Non-destructive LAI Measurement For Forest Canopy and Isolated Tree

Liukang Xu

Topics will be covered

1. Why do we want to know *LAI*
2. Terminology
3. Optical sensor
4. Theory
5. Step-by-step *LAI* calculation with Excel
6. Q & A

Why do we want to know *LAI* ?

1. Fundamental to radiation penetration, solar energy partitioning
2. Turbulent transport, canopy microclimate
3. Fundamental role in plant canopy processes
4. Evapotranspiration, CO_2 exchange
5. Plant growth and productivity
6. Modeling: describes the interaction between vegetation and the atmosphere
7. Precipitation interception
8. Soil temperature, affects plants and other organisms in soil

Terminology

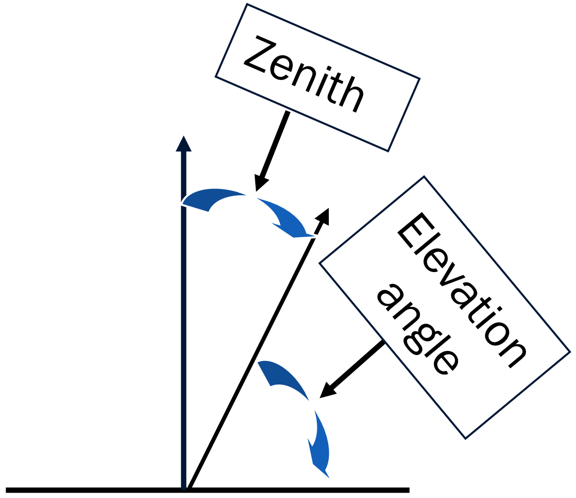
Leaf area index, *LAI* (m^2 m^{-2})

Foliage area density, μ (m^2 m^{-3})

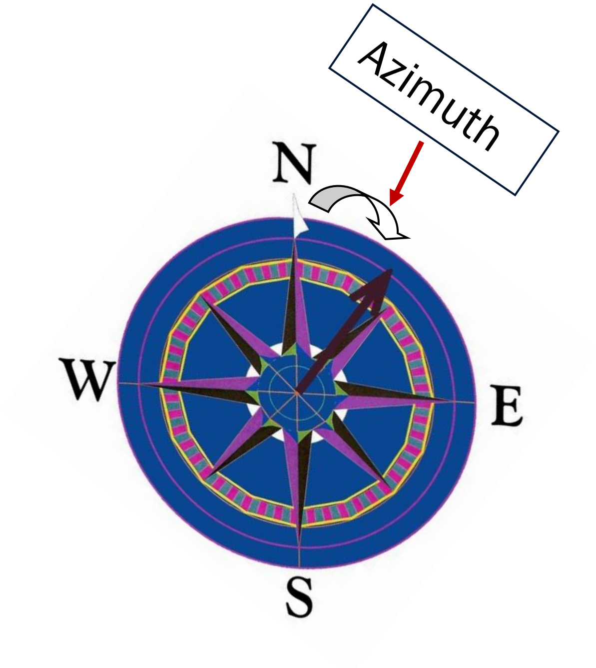
Terminology

Zenith angle，天顶角 （θ）

Elevation angle, 高度角

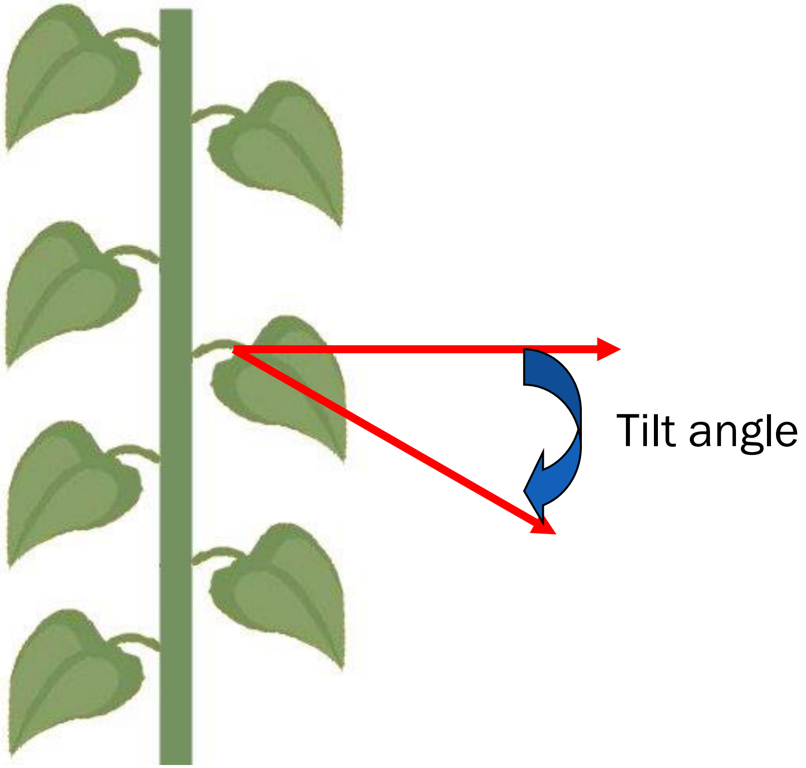


Azimuth angle，方位角 （ϕ）



Terminology

Tilt angle, mean tilt angle (MTA)



Terminology

Gap Fraction: The fraction of diffuse incident radiation that passes through a plant canopy

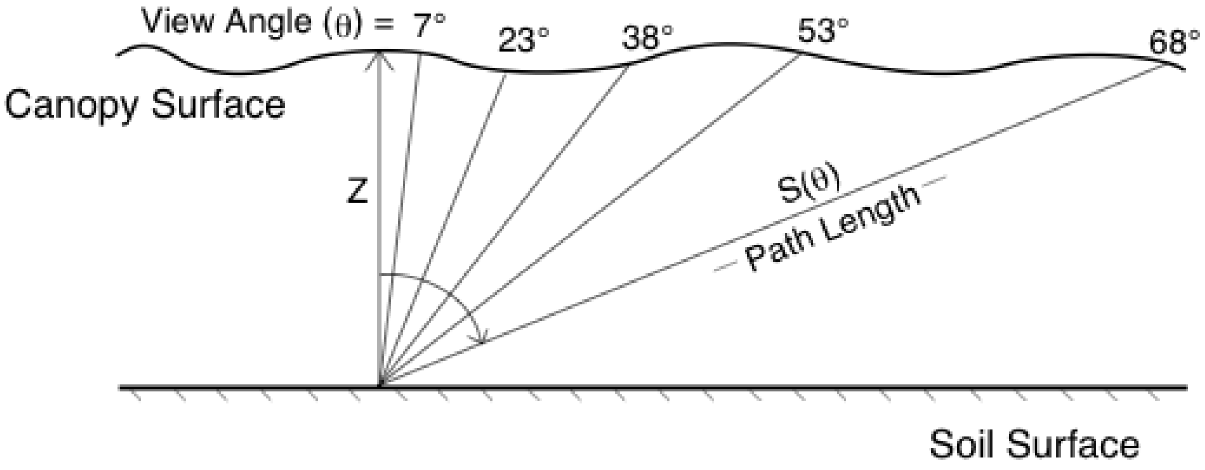
$$T(\theta) = \frac{R_{below}}{R_{Above}}$$

R_{below} = Diffuse intensity below the canopy at view angle θ

R_{above} = Diffuse intensity above the canopy at view angle θ

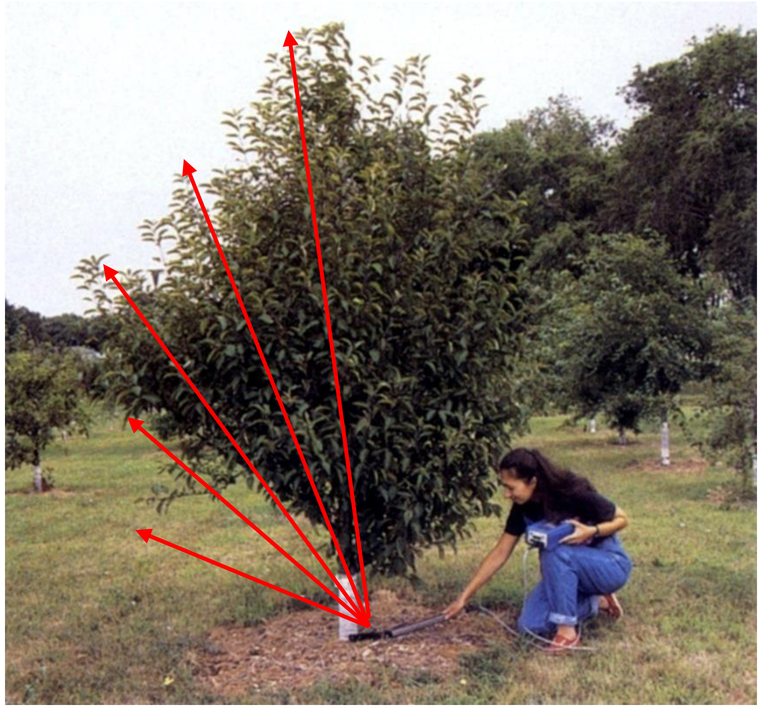
$T(\theta)$ the percentage of sky you can see from underneath the canopy. It is analogous to a transmittance （透光率).

Terminology: pathlength *S(θ)*



For a uniform large canopy

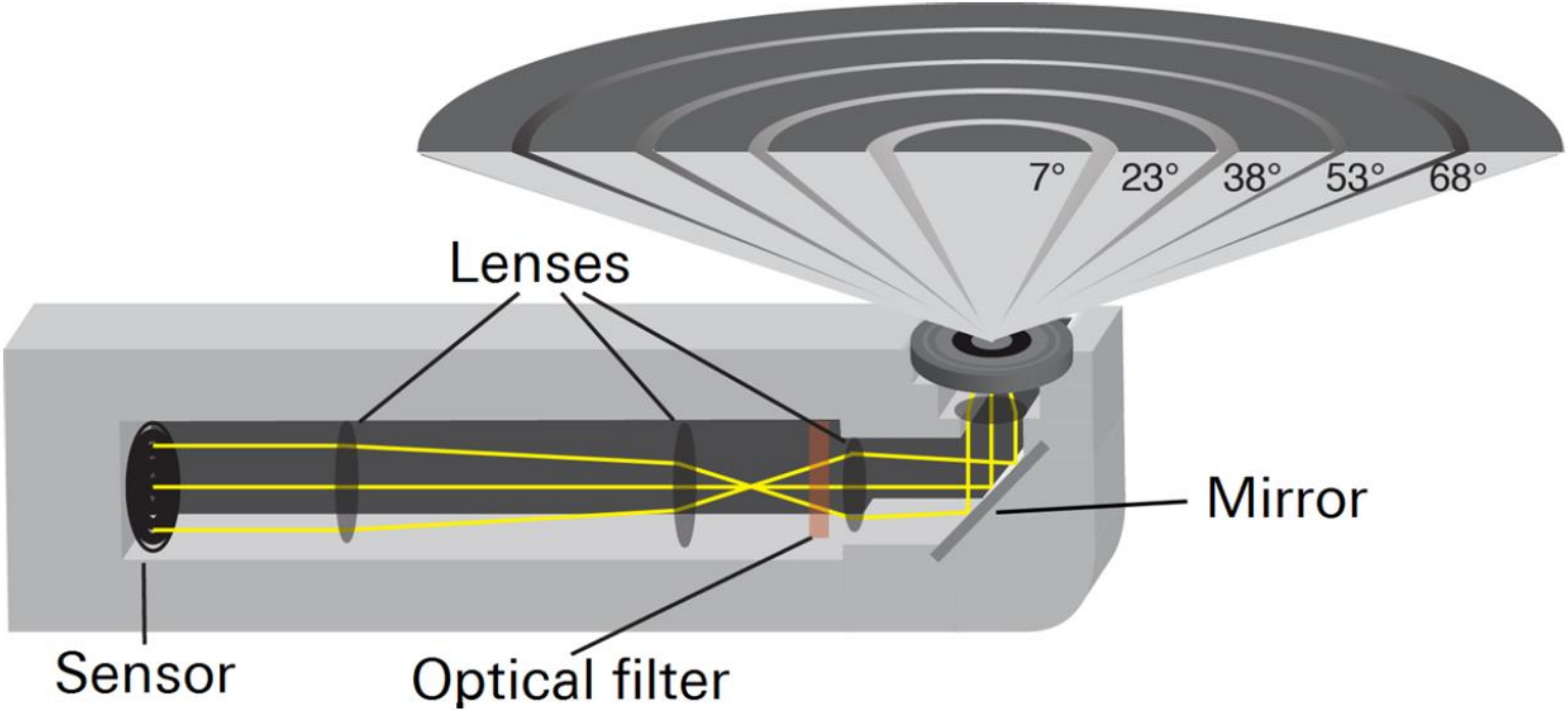
$$S(\theta) = \frac{z}{\cos(\theta)}$$



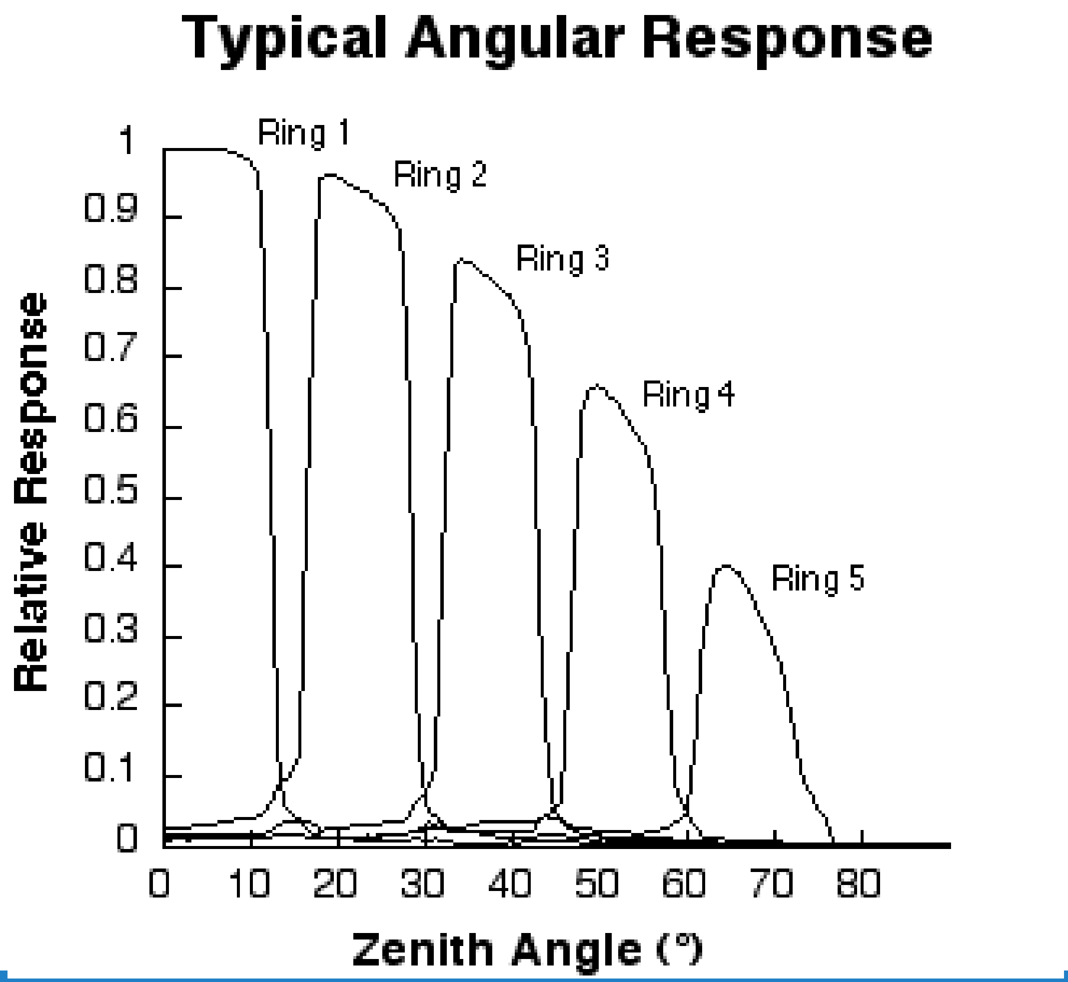
For an isolated tree

S(θ) must be measured

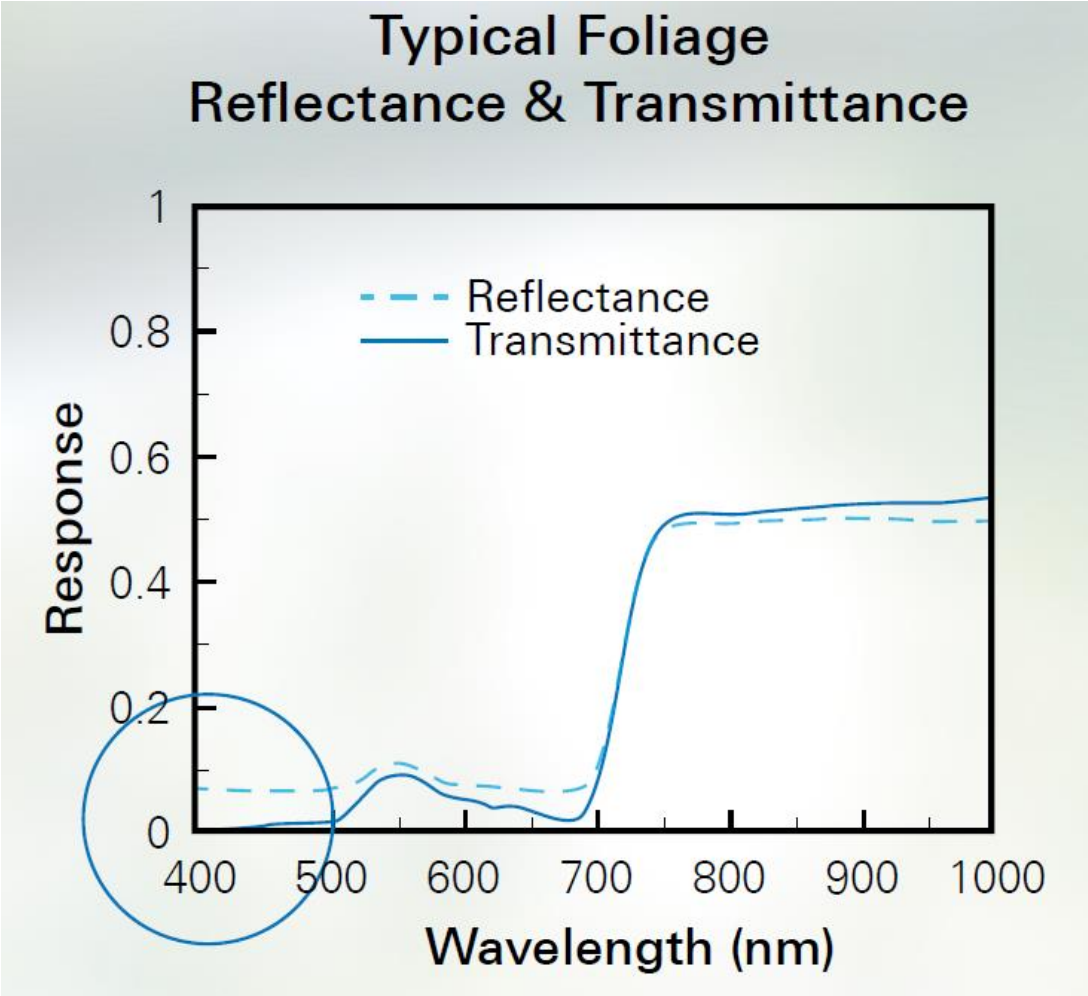
LAI-2250 optical sensor



LAI-2250 optical sensor



LAI-2250 optical sensor

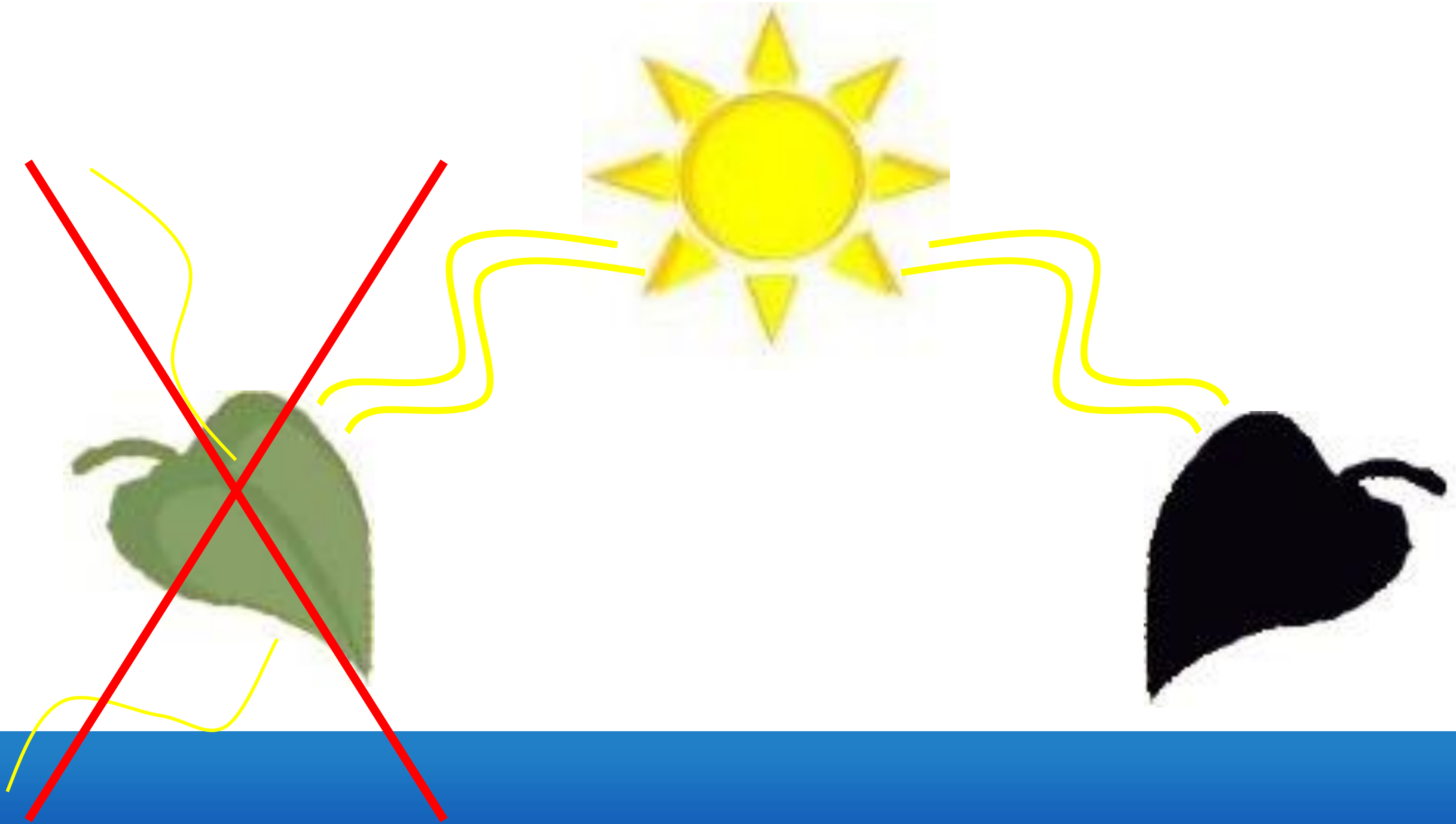


Sensor is filtered at 490 nm, so leaf looks “BLACK” for the detector

LAI-2250 optical sensor

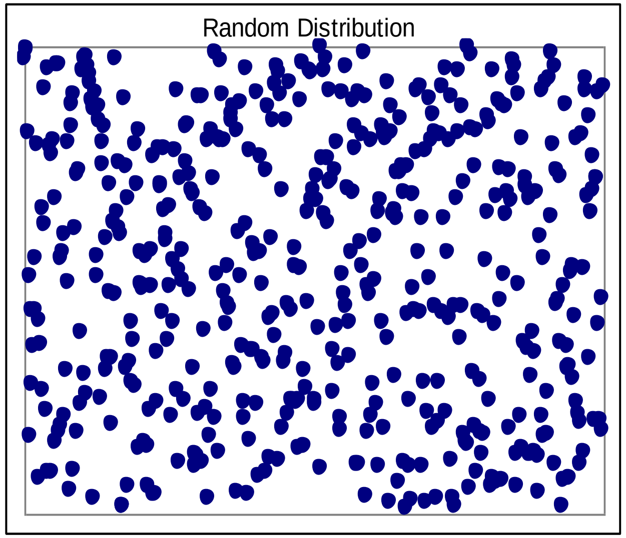
Assumption #1:

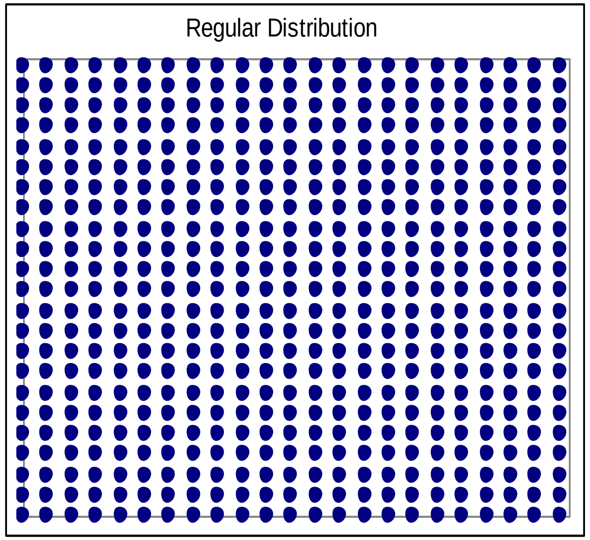
Foliage is Black, there is no reflected or transmitted radiation.



Assumption #2: Foliage is randomly distributed

Random vs. uniform distribution

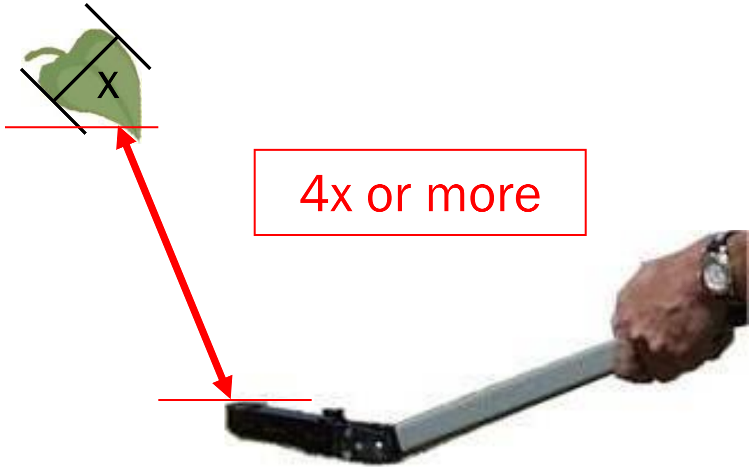




Assumption #2: Foliage is randomly distributed

Assumption #3:

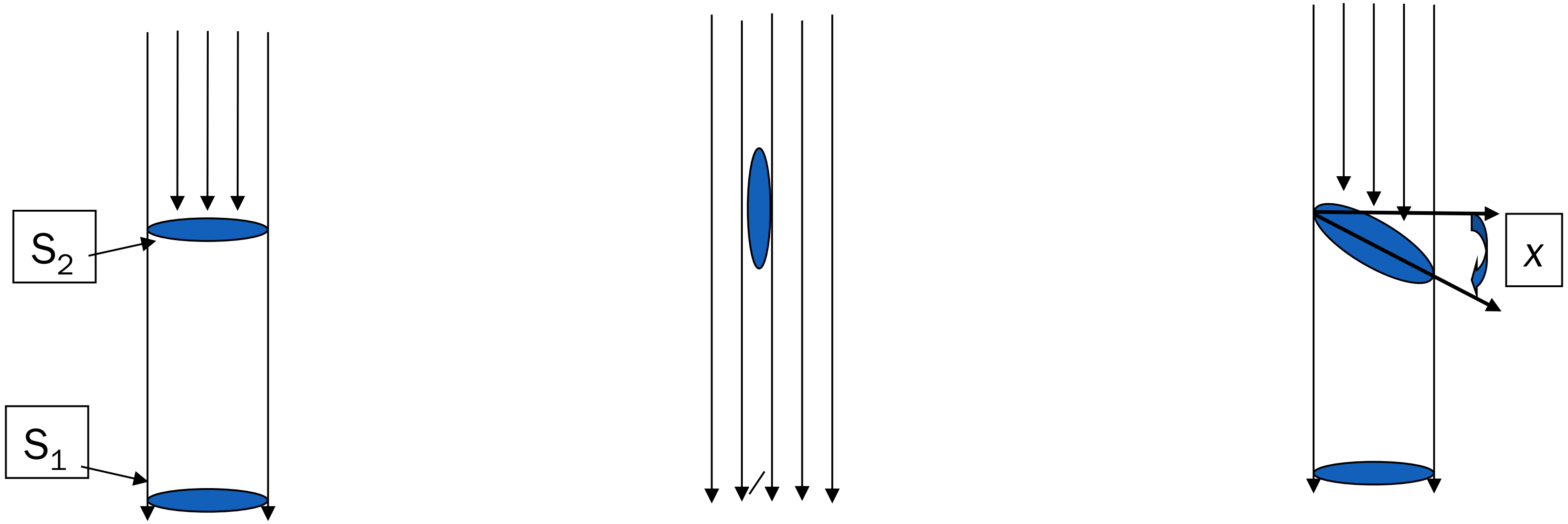
Foliage Elements are Small Compared to the Area of View of Each Ring



Terminology

G(θ), for a single leaf

Projected area on a plane normal to light (在垂直于光线的平面上投影面积)

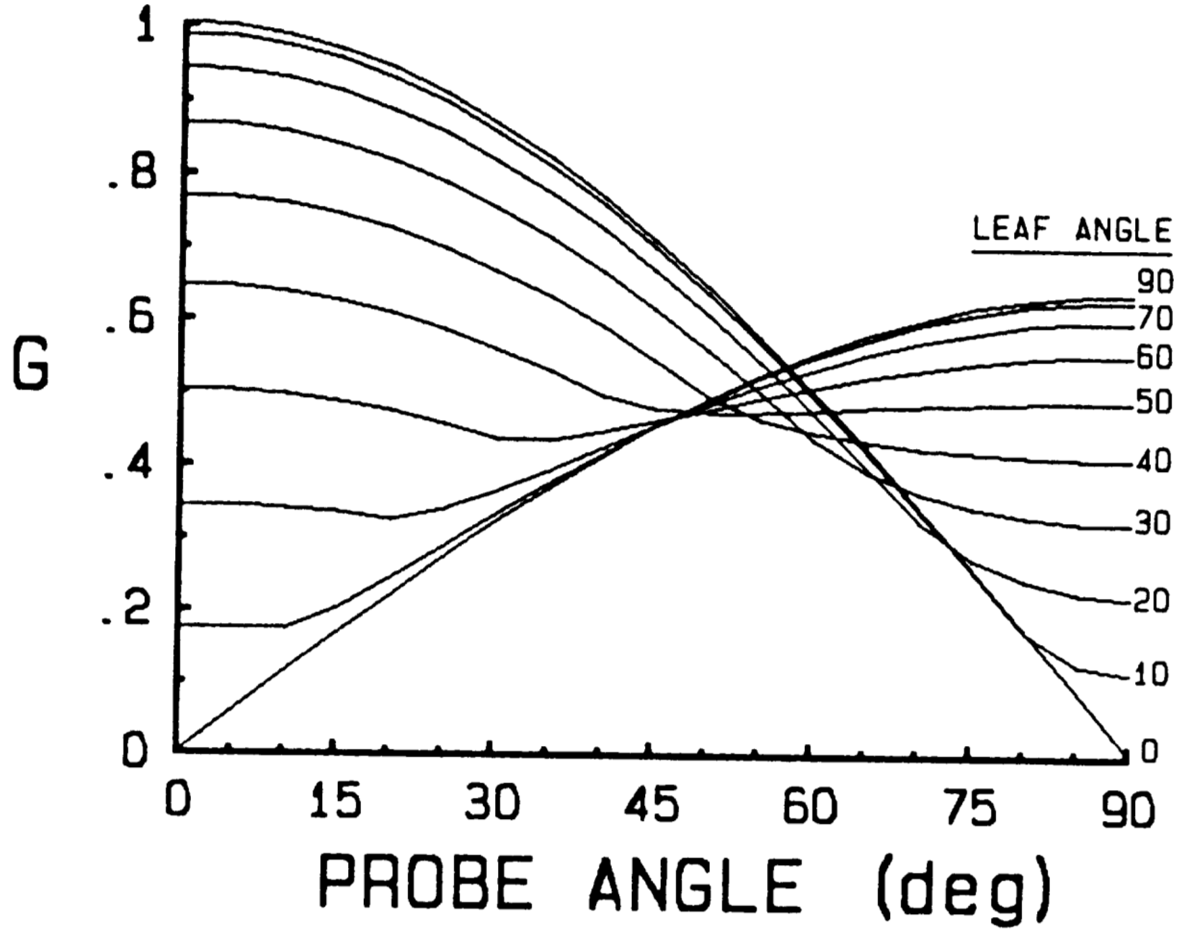


$G(\theta)=S_1/S_2=1$

$G(\theta)=0$
Only see a line.

$G(\theta)=\cos(x)$
x is tilt angle

LAI-2200C Theory



G(θ): Mean projection of unit area of leaf which has constant leaf elevation angle and is uniformly distributed with azimuth.

LAI-2200C Theory

$$T(\theta) = \frac{R_{below}}{R_{Above}}$$

R_{below}, Diffuse intensity below the canopy at view angle θ

R_{Above}, Diffuse intensity above the canopy at view angle θ

$T(\theta)$, gap fraction, depends on foliage orientation G, foliage density μ and path length S

$$T(\theta) = \exp[-G(\theta) \cdot \mu \cdot S(\theta)]$$

$$G(\theta)\mu = \frac{-\ln(T(\theta))}{S(\theta)}$$

LAI-2200C Theory

$$\mu = 2\int_0^{\pi/2} \frac{-\ln(T(\theta))}{S(\theta)} \sin\theta \, d\theta$$

Miller (1967)

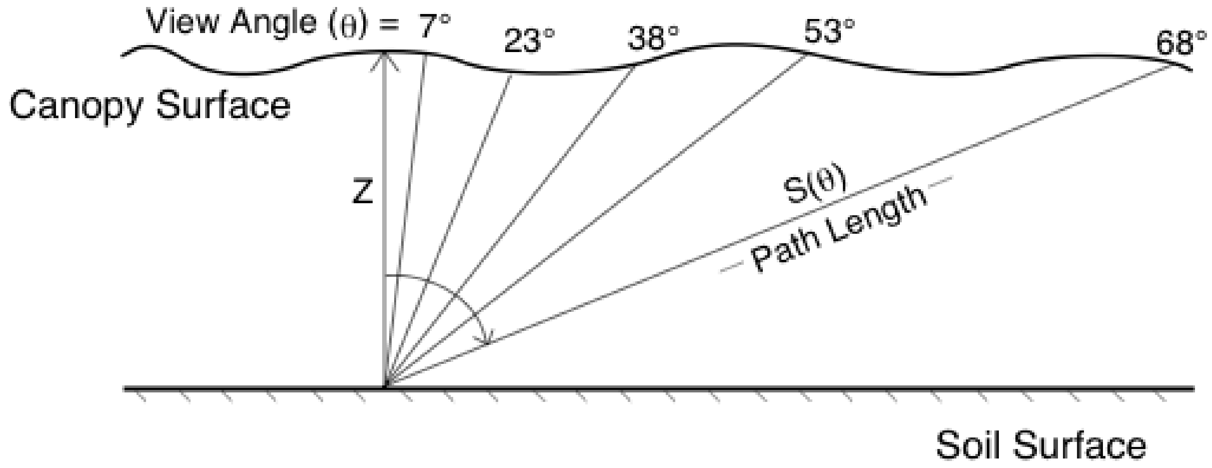
For a large, uniform canopy

$$LAI = \mu \cdot z = \frac{m^2}{m^3} m$$

$$S(\theta) = \frac{z}{\cos\theta}$$

$$LAI = 2\int_0^{\pi/2} -\ln(T(\theta)) \cos\theta \sin\theta \, d\theta$$

$$LAI = 2\int_0^{\pi/2} \frac{-\ln(T(\theta))}{s(\theta)} \sin\theta d\theta$$



$$S(\theta) = \frac{z}{\cos\theta}$$

Note: $s(\theta)$ in this equation is 1/cos(θ)

LAI-2200C Theory

For a large, uniform canopy

$$LAI = 2\int_0^{\pi/2} \frac{-\ln(T(\theta))}{s(\theta)} \sin\theta d\theta$$

$$s(\theta) = \frac{1}{\cos\theta}$$

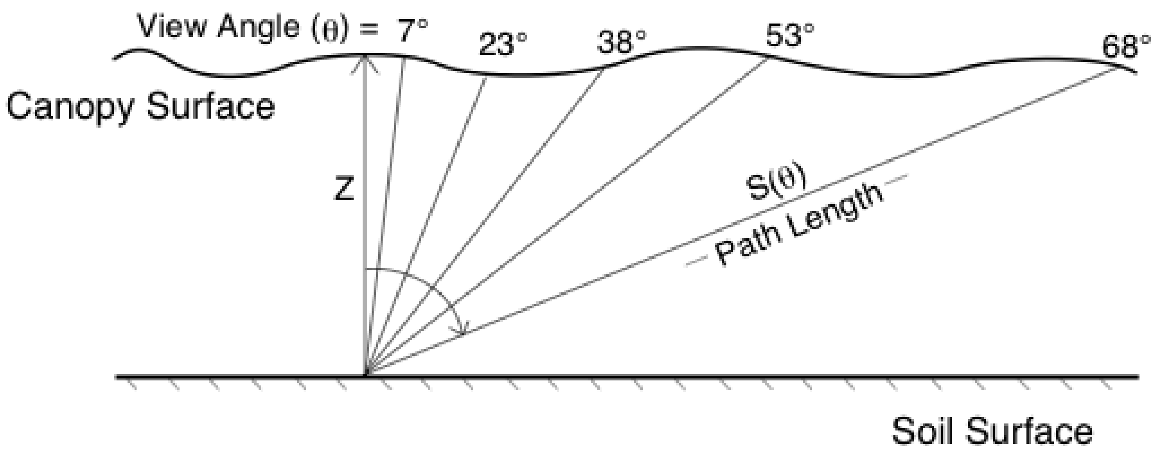
$s(\theta)$ is DISTS

$$K_i = \frac{-\ln(T(\theta_i))}{s(\theta_i)}$$

$K(\theta)$ is contact number (m^{-1})

$$W_i = \sin\theta_i \, d\theta_i$$

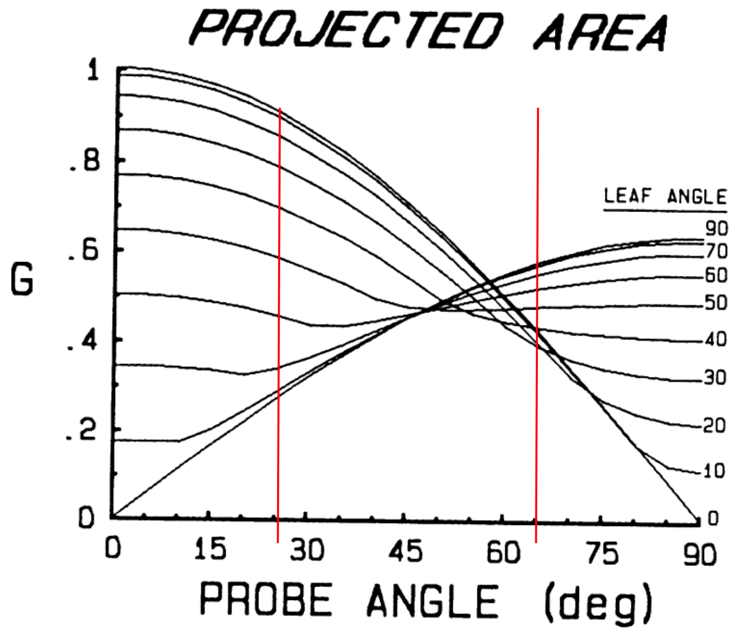
$$LAI = 2\sum_{i=1}^{5} K_i W_i$$

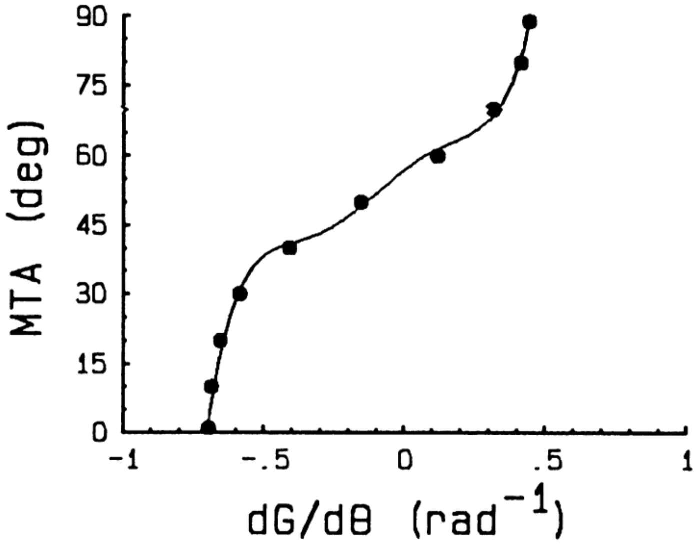


angle θ_i	$d\theta_i$	$W_i = \sin\theta_i d\theta_i$	Normalized
7	12.2	0.026	0.041
23	12.2	0.083	0.131
38	11.8	0.127	0.200
53	13.2	0.184	0.290
68	13.2	0.214	0.337
	Sum	0.634	0.999

LI-COR

LI-2200C Theory

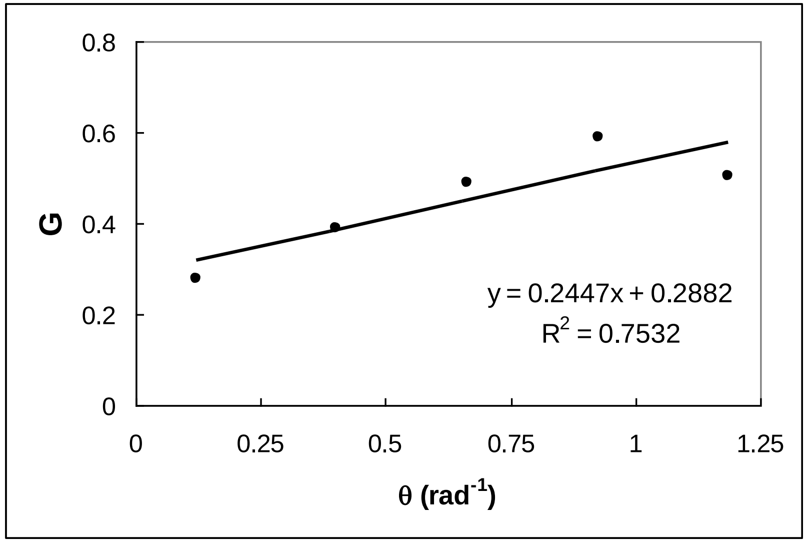


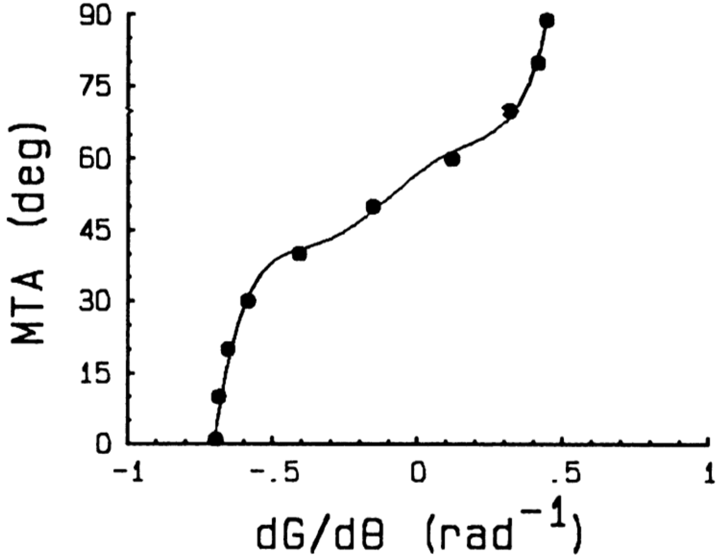


G(θ): Mean projection of unit area of leaf which has constant leaf elevation angle and is uniformly distributed with azimuth.

MTA vs. *dG/dθ*

LAI-2200C Theory



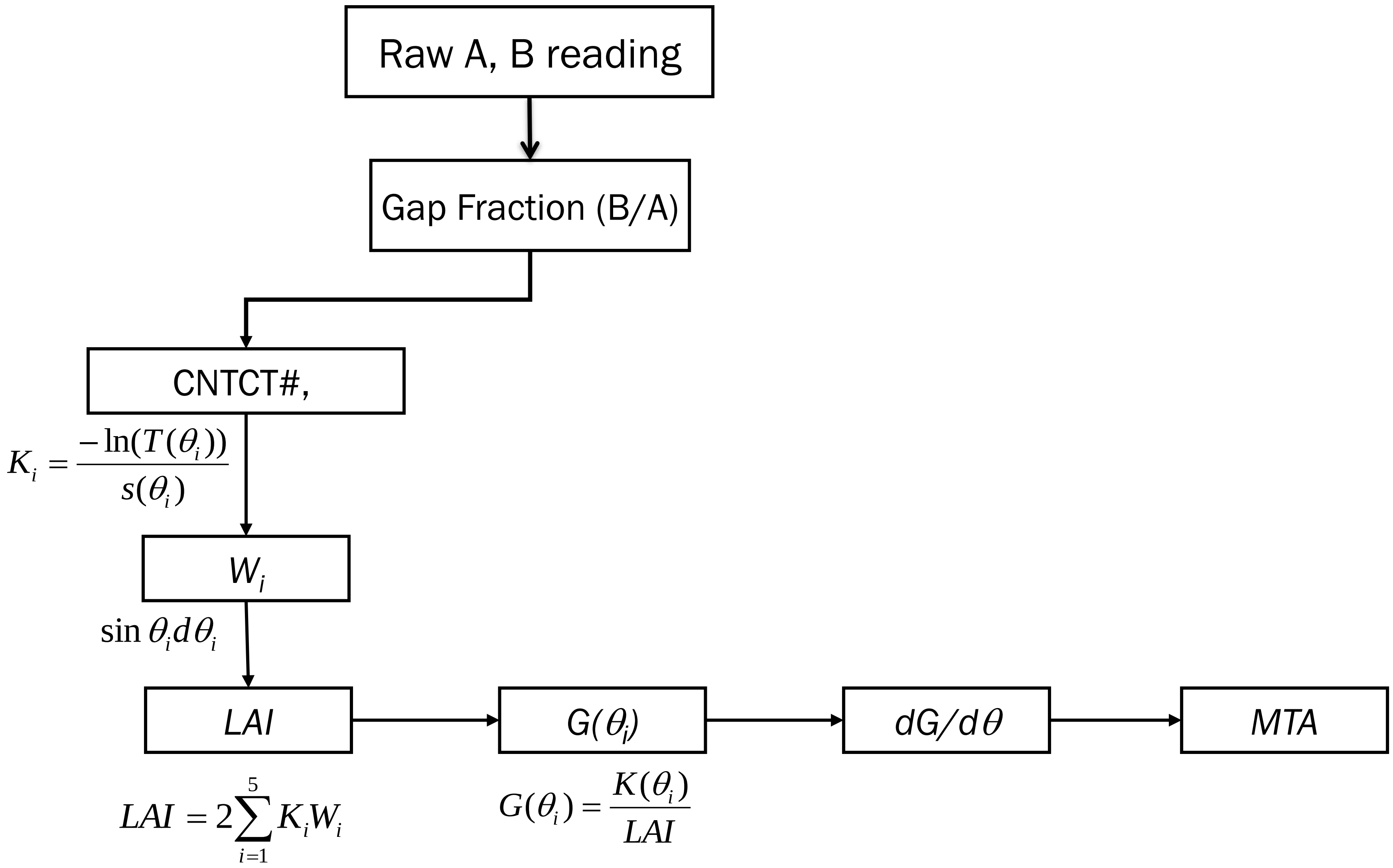


$$T(\theta) = \exp[-G(\theta)\cdot\mu\cdot S(\theta)]$$

$$G(\theta_i)\mu = \frac{-\ln(T(\theta_i))}{S(\theta_i)}$$

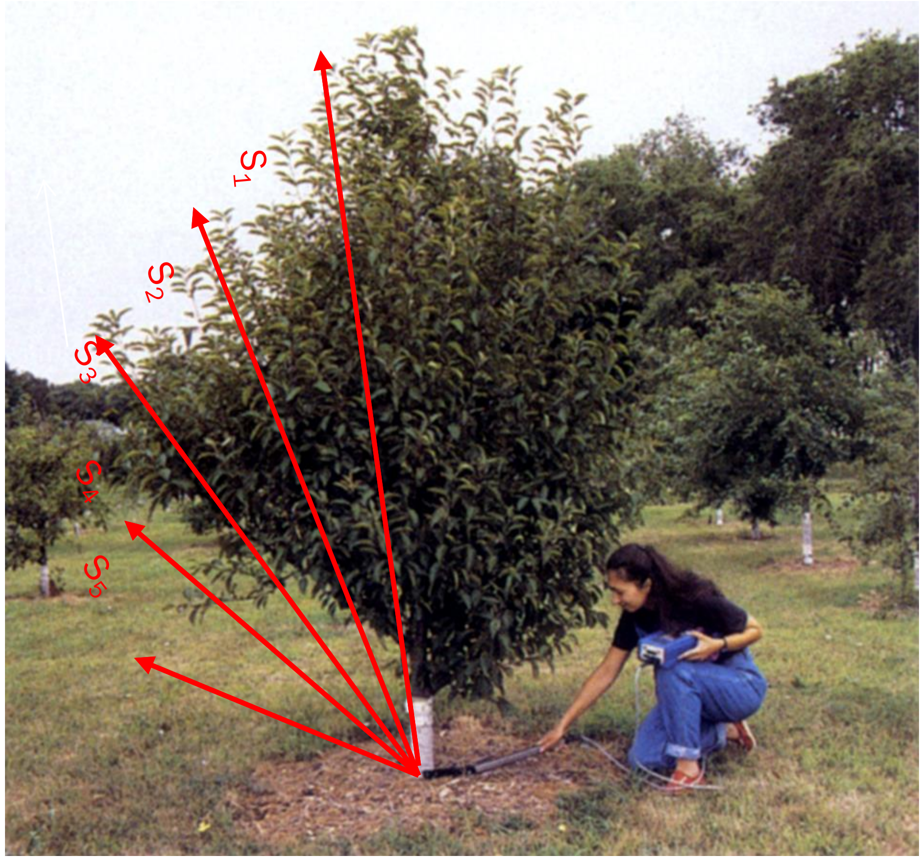
$$G(\theta_i) = \frac{-\ln(T(\theta_i))}{\mu\cdot S(\theta_i)} = \frac{-\ln(T(\theta_i))}{\mu\, z/\cos(\theta_i)} = \frac{K(\theta_i)}{LAI}$$

Step-by-step calculation



Step-by-step demo: how LAI is calculated with excel spreadsheet

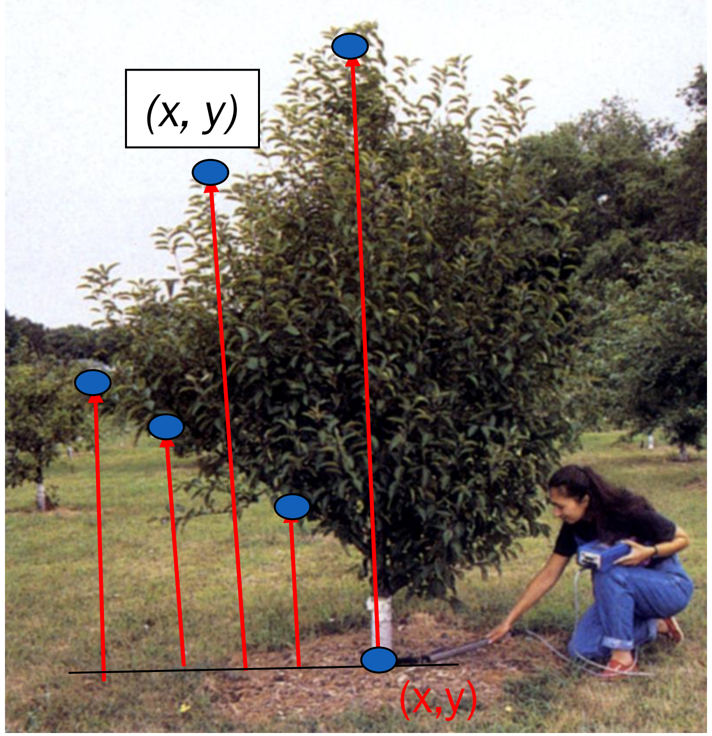
For an isolated tree, IsoMeasured
foliage density can be estimated ($m^2 m^{-3}$), not *LAI*

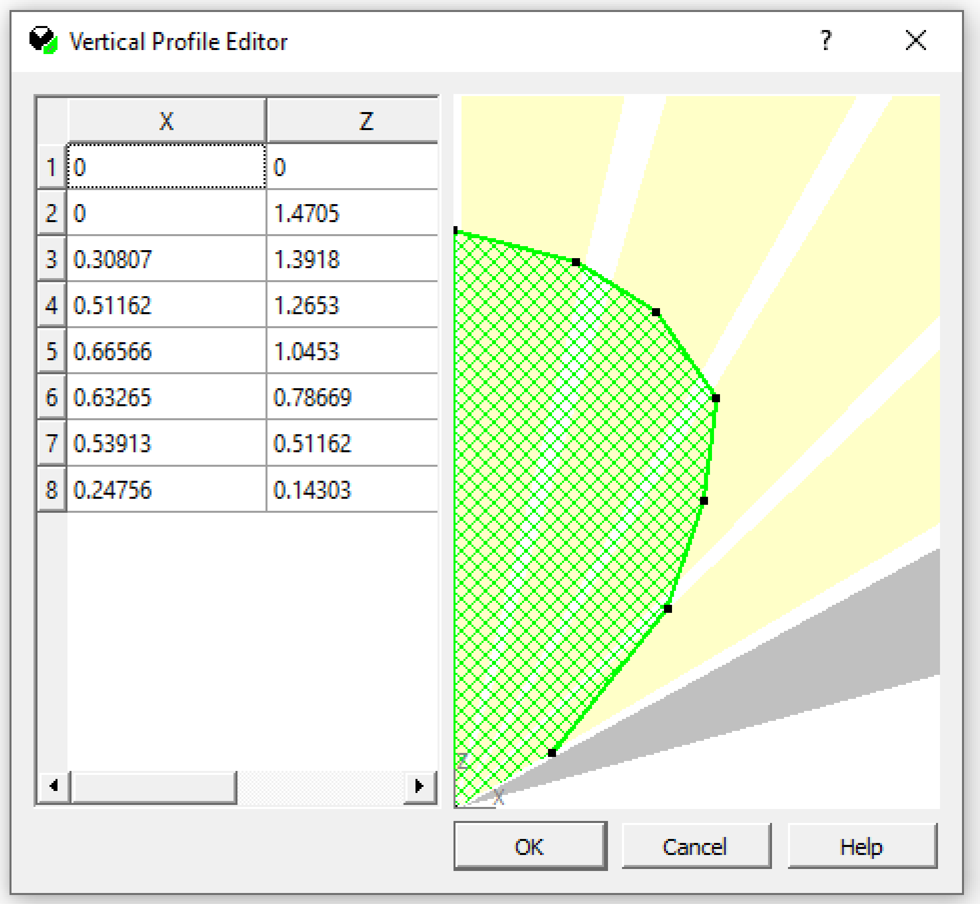


$$\mu = 2\int_0^{\pi/2} \frac{-\ln(T(\theta))}{S(\theta)} \sin\theta d\theta$$

$$\mu = -2\left[\frac{\ln(T_1)}{S_1}W_1 + \frac{\ln(T_2)}{S_2}W_2 + \frac{\ln(T_3)}{S_3}W_3 + \frac{\ln(T_4)}{S_4}W_4 + \frac{\ln(T_5)}{S_5}W_5\right](m^2m^{-3})$$

For an Isolated tree: IsoComputed



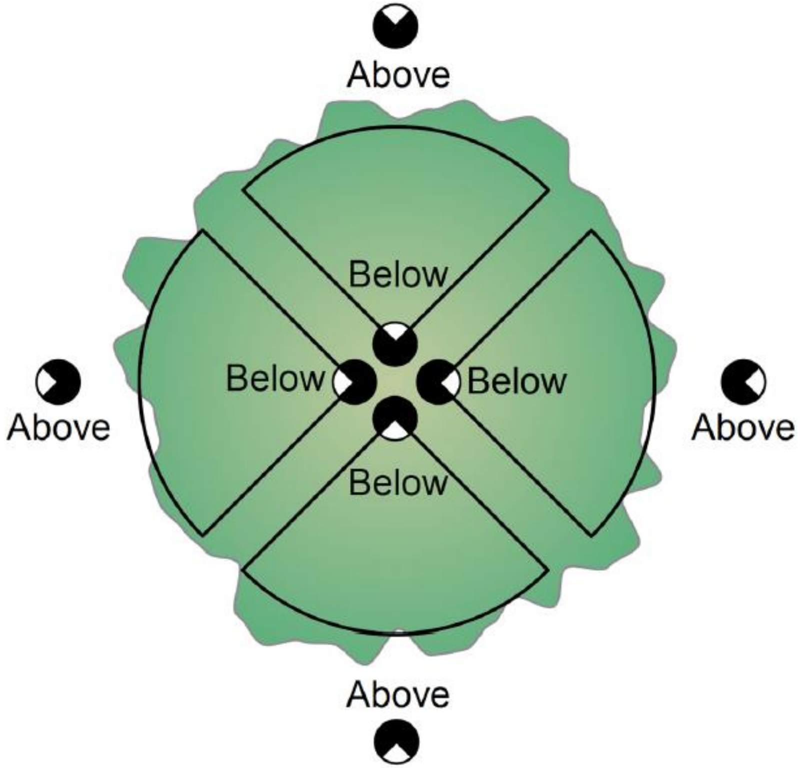


	X	Z
1	0	0
2	0	1.4705
3	0.30807	1.3918
4	0.51162	1.2653
5	0.66566	1.0453
6	0.63265	0.78669
7	0.53913	0.51162
8	0.24756	0.14303

Operational Considerations

For an Isolated Measured,

Use 90º or 45º view cap for 4 or more B readings



LI-COR

Verification

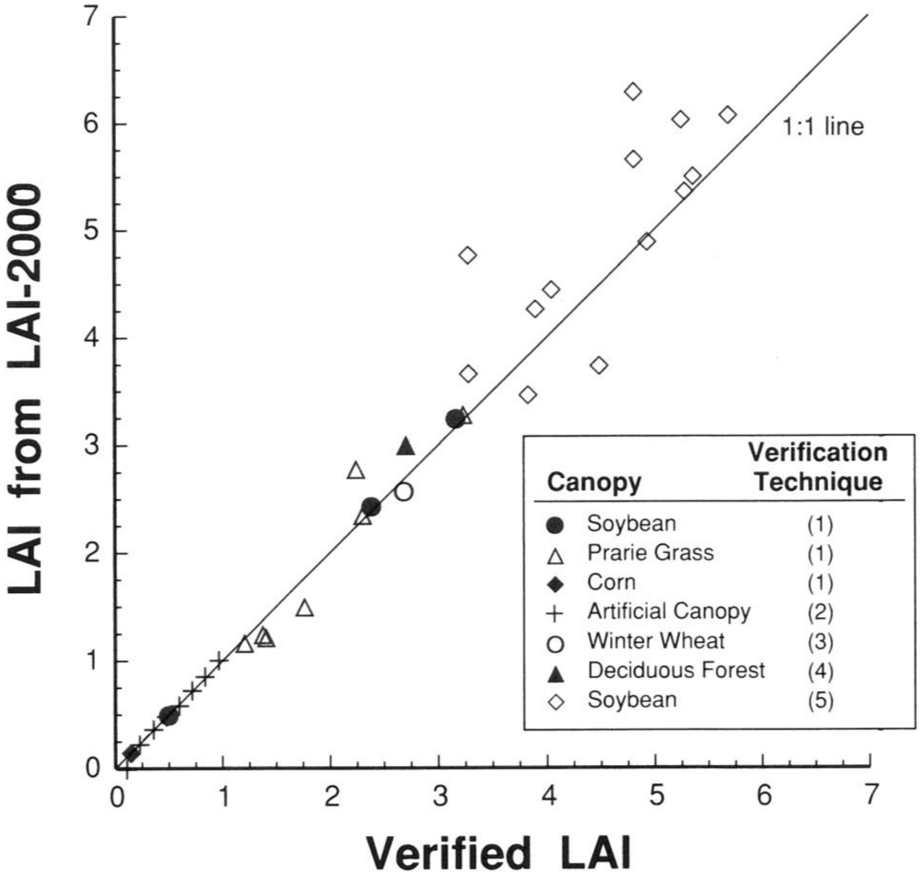
Verification

LAI-2000 Theory: Verification

minutes

Vs.

Hours/Days



What does LAI-2200 really measure?

What does LAI-2x00 really measure?

Operational Considerations

1. **Must be no change in radiation** when you take **A** and **B** readings.
2. LAI-2000 and LAI-2200 only work under diffuse radiation sky
3. LAI-2200C work under sunny sky also

$$T(\theta) = \frac{R_{below}}{R_{Above}}$$

Reference:

Wells, Norman. 1991. Instrument for indirect measurement of canopy architecture. *Agronomy Journal.* 83: 818-825.

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Data Analysis and FV-2200

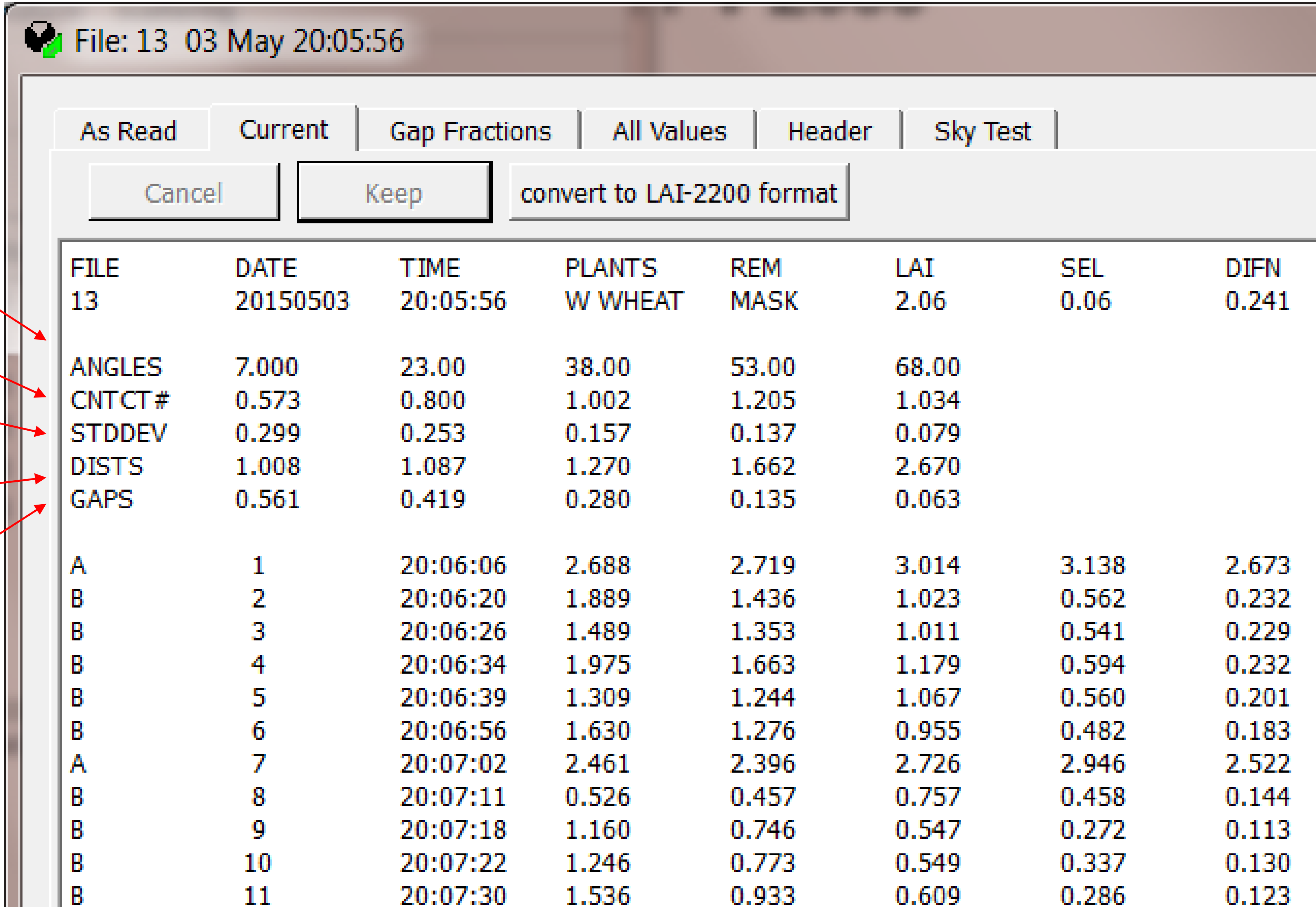
Zenith angle θ

$$K(\theta) = \frac{-\ln(T(\theta))}{s(\theta)}$$

Std Error of $K(\theta)$

$s(\theta)=1/\cos(\theta)$

$$T(\theta) = \frac{R_{below}}{R_{Above}}$$



File: 13 03 May 20:05:56

As Read | Current | Gap Fractions | All Values | Header | Sky Test

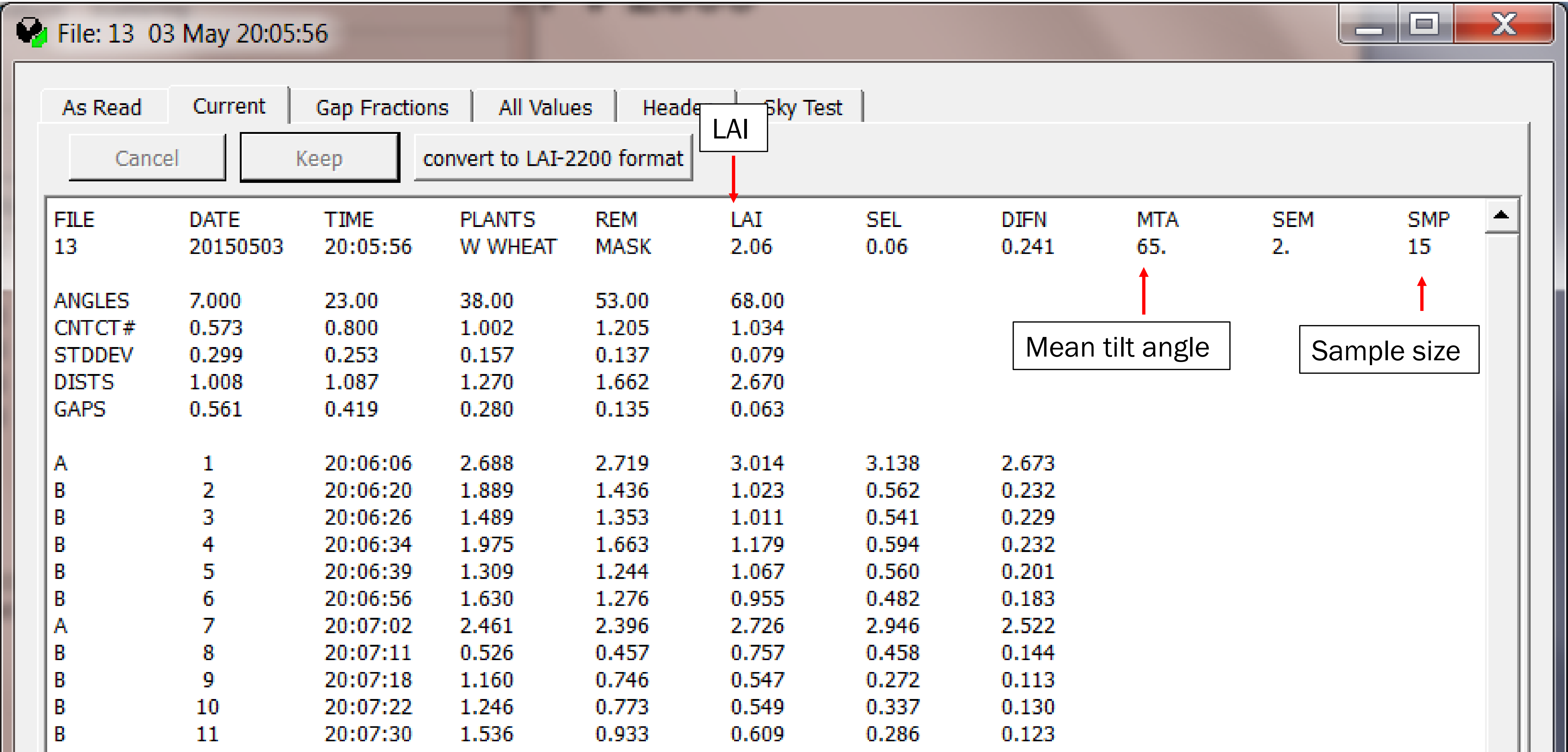
Cancel | Keep | convert to LAI-2200 format

FILE	DATE	TIME	PLANTS	REM	LAI	SEL	DIFN
13	20150503	20:05:56	W WHEAT	MASK	2.06	0.06	0.241

ANGLES	7.000	23.00	38.00	53.00	68.00
CNTCT#	0.573	0.800	1.002	1.205	1.034
STDDEV	0.299	0.253	0.157	0.137	0.079
DISTS	1.008	1.087	1.270	1.662	2.670
GAPS	0.561	0.419	0.280	0.135	0.063

A	1	20:06:06	2.688	2.719	3.014	3.138	2.673
B	2	20:06:20	1.889	1.436	1.023	0.562	0.232
B	3	20:06:26	1.489	1.353	1.011	0.541	0.229
B	4	20:06:34	1.975	1.663	1.179	0.594	0.232
B	5	20:06:39	1.309	1.244	1.067	0.560	0.201
B	6	20:06:56	1.630	1.276	0.955	0.482	0.183
A	7	20:07:02	2.461	2.396	2.726	2.946	2.522
B	8	20:07:11	0.526	0.457	0.757	0.458	0.144
B	9	20:07:18	1.160	0.746	0.547	0.272	0.113
B	10	20:07:22	1.246	0.773	0.549	0.337	0.130
B	11	20:07:30	1.536	0.933	0.609	0.286	0.123

Data Analysis and FV-2200



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B	11	20:07:30	1.536	0.933	0.609	0.286	0.123			

Then

What about this forest?

LAI-2200 &2200C, what's new?

1. GPS enabled
2. LAI mapping
3. Plot mapping
4. Clumping factor
5. Scattering correction

Clumping factor (Ω, 聚类因子)

$$LAI_e = \Omega \cdot LAI$$

LAI_e	effective leaf area index
Ω	clumping factor
LAI	true leaf area index

LAI_e: Effective leaf area index

What we would have for the LAI based on the gap fraction measured in the field with the assumption that all foliage were randomly distributed and no clumping.

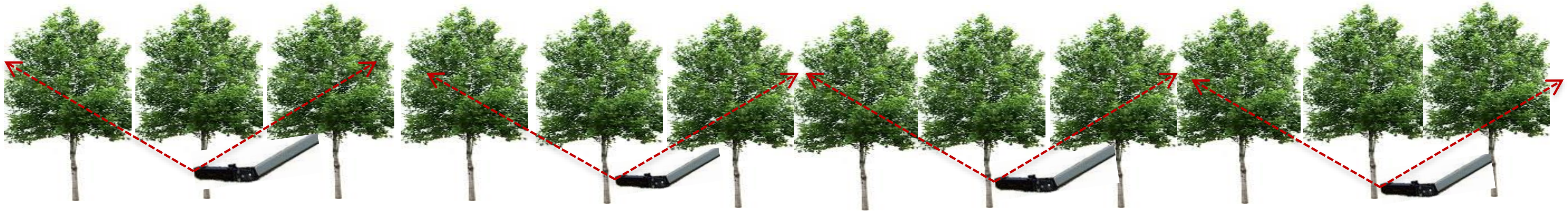
$$G(\theta) \cdot \mu = \frac{-\ln(T(\theta))}{S(\theta)} \equiv K(\theta)$$

$$G \cdot \mu = \frac{-\ln(T)}{S} \equiv K$$

$$LAI = \mu \cdot z$$

$$LAI = \frac{-\ln(T)}{G} \cos(\theta) = \frac{-\ln(T)}{G}$$ When θ=0

Assume: LAI=2, G=0.5, T_o=exp(-2x0.5)=0.368



$$LAI_e = \frac{-\overline{\ln(T_o)}}{G} = \frac{-(\ln(0.368)+\ln(0.368)+\ln(0.368)+\ln(0.368))}{4\times 0.5} = 2.0$$

$$LAI_e = \frac{-\ln(\overline{T_o})}{G} = \frac{-\ln((0.368+0.368+0.368+0.368)/4)}{0.5} = 2.0$$

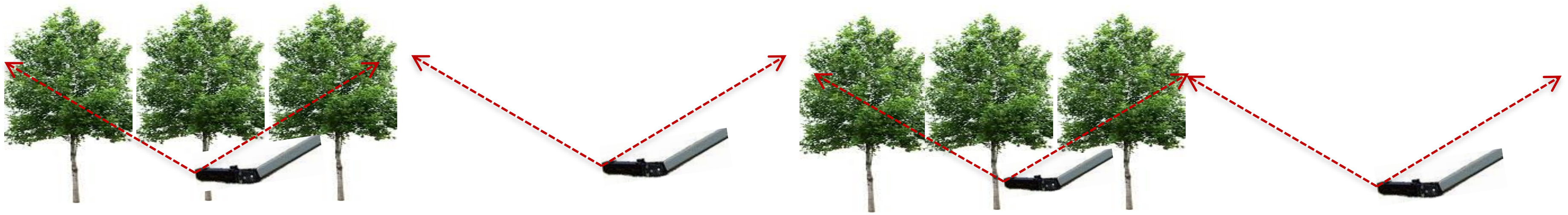
$$\Omega = \frac{LAI_e}{LAI} = 1.0$$

LAI=2.0
G=0.5,
T_o=exp(-2x0.5)=0.368

LAI=0
G=0.5,
T_o=1

LAI=2.0
G=0.5,
T_o=exp(-2x0.5)=0.368

LAI=0
G=0.5,
T_o=1



LAI = LAI_e =2 *LAI = LAI_e =0* *LAI = LAI_e =2* *LAI = LAI_e =0*

$$LAI_e = \frac{-\overline{\ln(T_o)}}{G} = \frac{-(\ln(0.368)+\ln(1)+\ln(0.368)+\ln(1))}{4\times 0.5} = 1.0$$

$$LAI_e = \frac{-\ln(\overline{T_o})}{G} = \frac{-\ln((0.368+1+0.368+1)/4)}{0.5} = 0.76$$

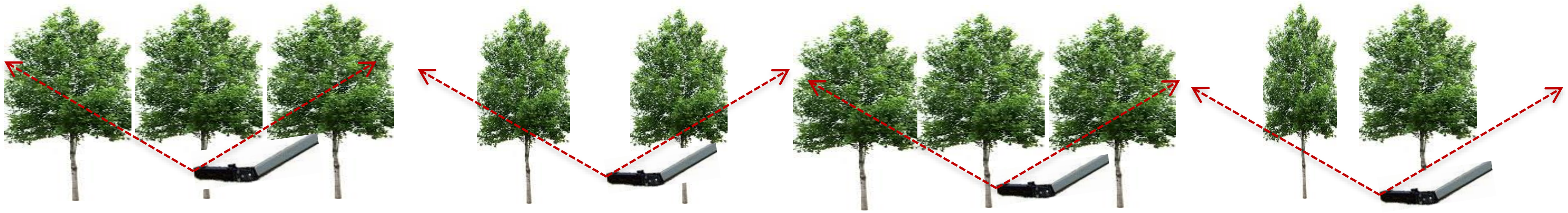
$$LAI = 1.0 \qquad \Omega = \frac{LAI_e}{LAI} = 0.76$$

LAI=2.0
G=0.5,
T_o*=exp(-2x0.5)=0.368*

LAI=1.0
G=0.5,
T_o*=exp(-1x0.5)=0.607*

LAI=2.0
G=0.5,
T_o*=exp(-2x0.5)=0.368*

LAI=1.0
G=0.5,
T_o*=exp(-1x0.5)=0.607*



$LAI = LAI_e = 2$ $\qquad$ $LAI = LAI_e = 1$ $\qquad$ $LAI = LAI_e = 2$ $\qquad$ $LAI = LAI_e = 1$

$$LAI_e = \frac{-\overline{\ln(T_o)}}{G} = \frac{-(\ln(0.368)+\ln(0.607)+\ln(0.368)+\ln(0.607))}{4\times 0.5} = 1.5$$

$$LAI_e = \frac{-\ln(\overline{T_o})}{G} = \frac{-\ln((0.368+0.607+0.368+0.607)/4)}{0.5} = 1.44$$

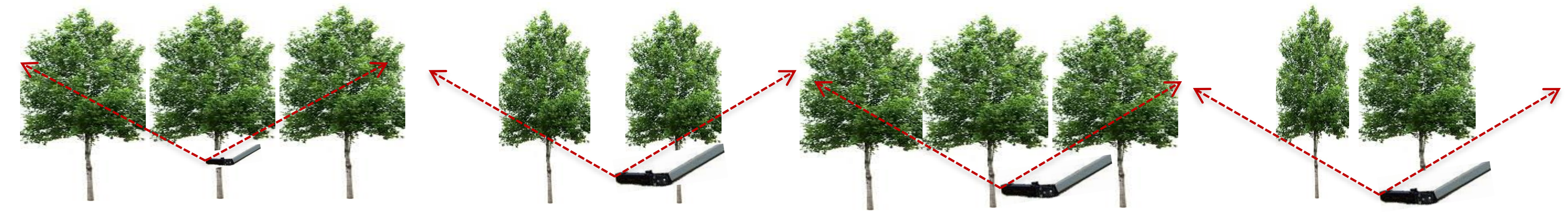
$$LAI = 1.5 \qquad \Omega = \frac{LAI_e}{LAI} = 0.96$$

Ω_{app}: apparent clumping factor, 表观聚类因子

$$\Omega_{app} = \frac{2\int_0^{\pi/2} -\frac{\ln \overline{T(\theta)}}{S(\theta)} \sin\theta d\theta}{2\int_0^{\pi/2} -\frac{\overline{\ln T(\theta)}}{S(\theta)} \sin\theta d\theta}$$

Is this LAI the true leaf index?

The denominator (LAI) doesn't account for the clumping effect on spatial scales smaller than the field view of the sensor, that's why we call it apparent clumping factor.



Clumping on spatial scales larger than the field view of the sensor

Clumping on spatial scales smaller than the field view of the sensor