CCSM Community Land Model Development for IPCC AR5

Gordon Bonan
National Center for Atmospheric Research
Boulder, Colorado

National Center for
Atmospheric Research
Boulder, Colorado

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

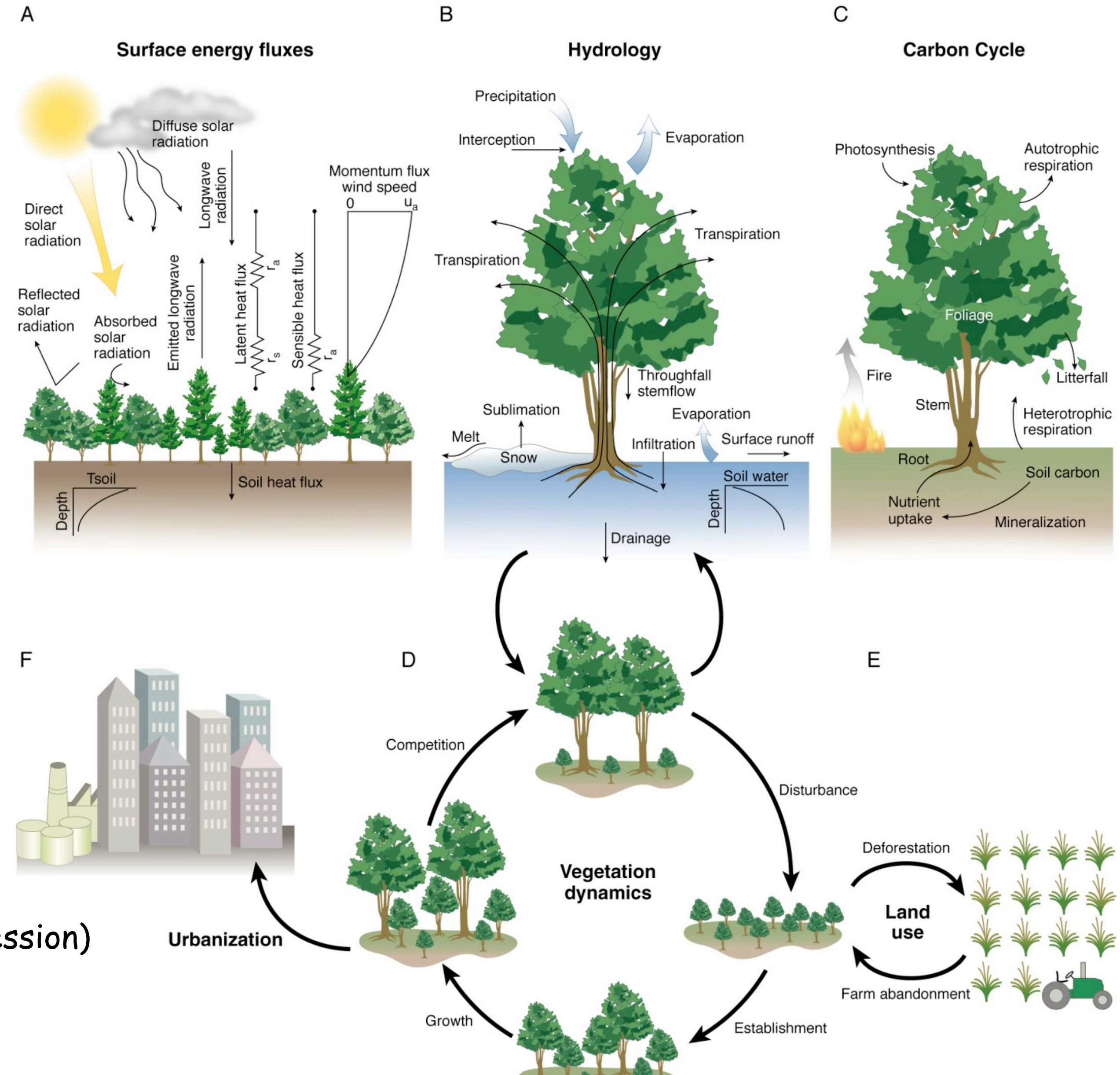
Oleson et al. (2008) JGR, 113, doi: 10.1029/2007JG000563

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

Spatial scale
2.5° longitude × 1.875° latitude

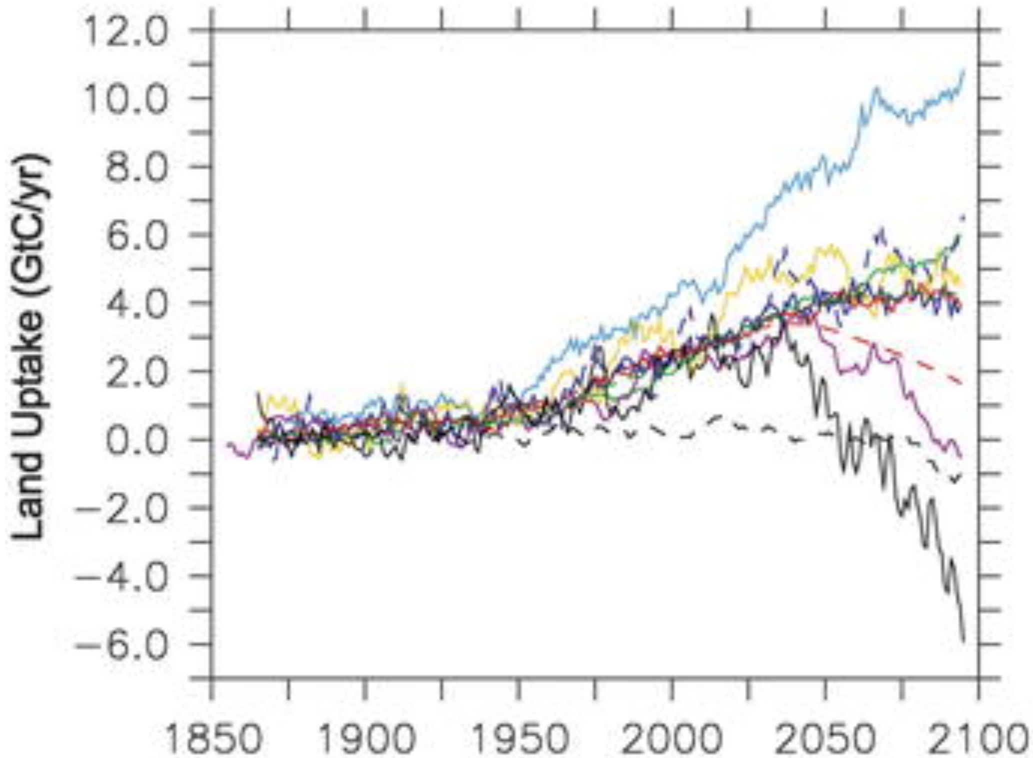
Temporal scale

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



Bonan (2008) Science 320:1444-1449

C4MIP – Climate and carbon cycle



Eleven carbon cycle-climate models of varying complexity

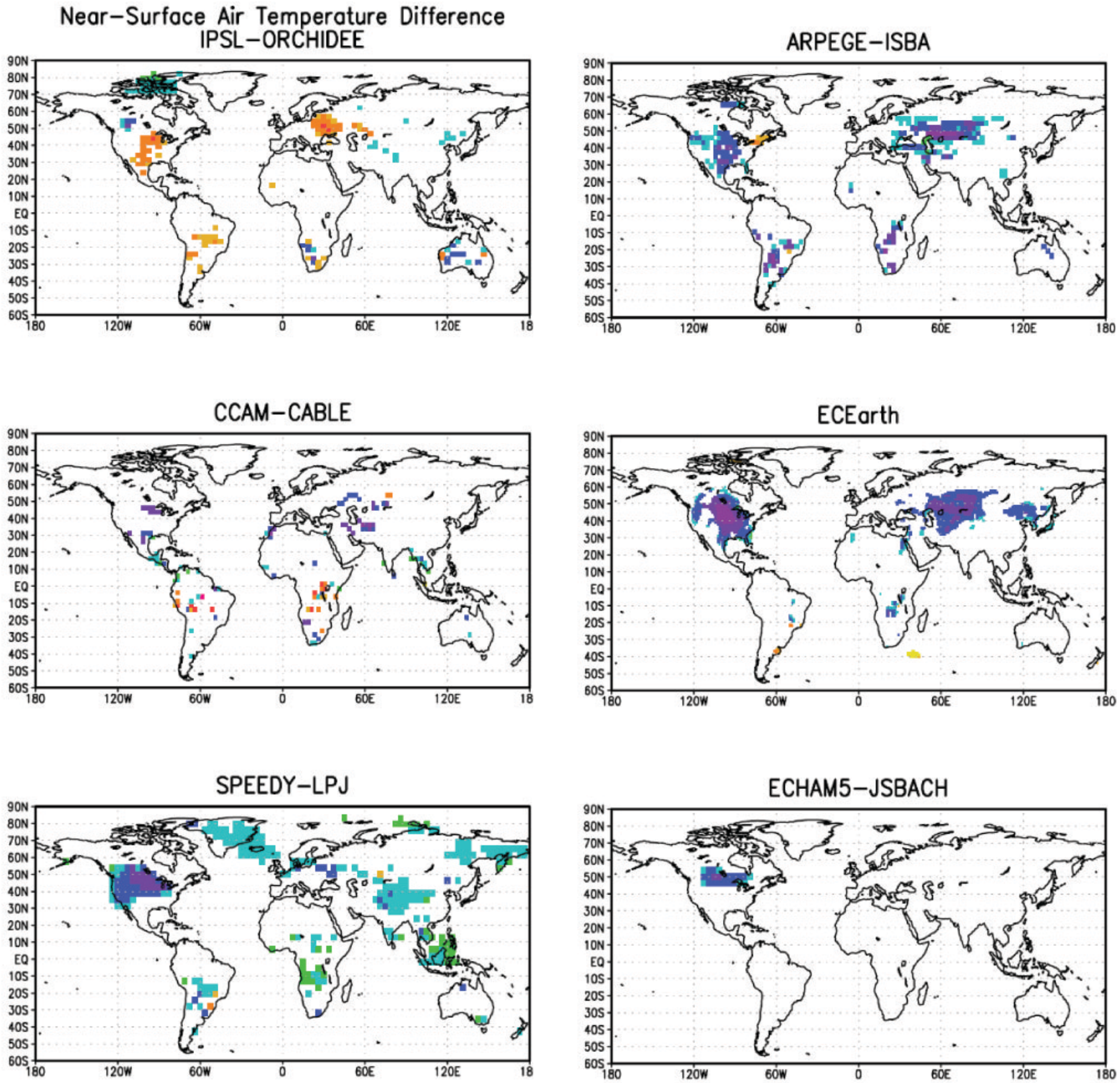
Large uncertainty in terrestrial flux at year 2100 ranging from a 6 Gt C/yr source of carbon from land to an 11 Gt C/yr terrestrial carbon sink

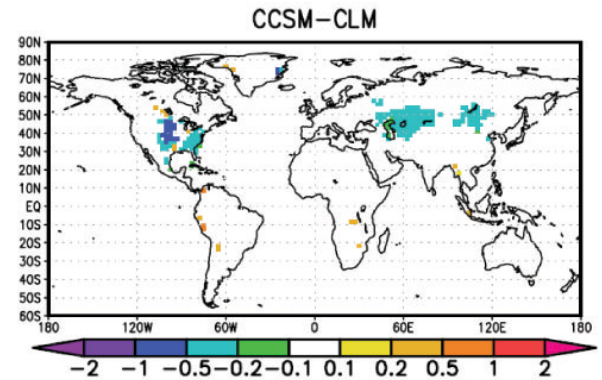
Friedlingstein et al. (2006) J Climate 19:3337–3353

National Center for
Atmospheric Research
Boulder, Colorado

The LUCID intercomparison study

Change in JJA near-surface air temperature (1992 – 1870)



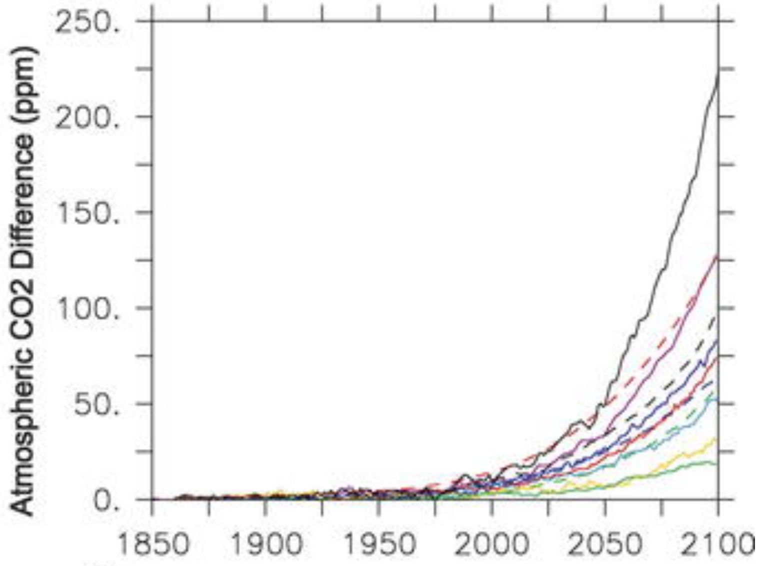


Seven climate models of varying complexity with imposed land cover change (1992-1870)

Pitman et al. (2009) GRL, 36, L14814, doi:10.1029/2009GL039076

Climate and carbon cycle

Effect of climate change on carbon cycle



Friedlingstein et al. (2006) J Climate 19:3337-3353

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

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

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

N fertilization

Carbon cycle-climate feedback in response to increasing atmospheric CO_2 and warming, with and without nitrogen

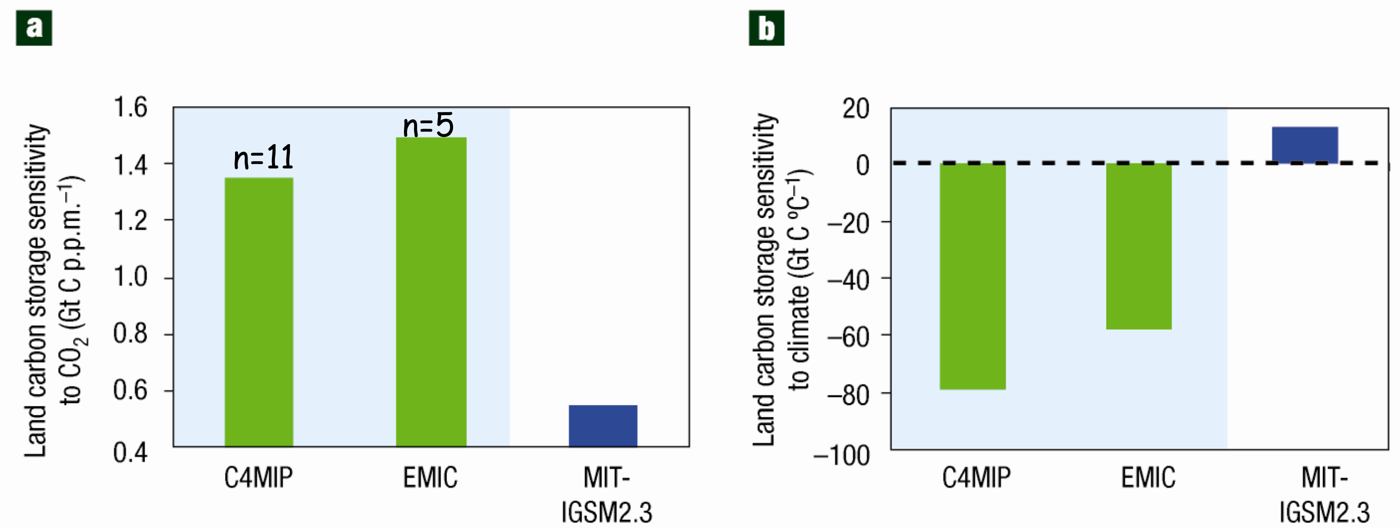


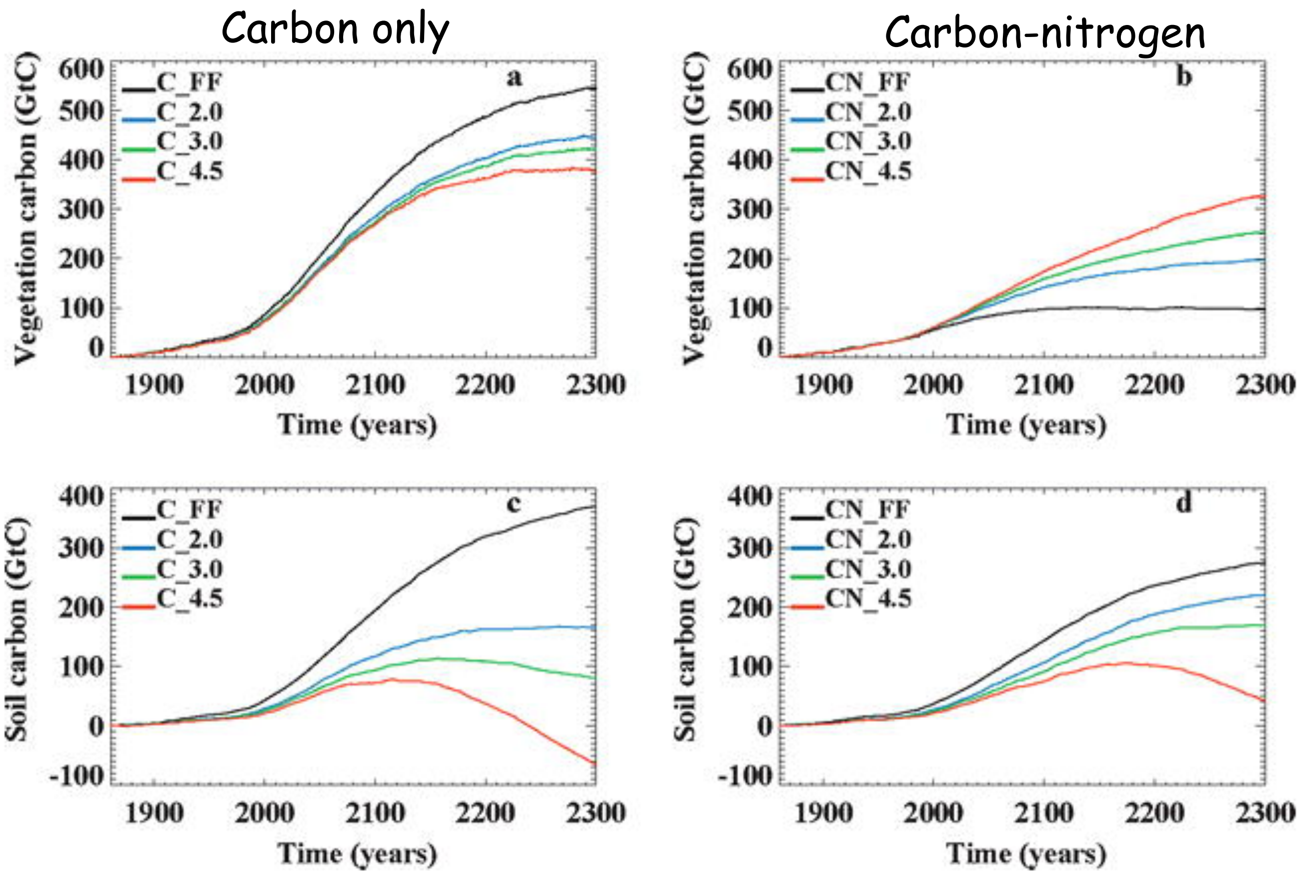
Figure from Bonan (2008) Nature Geoscience 1:645-646

Carbon-nitrogen interactions significantly reduce net terrestrial carbon uptake, even though, at least for small to moderate climate warming, enhanced nitrogen availability stimulates plant growth and changes the sign of the carbon cycle-climate feedback from positive to negative

Sokolov et al. (2008) J Climate 21:3776-3796

National Center for
Atmospheric Research
Boulder, Colorado

N fertilization



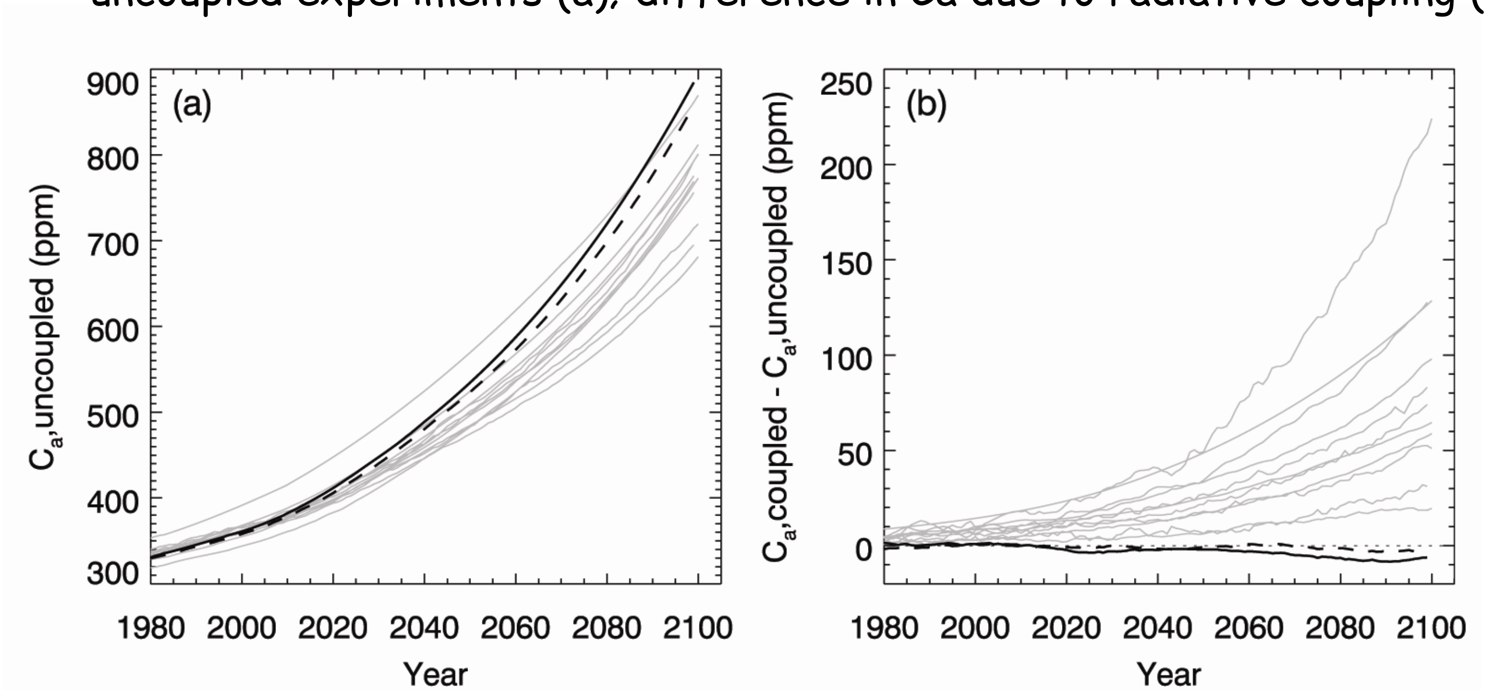
- Nitrogen limitation reduces the CO_2 fertilization effect
- Greater N mineralization with warming stimulates plant growth
- Overall, terrestrial carbon sequestration is reduced, but climate warming increases carbon sequestration in a negative, rather than a positive feedback

Sokolov et al. (2008) J Climate 21:3776-3796

National Center for
Atmospheric Research
Boulder, Colorado

CCSM3.1 carbon cycle-climate feedback

Predicted atmospheric CO_2 and climate-carbon cycle feedback: Ca from uncoupled experiments (a); difference in Ca due to radiative coupling (b)



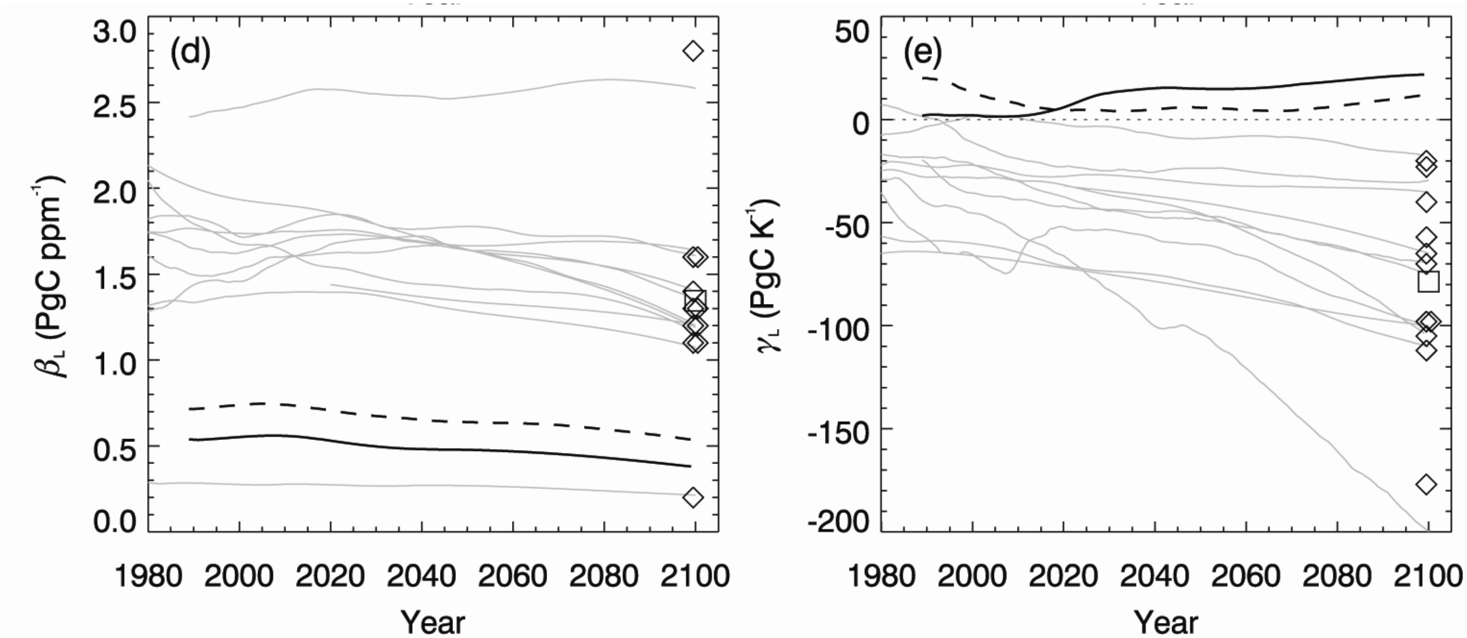
Thick solid line is with preindustrial nitrogen deposition
Thick dashed line is with anthropogenic nitrogen deposition
Thin gray lines are C4MIP models (Friedlingstein et al. 2006)

Inclusion of N cycle – High atmospheric CO_2 and introduces a negative carbon cycle-climate feedback

Thornton et al. (2009) Biogeosciences Discuss., 6, 3303-3354

National Center for
Atmospheric Research
Boulder, Colorado

CCSM3.1 carbon cycle-climate feedback



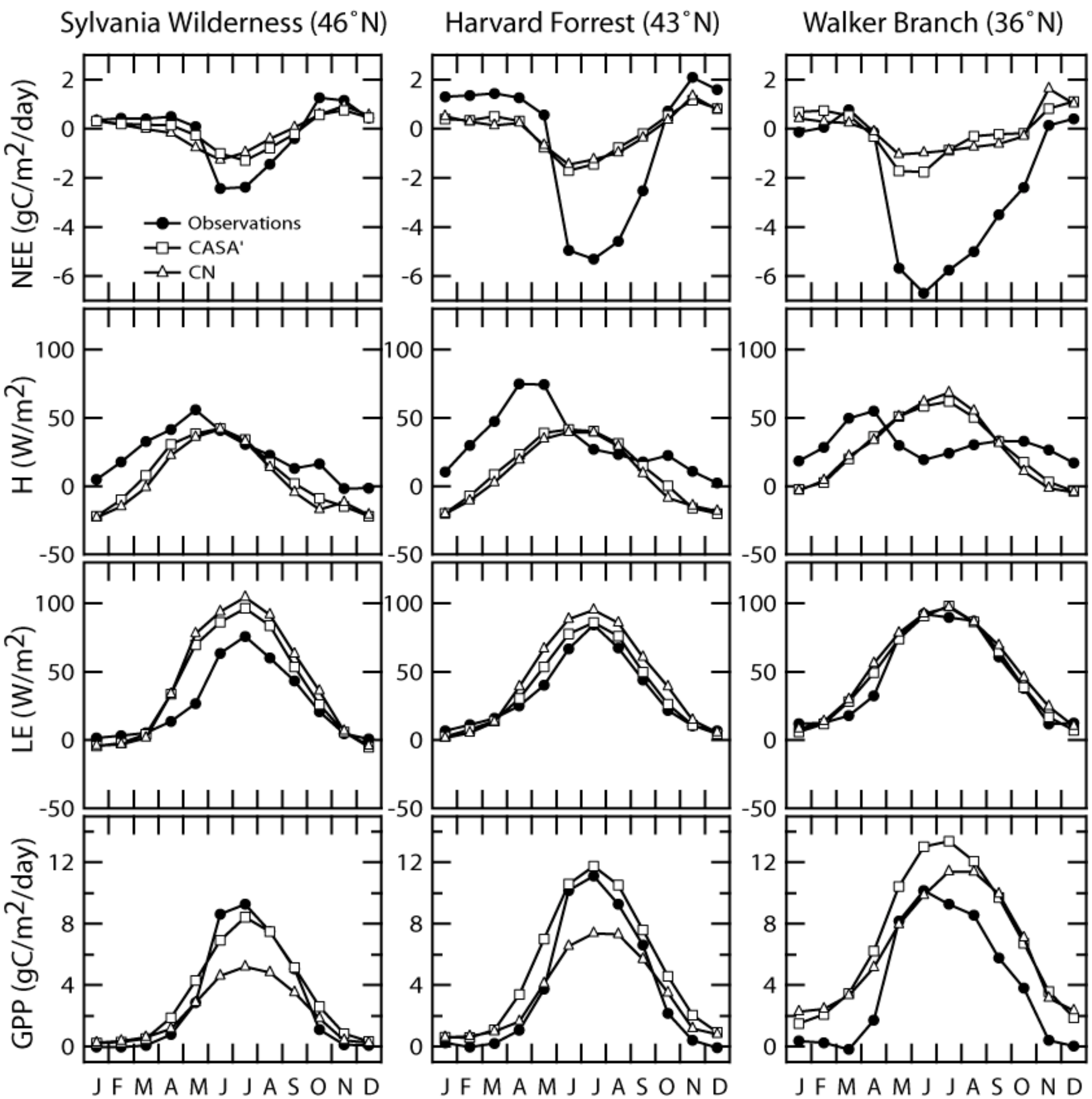
Land biosphere response to CO_2 Land biosphere response to temperature

Thick solid line is with preindustrial nitrogen deposition
Thick dashed line is with anthropogenic nitrogen deposition
Thin gray lines are C4MIP models (Friedlingstein et al. 2006)

Inclusion of N cycle reduces CO_2 fertilzation (β_L) and changes carbon cycle-temperature feedback (γ_L) negative

Thornton et al. (2009) Biogeosciences Discuss., 6, 3303-3354

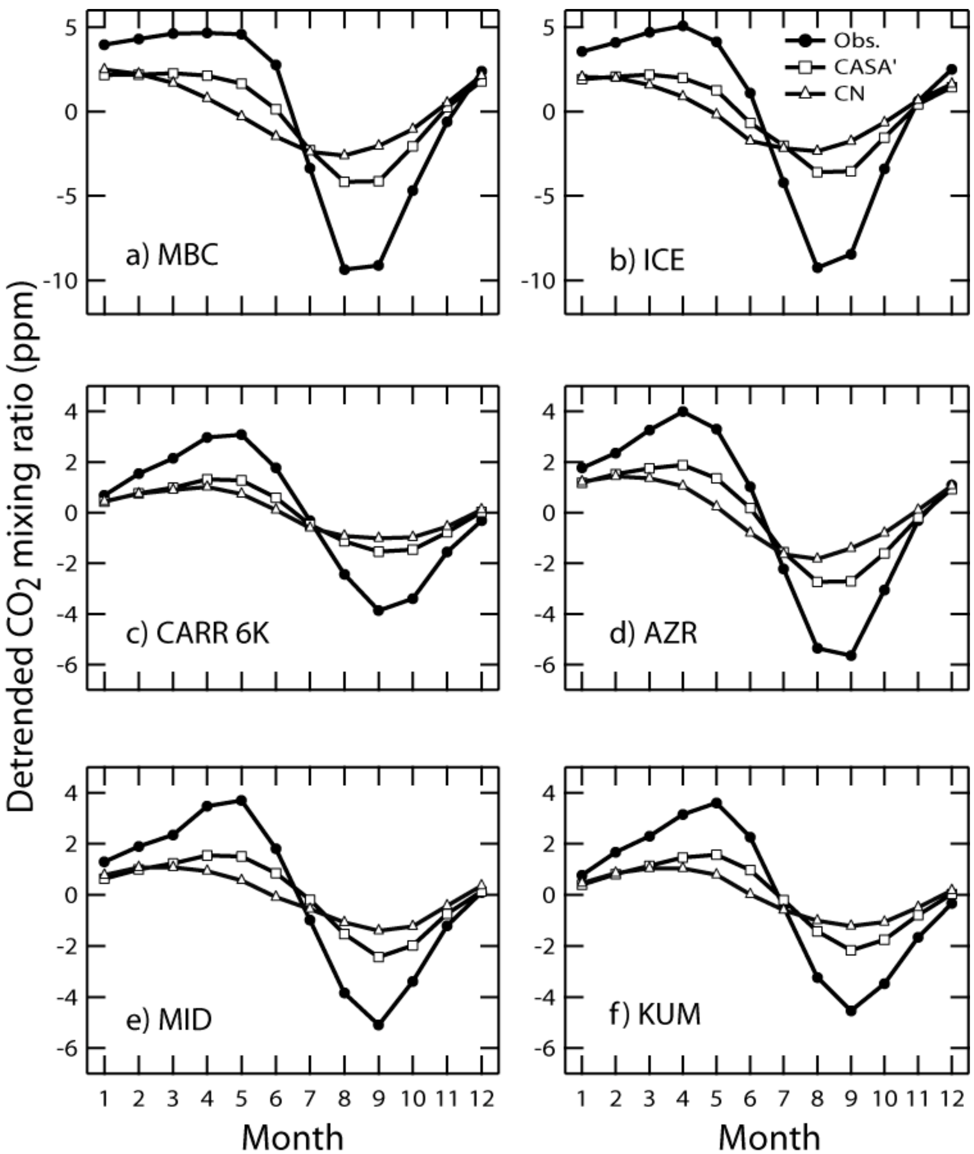
Annual cycle CO_2 fluxes



Ameriflux eddy covariance measurements

Randerson et al. (2009) GCB, in press

Annual cycle atmospheric CO_2

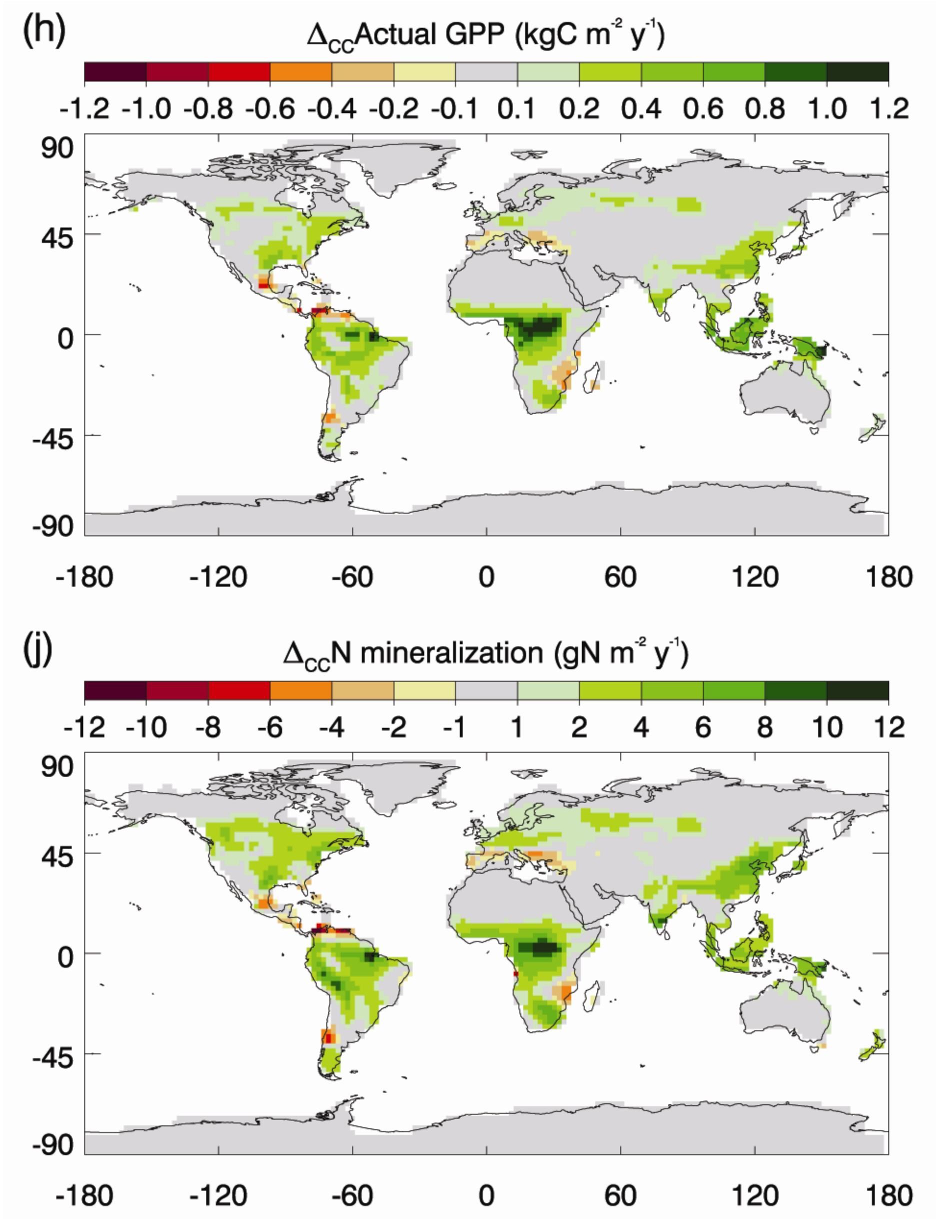


The annual cycle of atmospheric carbon dioxide at a) Mould Bay, Canada (76°N), b) Storhofdi, Iceland (63°N), c) Carr, Colorado (aircraft samples from 6 km masl; 41°N), d) Azores Islands (39°N), e) Sand Island, Midway (28°N), and Kumakahi, Hawaii (20°N)

Randerson et al. (2009) GCB, in press

National Center for
Atmospheric Research
Boulder, Colorado

CCSM3.1 carbon cycle-climate feedback

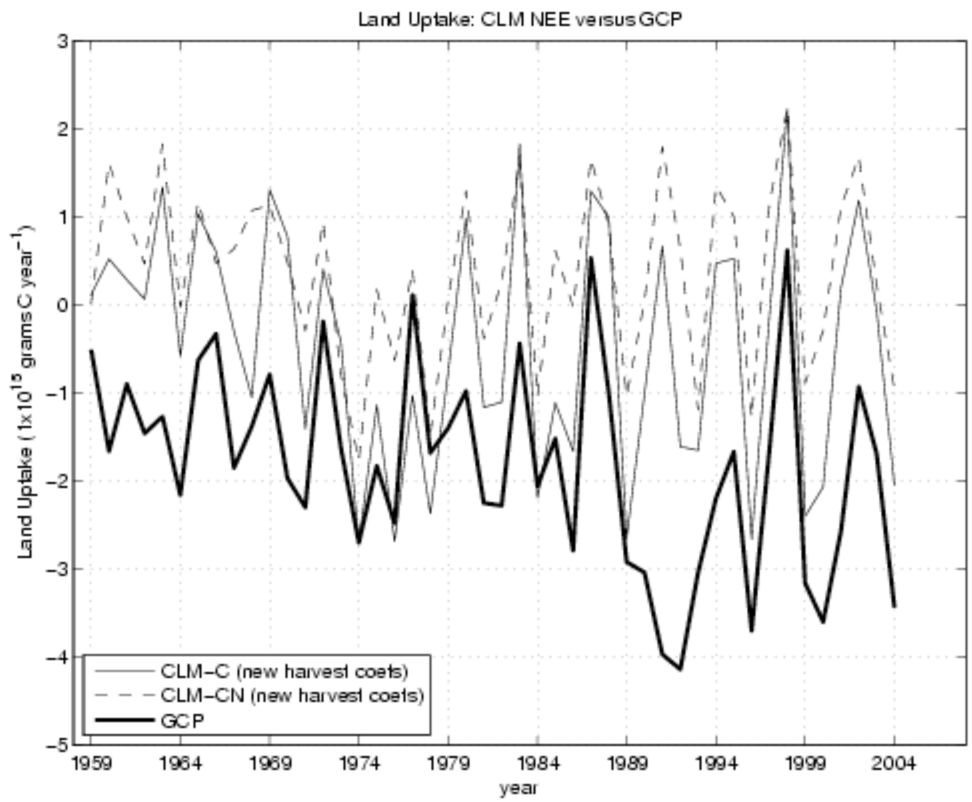


GPP response is highly correlated with gross N mineralization

Climate-driven increase in tropical C stocks

Thornton et al. (2009) Biogeosciences Discuss., 6, 3303-3354

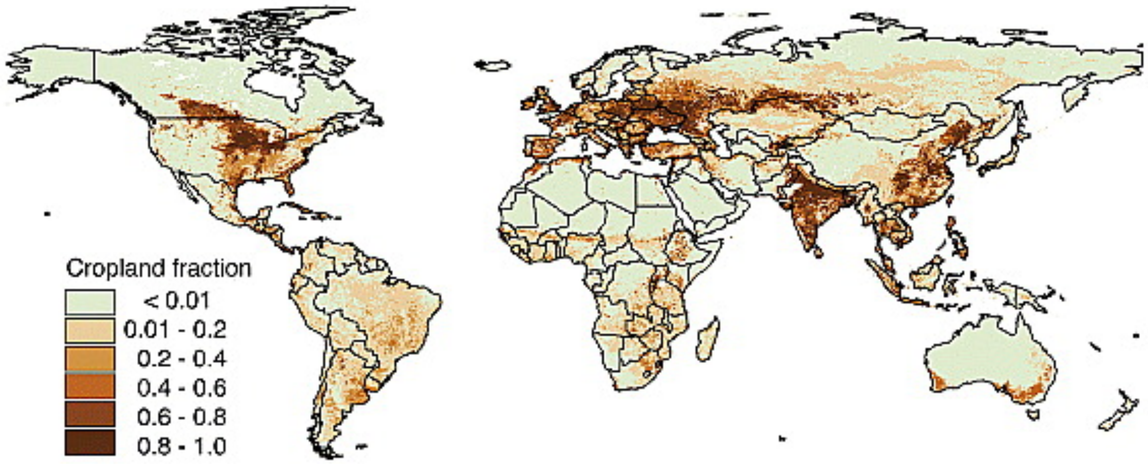
Carbon-only vs. C-N simulations



Carbon-only simulation of late-20th century is indistinguishable from C-N simulation, as compared with Global Carbon Project estimates of land carbon uptake

National Center for
Atmospheric Research
Boulder, Colorado

Multi-model ensemble of global land use climate forcing



The LUCID inter-comparison study of the land use forcing (1992-1870)

Models
Atmosphere - CAM3.5
Land - CLM3.5 + new datasets for present-day vegetation + grass optical properties
Ocean - Prescribed SSTs and sea ice

Experiments
30-year simulations (CO_2 = 375 ppm, SSTs = 1972-2001)
- PD – 1992 vegetation
- PDv - 1870 vegetation

30-year simulations (CO_2 = 280 ppm, SSTs = 1871-1900)
- PI – 1870 vegetation
- PIv – 1992 vegetation

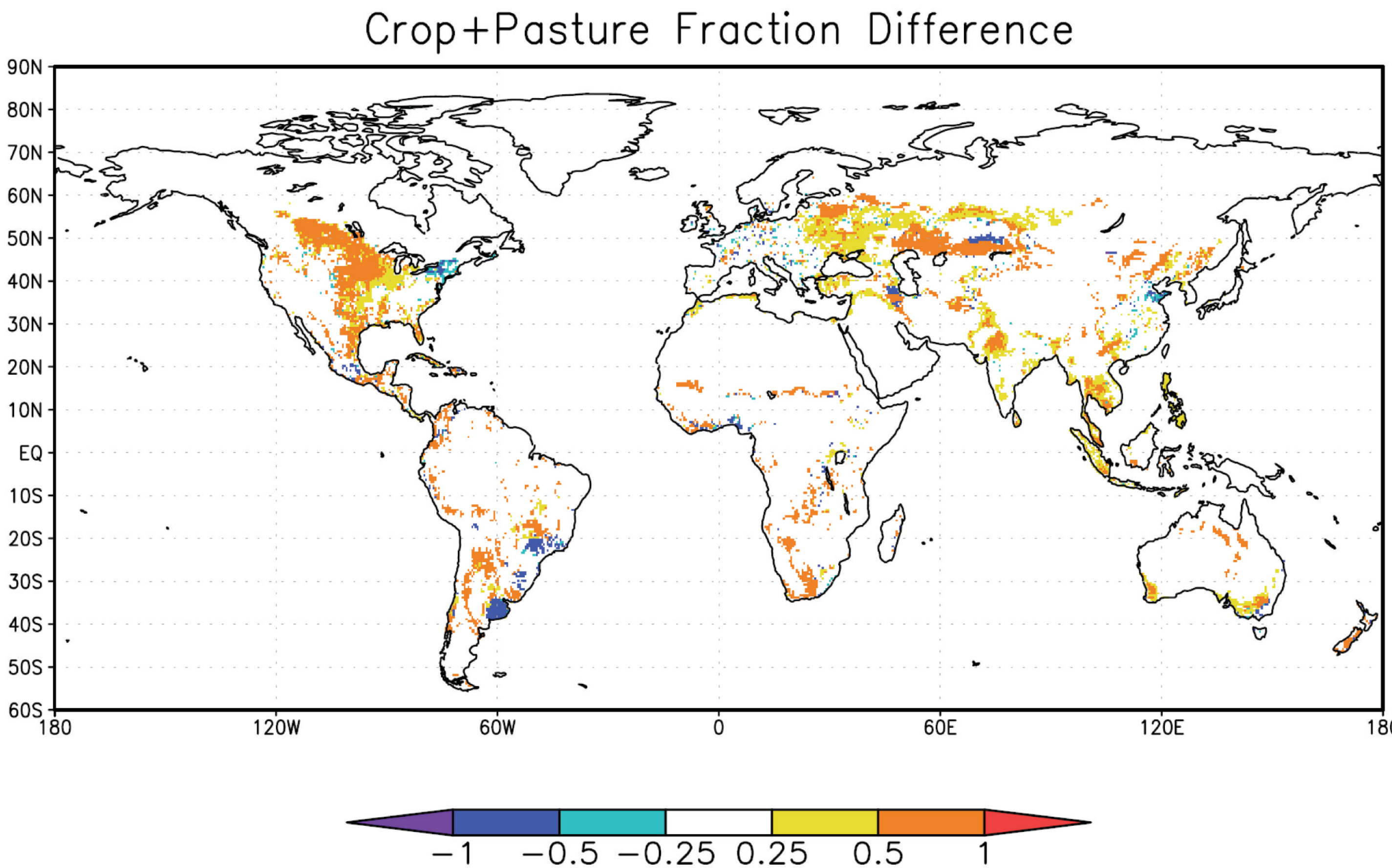
No irrigation

5-member ensembles each
Total of 20 simulations and 600 model years

Pitman et al. (2009) GRL, 36, L14814, doi:10.1029/2009GL039076

National Center for
Atmospheric Research
Boulder, Colorado

LUCID land cover change



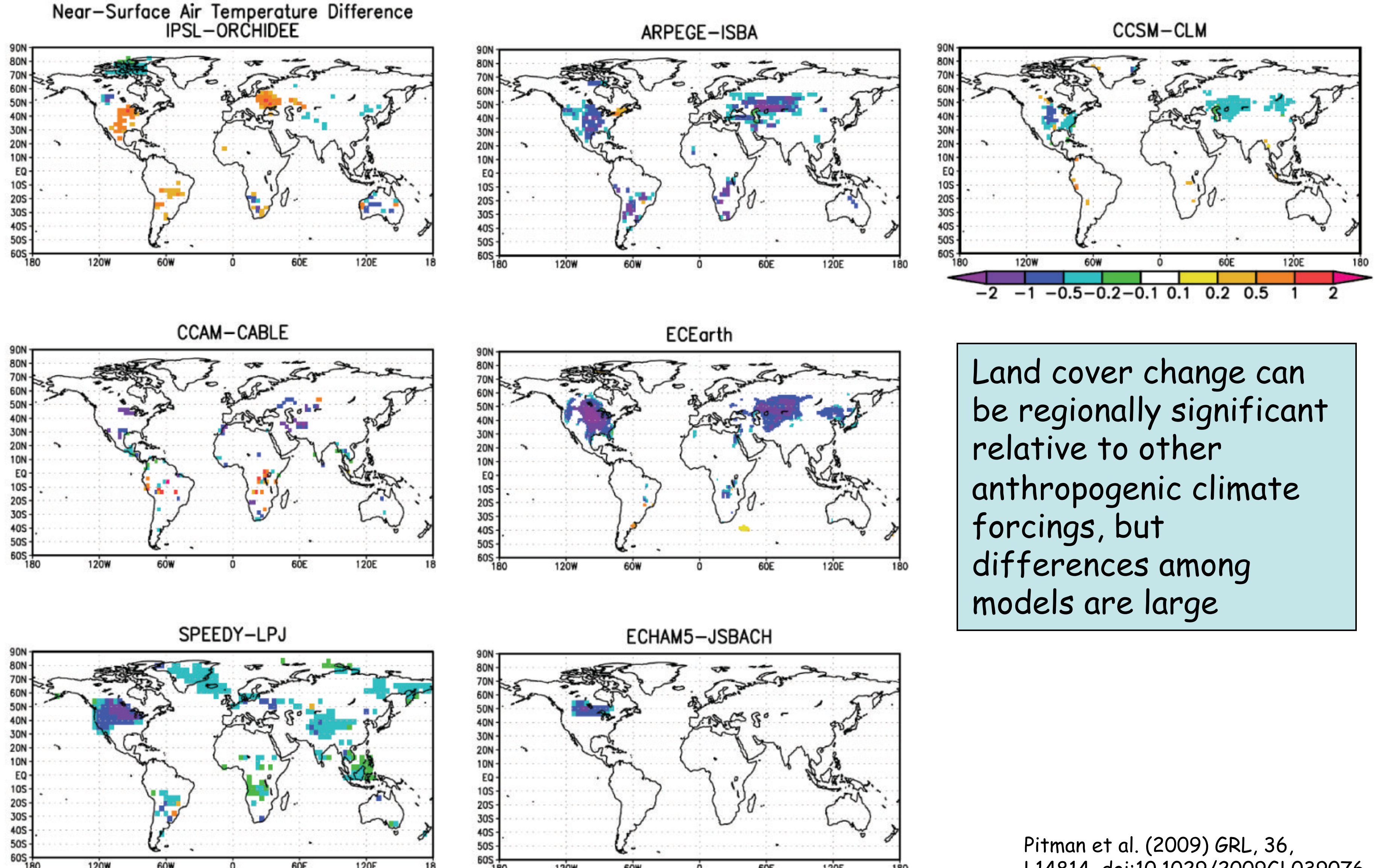
Extent of land cover change between experiments PD and PDv (PD – PDv) expressed as the difference in crop and pasture cover between the two experiments. Blue colours represent changes that decrease pasture and crop cover while yellows and browns are increases (25%-50% and 50-100% respectively).

Pitman et al. (2009) GRL, 36, L14814, doi:10.1029/2009GL039076

National Center for
Atmospheric Research
Boulder, Colorado

The LUCID intercomparison study

Change in JJA near-surface air temperature (PD – PDv)

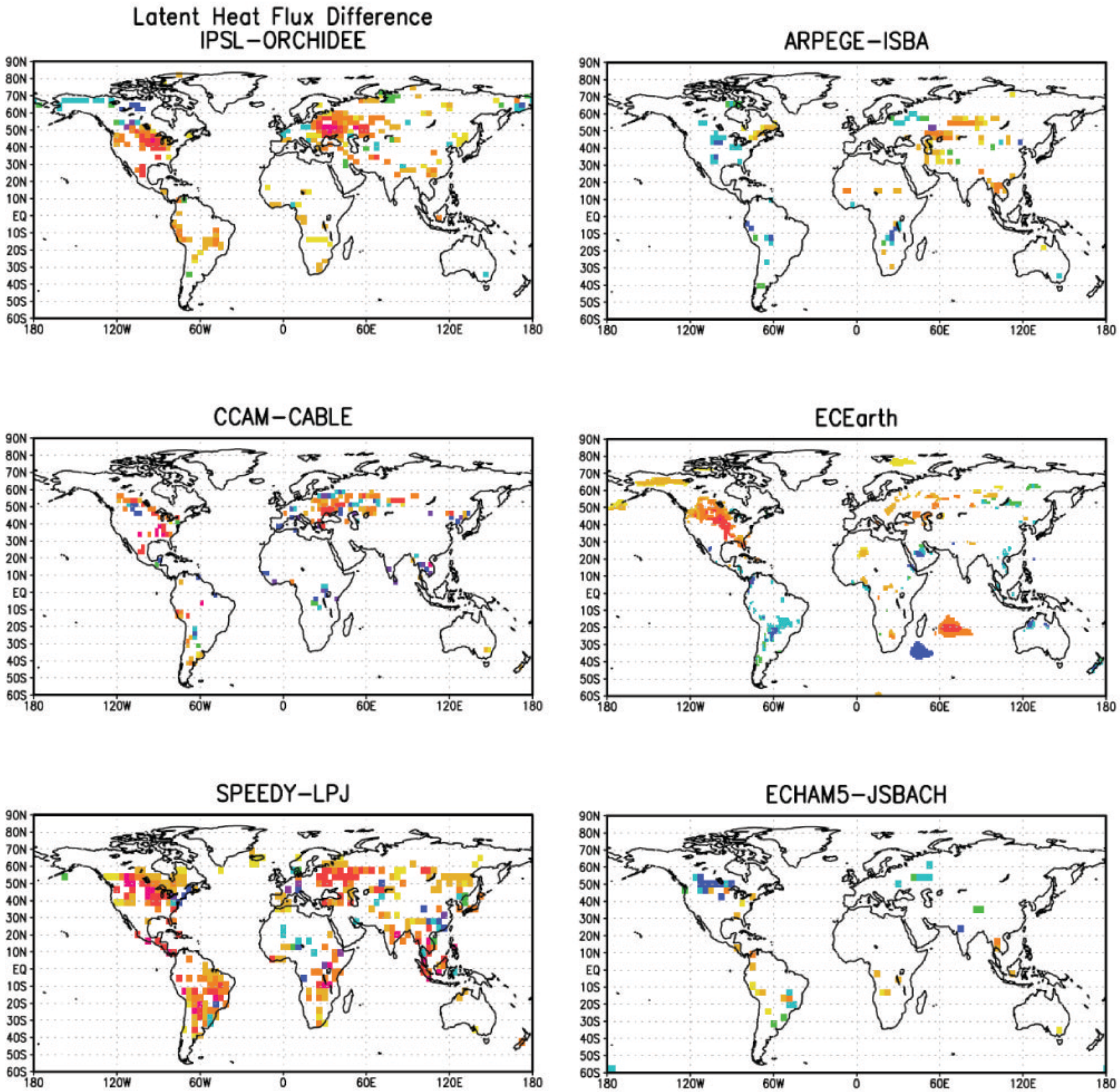


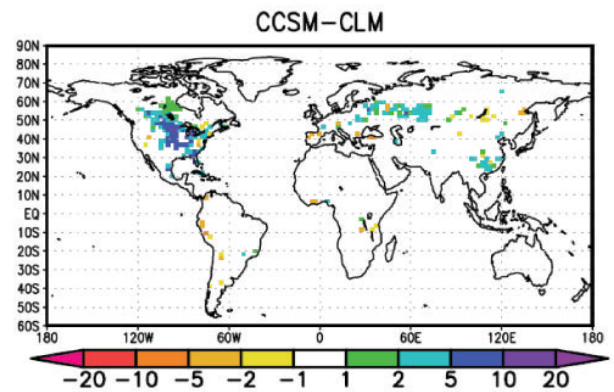
Land cover change can be regionally significant relative to other anthropogenic climate forcings, but differences among models are large

Pitman et al. (2009) GRL, 36, L14814, doi:10.1029/2009GL039076

National Center for
Atmospheric Research
Boulder, Colorado

The LUCID intercomparison study



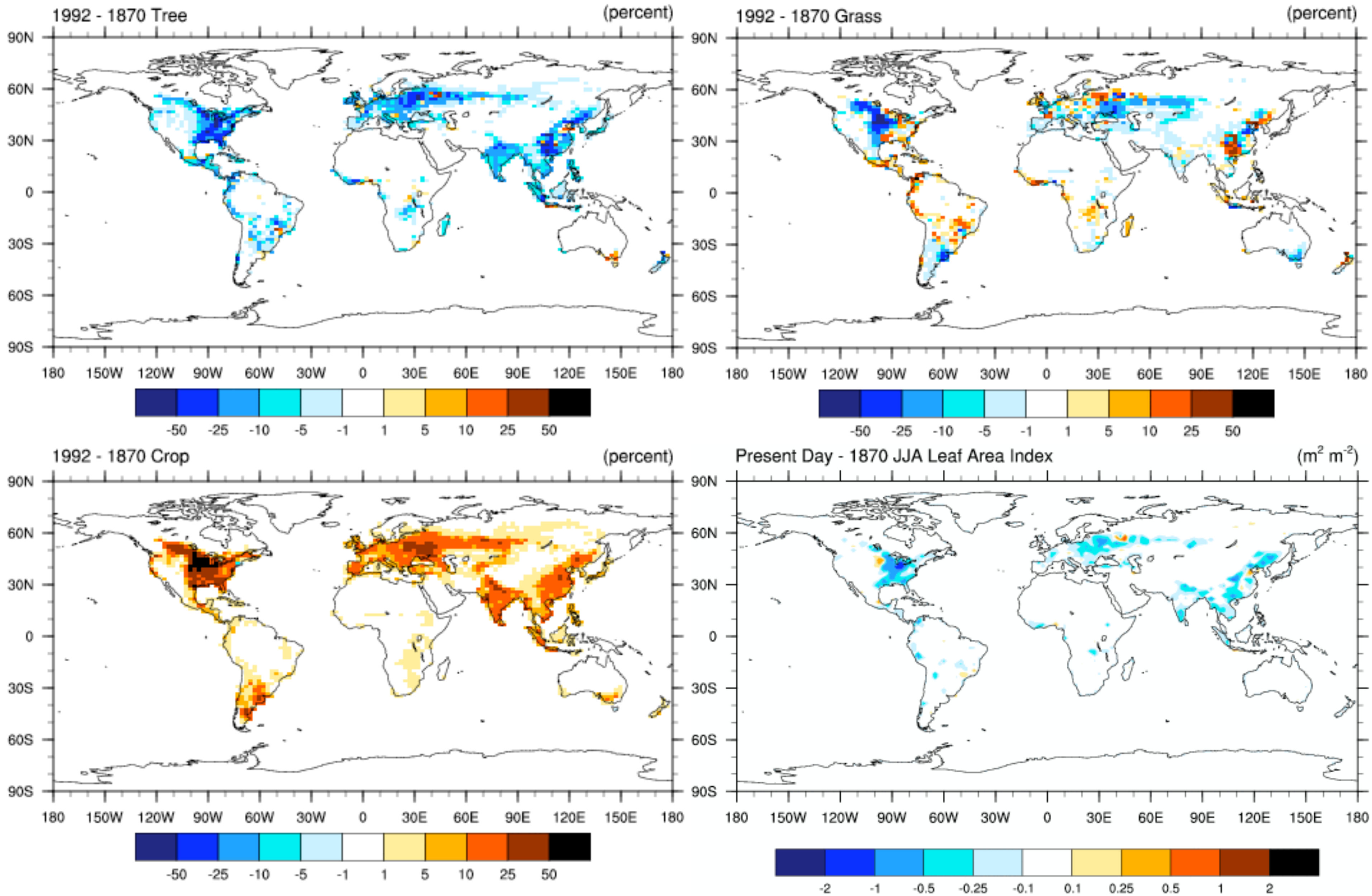


Change in JJA latent heat flux (W m^{-2}) resulting from land cover change (PD – PDv)

Pitman et al. (2009) GRL, 36, L14814, doi:10.1029/2009GL039076

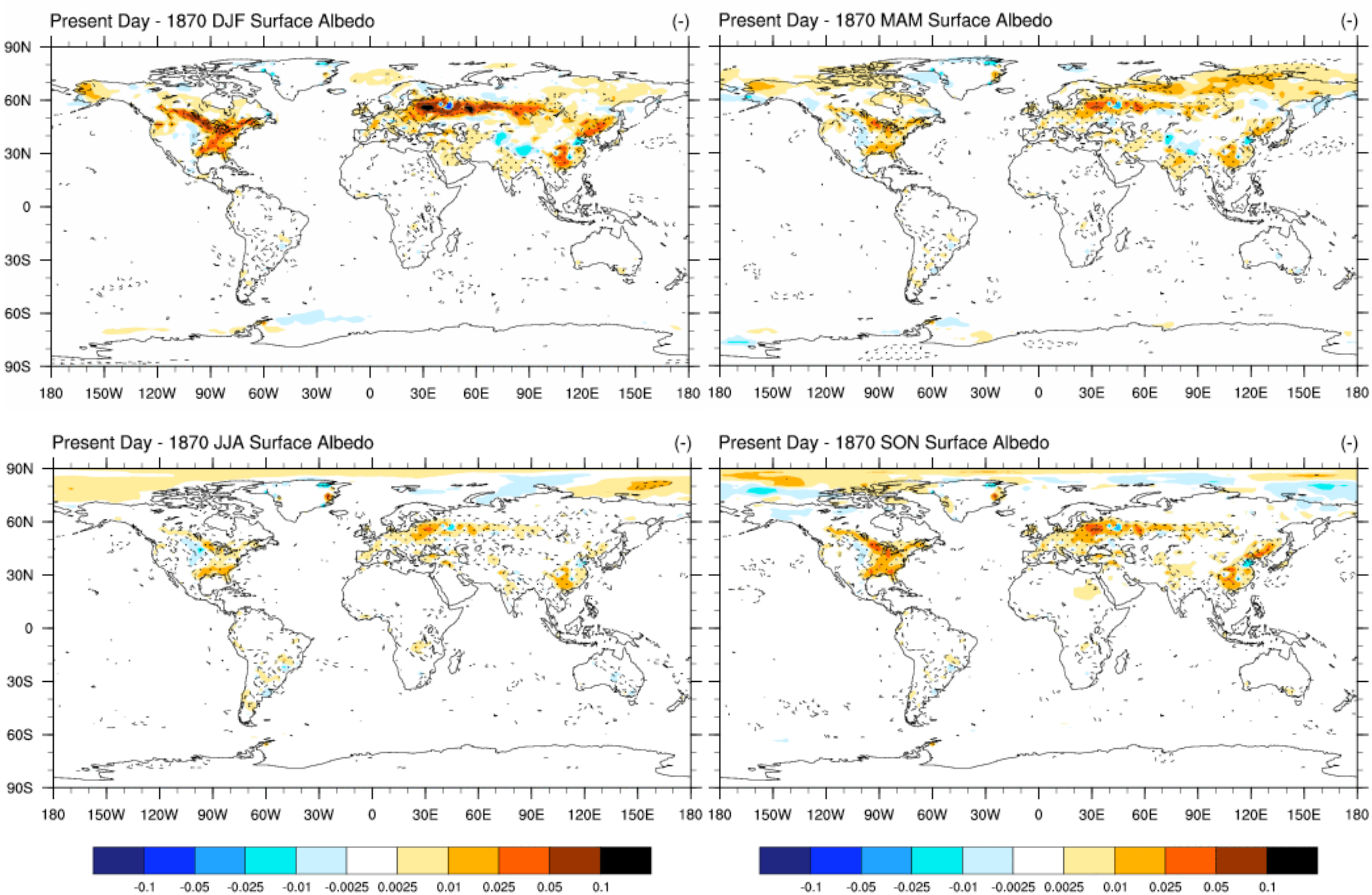
National Center for
Atmospheric Research
Boulder, Colorado

Land cover change, 1870 to 1992



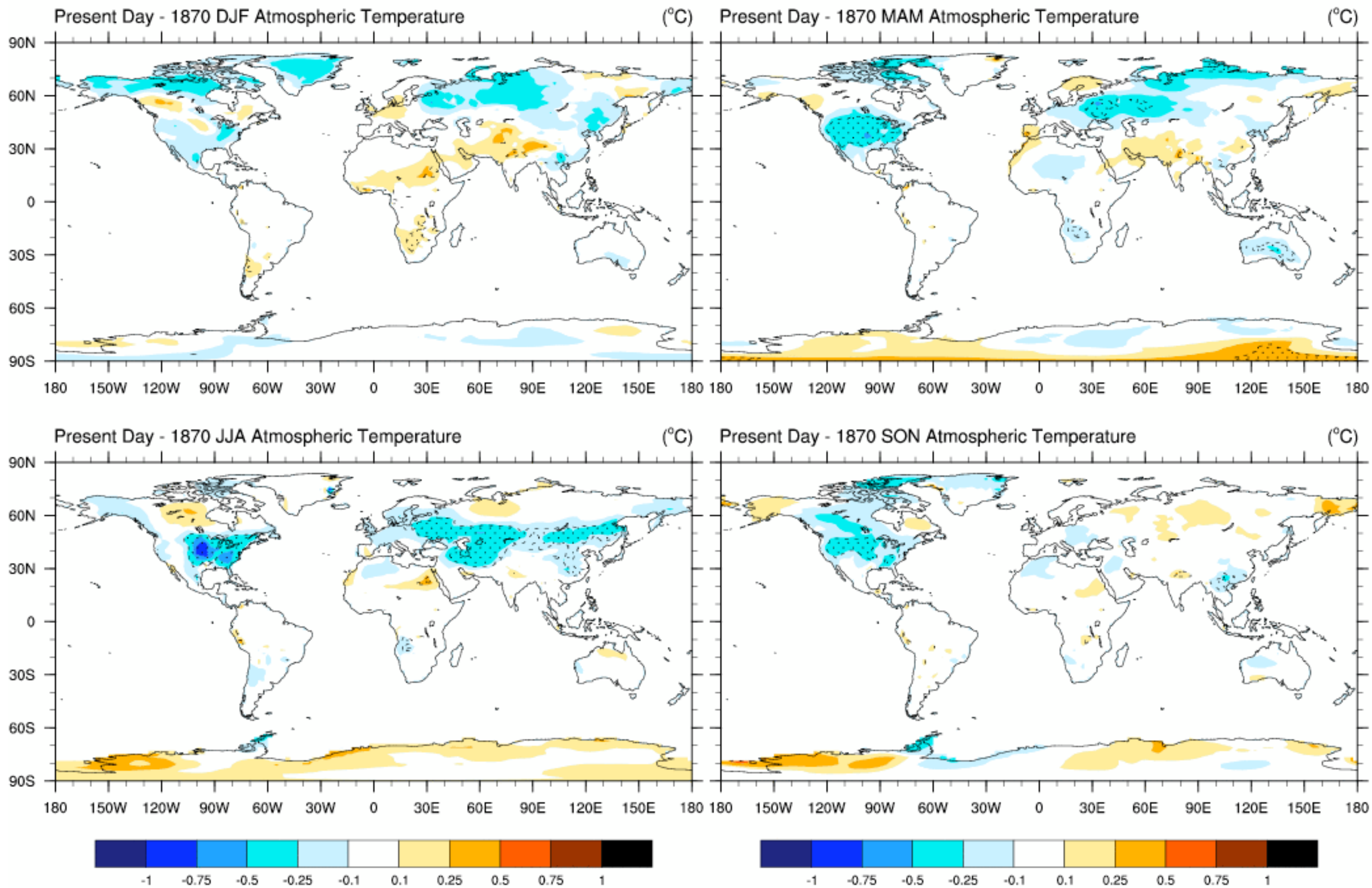
National Center for
Atmospheric Research
Boulder, Colorado

Albedo forcing, 1992-1870



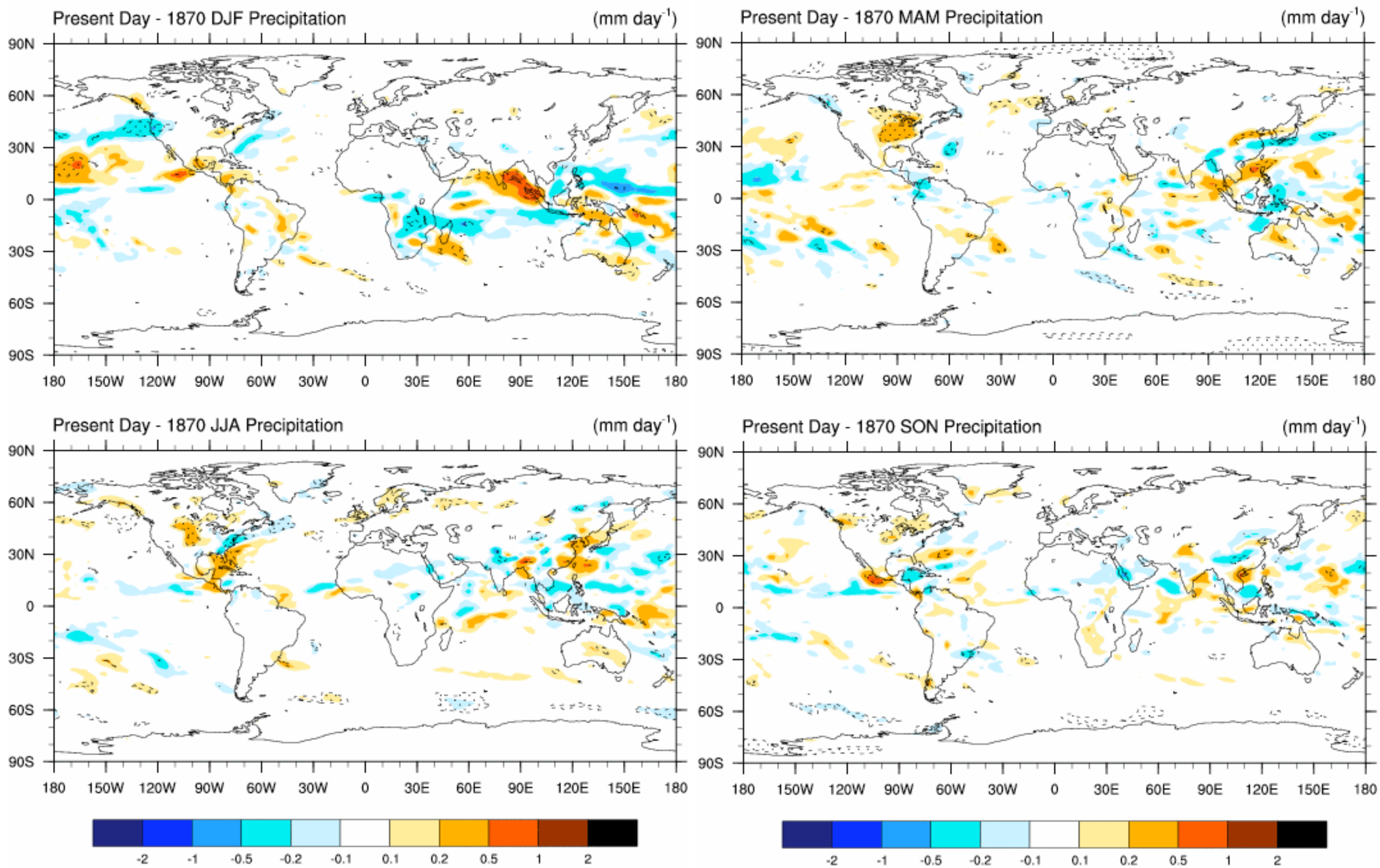
National Center for
Atmospheric Research
Boulder, Colorado

Near-surface temperature, 1992-1870



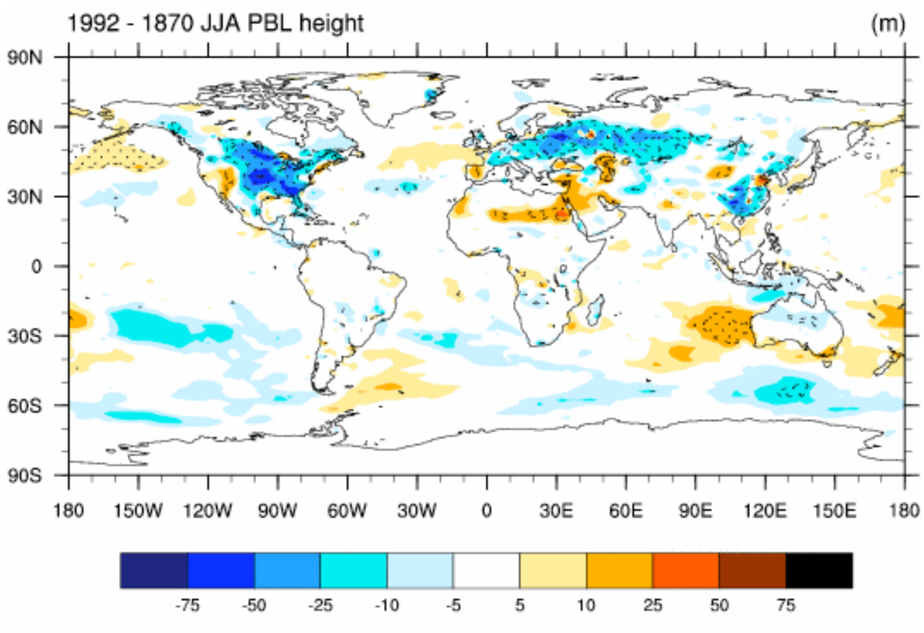
National Center for
Atmospheric Research
Boulder, Colorado

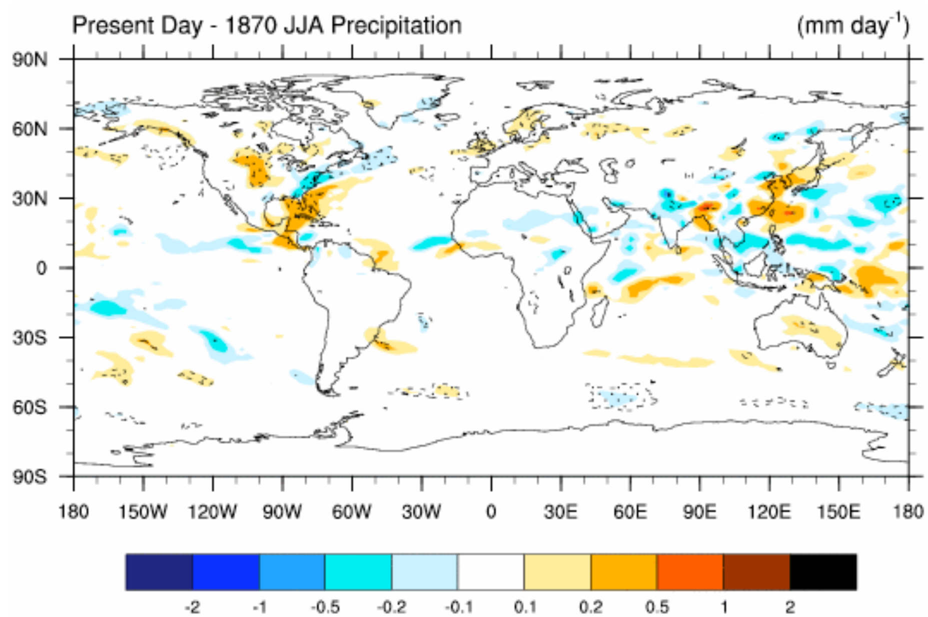
Precipitation, 1992-1870



National Center for
Atmospheric Research
Boulder, Colorado

Atmospheric feedbacks

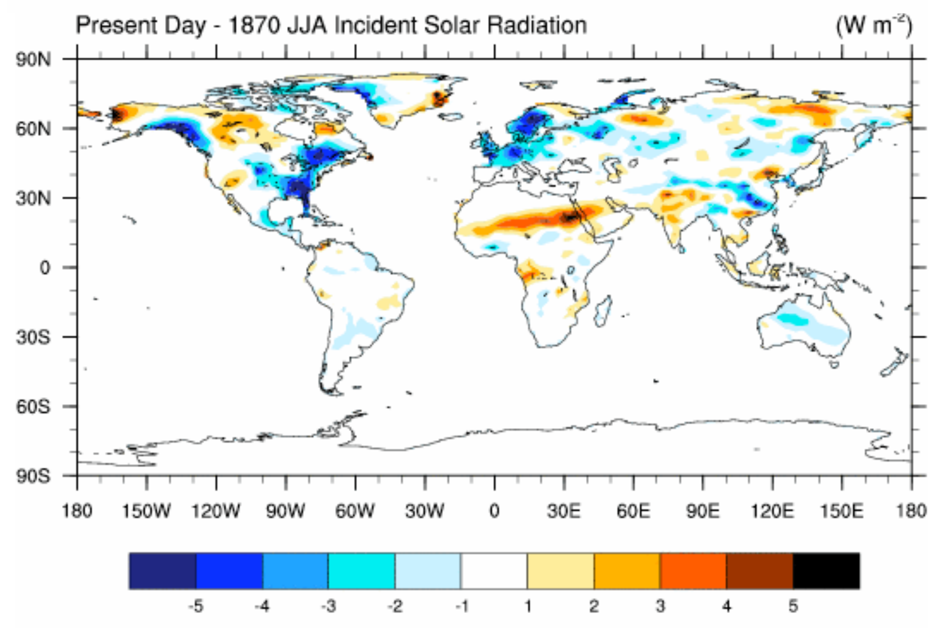




Climate models simulate the large-scale response and include feedbacks with the atmosphere:

- o Increased rainfall enhances latent heat flux
- o Increased cloudiness reduces solar radiation
- o Reduced PBL height

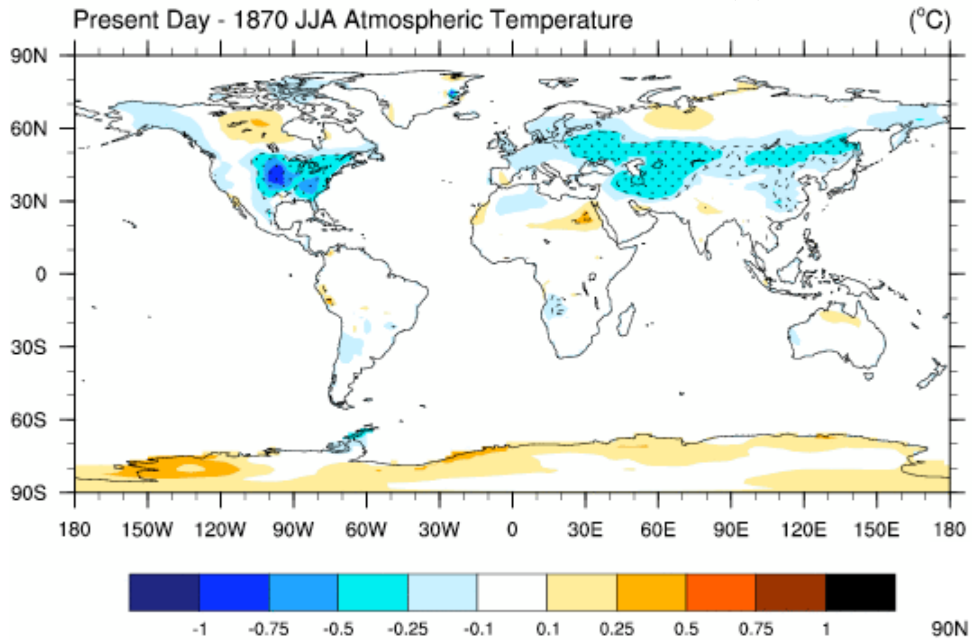
Flux towers measure local response



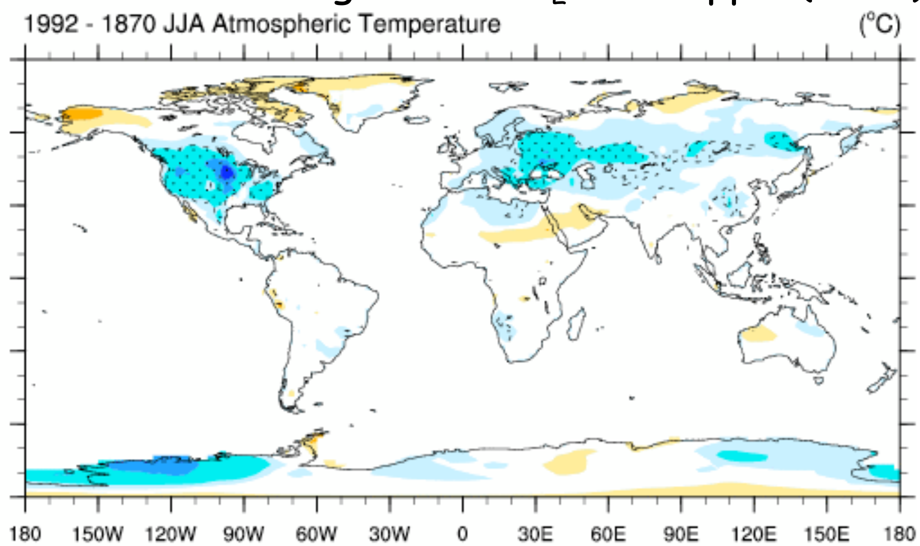
National Center for
Atmospheric Research
Boulder, Colorado

Land cover change offsets greenhouse gas warming

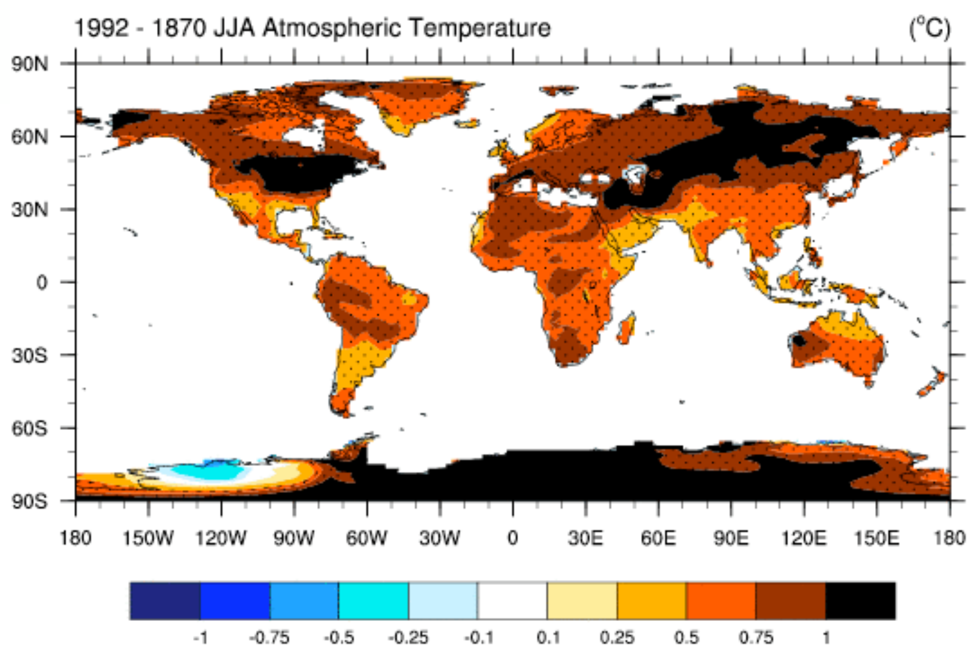
Land cover change with CO_2 = 375 ppm (1992)



Land cover change with CO_2 = 280 ppm (1870)



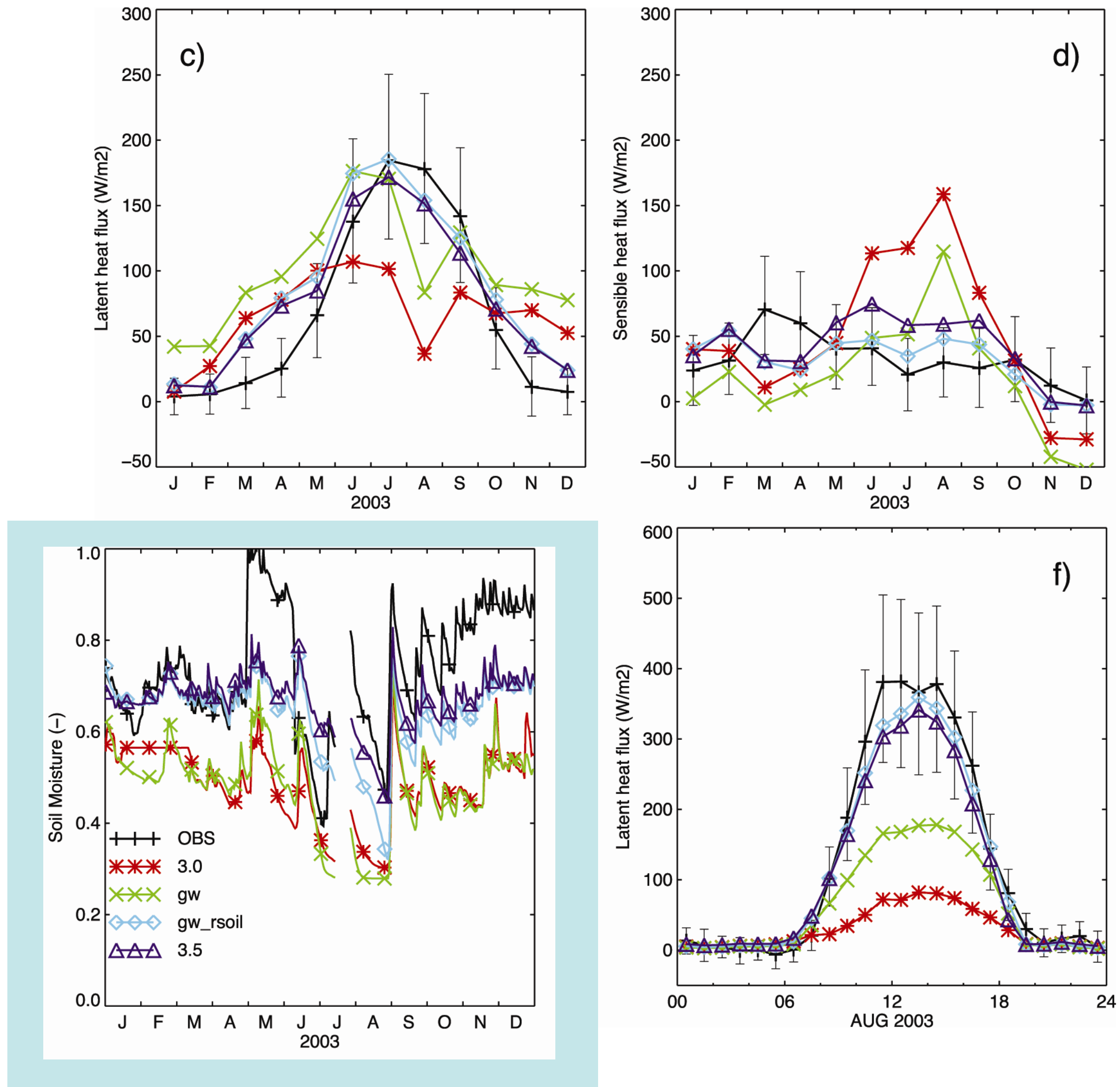
CO_2 forcing with
1870 land cover



National Center for
Atmospheric Research
Boulder, Colorado

Flux tower measurements – temperate deciduous forest

Morgan Monroe State Forest, Indiana



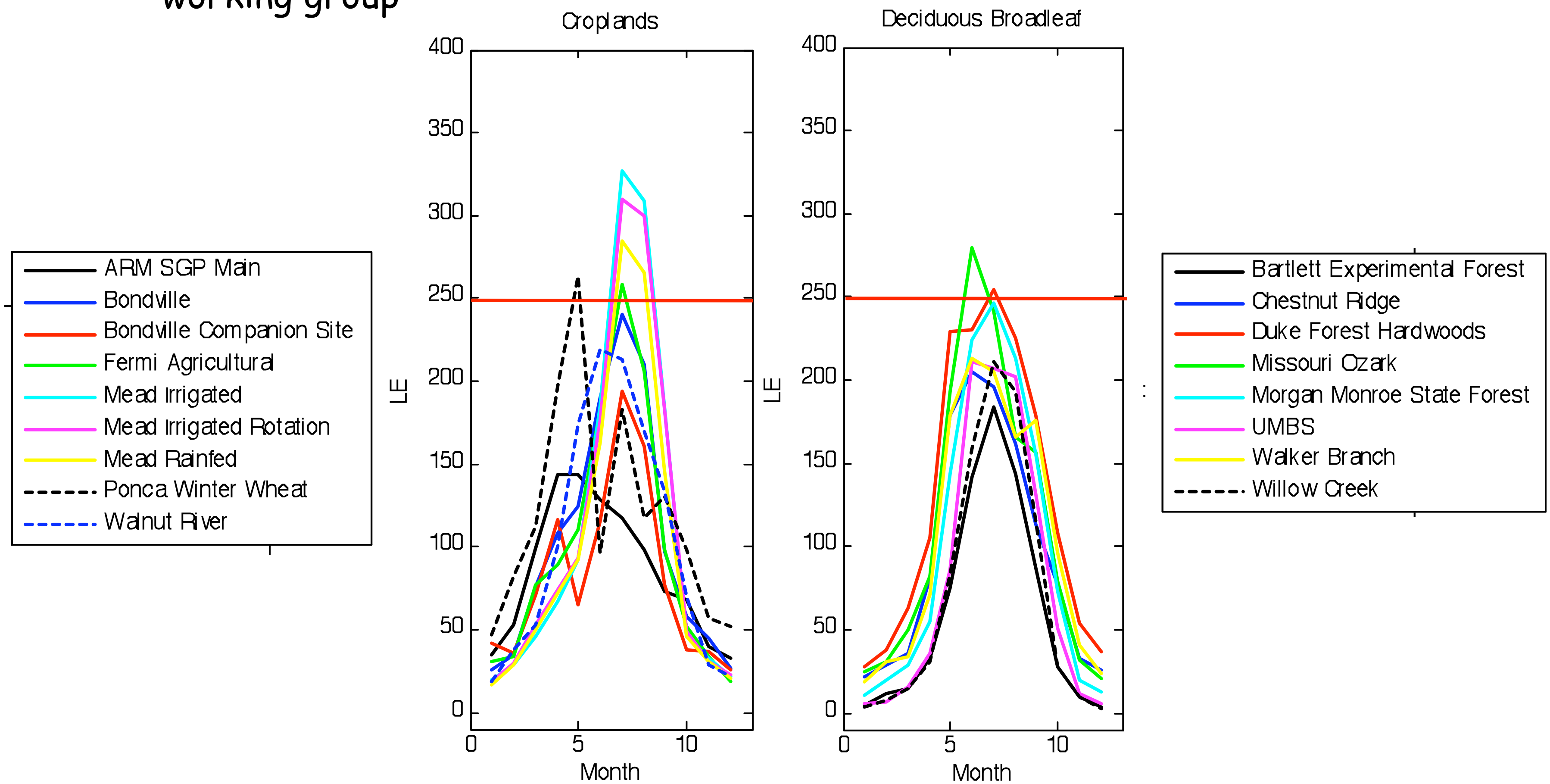
CLM3 – dry soil, low latent heat flux, high sensible heat flux
CLM3.5 – wetter soil and higher latent heat flux

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

National Center for
Atmospheric Research
Boulder, Colorado

Can Ameriflux provide insights?

NCEAS "Forest and Climate Policy"
working group



Crops

Mead irrigated sites have highest LH

LH varies with crop rotation

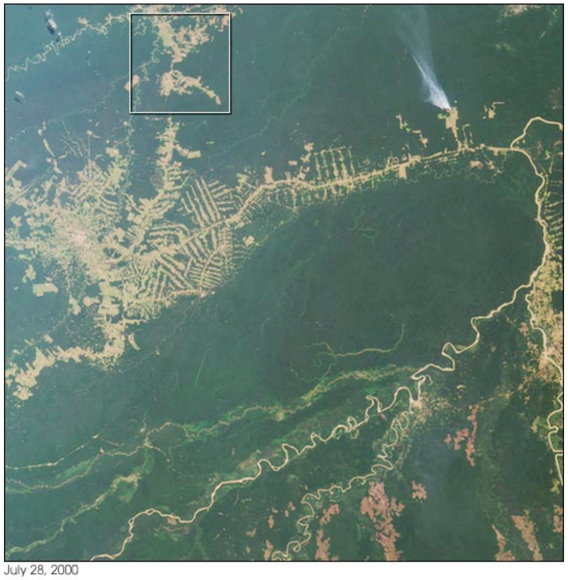
LH varies with crop type (winter wheat)

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

National Center for
Atmospheric Research
Boulder, Colorado

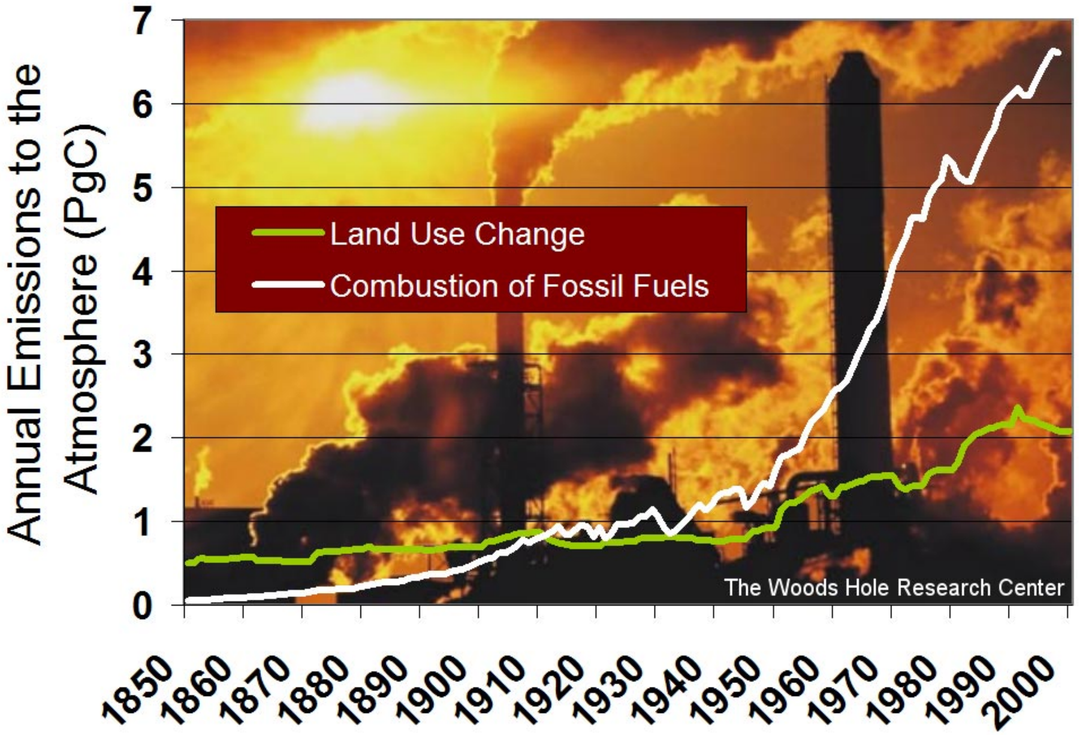
Land use and carbon

There is a net flux of carbon to the atmosphere from changes in land use:
- oTropical deforestation releases carbon
- oTemperate reforestation stores carbon



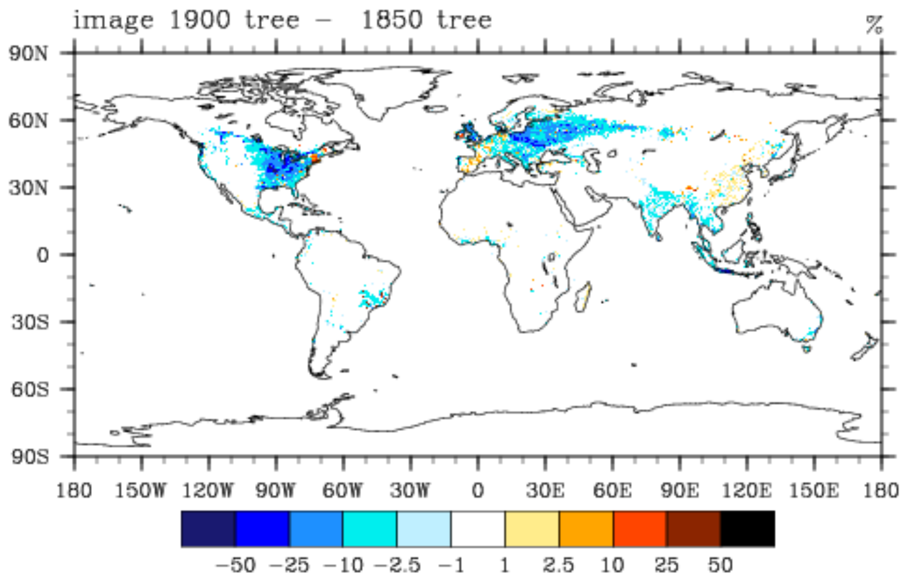
(NASA/GSFC/LaRC/JPL)

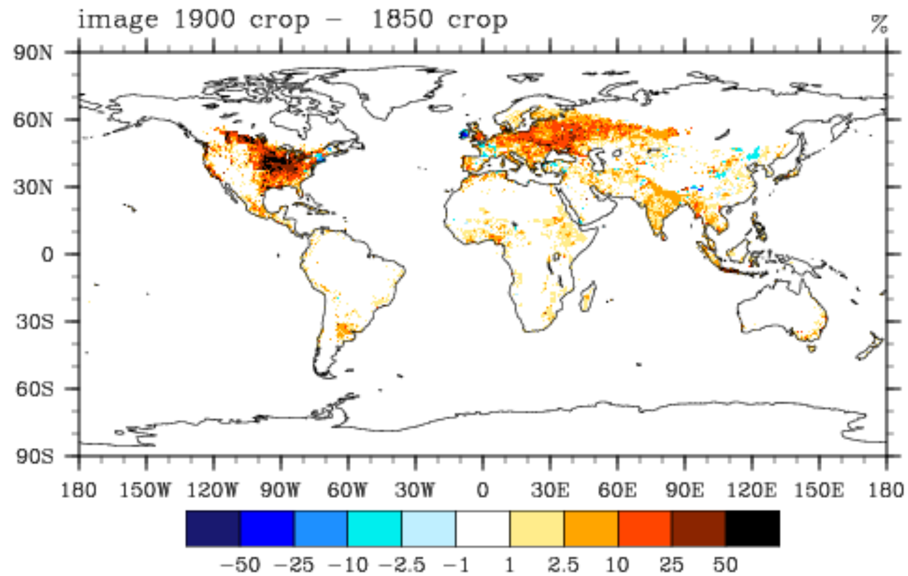
Settlement and deforestation surrounding Rio Branco, Brazil (10°S, 68°W) in the Brazilian state of Acre, near the border with Bolivia. The large image covers an area of 333 km x 333 km.

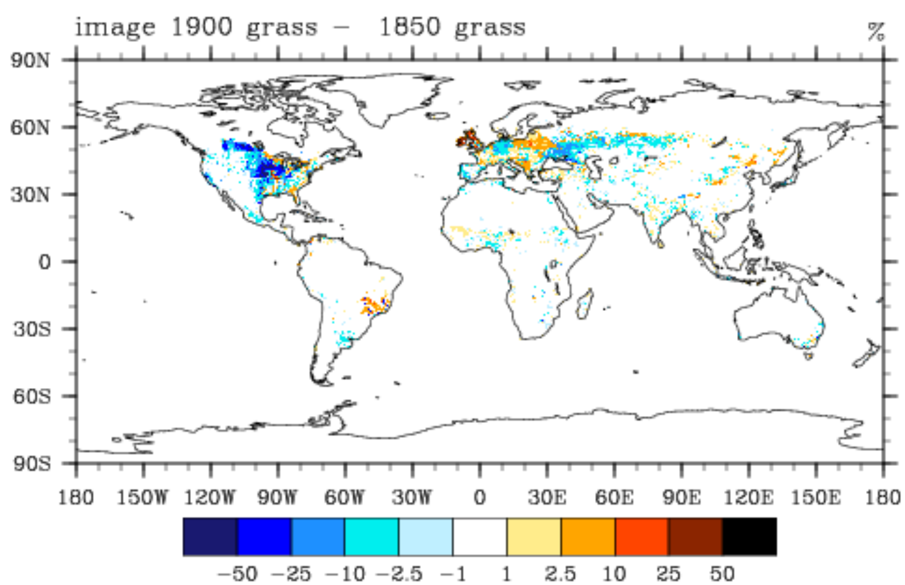


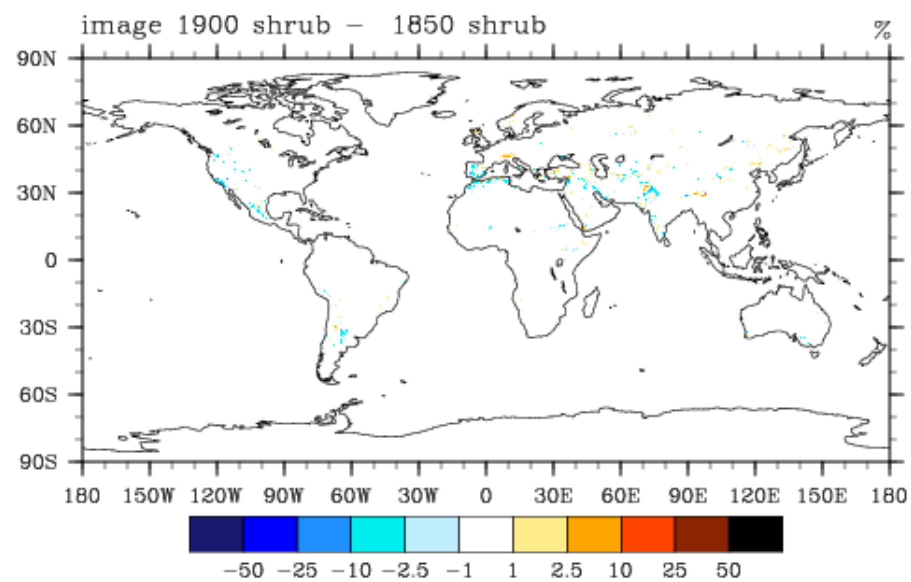
National Center for
Atmospheric Research
Boulder, Colorado

Historical land use – cropland and pastureland



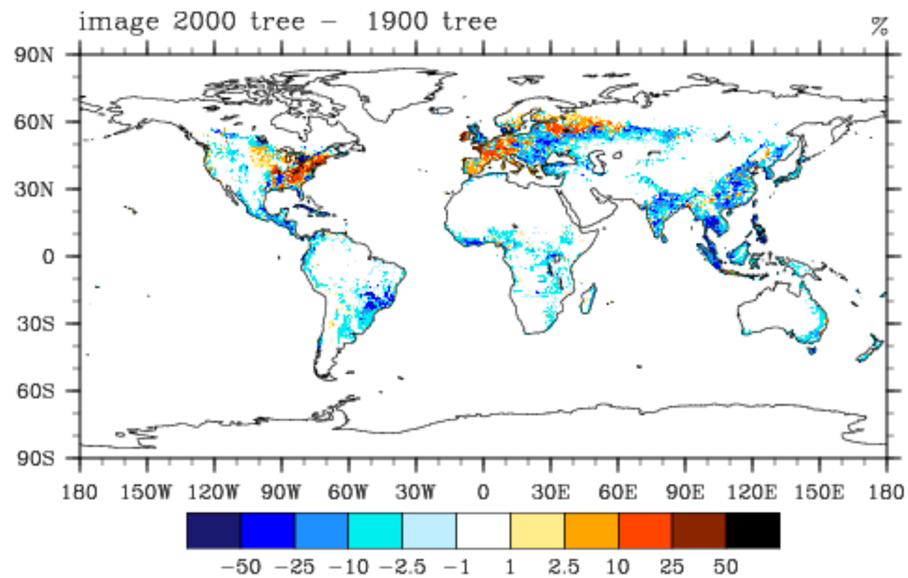


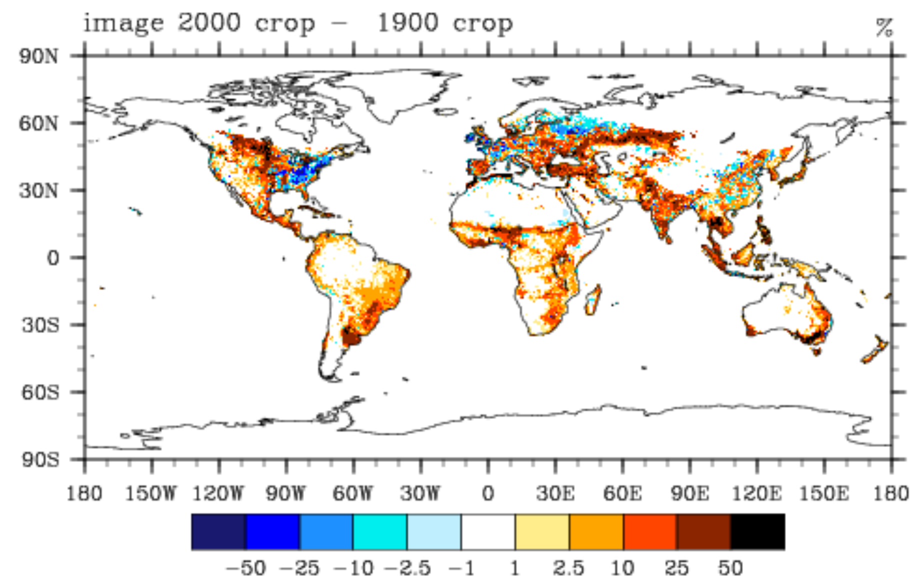


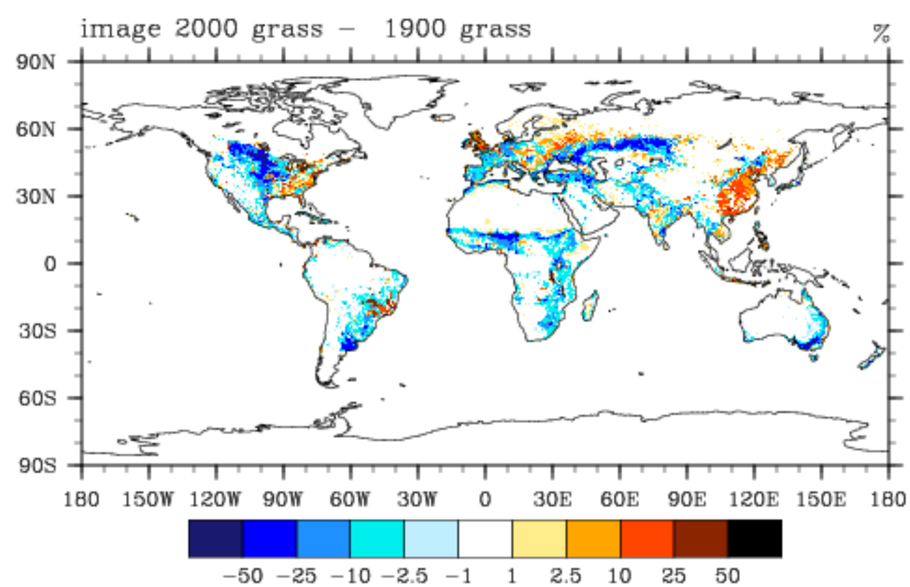


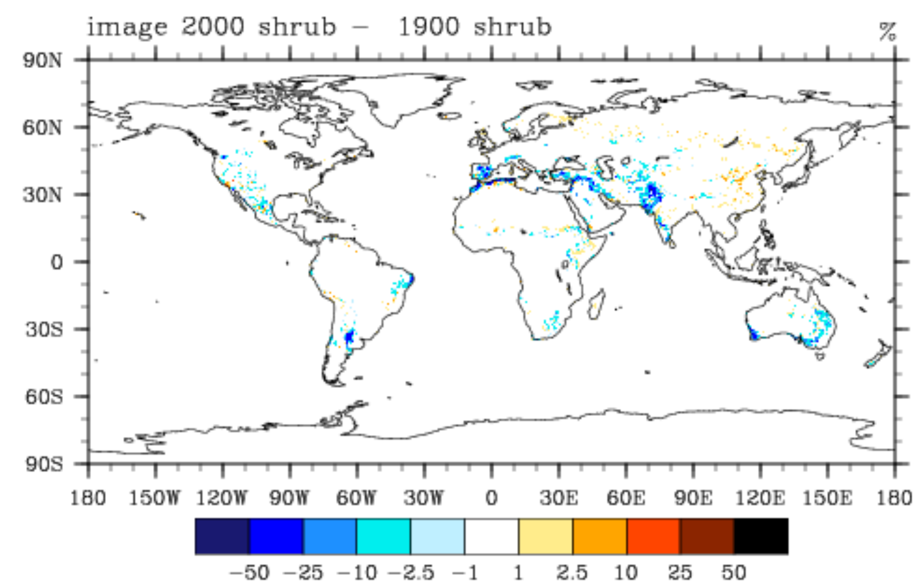
National Center for
Atmospheric Research
Boulder, Colorado

Historical land use – cropland and pastureland





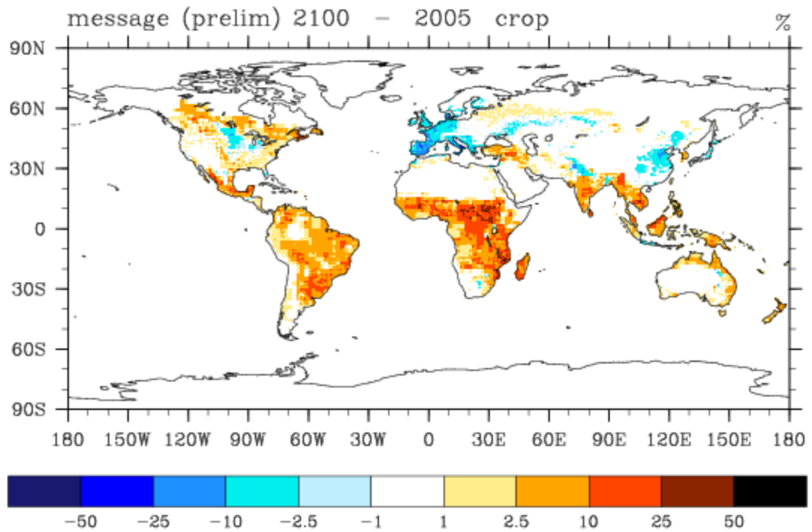




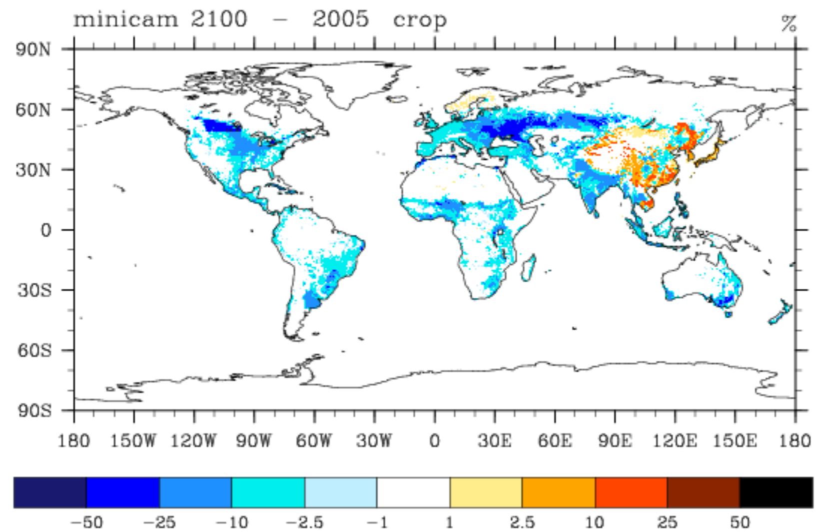
National Center for
Atmospheric Research
Boulder, Colorado

Future land use – cropland and pastureland

MESSAGE (RCP 8.5 W m^{-2})



MINICAM (RCP 4.5 W m^{-2})



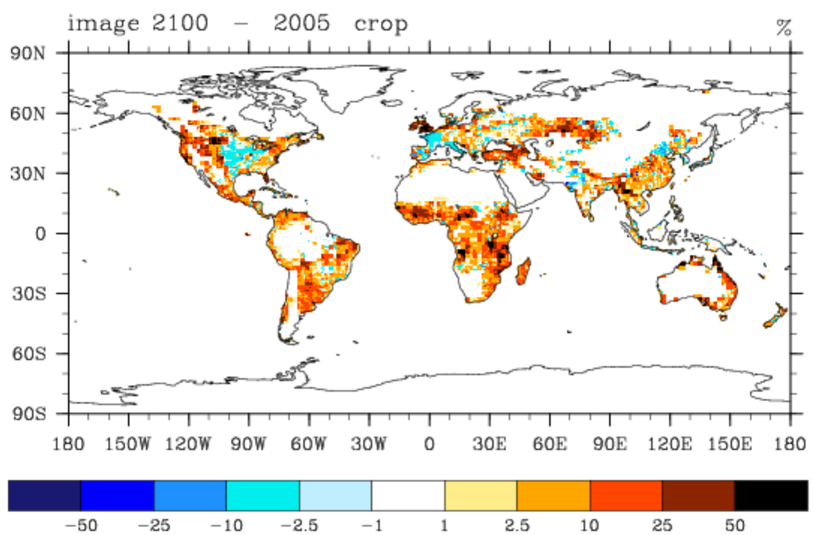
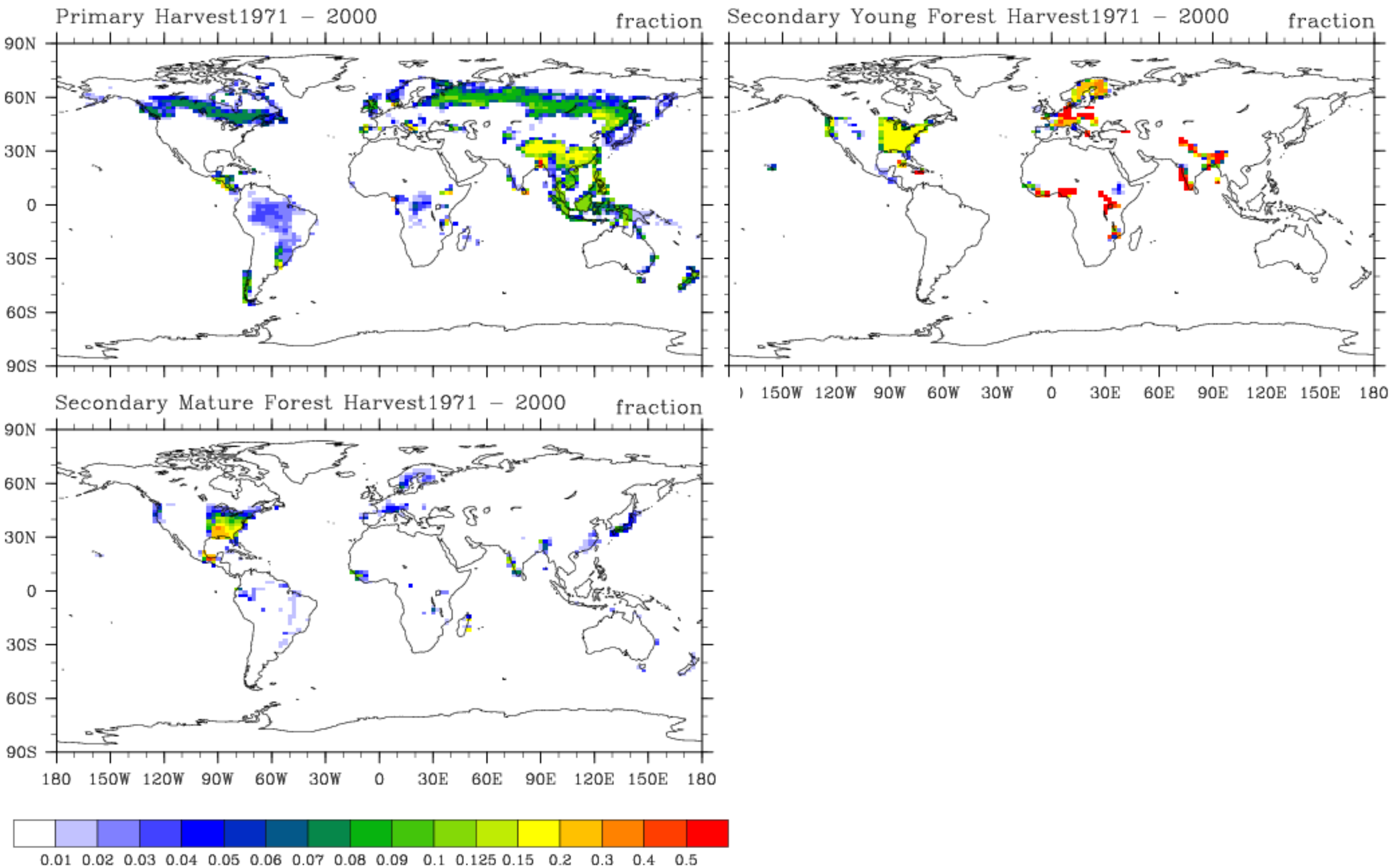


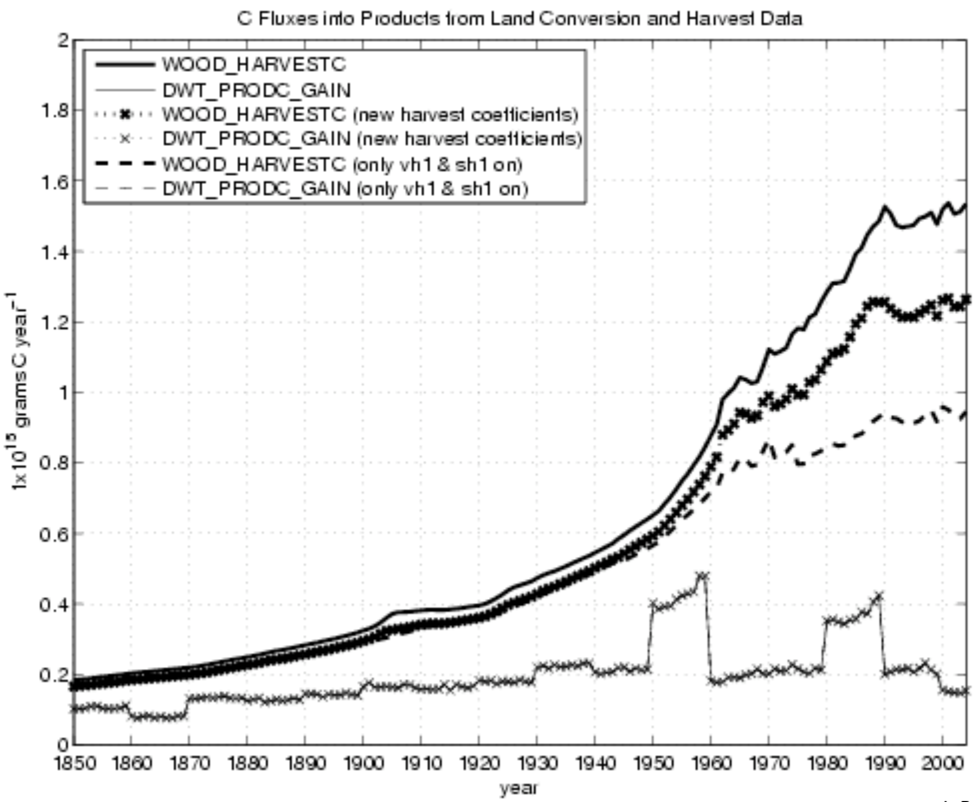
IMAGE (RCP 2.6 W m^{-2})

National Center for
Atmospheric Research
Boulder, Colorado

Land use – wood harvest

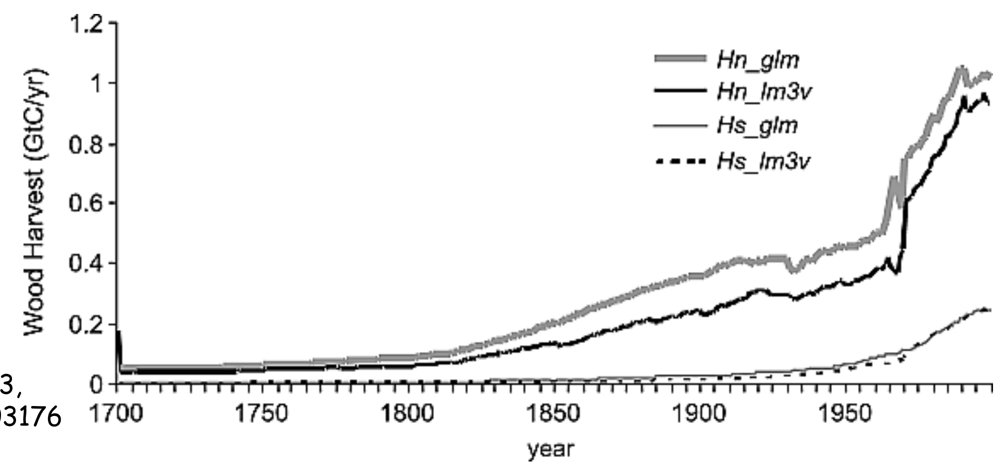


Carbon flux to wood products



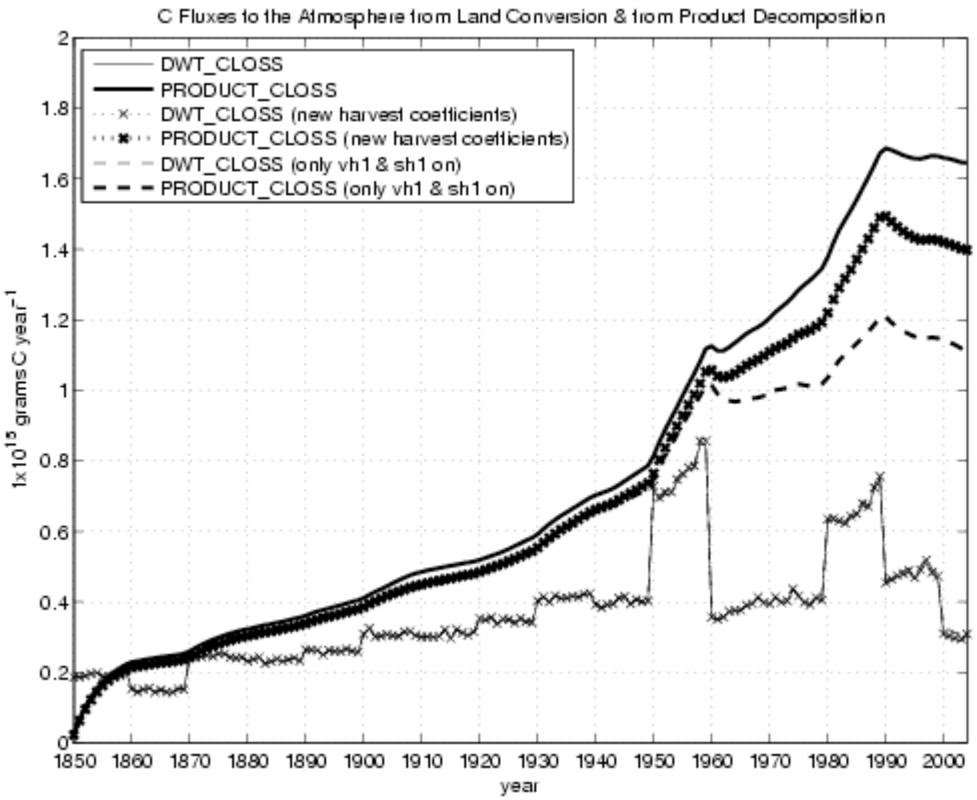
Wood harvesting

Land cover change
(e.g., deforestation)



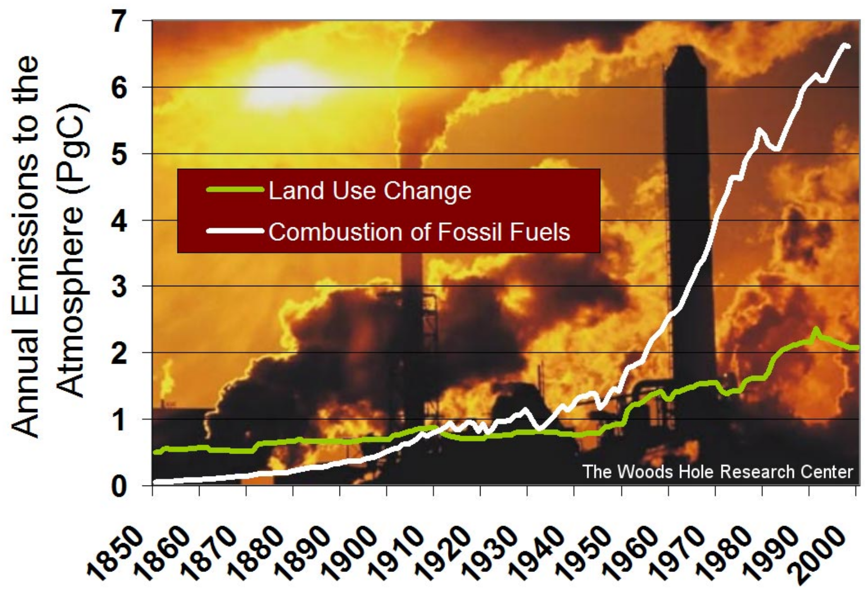
Shevliakova et al. (2009) *GBC*, 23, GB2022, doi:10.1029/2007GB003176

Land use carbon flux to atmosphere

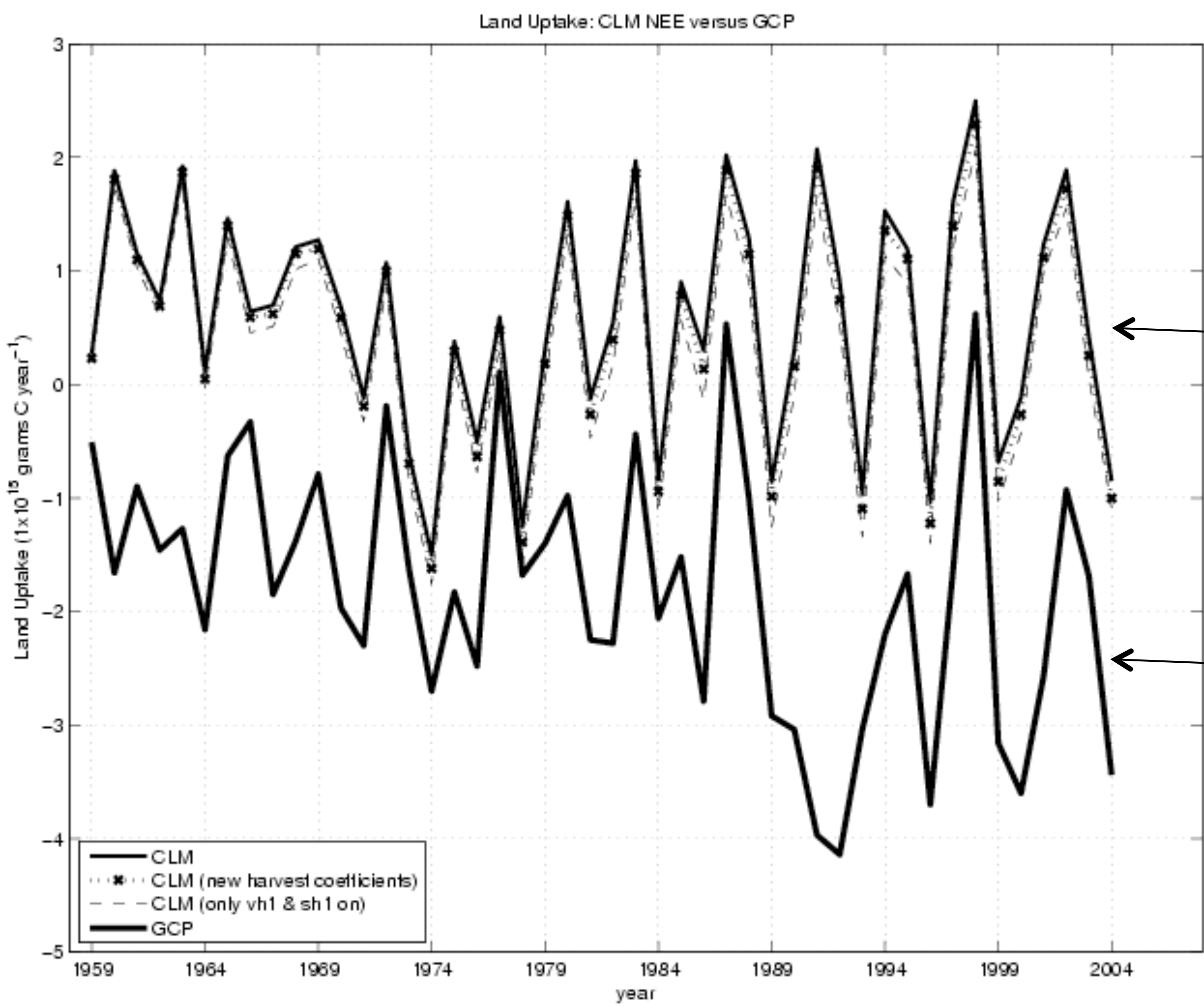


Wood harvesting

Land cover change
(e.g., deforestation)



Net land carbon flux to atmosphere



Three different harvest algorithms. Increased GPP compensates for increased land use flux

Global Carbon Project

Conclusions

Carbon cycle

- CO_2 fertilization enhances plant productivity, offset by decreased productivity and increased soil carbon loss with warming
- N cycle reduces the capacity of the terrestrial biosphere to store carbon (CO_2 fertilization) and changes sign of carbon cycle-climate feedback from positive to negative. The CO_2 fertilization effect is larger than the climate feedback effect

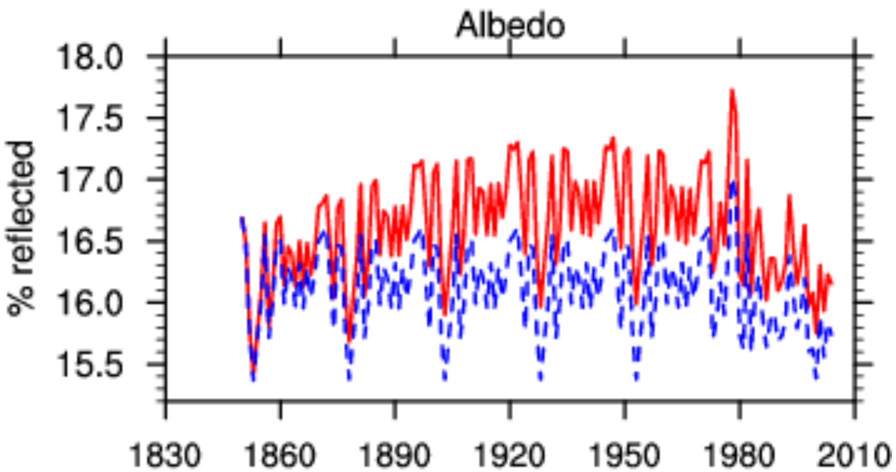
Land use and land cover change

Biogeophysics
- Higher albedo of croplands cools climate
- Less certainty about role of latent heat flux
- Implementation of land cover change (spatial extent, crop parameterization) matters

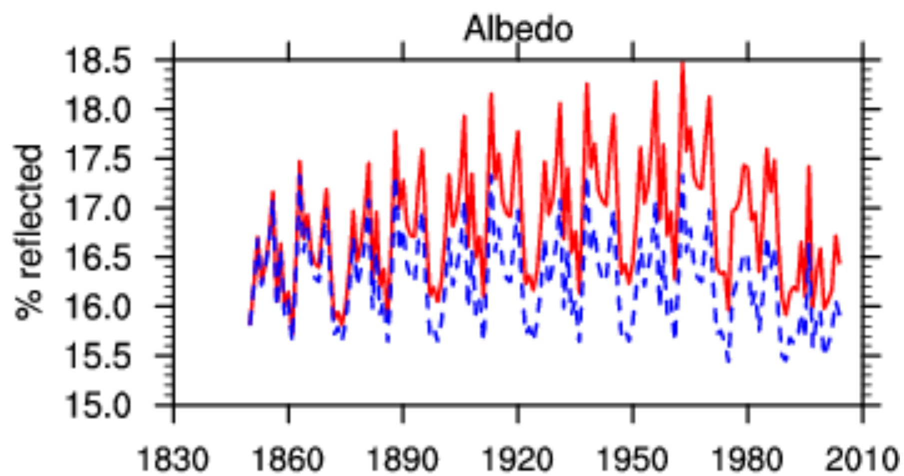
Biogeochemistry
- Wood harvest flux is important
- Uncertainty in harvest flux may be greater than the N-cycle feedback

National Center for
Atmospheric Research
Boulder, Colorado

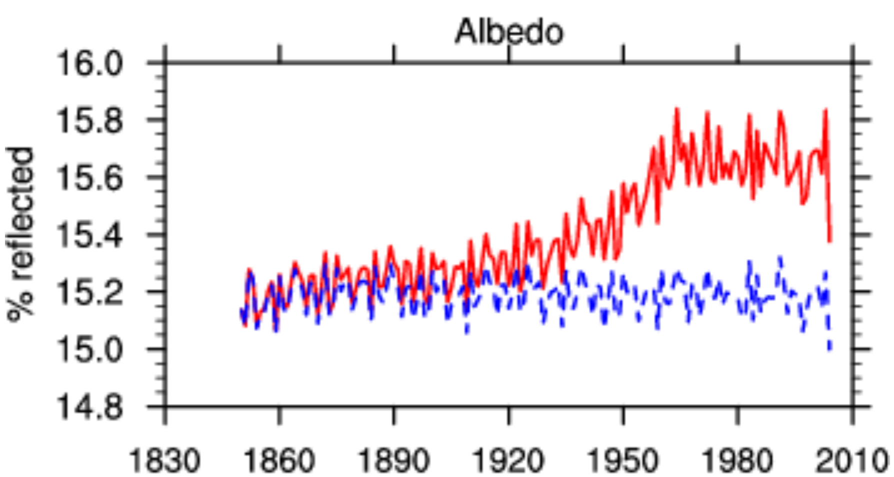
Eastern United States



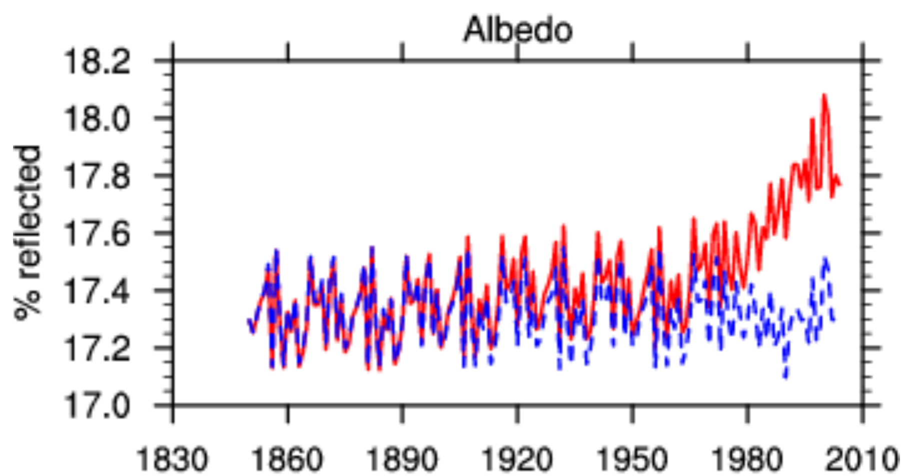
Europe



India

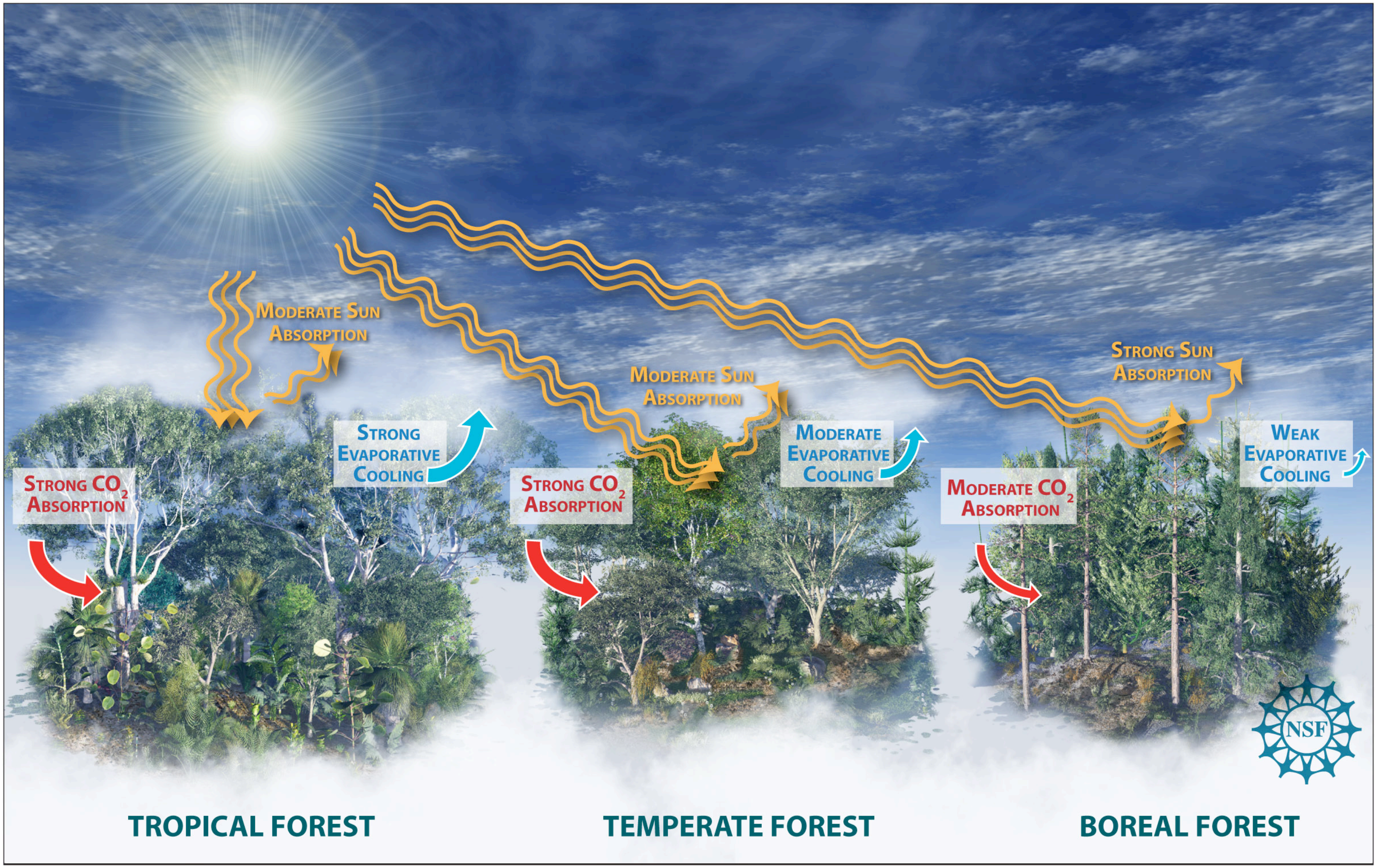


Eastern China



Forests and climate change

Multiple competing influences of ecosystems



Bonan (2008) Science 320:1444-1449

Credit: *Nicolle Rager Fuller, National Science Foundation*

Ecosystems and climate policy

Boreal forest – menace to society – no need to promote conservation

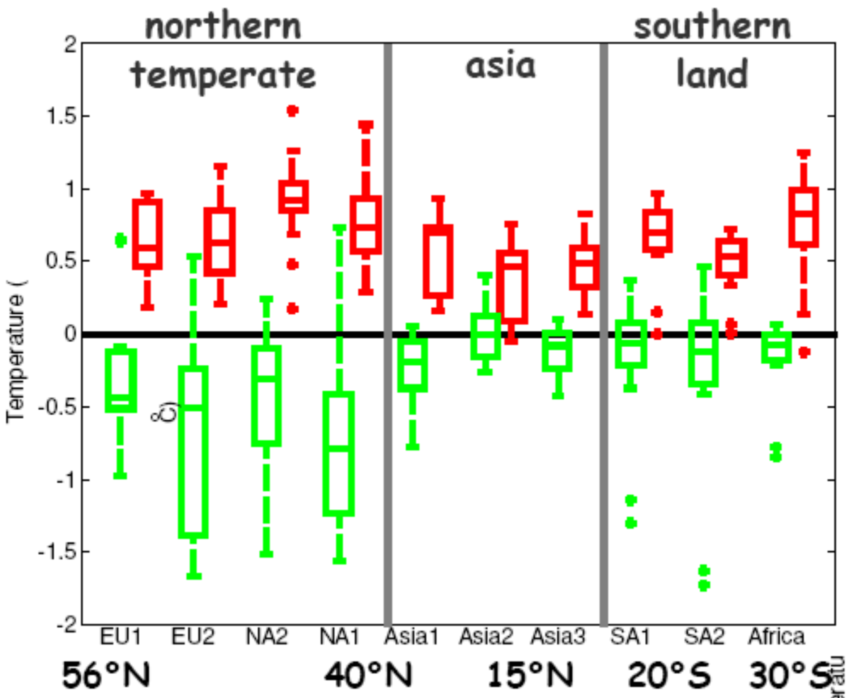
Temperate forest – reforestation and afforestation?

Tropical rainforest – planetary savior – promote avoided deforestation, reforestation, or afforestation

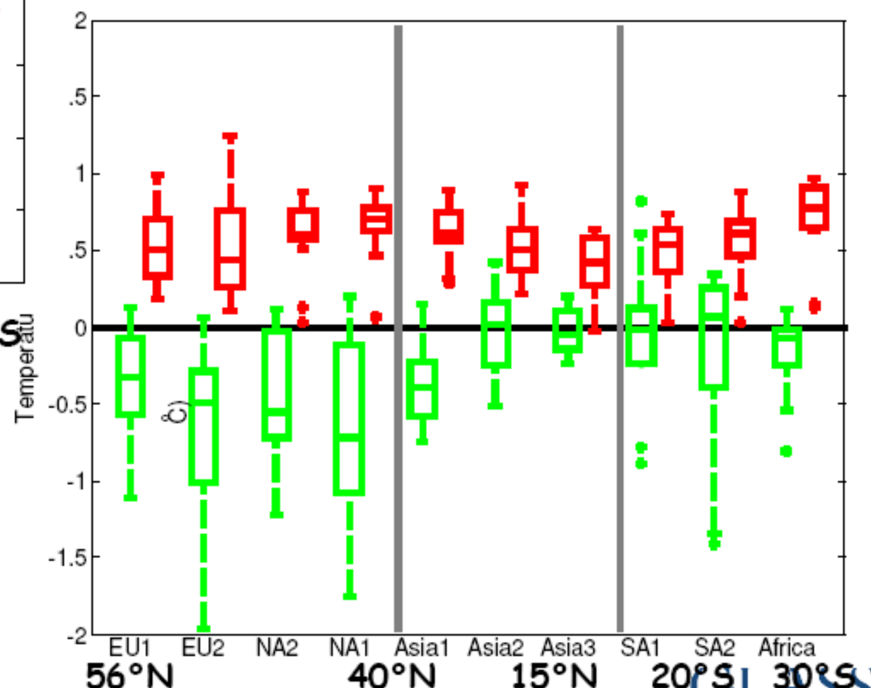
Biofuel plantations to lower albedo and reduce atmospheric CO_2

Relative importance of a) land-cover changes .vs. b) changes in SSTs, SiC and CO_2 concentration on the simulated surface climate

Changes in ambient air temperature (°C ; summer-JJA ; spring – MAM)



- → magnitude of changes = same order
- → larger dispersion resulting from LCC in temperate regions
- → Opposite regional changes (LCC dampens the climate signal ?)



Impact of LCC
Impact of SSTs+SiC+CO_2

iLEAPS

GLASS