Leaf Energy Balance, part 2

- IsoThermal Energy Balance
- Critical Limits on Evaporation
  - infinite surface conductance
  - infinite aerodynamic conductance
  - zero surface conductance
  - zero aerodynamic conductance
- Response surfaces, leaf-air temperature differences, Optimal Leaf Form, Size and Shape

IsoThermal Radiation Balance

$$R_{ni} = Q - \sigma \varepsilon T_a^4$$

$$R_n = Q - \sigma \varepsilon T_l^4 =$$
$$Q - (\sigma \varepsilon T_a^4 + 4\sigma \varepsilon T_a^3 (T_l - T_a)) =$$
$$R_{ni} - 4\sigma \varepsilon T_a^3 (T_l - T_a)$$

$$\lambda E = \frac{s R_{iso} + D \rho_a C_p (g_r + g_h)}{(s + \frac{\gamma g_r}{g_w} + \frac{\gamma g_h}{g_w})}$$

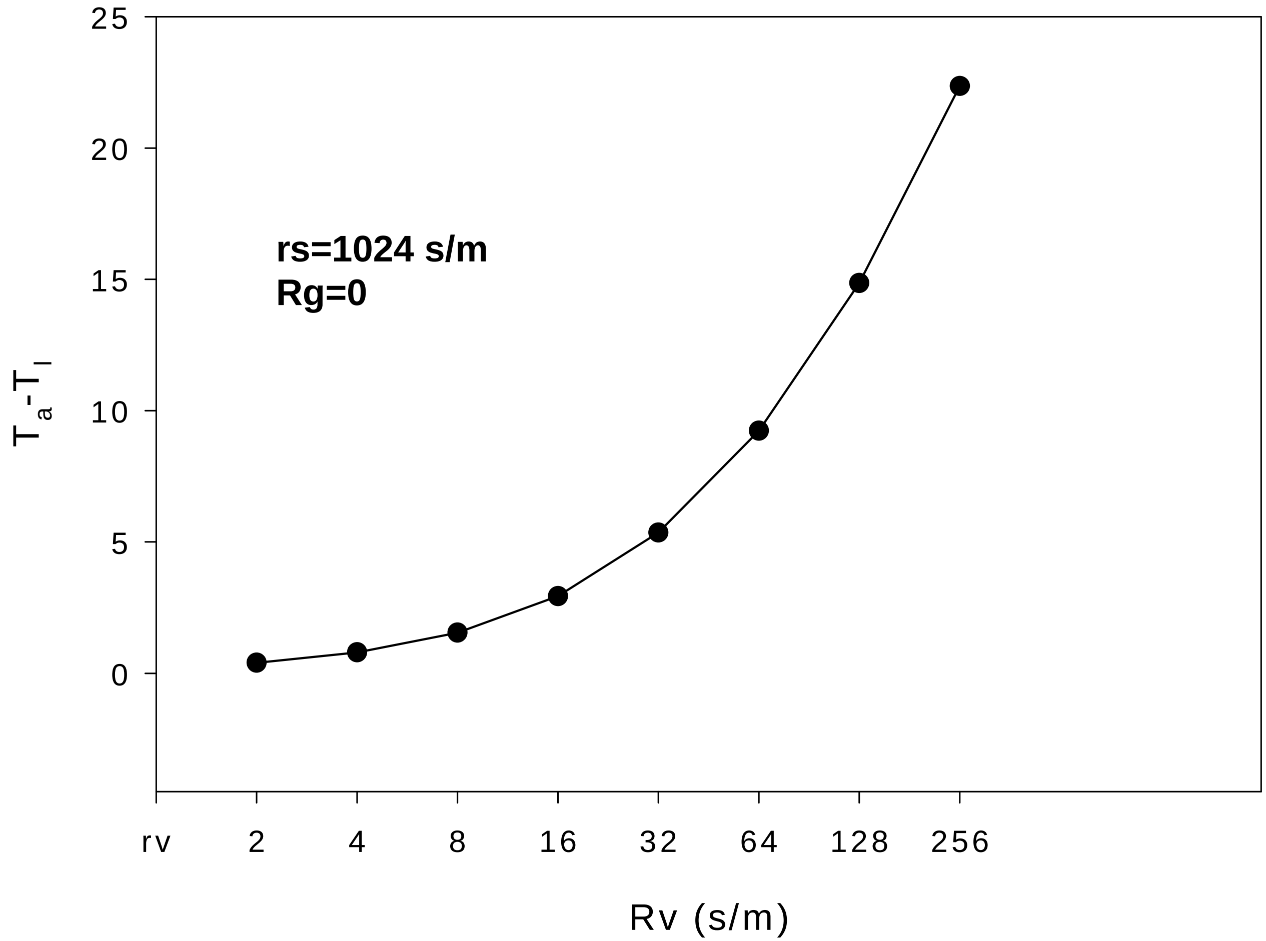
$$g_r = \frac{4 \varepsilon \sigma T_a^3}{\rho C_p}$$

Nocturnal Evaporation
surface conductance goes to infinity as the surface is wet with condensation

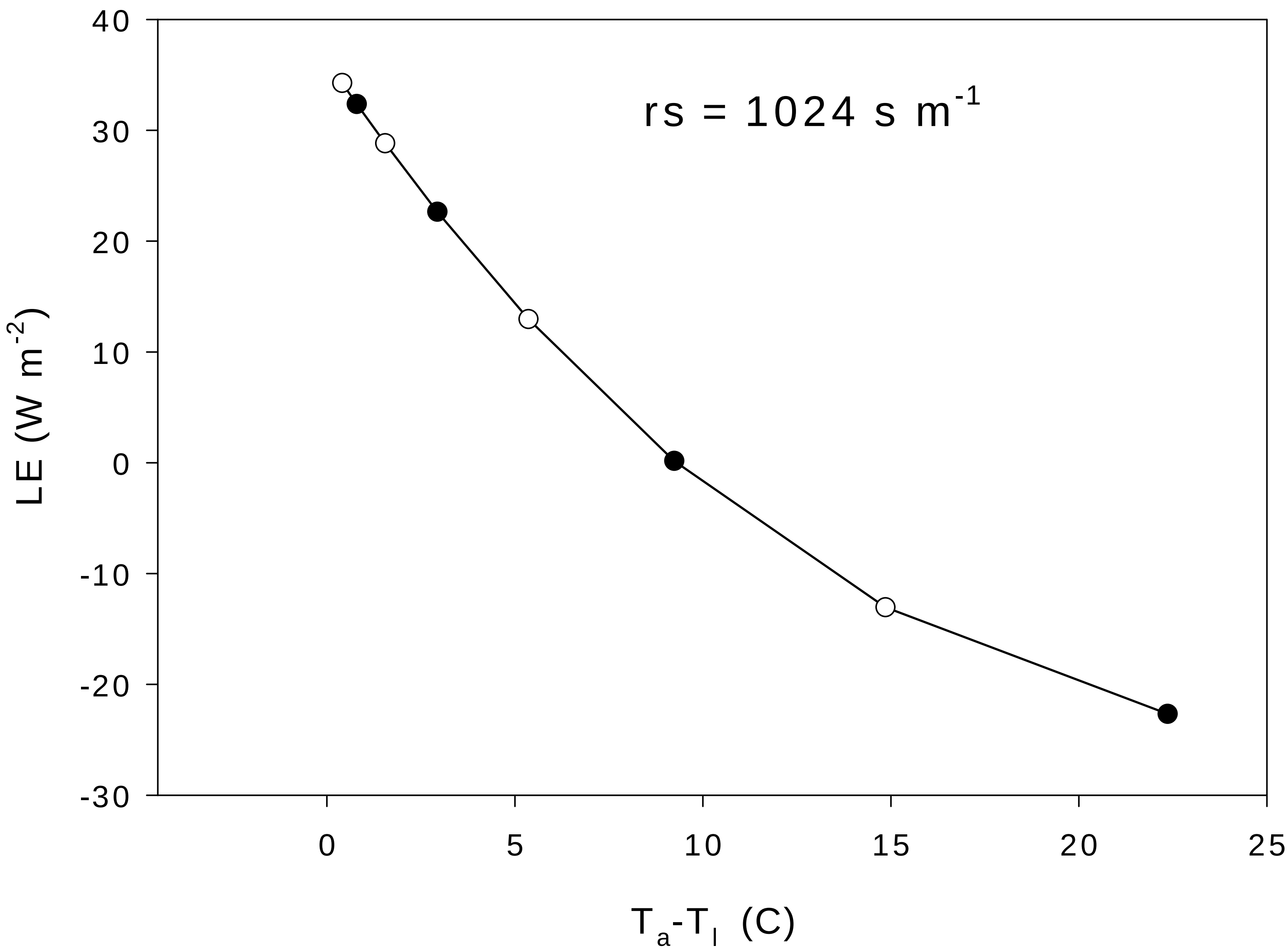
$$\lambda E = \frac{sR_{iso} + D\rho_a C_p (g_r + g_h)}{(s + \gamma (1 + \frac{g_r}{g_{av}})(1 + \frac{g_{av}}{\infty})}$$

$$\lambda E = \frac{sR_{iso} + D\rho_a C_p (g_r + g_h)}{(s + \gamma (1 + \frac{g_r}{g_{av}})}$$

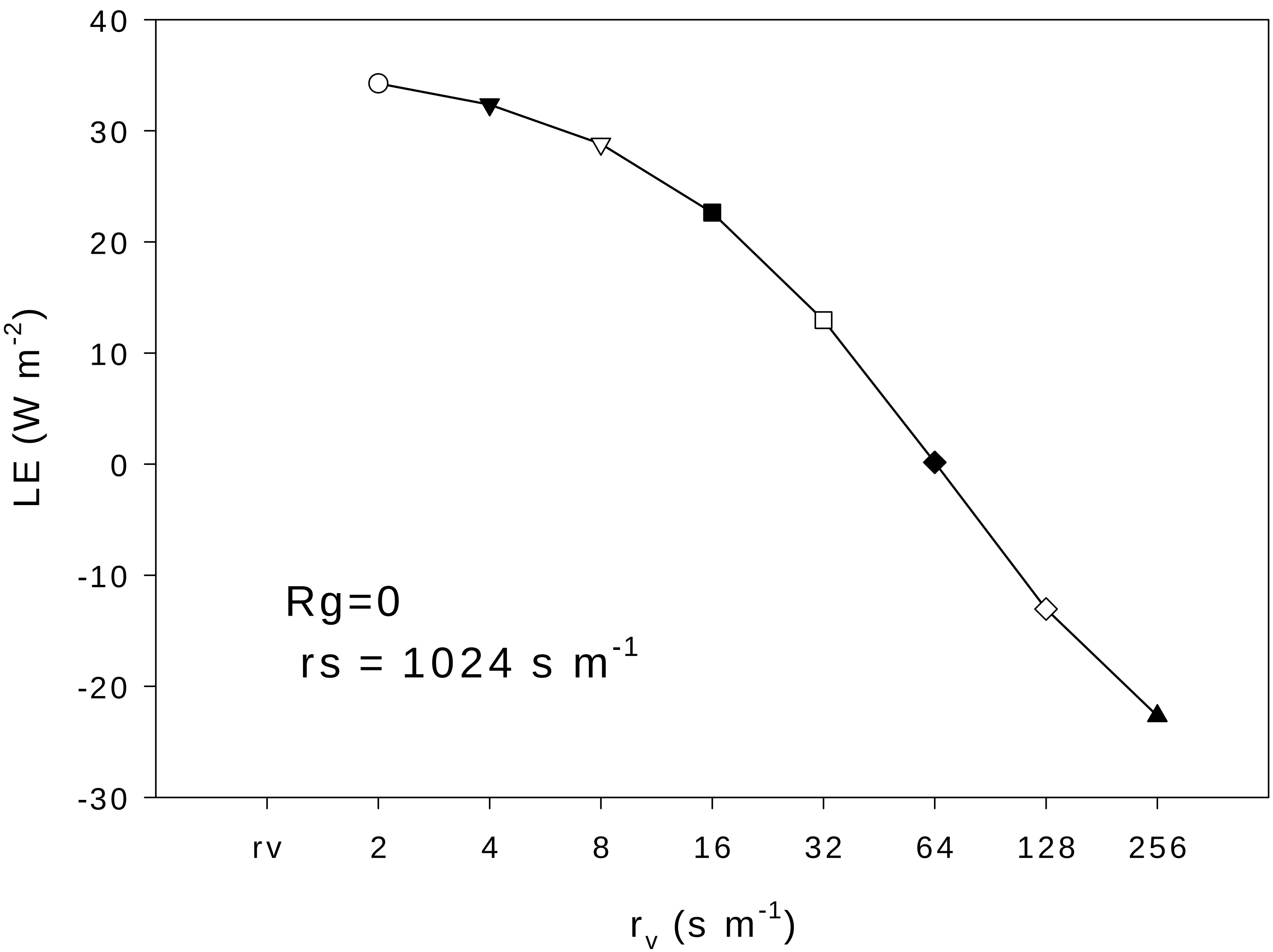
Leaf-air temperatures at night with closed stomata



Evaporation/dew formation at night with closed stomata



Evaporation/dew formation at night with turbulent mixing



Well-Mixed Case, Infinite Boundary Layer Conductance

$$\lambda E(g_a \to \infty) = \frac{sR_n + D\rho_a C_p \infty}{(s + \gamma(1 + \frac{\infty}{g_s}))}$$

$$\lambda E_{imposed}(g_a \to \infty) = \frac{\rho_a C_p}{\gamma} D g_s$$

Steps

$$\frac{sR_n}{(s+\gamma(1+\frac{\infty}{g_s}))}=0$$

$$\lambda E(g_h \to \infty) \sim \frac{D\rho_a C_p g_h}{(s+\gamma(1+\frac{g_h}{g_s}))}$$

$$\frac{1}{\{\lambda E\}} \sim \frac{(s+\gamma(1+\frac{g_h}{g_s}))}{D\rho_a C_p g_h}$$

$$\frac{s}{D\rho_a C_p \infty}+\frac{\gamma}{D\rho_a C_p \infty}+\frac{\gamma g_h}{g_s D\rho_a C_p g_h}$$

$$\frac{1}{\lambda E} \sim \frac{\gamma g_h}{g_s D\rho_a C_p g_h}=\frac{\gamma}{g_s D\rho_a C_p}$$

Still Air Case, boundary layer conductance goes to Zero

$$\lambda E(g_a \to 0) = \frac{sR_n + D\rho_a C_p 0}{(s + \gamma(1 + \frac{0}{g_s}))}$$

$$\lambda E_{eq}(g_a \to 0) = \frac{s}{s+\gamma} R_n$$

Equilibrium Evaporation

But, this Equality is physically nonsensical.

How can we expect the surface to exchange water and heat with the atmosphere if there is no transfer mechanism?

Humidity Deficit Must be Infinite in Still Air with Impending Energy

$$D(g_a \to 0) = \frac{\lambda E(s + \gamma(1 + \frac{0}{g_s}))}{\rho_a C_p 0} - sR_n = \infty$$

Alternatively Consider IsoThermal Radiation Balance

$$\lambda E(g_a \to 0) = \frac{sR_{iso} + D\rho_a C_p (g_r + 0)}{(s + \gamma(1 + \frac{g_r}{0})(1 + \frac{0}{g_s})} = \frac{[]}{\infty} = 0$$

It correctly and Physically Reveals Evaporation is Zero in Still Air

Equilibrium Evaporation

$$\frac{d\lambda E}{dt} = \frac{dE}{dD}\frac{dD}{dt}$$

$$\lambda E_{eq}(t \to \infty) = \frac{s}{s+\gamma} R_n$$

Wet Surface

$$\lambda E(g_s \to \infty) = \frac{sR_n + D\rho_a C_p g_h}{(s + \gamma(1 + \frac{g_h}{\infty}))}$$

$$\lambda E(g_s \to \infty) = \frac{sR_n + D\rho_a C_p g_h}{(s + \gamma)}$$

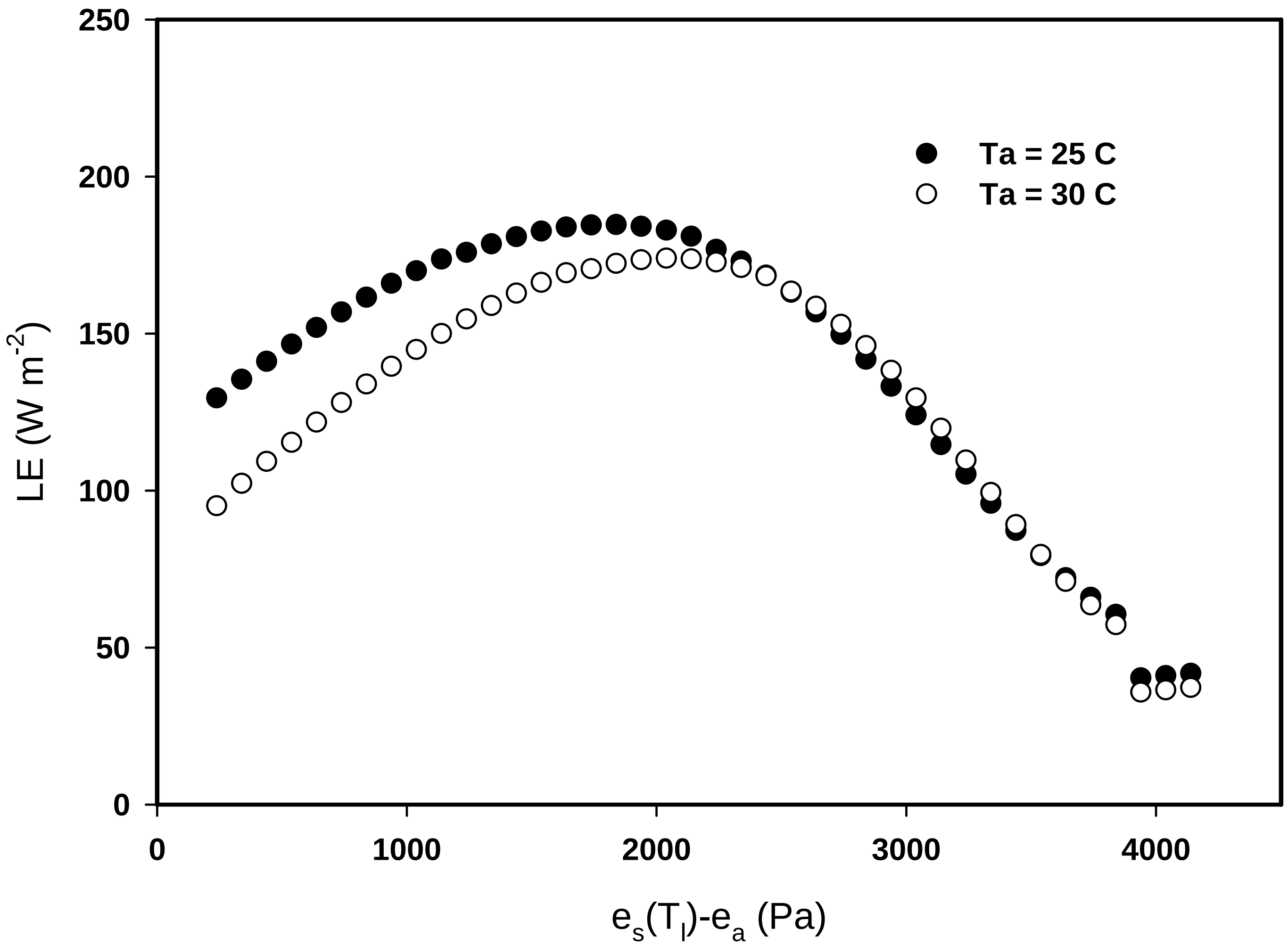
Coupling Theory

$$dE = (1-\Omega)\frac{E}{g_s}dg_s$$

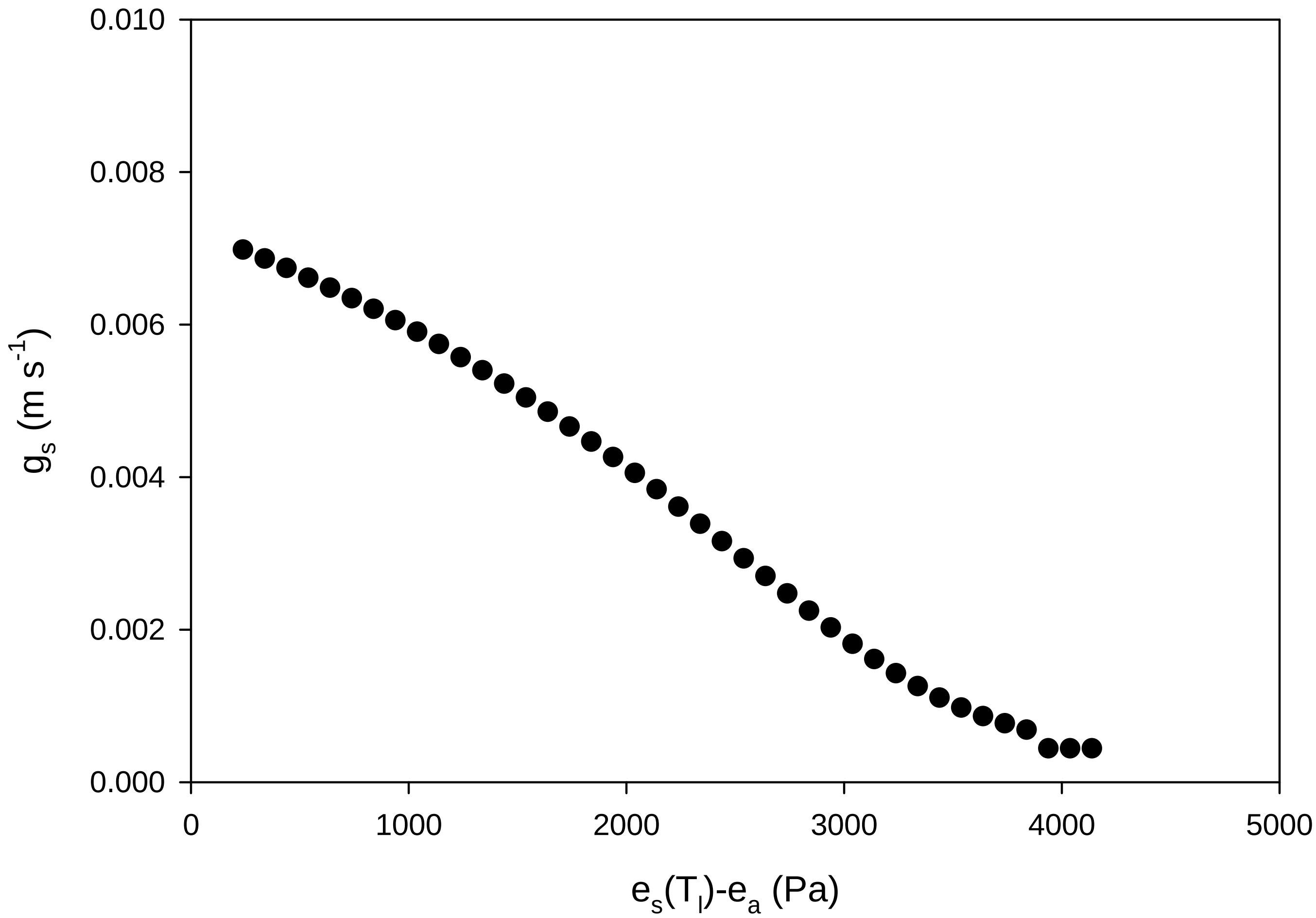
$$\Omega(R_{iso}) = \frac{1+\varepsilon+\frac{g_r}{g_b}}{1+\varepsilon+\frac{g_b+g_r}{g_s}+\frac{g_r}{g_b}}$$

species	gs	D (mm)	Ω (0.2 m/s)	Ω (5 m/s)
Sitka spruce	0.07	2	0.18	0.03
Beech	0.10	40	0.50	0.10
apple	.21	60	0.50	0.11

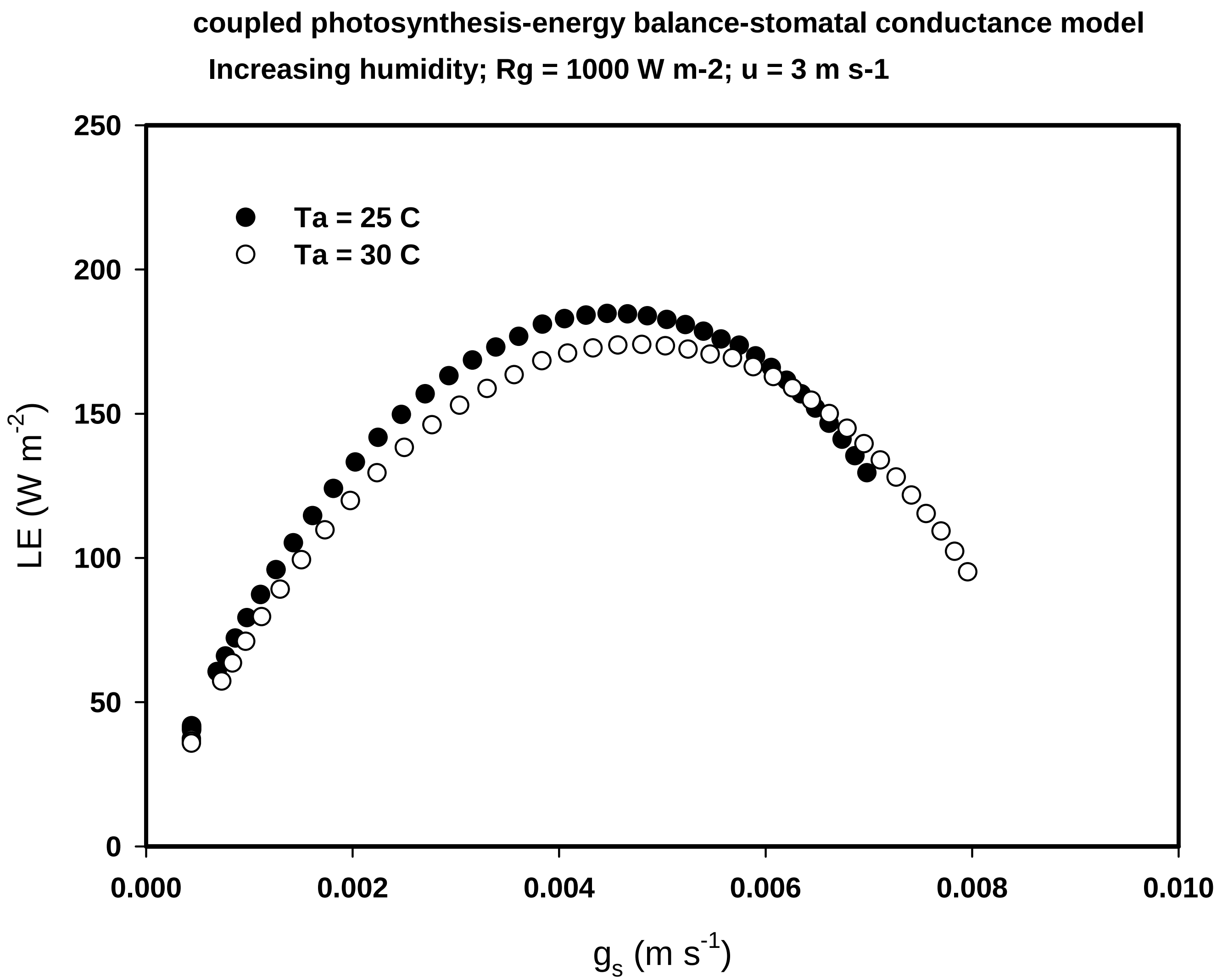
Response of evaporation to changes in vapor pressure differences



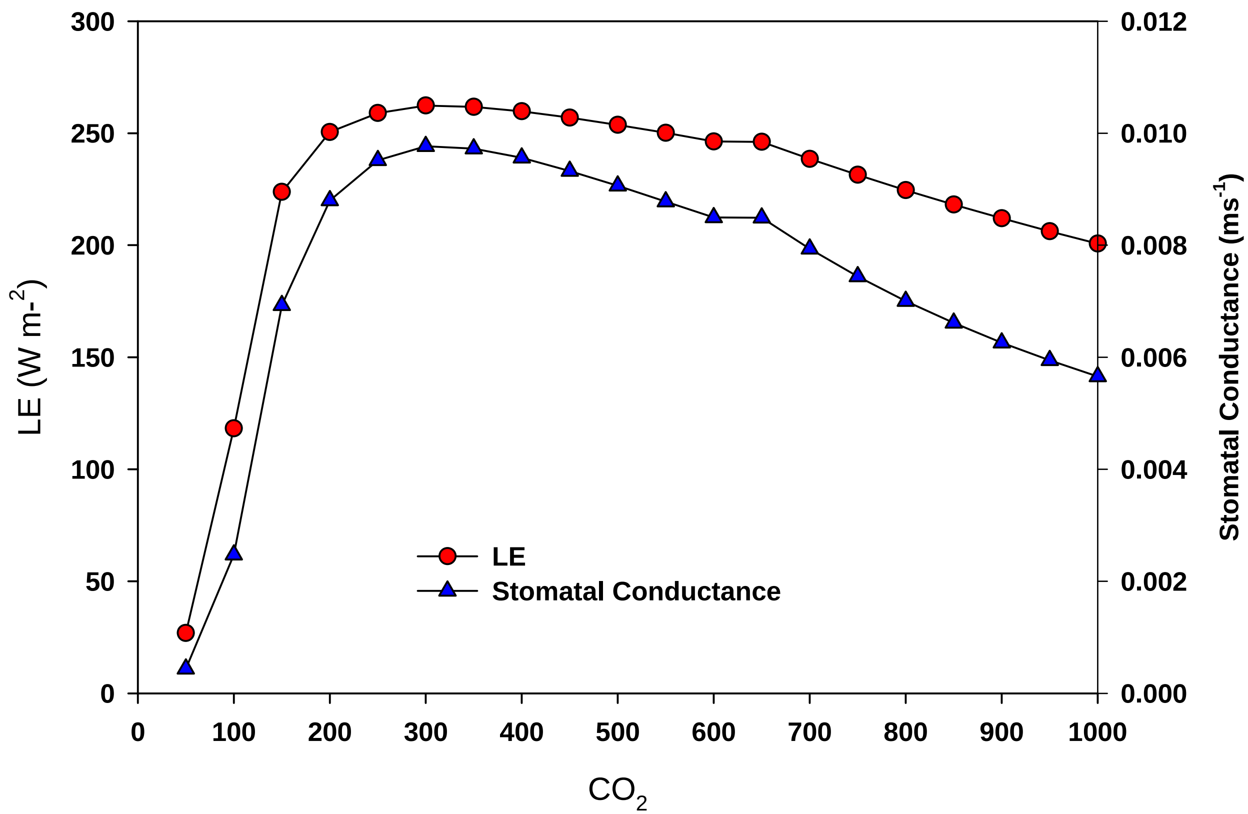
Response of stomatal conductance to humidity deficits



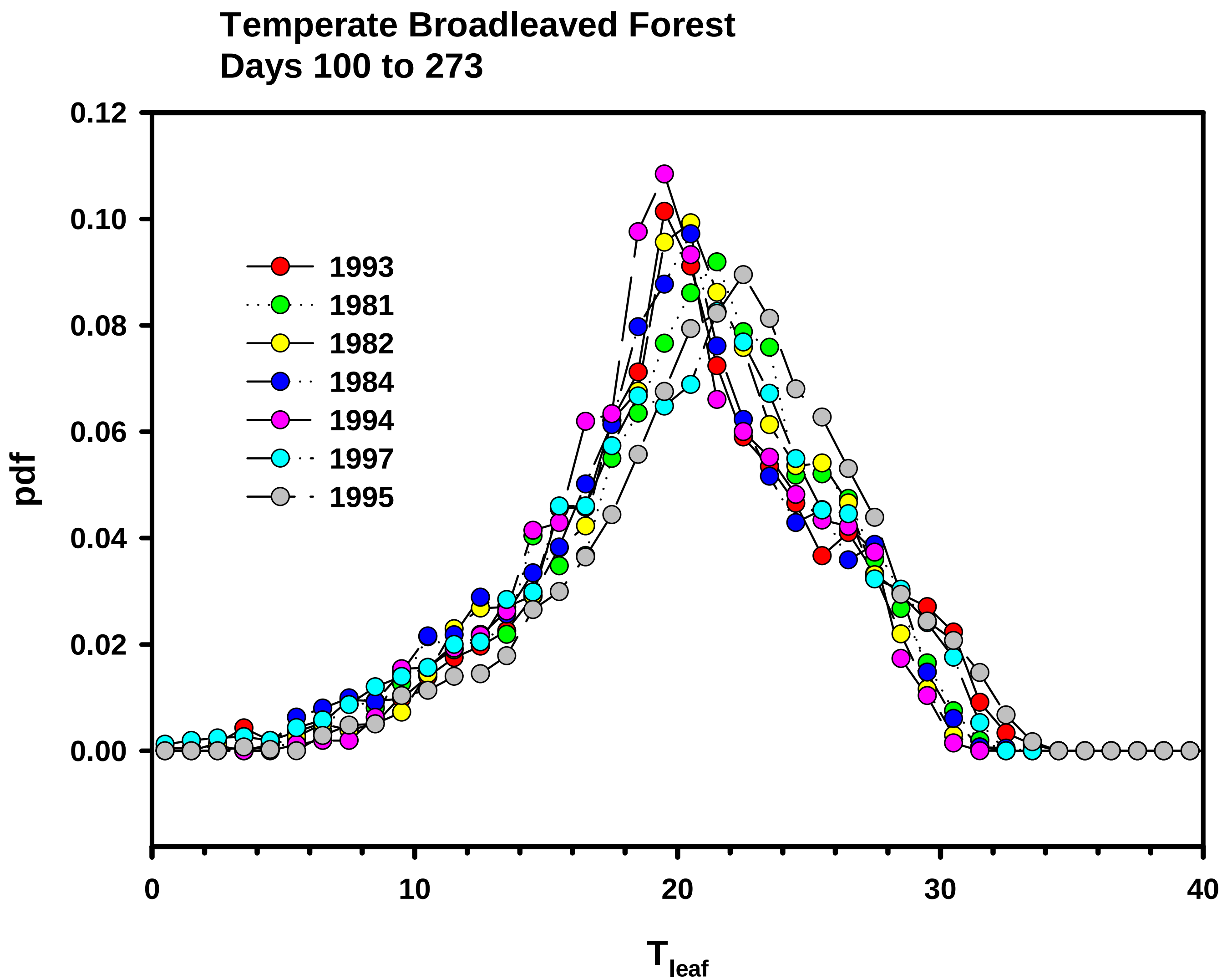
The relation between LE and stomatal conductances



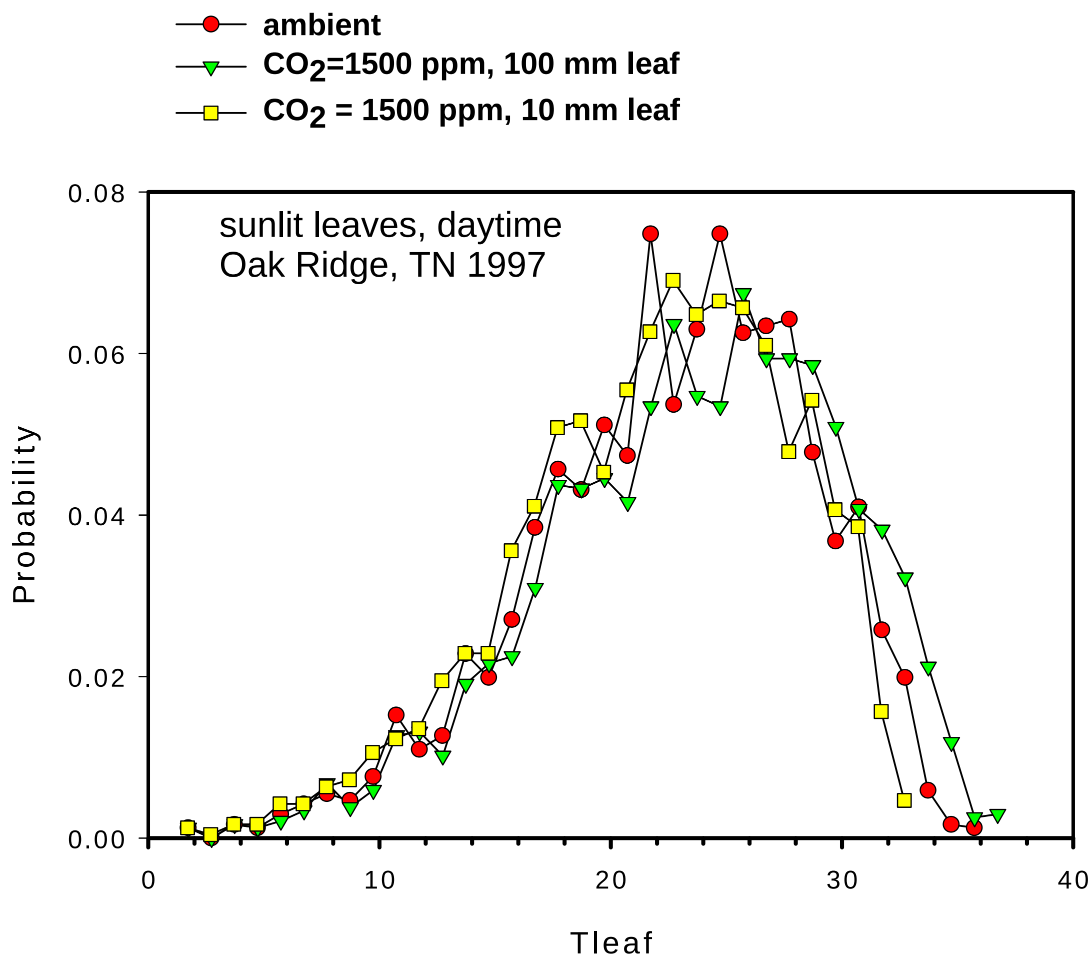
Transpiration and CO_2



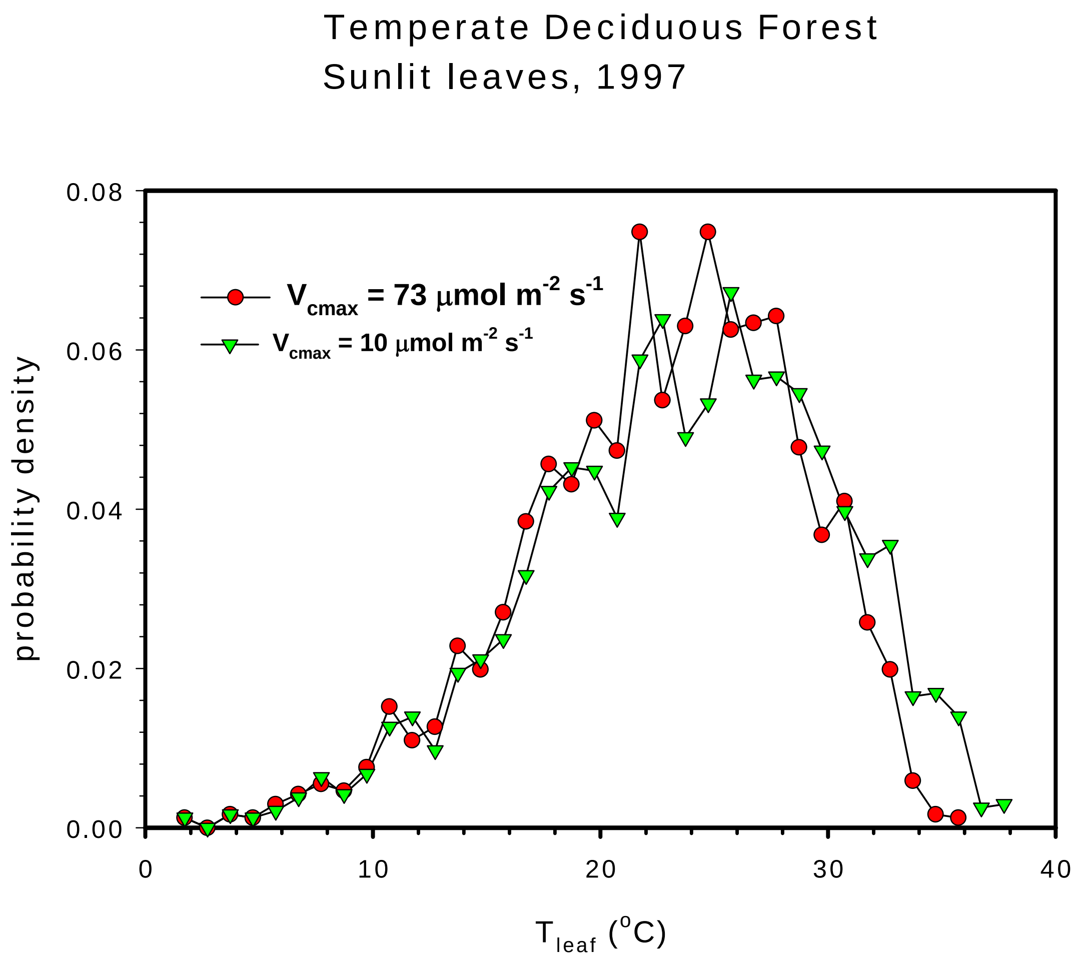
Probability density function of mean leaf temperature of a broadleaved forest in Tennessee



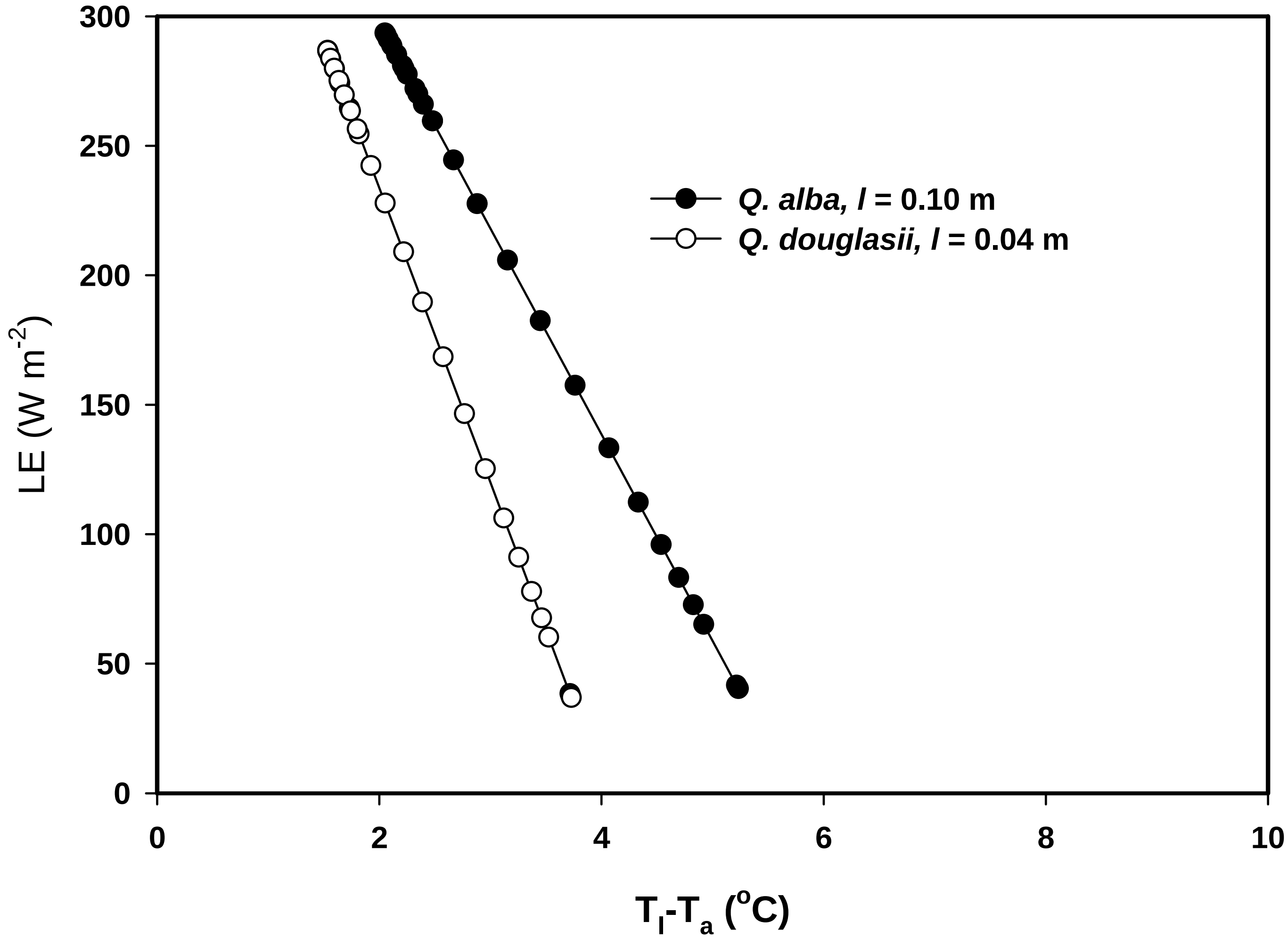
Theoretical calculations of leaf size based on climate scenarios

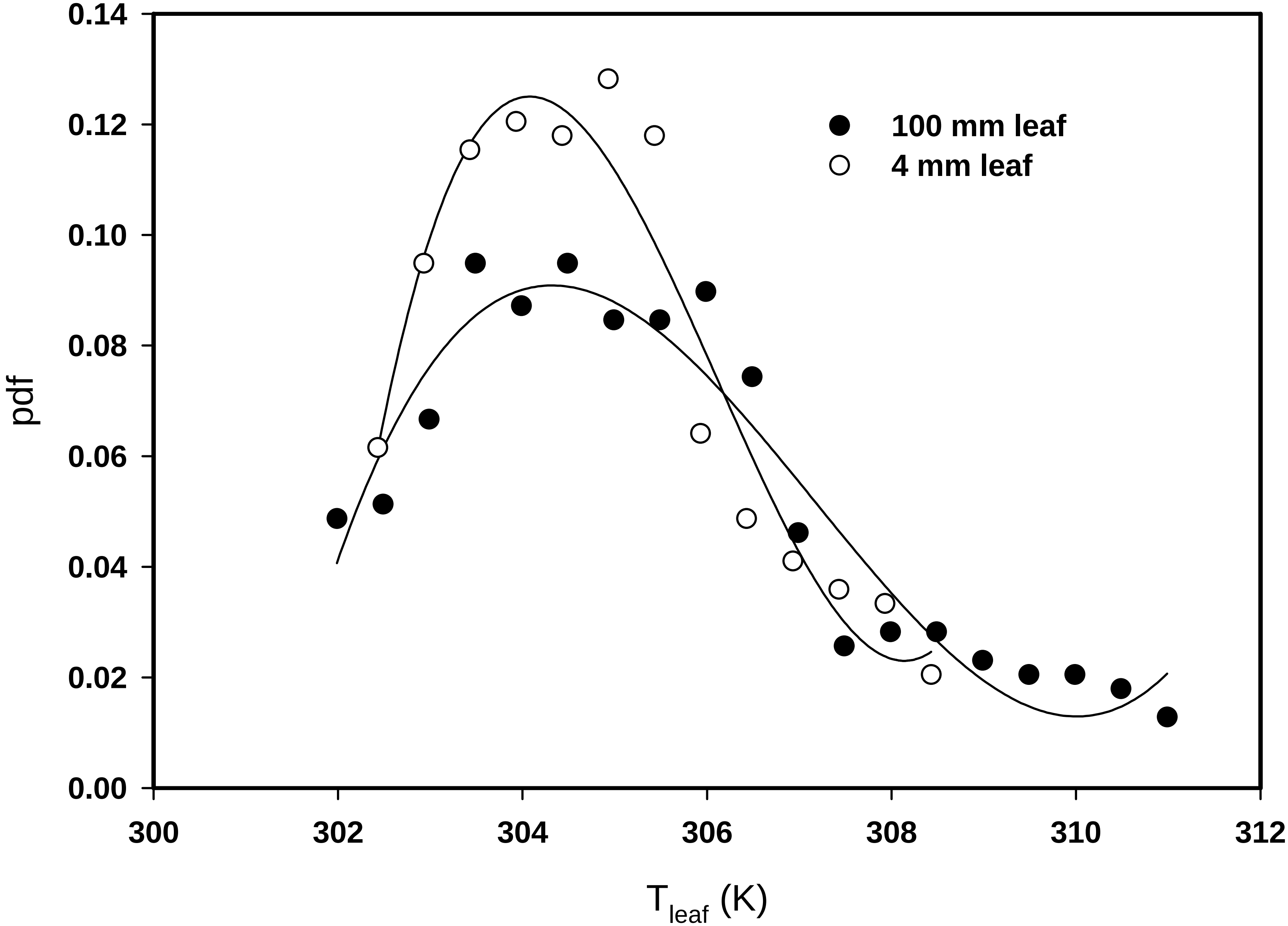


Role of leaf photosynthetic capacity and leaf temperature

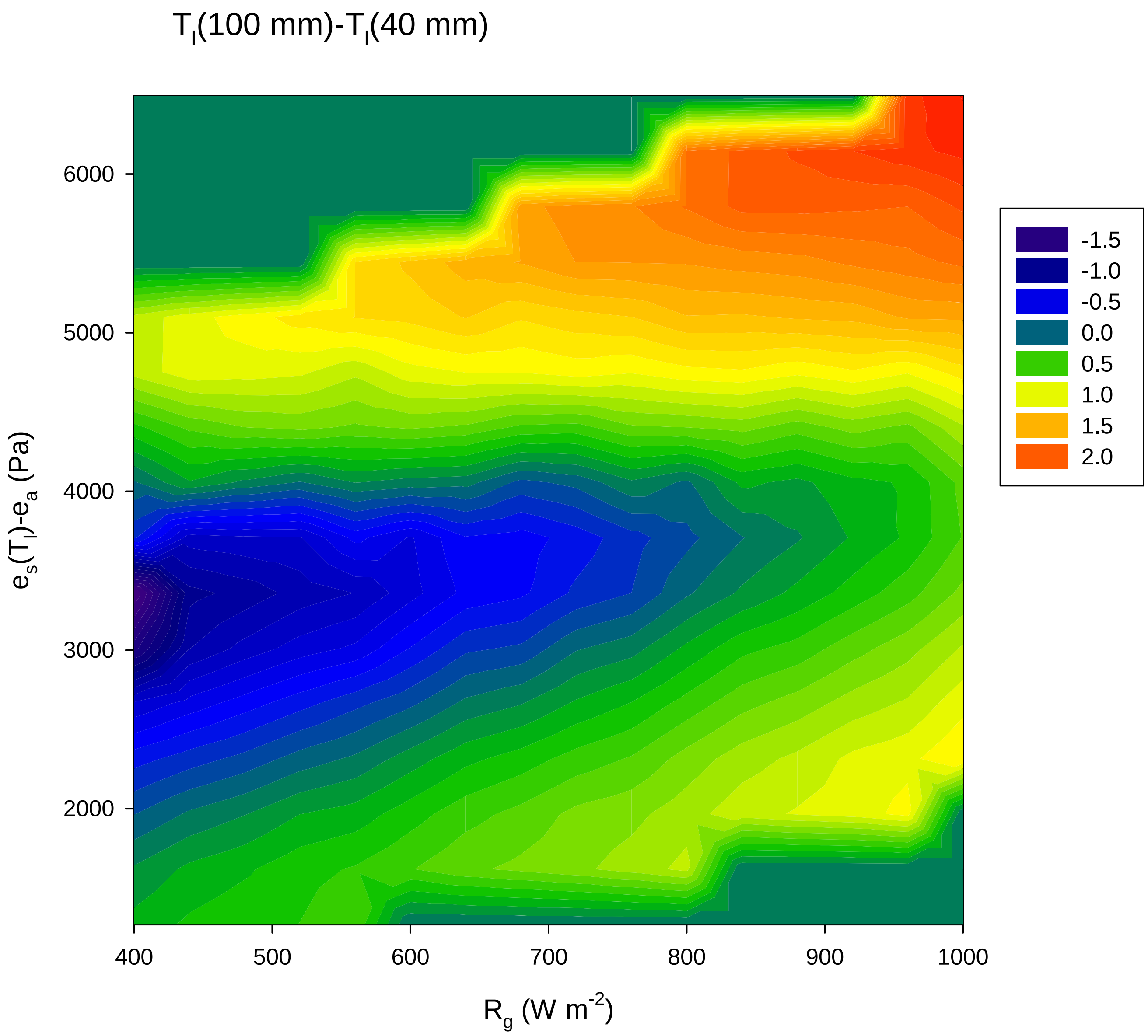


Leaf Size, Temperature and Evaporation





0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
pdf
300
302
304
306
308
310
312
T leaf (K)
100 mm leaf
4 mm leaf



T_l(100 mm)-T_l(40 mm)
6000
5000
4000
3000
2000
e_s(T_l)-e_a (Pa)
400
500
600
700
800
900
1000
R_g (W m^-2)
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0

Summary

- LE imposed is defined as the limit when boundary layer conductance goes to infinity. LE is independent of the net radiation balance!
- LE goes to zero when the boundary layer conductance approaches zero, for there is no physical mechanism to transfer water from the leaf to the atmosphere
- equilibrium evaporation is independent of stomatal conductance.
  - It results from the consequence of feedbacks between surface temperature, the temperature of the air and its water holding capacity.
  - It is also identical to the derivation based on the condition when $\lambda E(Rn)$ is evaluated as *ga* goes to zero.