Climate change mitigation through ecosystem management

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Multi-model mean surface warming (relative to 1980-1999) for the scenarios A2, A1B and B1

Multi-model mean warming and uncertainty for 2090 to 2099 relative to 1980 to 1999:

A2:  +3.4°C (2.0°C to 5.4°C)
A1B: +2.8°C (1.7°C to 4.4°C)
B1:   +1.8°C (1.1°C to 2.9°C)


For 5th assessment report
- As land cover change and the carbon cycle are added as climate forcings and feedbacks, will uncertainty in these simulations increase?
- Can ecosystems be managed to mitigate climate change?
Future IPCC SRES land cover scenarios for NCAR LSM/PCM

Land use choices affect 21st century climate

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
Land use choices affect 21st century climate

Change in temperature due to land cover

**B1**
- Weak temperate warming
- Weak tropical warming

**A2**
- Temperate cooling
- Tropical warming

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

A2 - cooling with widespread cropland
B1 - warming with temperate reforestation

Biogeochemical

A2 - large warming with 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

MESSAGE (RCP 8.5) vs IMAGE (RCP 3.0)

Less primary land, more secondary land, more cropland and pastureland

Hurtt et al. (UNH), unpublished
Forests and climate change

Multiple competing influences of land cover change

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 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
2.5º longitude × 1.875º latitude

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

CLM represents a model grid cell as a mosaic of up to 6 primary land cover types. Vegetated land is further represented as a mosaic of several plant functional types.

Local land use is spatially heterogeneous

NSF/NCAR C-130 aircraft above a patchwork of agricultural land during a research flight over Colorado and northern Mexico

Global land use is abstracted to the fractional area of crops and pasture

Foley et al. (2005) Science 309:570-574
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 \((CO_2 = 375 \text{ ppm}, \text{SSTs} = 1972-2001)\)
   - PD - 1992 vegetation
   - PDv - 1870 vegetation
30-year simulations \((CO_2 = 280 \text{ ppm}, \text{SSTs} = 1871-1900)\)
   - PI - 1870 vegetation
   - PIv - 1992 vegetation

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

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

No irrigation

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

Land cover change can be regionally significant relative to other anthropogenic climate forcings, but the uncertainty in the land use forcing is large.

Pitman et al. (2009) GRL, submitted
Change in JJA latent heat flux (W m$^{-2}$) resulting from land cover change (PD - PDv)

Pitman et al. (2009) GRL, submitted
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
Precipitation, 1992-1870

Present Day - 1870 DJF Precipitation (mm day\(^{-1}\))

Present Day - 1870 MAM Precipitation (mm day\(^{-1}\))

Present Day - 1870 JJA Precipitation (mm day\(^{-1}\))

Present Day - 1870 SON Precipitation (mm day\(^{-1}\))
Increased rainfall enhances latent heat flux
Increased cloudiness reduces solar radiation
Reduced PBL height

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
122 grid cells, 30-50 °N, east of 100 °W
North America (June-August)

119 grid cells, 45-60 °N, 15-50 °E
Europe (June-August)

ΔT = -0.24 - 0.02  ΔLH, r² = 0.18
ΔT = -0.27 - 0.01  ΔS_{net}, r² = 0.02

ΔT = -0.46 - 0.04  ΔLH, r² = 0.48
ΔT = -0.46 - 0.02  ΔS_{net}, r² = 0.05
Land cover change with CO$_2$ = 280 ppm (1870)

Land cover change with CO$_2$ = 375 ppm (1992)

Land cover change offsets greenhouse gas warming

CO$_2$ forcing with 1870 land cover
North America: 122 grid cells east of 100 °W and between 30-50 °N

<table>
<thead>
<tr>
<th></th>
<th>Forest (n=69)</th>
<th>Grassland (n=18)</th>
<th>Savanna (n=35)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1870</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tree (%)</td>
<td>78</td>
<td>4</td>
<td>50</td>
</tr>
<tr>
<td>Grass (%)</td>
<td>4</td>
<td>83</td>
<td>42</td>
</tr>
<tr>
<td>Crop (%)</td>
<td>10</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td><strong>1992-1870</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ΔTree (%)</td>
<td>-21</td>
<td>-3</td>
<td>-21</td>
</tr>
<tr>
<td>ΔGrass (%)</td>
<td>3</td>
<td>-40</td>
<td>-16</td>
</tr>
<tr>
<td>ΔCrop (%)</td>
<td>18</td>
<td>44</td>
<td>37</td>
</tr>
<tr>
<td>ΔLAI (m² m⁻²)ᵃ</td>
<td>-0.29</td>
<td>0.07</td>
<td>-0.43</td>
</tr>
<tr>
<td>ΔSAI (m² m⁻²)ᵃ</td>
<td>-0.15</td>
<td>-0.10</td>
<td>-0.25</td>
</tr>
</tbody>
</table>

ᵃ June-August

Decrease in LAI, SAI, and roughness explain part of the surface forcing

<table>
<thead>
<tr>
<th></th>
<th>z₀ (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NET</td>
<td>94</td>
</tr>
<tr>
<td>BDT</td>
<td>110</td>
</tr>
<tr>
<td>Grass</td>
<td>6</td>
</tr>
<tr>
<td>Crop</td>
<td>6</td>
</tr>
</tbody>
</table>
Leaf and stem albedo

<table>
<thead>
<tr>
<th></th>
<th>NET</th>
<th>BDT</th>
<th>Grass</th>
<th>Crop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaf</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VIS</td>
<td>0.02</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>NIR</td>
<td>0.11</td>
<td>0.24</td>
<td>0.20</td>
<td>0.20</td>
</tr>
<tr>
<td>Diffuse</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VIS</td>
<td>0.03</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>NIR</td>
<td>0.16</td>
<td>0.31</td>
<td>0.28</td>
<td>0.28</td>
</tr>
<tr>
<td>Stem</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VIS</td>
<td>0.03</td>
<td>0.03</td>
<td>0.09</td>
<td>0.09</td>
</tr>
<tr>
<td>NIR</td>
<td>0.09</td>
<td>0.10</td>
<td>0.26</td>
<td>0.26</td>
</tr>
<tr>
<td>Diffuse</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VIS</td>
<td>0.05</td>
<td>0.06</td>
<td>0.14</td>
<td>0.14</td>
</tr>
<tr>
<td>NIR</td>
<td>0.15</td>
<td>0.16</td>
<td>0.37</td>
<td>0.37</td>
</tr>
</tbody>
</table>

Albedo depends on: leaf and stem reflectance and transmittance, leaf orientation, leaf area index, stem area index, soil color, soil water, snow, and zenith angle. Calculations are for LAI = 6 m² m⁻² or SAI = 6 m² m⁻², soil albedo of 0.1 (visible) and 0.2 (near-infrared), and zenith angle = 30°.

Light-saturated photosynthesis and stomatal conductance under optimal conditions

<table>
<thead>
<tr>
<th></th>
<th>A (µmol CO₂ m⁻² s⁻¹)</th>
<th>gₛ (mm s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NET</td>
<td>11.5</td>
<td>4.6</td>
</tr>
<tr>
<td>BDT</td>
<td>9.4</td>
<td>5.6</td>
</tr>
<tr>
<td>C3 grass</td>
<td>10.6</td>
<td>6.3</td>
</tr>
<tr>
<td>C4 grass</td>
<td>31.2</td>
<td>10.5</td>
</tr>
<tr>
<td>Crop</td>
<td>11.8</td>
<td>7.0</td>
</tr>
</tbody>
</table>

Increase in albedo and stomatal conductance explain part of the surface forcing.
Offline CLM3.5 simulations with NCEP-derived forcing (1972-2001) using 1870 and 1992 land cover

Contour plots (PD-PDv) for 122 grid cells east of 100 °W and between 30-50 °N

Loss of tree cover
- Decreases LAI
- Decreases $S_{\text{net}}$
- Increases LH flux
- Decreases SH flux
Land cover change has cooled temperature of mid-latitudes, especially in summer
- Increased albedo, increased latent heat flux, and decreased sensible heat flux
- Atmospheric feedbacks: clouds, precipitation, PBL height
- The climate forcing is robust with respect to atmosphere (1870 vs 1992)
- Can be regionally important relative to greenhouse gas warming

The surface forcing
- Relatively small: ~10 W m⁻² changes in \( R_n \), LH flux, SH flux
- Related to changes in roughness, LAI, SAI
- Related to higher albedo and stomatal conductance of crops relative to trees
  - NET vs crop is particularly important
- Root profile is not important but
  - Relatively minor differences among plant functional types
  - Soils are wet
  - No deep roots or hydraulic redistribution
- Latent heat flux increases, mostly in soil evaporation
Monthly shortwave surface albedo for dominant US land cover types in the Northeast (b) and Southeast (d)


Cropland increases surface albedo

Cropland has a high winter and summer albedo compared with forest

Higher summer albedo

Forest masking
Albedo land use forcing

Expected

Current day - potveg DJF Albedo

Modeled

MODIS - potveg (new) DJF Albedo

Current day - potveg JJA Albedo

MODIS - potveg (new) JJA Albedo

Units are $\Delta \text{albedo} \times 100$
Summer air temperature difference (present day - natural vegetation)

LSM biome dataset

PFT dataset

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

**Temperate deforestation warms climate**

**RAMS with LEAF-2**
6-member July simulations

**Land cover**
- **1700**
- **1910**
- **1990**

**Dominant vegetation**
- Cropland
- Desert
- Semi-desert
- Grassland
- Woodland
- Broadleaf deciduous tree
- Needleleaf evergreen tree

**July temperature difference**
- **1910-1700**
- **1990-1910**
- **1990-1700**

Grass → crop: Increased ET
Forest → crop: Increased albedo, reduced $z_0$, reduced ET (rooting depth)

Observations: FLUXNET, a global network

Used Sites in our study:
- Fort Peck (2000-2005)
- Boreas (1994-2005)
- Tapajos KM67 (2002-2005)
- Castelporziano (2000-2005)
- El Saler (1999-2005)
- Kaamanen (2000-2005)
- Hyvliötä (1997-2005)
- Vielsalm (1997-2005)

Color Legend:
- temperate
- tropical
- boreal
- sub-alpine
- north-boreal
- Mediterranean

300+ sites covering global range of climates & ecosystems

15 sites

Climate gradient
- Tundra, boreal, subalpine, temperate, Mediterranean, tropical

Ecological gradient
- Evergreen broadleaf forest
- Deciduous broadleaf forest
- Evergreen needleleaf forest
- Mixed forest
- Grassland

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

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

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.

Reforestation cools climate

**Annual mean temperature change**

<table>
<thead>
<tr>
<th></th>
<th>OF to PP</th>
<th>OF to HW</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Albedo</strong></td>
<td>+0.9°C</td>
<td>+0.7°C</td>
</tr>
<tr>
<td><strong>Ecophysiology and aerodynamics</strong></td>
<td>-2.9°C</td>
<td>-2.1°C</td>
</tr>
</tbody>
</table>

**Forest**
- Lower albedo (+)
- Greater leaf area index, aerodynamic conductance, and latent heat flux (-)

Central France

1 August 2000       10 August 2003

Surface reflectance

<table>
<thead>
<tr>
<th></th>
<th>2000</th>
<th>2003</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Forest</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NDVI</td>
<td>0.87</td>
<td>0.87</td>
<td>0</td>
</tr>
<tr>
<td>Albedo</td>
<td>0.19</td>
<td>0.17</td>
<td>-0.02</td>
</tr>
<tr>
<td>(T_R) (°C)</td>
<td>29</td>
<td>40</td>
<td>+11</td>
</tr>
<tr>
<td><strong>Crops</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NDVI</td>
<td>0.81</td>
<td>0.43</td>
<td>-0.37</td>
</tr>
<tr>
<td>Albedo</td>
<td>0.22</td>
<td>0.22</td>
<td>0</td>
</tr>
<tr>
<td>(T_R) (°C)</td>
<td>30</td>
<td>54</td>
<td>+24</td>
</tr>
<tr>
<td><strong>Barren</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NDVI</td>
<td>0.27</td>
<td>0.29</td>
<td>+0.02</td>
</tr>
<tr>
<td>Albedo</td>
<td>0.24</td>
<td>0.22</td>
<td>-0.02</td>
</tr>
<tr>
<td>(T_R) (°C)</td>
<td>47</td>
<td>58</td>
<td>+11</td>
</tr>
</tbody>
</table>

Scale bar indicates 500 m

Soil water affects the \(\Delta(\text{forest-crop})\)

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
Shifts in surface energy balance from afforestation

Differences in energy fluxes among forest, cropland, and grassland

Based on ~90 site-years of AmeriFlux data.

O’Halloran et al., 2009. in prep.
The type of land cover change matters:

Forest → winter crop
Forest → spring crop
Forest → summer crop
Forest vs grassland

Current carbon models do not represent crop phenology.


- C3 grass
- C3 generic crop
- Corn
- Spring wheat
- Soybean

TLAI (m² leaf m⁻² plant area)

- CLM-CN stress deciduous phenology
- CN-crop phenology
Integrate ecological studies with earth system models

Environmental Monitoring
- Eddy covariance flux tower (courtesy Dennis Baldocchi)

Experimental Manipulation
- Soil warming, Harvard Forest
- CO₂ enrichment, Duke Forest

Test model-generated hypotheses of earth system functioning with observations

Planetary energetics
Planetary ecology
Planetary metabolism