Forests and climate change

Multiple competing influences of ecosystems

TROPICAL FOREST  TEMPERATE FOREST  BOREAL FOREST
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 CO₂
Fluxes of energy, water, and carbon and the dynamical processes that alter these fluxes

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

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

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

Outline of talk

1. Carbon cycle - climate feedback
   Nitrogen cycle and model evaluation

2. Land use and land cover change

   2a. Biogeochemical
       Wood harvesting
       Land use carbon flux

   2b. Biogeophysical
       Albedo and evapotranspiration
**Effect of climate change on carbon cycle**

![Graph showing atmospheric CO2 difference over time](image)

**Climate-carbon cycle feedback**

- 11 carbon cycle-climate models of varying complexity
- All models have a positive climate-carbon cycle feedback (20 ppm to >200 ppm)
- Atmospheric carbon increases compared with no climate-carbon cycle feedback, while land carbon storage decreases

**Prevailing model paradigm**

- CO₂ fertilization enhances plant productivity, offset by decreased productivity and increased soil carbon loss with warming ...

But what about the nitrogen cycle and land use?
Inclusion of N cycle reduces CO$_2$ fertilization ($\beta_L$) and changes carbon cycle-temperature feedback ($\gamma_L$) from positive to negative

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

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
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
Simulated atmospheric CO₂ 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 leads to high atmospheric CO₂ and introduces a negative carbon cycle-climate feedback

Thornton et al. (2009) Biogeosciences Discuss., 6, 3303-3354
Land biosphere response to $CO_2$  

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 $CO_2$ fertilization ($\beta_L$) and changes carbon cycle-temperature feedback ($\gamma_L$) negative
"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

Global Change Biology, in press, 2009
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
Annual cycle $CO_2$ fluxes

Ameriflux eddy covariance measurements

Randerson et al. (2009) GCB, in press
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
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
C-N interactions influence location of carbon sinks

C-TEM has larger sinks in the tropics and warmer temperate regions.

CN-TEM has larger sinks in boreal and cooler temperate regions.

Sokolov et al. (2008) J Climate 21:3776-3796
Carbon-only simulation of late-20th century is indistinguishable from C-N simulation, as compared with Global Carbon Project estimates of land carbon uptake.

Net land flux = -Residual flux + Land use

Global Carbon Project (www.globalcarbonproject.org)
1. For IPCC AR5 land use and land cover change are to be described consistently with Representative Concentration Pathways (RCP) scenarios.

2. All pathways share the same historical trajectory to 2005. After 2005 they diverge following own representative pathway.

3. For the historical period and for each RCP, land use that results in land cover change is described through annual changes in four basic land units:
   - Primary Vegetation (V)
   - Secondary Vegetation (S)
   - Cropping (C)
   - Pasture (P)

4. Harvesting of biomass is also prescribed for both primary and secondary vegetation land units.

5. George Hurtt and colleagues at University of New Hampshire are harmonizing the historical and RCP data.
Historical land cover change, 1850 to 2005

Tree PFTs

Crop PFT

Shrub PFTs

Grass PFTs

Feddema, Lawrence et al., unpublished
Future land cover change, 2005 to 2100

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

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

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

**AIM (RCP 6.0 W m^{-2})**

(In development)

Feddema, Lawerence et al., unpublished
Future land cover change, 2005 to 2100 (RCPs)

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

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

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

AIM (RCP 6.0 W m$^{-2}$)

(In development)

Feddema, Lawerence et al., unpublished
Land use - wood harvest

Primary Harvest 1971 - 2000

Secondary Young Forest Harvest 1971 - 2000

Secondary Mature Forest Harvest 1971 - 2000

Feddema, Lawerence et al., unpublished
Carbon flux to wood products

Wood harvesting

Land cover change (e.g., deforestation)

(simulations by Sam Levis)
Land use carbon flux to atmosphere

C Fluxes to the Atmosphere from Land Conversion & from Product Decomposition

Wood harvesting

Land cover change (e.g., deforestation)

Annual Emissions to the Atmosphere (PgC)

(simulations by Sam Levis)
Land use carbon flux to atmosphere

Land Use Carbon Flux: CLM DWT_CLOSS+PRODUCT_CLOSS vs. GCP

Three different harvest algorithms

Global Carbon Project (www.globalcarbonproject.org)

(simulations by Sam Levis)
Three different harvest algorithms. Increased GPP compensates for increased land use flux.

Global Carbon Project
(www.globalcarbonproject.org)

Net land flux = -Residual flux + Land use

(simulations by Sam Levis)
The LUCID intercomparison study

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

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

MULTI-MODEL ENSEMBLE OF GLOBAL LAND USE CLIMATE FORCING (1992-1870)

SEVEN CLIMATE MODELS OF VARYING COMPLEXITY WITH IMPOSED LAND COVER CHANGE (1992-1870)


No irrigation
The LUCID intercomparison study

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

The LUCID intercomparison study

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

Land cover change, 1870 to 1992
Albedo forcing, 1992-1870

Present Day - 1870 DJF Surface Albedo

Present Day - 1870 MAM Surface Albedo

Present Day - 1870 JJA Surface Albedo

Present Day - 1870 SON Surface Albedo
Near-surface temperature, 1992-1870

Present Day - 1870 DJF Atmospheric Temperature

Present Day - 1870 MAM Atmospheric Temperature

Present Day - 1870 JJA Atmospheric Temperature

Present Day - 1870 SON Atmospheric Temperature
Climate models simulate the large-scale response and include feedbacks with the atmosphere:

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

Flux towers measure local response
Land cover change with CO$_2$ = 280 ppm (1870) and CO$_2$ = 375 ppm (1992) offsets greenhouse gas warming.

CO$_2$ forcing with 1870 land cover.
Monthly shortwave surface albedo for dominant US land cover types in the Northeast (b) and Southeast (d)


- Cropland has a high winter and summer albedo compared with forest
- Higher summer albedo
- Forest masking
CLM albedo land use forcing (present-day minus potential vegetation)

Expected (MODIS) DJF

Modeled (CLM) DJF

(Present-day vegetation - Potential vegetation)
Units are Δalbedo × 100

Land cover change and evapotranspiration

Prevailing model paradigm

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

**Trees**
High latent heat flux because of:
- Increased roughness length
- 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.

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

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
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.