Earth System Modeling - Land Forcings and Feedbacks

Terrestrial ecosystems
Hydrology
Land cryosphere
Land use and land cover change
Climate change mitigation

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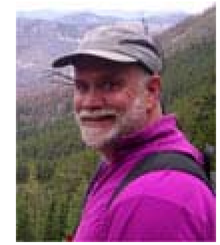
30 October 2007

Climate and Global Dynamics Division

Gordon Bonan – co-chair, Biogeochemistry Working Group
Virginia, environmental sciences

Sam Levis – land use change, dynamic vegetation
Wisconsin, atmospheric and oceanic sciences



Dave Schimel – NEON, NCAR
CSU, ecology

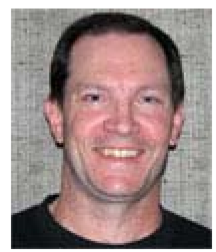
Kathy Hibbard – AIMES
Texas A&M, range ecology

Keith Lindsay – oceanography, carbon cycle
Michigan, mathematics

Peter Thornton – terrestrial C/N cycles
Montana, forestry

Eric Kluzek – software engineering

David Lawrence – co-chair, Land Model Working Group
Colorado, astrophysical, planetary and atmospheric sciences



Keith Oleson – land surface model, urbanization
Colorado, aerospace engineering

Biogeochemistry Working Group

Scott Doney (WHOI) – oceanography, carbon cycle
Jim Randerson (UC-Irvine) – working group co-chair, terrestrial ecology, carbon cycle
Natalie Mahowald (Cornell) – working group co-chair, global biogeochemical cycles
Inez Fung (UC-Berkeley) – global biogeochemical cycles
Curt Covey (PCMDI/LLNL) – data support
Forrest Hoffman (ORNL) – software engineering
and many more …

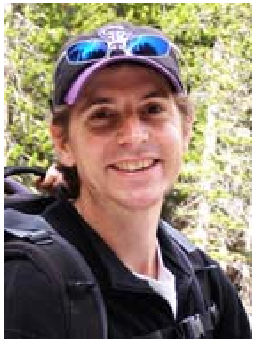
Land Model Working Group

Bob Dickinson (Georgia Tech.) – land surface processes
Johan Feddema (Kansas) – land cover change
Peter Lawrence (Colorado) – land cover change
Steve Running (Montana) – working group co-chair
Reto Stöckli (Switzerland) – flux tower data
Zong-Liang Yang (Texas) – hydrology
Xubin Zeng (Arizona) – land surface processes
and many more …

NCAR Partners

Dave Gochis – hydrology
Arizona, hydrology and water resources

Beth Holland – biogeosciences
CSU, ecology/environmental sciences



Peter Lawrence (CIRES/CU) – land cover change
Queensland, geography

Linda Mearns – land cover change
UCLA, geography

Advanced Study Program Post-docs

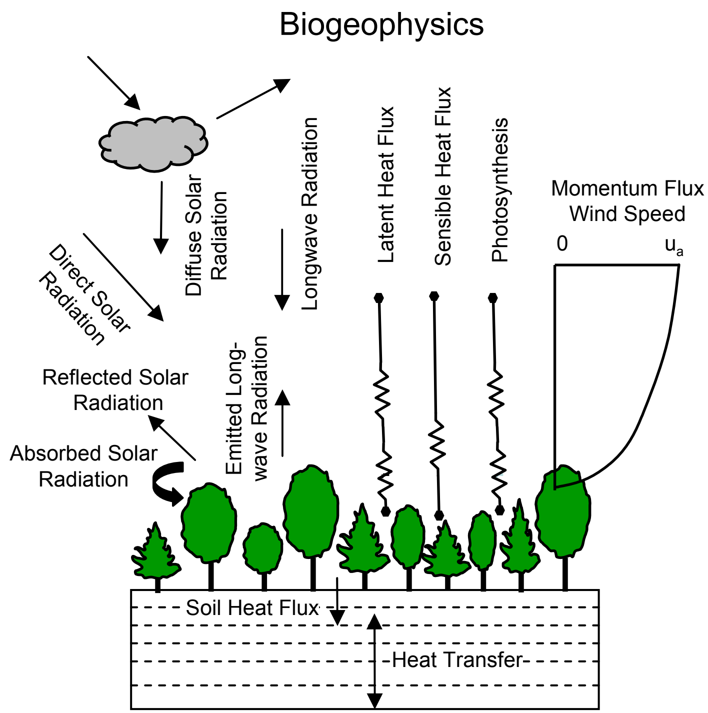
Mark Flanner - Aerosol darkening of snow, snow-albedo feedback, radiative effects of biomass burning
UC-Irvine, earth system science

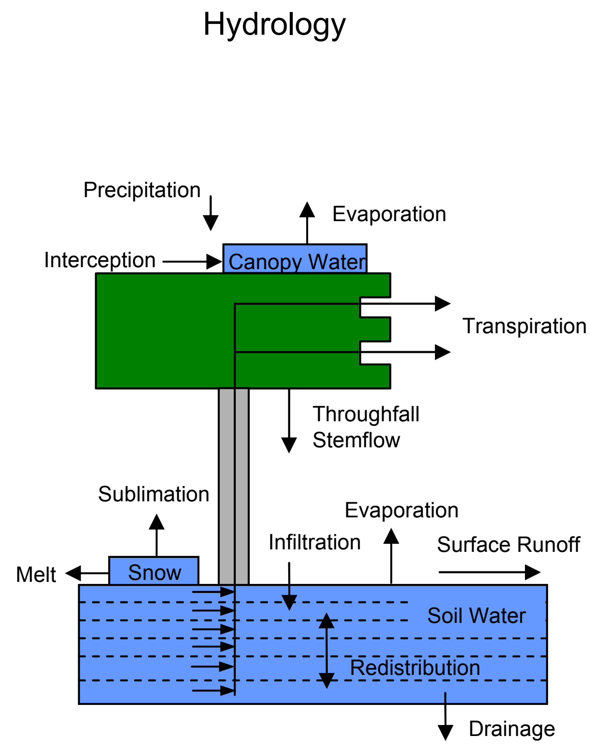
Andrea Sealy - land-atmosphere interactions and their impact on West African climate and adaptability of Caribbean islands to climate change
Howard Univ., atmospheric sciences

Sean Swenson - observations of the global water cycle and groundwater/surface water/climate interactions
Colorado, physics

Community Land Model

Hydrometeorology





<u>Community Land Model</u>

- Land model for Community Climate System Model
- Developed by the CCSM Land Model Working Group in partnership with university and government laboratory collaborators

Bonan et al. (2002) J Climate 15:3123-3149
Oleson et al. (2004) NCAR/TN-461+STR
Dickinson et al. (2006) J Climate 19:2302-2324
Oleson et al. (2008) JGR-Biogeosciences, in press
Stöckli et al. (2008) JGR-Biogeosciences, in press

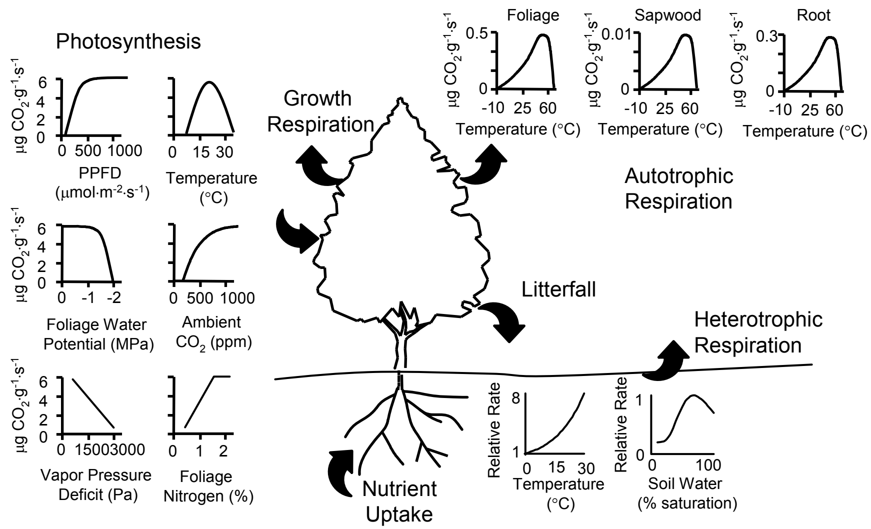
Energy fluxes: radiative transfer; turbulent fluxes (sensible, latent heat); heat storage in soil; snow melt

Hydrologic cycle: interception of water by leaves; infiltration and runoff; snow accumulation and melt; multi-layer soil water; partitioning of latent heat into evaporation of intercepted water, soil evaporation, and transpiration

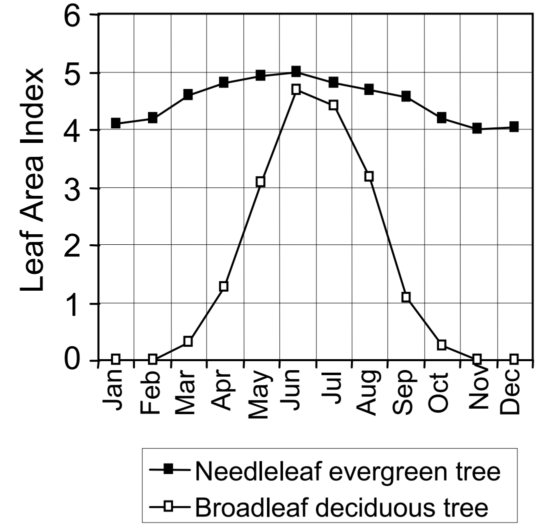
Community Land Model

Carbon cycle and dynamic vegetation

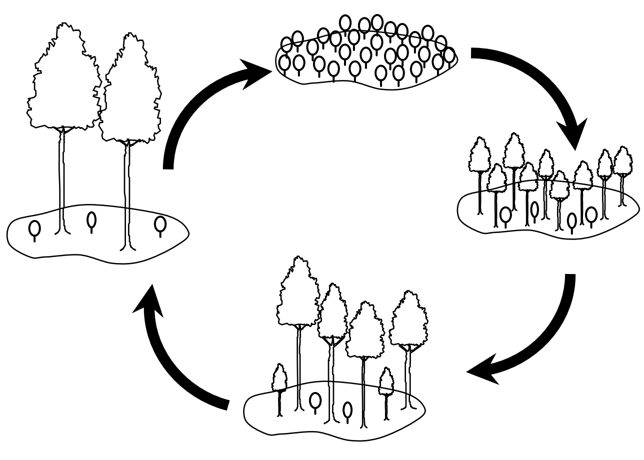
Ecosystem carbon balance



Leaf phenology



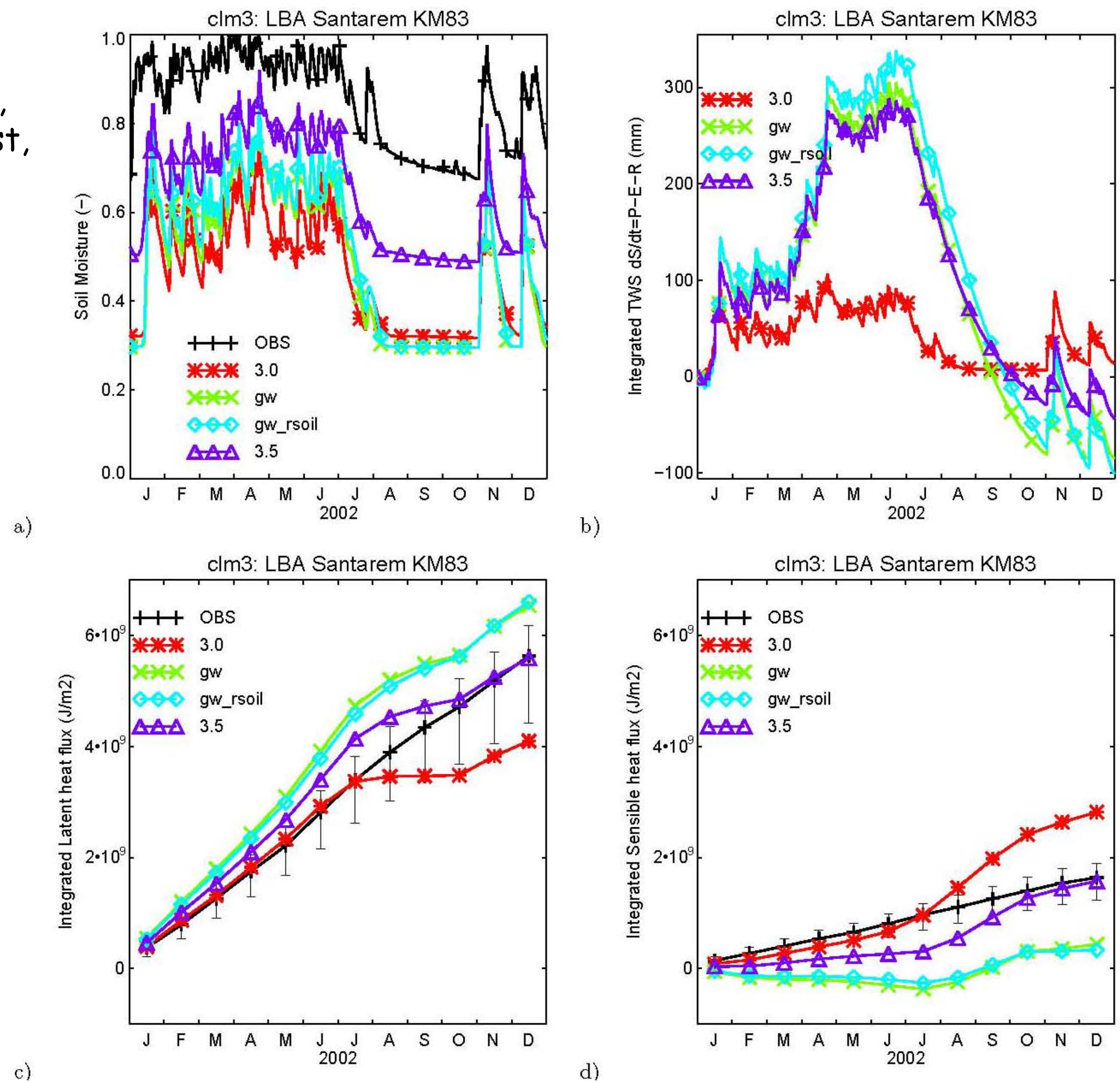
Vegetation dynamics



Bonan et al. (2003) Global Change Biology 9:1543-1566
Levis et al. (2004) NCAR/TN-459+IA

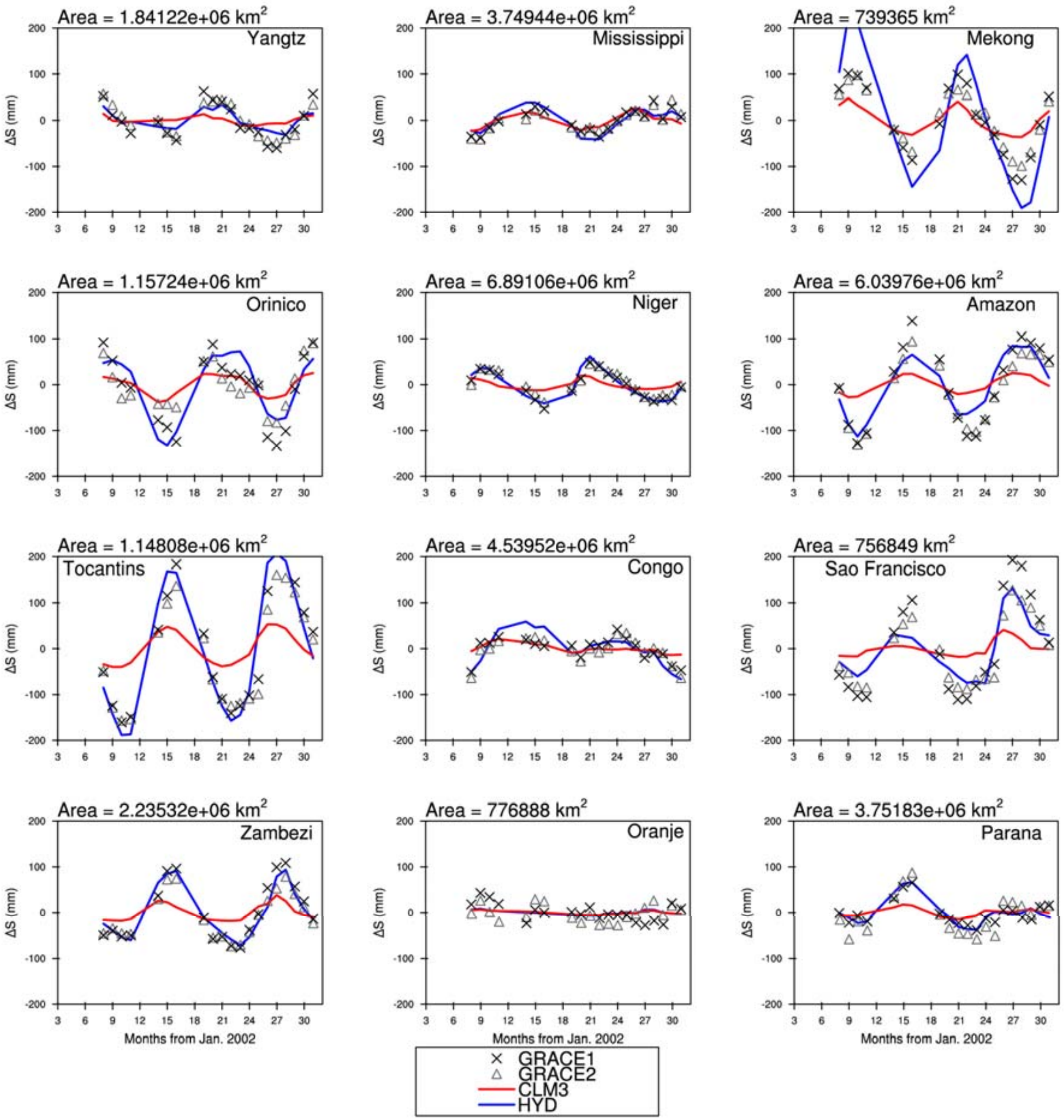
Hydrometeorology

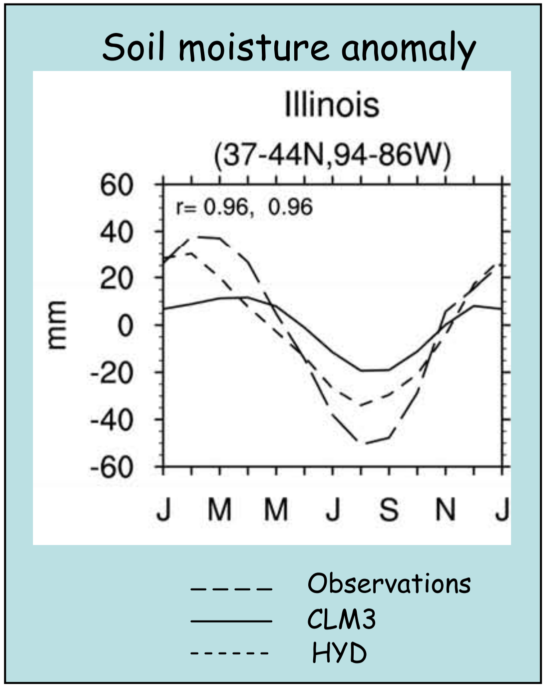
Flux tower observations, tropical evergreen forest, Brazil



Stöckli et al. (2008) JGR-Biogeosciences, in press

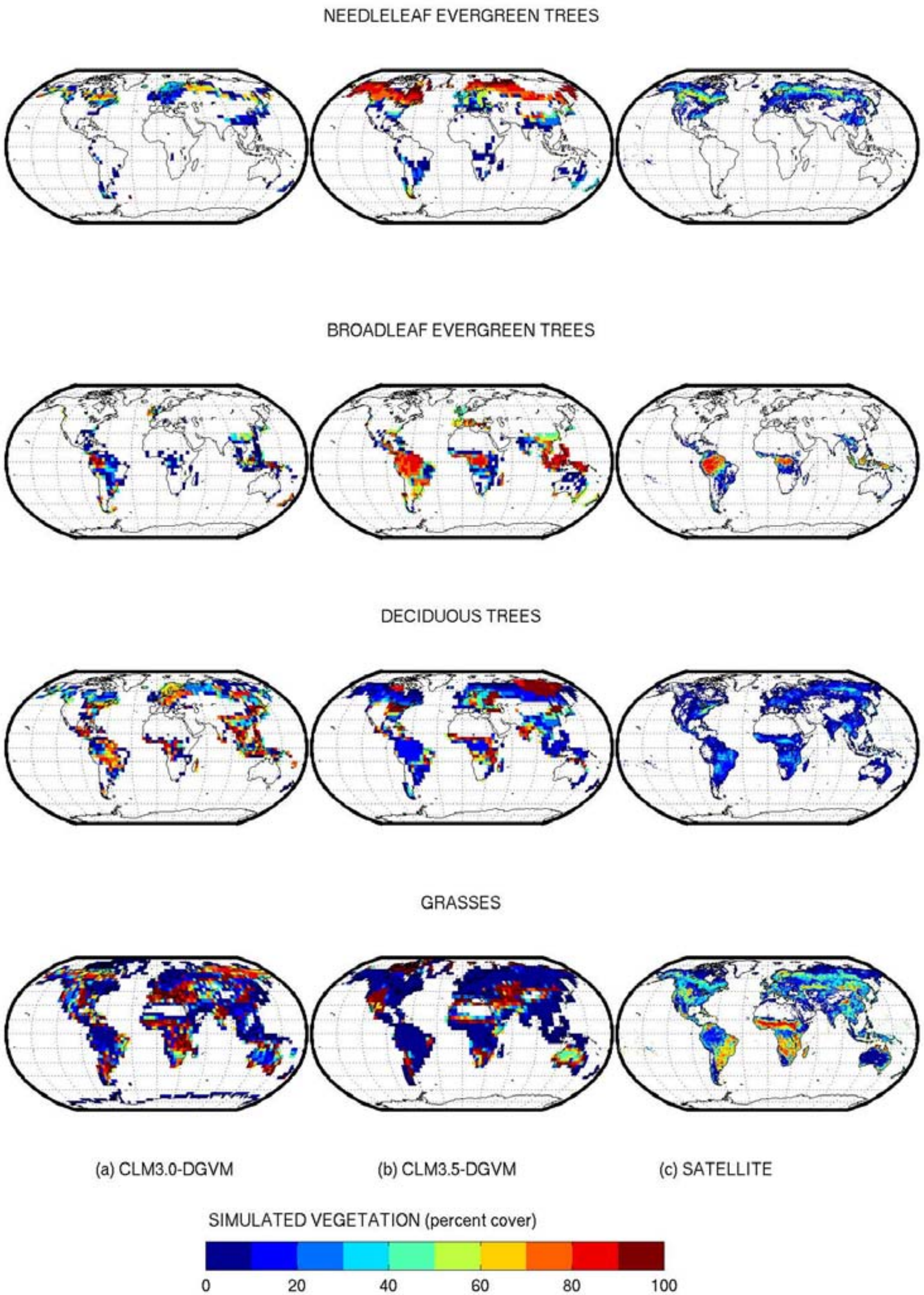
Hydrologic cycle

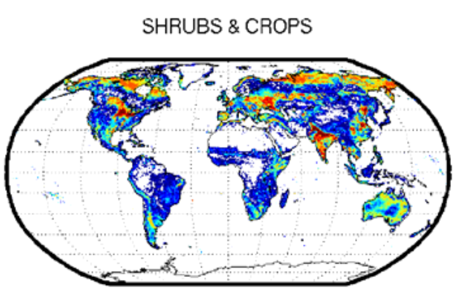




Oleson et al. (2008) JGR-Biogeosciences, in press

Global vegetation



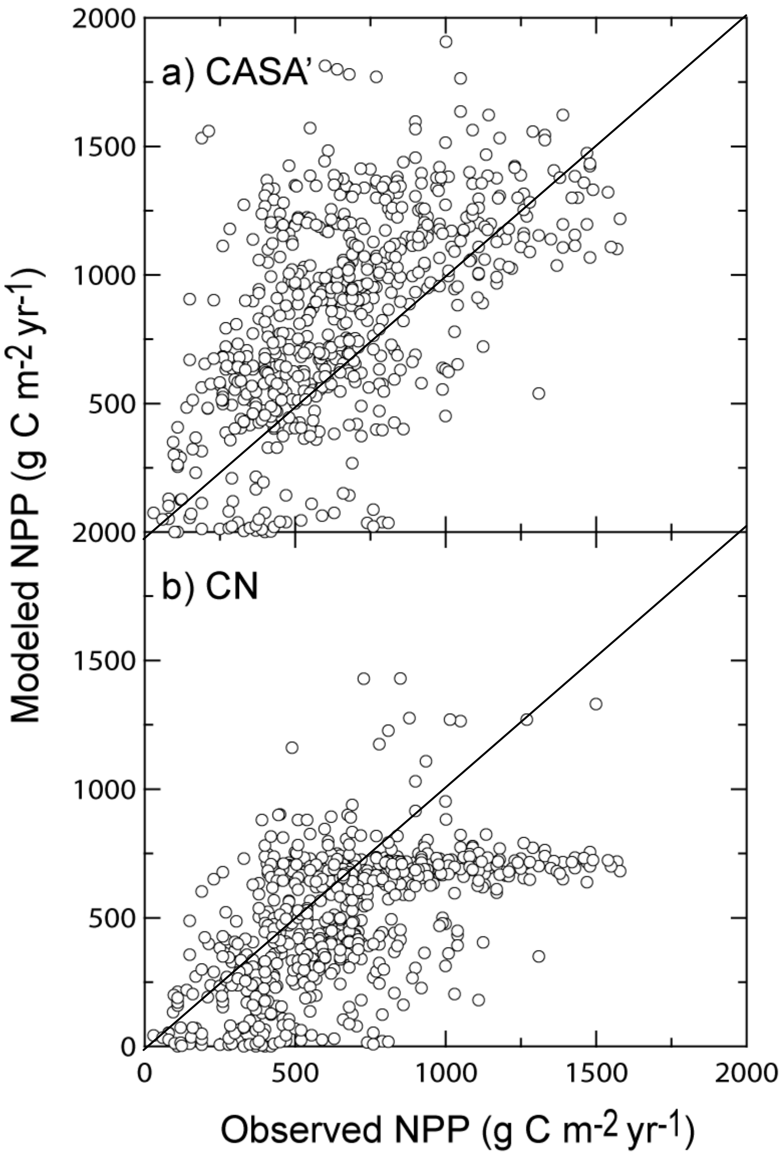


Oleson et al. (2008) JGR-Biogeosciences, in press

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., BGCWG, unpublished

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**

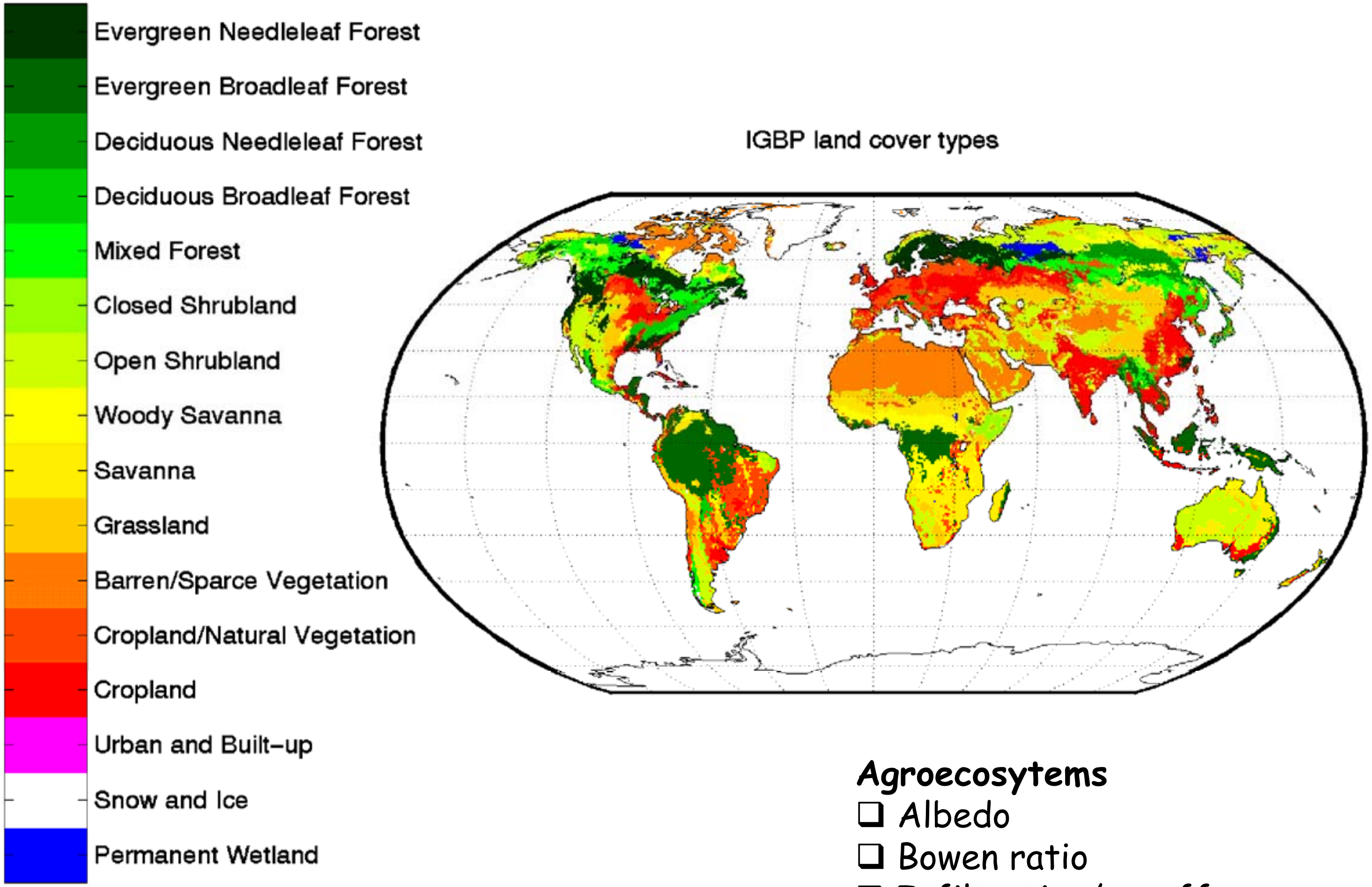
Observed NPP increase (376 -> 550ppm): 23%
CN predicted (376 -> 550ppm): 14%
CASA′ predicted (376 -> 550ppm): 21%

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

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

Randerson et al., BGCWG, unpublished

Anthropogenic land cover change



Land cover change occurs from human uses of land

Agroecosytems

- ❑ Albedo
- ❑ Bowen ratio
- ❑ Infiltration/runoff
- ❑ Soil water holding capacity
- ❑ Atmospheric CO_2
- ❑ Nitrogen cycle
- ❑ Dust

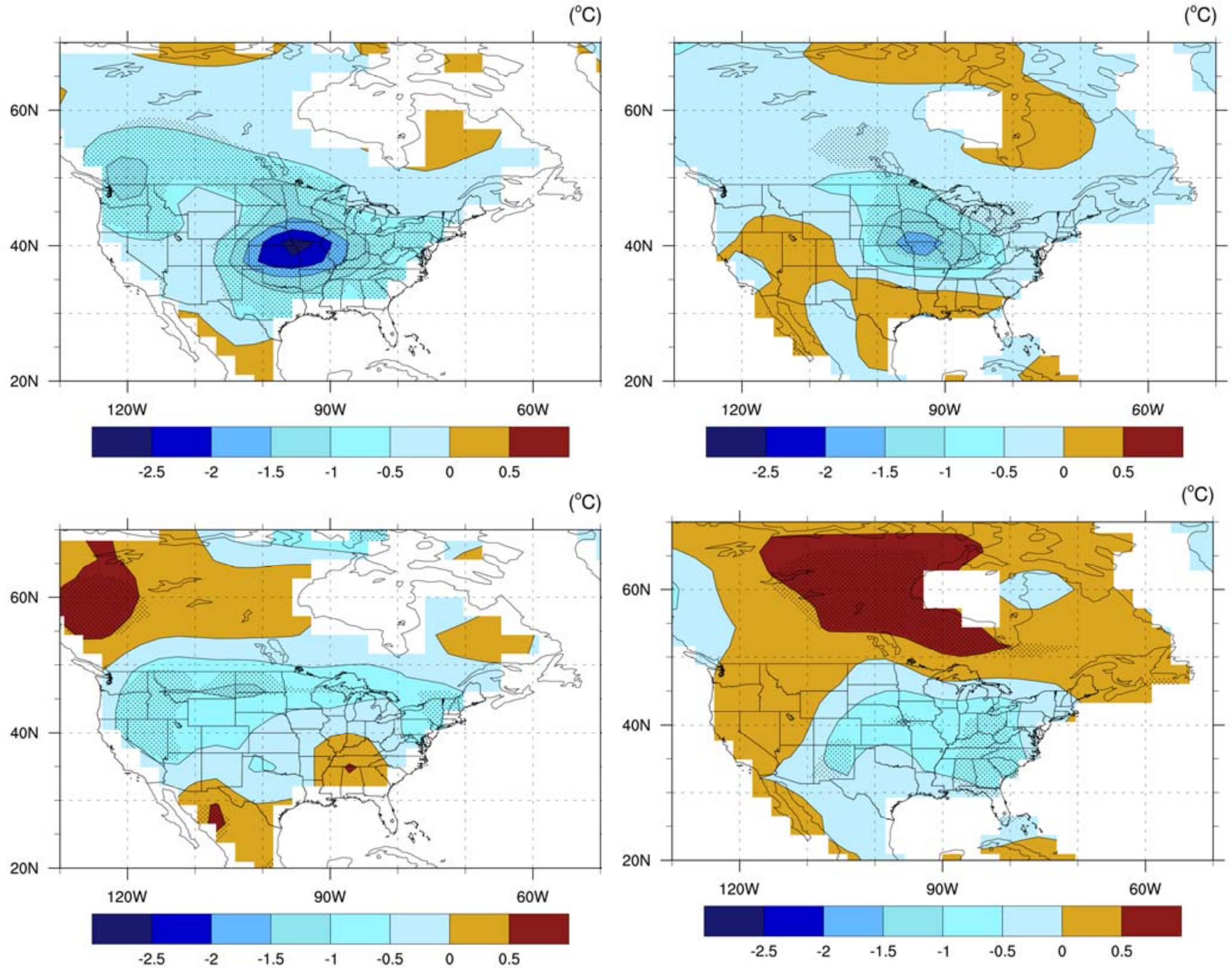
U.S. deforestation

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

LSM Biome Dataset | PFT Dataset

NCAR LSM

CLM2



Four paired climate simulations with CAM2 using two land surface models

- NCAR LSM
- CLM2

and two surface datasets

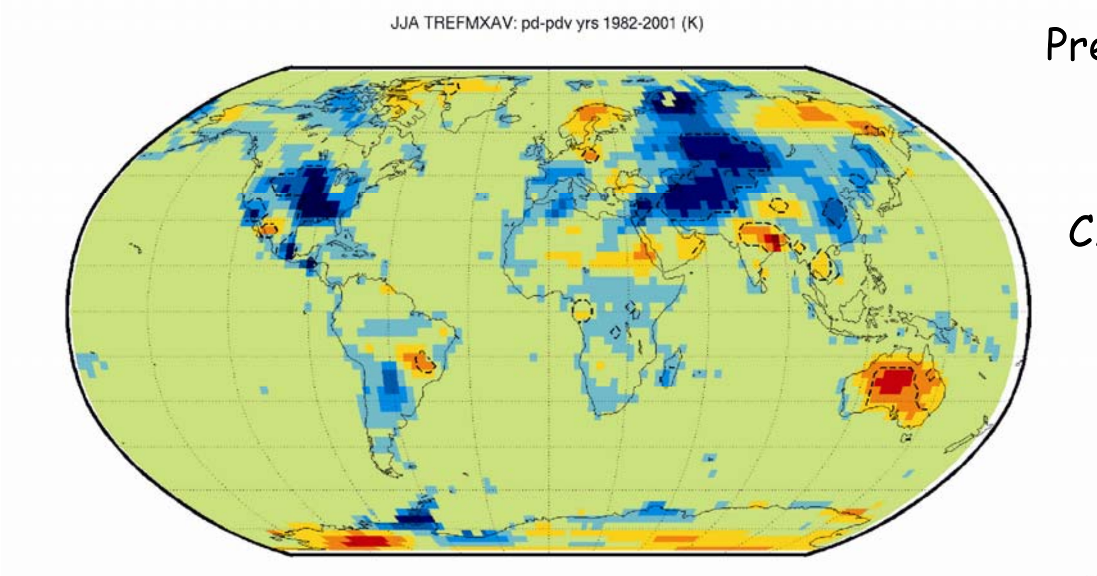
- Biome dataset without subgrid heterogeneity
- Dataset of plant functional types with subgrid heterogeneity

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

Oleson et al. (2004) Climate Dynamics 23:117-132

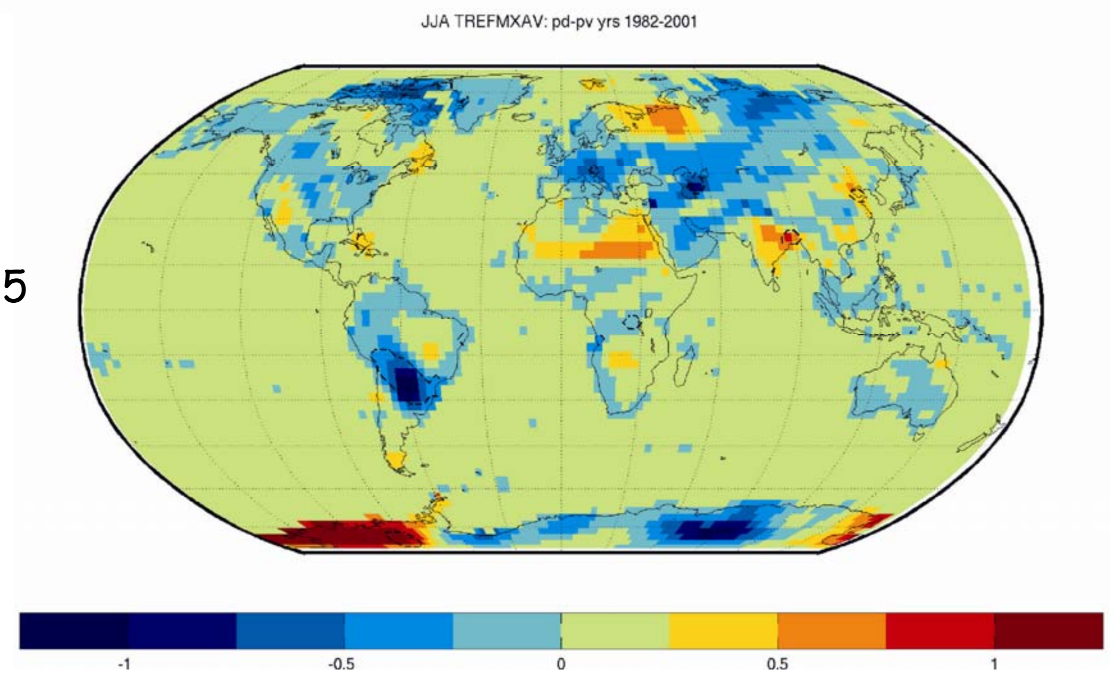
Sensitivity to atmospheric model

Present-day - potential vegetation



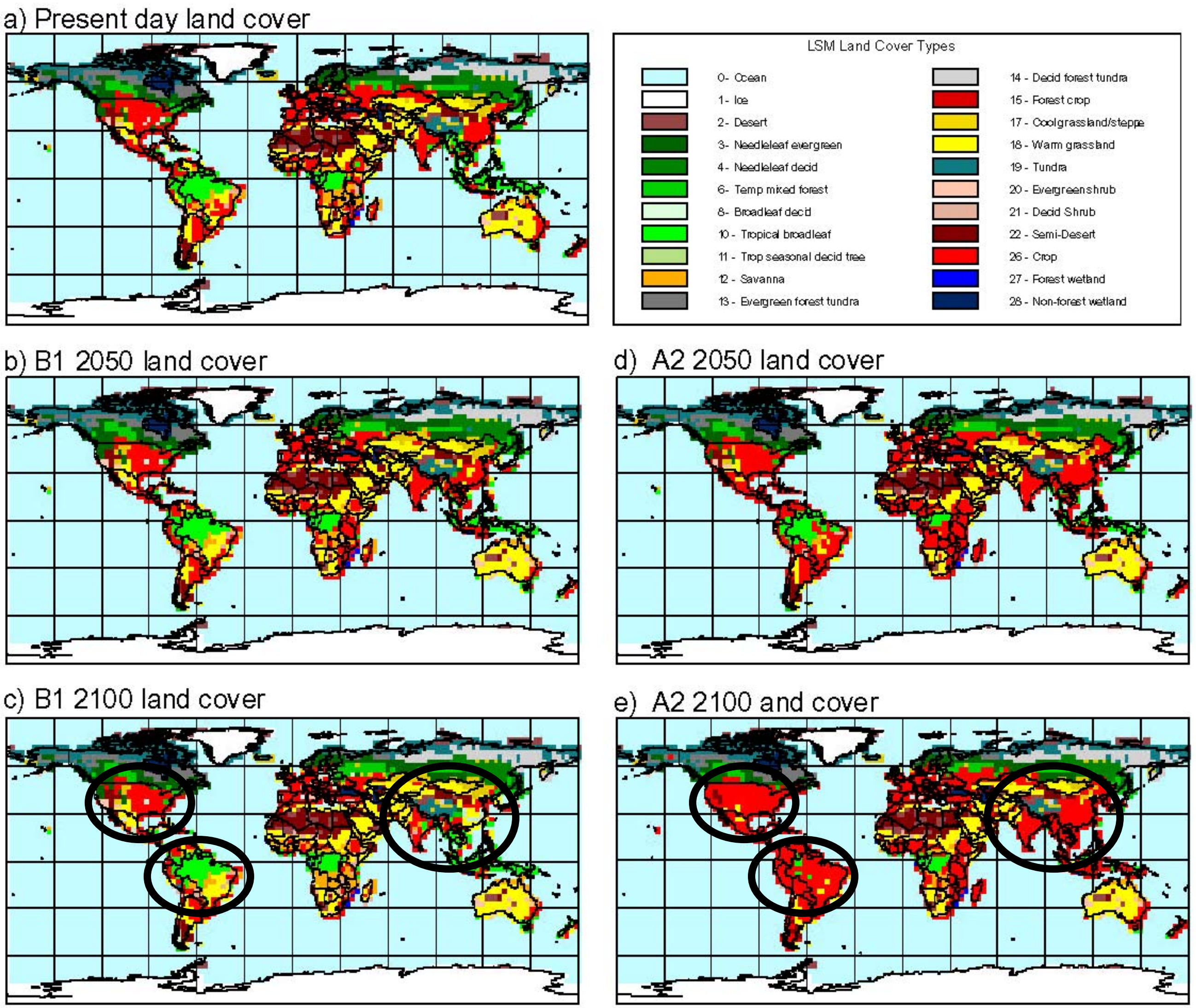
CAM3/CLM3.5

CAM3.5/CLM3.5



Future land cover change as a climate forcing

Future IPCC SRES Land Cover Scenarios for NCAR LSM/PCM

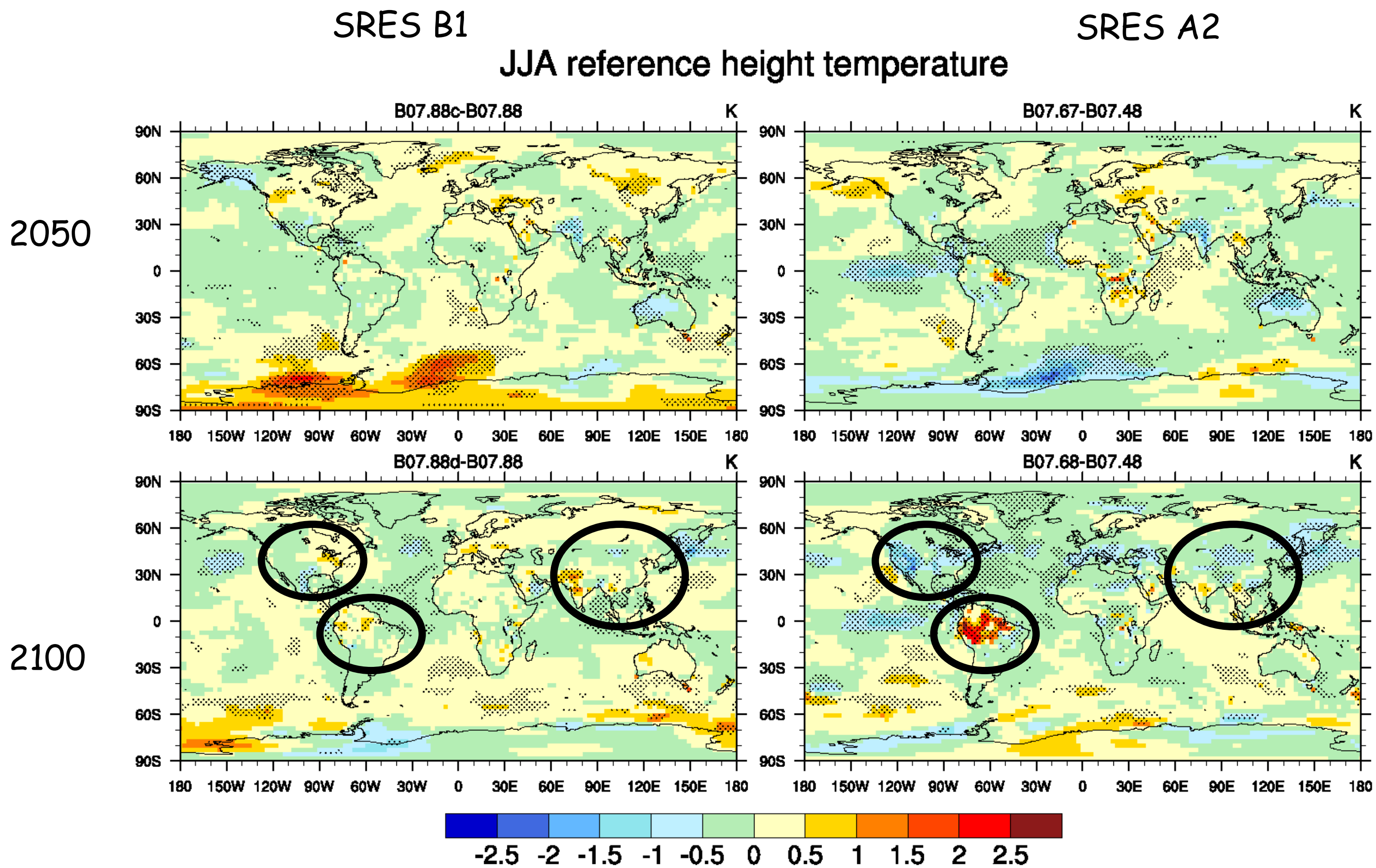


A2 – Widespread agricultural expansion with most land suitable for agriculture used for farming by 2100 to support a large global population

B1 - Loss of farmland and net reforestation due to declining global population and farm abandonment in the latter part of the century

Feddema et al. (2005) Science 310:1674-1678

Future land cover change as a climate forcing



Dominant forcing
Brazil – albedo, ET
U.S. – albedo
Asia - albedo

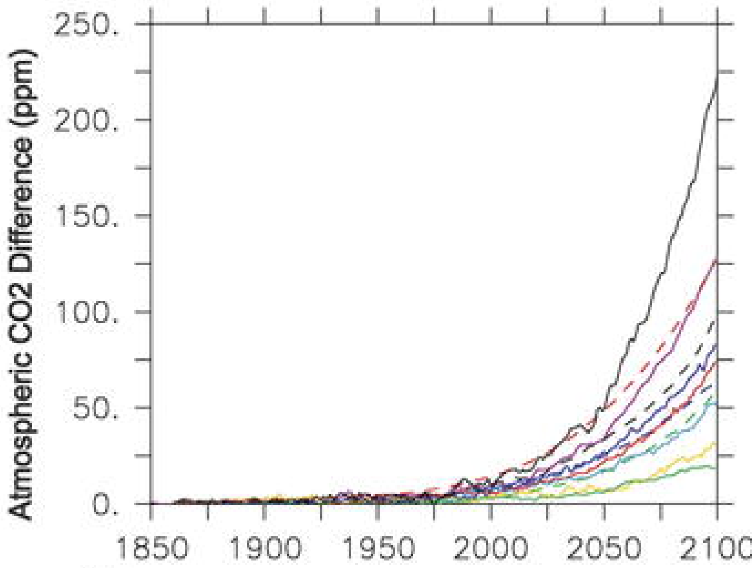
PCM/NCAR LSM transient climate simulations with changing land cover. Figures show the effect of land cover on temperature

(SRES land cover + SRES atmospheric forcing) - SRES atmospheric forcing

Feddema et al. (2005) Science 310:1674-1678

C4MIP – Climate and carbon cycle

Effect of climate change on carbon cycle

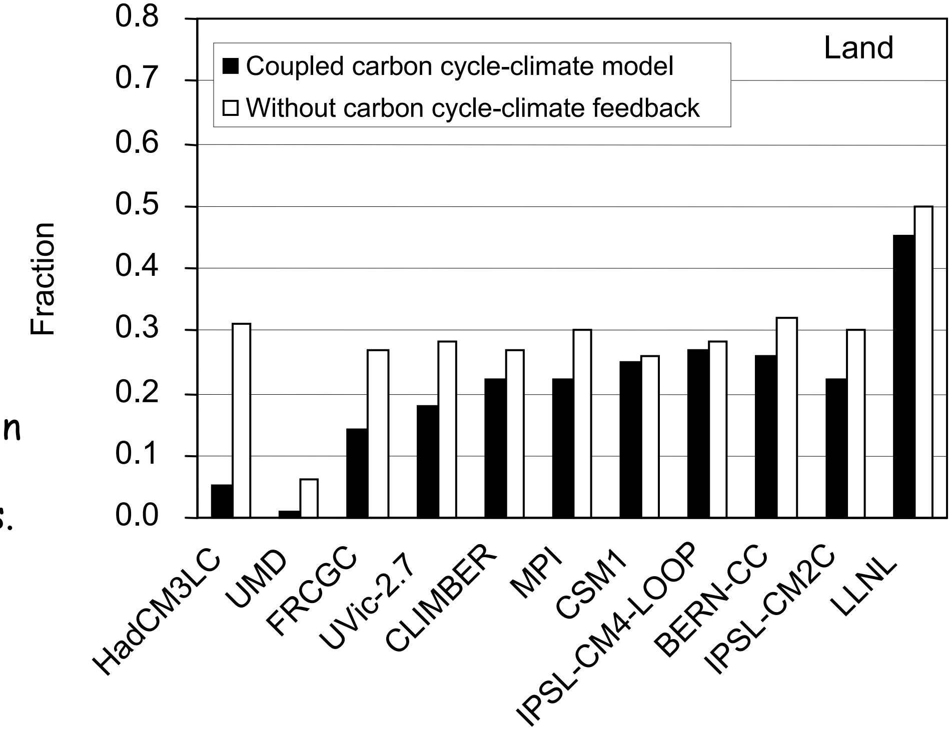


Climate-carbon cycle feedback

- All models have a positive climate-carbon cycle feedback
- The difference between fully coupled carbon cycle climate simulations and uncoupled simulations (CO_2 has no radiative effect) ranges from 20 ppm to 200 ppm

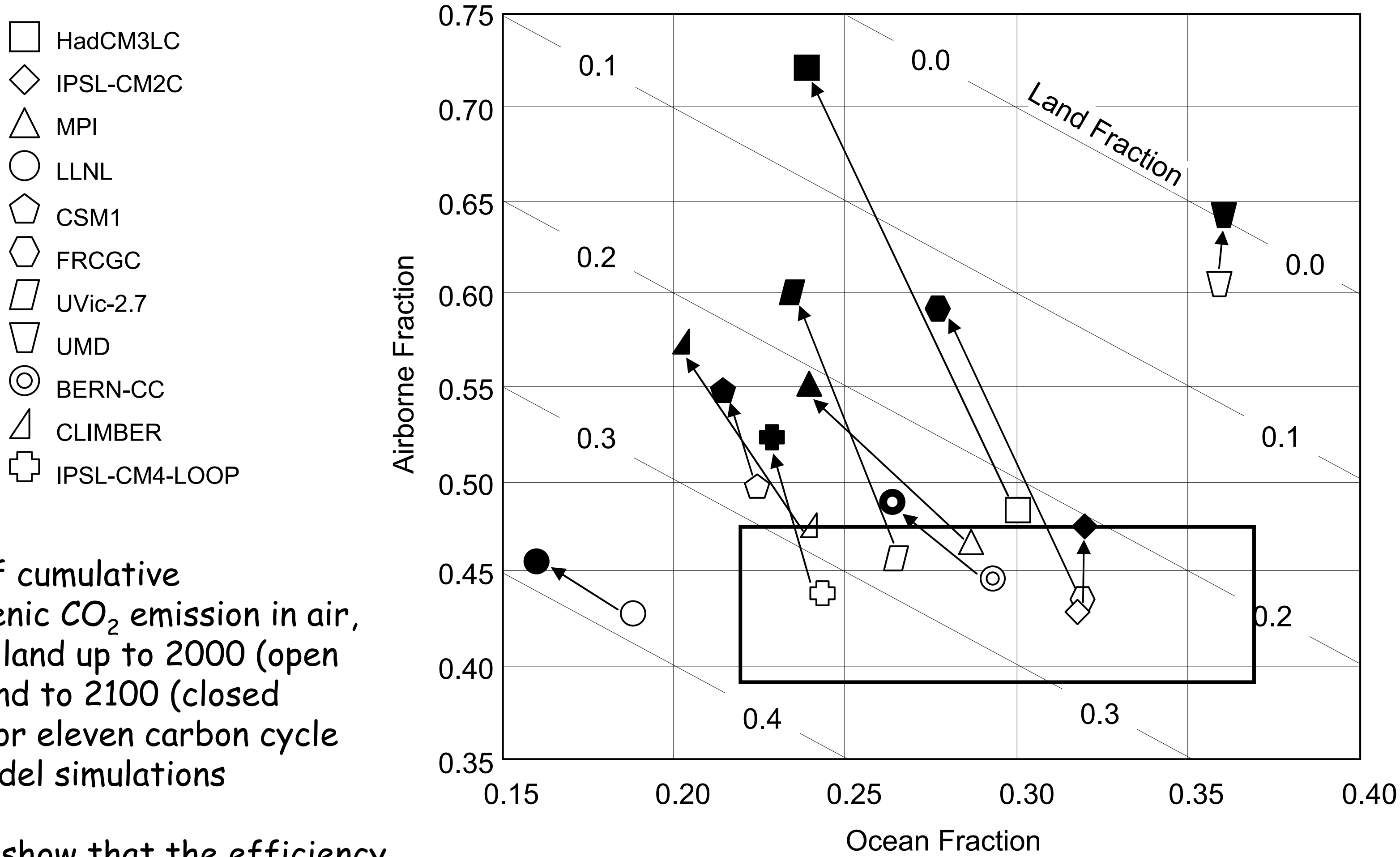
Distribution at 2100 of cumulative anthropogenic carbon emissions

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 Climate 19:3337-3353

C4MIP – Climate and carbon cycle



Fraction of cumulative anthropogenic CO_2 emission in air, ocean, and land up to 2000 (open symbols) and to 2100 (closed symbols) for eleven carbon cycle climate model simulations

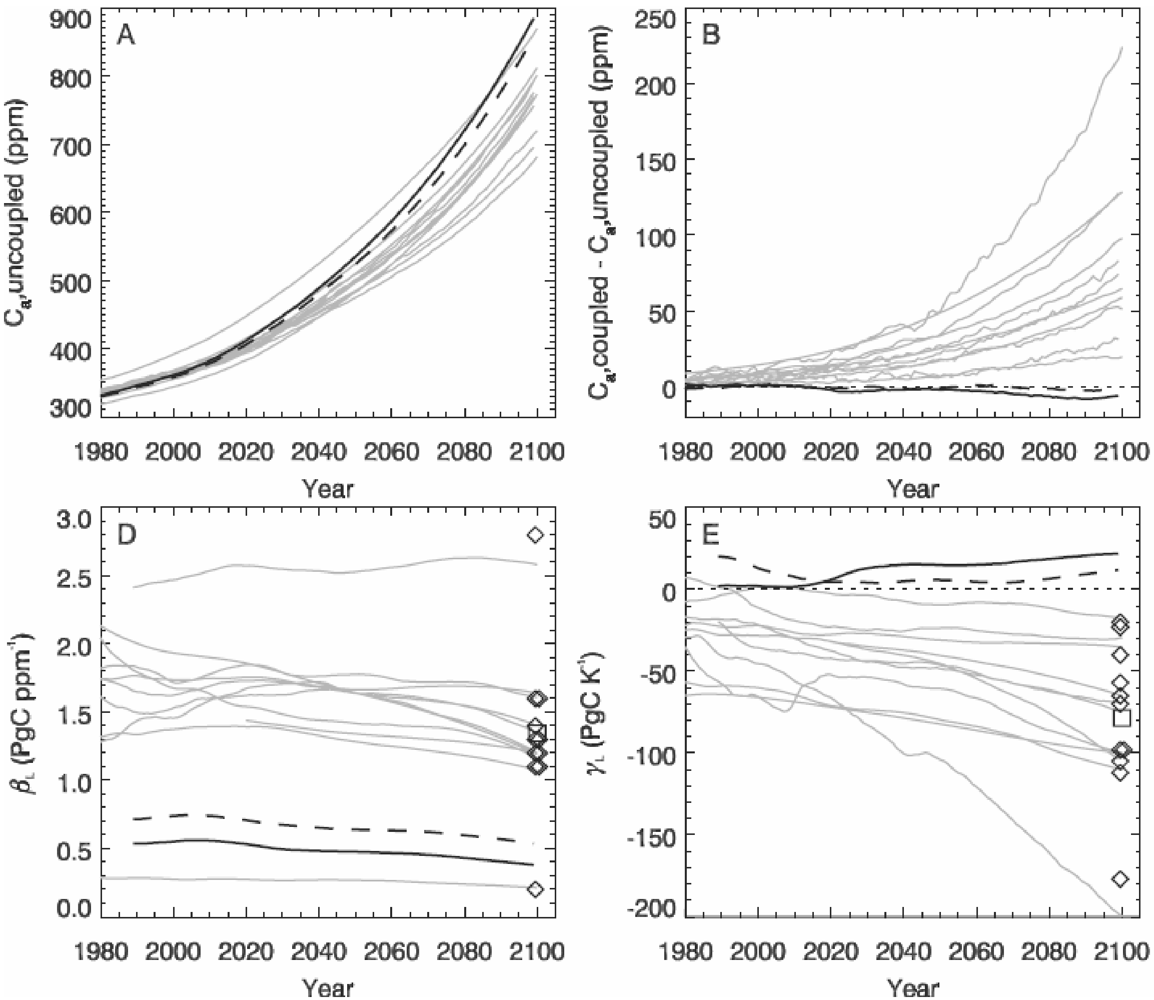
All models show that the efficiency of the carbon cycle to store anthropogenic CO_2 in ocean and land decreases in the future

Denman et al. (2007) in *Climate Change 2007: The Physical Science Basis*, Solomon et al., Eds., 499-587

Climate, carbon, and nitrogen cycle

Ca from uncoupled experiments

ΔCa due to radiative coupling



Land biosphere response to increasing atmospheric CO_2

Land biosphere response to increasing temperature

Panel A: Atmospheric CO_2 (Ca) of 884 ppm by 2100, radiatively-uncoupled

Panel B: Radiative coupling reduces Ca by 6 ppm, with a further reduction of 27 ppm due to anthropogenic N deposition

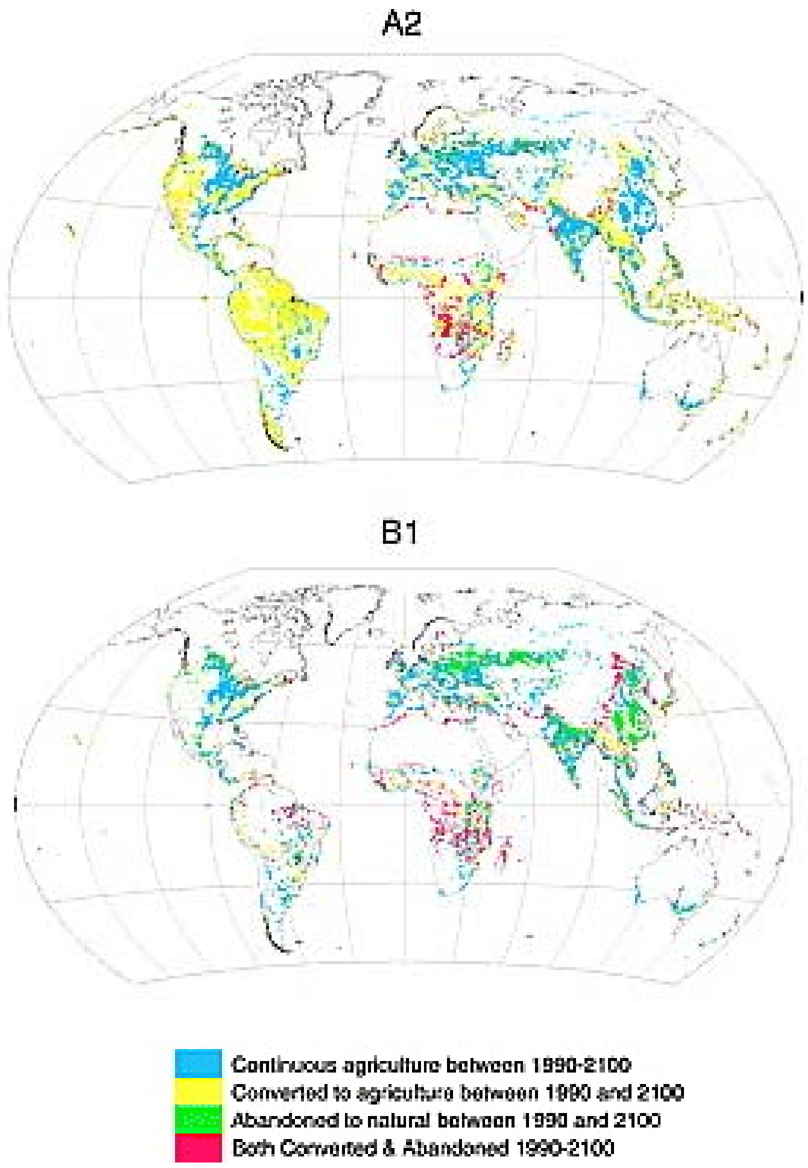
Gray lines show archived results from eleven previous studies

Thick solid line is for experiments with preindustrial N deposition

Thick dashed line for anthropogenic N deposition

Thornton et al., submitted

Future land cover change



A2 – Widespread agricultural expansion with most land suitable for agriculture used for farming by 2100 to support a large global population

B1 - Loss of farmland and net reforestation due to declining global population and farm abandonment in the latter part of the century

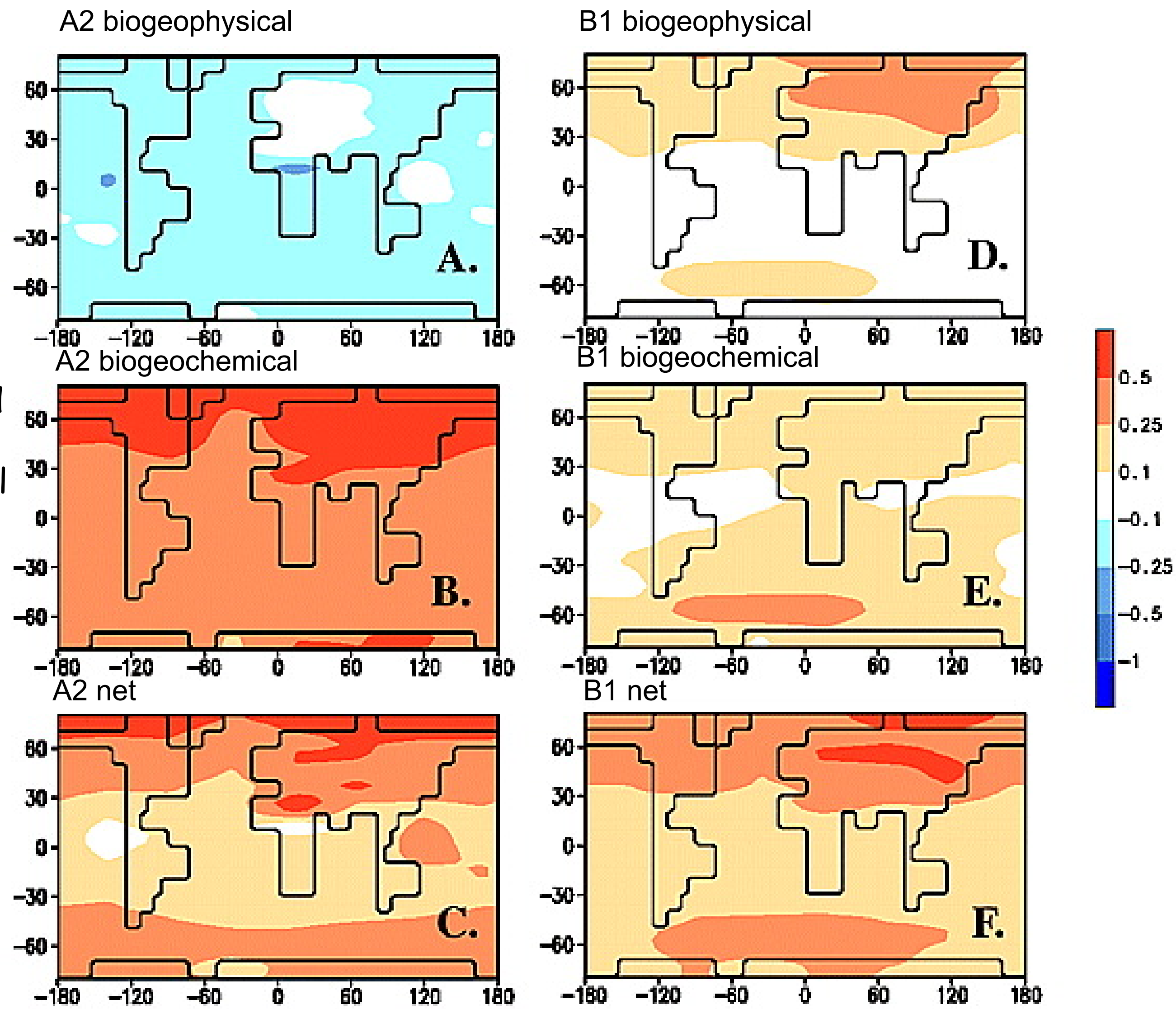
Sitch et al. (2005) GBC, 19, GB2013, doi:10.1029/2004GB002311

Future land cover change

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 similar
A2 – BGC warming offsets BGP cooling
B1 – moderate BGP warming augments weak BGC warming



Sitch et al. (2005) GBC, 19, GB2013, doi:10.1029/2004GB002311

Permissible anthropogenic CO_2 emissions

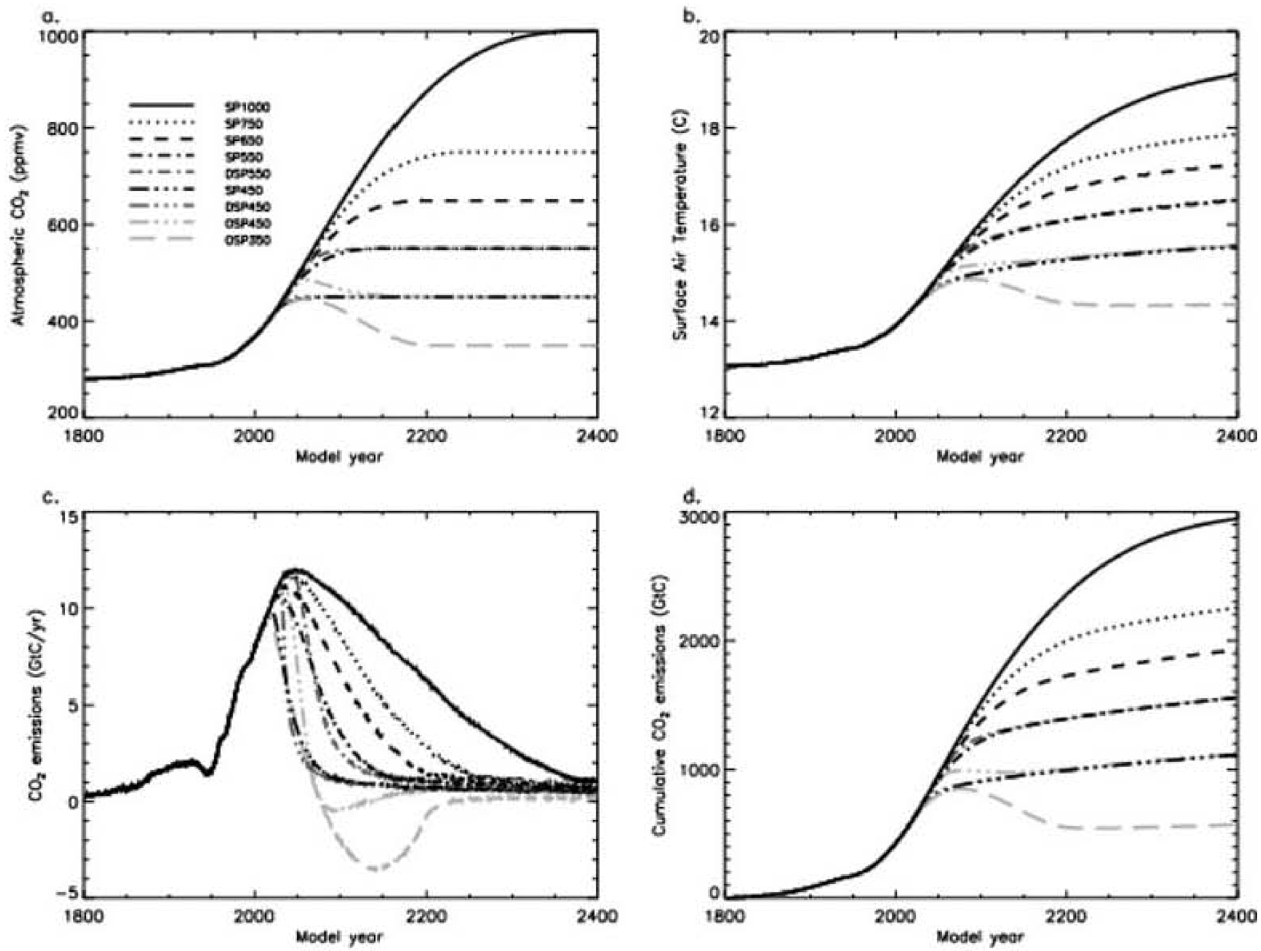


Fig. 1. Results from nine CO_2 stabilization scenario runs: (a) prescribed atmospheric CO_2; (b) modelled global mean surface air temperature; (c) calculated annual CO_2 emissions and (d) calculated cumulative CO_2 emissions.

Permissible anthropogenic CO_2 emissions to achieve a targeted atmospheric CO_2 are derived from specified atmospheric CO_2 concentration and simulated land and ocean carbon fluxes.

The positive carbon cycle-climate feedback reduces the ability of the biosphere to store anthropogenic carbon emissions and necessitates reductions in emissions to achieve stabilization goals.

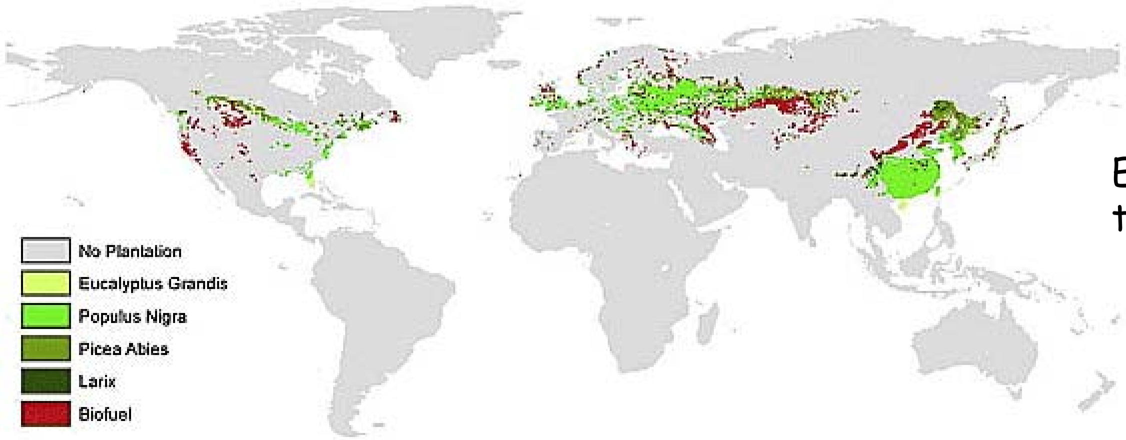
The CO_2 fertilization effect is particularly important as this increases the terrestrial carbon sink and allows high anthropogenic emissions.

Matthews (2006) Tellus 58B:591-602

Land management policies to mitigate climate change

Reforestation might be chosen as an option for the enhancement of terrestrial carbon sequestration or biofuel plantations as a substitute for fossil fuels

2100 land management, IPCC A1b scenario

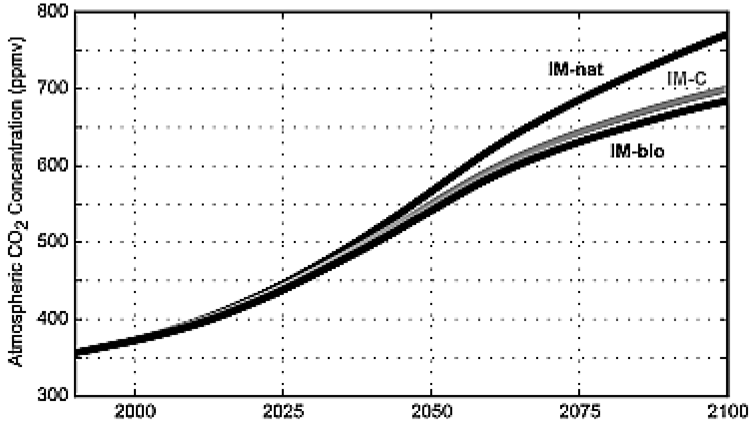


Excess agricultural land converted to carbon storage or biofuels

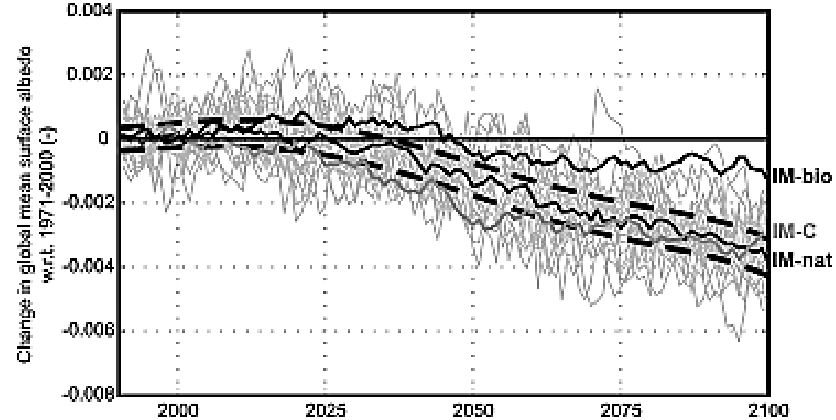
Green = carbon plantations
Green + red = biofuel plantations

Schaeffer et al. (2006) GBC, 20, GB2020, doi:10.1029/2005GB002581

Land management policies to mitigate climate change



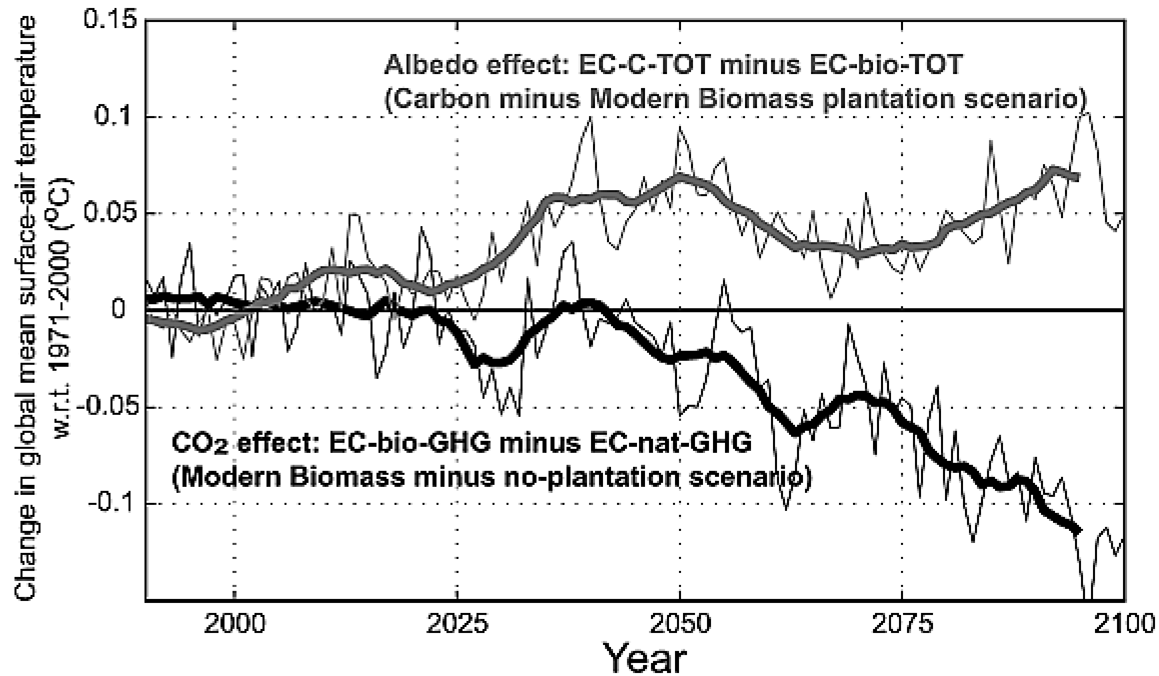
Carbon plantations (IM-C) and biofuels (IM-bio) reduce CO_2 by 70-80 ppm



Natural vegetation (IM-nat) and carbon plantations (IM-C) have lower albedo than biofuels (IM-bio)

Carbon plantations and biofuel plantations reduce atmospheric CO_2, leading to cooling.

Carbon plantations have lower albedo than biofuels, leading to warming

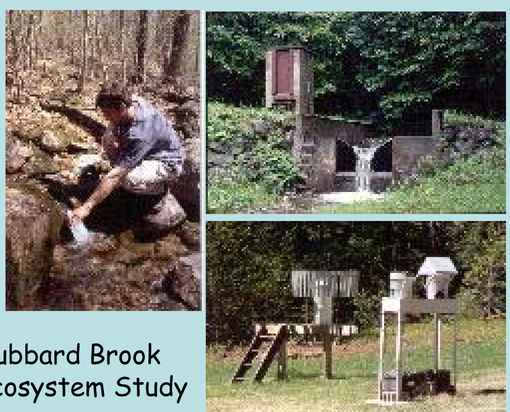


Schaeffer et al. (2006) GBC, 20, GB2020, doi:10.1029/2005GB002581

How to integrate ecological studies with earth system models?

Environmental Monitoring

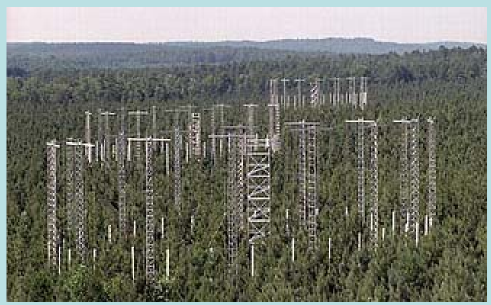
Eddy covariance flux tower
(courtesy Dennis Baldocchi)



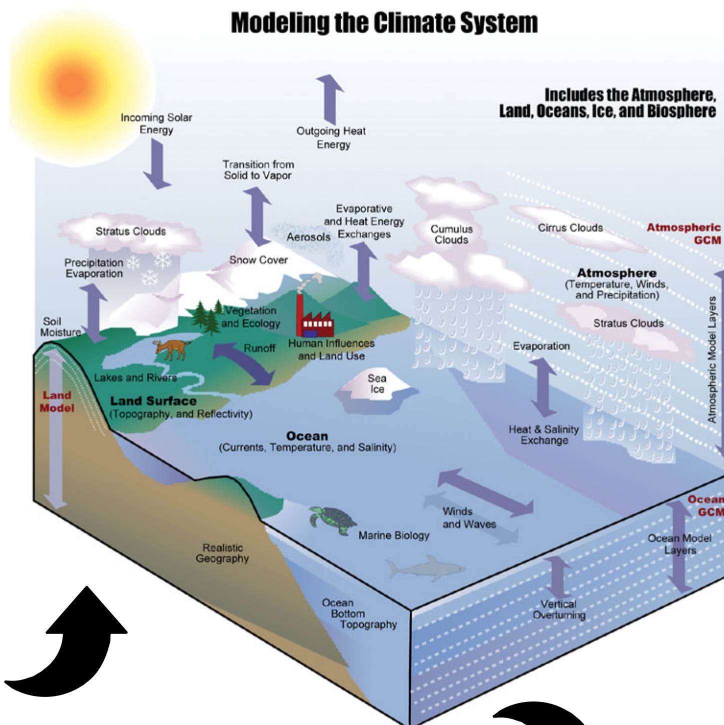
Hubbard Brook
Ecosystem Study

Experimental Manipulation

Soil warming, Harvard Forest



CO_2 enrichment, Duke Forest



Planetary energetics
Planetary ecology
Planetary metabolism

Ecology or climatology

Climatic Interpretation

Lamb (1977) Climate: Present, Past and Future. Volume 2, Climatic History and the Future

Lamb (1995) Climate, History and the Modern World

• Painted in the winter of 1565
• Records Bruegel's impression of severe winter
• Start of a long interest in Dutch winter landscapes that coincided with an extended period of colder than usual winters

Ecological Interpretation

Forman & Godron (1986) Landscape Ecology

Defines ecological concept of a landscape
• heterogeneity of landscape elements
• spatial scale
• movement across the landscape

Pieter Bruegel the Elder's "Hunters in the Snow"

Bonan (2008) Ecological Climatology. 2nd edition (Cambridge Univ. Press)