asner et al. (2003) Global synthesis of leaf area index observations: implications for ecological and remote sensing studies

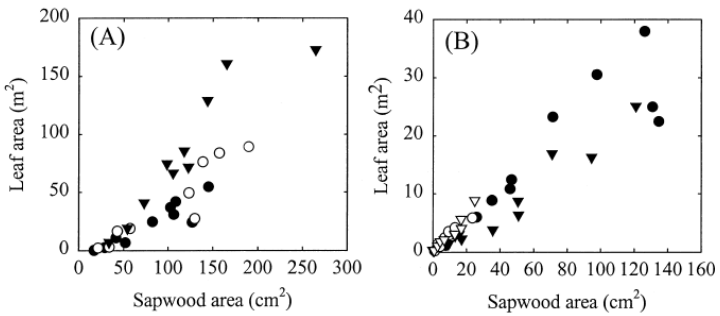
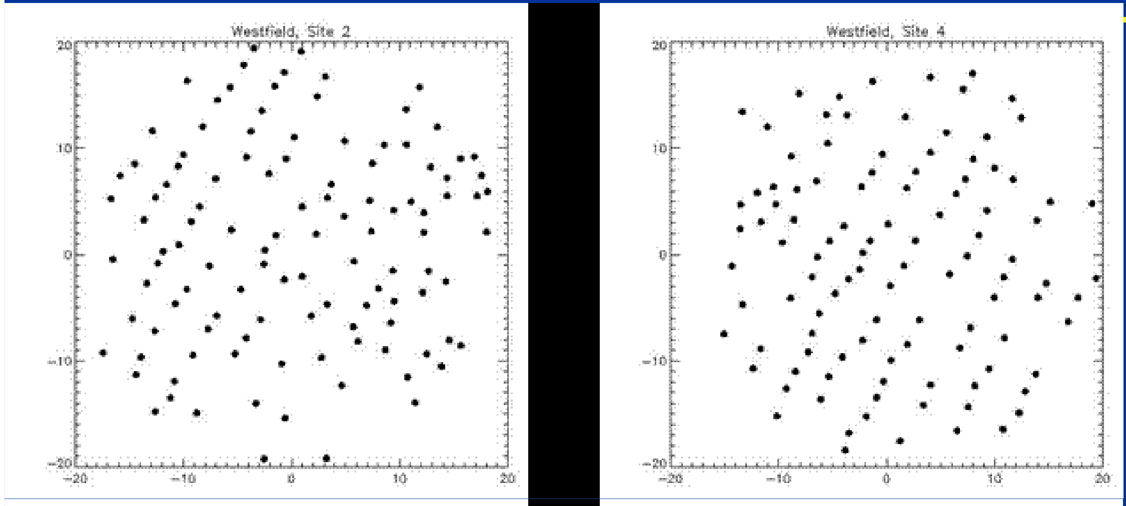


Figure 2. Leaf area sapwood allometric relationships for a) jack pine and b) western larch trees. Sources of data are S. T. Gower (unpublished data) and Kloeppel (1998).

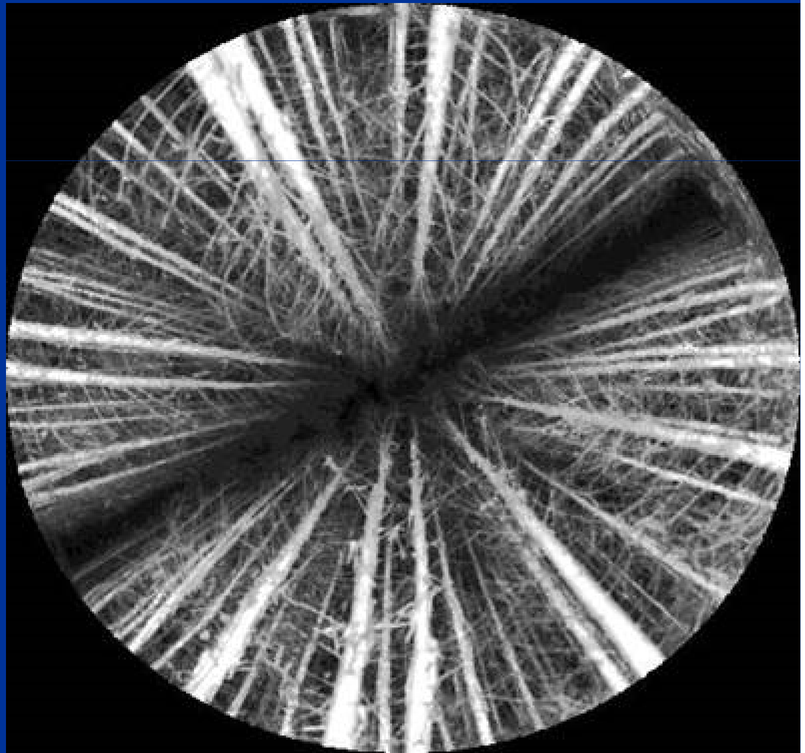
Indirect Methods

- **Optical instruments to measure radiation transmittance from which to calculate leaf properties and LAI.**
  - **Currently available commercial instruments include:**
    - ***Li-Cor LAI-2000 Plant Canopy Analyzer***
    - ***CID Digital Plant Canopy Imager***
    - ***Decagon Sunfleck Ceptometer***
    - ***Demon***
    - ***TRAC***
- **Or Hemispherical photos**
  - **Some systems include:**
    - ***WinSCANOPY from Regent***
    - ***Can-Eye***
    - ***Hemiview***
- **Or aircraft/satellite remote sensing**
  - **Spectral methods (e.g. MODIS LAI – Sea)**
  - **LiDAR**

Echnidna LiDAR



Spatial distribution of return points for two ECHIDNA™ horizontal scans



Cylindrical reprojection of the ECHIDNA™ data showing the separation of trunks and foliage

Hemispherical projection of waveform totals collected by ECHIDNA™

http://www.eoc.csiro.au/lidar/echidna05.htm

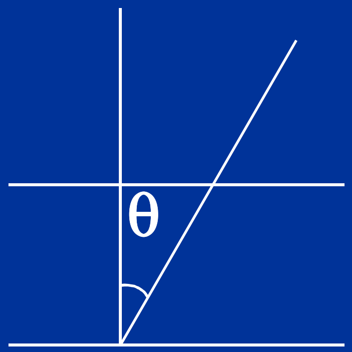
Two Key Canopy Attributes Affecting Radiation Penetration and Indirect LAI Measurements

1. **Leaf angular distribution**
   affecting radiation transmission through the canopy at different angles

2. **Leaf spatial distribution**
   affecting the amount of radiation transmitted. Generally more important.

Principle for Optical Measurements of LAI

The modified Beer's Law:



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

where P is the gap fraction
θ is the zenith angle,
Ω is the clumping index *(random=1)*
G(θ) is the projection coefficient
***L* is the leaf area index**

Leaf spatial distribution

Leaf angular distribution

$L_e = \Omega L$, effective LAI

Nilson 1971

Leaf Spatial Distribution

(1) **random distribution:** For each layer of leaves, there is 37% overlapping. Clumping index =1. True for some cr**ops.**

(2) **clumped distribution:** For each layer of leaves, there is more than 37% overlapping. Clumping index <1. True for almost all natural canopies.

(3) **regular distribution:** For each layer of leaves, there is less than 37% overlapping. Clumping index >1. True for few crops**.**

Courtesy Jing Chen

Gap Fraction vs. Gap Size

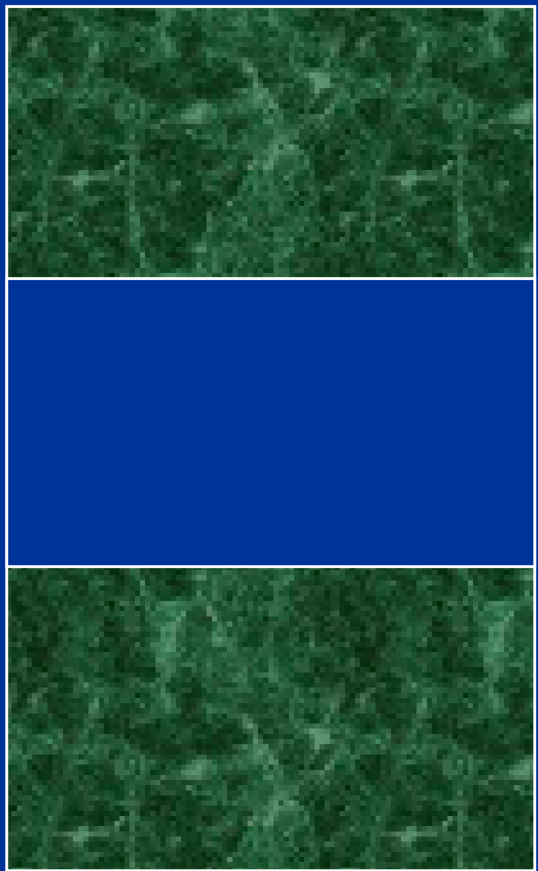
Gap fraction: it can be defined as the fraction of sky seen from underneath the canopy. It changes with the view zenith angle. It equals one minus crown closure at the zenith and always zero in the horizontal direction.

Gap size: physical dimension of a gap through the canopy. Gaps result from tree crown, branch, shoots and leaves have different sizes and the size distribution carries the information on the canopy architecture.

Difference: for the same gap fraction, there can be different gap size distributions.

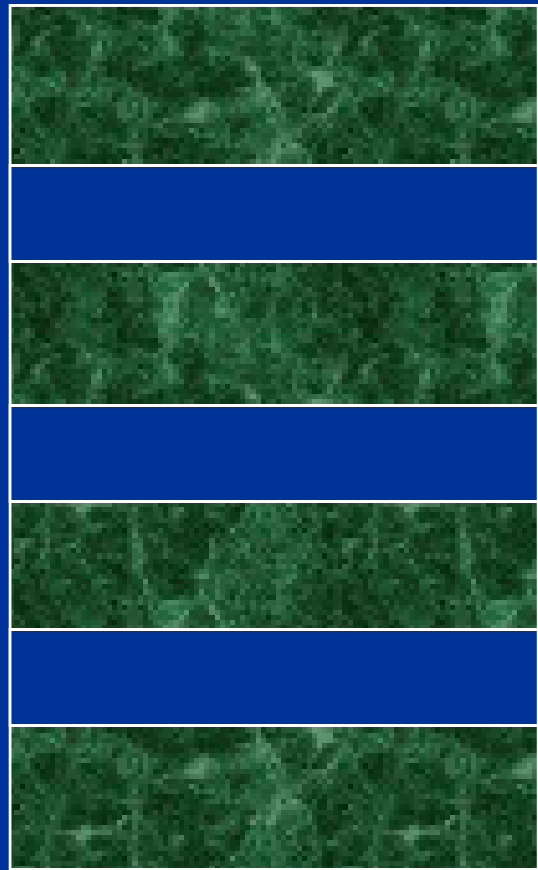
Same Gap Fraction, but Different Gap Sizes

1/3 gap fraction



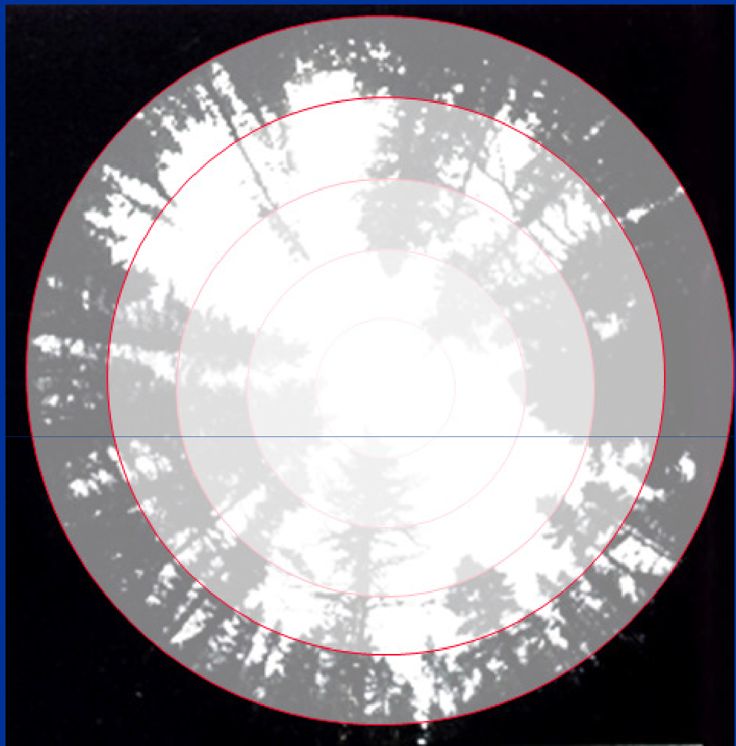
Large gap

1/3 gap fraction



Small gaps

Gap Fractions Measured by optical method



•Measures gap fraction - Doesn’t measure gap sizes
•Assumes random distribution elements
•Calculates effective PAI not LAI
•Due to clumping effective PAI less than real PAI (underestimate LAI)

Ground-based LAI Instrument TRAC CCRS

- Purpose: LAI
- new theory:
  gap size distribution
- new measurement concept:
  solar beam as probe
- new parameter:
  clumping index
- spin-off:
  FPAR and canopy architectural parameters

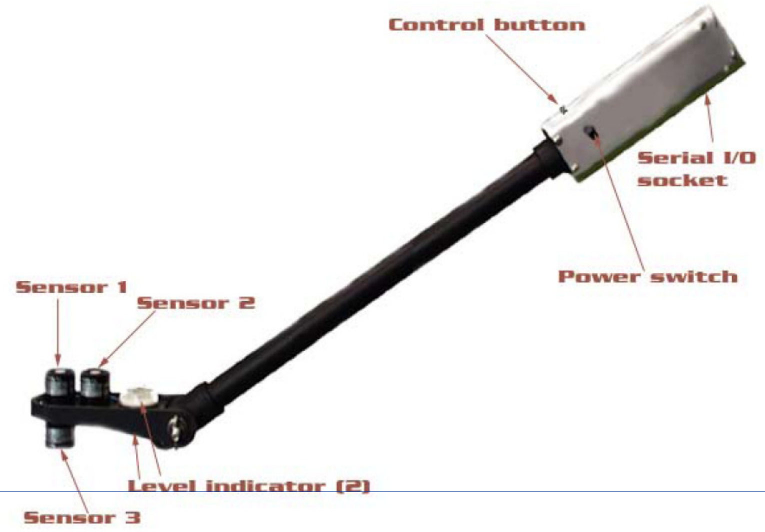
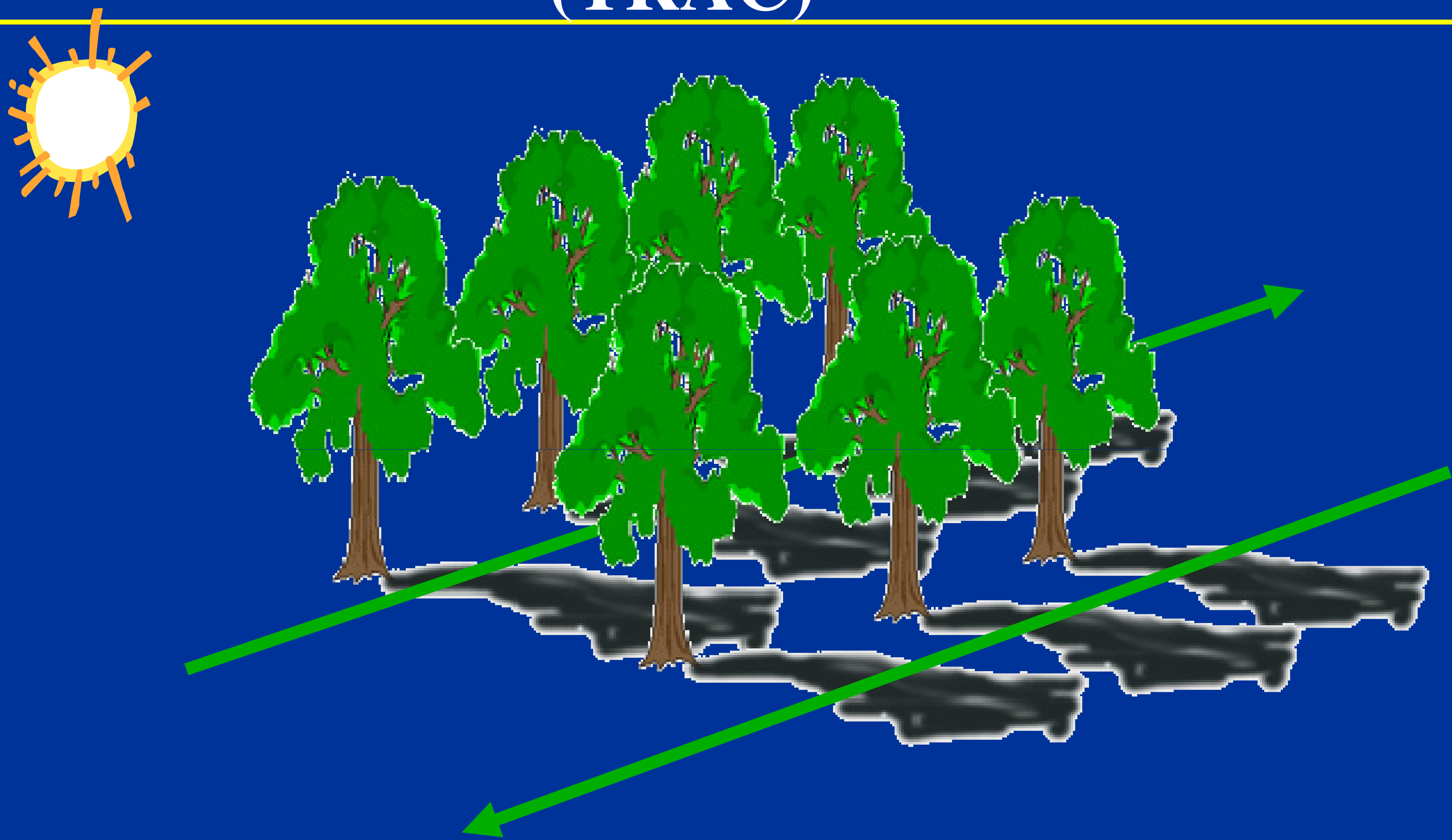


Figure 2.1: TRAC consists of 3 PAR sensors (400 to 700 nm) and amplifiers, an analog-to-digital converter, a

Ref.: Chen and Cihlar (1995), Leblanc/Chen/Kwong (2002)

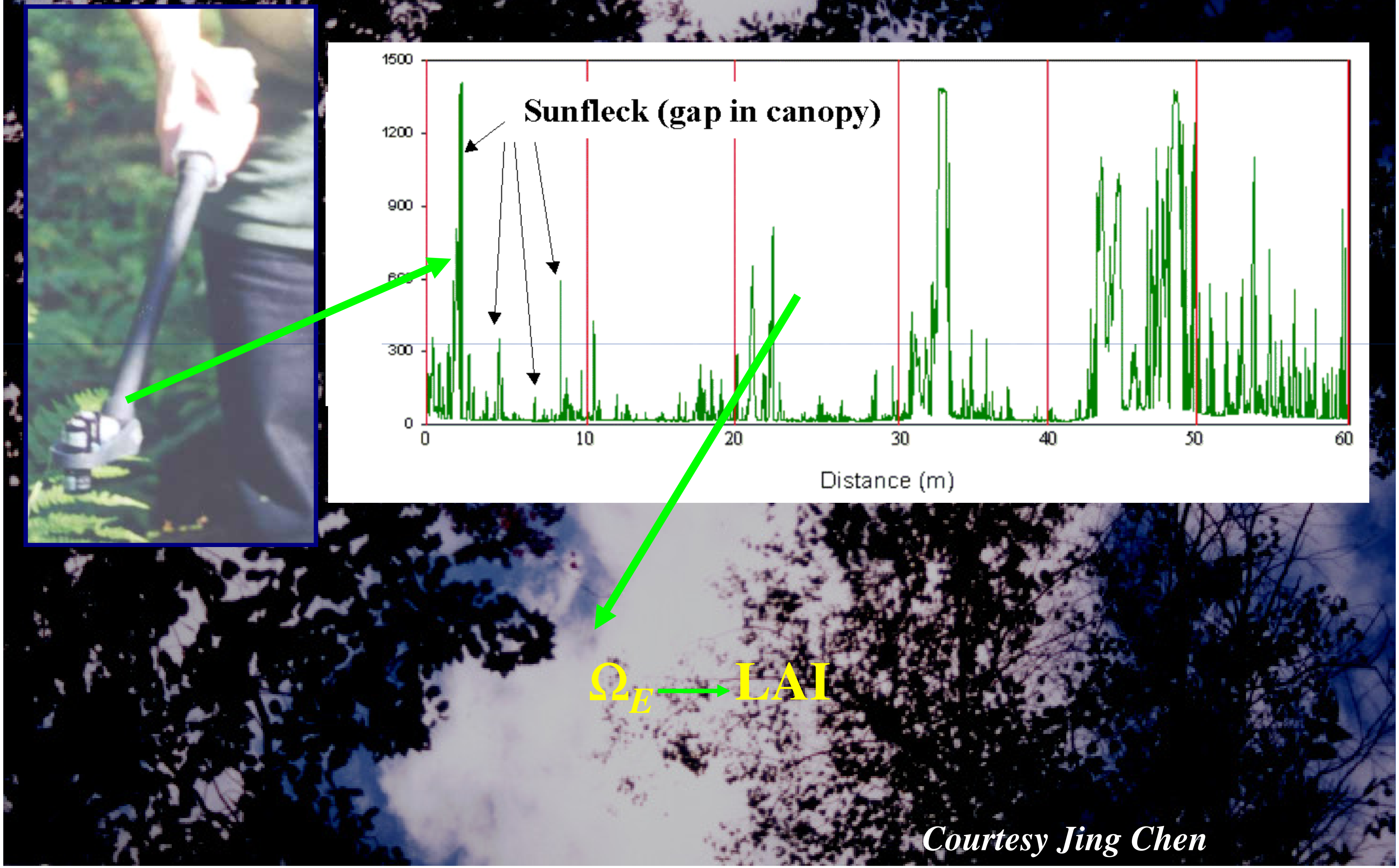
Courtesy Jing Chen

Tracing Radiation and Architecture of Canopies (TRAC)



Courtesy Jing Chen

TRAC for Measuring LAI



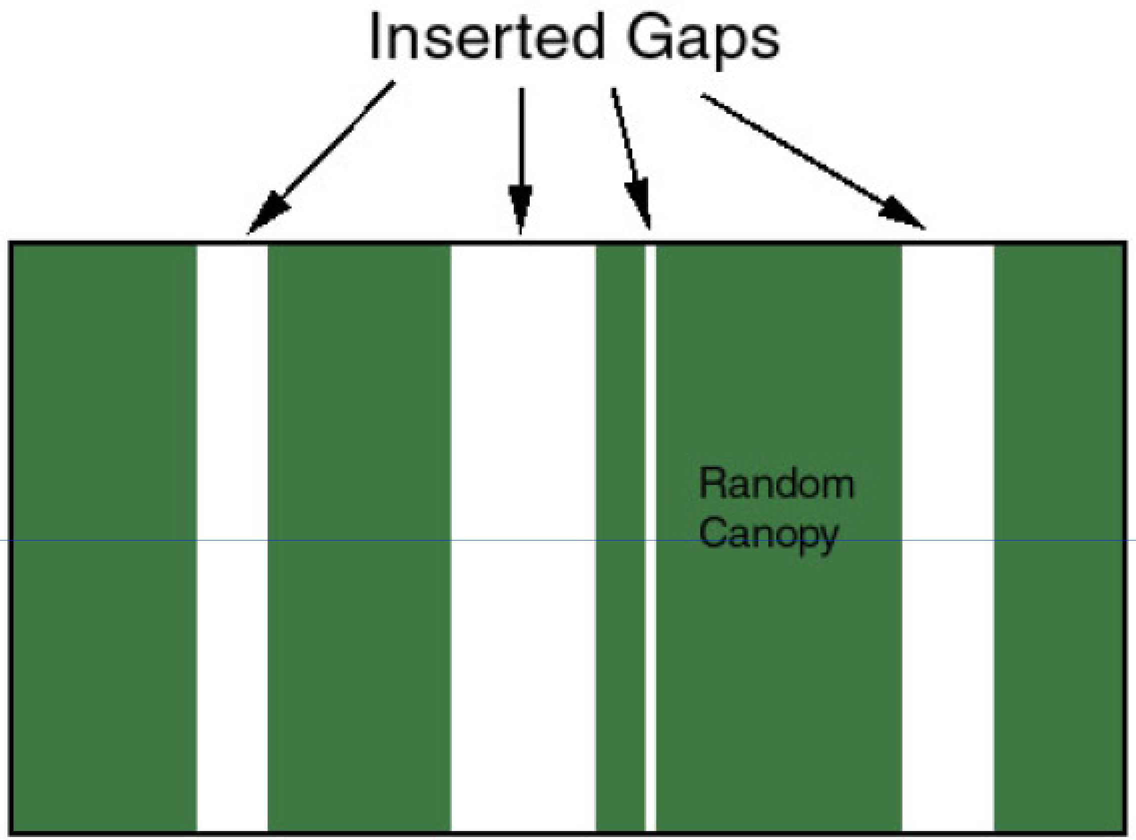
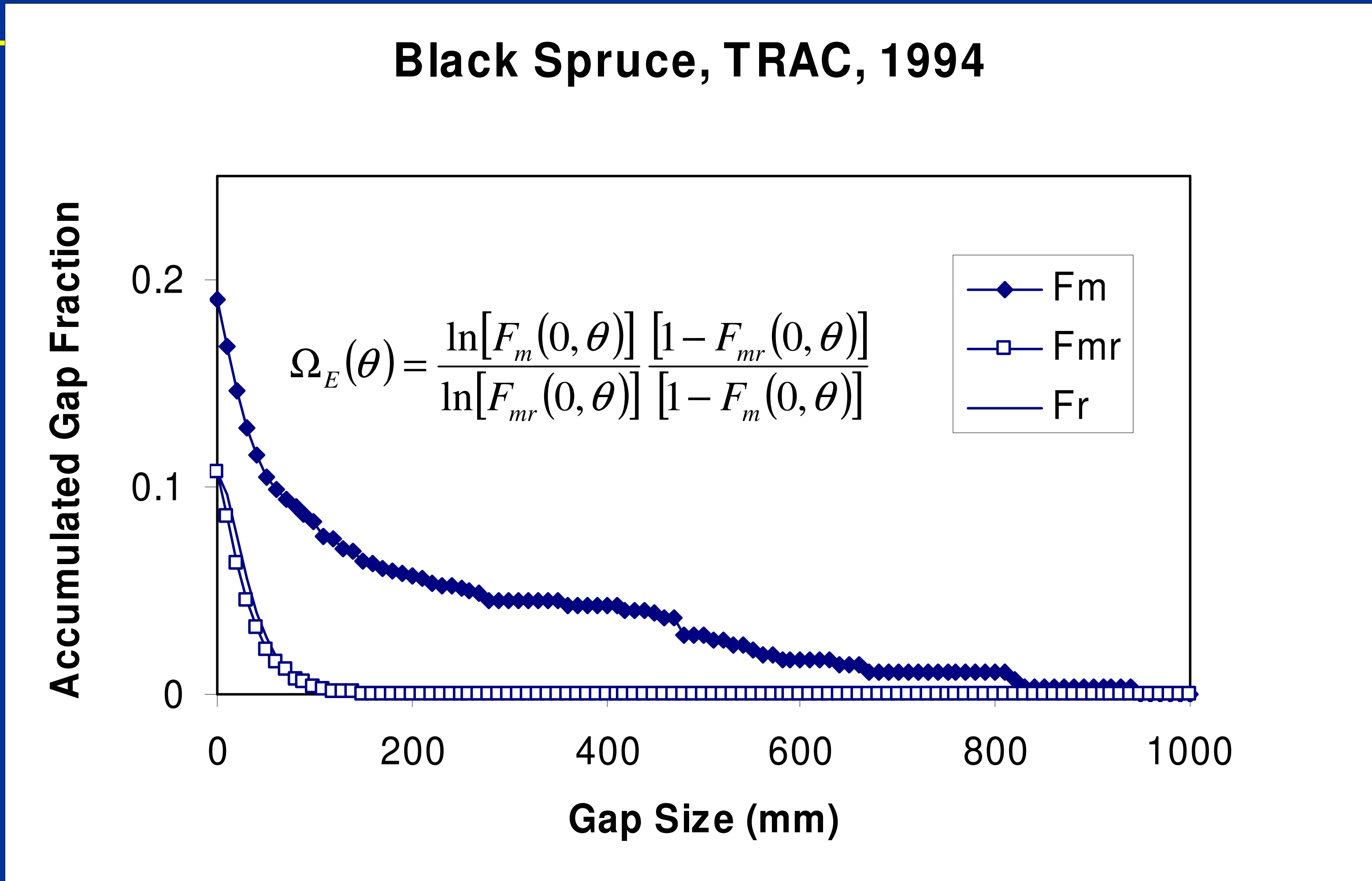


Figure 3.6. Gap removal approach to reconstructing a random canopy for LAI calculations. Large gaps between foliage clumps (crowns, branches, etc) are considered to be "inserted" non-random gaps.

Clumping Index (Ω) Derived After Gap Removal



Ref.: Chen and Cihlar (1995); Leblanc (2002)

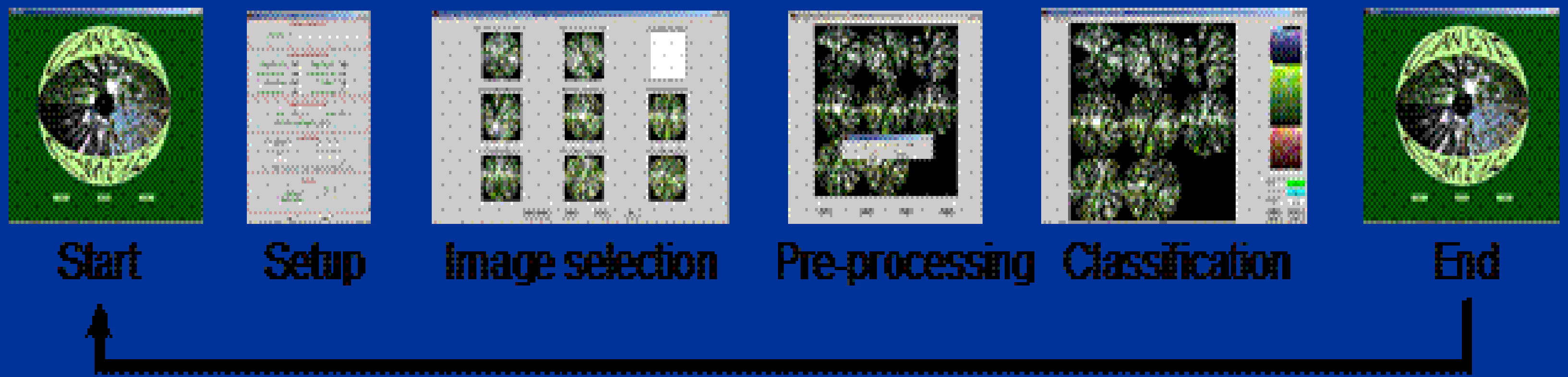
Courtesy Jing Chen

Hemispherical photos

Basic steps in hemispherical photo technique

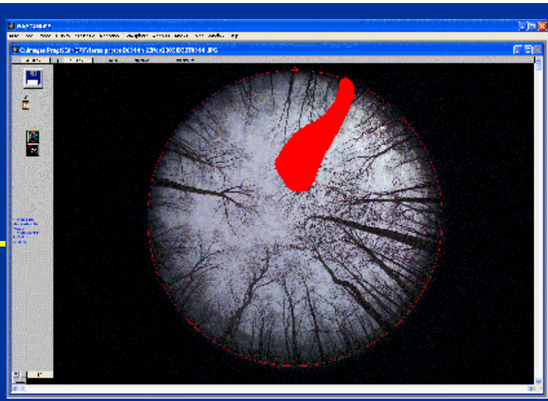
1. **Acquire photos (lens, sun conditions, sampling, camera settings)**
2. **Image processing**

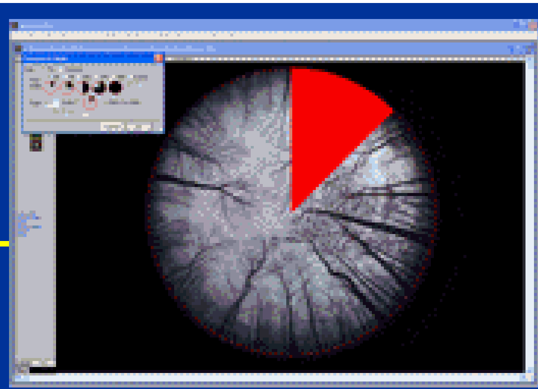
http ://www.INRA.fr/eyecan



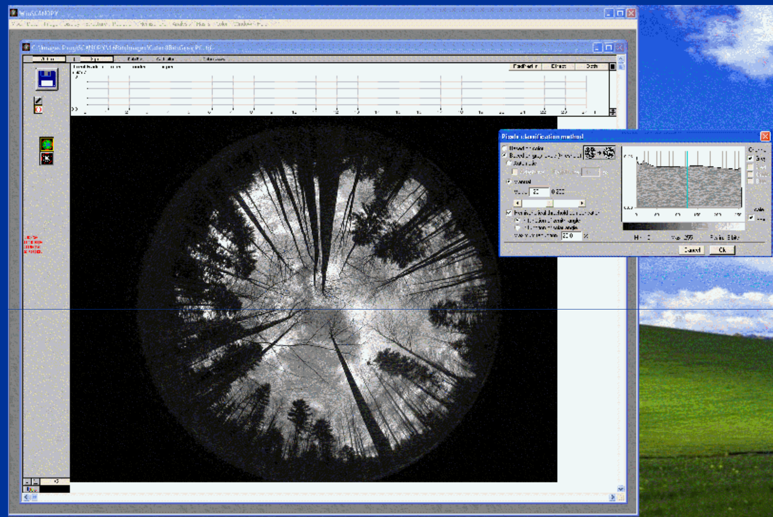
From Can_eye manual http ://www.INRA.fr/eyecan

Image lens correction



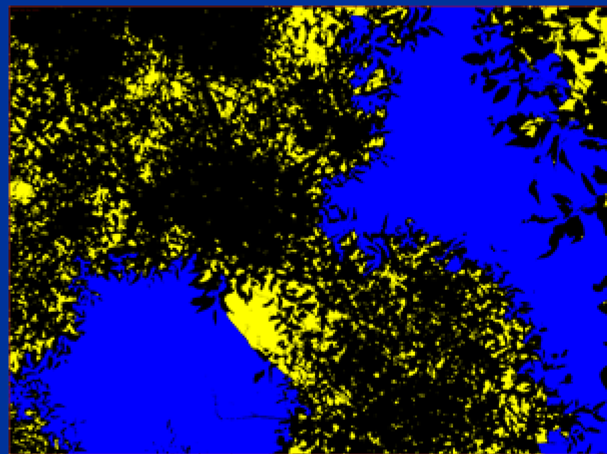


Masking

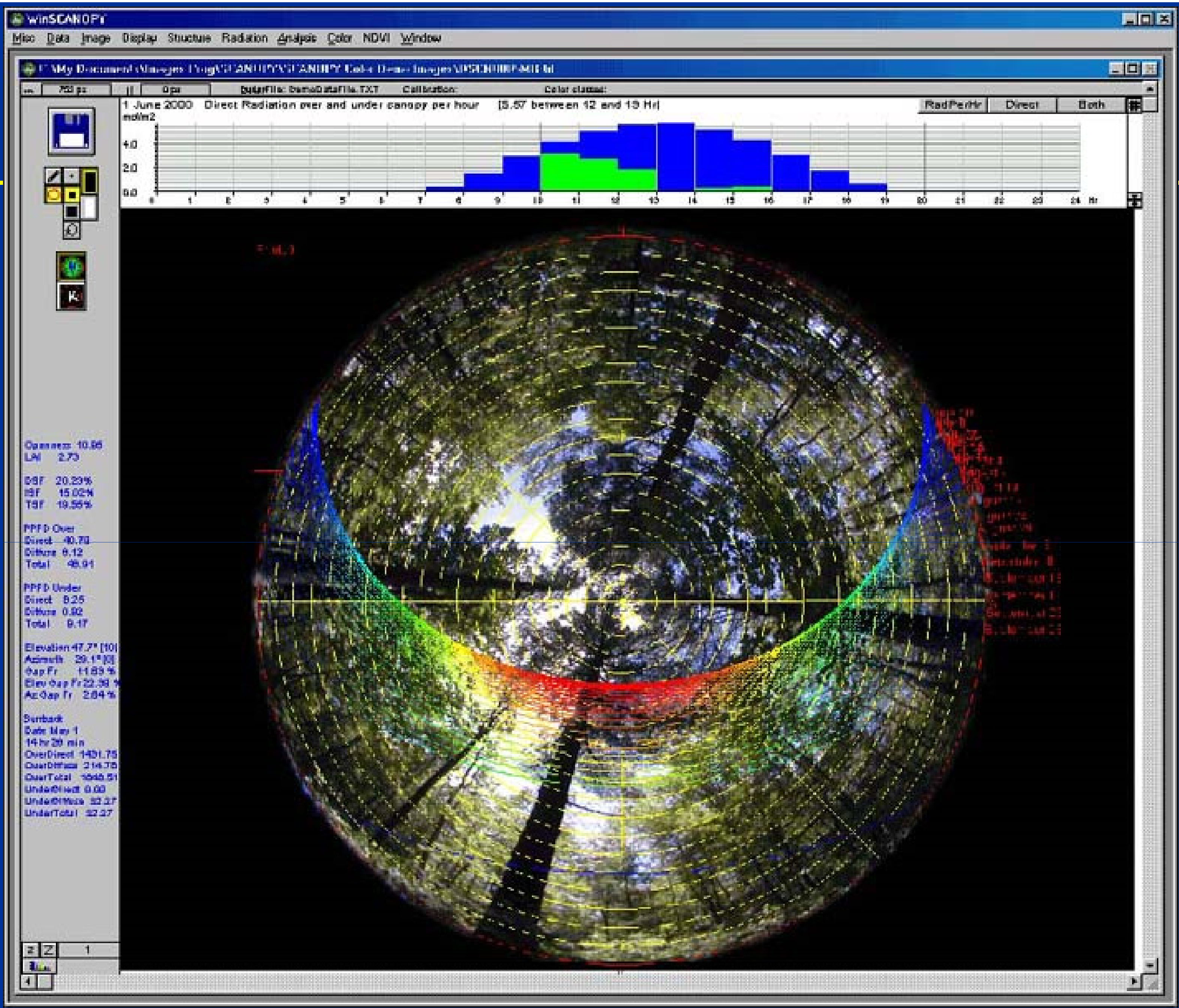


Colour correction

Image classification

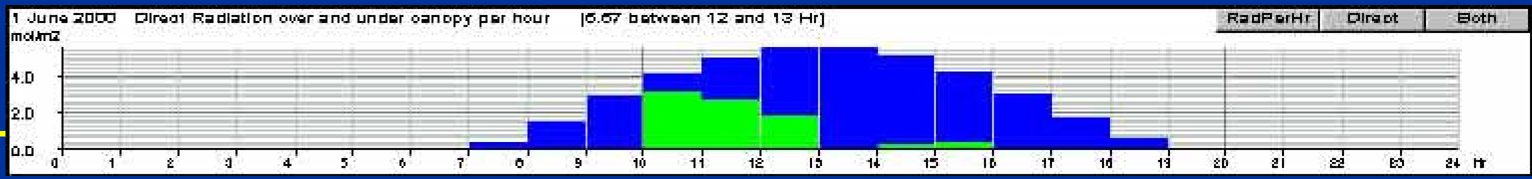


http://www.regent.qc.ca/products/Scanopy

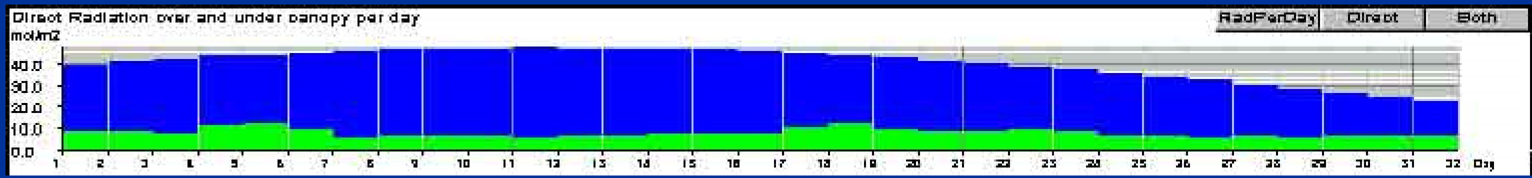


http://www.regent.qc.ca/products/Scanopy

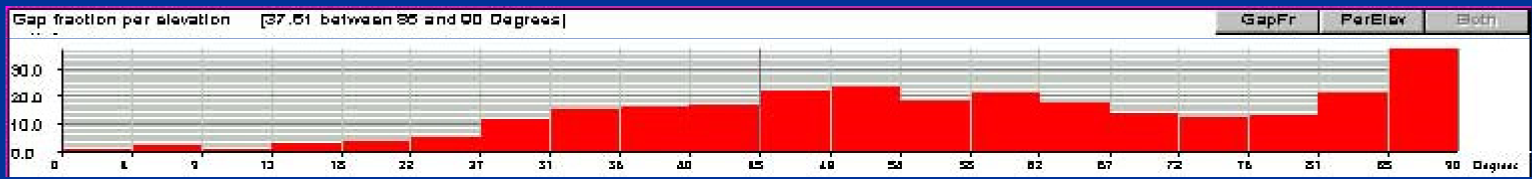
1) Radiation level per hour of the day for the active suntrack



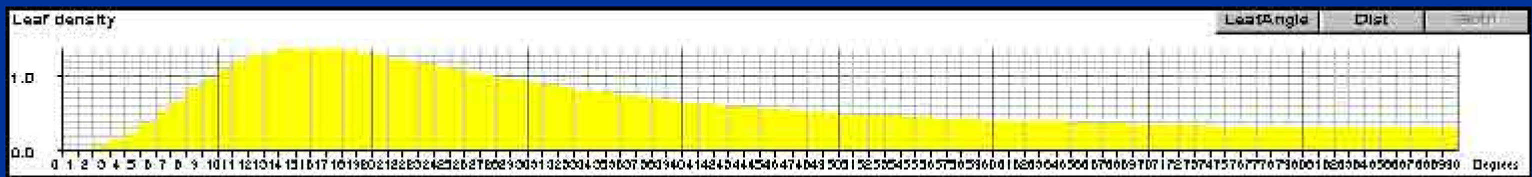
2) Radiation level per day



3)Gap fractions in function of zenith or azimuthal direction



4) Leaf angle distribution



5) Sunfleck frequency distribution (number in function of duration in minutes)
6) Sunfleck duration (total in minutes) per day of the growing season
7) Gaps size cumulative distribution
8) Leaf projection coefficient in function of zenith angle
9) Clumping index in function of zenith angle

http://www.regent.qc.ca/products/Scanopy

LAI Measurement Protocols Using Optical Instruments

$$L = L_e(1-\alpha)\gamma_s / \Omega_E$$

L is the leaf area index
L_e is the effective LAI
α is the woody-to-total area ratio
γ_s is the needle-to-shoot area ratio
Ω_E is the clumping index at scales larger than shoots

Recommended protocols:

1. Use LAI-2000 to measure L_e
2. Use TRAC to measure Ω_E for all forest stands and shrubs
3. Measure γ_s where possible, otherwise the default value is 1.4 for boreal conifer, and 1.8 for temperate conifer. For broadleaf forests, γ_s =1.0
4. Measure α where possible, otherwise use allometric equations or estimates

Ref.: Chen et al., (2002)

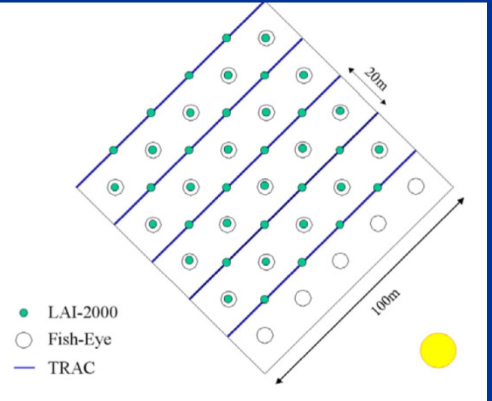


Figure 4.6 Suggested 1 ha plot (based on NASA SIBLAI project) where TRAC is combined with LAI-2000, Fish-Eye (hemispherical) photographs and forestry measurements. Note the morning sun south-east in the Northern hemisphere (North being up).

Courtesy Jing Chen