Land Use and the Carbon Cycle: a modeler’s perspective

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Land Use and the Carbon Cycle

- In the context of Earth System Models
- Concepts & processes represented
- Simulations

Diagram showing connections between atmosphere (atm), ocean, coupler, sea-ice, and land.
Current-generation land models (e.g. CLM)

Define:

Land Cover vs. Land Use vs. Land Management

Energy fluxes

Biogeophysics

Hydrology/Rivers

Ice sheets

Climate change

Disturbance

Vegetation dynamics

Establishment

Land use

Deforestation

Afforestation

Land Management

Urbanization

Photosynthesis

BVOC

Autotrophic respiration

Fire

Litterfall

Heterotrophic respiration

Dust

Stem

Nutrient uptake

Soil carbon

Mineralization

Absorbed solar radiation

Diffuse solar radiation

Longwave radiation

Latent heat flux

Sensible heat flux

Momentum flux

Wind speed

Precipitation

Canopy

Drainage

Transpiration

Sublimation

Throughfall

Evaporation

Soil heat flux

Heat transfer

Deforestation

Afforestation

Land Management

Urbanization

Competition

Growth

Nutrient uptake

Foliage

Stem

Root

Soil carbon

Mineralization

Fire

Dust

Heterotrophic respiration

Litterfall

Canopy

Establishment

Deforestation

Afforestation

Vegetation dynamics

Climate change

Disturbance

Land Cover vs. Land Use vs. Land Management

Current-generation land models (e.g. CLM)
why Land Use in ESMs?

Land-Atmosphere Interactions

LAND-ATMOSPHERE FEEDBACKS
Land-Atmosphere Interactions

LAND-ATMOSPHERE FEEDBACKS

• Land Cover Change due to Land Use → Atm. changes
• Atmospheric changes → Soil & vegetation affected...

A. Biogeophysical interactions:
   1. Surface radiation balance \( R_n = S + L \) think albedo
   2. Surface heat balance \( R_n = H + \lambda E \) think evapotransp.

B. Biogeochemical interactions
   1. Carbon cycle think biosphere
   2. Nutrient cycles think nitrogen, phosphorus, ...
   3. Dust, biogenic emissions, ...
Heterotrophic respiration

Photosynthesis

Autotrophic respiration

Litterfall

Heterotrophic respiration

Root

Nutrient uptake

Mineralization

Foliage

Stem

Soil

BVOC

Dust

Fire

GPP=S(Photosynthesis)

NPP = GPP-\( R_a \)

NEP = NPP-\( R_h \)

NBP = NEP-Fire

NEE = -NBP

Thornton et al.
All these processes are affected by and may also affect the physics
Define Land Use in a CLM grid cell...

Land Cover is all of it...

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<tbody>
<tr>
<td>“unmanaged” soil / vegetation</td>
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<tr>
<td>but wood harvesting</td>
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<tr>
<td>...is the land mgmt!</td>
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C3 “crop”

...is the Land Use

What do these acronyms mean then? LULCC? LULM?
C pools and fluxes in the CLM associated with LULCC and LULM

- Terrestrial Ecosystem Sink (NPP - Heter. Resp. - Fire)
- Net Primary Production (NPP)
- Heterotrophic Respiration
- Fire
- Net Ecosystem Exchange (NEE) (Land Use + Heter. Resp. + Fire - NPP)
- Land Use Flux (LCC + Prod Pool)
- Land Cover Change Flux
- Product Pool Decay Flux
- Wood Harvest
- Product Pools 10 and 100 year

1. Change in PFTs results in LCC fluxes as area of PFT changes but pool sizes all remain constant
2. Tree PFT Wood Harvest results in LCC fluxes as PFT pools are reduced to represent harvest but PFT area stays constant

* Ecosystem Carbon = Leaf + Wood + Root + Storage + Litter + Coarse Woody Debris + Soil Carbon
** CWD = Coarse Woody Debris
LULCC/LULM: input data to the CLM

Change in tree and crop cover (% grid cell)

(a) Historical (2005-1850) Tree PFTs

Wood harvest, cumulative % of grid cell

(b) Historical (2005-1850) Tree PFT Harvest

Peter Lawrence et al. (2012)
Simulated changes in Leaf Area Index 2005-1850

Historical simulation

$CO_2$
Climate
Nitrogen deposition
Land cover change

$LAI \uparrow$ except where crops expand

Single forcing simulation

Land cover change only

$LAI \downarrow$ except where reforestation
Simulated albedo & temperature changes

**Historical simulation**

Albedo

**Land cover change only**

Albedo

Air Temperature

Air Temperature

Peter Lawrence et al. (2012)
Effects of LULCC on 20th century temperature

*Prevailing paradigm...*
Competing signals from deforestation:
surface albedo ↗ countered by
carbon emission ↗

**Biogeophysical**
Weak global cooling (−0.03 °C)

**Biogeochemical**
Strong warming (0.16–0.18 °C)

**Net**
Warming (0.13-0.15 °C)

Pongratz et al. (2010) GRL
LULCC/LULM data out to 2100

Forest area ↑ to store C

Crop area ↑ largest

Crop ↓ largest

Biofuels assumed in wood harvest

Peter Lawrence et al. (2012)
Effects of LULCC on 21st century temperature

A2 - widespread cropland

B1 - temperate reforestation

Biogeophysical

Biogeochemical

Net effect

$\Delta T_{2100}$

Sitch et al. (2005)
Carbon model intercomparison

Uncertainty arises from differences in terrestrial fluxes

- One model simulates a large source of carbon from the land
- Another simulates a large terrestrial carbon sink
- Most models simulate modest terrestrial carbon uptake
- Terrestrial carbon cycle can be a large climate feedback
- Considerable more work is needed to understand this feedback

Figures courtesy of Pierre Friedlingstein
Carbon model intercomparison

Coupled Runs

Max > 1000 ppm
Min < 750 ppm...

Large uncertainty at 2100

Atmospheric CO2 (ppm)

Year

CSM1
courtesy of Pierre Friedlingstein
LAND TOTAL CARBON FLUXES

- Net Ecosystem Production
- Wildfire (+ is source)
- Land use (+ is source)

CCSM4 historical global land use flux = 120 PgC similar to AR4
134 PgC and 0.5 W/m²
CLM/CESM simulated LULCC carbon flux to atmosphere

consistent with estimated land use flux over the historical period

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CLM/CESM simulated wood harvest flux

consistent with estimated wood harvest flux over the historical period and the RCPs
Huh, so land use choices matter!

Ecosystem carbon
(excluding product pools)

: reforestation drives C gain

: deforestation & wood harvest drive C loss
Quantifying carbon-nitrogen feedbacks in the Community Land Model (CLM4)

Gordon B. Bonan¹ and Samuel Levis¹

Received 12 January 2010; revised 21 February 2010; accepted 26 February 2010; published 2 April 2010.

[1] Recent studies indicate that nitrogen biogeochemistry affects the carbon cycle feedback in climate simulations. We use the Community Land Model version 4 (CLM4) with carbon-only and carbon–nitrogen biogeochemistry to assess the influence of nitrogen on the land carbon budget for 1973–2004. Carbon-only simulations show that the carbon gain from increasing atmospheric CO₂ (the concentration–carbon feedback) is four times greater than the warming–induced carbon loss (the climate–carbon feedback) over the period 1973–2004. Nitrogen reduces both feedbacks compared with carbon-only biogeochemistry. The decrease in the concentration–carbon feedback is three times greater than the effect on the climate–carbon feedback. Thus, the influence of nitrogen on the CLM4 concentration–carbon feedback is of greater importance for near-term climate change simulations than its effect on the climate–carbon feedback. Furthermore, the land use carbon flux greatly exceeds these carbon–nitrogen biogeochemical feedbacks.


[3] This interpretation of the terrestrial carbon cycle feedbacks from models that do not include carbon biogeochemistry. Two carbon cycle-climate feedbacks of future climate change with carbon biogeochemistry find that nitrogen decreases β carbon feedbacks from negative to positive [Sokolov et al., 2009]. Limited mineral nitrogen availability increases plant productivity from the carbon feedback. Conversely, warming increases the position of organic material and nitrogen stimulating plant productivity. Other carbon–nitrogen feedbacks for the twentieth and twenty-first centuries find that β carbon decreases and carbon feedbacks decreases when nitrogen is included, but the effect is negative [Zaehle et al., 2010a, 2010b]. The nitrogen to change the climate–carbon feedback (−γ) to negative (+γ) is unclear, as is the sign of β carbon and γ to the overall land carbon feedback.

[4] Here, we report simulations using the Community Land Model version 4 (CLM4) for the late 20th century forced with historical meteorology, CO₂ atmospheric nitrogen deposition, and land use changes.
1st set of Conclusions

**Broad conclusions**
- LULM matters at the regional scale => include in detection & attribution
- LULM choices will likely influence future climate

**Biogeochemistry**
- Land use flux & wood harvest flux *both* contribute warming

**Biogeophysics**
- Higher albedo of croplands & grasslands cools climate

**Biogeophysical vs. BGC effects & Managed vs. Unmanaged vegetation**
- Biogeochemical effects from LULM dominate to a first order
- So human behavior is our greatest uncertainty in future scenarios
a CLM grid cell (default)

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### a CLM grid cell with interactive crop management

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<tr>
<td>maize (C4)</td>
</tr>
<tr>
<td>wheat/barley/rye</td>
</tr>
<tr>
<td>soybean</td>
</tr>
</tbody>
</table>

} crop-specific phenology + C allocation
Maize + Soybean + Temperate Cereals

Ramankutty et al. (% of gridcell)
2nd set of Conclusions

• Interactive crop management in the CLM
  ➢ Better simulated annual cycle of crop LAI
  ➢ Better annual cycle of the NEE (and CO$_2$)
  ➢ Promising for simulations with interactive CO$_2$
  ➢ Better summer precip over MW N. America, too

• Human dimensions: new frontier in CESM research
  ➢ LULM & urbanization: steps in that direction
  ➢ Still also resolving more basic issues: biogeophys. & bgc
  ➢ Coupling ESMs and IAMs in the not so distant future...
forms of land management other than planting & harvesting: irrigation, fertilization, tillage, crop rotation, multi-cropping

% of crops equipped for irrigation
Figure 5.18  Decline in soil organic matter following conversion of native soil to agriculture for two grassland soils.
questions