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

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3/8/16

Outline

- Network Background/History
- 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

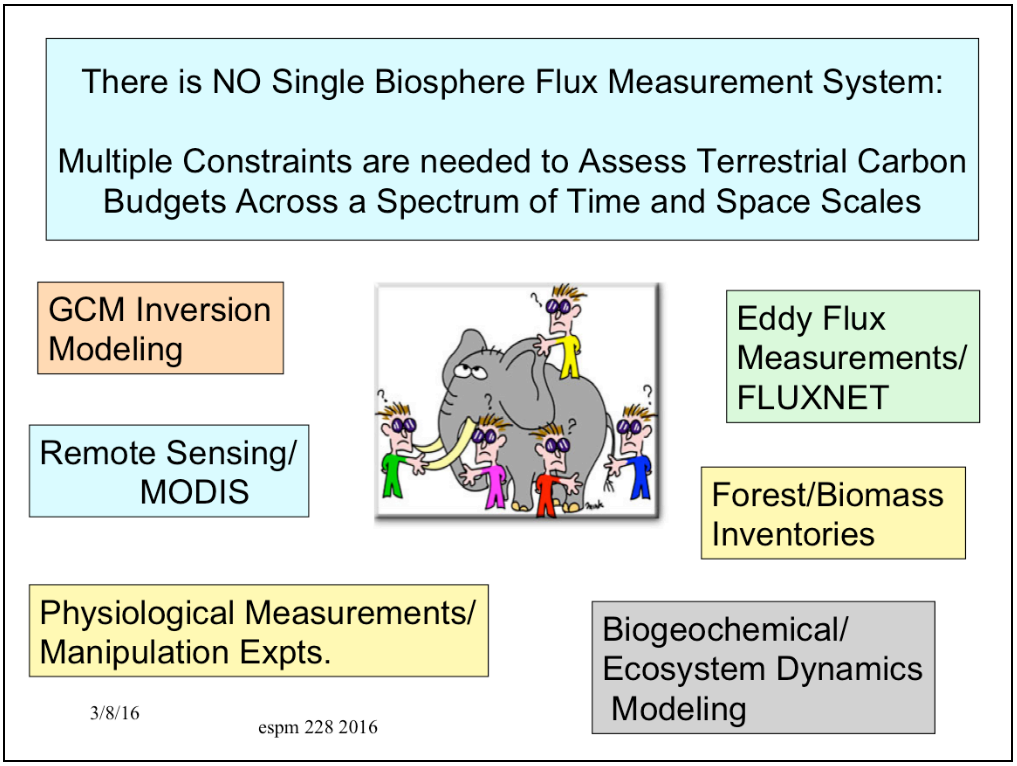
Reference

CSIRO PUBLISHING
www.publish.csiro.au/journals/ajb *Australian Journal of Botany*, 2008, **56**, 1–26

TURNER REVIEW No. 15

'Breathing' of the terrestrial biosphere: lessons learned from a global network of carbon dioxide flux measurement systems

Dennis Baldocchi

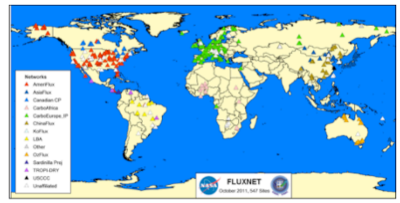


There is no simple or single method for studying atmospheric CO_2. Each method has strengths for given time and space scales.

Role of Flux Networks in Biogeosciences

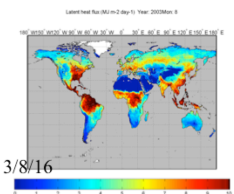
Eddy covariance flux system

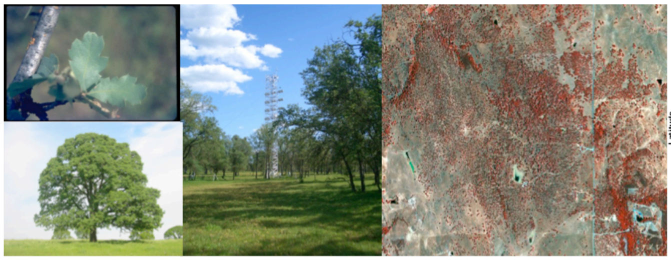
Global network of flux towers

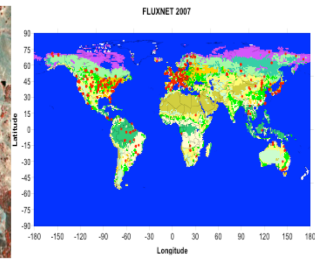


Database

Remote sensing and Earth system science model user community







To Develop a Scientifically Defensible Virtual World
'You Must get your boots dirty', too

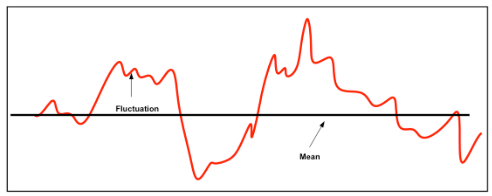
Collecting Real Data Gives you Insights on What is Important
& Data to Parameterize and Validate Models

Collecting real data

Eddy Covariance Technique

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

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

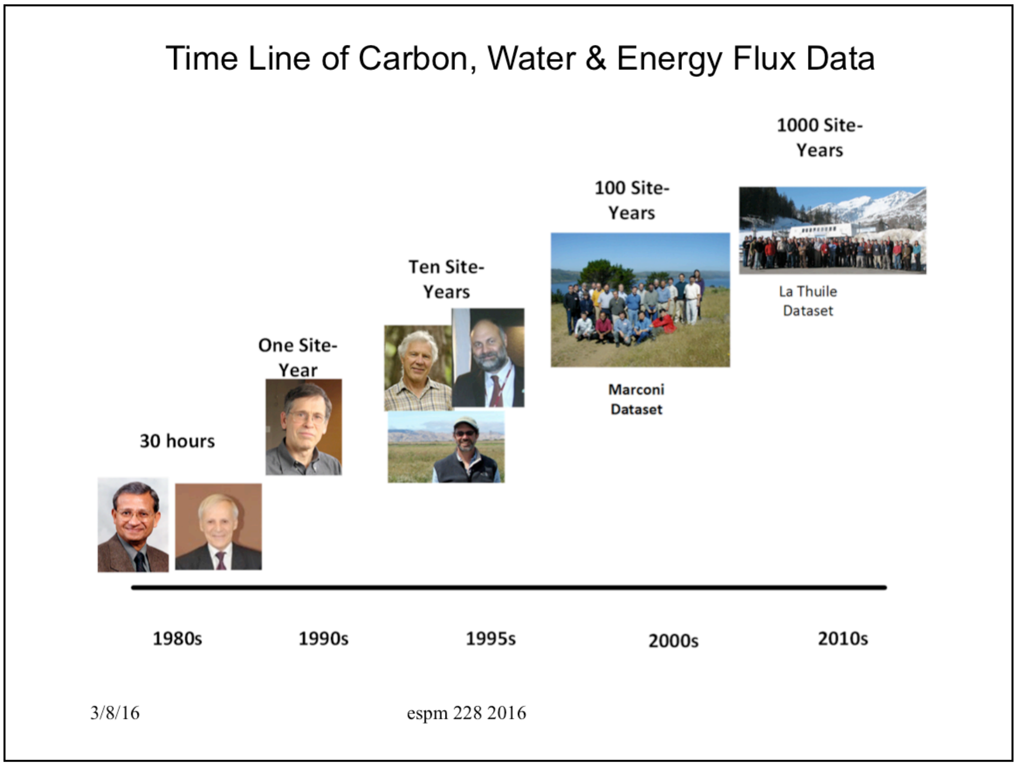


Attributes of Eddy Covariance

- Direct Flux Measurement of an Integrated Population of Leaves and Soil
- Evaluates Fluxes on Diel, Seasonal and Interannual Time Scales
- 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)
- Advection and Drainage Biases in Complex Terrain
- Network of Towers is Discrete in Space



The art and science of making long term and continuous flux measurements is relatively new. Shashi Verma, my PhD mentor at Nebraska, was one of the first to make eddy covariance flux measurements over crops with a new open path infrared gas analyzers. And together in 1984 we made the first CO2 flux measurements over a deciduous forest. Wofsy at Harvard made the first year round flux measurements and then confidence was gained during the Boreas experiment in the early 1990s. Now hundreds of teams are active and thousands of site years of data have been collected.

FLUXNET, circa 2015; > 700 sites

Flux Networks

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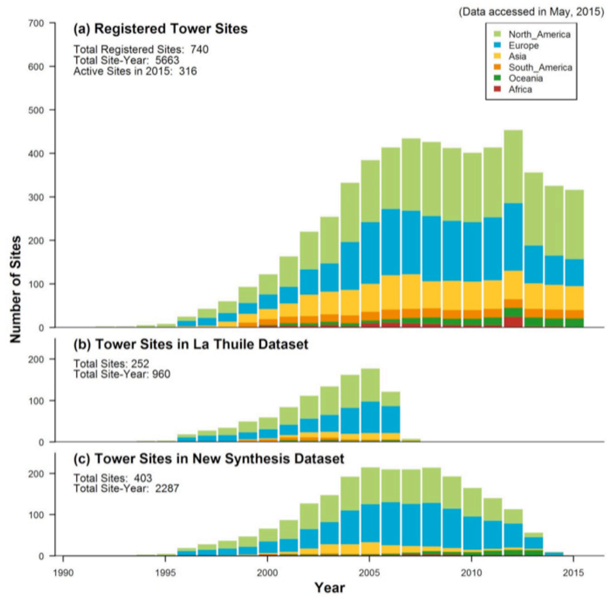
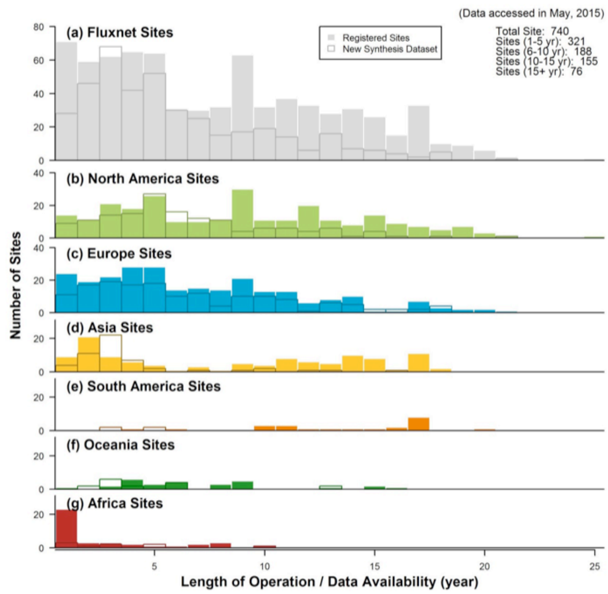
Active, emerging and defunct flux networks. There is no single funding agency for a global flux network. It is a coalition of the willing and is an exercise in sharing and scientific and cultural collaborations. It works well to some degree, but fails on others. Those who see the win win aspect of the network, contribute data willing. Others tend to be more users than contributors.

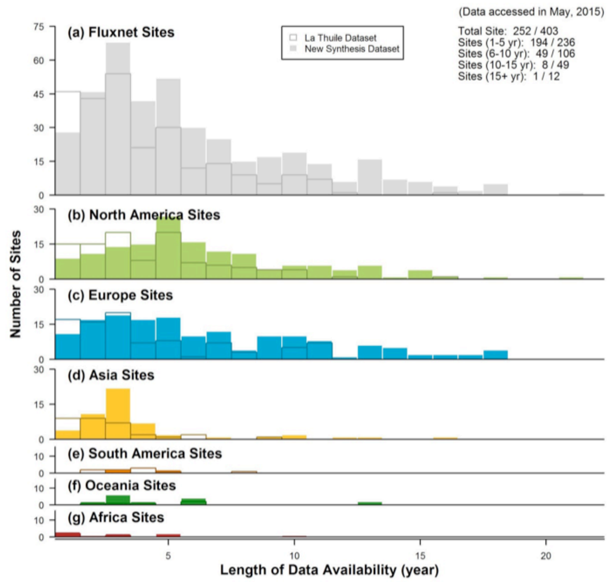
Database Stats and Network Growth



Length of Operation



Length of Datasets Submitted



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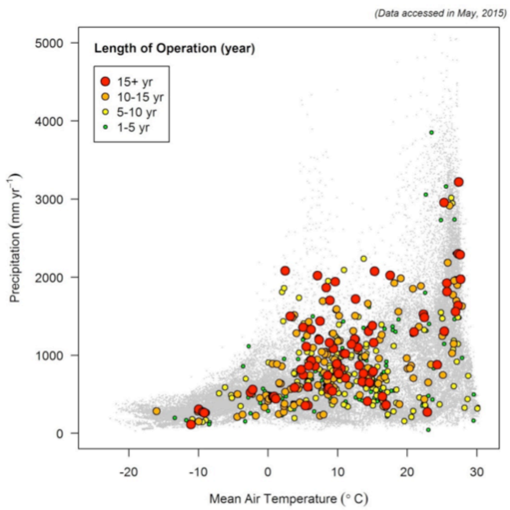
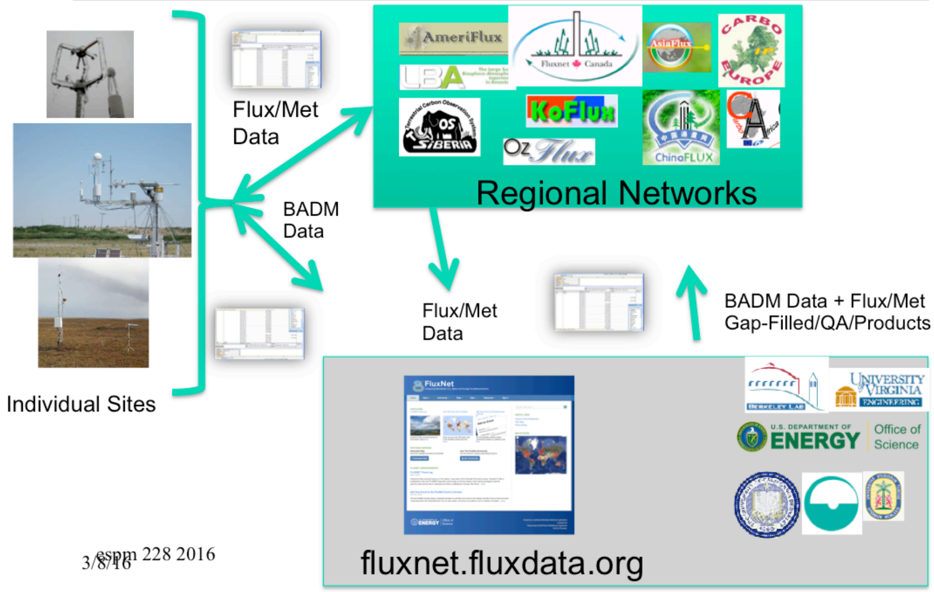
Global distribution of Flux Towers Covers Climate Space Well



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



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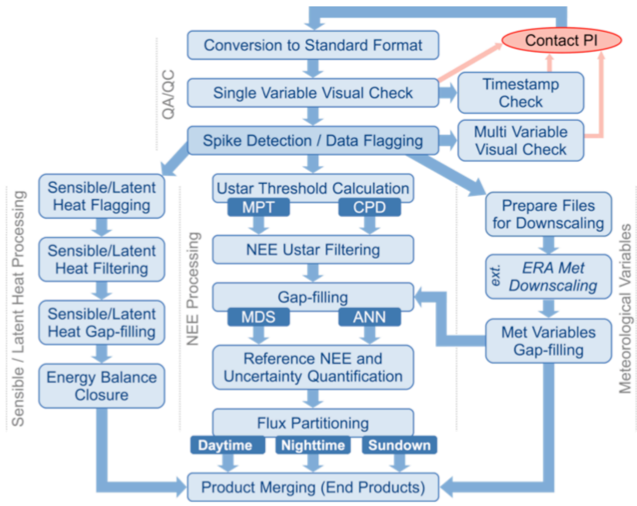
FLUXNET Data Services and Procedures



D. Papale 3/8/16

What Information Do Networks of Flux Towers Produce?

- Groups of towers at the landscape, regional, continental, and global scales allow scientists to study a greater range of climate and ecosystem conditions
  - Dominant plant functional type/Traits/Land Use (Evergreen/Deciduous Forests, Grasslands, Crops, Savanna, Conifer/Broadleaved, Tundra)
  - Biophysical attributes (C_3/C_4 Photosynthesis; Aerodynamic Roughness; Albedo; Bowen Ratio, Surface Conductance, Photosynthetic Capacity, Weather/Climate, Soil Moisture)
  - Climate Gradients
  - Phenology and Seasonality
  - Biodiversity
  - Time since the last Disturbance
  - Type of Disturbance, fire, logging, wind throw, flooding, or insect infestation
  - The effect of Management practices such as fertilization, irrigation, cultivation or air pollution
- A global flux network has the potential to observe how ecosystems are affected by, and recover from, low-probability but high-intensity disturbances associated with rare weather events.

Topics Dependent Upon Products from Networks of Flux Towers

- Carbon Balances of Ecosystems
- Water Balances of Ecosystems
- Ecophysiological Responses of Carbon and Water Fluxes to Biophysical Drivers
- Ground Truth to Satellites for:
  - Radiation Data, Light Use Efficiency, Fraction of Absorbed PAR
- Ground Truth and Parameters for Land Surface Models, Ecosystem Dynamic and Data Fusion Models
- Structure and Function of Ecosystems
- Boundary Layer and Micrometeorological Flux Theory
- Atmospheric Chemistry and Greenhouse Gas Budgets

Guidelines for Effective Networks, 1.0

- Data are best when there are standards and protocols for instrument performance, data quality, and calibration; data gaps are minimized if redundant or replacement sensors are available; data gaps are filled with vetted methods
- Instruments don't need to be uniform, as Long as they meet standards of performance
  - We learn about instrument performance by having a diverse suite of sensors; Multiple Constraints

Guidelines for Effective Networks, 2.0

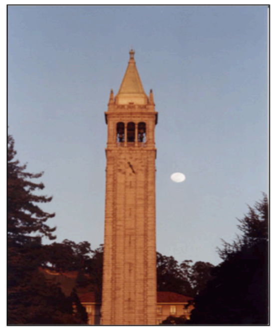
- Data are converted into information and knowledge when there is a shared and integrated database with which researchers can merge flux measurements with a cohort of meteorological, ecological, and soil variables.
- A centralized database can harmonize data processing and gap-filling to produce value-added products such as daily or annual sums or averages, establish version control and sharing policies, and archive data.
- Databases can be queried to pull data for specific times, locations, or variables.

Guidelines for Effective Networks, 3.0

- The success of a scientific flux network relies on creating a human network~~,~~ too.
- Data sharing depends upon fostering trust among colleagues, crossing cultural and political obstacles and devising a fair–use data sharing policy.
- To Remain Relevant and Serve the Broader Community, the Next Generation of Fluxnet **MUST** adopt a Policy of **Open-Access Data**

Temporal Dynamics of C Fluxes

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



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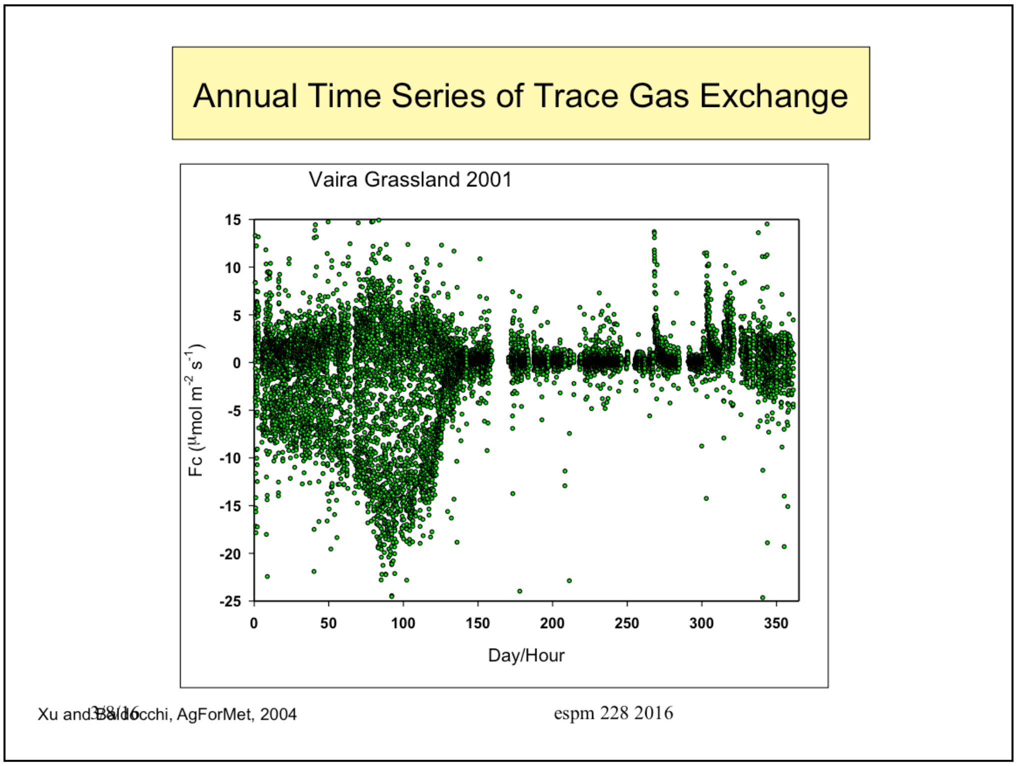
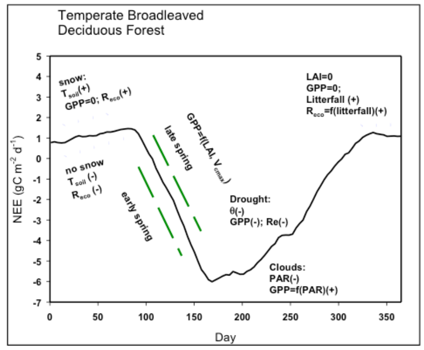


Plot of hour by hour data over a year. Look at degree of outliers and gaps, trends in uptake and respiration, role of pulses, following rain

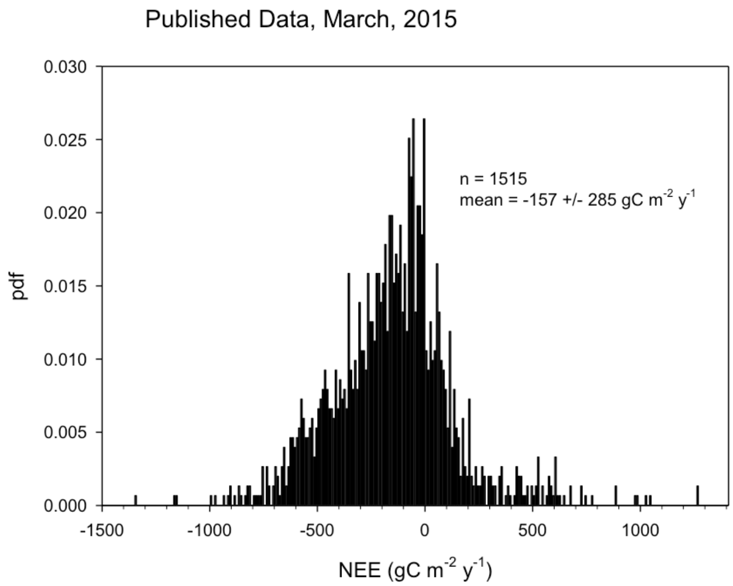
Complicating Dynamical Factors

- Switches
  - Phenology
  - Drought
  - Frost/Freeze
  - Insect/Pathogen Infestation
  - Snow
- Pulses
  - Rain
  - Litterfall, Fire, Windthrow
- Emergent Processes
  - Diffuse Light/LUE
  - Coupling of Photosynthesis and Soil Respiration
  - Surface Fluxes coupled to PBL
- Hysteresis
- Acclimation
- Lags
- Stand Age/Disturbance



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?



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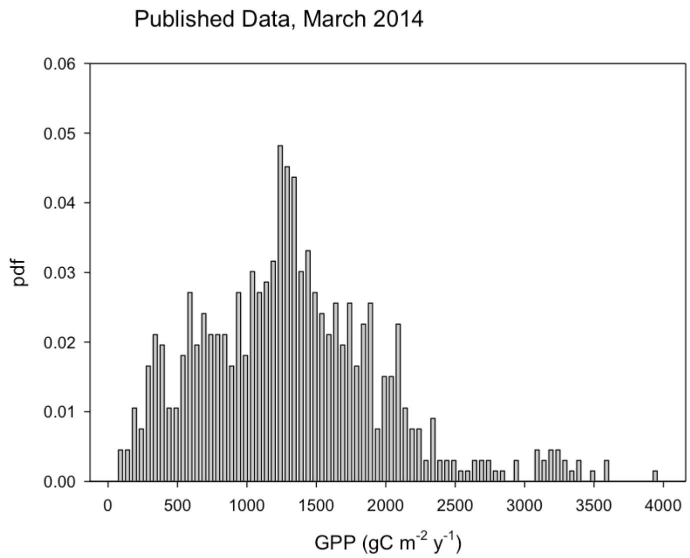
I've been compiling a record of published data on annual fluxes of Net and gross carbon fluxes. So far over 1400 site years are produced. The pdf gets smoother and smoother with time and the central tendency is about -154 gC m-2 y-1

How Much C is ~ 150 gC m^{-2} y^{-1}?

About 2 Pieces of Paper, 1 by 1 m.

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



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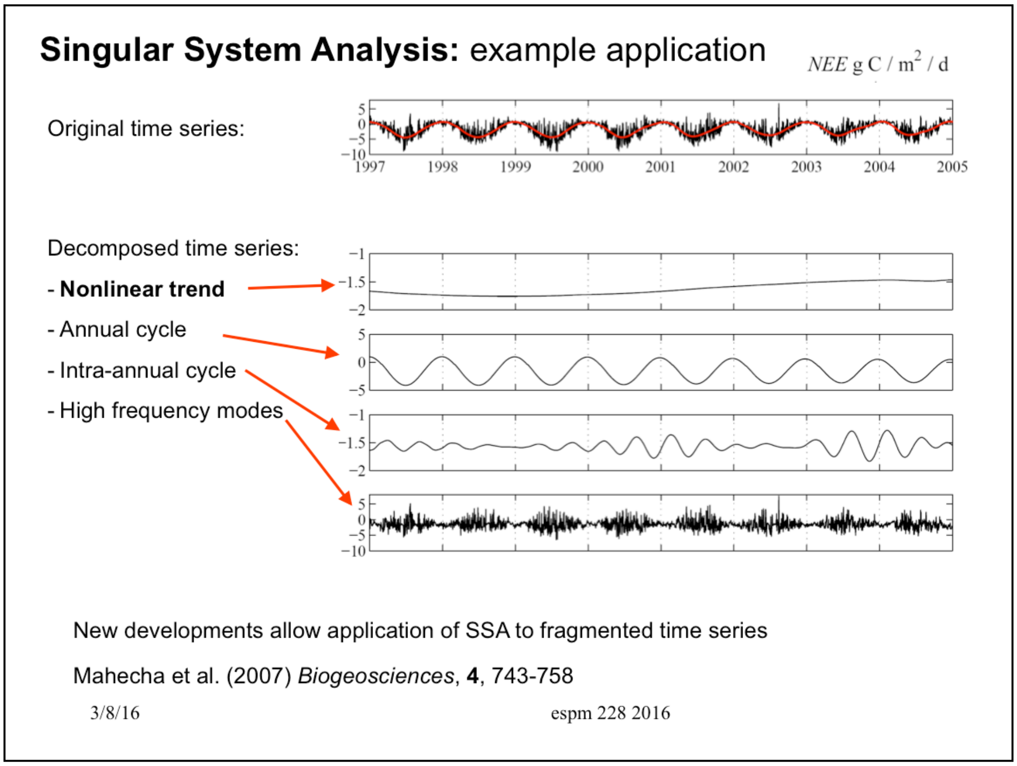
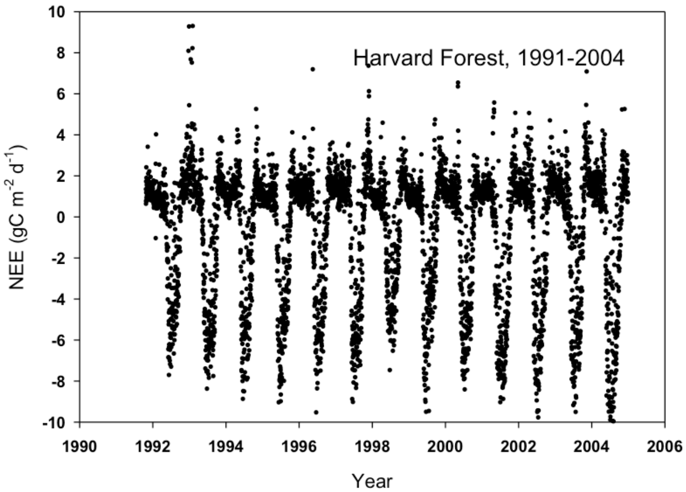
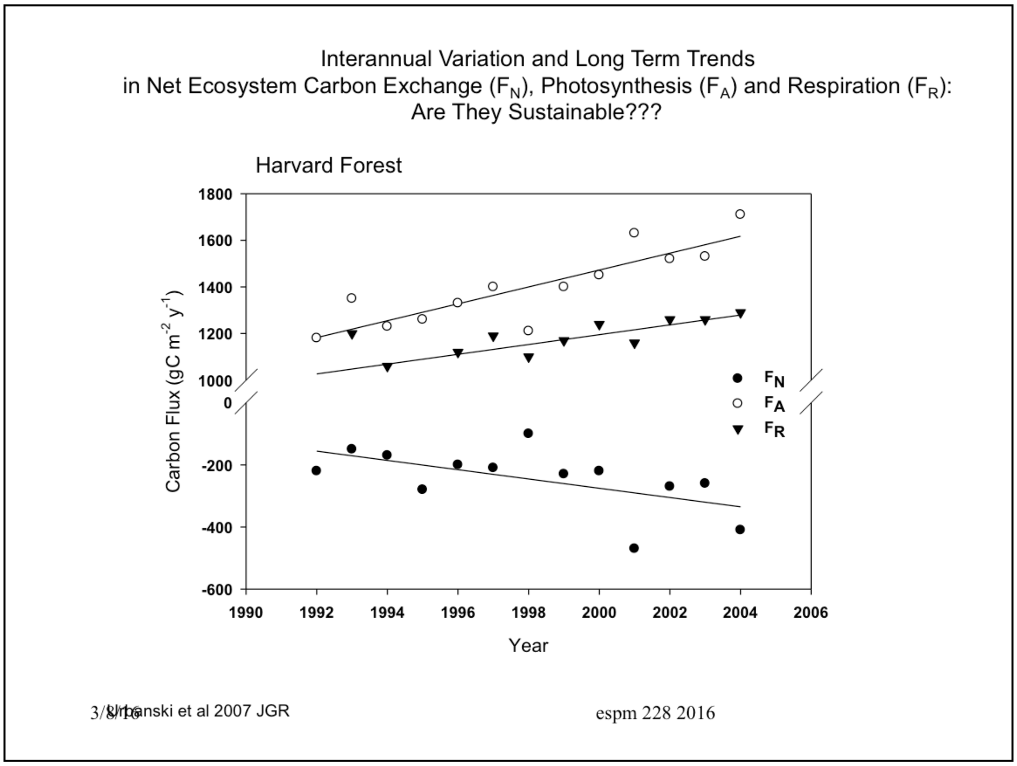


Time series analysis can tease out the various modes that modulate fluxes.

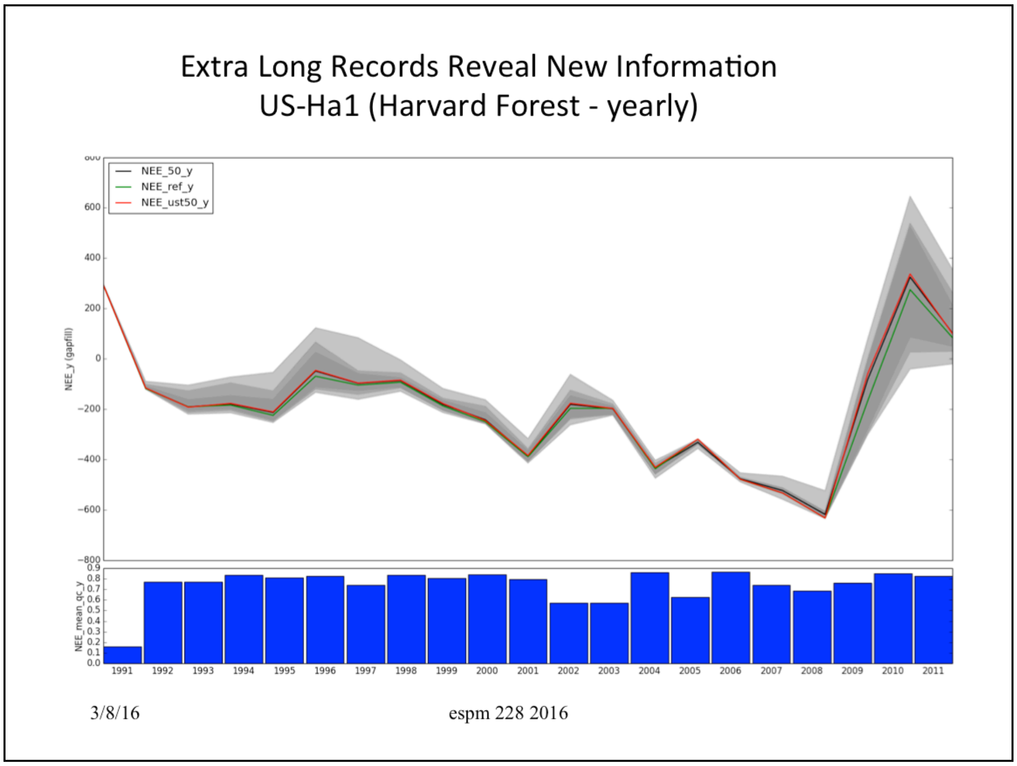
Decadal Plus Time Series of NEE:
Flux version of the Keeling's Mauna Loa Graph



Data of Wofsy, Munger, Goulden, et al.; Urbanski et al 2007 JGR.



Interesting trends emerging in long term record

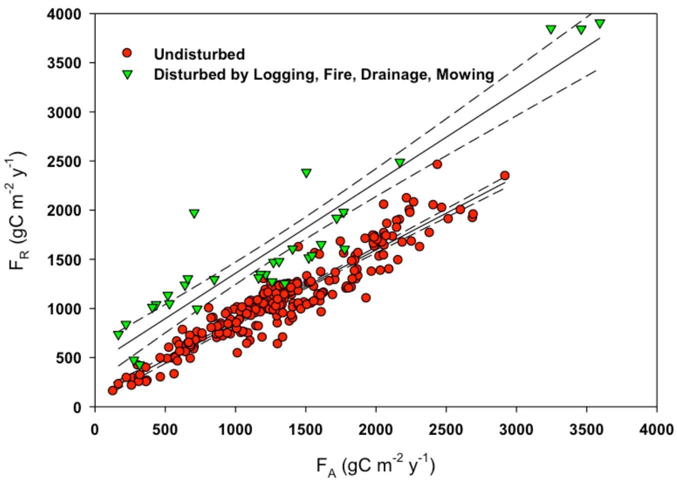


After papale.

Extension of the harvard forest data record is now showing a reverse in the trend in increasing carbon uptake. Another example of the surprises found when looking at longer and longer records.

Structure, Function, Traits and Emerging Processes

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



Baldocchi, Austral J Botany 2008 3/8/16 espm 228 2016

On the other hand, respiration and photosynthesis are tightly coupled. Future models should evaluate respiration in terms of assimilation and the exudates and biomass that can result

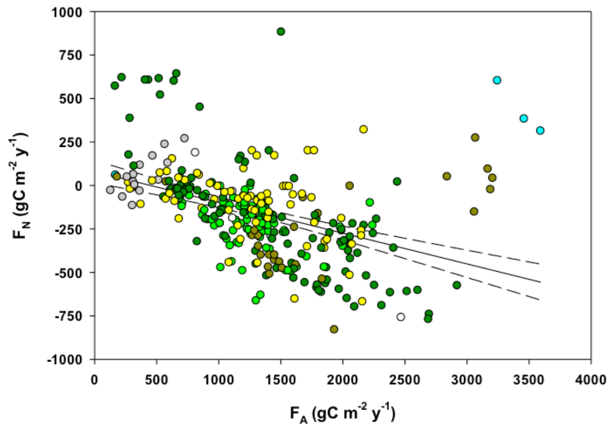
An Artifact of Spurious Correlation Among NEE, GPP and R_{eco}?

$$r_{sc} = \frac{-\overline{z'z'}}{(\overline{x'x'} + \overline{z'z'})^{1/2}(\overline{y'y'} + \overline{z'z'})^{1/2}}$$

$r_c = -0.157$

Baldocchi and Sturtevant, 2015 AgForMet

Does Net Ecosystem Carbon Exchange Scale with Photosynthesis?

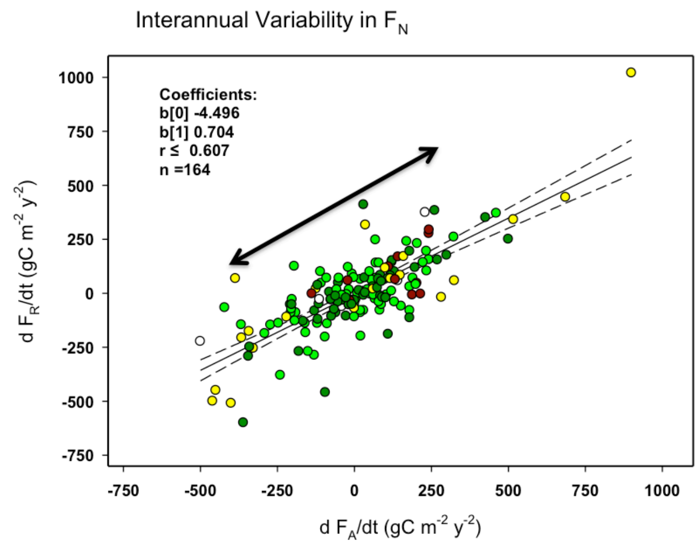


Ecosystems with greatest GPP don't necessarily experience greatest NEE

Baldocchi, Austral J Botany, 2008

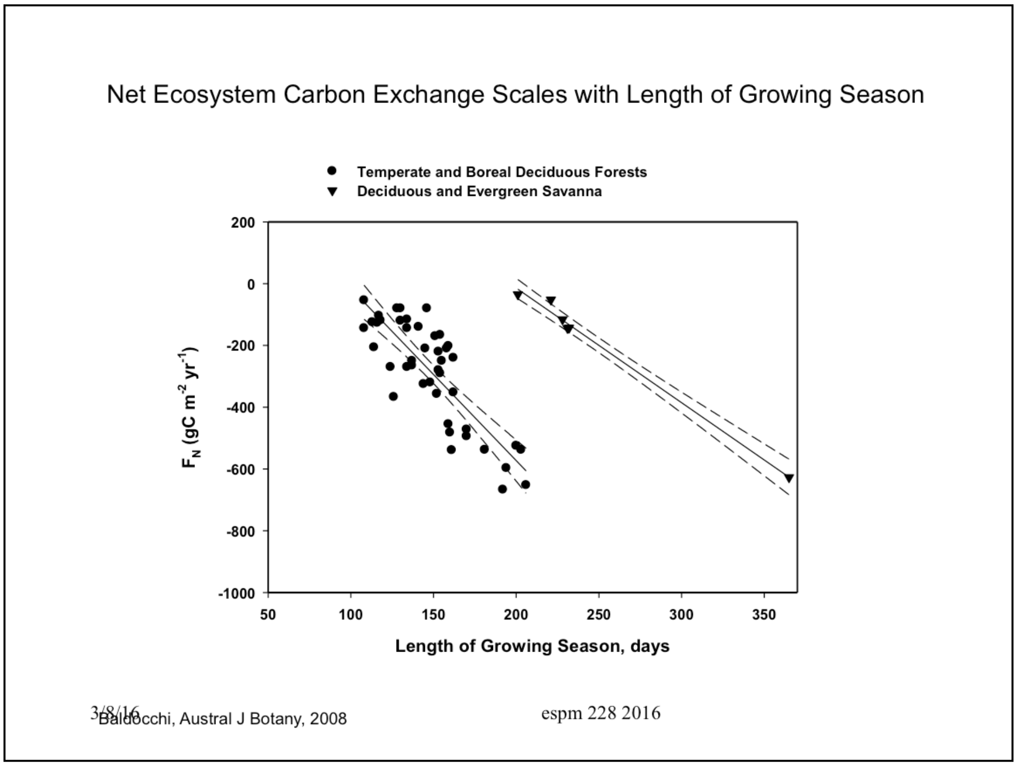
Net carbon exchange does not scale well with photosynthesis. R2 = 0.16. Though this may sound counter intuitive it is widely known by crop breeders and agronomists. It is not all carbon assimilation, but how it is partitioned to define net fluxes. An important lesson

Interannual Variations in Photosynthesis and Respiration are Coupled

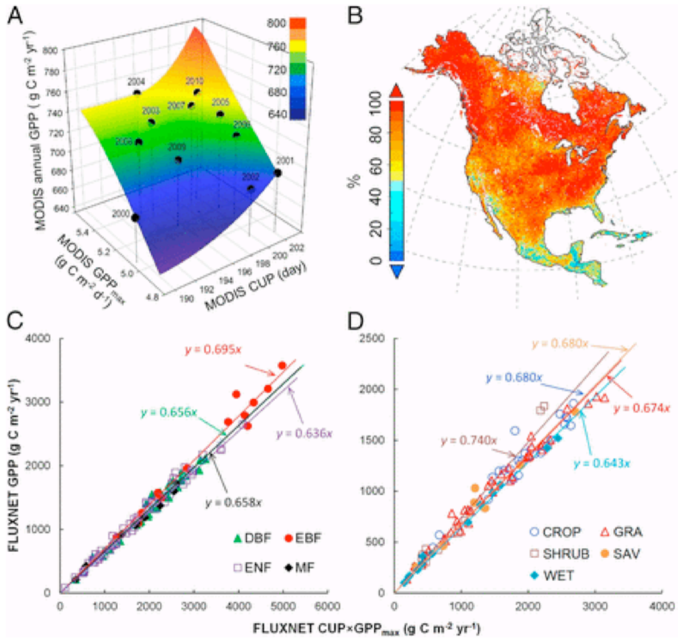


Baldocchi, Austral J Botany, 2008

Year to year changes in photosynthesis are Positively correlated with respiration. Hence factors that limit photosynthesis, like drought and heat spells, inhibit respiration, not promote it, as some models may suggest. Really important finding.

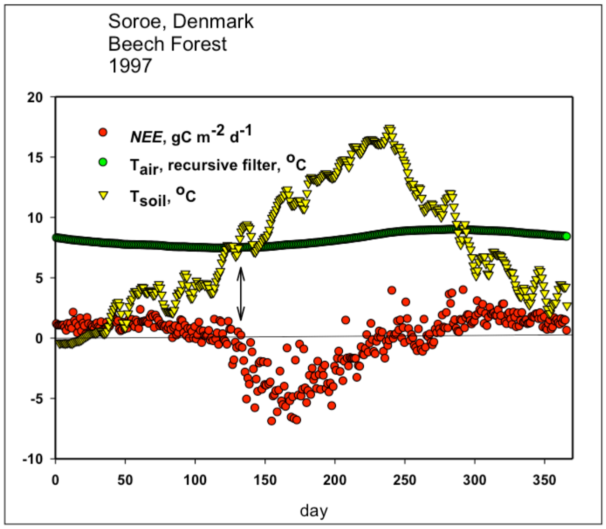


How does length of growing season affect carbon fluxes. Across the network we see longer seasons produce more carbon uptake. This may not not hold at given sites as early seasons us more water and can lead to drought and less carbon uptake later.



Xia et al 2015 PNAS espm 228 2016

Soil Temperature:
An Objective Indicator of Phenology??



Data of Pilegaard et al.

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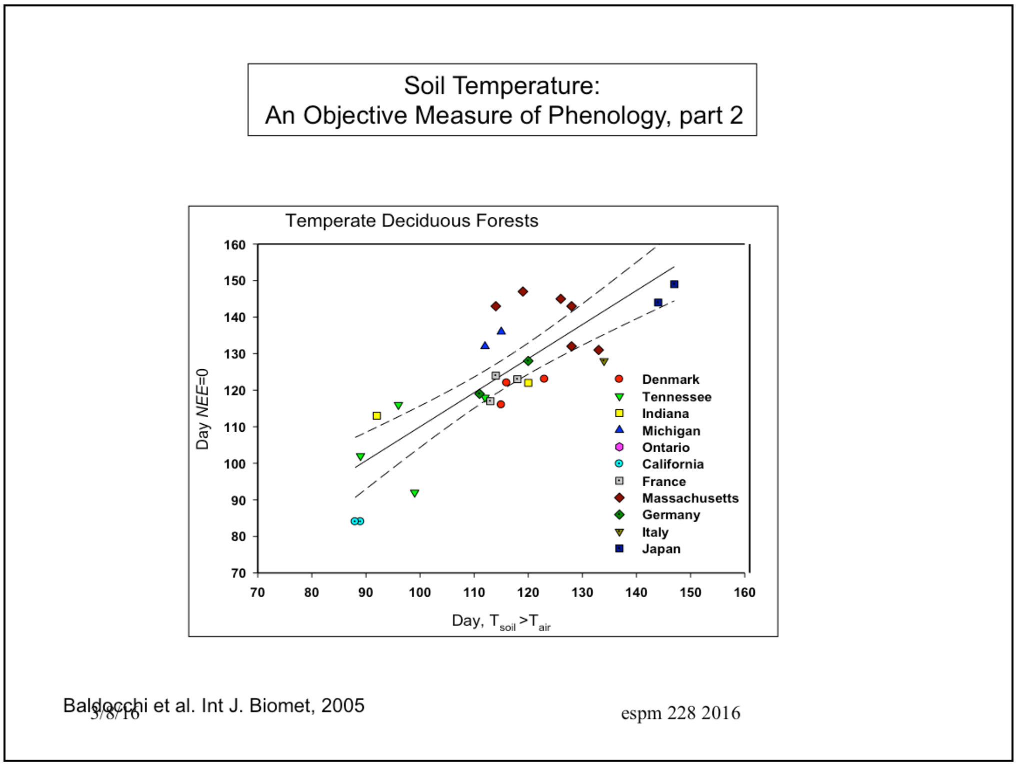
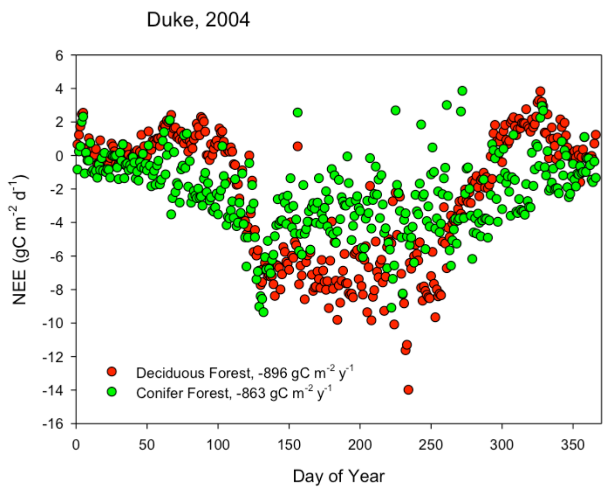
When does leaf out occur. Current phenology models are very empirical and are based on highly tuned growing degree day models. Our hypothesis is leaf out occurs when soil temperature matches mean annual air temperature. Leaf out too early and face frost and cold. Leaf out too late and shorten your growing season.



Fluxnet provided new ways towards understanding phenology. We find that leaf out occurs when soil temperature crosses mean annual air temperature. A simple, but powerful way to describe phenology.

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

Evergreeness vs deciduousness. Here are two forests nearby at Duke. We did a similar analysis with evergreen and deciduous oaks growing in CA, Italy, France and Portugal and found normalized fluxes were about the same

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	$g\ C \cdot m^{-2} \cdot yr^{-1}$	1251 ± 69	1288 ± 83	152
R_{eco}	$g\ C \cdot m^{-2} \cdot yr^{-1}$	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

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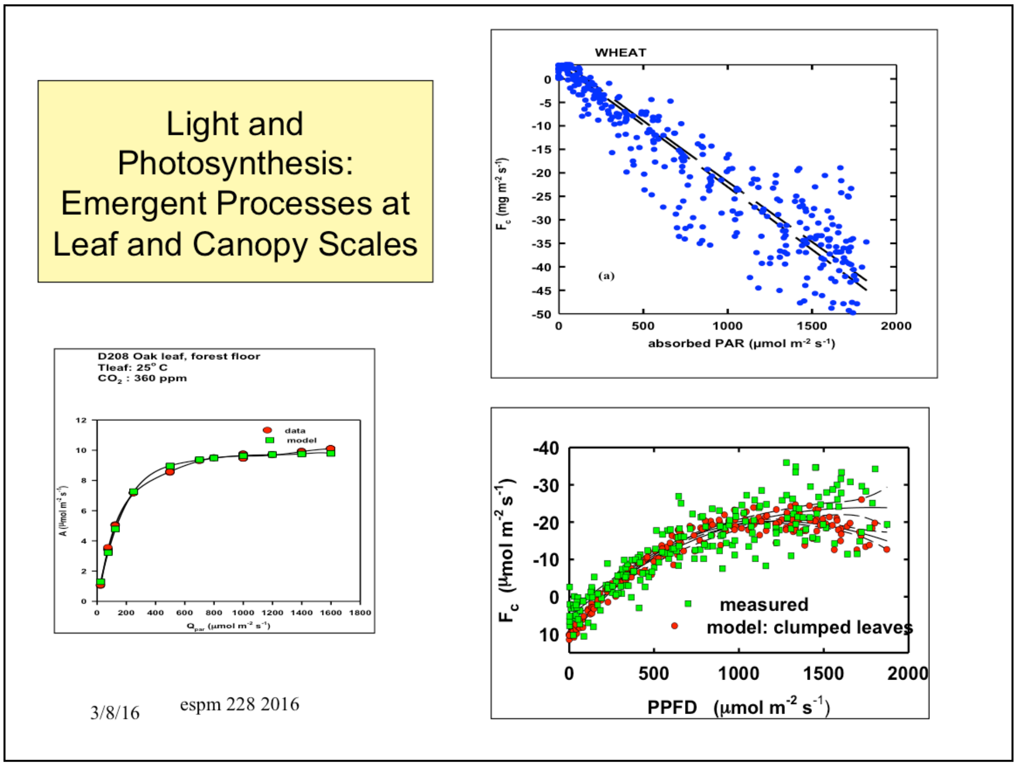
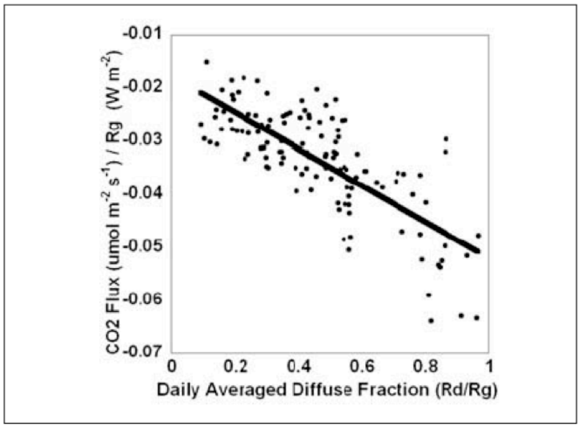
Baldocchi et al 2010 Ecological Applications



Canopy photosynthesis can become linearized as a function of Par under certain circumstances

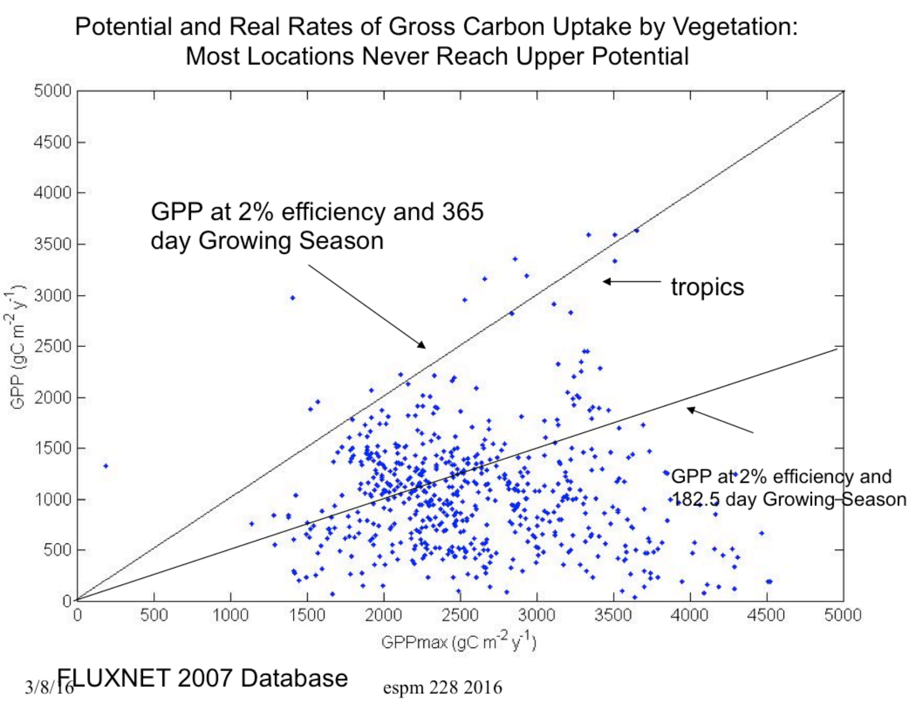
Emergent Scale Process:
CO_2 Flux and Diffuse Radiation

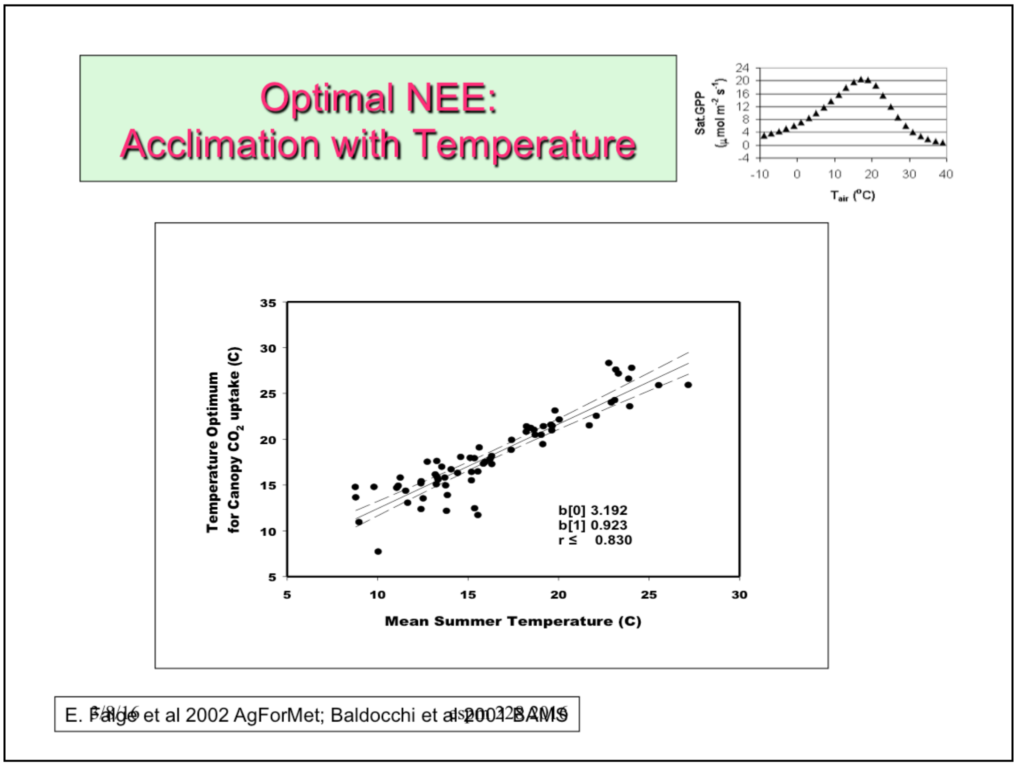


•We are poised to see effects of Cleaner/Dirtier Skies and Next Volcano

Niyogi et al., GRL 2004

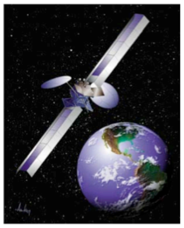
Light Use efficiency, LUE, is a strong function of diffuse light

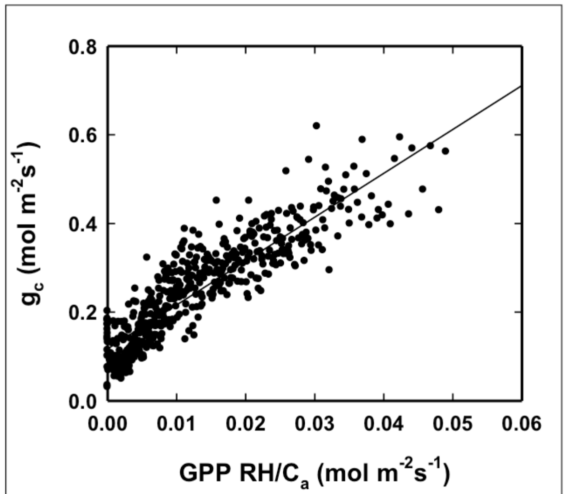

Potential and Real Rates of Gross Carbon Uptake by Vegetation:
Most Locations Never Reach Upper Potential
GPP at 2% efficiency and 365 day Growing Season
tropics
GPP at 2% efficiency and 182.5 day Growing Season
GPP (gC m-2 y-1)
GPPmax (gC m-2 y-1)
FLUXNET 2007 Database



Temperature response function of photosynthesis acclimates

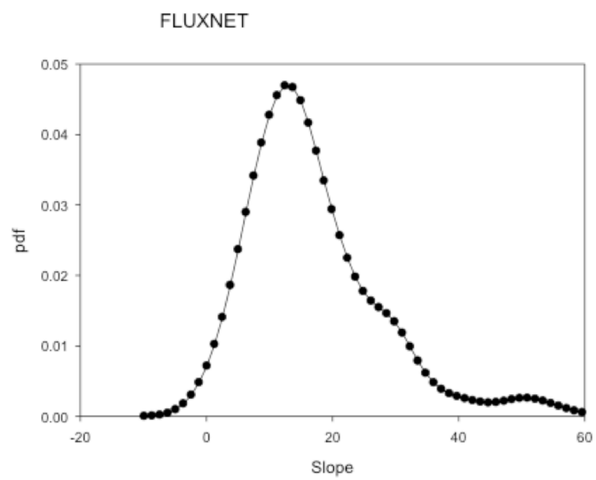
Linking Water and Carbon:
Potential to assess G_c with Remote Sensing





Xu + DDB, 2003 AgForMet

Gc Scale Invariance?
Task to Expand with New Database



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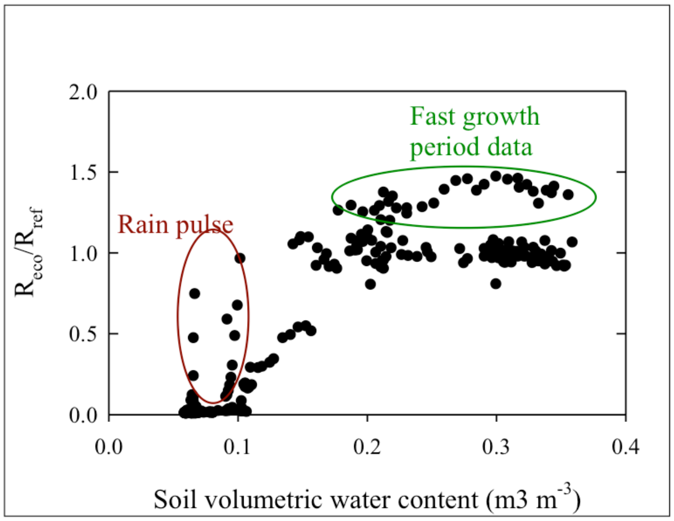
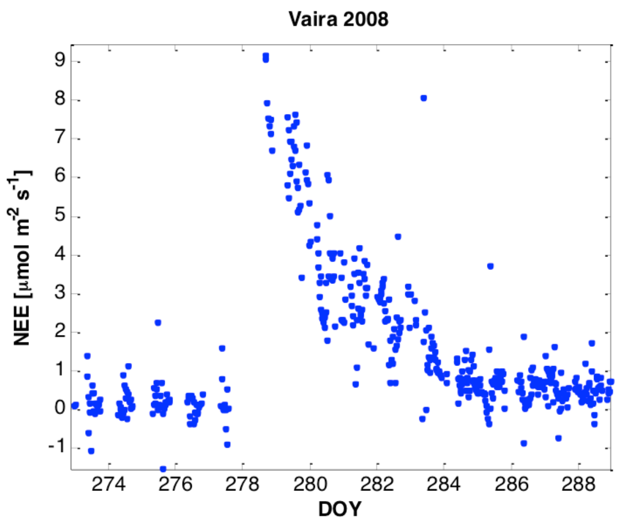
Environmental Controls on Respiration



Xu + Baldocchi, AgForMet 2004

Sustained and Elevated Respiration after Fall Rain



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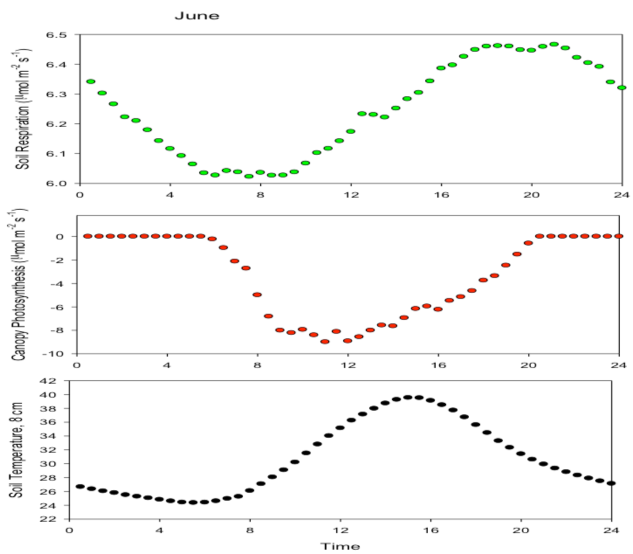
Lags and Leads in Ps, Soil Temperature and Soil Respiration



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Tang et al, Global Change Biology 2005.

New Math to Look at Cause and Effect

- Granger Causality
- Transfer Entropy
- Shannon Entropy
- Mutual Information Theory

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Granger causality:
A measure of coupling with explicit time directionality

Compare the bivariate

$$x_n = \sum_{j=1}^{m} a_{1,j} x_{n-j} + \sum_{j=1}^{m} a_{2,j} y_{n-j} + \varepsilon_n,$$

To the univariate case:

$$x_n = \sum_{j=1}^{m} a_j x_{n-j} + \eta_n$$

Calculate G-causality:

$$G_{y \to x} = \ln \frac{\sigma_\eta^2}{\sigma_\varepsilon^2}$$

No interaction, G ≈ 0
Interaction, G > 0

A variable, x, Granger Causes
y if the bivariate equation outperforms
The univariate

Detto et. al., *Am. Nat.* [2012]
Geweke, *JASA* [1982]
Dhamala, *Phys. Rev. Lett.* [2008]
Chen, *J. Neurosci. Meth.* [2006]

Can Be Expressed in Spectral Domain

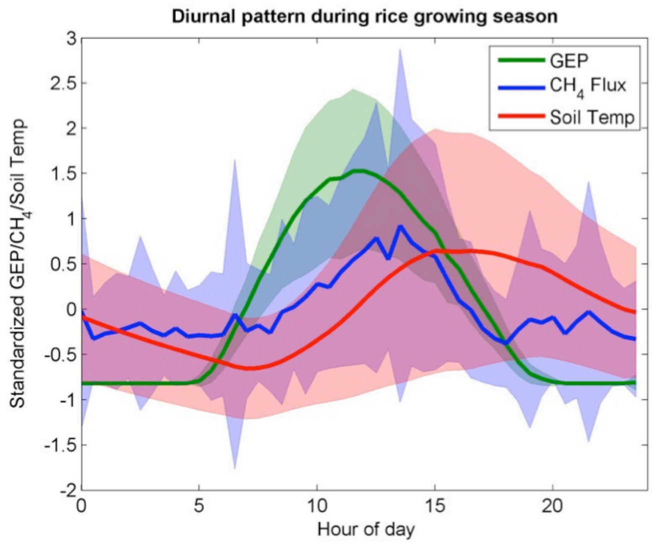
In frequency (f) domain:

$$I(f)_{y\to x} = \ln\left\{\frac{S_{xx}(f)}{S_{xx}(f) - [\mathbf{\Gamma}_{yy} - (\mathbf{\Gamma}_{xy}^2/\mathbf{\Gamma}_{xx})]|\mathbf{H}_{xy}(f)|^2}\right\}$$

No interaction, G ≈ 0
Interaction, G > 0

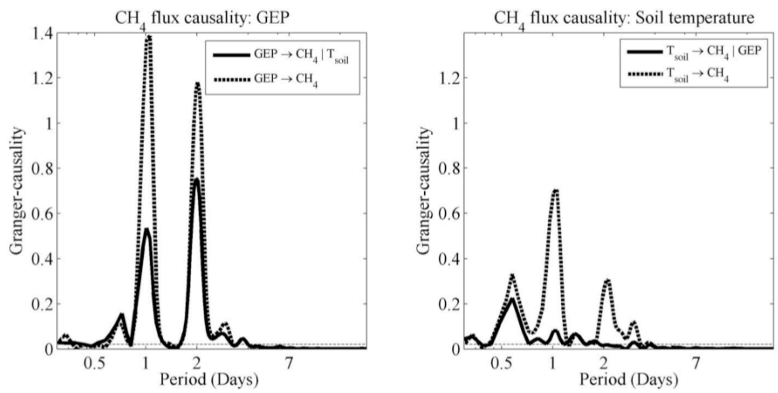
$S_{xx}(f)$ = power spectrum of x at frequency f
Γ = error covariance matrix of the bivariate model
H = transformation matrix from writing model in Fourier space

Does Photosynthesis Prime Methane Production in Rice?



Hatala et al. GRL 2012

Methane scales with Photosynthesis



Hatala et al. GRL 2012

Mutual Information

$$I_{XY} \underset{(9)}{=} \sum_{x_t} \sum_{y_t} p(x_t, y_t) \log_2 \frac{p(x_t, y_t)}{p(x_t) p(y_t)}$$

$$I_{XY} = H_X + H_Y - H_{XY}$$

Relative Mutual Information

$$I_{XY}^R = I_{XY} / H_Y$$

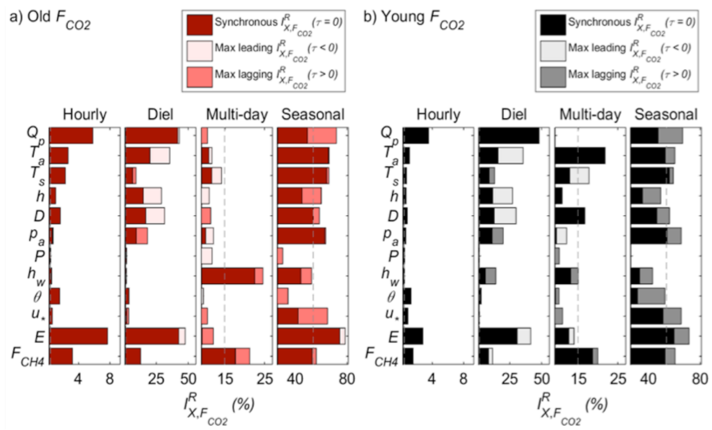
Shannon Entropy

$$H_X = -\sum_{x_t} p(x_t) \log_2 p(x_t)$$

$$H_{XY} = -\sum_{x_t} \sum_{y_t} p(x_t, y_t) \log_2 p(x_t, y_t)$$

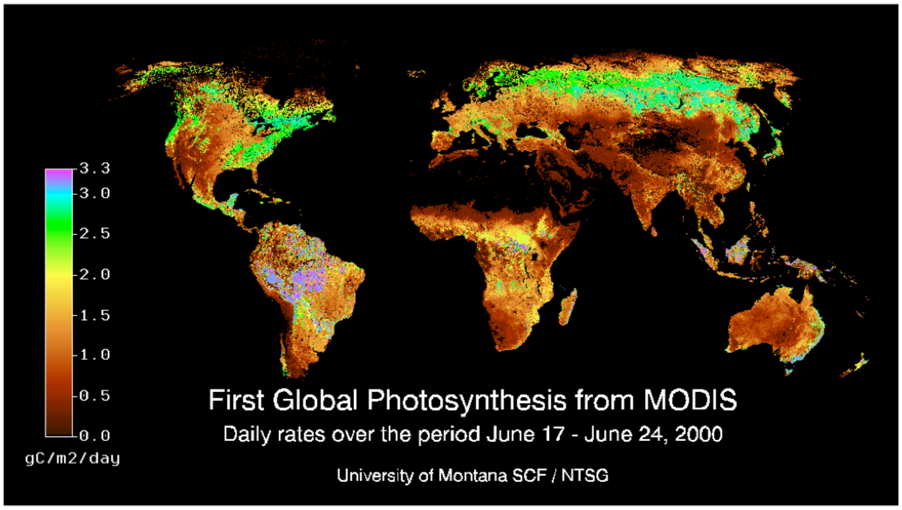
$$H_Y = -\sum_{y_t} p(y_t) \log_2 p(y_t)$$

Relative Information on CO_2 Flux



Sturtevant et al. 2016 JGR Biogeoscience

Spatial Variations in C Fluxes



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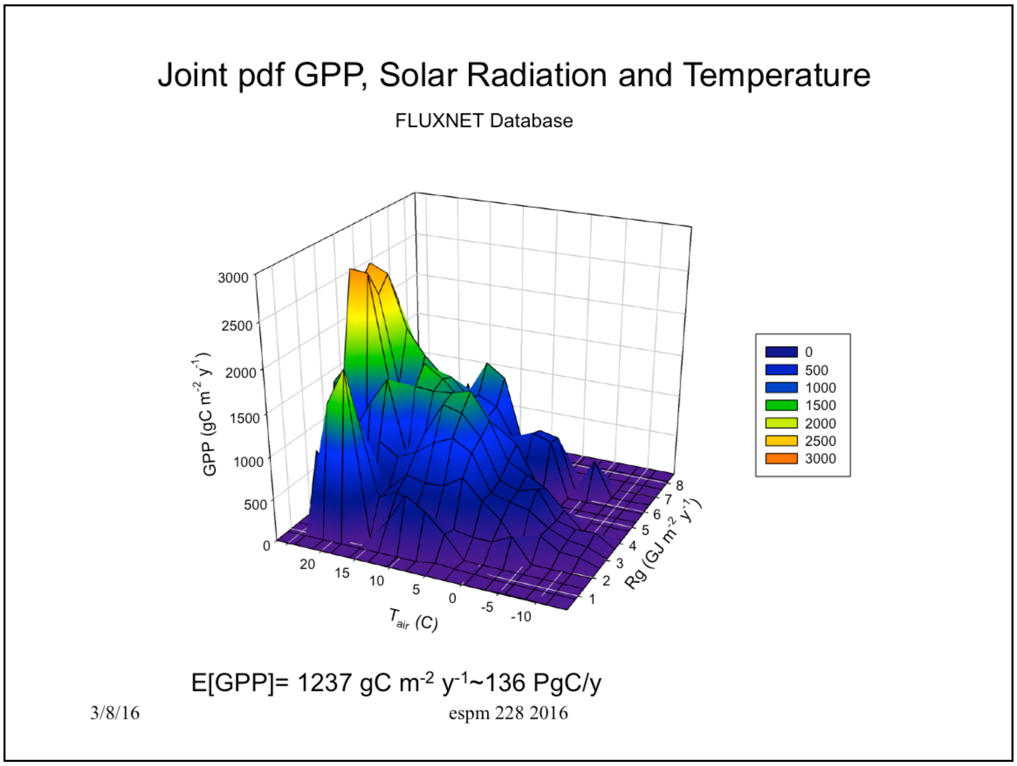
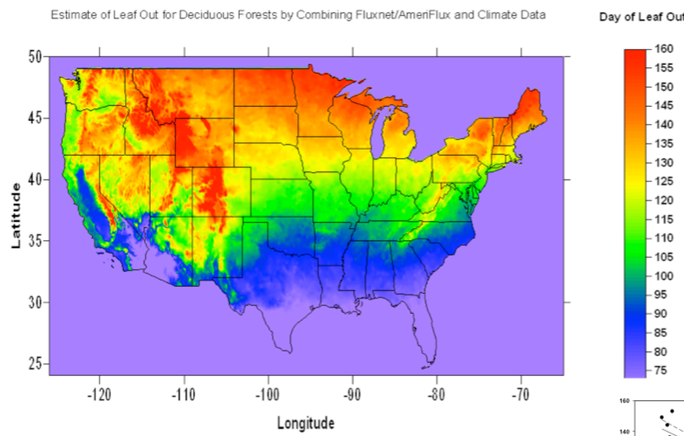
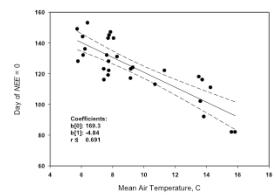
Partnership with MODIS improves spatial maps of carbon fluxes



Repeat using Metropolis algorithm with climate database (like the random number generator I use)..this is the prior from fluxnet…adjust with global map of Tair and Rg…better yet repeat with Rg and ppt

Spatialize Phenology with Transformation Using Climate Map





Baldocchi, unpublished

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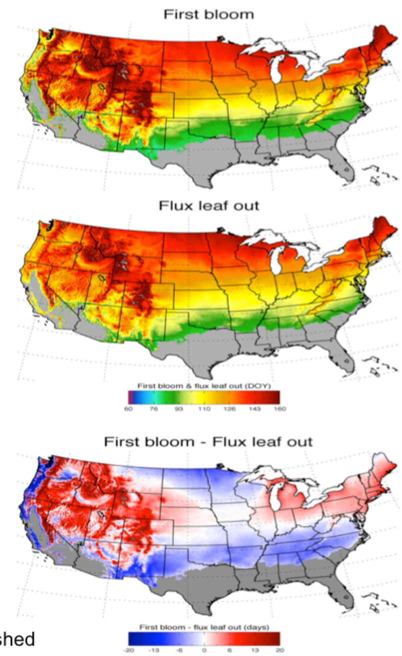
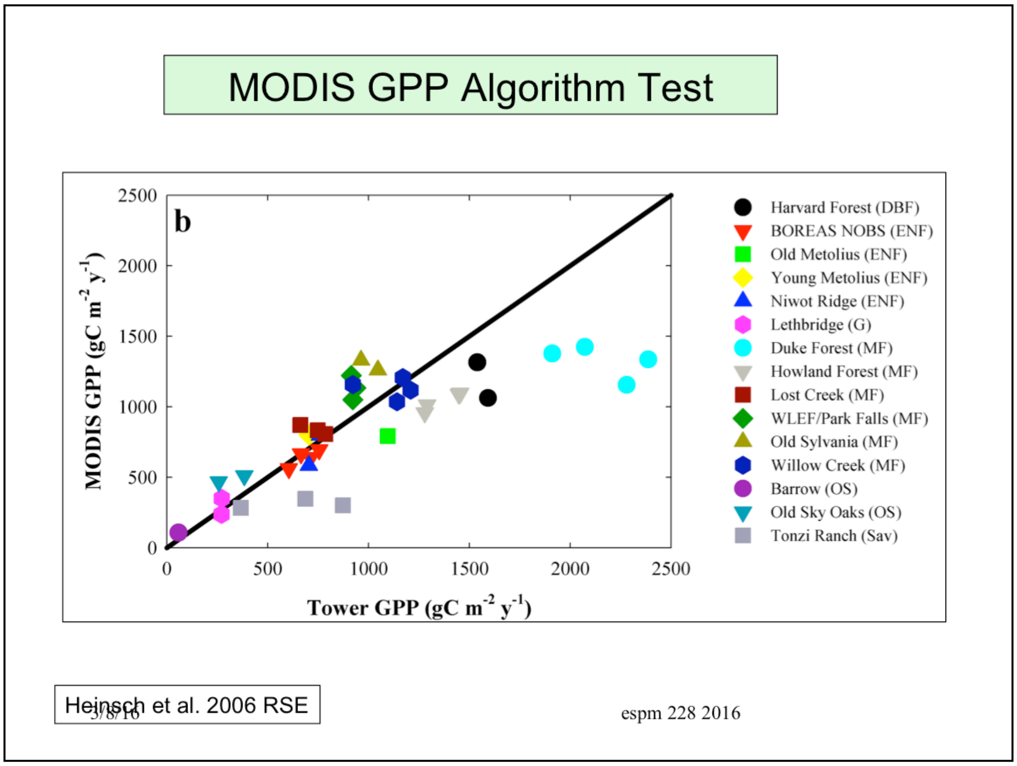
Environmental response functions, determined with fluxnet data, can then be spatialized to examine spatial patterns like phenology and time of greenup

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

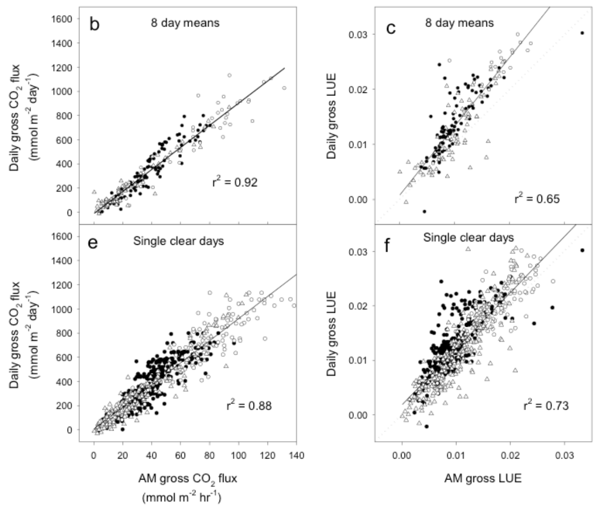


White, Baldocchi and Schwartz, unpublished



Bias errors in LUE based remote sensing models can be validated and parameterized

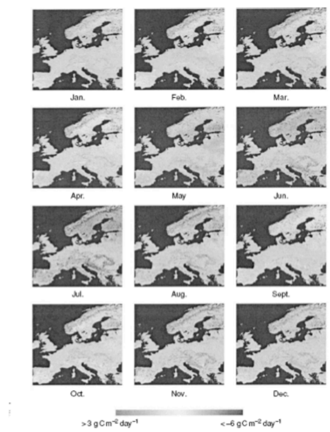
Do Snap-Shot C Fluxes, inferred from Remote Sensing, Relate to Daily C Flux Integrals?

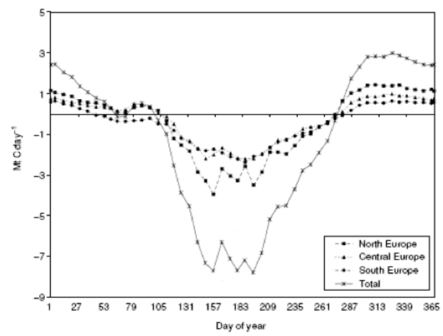


Sims et al 2005 AgForMet

Daily integrals of flux measurements scale well with snap shots

Upscaling Tower Measurements with Neural Network Model and Remote Sensing





Papale and Valentini, 2003 GCB

What are Pros and Cons?

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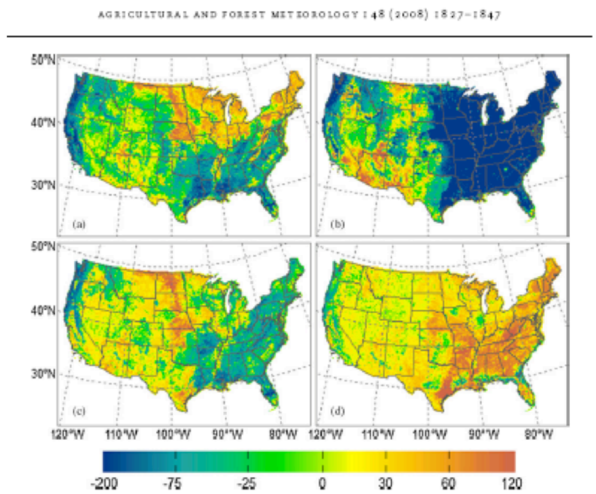
Neural network models can be used to produce spatial maps of fluxes. Discuss Pros and Cons

Spatial Variations in C Fluxes

spring

summer



autumn

winter

Xiao et al. 2008, AgForMet

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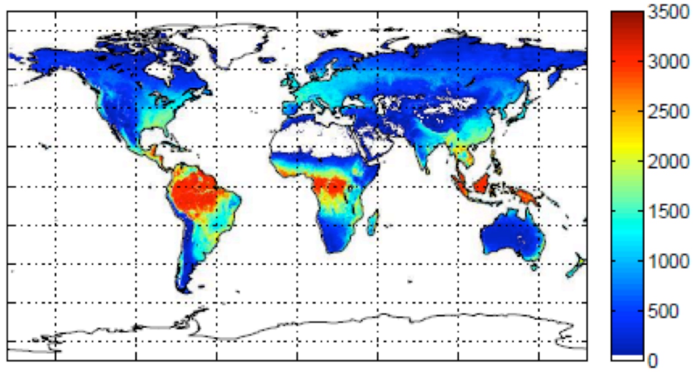
Use of regression tree models produce alternative maps. Interesting anomalies are discovered

Global Primary Productivity



GPP = 123 +/- 8 PgC y-1

Beer et al., 2010 Science

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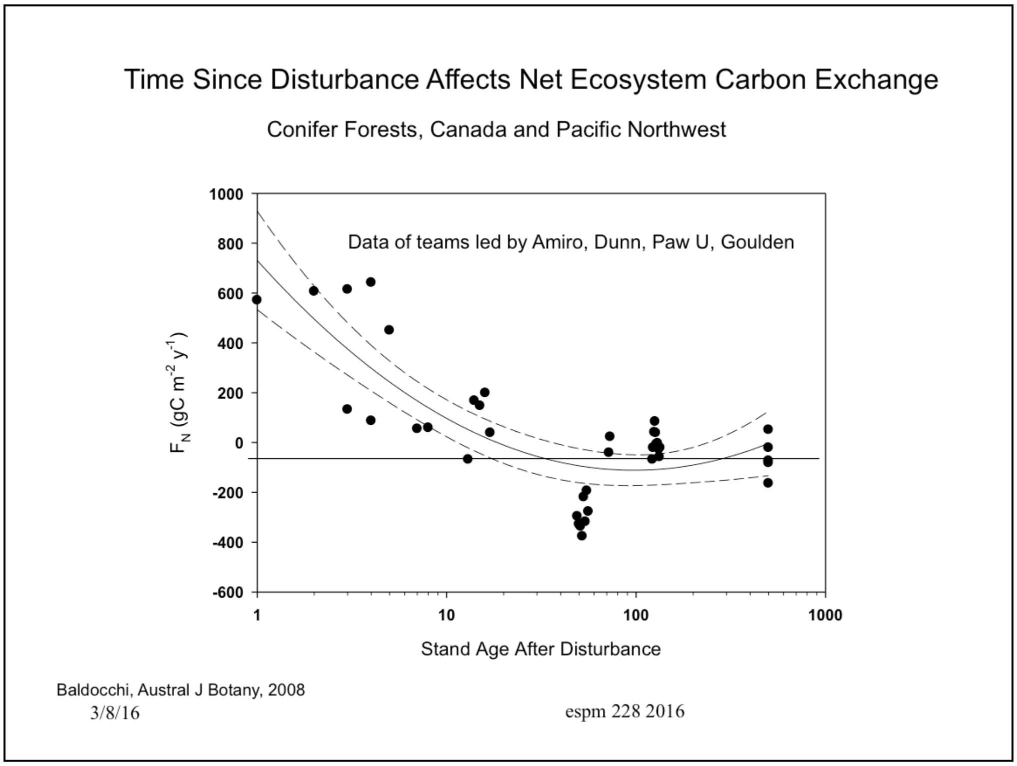
Data driven products using flux networks can improve estimates of global primary productivity

Limits to Landscape Classification by Functional Type

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



Carbon fluxes are a function of time since disturbance. We must know land use and land use history to interpret fluxes

Other Activities and Uses of Fluxnet Data

- EcoHydrology and Water Balance
- Ecosystem Modeling
- Biodiversity
- Climate

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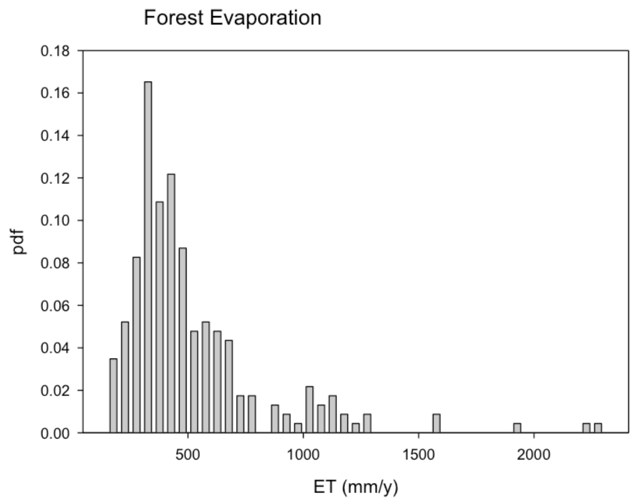
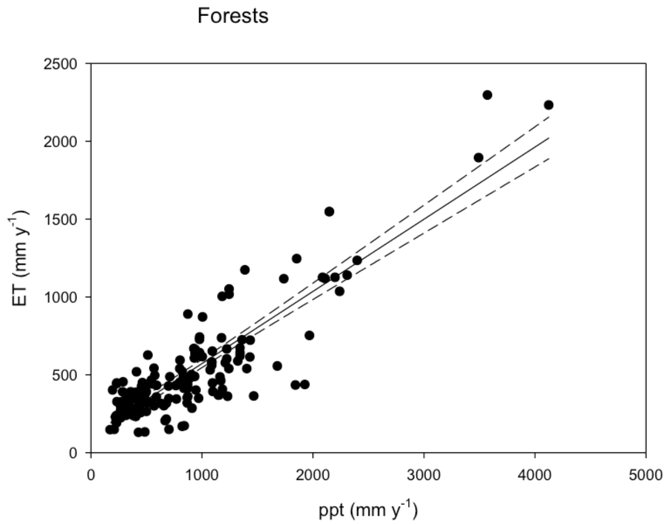
Fluxnet is more than just carbon fluxes. It has much potential to address questions, models and theories in biogeochemistry, ecology, climate and weather modeling, hydrology, etc



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



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

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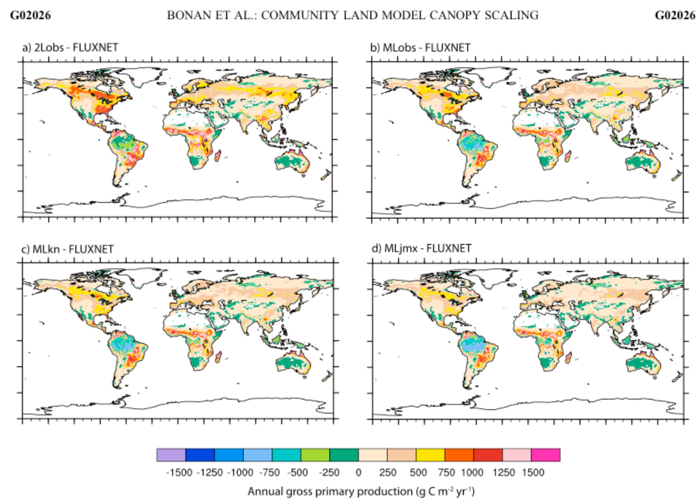
Fluxnet produces the first direct and long term measurements of annual ecosystem evaporation. In the past these budgets were inferred as RESIDUALS of water balances, with all their attendant assumptions and errors. Here is new information on the variation of ET among landscapes with with precipitation

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



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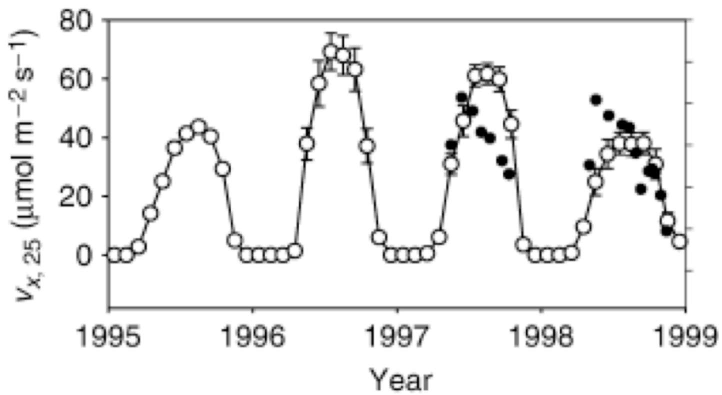
Prior to the mid aughts, most/many model tests were model/model intercomparisons. The availability of Fluxnet data gave the modeling community new test beds for model validation, verification and refinement

Seasonality of Photosynthetic Capacity



Wang et al, 2007 GCB

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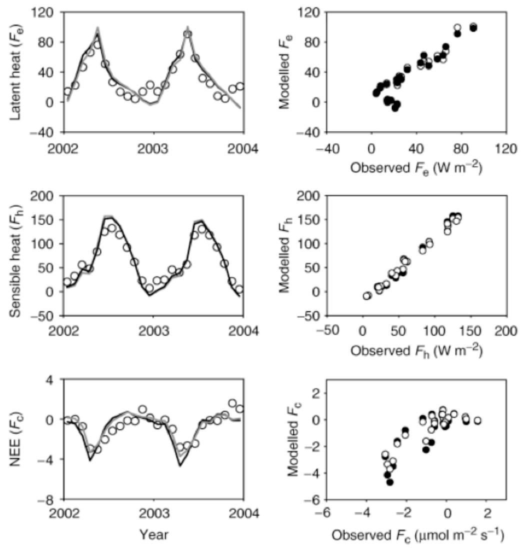
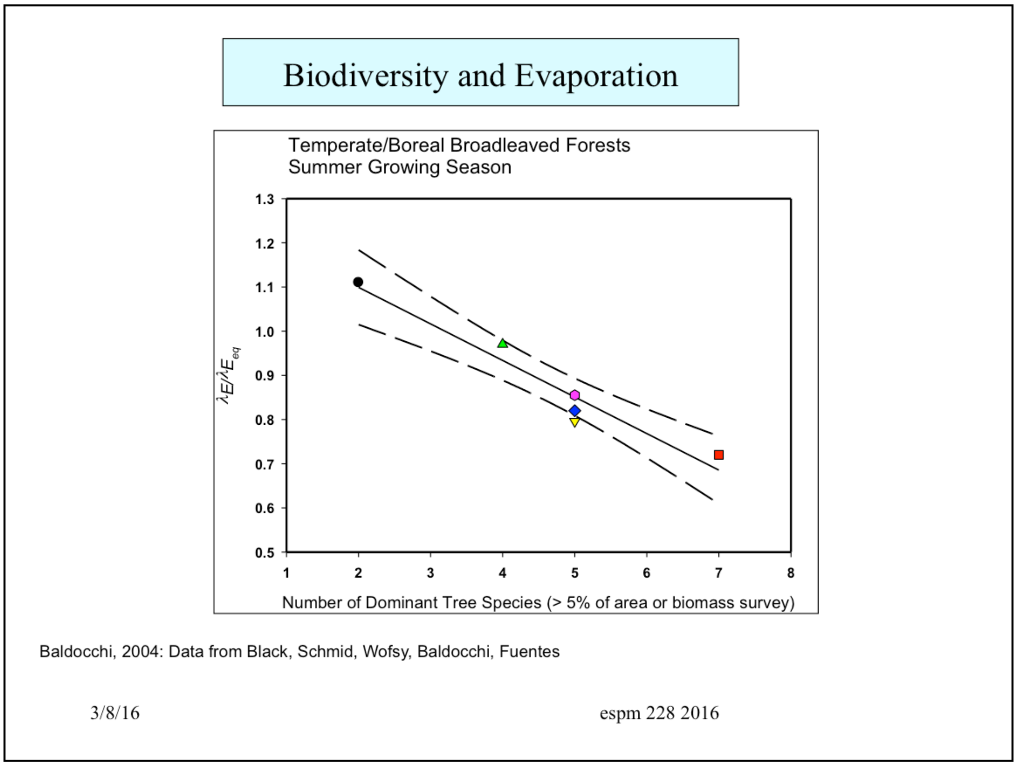
Physiological status of plants is not static. It is dynamic, changes with seasons and this dynamic needs to be incorporated into models

Optimizing Seasonality of Vcmax improves Prediction of Fluxes

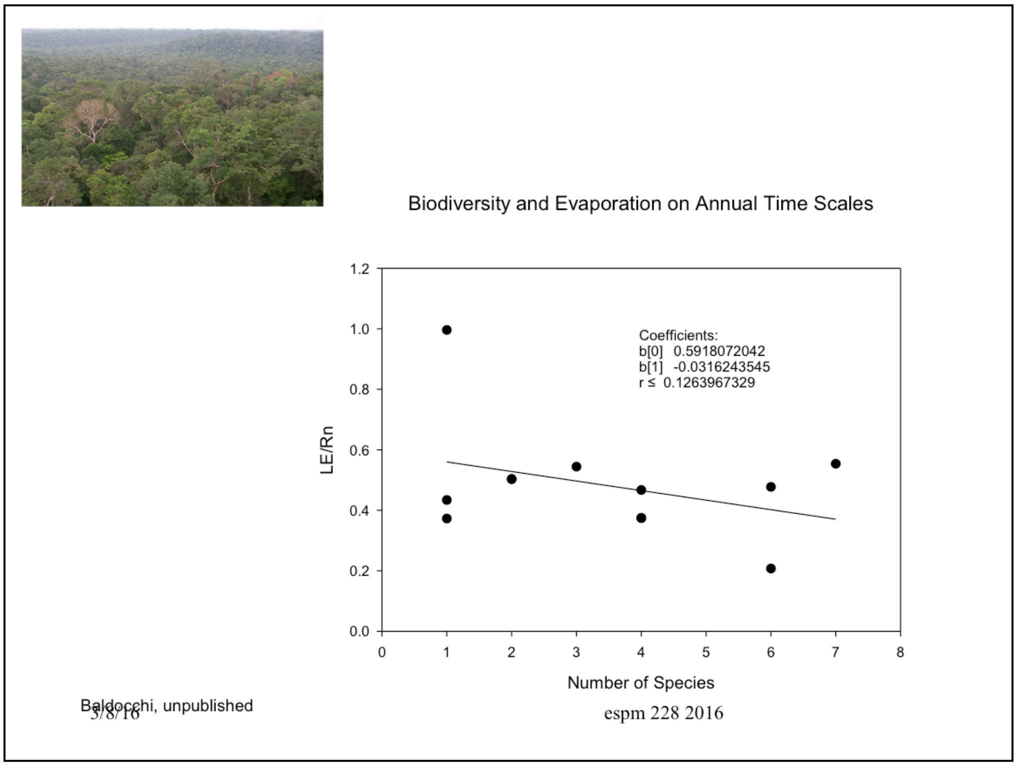


3/8/16 Wang et al, 2007 GCB espm 228 2016

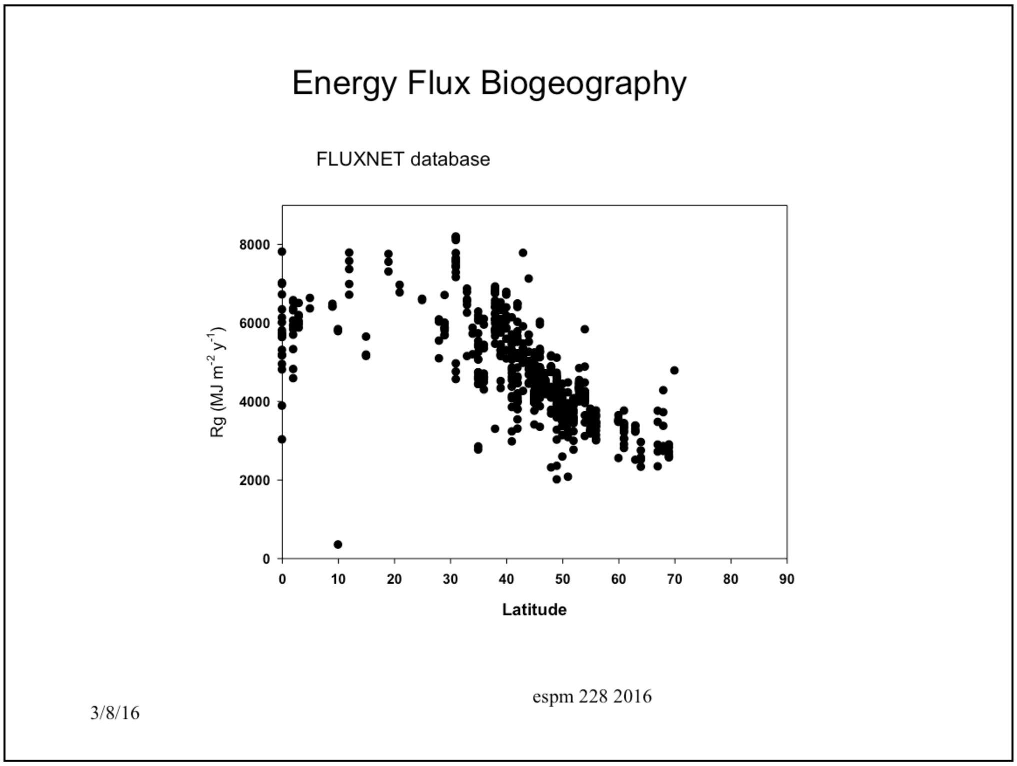
Flux data are critical in testing model assumptions and their parameterization. In the past physiological parameters, like Vcmax, the maximum rate of carboxylation velocity for photosynthesis, were held constant. Our own leaf measurements showed strong seasonality. So what happens if this seasonality is incorporated into land-atmosphere models? The fidelity of the flux computations improved greatly.



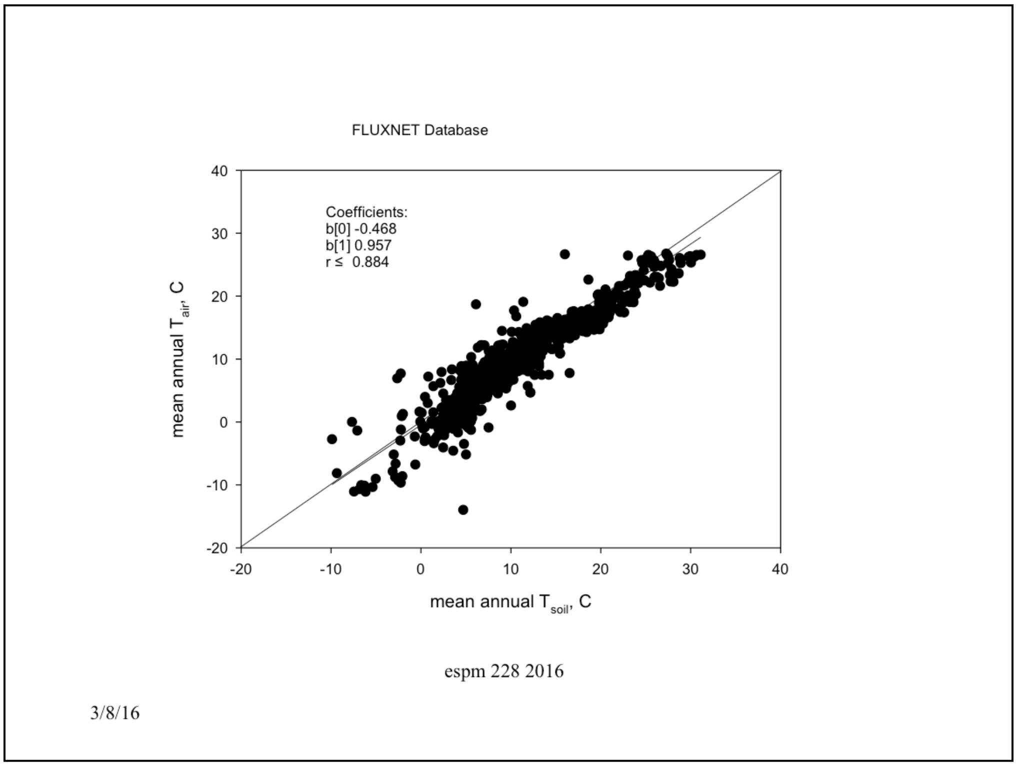
According to this preliminary analysis more species decreases evaporation, normalized by energy? Does this make sense? Is it feasible, or not?



Measurements across various locales enable us to test certain ecological theories like the role of biodiversity on water use. While we know trees of different species may transpire more or less than one another, what happens when they are assembled across a landscape? Adding data from more sites increases the robustness of the findings.



Interested in solar energy for biofuels and solar panels? Fluxnet provides an unprecedented global dataset of direct solar radiation measurements across the globe. This figure gives one the range of MJ that are available with latitude.



For climate slab models, the deep soil temperature is a lower boundary condition. How can we assess that? We find a strong correlation between annual air temperature and soil temperature (at 2 to 8 cm, depending on the site)

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

Ranking of fluxes by functional groups

FLUXNET 2014++
New Issues/Questions Raised

- Production of New, Expanded, Open and Shared 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

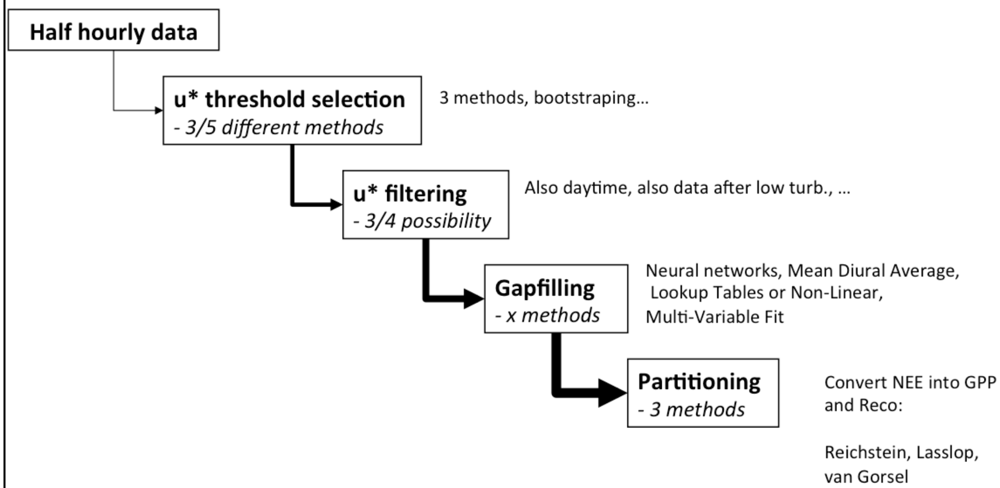
Current and Future Scientific Directions

- 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

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, ++++

Data processing, Value Added Products and Uncertainty Estimation



Courtesy of Dario Papale

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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
  - Asilomar 2009
  - Berkeley 2011

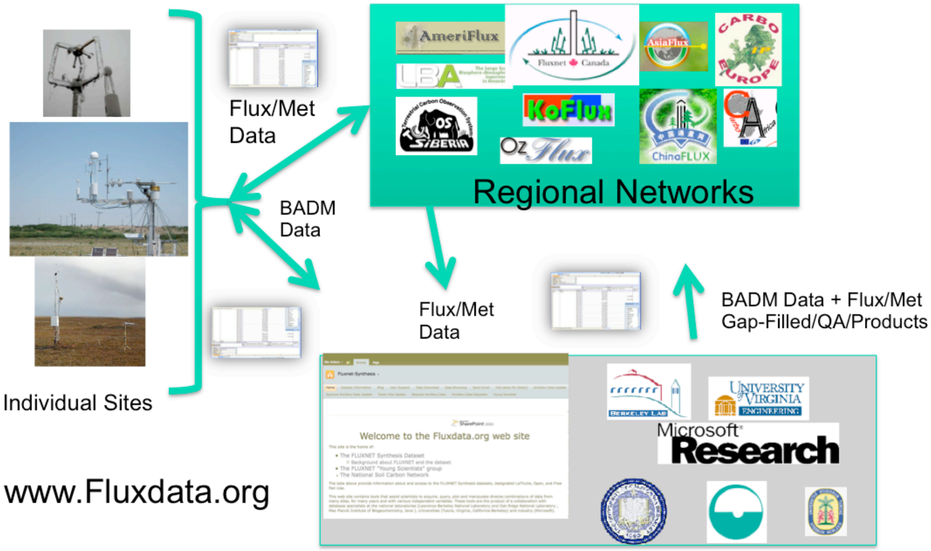
FLUXNET Successes

- ‘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

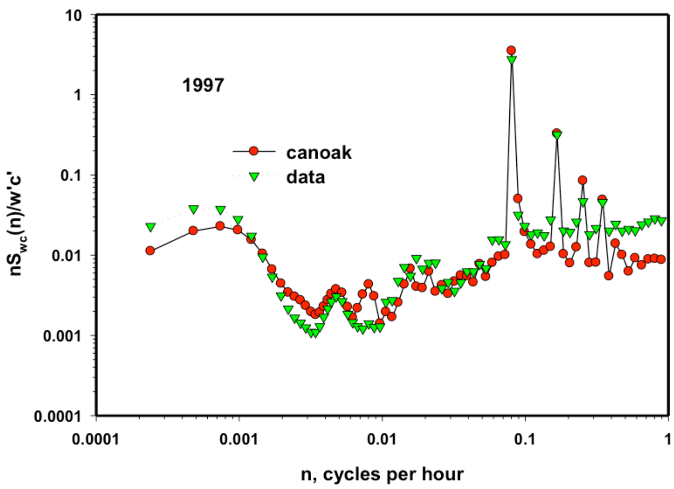
‘Failures’/’Un-resolved’ Issues

- Need to Share Data in an Open Format
- Achieve Better and Timely Data Submission from Partners
- 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 of New Generation of Fluxnet Scientists
  - Being Rectified with Flux Short Courses in Europe and US
  - Partly why I am here

Fluxdata.org – A Common, Shared Database



Modeling and Measuring the Power Spectrum of CO_2 Fluxes



Spectra is another way to study the time series