Role of Flux Networks in Benchmarking Land Atmosphere Models

Dennis Baldocchi and FluxNet Team,

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ILAMB Workshop May 2016

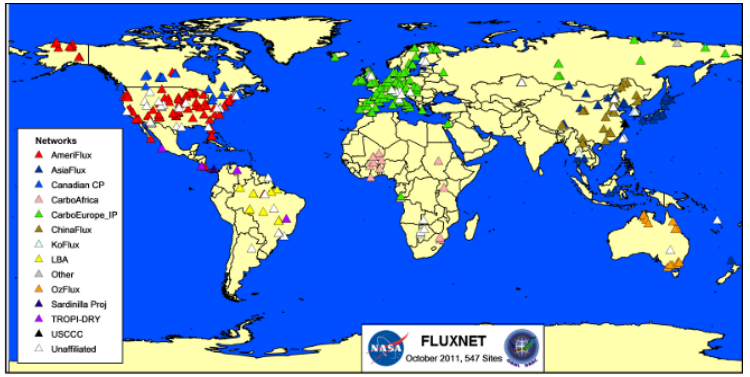
Outline

- Status of FluxNet
  - Map of Network
  - Growth of Network
  - Database, Site-Year Timeline
  - Use of Network
- How FluxNet Serves the Broad Scientific Community
- Examples of Findings

Role of Flux Networks in Biogeosciences

Eddy covariance flux system

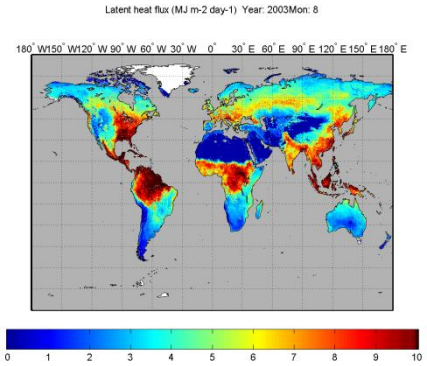
Global network of flux towers



Database

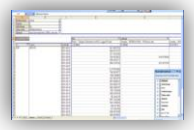
ILAMB Workshop May 2016

Remote sensing and Earth system science model user community

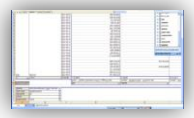


Fluxnet.Fluxdata.org – A Common, Shared Database and Information System

Individual Sites



Flux/Met Data



BADM Data

AmeriFlux

Fluxnet Canada

AsiaFlux

CARBO EUROPE IP

LBA

Terrestrial Carbon Observation System TOS SIBERIA

KoFlux

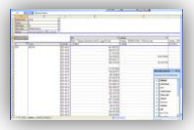
CarboAfrica

OzFlux

ChinaFLUX

Regional Networks

Flux/Met Data



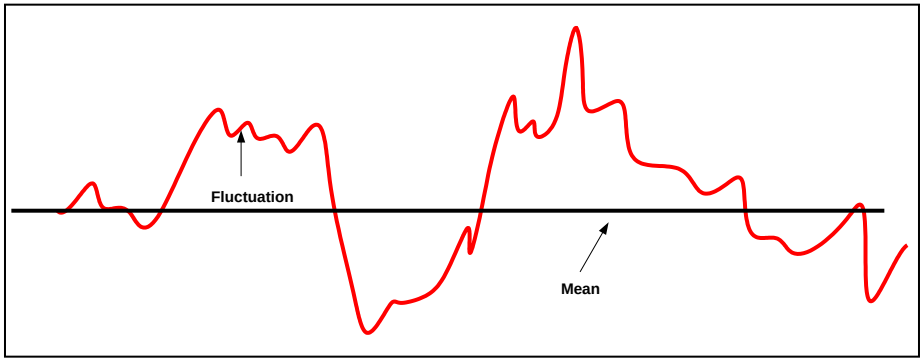
BADM Data + Flux/Met Gap-Filled/QA/Products

fluxnet.fluxdata.org

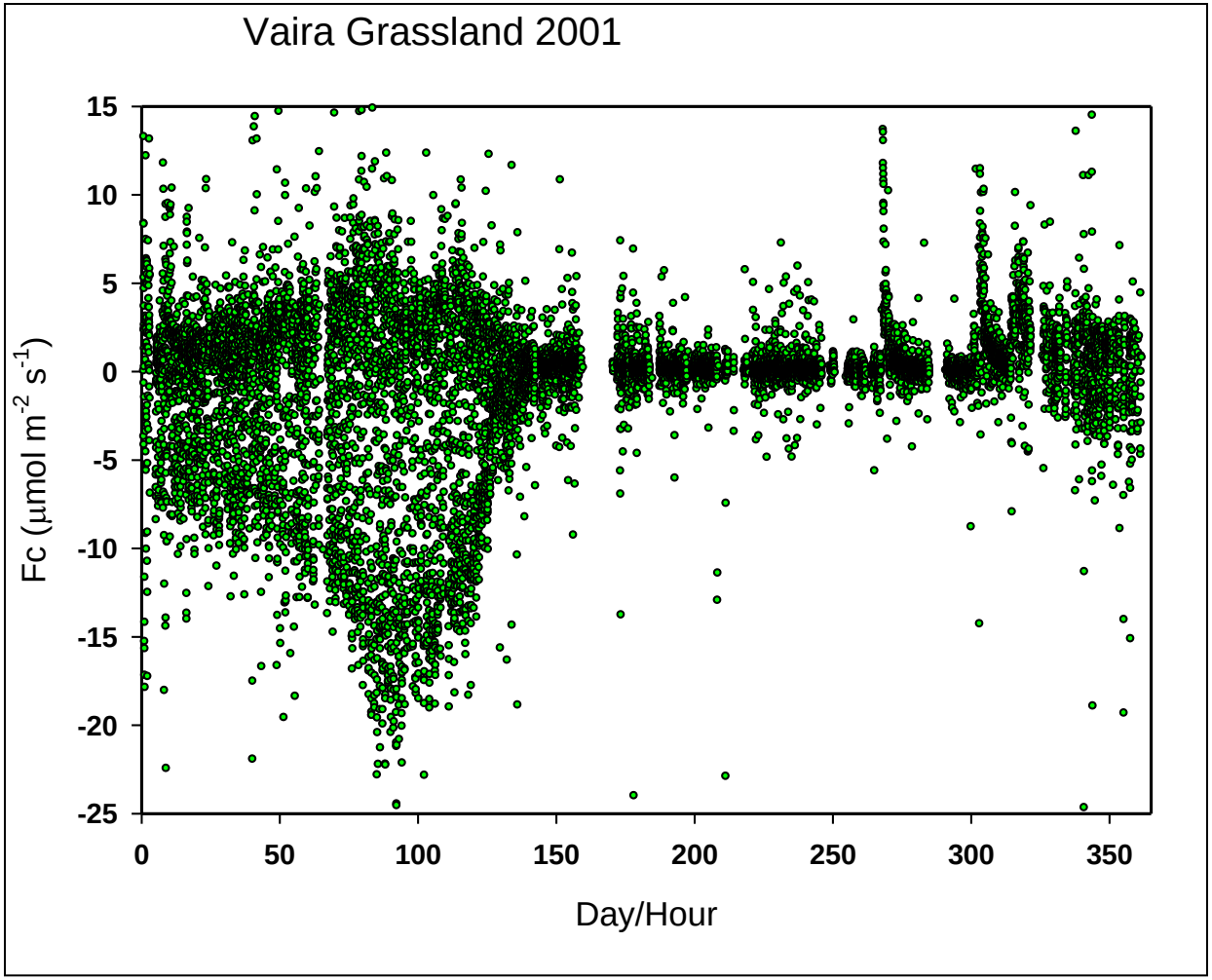
Eddy Covariance Technique

$$F = \overline{\rho w s} \sim \overline{\rho_a} \cdot \overline{w's'}$$

$$s = \left(\frac{\rho_c}{\rho_a}\right)$$



Annual Time Series of Trace Gas Exchange



Xu and Baldocchi, AgForMet, 2004

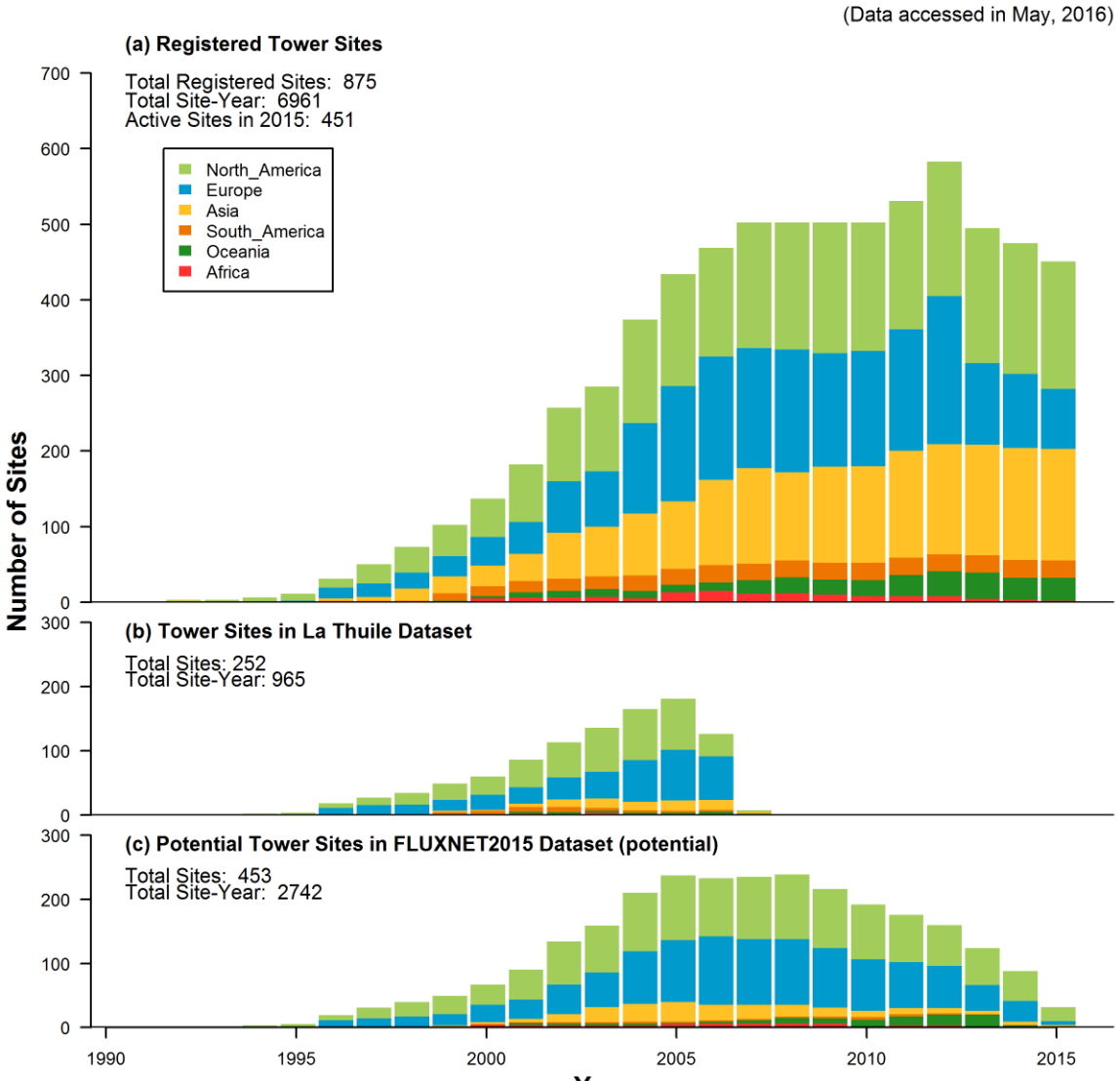
Attributes of Eddy Covariance

- Direct Flux Measurement of an Integrated Population of Leaves and Soil
- Evaluates Fluxes on Diel, Seasonal, Annual and Interannual Time Scales
- Individual Towers Represent Wide EcoRegion and Footprints
- Provides Process information on How Fluxes Respond to Environmental, Physiological and Ecological Conditions
- Provides Ground Truth for Satellite Remote Sensing
- Provides Priors and Model Parameters for Data Assimilation Models and Biophysical Models

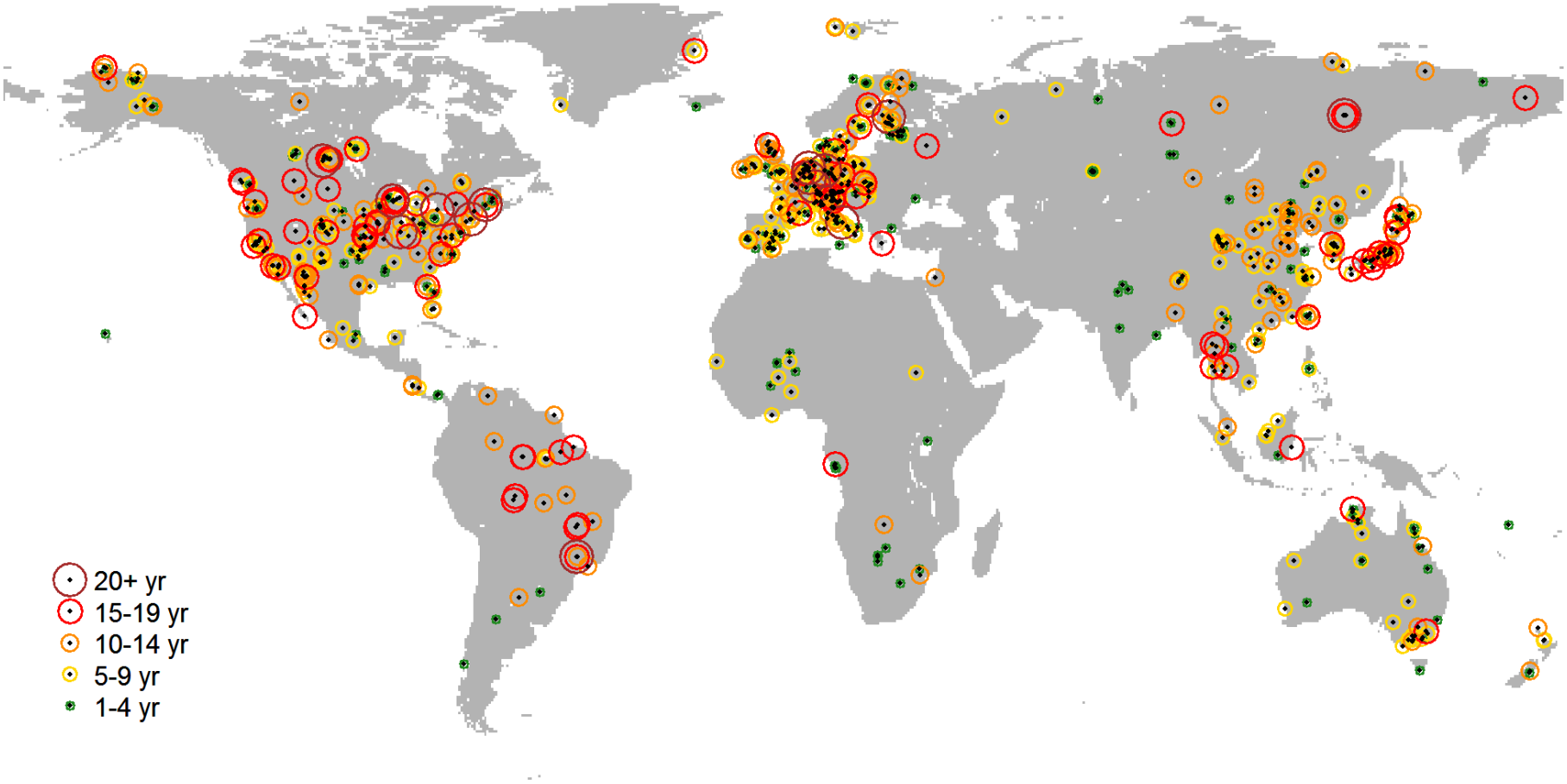
Cons of Eddy Covariance

- Nighttime Biases with Low Turbulence
- Smallish Footprint (< 1 km) compared to model grid
- Advection and Drainage Biases in Complex Terrain
- Network of Towers is Discrete in Space

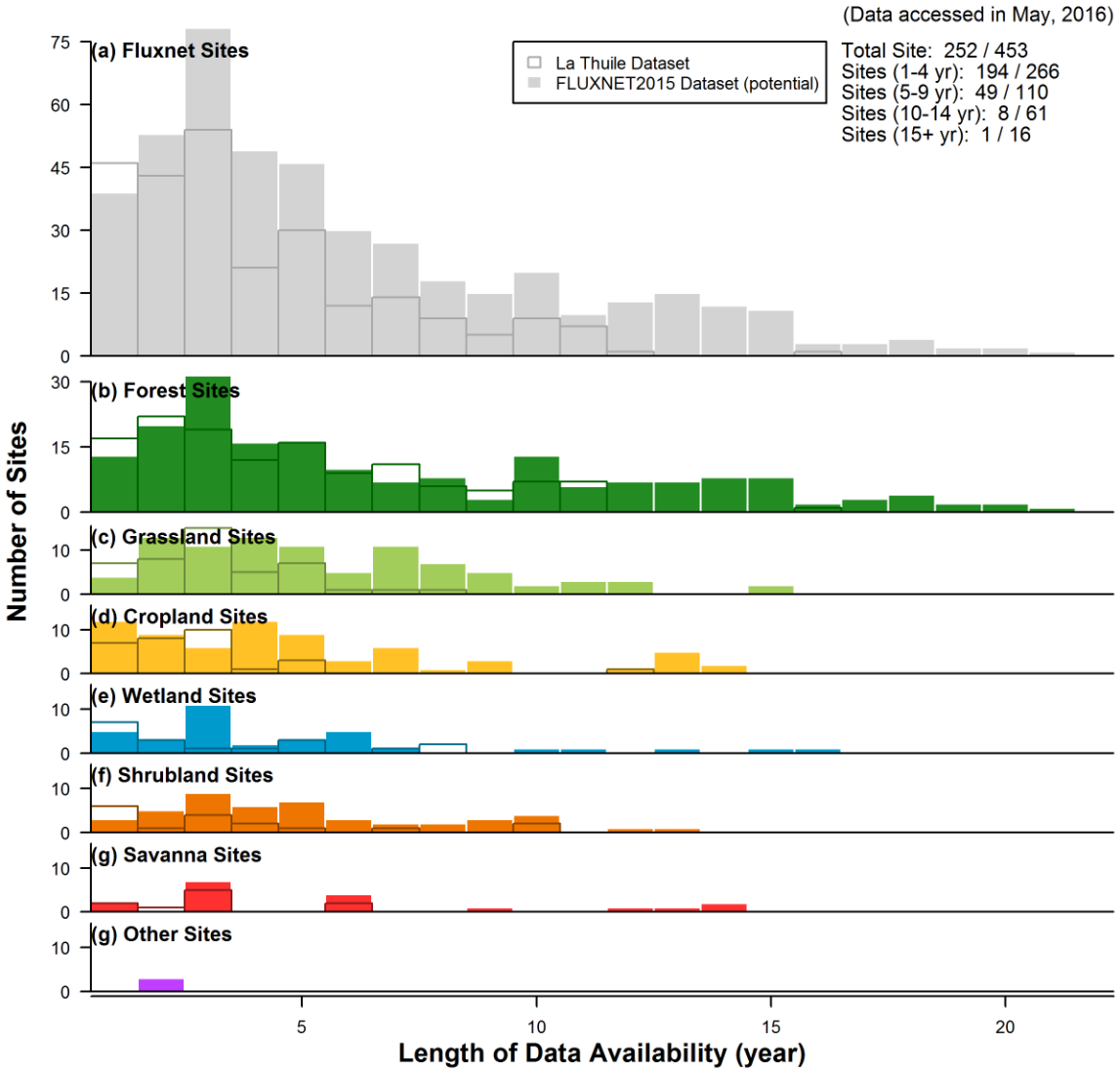
Database Stats and Network Growth



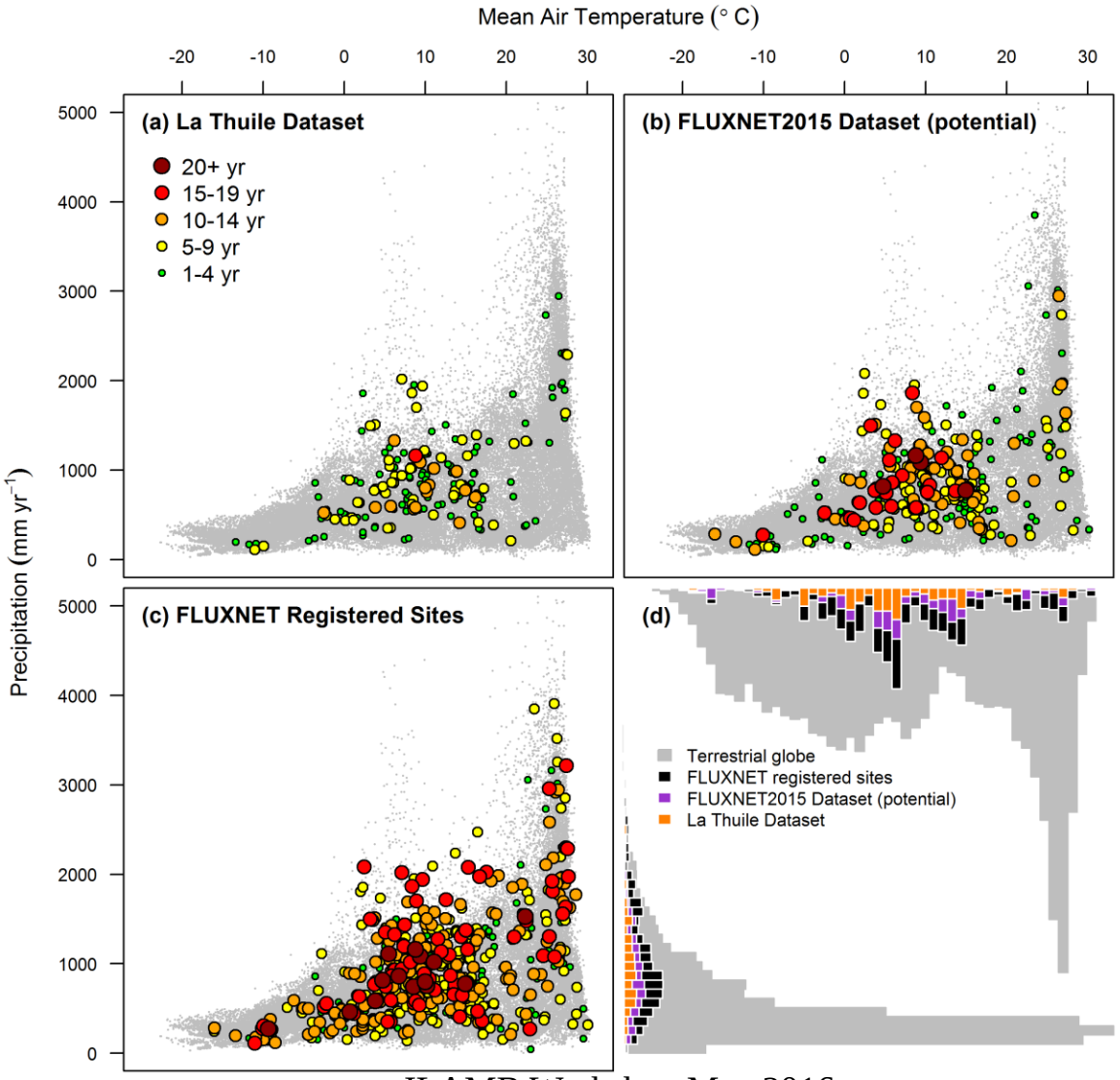
FLUXNET, circa 2016



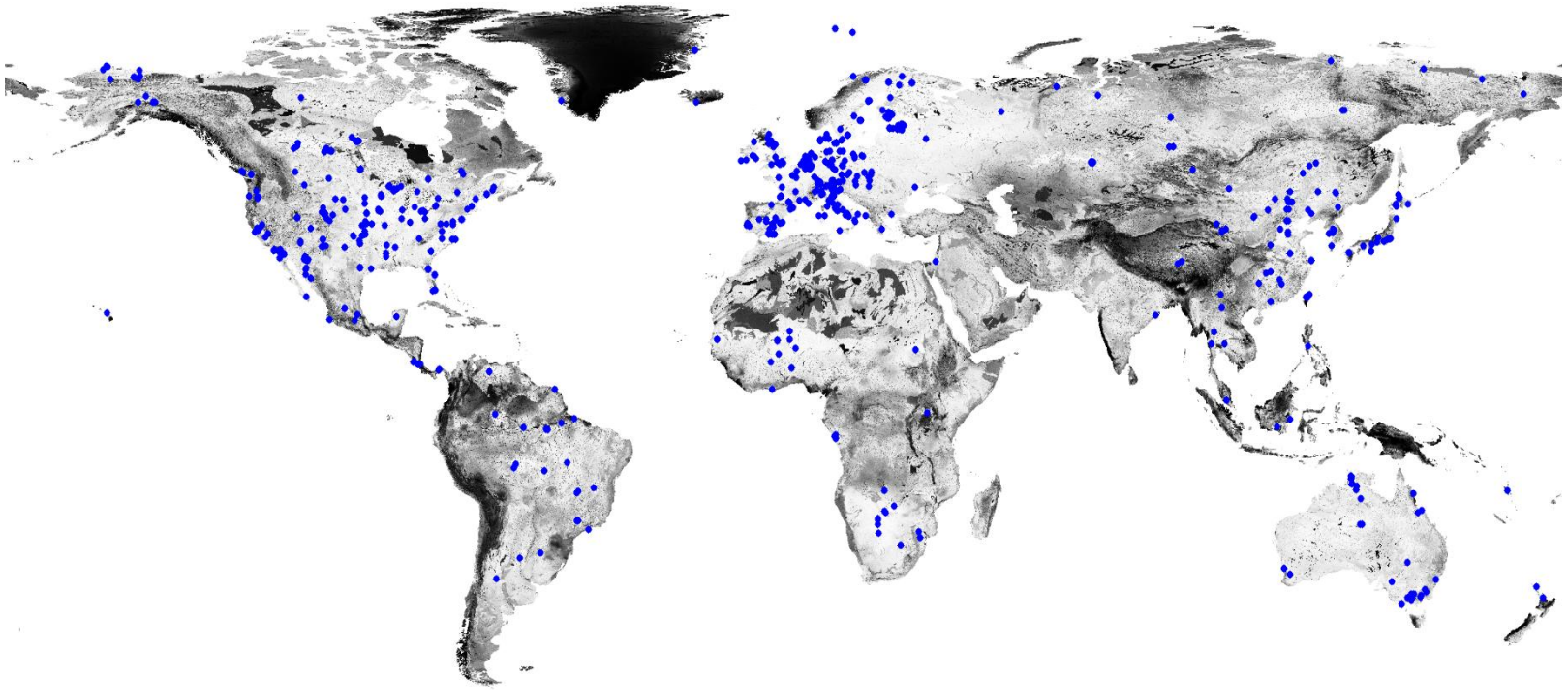
Length of Operation



Global distribution of Flux Towers Covers Climate Space Well

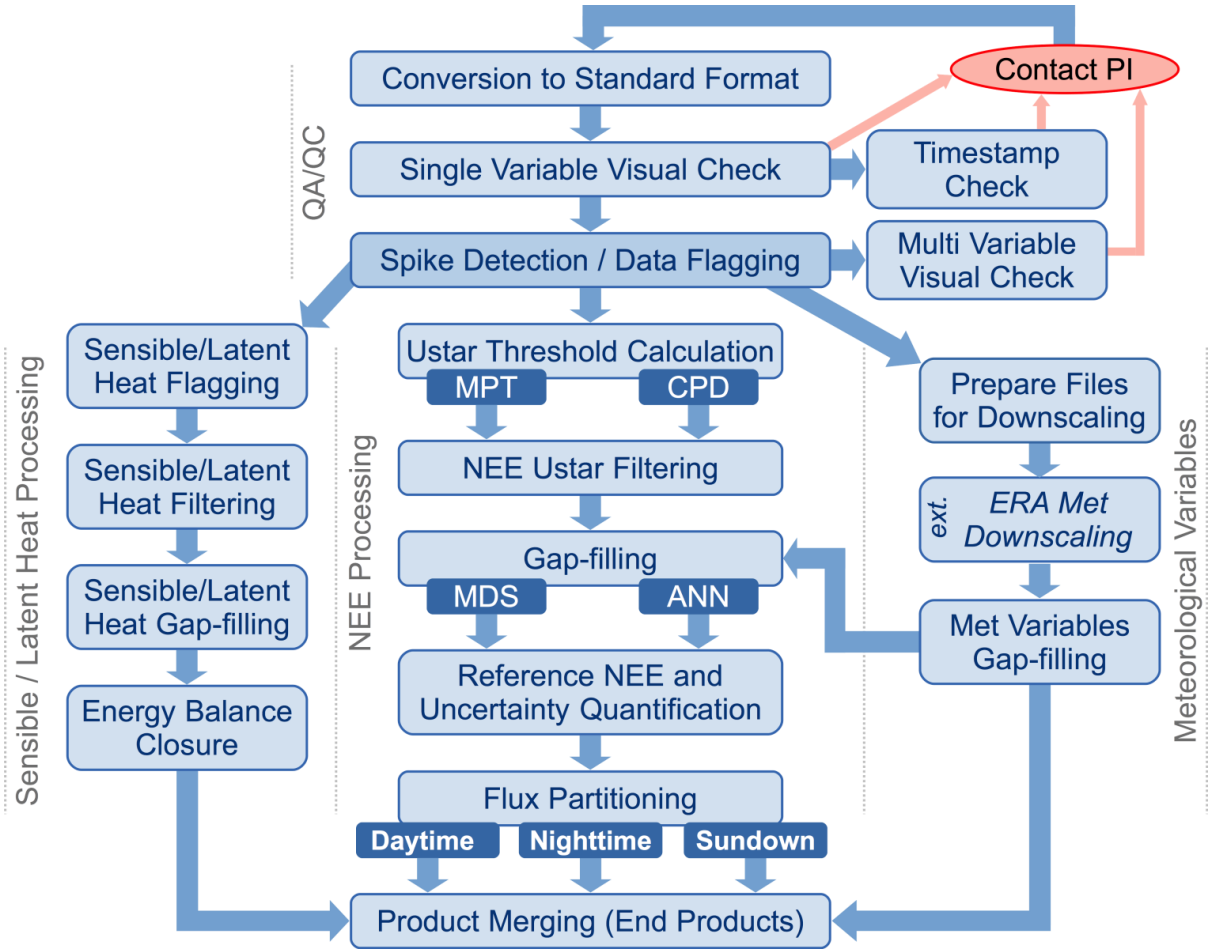


Tower Representativeness by EcoRegion



Forrest Hoffman and Jitendra Kumar

FLUXNET Data Services and Procedures

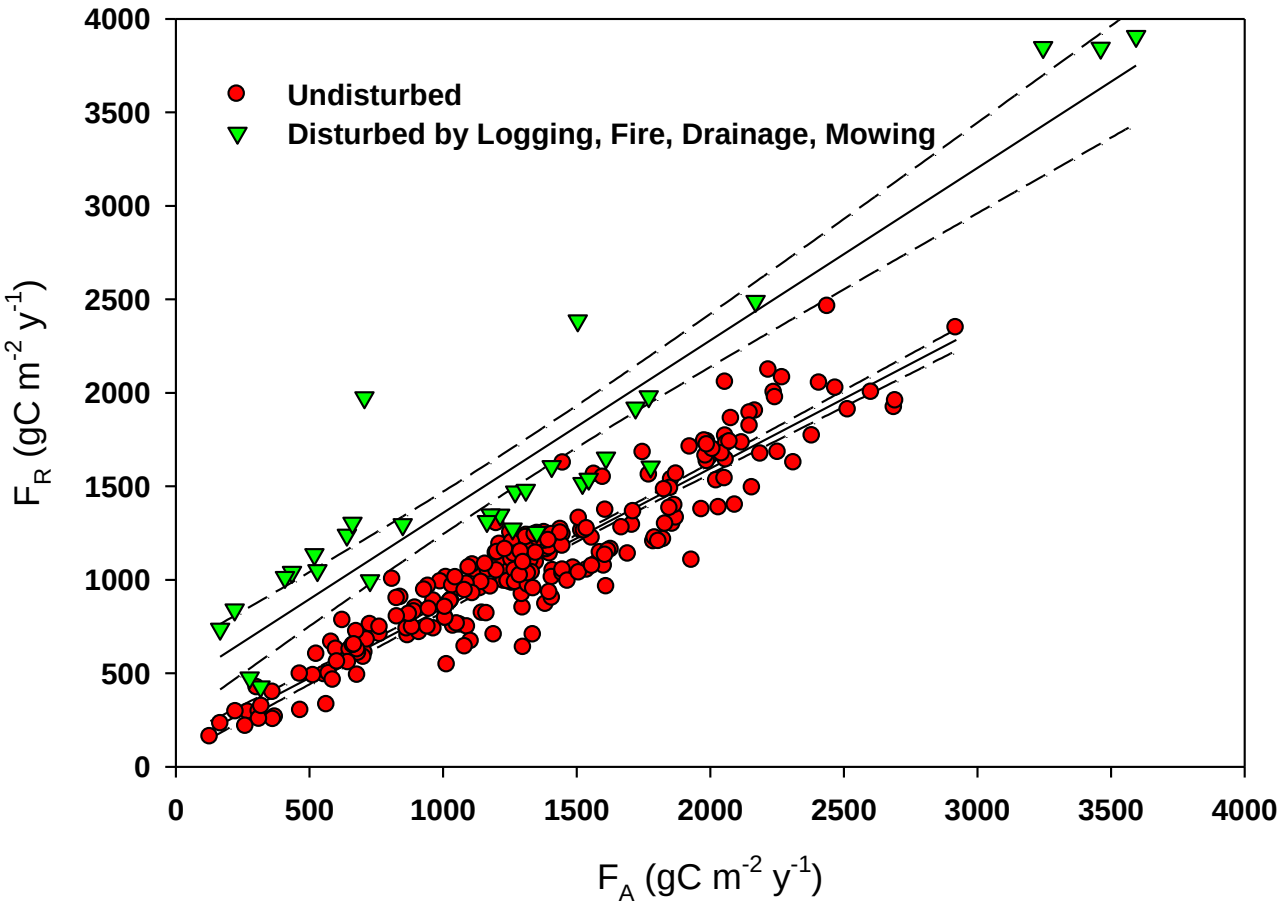


D. Papale

What FluxNet can Do for Us: Processes, Mechanisms

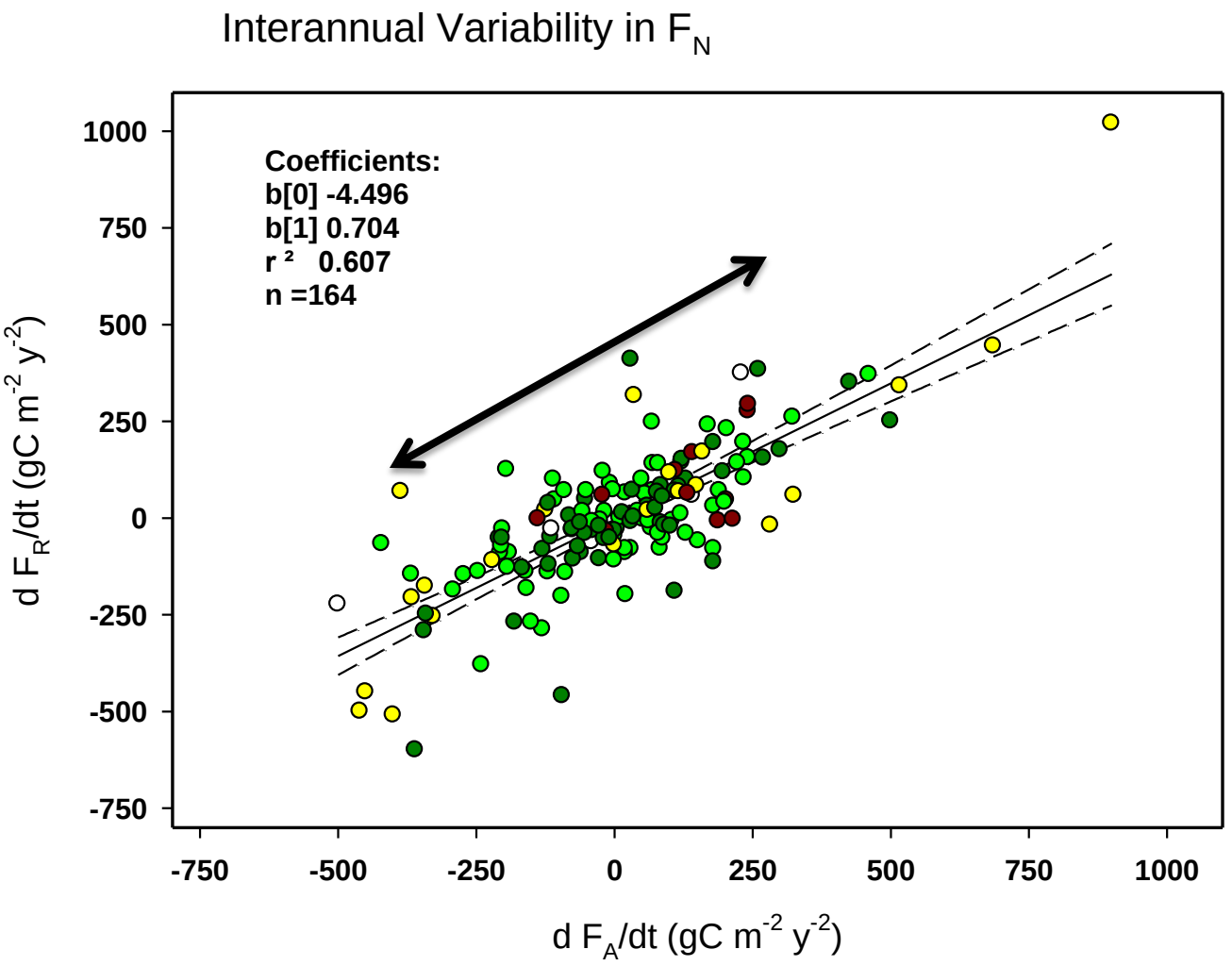
- Assess Biophysical Roles of Weather, Ecosystems/Canopy Structure and Function on Carbon, Water and Energy Fluxes
  - Clusters of Towers, Climate and Ecological Gradients
- Assess Roles of Management and Disturbance on Fluxes
  - Clusters of Towers
- Biophysical Controls and Trends on Phenology;
- Quantifying Biophysical Properties of the Land Surface
  - Albedo, Surface Roughness, Surface Conductance

Ecosystem Respiration Scales Tightly with Ecosystem Photosynthesis, But Is with Offset by Disturbance



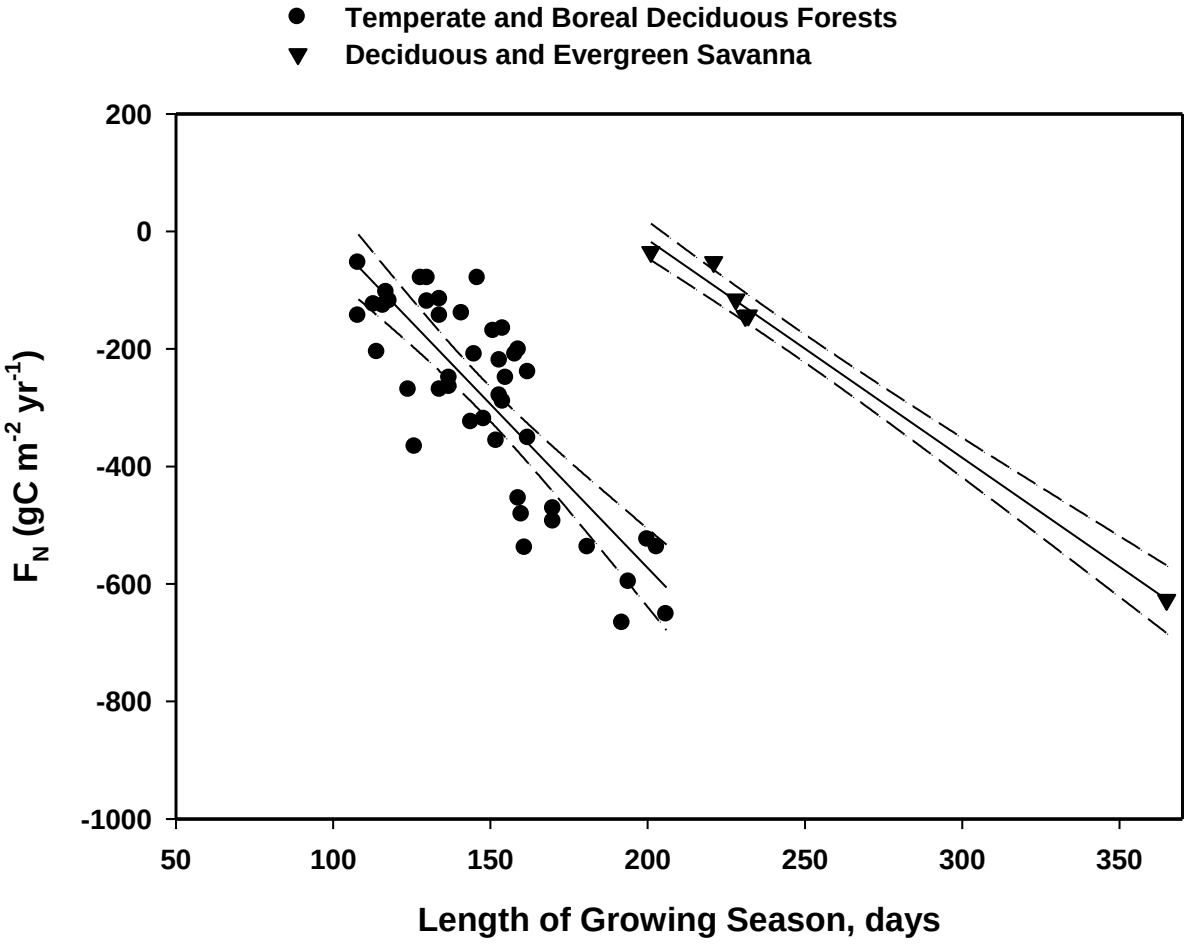
Baldocchi, Austral J Botany 2008

Interannual Variations in Photosynthesis and Respiration are Coupled



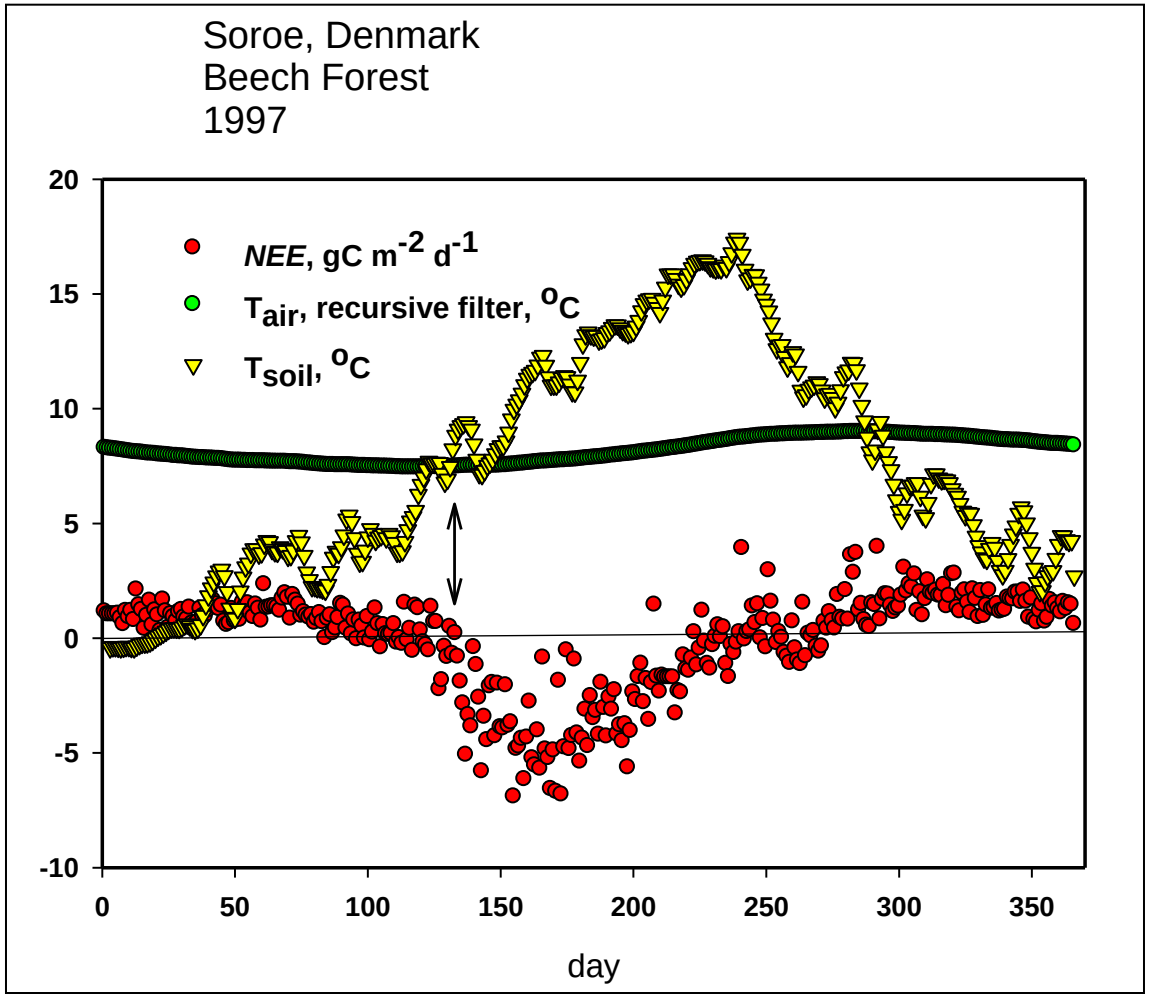
Baldocchi, Austral J Botany, 2008

Net Ecosystem Carbon Exchange Scales with Length of Growing Season



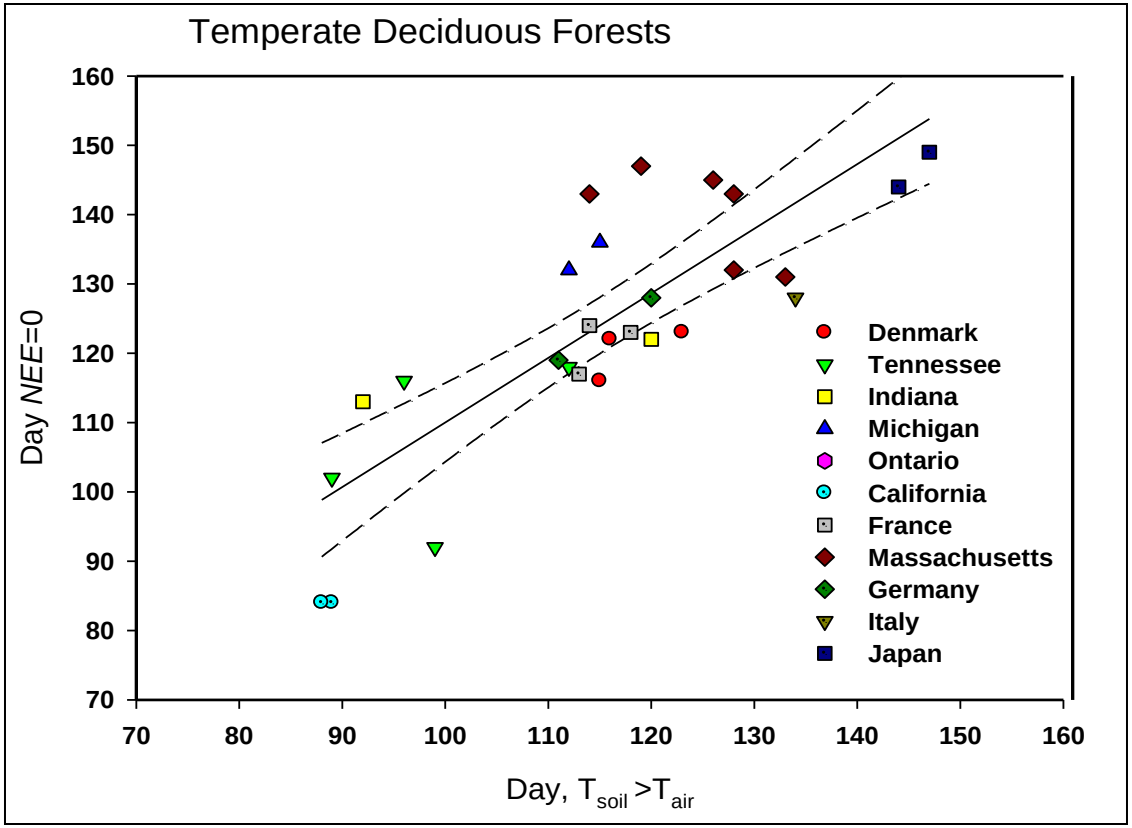
Baldocchi, Austral J Botany, 2008

Soil Temperature: An Objective Indicator of Phenology??



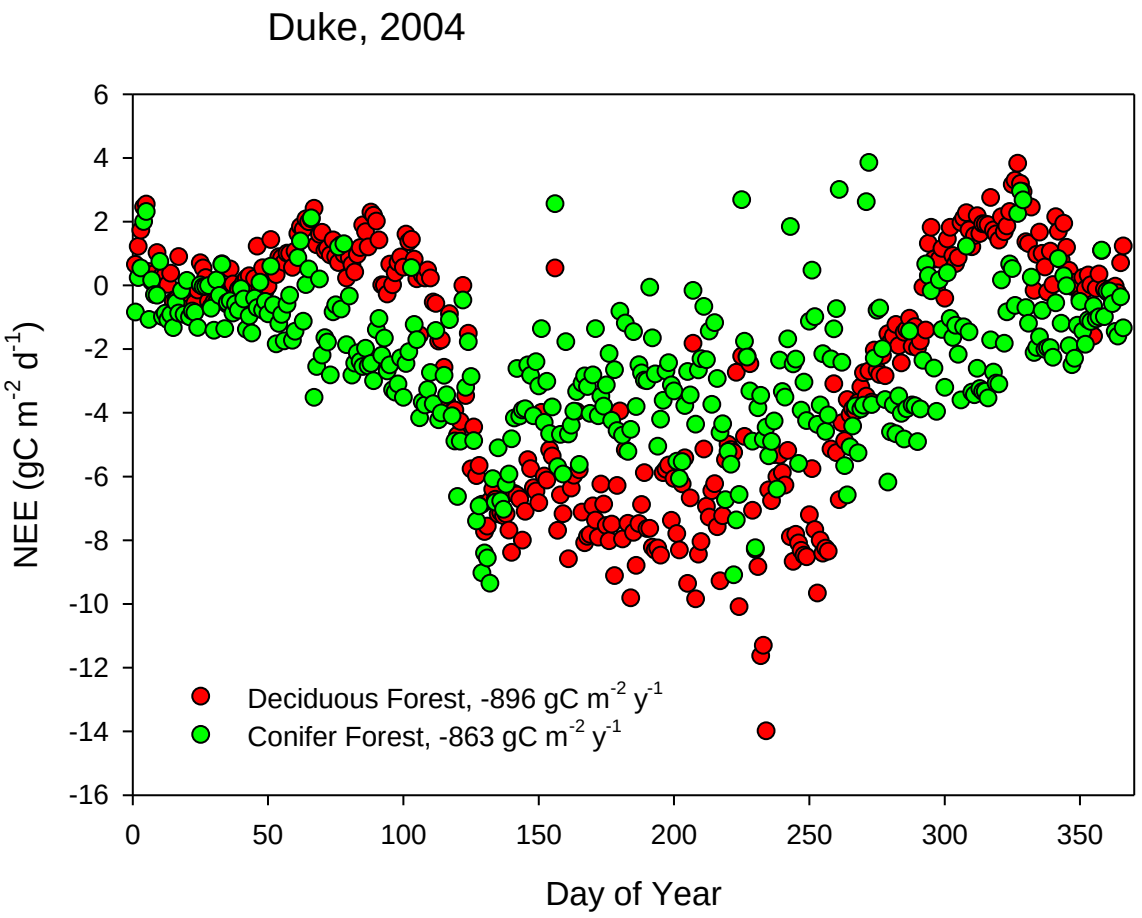
Data of Pilegaard et al.

Soil Temperature: An Objective Measure of Phenology, part 2



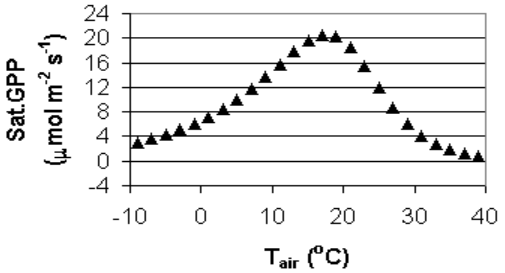
Baldocchi et al. Int J. Biomet, 2005

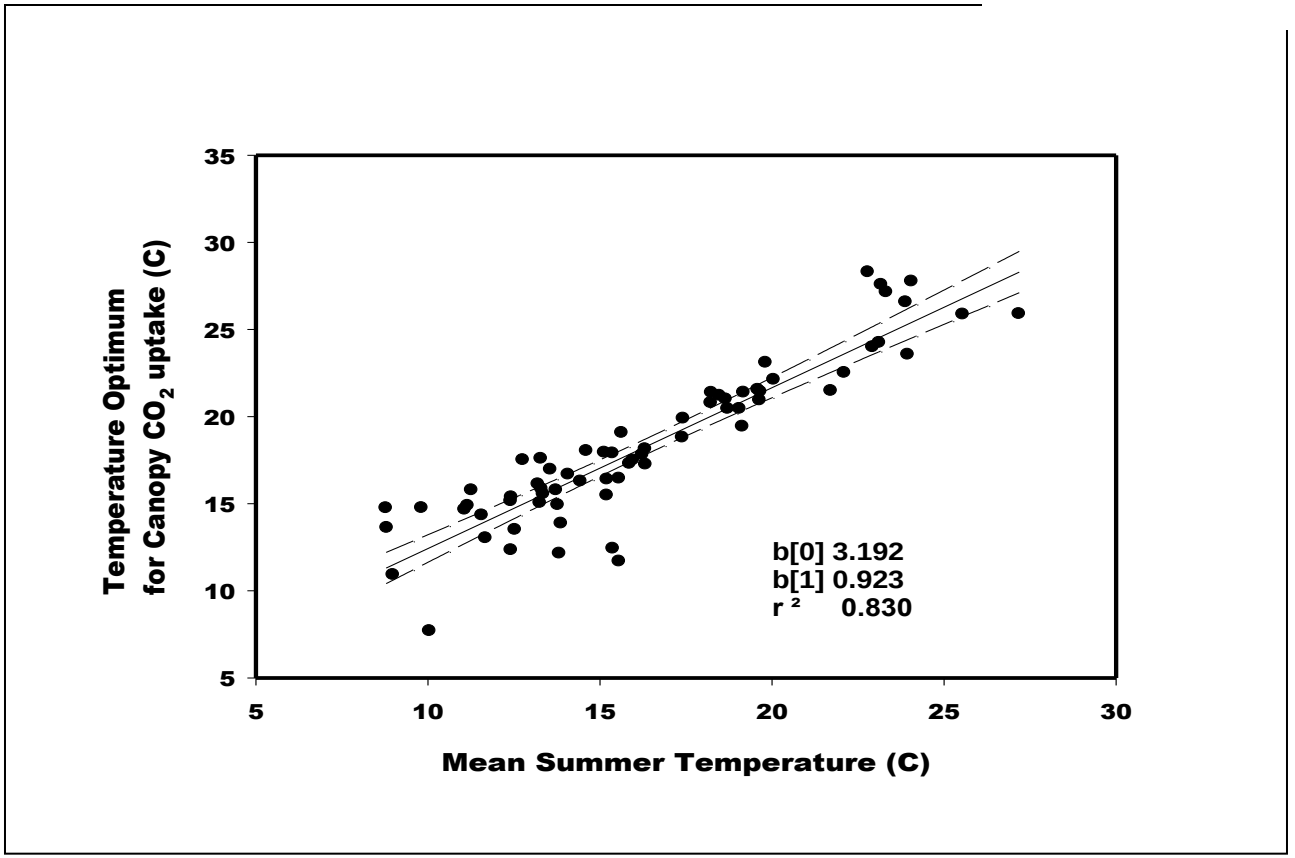
Effect of Plant Functional Types



Deciduous: Higher Capacity, shorter Growing Season
Conifer: Lower Capacity, longer Growing Season
Net Difference in NEE is small; similar finding for oaks

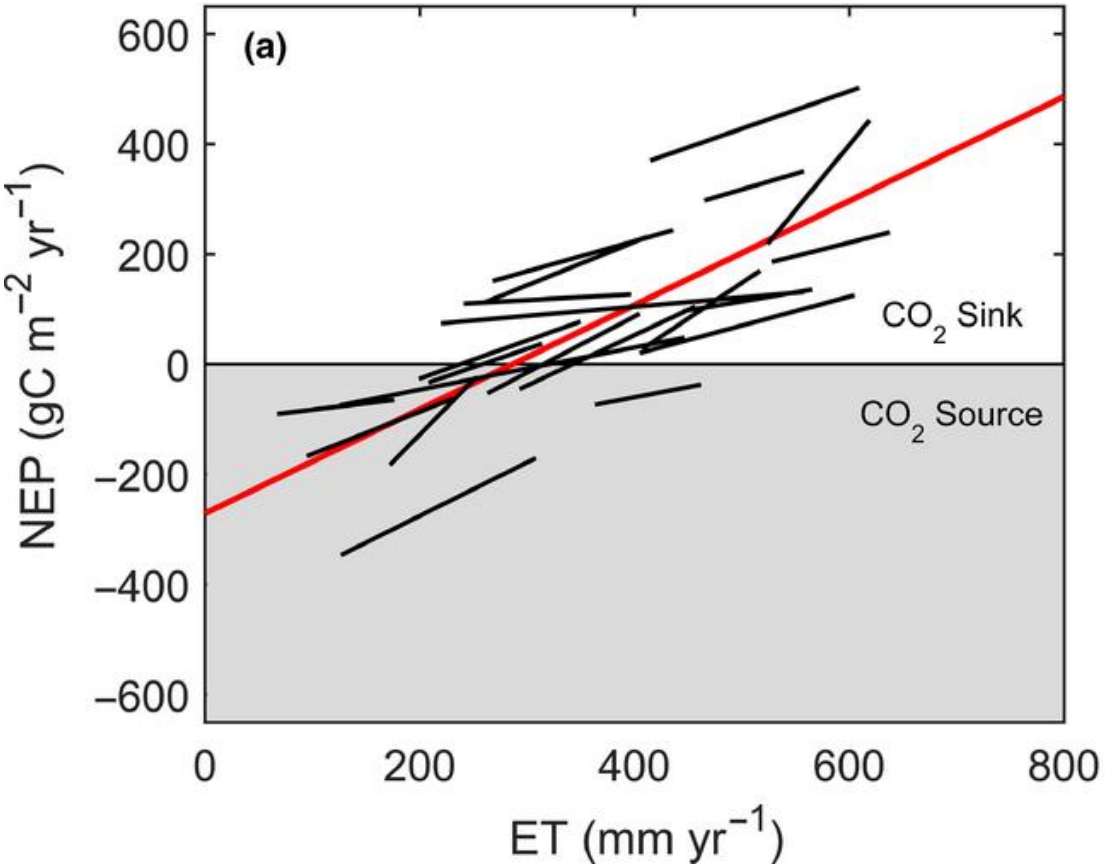
Optimal NEE: Acclimation with Temperature

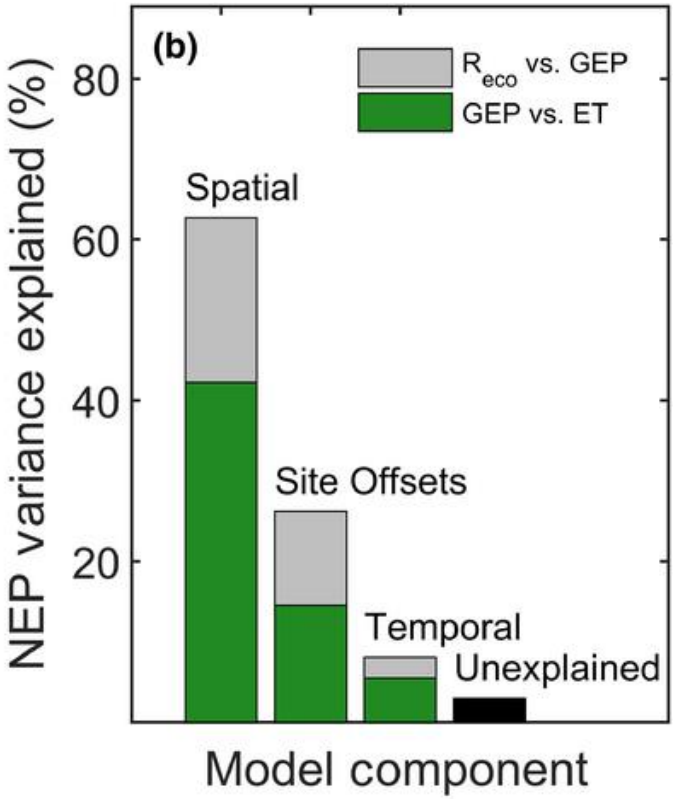




E. Falge et al 2002 AgForMet; Baldocchi et al 2001 BAMS

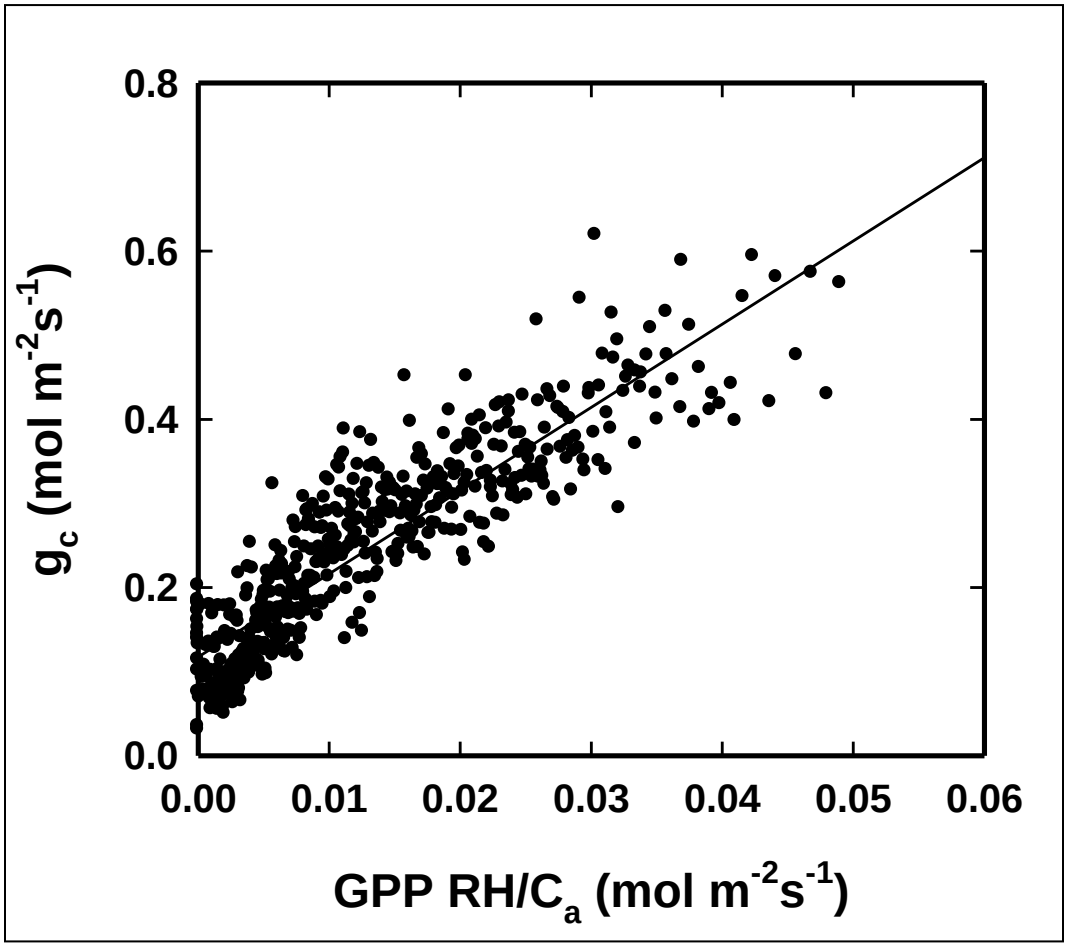
Terrestrial carbon balance in a drier world: the effects of water availability in southwestern North America





Global Change Biology
Volume 22, Issue 5, pages 1867-1879, 15 FEB 2016 DOI: 10.1111/gcb.13222
http://onlinelibrary.wiley.com/doi/10.1111/gcb.13222/full#gcb13222-fig-0005

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



Xu + DDB, 2003 AgForMet

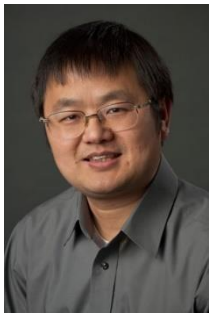
Slope of Surface Conductance-GPP model

Plant Group	Mean slope	Std dev
Crop	9.379	3.222
Deciduous Broadleaved Forest	12.78	4.331
Evergreen Broadleaved Forests	16.76	6.241
Evergreen Needleleaved Forests	15.14	6.707
Grassland	22.30	19.48
Mixed Forest	17.17	5.552

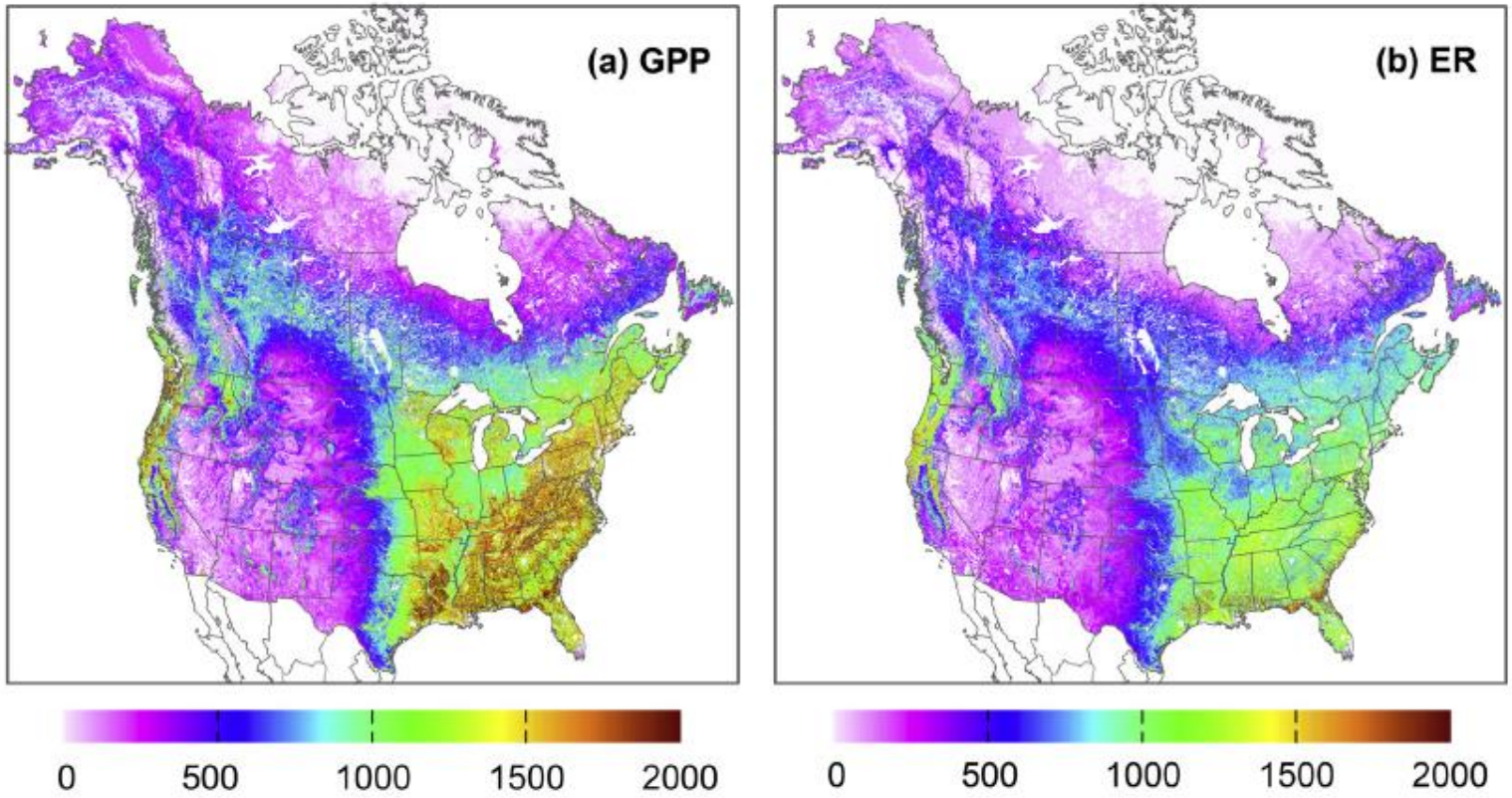
What FluxNet can Do for Us: Spatial-Temporal Upscaling of Fluxes

- Upscaling of Carbon Fluxes, Net and Gross Primary Productivity
  - Neural Networks
  - Regression Tree
  - Light Use Efficiency Models
- Upscaling Evaporation
- Upscaling Fields of Surface Radiation Measurements
  - PAR, Shortwave, Net Radiation, Longwave, Diffuse Radiation, Albedo, fpar

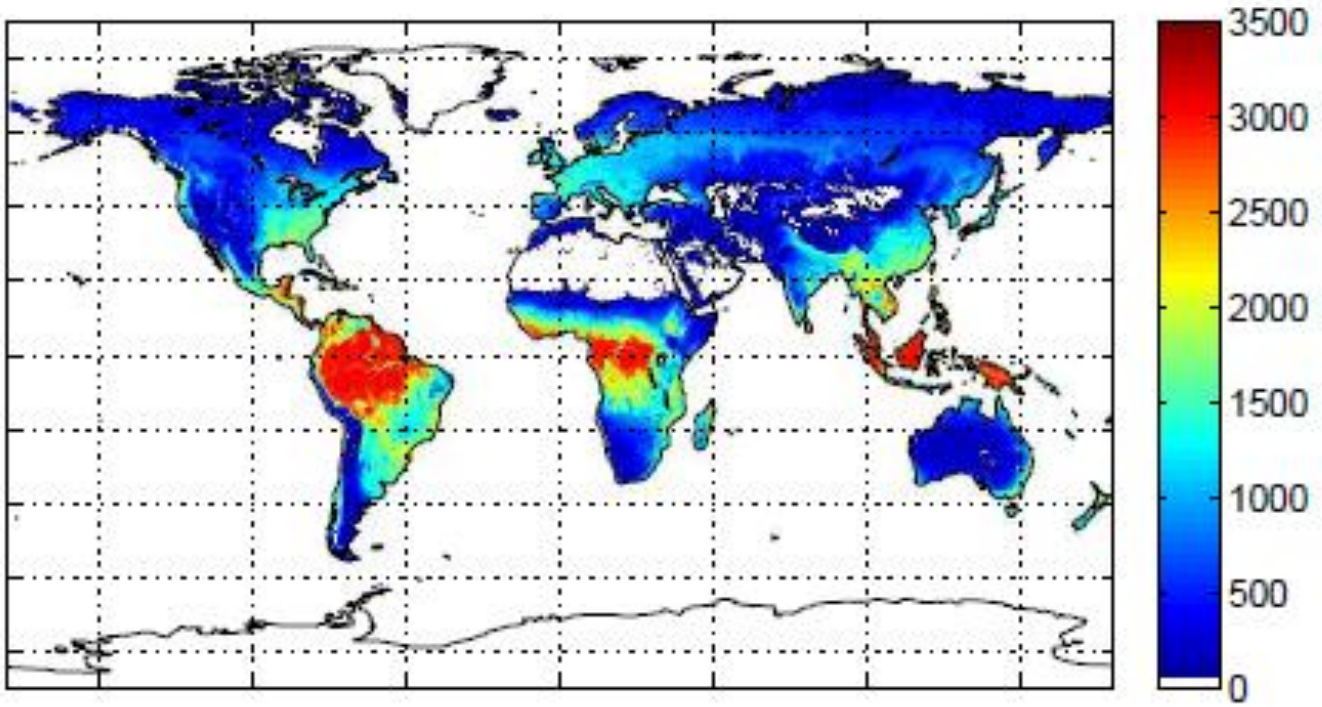
Mapping NEE, GPP, Reco



J. Xiao et al. / Agricultural and Forest Meteorology 197 (2014) 142–157



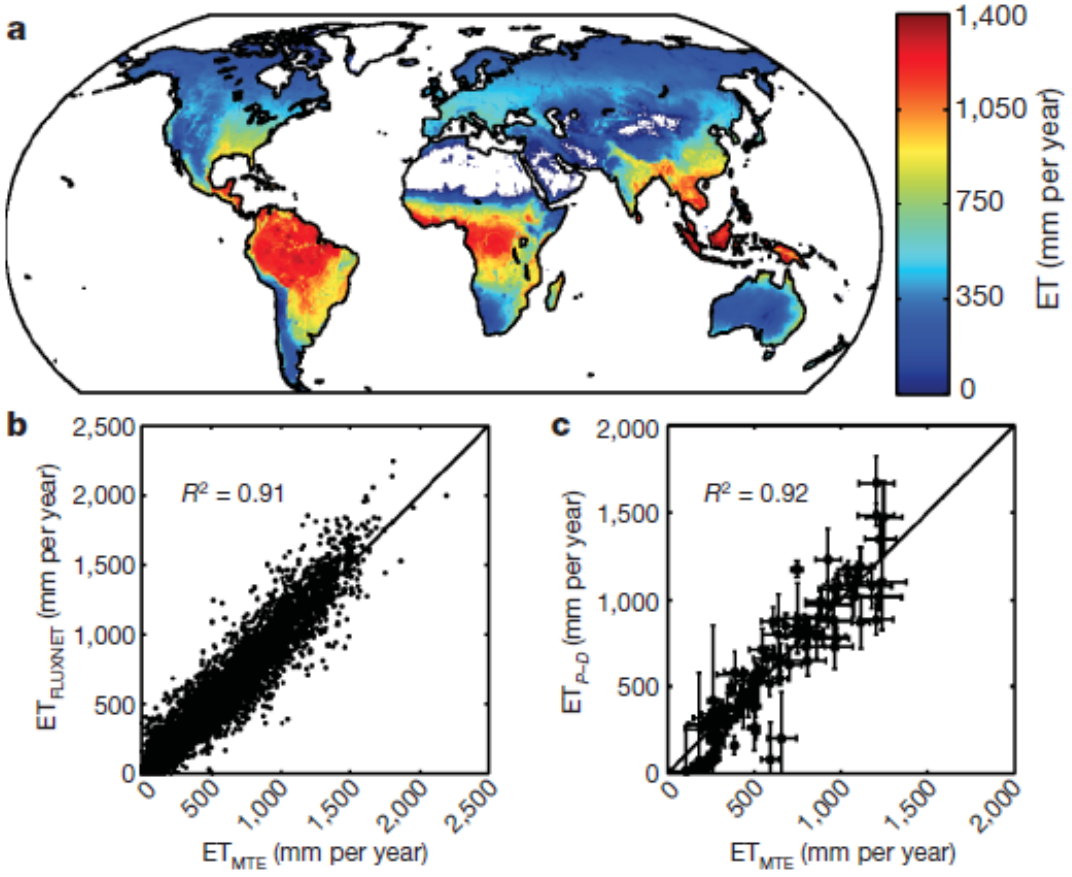
Data Driven Global Primary Productivity



GPP = 123 +/- 8 PgC y-1

Beer et al., 2010 Science

Machine Learning, Data Driven Evaporation Map

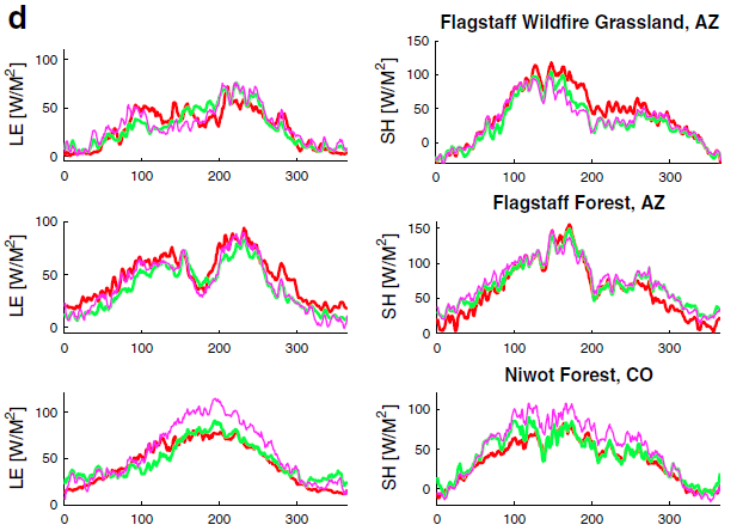


65,000 km^3/y

Jung et al 2010 Nature

ET UpScaling

- Rigden and Salvucci
- Gentine and Salvucci



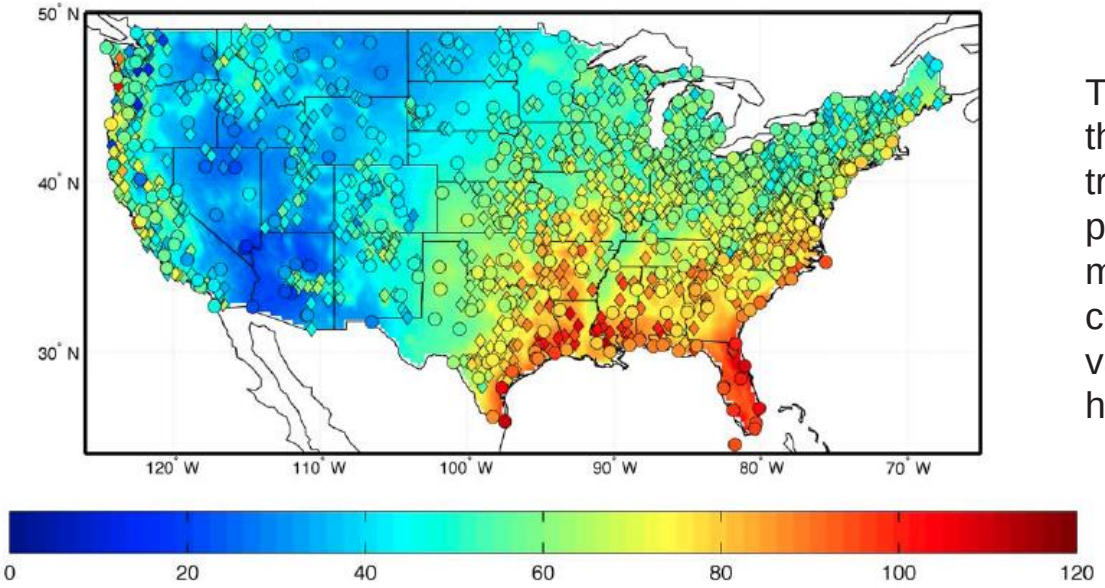


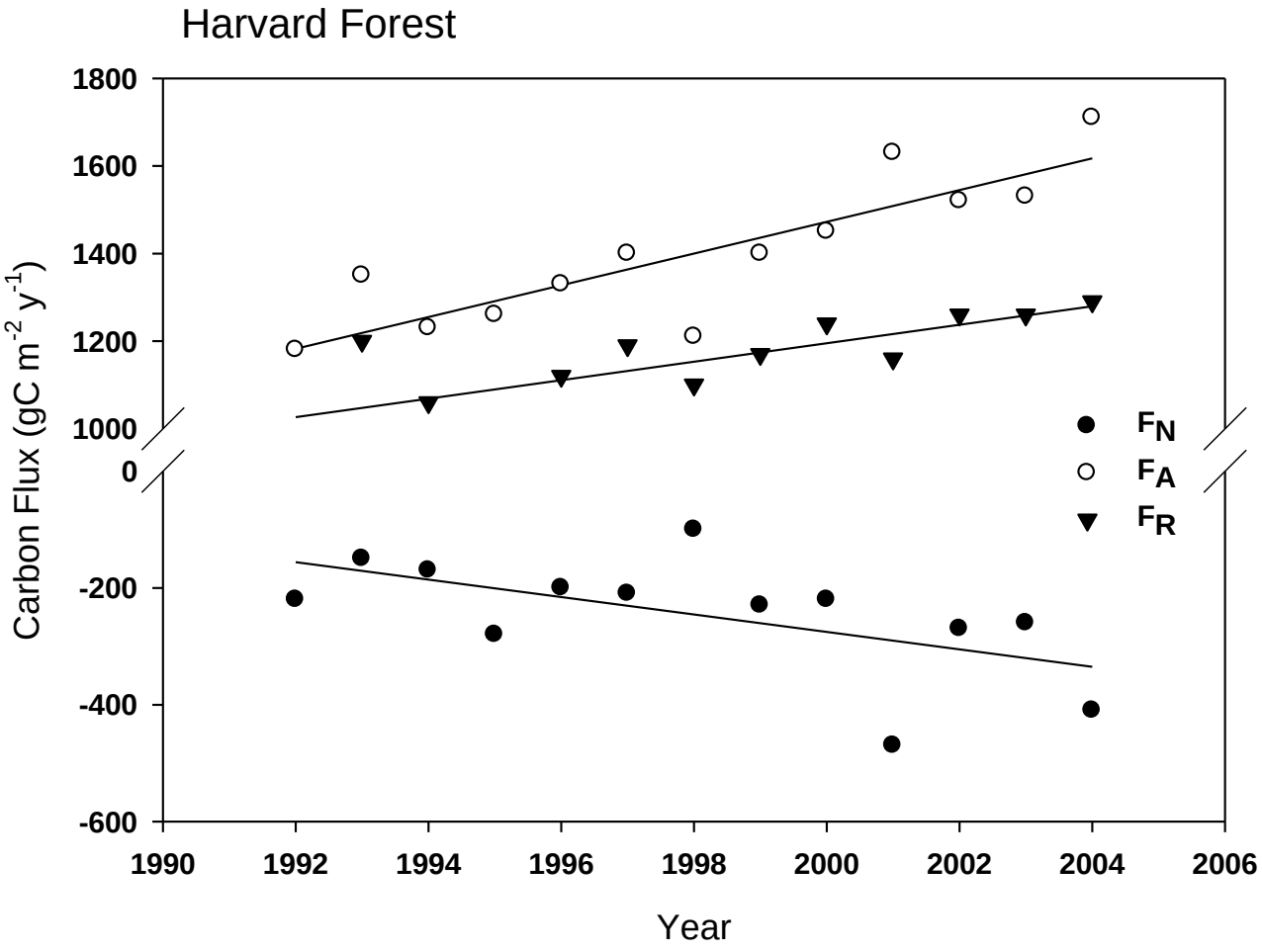
Figure 2. U.S. map of ETRHEQ *ET* (cm·yr^{-1}). Circles represent *ET* predictions at the stations, and diamonds represent watershed water budget *ET* estimates. The map background is ETRHEQ *ET* predictions, which are interpolated to a grid using a multivariate thin-plate smoothing spline (section 2.6.1).

The ETRHEQ method estimates the surface conductance to water vapor transport, which is the key rate-limiting parameter of typical ET models, by choosing the surface conductance that minimizes the vertical variance of the calculated relative humidity profile averaged over the day.

What FluxNet can Do for Us: Trends, Leads, Lags, Extremes

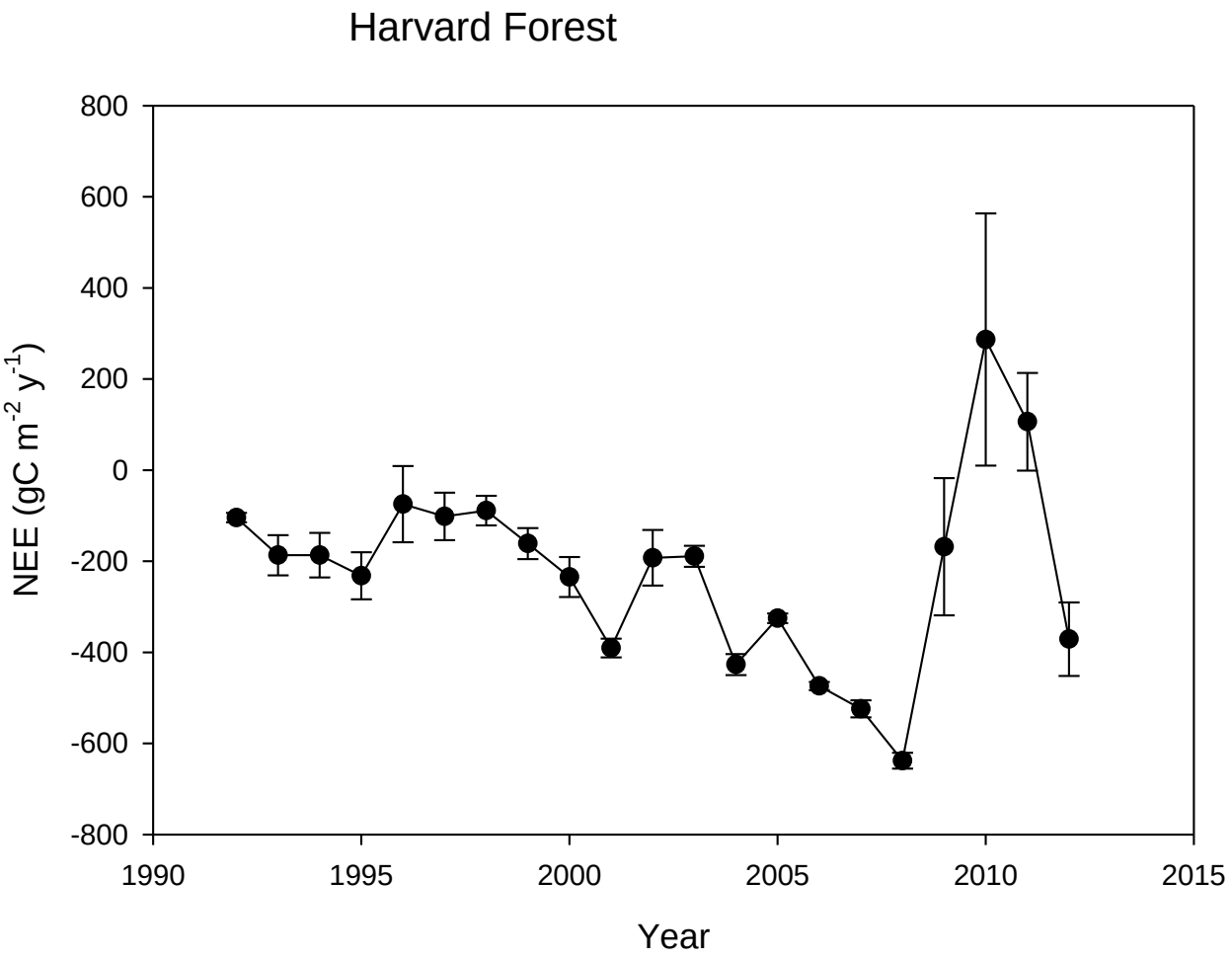
- Providing a statistically robust data set to assess the role of extreme events on mass and energy exchange;
  - Extreme Droughts and Heat/Cold Spells
  - Pulses and Switches due to Rain
- Providing a Statistically Long Time Series, > Decade, to Assess Factors Causing Interannual Variability of Carbon and Water Fluxes
  - Roles of Elevated CO2, Regional Warming and Drying
  - Roles of Antecedent Conditions or Legacy Effects
- Detecting changes in soil moisture/ground water coupling;

Interannual Variation and Long Term Trends in Net Ecosystem Carbon Exchange (F_N), Photosynthesis (F_A) and Respiration (F_R): Are They Sustainable???



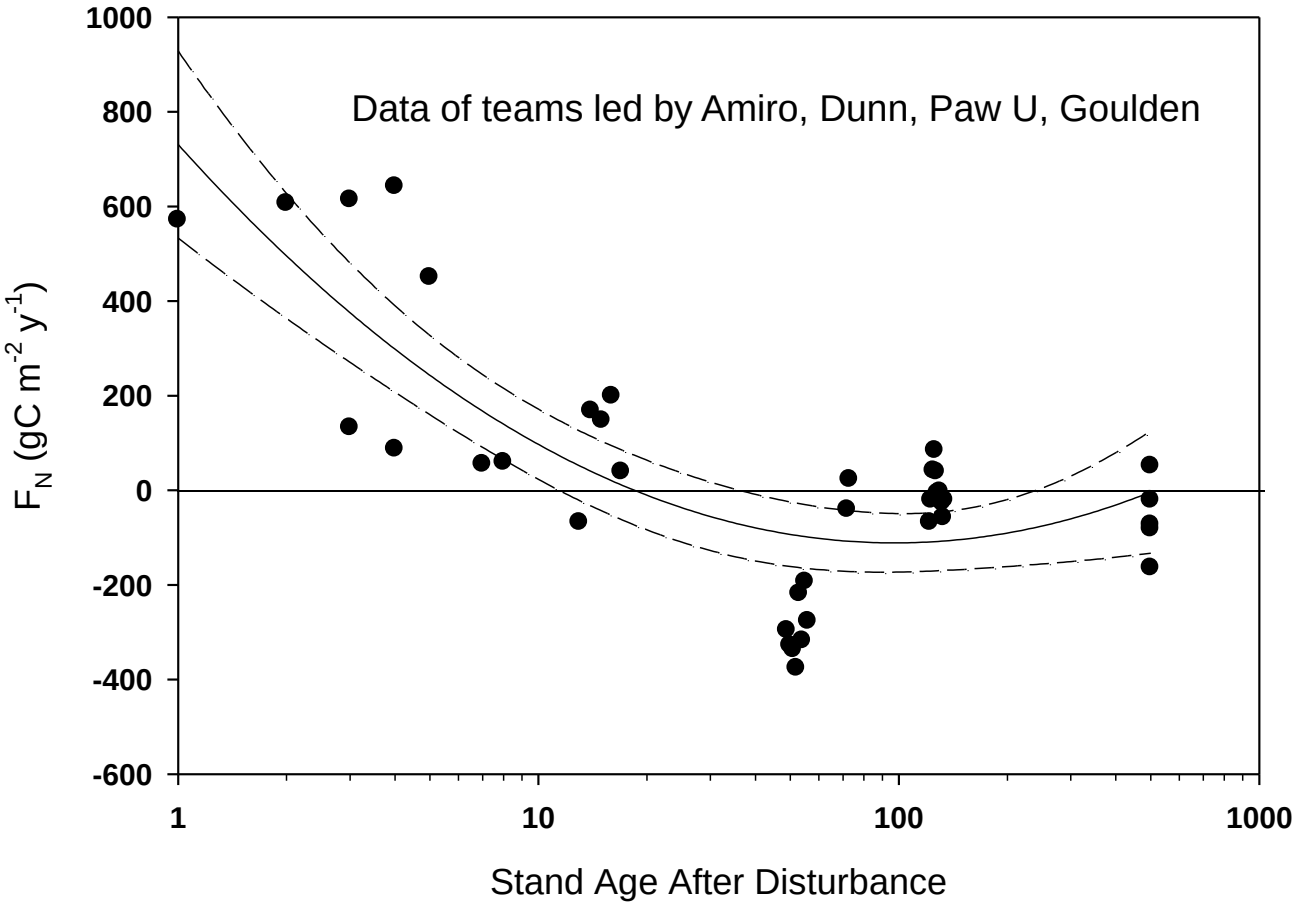
Urbanski et al 2007 JGR

Extended Record with New Fluxnet Data set



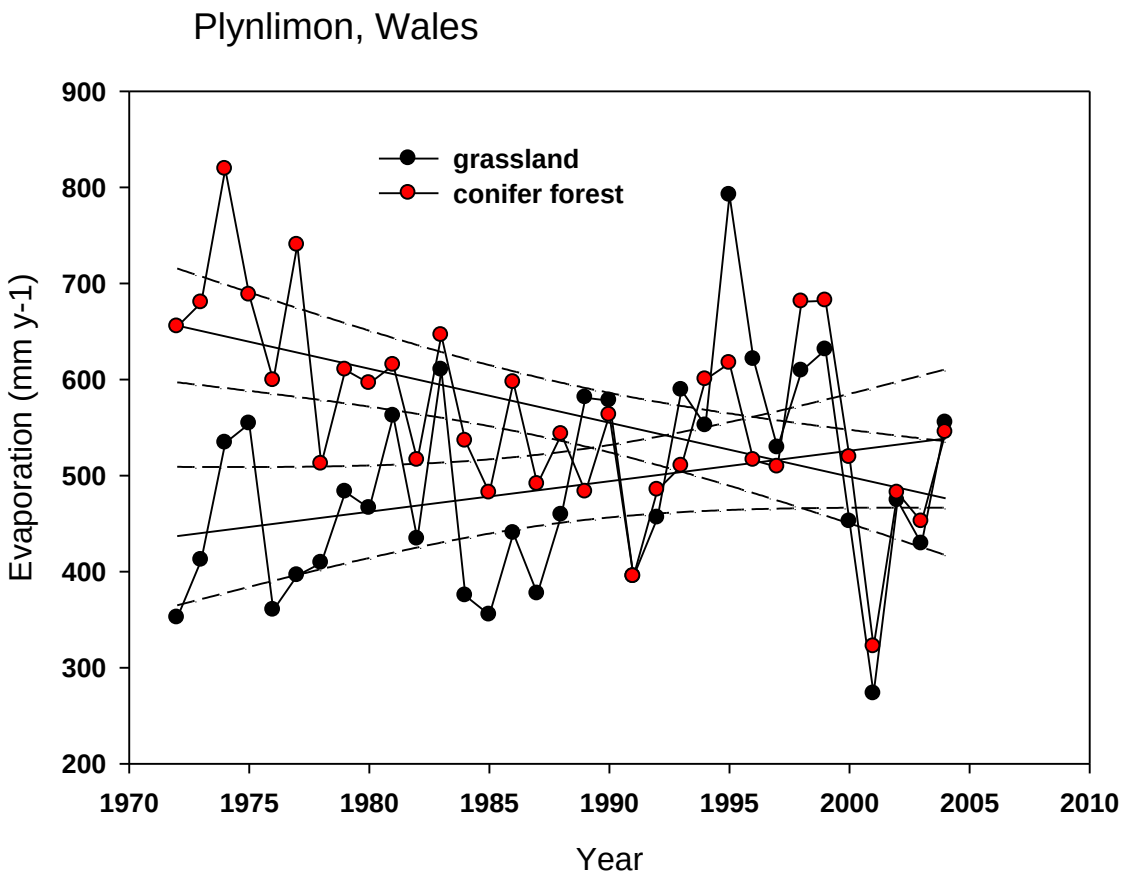
Time Since Disturbance Affects Net Ecosystem Carbon Exchange

Conifer Forests, Canada and Pacific Northwest



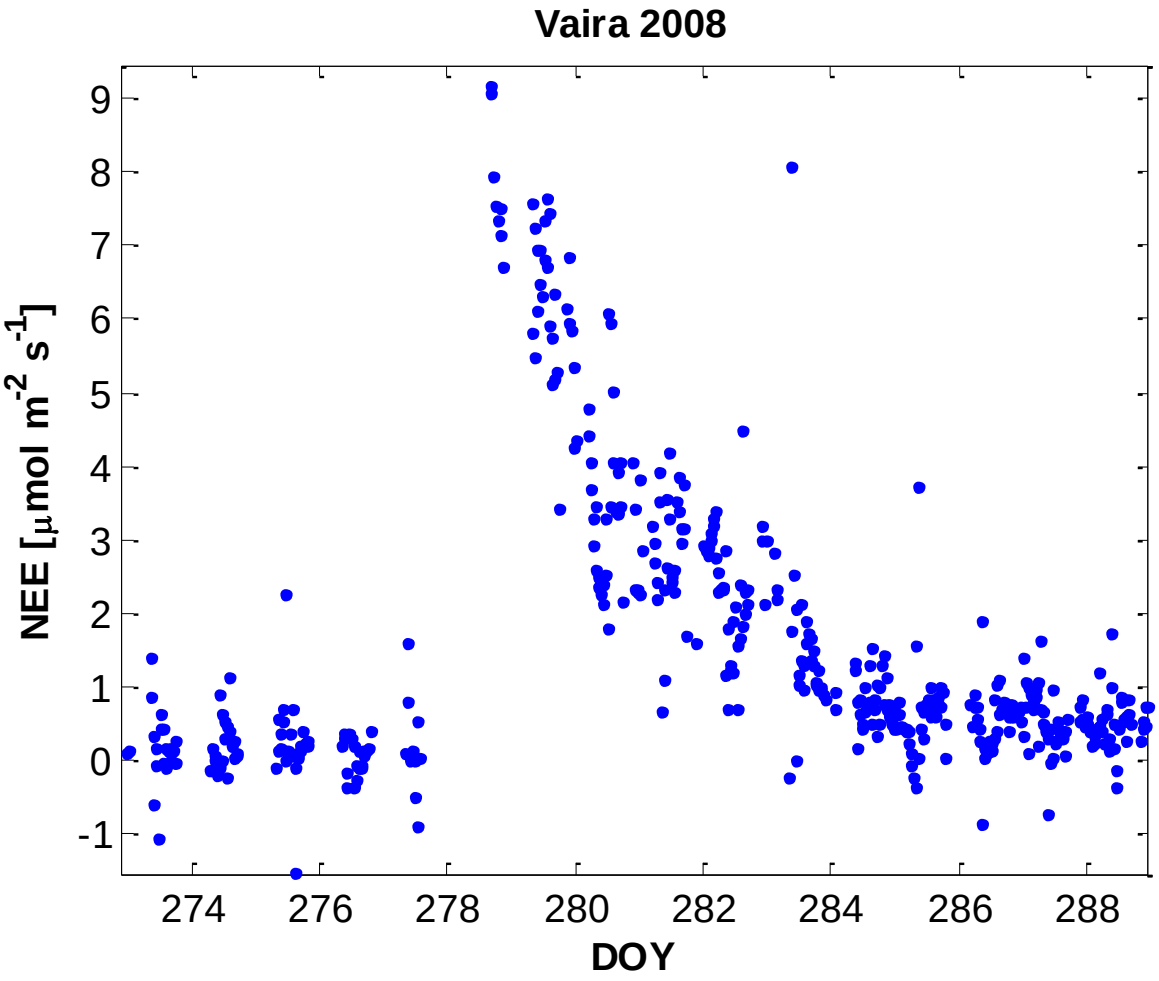
Baldocchi, Austral J Botany, 2008

Don’t Forget Ecology
Stand Age also affects differences between ET of forest vs grassland



Marc and Robinson, 2007 HESS

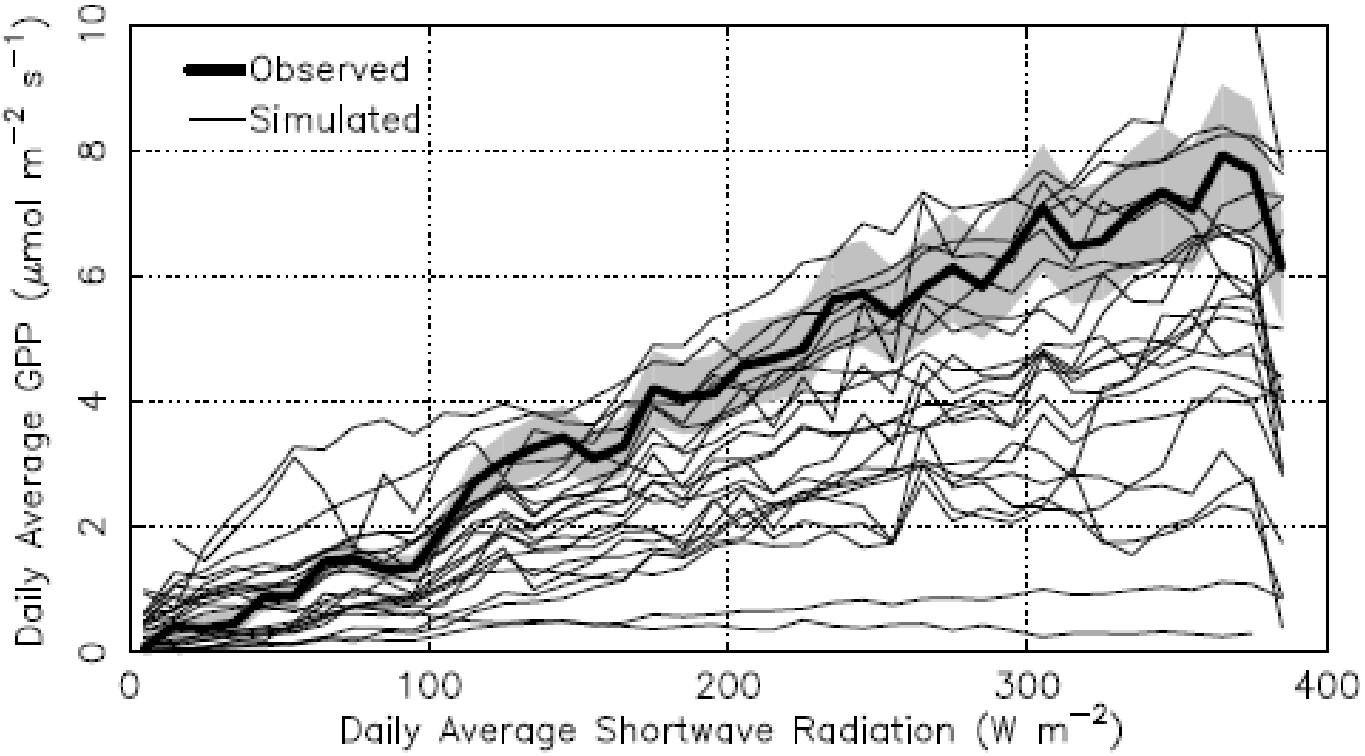
Sustained and Elevated Respiration after Fall Rain



What FluxNet can Do for Us: Model Validation and Parameterization

- Providing Ground Truth and Lessons Learned for Land Surface Modeling and Land-Atmosphere Interactions;
- Providing data for Data-Model Fusion Schemes for Carbon Cycle
- Providing Ground Truth and Parameterization Data for Light Use Efficiency Models, coupled to Satellite Remote Sensing
  - MODIS, Hyperion
- Providing Ground Truth to New Product derived from Satellite Radar Platforms
  - SMAP, COSMOS
- Resource on Site MetaData for Synthesis and Distillation
  - Soil Properties (Polaris)
  - Structure and Function (TRY)
  - Phenology (PhenoCam)
  - LIDAR

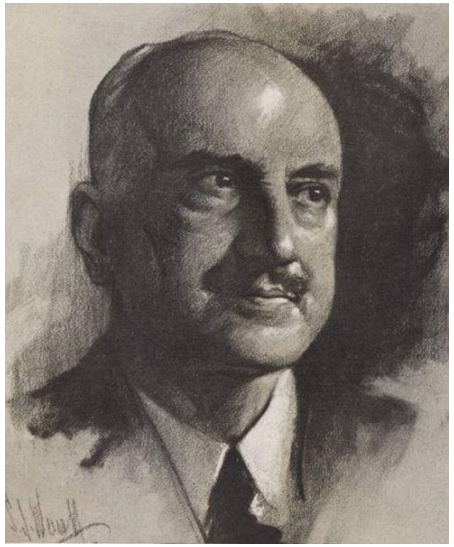
Many C Cycles Model Don't Simulate GPP-Light Response, Well



If One Doesn't Get C Inputs Right, How can one Compute the Carbon Cycle Right?

Schaeffer et al 2012, JGR Biogeosciences

"Those who cannot remember the past are condemned to repeat it",



George Santayana

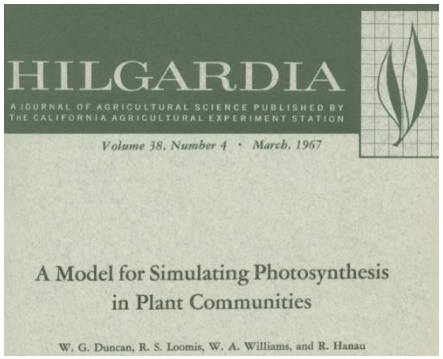
We Need to Simulate the Light Environment on Sun and Shaded Leaves Because the 'Mean of the Function Does Not Equal Function of the Mean'

C. T. de Wit

Institute for Biological and Chemical Research on Field Crops and Herbage, Wageningen

Photosynthesis of leaf canopies

1965

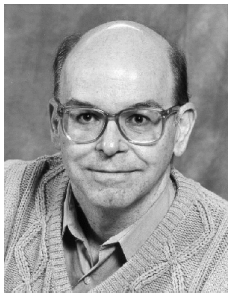


1967

BIOMETEOROLOGY IN INTEGRATED PEST MANAGEMENT

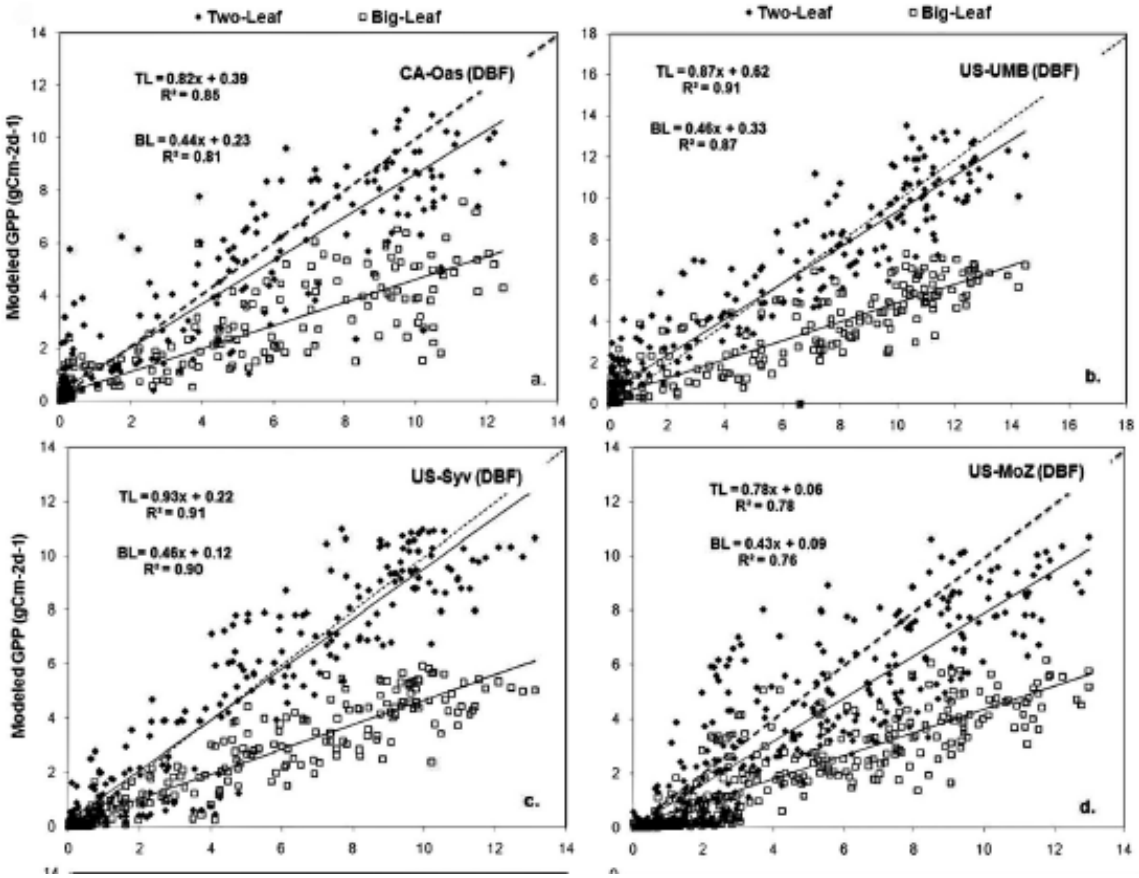
SIMULATION OF MICROCLIMATES

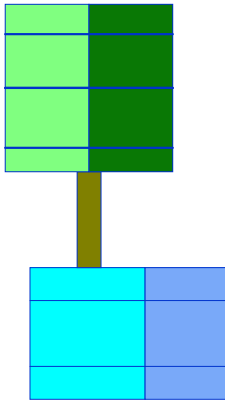
John M. Norman
Department of Agronomy
University of Nebraska
Lincoln, Nebraska



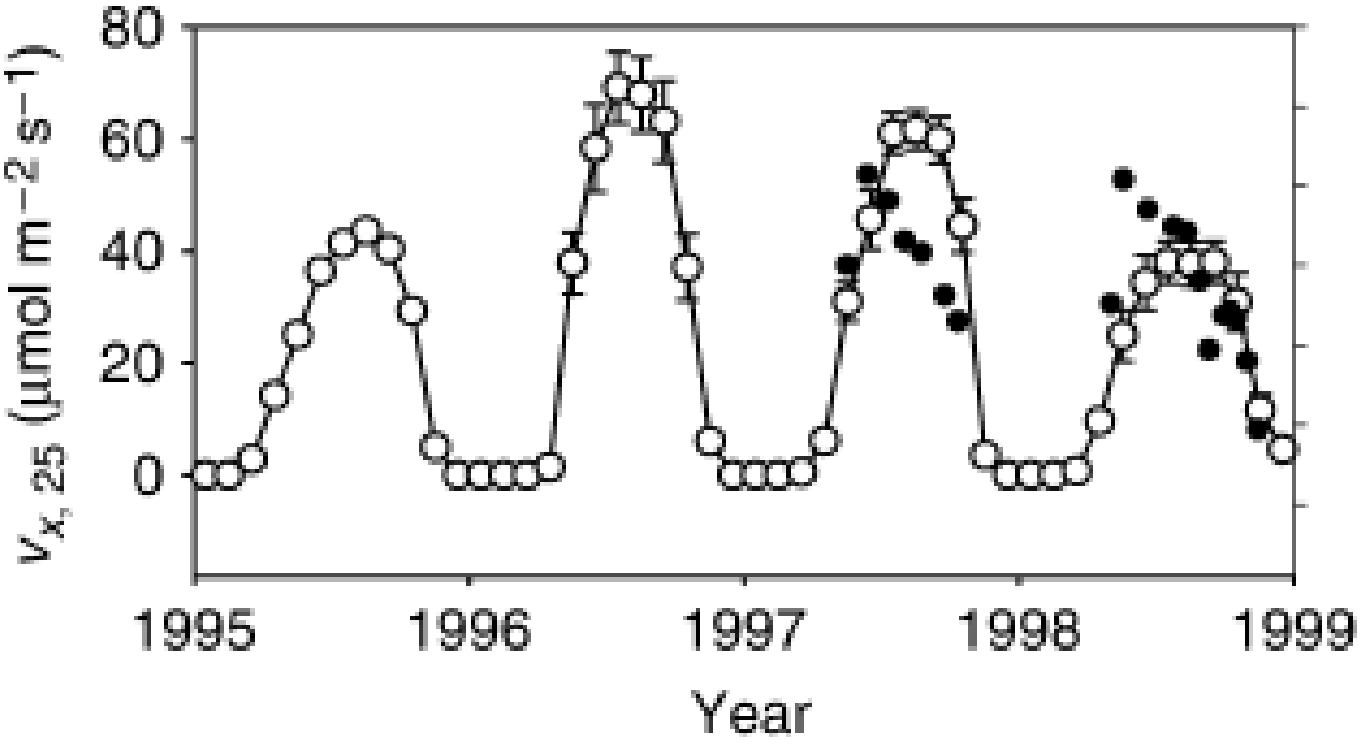
1979

Ignore Biometeorology at Your Peril: Marked Improvement with Sun-Shade Models



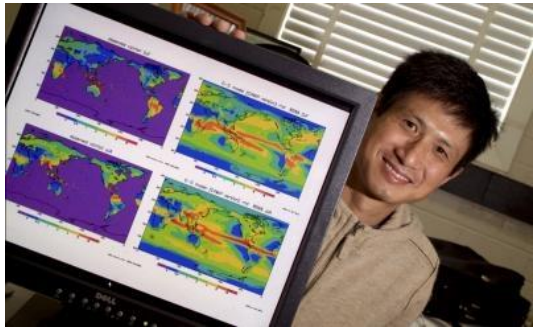


Seasonality of Photosynthetic Capacity

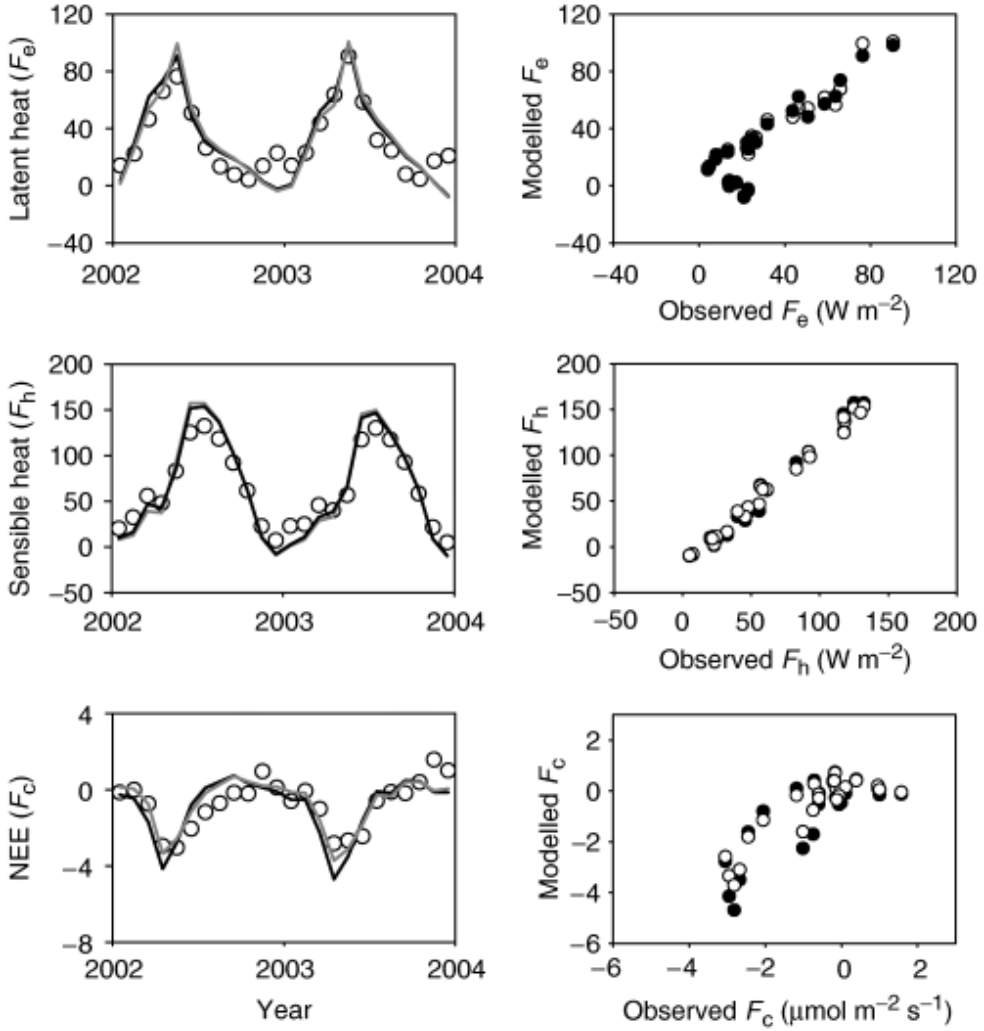


Wang et al, 2007 GCB

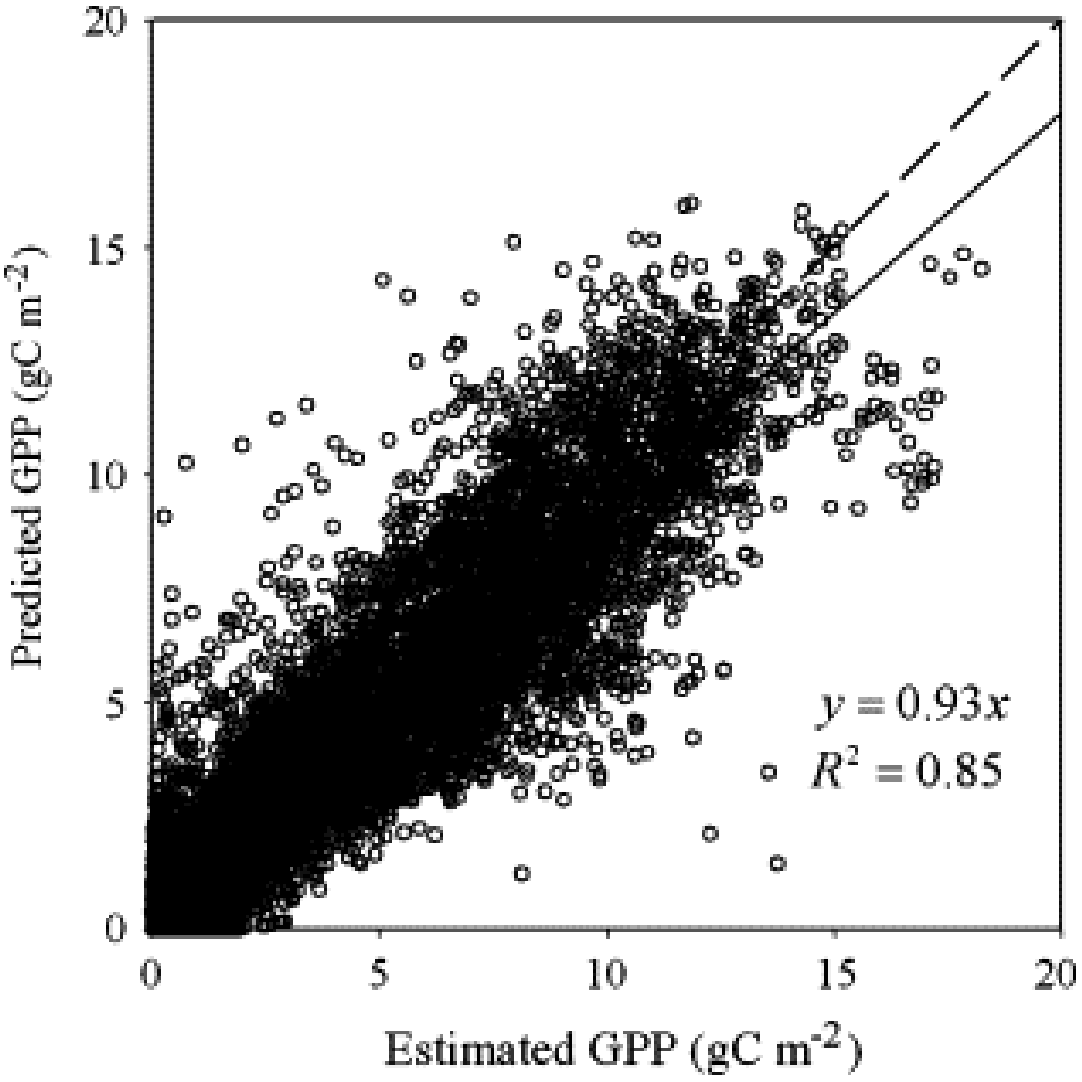
Optimizing Seasonality of Vcmax improves Prediction of Fluxes

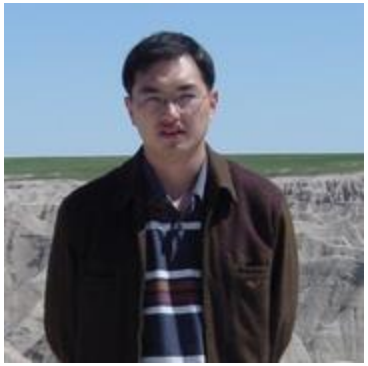


Wang et al, 2007 GCB



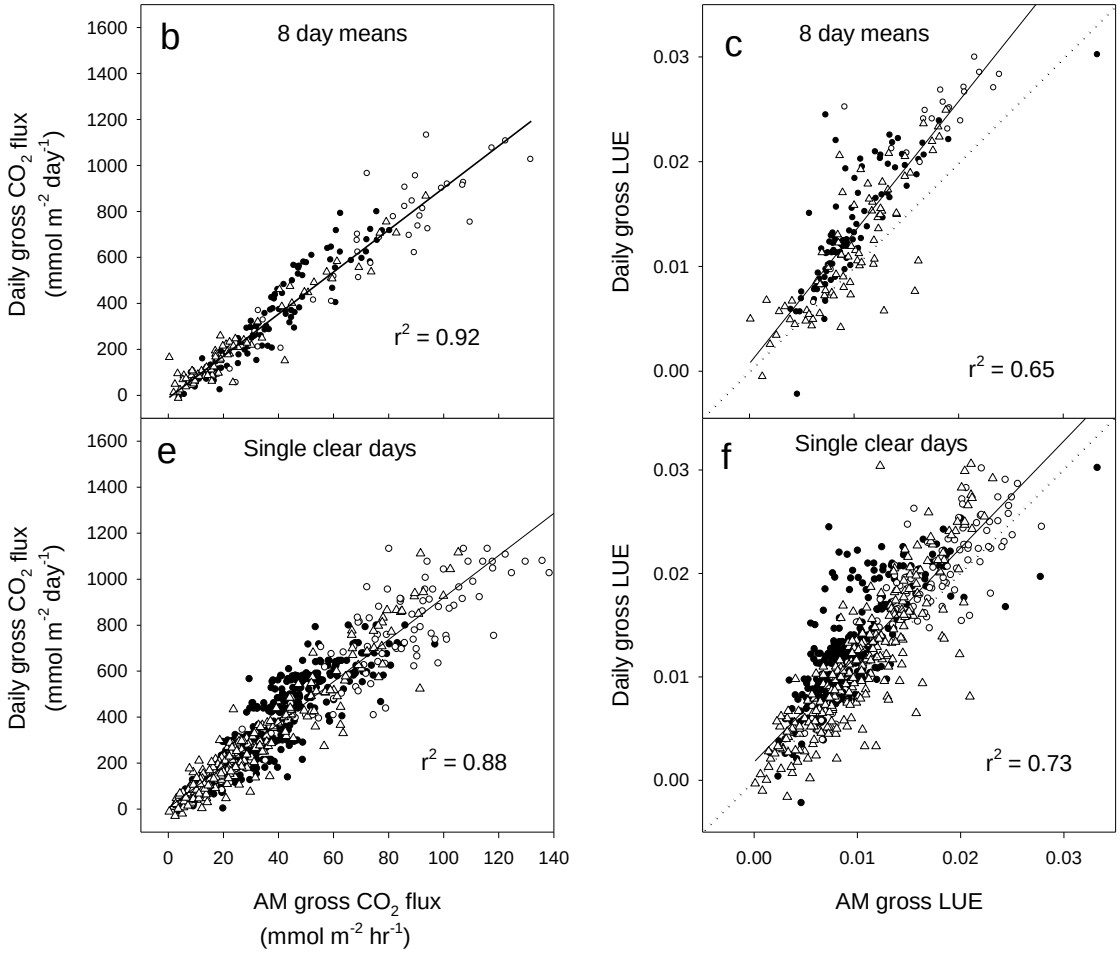
Testing Light Use Efficiency Models





Yuan et al 2007 AgForMet

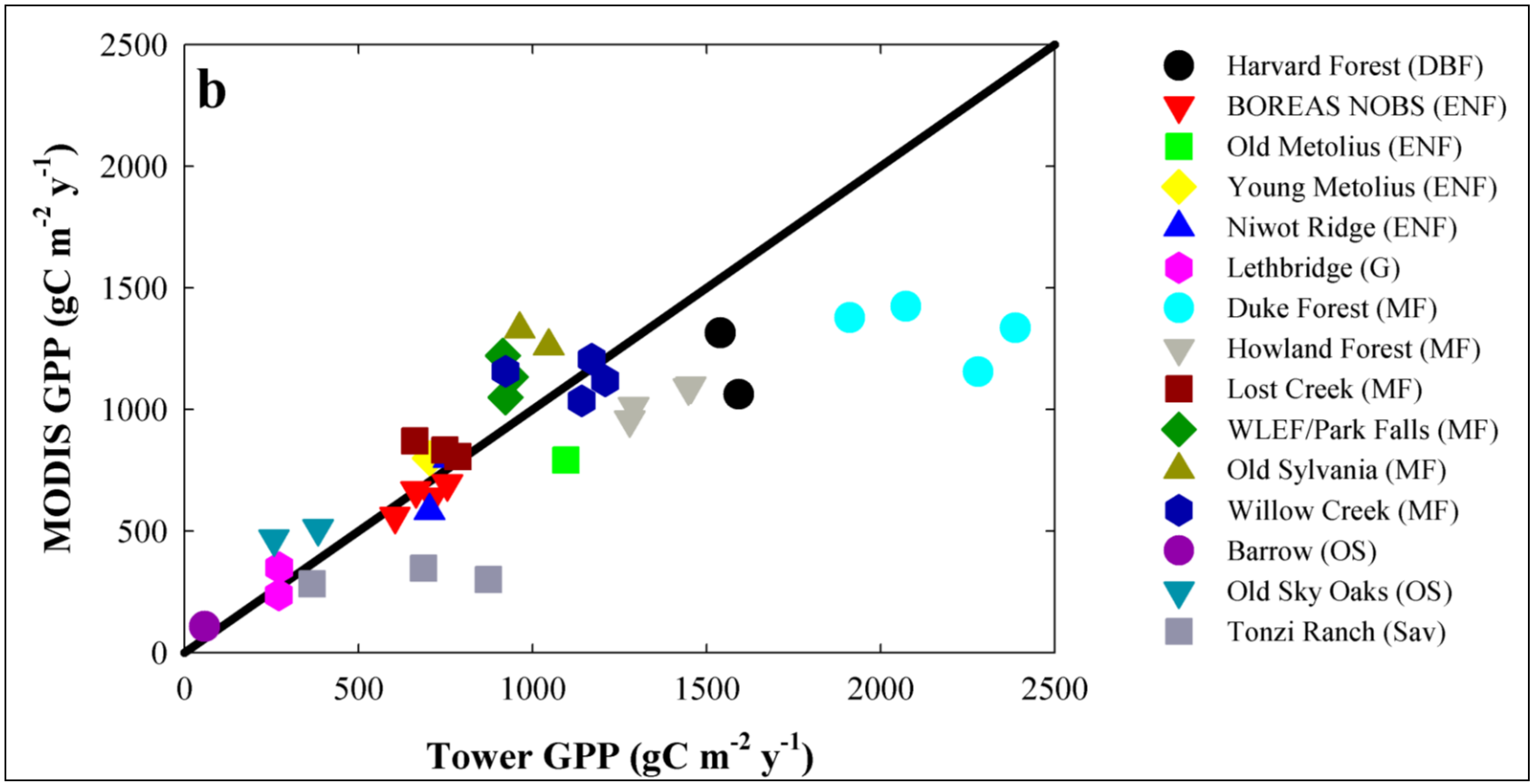
Do Snap-Shot C Fluxes, inferred from Remote Sensing, Relate to Daily C Flux Integrals?



Sims et al 2005 AgForMet

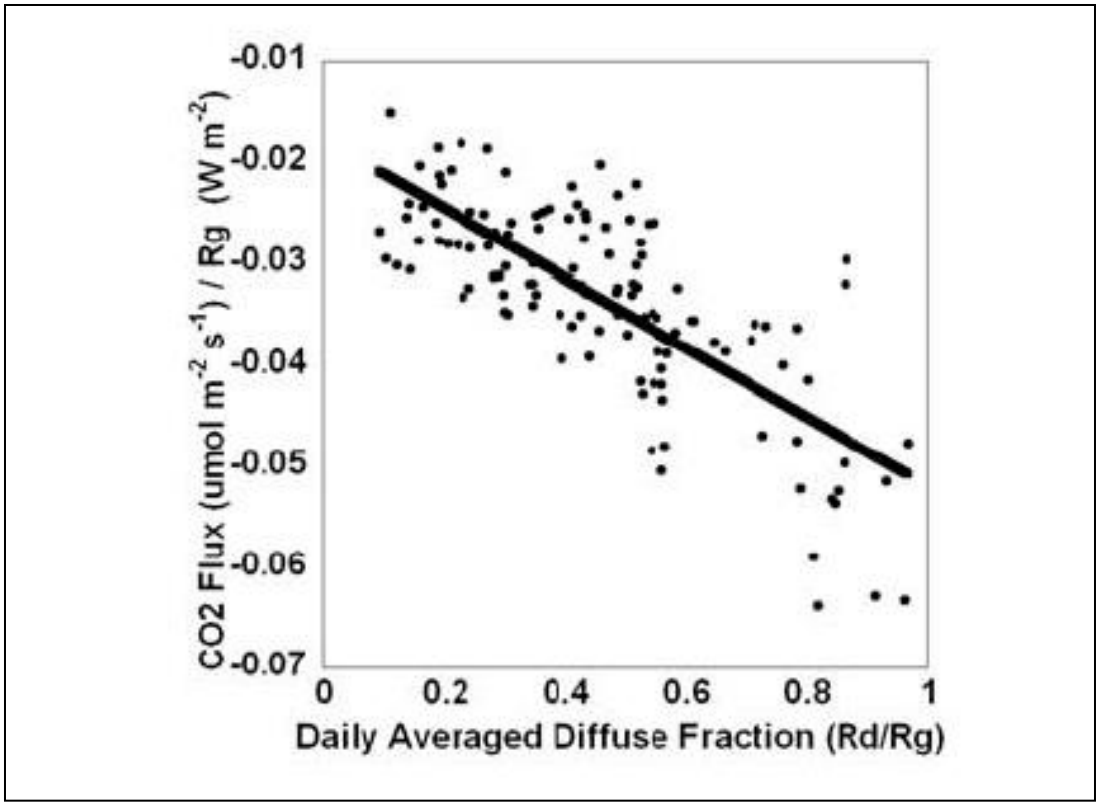
ILAMB Workshop May 2016

MODIS GPP Algorithm Test



Heinsch et al. 2006 RSE

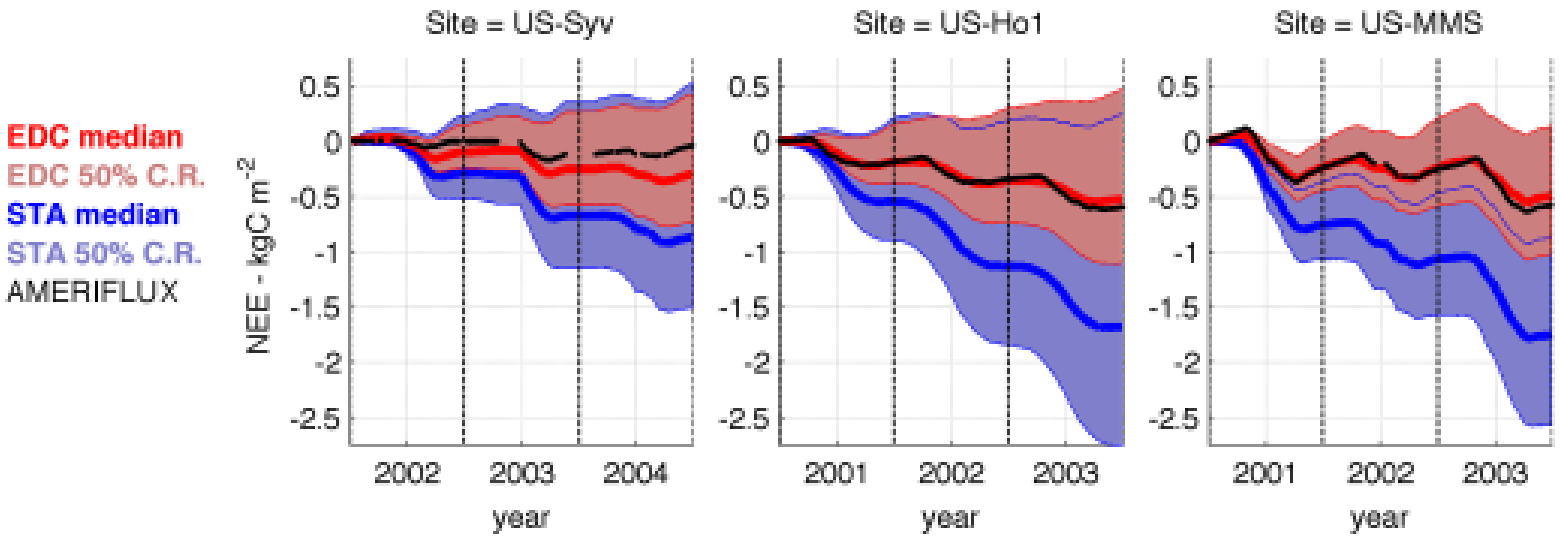
Emergent Scale Process: CO_2 Flux and Diffuse Radiation



- We are poised to see effects of Cleaner/Dirtier Skies and Next Volcano
- Satellites are Biased Against Sampling during Cloudy Days

Niyogi et al., GRL 2004

Eddy Flux Data and Model-Data Fusion

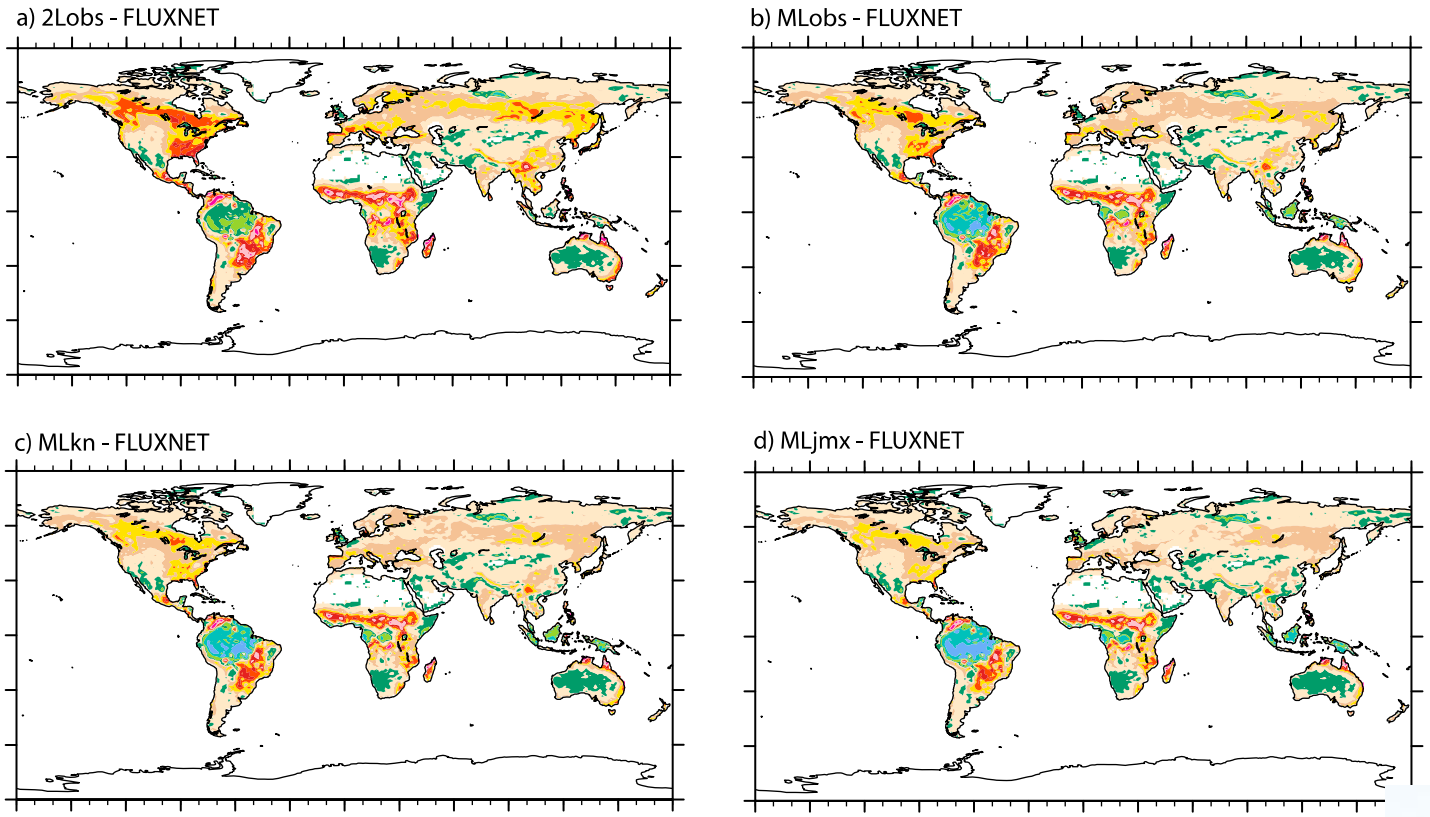


Constraining ecosystem carbon dynamics in a data-limited world: integrating ecological "common sense" in a model–data fusion framework

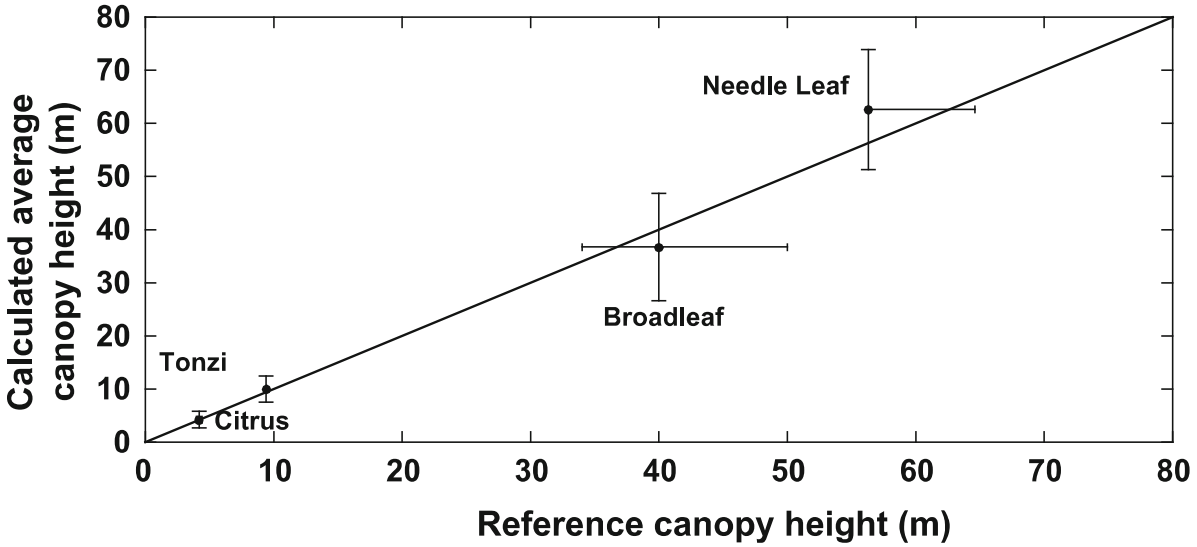
A. A. Bloom[1,*] **and M. Williams**[1]

[1]School of GeoSciences, University of Edinburgh, Edinburgh, UK
[*]now at: Jet Propulsion Laboratory, California Institute of Technology, Pasadena, USA

FLUXNET Data use to Test Algorithms in the Community Land Model, CLM



Canopy Structure



Boundary-Layer Meteorol
DOI 10.1007/s10546-015-0090-0

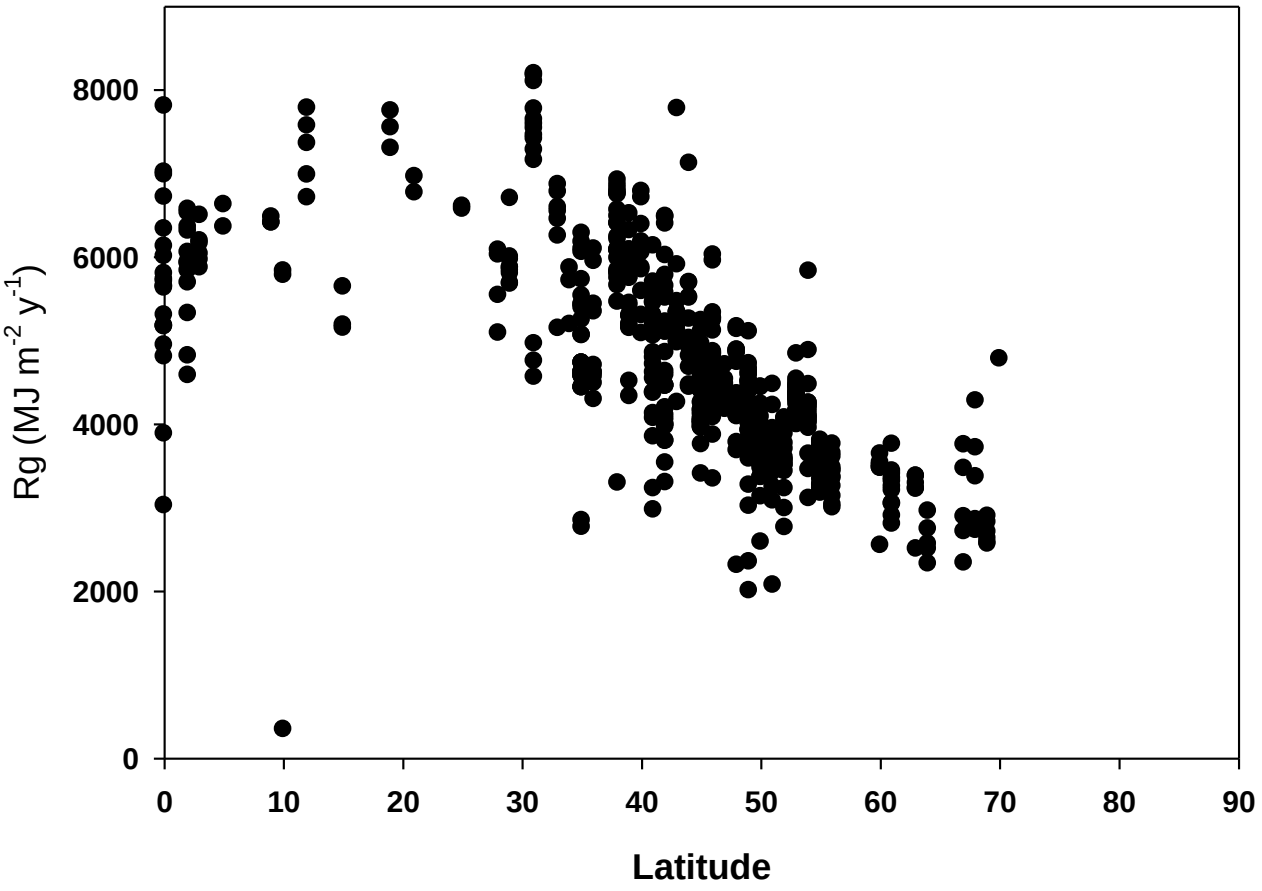
ARTICLE

Seeing the Fields and Forests: Application of Surface-Layer Theory and Flux-Tower Data to Calculating Vegetation Canopy Height

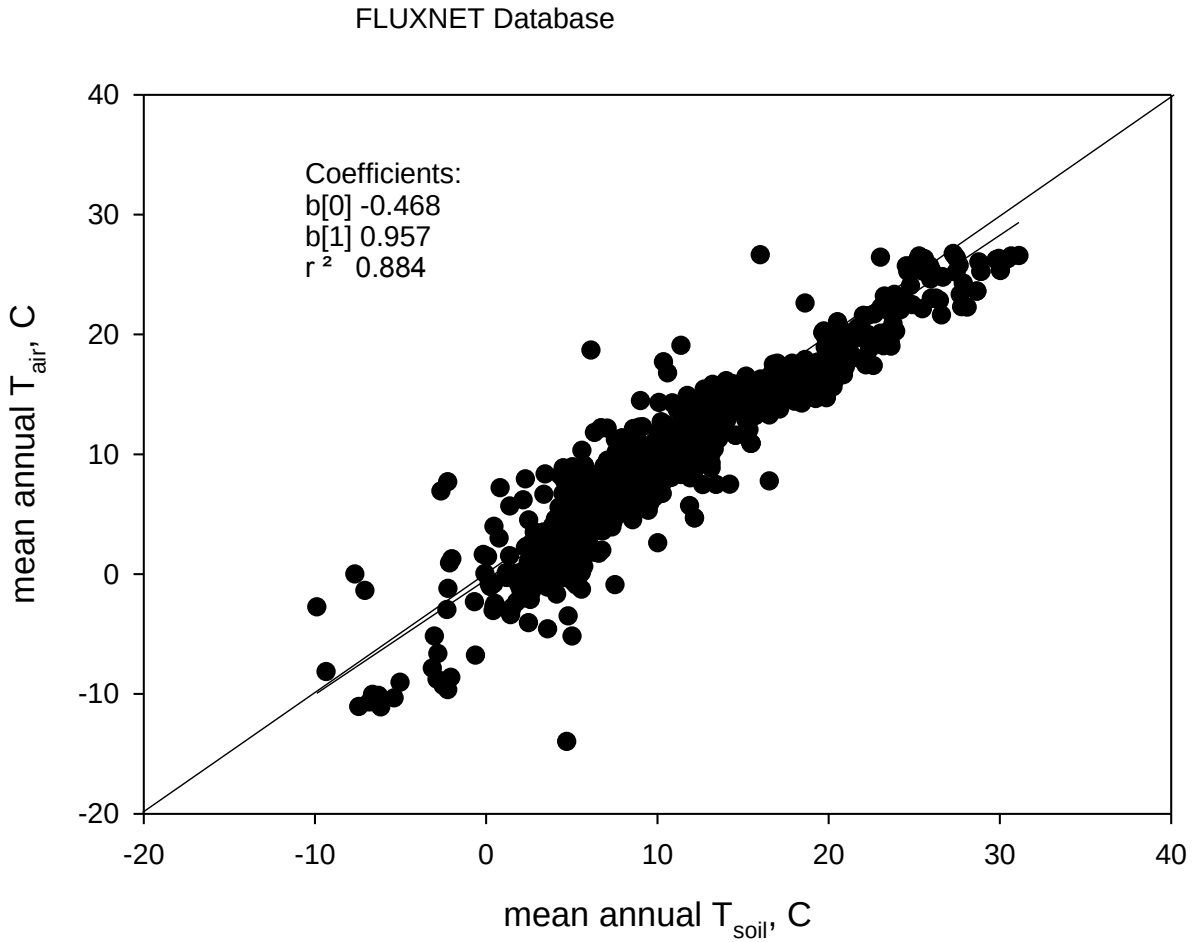
Sam Pennypacker[1] · Dennis Baldocchi[2]

Energy Flux Biogeography

FLUXNET database



Initial Conditions for Forced Restore Model of Soil Heat Flux

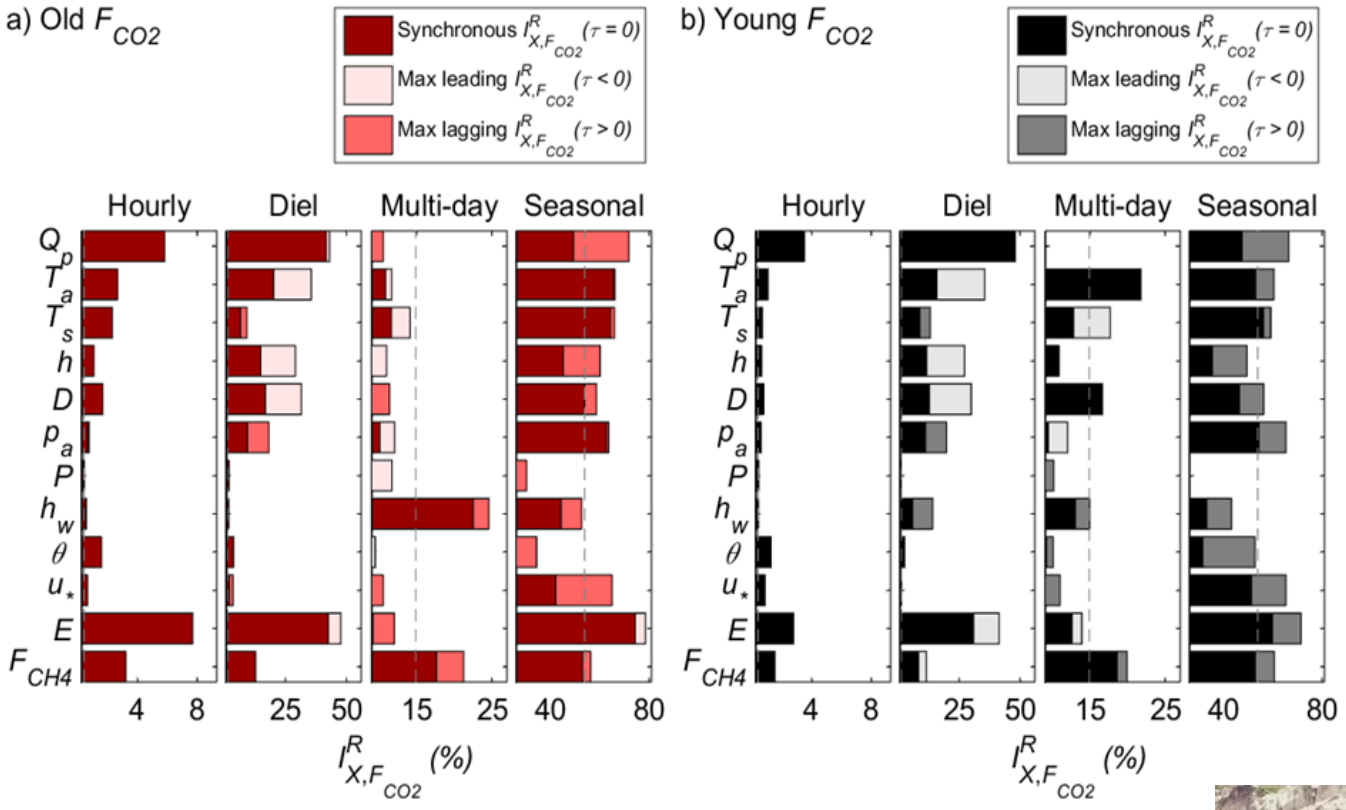


What FluxNet can Do for Us: Technology and Methods

- Refining and advancing the development and application of the eddy covariance method
  - Stable Boundary Layers, Complex Terrain, Heteogeneous Source Fields, Decoupled Fluxes, Dual Flux Systems, Advection, Energy Balance Closure
- Providing multi-scaled data set for the application of information and complexity theory
  - Granger Causality
  - Transfer Entropy
  - Mutual Information Theory
  - Neural Networks

- Proof of Concept as a System and Model for the sharing and distributing complex and multi-sourced environmental data.

Relative Information on CO_2 Flux



Sturtevant et al. 2016 JGR Biogeoscience

Links to Other National/International Programs and Networks

- Phenology, Phenocam
- Soil Moisture, SMAP and Cosmos
- Soil Characteristics, POLARIS, SURRGO
- Land Parameterization, ILAMB
- Radiation Fields, ARM
- Plant Functional Traits, TRY

Conclusions and Directions @ 20 Years

- Continued Development of Data System to Serve the Community
- Continued Site Comparison Studies to Maintain Quality of Data
- Expand into other Trace Gases, e.g. Methane
- Continue to Recruit Site Metadata information, including LIDAR, Soils, Physiological Capacity.
- New Generation of Studies on Trend Detection and Sources of Interannual Variability

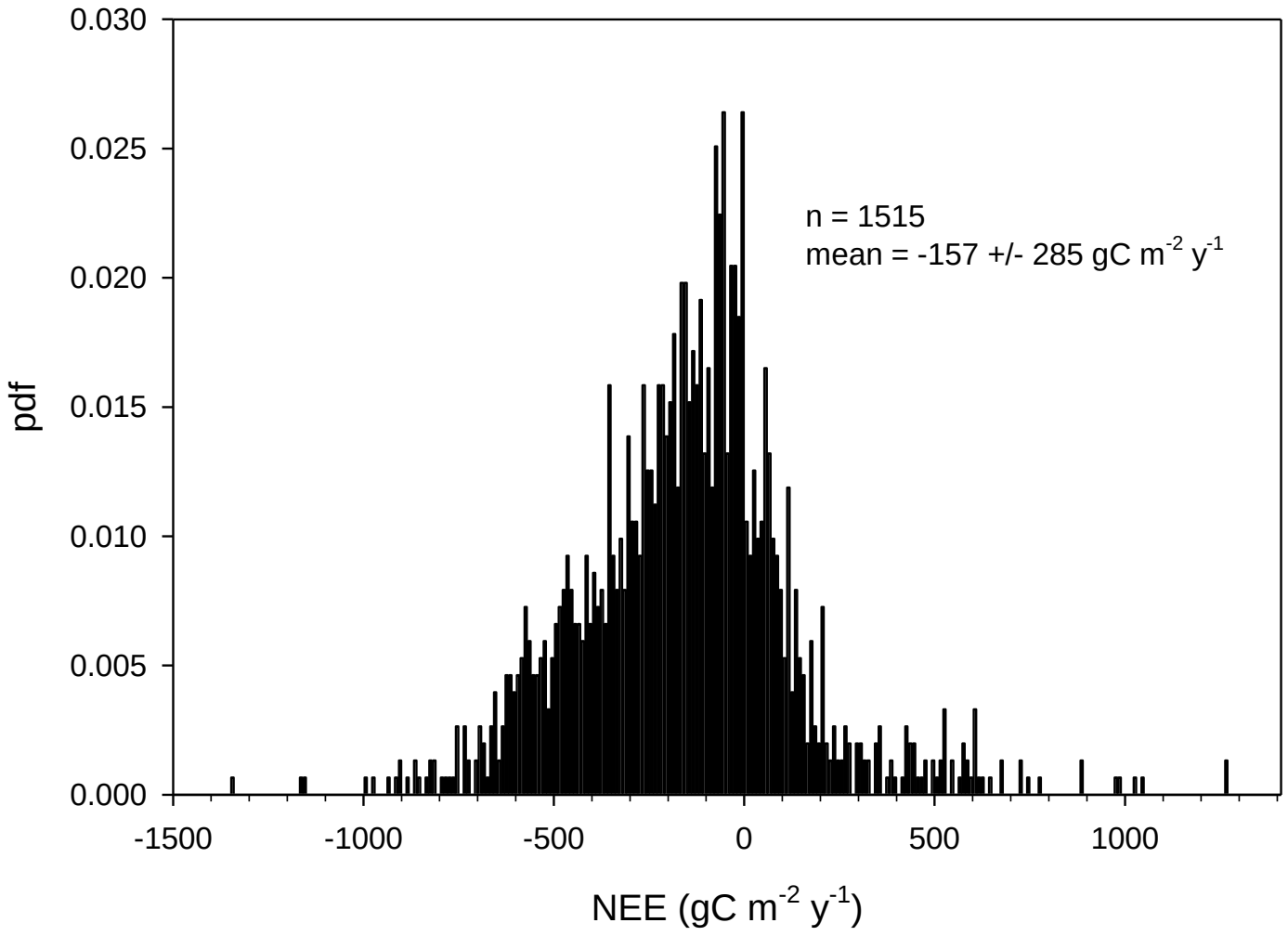
Acknowledgements

- Data Preparation
  - Dario Papale, Markus Reichstein, Catharine Van Ingen, Deb Agarwal, Tom Boden, Bob Cook, Susan Holliday, +++
- Networks
  - AmeriFlux, CarboEurope, AsiaFlux, ChinaFlux, Fluxnet Canada, OzFlux, +++
- Agencies
  - NSF/RCN, ILEAPS, DOE/TCP, NASA, Microsoft, ++++

Early Questions

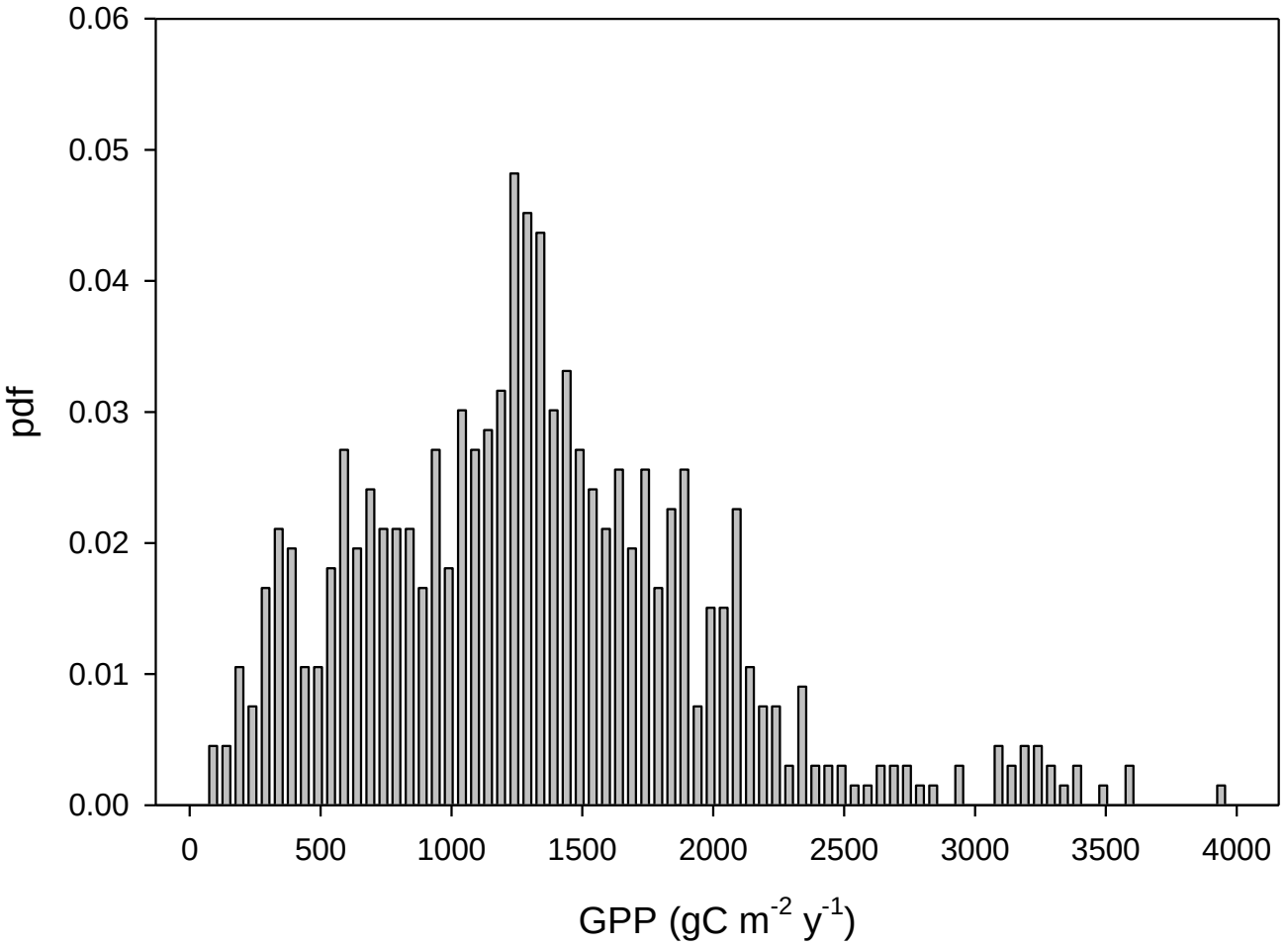
- What is the Annual Sum of Ecosystem Carbon Exchange, as a function of Climate Zone, Plant Functional Type, Time since Disturbance, Weather, and Size of the Network?

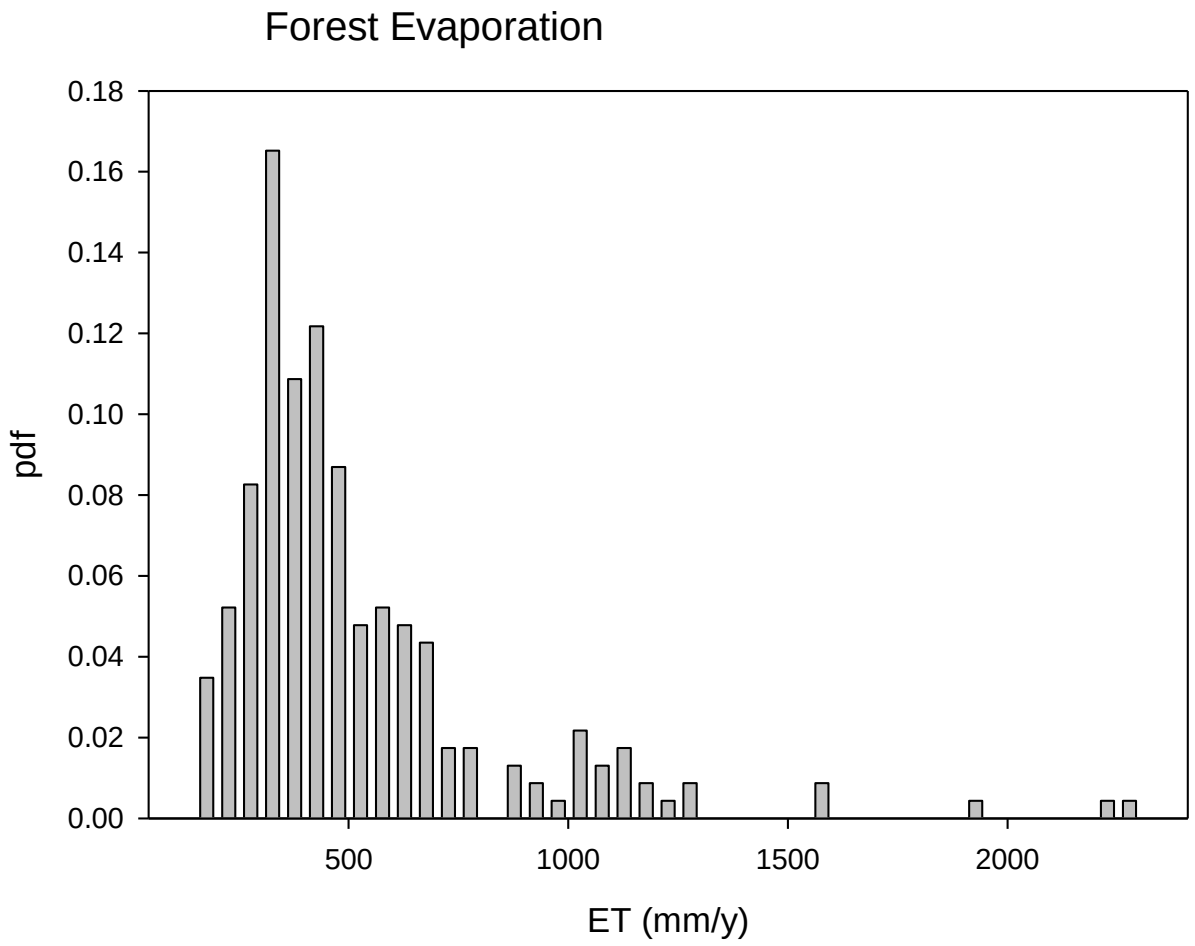
Published Data, March, 2015



Day-Night sampling Enables Us to Partition Net Carbon Exchange Into Carbon Assimilation and Ecosystem Respiration

Published Data, March 2014

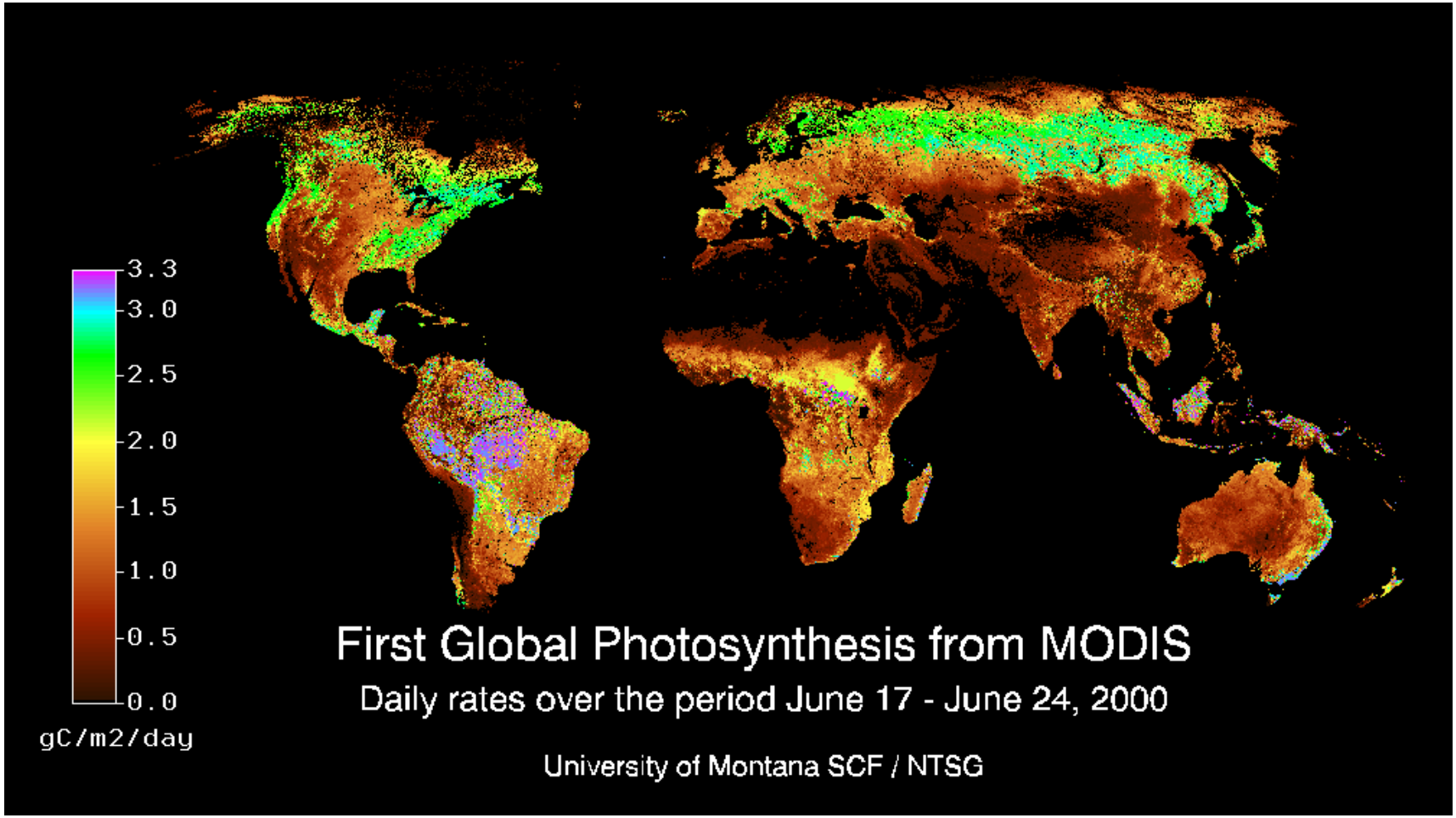




Baldocchi and Ryu, 2011
in *Forest Hydrology and Biogeochemistry: Synthesis of Past Research and Future Directions*

Structure, Function, Traits and Emerging Processes

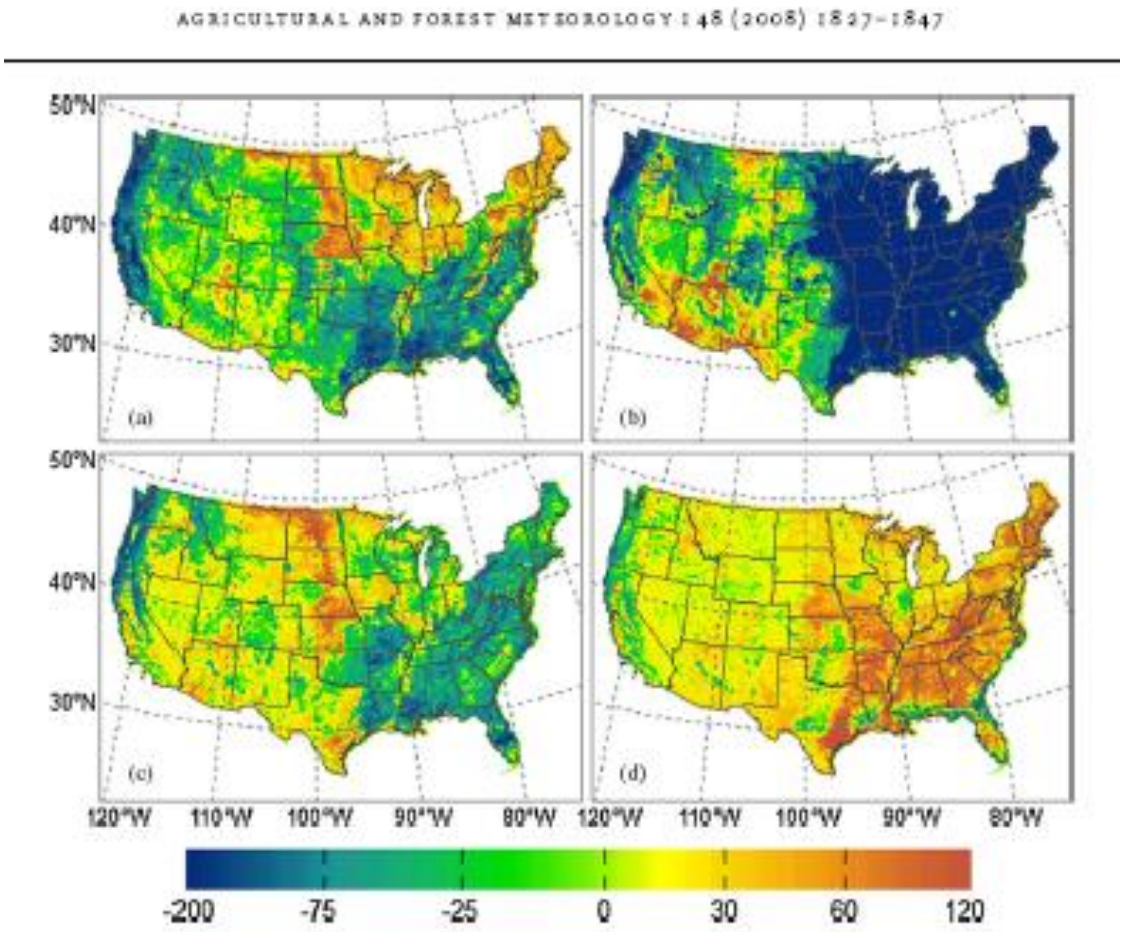
Spatial Variations in C Fluxes



Spatial Variations in C Fluxes

spring

summer



autumn

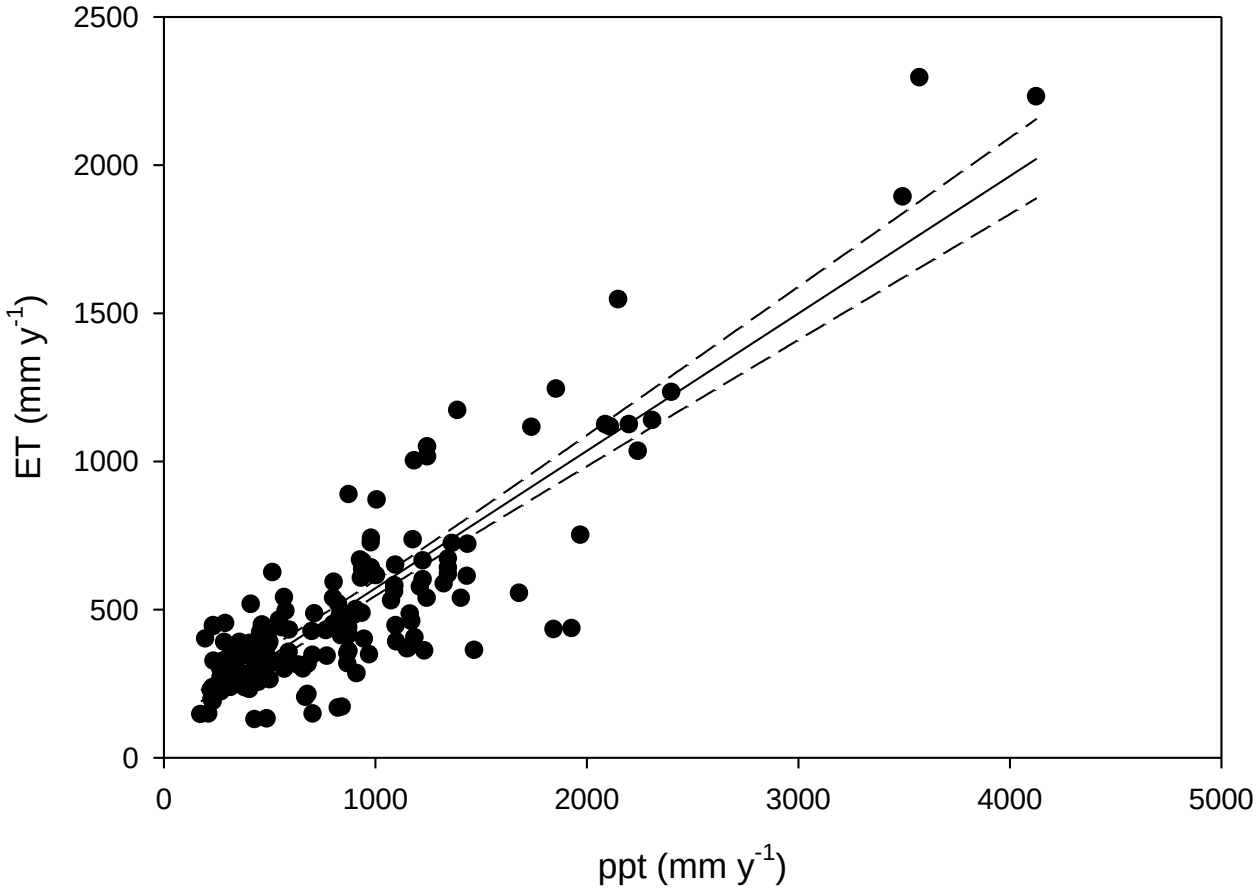
winter

Xiao et al. 2008, AgForMet

Limits to Landscape Classification by Functional Type

- Stand Age/Disturbance
- Biodiversity
- Fire
- Logging
- Insects/Pathogens
- Management/Plantations
- Kyoto Forests
- Functional Traits Trump Functional Types

Forests



Baldocchi and Ryu, 2011
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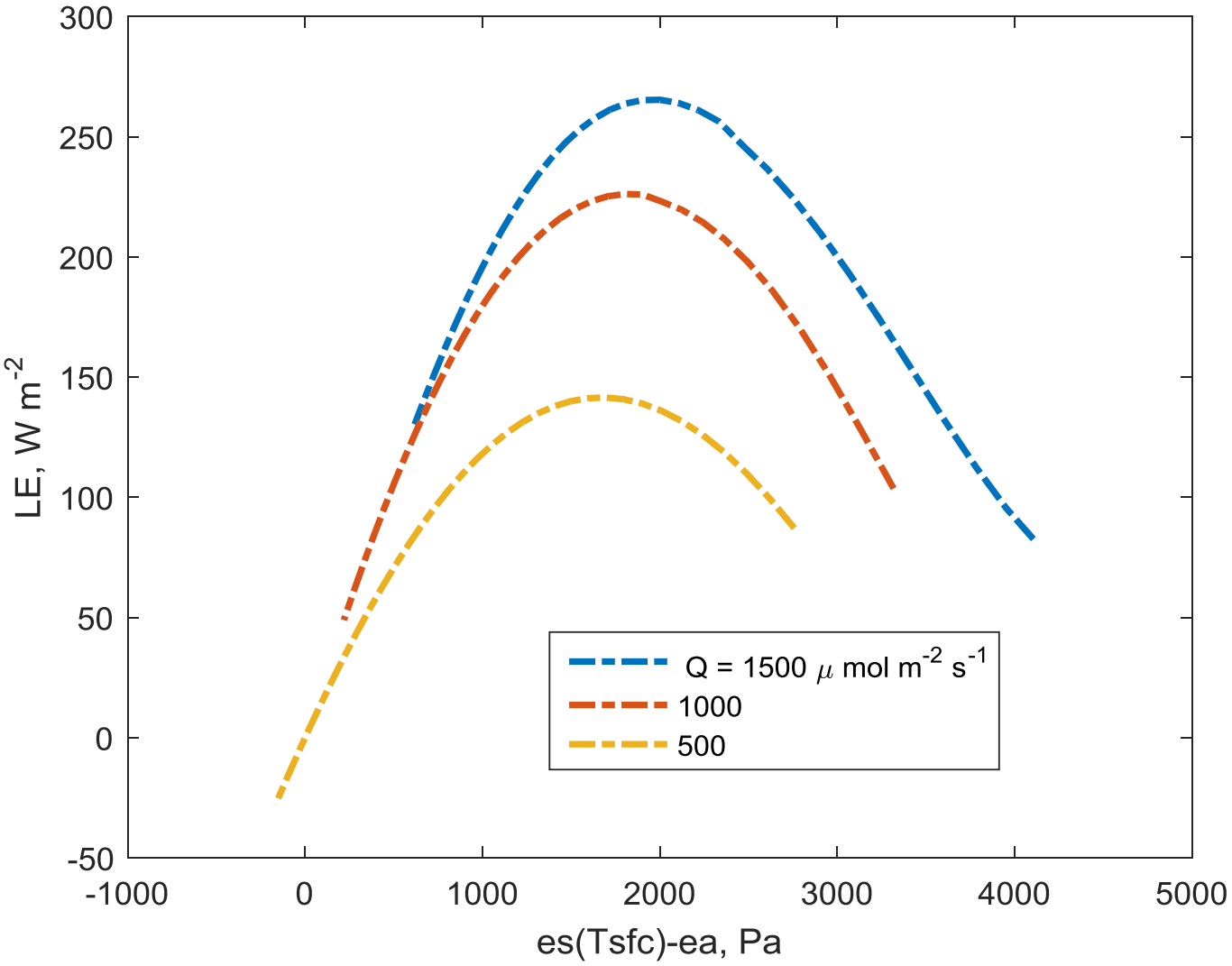
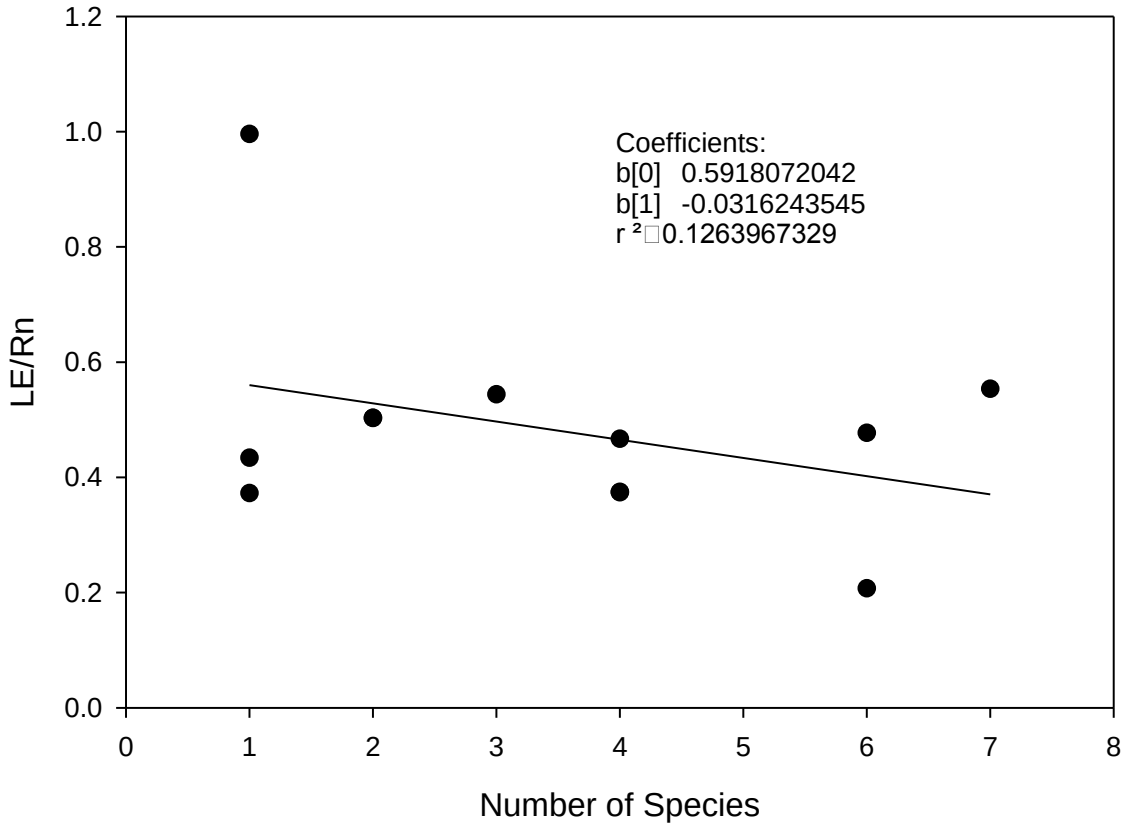
Evaporation vs Humidity Deficits



Biodiversity and Evaporation on Annual Time Scales



Baldocchi, unpublished

Annual Fluxes by Functional Group

	Rg	Rn	albedo	H	LE	G_s	NEE
	GJ m^{-2} y^{-1}	GJ m^{-2} y^{-1}	--	GJ m^{-2} y^{-1}	GJ m^{-2} y^{-1}	mmol m^{-2} s^{-1}	gC m^{-2} y^{-1}
Crop	4.375	2.063	0.156	0.478	1.217	510	-237
Std. dev.	1.051	0.678		0.296	0.433	205	182
Grassland	4.707	1.6866	0.239	0.632	1.097	437	-156
Std.dev.	1.11	1.17		0.478	0.413	224	171
Wetland	3.427	1.3279	0.240	0.359	0.725	454	-107
Std.dev.	0.818	0.574		0.208	0.421	159	123
Evergreen needle leaved forest	4.046	2.242	0.106	0.891	0.954	432	-247
Std.dev.	0.988	0.952		0.477	0.456	173	331
Evergreen broadleaved forest	5.216	3.289	0.0825	0.893	1.888	672	-381
Std.dev	0.909	0.963		0.329	0.899	456	331
Deciduous broadleaved forest	4.086	2.310	0.204	0.651	1.081	497	-403
Std.dev	1.000	0.664		0.372	0.4659	196	289
Savanna	6.058	2.93	0.121	1.304	1.388	355	-136
Std.dev.	1.605	1.543		0.507	0.920	240	166

The Advantages of Evergreeness vs Deciduousness in Mediterranean Oak

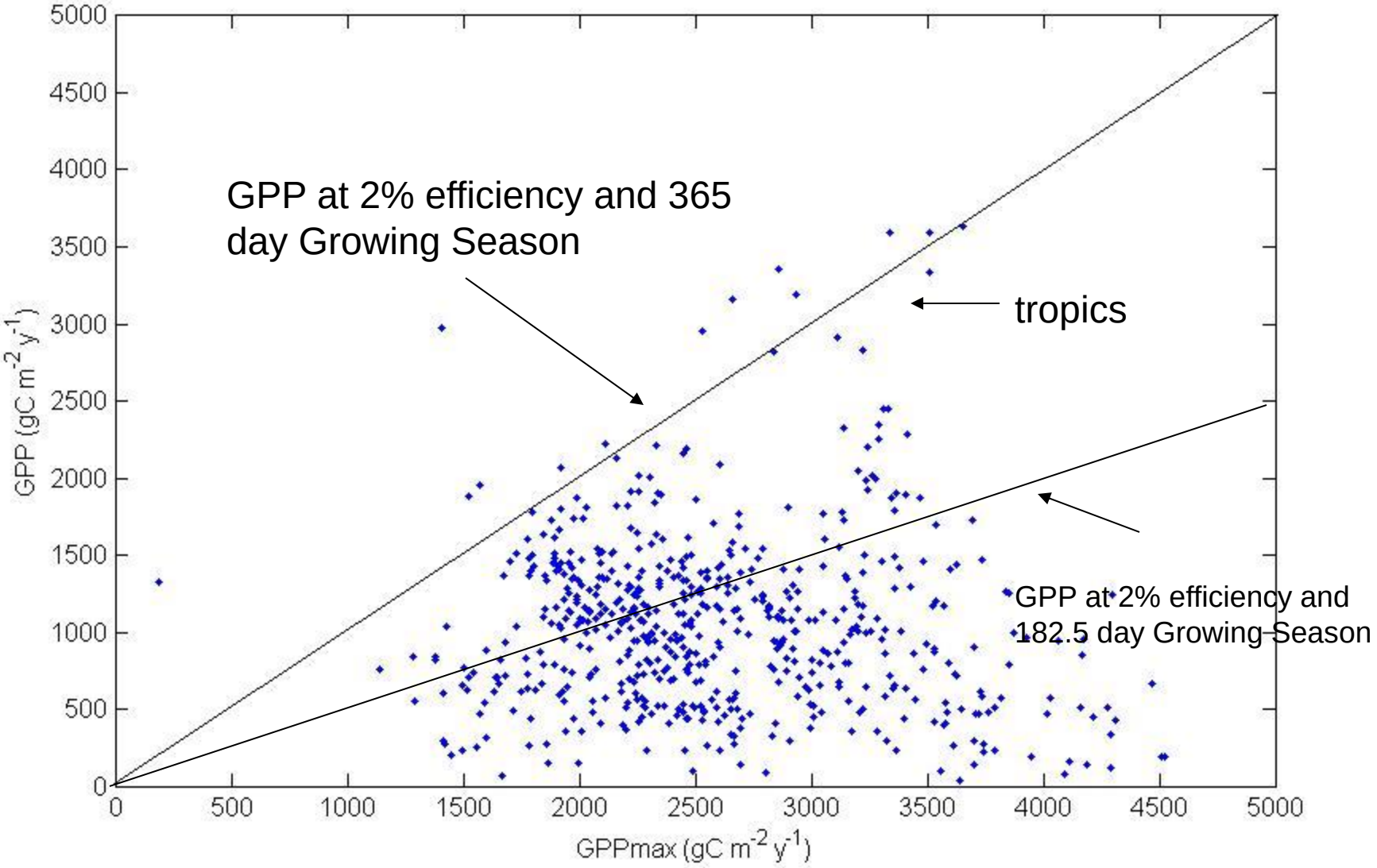
TABLE 2. Analysis of deciduous vs. evergreen leaves (mean ± SE) for annual total gross primary productivity (GPP), ecosystem respiration (R_{eco}), and evapotranspiration (ET).

Variable	Units	Deciduous	Evergreen	LSD
GPP	g C·m^{-2}·yr^{-1}	1251 ± 69	1288 ± 83	152
R_{eco}	g C·m^{-2}·yr^{-1}	1050 ± 56	958 ± 49	137
ET	mm/yr	343 ± 37	368 ± 29	46

Notes: The database consists of 11 site-years for deciduous oaks and 15 site-years for evergreen oaks. For all variables and both leaf types, each flux pair was found to be identical according to Duncan's test. LSD is least significant difference at $\alpha = 0.05$.

Baldocchi et al 2010. Ecol Applications

Potential and Real Rates of Gross Carbon Uptake by Vegetation: Most Locations Never Reach Upper Potential



FLUXNET 2007 Database