FLUXNET Data and Land Surface Models for Climate Simulation

Gordon Bonan
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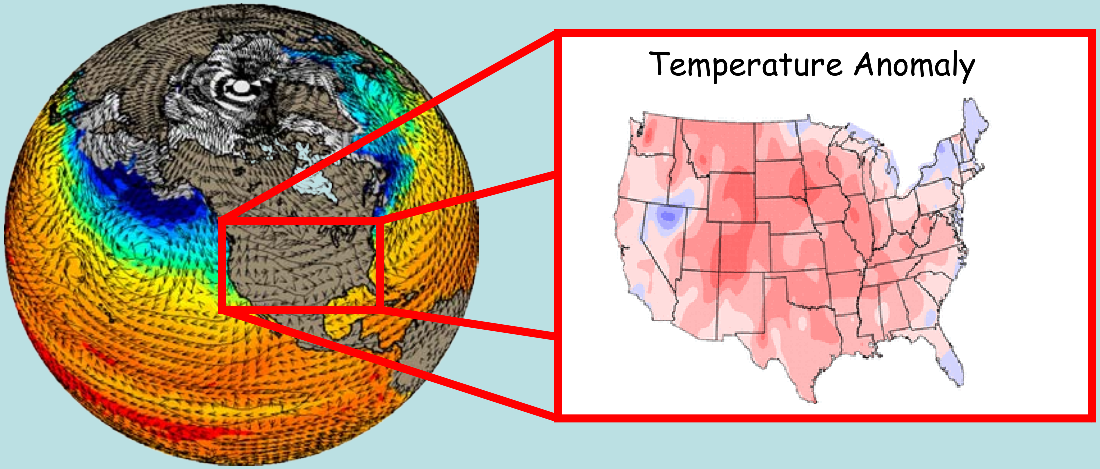


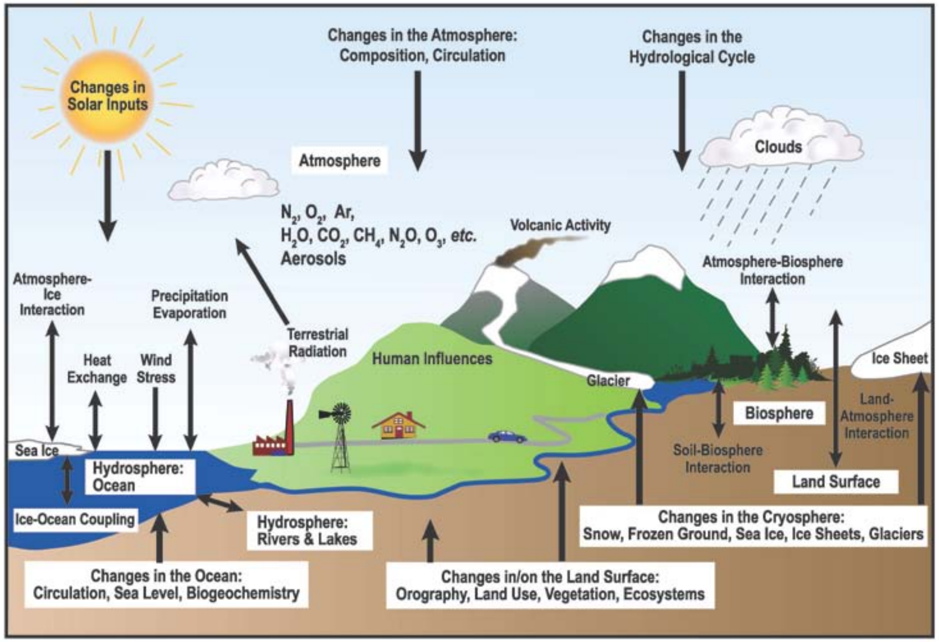
FlUXNET Asilomar Modeling Workshop
Pacific Grove, California
February 11, 2009

Our research

The land surface as the critical interface through which people affect, adapt to, and mitigate global environmental change

- Expanded capability to simulate ecological, hydrological, biogeochemical, and socioeconomic forcings and feedbacks in the earth system
- Increased emphasis on impacts, adaptation, and mitigation
- Requires an integrated assessment modeling framework
  - Human systems (land use, urbanization, energy use)
  - Biogeochemical systems (C-N-P, trace gas emissions, constituent tracing, isotopes)
  - Water systems (resource management, freshwater availability, water quality)
  - Ecosystems (disturbance, vulnerability, goods and services)

(IPCC 2007)



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The Community Land Model

Fluxes of energy, water, and carbon and the dynamical processes that alter these fluxes

Oleson et al. (2004) NCAR/TN-461+STR

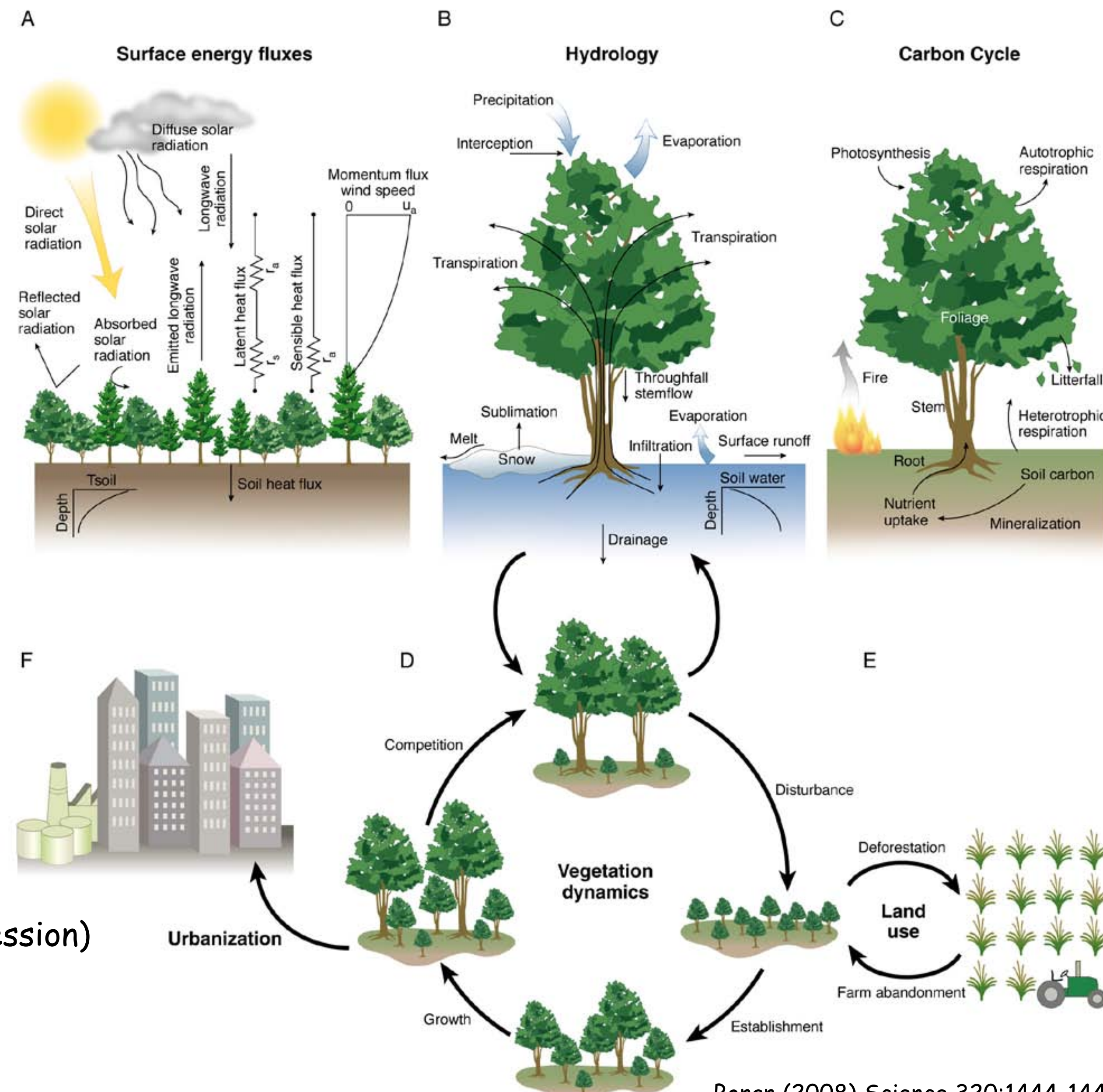
Oleson et al. (2008) JGR, 113, doi:10.1029/2007JG000563

Stöckli et al. (2008) JGR, 113, doi:10.1029/2007JG000562

Spatial scale
2.5° longitude × 1.875° latitude

Temporal scale

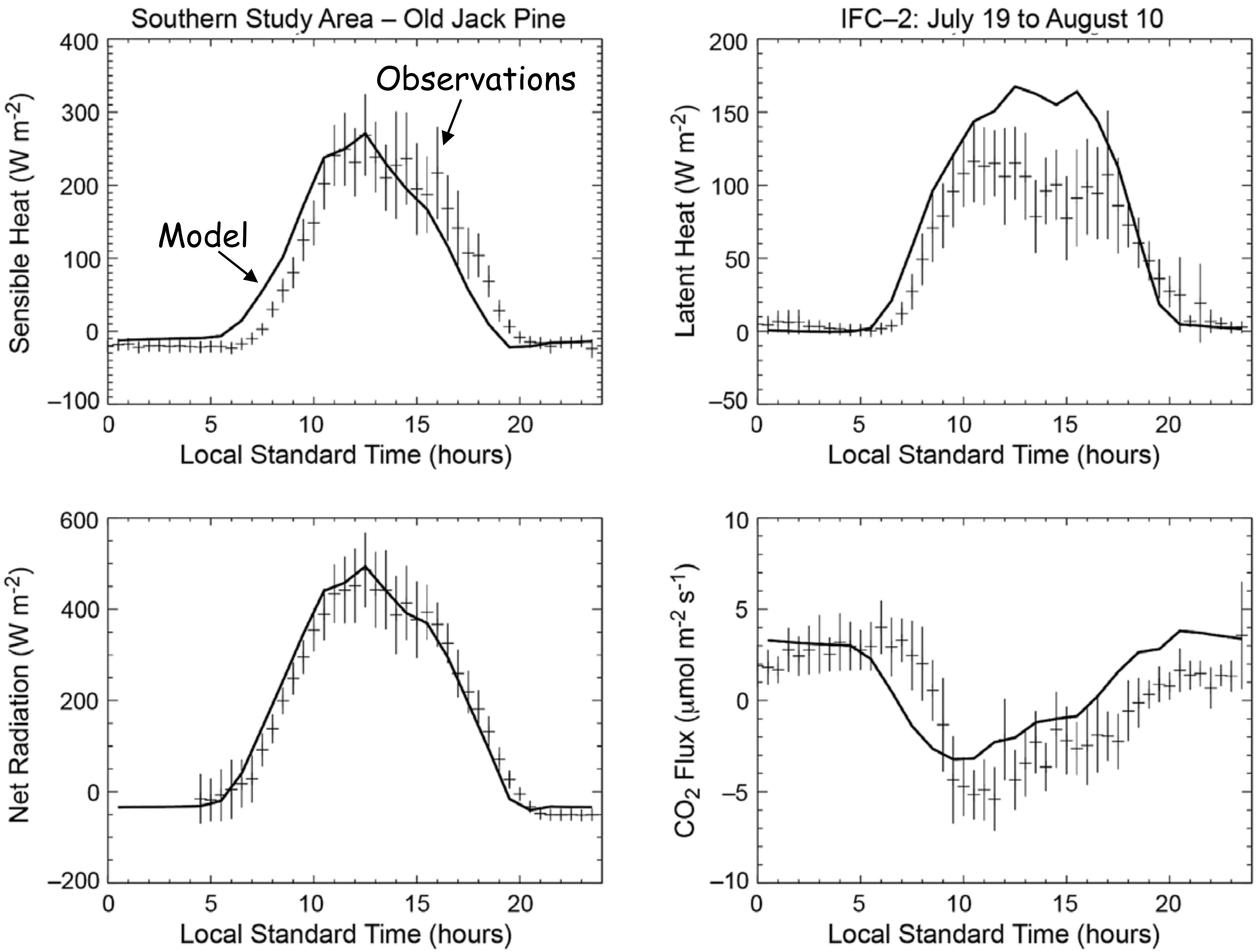
- o <30-minute coupling with atmosphere
- o Seasonal-to-interannual variability (phenology)
- o Decadal-to-century climate (disturbance, land use, succession)
- o Paleoclimate (biogeography)



Bonan (2008) Science 320:1444-1449

Model validation with tower fluxes

Boreal Ecosystem Atmosphere Study (BOREAS)



Bonan et al. (1997) JGR 102D:29065-75

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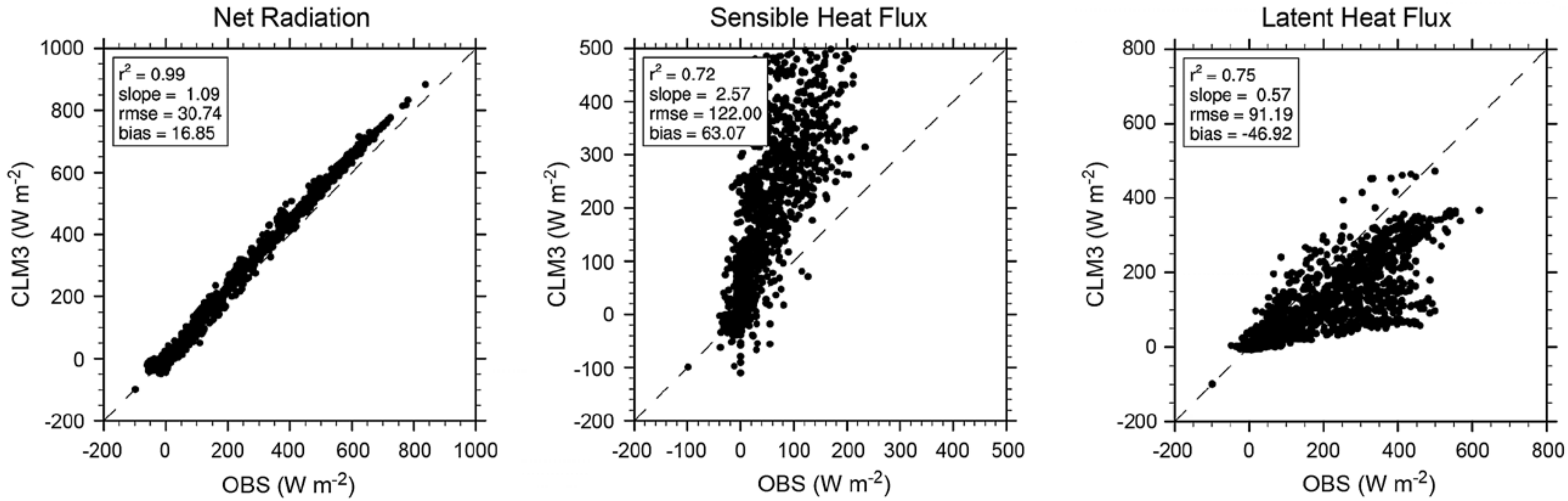
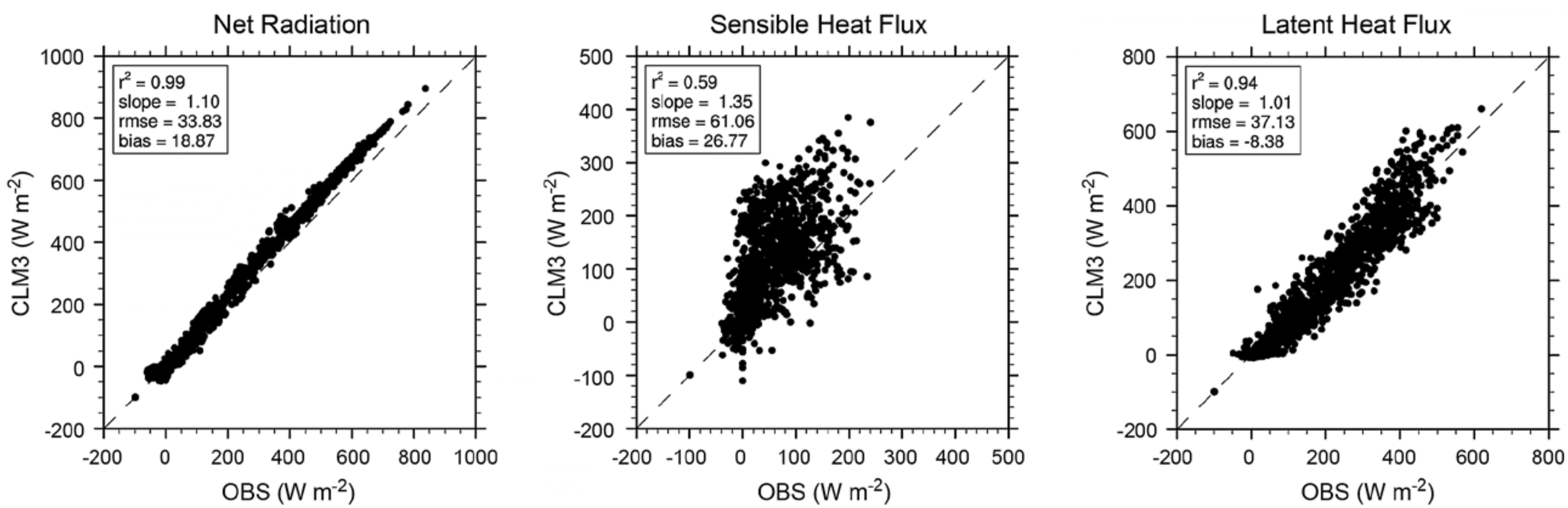
Model improvement with tower fluxes

Anglo-Brazilian Amazonian Climate Observation Study (ABRACOS) tropical rainforest, 4 April-26 July 1993

CLM3



CLM3+



Keith Oleson and David Lawrence (NCAR), unpublished

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Use of FLUXNET in the Community Land Model development

Observations: FLUXNET, a global network

USED SITES IN OUR STUDY:

- Morgan Monroe (1999-2005)
- Fort Peck (2000-2005)
- Harvard Forest (1994-2003)
- Niwot Ridge (1999-2004)
- Boreas (1994-2005)
- Lethbridge (1998-2004)

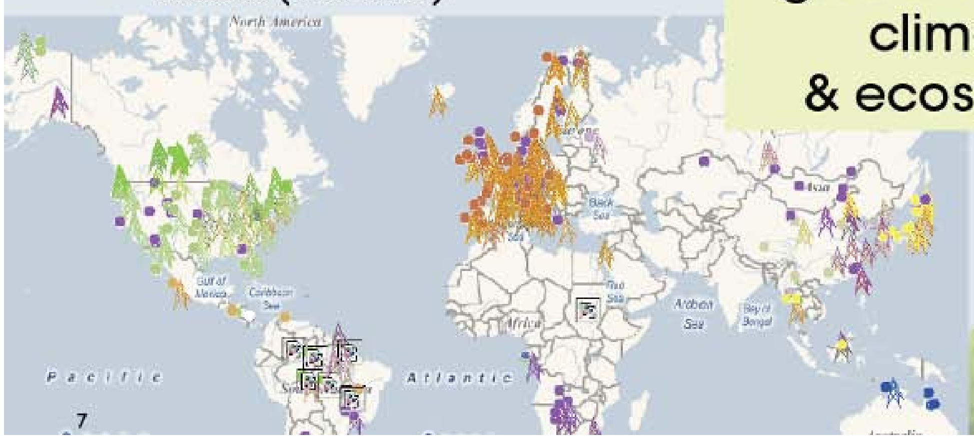
- Santarem KM83 (2001-2003)
- Tapajos KM67 (2002-2005)

- Castelporziano (2000-2005)
- Collelongo (1999-2003)
- El Saler (1999-2005)
- Kaamanen (2000-2005)
- Hyytiälä (1997-2005)
- Tharandt (1998-2003)
- Vielsalm (1997-2005)

Color Legend:

temperate
tropical
boreal
sub-alpine
north-boreal
mediterranean

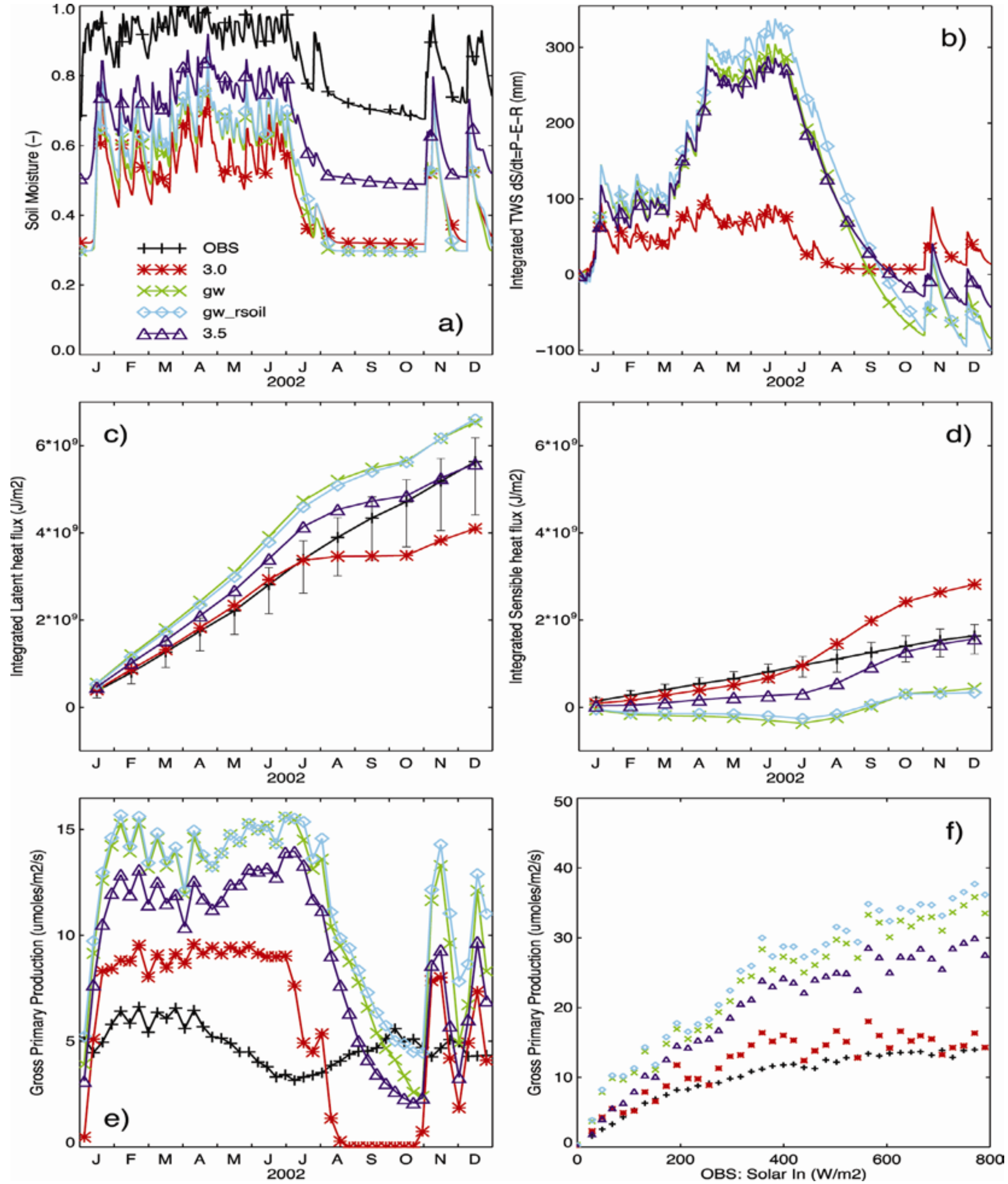
300+ sites covering global range of climates & ecosystems



Stöckli et al. (2008) JGR, 113, doi:10.1029/2007JG000562

Flux tower measurements – tropical evergreen forest

Tropical evergreen forest (Santarem KM83, Brazil)



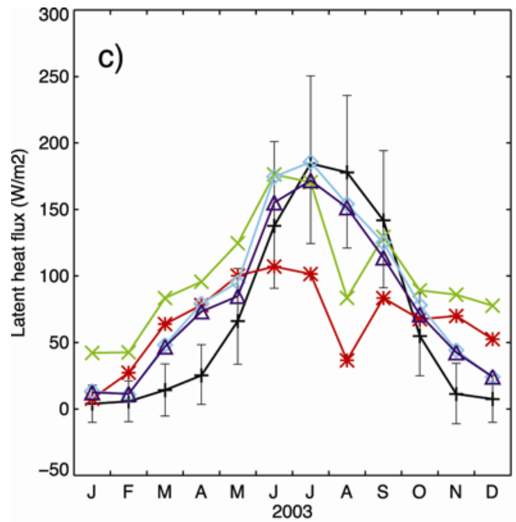
CLM3 – dry soil, low dry season latent heat flux, high dry season sensible heat flux

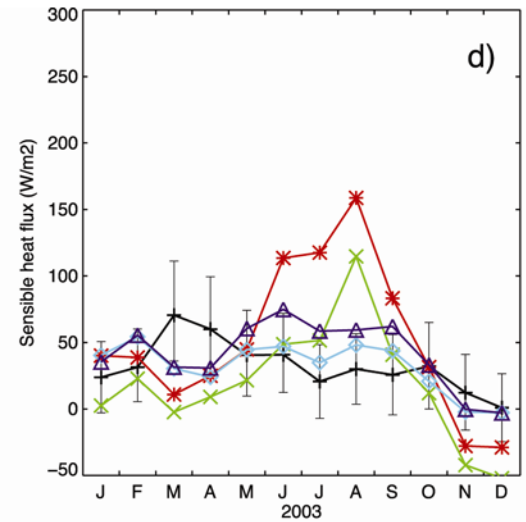
CLM3.5 – wetter soil and higher latent heat flux during dry season

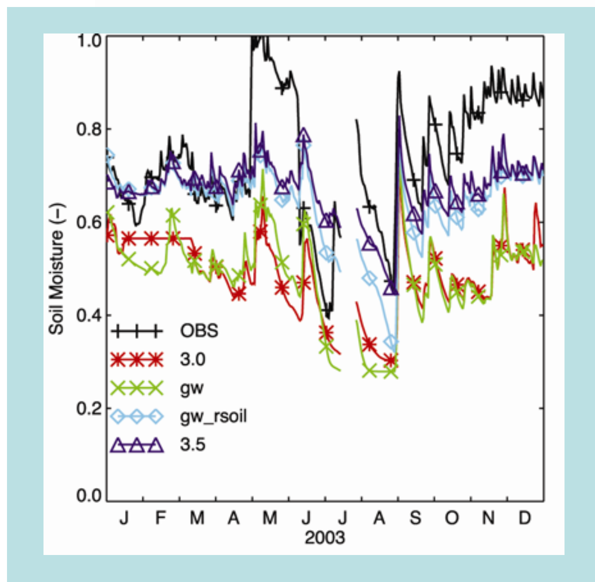
Stöckli et al. (2008) JGR, 113, doi:10.1029/2007JG000562

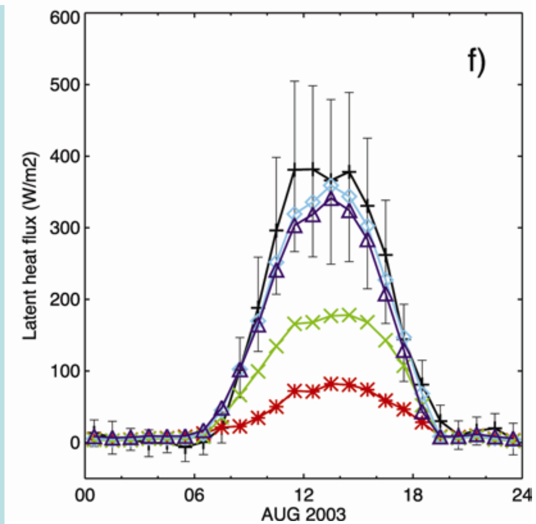
Flux tower measurements – temperate deciduous forest

Temperate deciduous forest
(Morgan Monroe, Indiana)









CLM3 – dry soil, low latent heat flux, high sensible heat flux
CLM3.5 – wetter soil and higher latent heat flux

Stöckli et al. (2008) JGR, 113, doi:10.1029/2007JG000562

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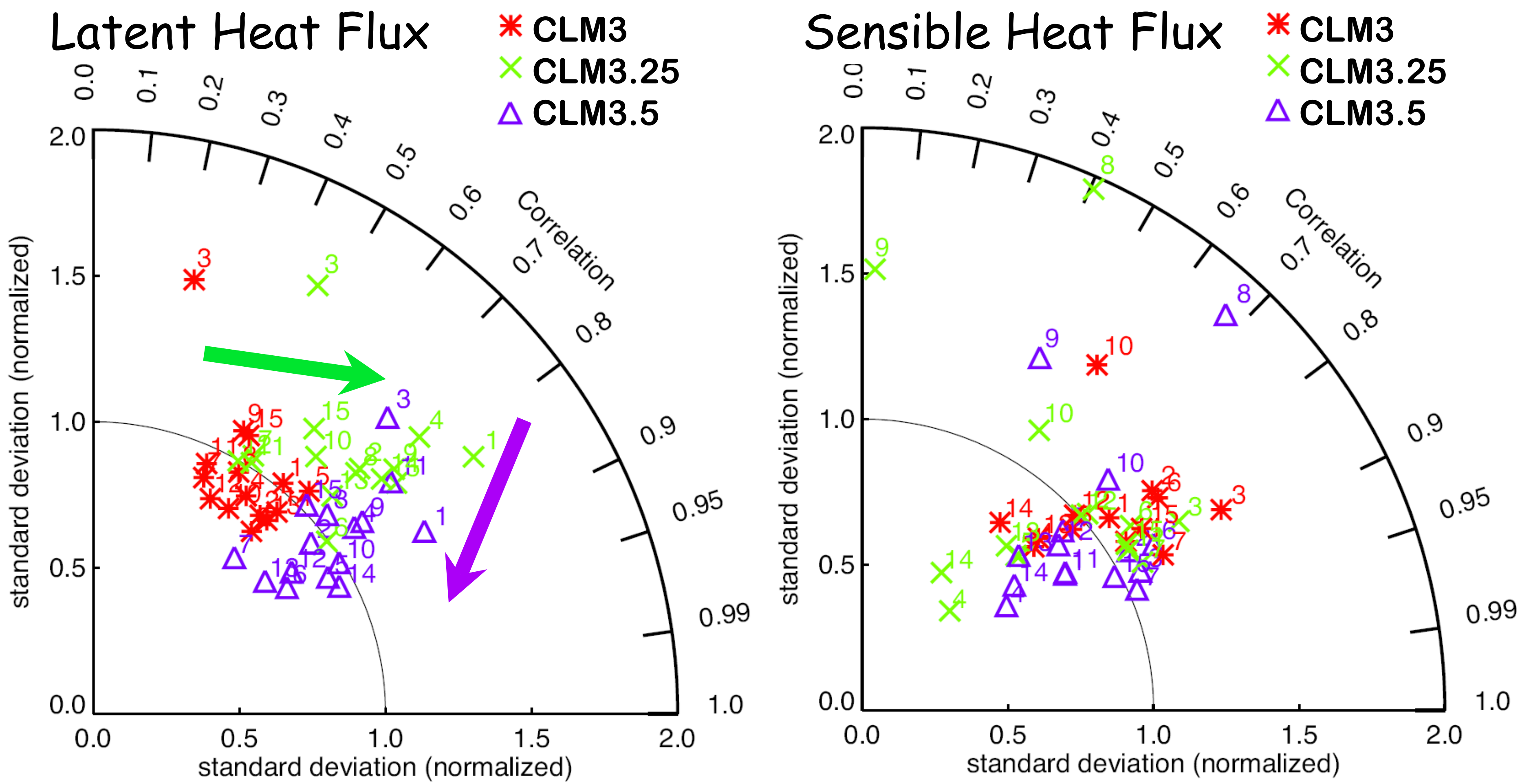
Flux tower measurements – all sites

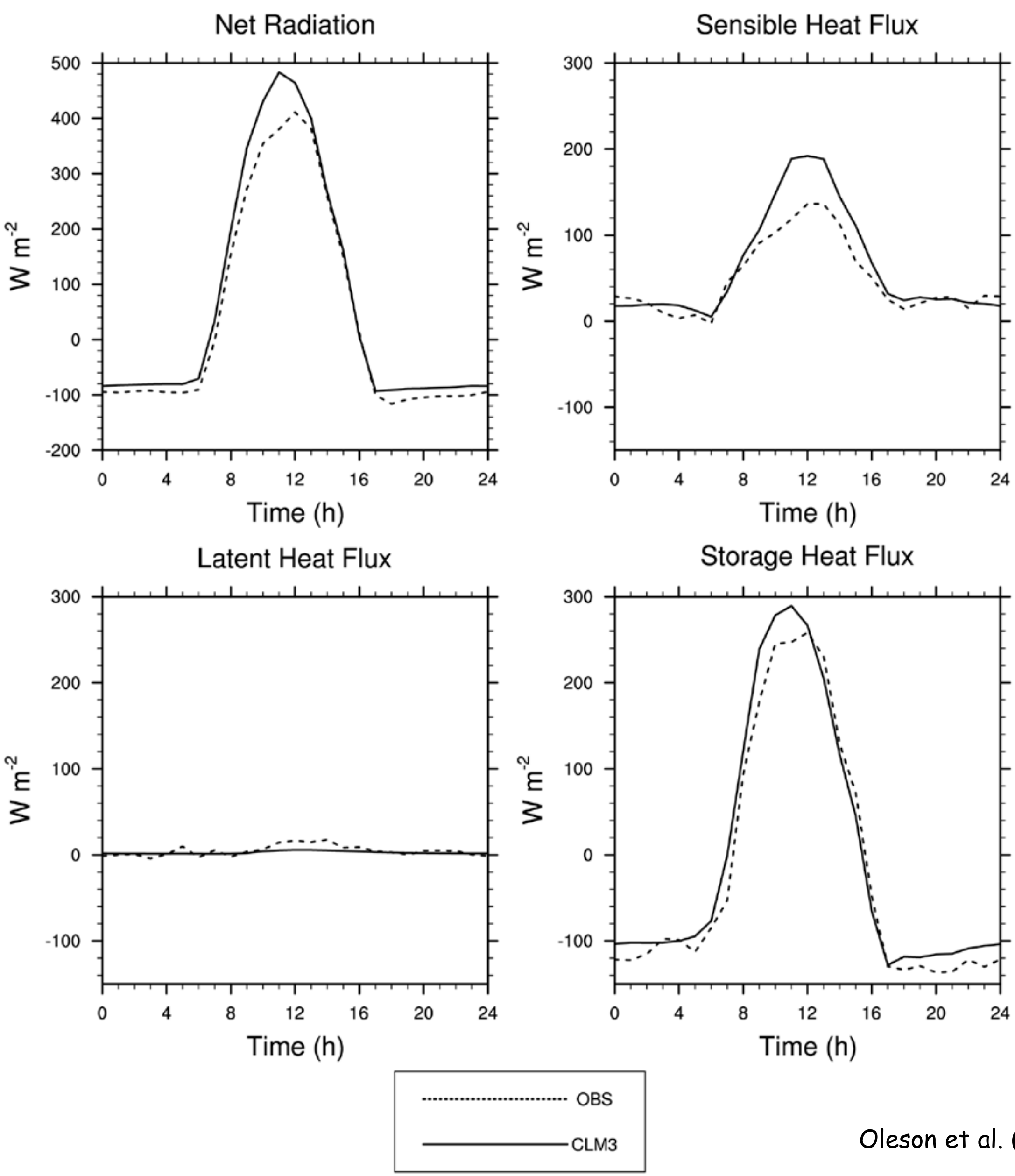
Multi-site, multi-year synthesis



CLM3.25 – increases correlation with observations
CLM3.5 – reduces variance compared with observations

Stöckli et al. (2008) JGR, 113, doi:10.1029/2007JG000562

Urban systems



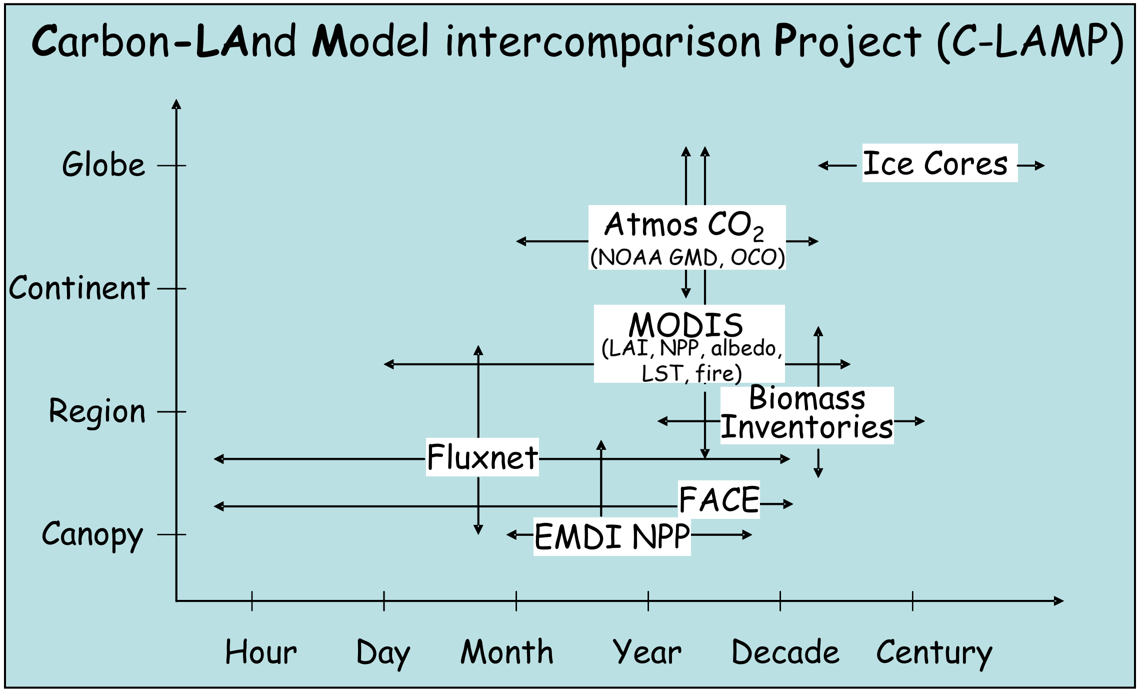
Average diurnal cycle of simulated and observed heat fluxes for the Mexico City site (Me93) for Dec 2-7, 1993

Key features

- Diurnal cycle is well represented
- Simulated net radiation is too high (model ignores pollution), which drives high sensible heat
- Negligible latent heat flux
- Large storage heat flux

Oleson et al. (2008) J. Appl. Meteor. Climatol. 47:1038-1060, 1061-1076

Multi-scale carbon cycle evaluation

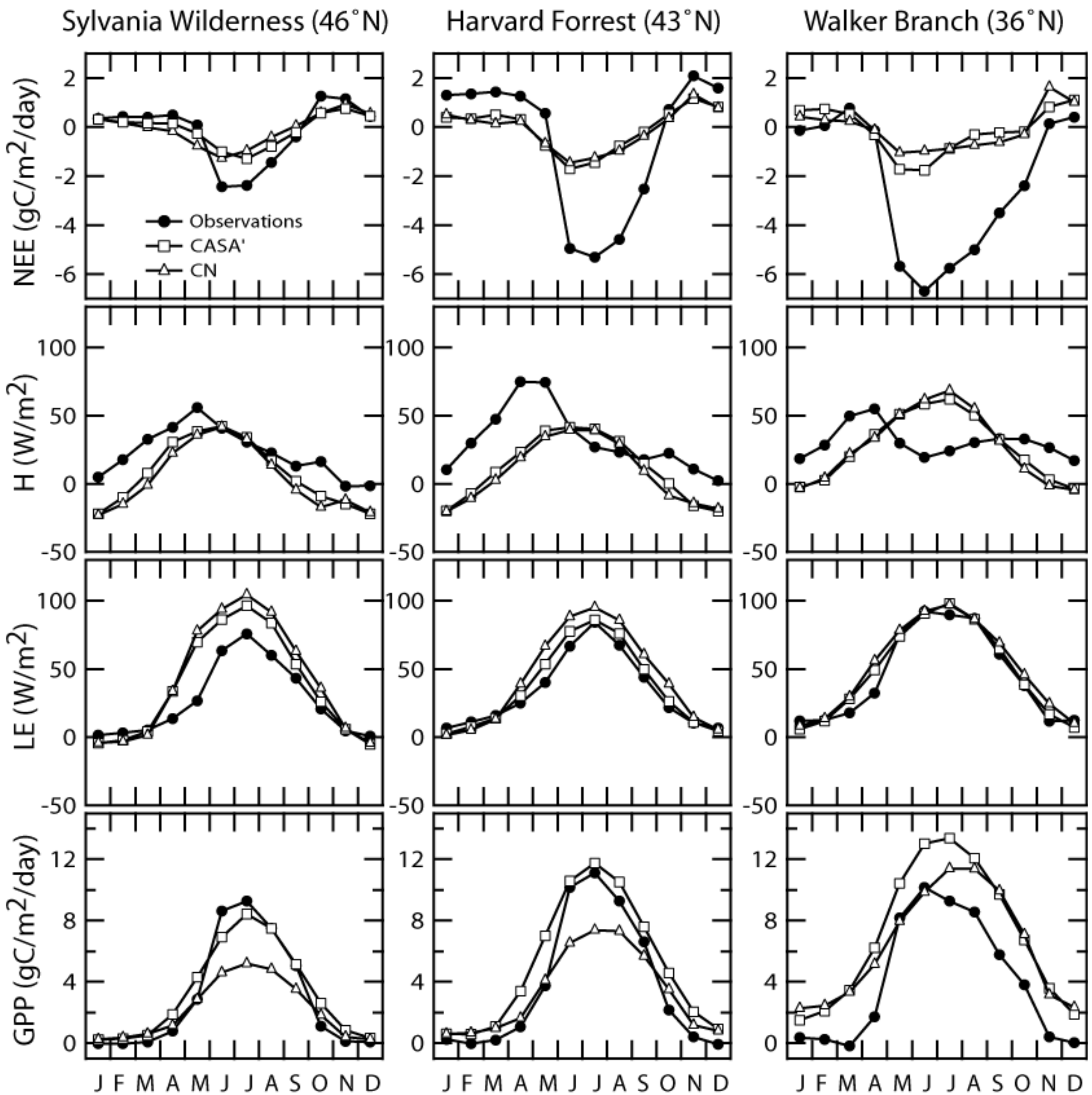


"Systematic assessment of terrestrial biogeochemistry in coupled climate-carbon models"

James T. Randerson, Forrest M. Hoffman, Peter E. Thornton, Natalie M. Mahowald, Keith Lindsay, Yen-Hui Lee, Cynthia D. Nevison, Scott C. Doney, Gordon Bonan, Reto Stocki, Steven W. Running, and Inez Fung

Submitted to Global Change Biology

Annual cycle CO_2 fluxes



Ameriflux eddy covariance measurements

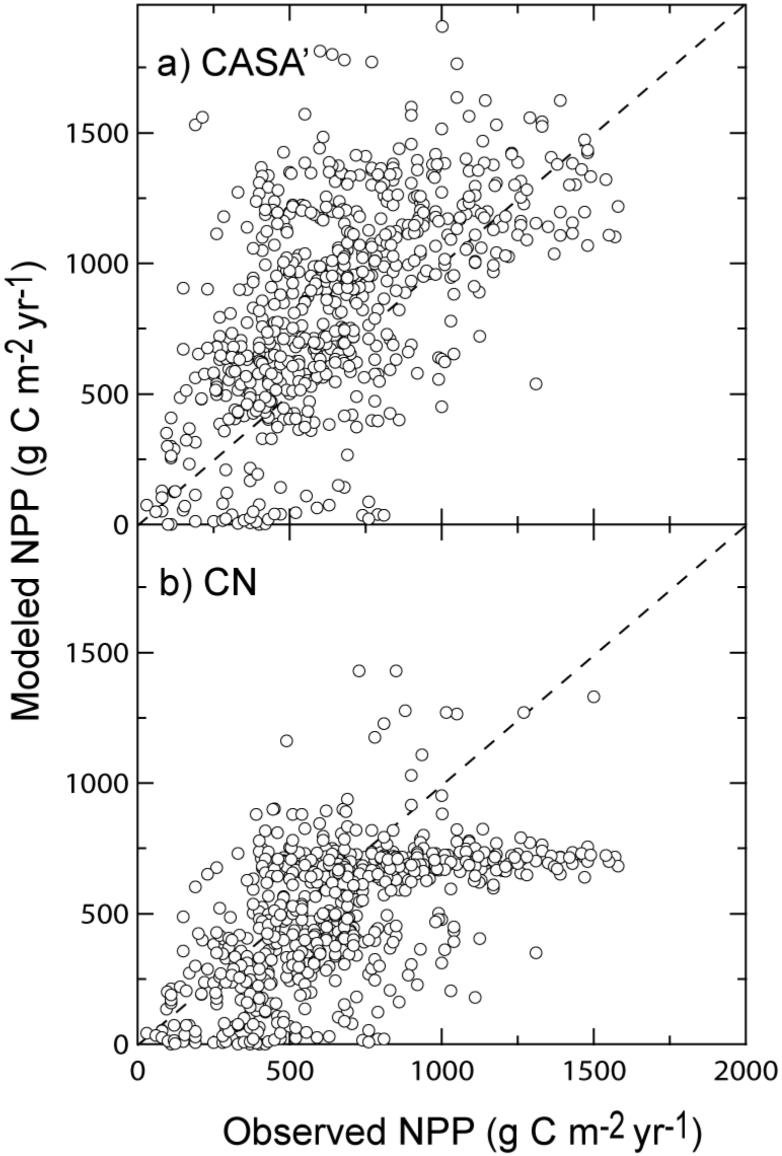
Randerson et al. (2008) GCB, submitted

Annual net primary production

Ecosystem Model-Data Intercomparison (EMDI) compilation of observations

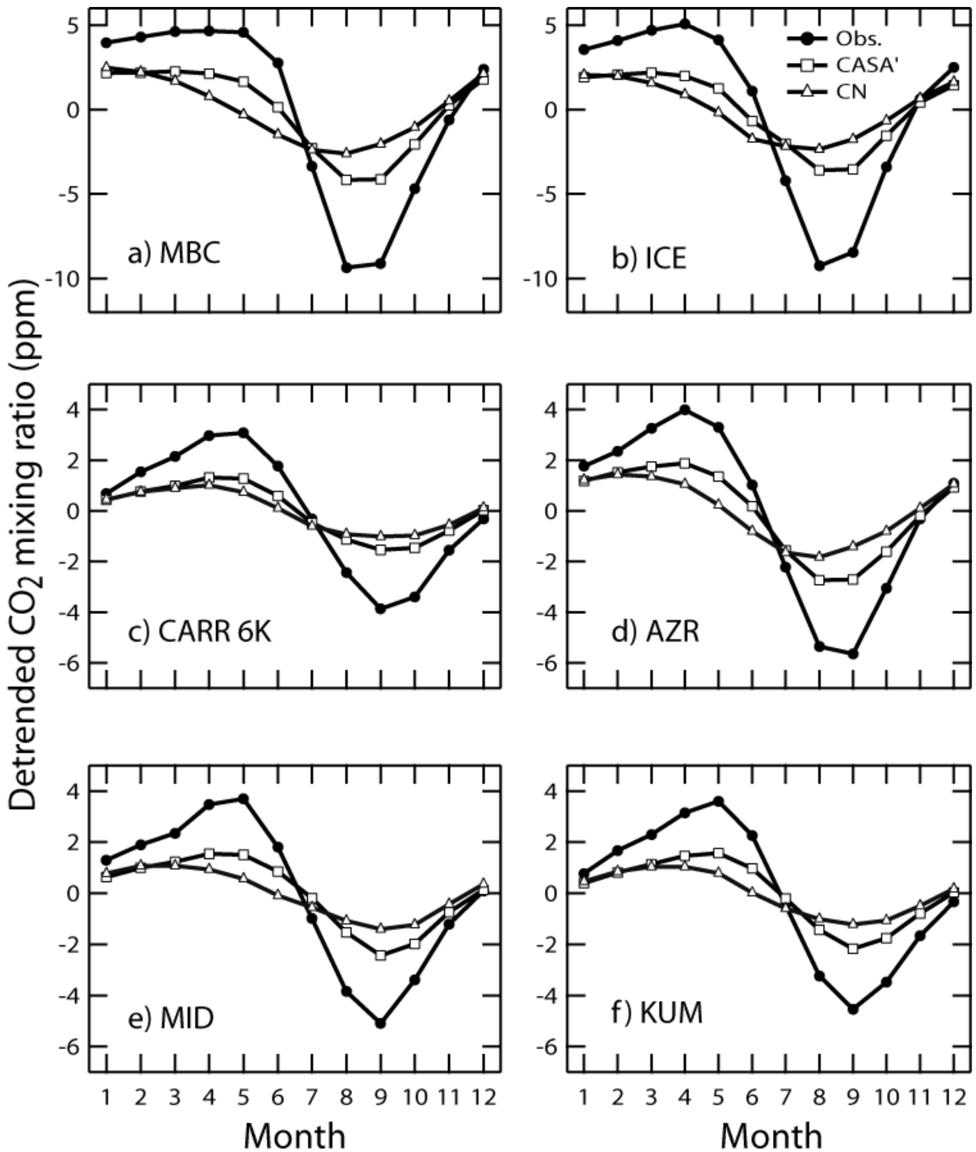
- Class A (81 sites)
- Class B (933 sites)

NPP extracted for each model grid cell corresponding to a measurement location



Randerson et al. (2008) GCB, submitted

Annual cycle atmospheric CO_2



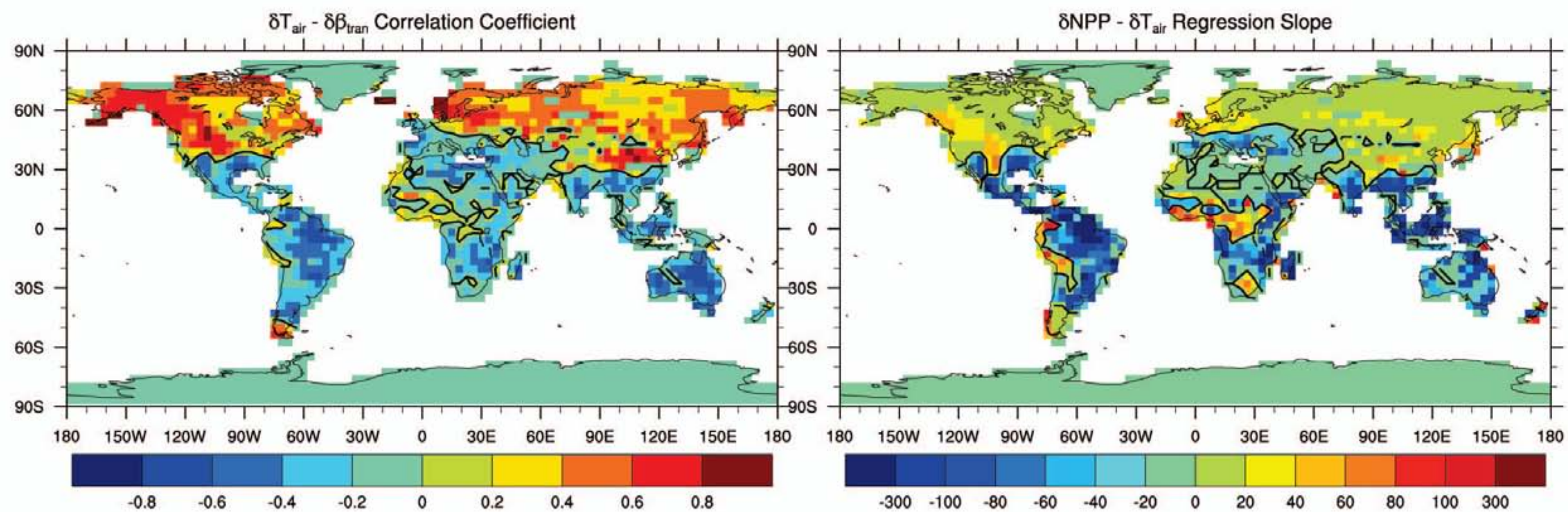
The annual cycle of atmospheric carbon dioxide at a) Mould Bay, Canada (76°N), b) Storhofdi, Iceland (63°N), c) Carr, Colorado (aircraft samples from 6 km masl; 41°N), d) Azores Islands (39°N), e) Sand Island, Midway (28°N), and Kumakahi, Hawaii (20°N)

Randerson et al. (2008) GCB, submitted

Geography of carbon cycle feedback

Correlation of air temperature with soil moisture

Correlation of NPP with air temperature



Correlation coefficient

kg C m^{-2} yr^{-1} per °C

Low latitudes
Negative correlation: warming leads to drier soil in warm regions

Middle to high latitudes
Positive correlation: warming leads to wetter soil in cold regions

Low latitudes
Negative correlation: NPP decreases with warming because of soil desiccation

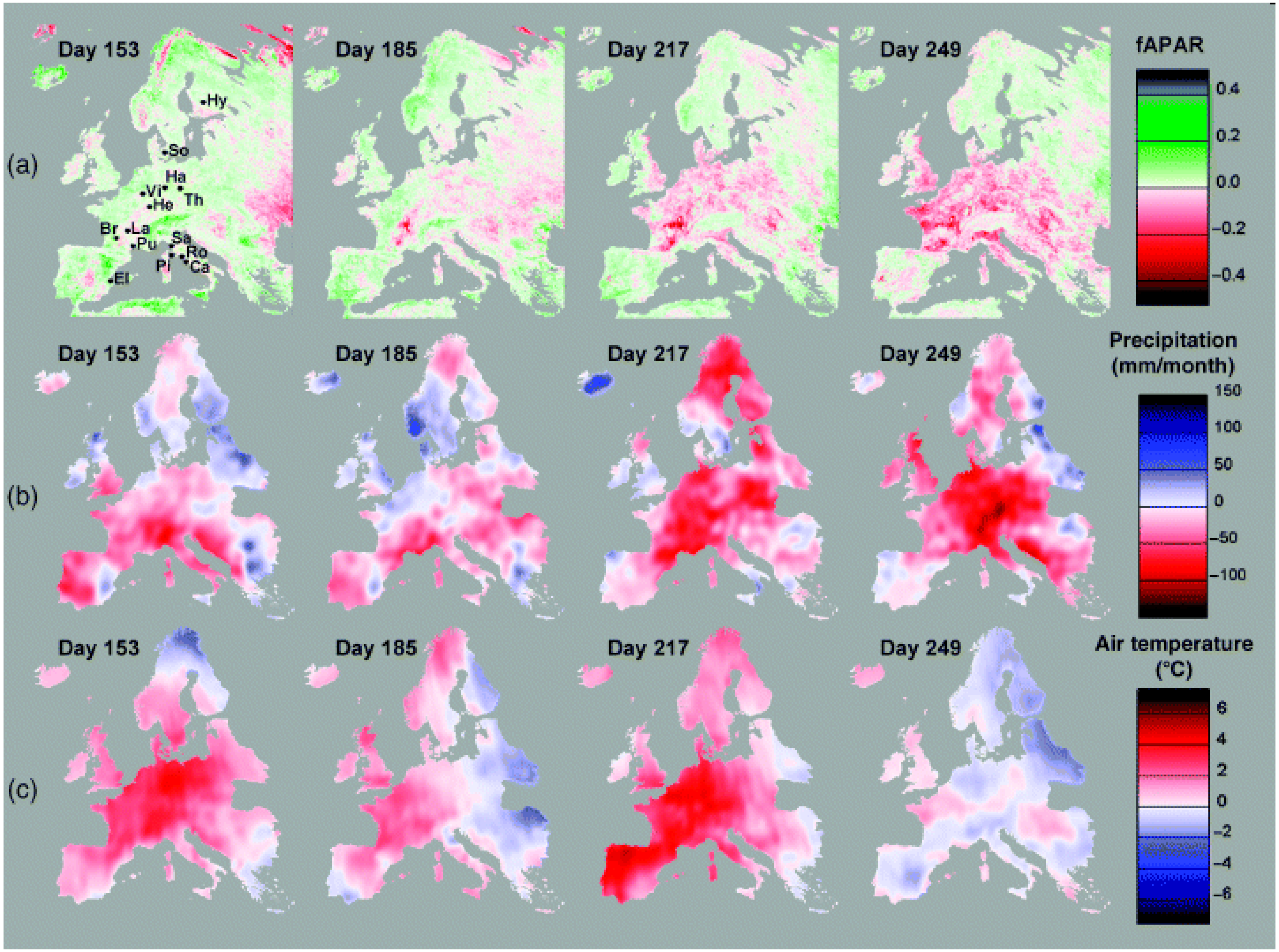
Middle to high latitudes
Positive correlation: NPP increases with warming because of more favorable climate

Fung et al. (2005) PNAS 102:11201-11206

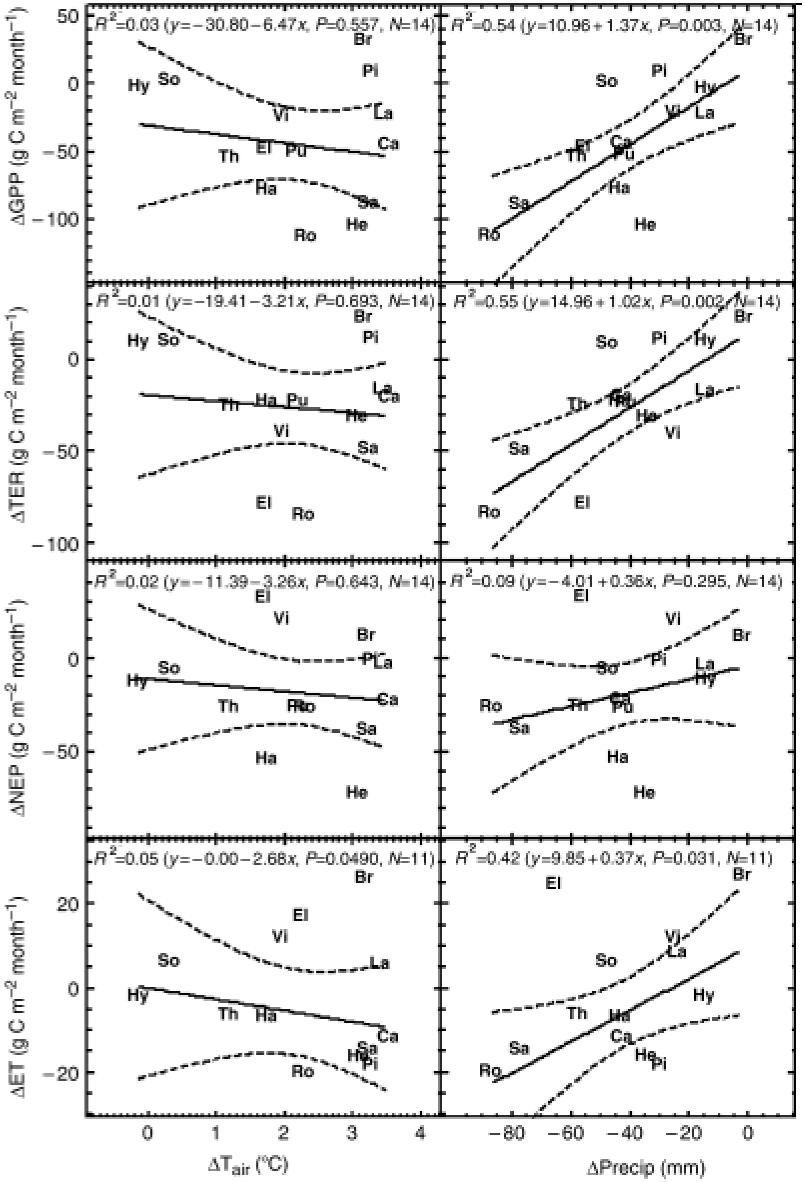
Large-scale natural "experiments"

Anomaly spatial pattern of (a) the fraction of absorbed photosynthetically active radiation (fAPAR), (b) precipitation and (c) air temperature during 2003 from June (day 153) to September (day 249)

Reichstein et al. (2007) *GCB* 13:634-651



Large-scale natural "experiments"



Correlation plots of year 2003 minus year 2002 differences of gross primary productivity (ΔGPP), ecosystem respiration (ΔTER), net ecosystem productivity (ΔNEP) and evapotranspiration (ΔET) with respective temperature (ΔTair) and precipitation (ΔPrecip) differences. Anomalies are calculated for months July–September, except for precipitation that are for June–August to better account for lag effects.

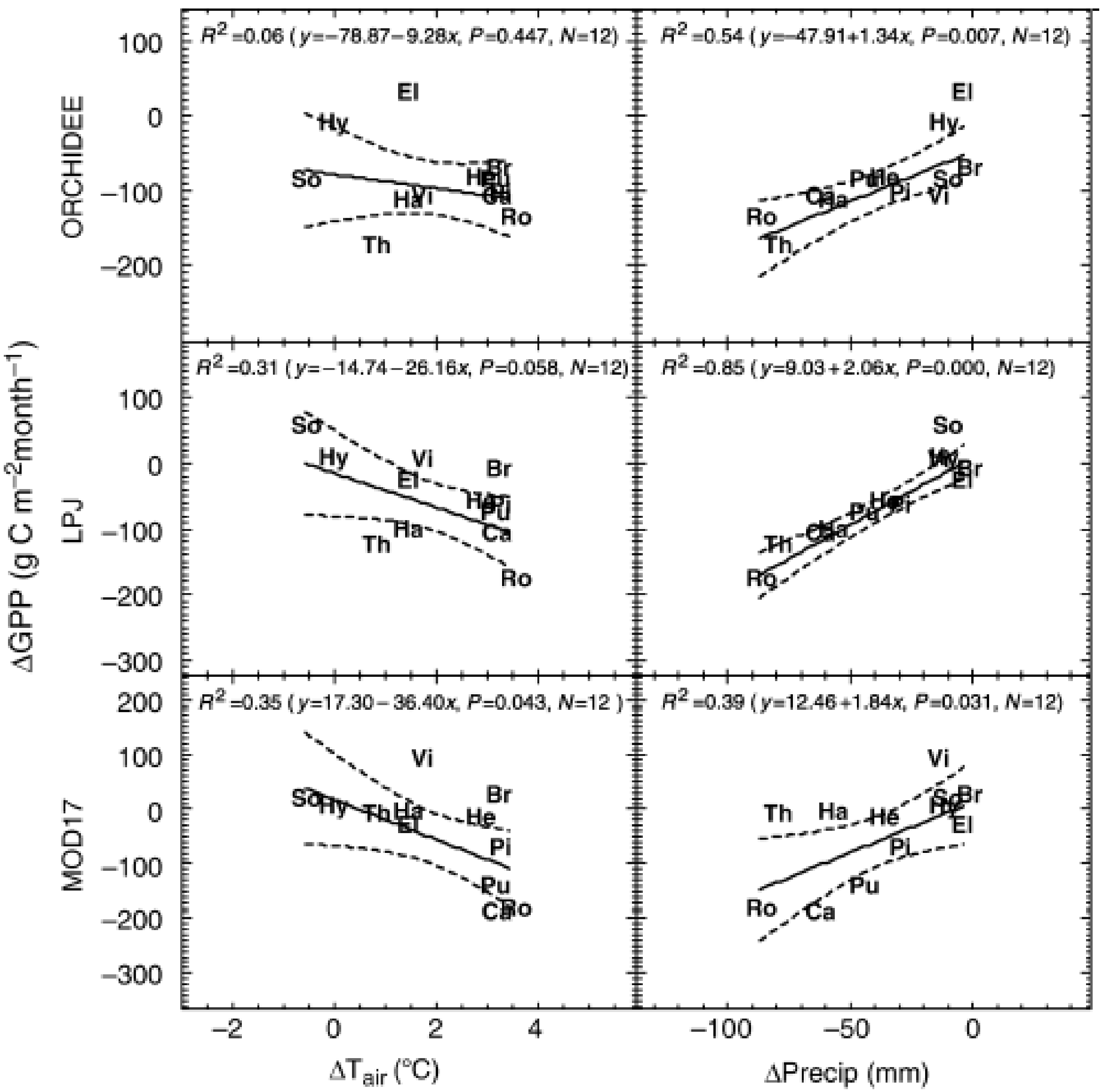
Reichstein et al. (2007) *GCB* 13:634-651

> Eddy covariance measurements show "drought stress" is more important than "heat stress"

Large-scale natural "experiments"

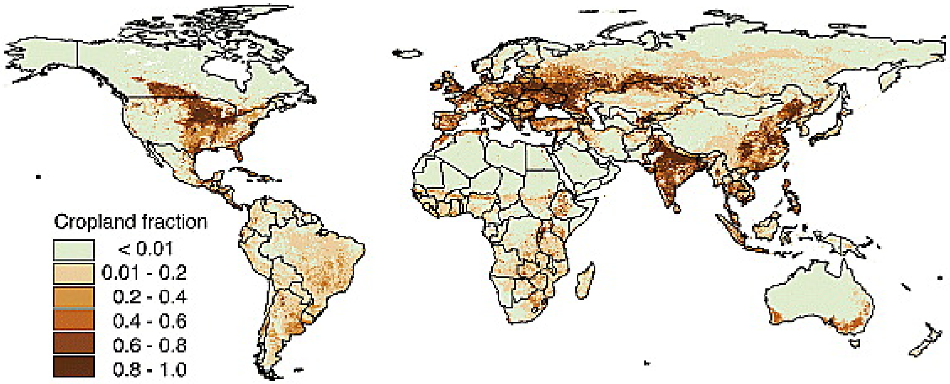
Correlation plots of year 2003 minus year 2002 differences of gross primary productivity (ΔGPP), modelled at the eddy covariance sites by the ORCHIDEE, LPJ and MOD17 model with respective temperature (ΔTair) and precipitation (ΔPrecip) differences

Reichstein et al. (2007) *GCB* 13:634-651



Process models similarly show "drought stress" is more important than "heat stress"

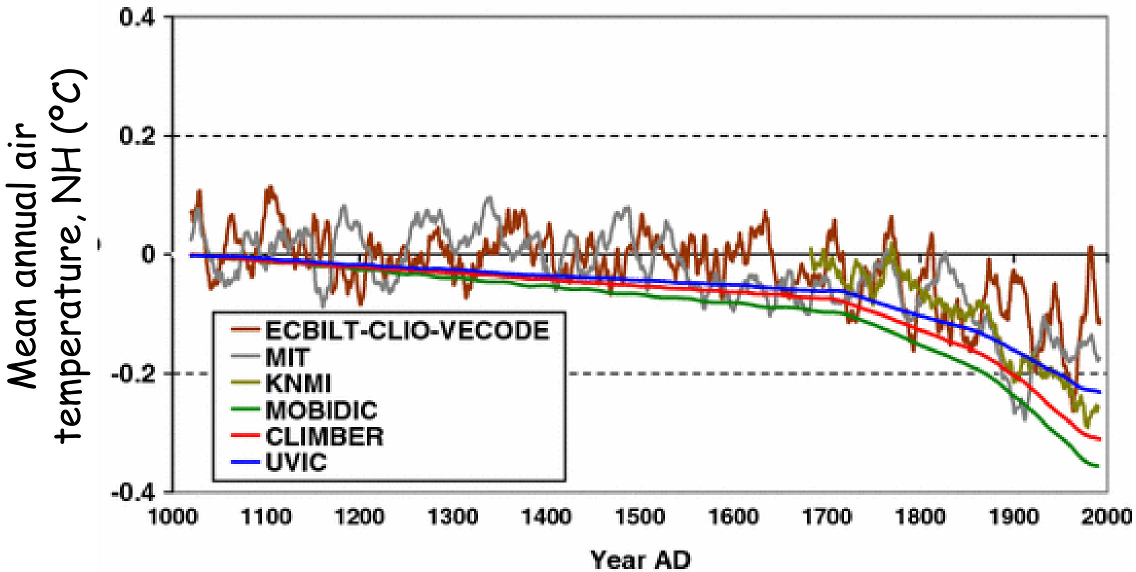
Land use forcing of climate



The emerging consensus is that land cover change in middle latitudes has cooled the Northern Hemisphere (primarily because of higher surface albedo in spring)

Northern Hemisphere annual mean temperature decreases by 0.19 to 0.36 °C relative to the pre-industrial era

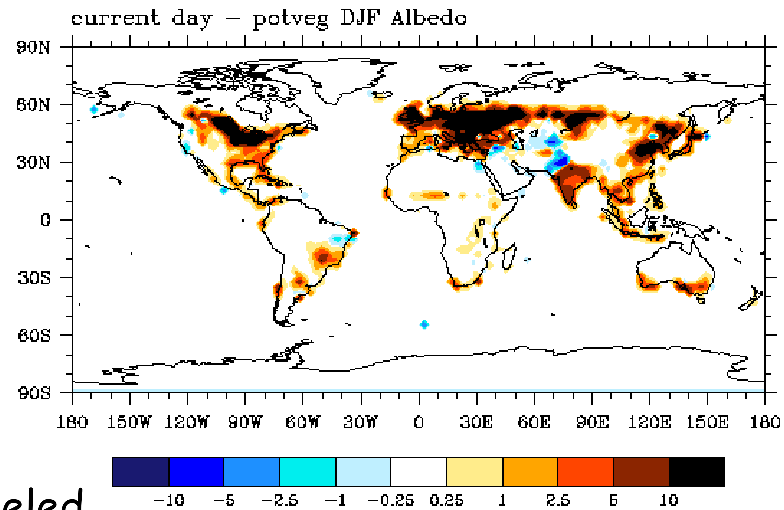
Comparison of 6 EMICs forced with historical land cover change, 1000-1992

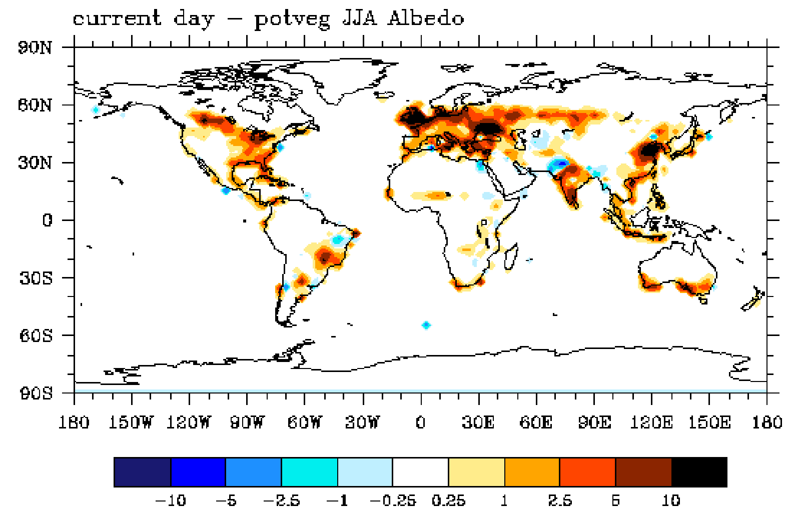


Brovkin et al. (2006) Clim Dyn 26:587-600

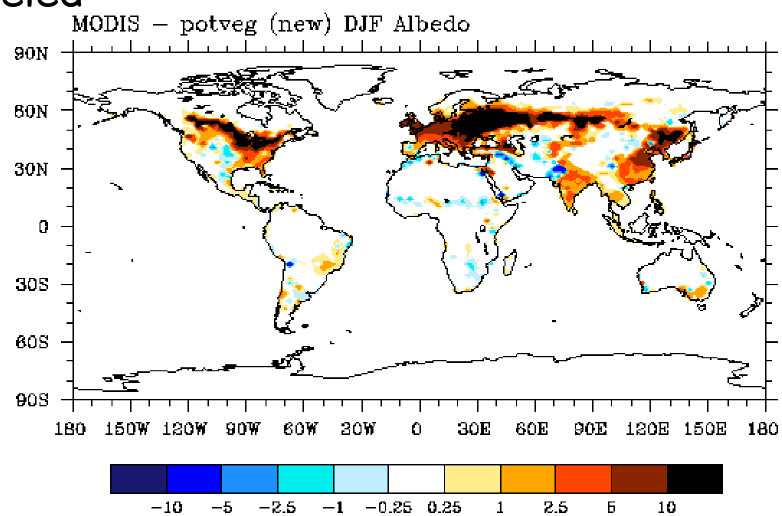
Albedo land use forcing

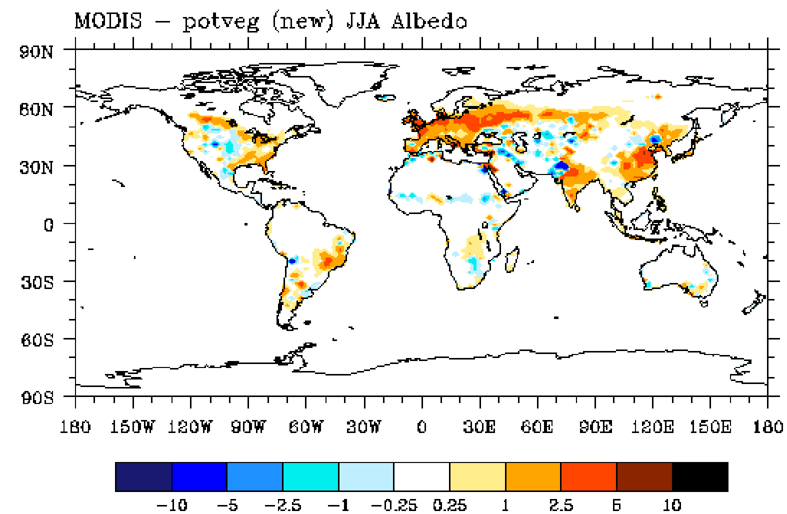
Expected





Modeled



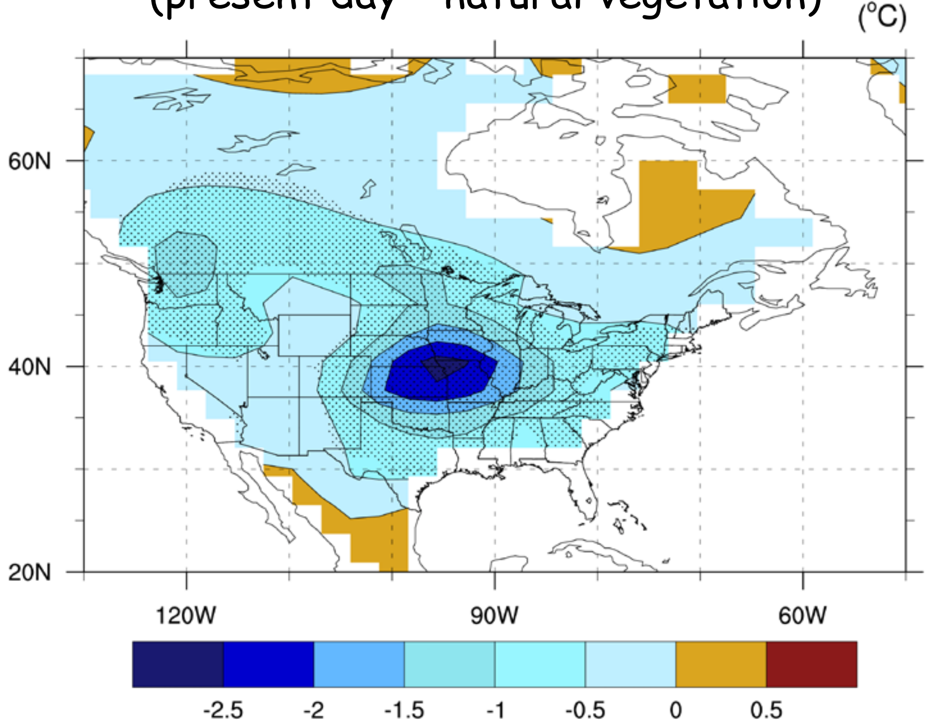


Units are Δalbedo $\times$ 100

Peter Lawrence (NCAR), unpublished

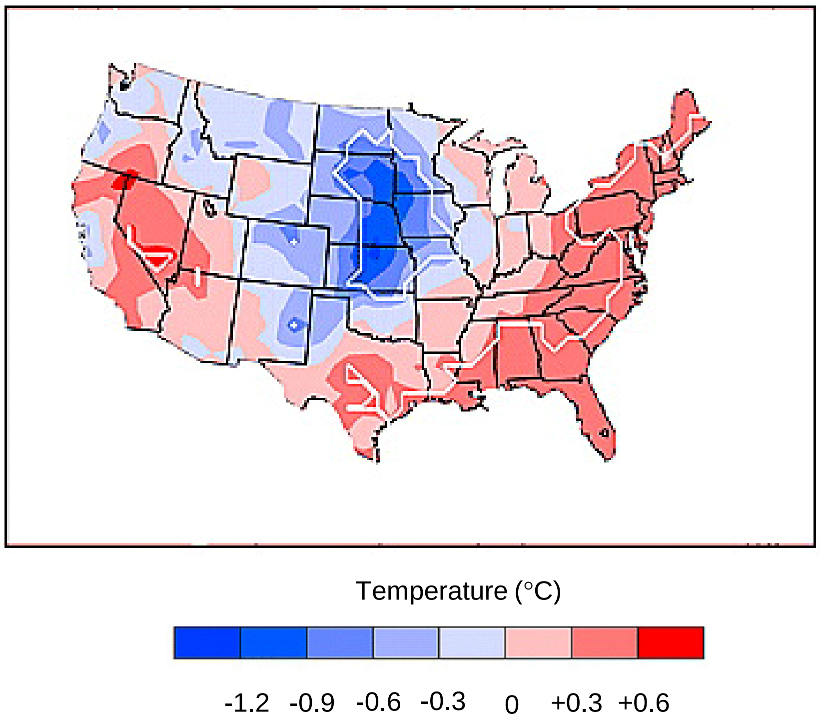
Temperate deforestation – two views

Summer (JJA) temperature difference
(present day – natural vegetation)



Oleson et al. (2004) Clim Dyn 23:117-132

July temperature difference
(1990 – 1700)

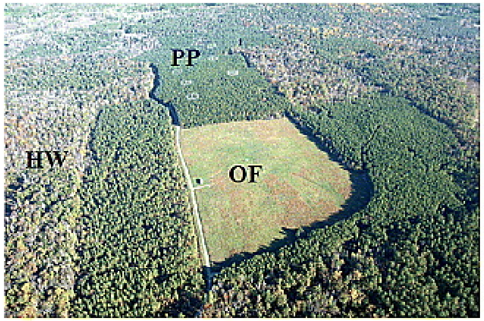


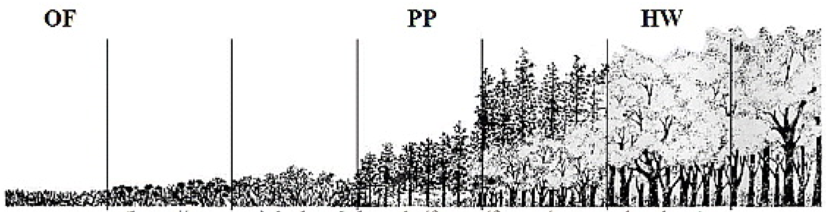
Baidya Roy et al. (2003) JGR, 108, doi:10.1029/2003JD003565

Two contrasting model-generated hypotheses of how deforestation affects climate

Grass → crop: Increases ET
Forest → crop: Increases albedo, reduces z0, reduces ET (rooting depth)

Reforestation cools climate





(http://www.nicholas.duke.edu/forest/forest/succession.htm)

Annual mean temperature change

	OF to PP	OF to HW
Albedo	+0.9°C	+0.7°C
Ecophysiology and aerodynamics	-2.9°C	-2.1°C

Forest
- o Lower albedo (+)
- o Greater leaf area index, aerodynamic conductance, and latent heat flux (-)

Juang et al. (2007) GRL, 34, doi:10.1029/2007GL031296

Soil water affects the Δforest-crop

Central France

1 August 2000 10 August 2003

Surface reflectance

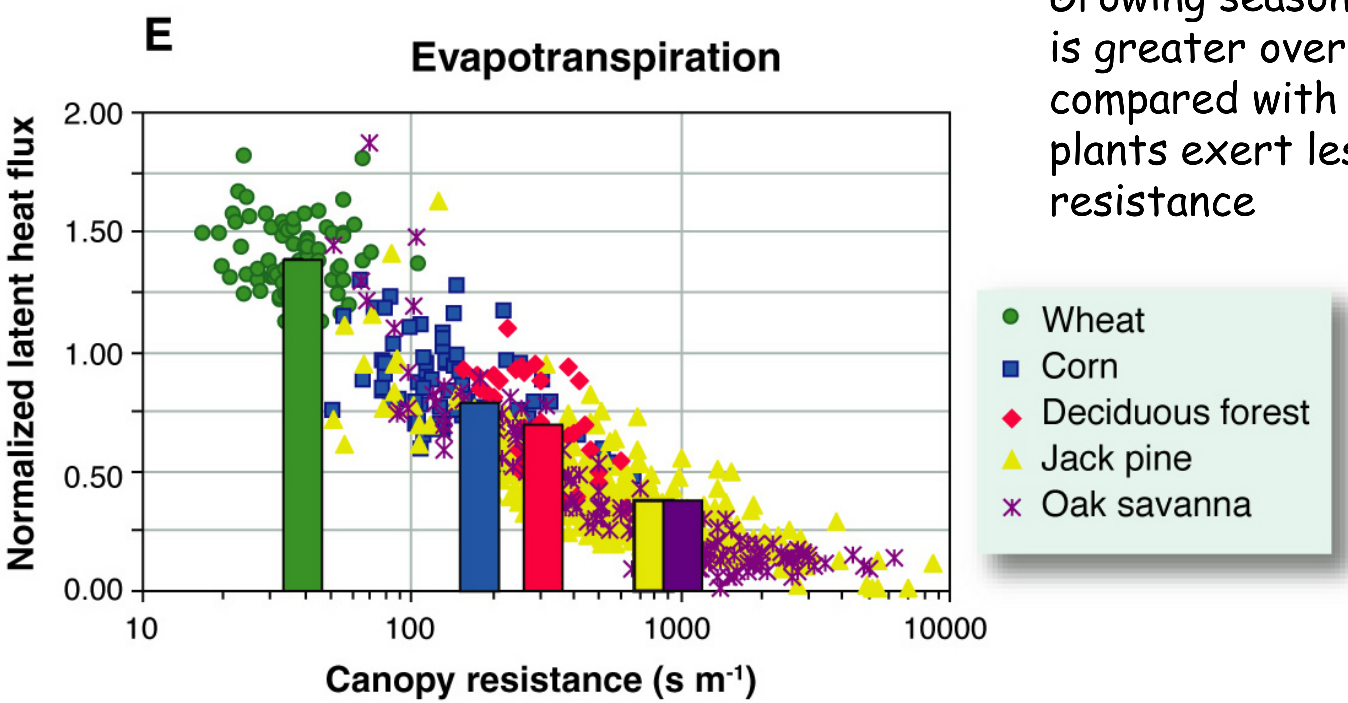
	2000	2003	Change
Forest			
NDVI	0.87	0.87	0
Albedo	0.19	0.17	-0.02
T_R (°C)	29	40	+11
Crops			
NDVI	0.81	0.43	-0.37
Albedo	0.22	0.22	0
T_R (°C)	30	54	+24
Barren			
NDVI	0.27	0.29	+0.02
Albedo	0.24	0.22	-0.02
T_R (°C)	47	58	+11

Scale bar indicates
500 m

Surface temperature

Zaitchik et al. (2006) Int J Climatol 26:743-769

Crop latent heat flux



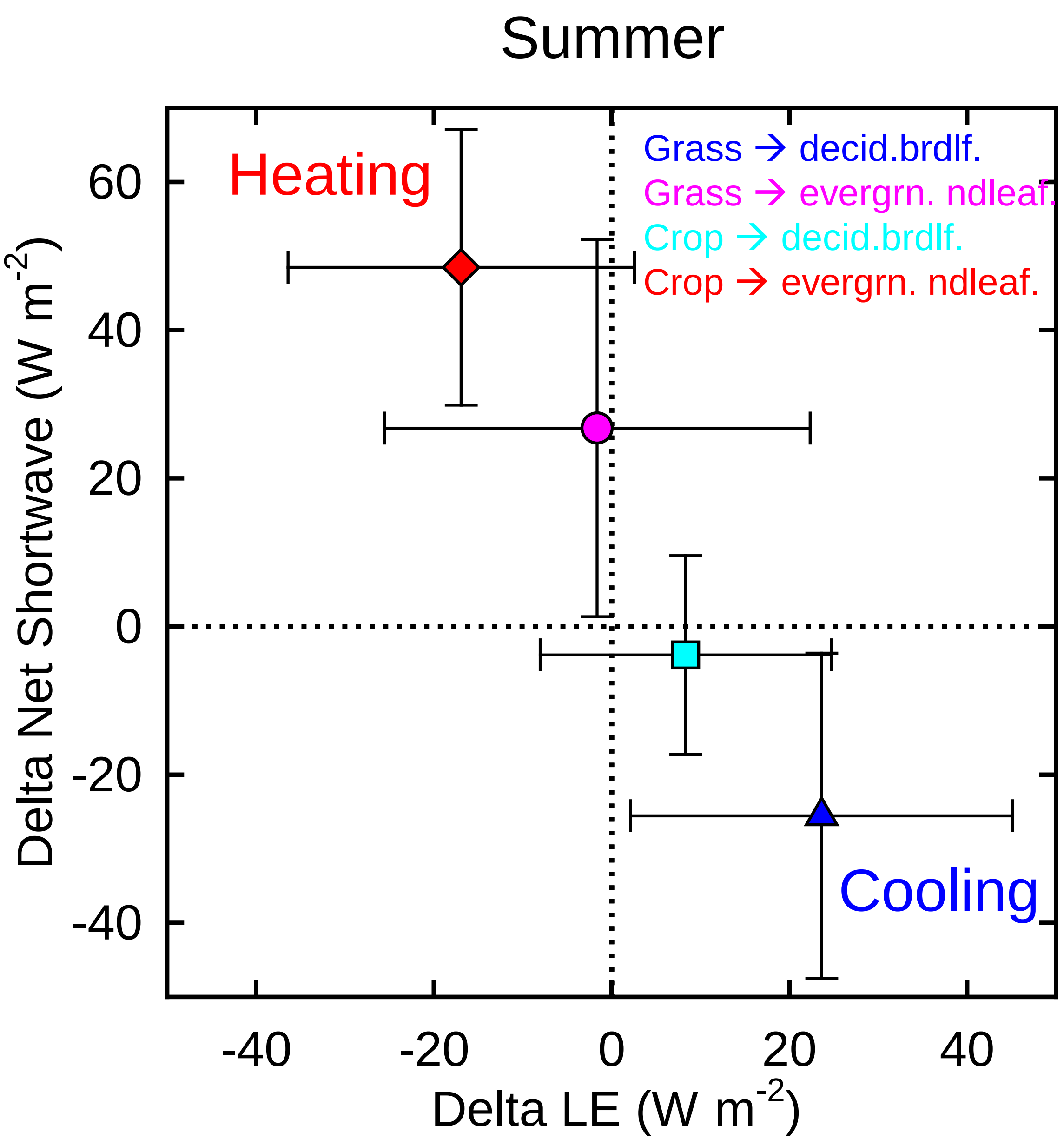
Bonan (2008) Science 320:1444-1449

Growing season evaporative cooling is greater over watered crops compared with forests and these plants exert less evaporative resistance

Evapotranspiration normalized by its equilibrium rate in relation to canopy resistance for wheat, corn, temperate deciduous forest, boreal jack pine conifer forest, and oak savanna. Shown are individual data points and the mean for each vegetation type.

Original data from: Baldocchi et al. (1997) JGR 102D:28939-51; Baldocchi & Xu (2007) Adv. Water Resour. 30:2113-2122

Shifts in surface energy balance from afforestation



NCEAS "Forest and Climate Policy" working group

Based on ~100 site-years of AmeriFlux data. *O'Halloran et al., 2009. in prep.*

Δ affected by:

- Proximity of towers
- Leaf area index
- Soil water status

Thomas O'Halloran
Oregon State University
Department of Forest Ecosystems & Society

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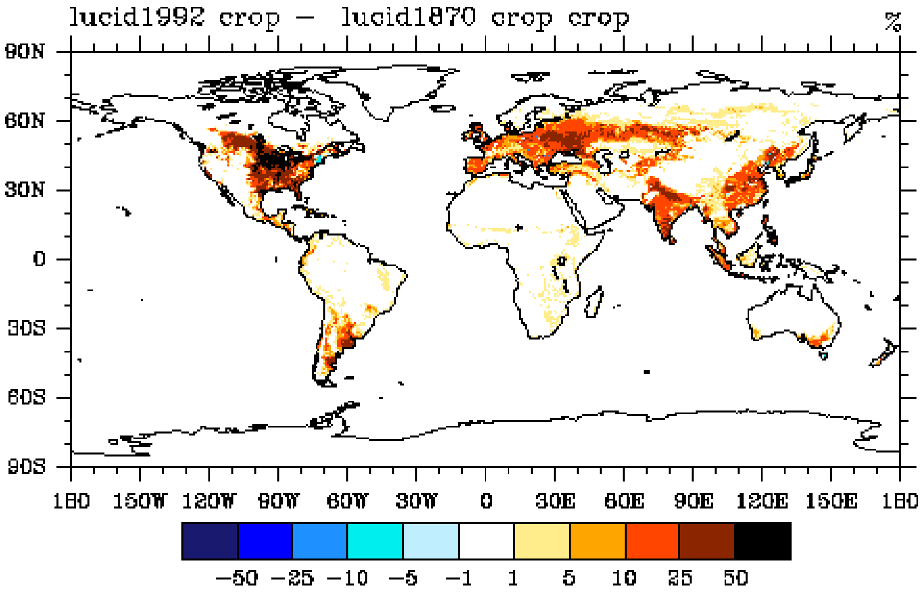
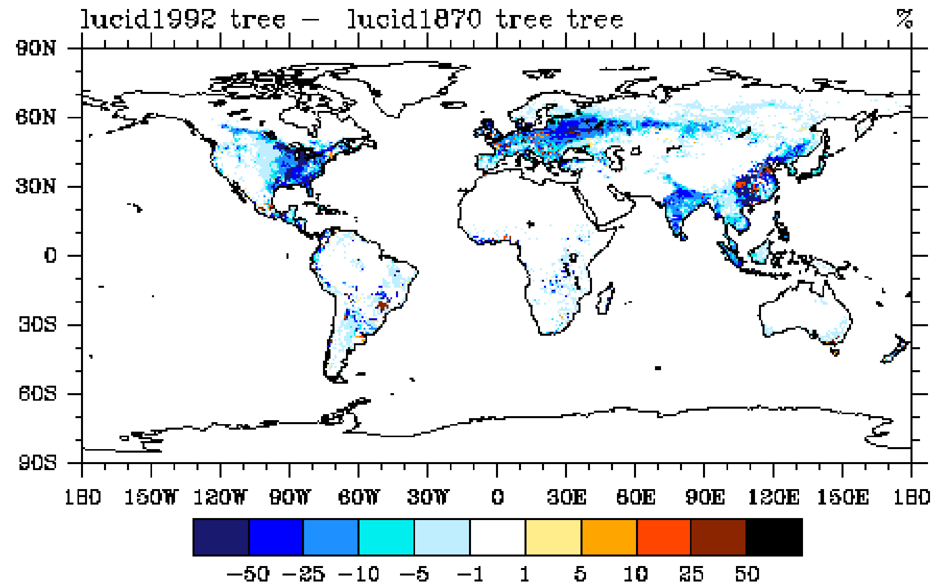
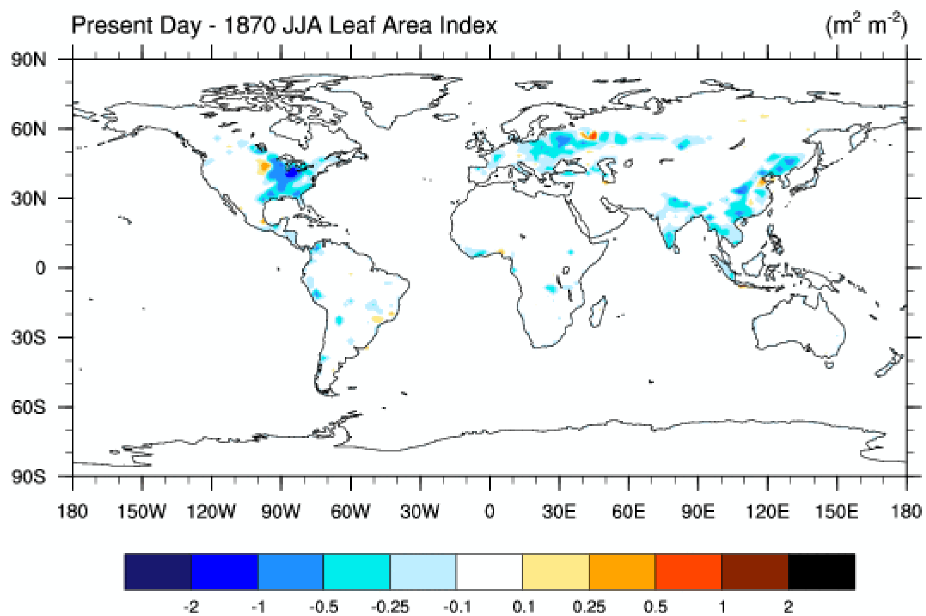
Land cover change, 1870 - 1992







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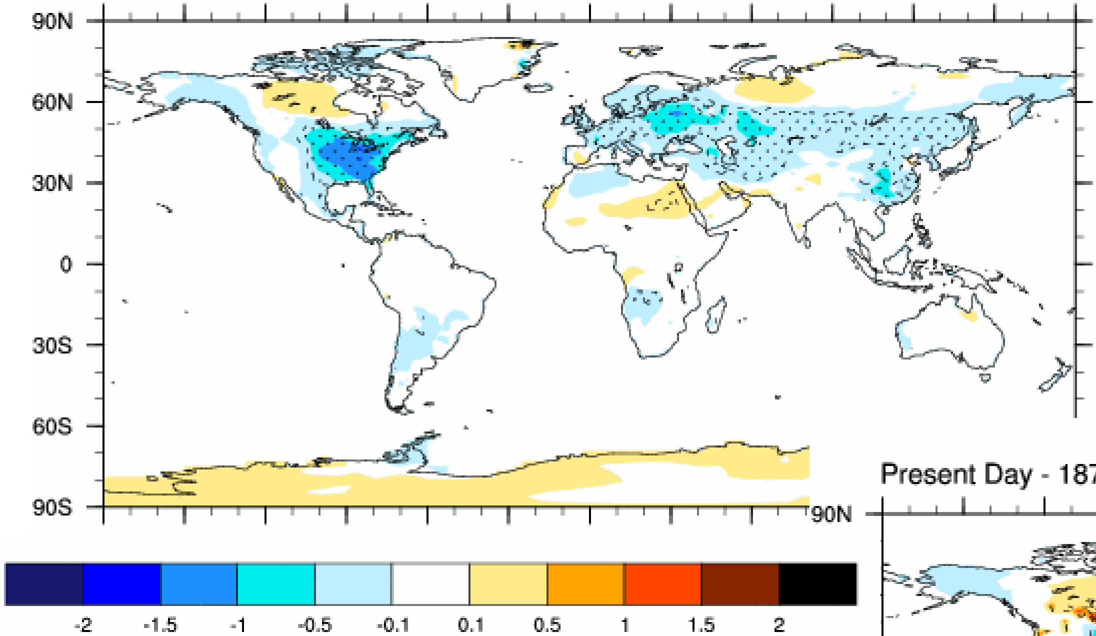
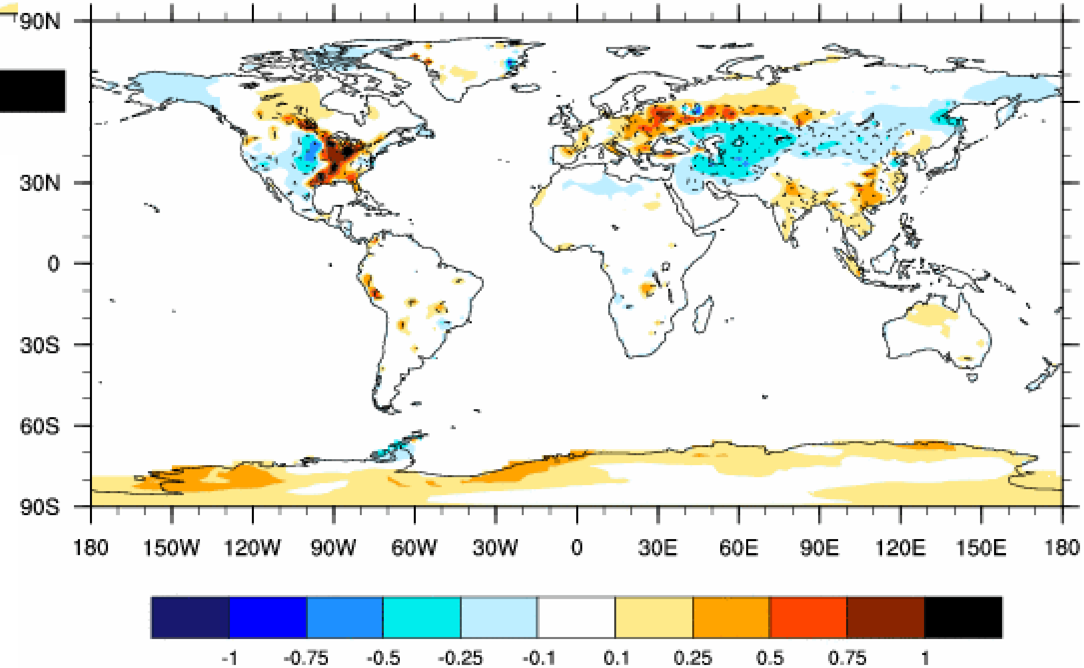
Land cover change, 1870 - 1992

Present Day - 1870 JJA Daily Maximum Temperature (°C)



Present Day - 1870 JJA Daily Minimum Temperature (°C)

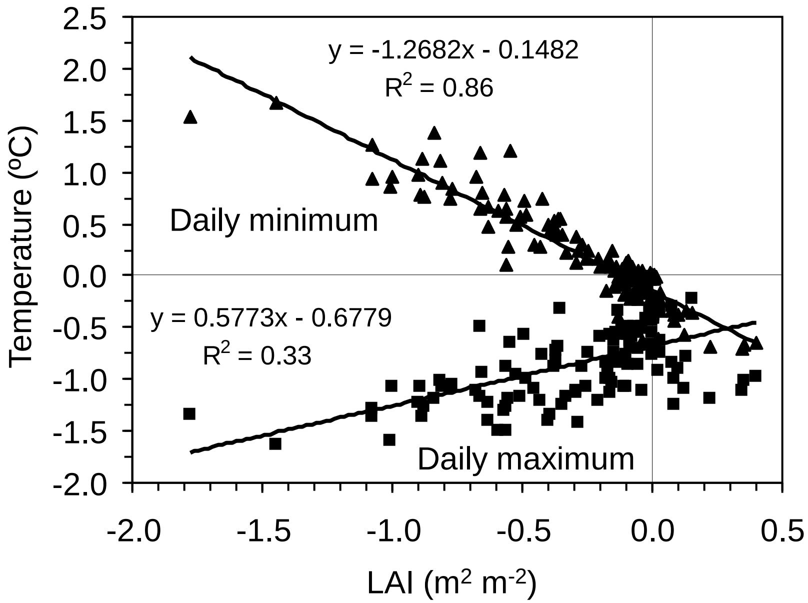


Functional relationships to explain model response

Eastern North America

Summer season (June-August)

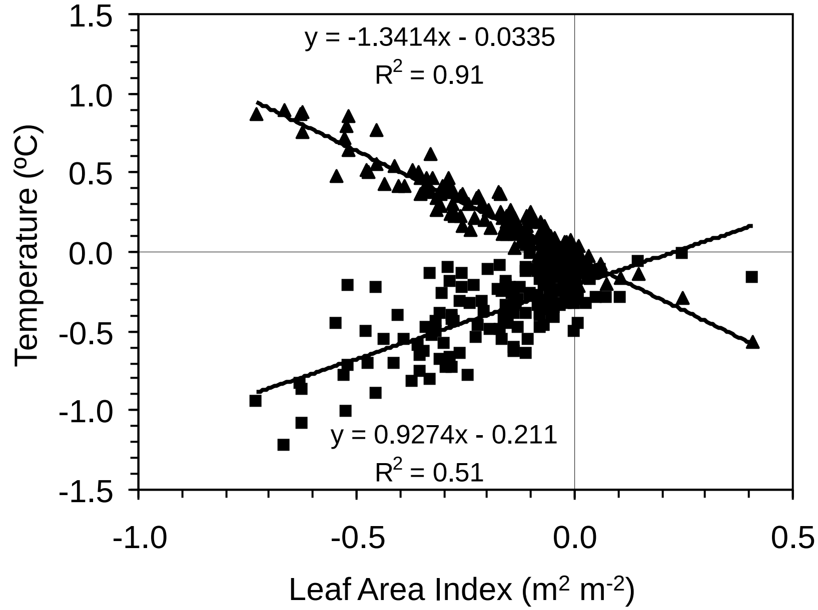
(PD – PDv)



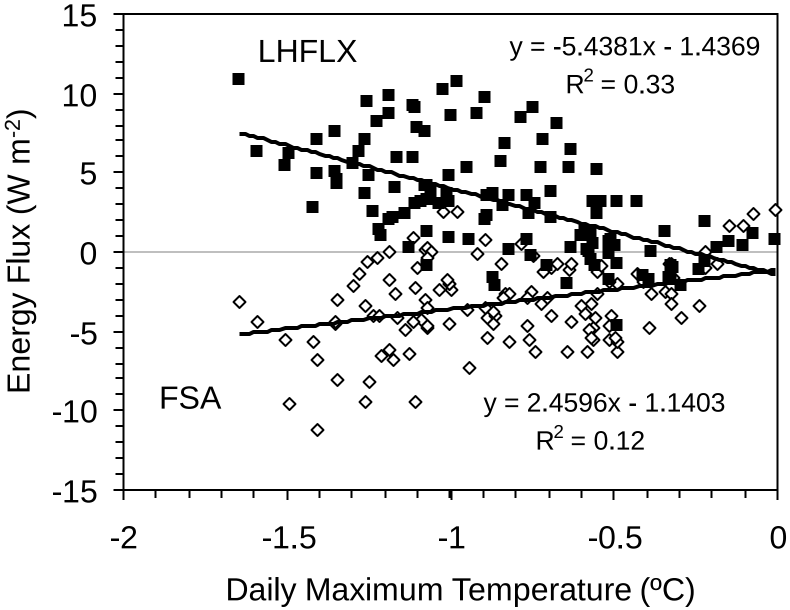
Europe

Summer season (June-August)

(PD – PDv)



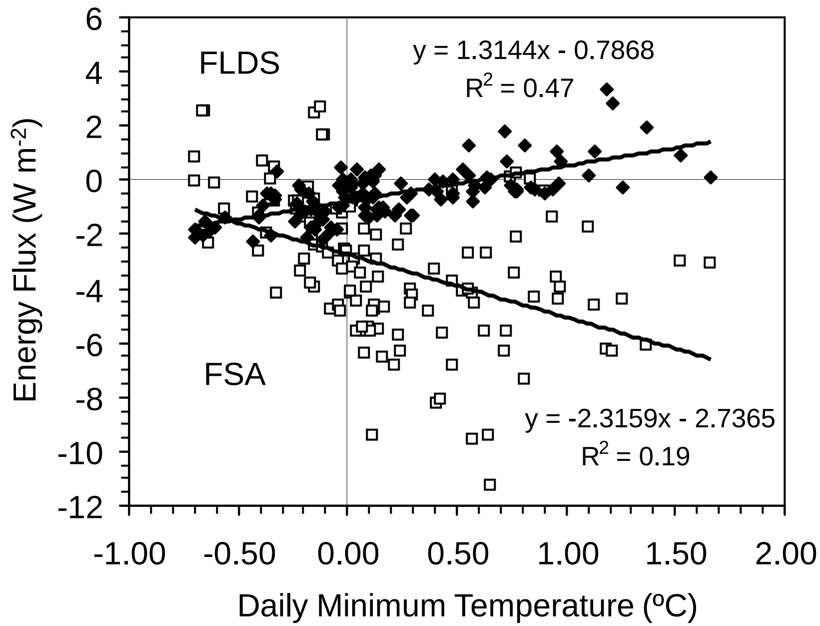
Functional relationships to explain model response



Eastern North America

Summer season (June-August)

(PD – PDv)

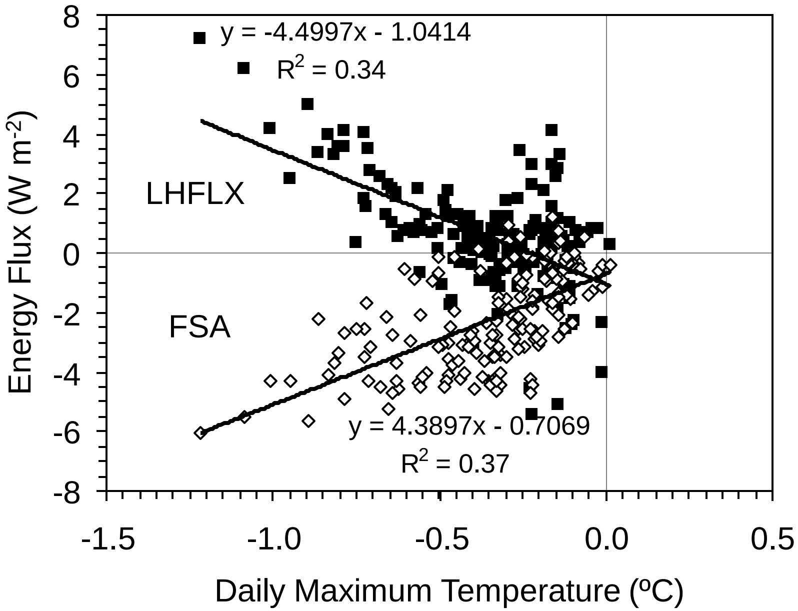


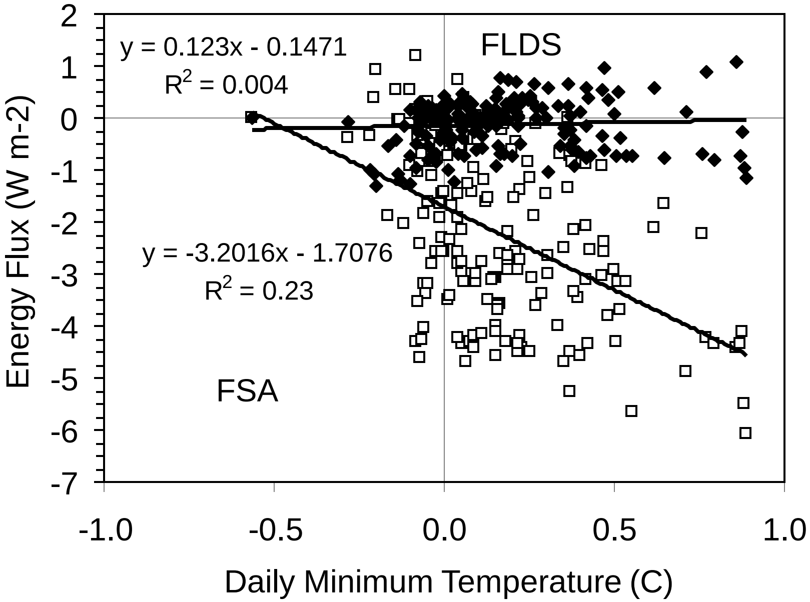
Functional relationships to explain model response

Europe

Summer season (June-August)

(PD – PDv)





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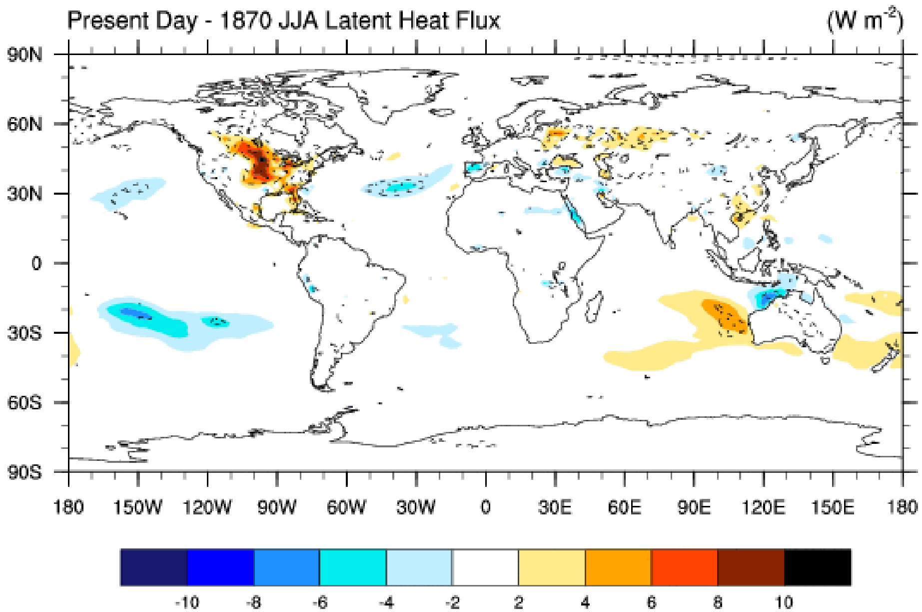
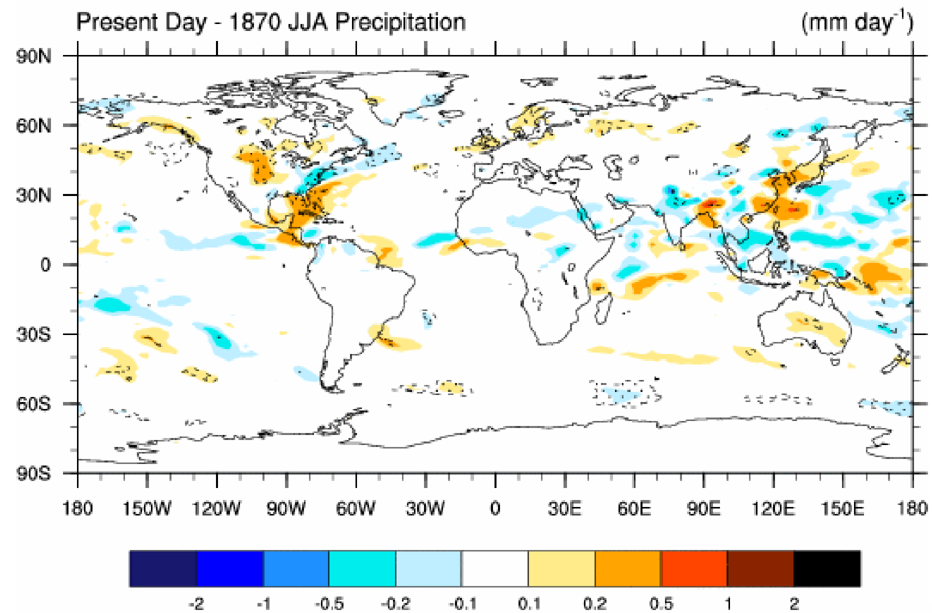
Model includes atmospheric feedbacks

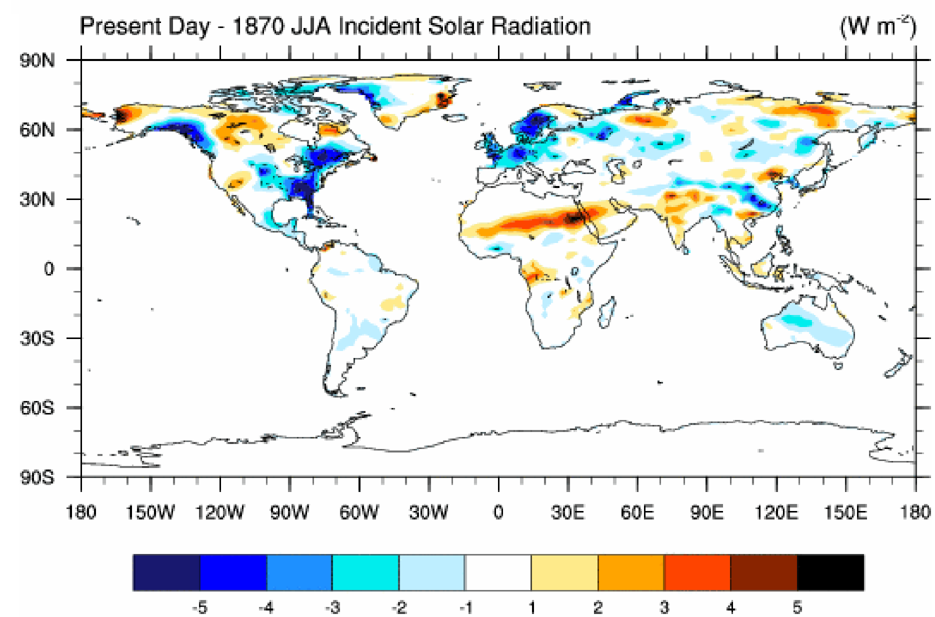




Climate models simulate the large-scale response and include feedbacks with the atmosphere:

- Increased rainfall enhances latent heat flux
- Increased cloudiness reduces solar radiation

Flux towers measure local response



Integrate ecological studies with earth system models

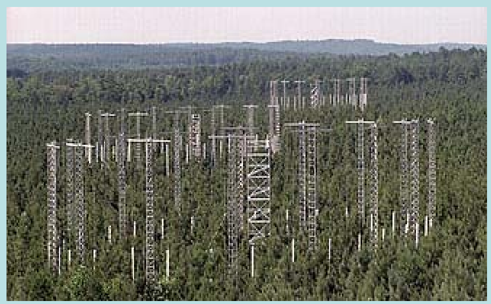
Environmental Monitoring

Eddy covariance flux tower
(courtesy Dennis Baldocchi)

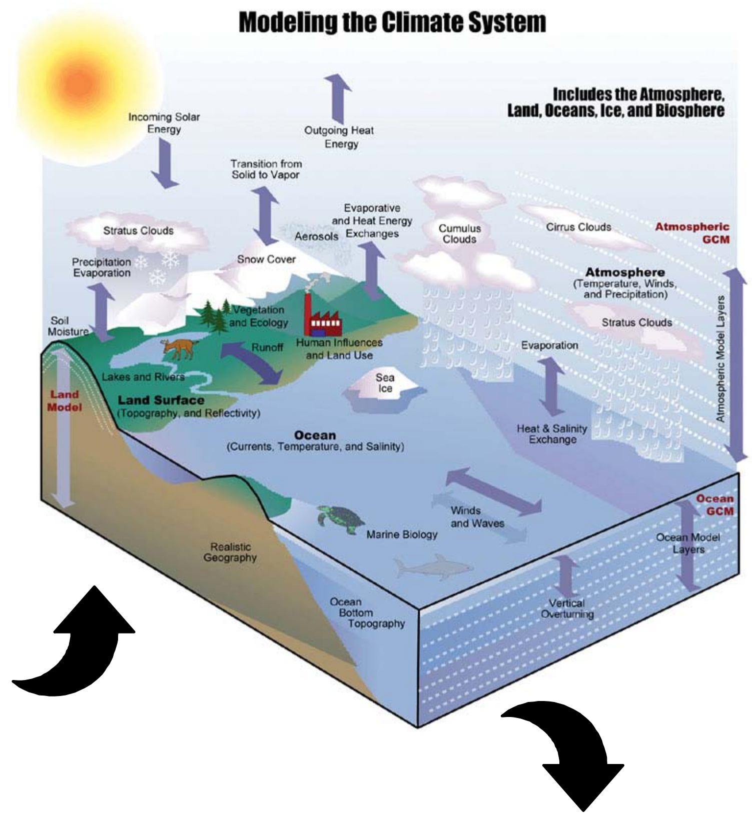
Hubbard Brook
Ecosystem Study

Experimental Manipulation

Soil warming, Harvard Forest



CO_2 enrichment, Duke Forest



Planetary energetics
Planetary ecology
Planetary metabolism

Test model-generated hypotheses of earth system functioning with observations