Attribution of the Biogeochemical and Biogeophysical Impacts of CMIP5 Land Cover Change in CESM

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CMIP5 Land Cover Change Attribution

1. CMIP5 Prescribed Land Cover Change and Wood Harvest as a major climate forcing for both historical and future RCP simulations.

2. The transient changes in CLM4 Biogeochemistry and Biogeophysics were assessed in Lawrence et al. (2012).

3. Attribution of these changes to Land Cover Change was not possible however, due to the interactions between climate change, CO$_2$ fertilization, and land cover change.

4. To address this we have performed three member ensembles of concentration driven fully coupled transient CESM 1.0 simulations for the Historical, RCP 4.5 and RCP 8.5 time periods with and without Land Cover Change with all other forcings following the CMIP5 protocol.
## CMIP5 Land Cover Change Attribution – Exp. Design

<table>
<thead>
<tr>
<th>Simulations</th>
<th>Land Cover</th>
<th>Wood Harvest</th>
<th>Other Forcings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1a</strong> Historical Control x3</td>
<td>Transient</td>
<td>Transient</td>
<td>Full Transient</td>
</tr>
<tr>
<td><strong>1b</strong> Historical No Land</td>
<td>Constant 1850</td>
<td>No Wood Harvest</td>
<td>Full Transient</td>
</tr>
<tr>
<td>Cover Change x3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>2a</strong> RCP 4.5 Control x3</td>
<td>Transient</td>
<td>Transient</td>
<td>Full Transient</td>
</tr>
<tr>
<td><strong>2b</strong> RCP 4.5 No Land Cover</td>
<td>Constant 2005</td>
<td>1995 – 2005 average wood harvest</td>
<td>Full Transient</td>
</tr>
<tr>
<td>Change x3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>3a</strong> RCP 8.5 Control x3</td>
<td>Transient</td>
<td>Transient</td>
<td>Full Transient</td>
</tr>
<tr>
<td><strong>3b</strong> RCP 8.5 No Land Cover</td>
<td>Constant 2005</td>
<td>1995 – 2005 average wood harvest</td>
<td>Full Transient</td>
</tr>
<tr>
<td>Change x3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Global Plant Functional Composition (%)

- **Trees**
- **Grass**
- **Crops**

- **Historical**
- **RCP 4.5**
- **RCP 8.5**
CMIP5 Land Cover Change – Total Ecosystem Carbon

Global Total Ecosystem Carbon (PgC)

- Historical
- RCP 8.5
- RCP 8.5 No LCC

Historical: +119.8 PgC
RCP 8.5: Total = -168.8 PgC
RCP 8.5 No LCC: -61.2 PgC

From 1850 to 2100
CMIP5 Land Cover Change – Total Ecosystem Carbon

### Table: CMIP5 Land Cover Change

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Transient LCC</th>
<th>No LCC</th>
<th>Net LCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Historical</td>
<td>-61.2 PgC</td>
<td>+68.4 PgC</td>
<td>-129.6 PgC</td>
</tr>
<tr>
<td>RCP 4.5</td>
<td>+62.8 PgC</td>
<td>+68.6 PgC</td>
<td>-5.8 PgC</td>
</tr>
<tr>
<td>RCP 8.5</td>
<td>-49.0 PgC</td>
<td>+119.8 PgC</td>
<td>-168.8 PgC</td>
</tr>
</tbody>
</table>
CMIP5 Land Cover Change – Total Ecosystem Carbon

Historical Total Ecosystem Carbon (PgC)

- Historical
- Historical No LCC
CMIP5 Land Cover Change – Total Ecosystem Carbon

RCP 8.5 Total Ecosystem Carbon (PgC)

- RCP 8.5
- RCP 8.5 No LCC

Year: 2006 to 2096
CMIP5 Land Cover Change – Total Ecosystem Carbon

RCP 4.5 Total Ecosystem Carbon (PgC)

- RCP 4.5
- RCP 4.5 No LCC
CMIP5 Land Cover Change – Wood Harvest

<table>
<thead>
<tr>
<th></th>
<th>Transient LCC</th>
<th>No LCC</th>
<th>Over No LCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Historical</td>
<td>62.5 PgC</td>
<td>0 PgC</td>
<td>62.5 PgC</td>
</tr>
<tr>
<td>RCP 4.5</td>
<td>145.0 PgC</td>
<td>97.7 PgC</td>
<td>47.3 PgC</td>
</tr>
<tr>
<td>RCP 8.5</td>
<td>242.4 PgC</td>
<td>101.7 PgC</td>
<td>140.7 PgC</td>
</tr>
</tbody>
</table>
Land Cover Change Carbon Impacts 1.

1. Historical Full Trans loses 61.2 PgC from Ecosystem Carbon but compared to No LCC it loses 129.6 PgC.

2. RCP 4.5 Full Trans gains 62.8 PgC in Ecosystem Carbon but compared to No LCC it loses 5.8 PgC.

3. RCP 8.5 Full Trans loses 49 PgC from Ecosystem Carbon but compared to No LCC it loses 168.8 PgC.

4. Historical losses are greatest in South East Asia, China and Eastern North America.

5. RCP 4.5 gains carbon in South East Asia and Eastern North Am. but these are offset by losses of carbon in Amazon and China.

6. RCP 8.5 carbon losses are largest in Central Africa, South East Asia and the Amazon.
Land Cover Change Carbon Impacts 2.

7. The Ecosystem Carbon changes between Full Trans and No LCC are predominantly in Wood and Coarse Woody Debris carbon pools.

8. Other carbon pool changes are very small including Soil Carbon.

9. The RCP 4.5 Full Trans afforestation scenario results in lower carbon uptake than the RCP 4.5 No LCC simulations.

10. This result comes from the higher wood harvest rates of RCP 4.5 which reduce carbon more than the increased uptake through afforestation.
CMIP5 Land Cover Change – Land Surface Temperature

Global Land Air Temperature (Deg C)

Historical
Historical No LCC
RCP 4.5
RCP 4.5 No LCC
RCP 8.5
RCP 8.5 No LCC

Global Difference in Land Air Temperature (Deg C)

Historical
RCP 4.5
RCP 8.5

* Ten Year Running Mean of Ensemble Difference Between Trans and No LCC
CMIP5 Land Cover Change – Historical Temperature

Historical 2000 - 1850 Annual Ref Temp

Degrees C

Historical 2000 - No LCC 2000 Annual Ref Temp

Degrees C

Historical Change in 2m Air Temp (Deg C)

- Full Trans
- No LCC
- F. Tr - No LCC

Amazon
Cerrado
Australia
South East Asia
East North Am
Russia
India
China
Europe
Central Africa
CMIP5 Land Cover Change – RCP8.5 Temperature

RCP 8.5 Global Land Air Temperature (Deg C)

- RCP 8.5
- RCP 8.5 No LCC
CMIP5 Land Cover Change – Albedo

Global Land Albedo (Fraction)

- Historical
- Historical No LCC
- RCP 4.5
- RCP 4.5 No LCC
- RCP 8.5
- RCP 8.5 No LCC

Global Difference in Land Albedo (Fraction)

- Historical
- RCP 4.5
- RCP 8.5

* Ten Year Running Mean of Ensemble Difference Between Trans and No LCC
CMIP5 Land Cover Change – Leaf Area Index

**Global Leaf Area Index (m²/m²)**
- Historical
- Historical No LCC
- RCP 4.5
- RCP 4.5 No LCC
- RCP 8.5
- RCP 8.5 No LCC

**Global Difference in Leaf Area Index (m²/m²)**
- Historical
- RCP 4.5
- RCP 8.5

* Ten Year Running Mean of Ensemble Difference Between Trans and No LCC
Land Cover Change Biogeophysical Impacts 1.

1. Historical reduction of warming of -0.13°C for global land temperature for Full Trans compared to 150 year warming of +1.2°C in No LCC simulations

2. Historical reductions in warming largest in East North America and Russia in winter of -0.9°C compared to warming of +2°C in No LCC

3. RCP 4.5 has increased warming +0.06°C for global land temperature relative to +1.5°C. Predominantly at high latitudes

4. RCP 8.5 has almost no change in global land temperatures compared to increases of +3.6°C in both Full Trans and No LCC

5. Albedo increases/decreases between Full Trans and No LCC correspond with reduced/increased warming

6. Albedo increases/decreases correspond with lower/higher LAI but spatial location and vegetation type also important
7. Historical biogeophysical impacts are relatively larger and more robust than RCP biogeophysical impacts.

8. As the total warming of the scenarios get larger the relative impacts get smaller impacted by reduced snow – vegetation albedo impacts.

9. Ensembles show that at higher warming scenarios the Full Trans and No LCC differences become indistinguishable from ensemble spread.
Relevance to SDWG

Fostering dialogue
- Carbon and climate Land Cover Change impacts in LUMIP/ScenarioMIP CMIP6 scenarios

Needs for CESM development
- Assessment of CLM4.5/5 Land Cover Change
- Creation of new LUMIP land cover change parameters

Relevant CESM simulations
- CLM4.5/5 offline and coupled simulations

New CESM linkage code
  - Land Cover Change and Wood Harvest Parameter Generation for LUMIP/CMIP6 with CLM-Crop and new management functionality
Need for Land Cover Change

1. Direct Biogeophysical Impacts:
   - Albedo – Radiation (Snow Interactions)
   - Surface Hydrology (Irrigation)
   - Surface Roughness

2. Direct Biogeochemical Impacts:
   - Vegetation and Soil Carbon Fluxes
     from Conversion Natural -> Human systems
   - Harvesting from Forestry and Agriculture

3. Indirect Impacts:
   - Increased Photosynthesis through higher
     CO₂, Nitrogen, Phosphorus and Potassium
   - Atmospheric Responses in Temperature, Cloud,
     Precipitation and Larger Scale Circulation
   - Fire, Methane, Dust, Volatile Organics, Aerosols