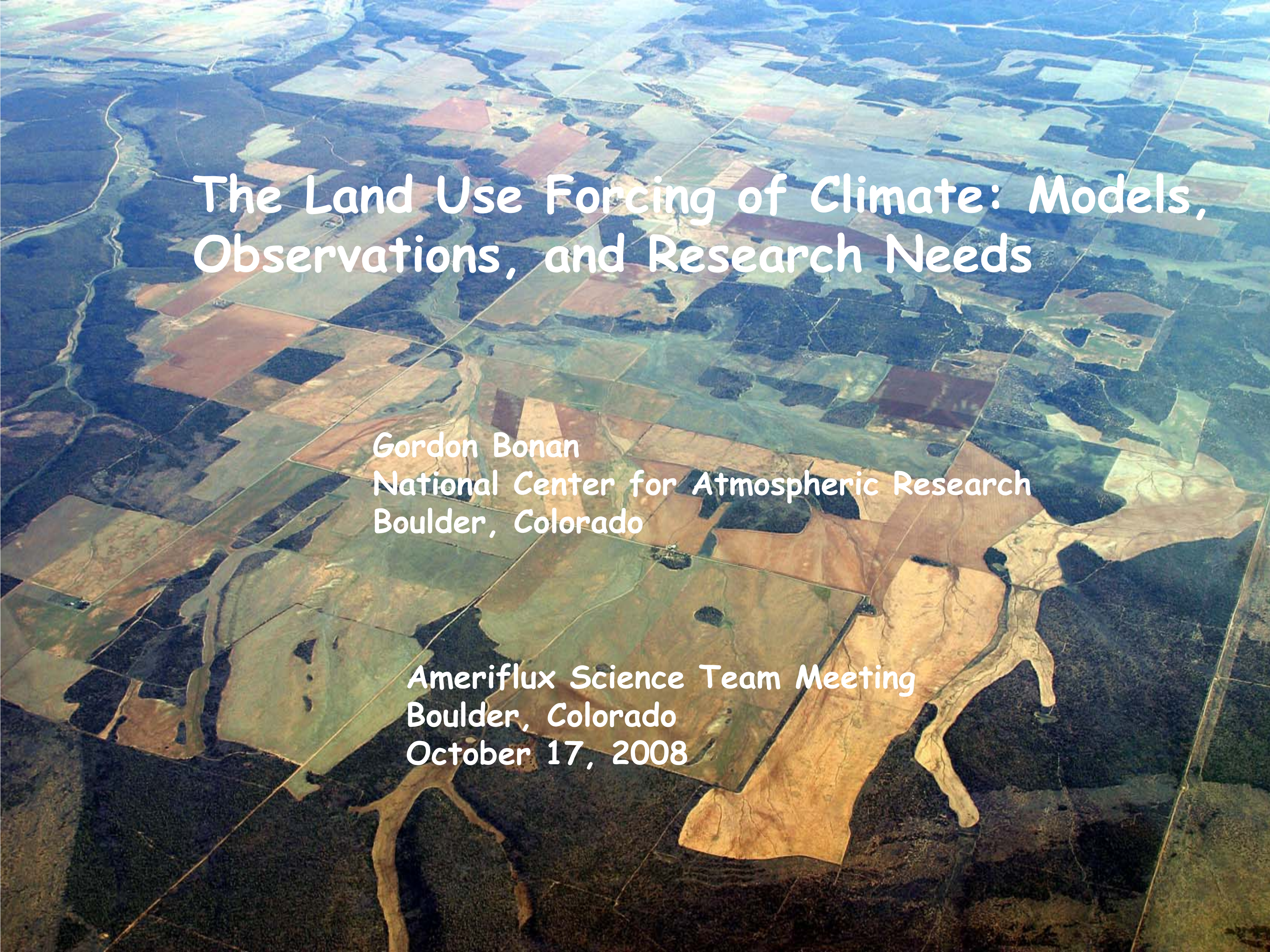


The Land Use Forcing of Climate: Models, Observations, and Research Needs

Gordon Bonan
National Center for Atmospheric Research
Boulder, Colorado

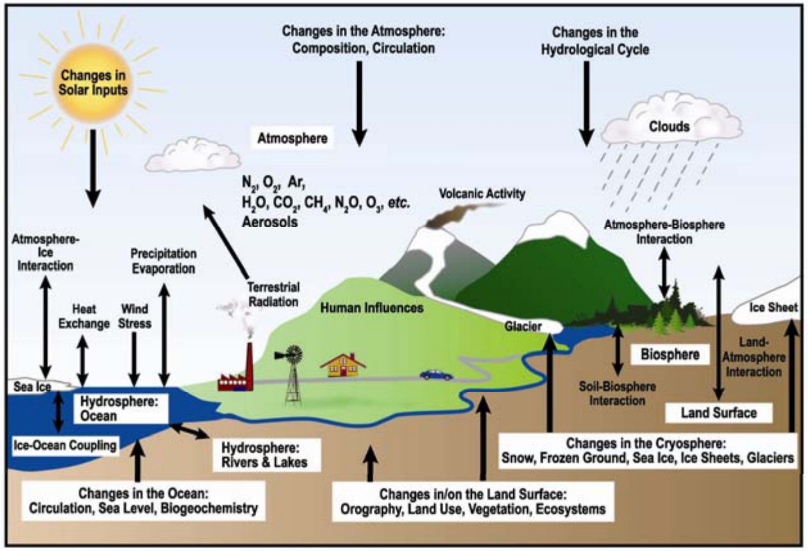
Ameriflux Science Team Meeting
Boulder, Colorado
October 17, 2008

Our research

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

- **Continued expansion of capability to simulate ecological, hydrological, and biogeochemical <u>forcings and feedbacks</u> in the earth system**
- **Increased emphasis on ability to conduct <u>impacts, adaptation, and mitigation</u> research**
- **Requires an <u>integrated assessment modeling</u> framework**
  - Human systems (land use, urbanization, energy use)
  - Biogeochemical systems (C-N-P, trace gas emissions, constituent tracing, isotopes)
  - Water systems (water resource management, freshwater availability, water quality)
  - Ecosystems

    (disturbance, vulnerability, goods and services)



(IPCC 2007)

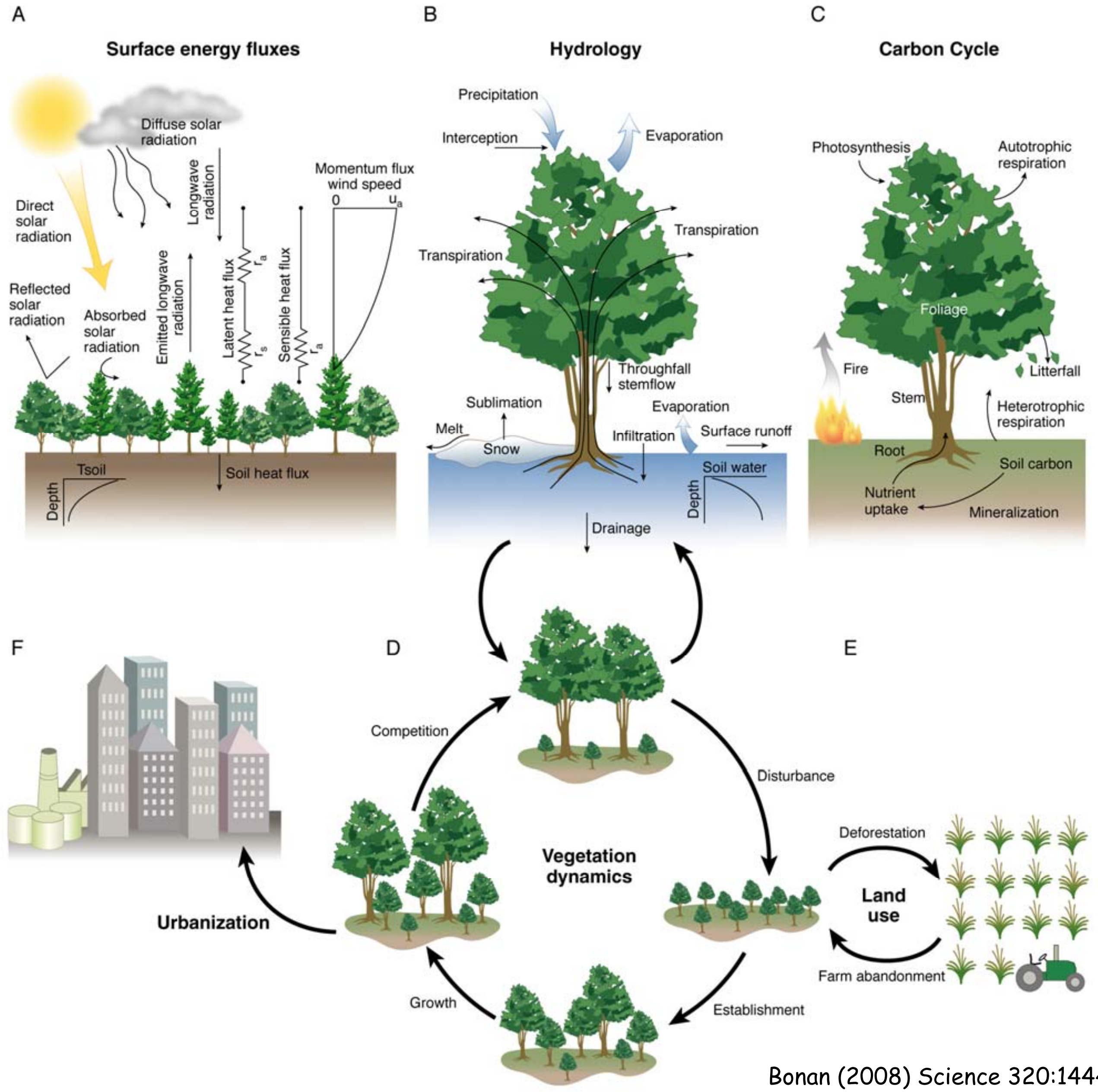
The Community Land Model

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

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

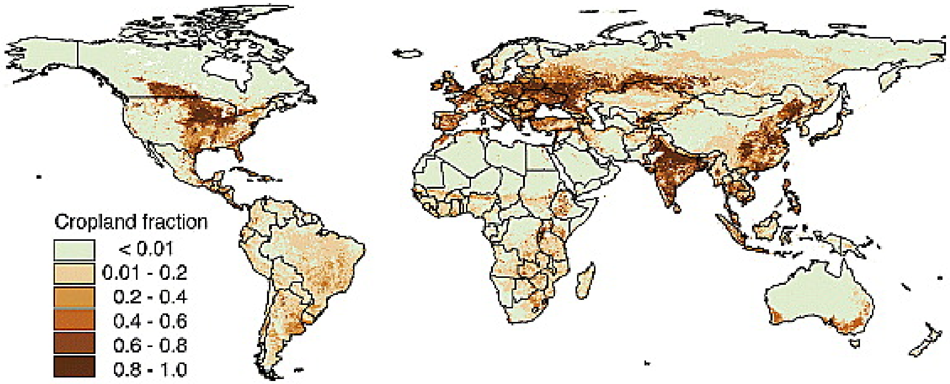
Oleson et al. (2008) JGR, 113, doi:10.1029/2007JG000563

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



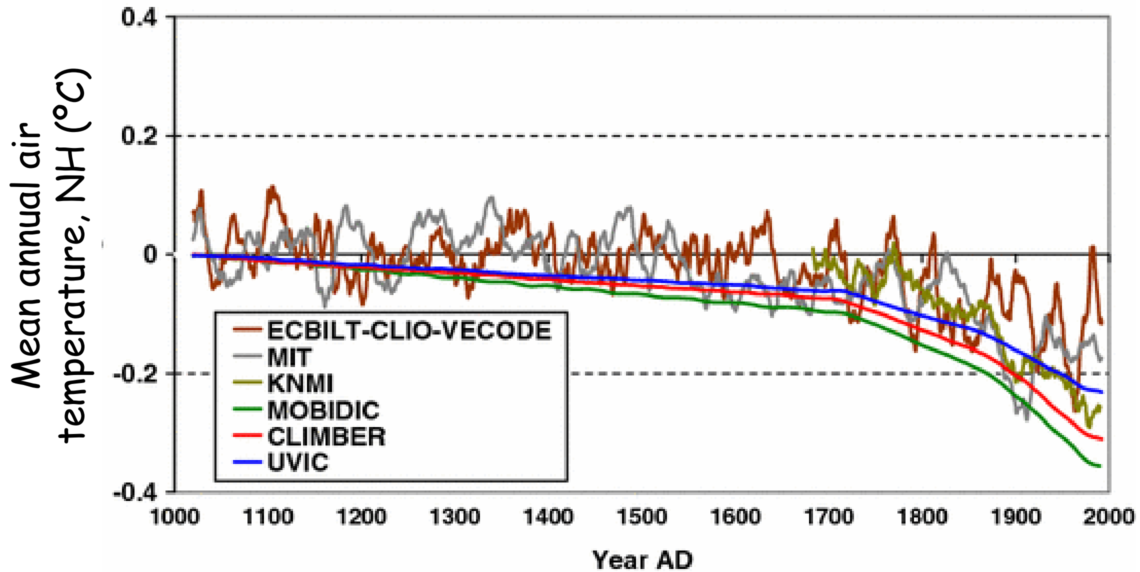
Bonan (2008) Science 320:1444-1449

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)

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

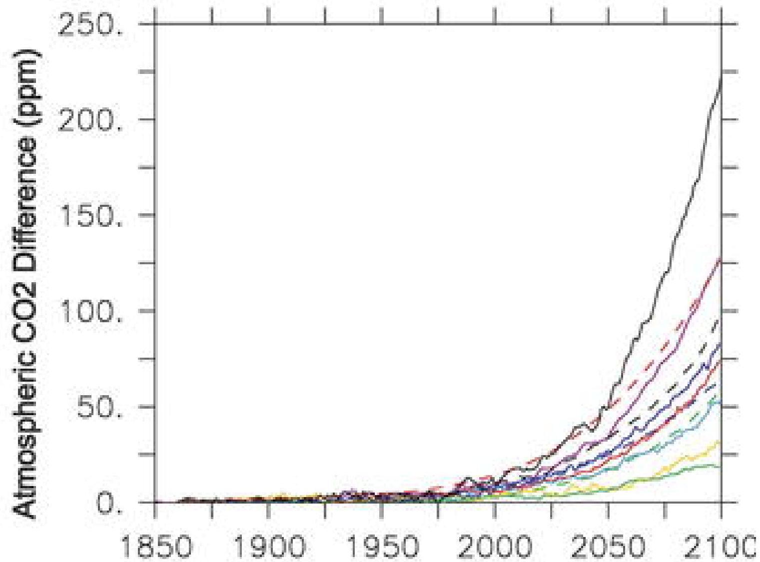


Northern Hemisphere annual mean temperature decreases by 0.19 to 0.36 °C relative to the pre-industrial era

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

C4MIP – Climate and carbon cycle

Effect of climate change on carbon cycle

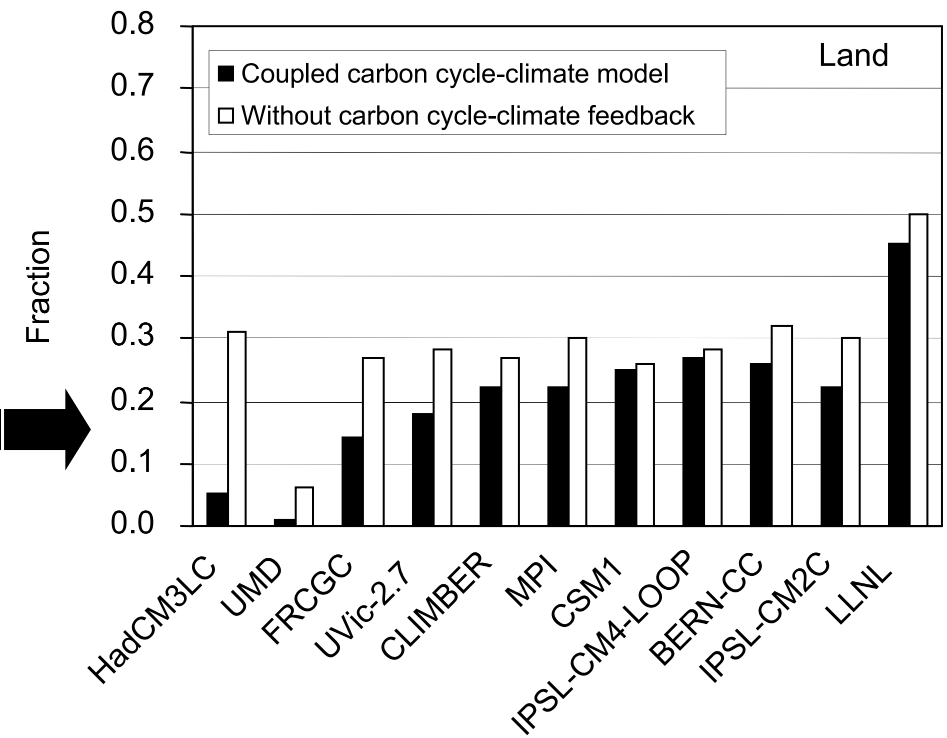


Climate-carbon cycle feedback

All models have a positive climate-carbon cycle feedback. The magnitude of this feedback ranges from 20 ppm to >200 ppm

Distribution at 2100 of cumulative anthropogenic carbon emissions

The amount of carbon stored in the atmosphere increases in each model compared with the comparable simulation without climate-carbon cycle feedback, while the land carbon storage decreases.



Friedlingstein et al. (2006) J Clim 19:3337–3353

Integrated effects of land cover change (2100)

Biogeophysical

A2 – cooling with widespread cropland

B1 – warming with temperate reforestation

Biogeochemical

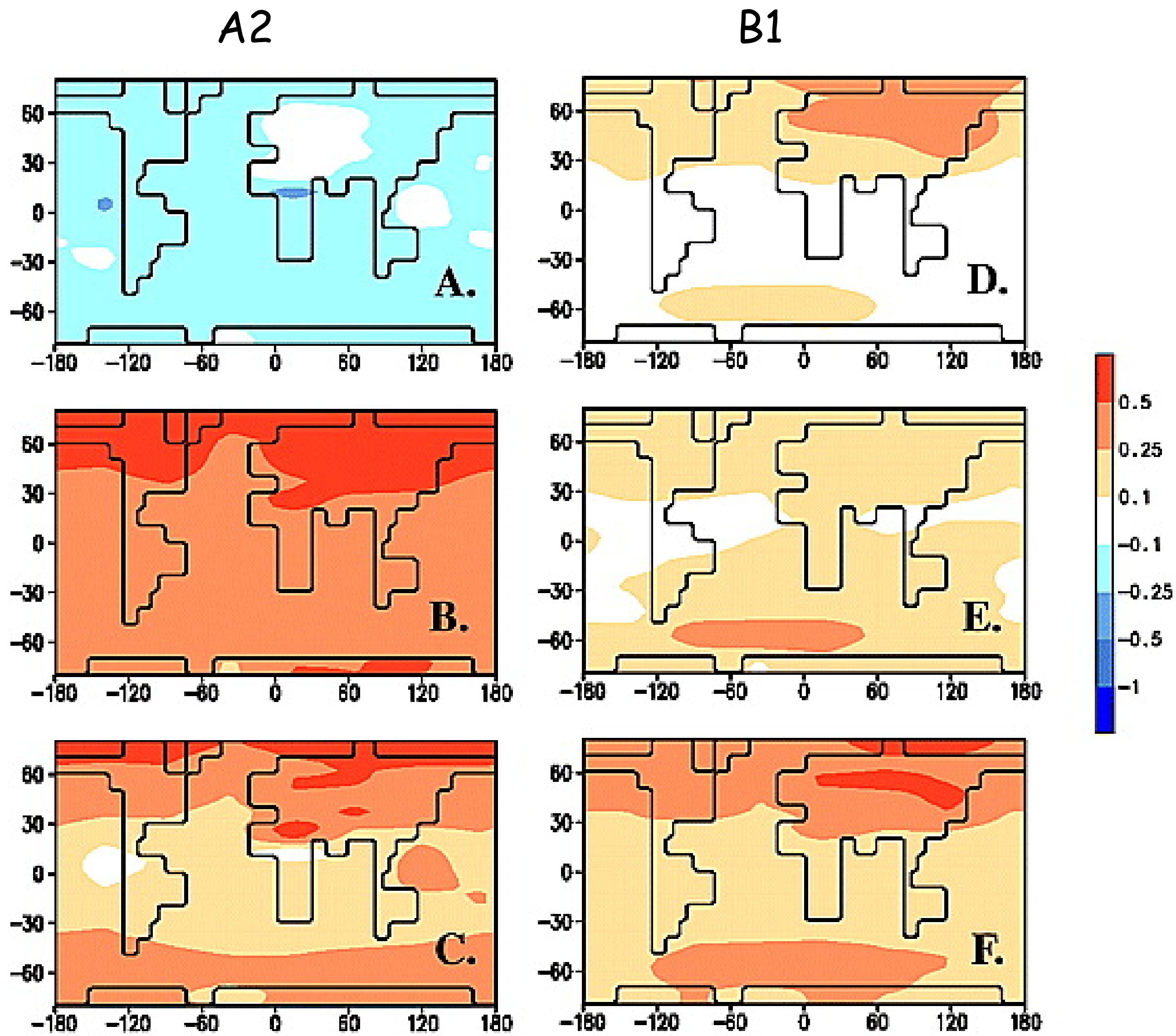
A2 – large warming; widespread deforestation

B1 – weak warming; less tropical deforestation, temperate reforestation

Net effect

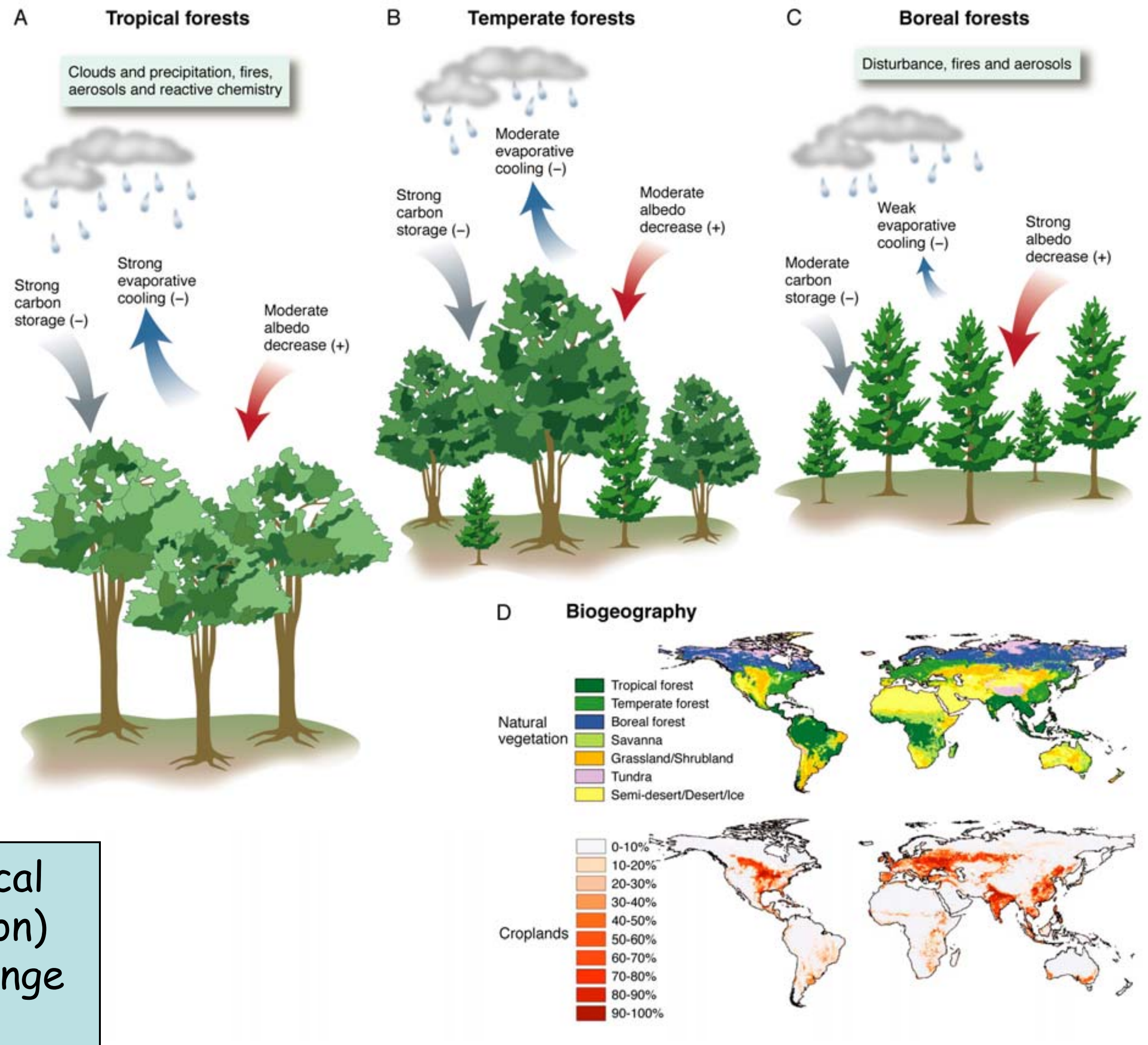
A2 – BGC warming offsets BGP cooling

B1 – moderate BGP warming augments weak BGC warming



Sitch et al. (2005) GBC, 19, doi:10.1029/2004GB002311

Forests and climate change

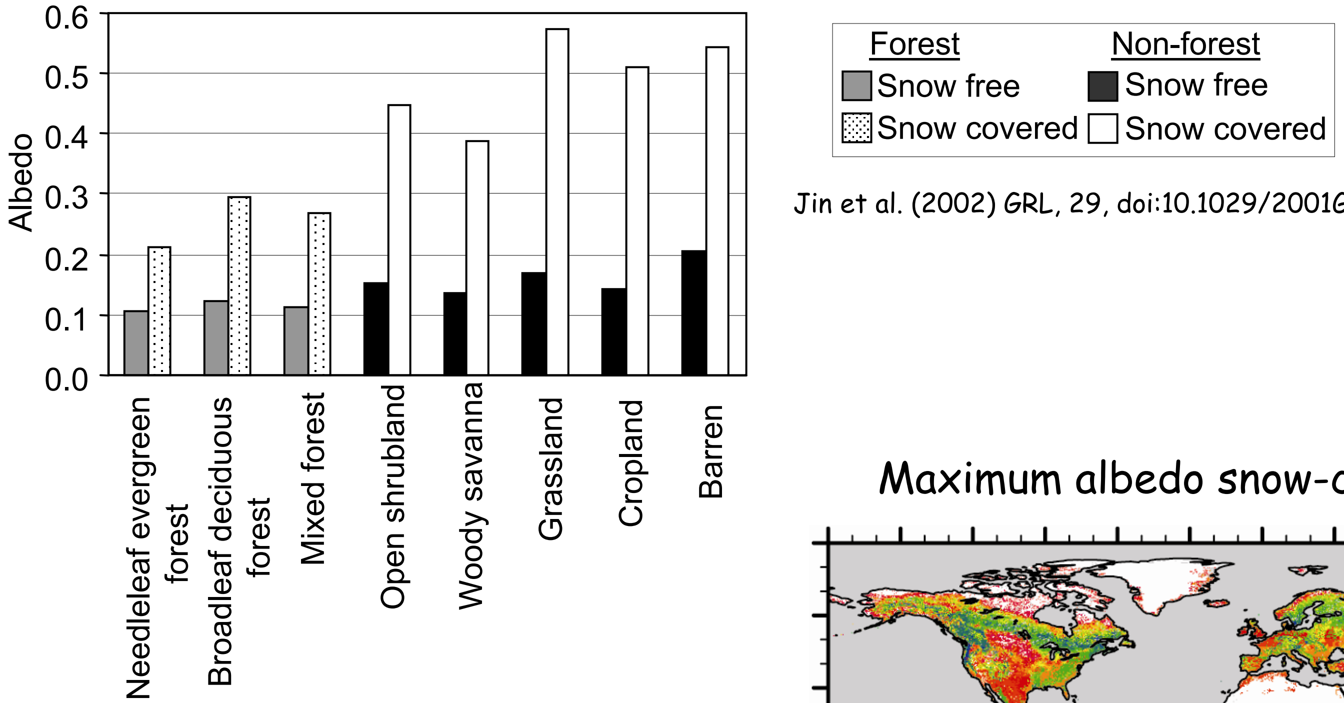


Contrast the biogeophysical (albedo, evapotranspiration) effects of land cover change with the biogeochemical effects (carbon)

Bonan (2008) Science 320:1444-1449

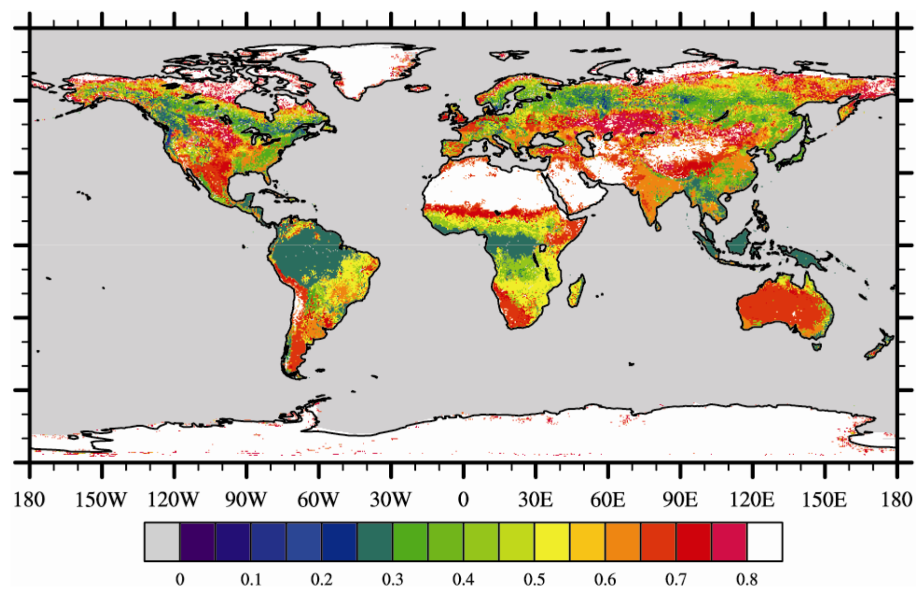
Albedo

Broadband direct beam albedo (40° N and 50° N)



Jin et al. (2002) GRL, 29, doi:10.1029/2001GL014132

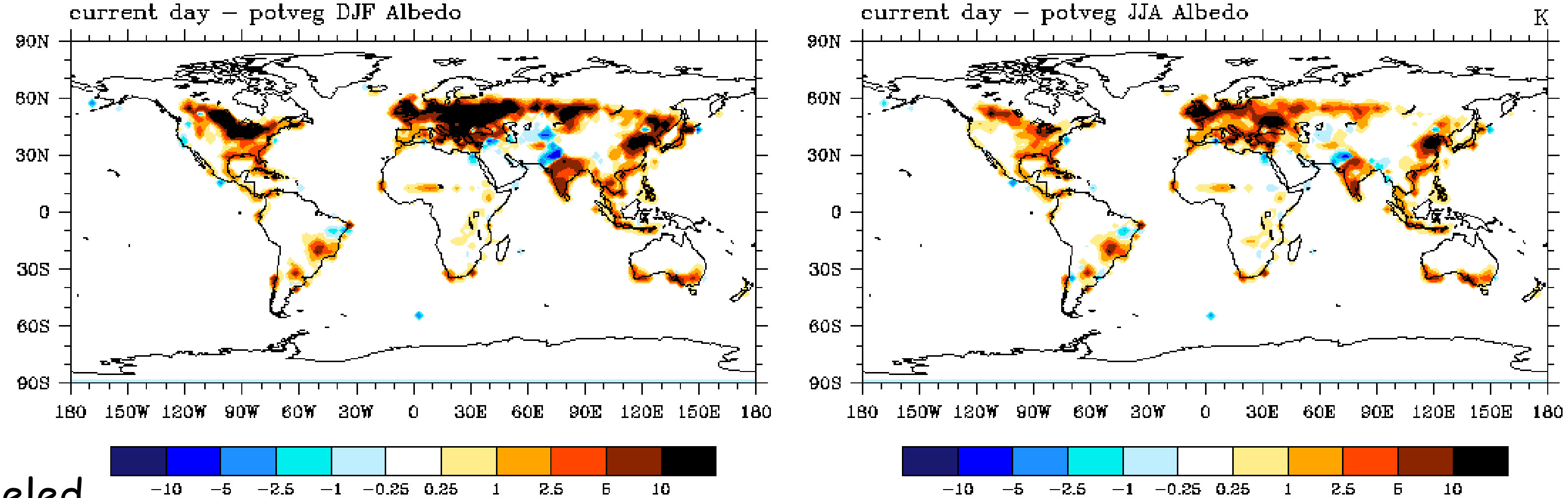
Maximum albedo snow-covered land



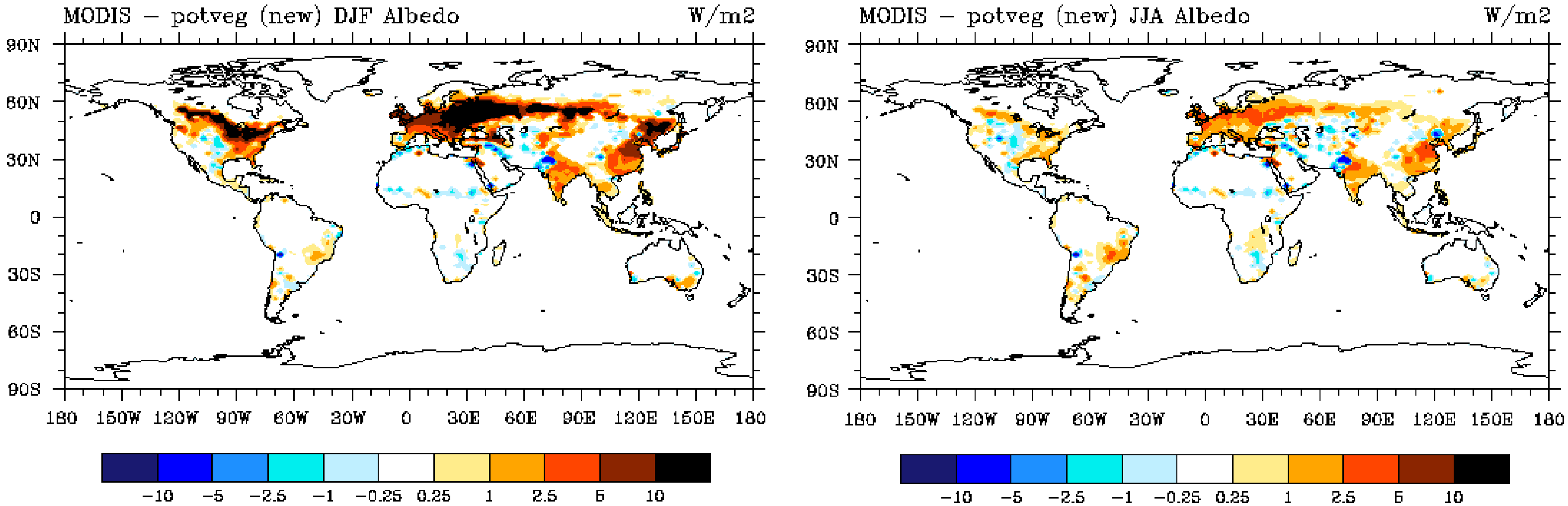
Barlage et al. (2005) GRL, 32, doi:10.1029/2005GL022881

Albedo land use forcing

Expected



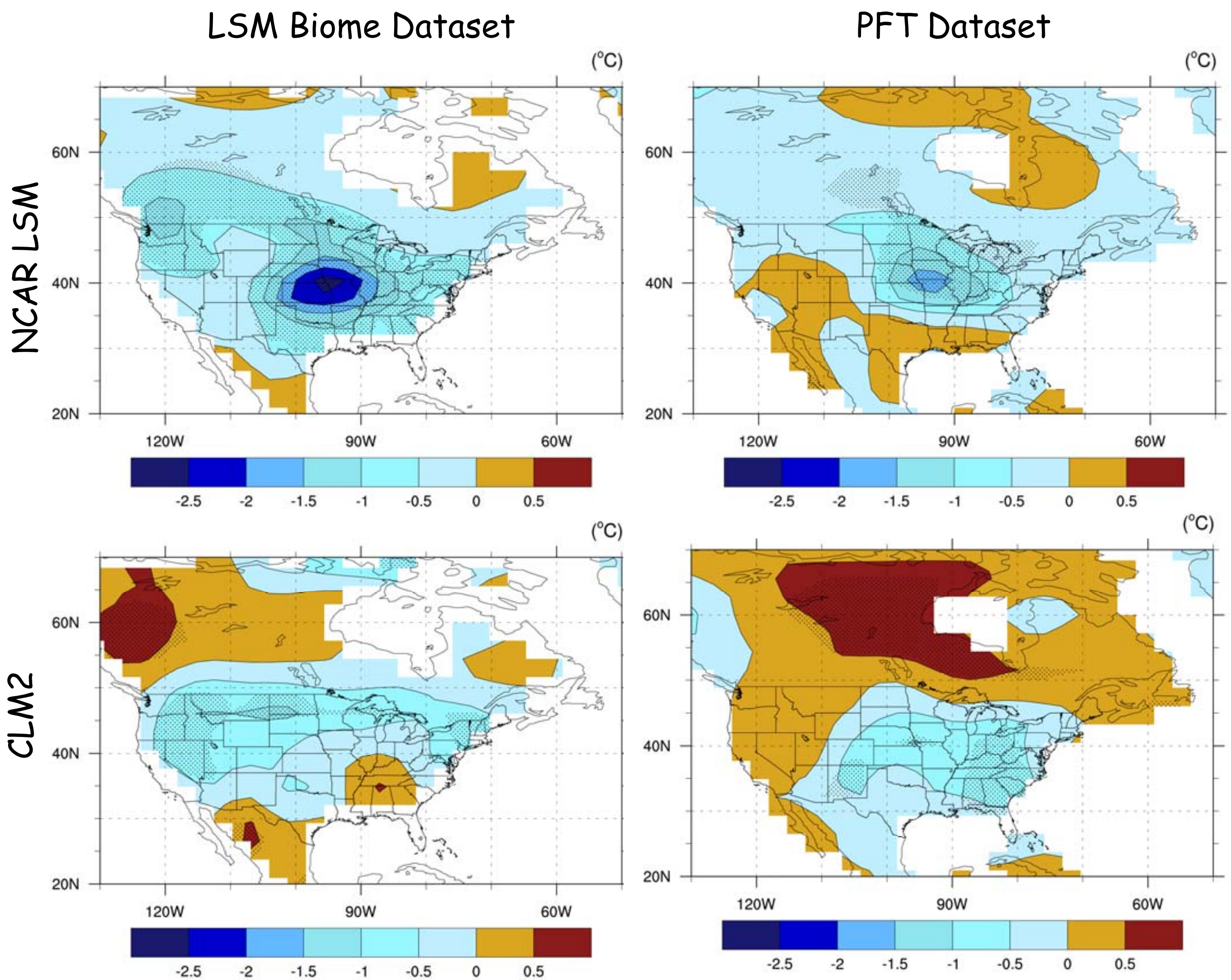
Modeled



Peter Lawrence (NCAR), unpublished

Temperate deforestation cools summer climate

Summer Surface Air Temperature Difference (Present Day – Natural Vegetation)



Four paired climate simulations with CAM2 using two land surface models

- NCAR LSM
- CLM2

and two surface datasets

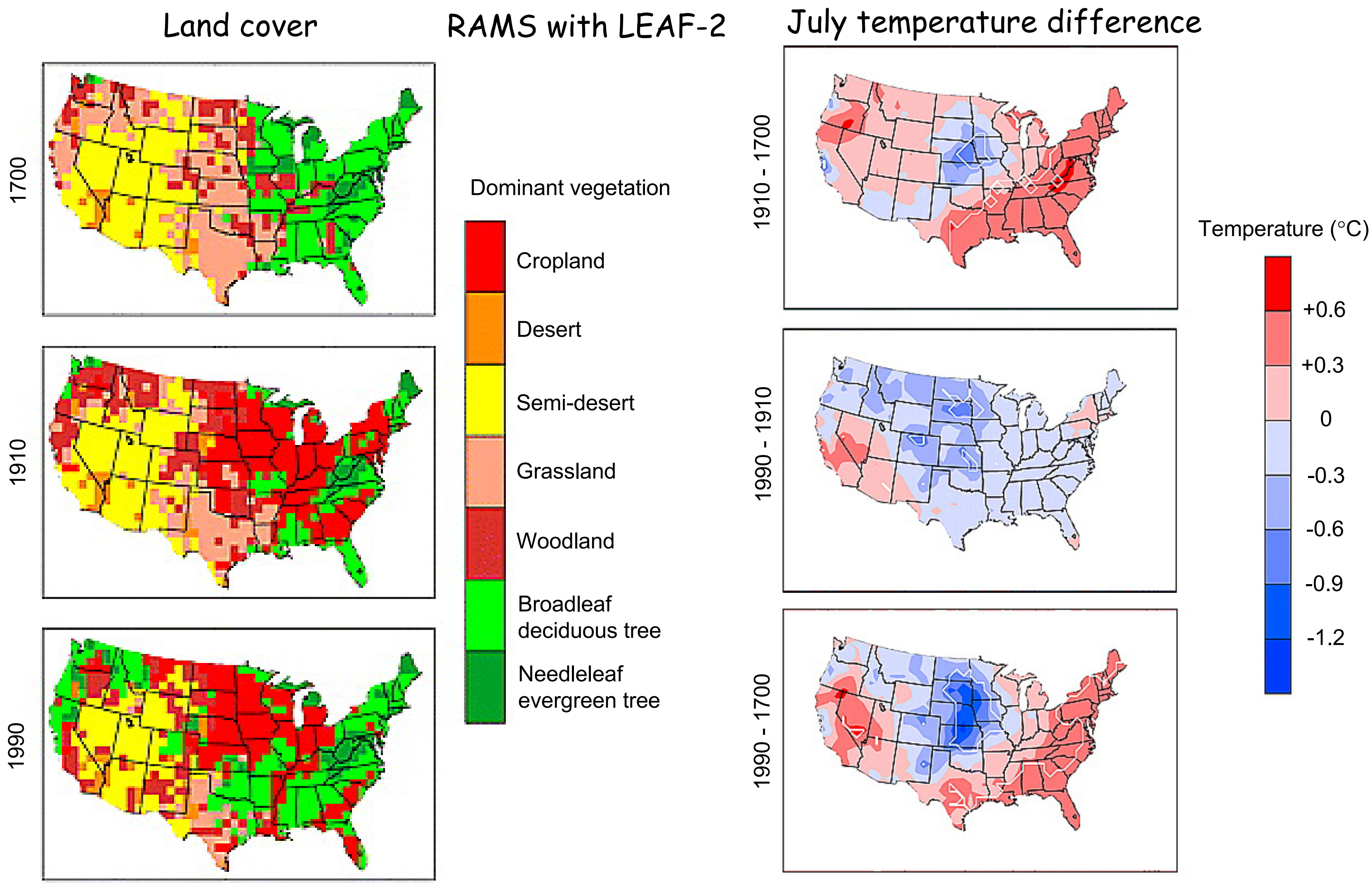
- Biome dataset without subgrid heterogeneity
- Dataset of plant functional types with subgrid heterogeneity

Conclusion

Magnitude of cooling associated with croplands is sensitive to surface datasets and model physics

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

Temperate deforestation warms summer climate



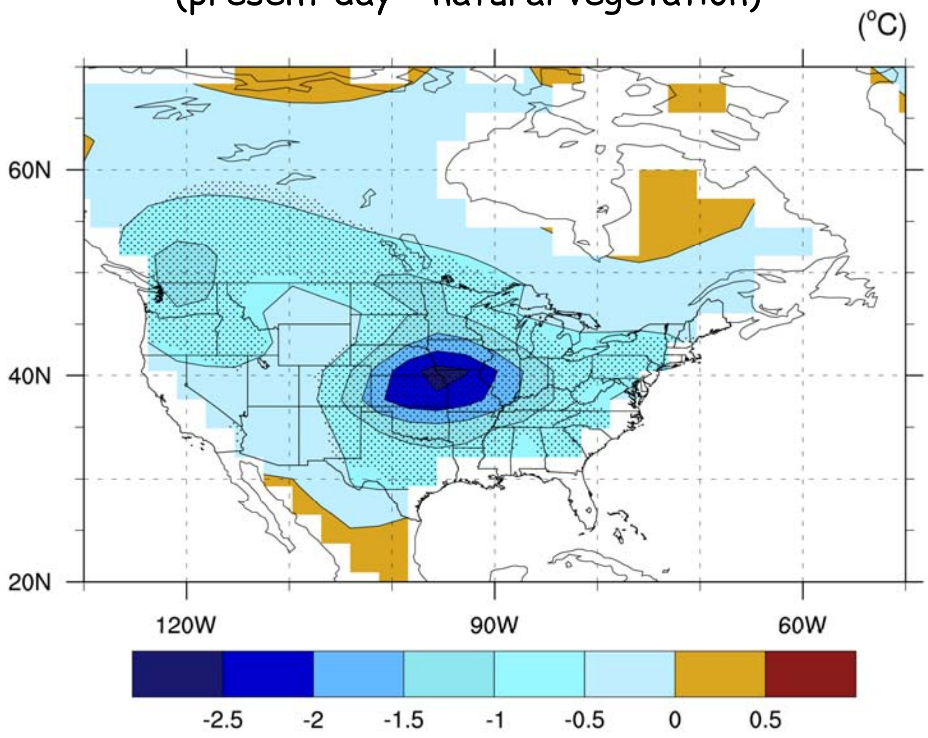
1700 → 1910: Forest → cropland in east
Grass → cropland in central US
1910 → 1990: Reforestation in east
Greater cropland in central US

Grass → crop: Increased ET
Forest → crop: Increased albedo, reduced z0, reduced ET (rooting depth)

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

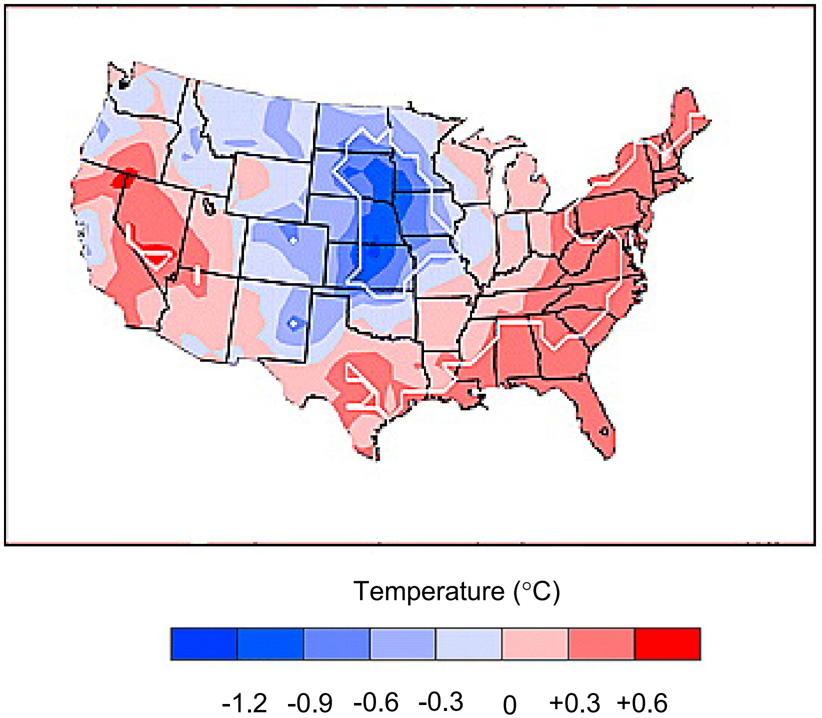
Temperate deforestation and latent heat flux?

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

Flux tower measurements to guide model development

Observations: FLUXNET, a global network

USED SITES IN OUR STUDY:

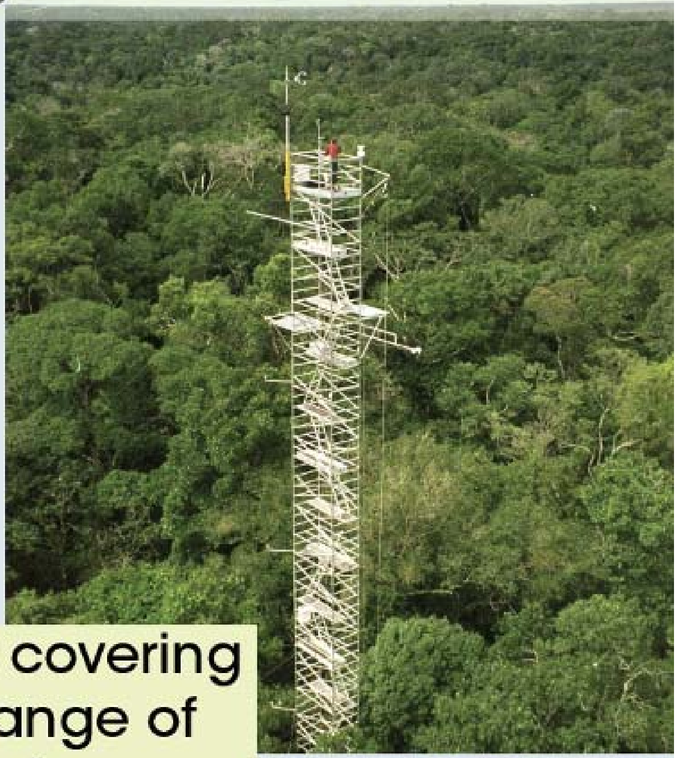
- Morgan Monroe (1999-2005)
- Fort Peck (2000-2005)
- Harvard Forest (1994-2003)
- Niwot Ridge (1999-2004)
- Boreas (1994-2005)
- Lethbridge (1998-2004)

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

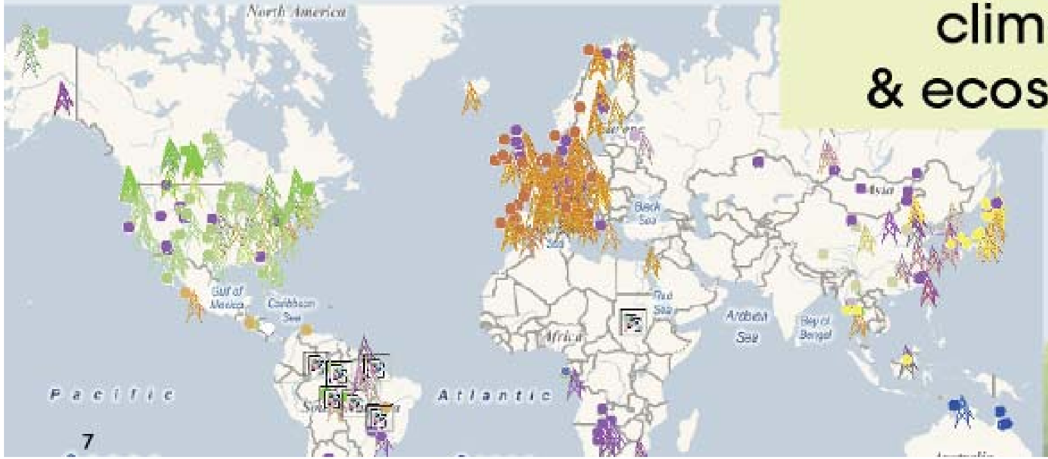
- Castelporziano (2000-2005)
- Collelongo (1999-2003)
- El Saler (1999-2005)
- Kaamanen (2000-2005)
- Hyytiälä (1997-2005)
- Tharandt (1998-2003)
- Vielsalm (1997-2005)

Color Legend:

temperate
tropical
boreal
sub-alpine
north-boreal
mediterranean

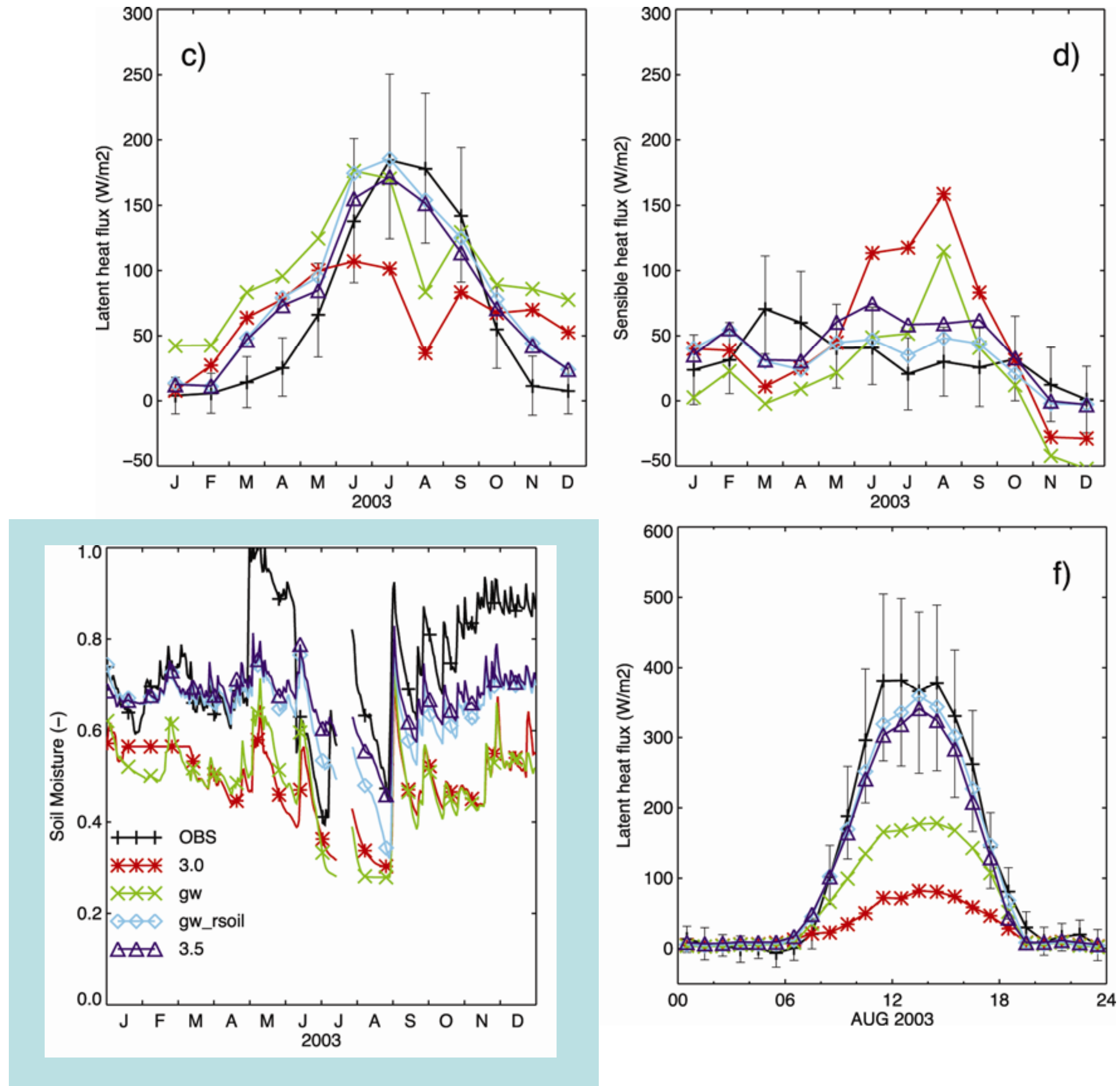


300+ sites covering global range of climates & ecosystems



Flux tower measurements to guide model development

Morgan Monroe State Forest, Indiana



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

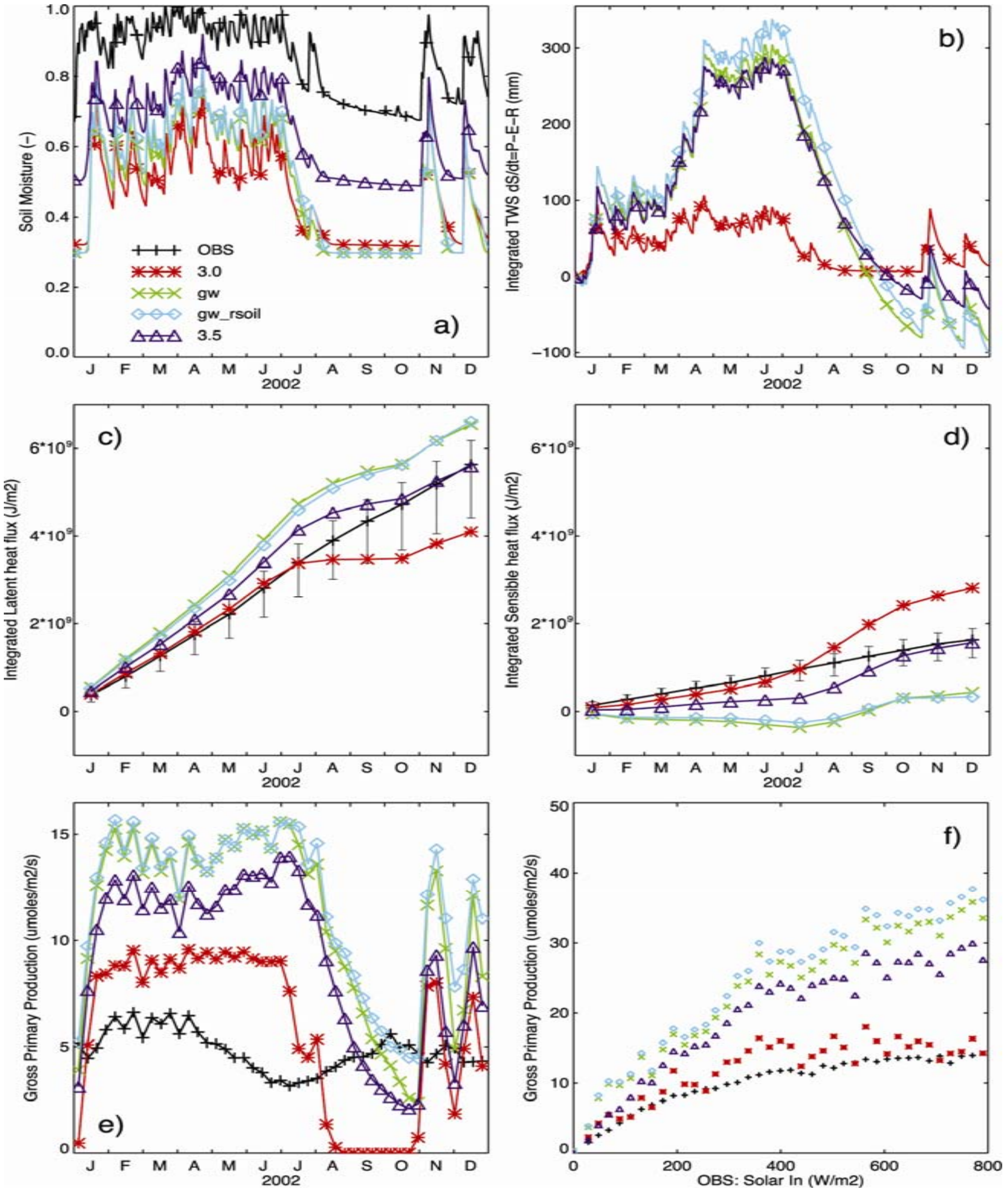
Stöckli et al. (2008) JGR, 113, doi:10.1029/2007JG000562

Flux tower measurements to guide model development

Tropical evergreen forest, Brazil (Santarem KM83, Brazil)

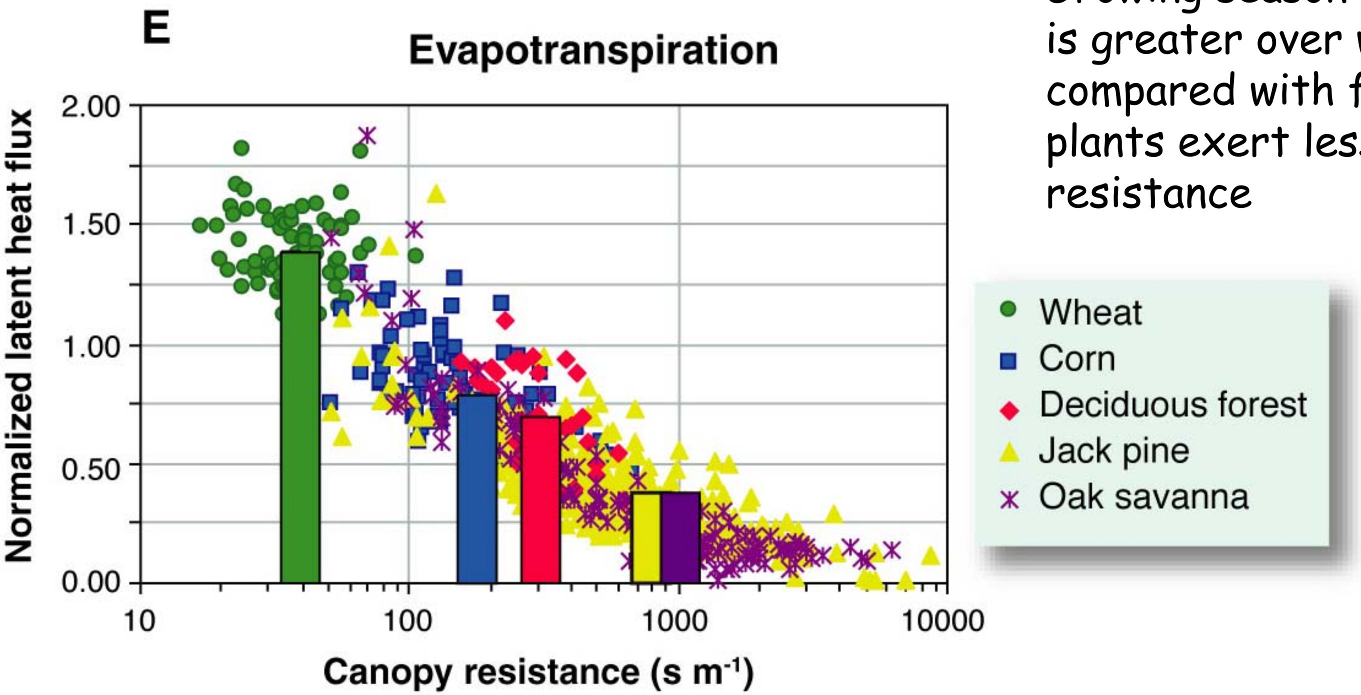
CLM3 – dry soil, low dry season latent heat flux, high dry season sensible heat flux

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



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

Do crops have greater latent heat flux vs. forests?



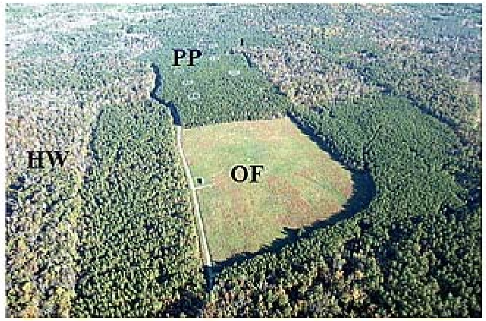
Growing season evaporative cooling is greater over watered crops compared with forests and these plants exert less evaporative resistance

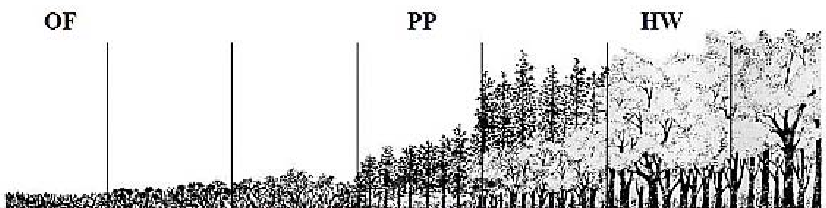
Bonan (2008) Science 320:1444-1449

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

Reforestation cools climate

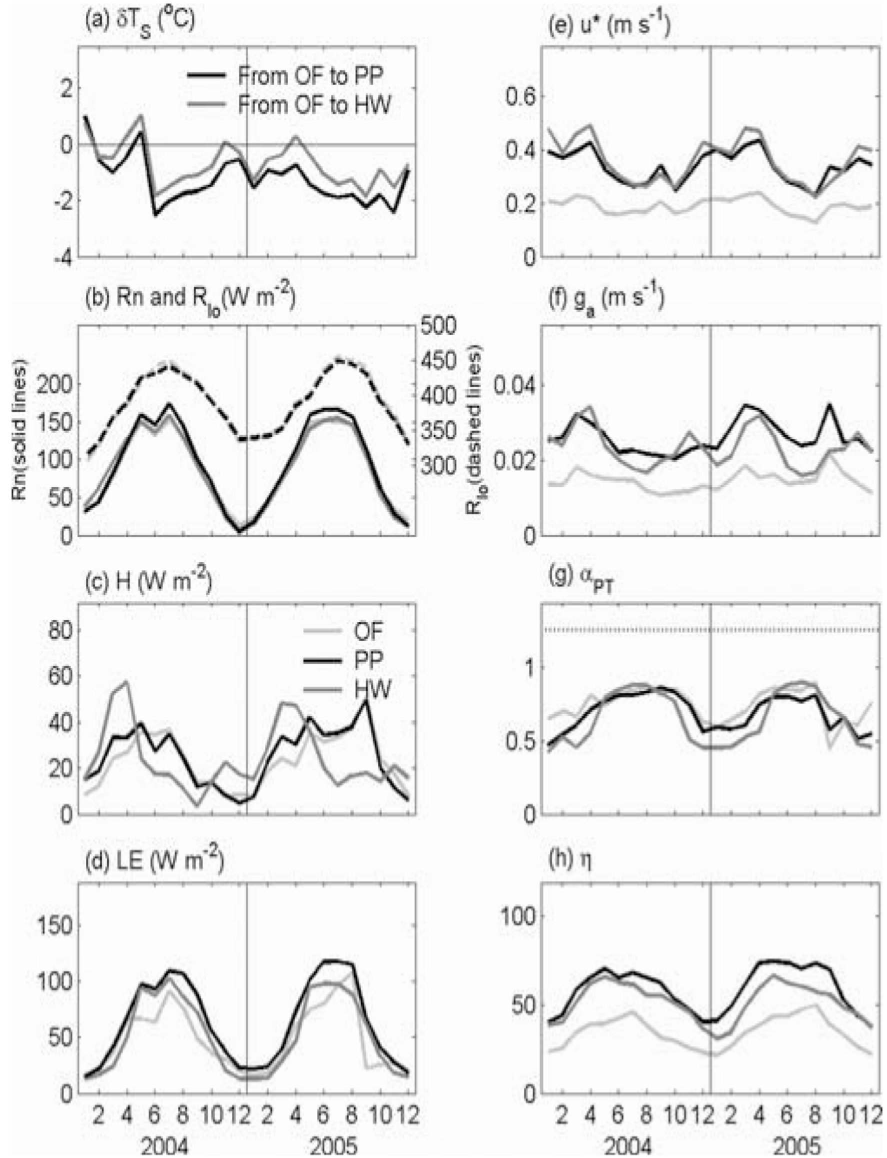




(http://www.nicholas.duke.edu/forest/forest/succession.htm)

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



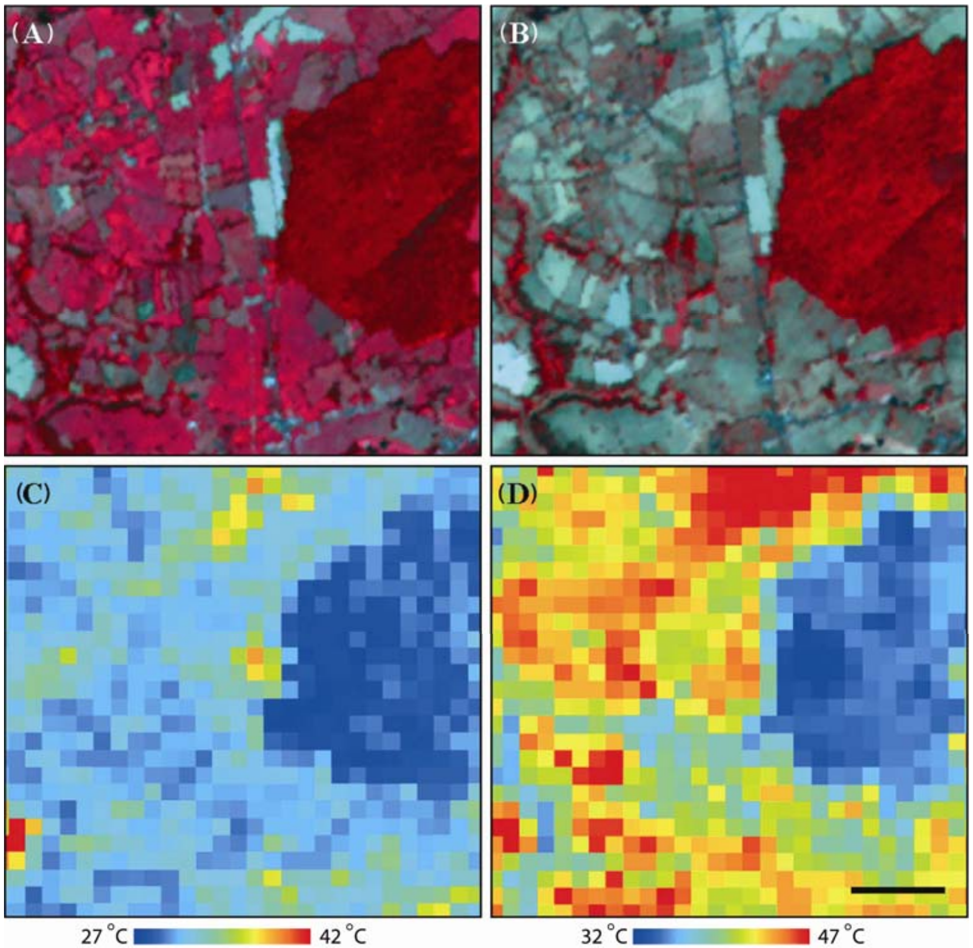
Juang et al. (2007) GRL, 34, doi:10.1029/2007GL031296

Soil water affects the forest-crop difference

Central France

1 August 2000   10 August 2003

Surface reflectance



Surface temperature

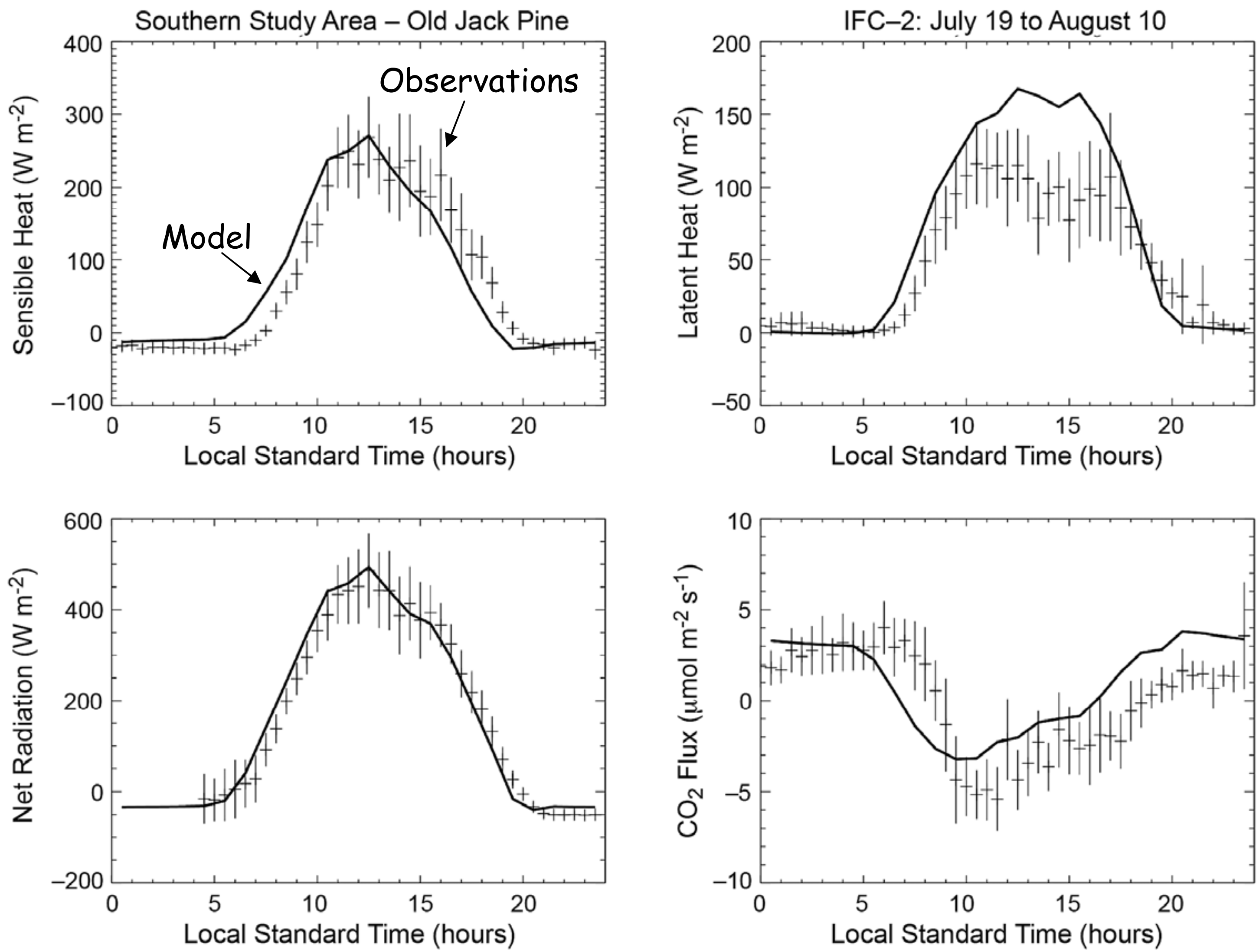
	2000	2003	Change
Forest			
NDVI	0.87	0.87	0
Albedo	0.19	0.17	-0.02
T_R (°C)	29	40	+11
Crops			
NDVI	0.81	0.43	-0.37
Albedo	0.22	0.22	0
T_R (°C)	30	54	+24
Barren			
NDVI	0.27	0.29	+0.02
Albedo	0.24	0.22	-0.02
T_R (°C)	47	58	11

Note the large contrast between agricultural lands and forest patches in the 2003 image. Scale bar indicates 500 m and applies to all four images

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

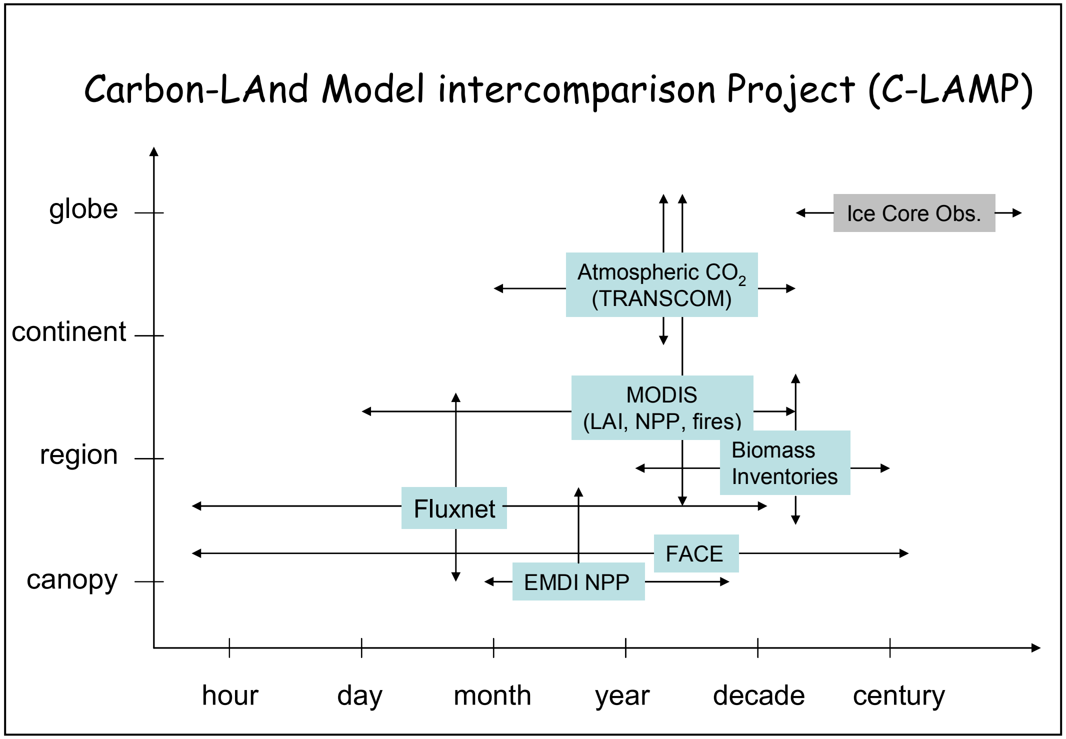
Carbon model validation with tower fluxes

Boreal Ecosystem Atmosphere Study (BOREAS)



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

Carbon cycle



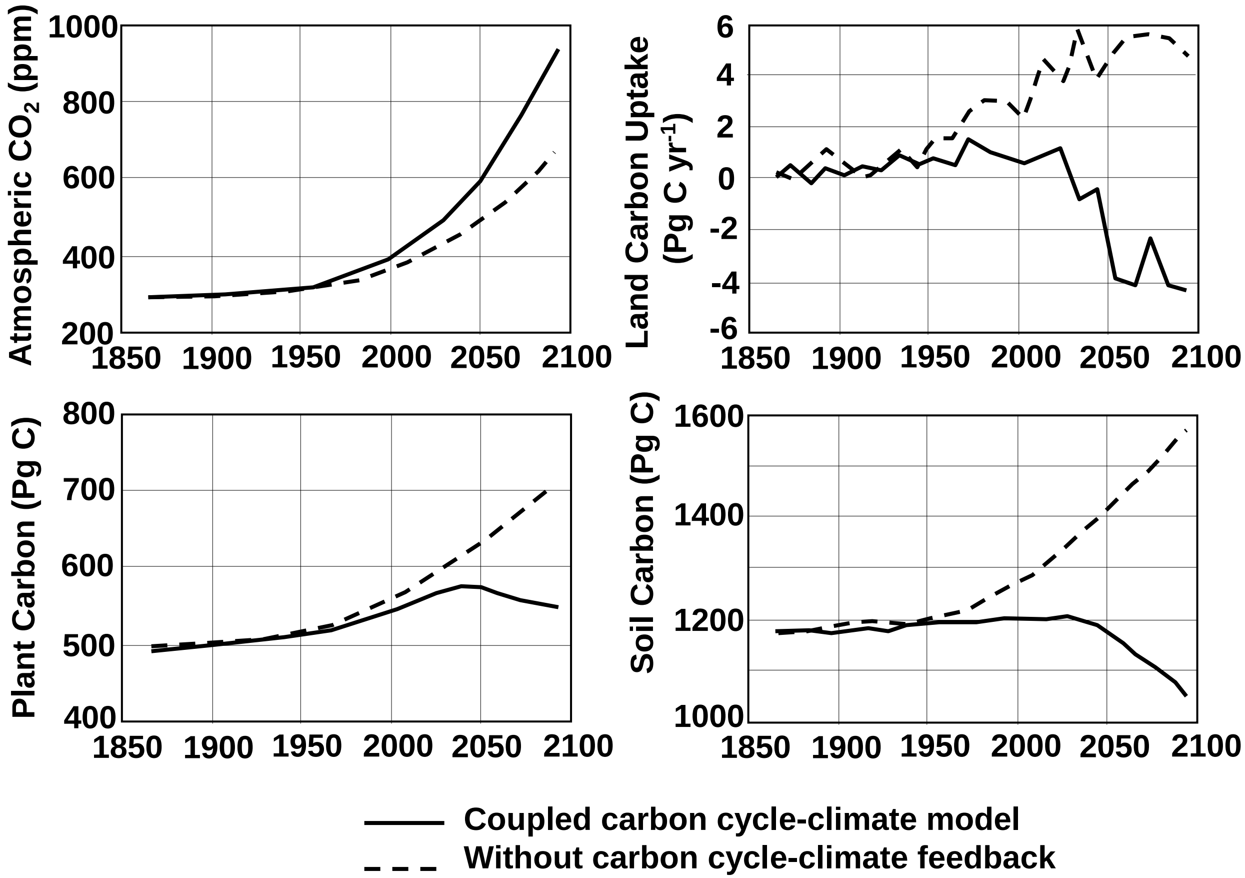
"Systematic assessment of terrestrial biogeochemistry in coupled climate-carbon models"

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

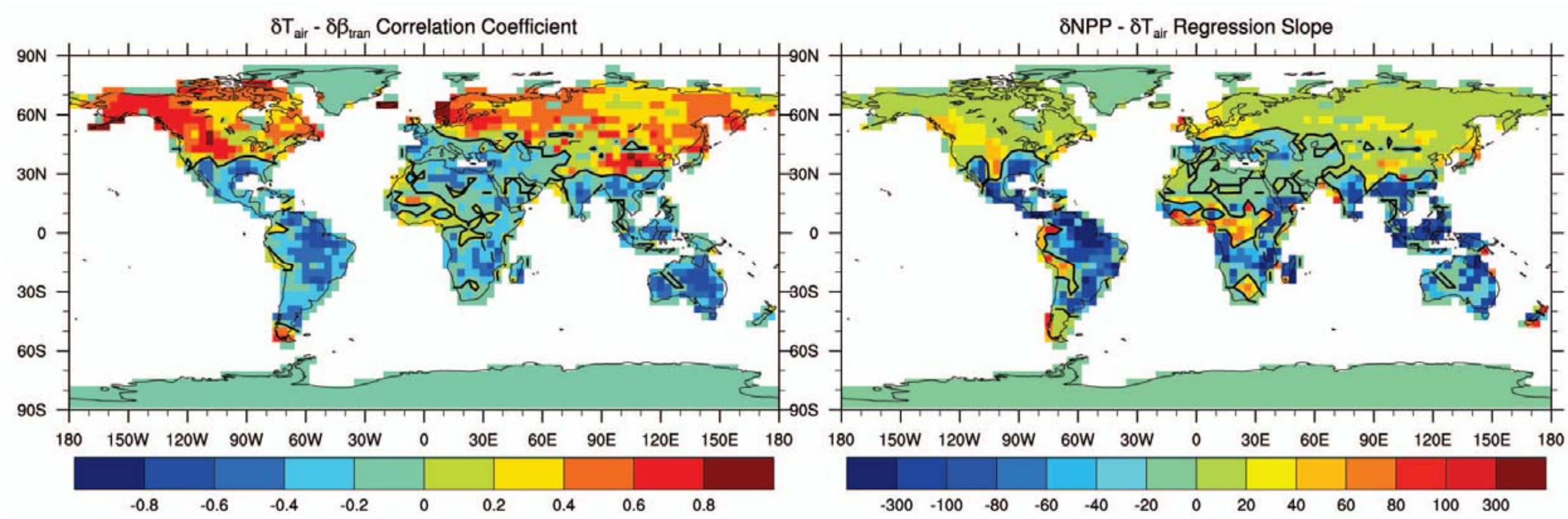
Prevailing modeling paradigm

CO_2 fertilization enhances plant productivity, offset by decreased productivity and increased soil carbon loss with warming



Cox et al. (2004) Theor. Appl. Climatol. 78:137-156

CCSM1 – C4MIP simulation



Correlation of air temperature with soil moisture

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

Correlation of NPP with air temperature

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

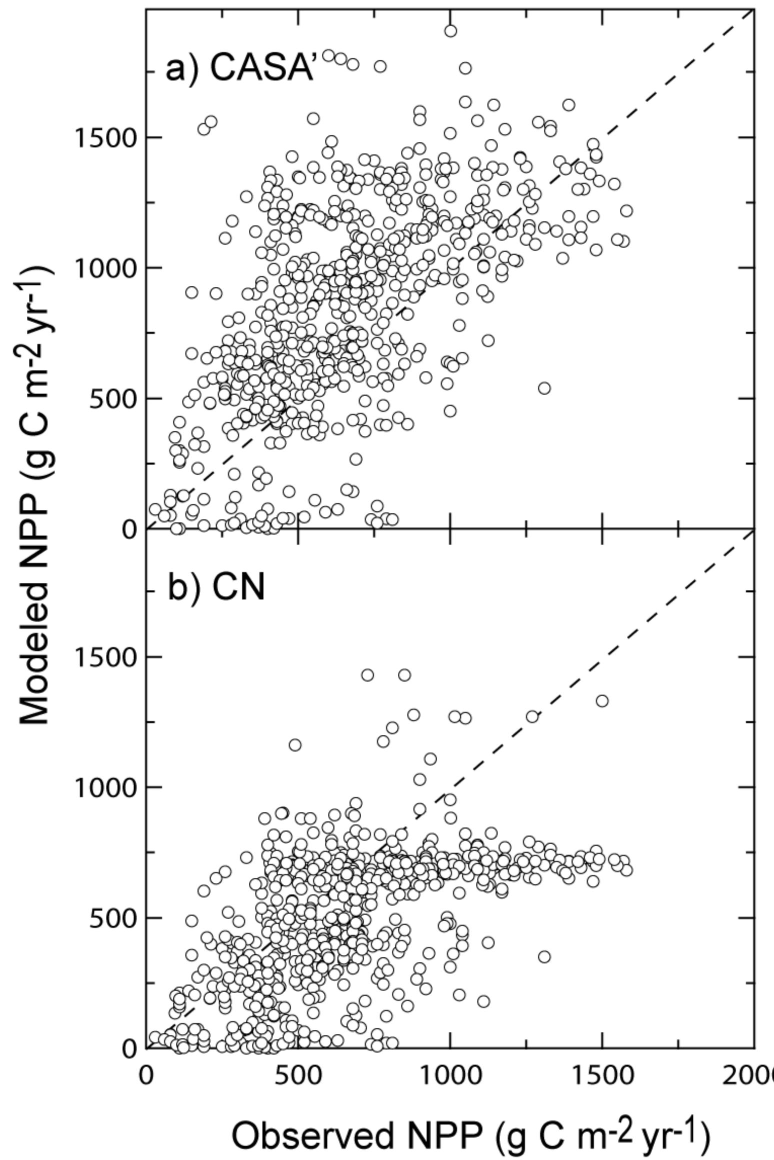
Middle to high latitudes
Positive correlation: NPP increases with warming because of more favorable climate

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

Annual net primary production

Ecosystem Model-Data Intercomparison (EMDI) compilation of observations

- Class A and Class B observations used
- NPP extracted for each model grid cell corresponding to a measurement location



Randerson et al. (2008) GCB, submitted

Comparison with FACE experiments

Experiment	Latitude (°N)	CO_2 initial	CO_2 final	CN Initial NPP	CN final NPP	CN Beta	CASA' Initial NPP	CASA' final NPP	CASA' Beta
DukeFACE	35.6	283.2	364.1	661	733	0.43	1091	1241	0.55
AspenFACE	45.4	283.2	364.1	358	397	0.43	524	595	0.54
ORNL-FACE	35.5	283.2	364.1	828	901	0.35	1090	1248	0.58
POP-EUROFACE	42.2	283.2	364.1	235	253	0.30	397	453	0.56
Mean:						**0.38**			**0.56**

Observed mean β: **0.60**
CN model mean β: **0.38**
CASA′ model mean β: **0.56**

Observed NPP increase (376 -> 550ppm): 23%
CN predicted (376 -> 550ppm): 14%
CASA′ predicted (376 -> 550ppm): 21%

$$\beta = \frac{\left(\frac{NPP(f)}{NPP(i)} - 1\right)}{\ln\left(\frac{CO_2(f)}{CO_2(i)}\right)}$$

$$NPP(t) = NPP(i) \cdot \left[\beta \cdot \ln\left(\frac{CO_2(t)}{CO_2(i)}\right) + 1\right]$$

Randerson et al. (2008) *GCB*, submitted

How to integrate ecological studies with earth system models?

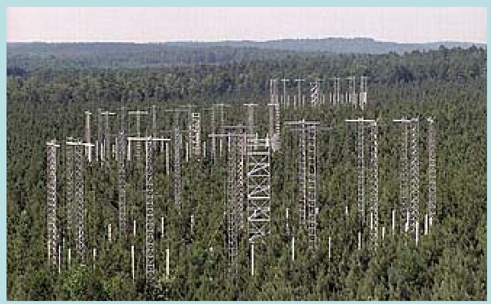
Environmental Monitoring

Eddy covariance flux tower
(courtesy Dennis Baldocchi)

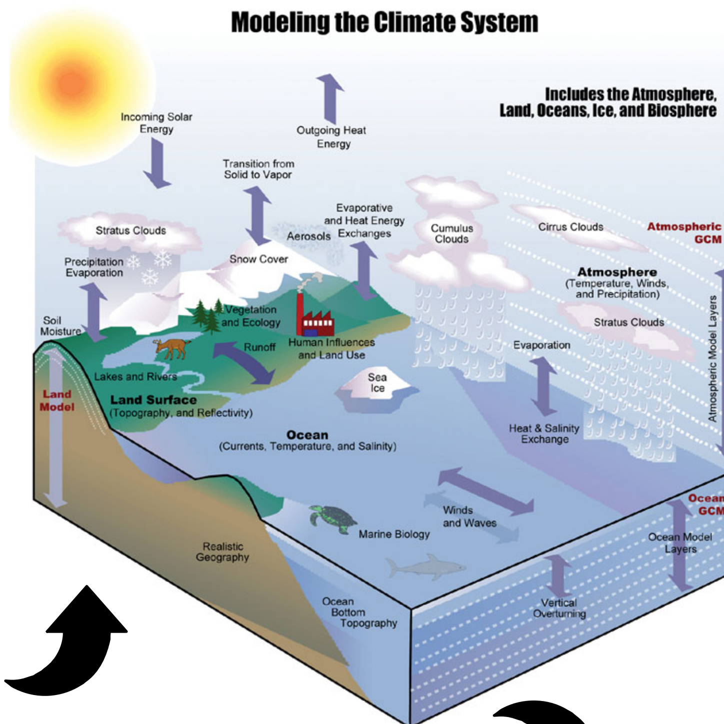
Hubbard Brook
Ecosystem Study

Experimental Manipulation

Soil warming, Harvard Forest



CO_2 enrichment, Duke Forest



Planetary energetics
Planetary ecology
Planetary metabolism