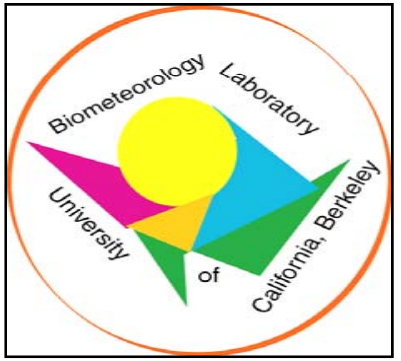
Physical and Biological Processes that Controls Water Vapor Exchange between Vegetation and the Atmosphere

Dennis Baldocchi
Department of Environmental Science, Policy and Management
University of California, Berkeley

Contributions from the Biometeorology Lab

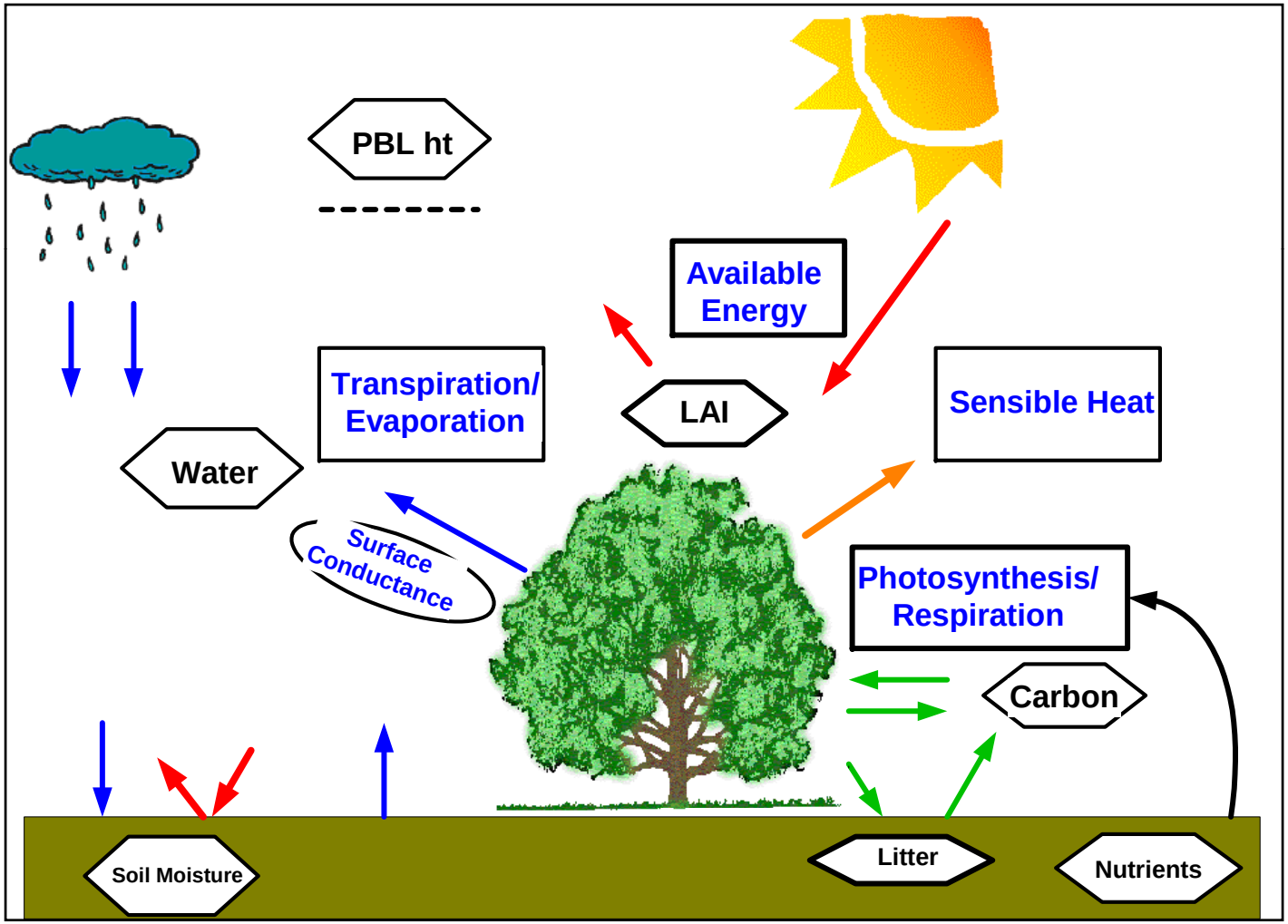
Youngryel Ryu
Josh Fisher
Siyan Ma
Xingyuan Chen
Gretchen Miller
Matthias Falk
Kevin Tu



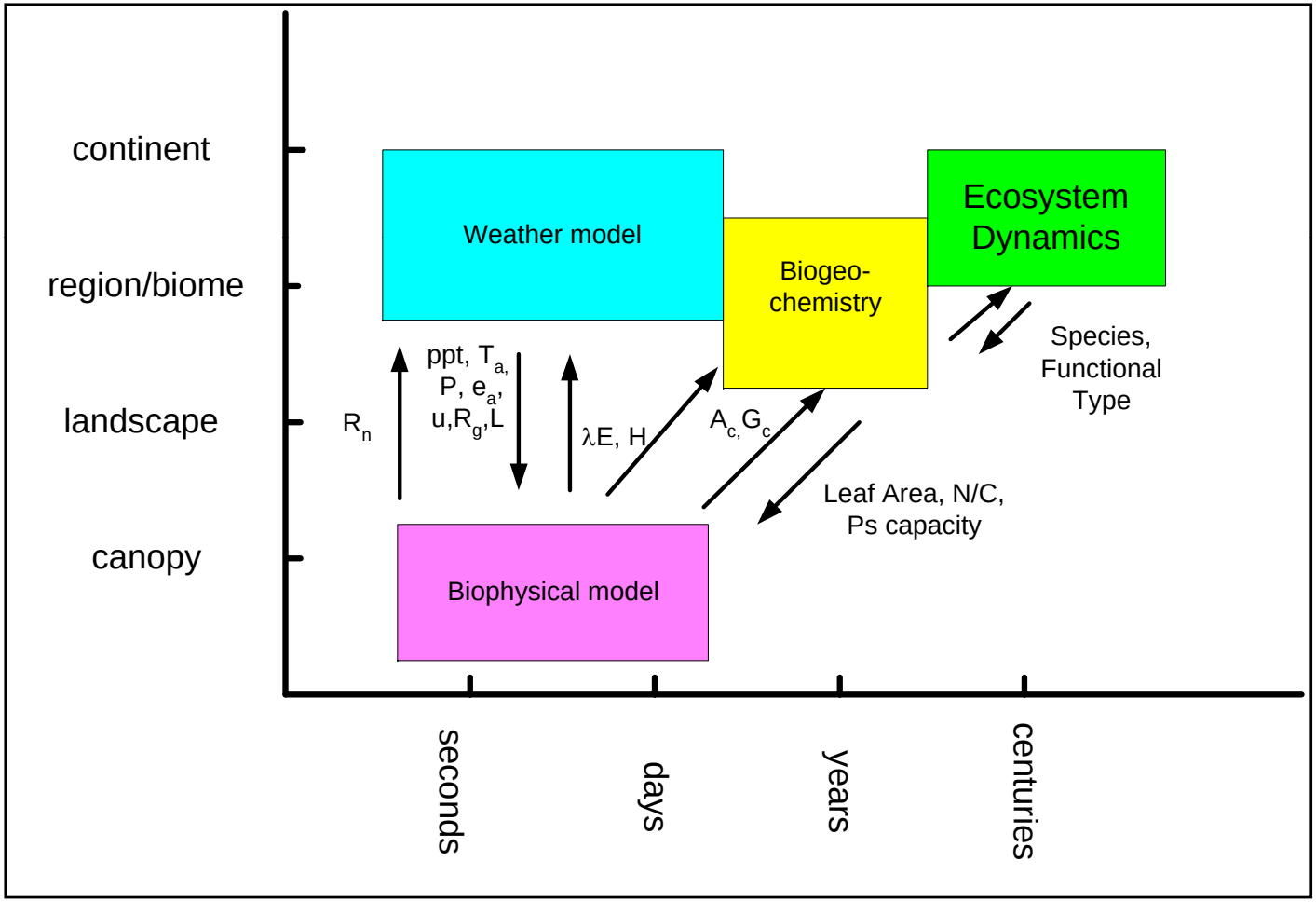
Outline

- Processes, Supply vs Demand, Short and Long Time scales
  - Short
    - Energy
    - Meteorology
  - Long
    - Leaf area index
    - Nutrition
    - Plant Functional type
  - Short to Long
    - Surface Conductance
    - Soil Moisture
- Time
  - Day/Night
  - Seasonal
  - Interannual
- Space
  - Land Use
  - PBL/Landscape
  - Globe

Water and the Environment: Biogeophysical-Ecohydrological View



Processes and Linkages: Roles of Time and Space Scales



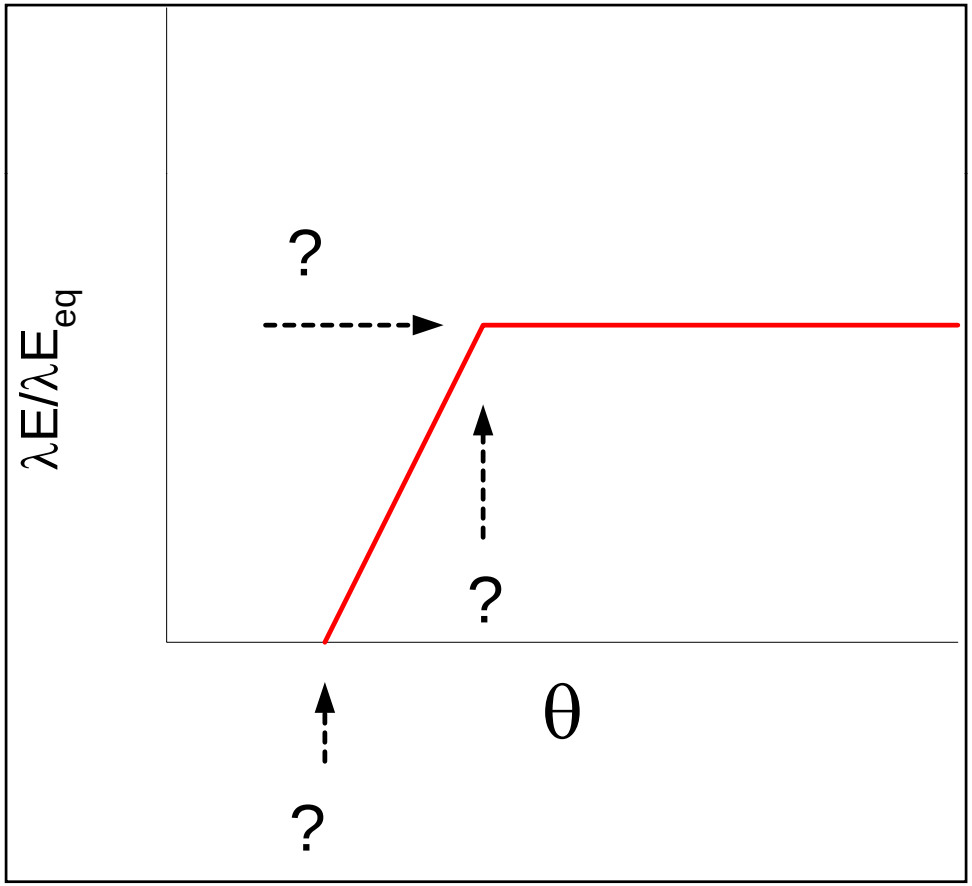
Penman Monteith Equation

$$\lambda E = \frac{s(R_n - S) + \rho \cdot C_p \cdot G_H \cdot D}{s + \gamma + \gamma \frac{G_H}{G_s}}$$

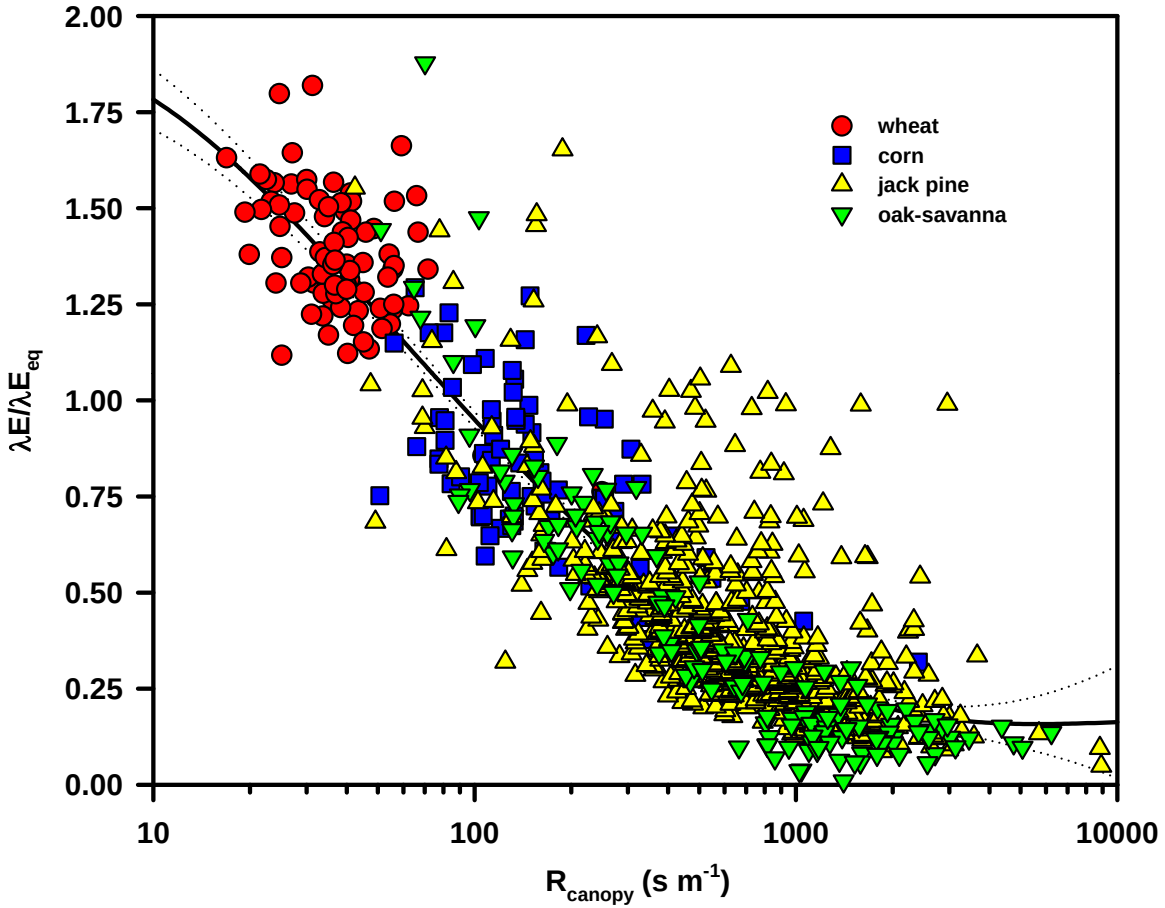
Function of:

- Available Energy (Rn-S)
- Vapor Pressure Deficit (D)
- Aerodynamic Conductance (Gh)
- Surface Conductance (Gs)

Eco-hydrology:
ET, Functional Type, Physiological Capacity and Drought



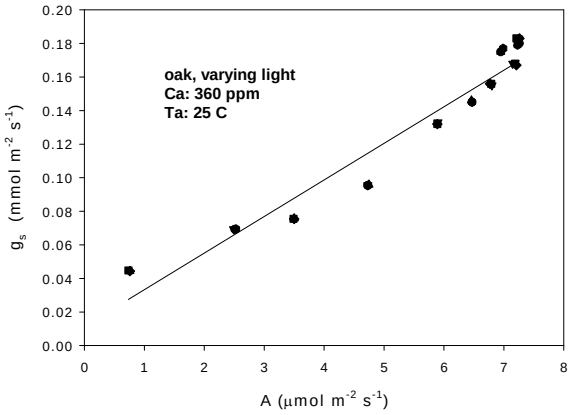
Effects of Functional Types and R_{sfc} on Normalized Evaporation



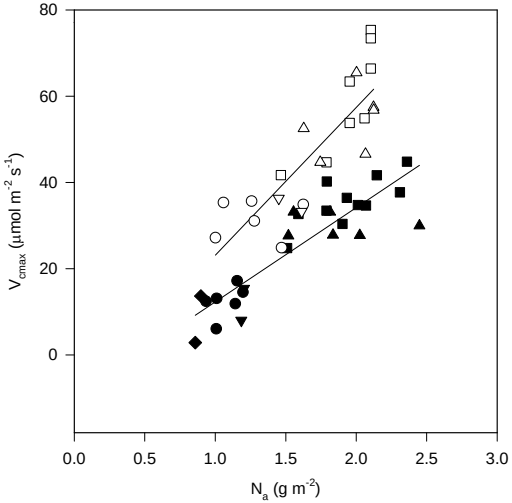
R_c is a f(LAI, N, soil moisture, Ps Pathway)

Stomatal Conductance Scales with N, via Photosynthesis

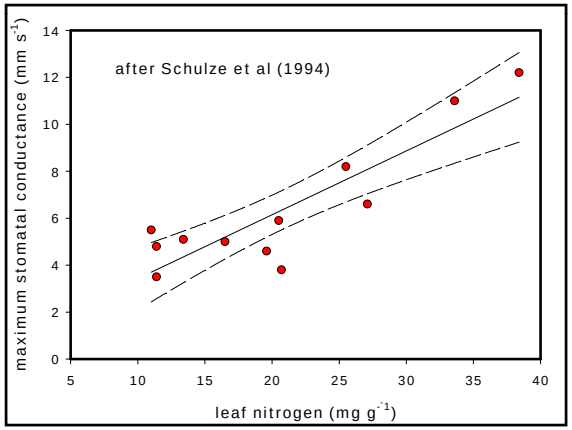
Stomatal Conductance Scales with Photosynthesis



Photosynthetic Capacity Scales with Nitrogen

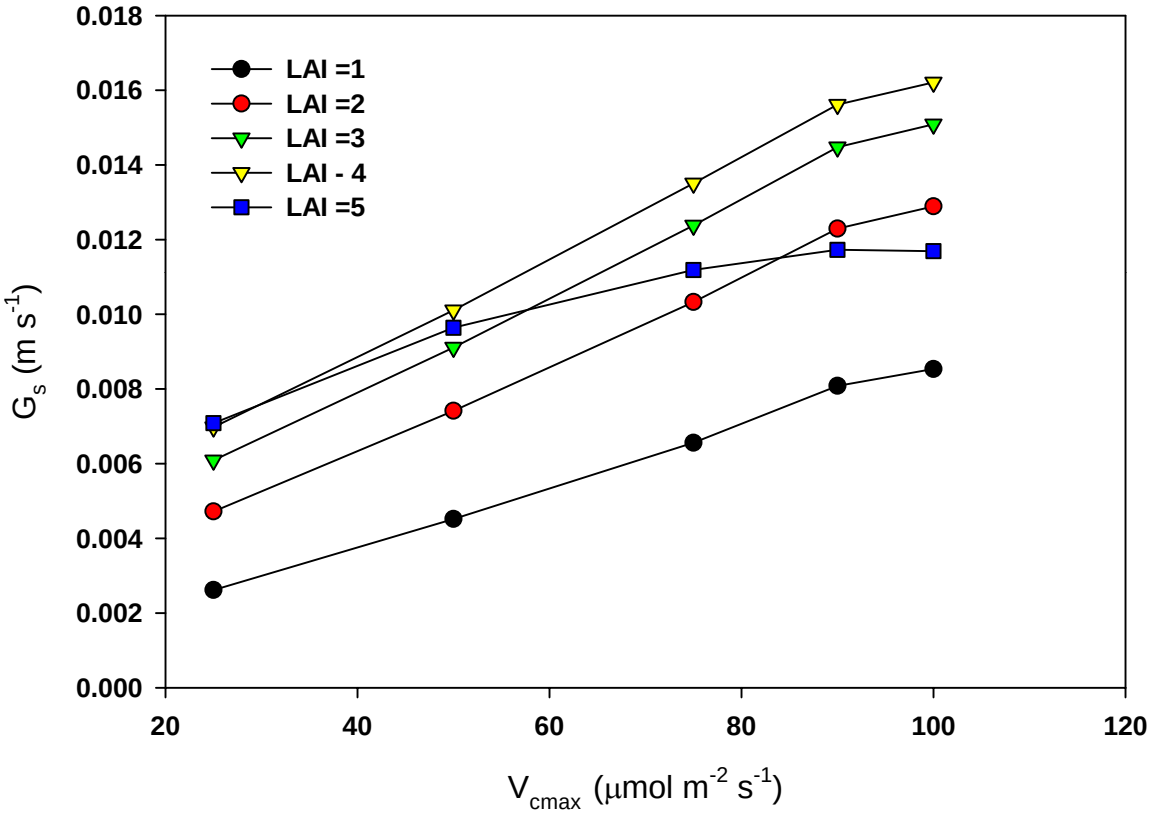


Stomatal Conductance scales with Nitrogen



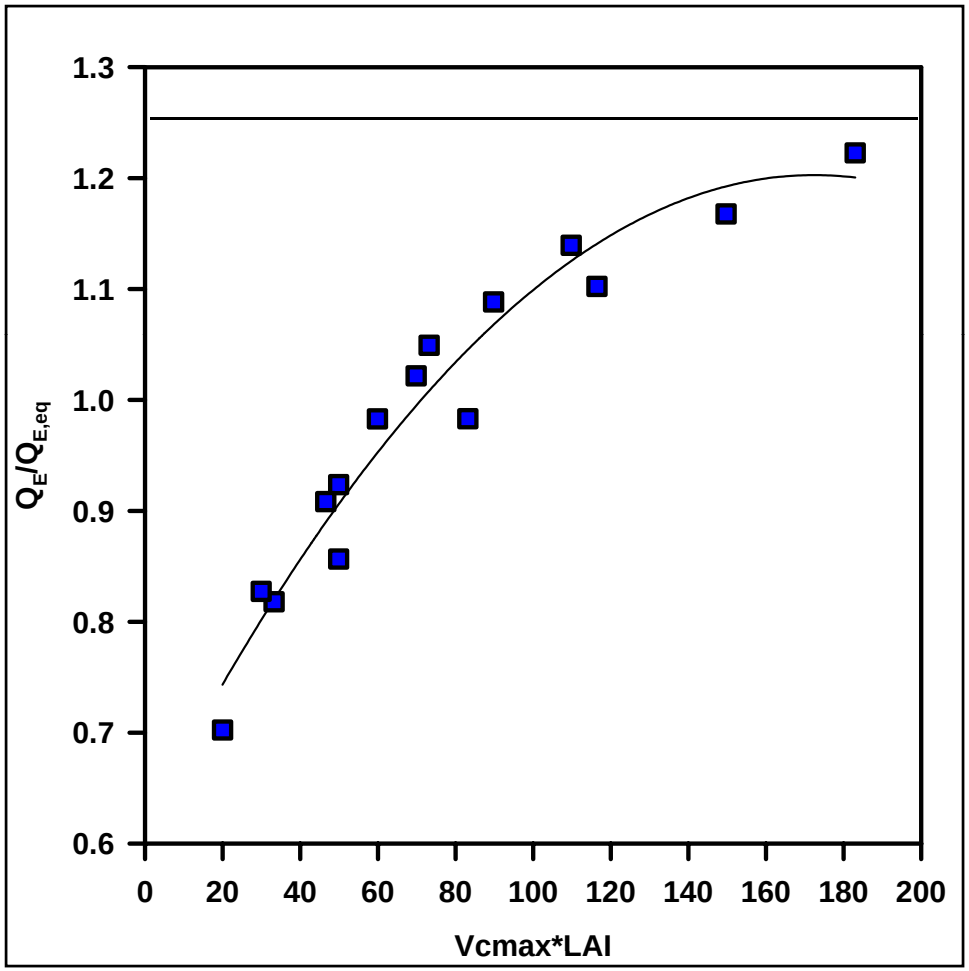
Wilson et al. 2001, Tree Physiology
Schulze et al 1994. Annual Rev Ecology

Integrated Stomatal Conductance Scales with Photosynthetic Capacity and LAI



CANVEG Computations

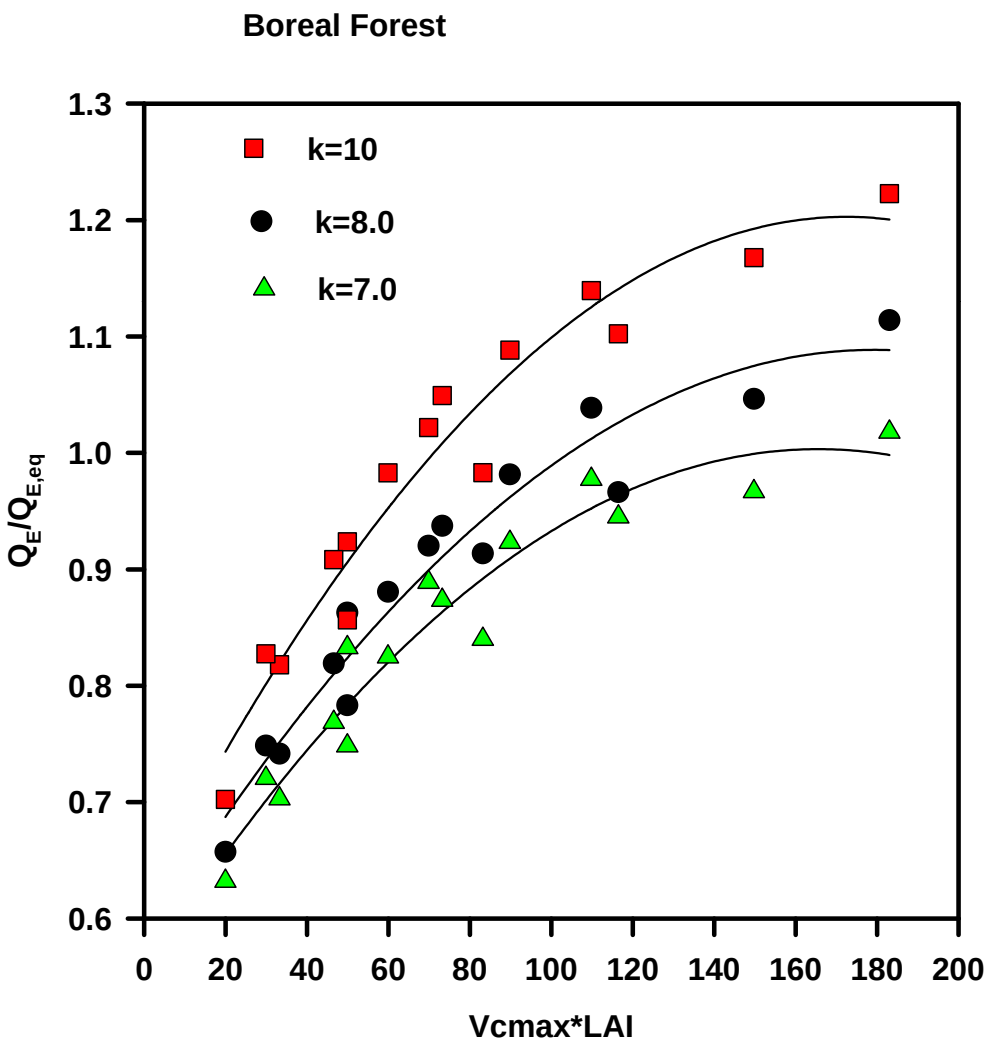
Effects of Leaf Area and Photosynthetic Capacity on Normalized Evaporation: Well-Watered Conditions



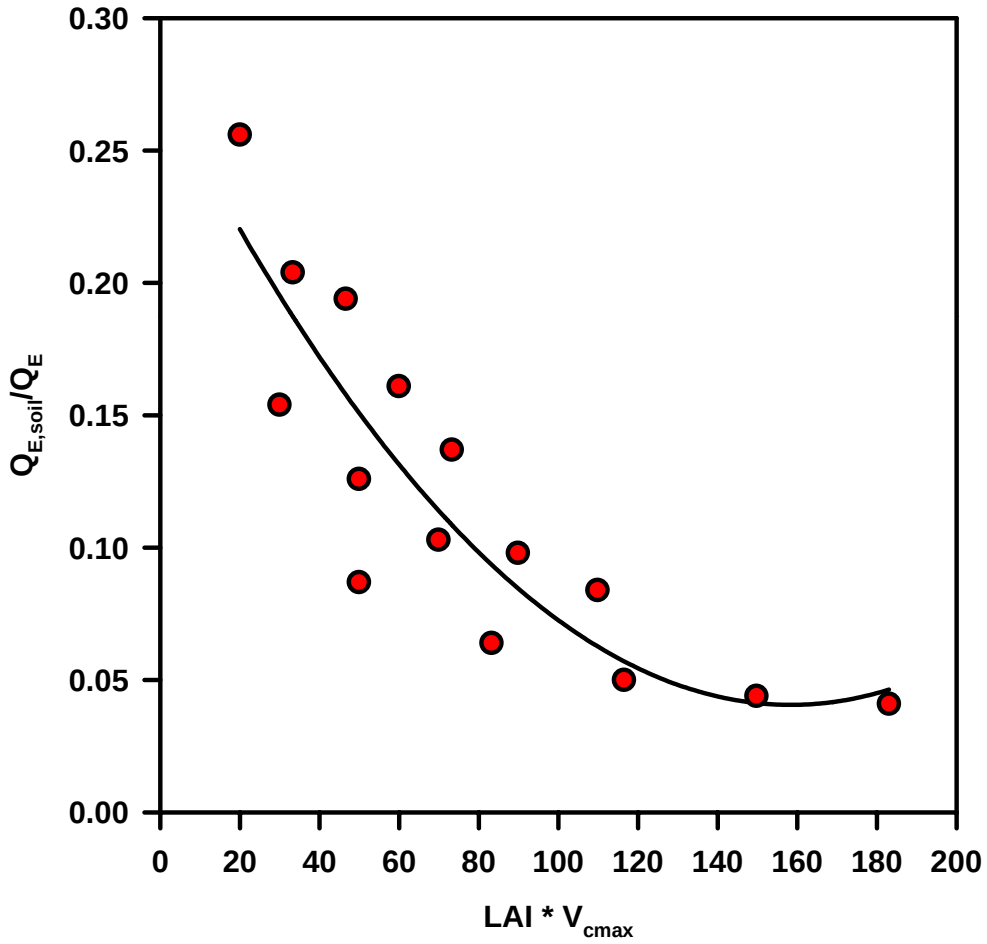
Priestley-Taylor = 1.26

Canveg Model, Baldocchi and Meyers, 1998 AgForMet

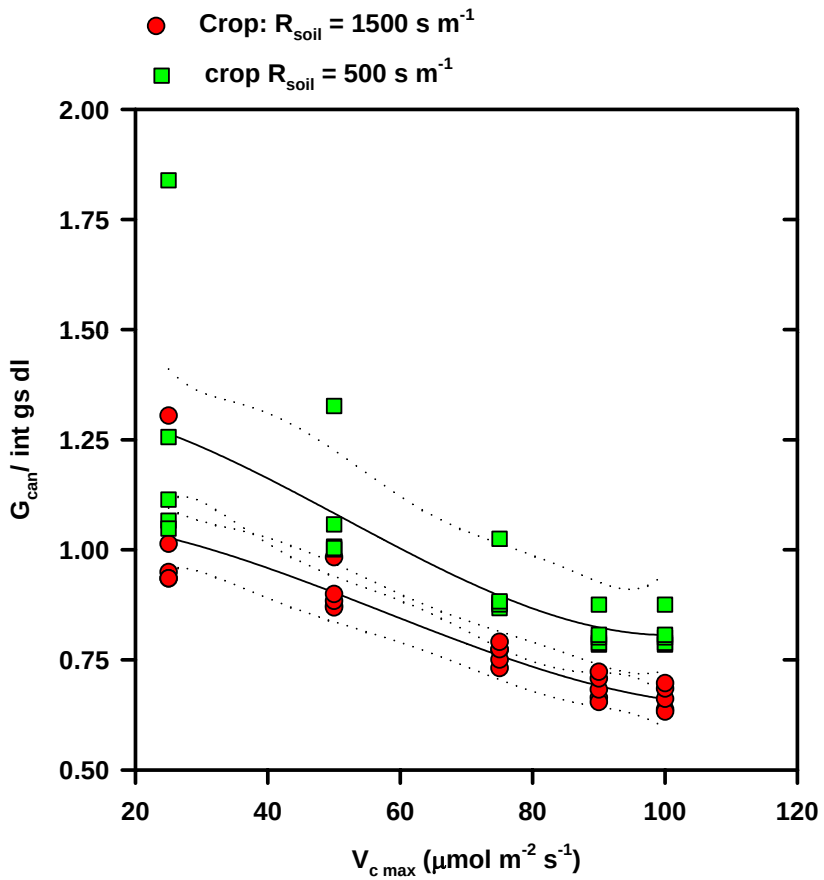
Effects of Leaf Area and Photosynthetic Capacity on Normalized Evaporation: Watered-Deficits



LAI and Ps Capacity also affects Soil vs Total Evaporation

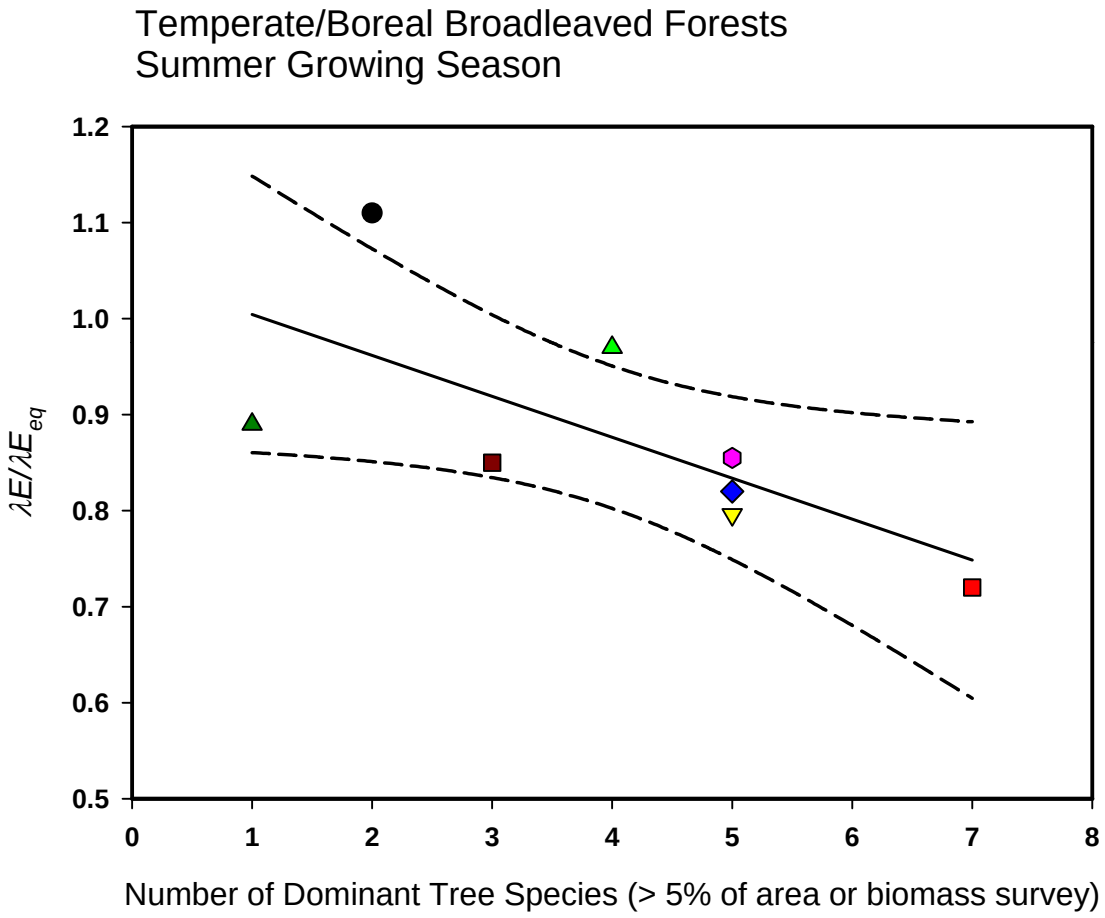


Canopy Surface Conductance does not equal the Canopy Stomatal Conductance



Be Careful about using G_{can} to compute isotopic discrimination

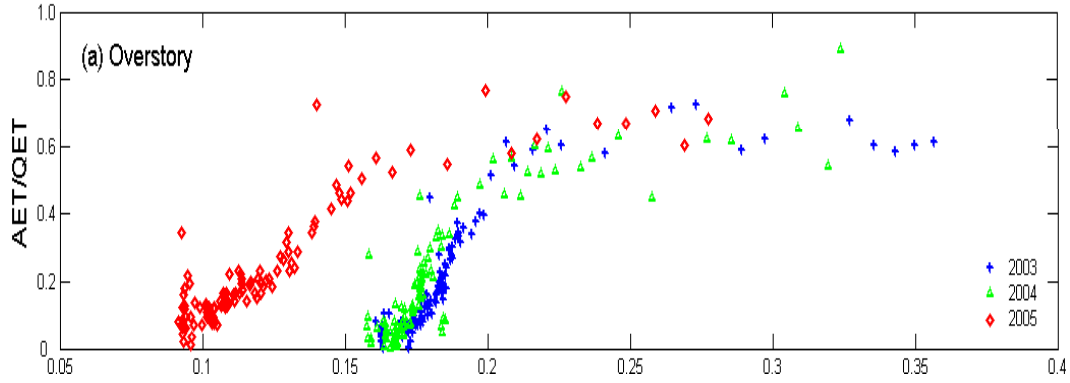
Forest Biodiversity is Negatively Correlated with Normalized Evaporation



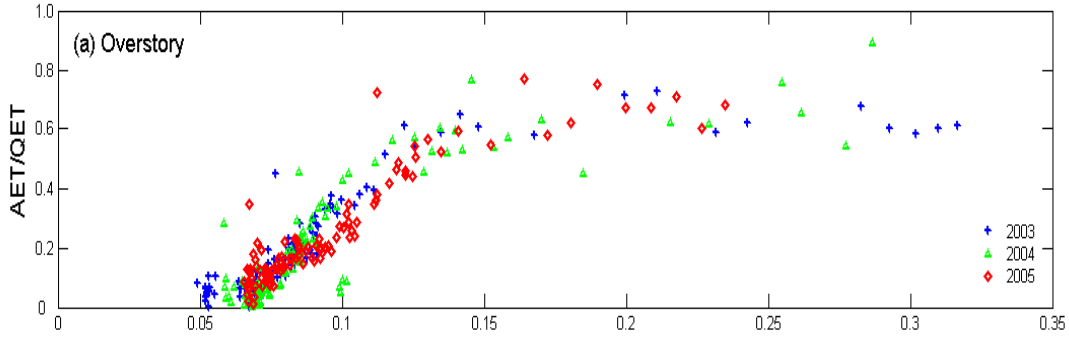
Baldocchi, 2005 In: Forest Diversity and Function: Temperate and Boreal Systems.

Use Appropriate and Root-Weighted Soil Moisture

$$\langle\theta\rangle = \frac{\int_0^z \theta(z)\,dP(z)}{\int_0^z dP(z)}$$



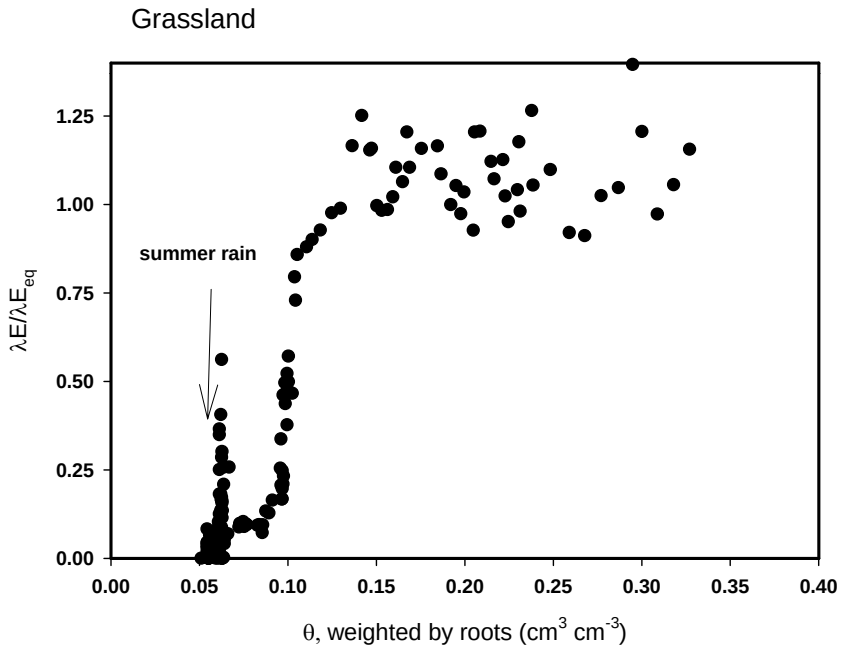
Soil Moisture, arthimetic average

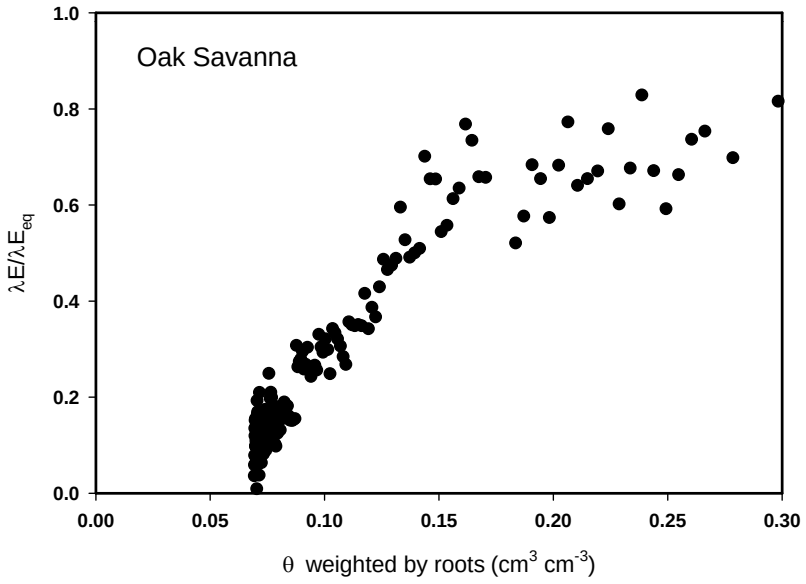


Soil Moisture, root-weighted

Chen, Baldocchi et al, in prep.

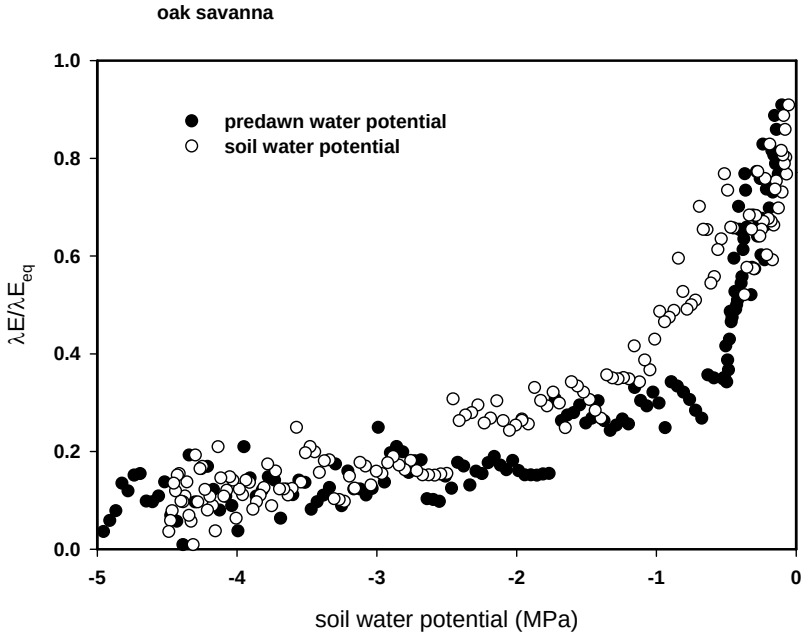
ET and Soil Water Deficits: Root-Weighted Soil Moisture



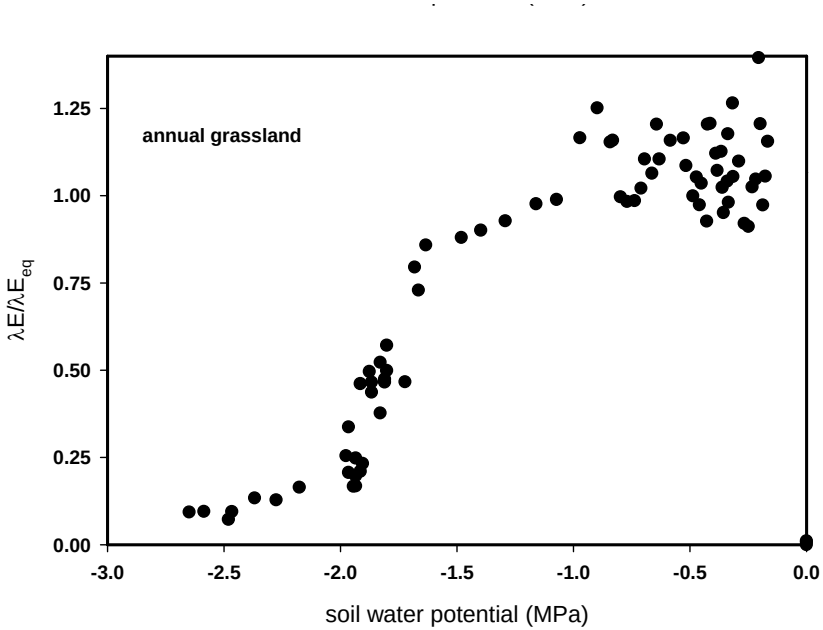


Baldocchi et al., 2004 AgForMet

ET and Soil Water Deficits: Water Potential



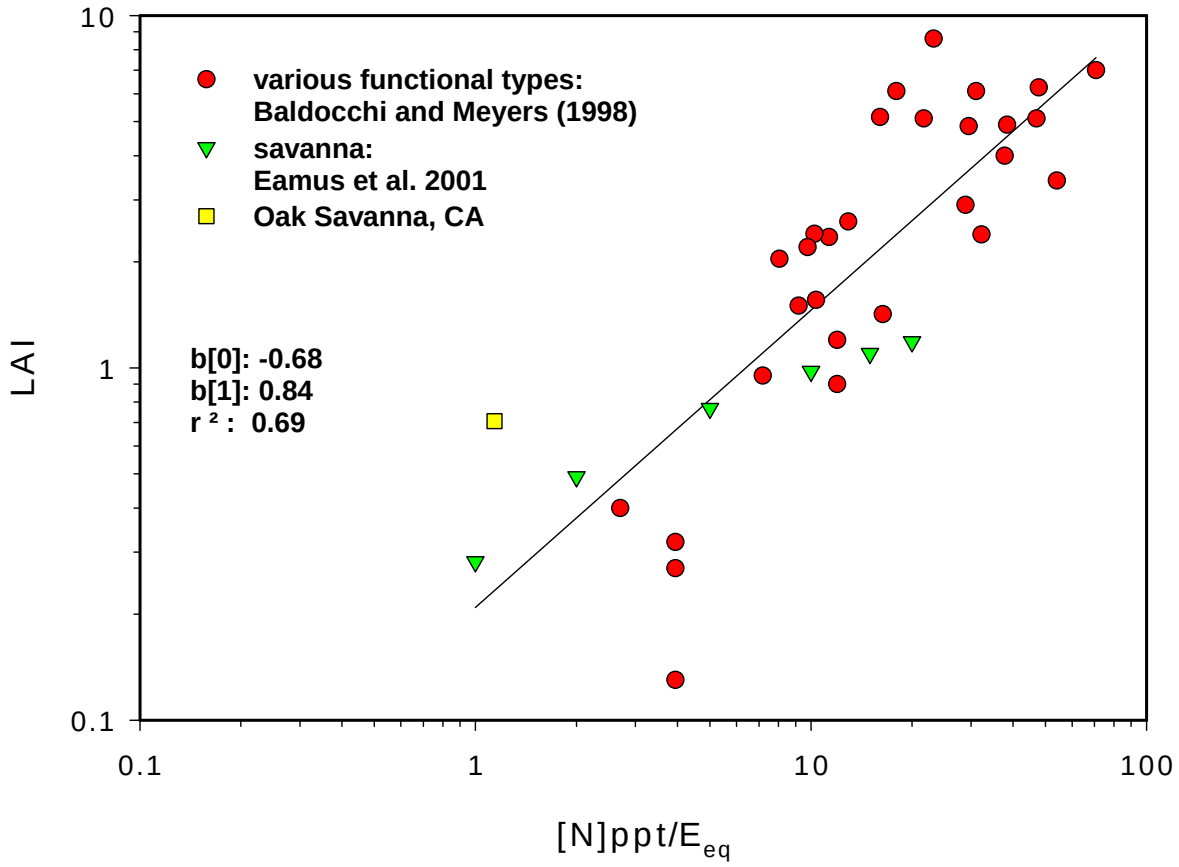
Root-Weighted Soil Moisture Matches Pre-Dawn Water Potential



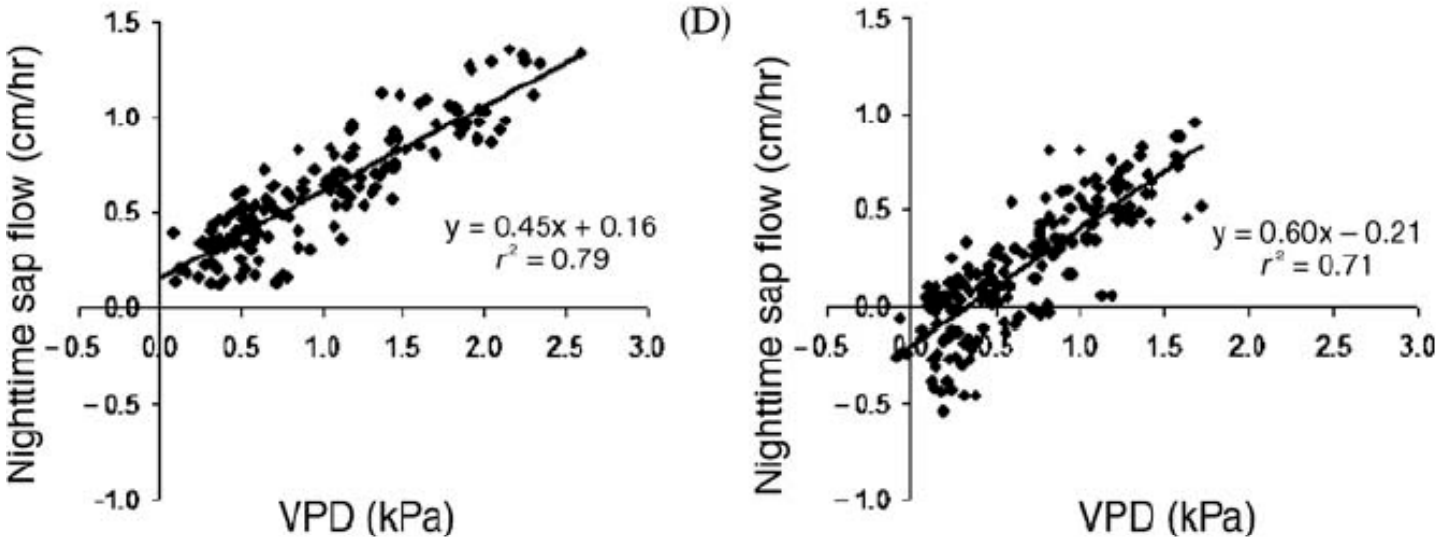
ET of Annual Grass responds to water deficits differently than Trees

Baldocchi et al., 2004 AgForMet

Leaf Area Index scales with Water Balance Deficits

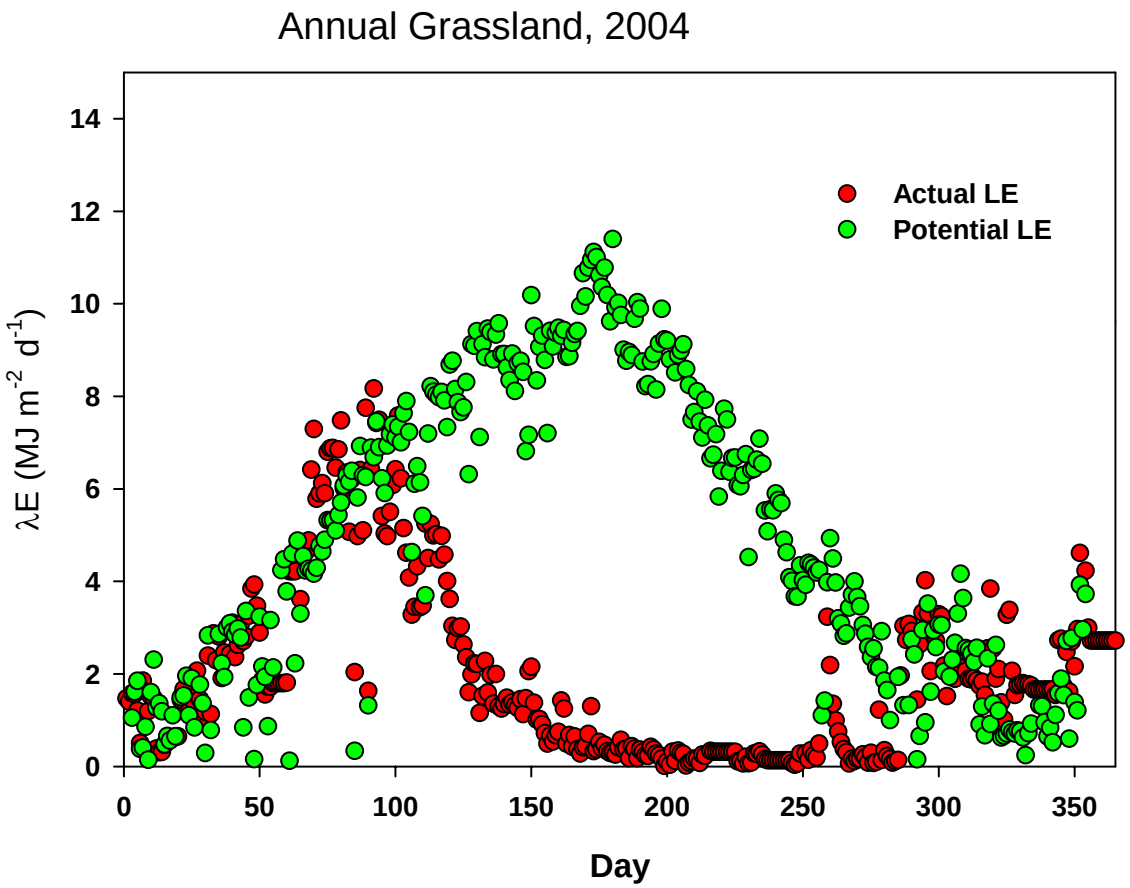


Nocturnal Transpiration from Blue Oak



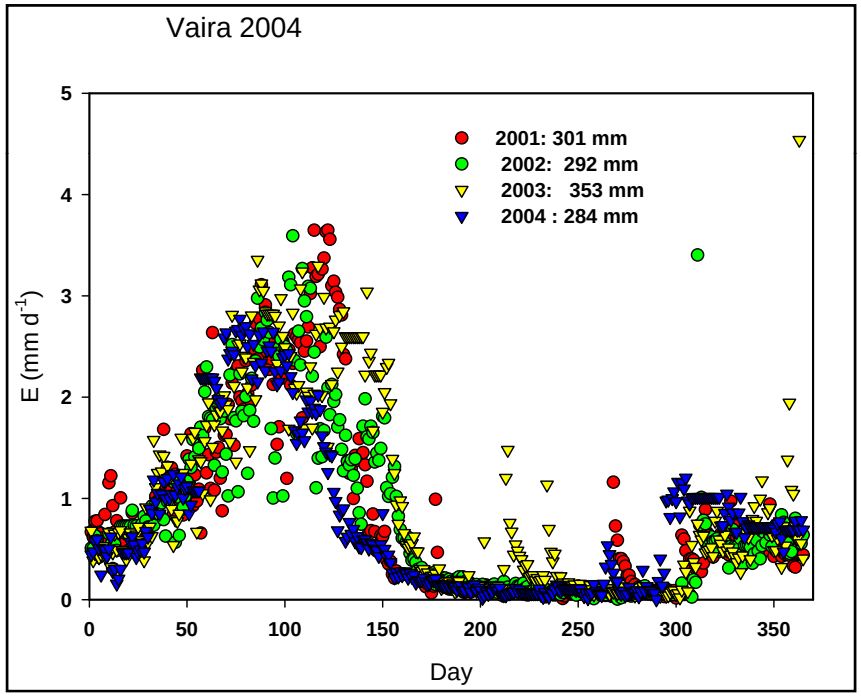
Fisher et al. 2006, Tree Physiology

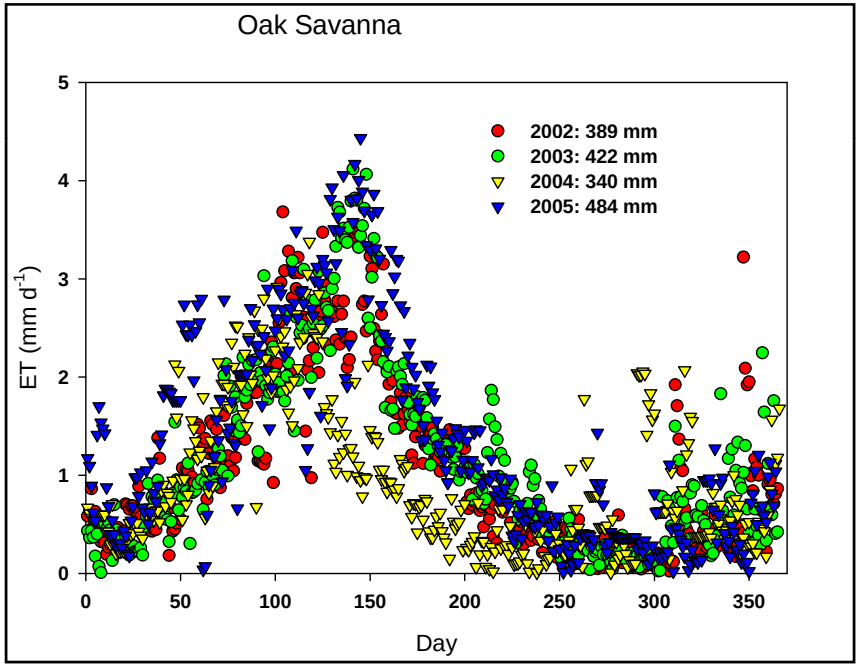
Seasonal and Annual Time Scales



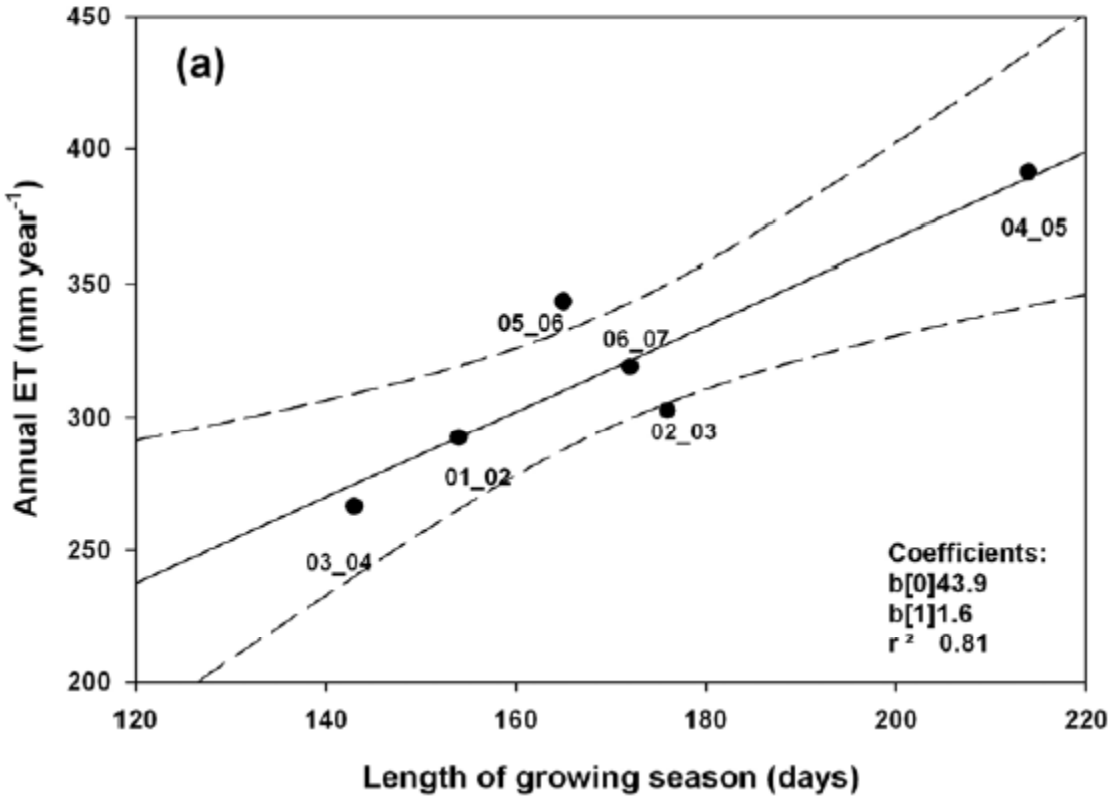
Potential and Actual Evaporation are Decoupled in Semi-Arid System

Interannual Variation ET



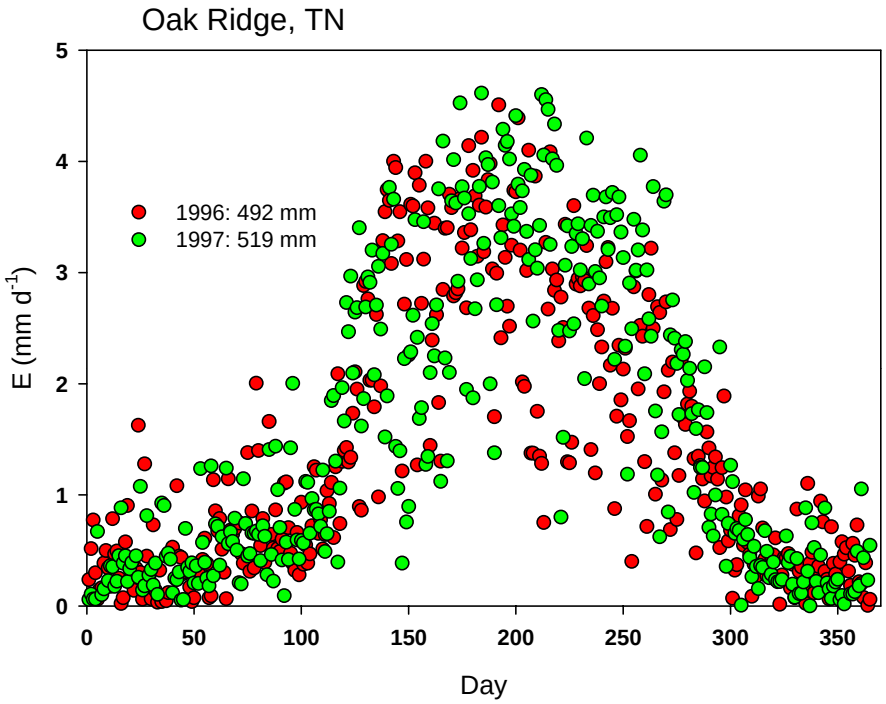


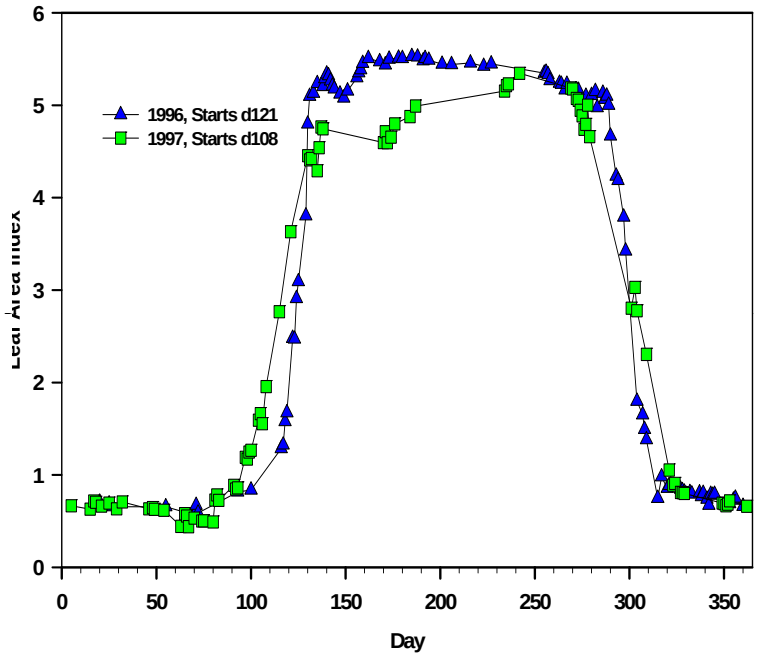
Annual ET of Annual Grassland varies with Hydrological Growing Season



Ryu, Baldocchi, Ma and Hehn, JGR-Atmos, submitted

Growing Season Length and ET, Temperate Forest



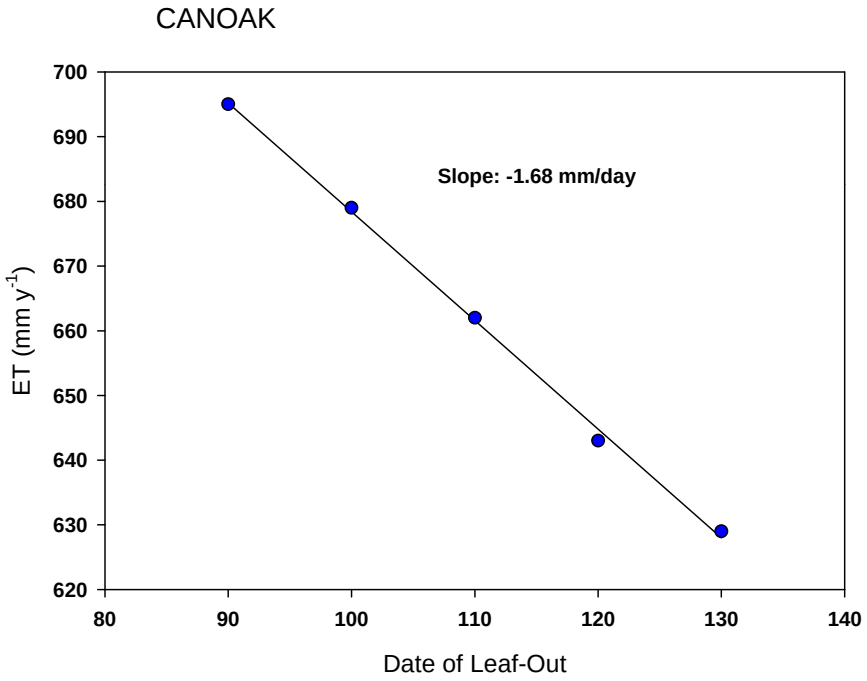


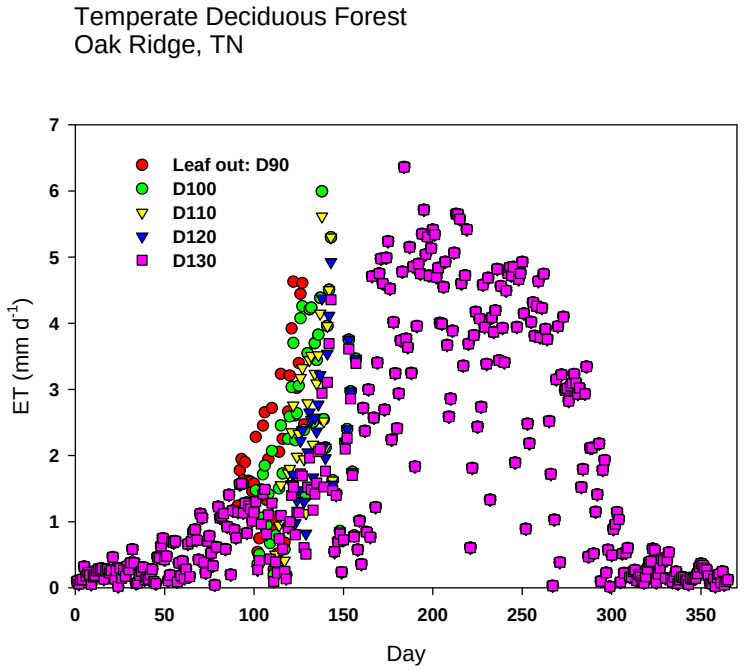
Year with Longer Growing Season (13 days)
Evaporated More (27 mm).

Other Climate Factors could have confounded results,
but R_g (5.43 vs 5.41 GJ m^{-2}) and T_{air} (14.5 vs 14.9 C)
were similar and rainfall was ample (1682 vs 1435 mm)

Wilson and Baldocchi, 2000, AgForMet

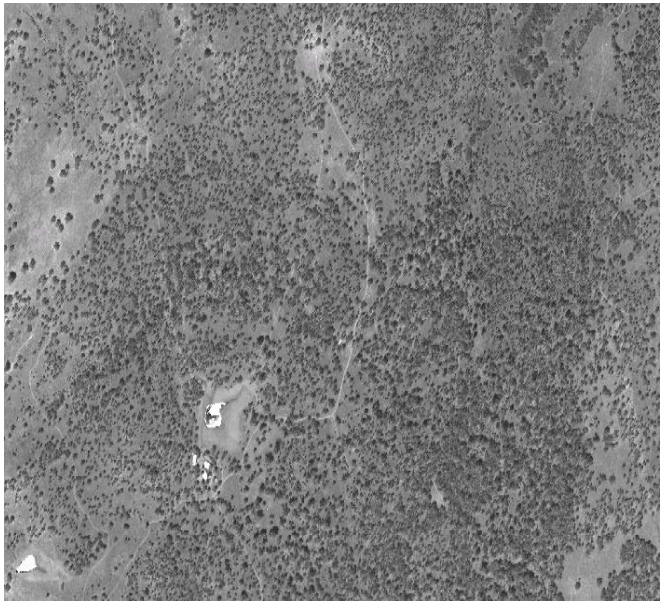
Year to Year differences in ET is partly due to differences in Growing Season Length

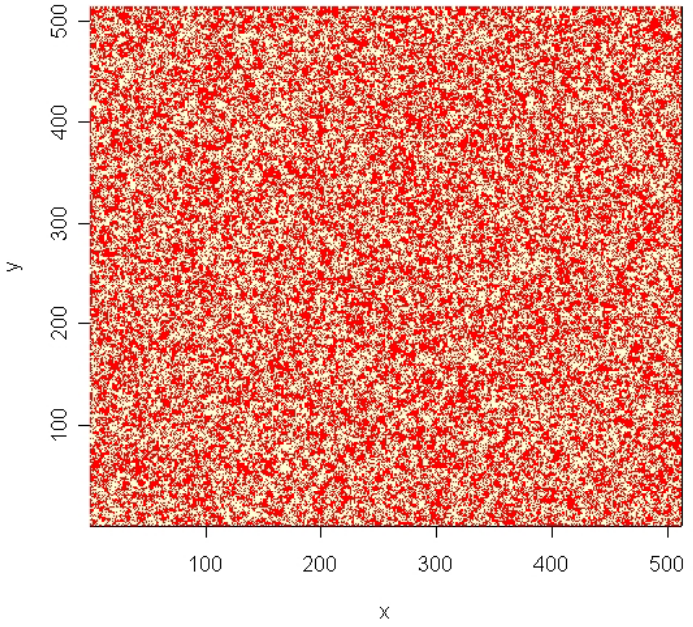




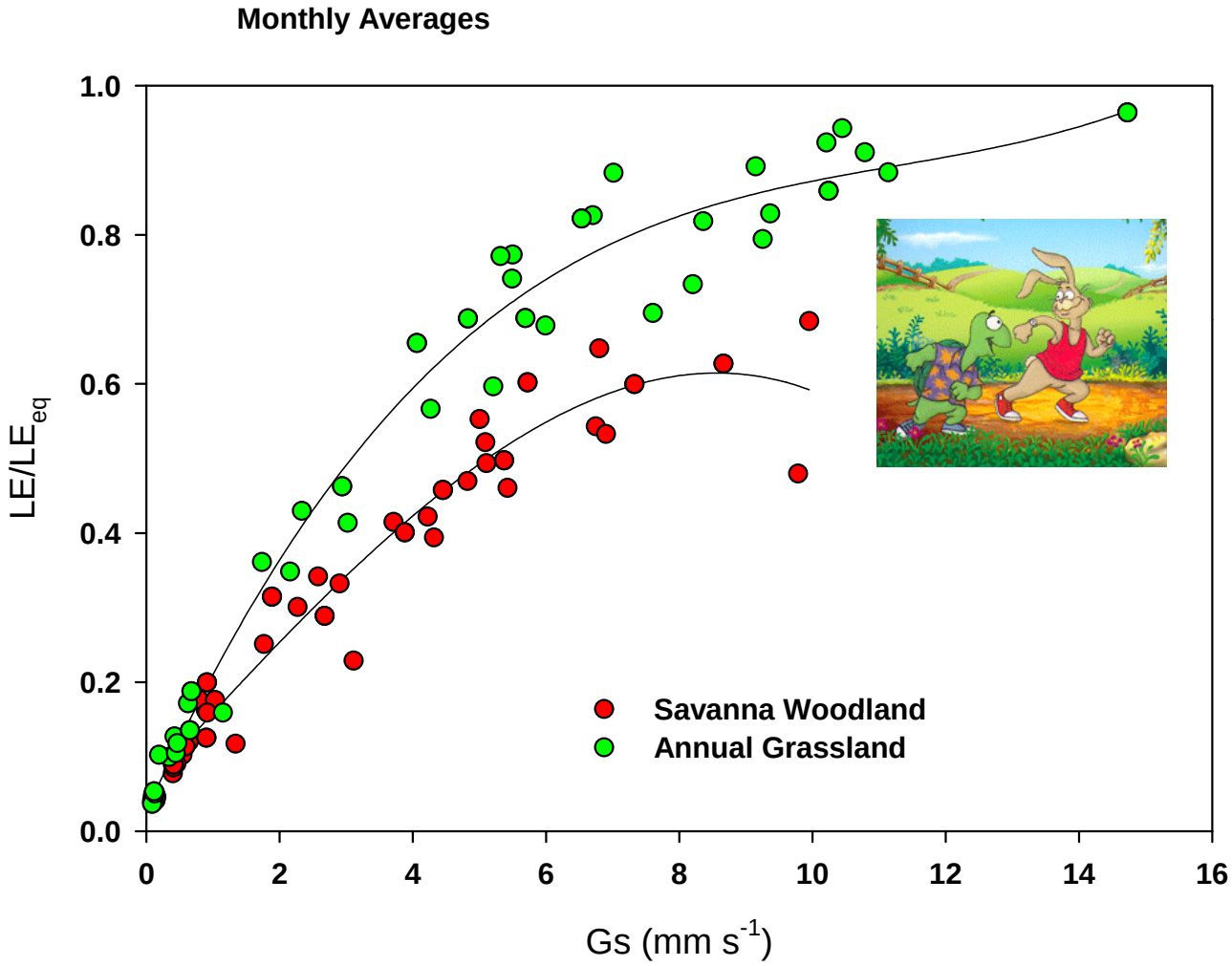
Field data show that ET decreases by 2.07 mm for each day the start of the growing season is delayed

ET: Spatial Scale





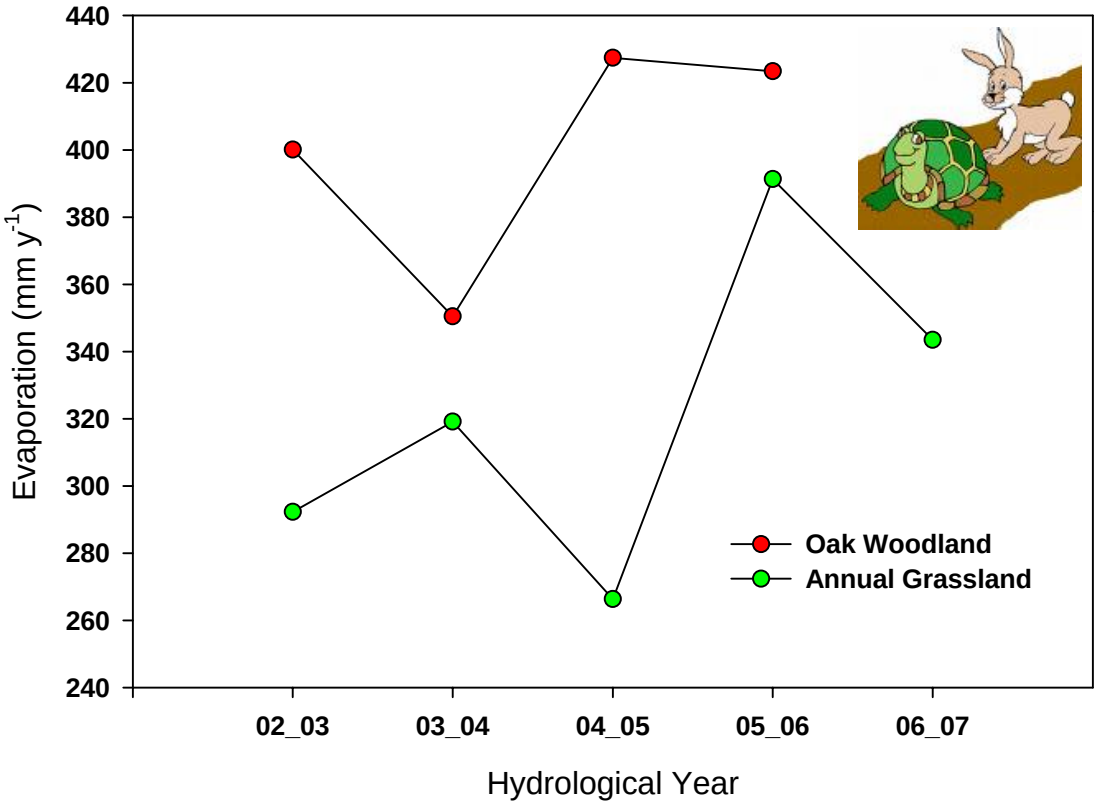
Landscape Differences
On Short Time Scales, Grass ET > Forest ET



Ryu, Baldocchi, Ma and Hehn, JGR-Atmos, submitted

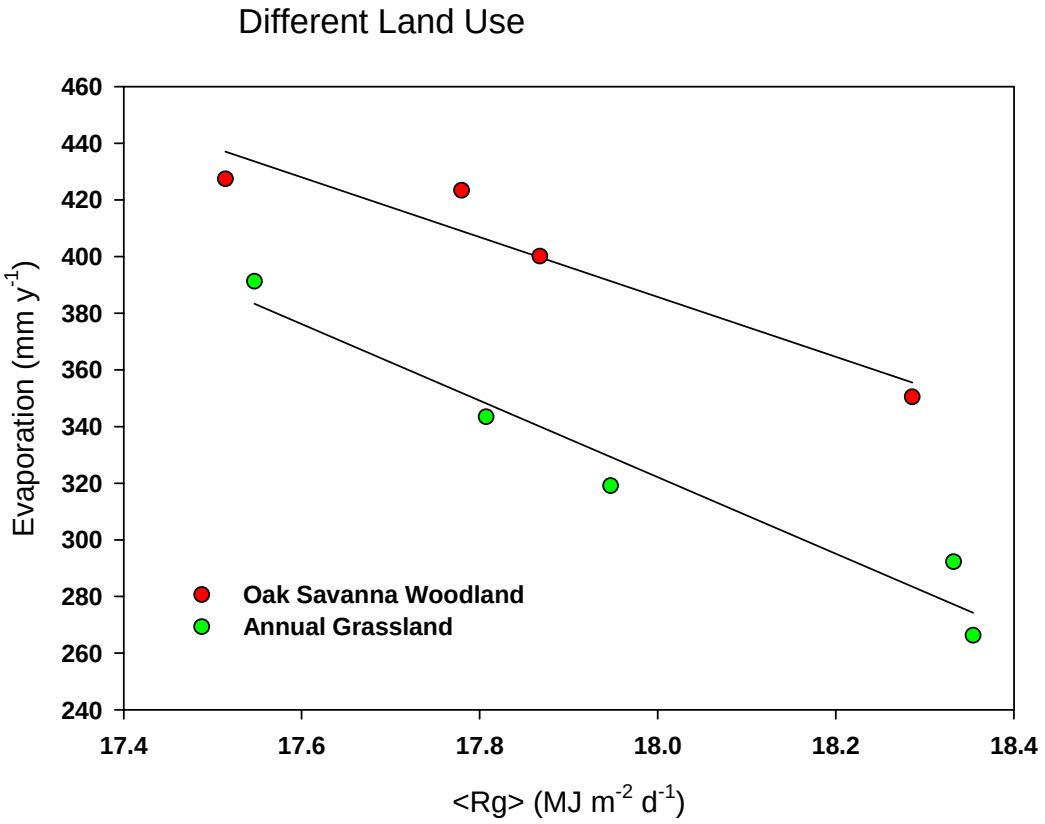
Role of Land Use on ET:
On Annual Time Scale, Forest ET > Grass ET

California Savanna



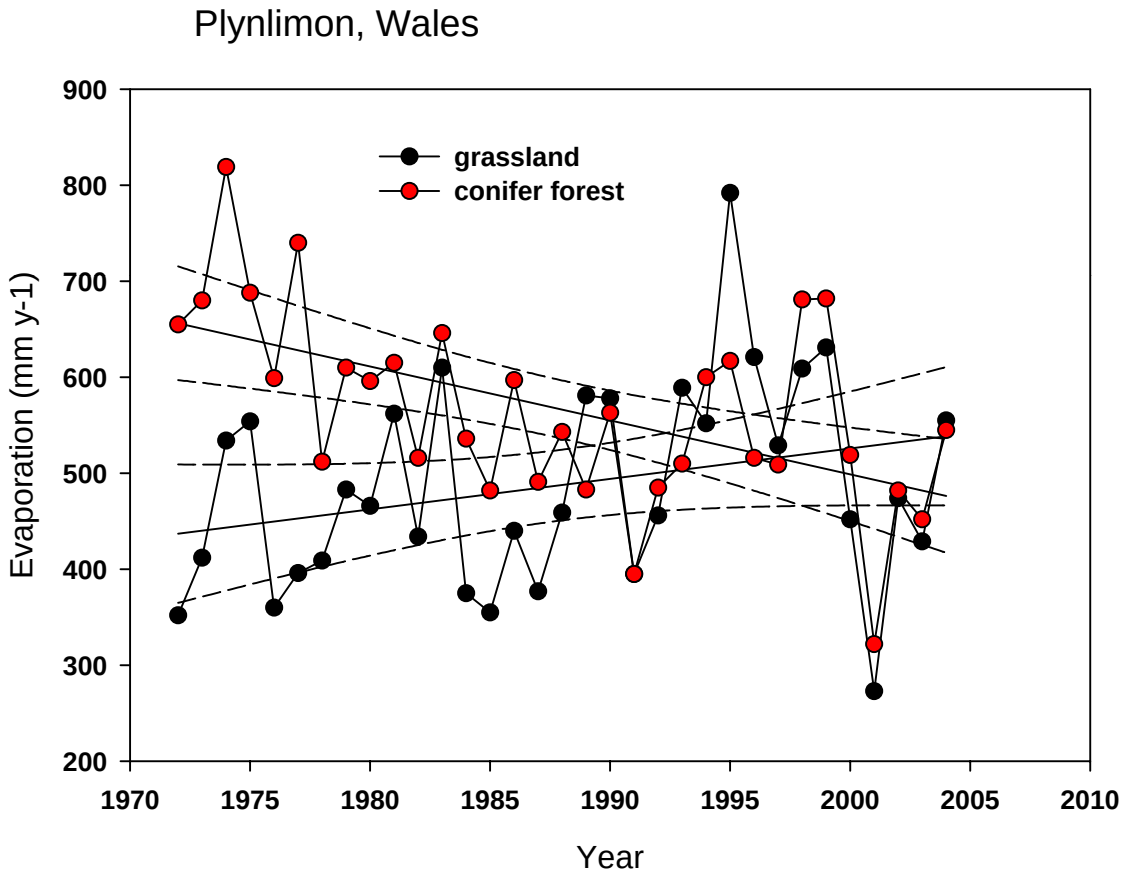
Ryu, Baldocchi et al, JGR-Atmos, submitted

- **Savanna Uses More Water than Grassland**
- **Savanna Soil holds about 78 mm more Water**
- **Annual ET Decreases with Rg**
- **Rg is negatively correlated with Rain and Clouds**
- **System is Water not Radiation Limited**

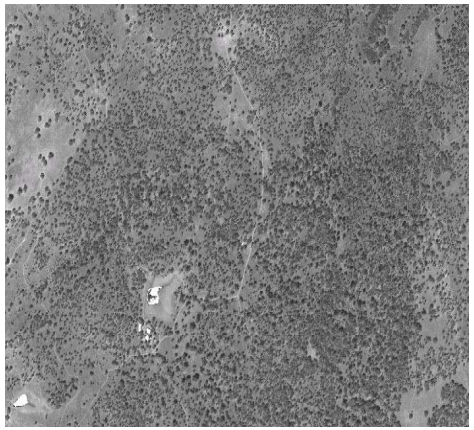


Ryu, Baldocchi, Ma, Hehn, JGR-Atmos, submitted

Stand Age also affects differences between ET of forest vs grassland



Marc and Robinson, 2007 HESS

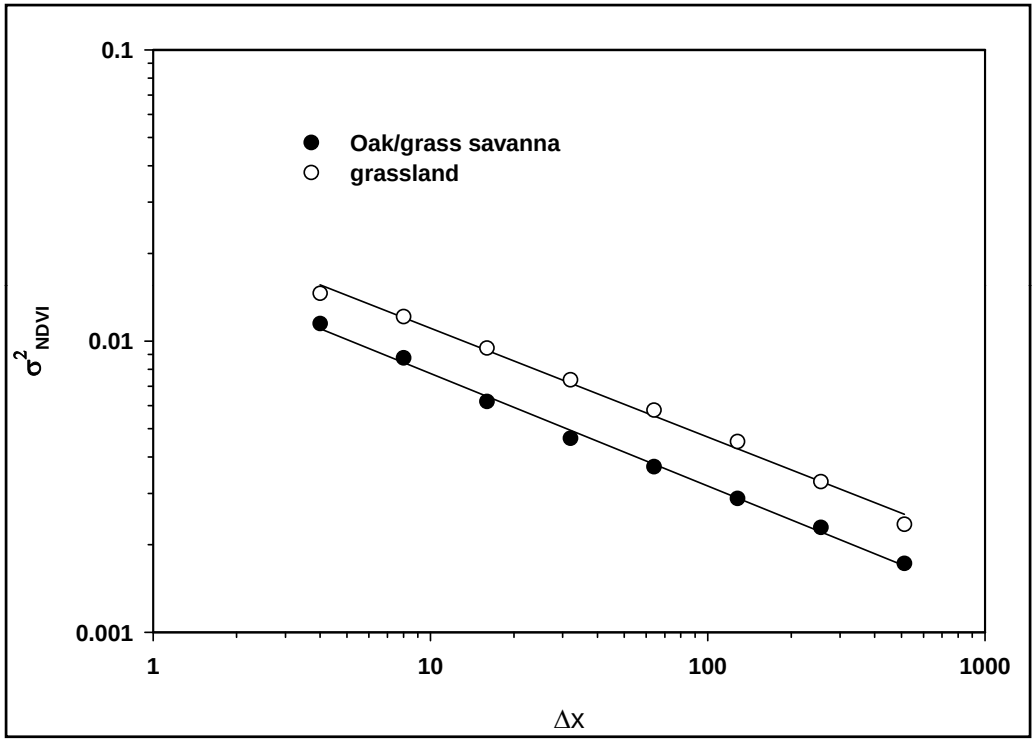


Assessing Spatial Averages with Subgrid Variability

$$E[\lambda E] = \frac{\overline{s}\,\overline{A} + \overline{s'A'} + \rho C_p(\overline{D}\,\overline{g}_a + \overline{D'g_a'})}{(\overline{s} + \gamma + \gamma(\overline{g}_a / \overline{g}_s + \overline{g_a r_s'}))}$$

$$E[\lambda E] = \frac{\overline{s}\,\overline{A} + \overline{r_{As}\sigma_s\sigma_A} + \rho C_p(\overline{D}\,\overline{g}_a + \overline{r_{Dga}\sigma_D\sigma_{ga}})}{(\overline{s} + \gamma + \gamma(\overline{g}_a / \overline{g}_s + \overline{r_{gr}\sigma_{ga}\sigma_{rs}}))}$$

Sub-Grid Variability: MODIS and IKONOS



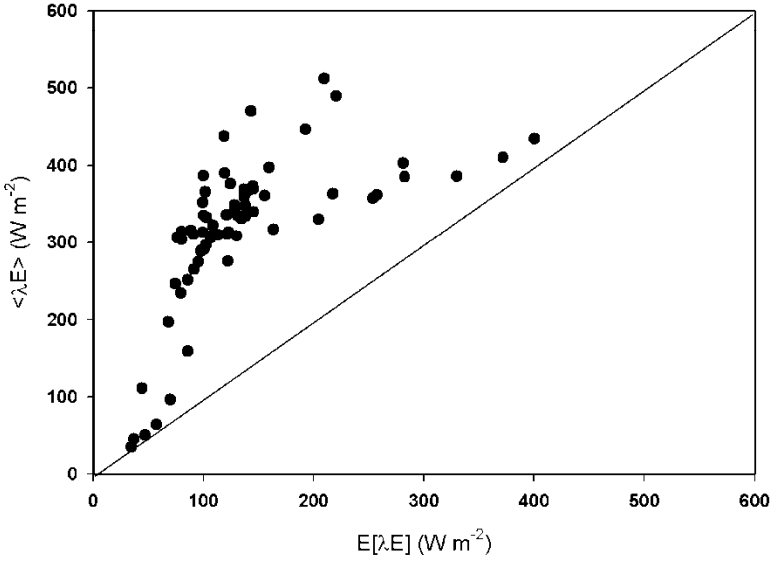
Use Power Law scaling to Estimate small scale Variance

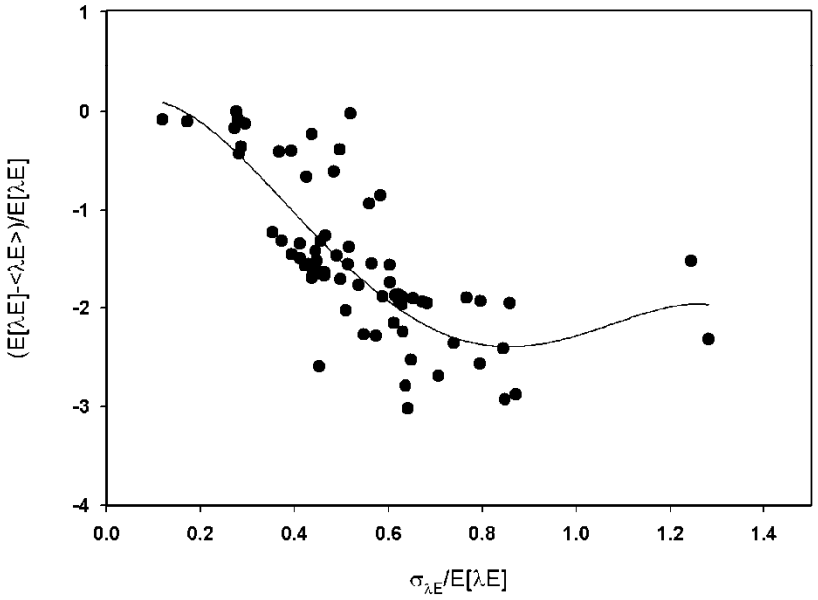
$$E[f(x)] = f(\bar{x}) + \frac{1}{2}\frac{\partial^2 f(\bar{x})}{\partial x^2}\sigma(\bar{x})^2$$

Baldocchi et al 2005 Tellus

Errors in ET Scaling

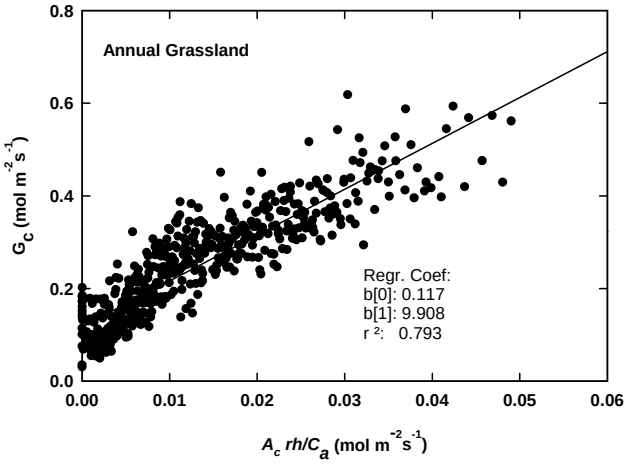
$$E[f(x)] = f(\bar{x}) + \frac{1}{2}\frac{\partial^2 f(\bar{x})}{\partial x^2}\sigma(\bar{x})^2$$

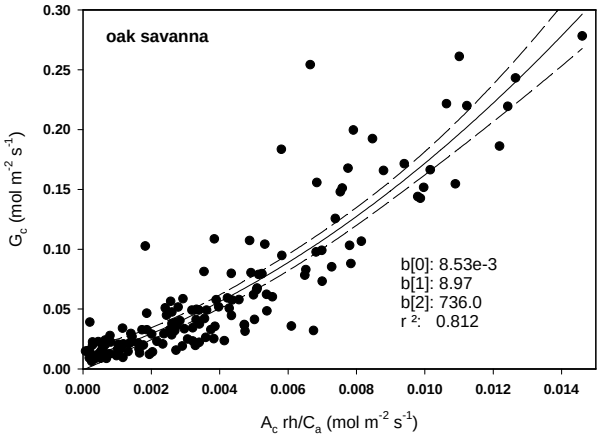




Baldocchi et al 2005 Tellus

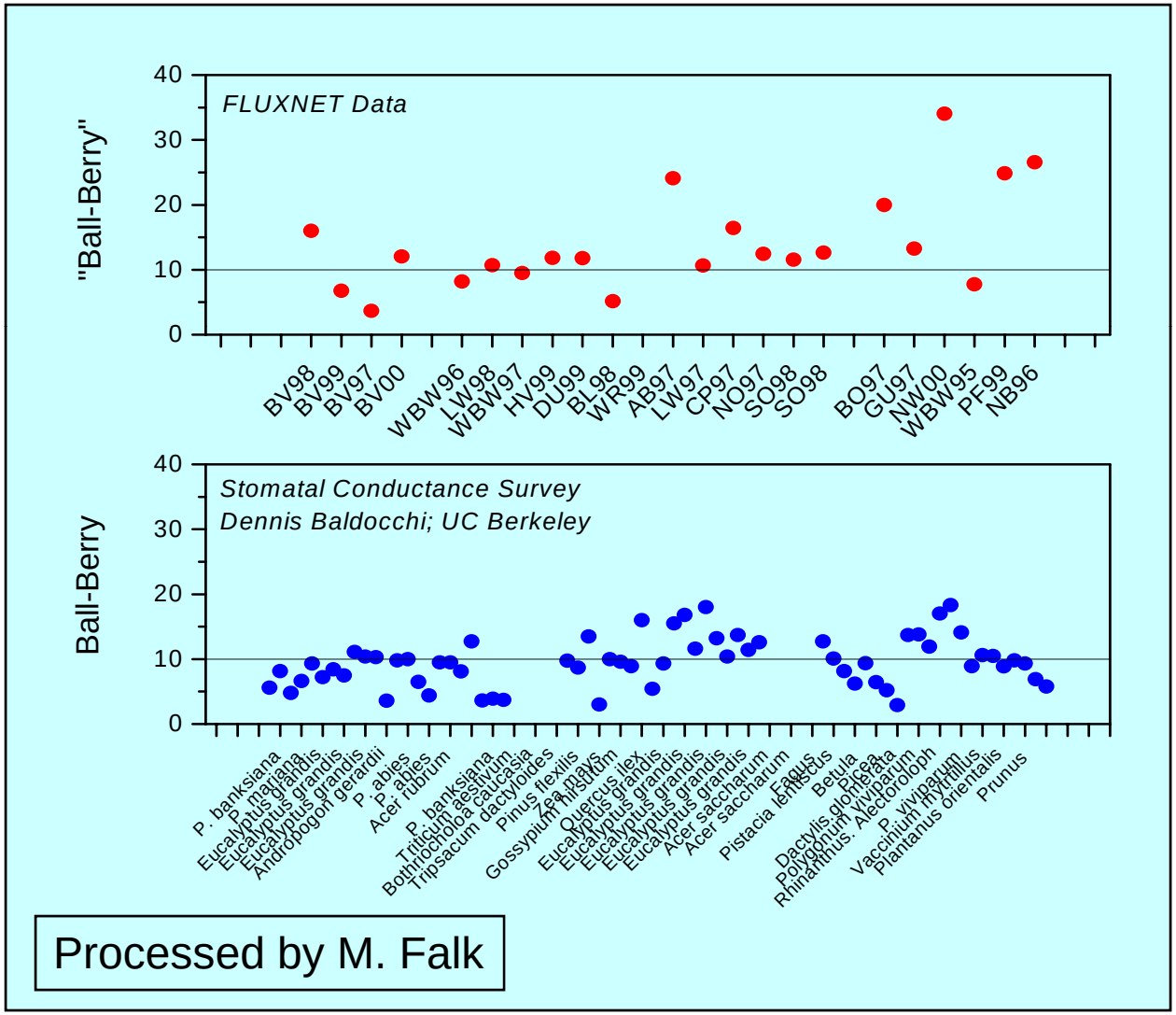
Linking Water and Carbon: Potential to assess G_c with Remote Sensing





Xu + DDB, 2003 AgForMet

Gc Exhibits Scale ‘Invariance’



Processed by M. Falk

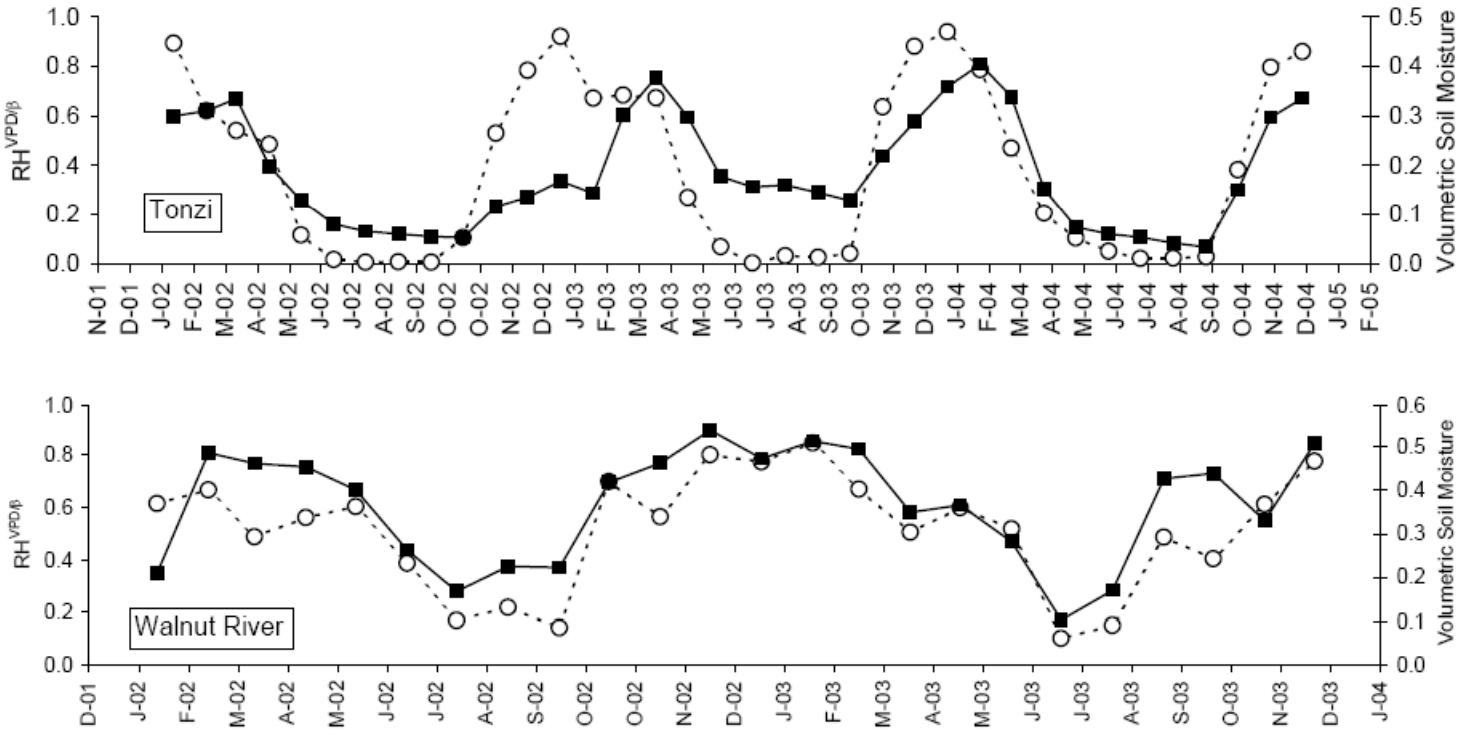
Fisher et al Global ET Model

Total Latent heat flux	$LE_s + LE_c + LE_i$
Canopy Transpiration	$(1 - f_{wet}) f_g f_T \alpha \frac{\Delta}{\Delta + \gamma} R_{nc}$
Soil Evaporation	$(f_{\text{wet}} + f_{\text{SM}}(1 - f_{\text{wet}}))\alpha \frac{\Delta}{\Delta + \gamma}(R_{ns} - G)$
Intercepted Evaporation	$f_{\text{wet}} \alpha \frac{\Delta}{\Delta + \gamma} R_{nc}$

f_{wet}	RH^{10}
f_g	$\frac{f_{APAR}}{f_{IPAR}}$
f_{APAR}	$m_1 SAVI + b_1$
f_{IPAR}	$m_2 NDVI + b_2$
f_c	f_{IPAR}
f_T	$\exp\left(-\left(\frac{T_a - T_{opt}}{\lambda}\right)^2\right)$
f_{SM}	RH^{VPD}
T_{opt}	T_a at $\max\{f_{APAR} T_a RH^{VPD}\}$

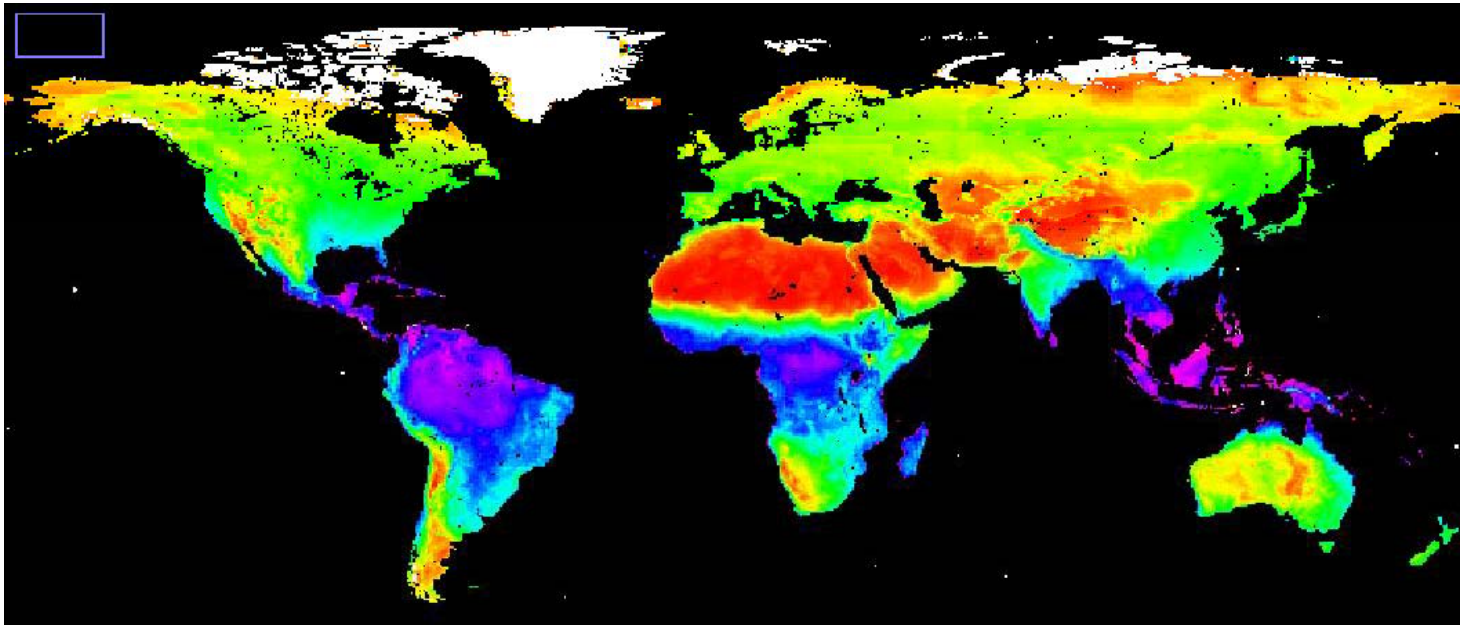
RH^{VPD}

A measure for downscaling ET with Drought???



Fisher, Tu and Baldocchi, RSE in press

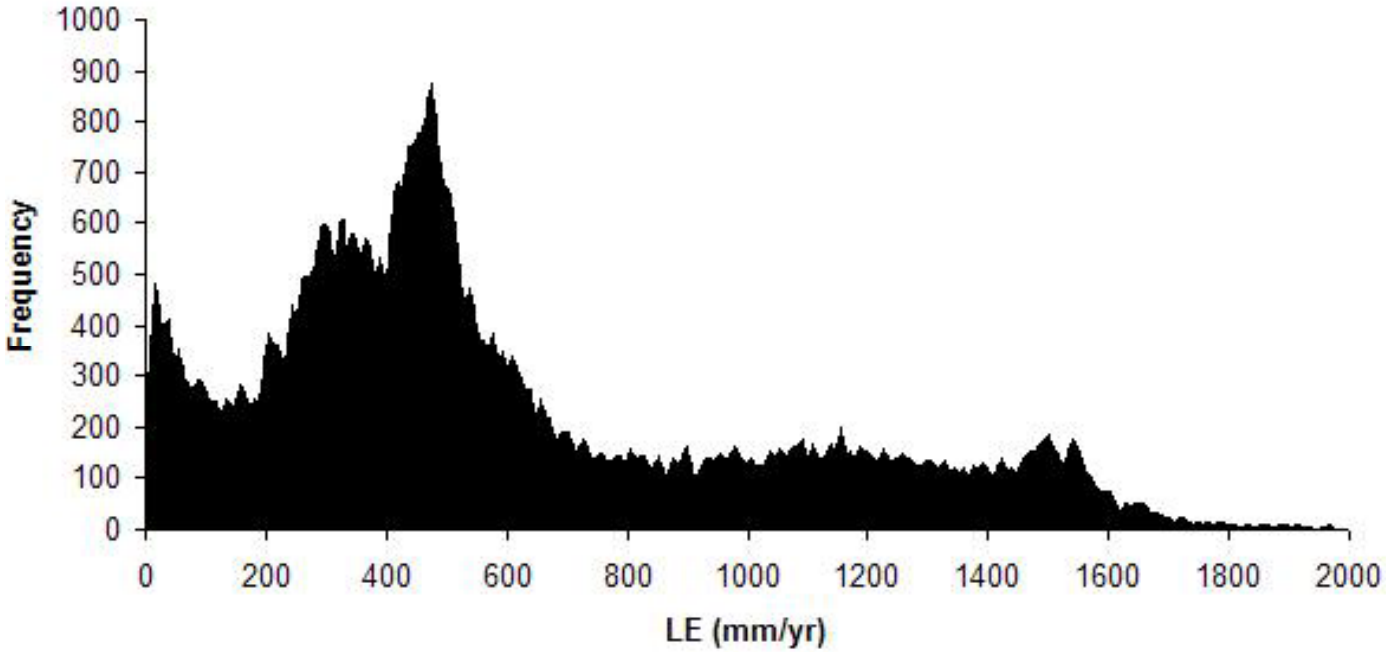
Global ET, 1989, ISLSCP



ET (mm/y)	reference
613	Fisher et al
286	Mu et al. 2007
467	Van den Hurk et al 2003
649	Boslilovich 2006
560	Jackson et al 2003

Fisher et al, in press

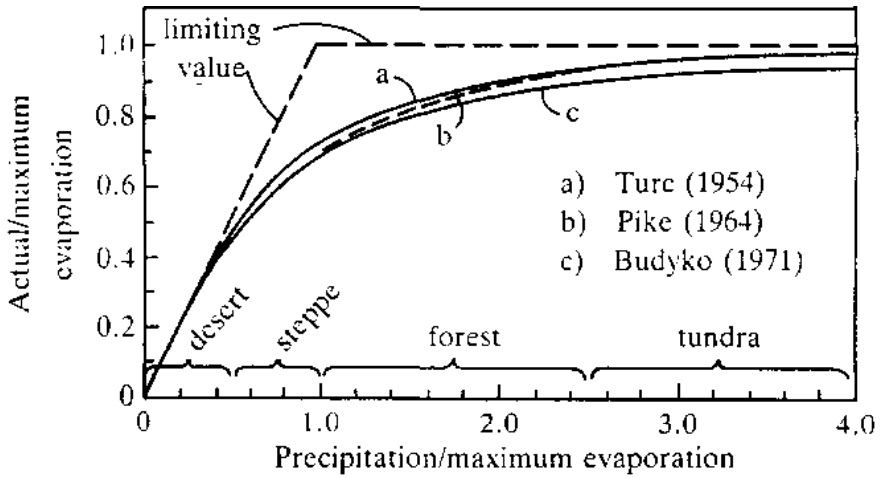
Global ET pdf, 1989, ISLSCP



Fisher et al.

Conclusions

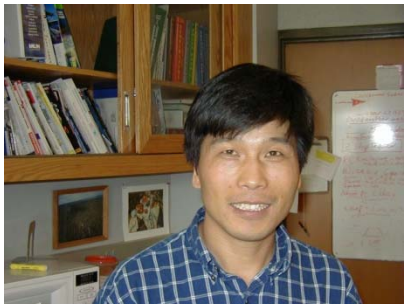
- Biophysical data and theory help explain powerful ideas of Budyko and Monteith that provide framework for upscaling and global synthesis of ET
  - ET scales with canopy conductance, which scales with LAI and Ps capacity, which scales with precipitation and N



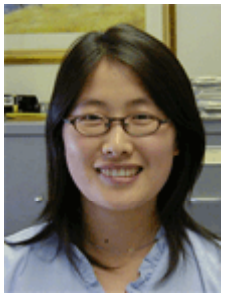
Be Careful

- Short-Term Differences in Potential and Actual ET may not hold at Annual Time Scales
  - Grass has greater potential for ET than Savanna
- Sub-Grid Variability in surface properties can produce huge errors in upscaled ET at the 1 km Modis Pixel Scale

Present and Past Biometeorology ET Team

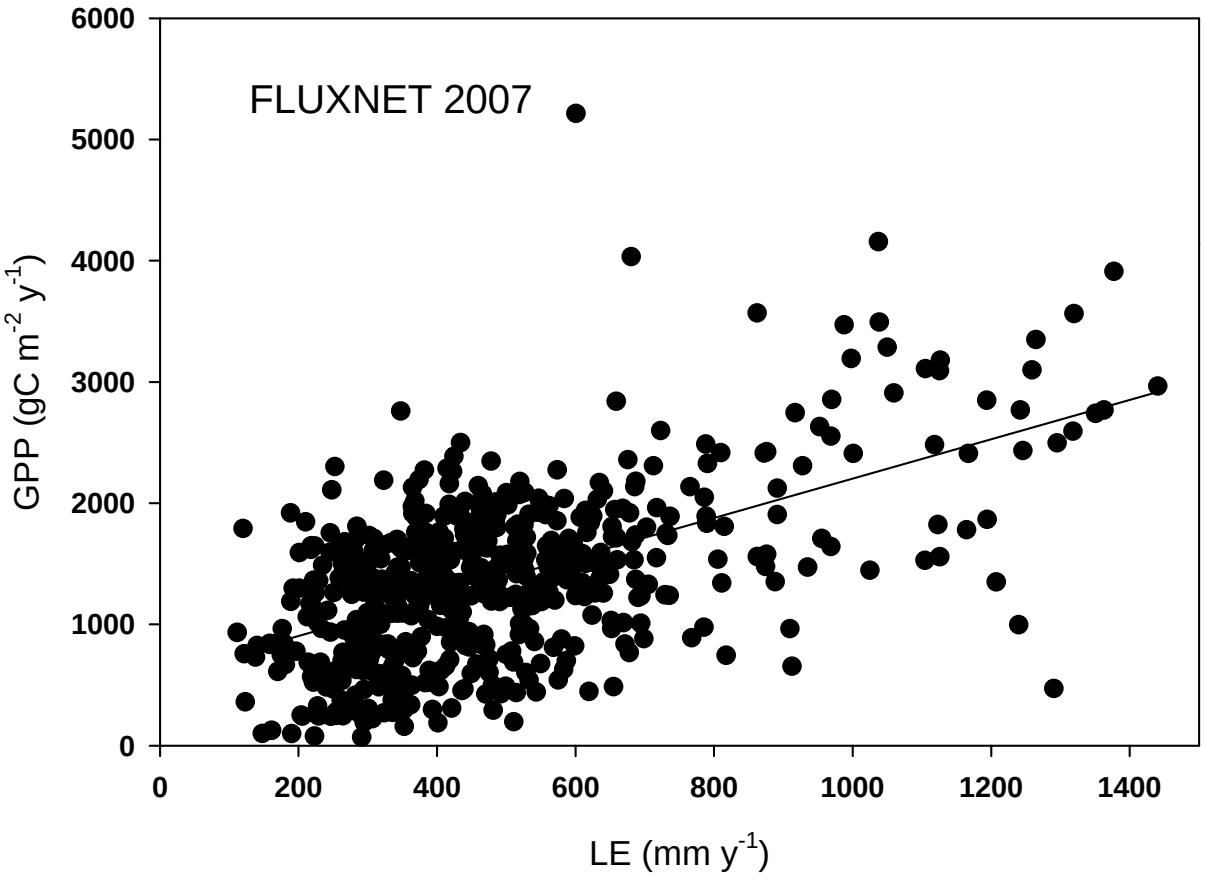






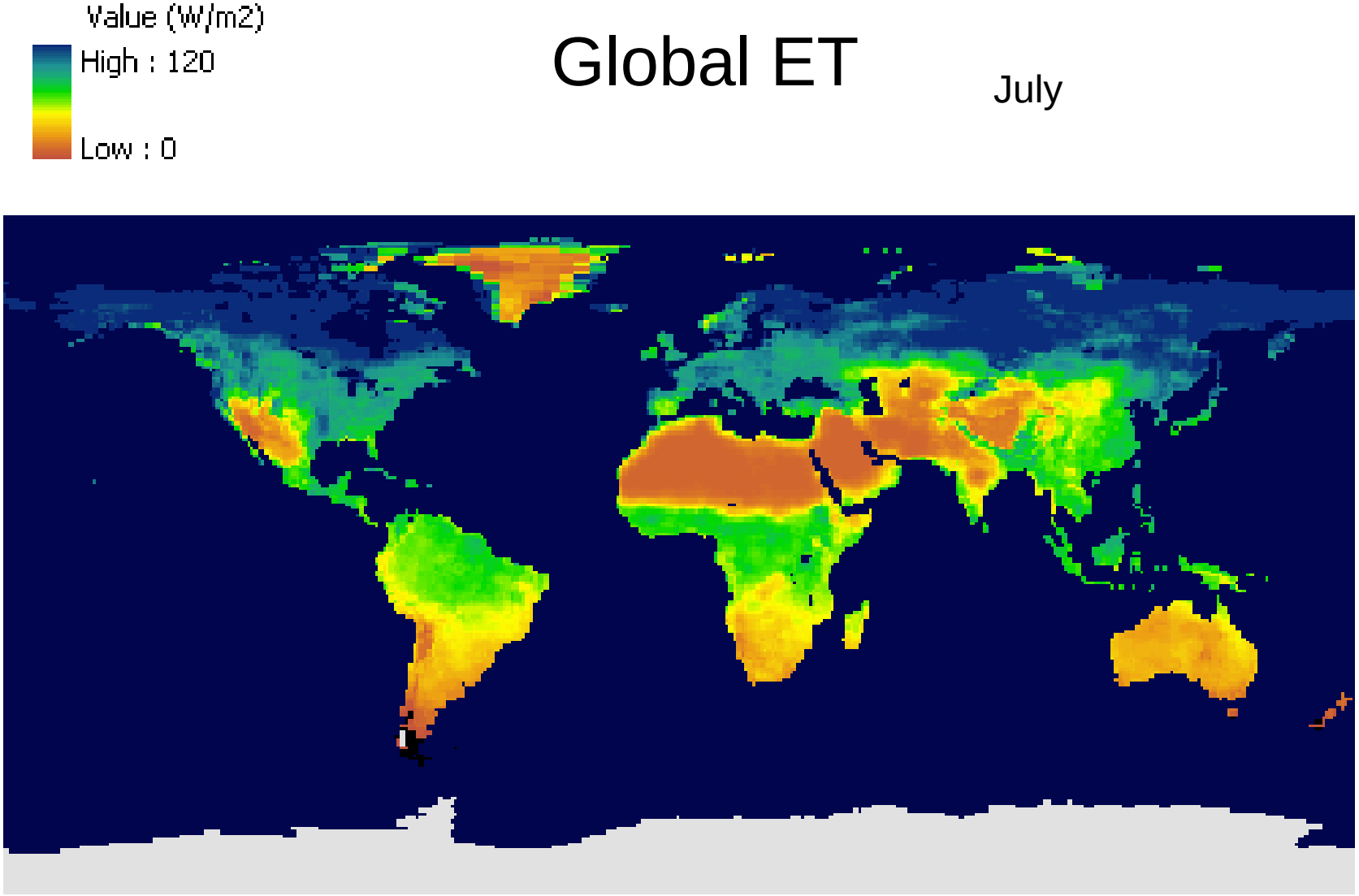

Funding: US DOE/TCP; NASA; WESTGEC; Kearney; Ca Ag Expt Station

FluxNET WUE

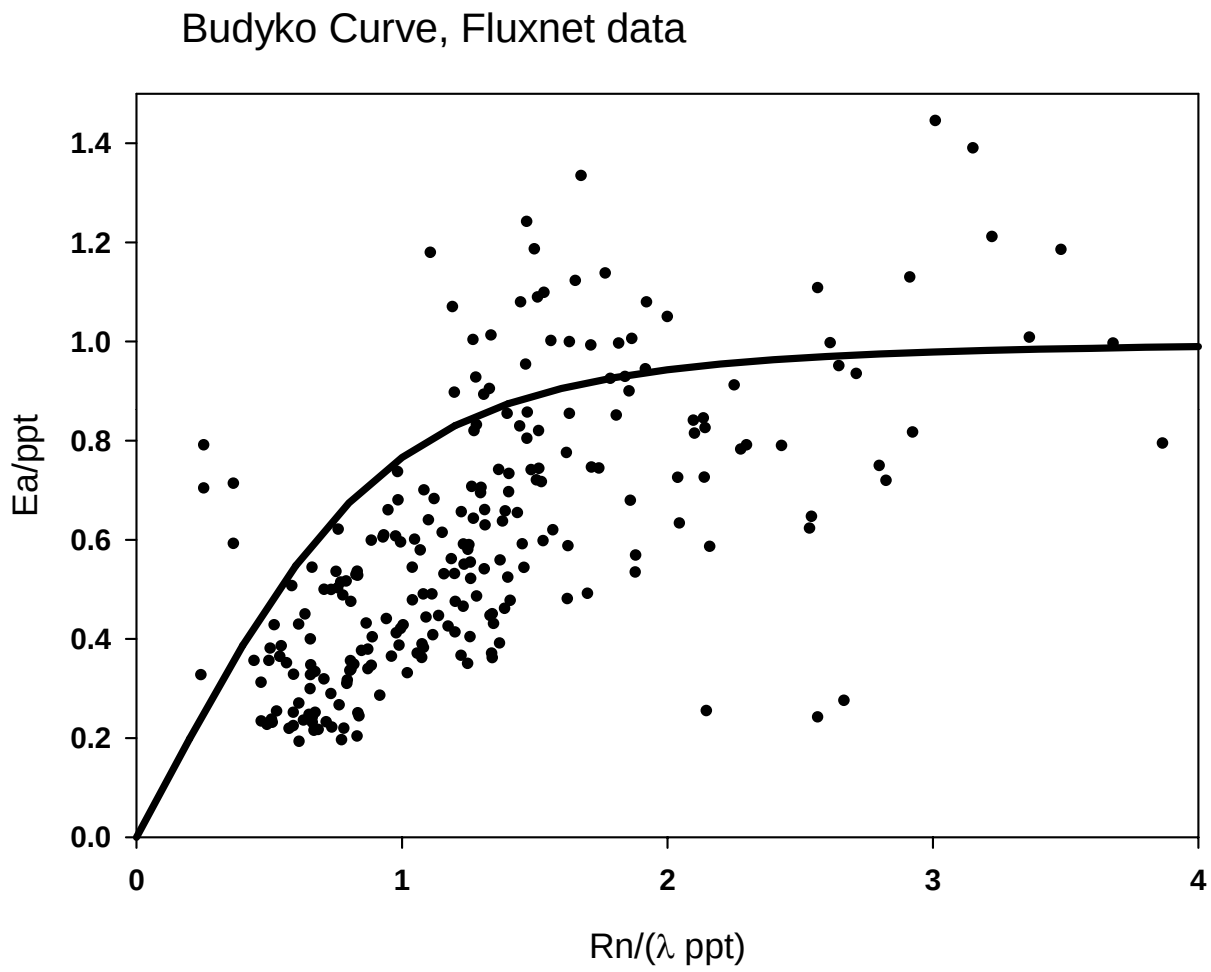

FLUXNET 2007
GPP (gC m-2 y-1)
LE (mm y-1)
0
1000
2000
3000
4000
5000
6000
0
200
400
600
800
1000
1200
1400

Global ET

July

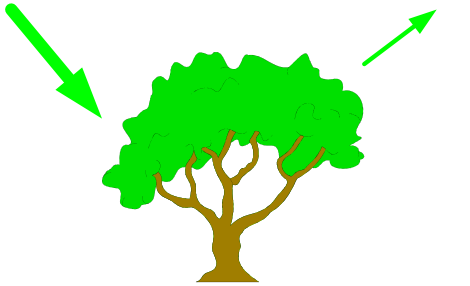


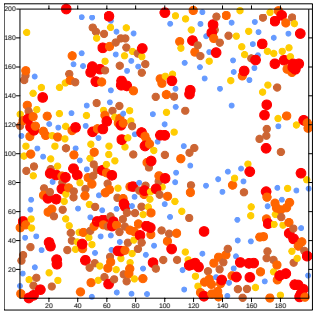
Fisher et al, in press


Budyko Curve, Fluxnet data
Ea/ppt
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
Rn/(λ ppt)

Photosynthesis > Respiration

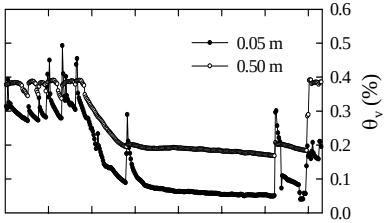
CO_2

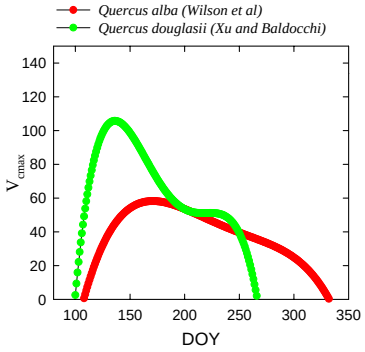




Limited Lear Area and Sparse Canopy Reduce ET, too

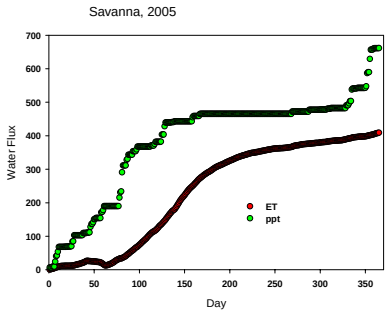
Short growing season with available moisture

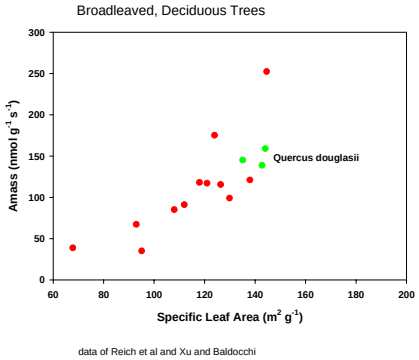




Ps Capacity must be Great, For Short Period

Stomatal Closure so Evaporation > Precipitation

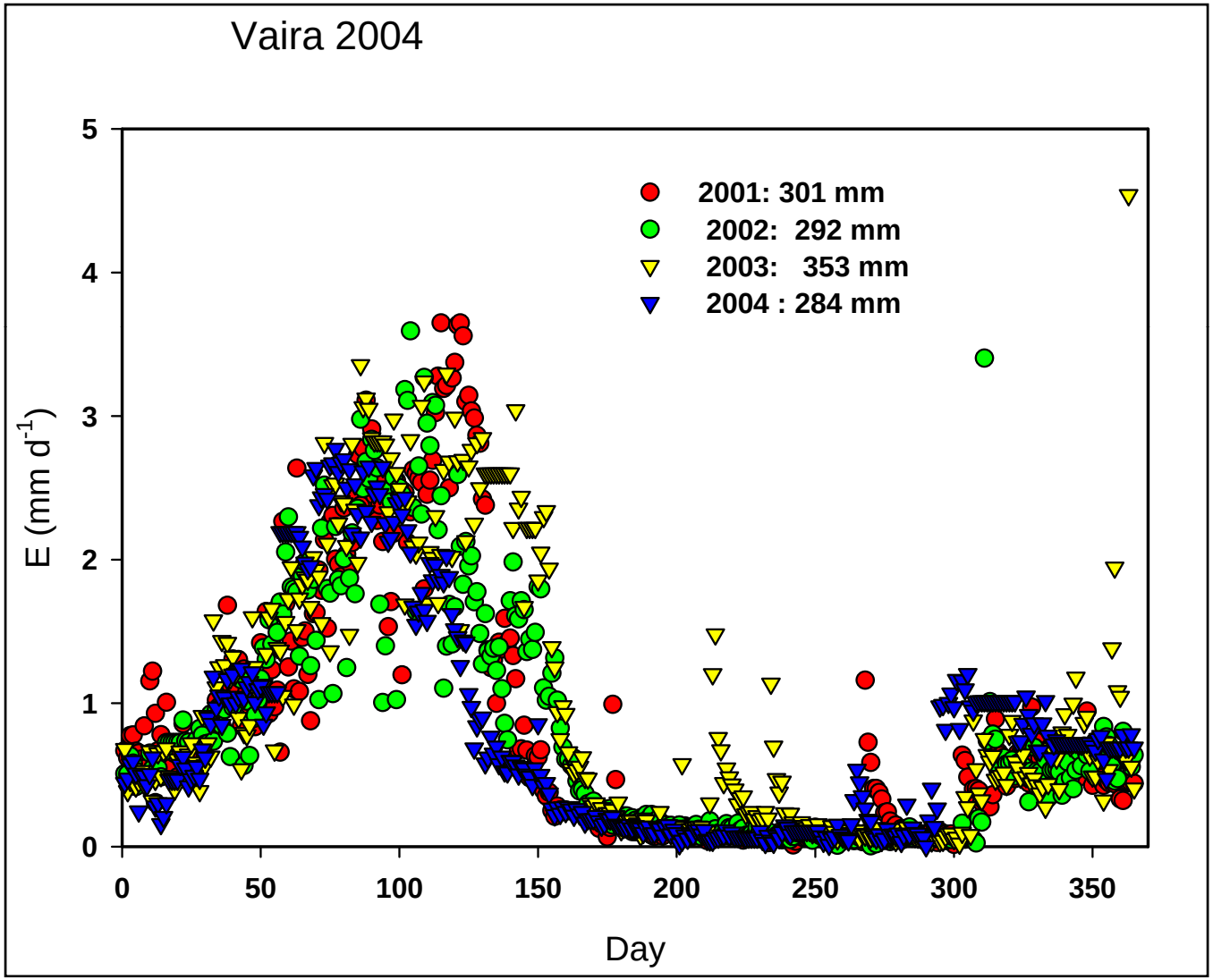




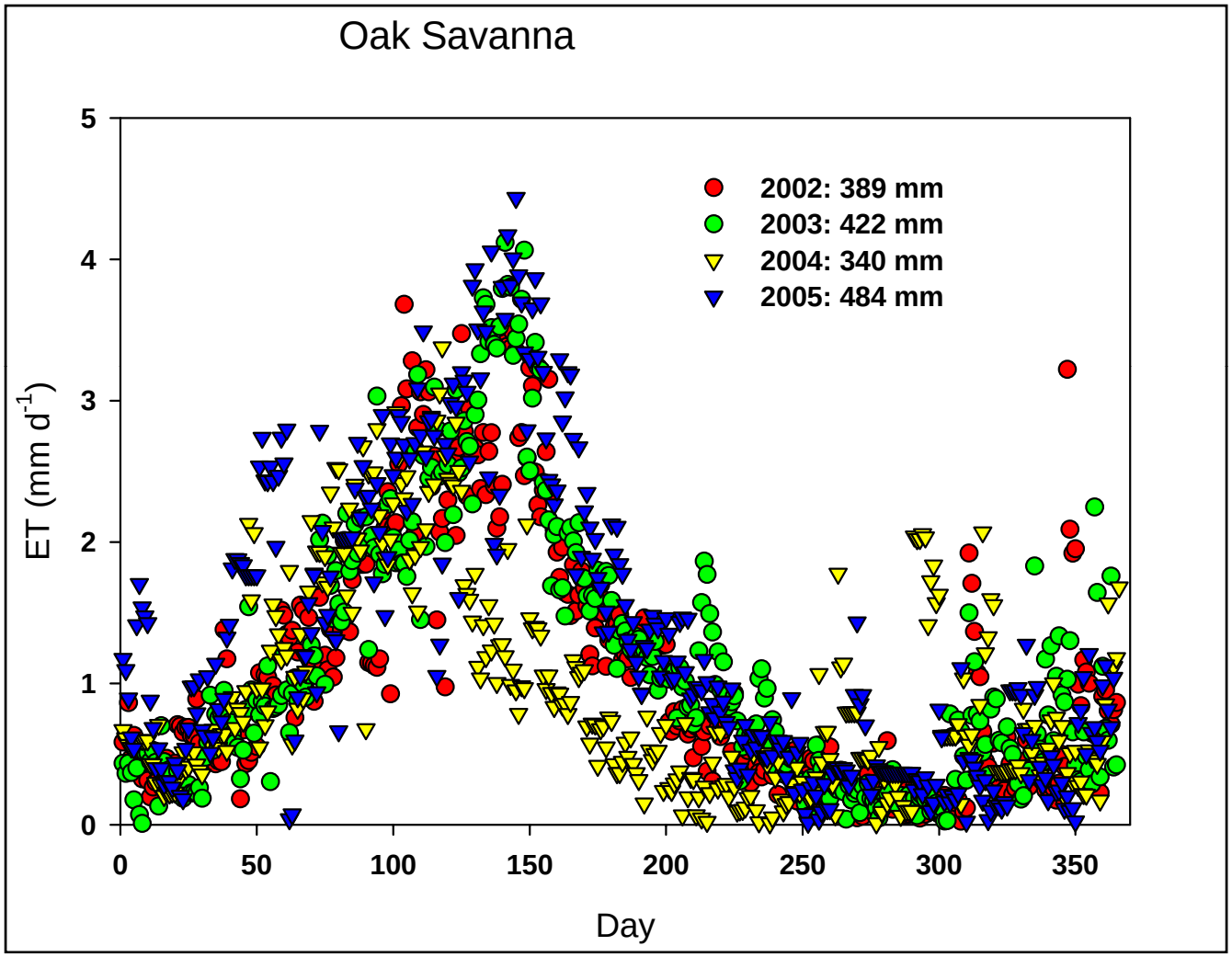
data of Reich et al and Xu and Baldocchi

Leaf N and Leaf Thickness must support Ps Machinery

Interannual Variation ET: Grassland

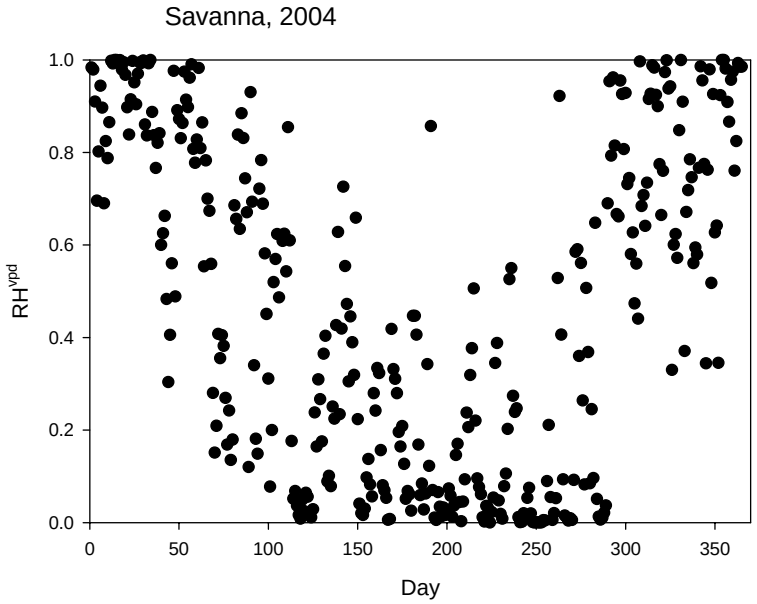


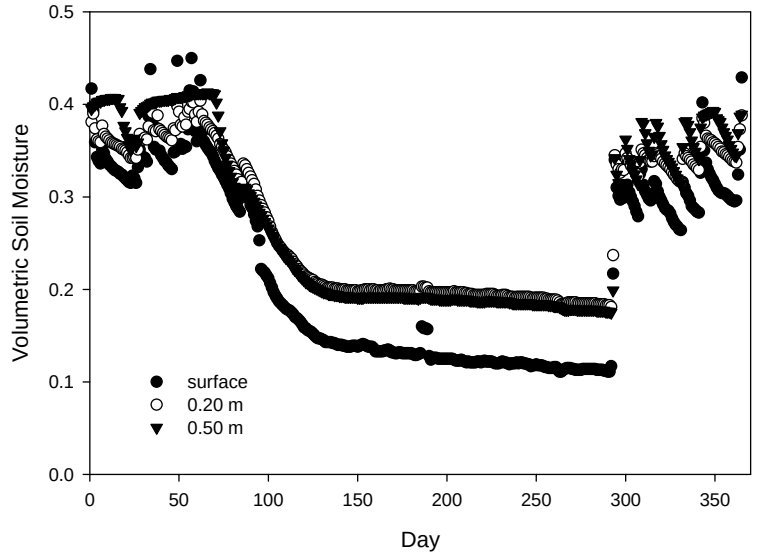
Inter annual Water Balance



RH^{VPD}

A measure for downscaling ET with Drought???





Fisher et al. Remote Sensing Environment, in press