Using a Global Flux Network—FLUXNET— to Study the Breathing of the Terrestrial Biosphere

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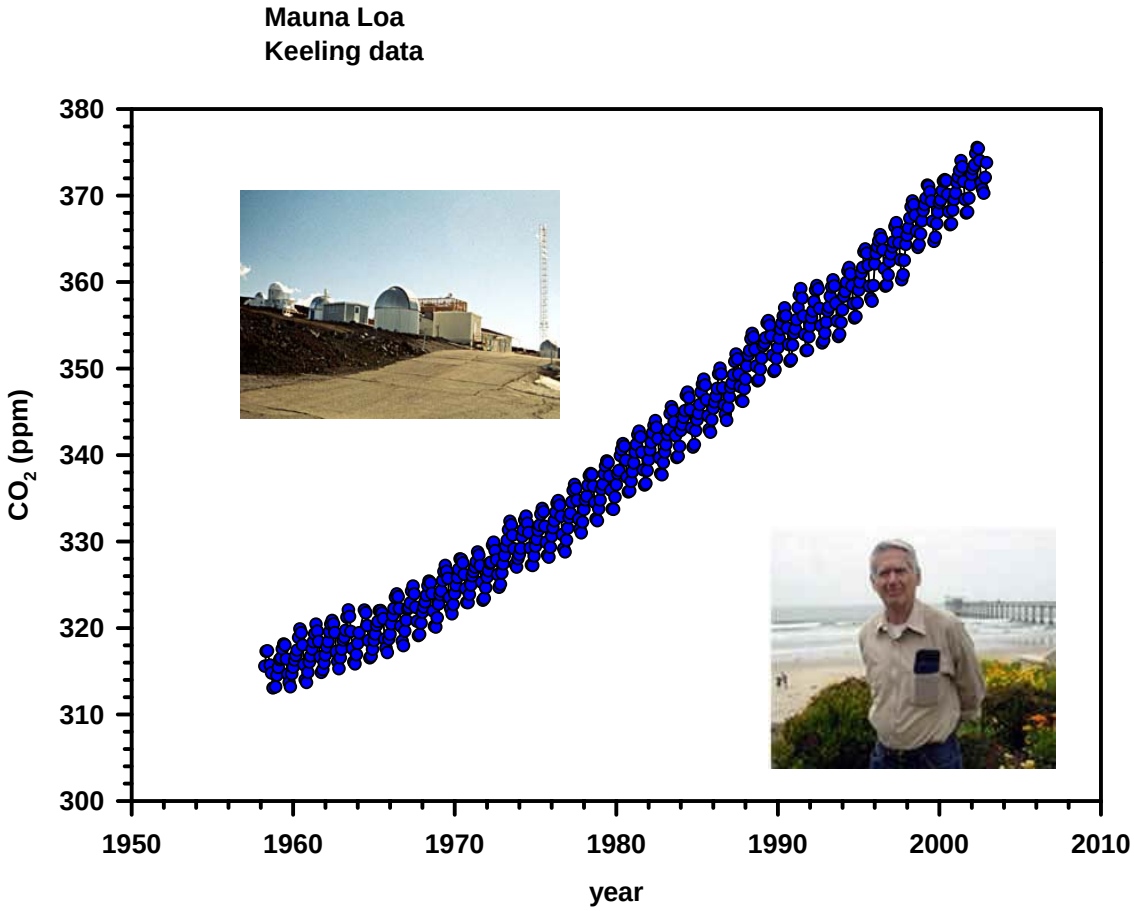
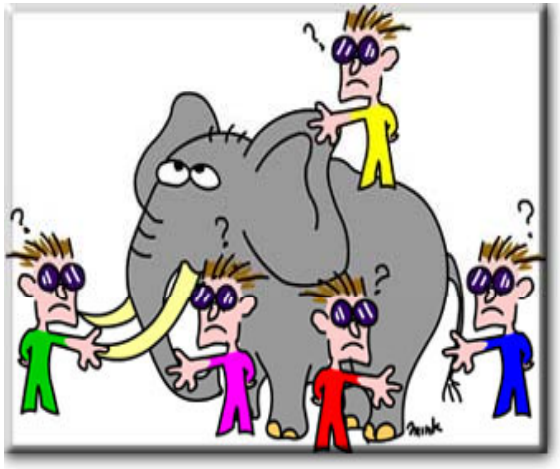
Lecture 6:
ESPM 228

Contemporary CO_2 Record



Methods To Assess Terrestrial Carbon Budgets at Landscape to Continental Scales, and Across Multiple Time Scales

GCM Inversion Modeling



Eddy Flux Measurements/ FLUXNET

Remote Sensing/ MODIS

Forest/Biomass Inventories

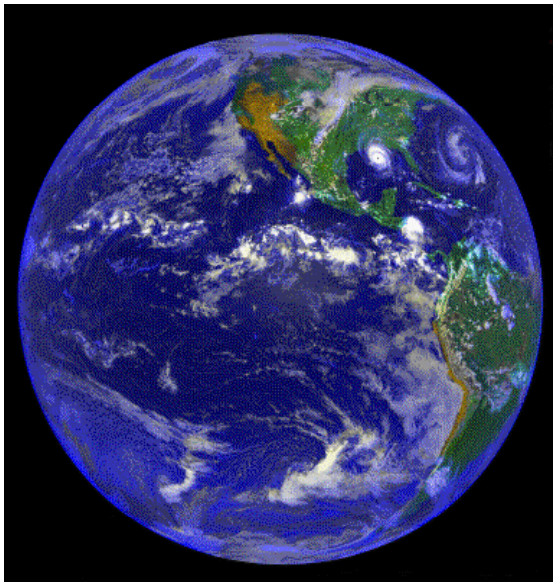
Physiological Measurements/ Manipulation Expts.

Biogeochemical/ Ecosystem Dynamics Modeling

Flask Network and Inversion models

- **Pros**
- Produces Global and Zonal C fluxes

- **Cons**
- Sparse flask network
- Biased to marine boundary layer
- Ill-posed problem
- Crude spatial resolution



Remedy

Use isotopes (^{13}C) and surface flux measurements to constrain source/sink calculations

More sites measuring C in x,y and z

Better Transport Model

Carbon Satellite, OCO

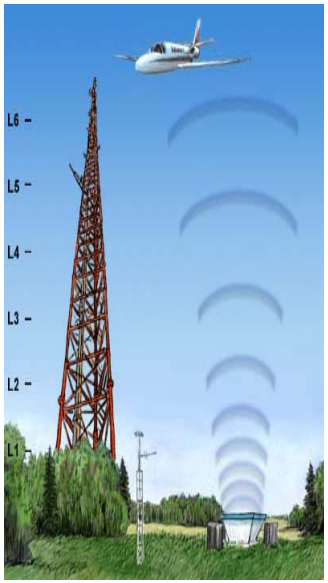
Satellites

Remedy
New Satellite platforms (EOS)
Validate Algorithms with Direct Eddy Flux Measurements

- **Pros**
- Global, Regional and Local Coverage
- Can detect Seasonal trends

- **Cons**
- Inferred estimates of NPP and LAI
- Relies on Unvalidated Algorithms
- Intermittent Coverage
- Can’t Assess NEP

CBL Budgets



- **Pro**
- Provides mixed layer estimate of CO_2 for inversion models
- Provides landscape scale fluxes

- **Con**
- Valid only under ideal conditions
- Affected by Advection
- Needs information on CO_2 above PBL

Remedy

Improve estimates of entrainment fluxes

Micrometeorological Eddy Fluxes

- **Pros**
- Direct measurement
- Evaluates Fluxes on diurnal, seasonal and interannual time scales
- Provides Process information

Remedy

Validate with Leaf physiology and plant/soil samples, sapflow, biometry and watershed measurements

- **Cons**
- Nighttime biases
- Small footprint (< 1 km)
- Not applicable in Complex Terrain
- Network of Towers is Discrete in Space

Biomass and Soil Surveys

- **Pros**
- A direct measure of plant growth and soil C sequestration

- **Cons**
- High spatial variability
- Below-ground NPP is rarely measured
- No mechanistic information on C fluxes
- Takes several years to resolve significant differences

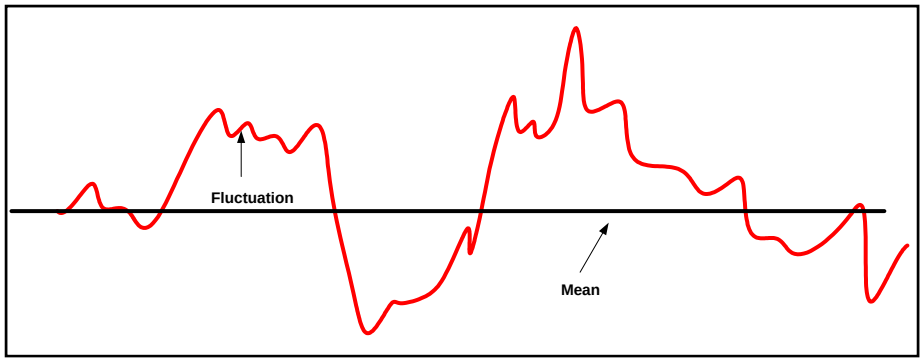
Remedy

C isotope studies

More root and below ground measurements

Eddy Covariance Technique

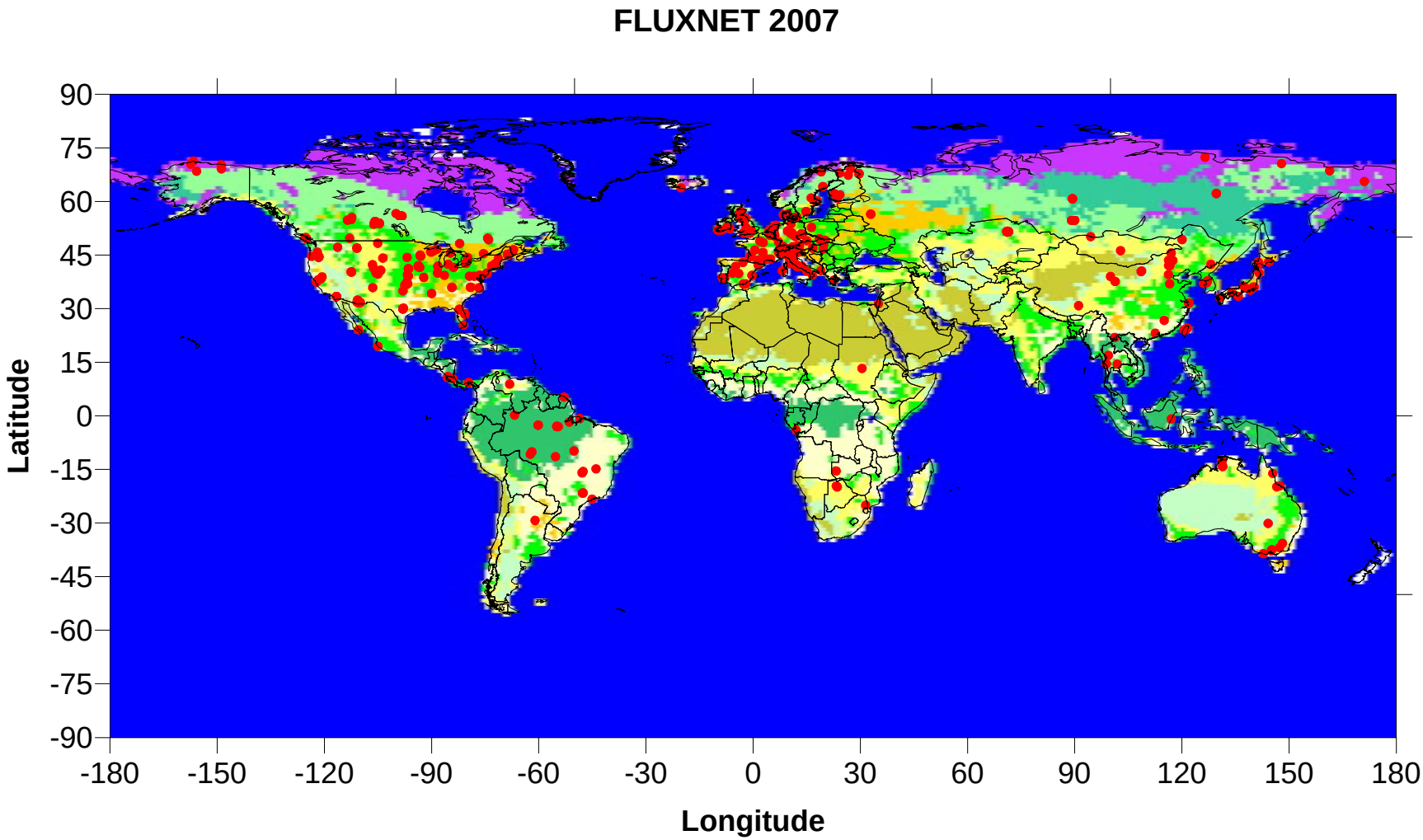
$$F = \overline{\rho w s} \sim \overline{\rho_a} \cdot \overline{w' s'} \qquad s = (\frac{\rho_c}{\rho_a})$$



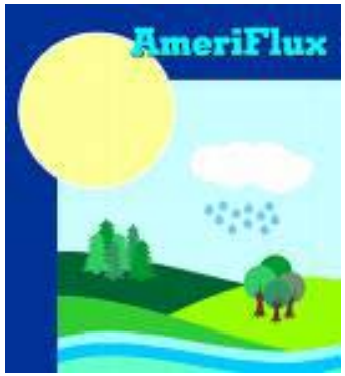
Objectives

- Network Background
- Time
  - Daily and Annual Integration
  - Seasonal Dynamics
  - Inter-Annual Variability
  - Disturbance/Chronosequence
- Processes
  - Photosynthesis = f(Q,T,functional type)
  - Respiration = f(T, growth, ppt, θ)
- Space
- Other Uses and Application
  - Ecosystem Modeling

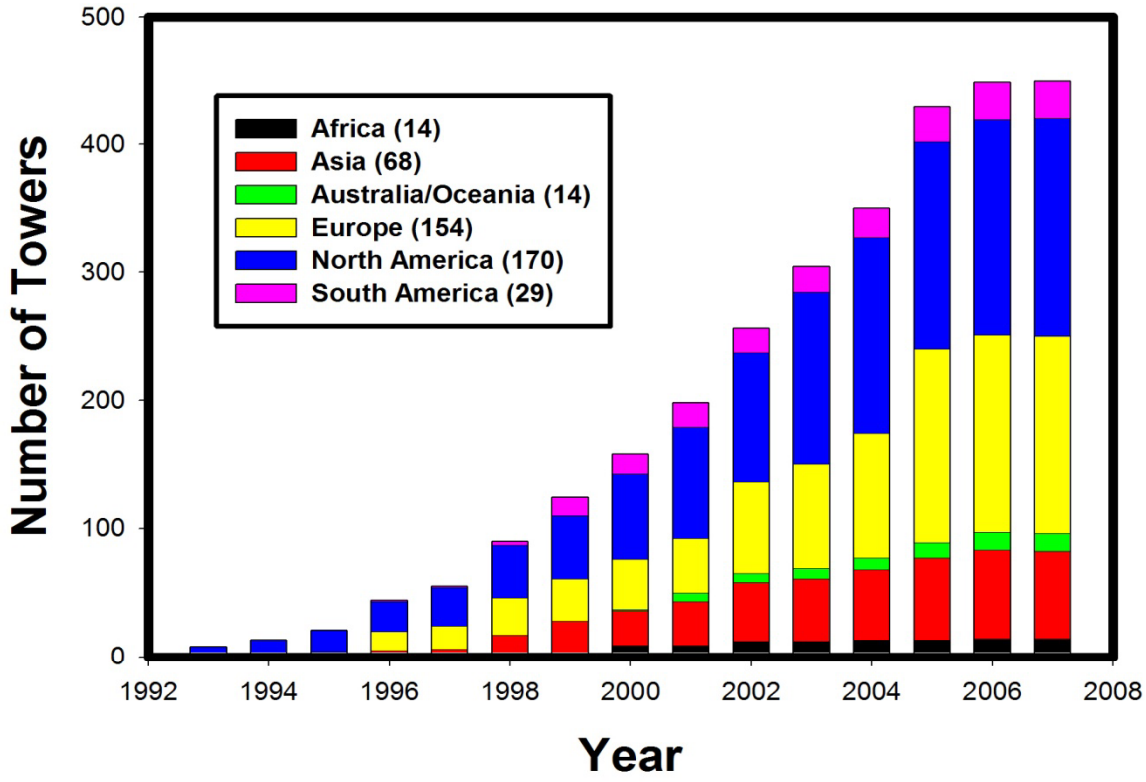
FLUXNET: From Sea to Shining Sea
400+ Sites, *circa* 2007



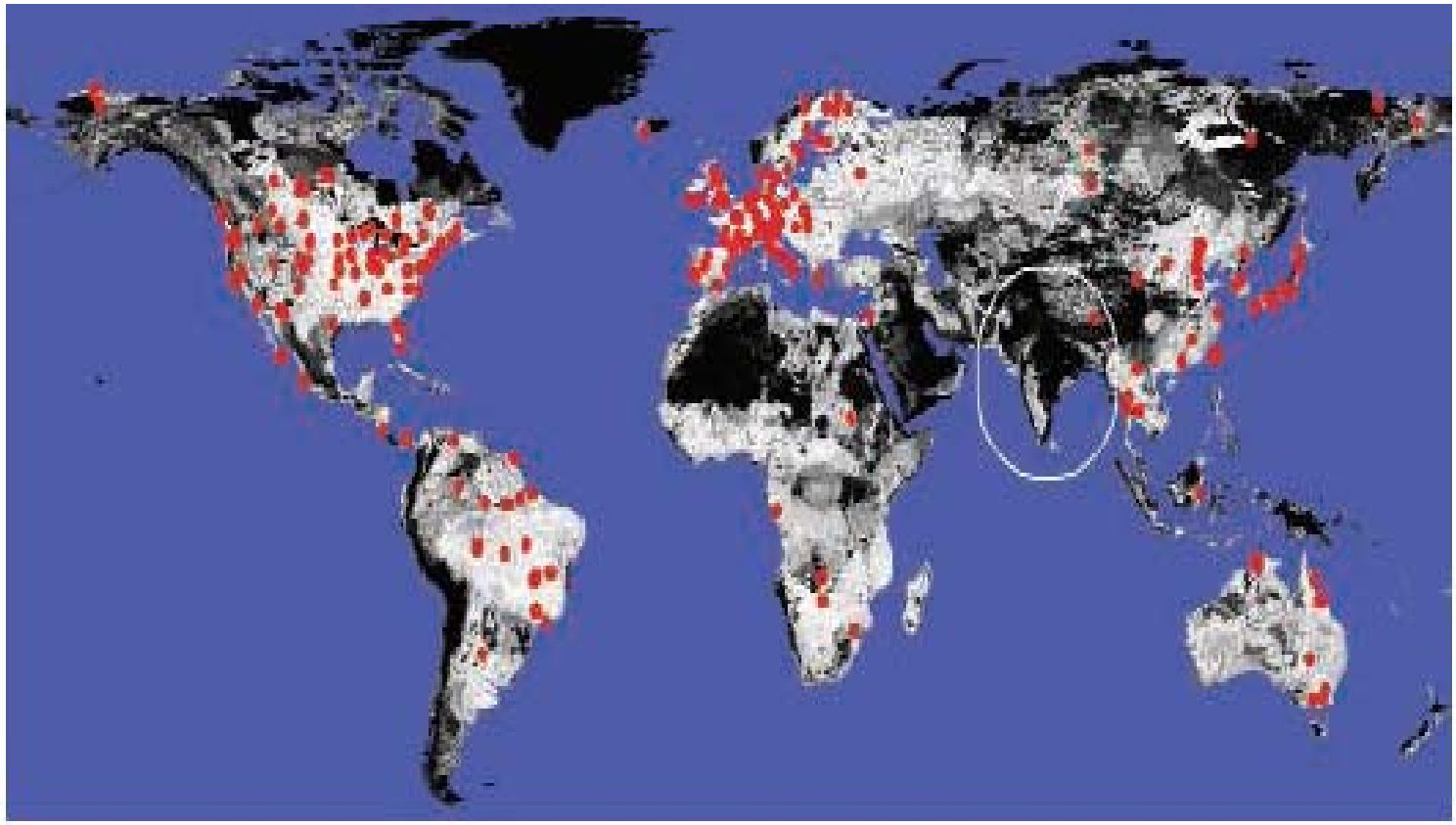
Flux Networks



Growth of Fluxnet
466 Towers as of March 30, 2007



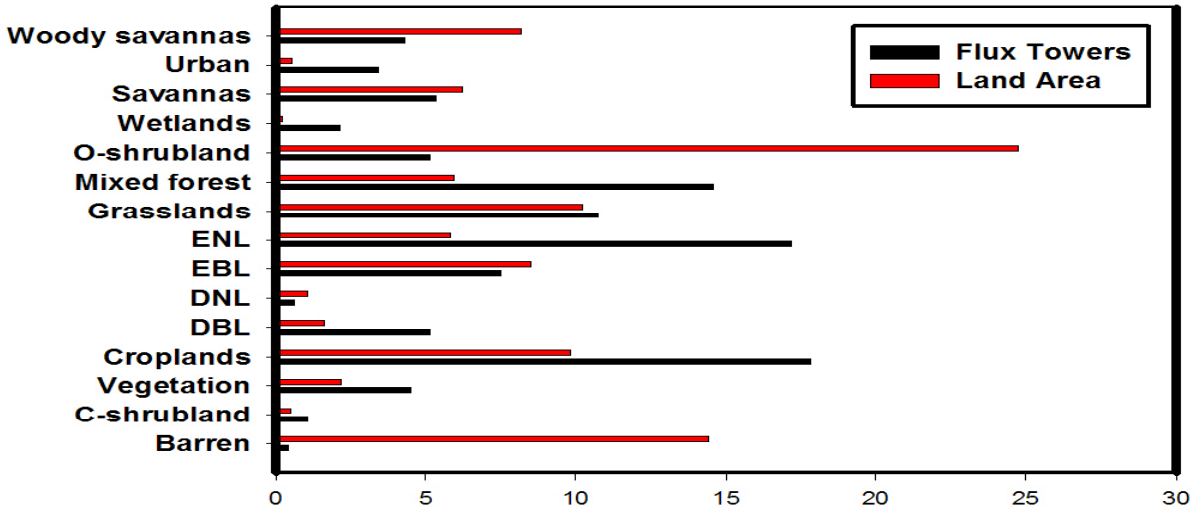
Network Representativeness



Sundareshwar et al, 2007 Science

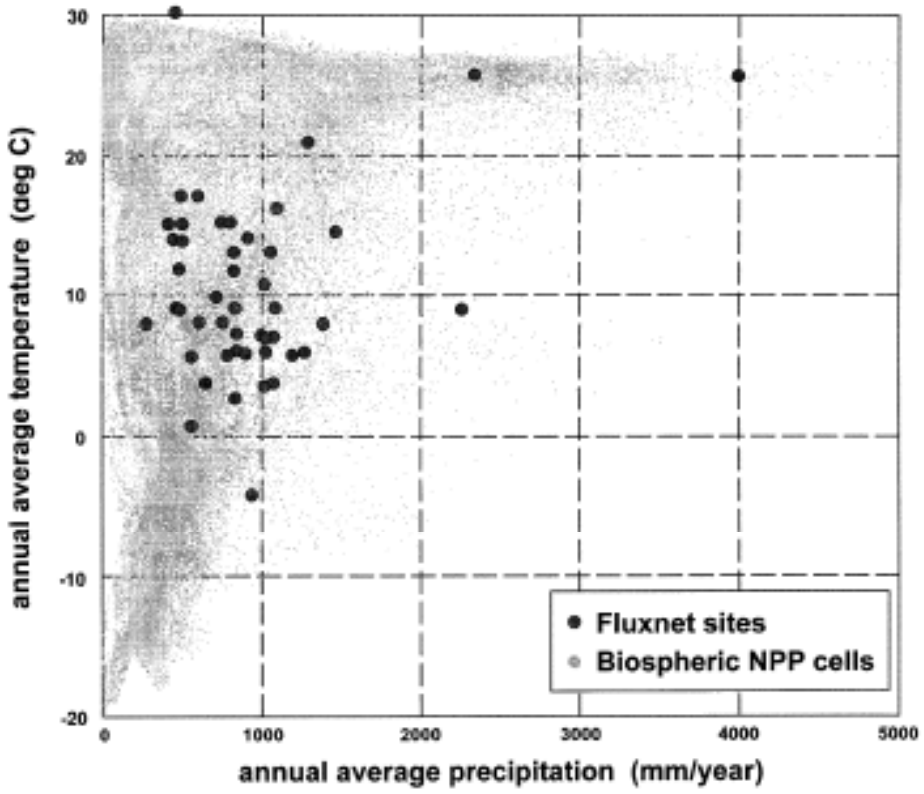
Distribution of Flux Towers by Landcover (MOD12Q1)

Black - 466 Flux Towers
Red - Land Area
March 2007



Landcover codes:
C-shrubland - closed shrubland
DBL - deciduous broadleaf
DNL - deciduous needeleaf
EBL - evergreen broadleaf,
ENL - evergreen needleleaf
O-shrubland - open shrubland

Global distribution of Flux Towers with Respect to Climate



Institutional Memory: Evolution of FLUXNET

- Measure Annual Cycle of NEE
  - Micromet issues of *Detrending*, *Transfer Functions*, Flux *Sampling and Measurements, Gap-filling, Error Assessment*
- Measure and Interpret Intra-annual Variation of NEE
  - Flux partitioning (GPP & R_{eco}); assessment of metadata,e.g. V_{cmax}, soil respiration, LAI, biomass inventories.
  - Quantifying Biophysical Controls on Fluxes
- Measure and Interpret Inter-annual variations of NEE
- Measure NEE over multiple Land-Use Classes
  - crops, grasslands, deciduous and evergreen broadleaf and conifer forests
  - Disturbance, logging, biodiversity and fire
- Manipulative Studies
  - Nitrogen and H_2O additions
- Measure NEE over Representative Areas
  - Scaling Flux Information of Footprint to MODIS pixel

- Workshops
  - LaThuile Italy, 1995
  - Flathead Lake MT, 1997
  - Marconi CA, 2000
  - Orvieto Italy, 2002
  - Lake Tahoe CA, 2003
  - Firenze Italy, 2004
  - LaThuile, 2007

FLUXNET Successes

- 'Mountains' of data from a spectrum of canopy roughness and stability conditions, functional types and climate spaces have been collected
- A Model for Data Sharing
  - FLUXNET Web Site, a venue for distributing Primary, Value-added and Meta-Data products
- Value-Added Products have been produced
  - Development of Gap-Filling Techniques
  - Production of Gap-Filled Daily and Annual Sums
- Many New Findings on Emergent Processes, Environmental Controls and Seasonality and Annual C fluxes
- Data for Validating and Improving SVAT models used for weather, climate, biogeochemistry and ecosystem dynamics
- Collaboration & Synthesis through Workshops and Hosting Visitors
  - Building a Collaborative, Cooperative, Multi-Disciplinary & International Community of Researchers
- Training New and Next Generation of Scientists, Postdocs, Students

LaThuile Fluxnet Workshop, Feb. 2007

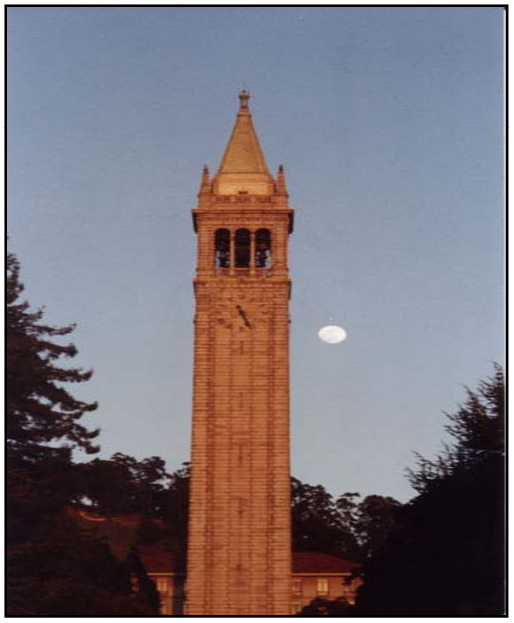
- New Gap-Filled, Qa/Qc Dataset
- 250 Sites; 930 Site-years of Data
- www.fluxdata.org

‘Failures’/’Un-resolved’ Issues

- Not Measuring Night-time Fluxes Well
  - ImPerfect U* correction
- Not Measuring Fluxes over Complex terrain and during Advection Well
- ImPerfect Flux Partitioning
  - Works Better on Longer Time Scales
- ImPerfect Energy Balance Closure
  - Could be ‘red-herring’ based limited Rn and G fetch
- Need Better Outreach and Training
  - Being Rectified at LaThuile with Participation of New Generation of Fluxnet Scientists

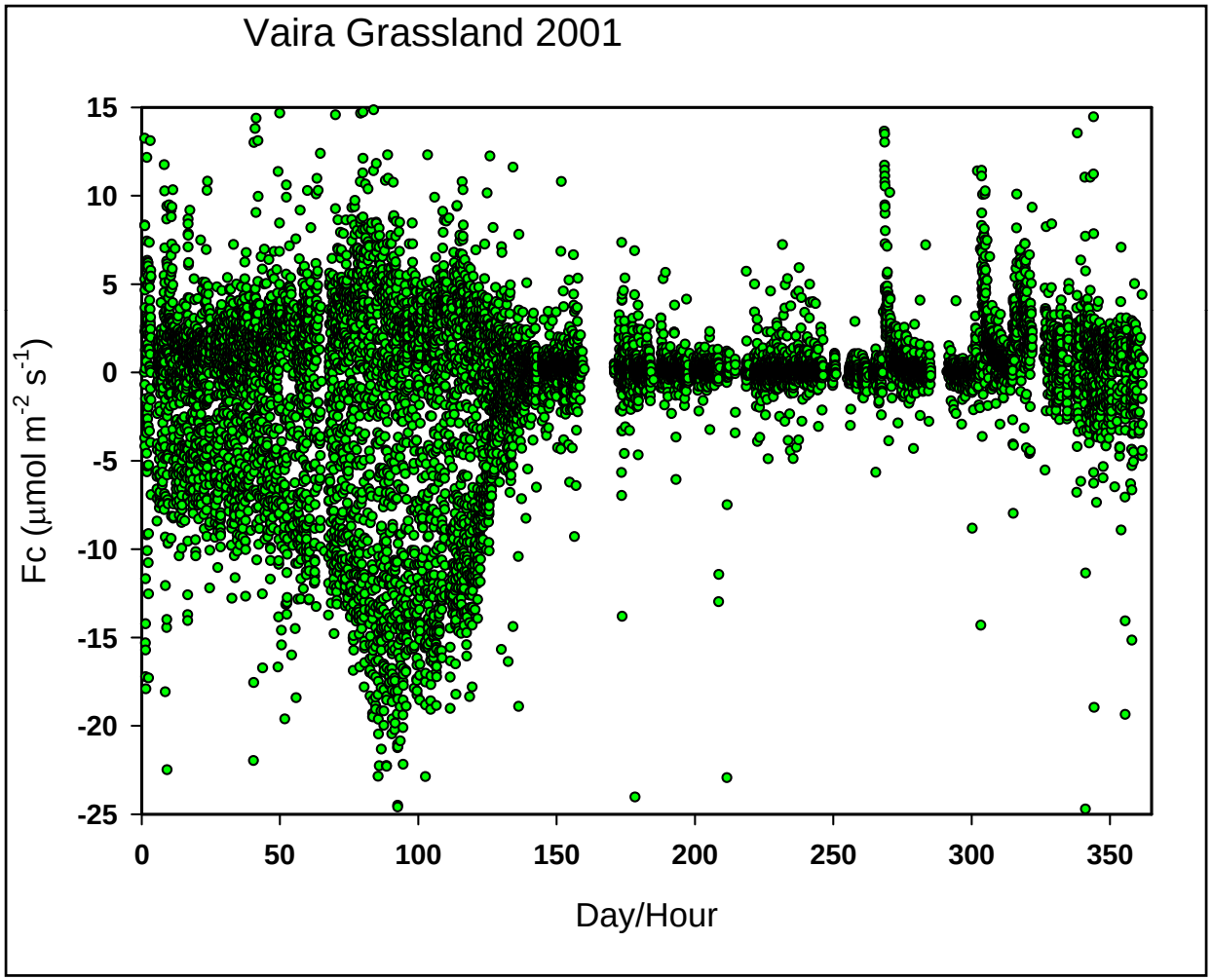
Temporal Dynamics of C Fluxes

- Hour
- Day
- Month
- Season
- Year
- Multiple Years



- Pulses
- Lags
- Switches

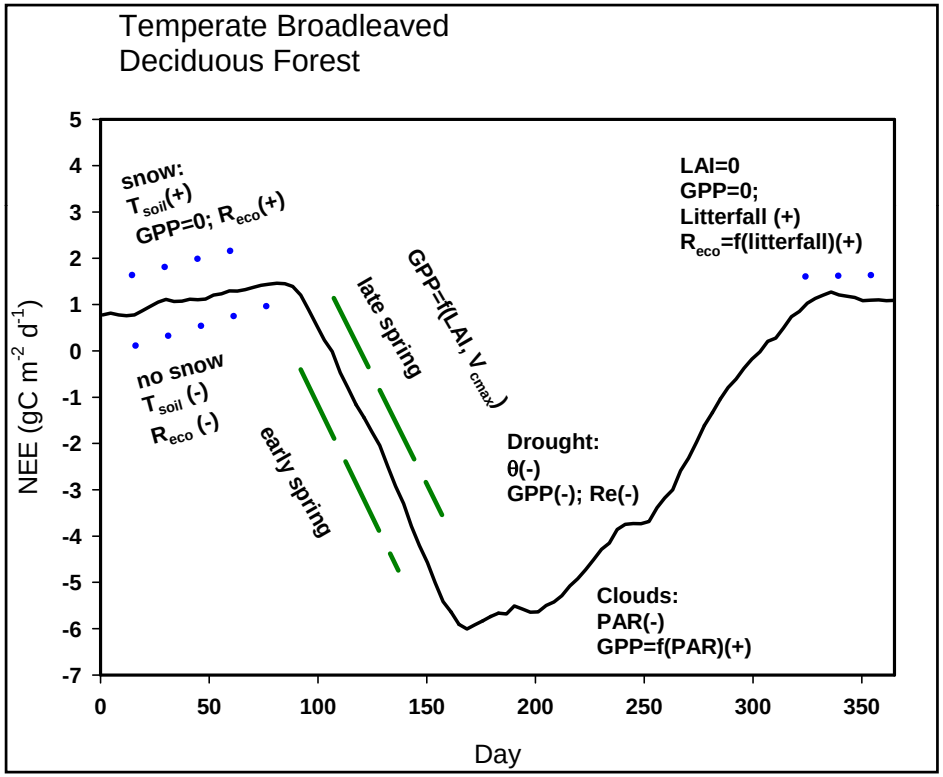
Annual Time Series of Trace Gas Exchange



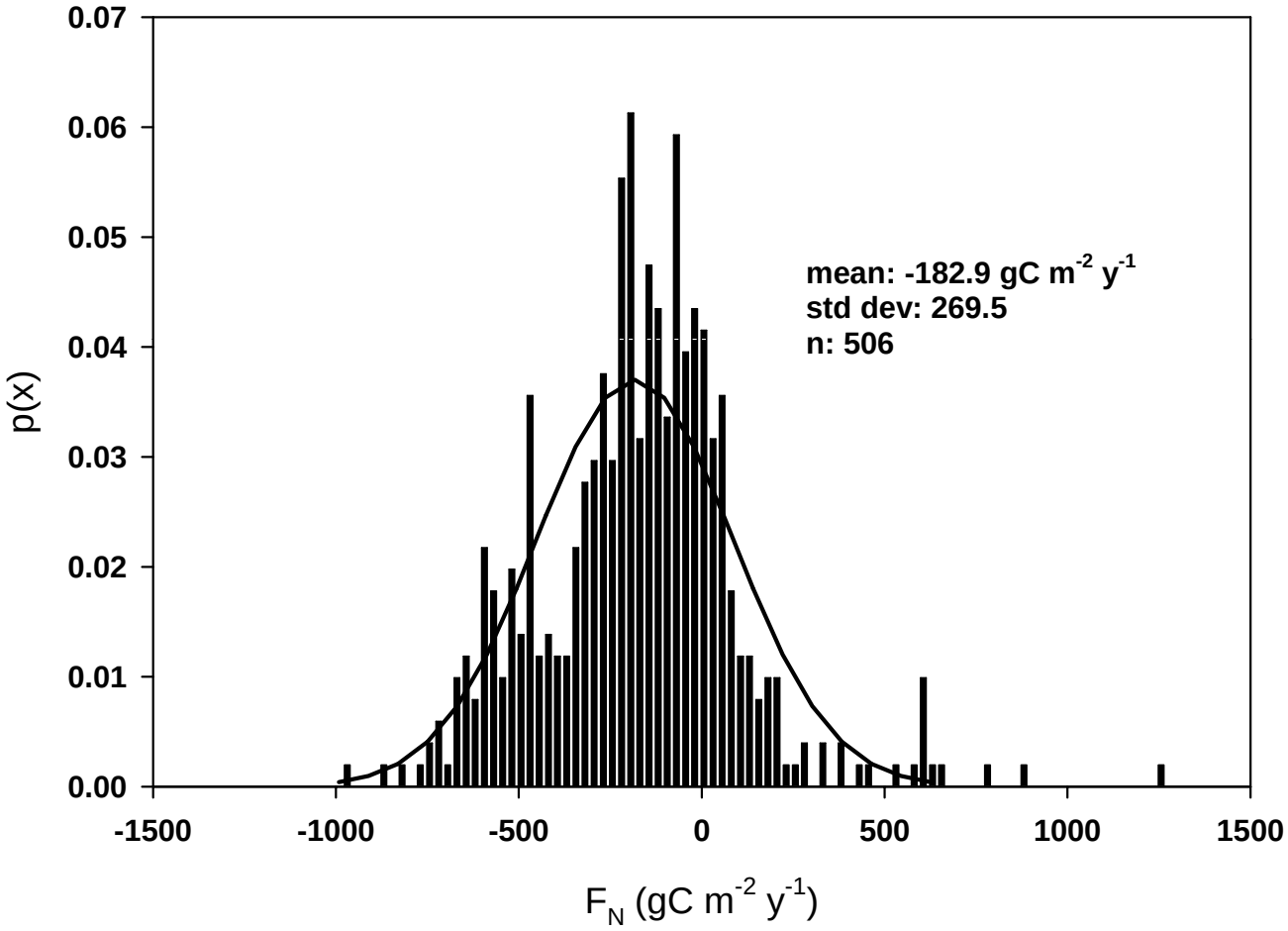
Xu and Baldocchi, AgForMet, 2004

Complicating Dynamical Factors

- Switches
  - Phenology
  - Drought
  - Frost/Freeze
- Pulses
  - Rain
  - Litterfall
- Emergent Processes
  - Diffuse Light/LUE
- Acclimation
- Lags
- Stand Age/Disturbance

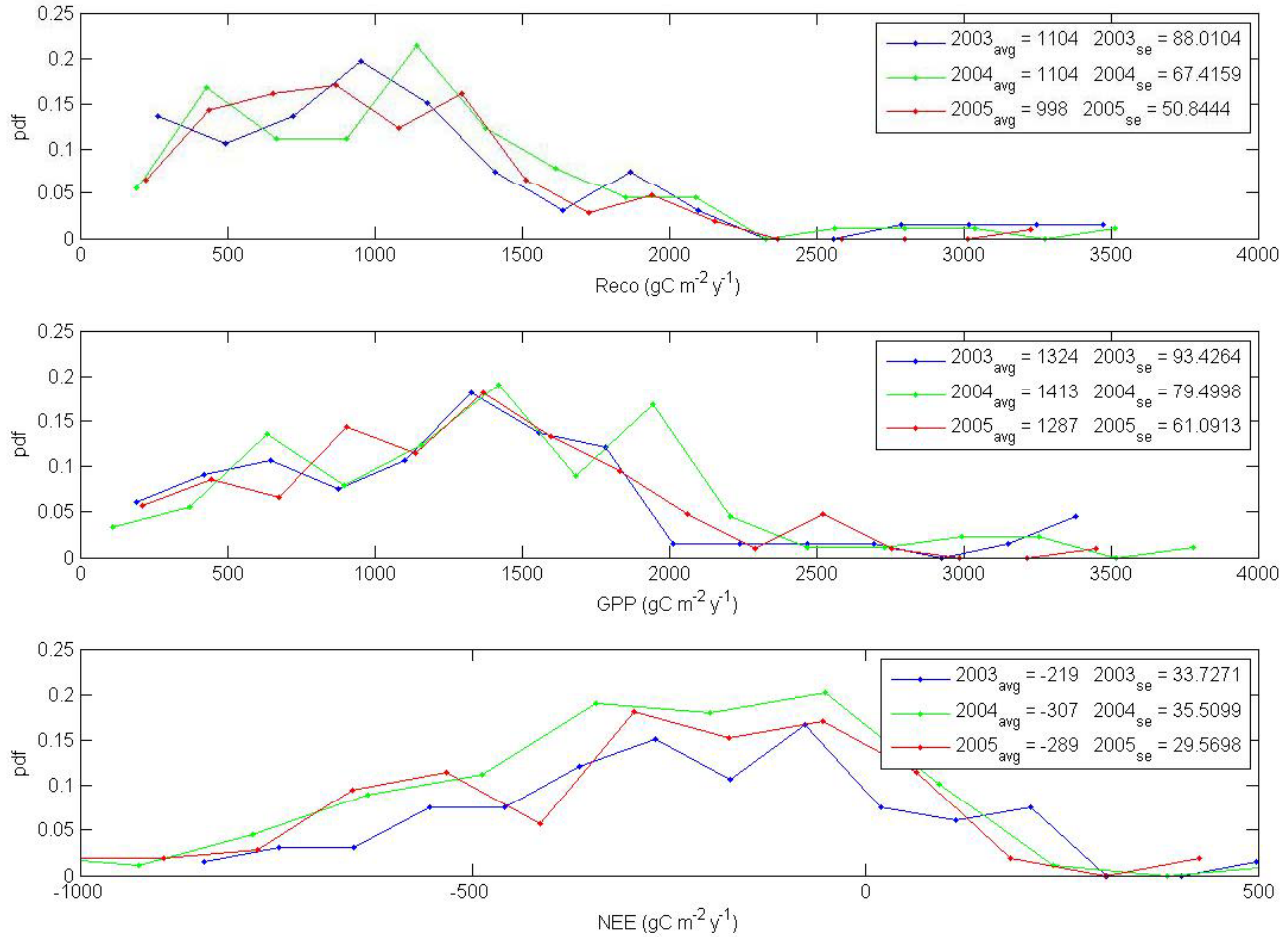


Probability Distribution of Published NEE Measurements, Integrated Annually



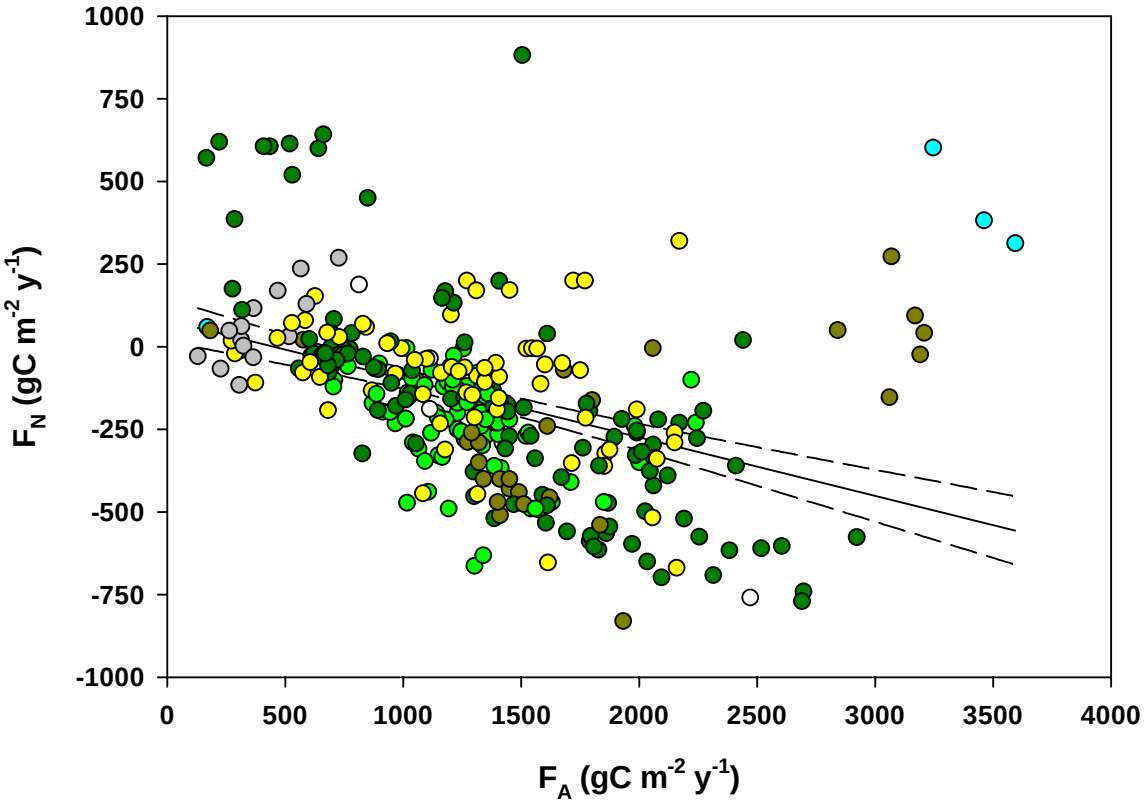
Baldocchi, Austral J Botany, in press

Does pdf change with Time and/or as the Network Grows?



FLUXNET Database: n ~ 300 in 2003; n ~ 430 in 2005

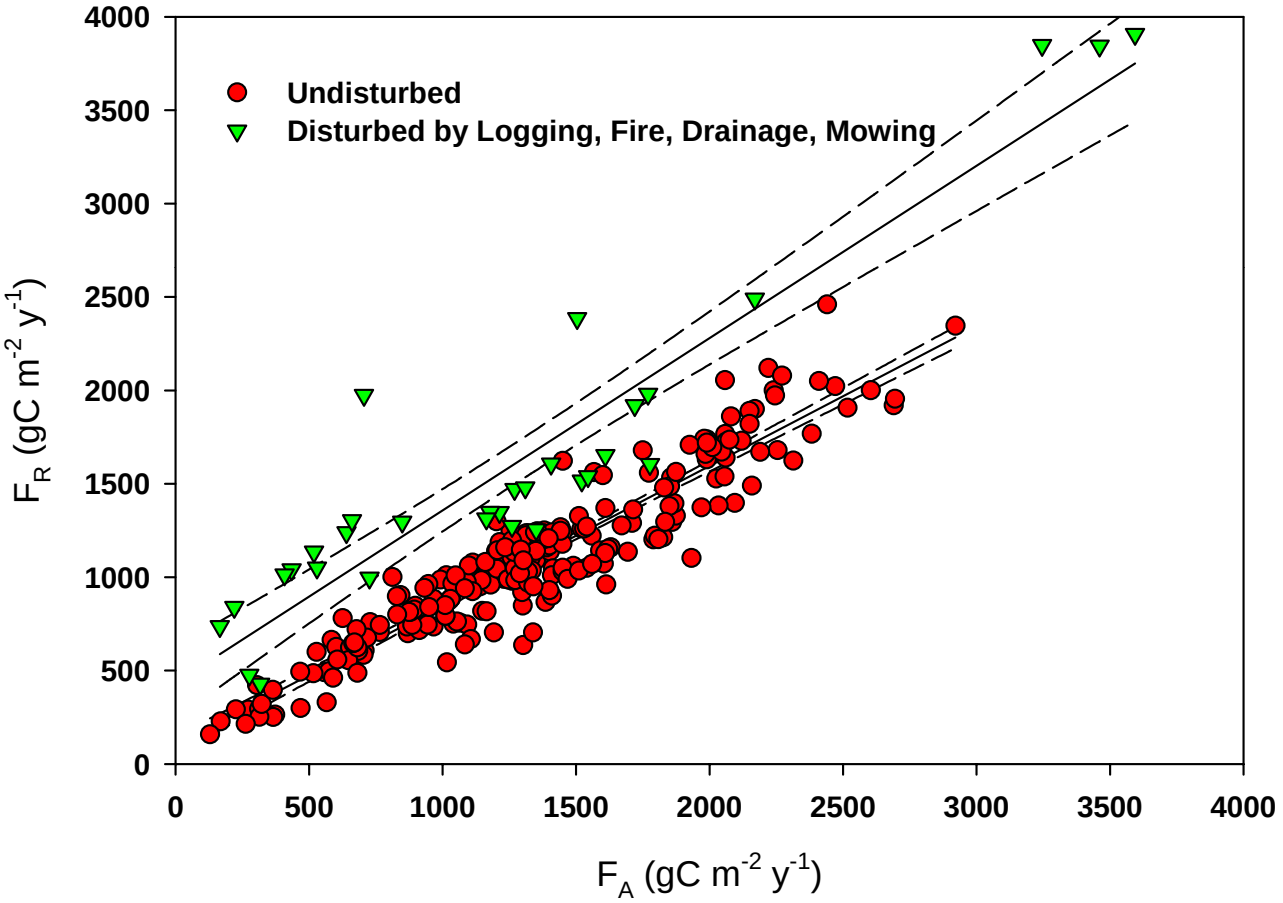
Does Net Ecosystem Carbon Exchange Scale with Photosynthesis?



Ecosystems with greatest GPP don't necessarily experience greatest NEE

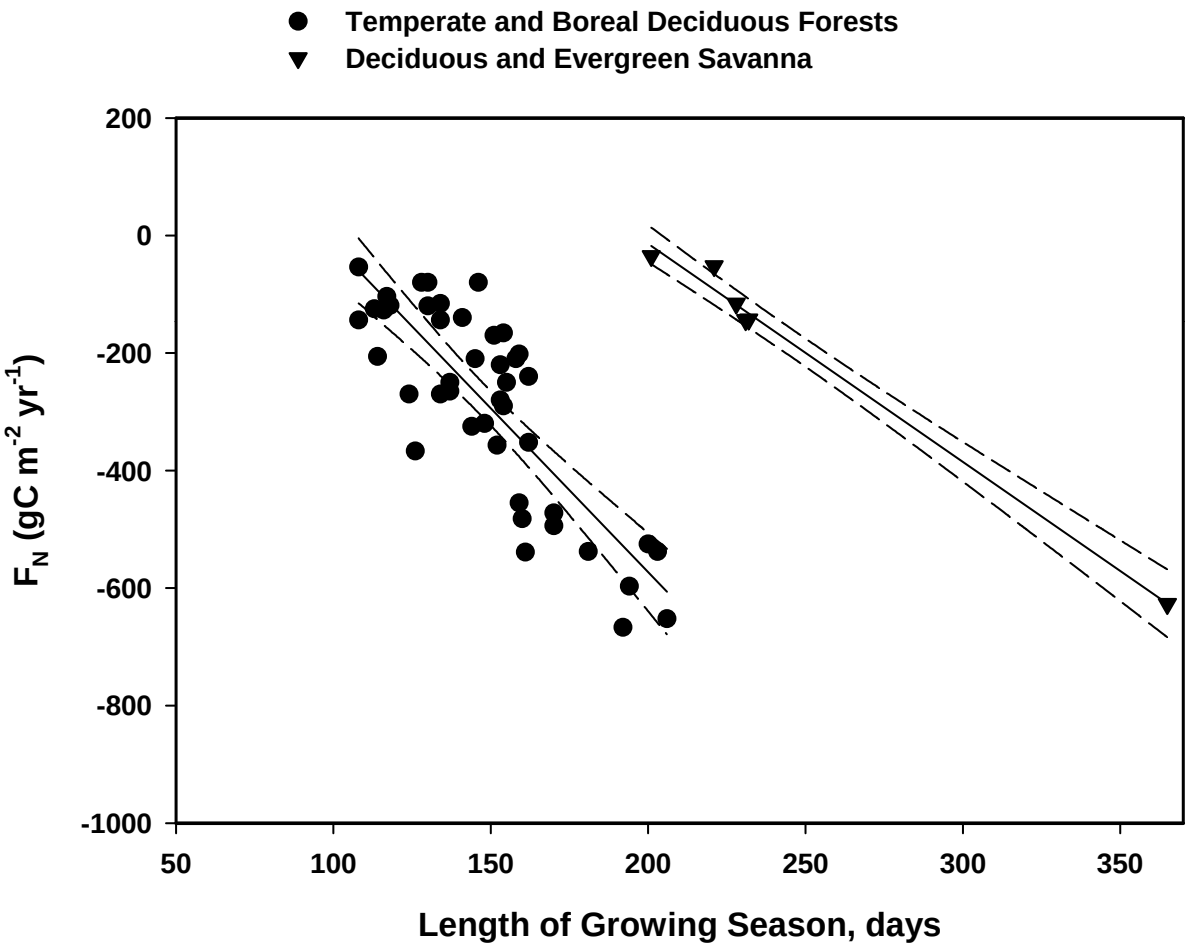
Baldocchi, Austral J Botany, in press

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



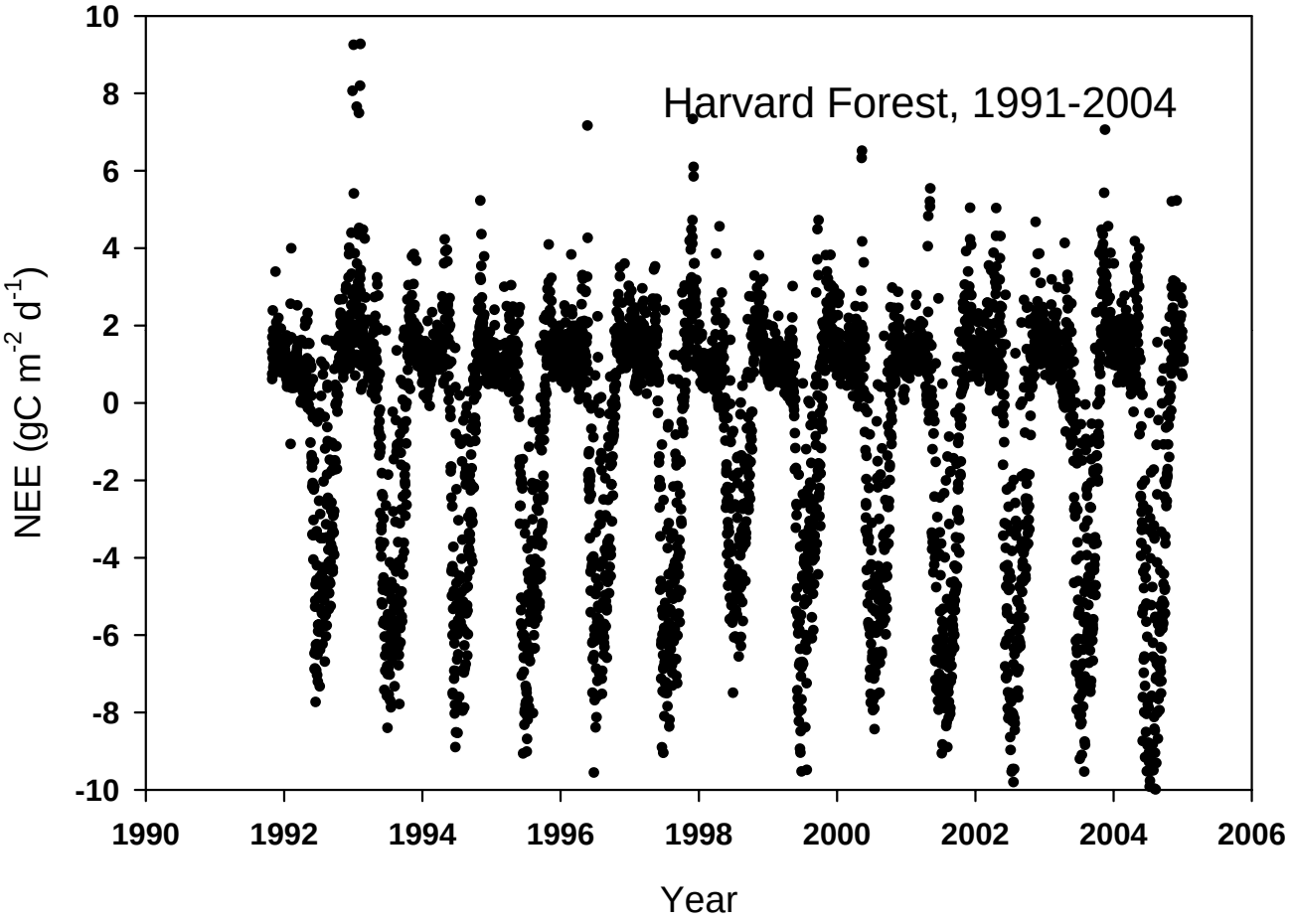
Baldocchi, Austral J Botany, in press

Net Ecosystem Carbon Exchange Scales with Length of Growing Season



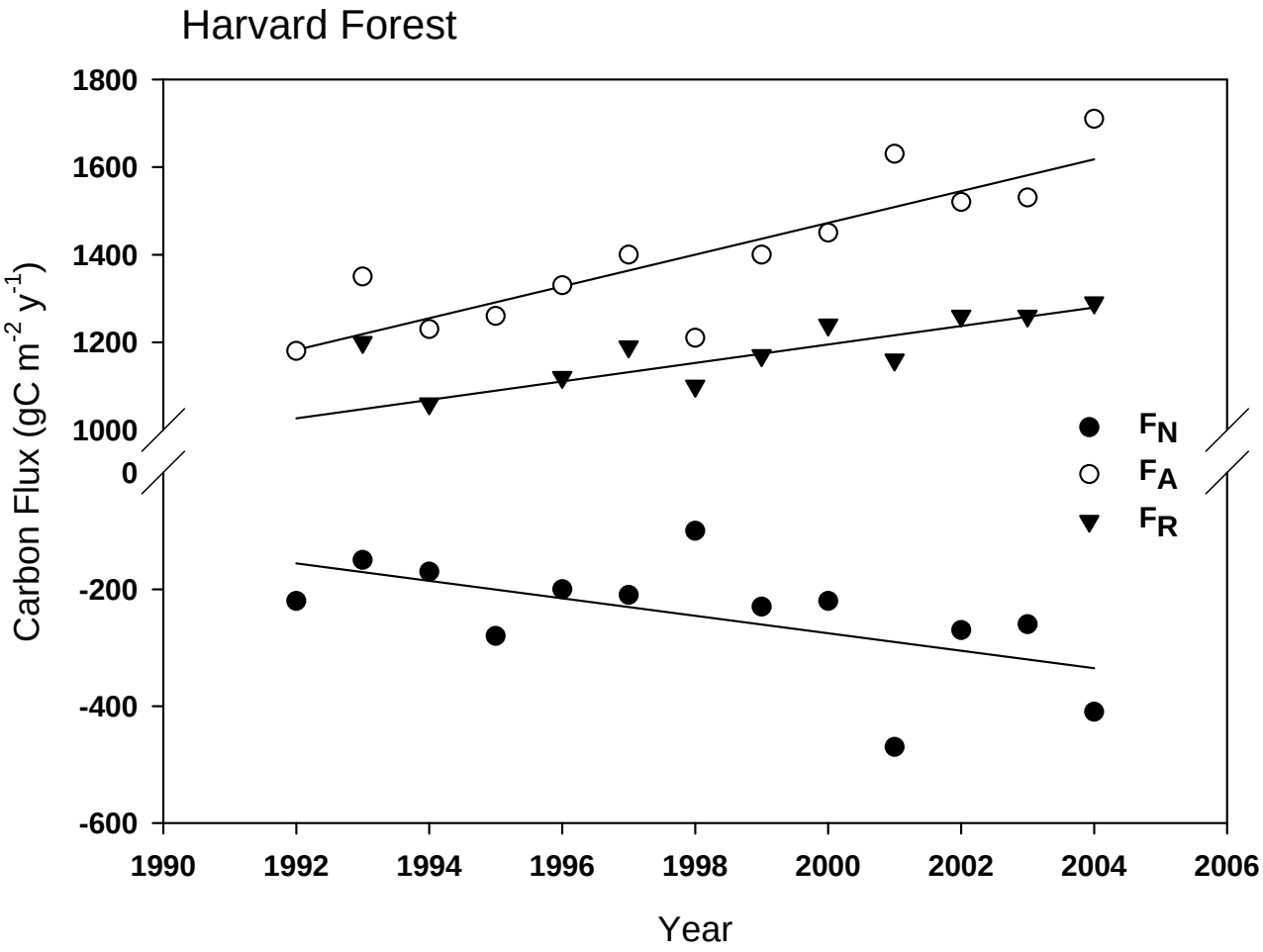
Baldocchi, Austral J Botany, in press

Decadal Plus Time Series of NEE:
Flux version of the Keeling's Mauna Loa Graph



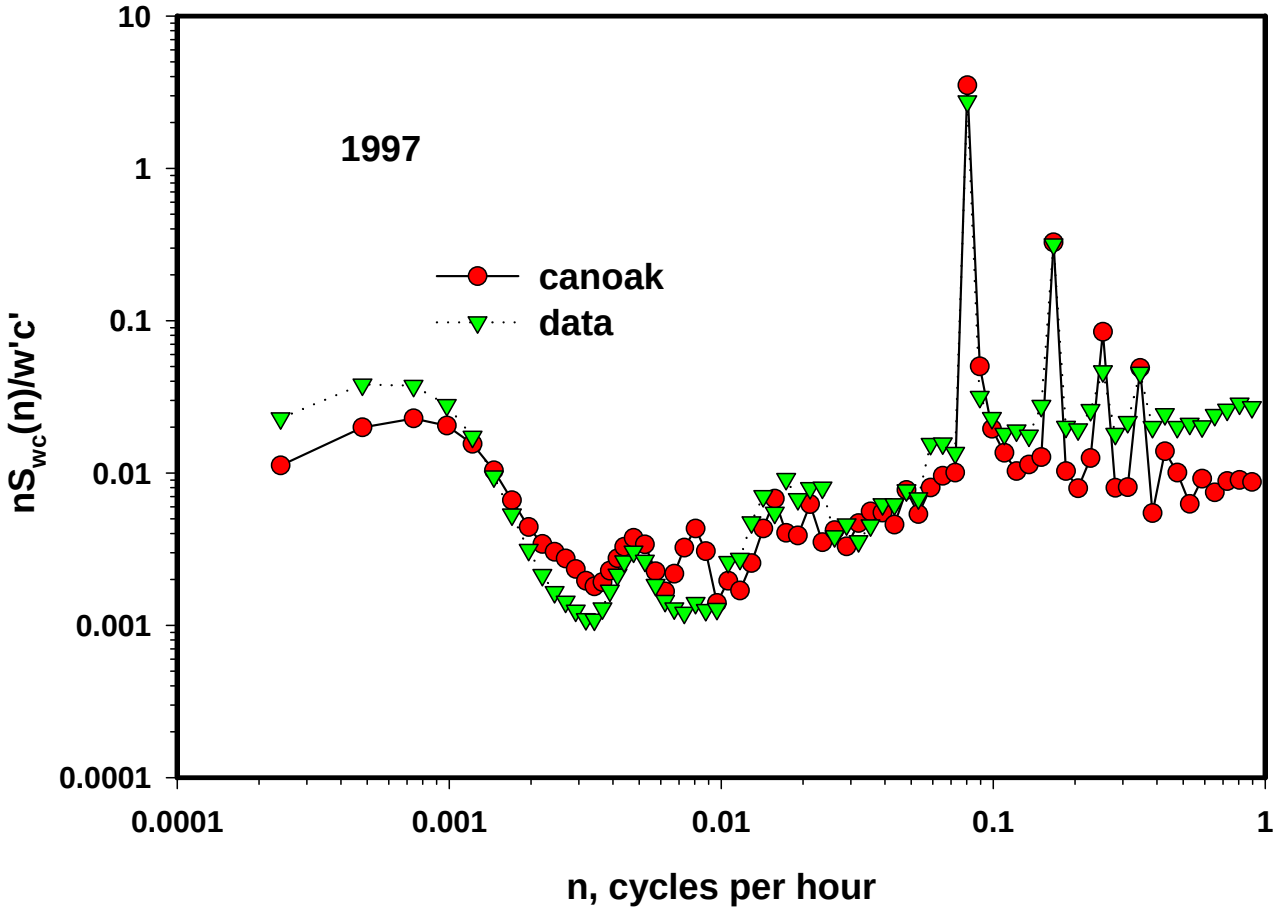
Data of Wofsy, Munger, Goulden, et al.

Interannual Variation and Long Term Trends in Net Ecosystem Carbon Exchange (F_N), Photosynthesis (F_A) and Respiration (F_R)



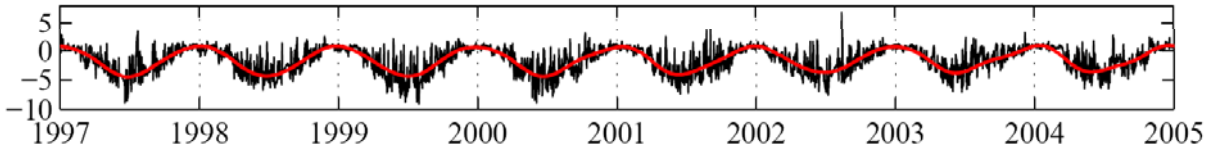
Urbanski et al 2007 JGR

Power Spectrum of CO_2 Fluxes



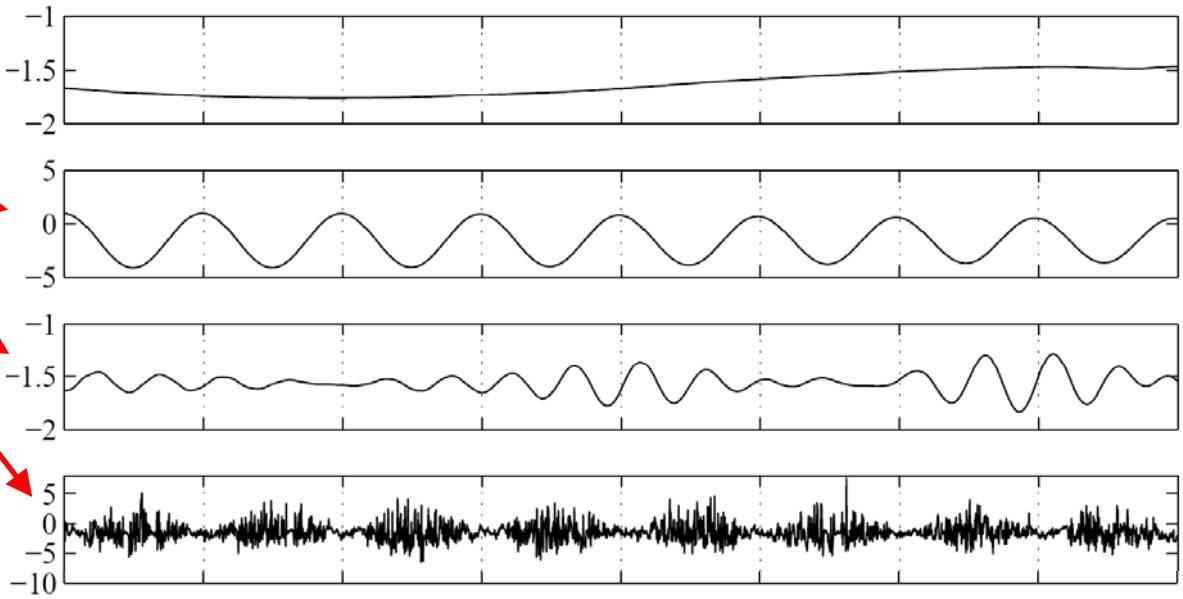
Singular System Analysis: example application

Original time series:



Decomposed time series:

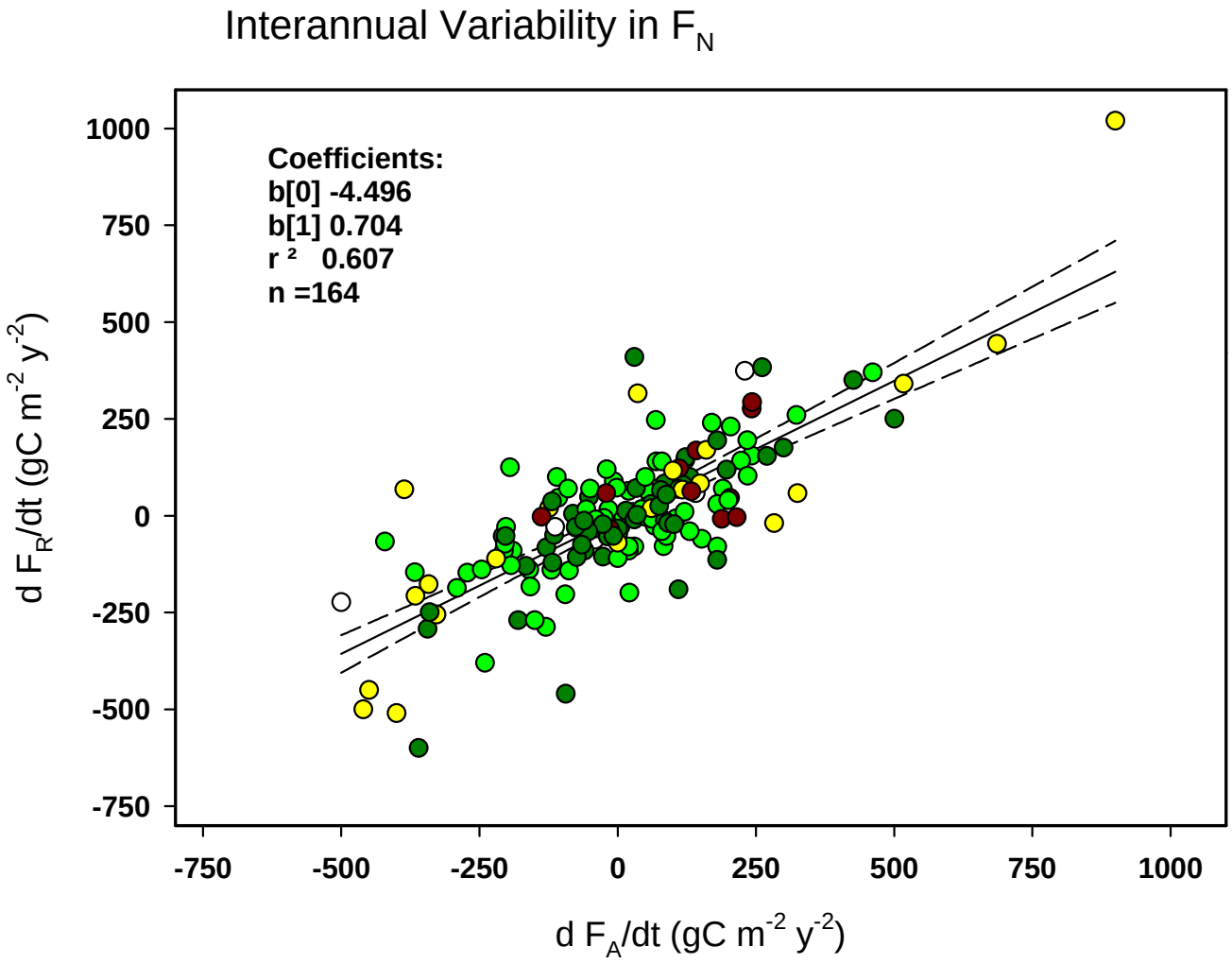
- **Nonlinear trend**
- Annual cycle
- Intra-annual cycle
- High frequency modes



New developments allow application of SSA to fragmented time series

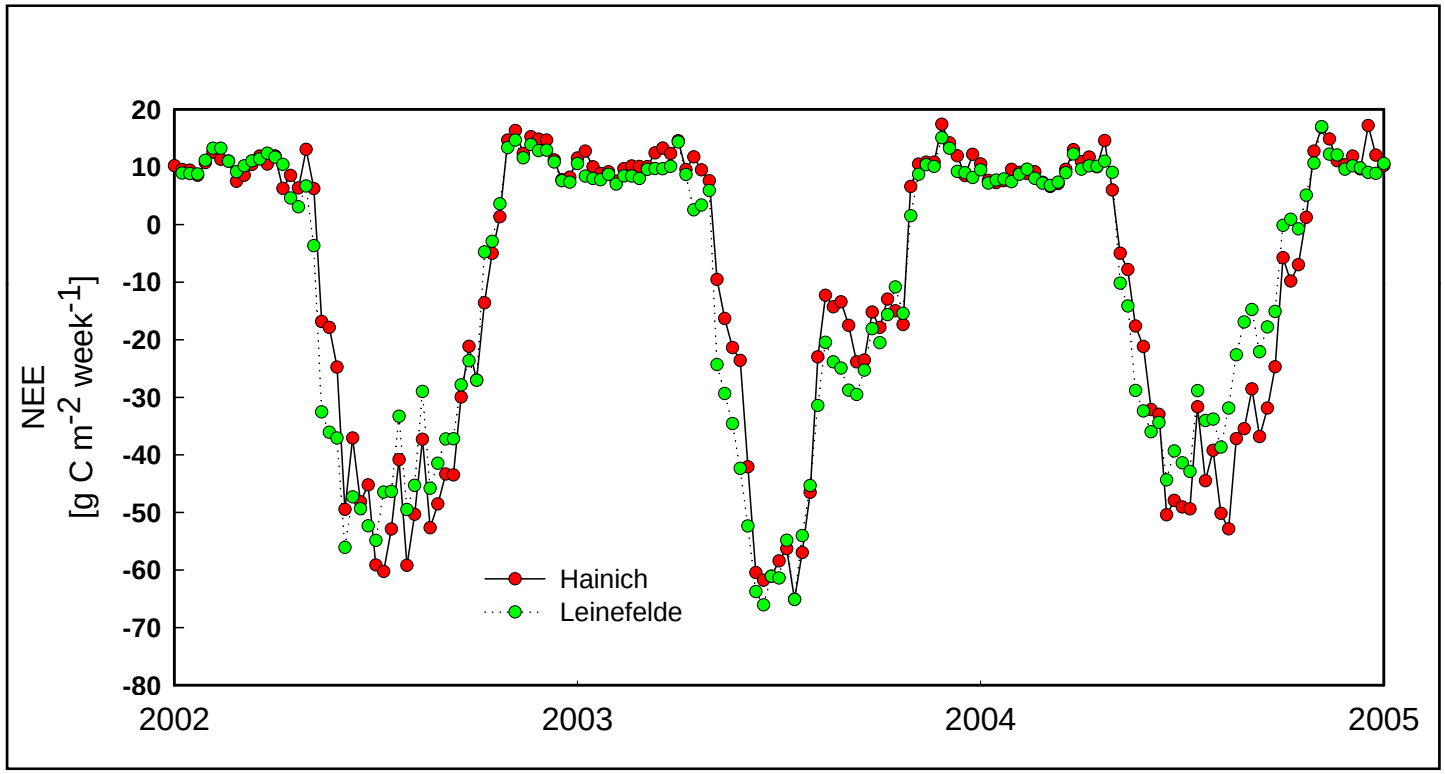
Mahecha et al. (2007) *Biogeosciences*, **4**, 743-758

Interannual Variations in Photosynthesis and Respiration are Coupled



Baldocchi, Austral J Botany, in press

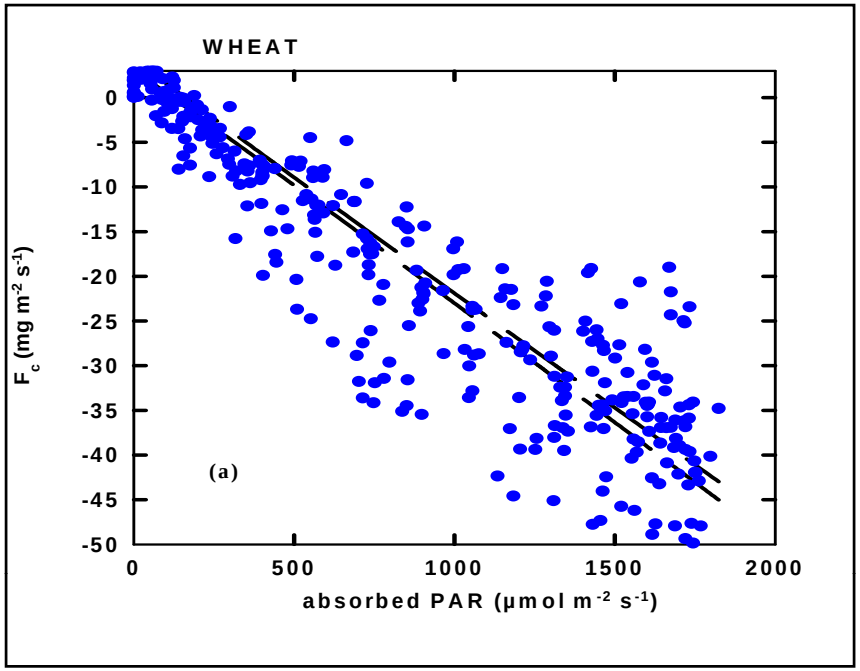
Lag Effects Due to 2003 European Drought/Heat Stress

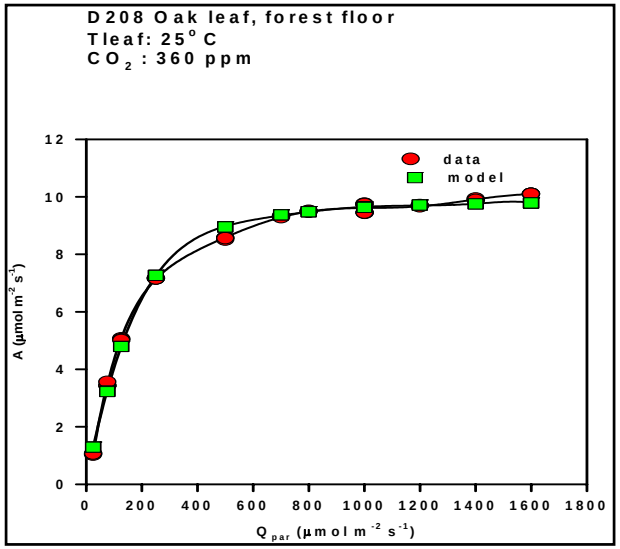


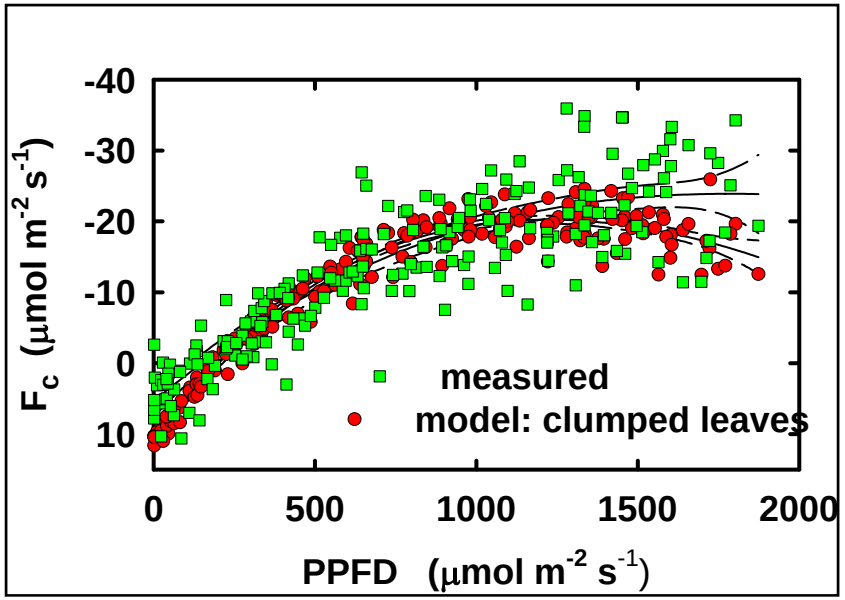
Knohl et al Max Planck, Jena

Emerging Processes

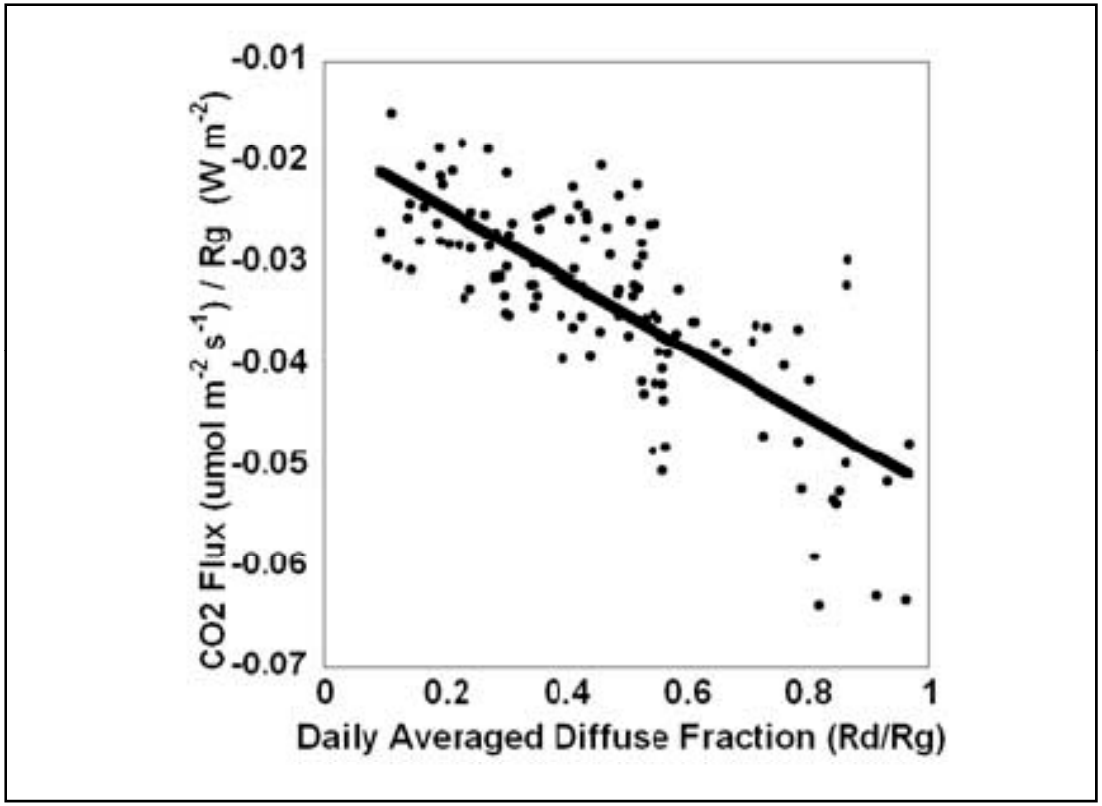
Light and Photosynthesis: Emergent Processes at Leaf and Canopy Scales







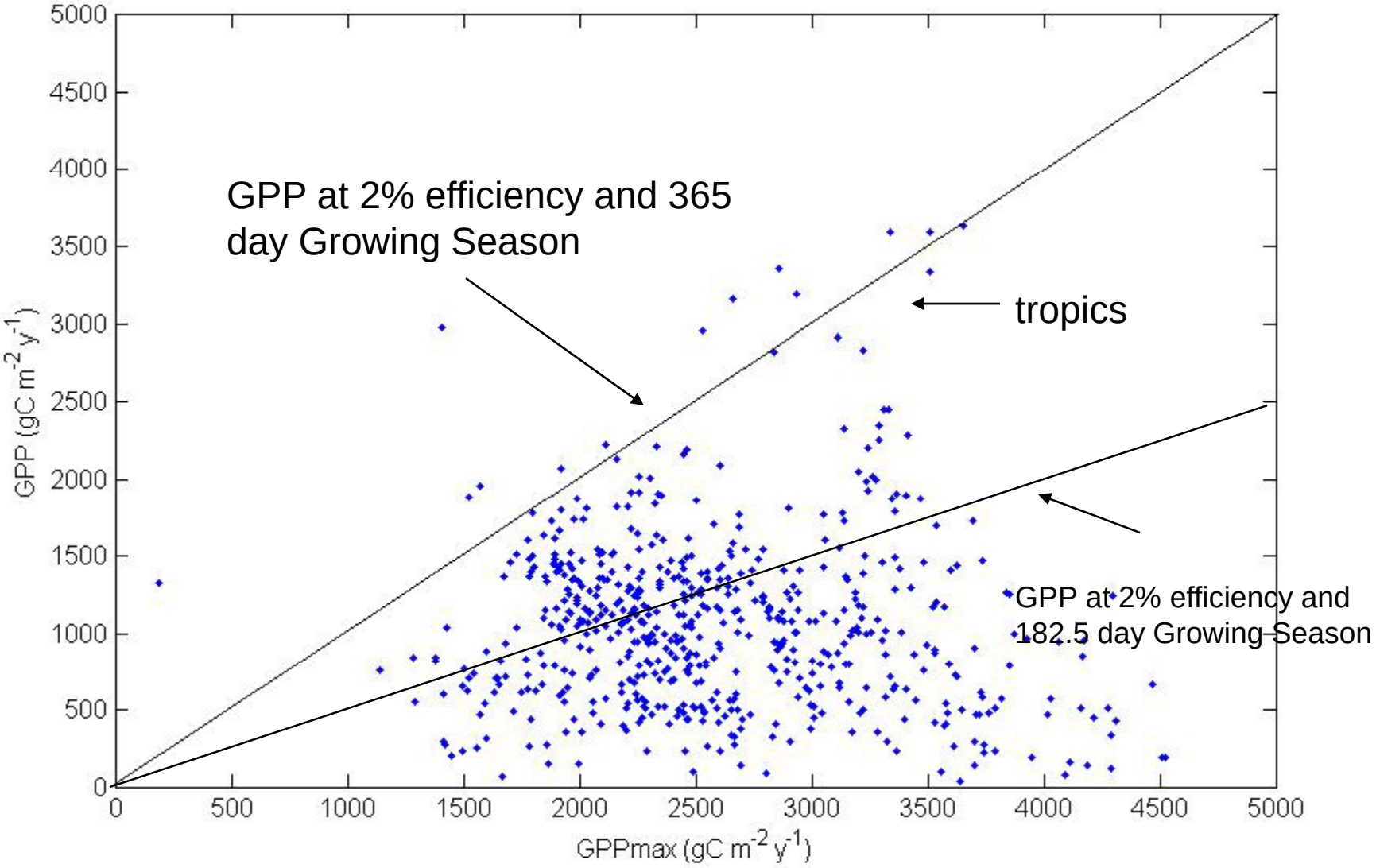
Emergent Scale Process: CO_2 Flux and Diffuse Radiation



•We are poised to see effects of Cleaner/Dirtier Skies and Next Volcano

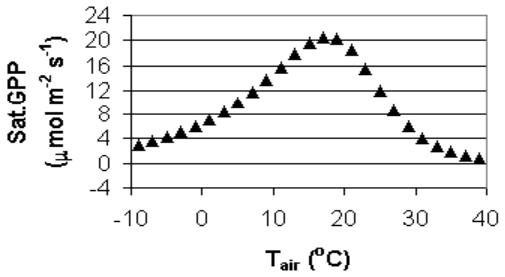
Niyogi et al., GRL 2004

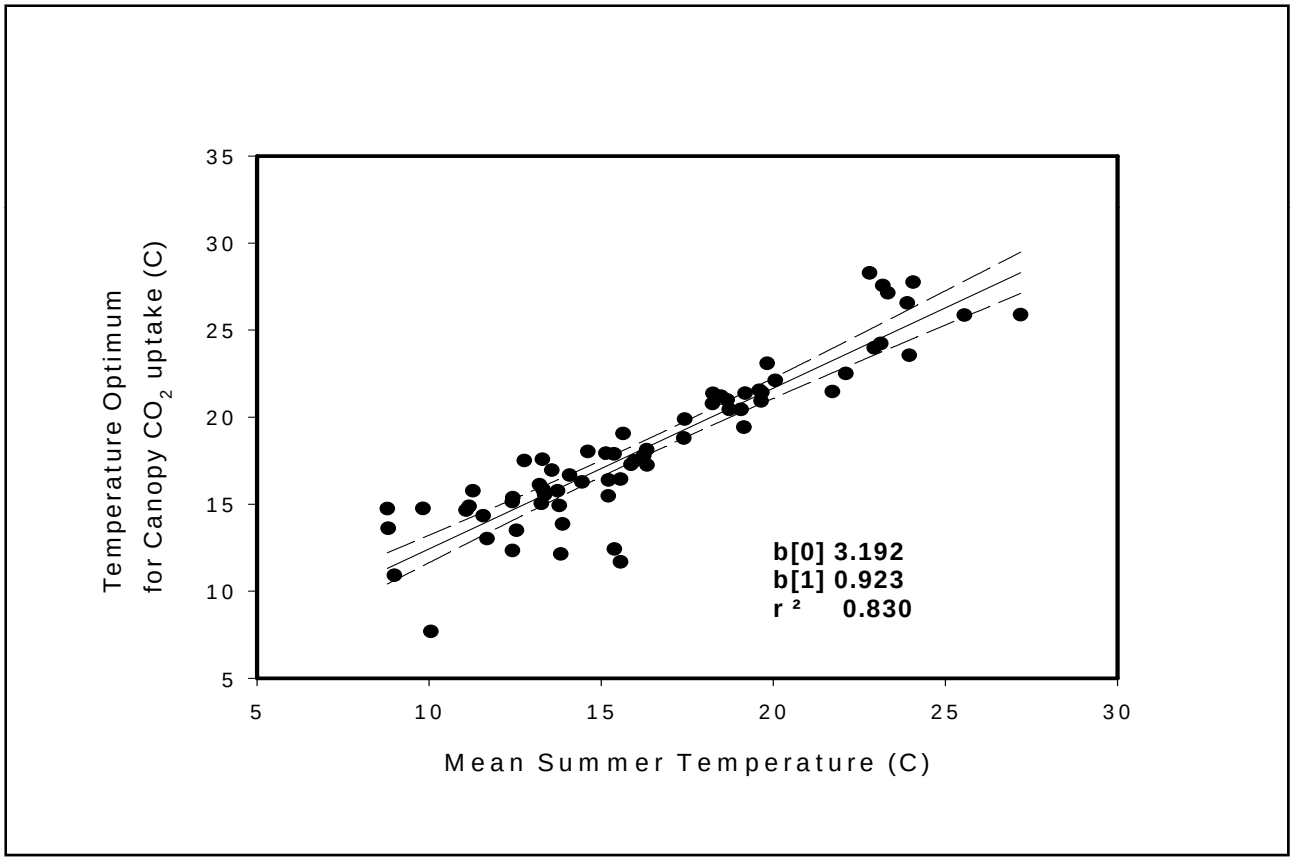
Potential and Real Rates of Gross Carbon Uptake by Vegetation: Most Locations Never Reach Upper Potential



FLUXNET 2007 Database

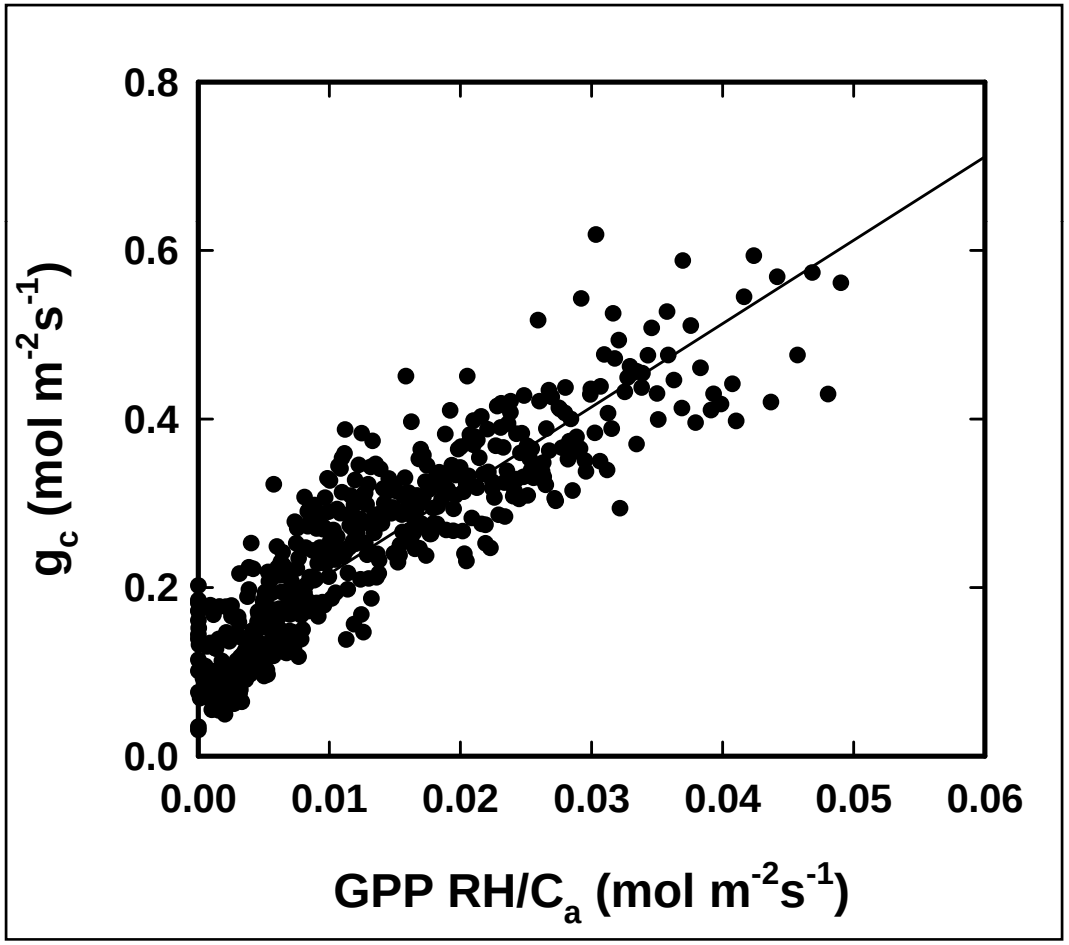
Optimal NEE: Acclimation with Temperature





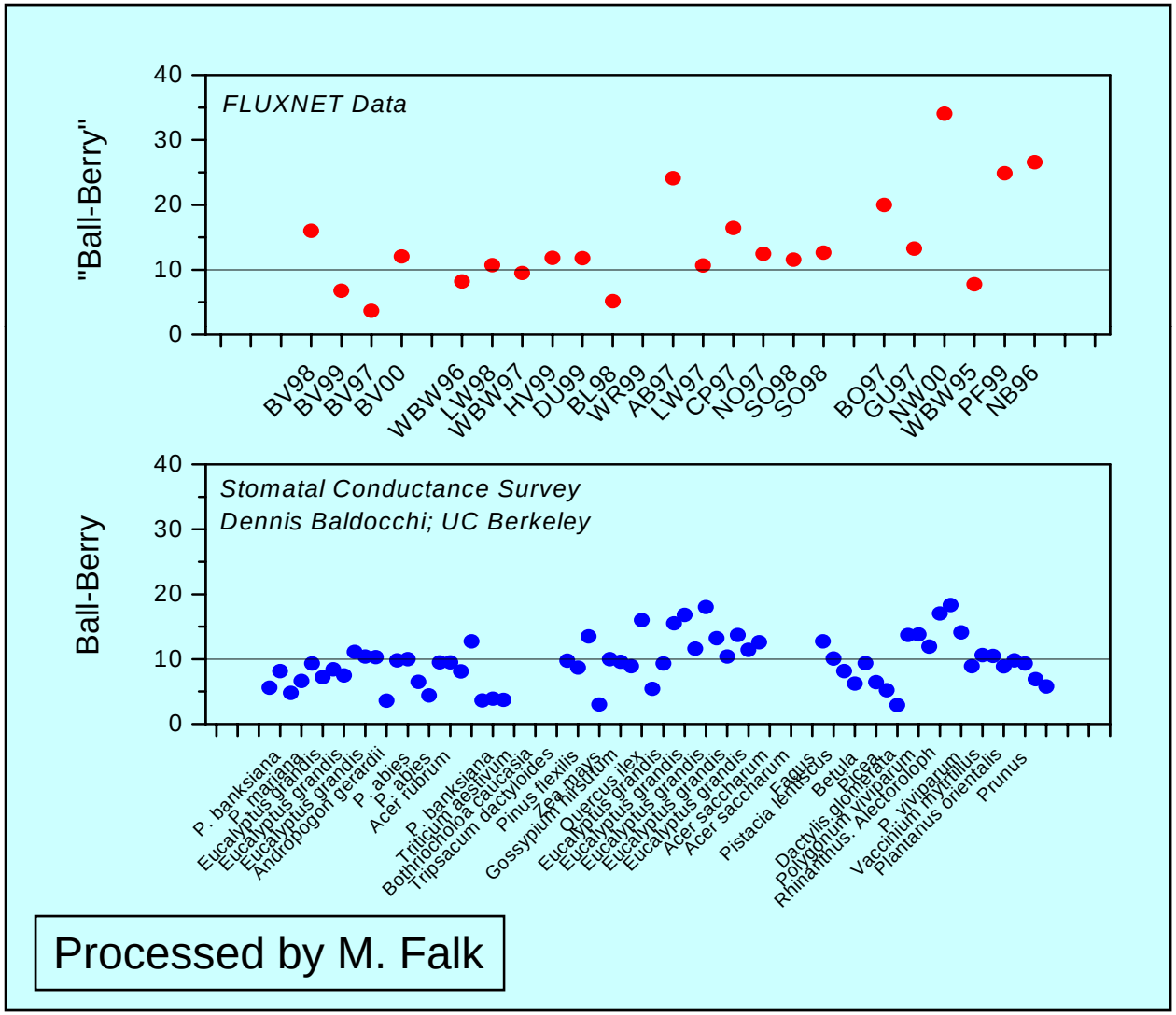
E. Falge et al 2002 AgForMet; Baldocchi et al 2001 BAMS

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



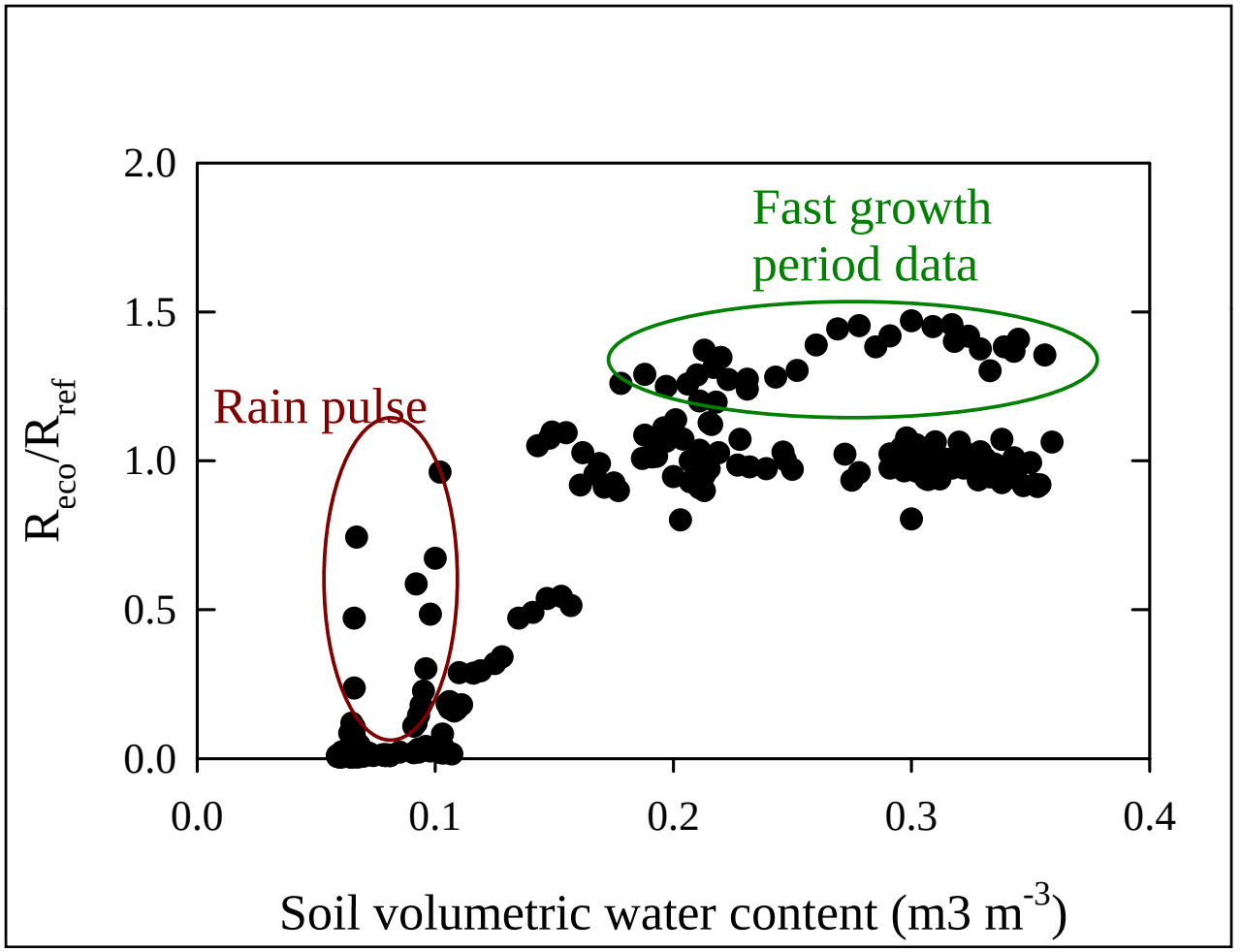
Xu + DDB, 2003 AgForMet

Gc Scale Invariance?
Task to Expand with New Database



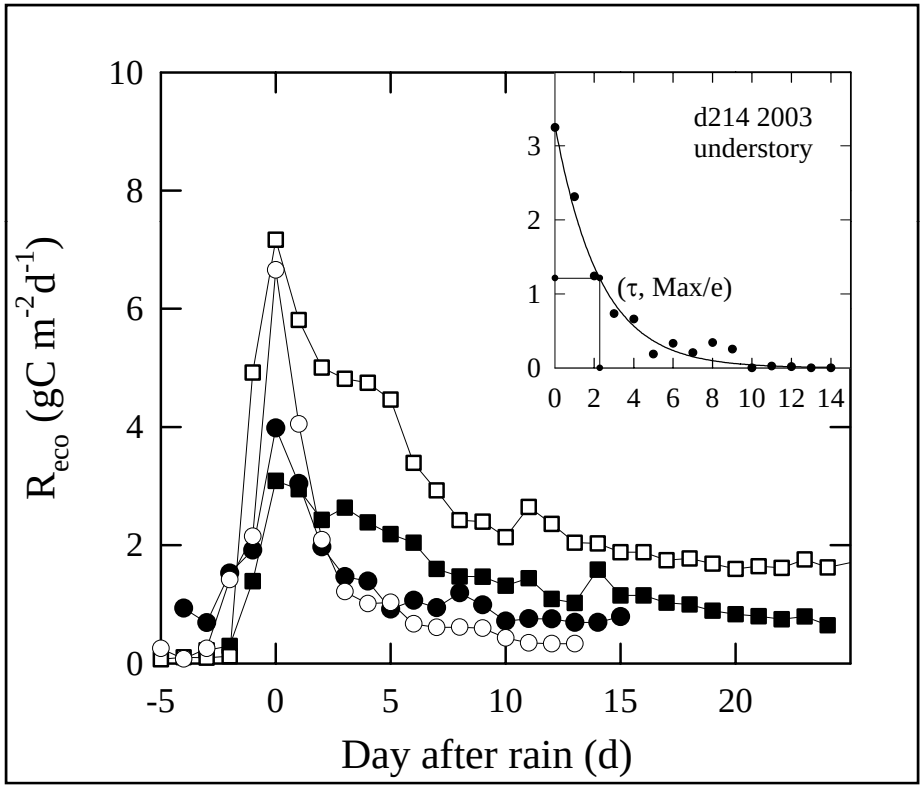
Processed by M. Falk

Environmental Controls on Respiration



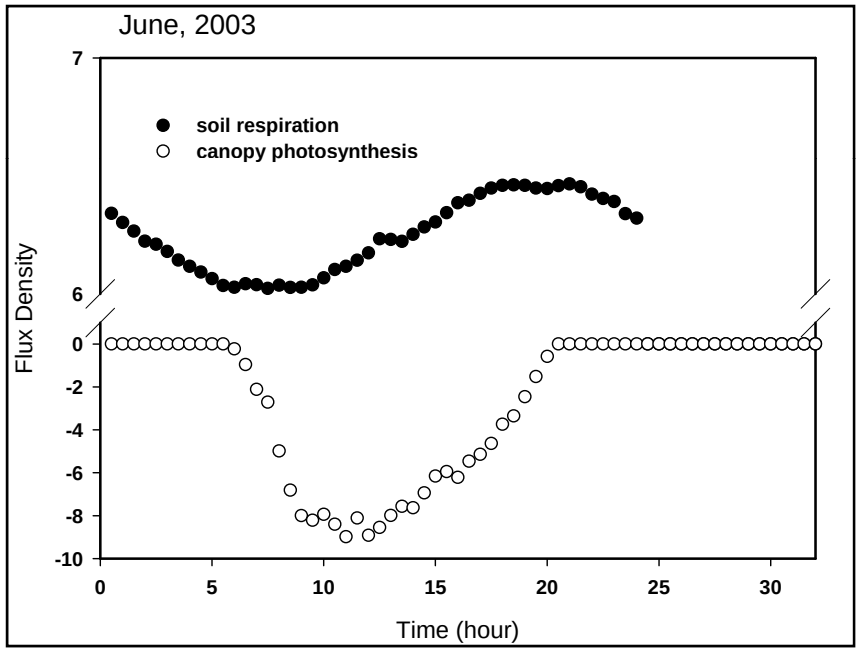
Xu + Baldocchi, AgForMet 2004

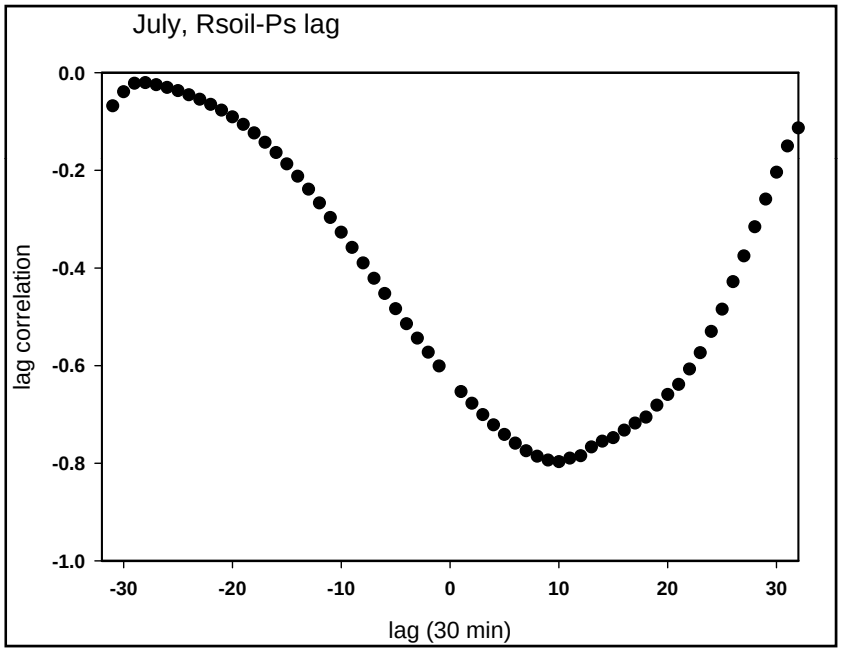
Quantifying the impact of rain pulses on respiration



Xu, Baldocchi, Tang, 2004
Global Biogeochem Cycles

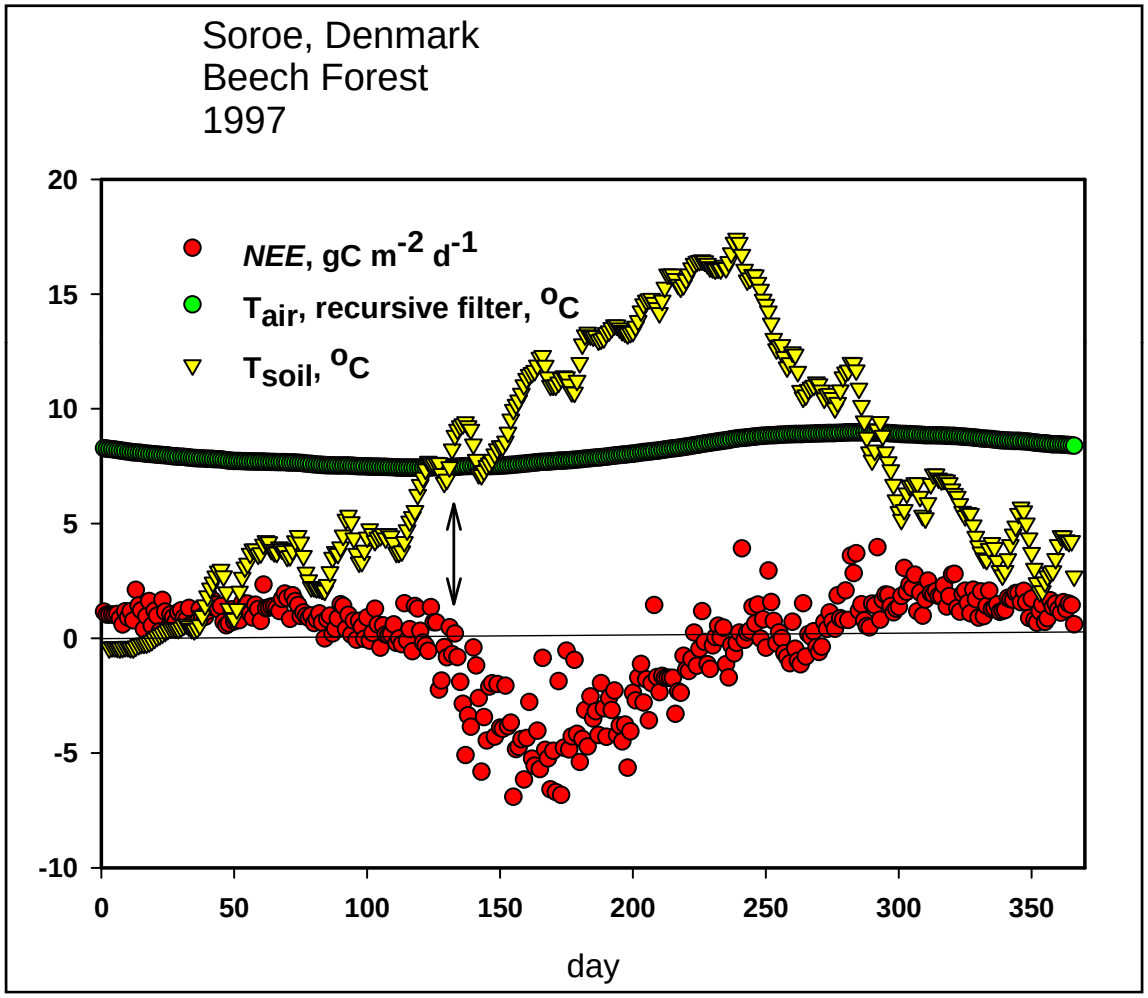
Soil Respiration Lags Photosynthesis on Hourly Scale





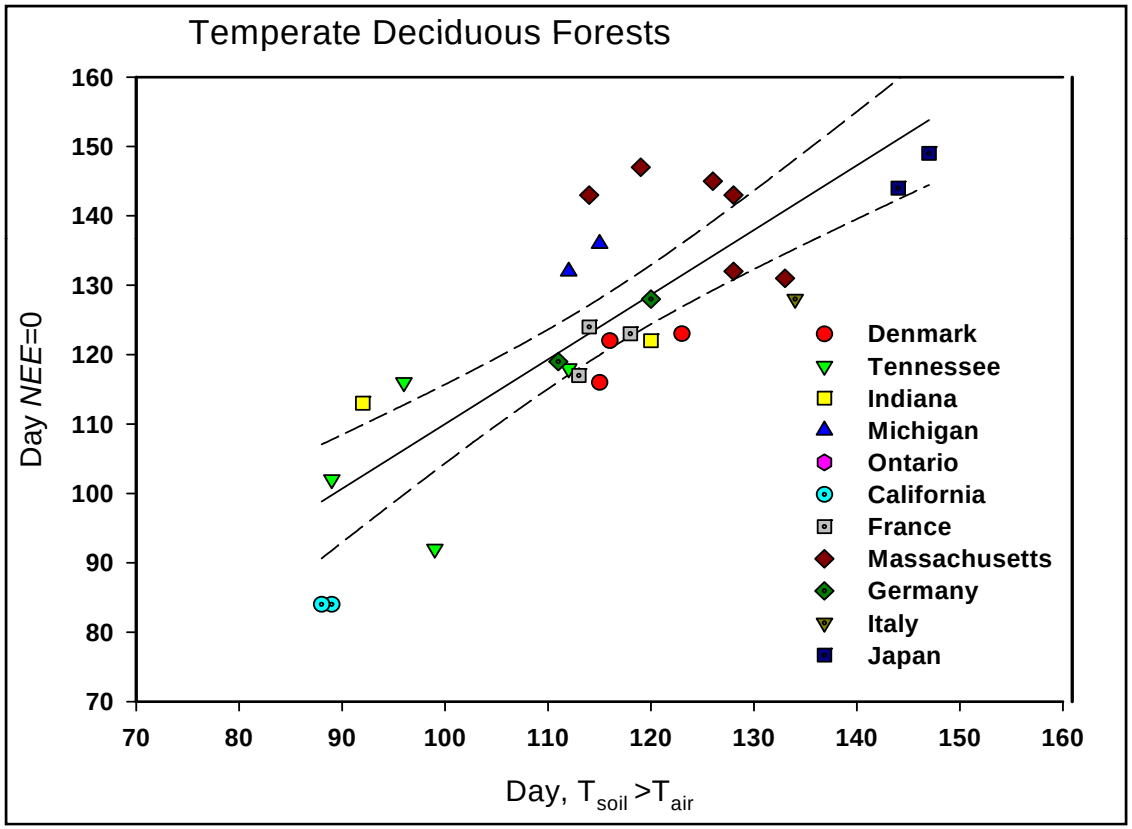
Tang et al. 2006, GCB

Soil Temperature:
An Objective Indicator of Phenology??



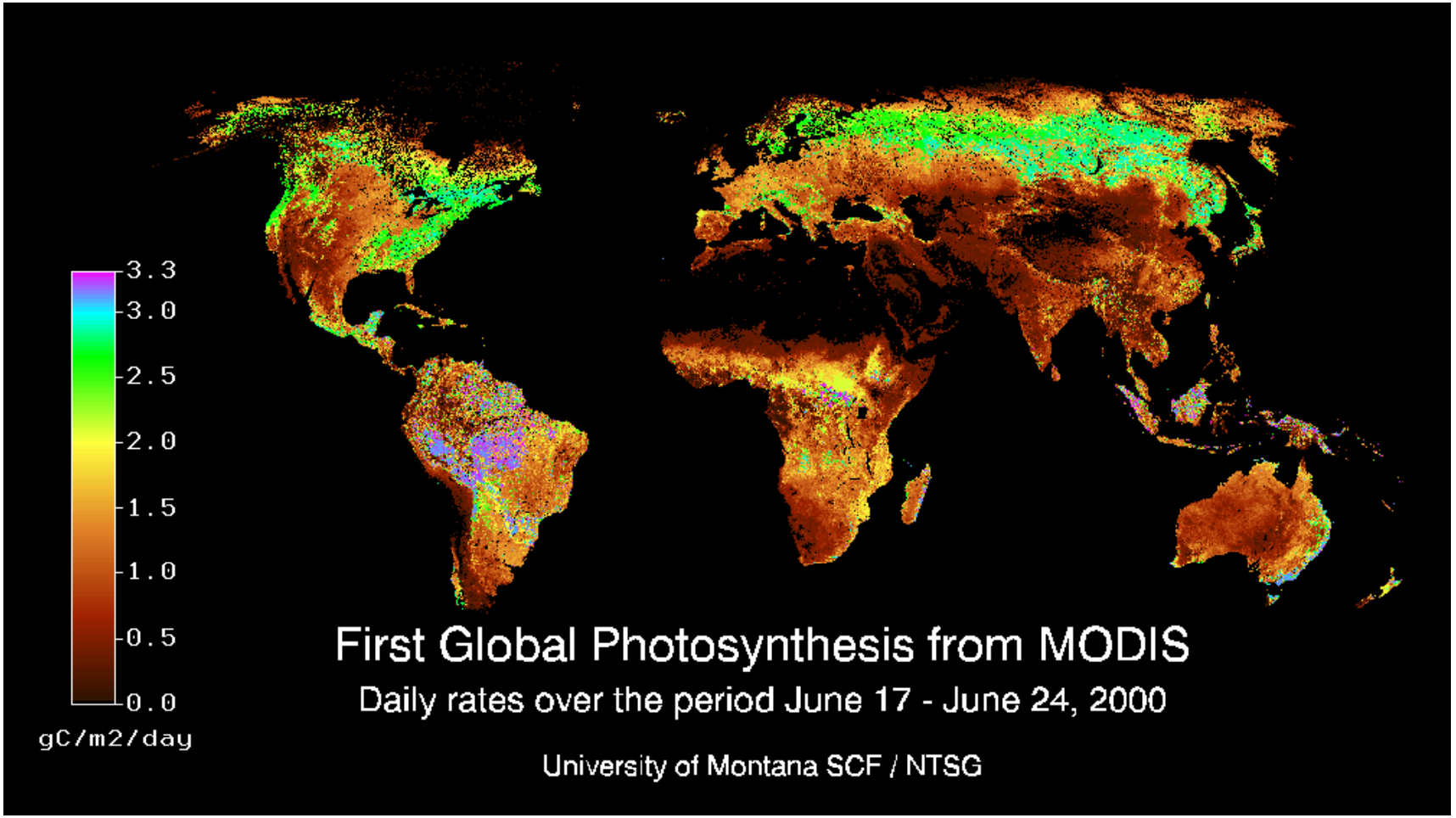
Data of Pilegaard et al.

Soil Temperature:
An Objective Measure of Phenology, part 2

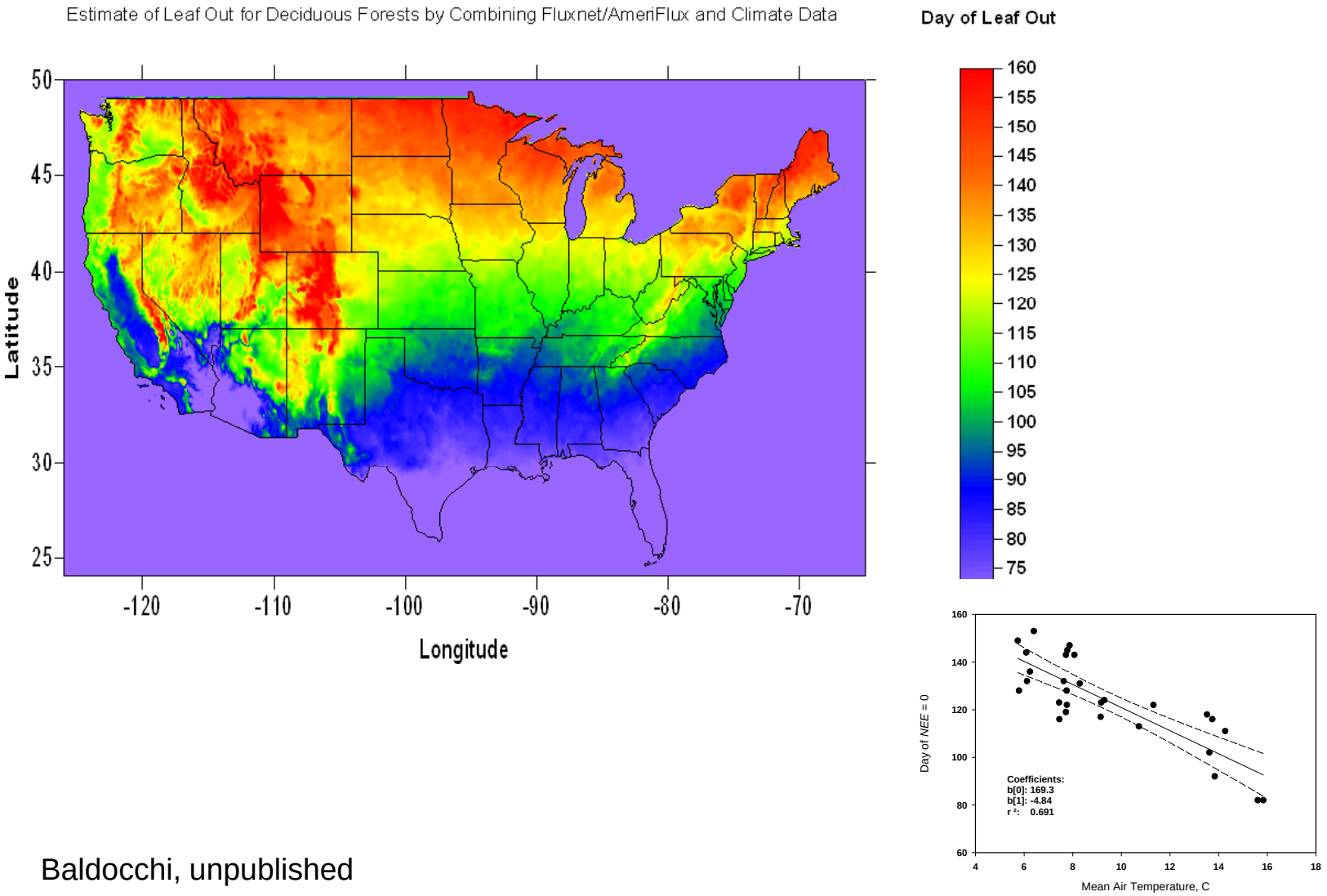


Baldocchi et al. Int J. Biomet, 2005

Spatial Variations in C Fluxes

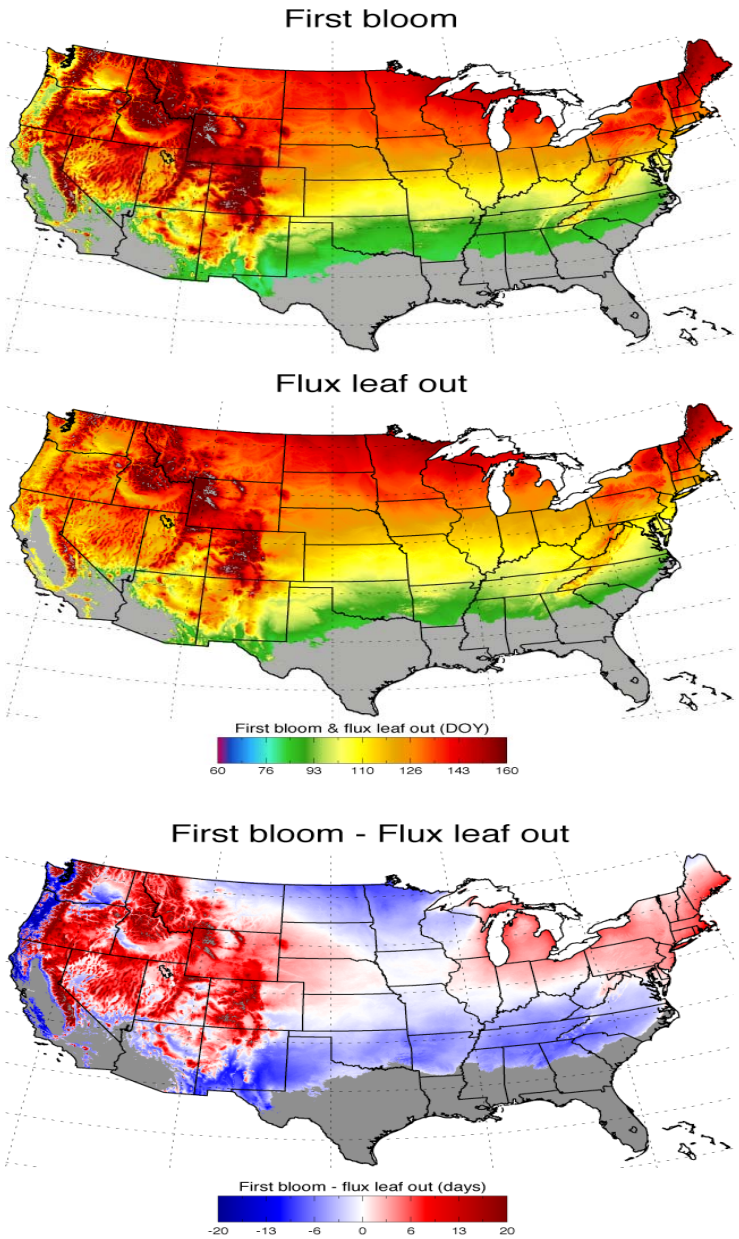


Spatialize Phenology with Transformation Using Climate Map



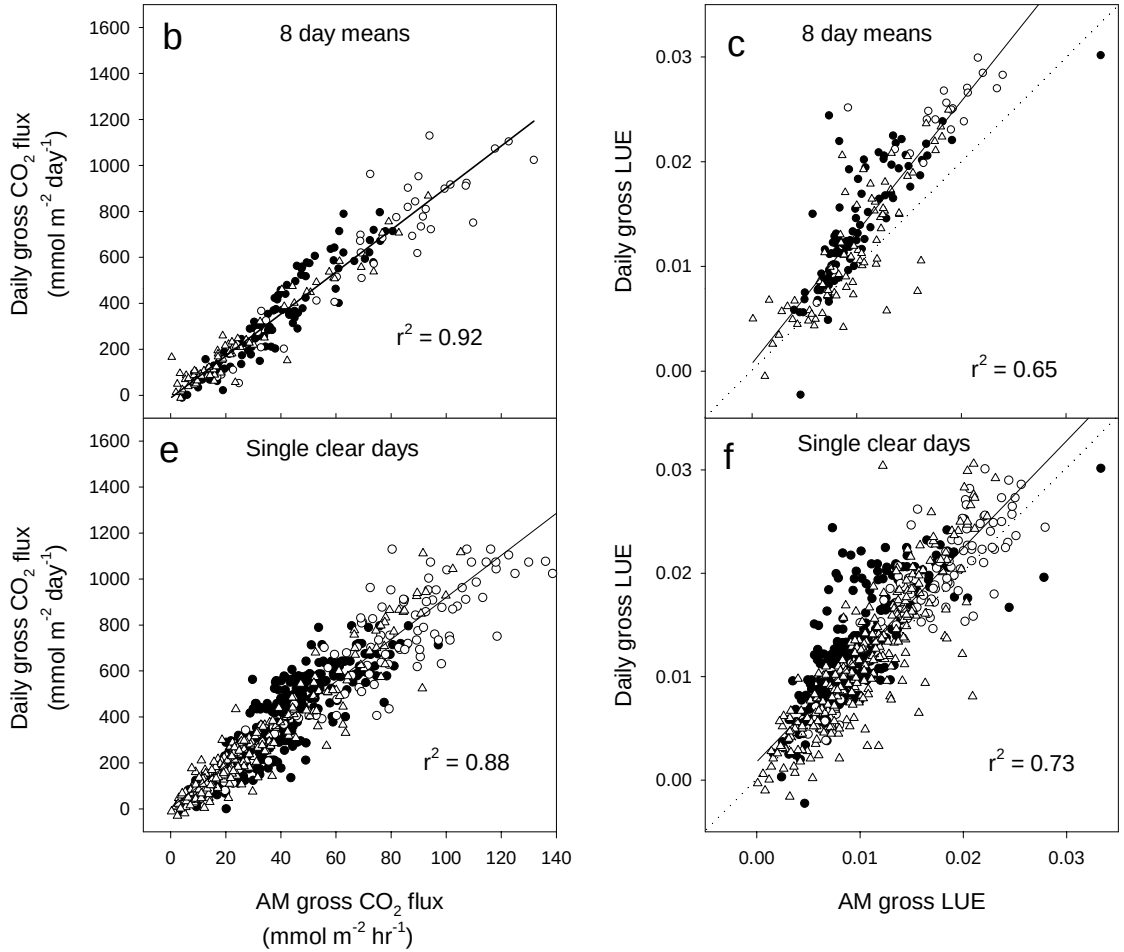
Baldocchi, unpublished

Flux Based Phenology Patterns with Match well with data from Phenology Network



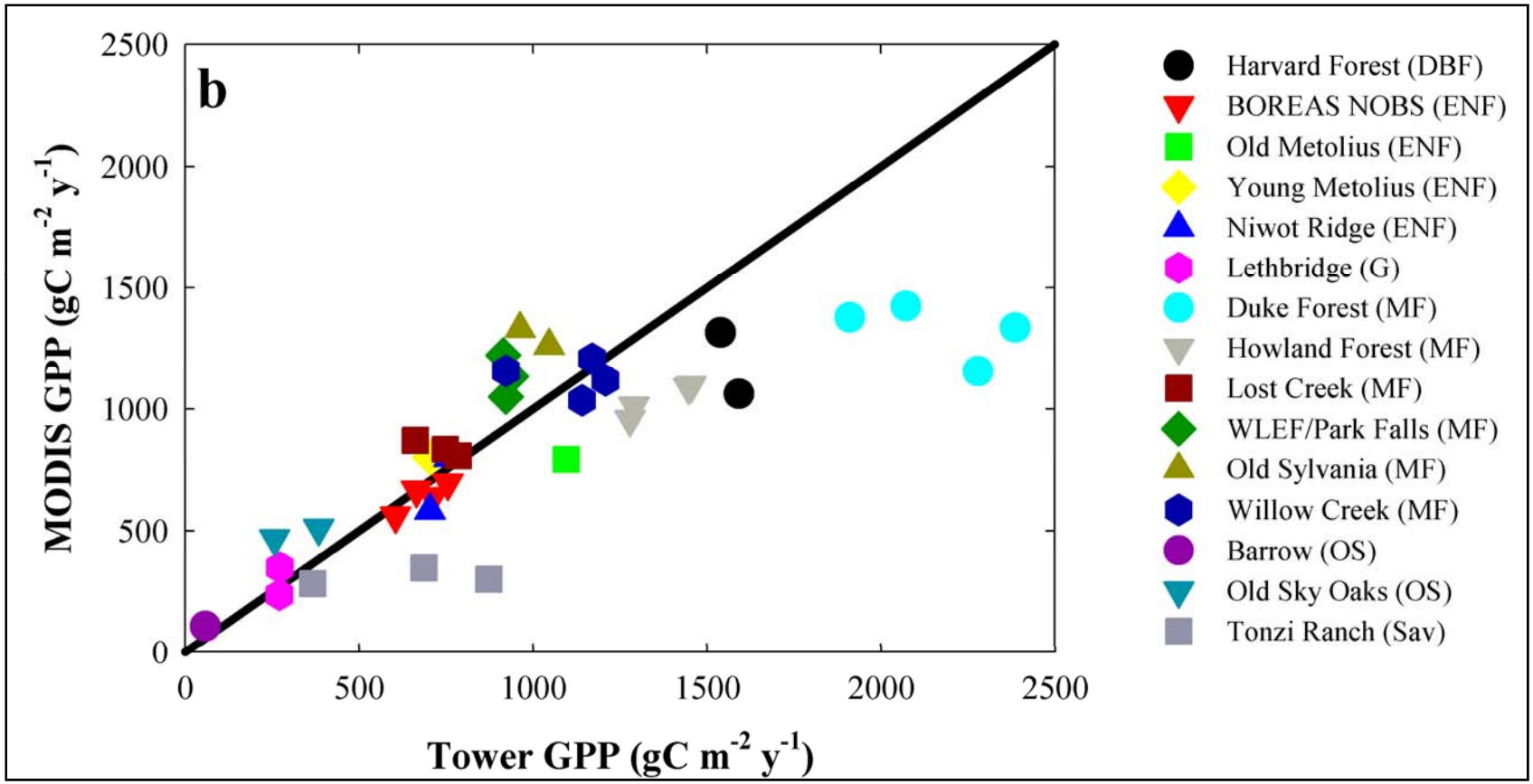
White, Baldocchi and Schwartz, unpublished

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



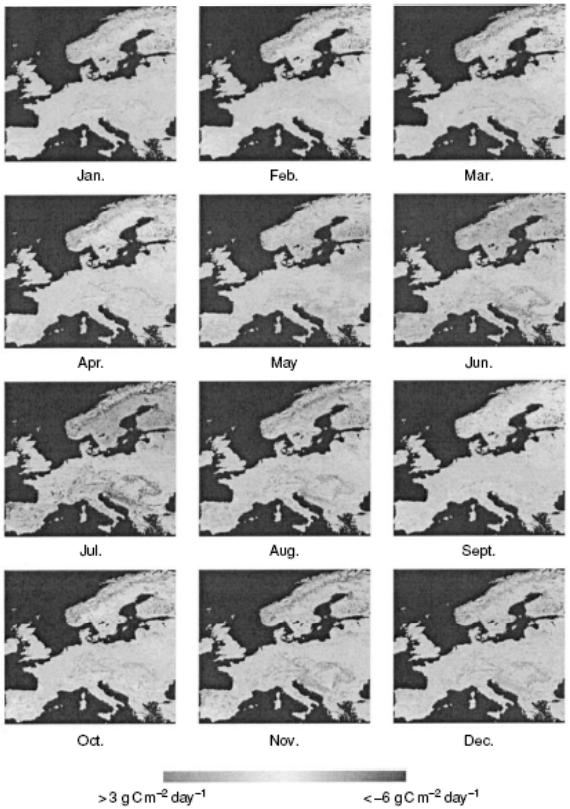
Sims et al 2005 AgForMet

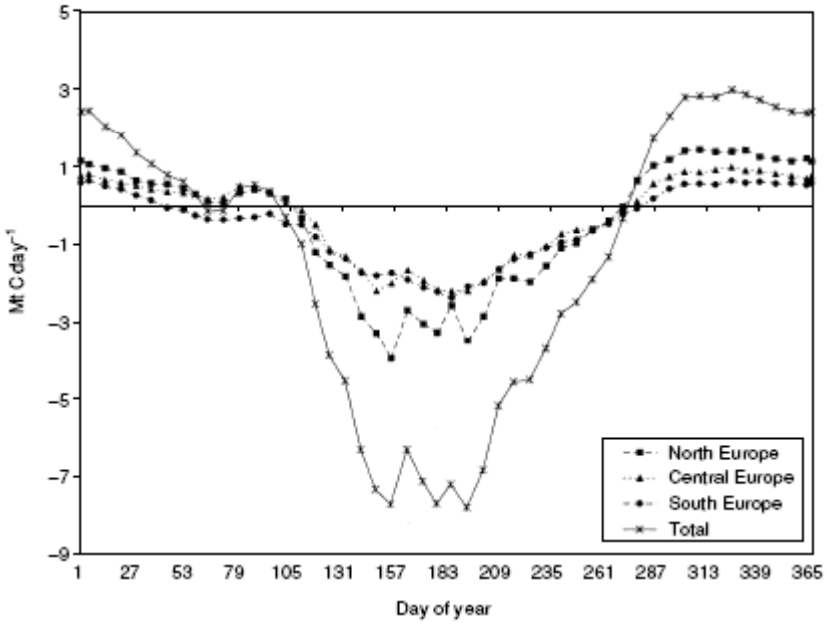
MODIS GPP Algorithm Test



Heinsch et al. 2006 RSE

Upscaling Tower Measurements with Neural Network Model and Remote Sensing





What are Pros and Cons?

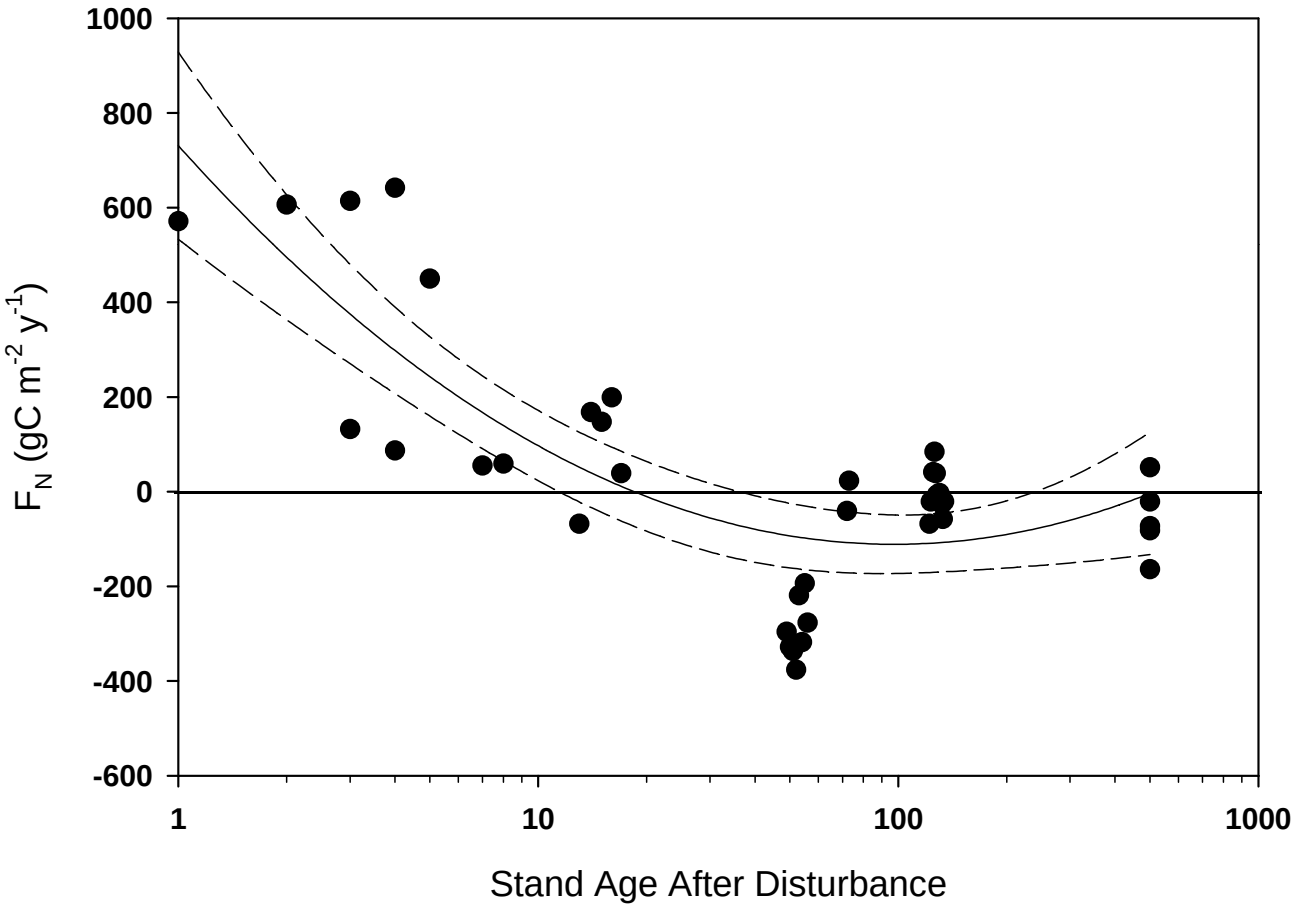
Papale and Valentini, 2003 GCB

Limits to Landscape Classification by Functional Type

- Stand Age/Disturbance
- Biodiversity
- Fire
- Logging
- Insects/Pathogens
- Management/Plantations
- Kyoto Forests

Time Since Disturbance Affects Net Ecosystem Carbon Exchange

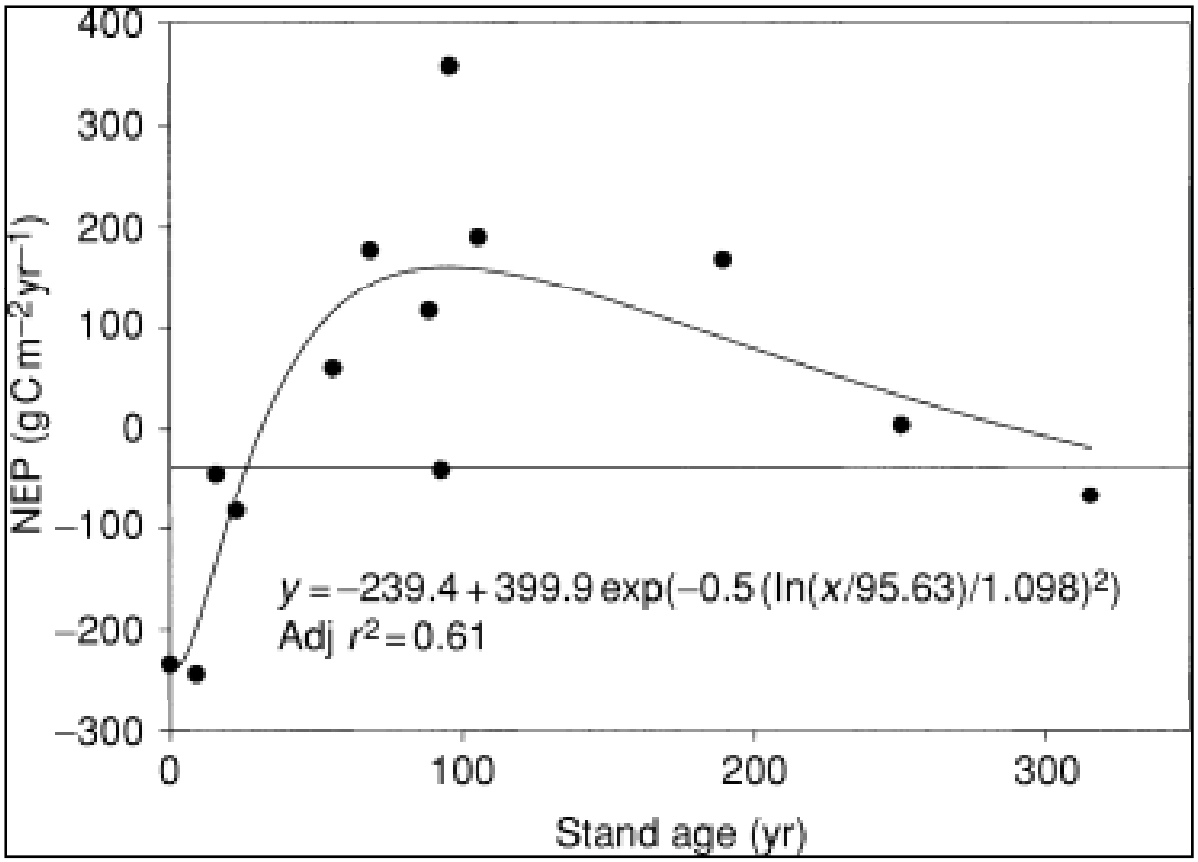
Conifer Forests, Canada and Pacific Northwest



Baldocchi, Austral J Botany, in press

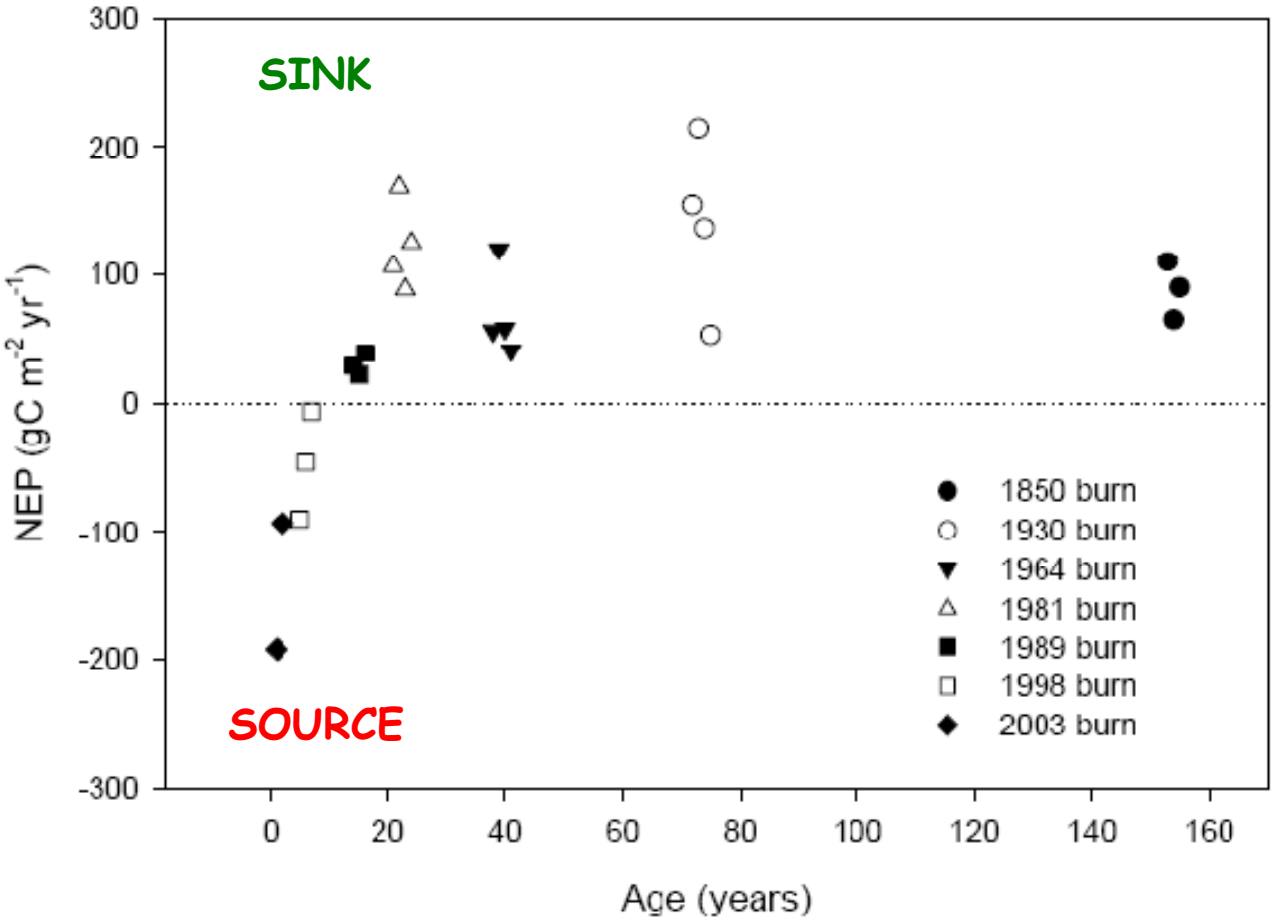
Data of teams lead by Amiro, Dunn, Paw U, Goulden

Effects of Stand Age: After Logging



Law et al. 2003 Global Change Biology

Northern Manitoba: Black Spruce chronosequence (Goulden et al.)

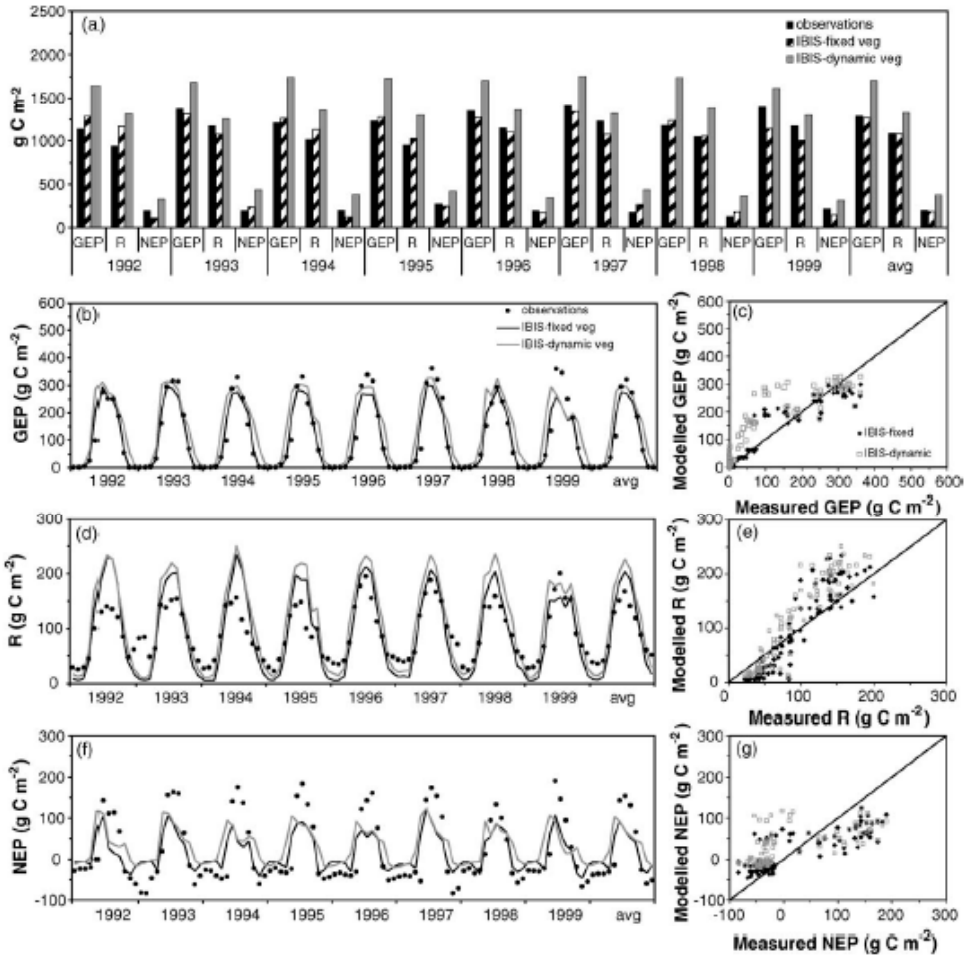


Other Activities and Uses of Fluxnet Data

- Ecosystem Modeling
- EcoHydrology
- Biodiversity
- Climate

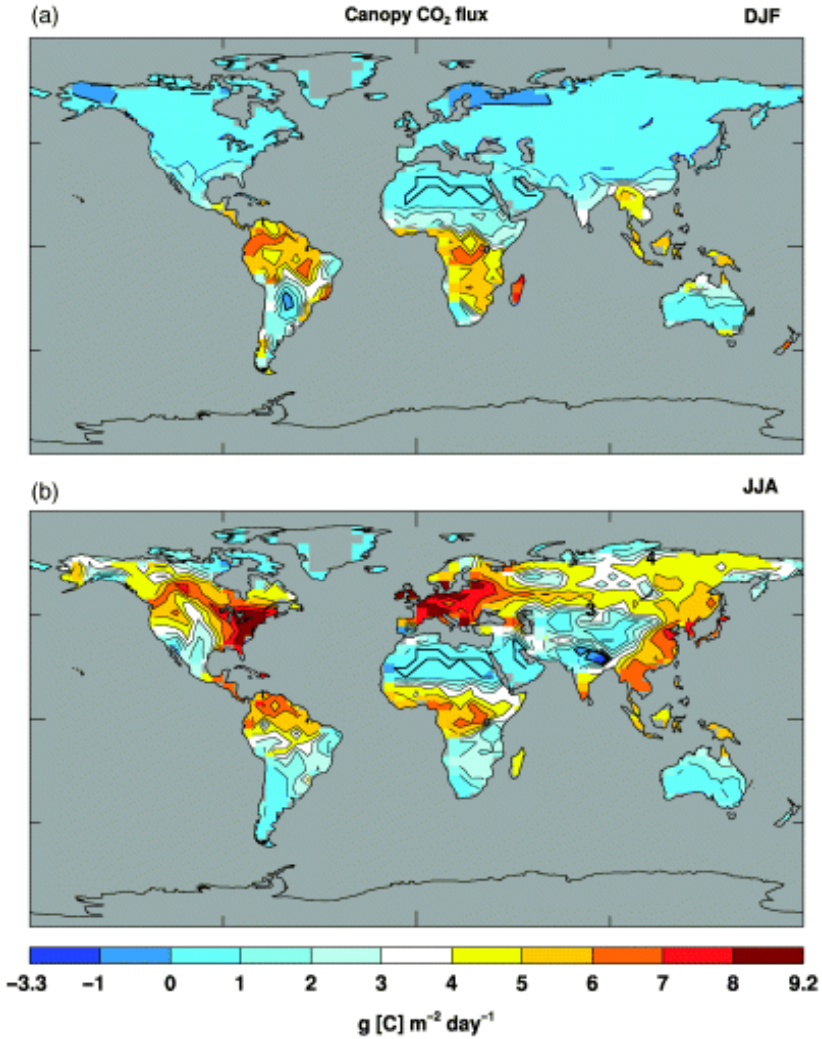
Ecosystem Model Testing and Development

ECOLOGICAL MODELLING 196 (2006) 1–31



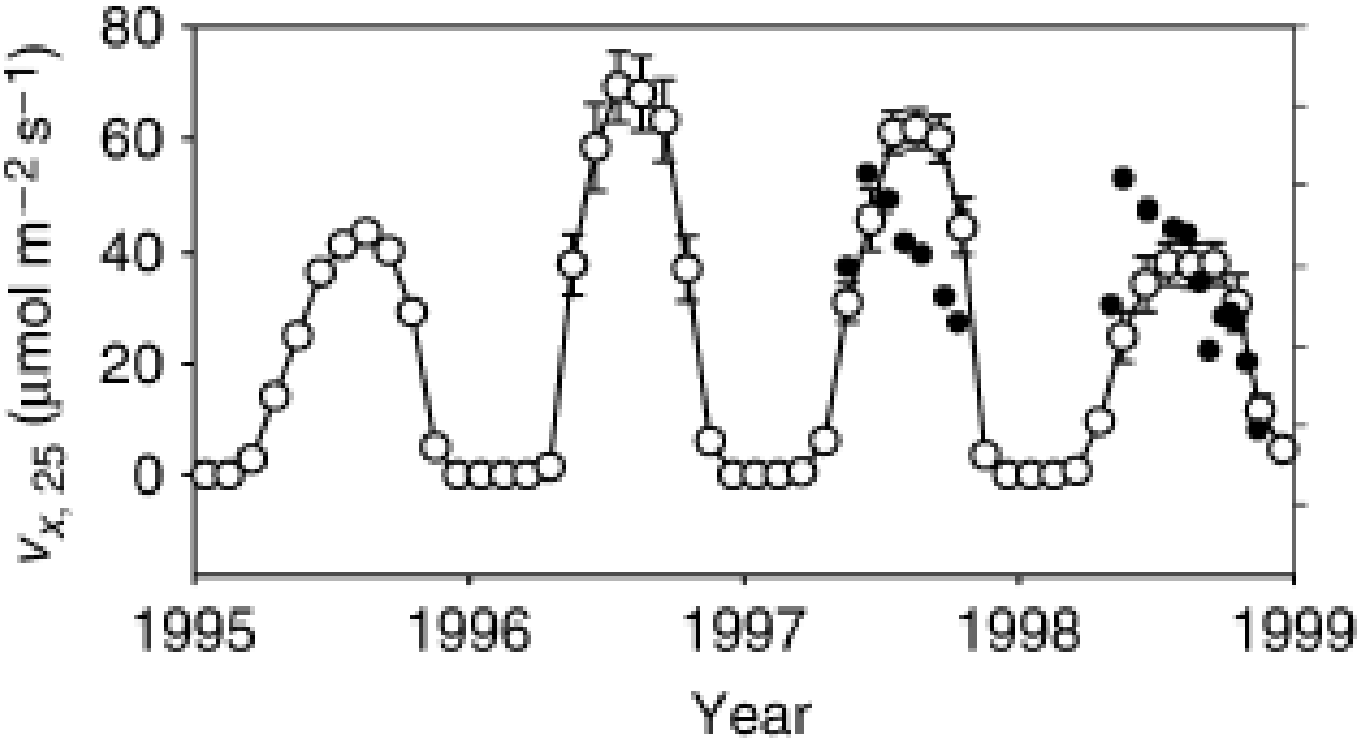
Kucharik et al., 2006 Ecol Modeling

Net ecosystem exchange of CO2 (NEE) predicted by different terrestrial biosphere models compares favourably with FLUXNET observations at diurnal and seasonal timescales.



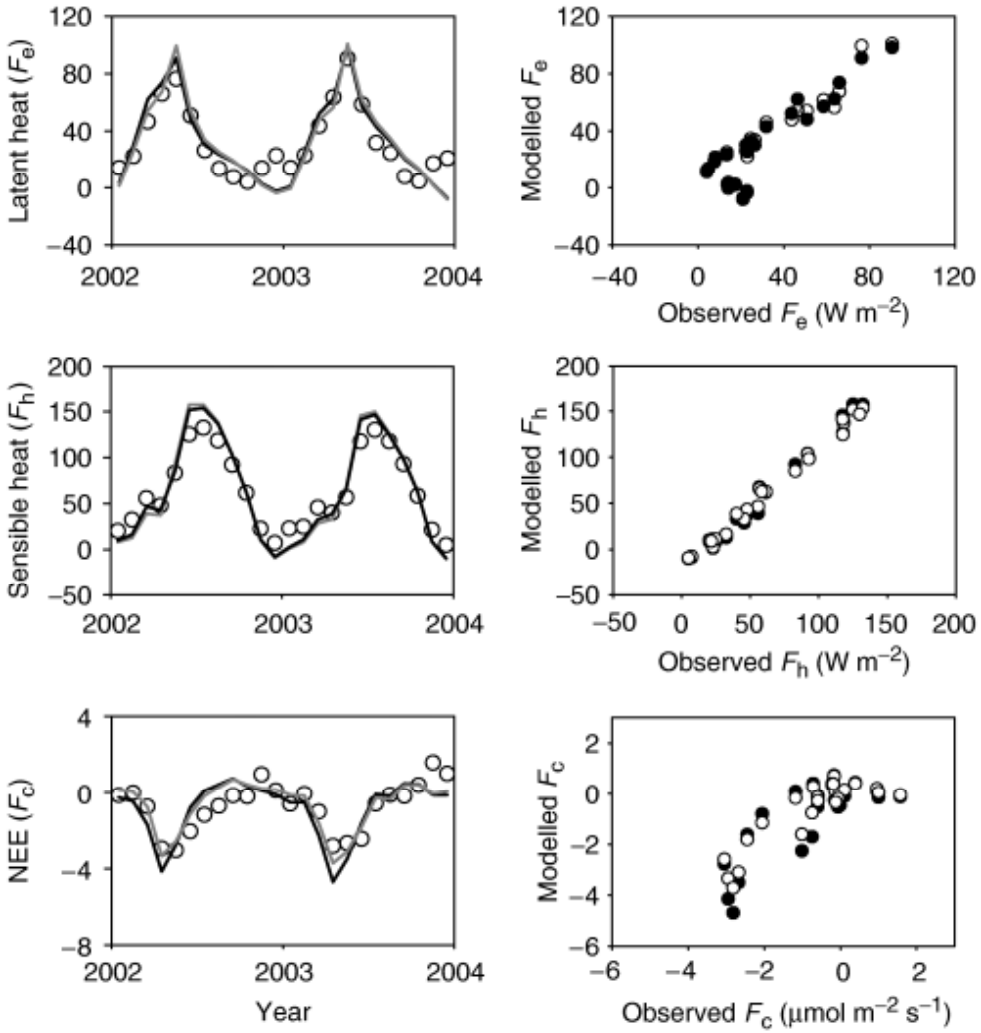
Friend et al 2007, GCB

Seasonality of Photosynthetic Capacity



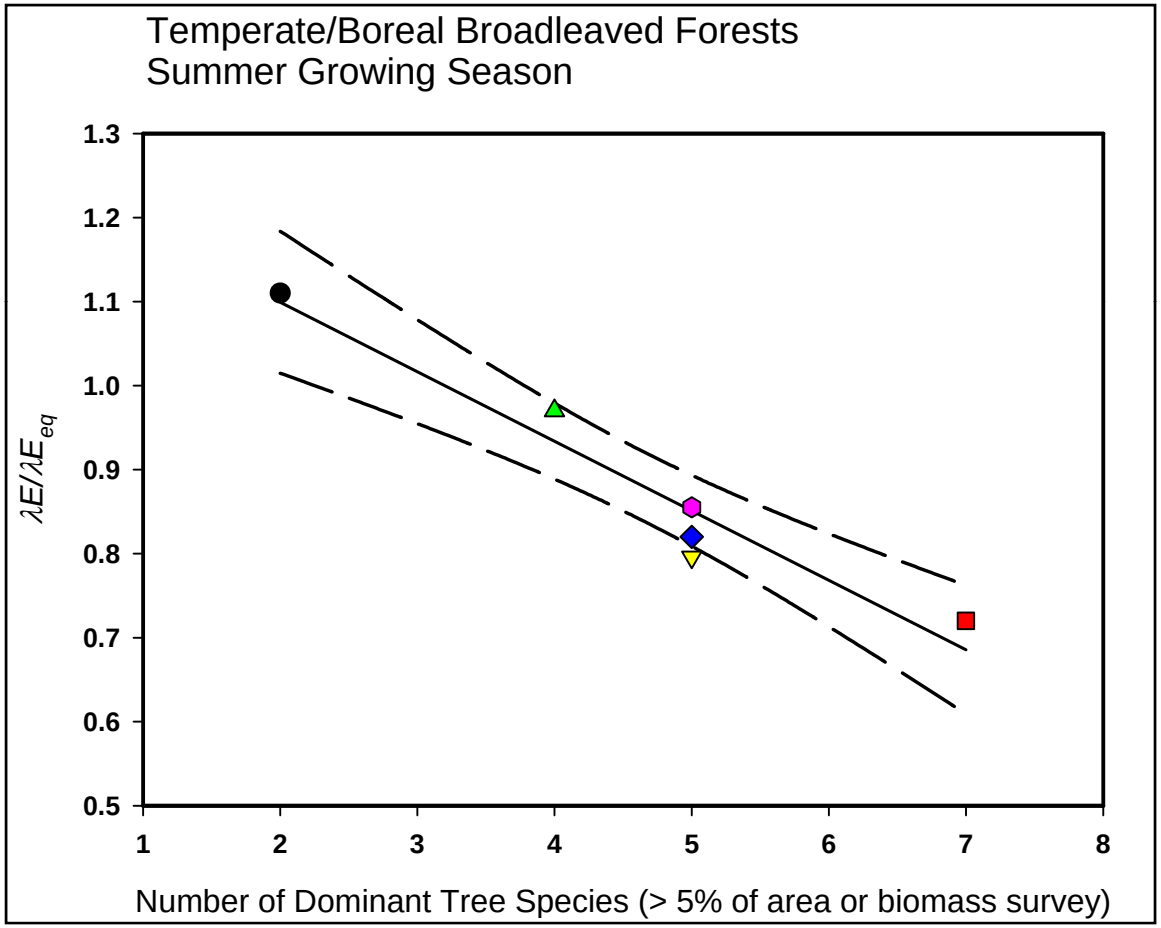
Wang et al, 2007 GCB

Optimizing Seasonality of Vcmax improves Prediction of Fluxes



Wang et al, 2007 GCB

Biodiversity and Evaporation



Baldocchi, 2004: Data from Black, Schmid, Wofsy, Baldocchi, Fuentes

Testbed for Ecohydrological Theory

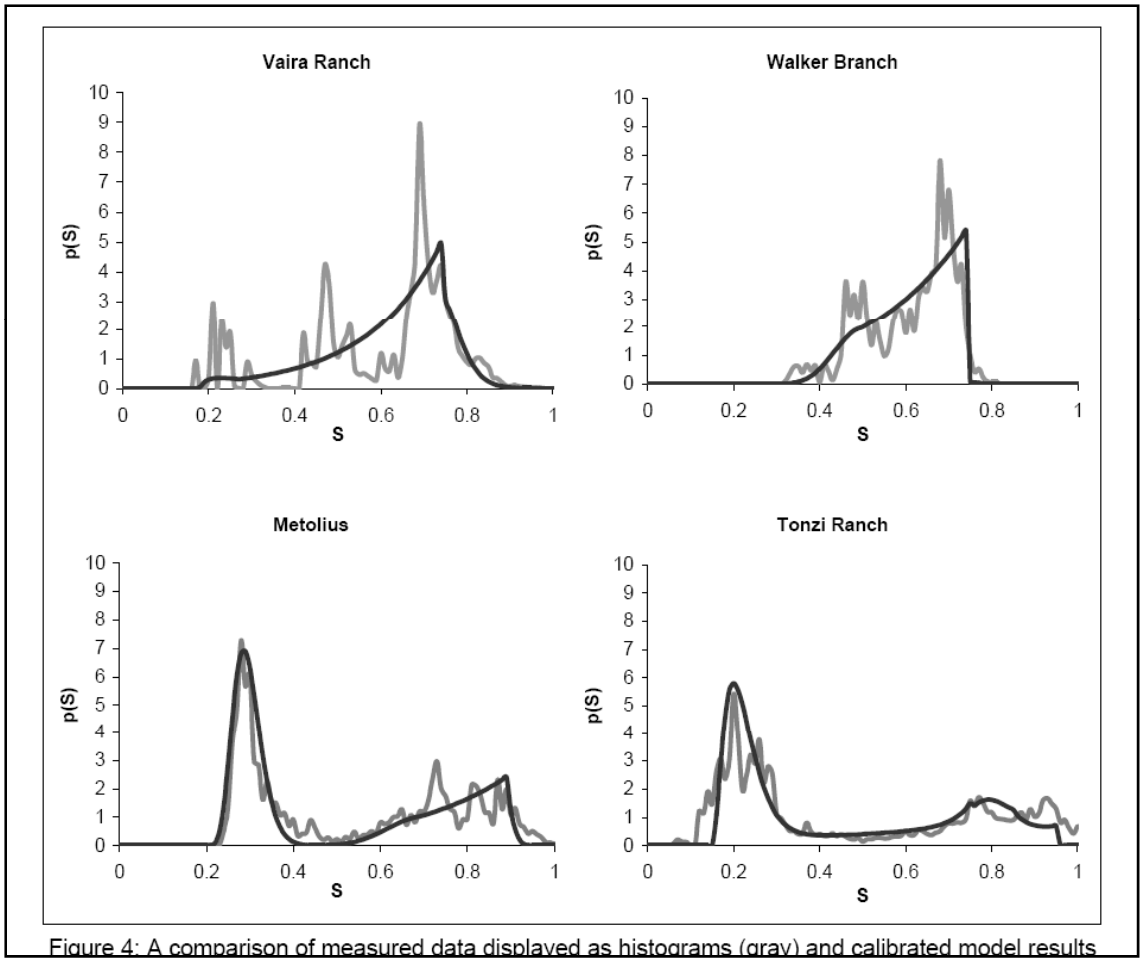
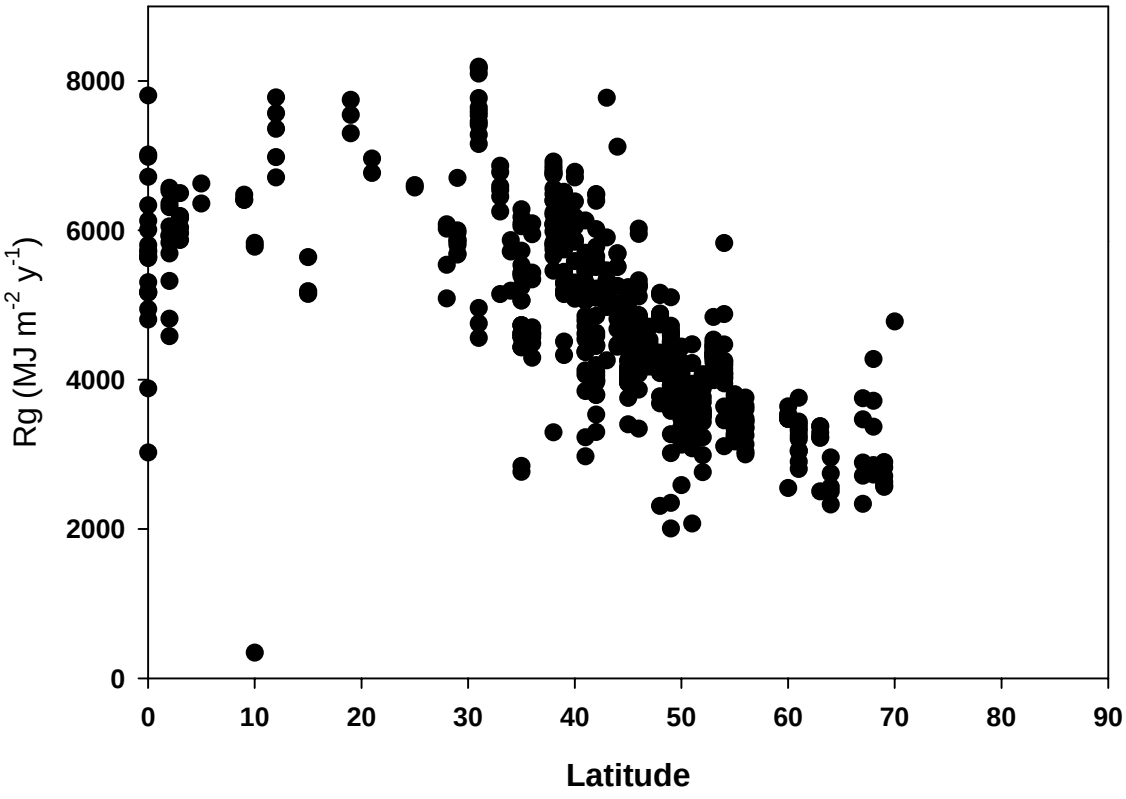


Figure 4: A comparison of measured data displayed as histograms (gray) and calibrated model results

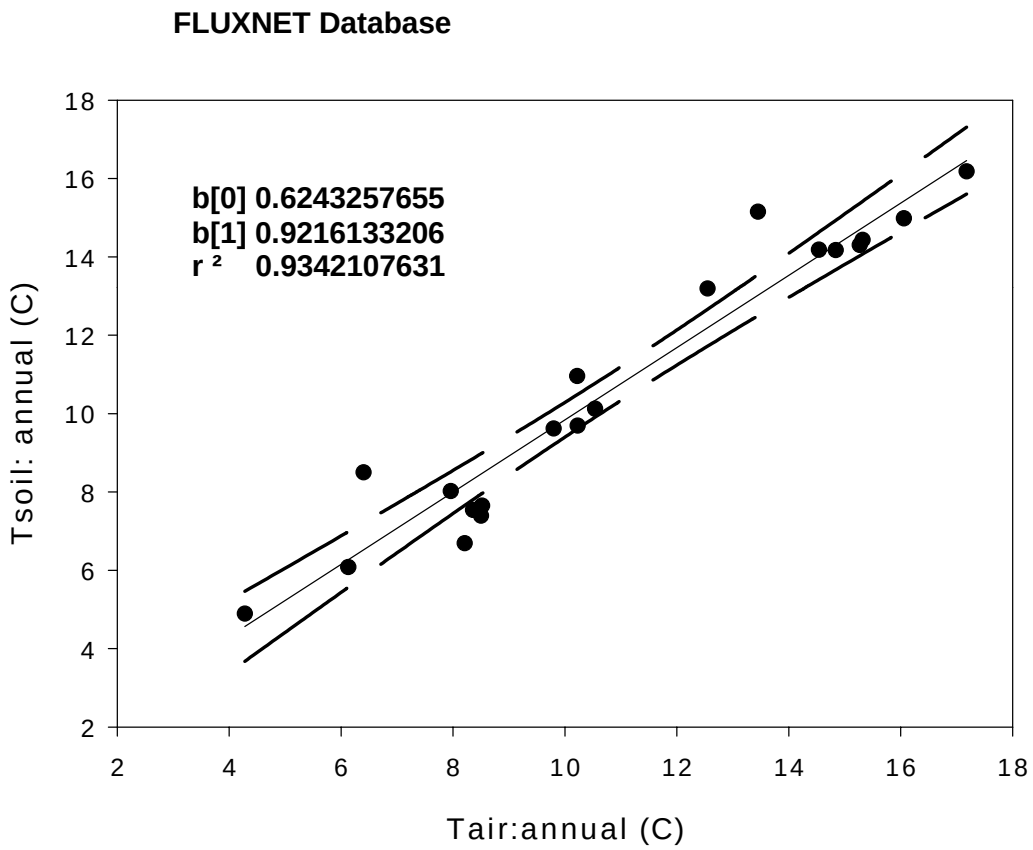
Miller et al, Adv. Water Research, 2007

Energy Flux Biogeography

FLUXNET database



Mean Soil Temperature Scales with Mean Air Temperature



Current and Future Scientific Directions

- NEE in Urban and Suburban, Africa, India, Latin America and High Arctic Environments
- Quantifying and Understanding the controls on Interannual Variability of C and energy Fluxes
- Monitoring the Metabolism of Ecosystems as we undergo Global Change
- Coupling CO_2, Trace Gas Deposition/Emission (O_3, voc) and Methane Fluxes
- Adopting New Technology (TDL, wireless networks) to embellish flux measurements
- Couple tower data with Real-time Data Assimilation Models.
- Boundary Layer Budgets using Fluxes and High Precision CO_2 measurements
- Spectral reflectance measurements and Digital Photos across the network for phenology and dynamics of structure and function
- Spatial-Temporal Network-Scale Analysis
- Real-time Data Assimilation
- Matching Footprints of Tower and Pixels
- Model Lags, Switches and Pulses
- Using Fluxnet data to assess problems in
  - Ecology, Ecohydrology, Biogeochemistry, Biogeography, Remote Sensing, Global Modeling, Biodiversity
  - Testing Maximum Entropy, Ecosystem Ecology, Biogeography and EcoHydrology Theories

FLUXNET 2007++
New Issues/Questions Raised

- Production of New, Expanded DataBase
- Use of New Software Tools to Facilitate DataBase Navigation & Exploration
- Broader representation of vegetation types and climates on NEE, GPP and R_{eco}.
- Roles of natural and human induced disturbance on C Fluxes
- Impacts of climate and ecosystem factors on inter-annual variations of carbon, water and energy fluxes.
- Use FLUXNET data to provide ground-truth information to validate and 'anchor' *NPP* and *fpar* products being produced by MODIS LAND
- Perform geostatistical analyses with the FLUXNET database to examine the scales of spatial coherence of net carbon, water and energy fluxes across landscapes, regions and continents and to quantify the 'network connectivity' among groups of sites.
- Revisit many basic tenets of bio- & micrometeorology
  - Data are being collected from a spectrum of land surface types (short grasses and crops, through open heterogeneous canopies to tall, closed forests) on flat to moderately undulating terrain over a wide range of atmospheric stability conditions
  - Intermittent Turbulence

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