Impacts of Forest Canopy Structure on Energy, Water and Carbon Fluxes

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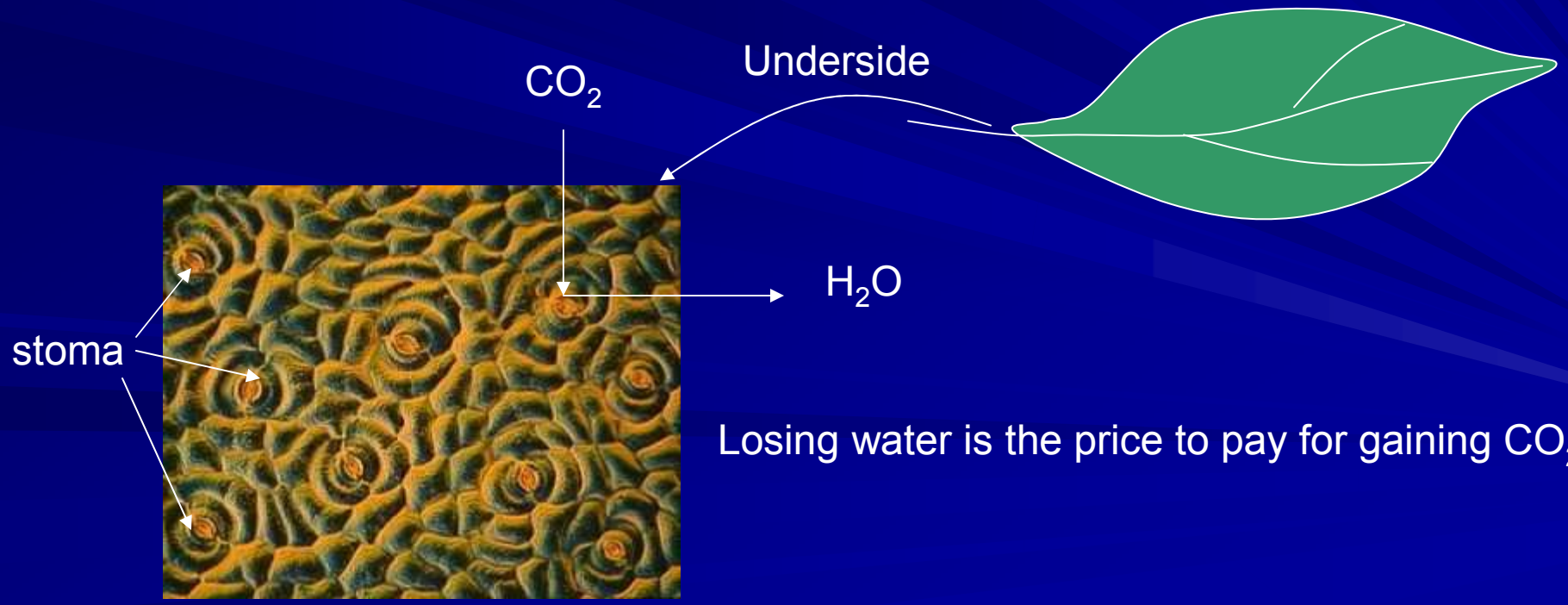
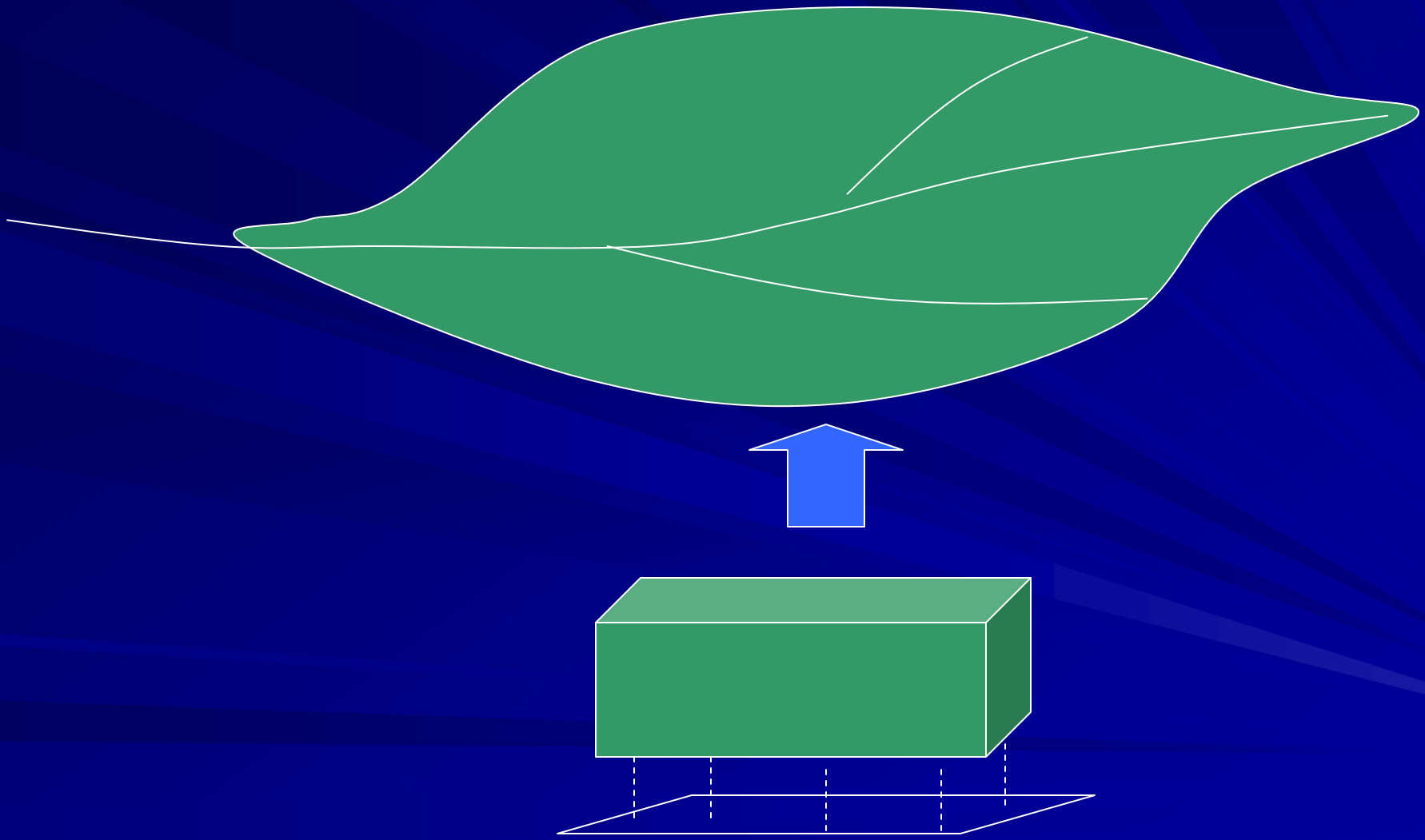
Small Leaves Do the Big Job

$$6CO_2 + 6H_2O \xrightarrow{\text{light/Chloroplast}} C_6H_{12}O_6 + 6O_2 \uparrow$$

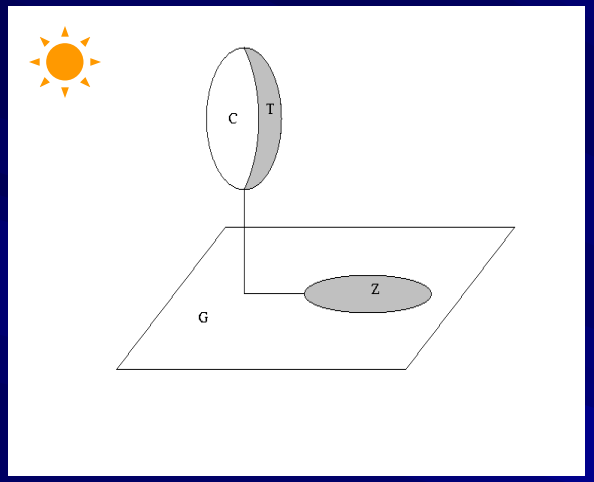


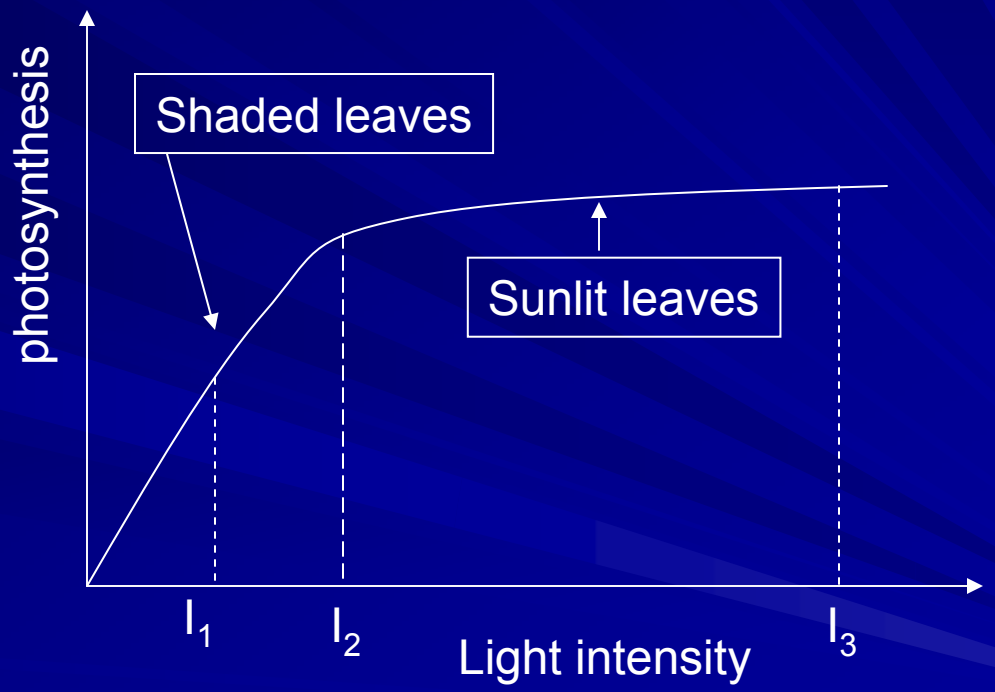
Losing water is the price to pay for gaining CO_2

Big-Leaf Scaling up



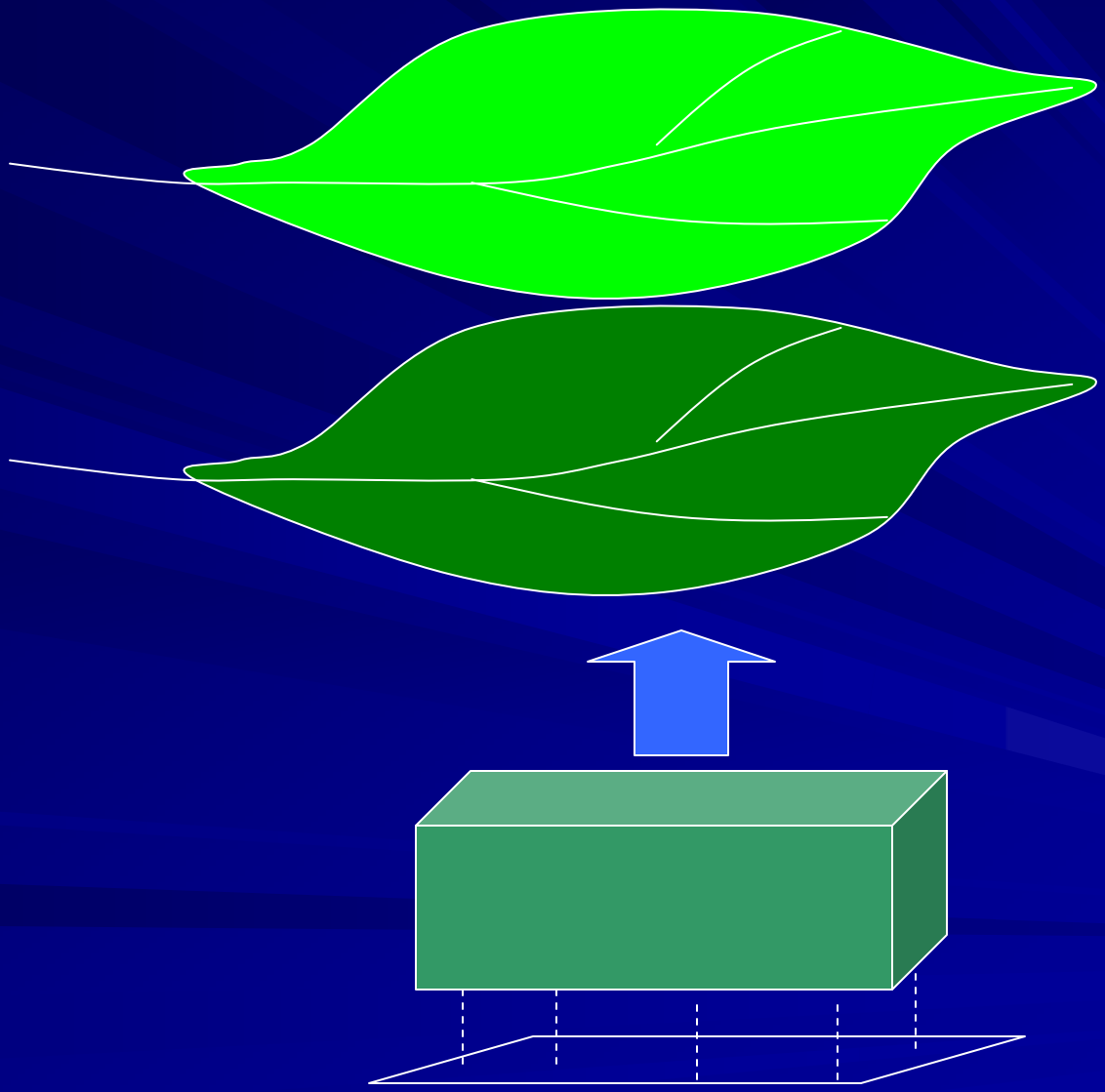
Sunlit and Shaded Leaves



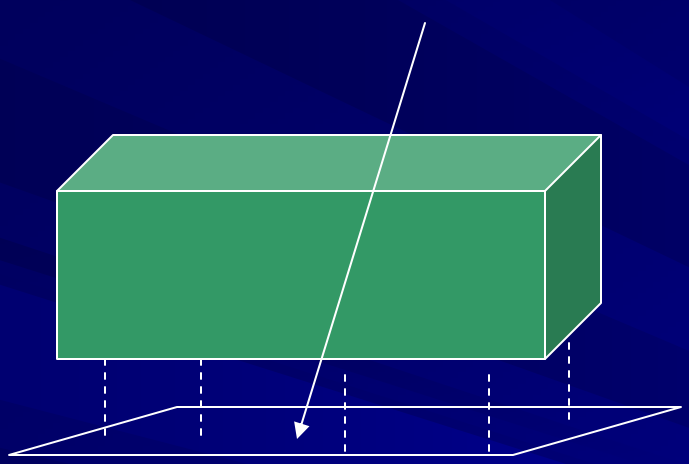


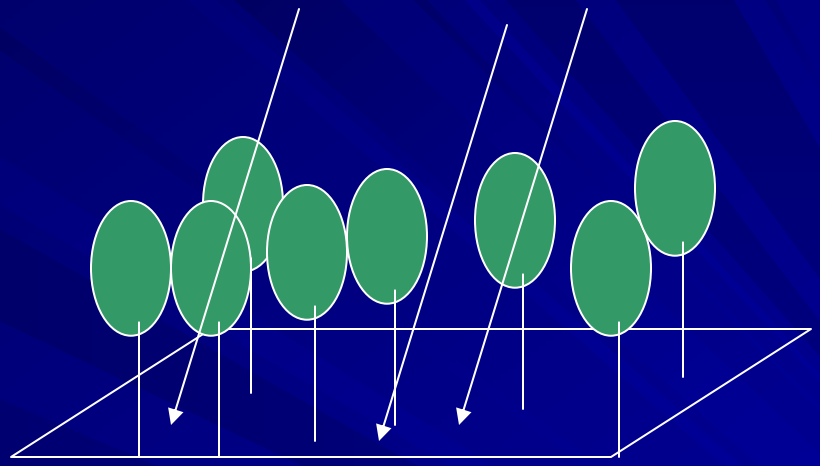
$$\mathrm{PSN}\left(\frac{\text{diffuse light}}{\text{shaded leaves}}\right)+\mathrm{PSN}\left(\frac{\text{direct light}}{\text{sunlit leaves}}\right)\neq\mathrm{PSN}\left(\frac{\text{diffuse light}+\text{direct light}}{\text{shaded leaves}+\text{sunlit leaves}}\right)$$

Two-Leaf Scaling up



Uniform vs Gappy Canopy



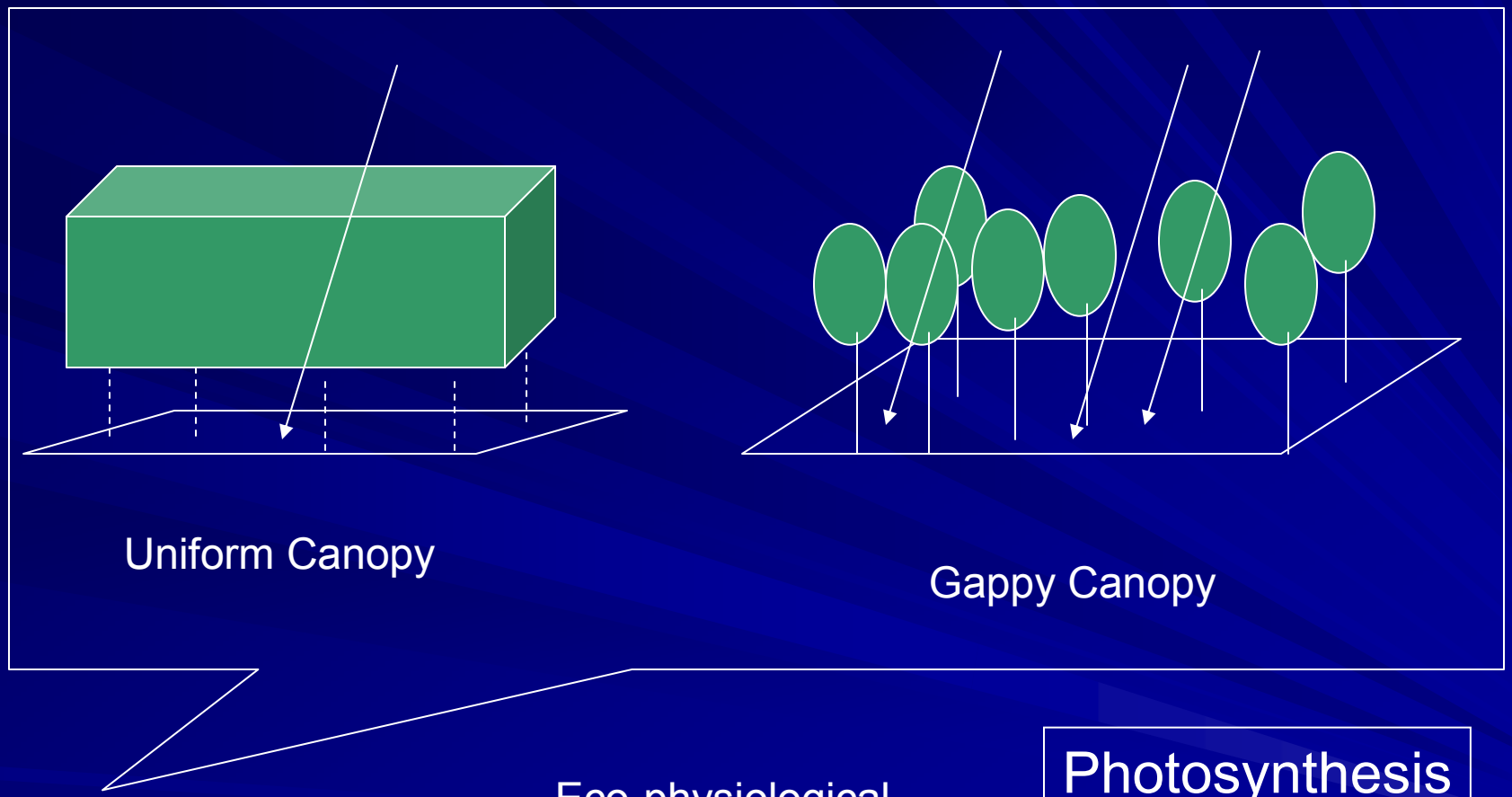


Uniform Canopy

Gappy Canopy

Sun flecks

Impacts of Canopy Structure on Ecosystem Processes



Intercepted Radiation

(two leaf scaling up)

Eco-physiological

models

Photosynthesis

Transpiration

Sources of Data for Model Verification

AmeriFlux Tower

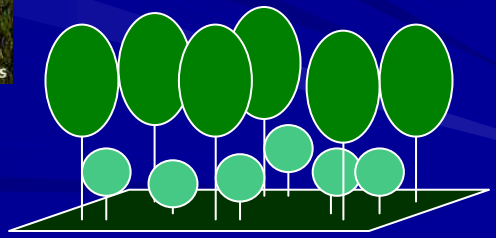
Duke Forest FACE Site

Pine density:
1377 trees/ha

Understory hardwoods:
1470 trees/ha

Leaf area index:

4.7-5.9



Measured Data: net radiation, evapotranspiration, net ecosystem exchange during May to Sept for 2001

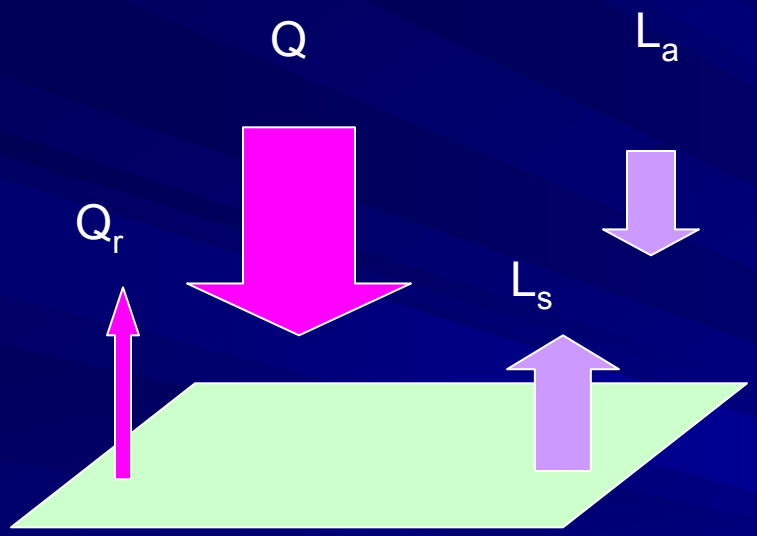
Model Inputs

- Incoming radiation
- Precipitation
- Air temperature
- Soil temperature
- Soil moisture
- Wind speed
- Vapor Pressure Deficit
- Leaf Area Index (LAI)

All input data are obtained from the on-site measurements. The data in 2001 were used for model evaluation.

Net Radiation

Radiation Budget:



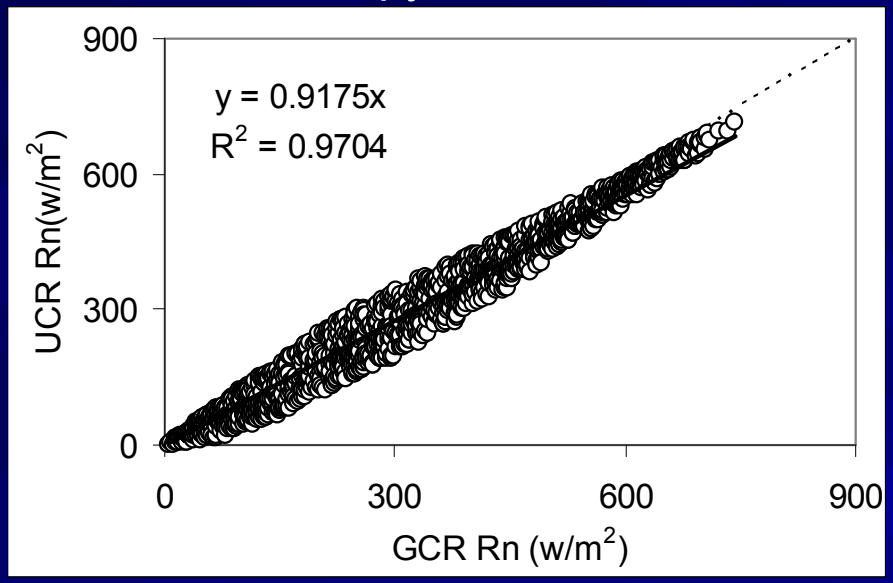
$$R_n = (Q - Q_r) - (L_s - L_a)$$

$$Q = PAR + NIR$$

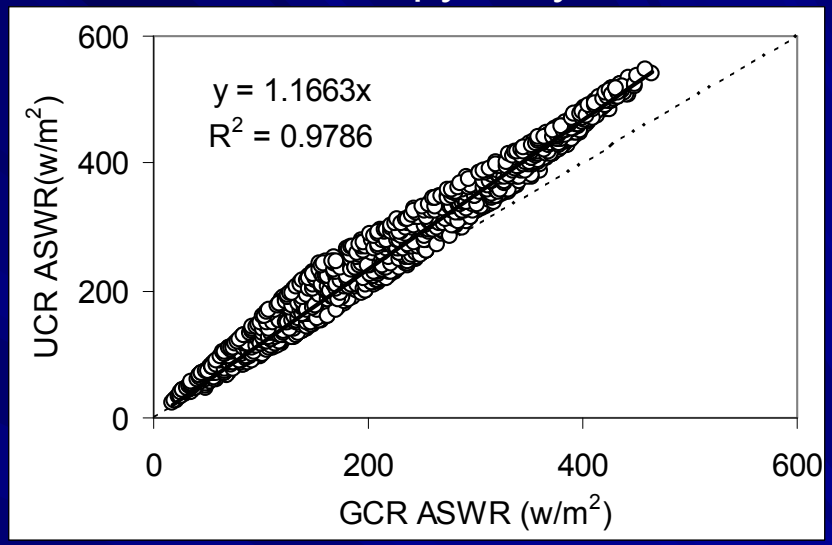
Energy Budget: Net radiation is used for heat storage in the soil and plant body, evaporate water (latent heat), heating the air near the surface (sensible heat), and photosynthesis

Modeling of Net Radiation

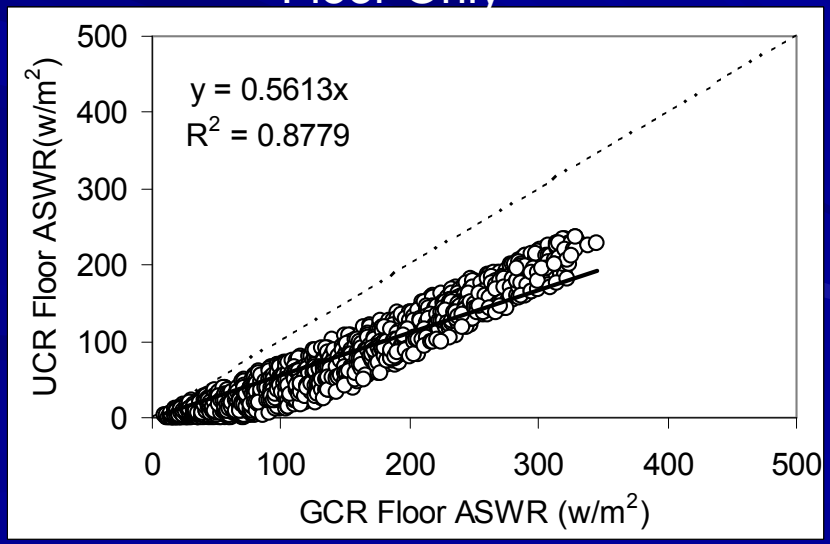
Canopy+Floor



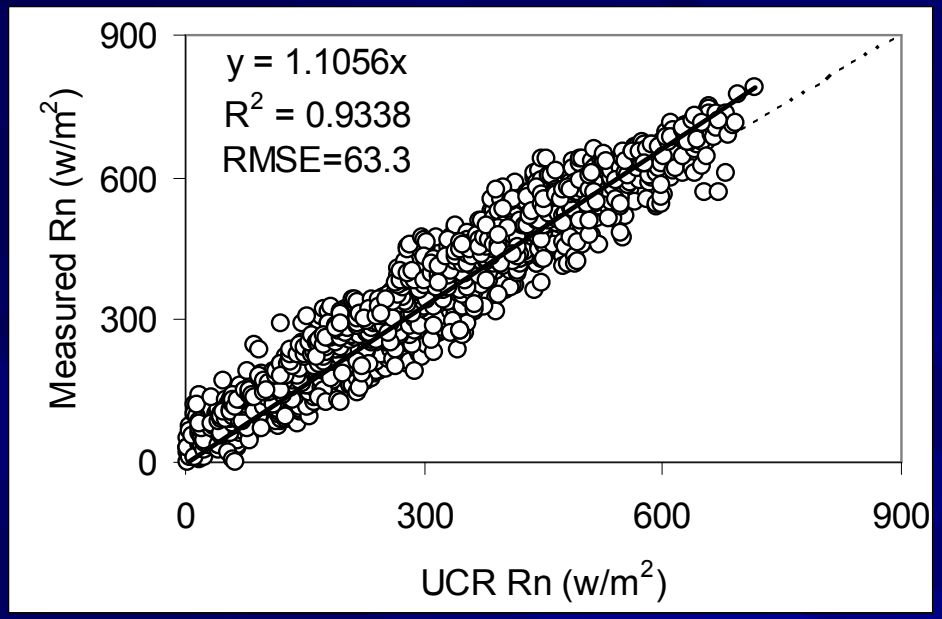
Canopy Only

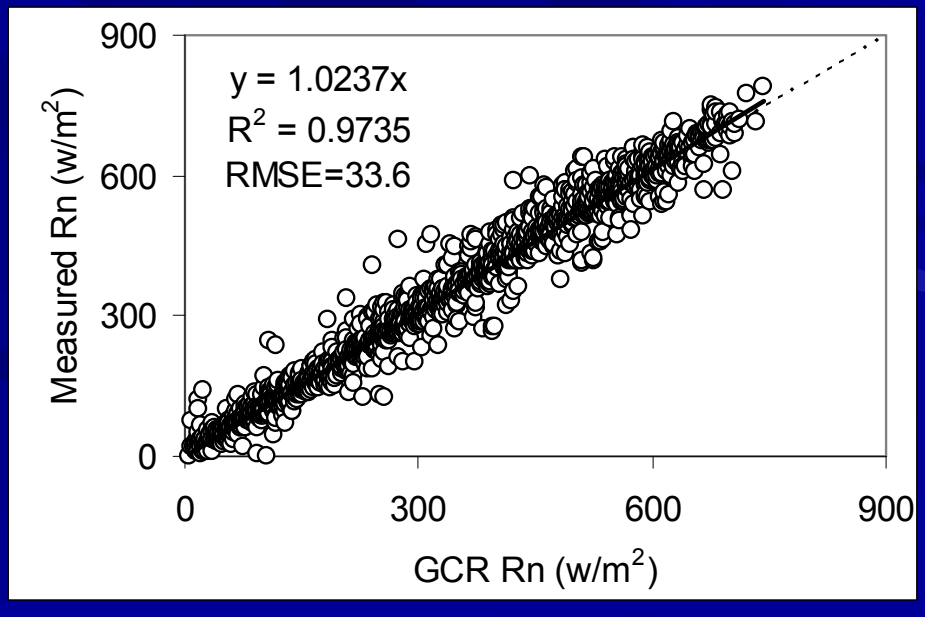


Floor Only



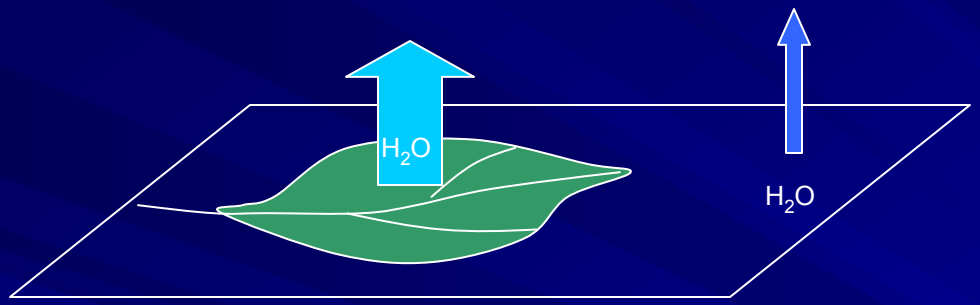
Validation of Net Radiation





Latent Heat (Evapotranspiration)

Transpiration + Evaporation = Evapotranspiration

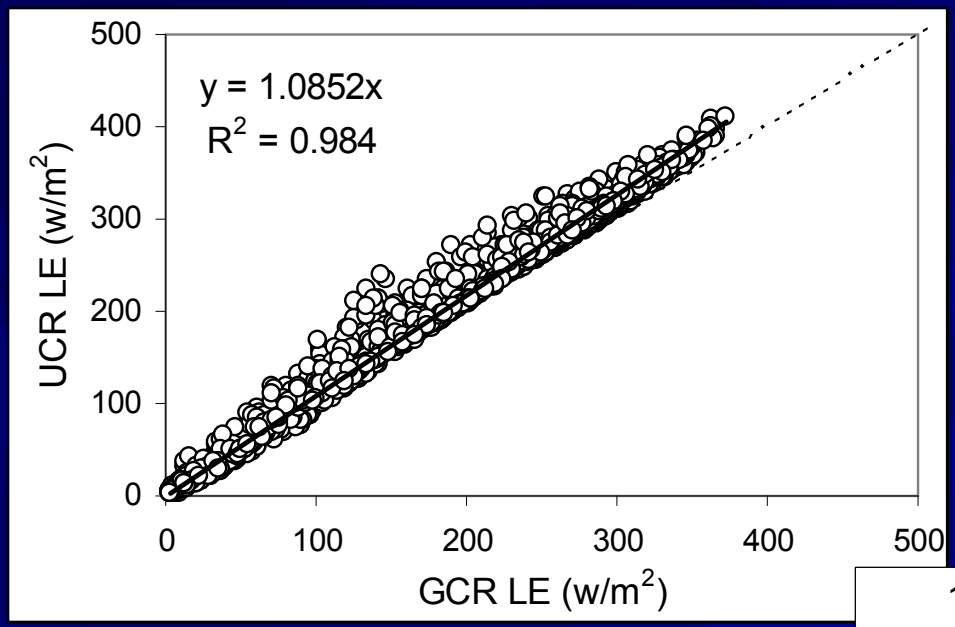


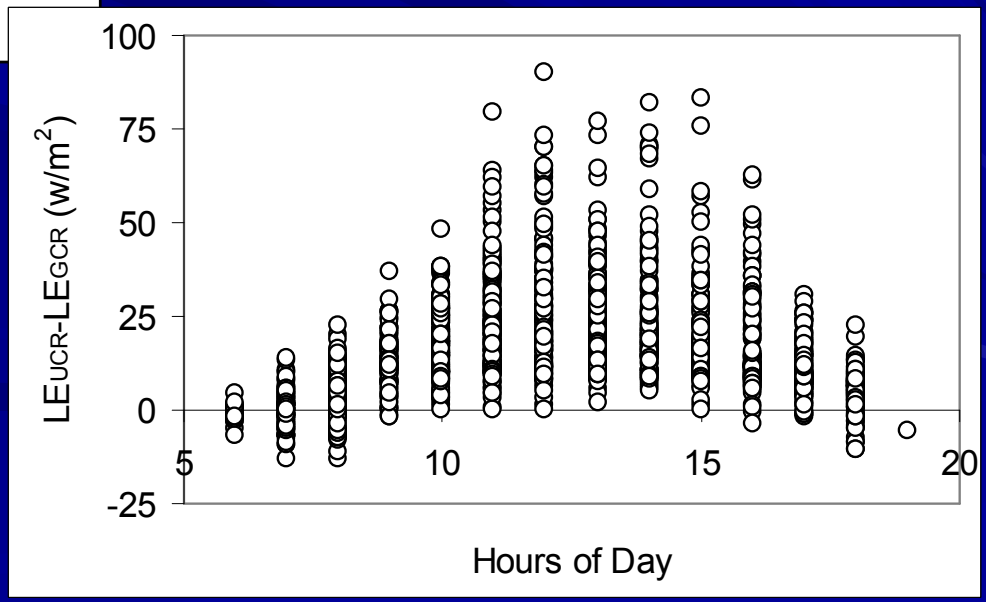
Penman-Monteith equation coupled with Ball-Woodward-Berry model

$$LE_T = \frac{\Delta R_n + g_a \rho c_p [e_s(T) - e(T)]}{\Delta + \gamma_0 (1 + \frac{g_a}{g_{sw}})}$$

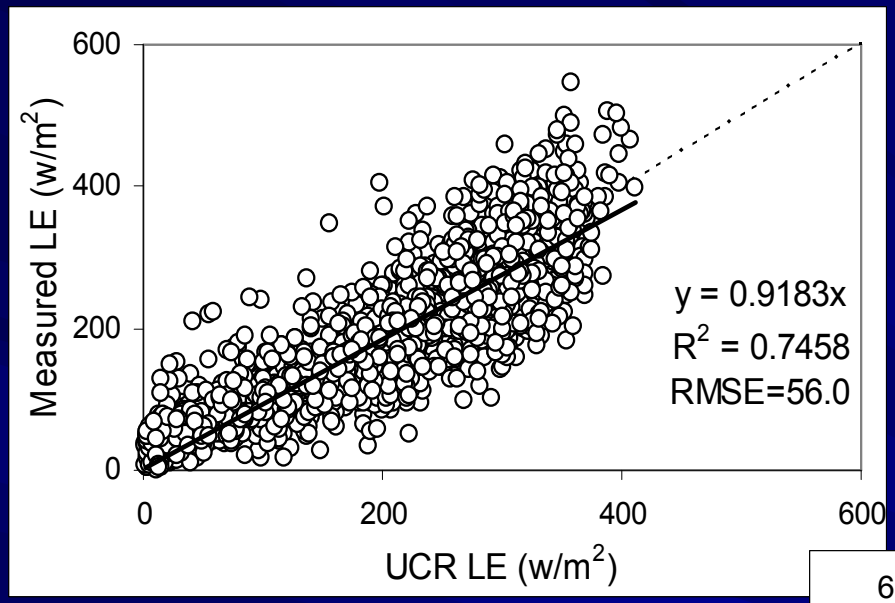
R_n: Uniform vs. Gappy Canopy (two-leaf scaling up)
g_{sw}: Stomatal conductance based on Ball-Woodward-Berry model
g_a: Aerodynamic conductanceneutrally stratified rough-wall boundary layer formulation

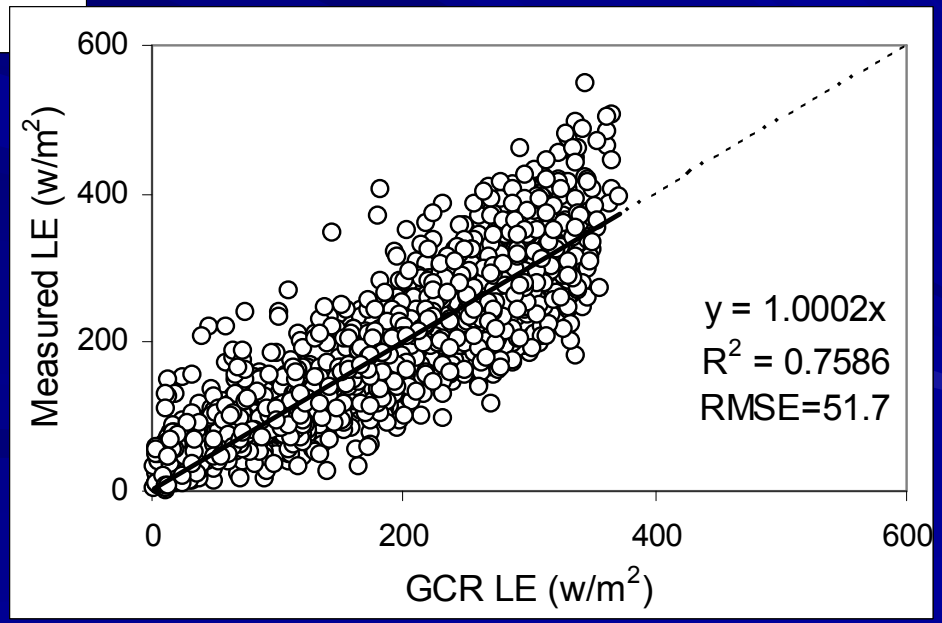
Modeled Latent Heat Flux



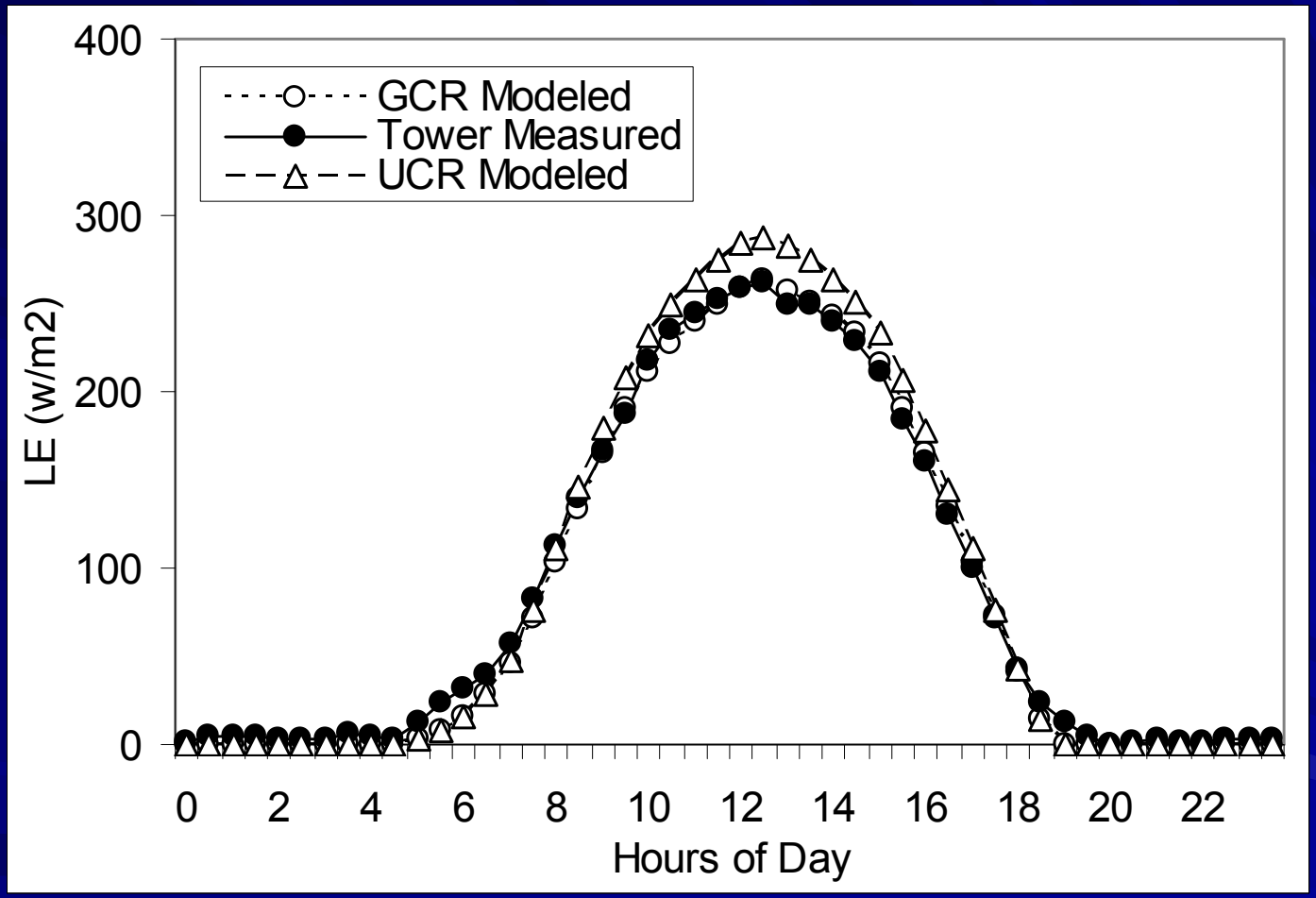


Validation of Modeled Latent Heat at Half Hourly Scale

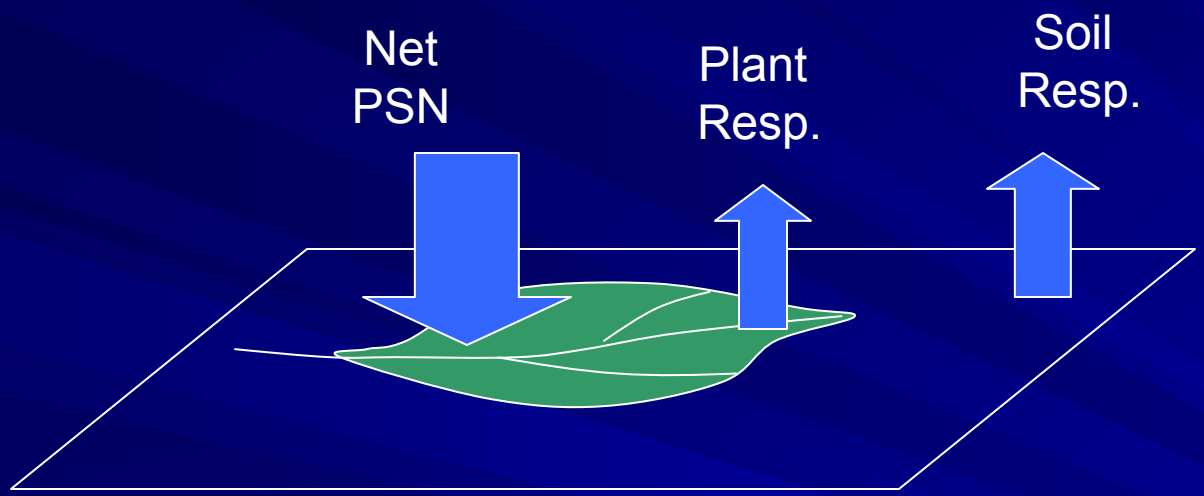




Validation of Daytime Trend over the Growing Season

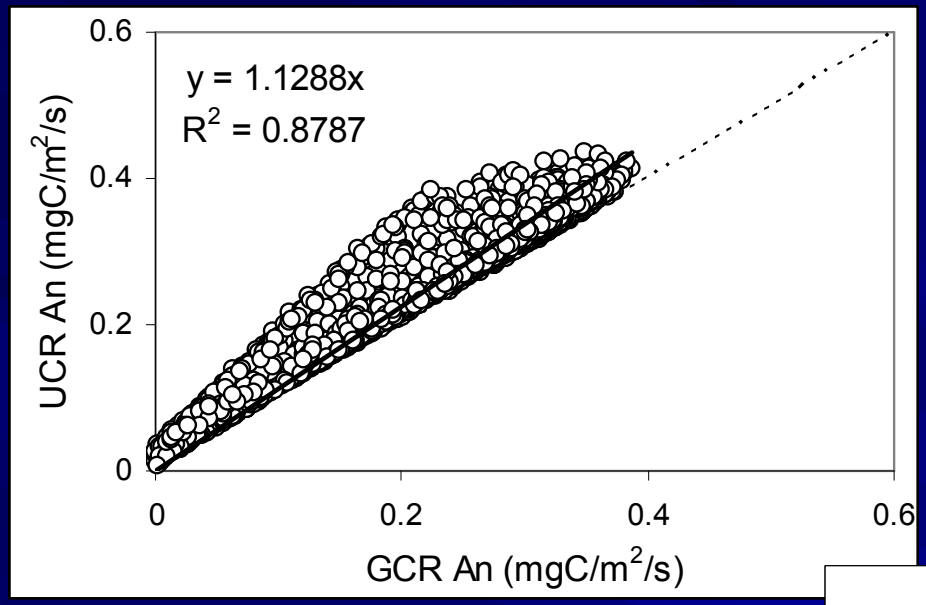


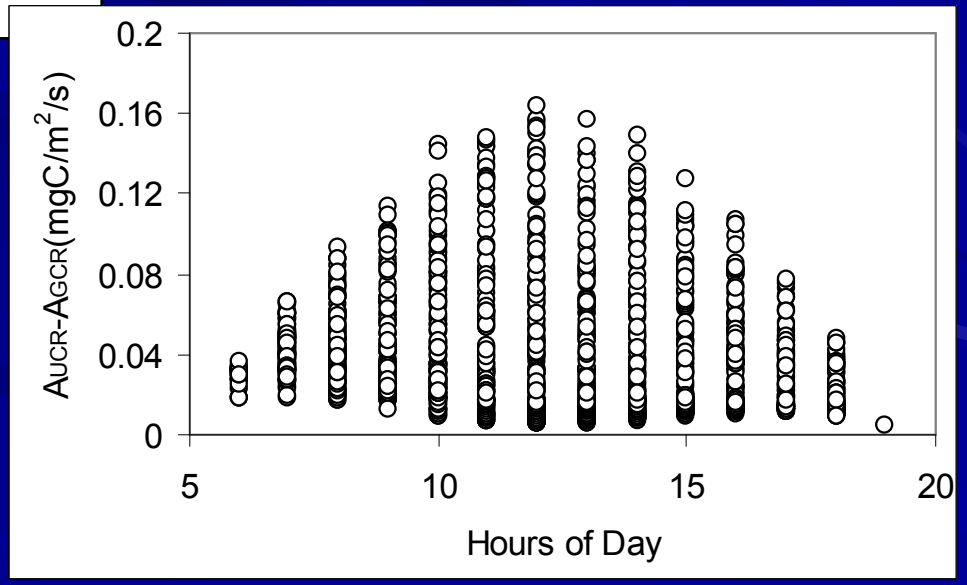
Carbon Assimilation



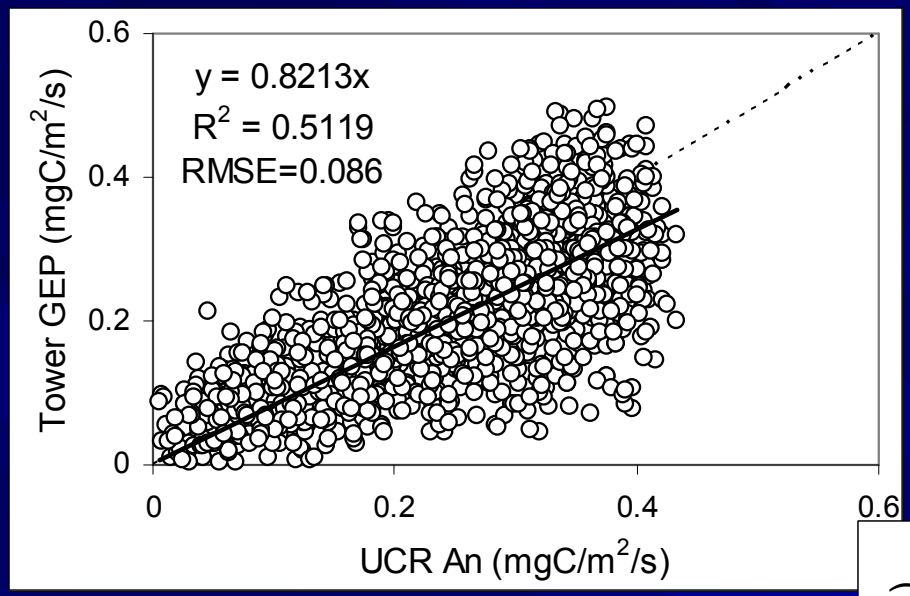
Tower Measurement: Net Ecosystem Exchange (NEE)
Measured data cannot separate Net PSN from plant (stems, leaves and roots) and soil (dead biomass) respiration. A model is needed to estimate the plant and soil respiration in order to get Net PSN.

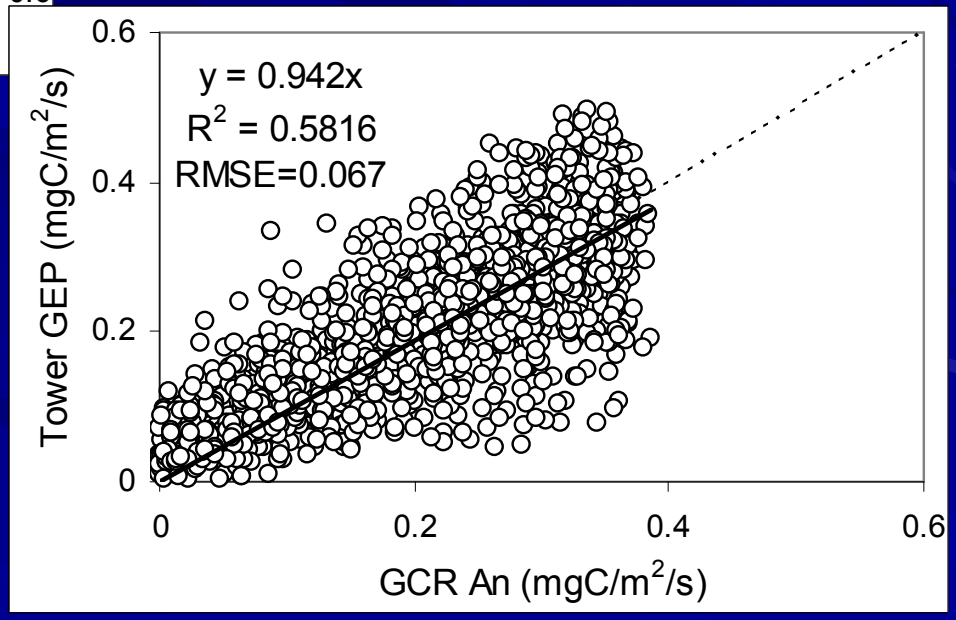
Modeling of Net PSN



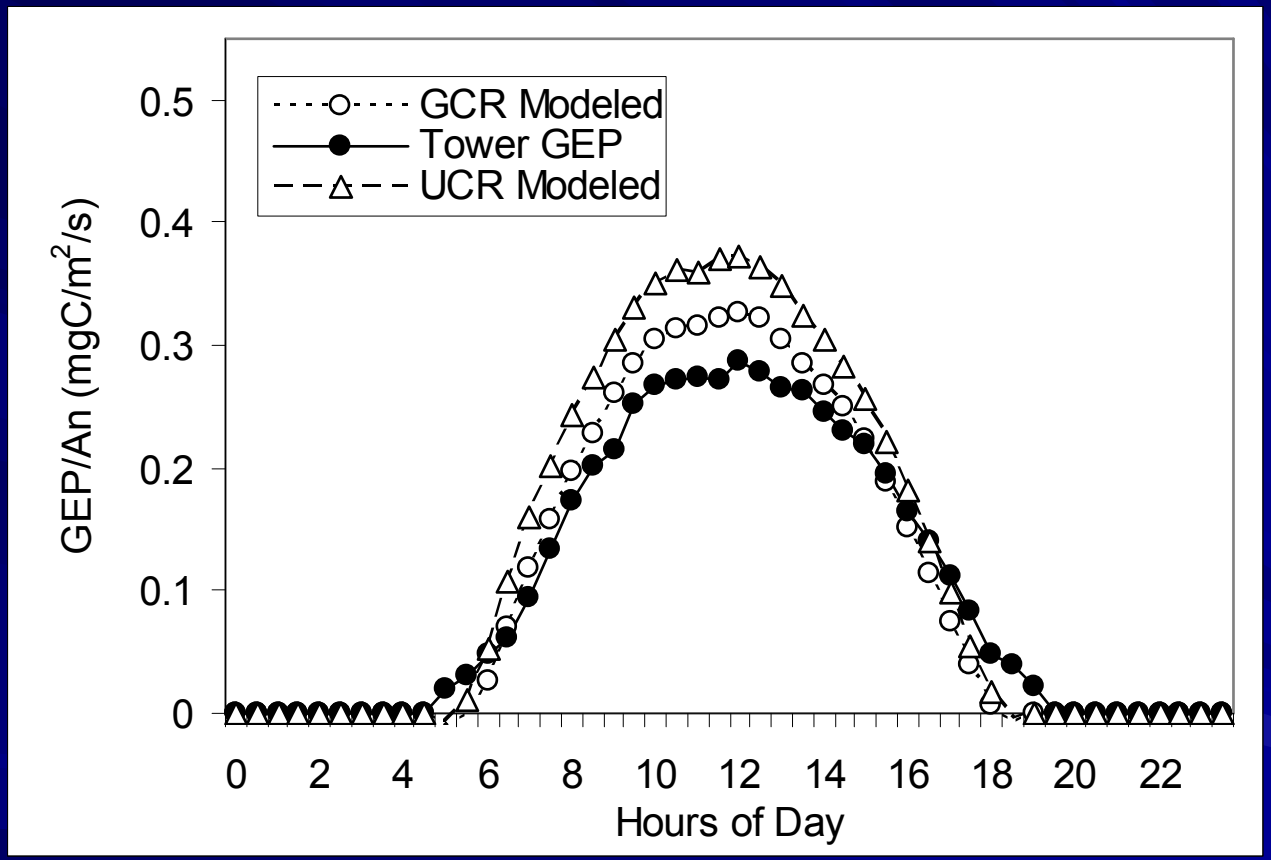


Validation of Net PSN at Half Hourly Scale





Validation of Net PSN Daytime Trend



Conclusions

1. Canopy Structure has significant impacts in modeling energy, water and carbon exchange between the forest ecosystem and the atmosphere.
2. Uniform canopy overestimates shortwave interception in the canopy, underestimates shortwave absorption on the forest floor, underestimates stand net radiation.
3. Differences in modeling results between uniform canopy and gappy canopy are nonlinear, indicating the bias cannot be corrected with linear scalar parameters.
4. Modeling of terrestrial ecosystem processes over large areas without explicit consideration of vegetation structure can lead to serious bias.

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