Modeling the integrated ecology, biogeochemistry, and hydrology of the global terrestrial biosphere in the Community Land Model (CLM4)

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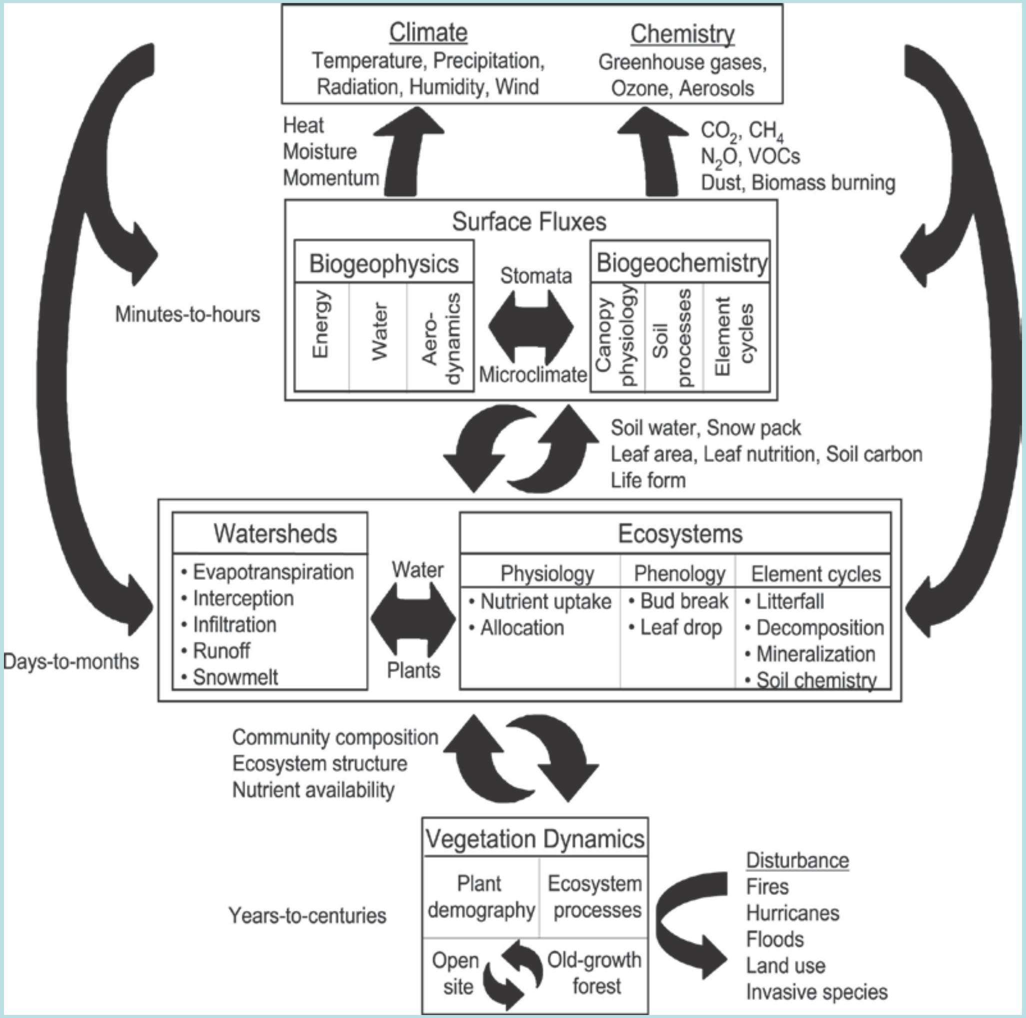
17 December 2010
2010 AGU Fall Meeting
San Francisco, California

NCAR is sponsored by the National Science Foundation

Multi-disciplinary science



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

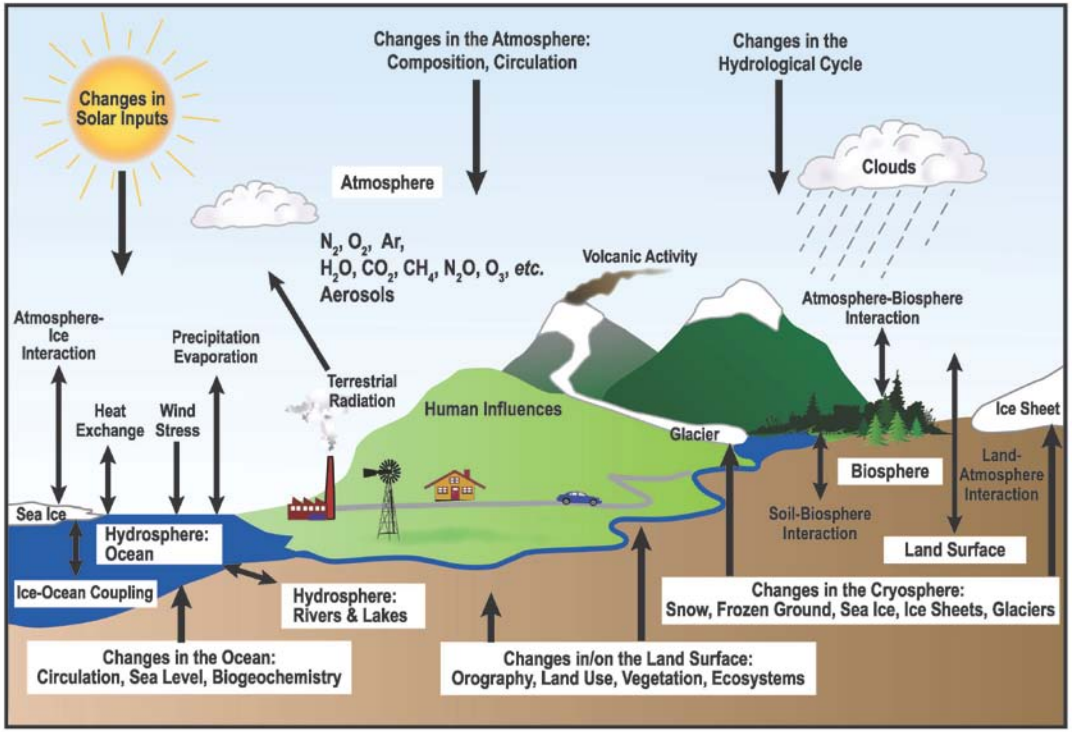
Ecosystem-climate models

- ❑ Terrestrial ecosystems influence climate through physical, chemical, and biological processes that affect planetary energetics, the hydrologic cycle, and atmospheric composition
- ❑ The hydrologic cycle regulates ecosystem-climate coupling
- ❑ The simulated hydrologic cycle is an emergent property of the ecology and biogeochemistry represented in the model

Two examples

- ❑ Photosynthesis and evapotranspiration
- ❑ Anthropogenic land cover change

The Community Earth System Model



(IPCC 2007)

Earth system models use mathematical formulas to simulate the **physical**, **chemical**, and **biological** processes that drive Earth's atmosphere, hydrosphere, biosphere, and geosphere

A typical Earth system model consists of coupled models of the **atmosphere**, **ocean**, **sea ice**, and **land**

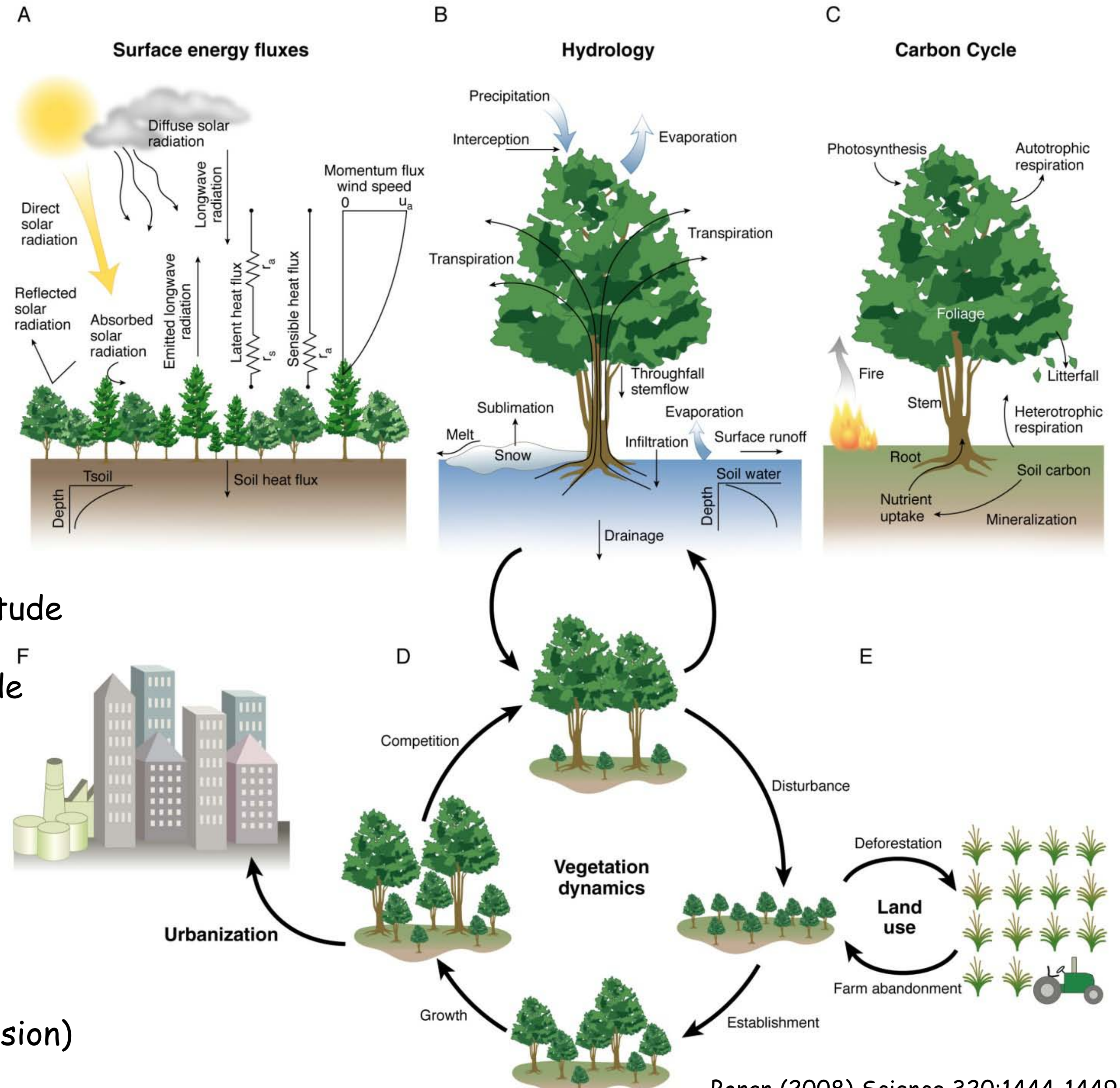
Land is represented by its **ecosystems**, **watersheds**, **people**, and **socioeconomic** drivers of environmental change

The model provides a comprehensive understanding of the processes by which people and ecosystems **feed back**, **adapt to**, and **mitigate** global environmental change

The Community Land Model

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

Oleson et al. (2010) NCAR/TN-478+STR



Spatial scale

- 1.25° longitude × 0.9375° latitude (288 × 192 grid)
- 2.5° longitude × 1.875° latitude (144 × 96 grid)

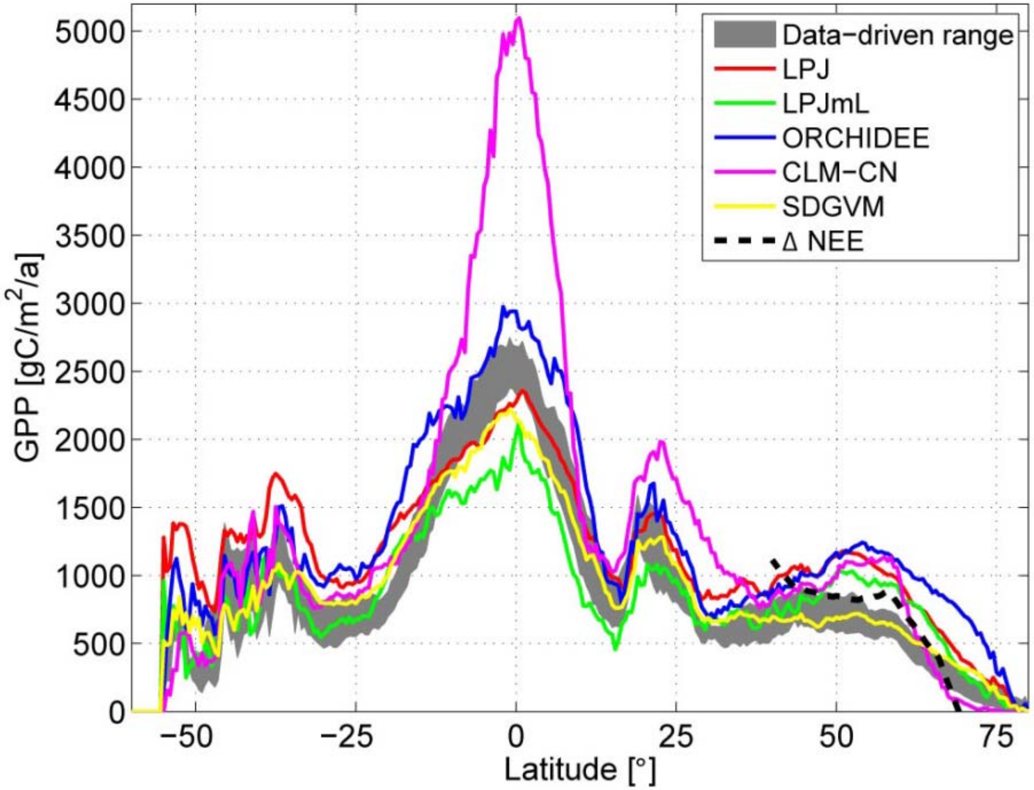
Temporal scale

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

Bonan (2008) Science 320:1444-1449

Gross primary production biases

CLM4 (purple line) overestimates annual gross primary production (GPP) compared with data-driven estimates and other models



Beer et al. (2010) Science 329:834-838

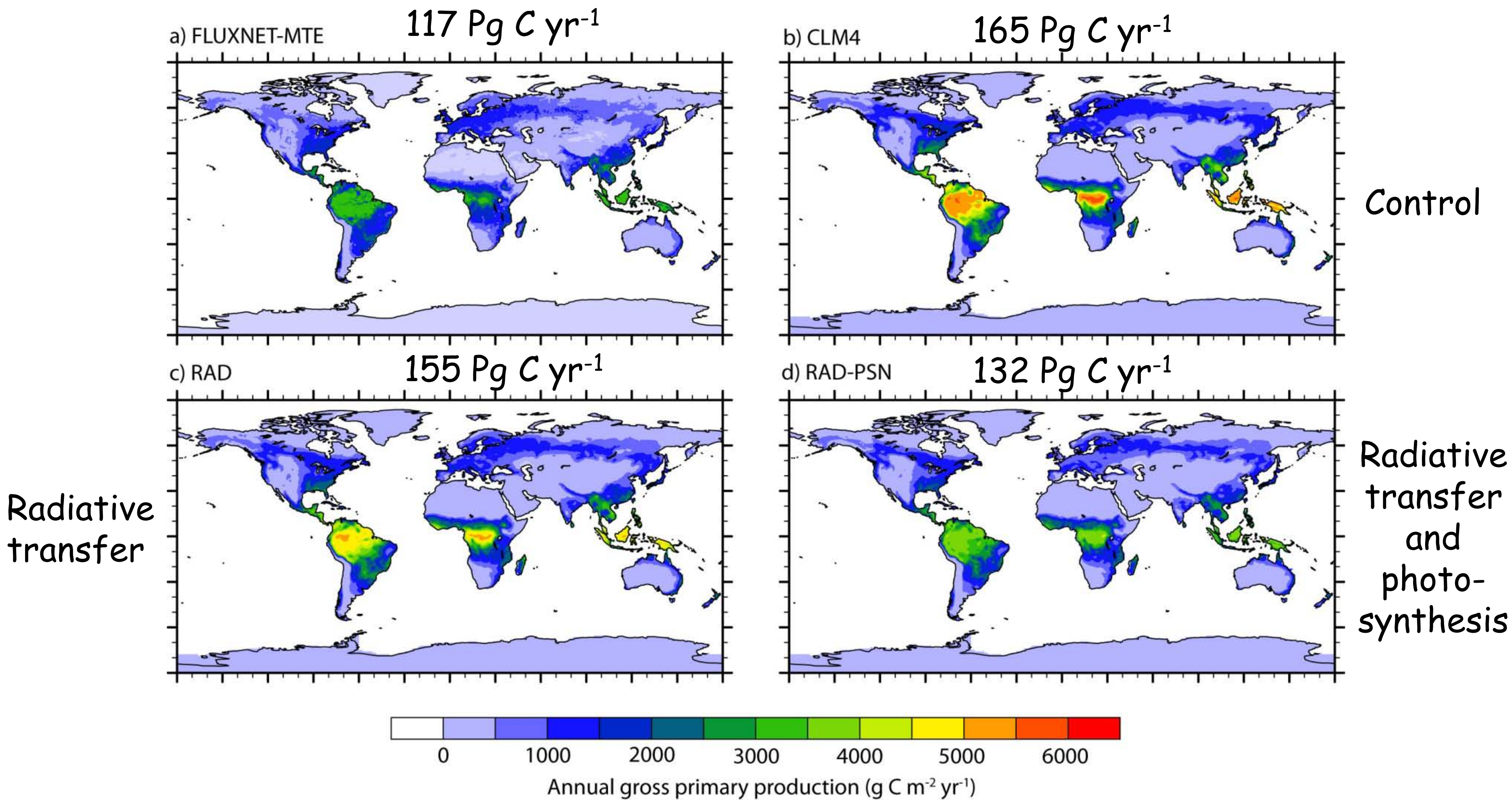
Causes of GPP bias

Model structural error
Canopy radiative transfer
Photosynthesis-stomatal conductance
Canopy integration

Model parameter uncertainty
Vcmax

Bonan et al. (2010) JGR-Biogeosciences, submitted

Gross primary production bias reduction (1982-2004)

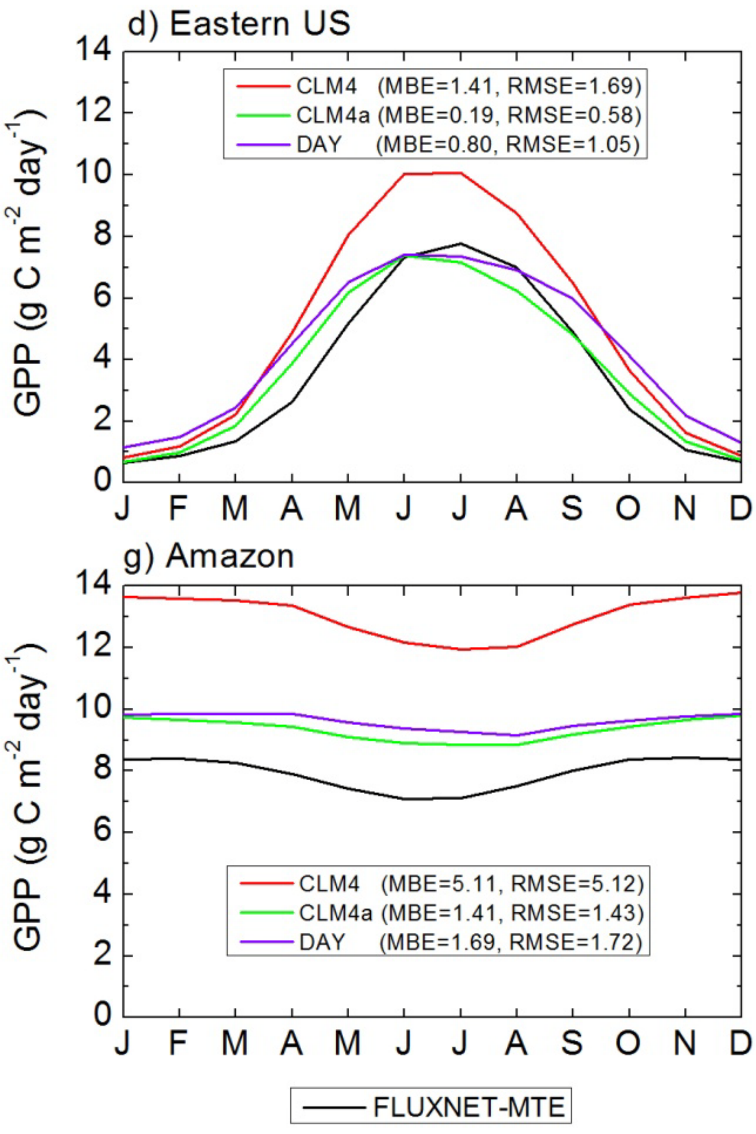


Model improvements (RAD-PSN [CLM4a]) reduce annual GPP biases in tropics and extra-tropics compared with CLM4. Similar improvements are seen in monthly fluxes.

FLUXNET-MTE data from Martin Jung and Markus Reichstein (M-P-I Biogeochemistry)

Bonan et al. (2010) JGR-Biogeosciences, submitted

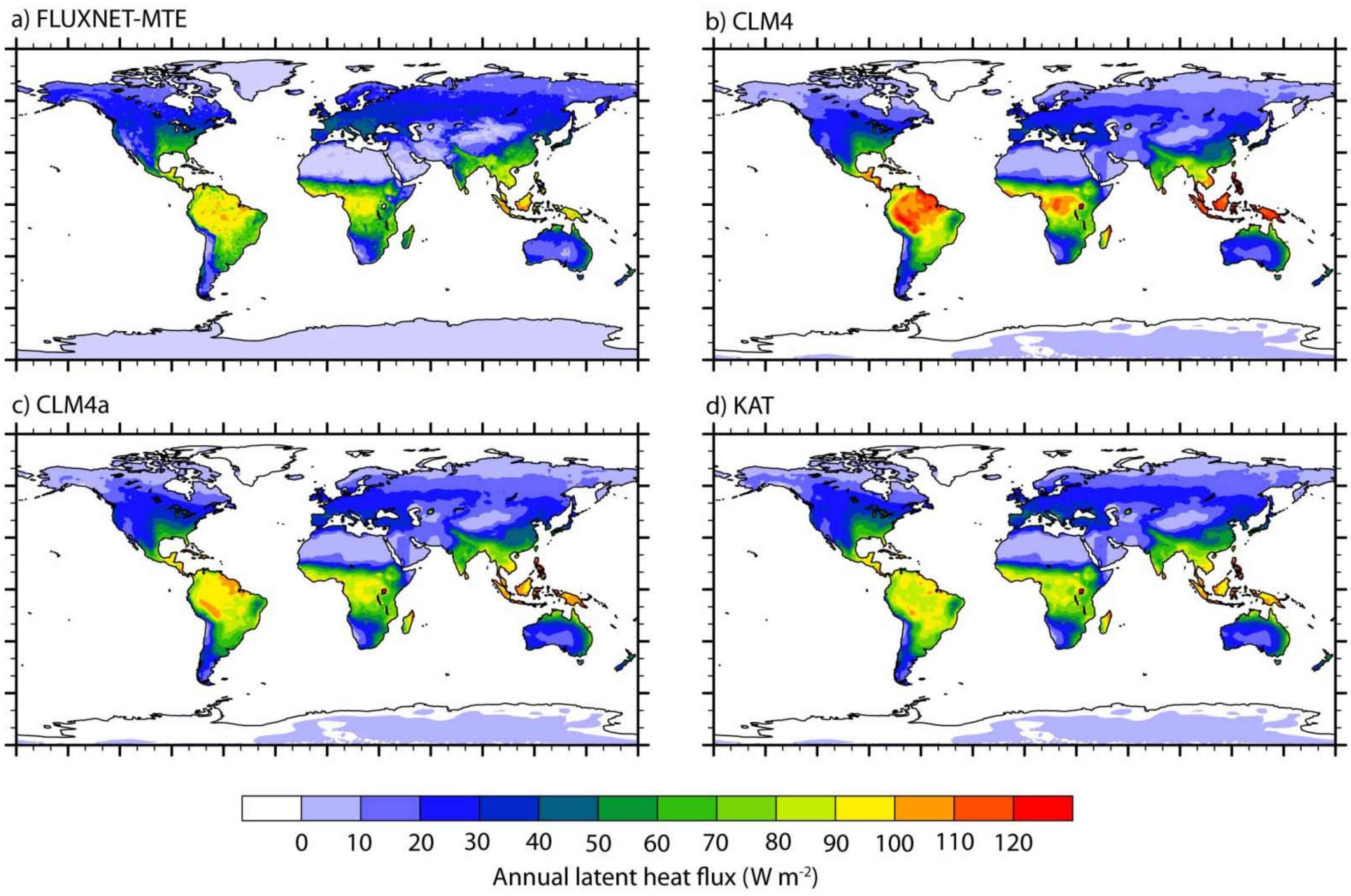
Improved annual cycle



CLM4a (green) has improved monthly fluxes compared with CLM4 (red) and FLUXNET-MTE (black)

Bonan et al. (2010) JGR-Biogeosciences, submitted

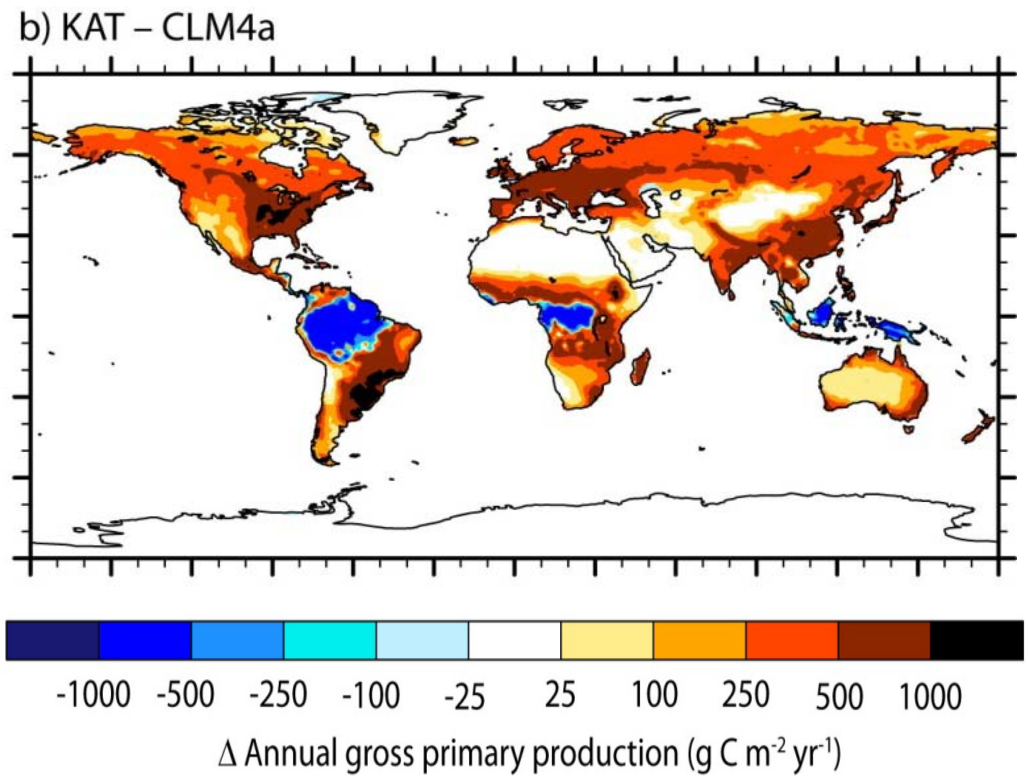
Improved annual latent heat flux



Model improvements (CLM4a) reduce ET biases, especially in tropics

Bonan et al. (2010) JGR-Biogeosciences, submitted

Vcmax parameter uncertainty



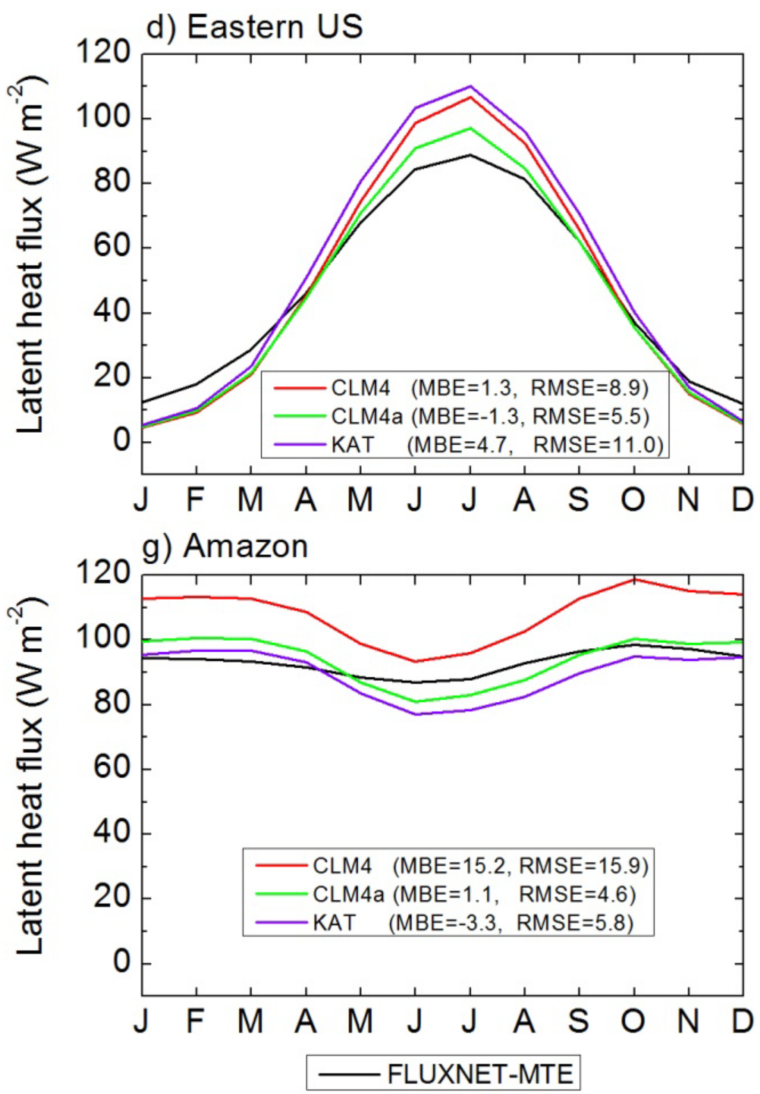
Simulation	Global GPP ($Pg\ C\ yr^{-1}$)
CLM4	165
CLM4a	130
KAT	164

CLM4 Vcmax values differ from synthesis studies (Kattge et al., 2009, GCB 15:976–991)

Parameter uncertainty produces effects of comparable magnitude as model structural errors, but of offsetting sign

Bonan et al. (2010) JGR-Biogeosciences, submitted

Vcmax and monthly latent heat flux

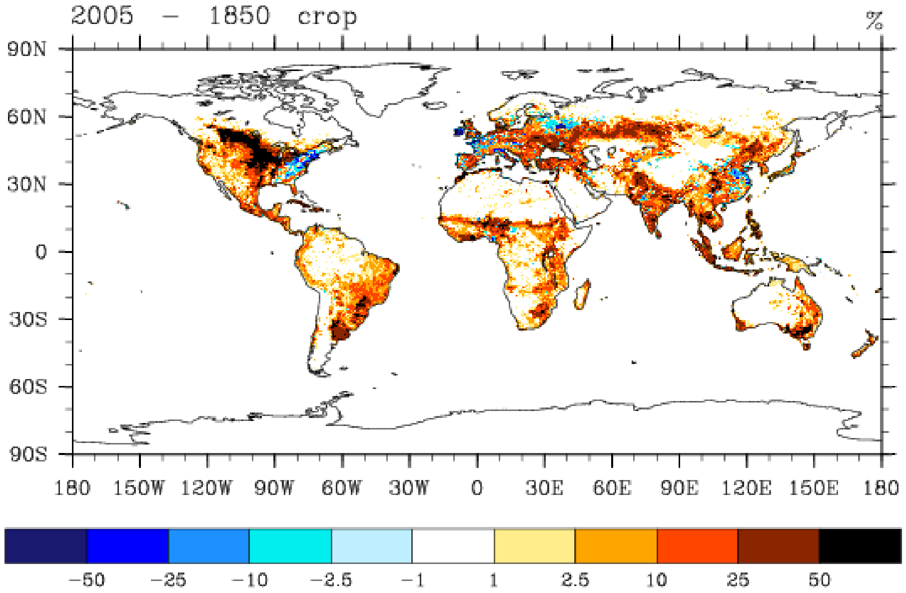


CLM4a (green) has improved monthly fluxes compared with CLM4 (red), Kattge et al. [2009] Vcmax (purple), and FLUXNET-MTE (black)

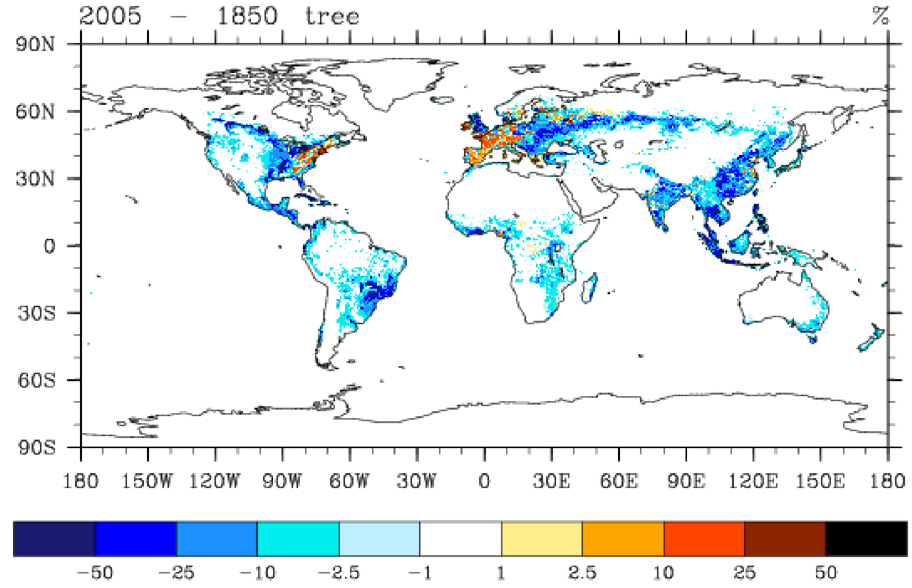
Bonan et al. (2010) JGR-Biogeosciences, submitted

Historical land cover change, 1850 to 2005

Crop PFT



Tree PFTs



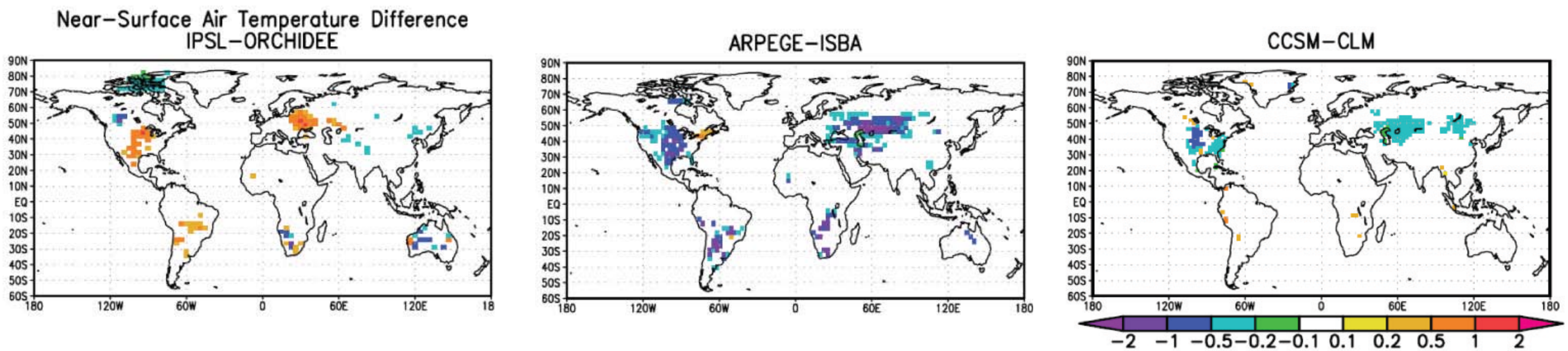
(datasets by Peter Lawrence & Johan Feddema)

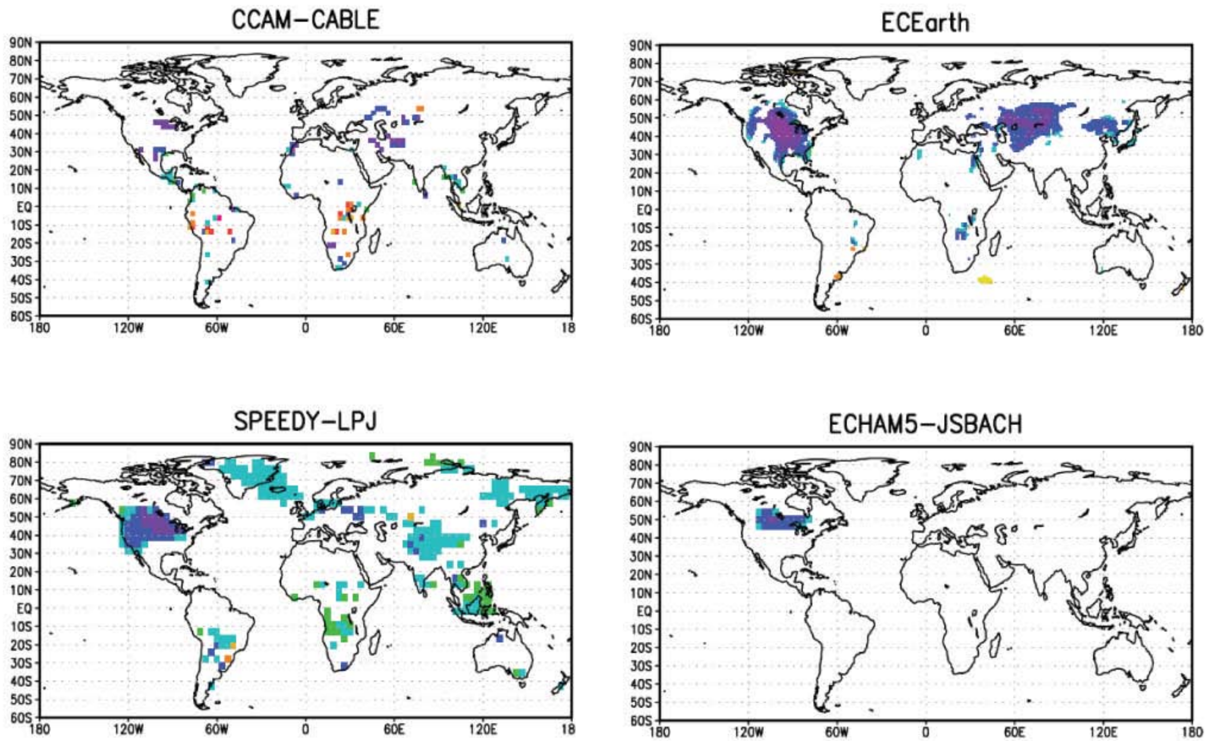
Prevailing paradigm

- ❑ Anthropogenic land cover change cools mid-latitude climate, primarily from increased surface albedo
- ❑ Land use carbon emissions warms climate

How does this understanding depend on hydrology?

The LUCID intercomparison study

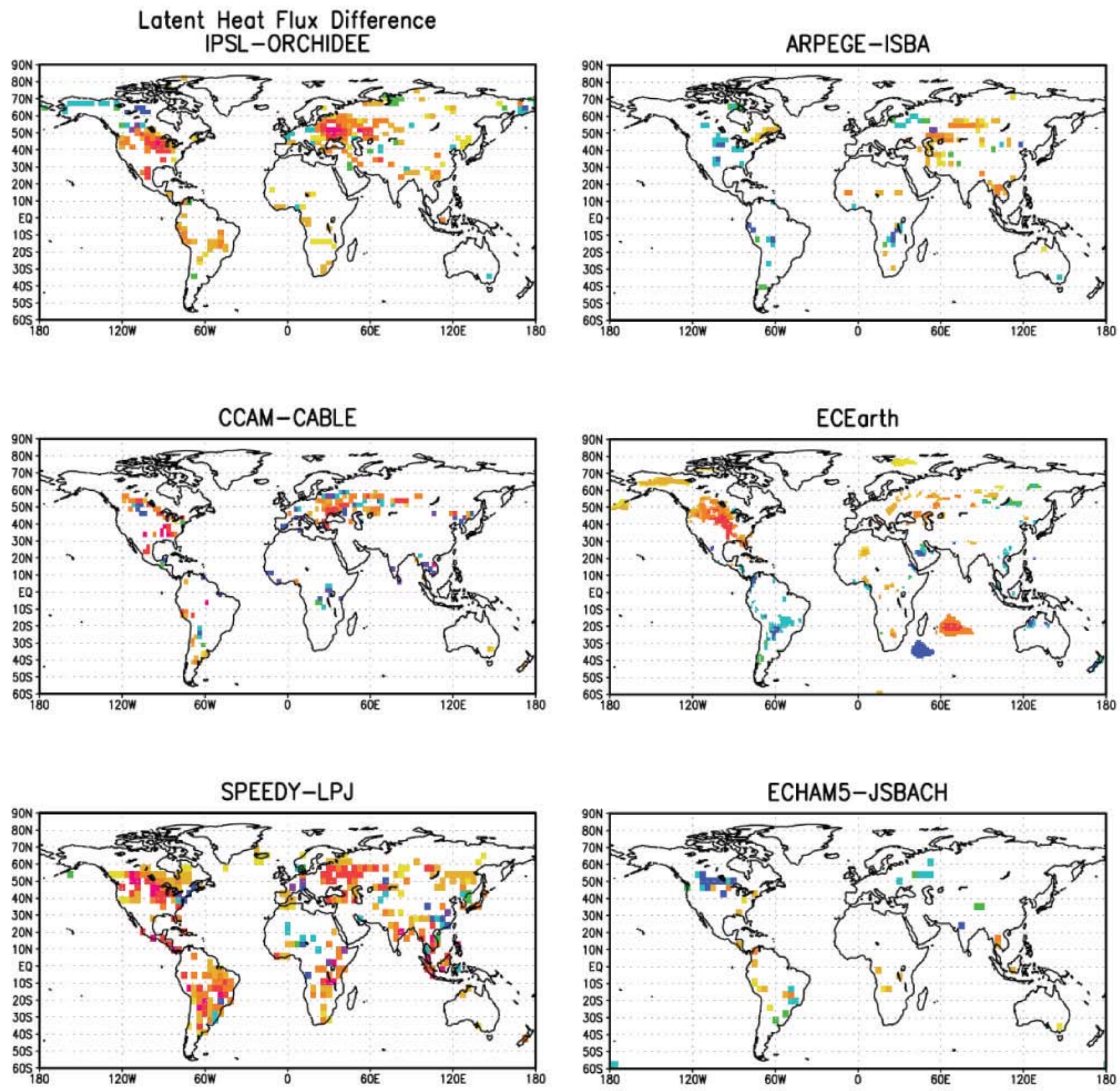


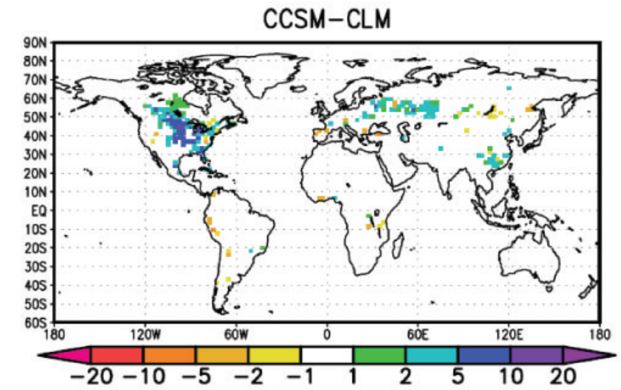


Change in JJA near-surface air temperature (°C) resulting from land cover change (PD – PDv)

Pitman, de Noblet-Ducoudré, et al. (2009) GRL, 36, doi:10.1029/2009GL039076

The LUCID intercomparison study





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

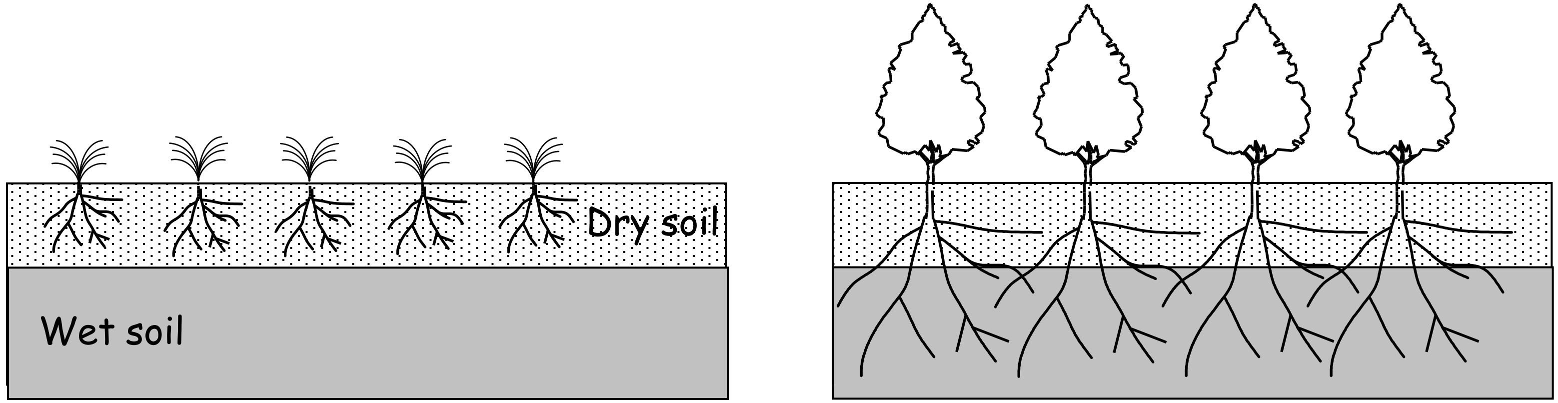
Pitman, de Noblet-Ducoudré, et al. (2009) GRL, 36, doi:10.1029/2009GL039076

Land cover change and evapotranspiration

Prevailing model paradigm

Crops
Low latent heat flux because of:
- Low roughness
- Shallow roots decrease soil water availability

Trees
High latent heat flux because of:
- High roughness
- Deep roots allow increased soil water availability

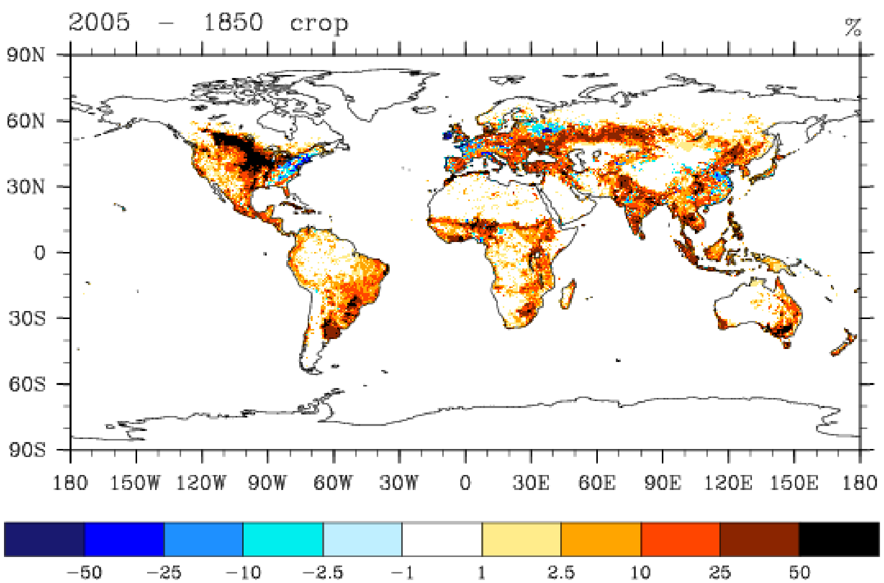


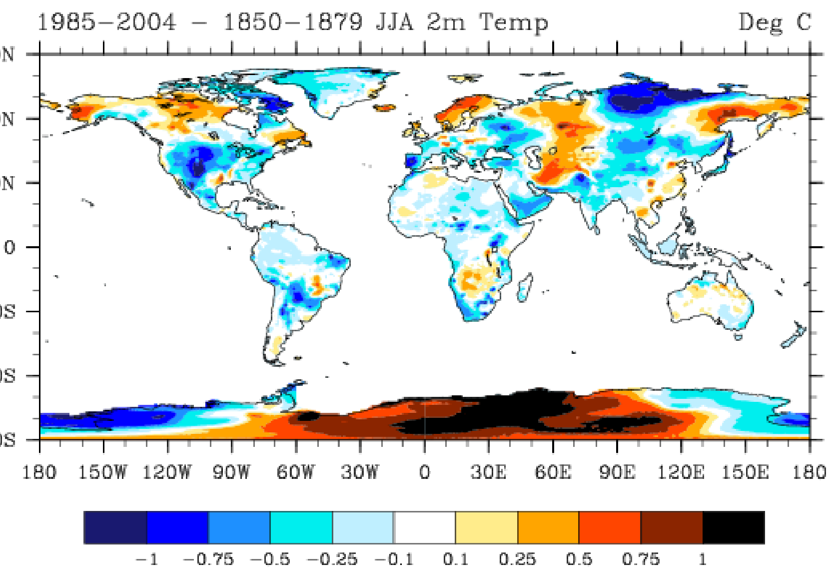
Tropical forest – cooling from higher surface albedo of cropland and pastureland is offset by warming associated with reduced evapotranspiration

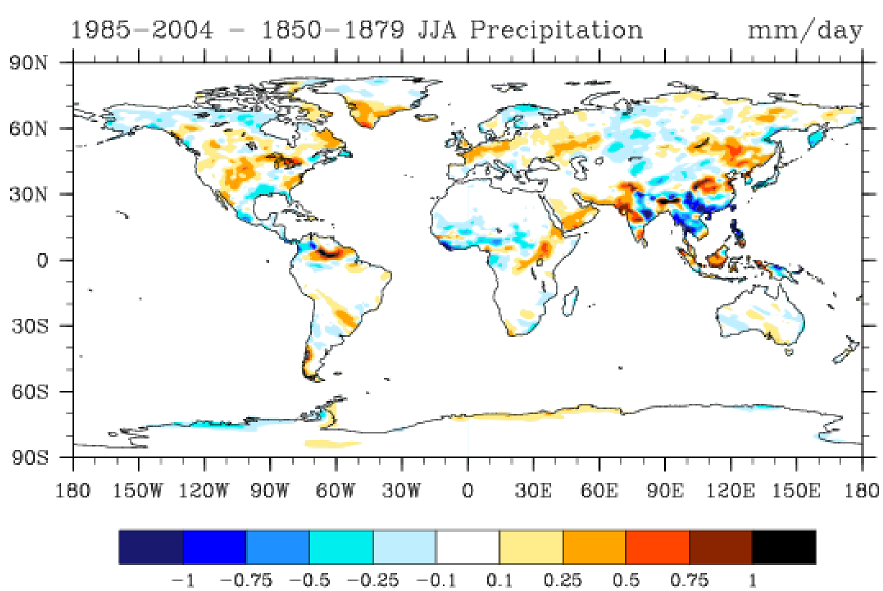
Temperate forest - higher albedo leads to cooling, but changes in evapotranspiration can either enhance or mitigate this cooling

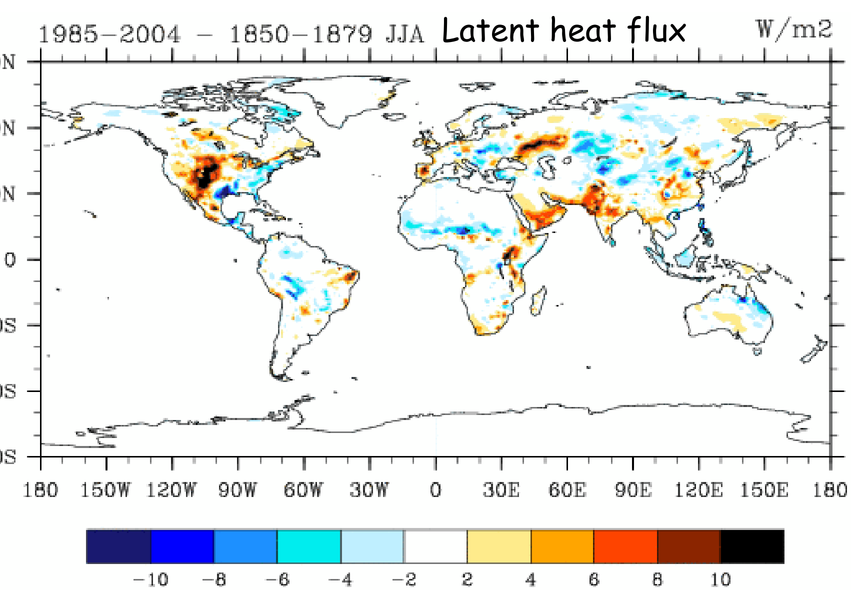
Bonan (2008) Science 320:1444-1449

Community Earth System Model, CESM1 (single forcing)









Conclusions

Integrated ecology, biogeochemistry, and hydrology

Terrestrial ecosystems influence climate through physical, chemical, and biological processes that affect planetary energetics, the hydrologic cycle, and atmospheric composition

Photosynthesis-evapotranspiration coupling

- Improvements to GPP also improve ET
- Effect of model parameter errors on GPP and ET is comparable to, but offsetting, that of model structural errors
- The hydrologic cycle is an emergent property of the ecology and biogeochemistry represented in the model
- Suggest that we still have much to learn about photosynthesis, evapotranspiration, and how to represent these processes in models of the terrestrial biosphere for climate simulation

Anthropogenic land cover change

- Higher albedo of croplands cools climate
- Less certainty about role of evapotranspiration