

Carbon & Water Exchange of an Oak-Grass Savanna Ecosystem

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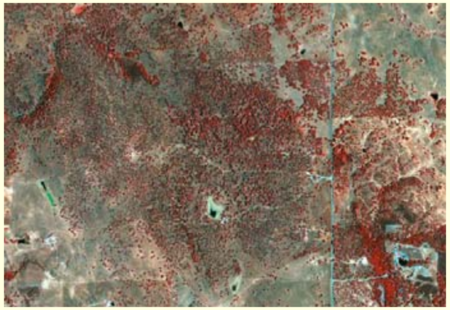


Oak-Savanna Model System for Studying Ecosystem Ecology

- Structure/Function
  - Oak and grasses provide contrasting life forms, woody/herbaceous, perennial/annual
  - The Canopy is open and heterogeneous, giving us a opportunity to test the applicability of ecosystem and biogeophysical models, mostly developed for ideal and closed canopies
- Environmental Biology
  - The Mediterranean climate provides distinct wet/ cool and dry/hot seasons to examine the ecosystem response (photosynthesis, transpiration, respiration, stomatal conductance) to a spectrum of soil moisture and temperature conditions
- Global Change
  - The Mediterranean climate experiences great extremes in inter-annual variability in rainfall; we experience a wider range in ppt over a few years than long-term predicted changes.

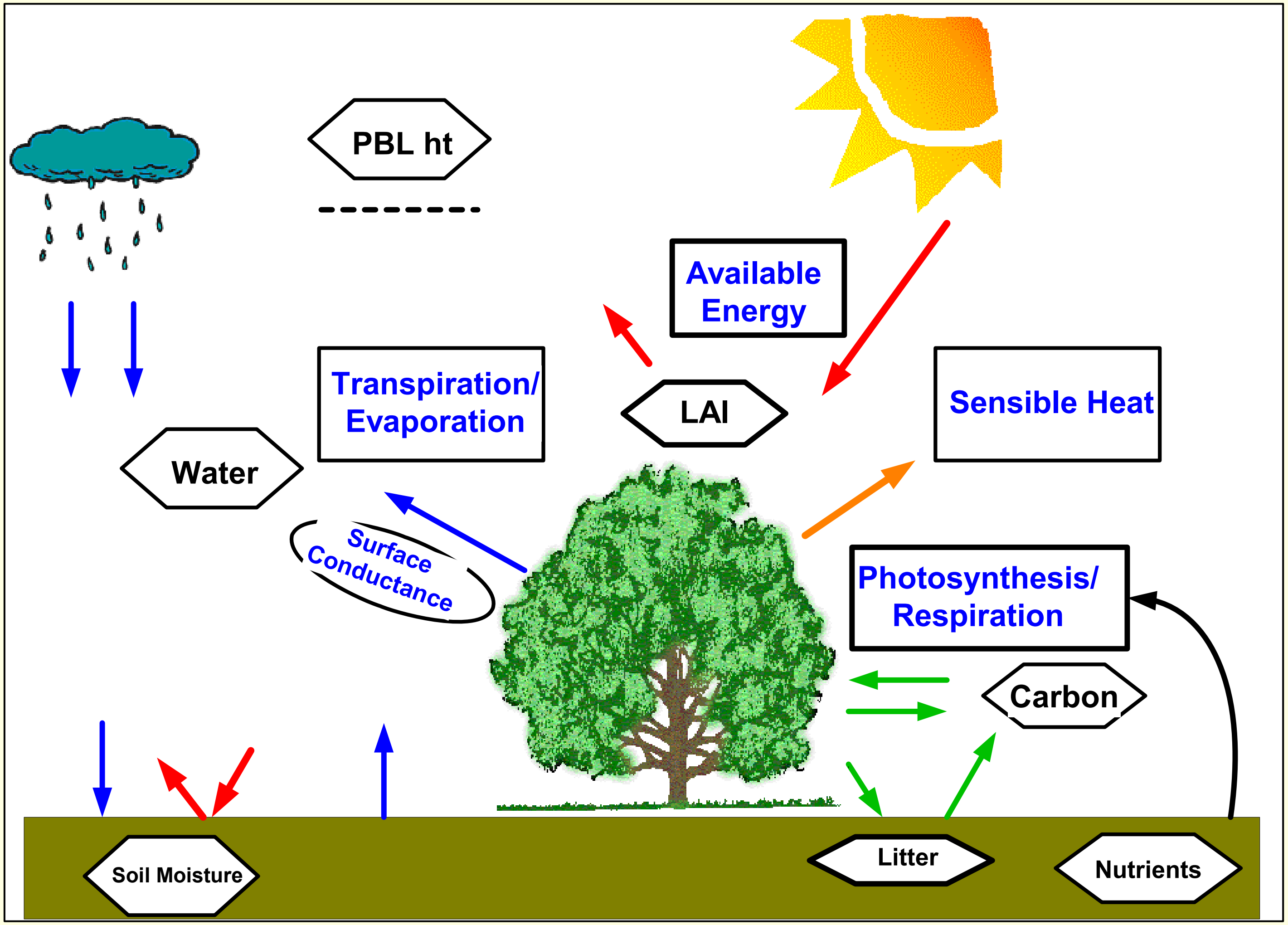
Oak-Grass Savanna: A Two Layer System

Winter:
Trees deciduous; grass green

Spring:
Trees green;grass green

Summer:
Trees green; grass dead

Water and the Environment: Biogeophysical-Ecohydrological View

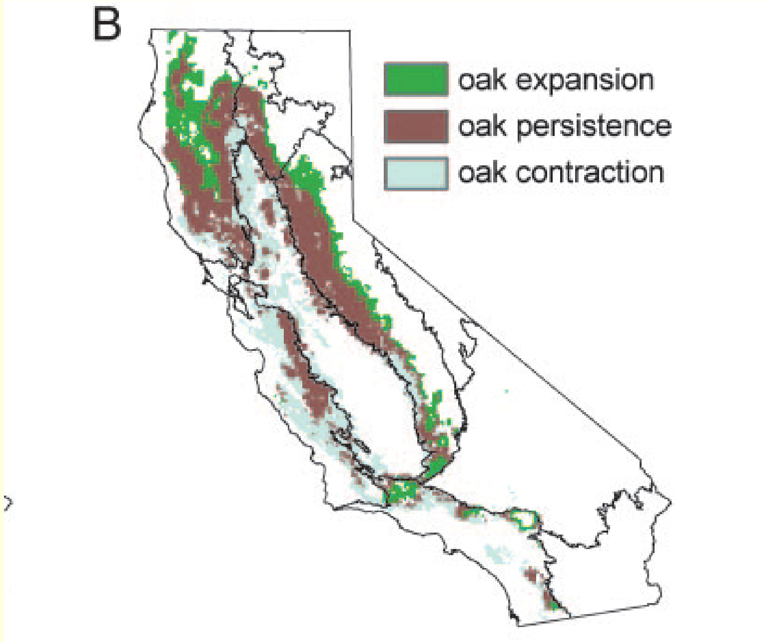


Goals of Research

- Quantify the Biophysical Controls on Ecosystem Metabolism (carbon gains and losses) and Water Balance of Oak Woodlands

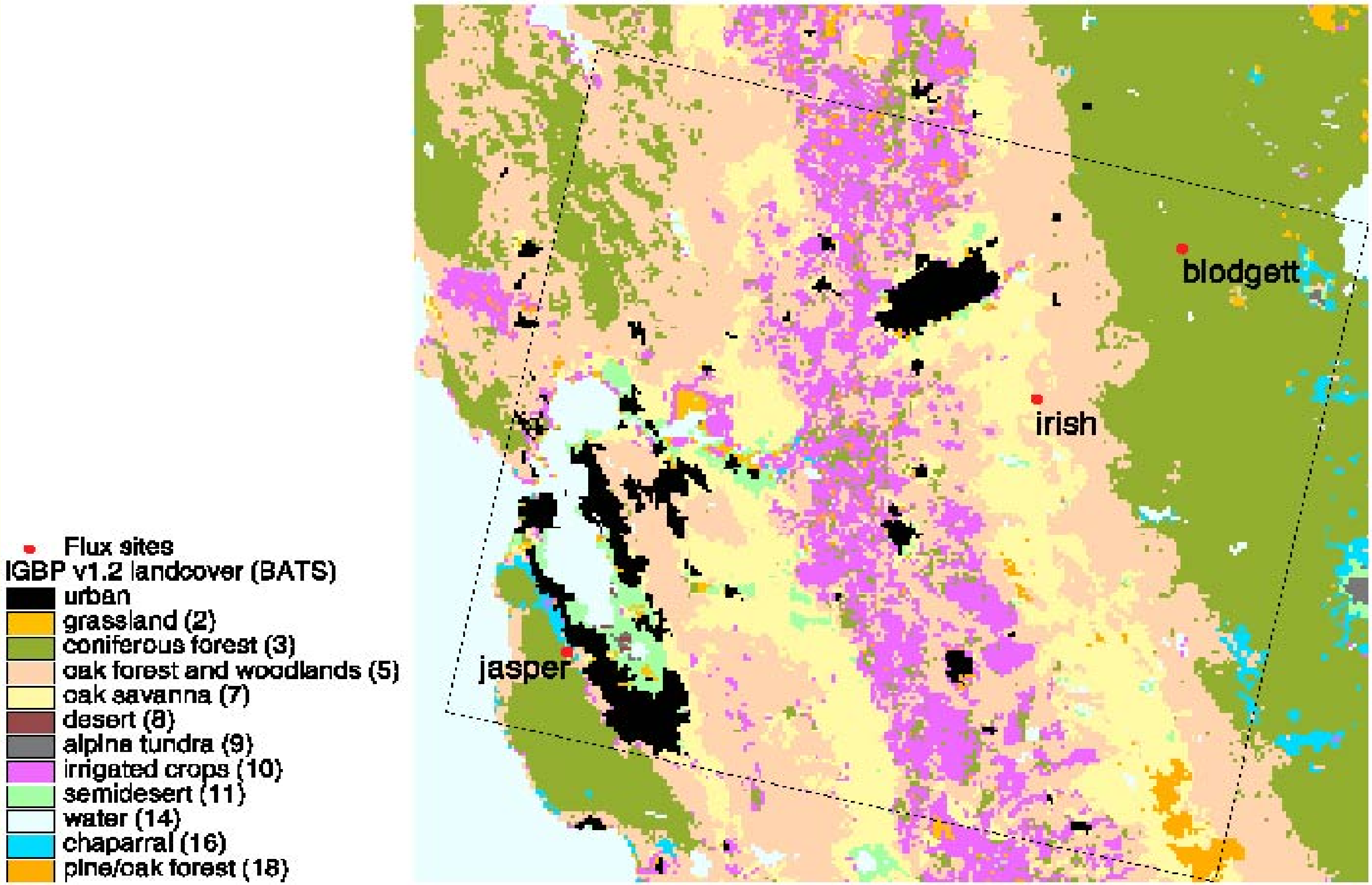
- Quantify net annual budgets and inter-annual variability of carbon, water and energy exchange of oak woodland and annual grassland

- Produce predictive and mechanistic ability to quantify future conditions, e.g. global warming, elevated CO_2 and ozone, perturbed water supply, and land use change, in order to manage rangelands



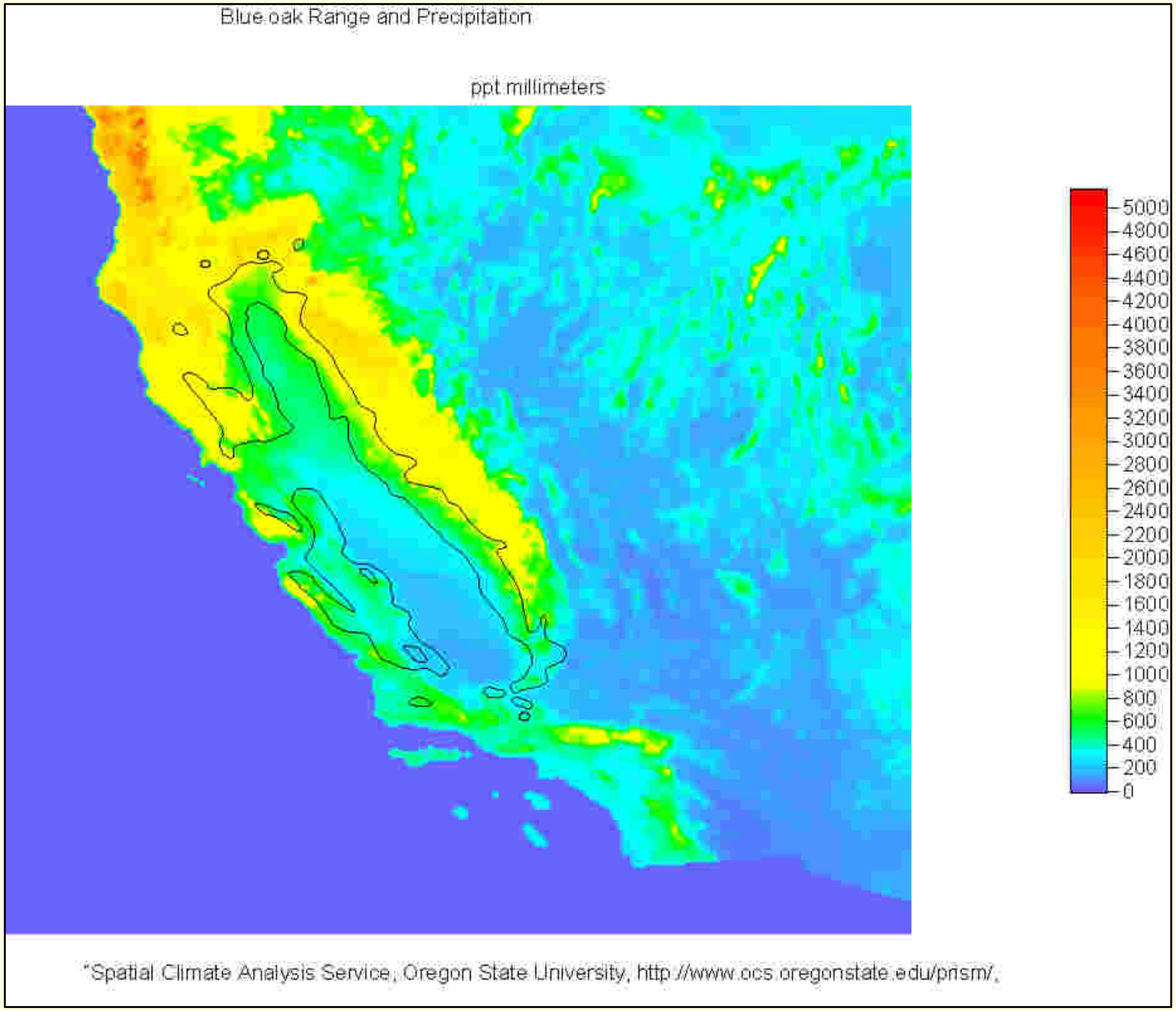
Kueppers et al 2005 PNAS

Land use in Northern CA

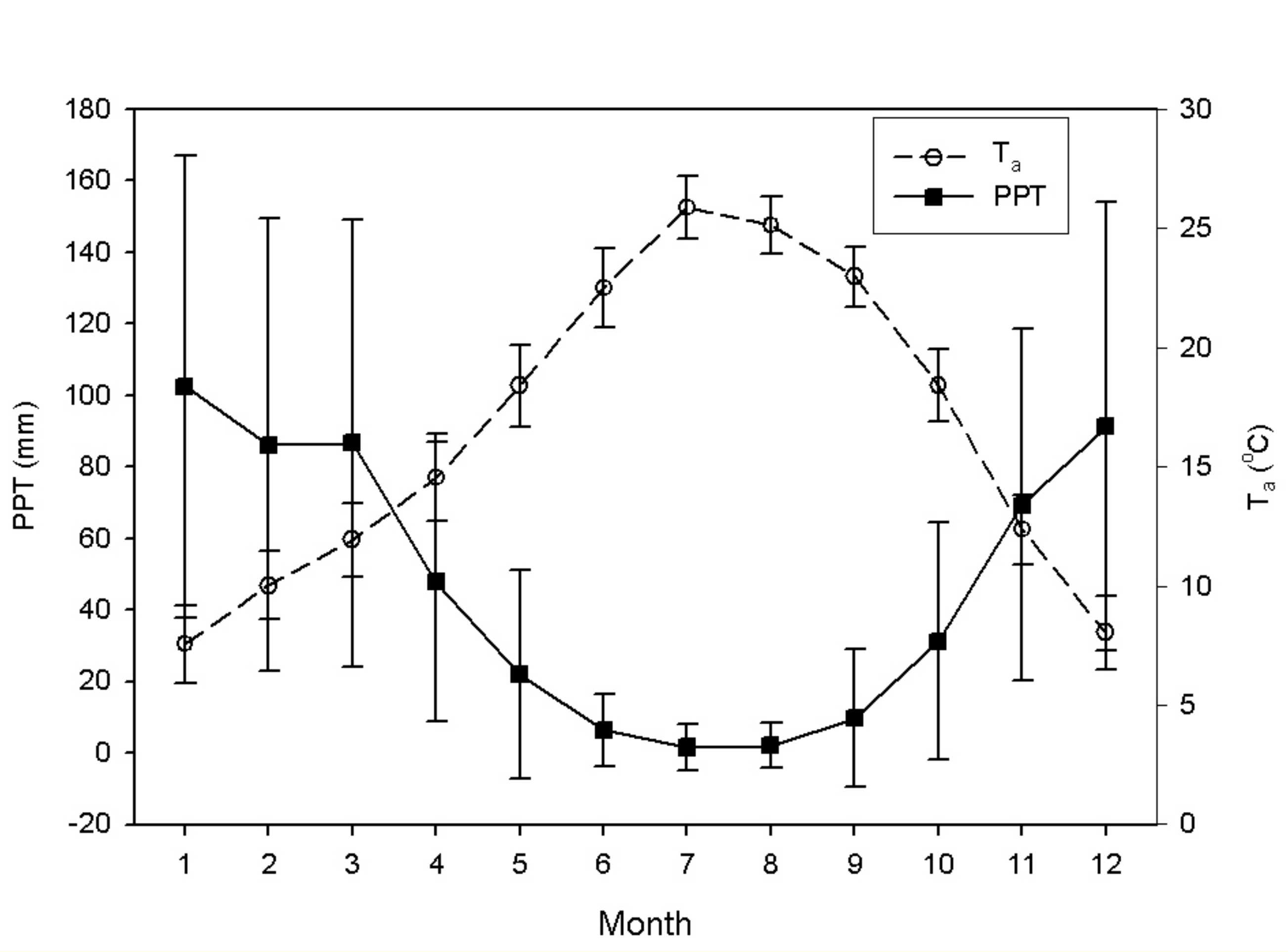


From Joe McFadden

Precipitation ~500 - 700 mm/y



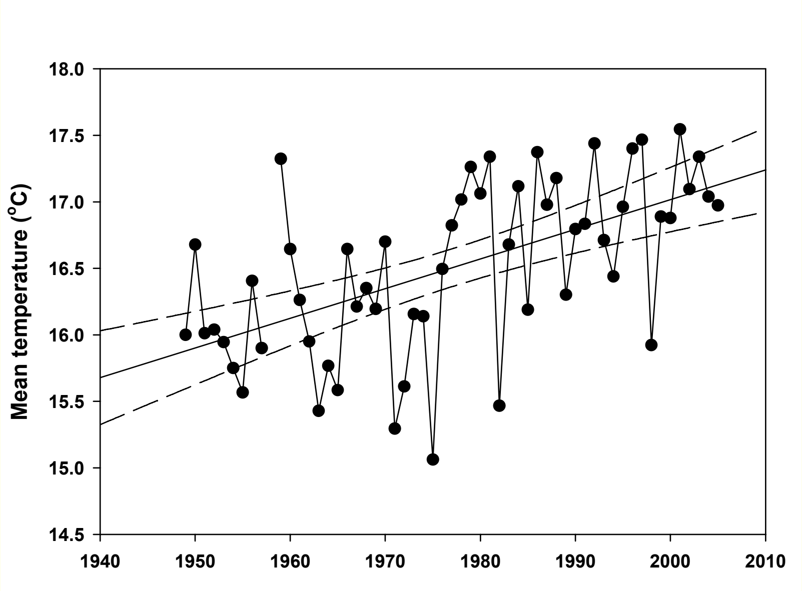
Mean Temperature and Precipitation

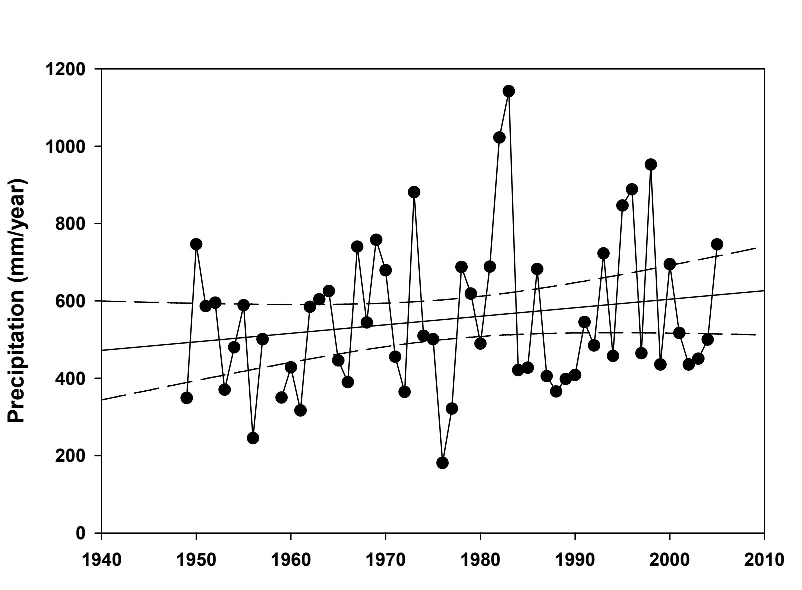


Camp Pardee, CA

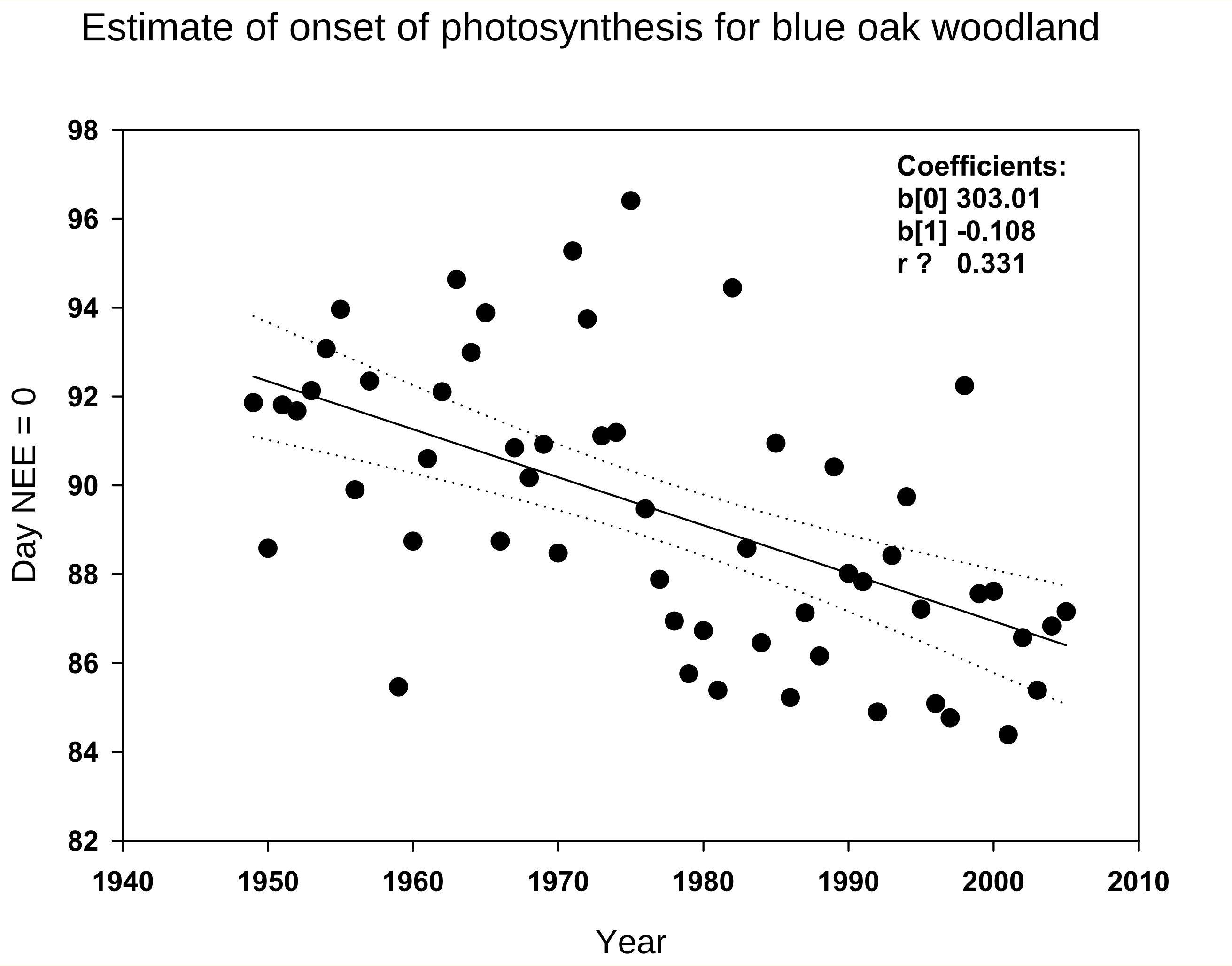
Climate Trends:
Pardee, CA

Temperature Increased by about 1.25 C over 50 Years





Inferred Trends in Phenology;
leaf-out about 10 days earlier over 50 years

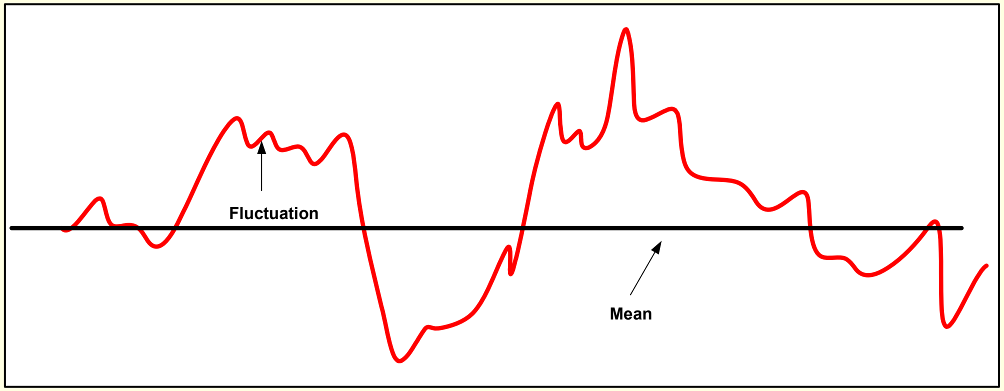


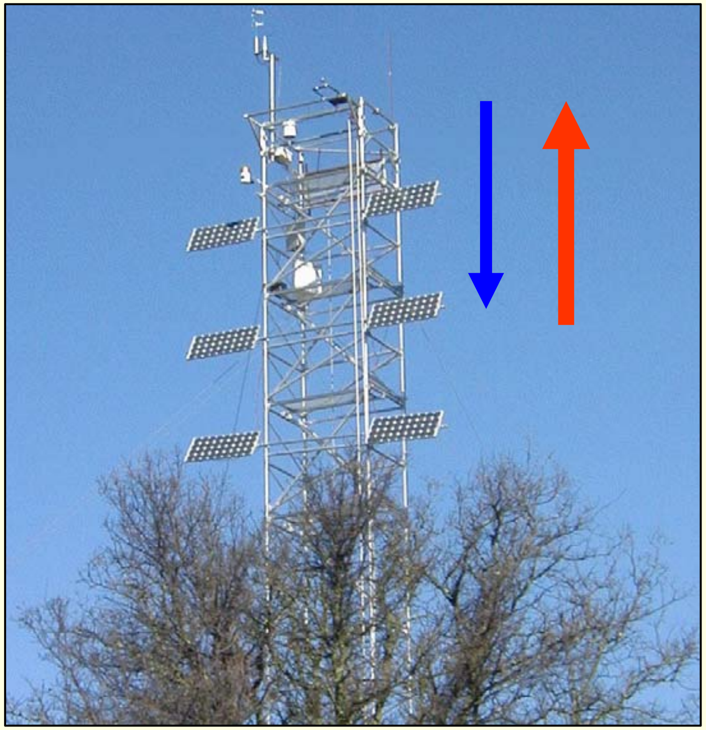
Experimental Methods

- Eddy Covariance
  - above the stand (20 m tower)
  - below the stand (2 m tower)
- Micrometeorology
- Sap flow (heat pulse)
- Soil respiration chambers
- Leaf Physiology (A-Ci curves)

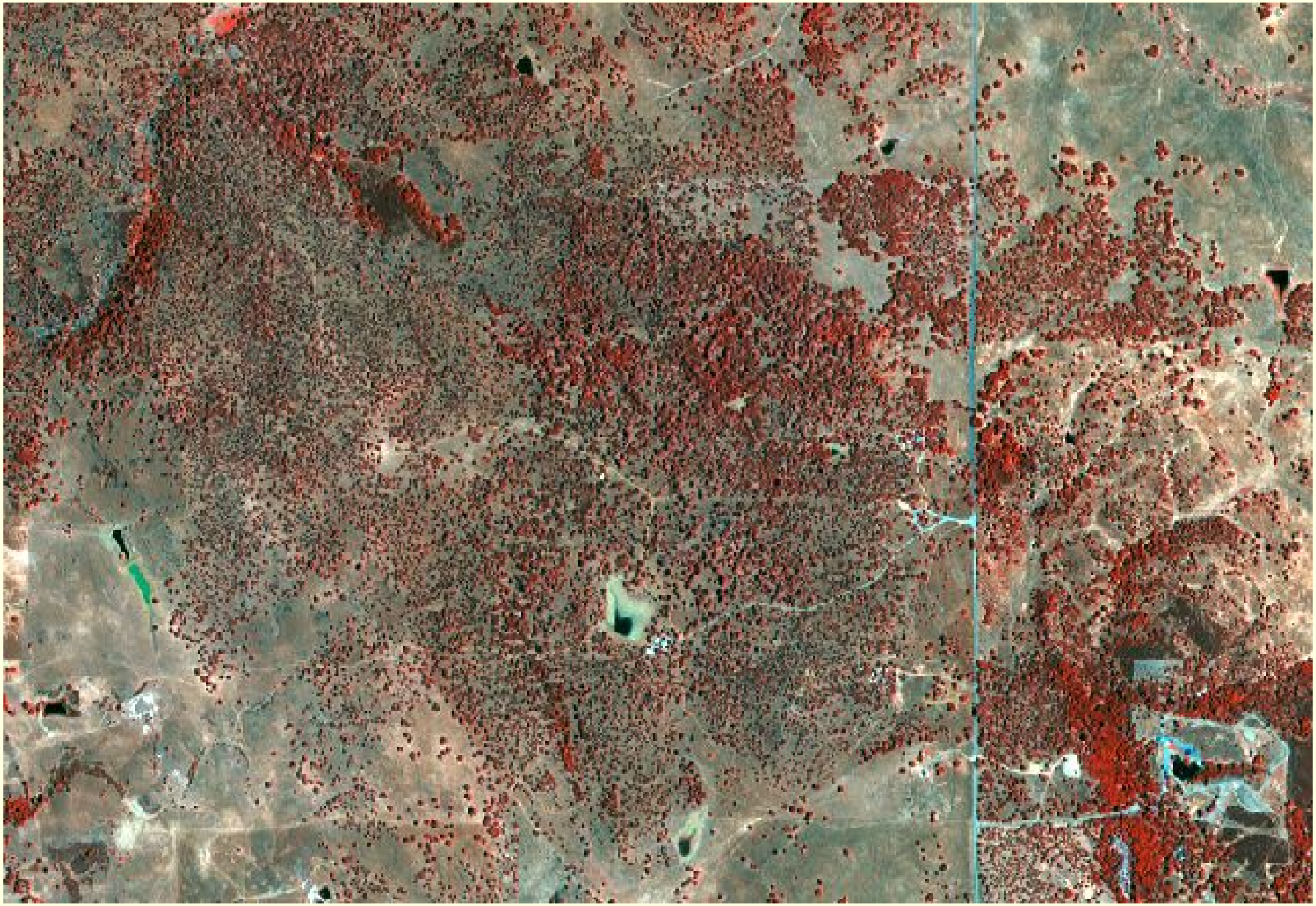
Eddy Covariance

$$F = \overline{w'c'}$$

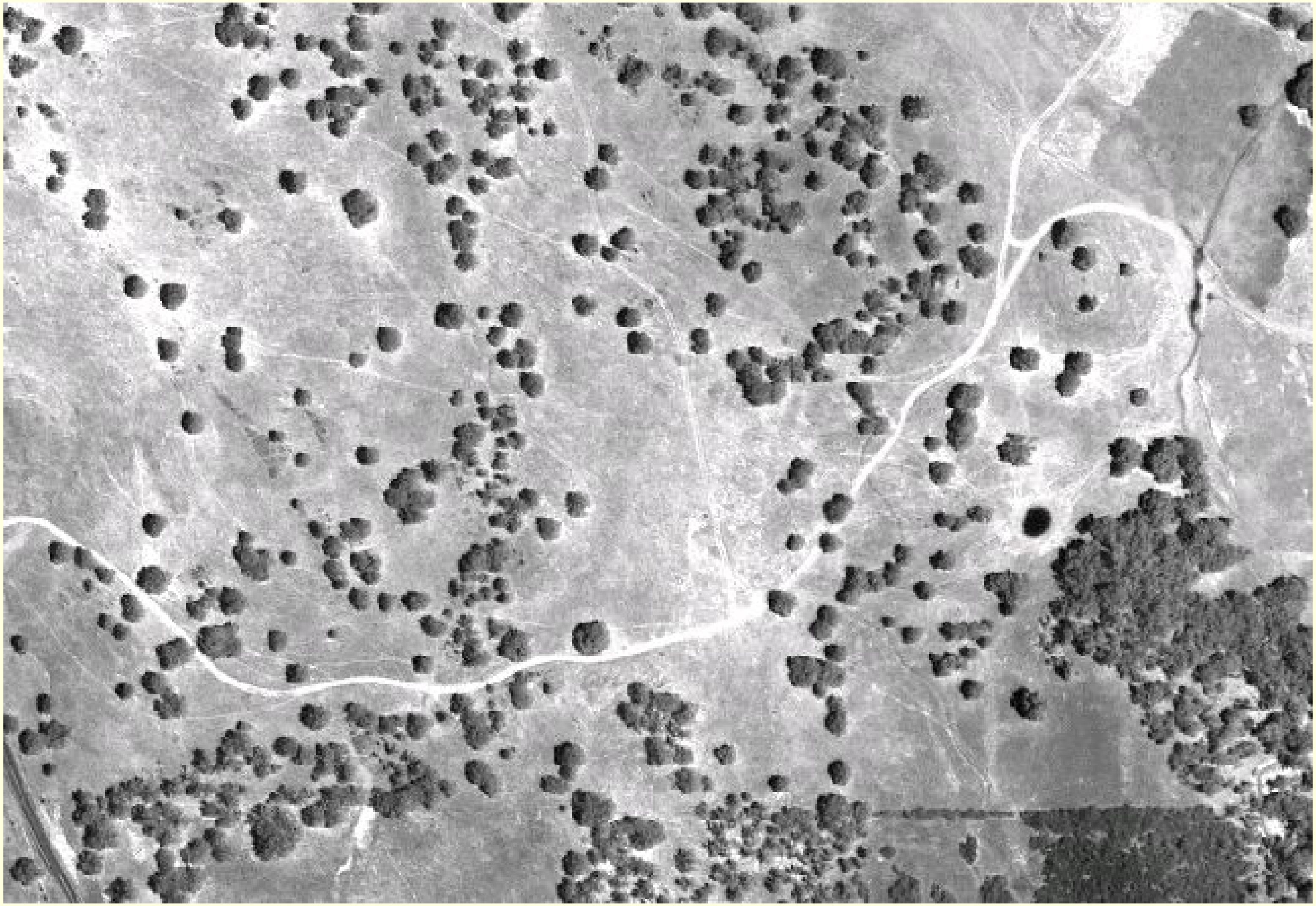




IKONOS: Savanna & Fetch



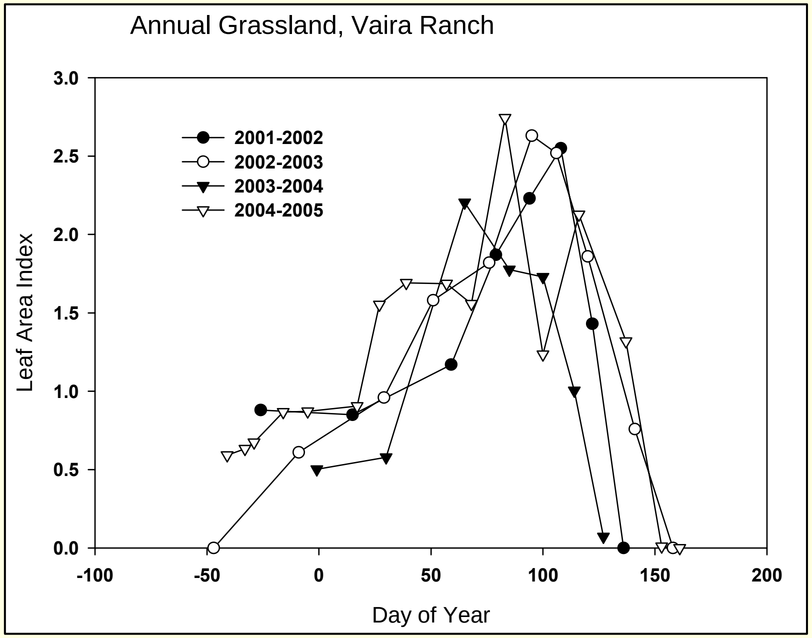
IKONOS:Grassland

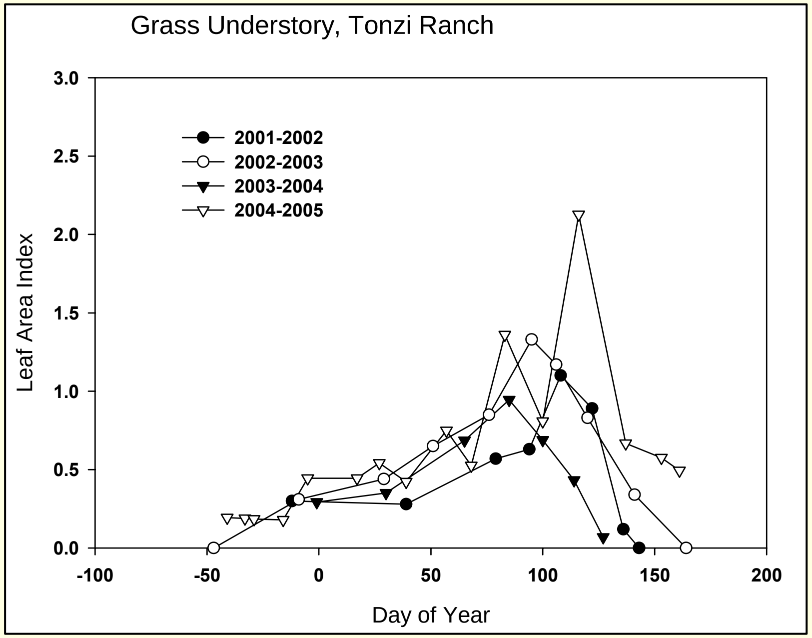


Results and Discussion

http://www.terrysteinke.com/pixpages/etchingpages/valleyoak.ht
ml

Dynamics of Canopy Structure

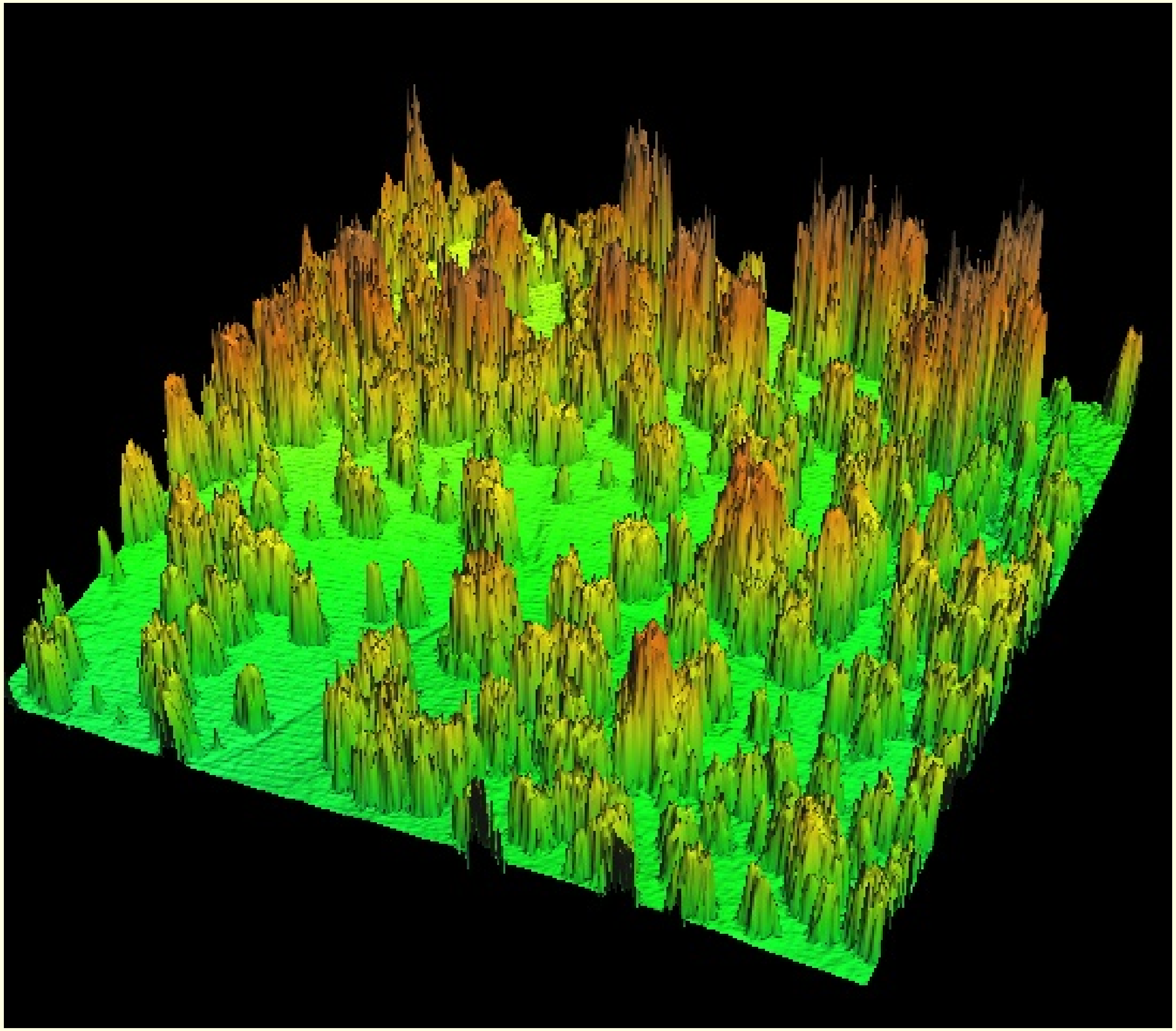




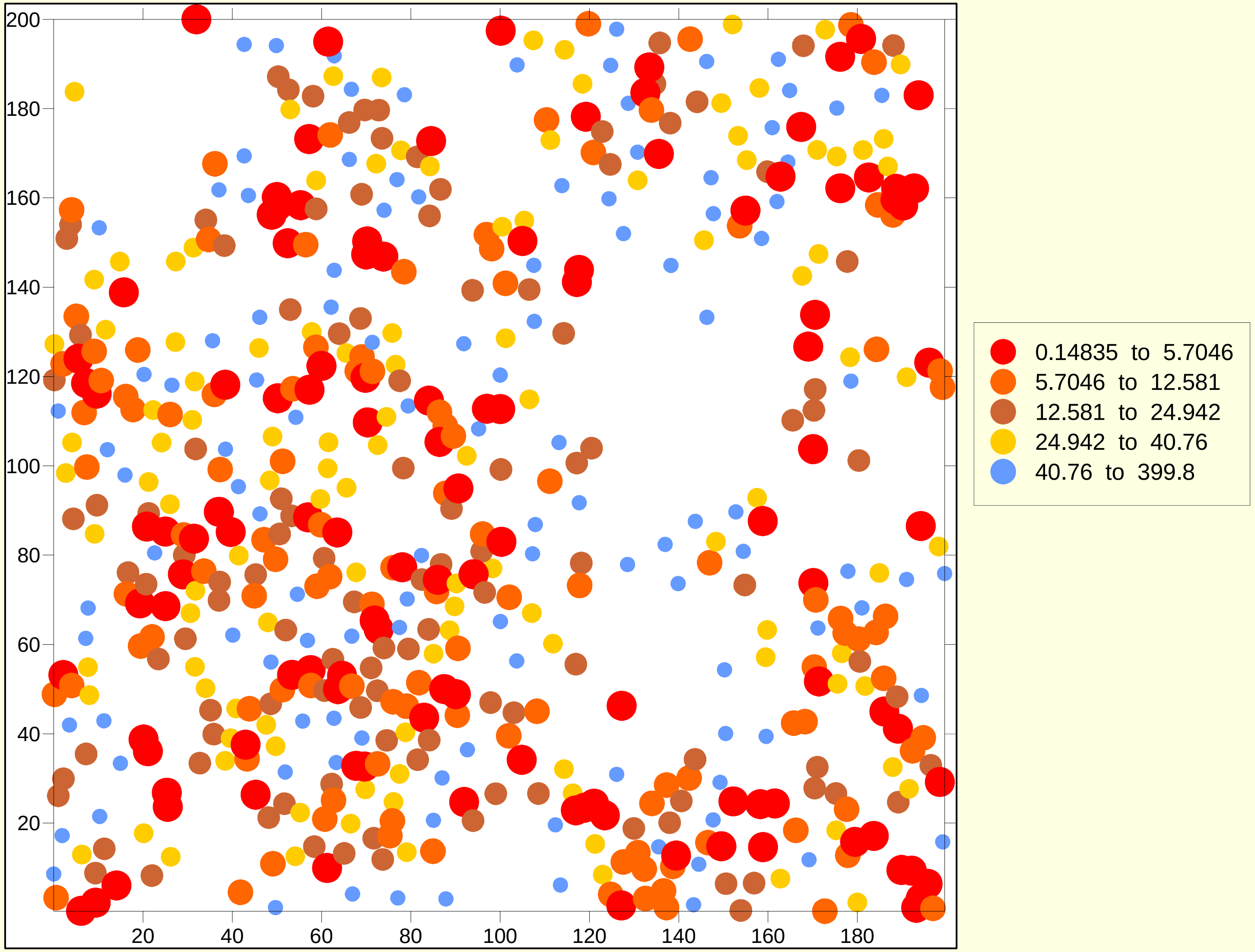
Canopy Structure: Tonzi Ranch

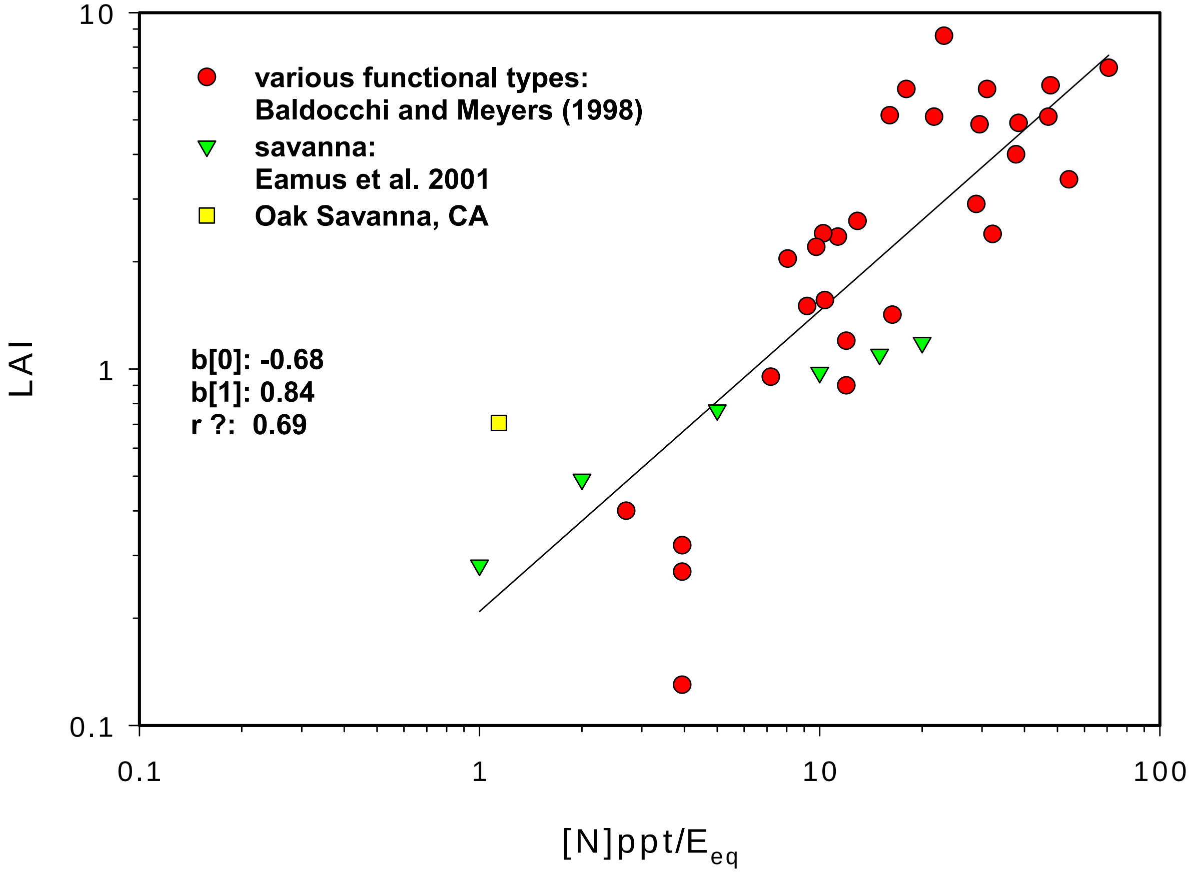
- Blue oak (*Quercus douglasii*)
- LAI=0.90
- Height 7.1 +/- 3.05 m
- Diameter at breast height 26.6 +/- 0.11 cm
- Understory: annual C_3 grasses
  - *Brachypodium distachyon, Hypochaeris glabra, Bromus madritensis*

Canopy Structure:
Laser Altimeter Data



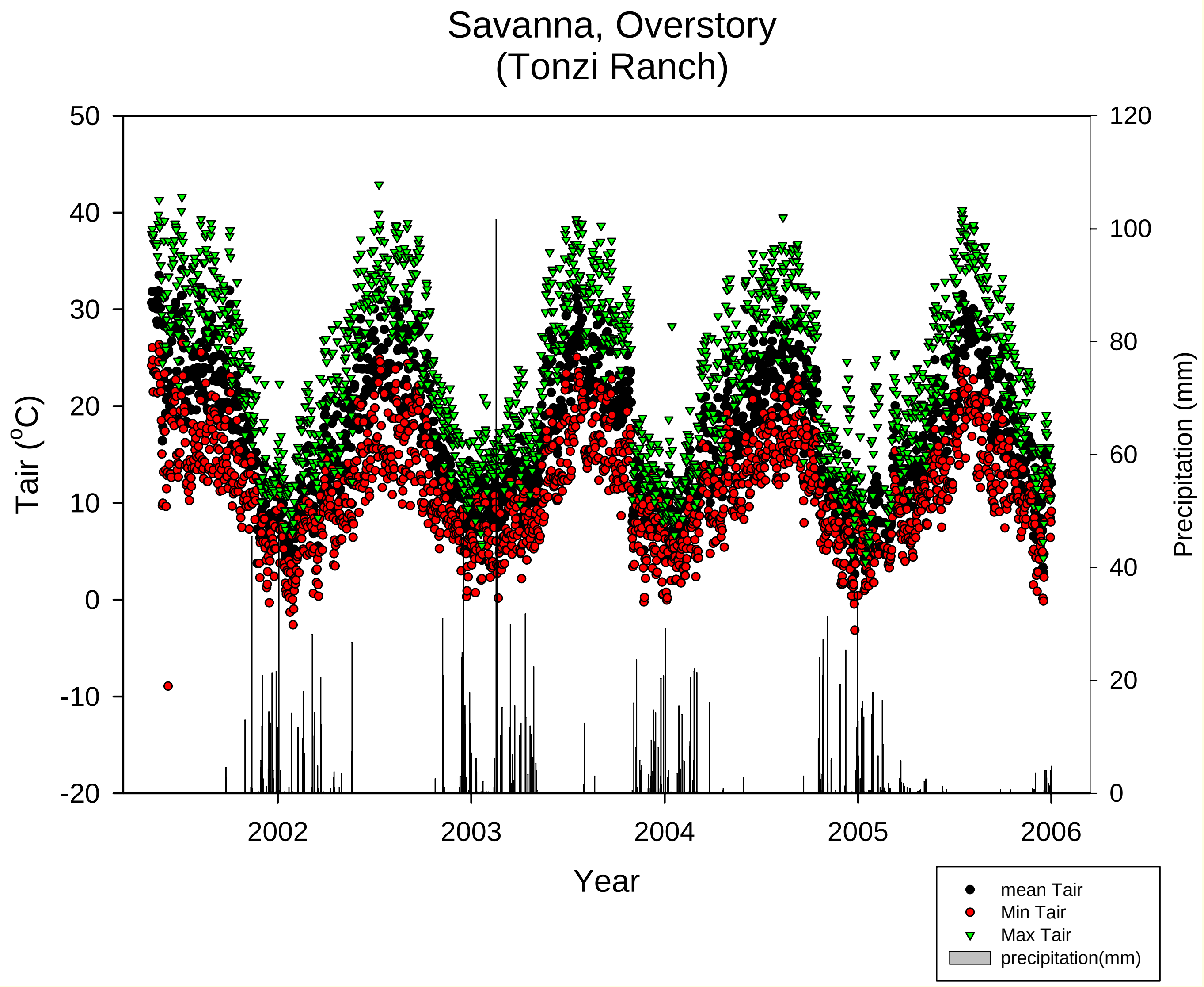
Trees and Leaf Area Index



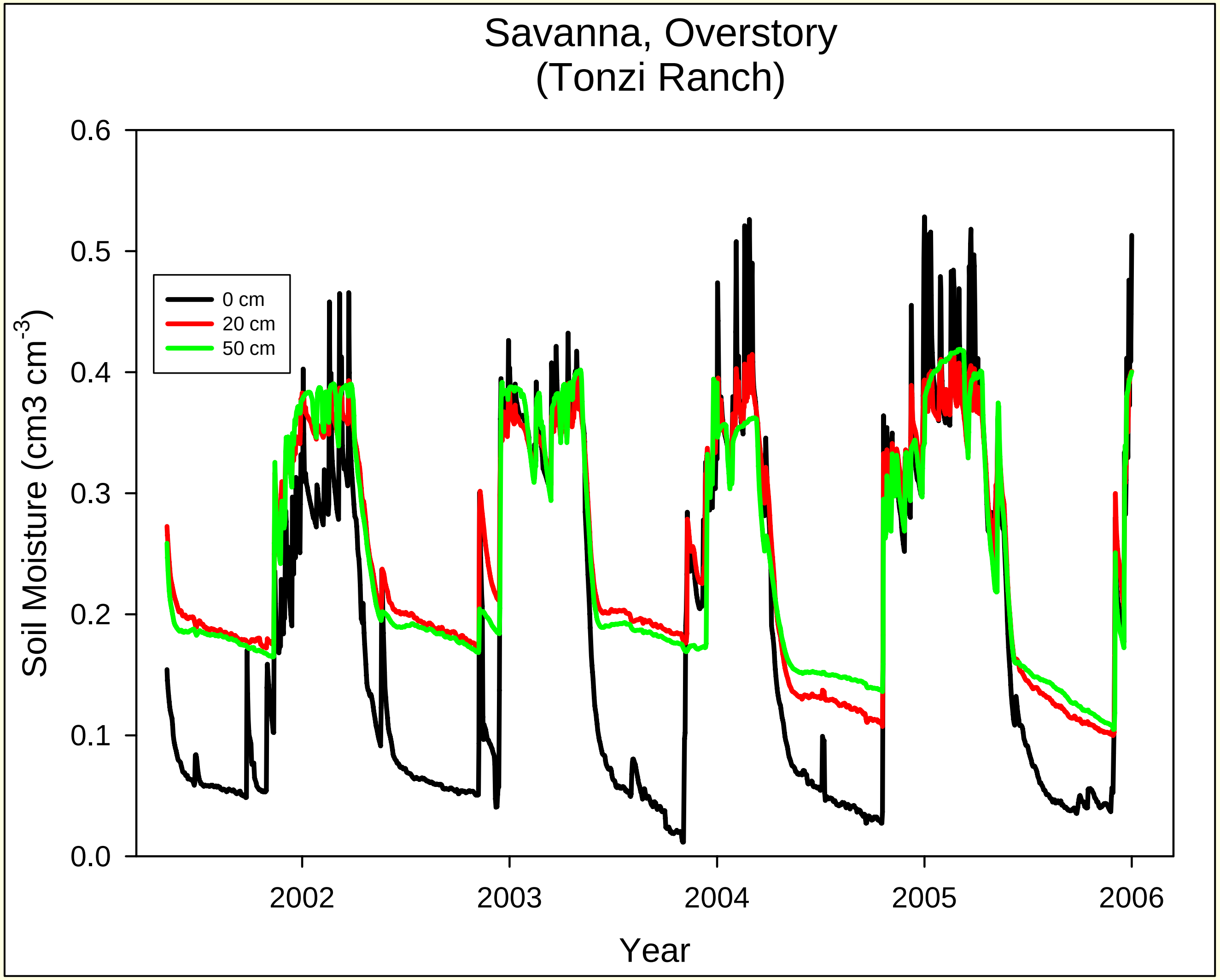


10
1
0.1
0.1
1
10
100
LAI
[N]ppt/E$_{eq}$
various functional types:
Baldocchi and Meyers (1998)
savanna:
Eamus et al. 2001
Oak Savanna, CA
b[0]: -0.68
b[1]: 0.84
r ?: 0.69

Meteorology



Soil Moisture

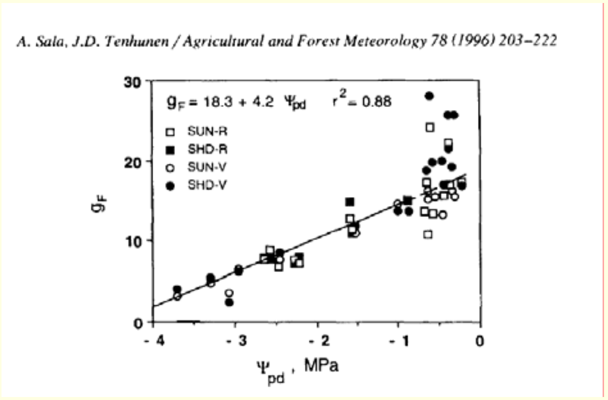


Leaf Physiology

How Does Stomatal Conductance Respond to Drought?

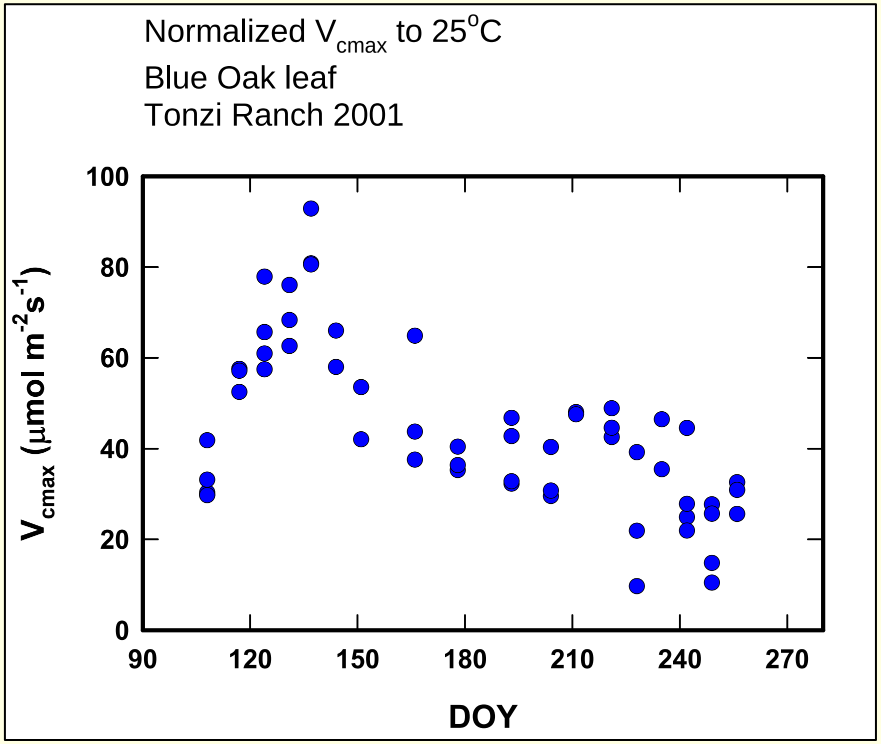
$$g_s = \frac{k\,A\,rh}{C_s} + g_0$$

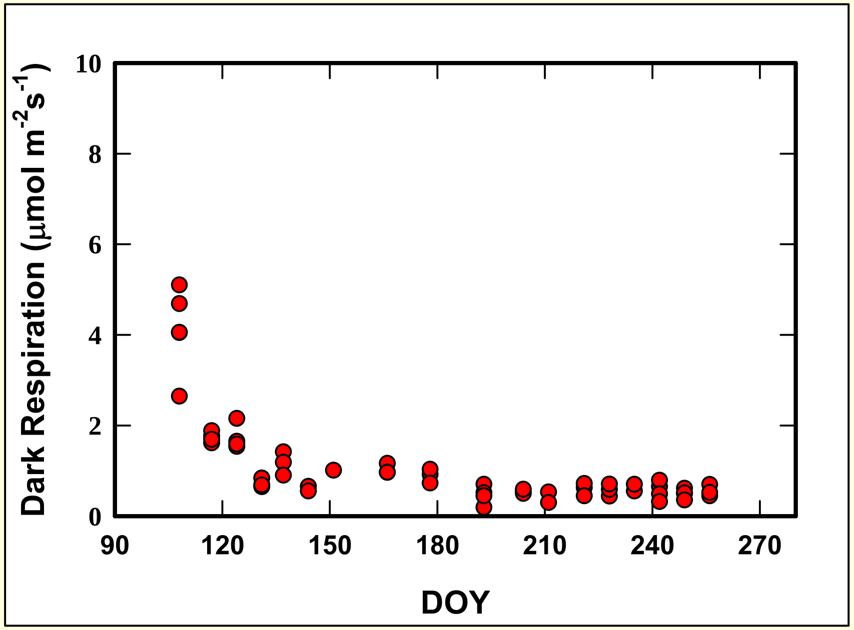
- H_0: Ball-Berry Coefficient Varies
  - Sala & Tenhunen
  - Damesin, Rambal, Joffre



- H_1: Ball-Berry Coefficient is constant
  - V_{cmax} varies and stomata gradually close to keep Ci/Ca ~ 0.7
  - Joe Berry, SIB II
  - Gabriel Cornic

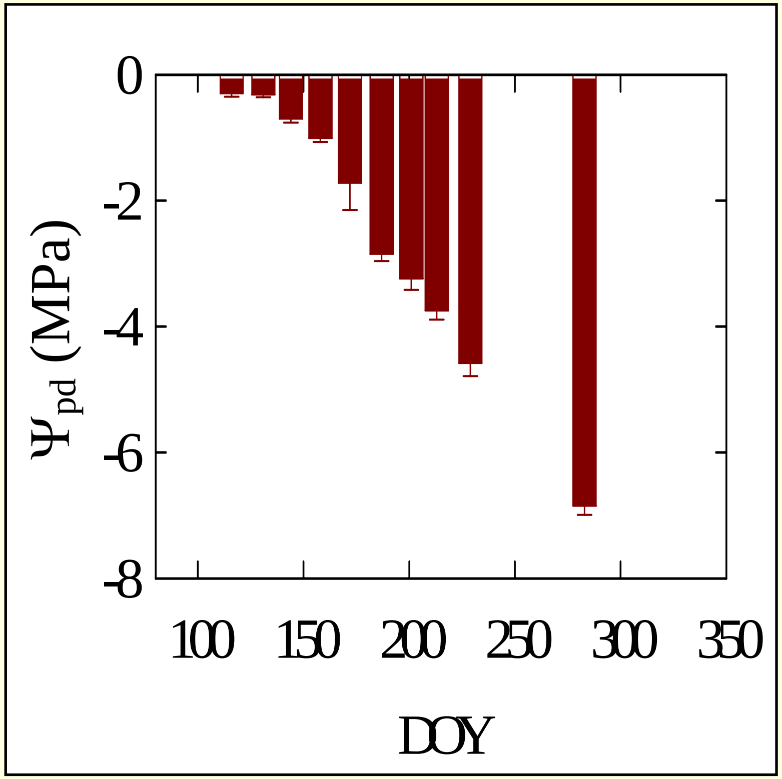
Physiological Capacity: Seasonal Dynamics

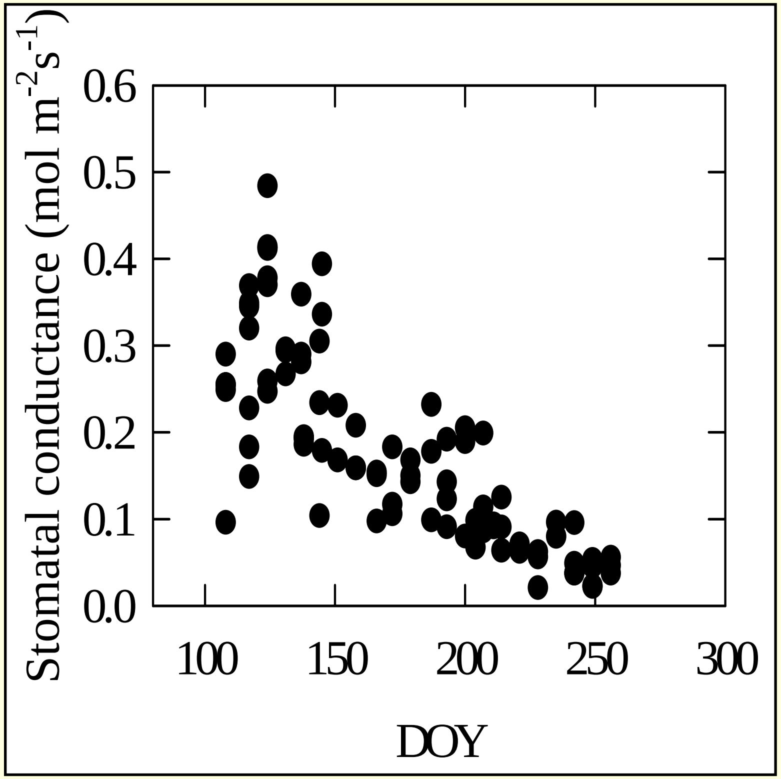




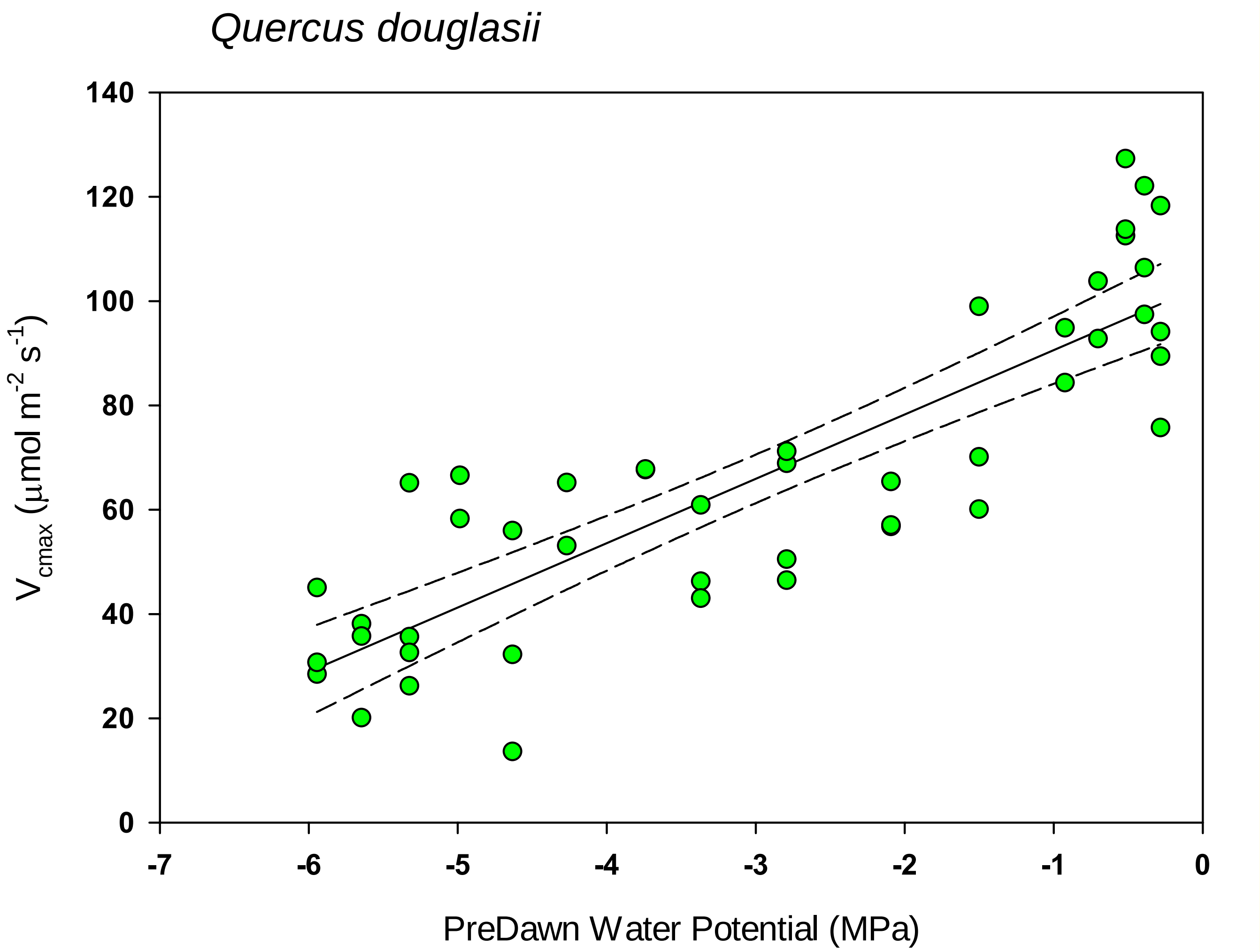
Xu and Baldocchi, 2003 Tree Physiology

Predawn Ψ and Stomatal conductance

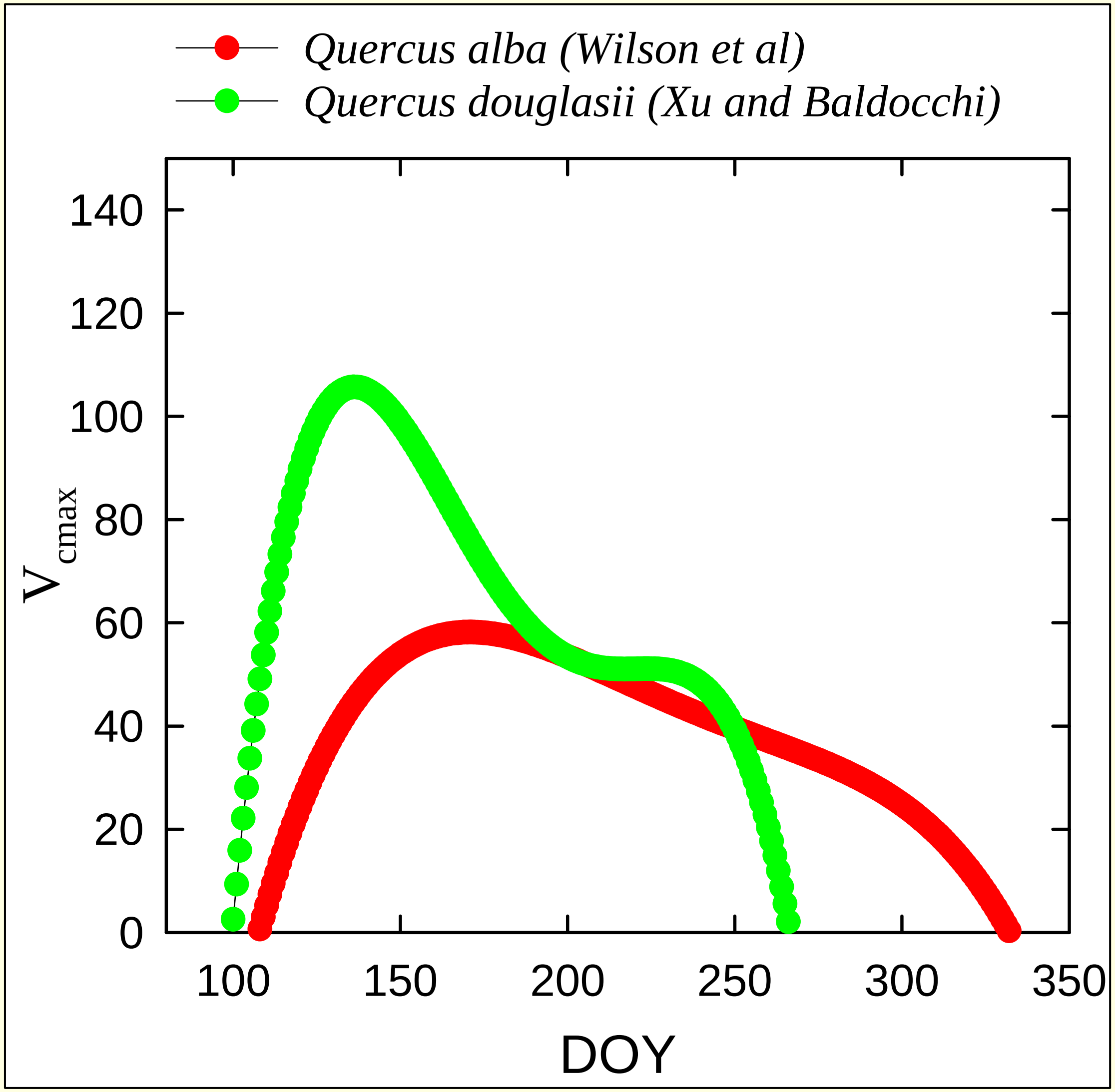




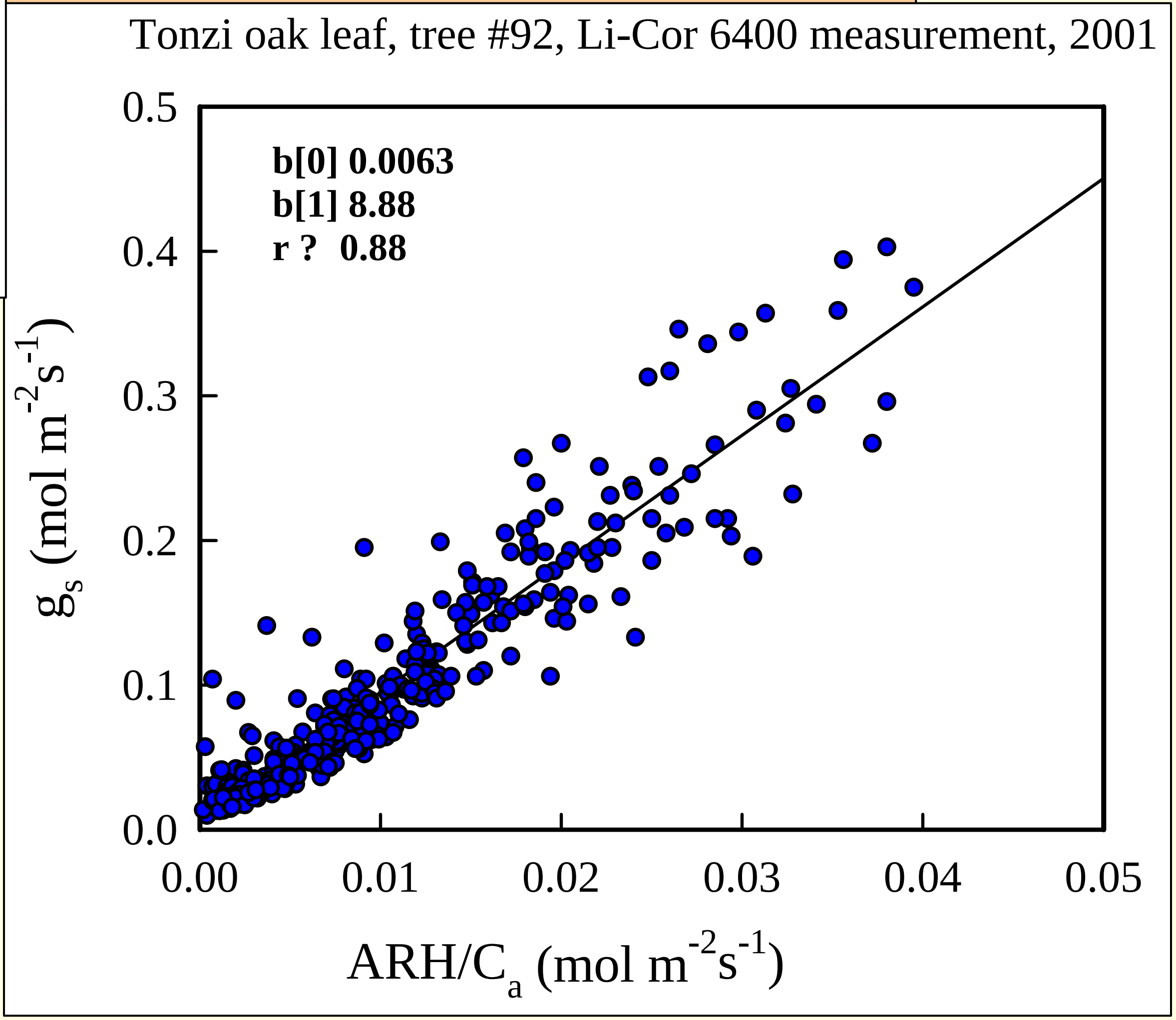
V_{cmax} varies with time and scales with Pre-Dawn Water Potential



High V_{cmax} must be Achieved in Seasonal ly Droughted Ecosystems to attain Positive Carbon Balance



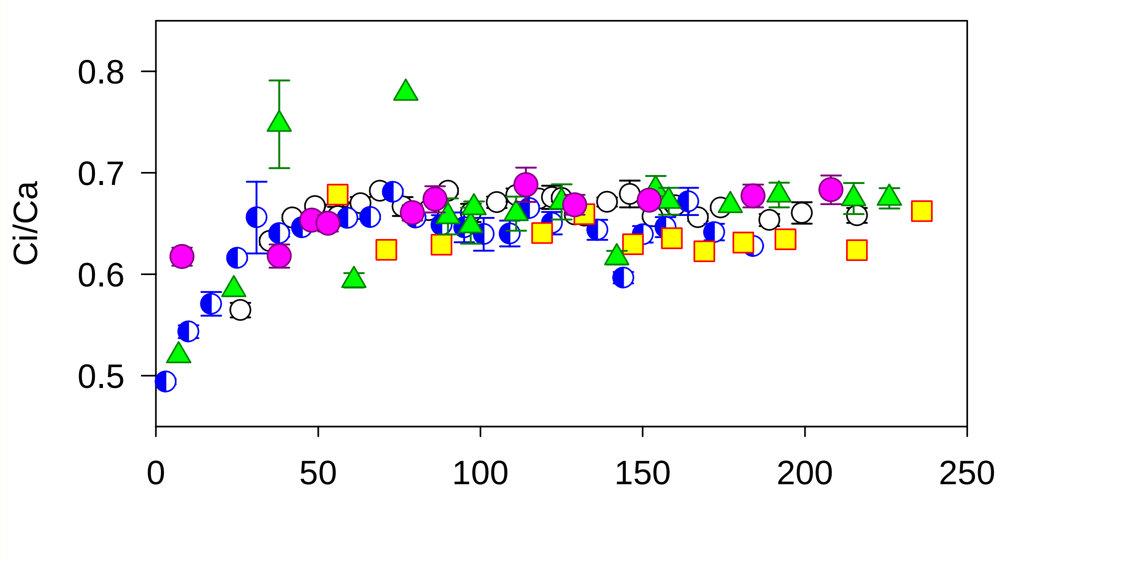
Stomatal Conductance

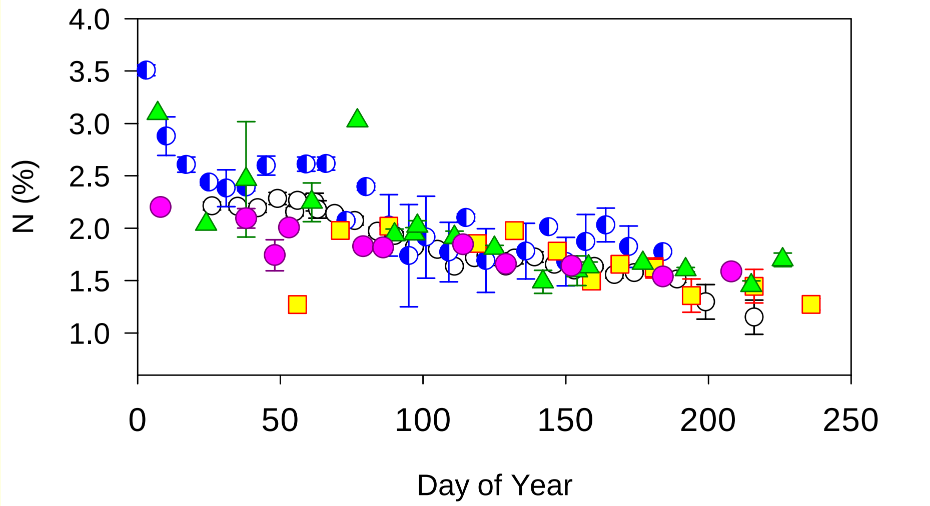


Xu and Baldocchi
2003, Tree Physiol

Ball-Berry Coef is constant with Pre-dawn water potential down to –70 bars

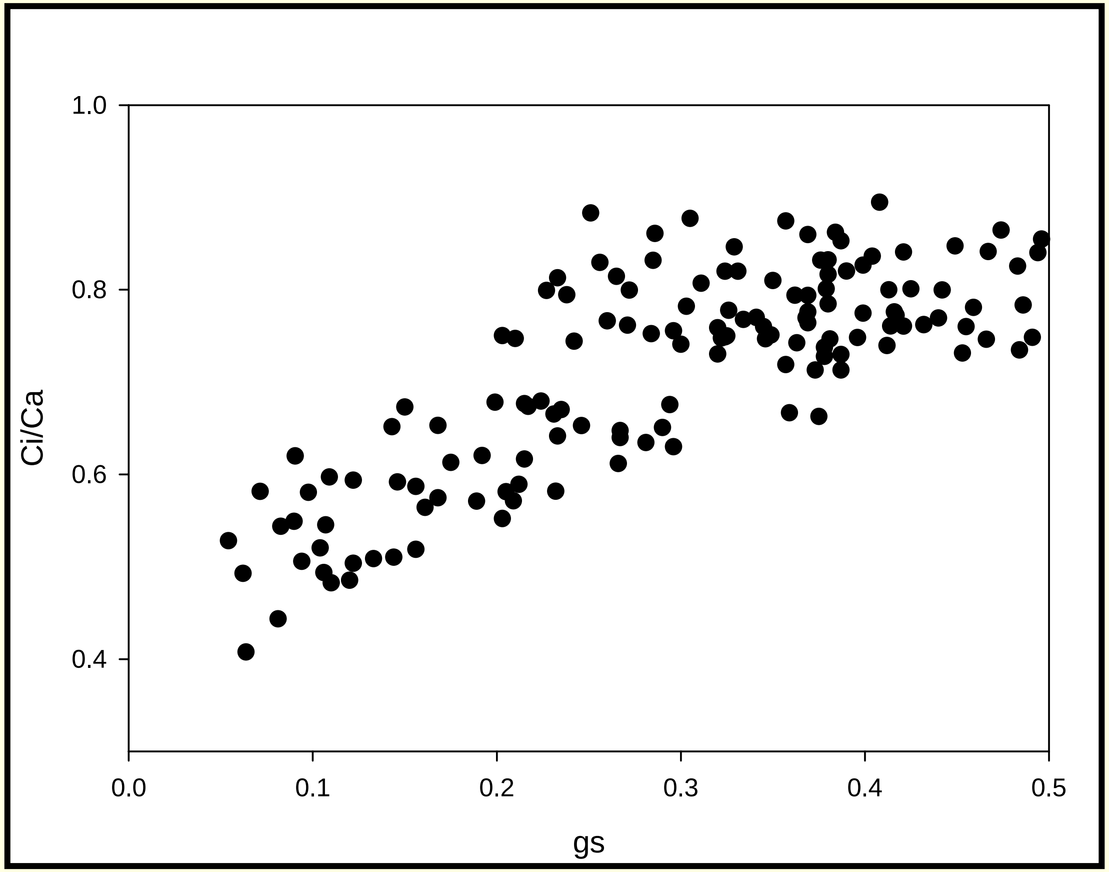
From Leaf Isotope and Nutrition Measurements, Ci/Ca is relatively constant, near 0.7, and N is high early in the season





Ma et al in prep

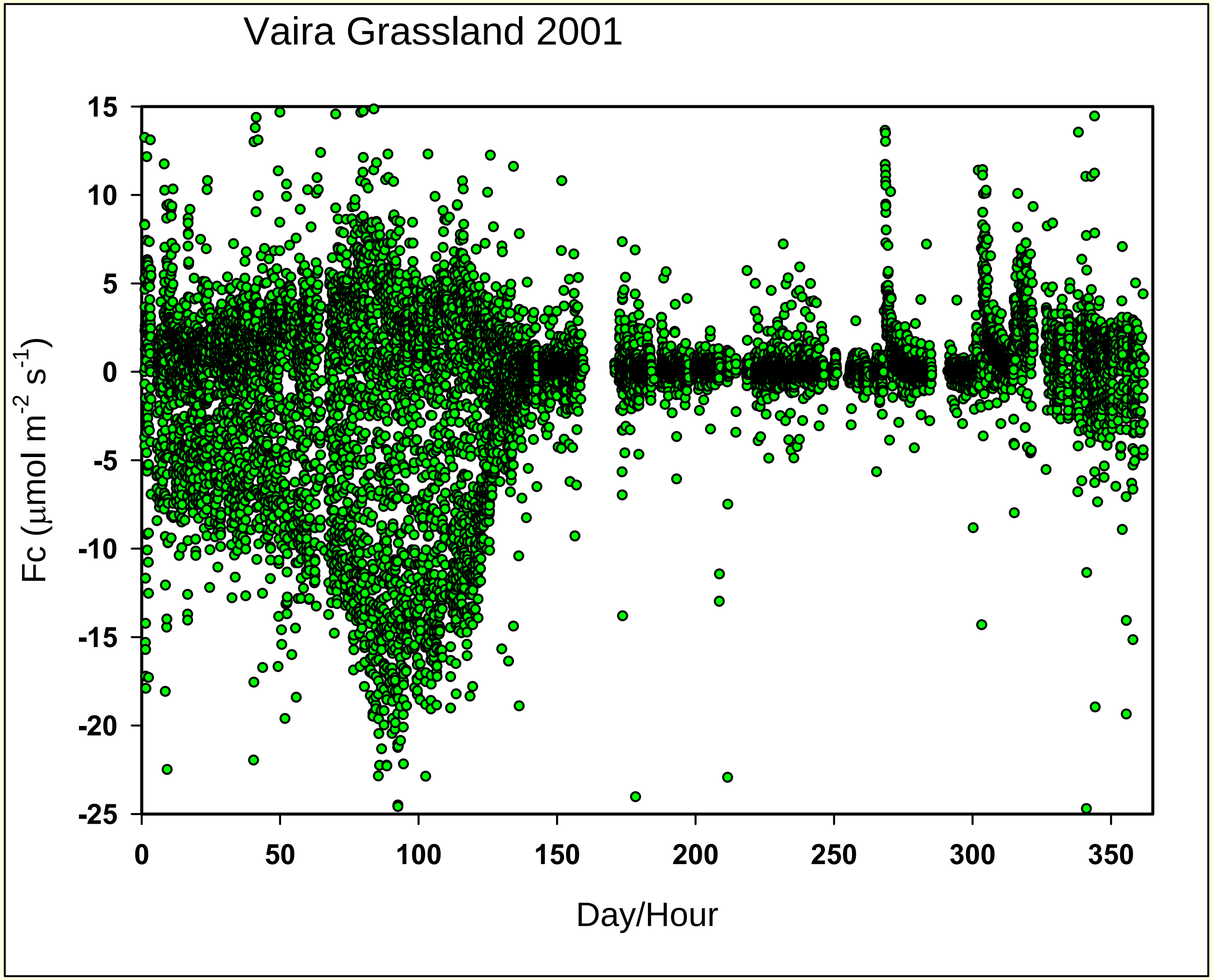
Gas Exchange Data suggest Ci/Ca decreases with Drought



'Isotope derived Ci/Ca are cumulative,
Not the same as gas exchange' Kevin Tu

Ecosystem Ecology

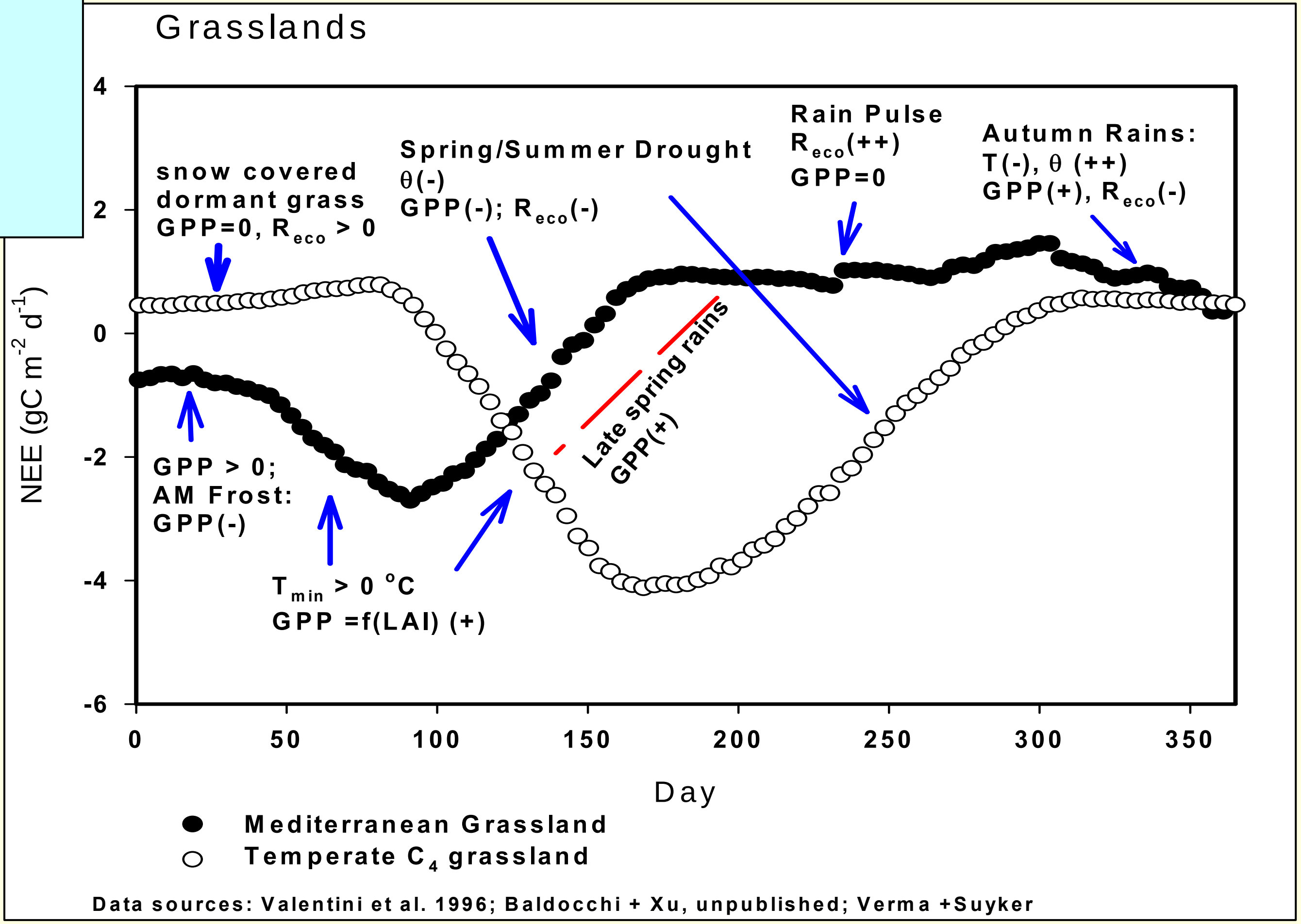
Switches, Pulses and Lags are Evident in Annual Time Series of Trace Gas Exchange



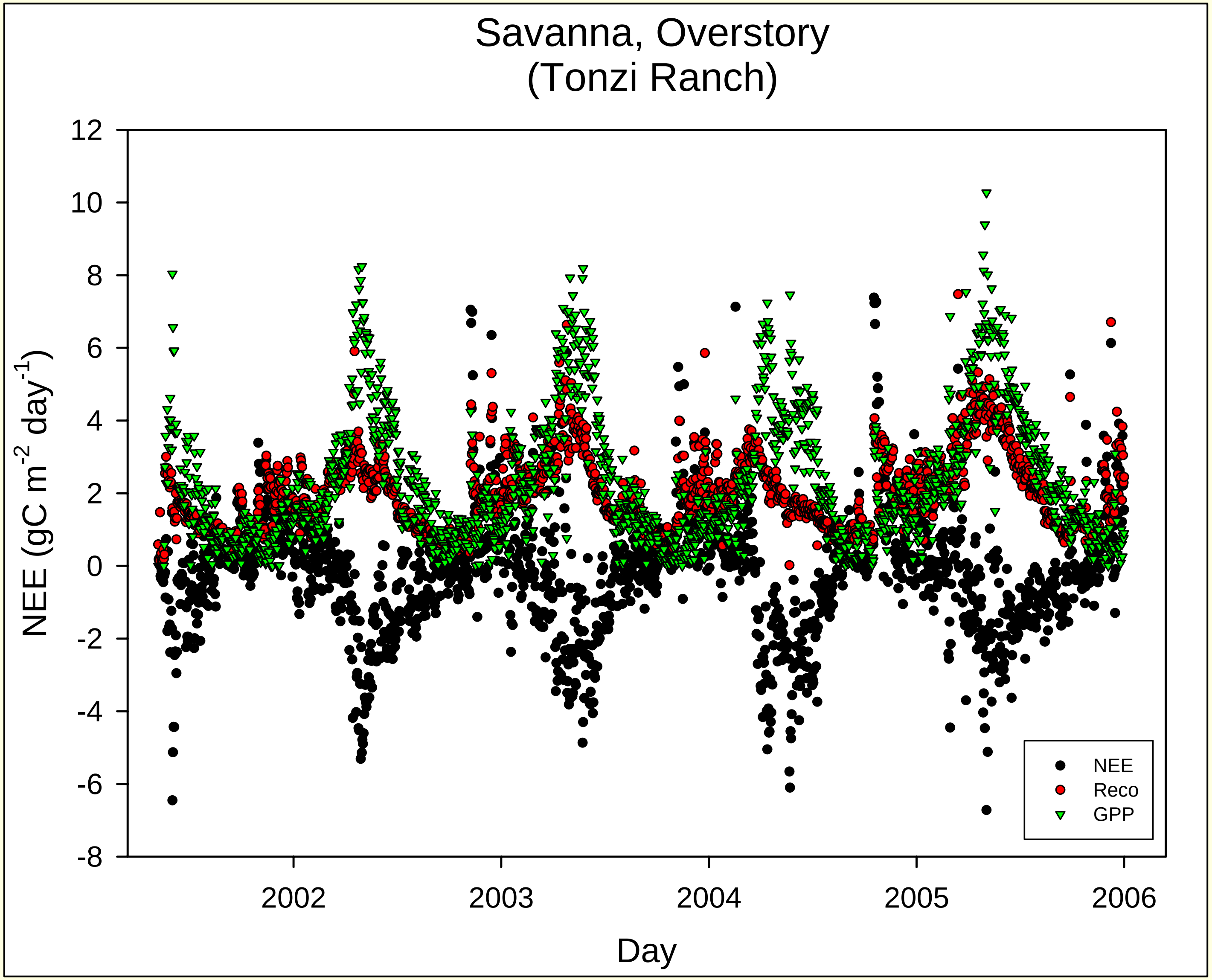
Xu and Baldocchi, AgForestMet, 2004

Complicating Dynamical Factors

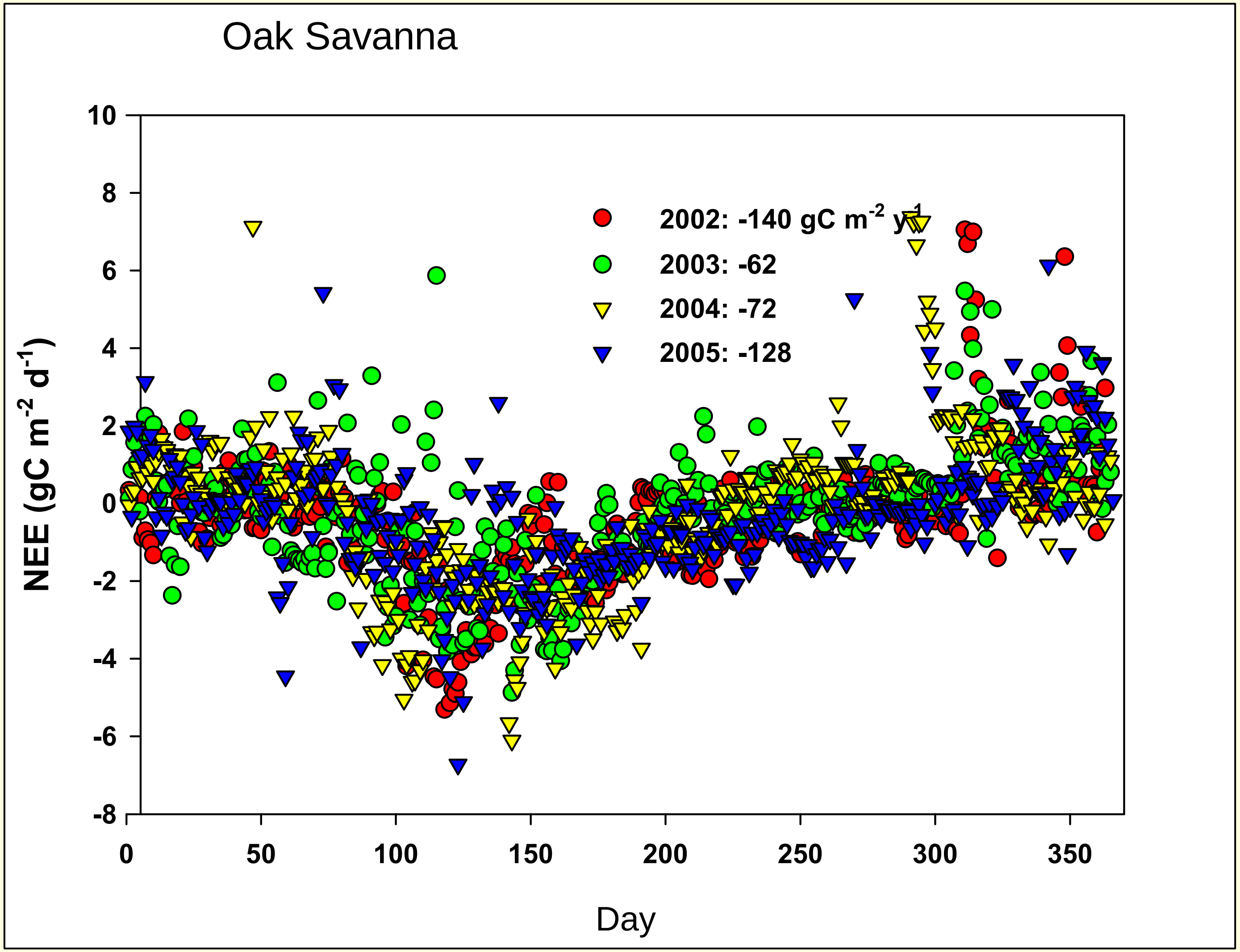
- Pulses
- Switches
- Lags

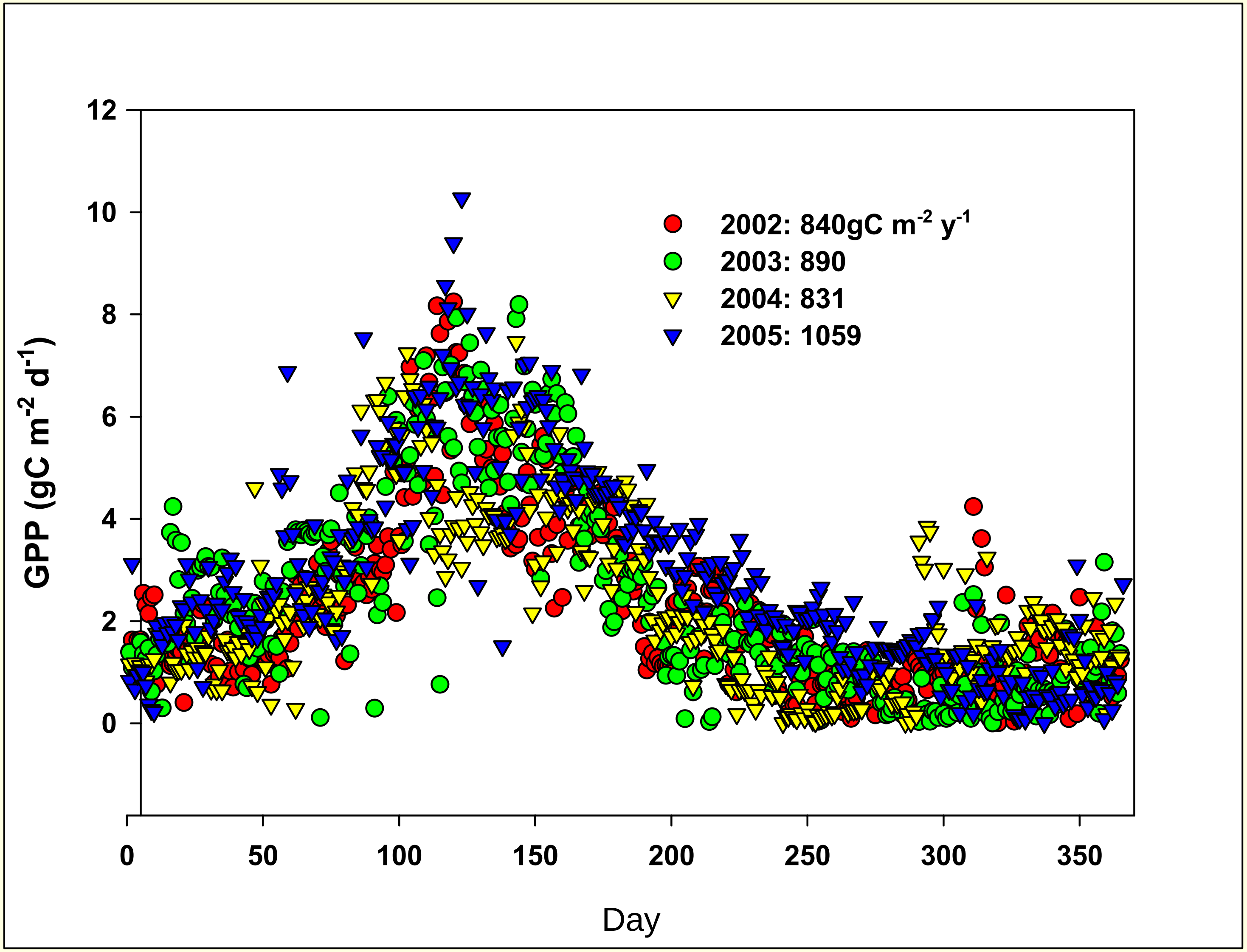


Daily Carbon Fluxes

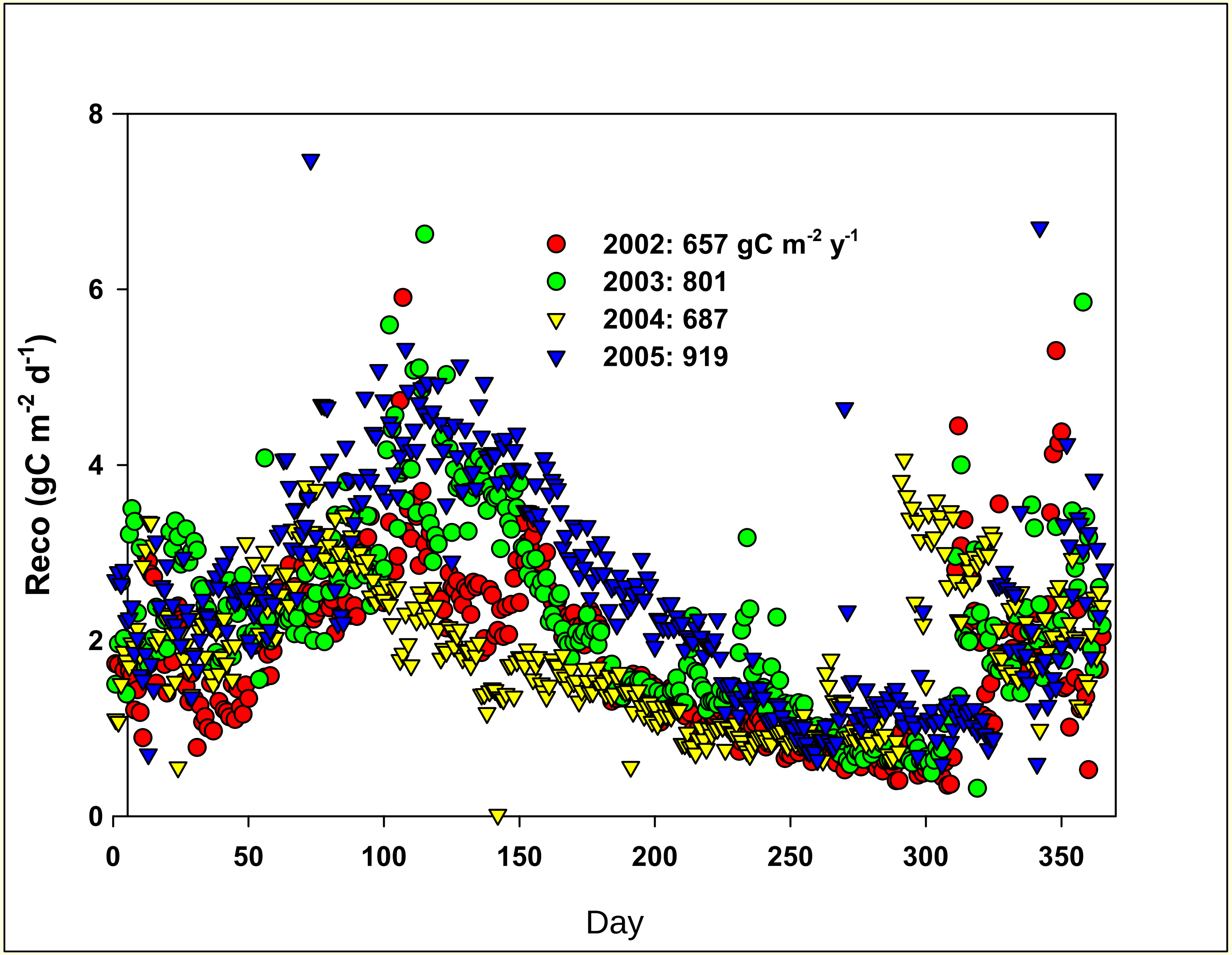


Annual C balance:
$NEE = GPP + R_{eco}$



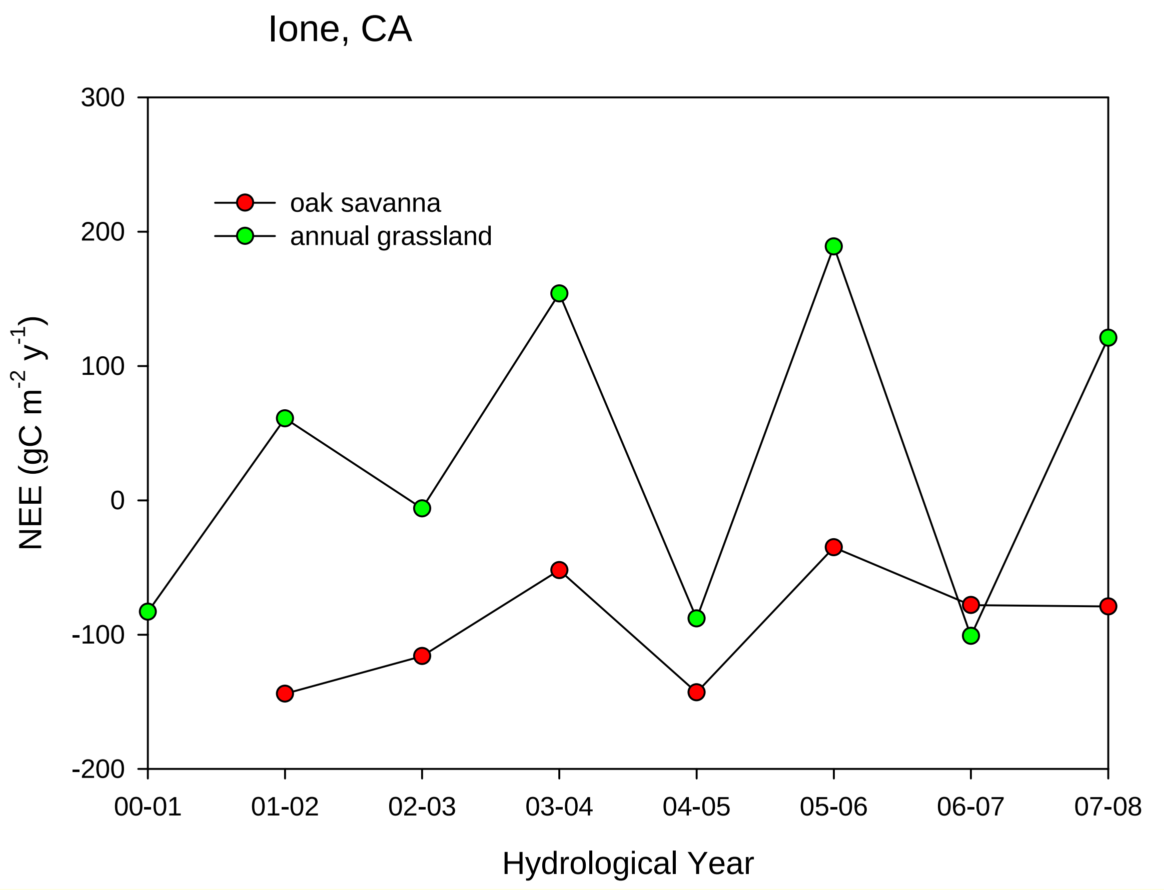


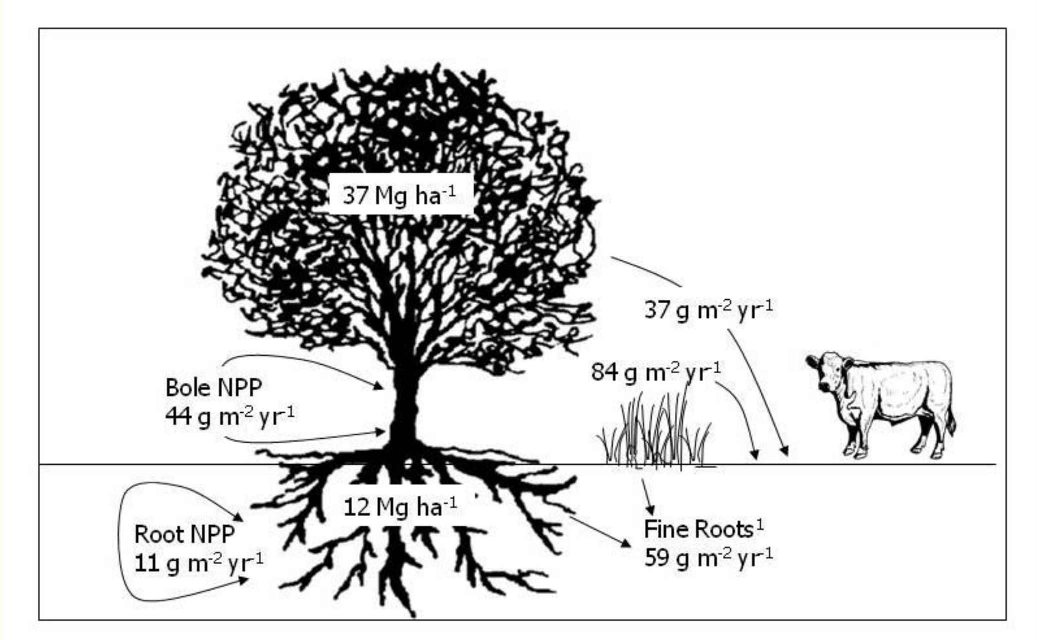
GPP (gC m-2 d-1)
Day
2002: 840gC m-2 y-1
2003: 890
2004: 831
2005: 1059
0
2
4
6
8
10
12
0
50
100
150
200
250
300
350



2002: 657 gC m-2 y-1
2003: 801
2004: 687
2005: 919
Reco (gC m-2 d-1)
Day
0
2
4
6
8
0
50
100
150
200
250
300
350

Oak Woodlands are Risk Adverse, they Experience less inter-annual variation in NEE than Grasslands



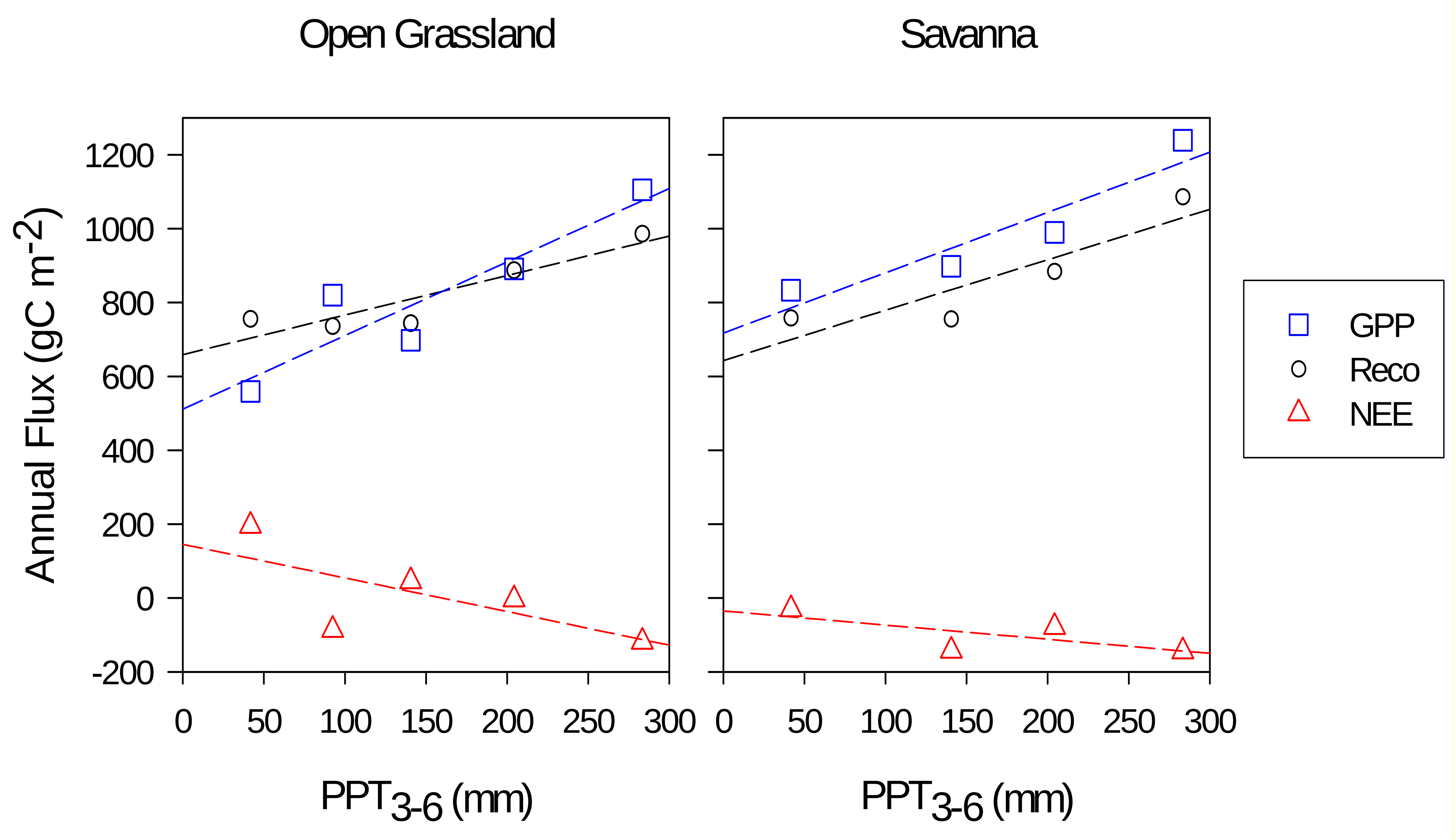


John Battle's biometric NPP = 235 gC m-2 yr-1.

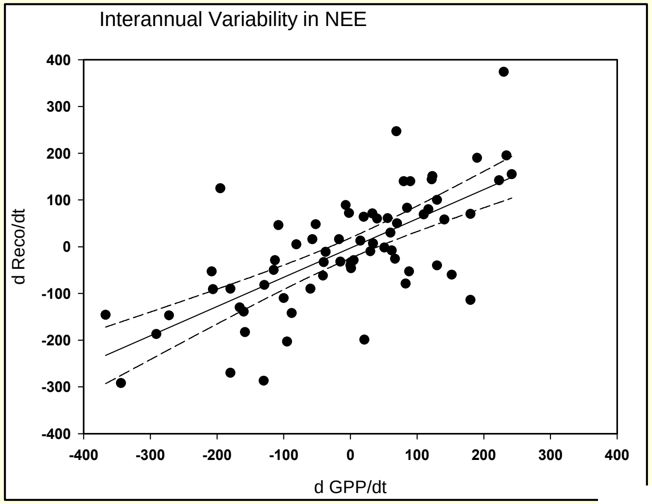
NPP = GPPtree - Ra_tree - Rh = 299 gC m-2 yr-1

NPP=NEP+Rh=97+186=283 gC m-2 yr-1.

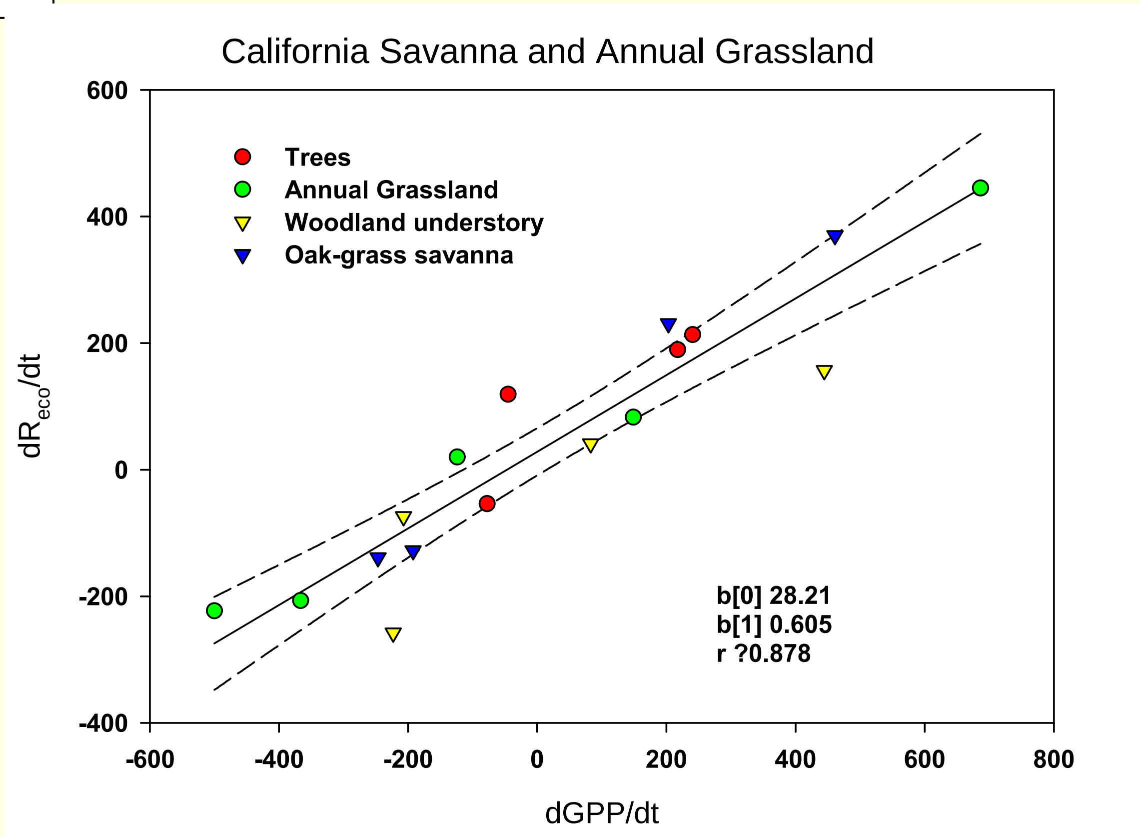
Carbon Fluxes Scale with Spring Rainfall



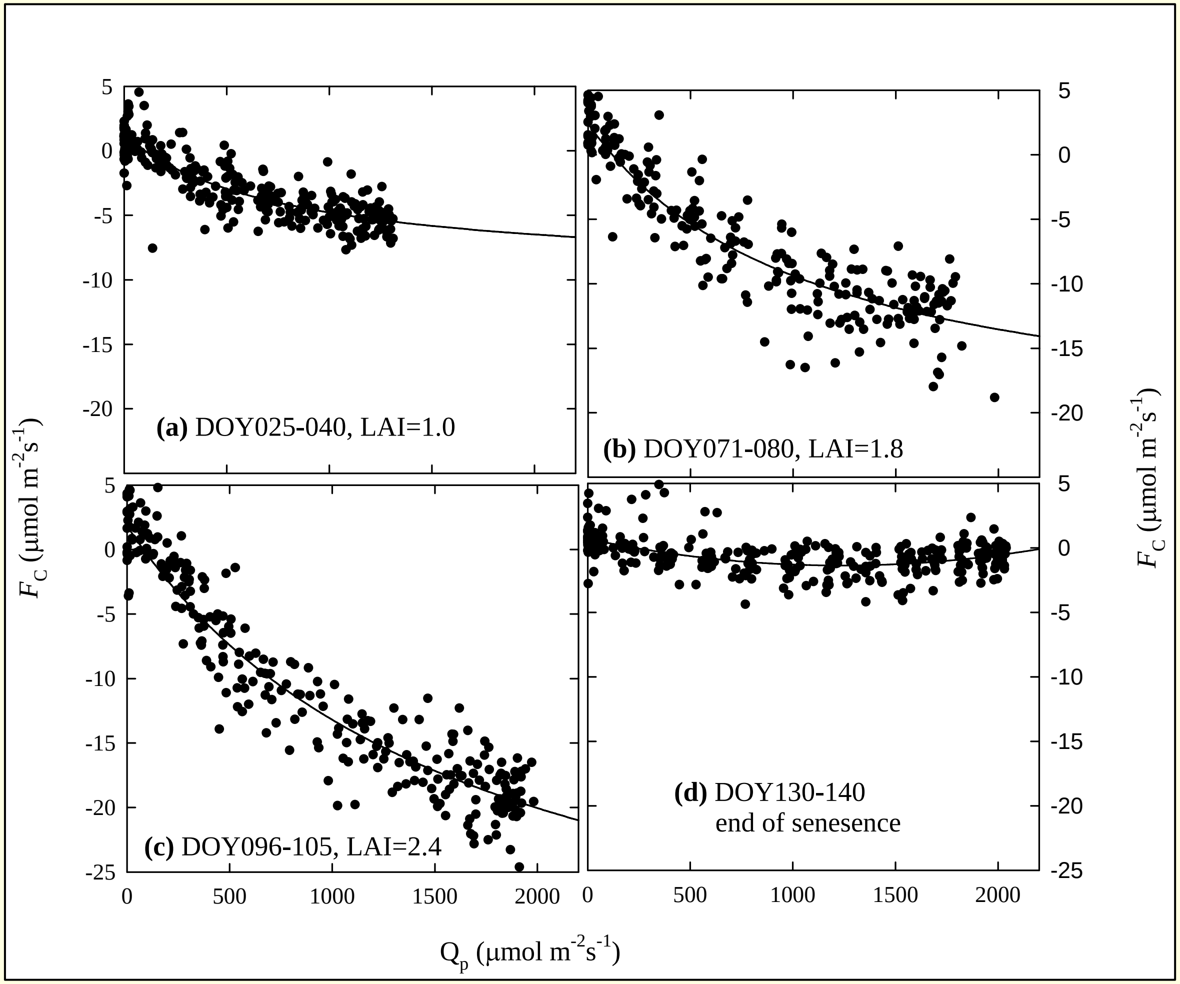
Ma et al, 2007 AgForMet



Interannual Variability in GPP and Reco scale with one another

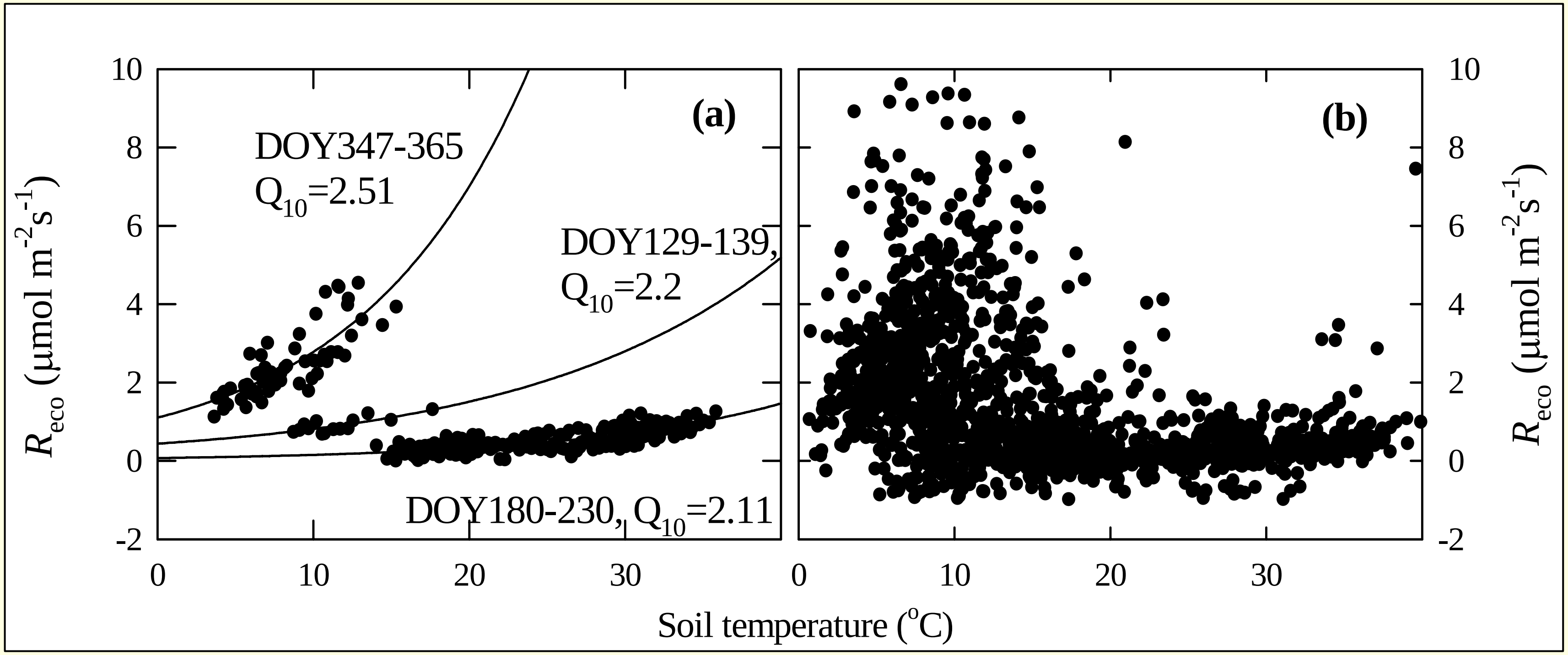


Grassland CO_2 flux vs Sunlight at different LAI



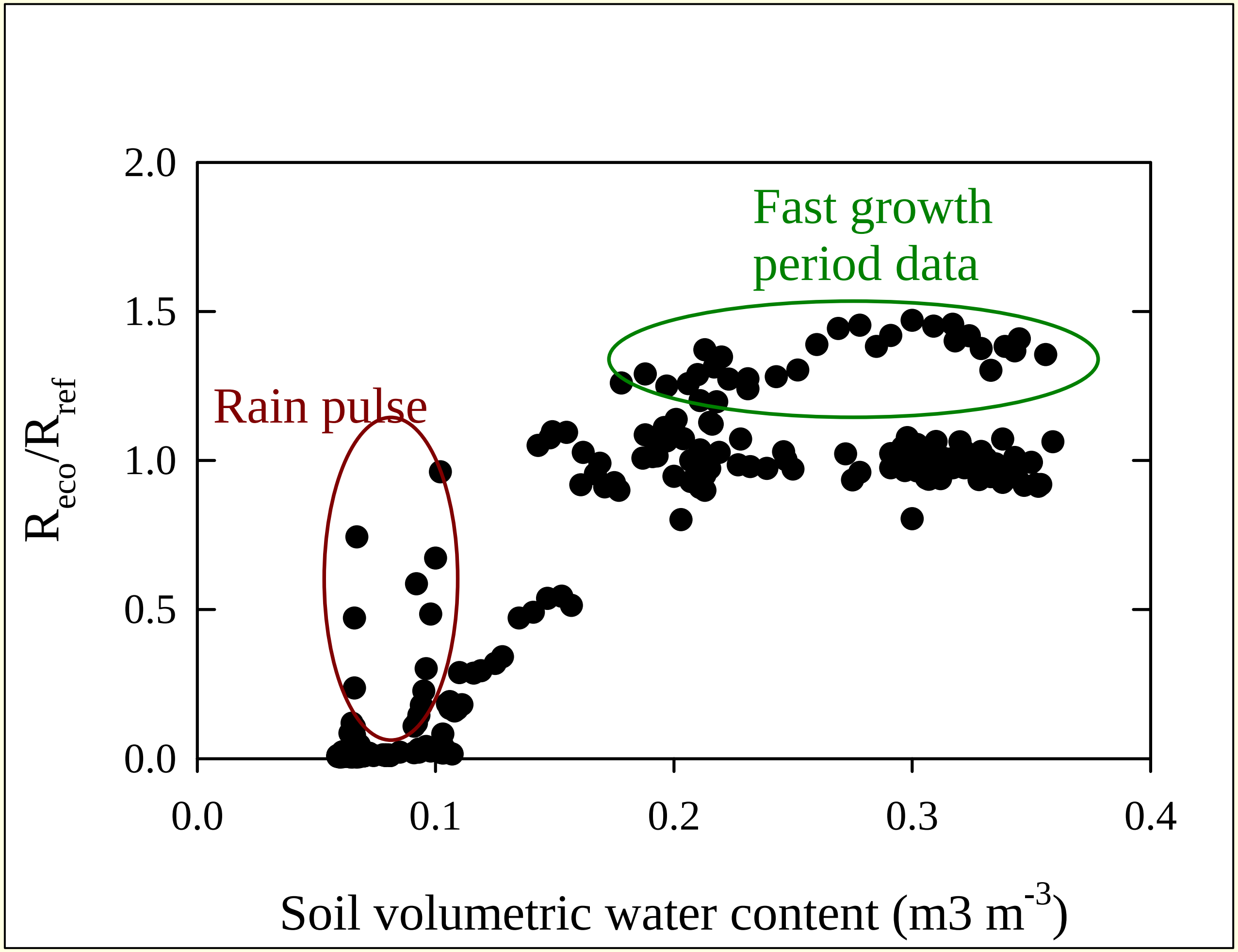
Xu + Baldocchi, AgForMet 2004

Ecosystem Respiration



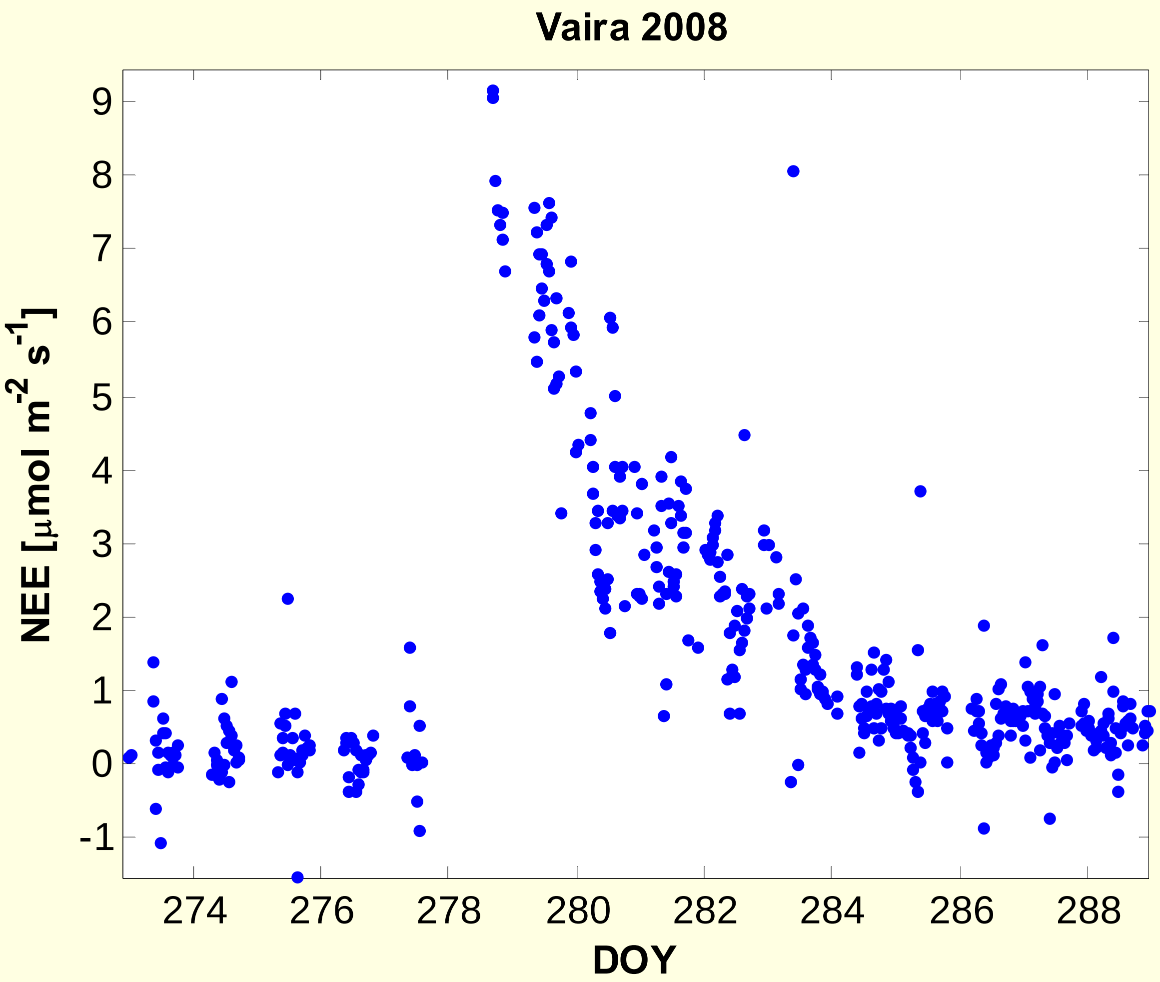
Xu + Baldocchi, AgForMet 2004

Environmental Controls on Respiration

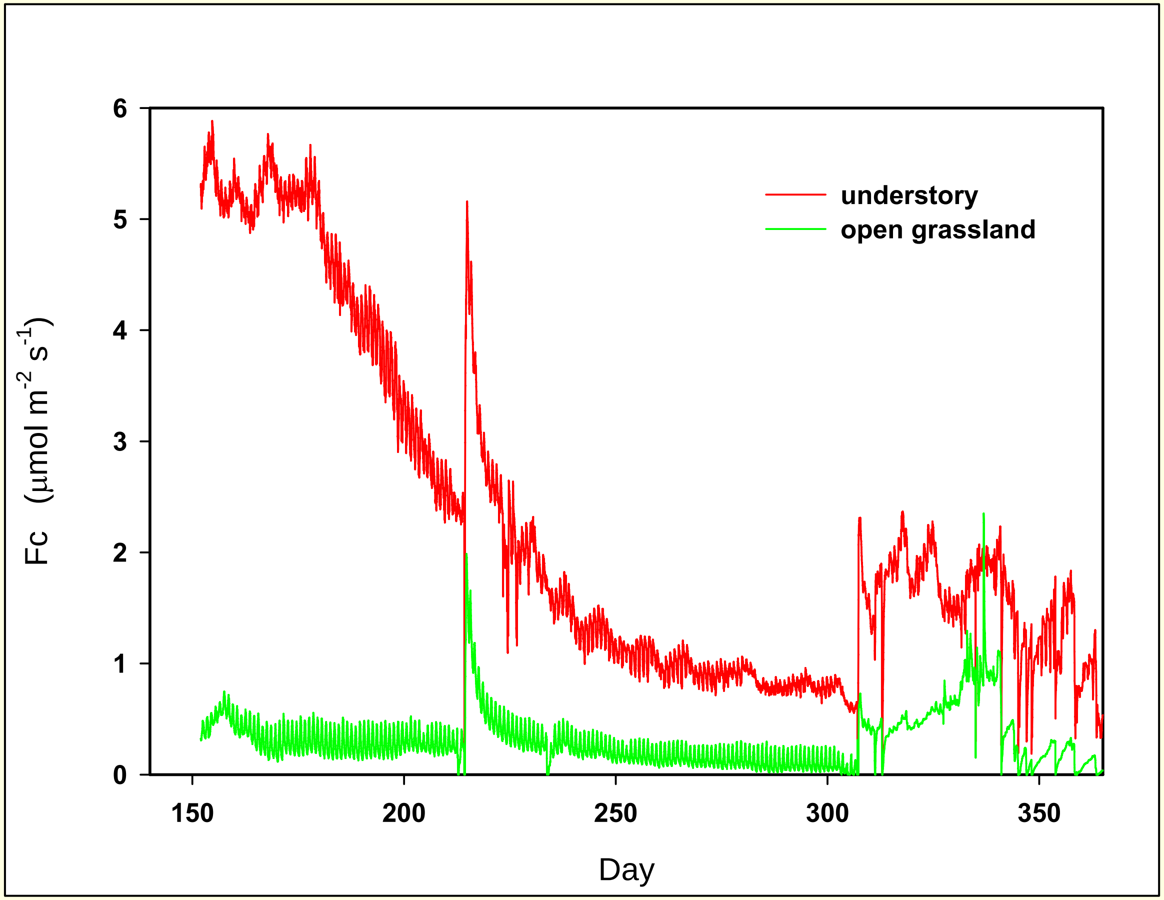


Xu + Baldocchi, AgForMet 2004

Sustained and Elevated Respiration after Fall Rain

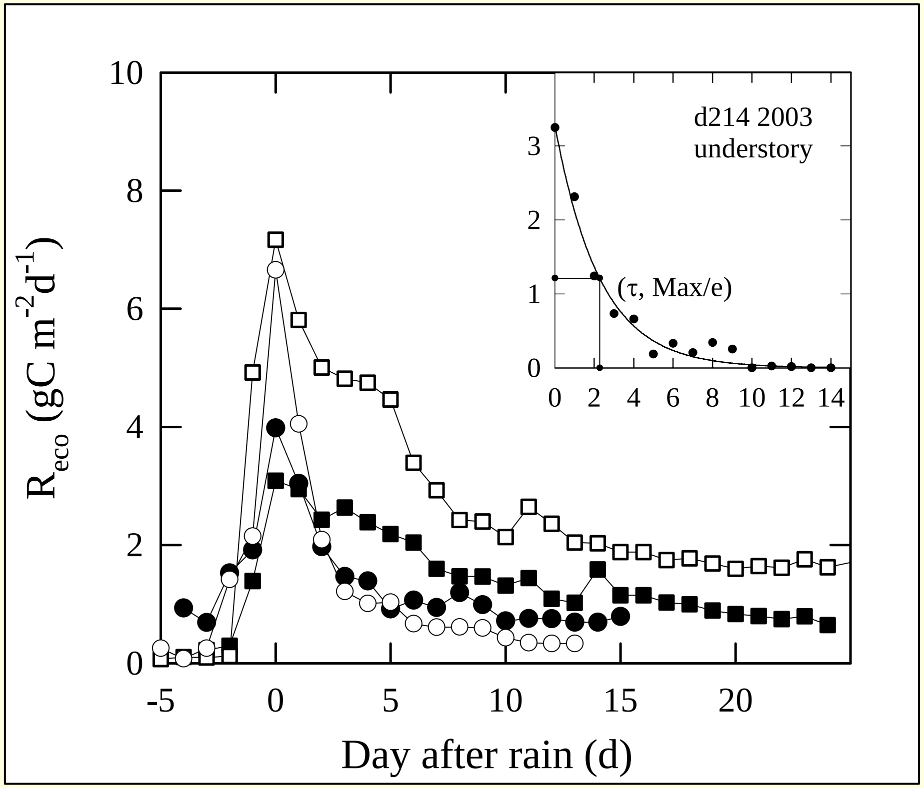


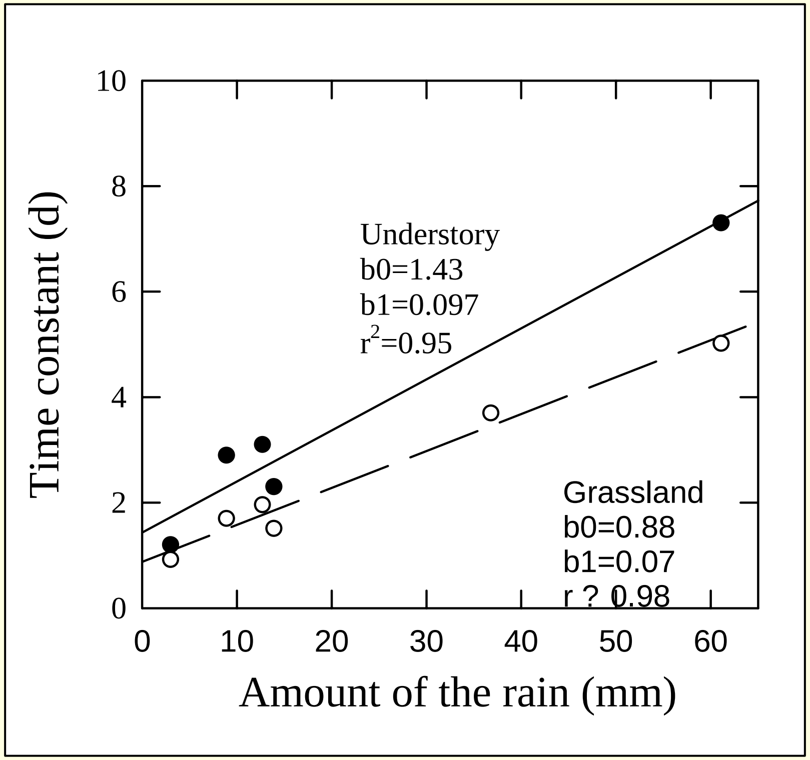
Impact of rain pulse on ecosystem respiration:
Fast response



Baldocchi et al, JGR, Biogeosciences, 2006

Quantifying the impact of rain pulses on respiration: Assessing the Decay Time constant

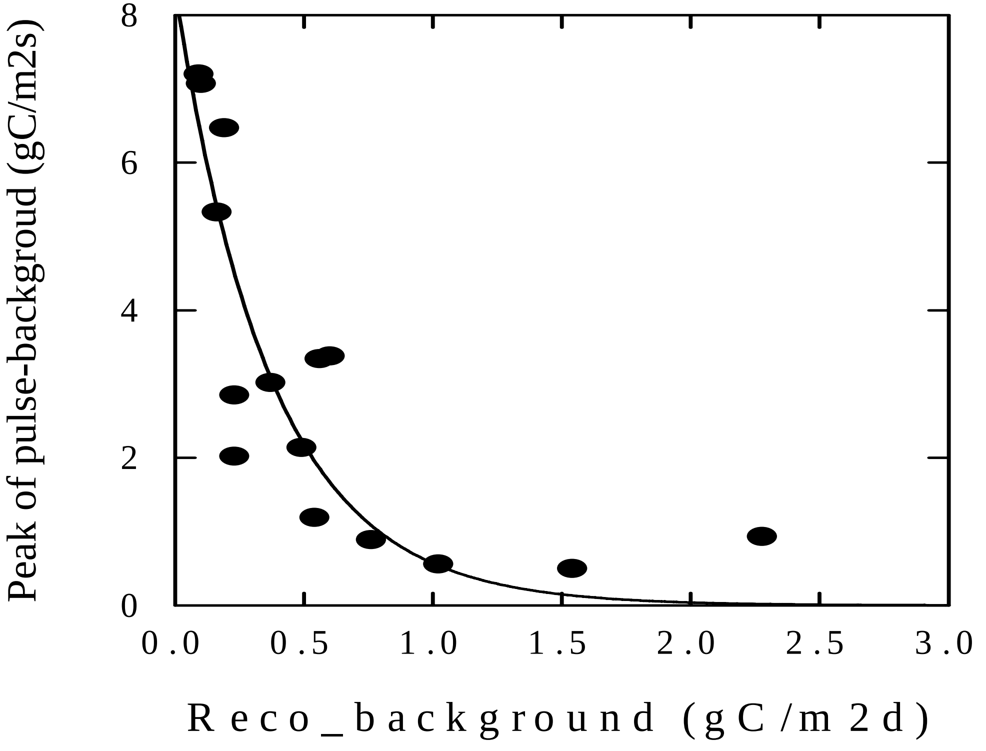




Xu, Baldocchi, Tang, 2004
Global Biogeochem Cycles

$$R_{eco} = b_0 + b_1 \exp(\frac{-t}{\tau})$$

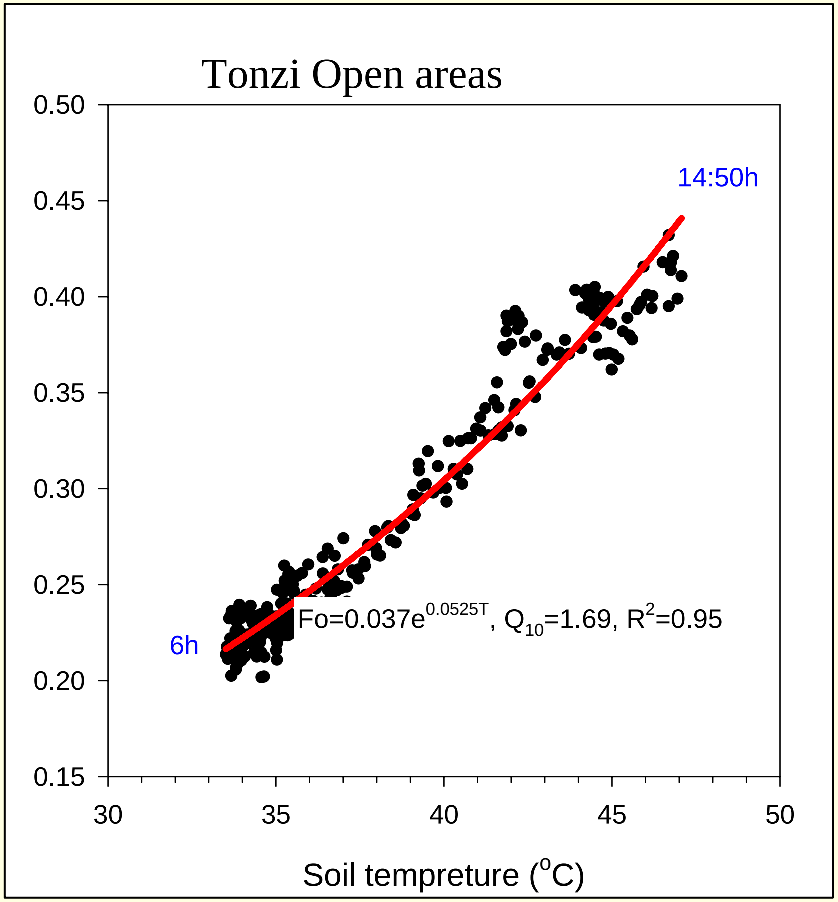
Respiration Enhancement Depends on Initial Condition

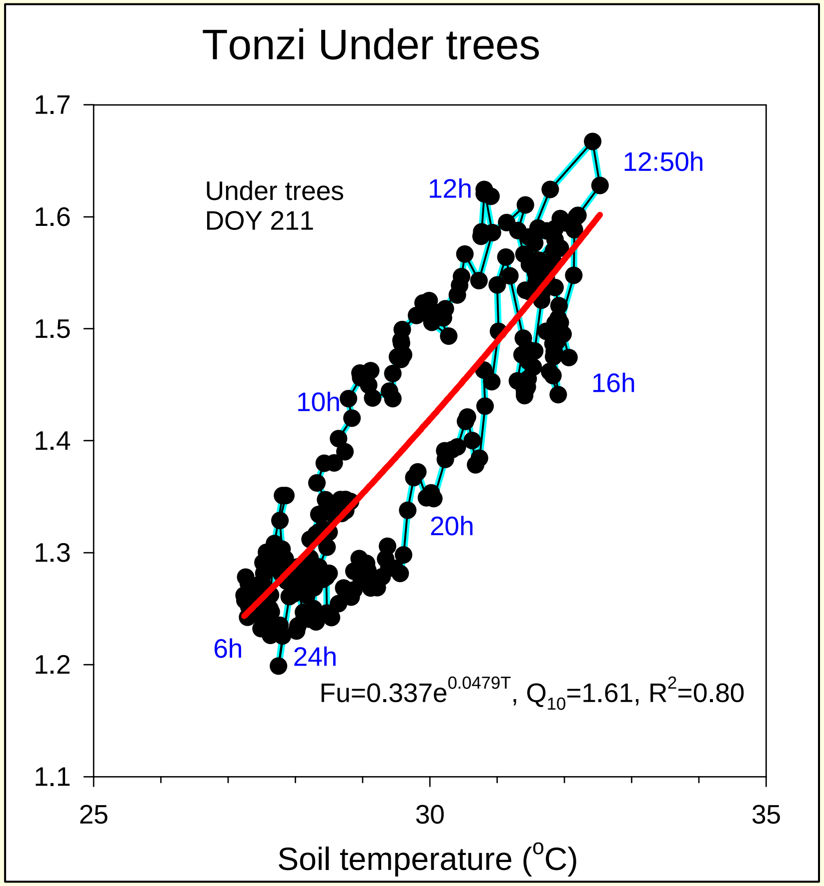


Reco pulse-background vs background.
data from grassland and savanna

Xu, Baldocchi, Tang
Global Biogeochem Cycles 2004

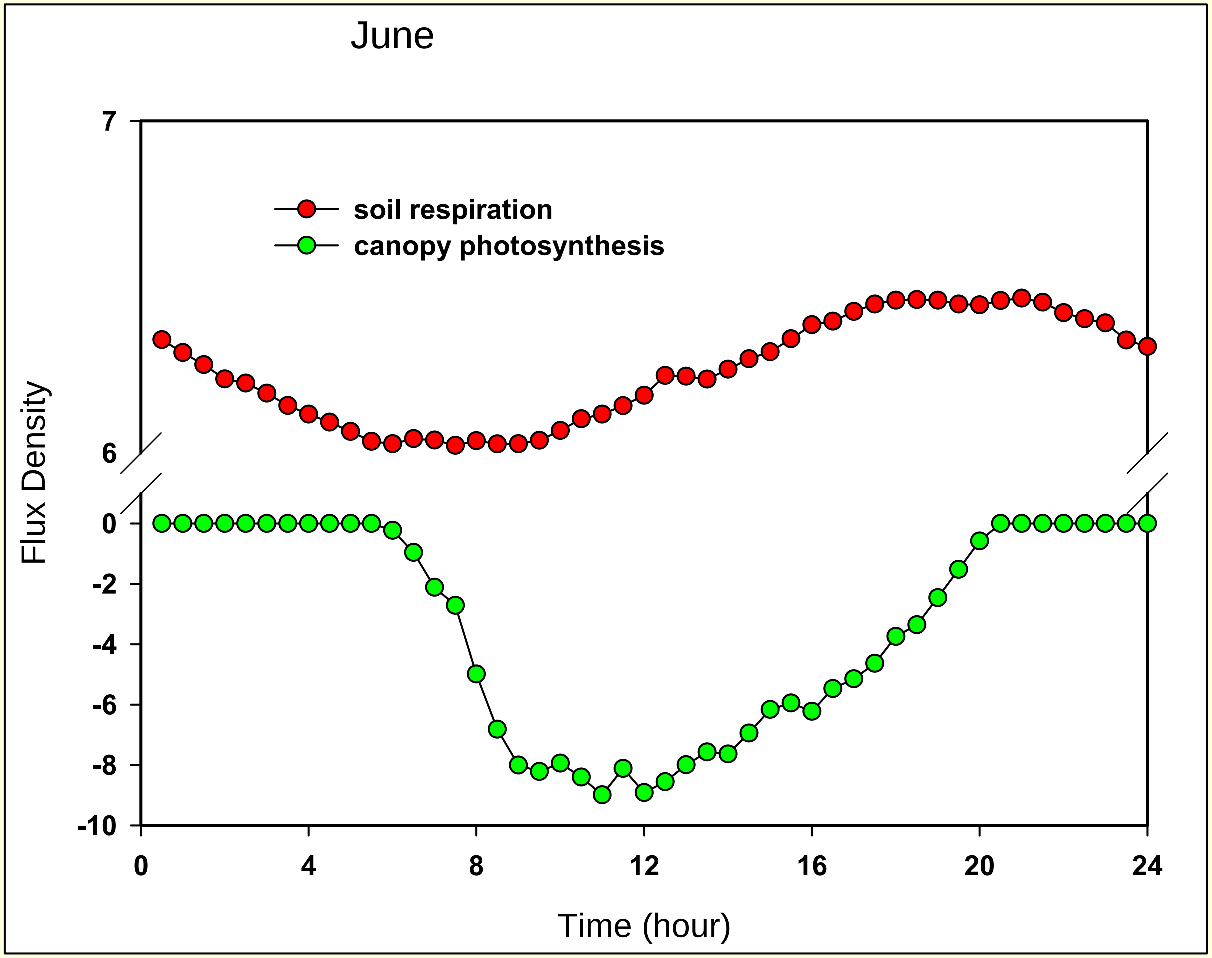
Respiration and Photosynthesis





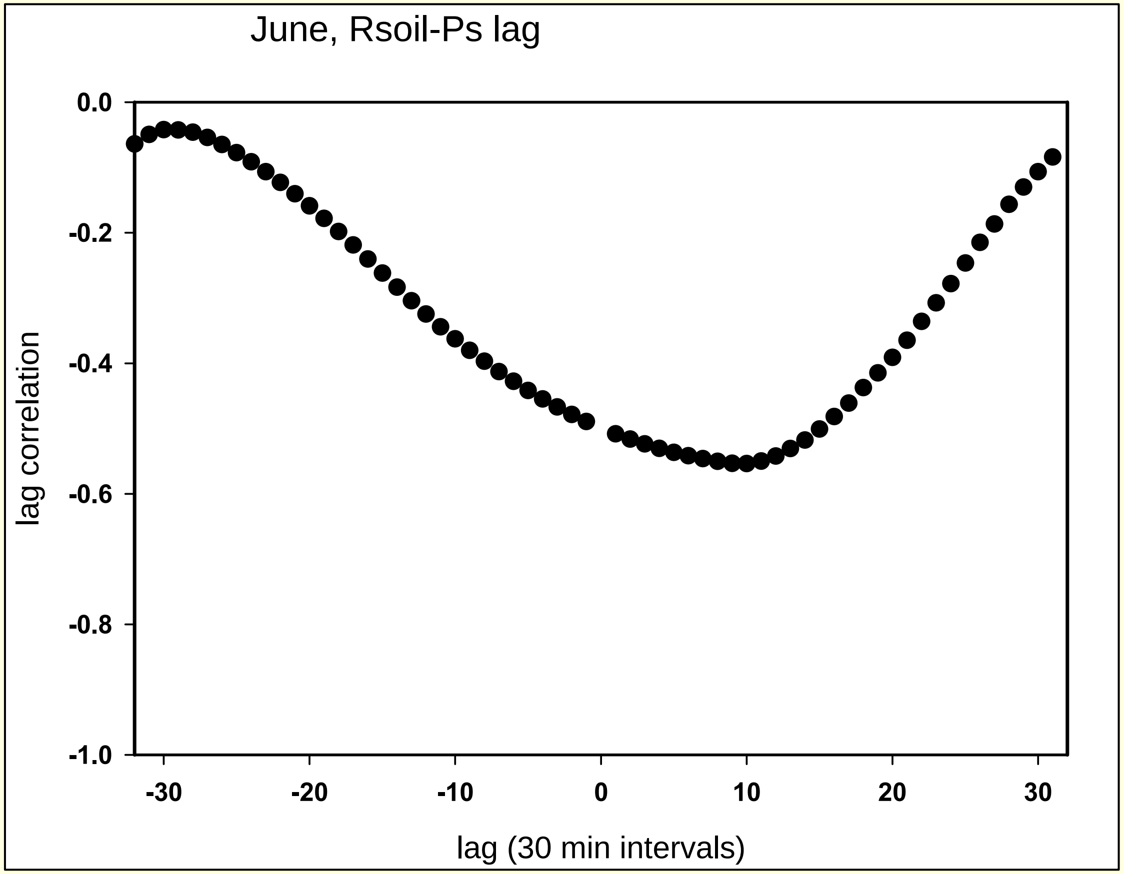
Tang, Baldocchi, Xu, Global Change Biology, 2005

Lags and Leads in Ps and Resp: Diurnal



Tang et al, Global Change Biology 2005.

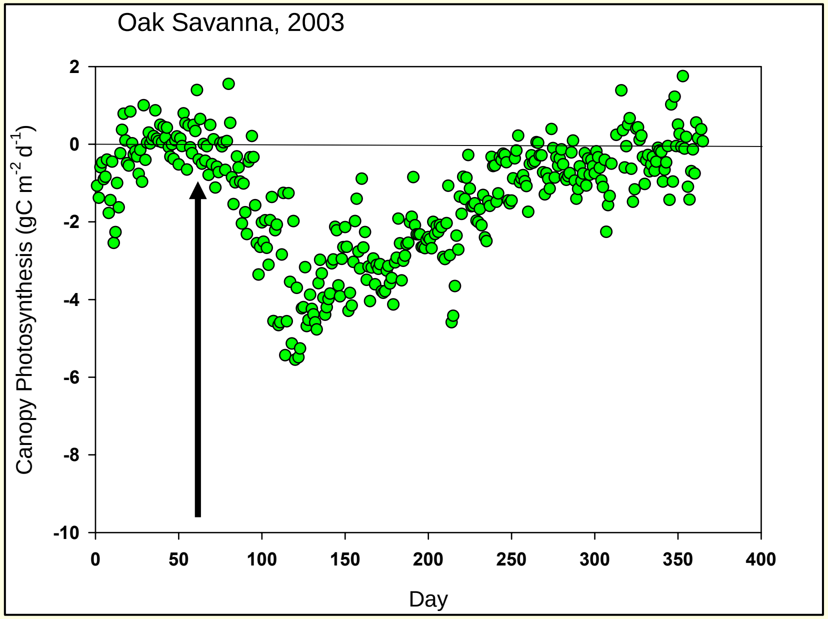
Soil Resp Lags Ps by about 5 to 6 hours

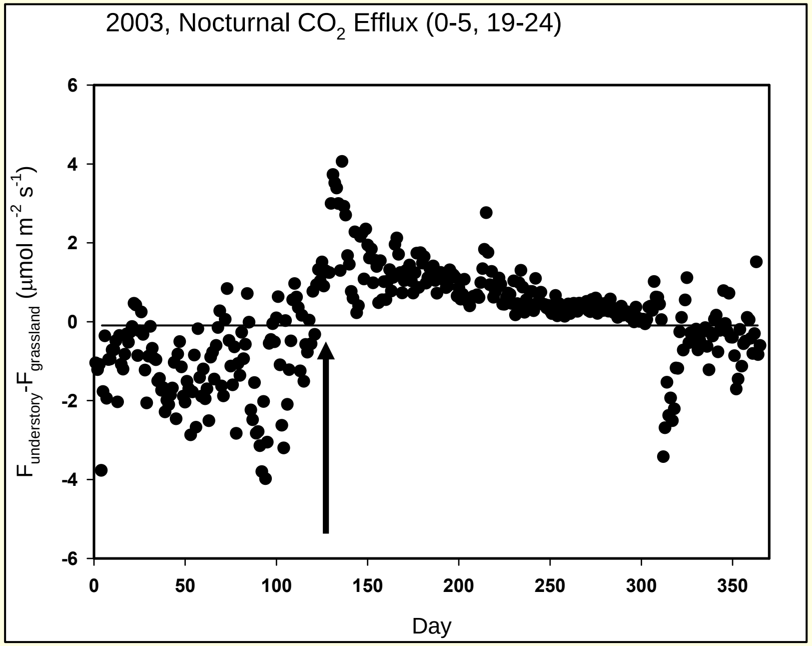


Tang et al, Global Change Biology 2005.

•Photosynthesis Switches Partitioning between dominance by Roots vs Microbes

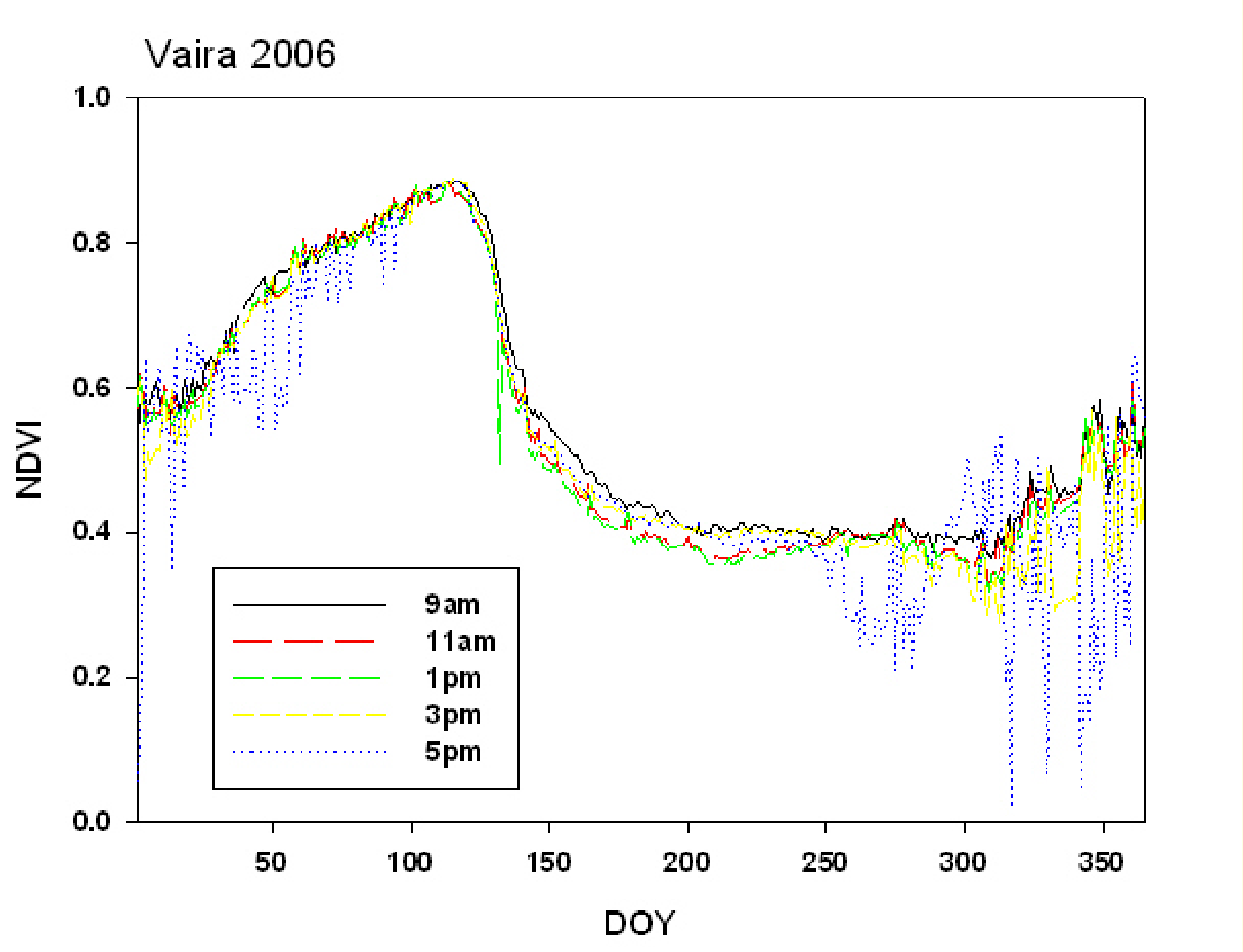
Stimulation of Autotrophic is much delayed after onset of photosynthesis



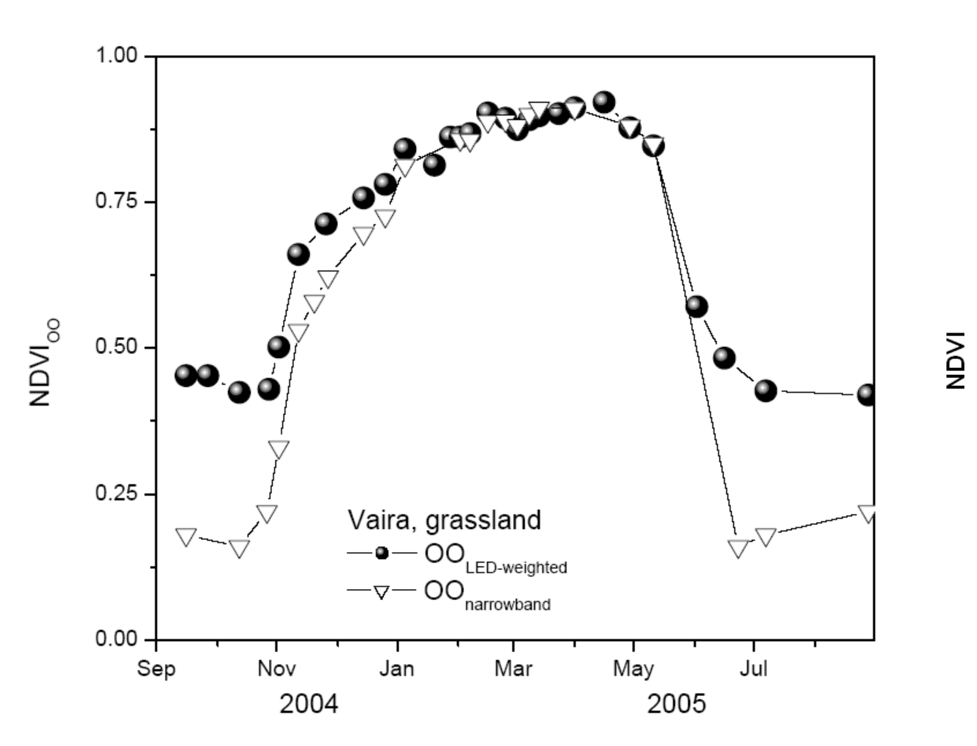


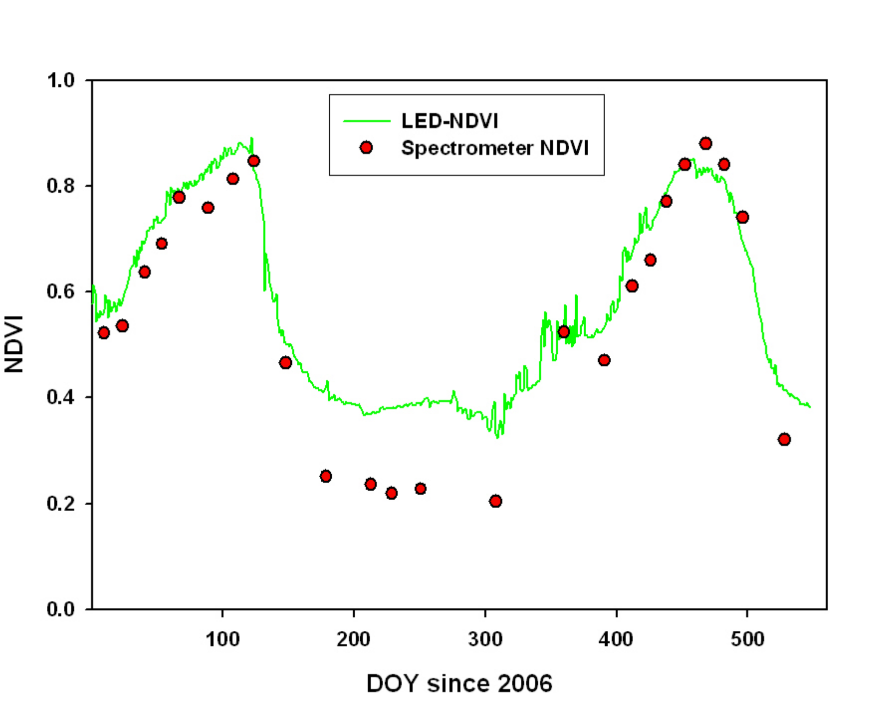
Baldocchi et al, JGR, Biogeosciences, 2006

Remote Sensing of NPP

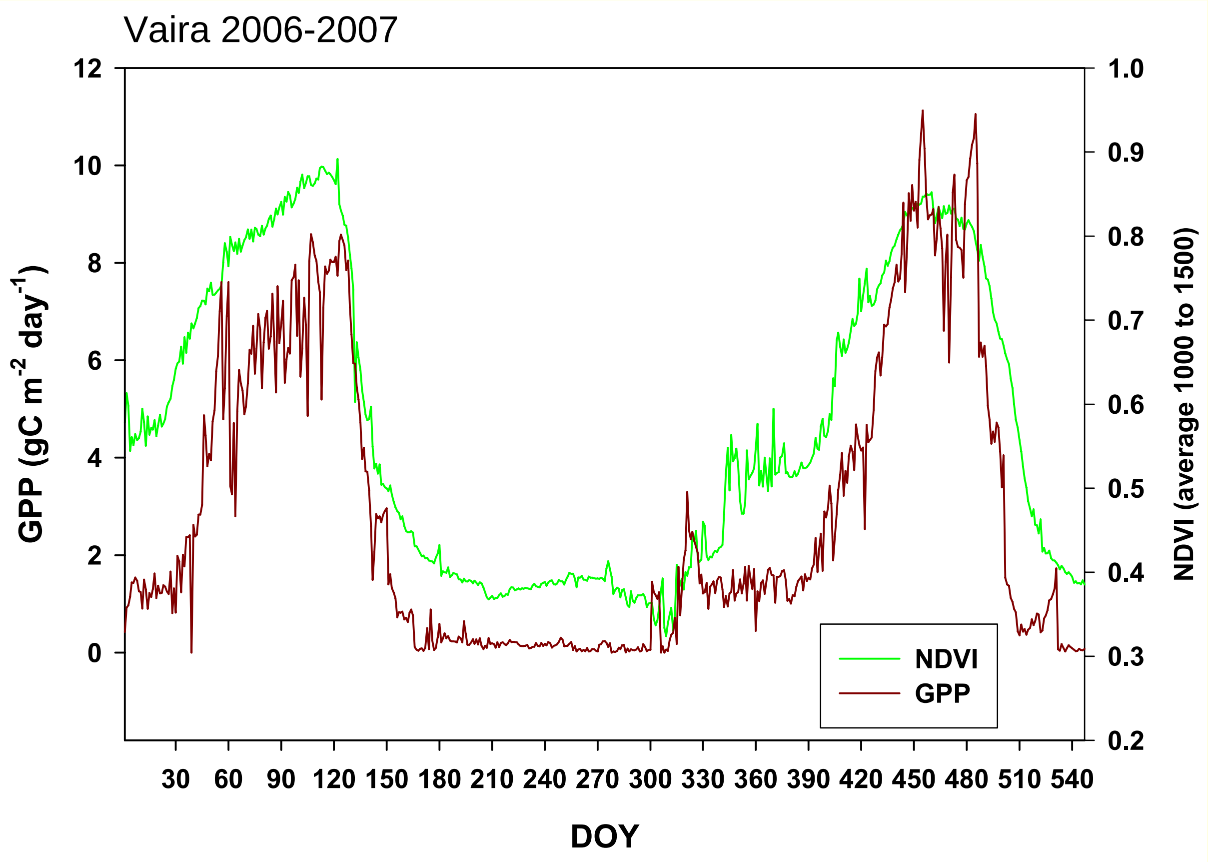

Vaira 2006
1.0
0.8
0.6
0.4
0.2
0.0
NDVI
50
100
150
200
250
300
350
DOY
9am
11am
1pm
3pm
5pm

LED sensor intercomparison and calibration



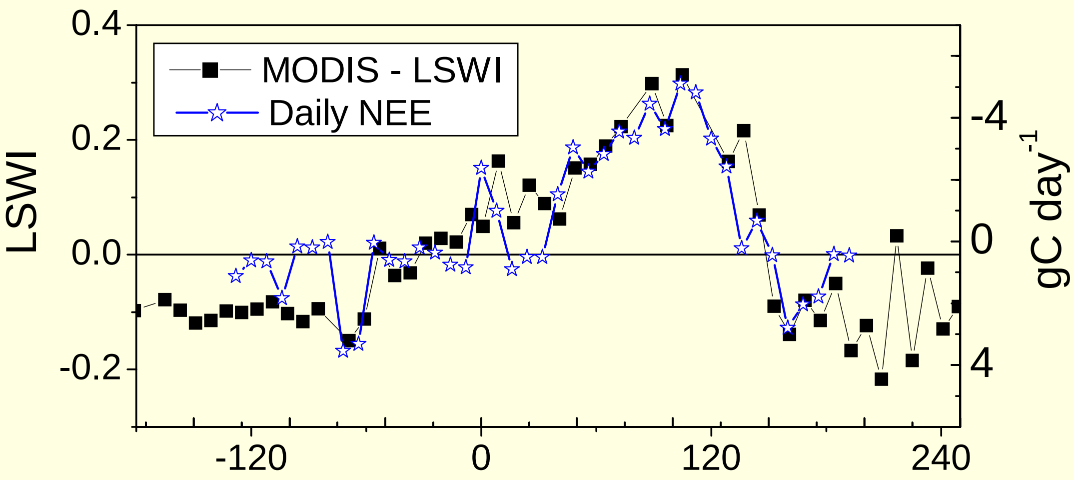


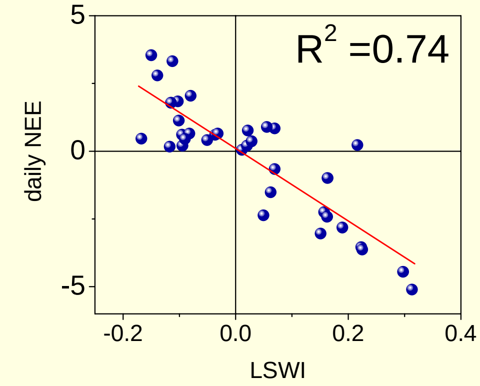
Falk, Ma, Ruiz, Hehn, Baldocchi . in prep


Vaira 2006-2007
12
10
8
6
4
2
0
GPP (gC m-2 day-1)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
NDVI (average 1000 to 1500)
30 60 90 120 150 180 210 240 270 300 330 360 390 420 450 480 510 540
DOY
NDVI
GPP

Land Surface Water Index (LSWI) plotted with daily NEE for 2004/2005

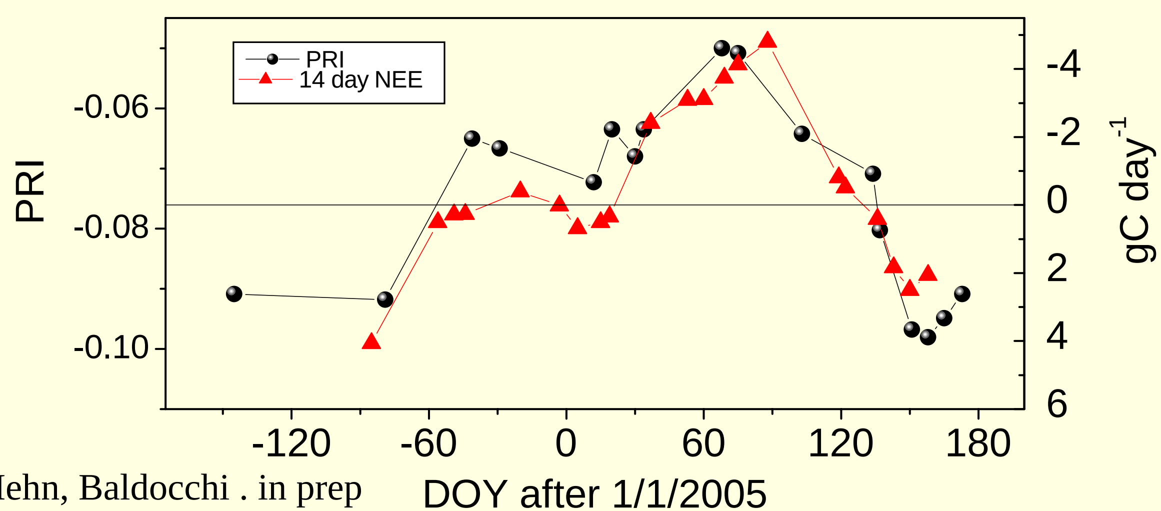
Land Surface Water Index LSWI = (ρ860 - ρ1640)/(ρ860 + ρ1640)



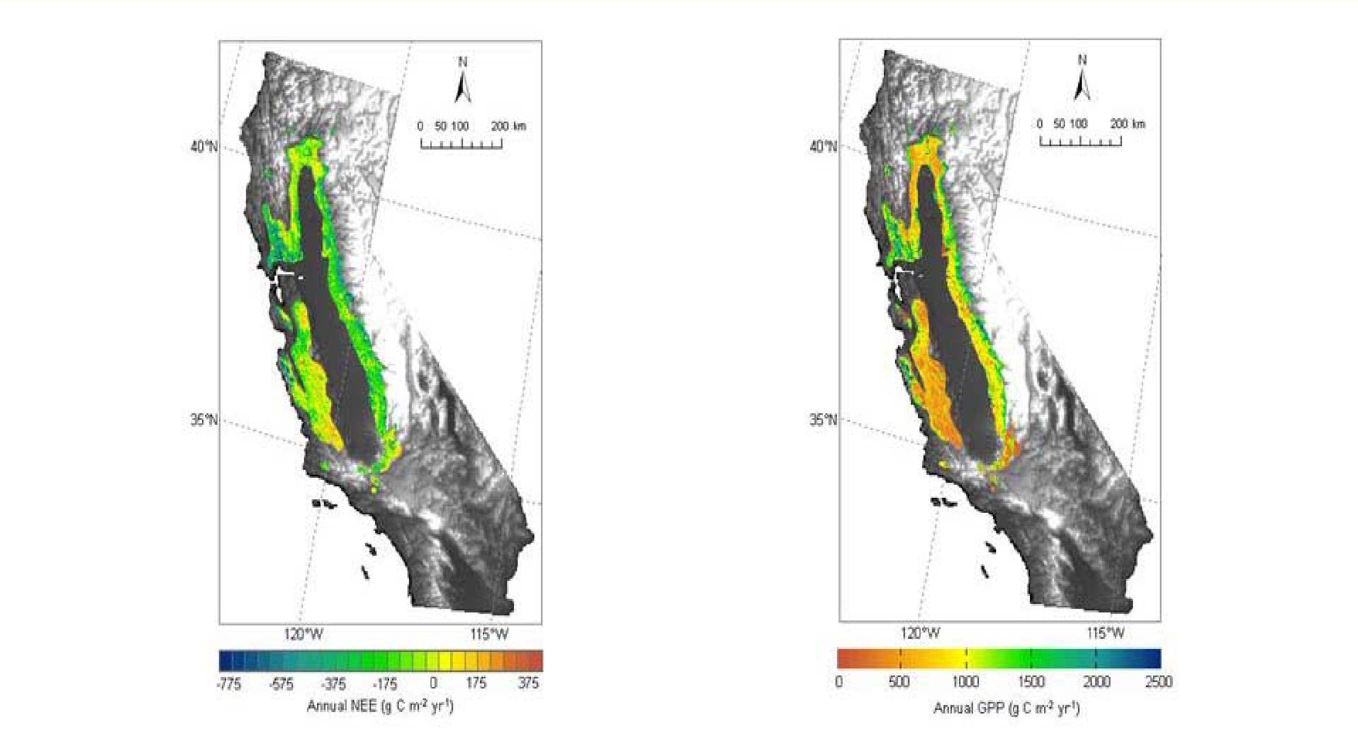


PRI and NEE

$PRI = (\rho_{531} - \rho_{570}) / (\rho_{531} + \rho_{570})$



Falk, Ma, Ruiz, Hehn, Baldocchi . in prep



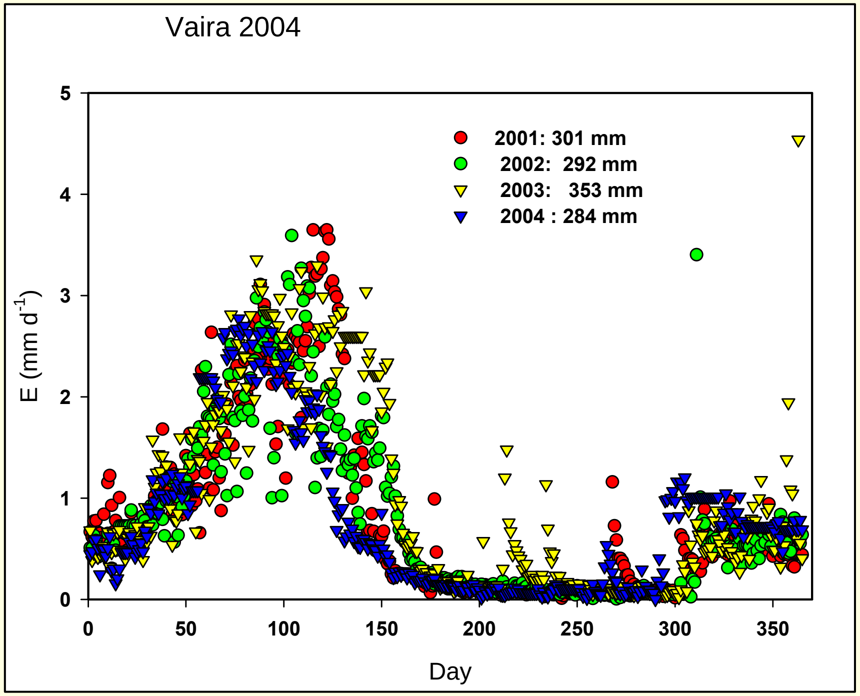
area-averaged fluxes of *NEE* and *GPP* were -150 and 932 gC m^{-2} y^{-1}

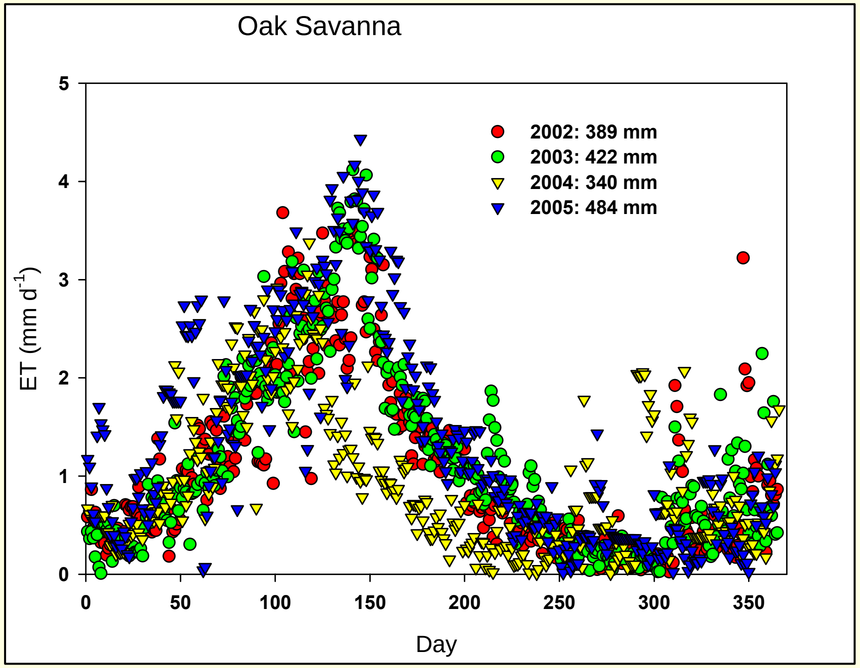
net and gross carbon fluxes equal -8.6 and 53.8 TgC y^{-1}

Jingfeng Xiao and D Baldocchi

Water and Evaporation

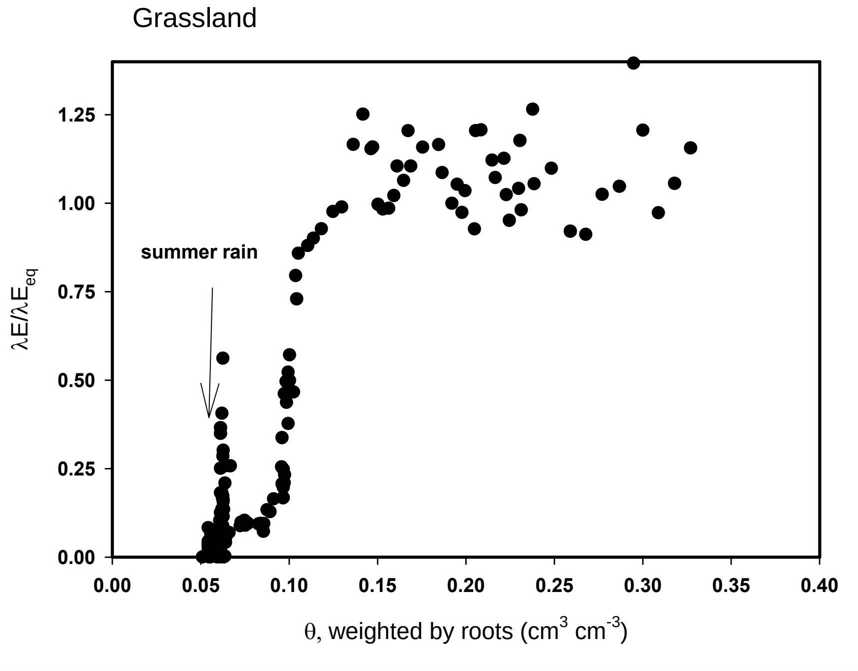
Annual ET and Interannual Variation

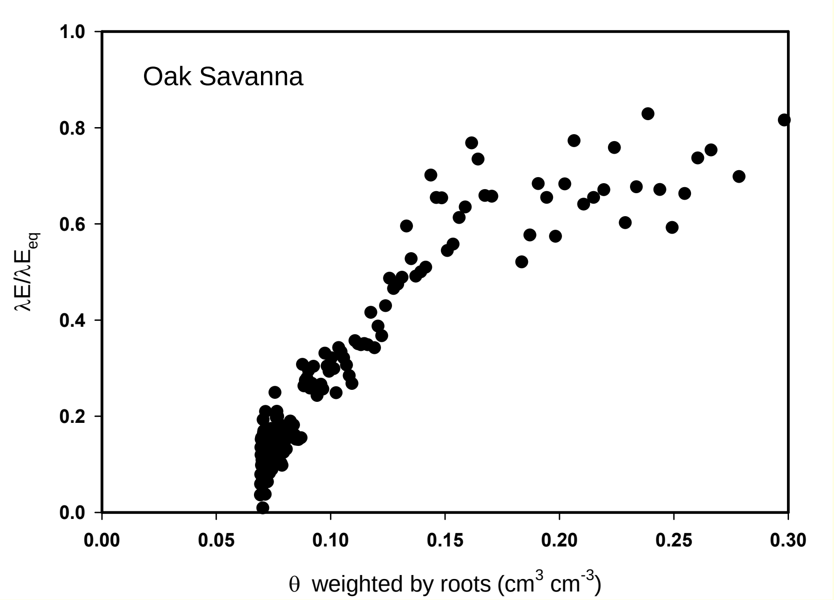




Savanna Soil Stores about 80 mm water and uses that much extra to sustain a sparse woodland, over a grassland

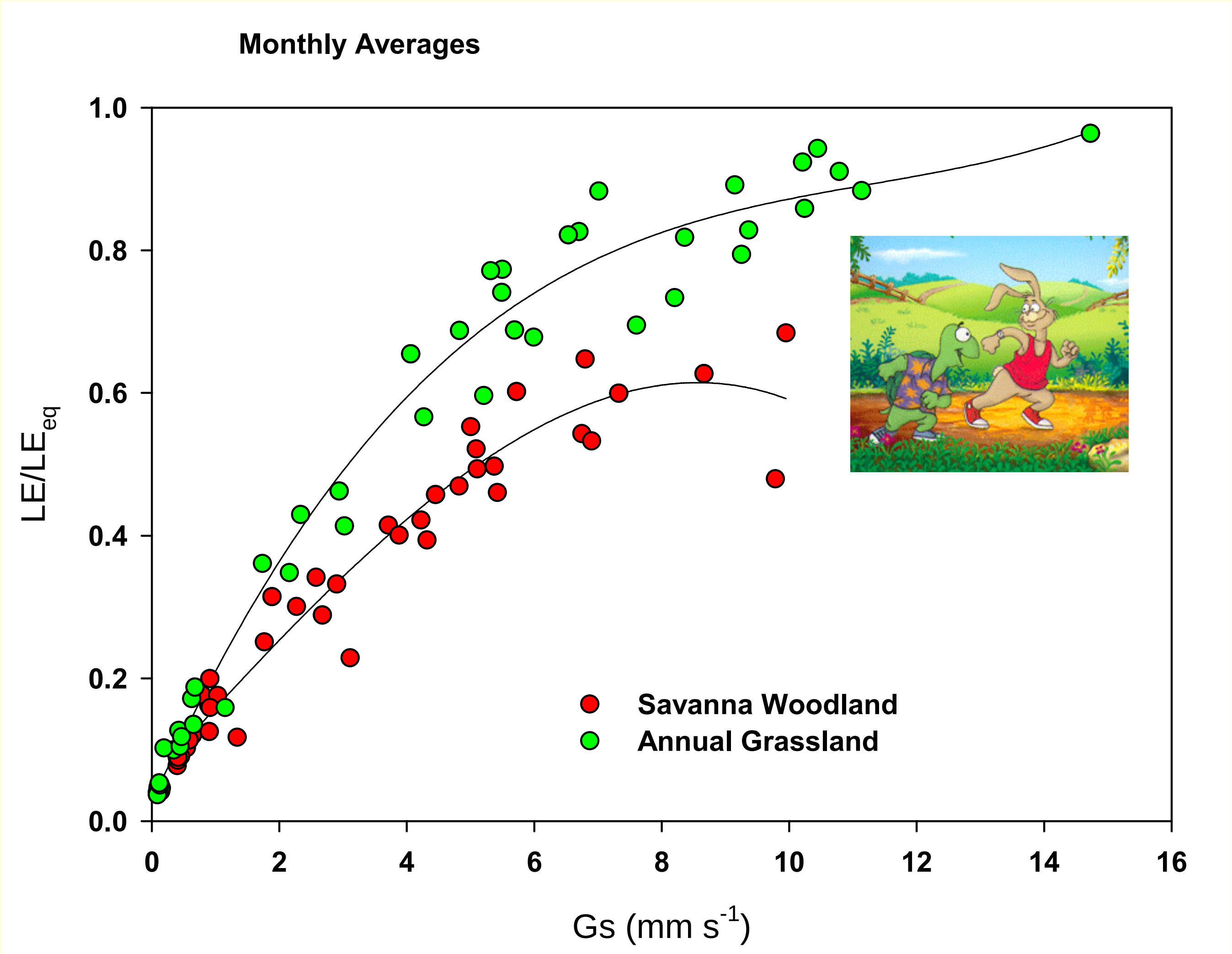
ET and Soil Water Deficits: Root-Weighted Soil Moisture





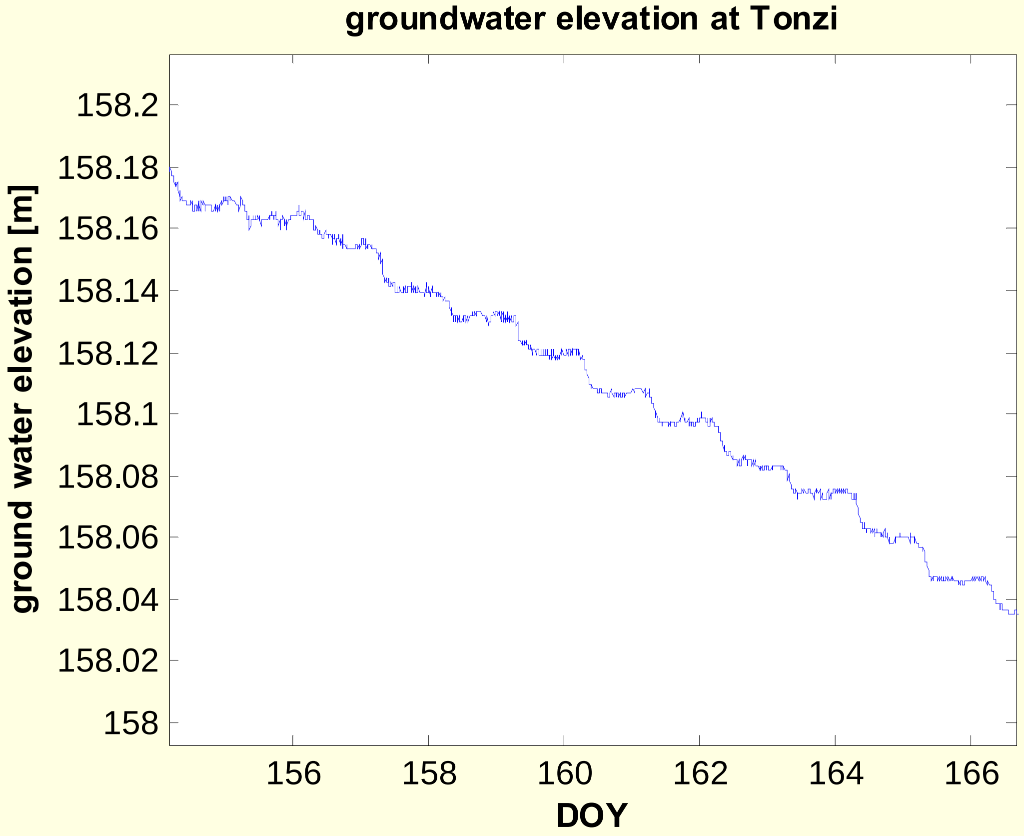
Baldocchi et al., 2004 AgForMet

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



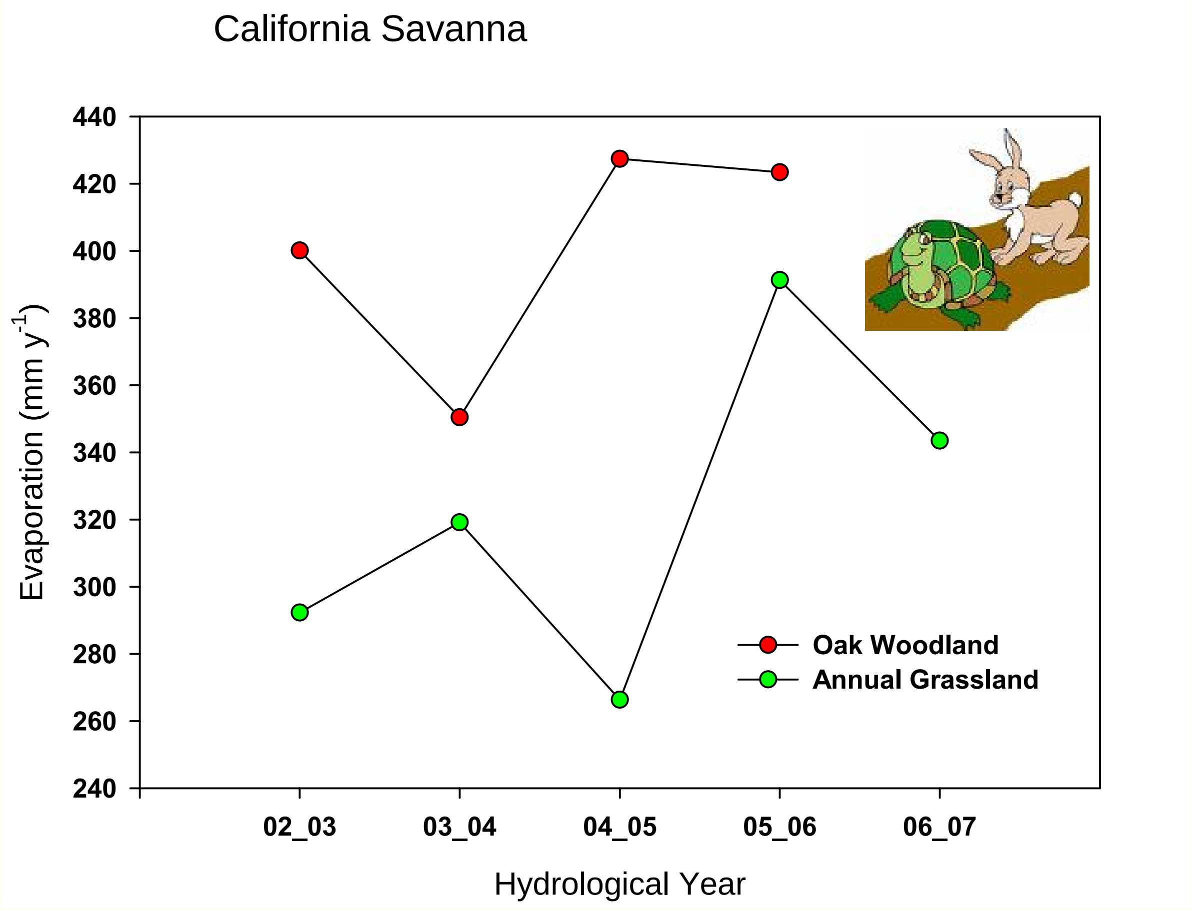
Ryu, Baldocchi, Ma and Hehn, JGR-Atmos, submitted

Oak Trees Tap Ground Water



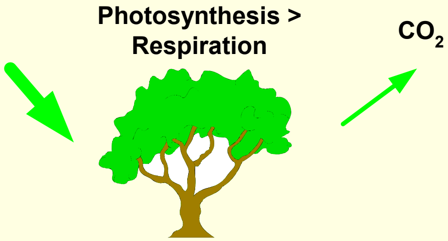
G. Miller, Y. Rubin, D. Baldocchi unpublished data

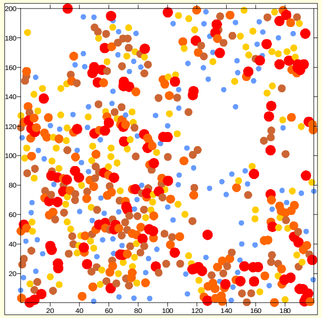
Role of Land Use on ET:
On Annual Time Scale, Forest ET > Grass ET



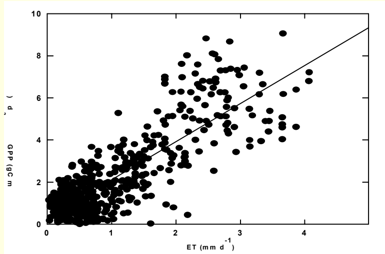
Ryu, Baldocchi, Ma and Hehn, JGR-Atmos, submitted

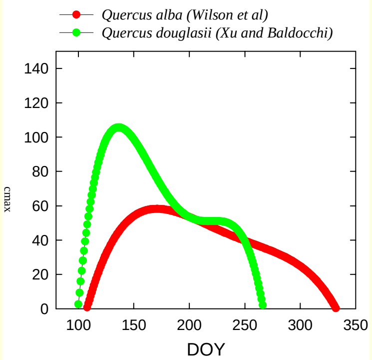
Synthesis/Conclusions



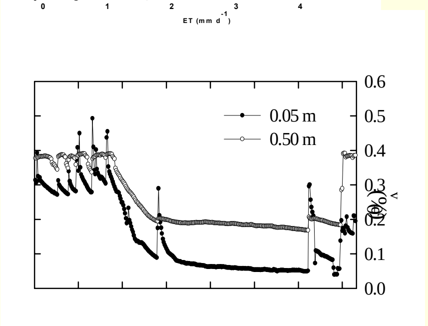


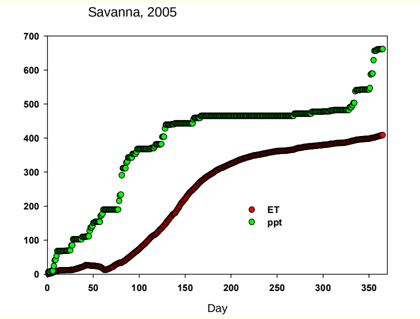
At Ecosystem scale Leaf Area is limited enabling the Sparse Canopy to Reduce ET, too

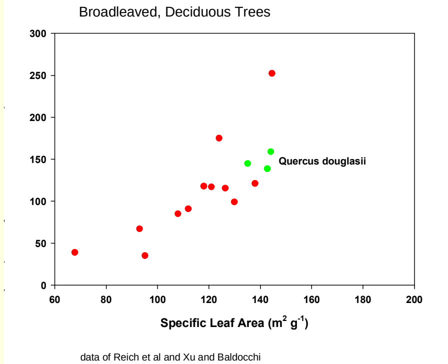




Ps Capacity must be Great, For Short Period to Facilitate high rates of photosynthesis







Leaf N and Leaf Thickness must be adequate to support Ps Machinery

Role of Land Management on Water and Energy Exchange and Climate

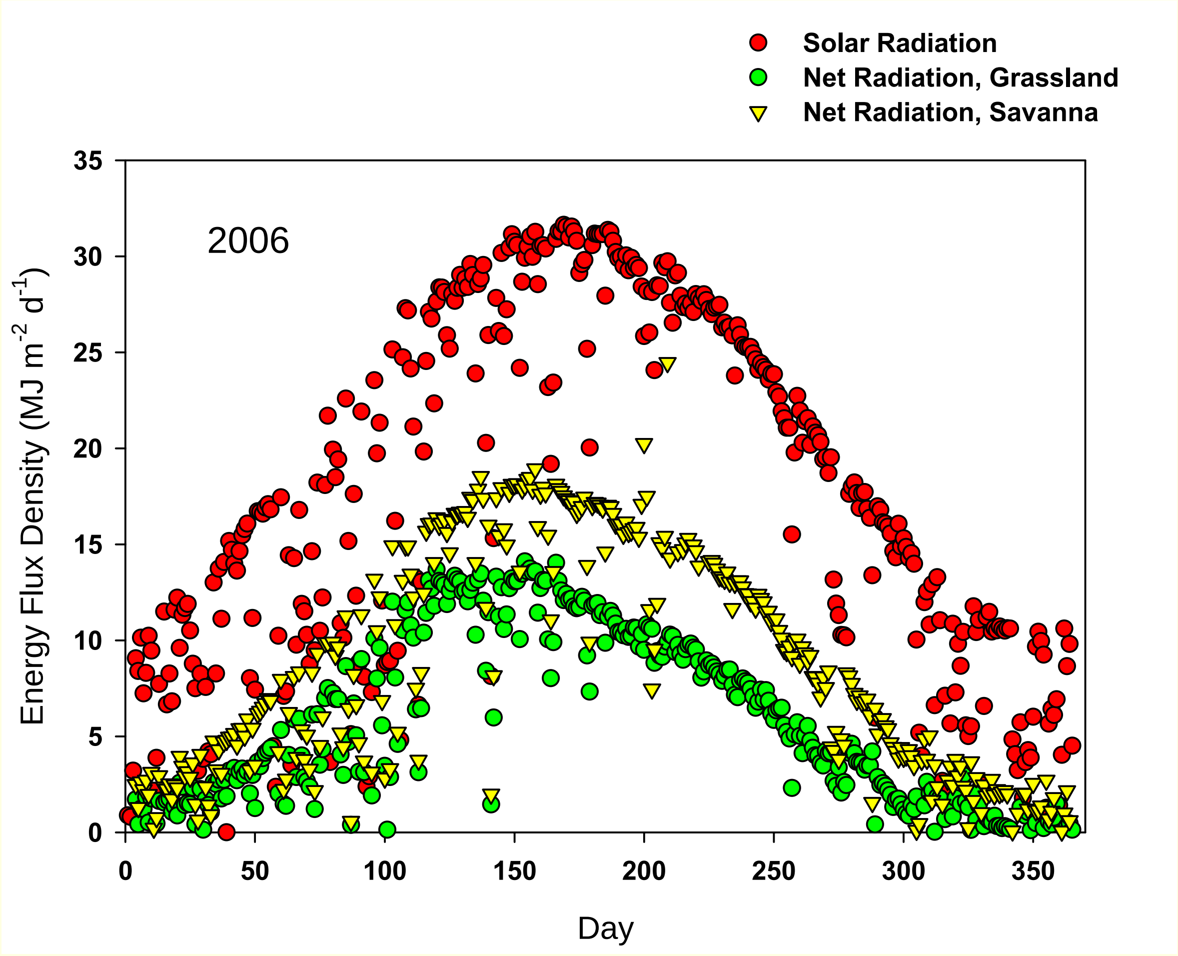
Case Study:
Savanna Woodland vs Grassland

Case Study:

Energetics of a Grassland and Oak Savanna

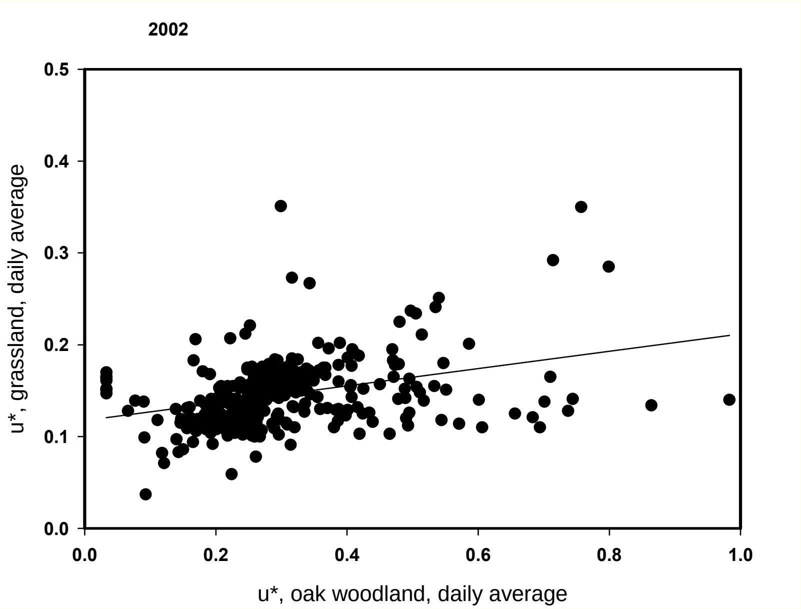
Measurements and Model

Available Energy Drives Heat Exchange and Evaporation

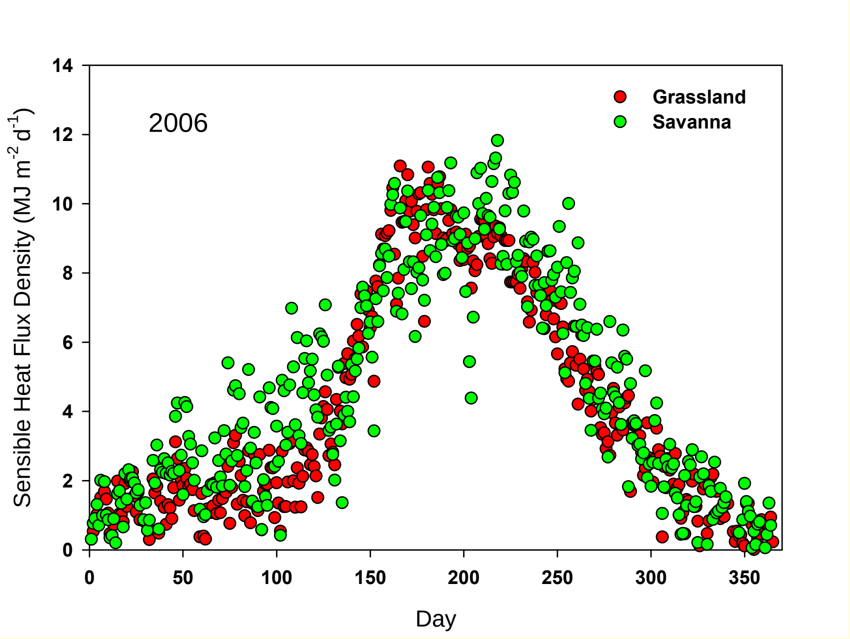


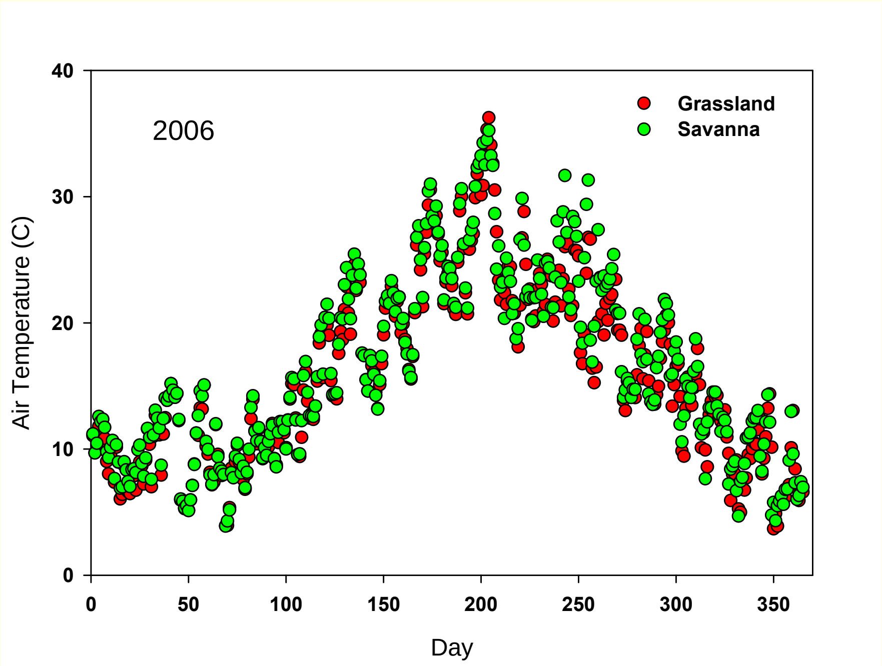
1. Savanna absorbs much more Radiation (3.18 GJ m^{-2} y^{-1}) than the Grassland (2.28 GJ m^{-2} y^{-1}) ; ΔRn: 28.4 W m^{-2}

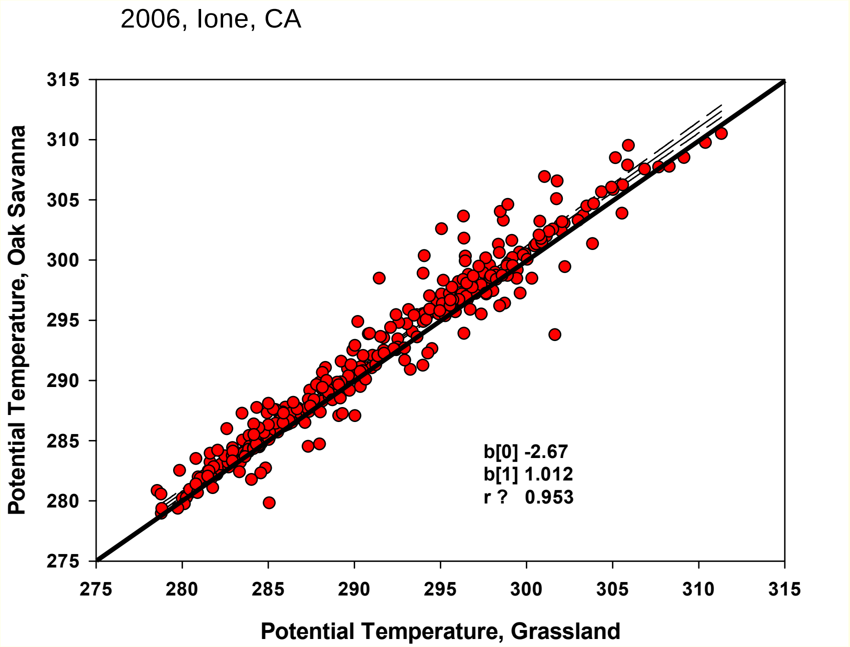
4a. U* of tall, rough Savanna > short, smooth Grassland



4b. Savanna injects more **Sensible Heat** into the atmosphere because it has more **Available Energy** and it is **Aerodynamically**



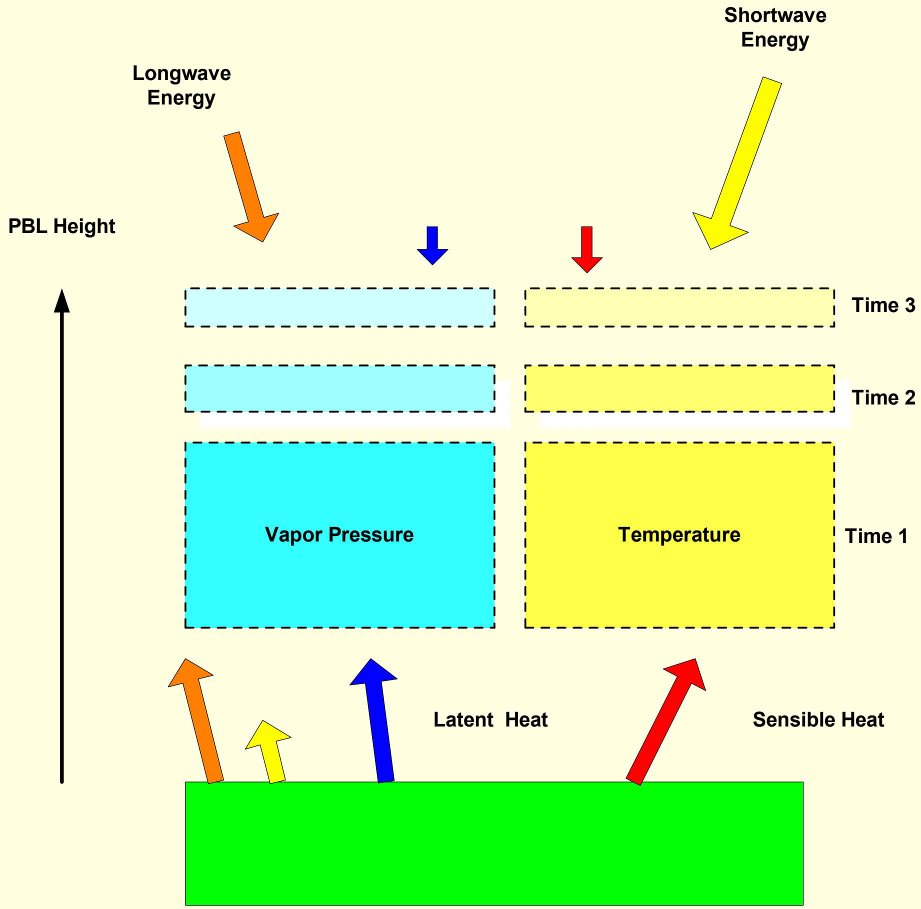


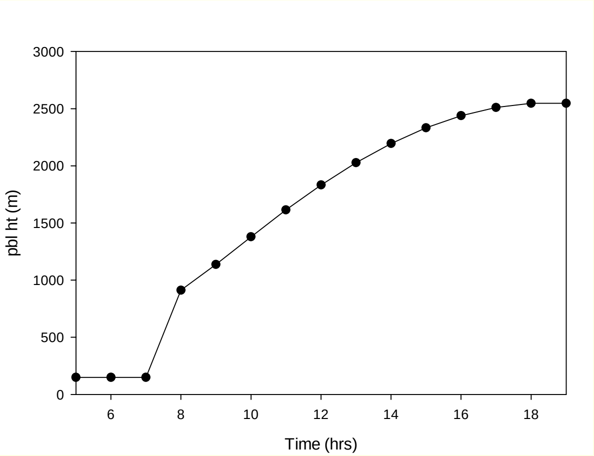


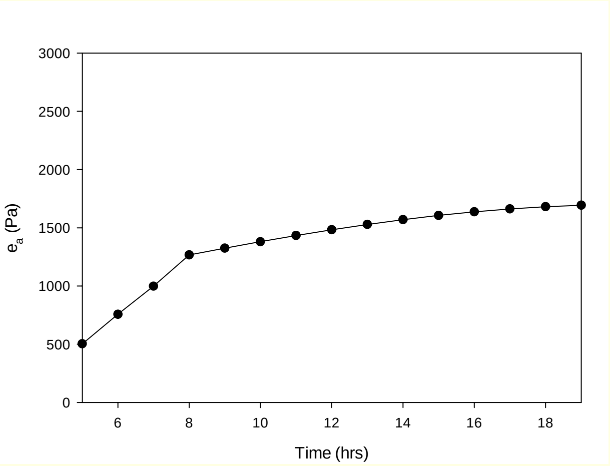
5. Mean **Potential Temperature** differences are relatively small (0.84 C; grass: 290.72 vs savanna: 291.56 K); despite large differences in Energy Fluxes--albeit the **Darker** vegetation is **Warmer**

Compare to Greenhouse Sensitivity ~2-4 K/(4 W m^{-2})

Conceptual Diagram of PBL Interactions





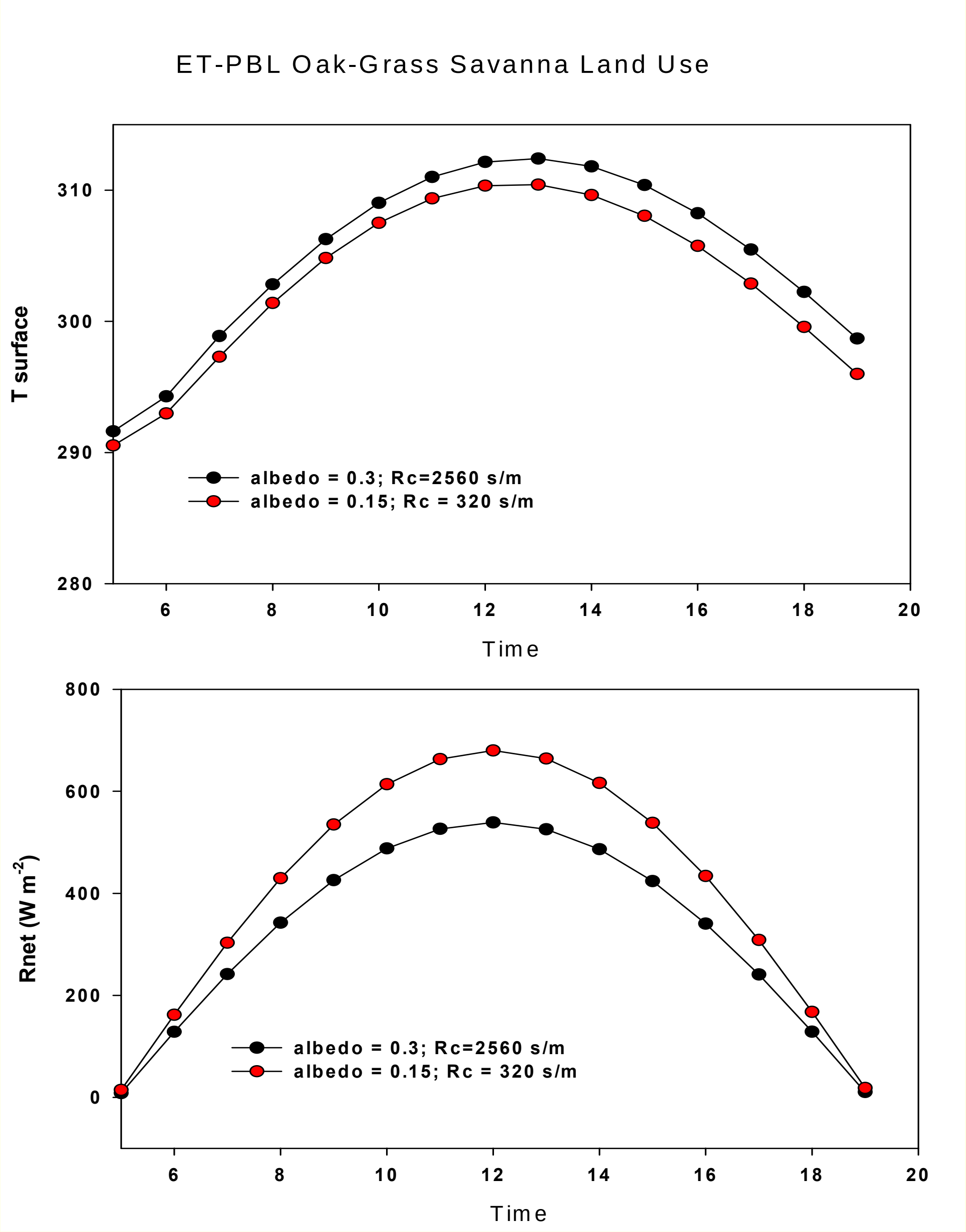


H and LE: Analytical/Quadratic version of Penman-Monteith Equati

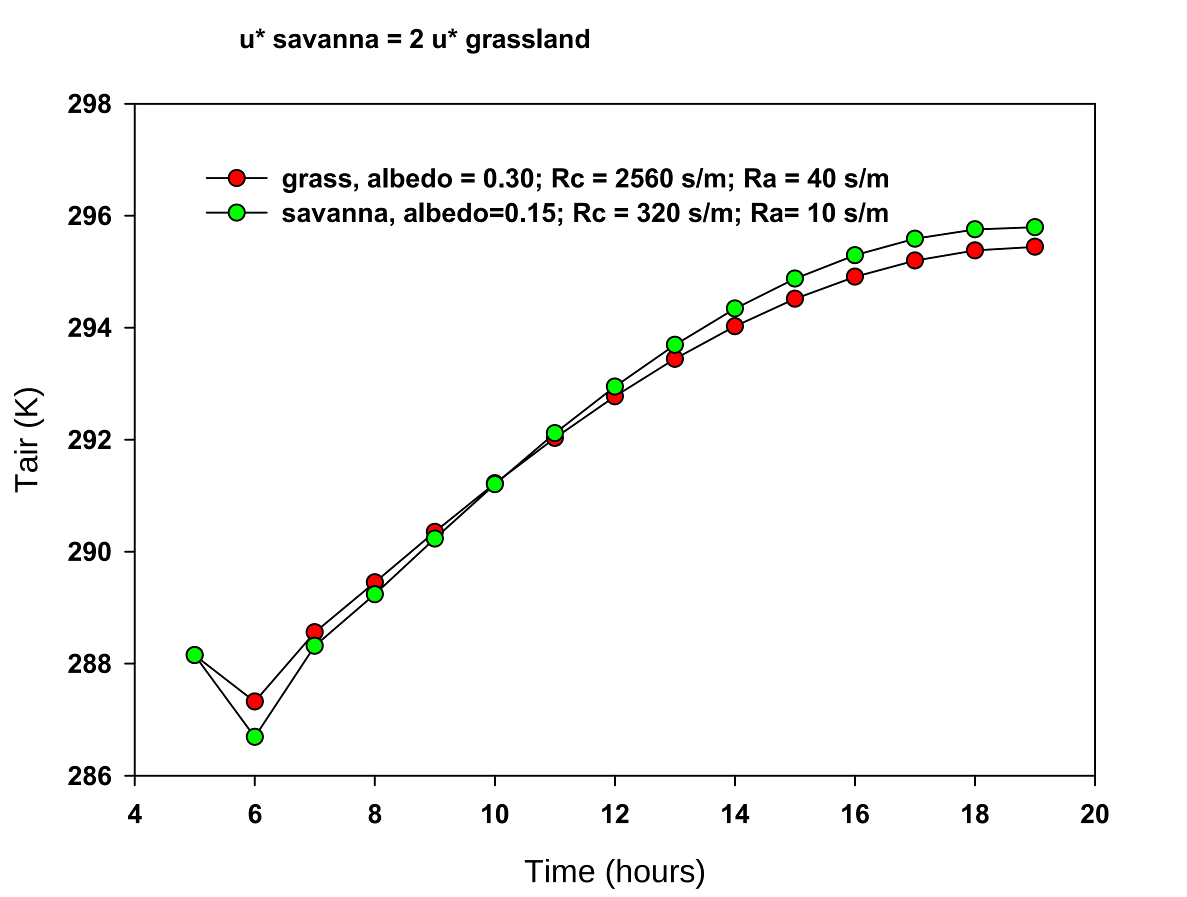
•The Energetics of afforestation/deforestation is complicated

•Forests have a low albedo, are darker and absorb more energy

•But, Ironically the **darker** forest maybe **cooler** (T_{sfc}) than a bright grassland due to evaporative cooling

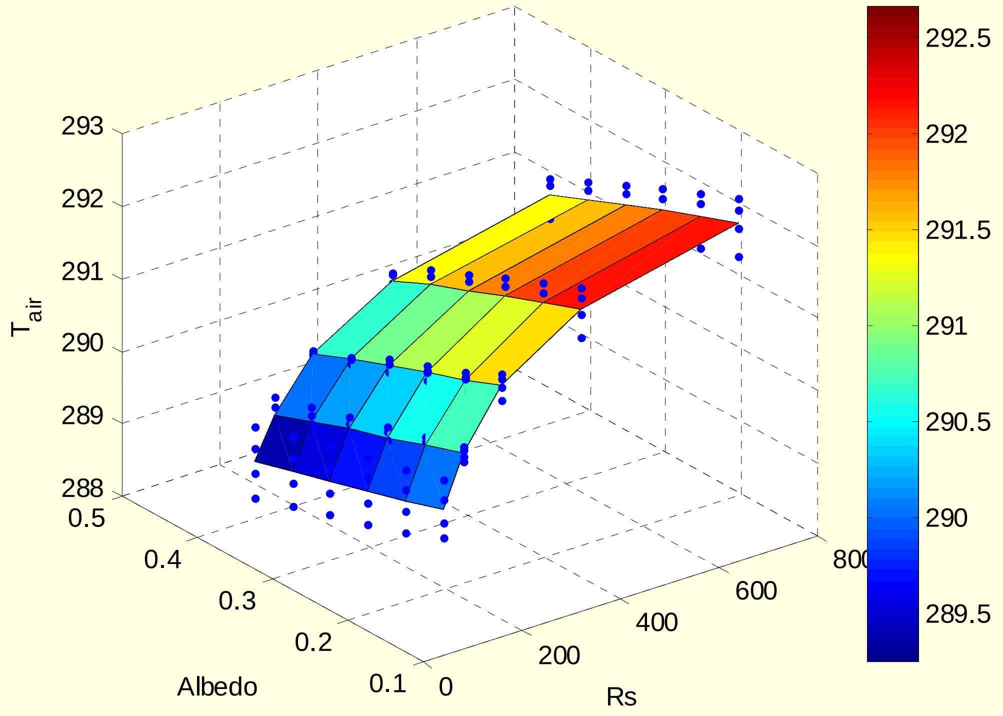


And Smaller Temperature Difference, like field measurements, if we consider PBL, R_c, R_a and albedo….!!



Summer Conditions

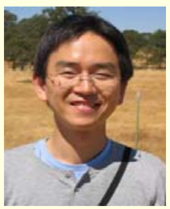
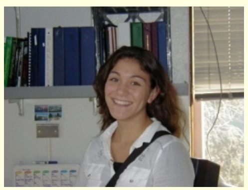
Tair can vary by 3 C by changing albedo and Rs

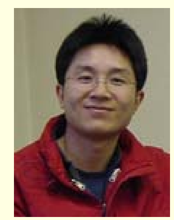
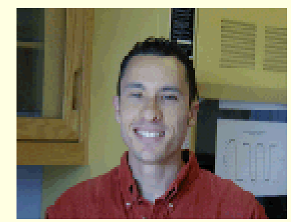


Biometeorology Team









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

Conclusions

- Savanna woodlands need about 80 mm more water to function than nearby grasslands
- Year to year variability in Carbon Uptake is due to length of wet season.
- Photosynthesis and Respiration are tightly linked