Collaborators

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- Guenther Fischer\(^5\)
- Justin Fisk\(^1\)
- Kees Klein Goldewijk\(^6\)
- Kathy Hibbard\(^9\)
- Richard Houghton\(^8\)
- Anthony Janetos\(^9\)
- Chris Jones\(^3\)
- Georg Kindermann\(^5\)
- Tsuguki Kinoshita\(^10\)
- Keywan Riahi\(^5\)
- Elena Shevliakova\(^11\)
- Steve Smith\(^9\)
- Elke Stehfest\(^6\)
- Allison Thomson\(^9\)
- Peter Thornton\(^12\)
- Detlef van Vuuren\(^6\)
- Yingping Wang\(^13\)

Questions

• What are the combined biogeochemical and biogeophysical effects of land-use change on Earth System dynamics (past-future)?

• How can future needs for food, fuel, and fiber, be met while minimizing negative effects of land-use changes?
Proposed AR5 Scheme (Land-use)

LAND-USE HISTORY
Reconstruction:
Agriculture
Wood harvest
Transitions
Gridded
1500-2005

LAND-USE FUTURE
IAM RCPs:
Population
Socioeconomic
Energy
Land-use
Gridded/Regional
2005-2100

LAND-USE HARMONIZATION
Consistency
Integration
Gridding
1500-2100

ESMs
Climate
C Stocks/Fluxes
Biophysical effects

Hurtt et al. (2009)
Harmonization Steps

• Develop consensus land-use history reconstruction
• Minimize differences between end of historical reconstruction and beginning of future projections
• Preserve as much information from IAMs on future as possible
Gridded (5°) land-use states 1500-2005

Gridded (0.5°x0.5°) potential biomass density and recovery rate

National annual wood harvest 1500-2005

Regional/gridded land-use states and wood harvest 2005-2100

- Spatial pattern of crop and pasture
- Residency time of agriculture
- Inclusiveness of wood harvest statistics
- Prioritization of land for conversion/logging
- Spatial pattern of wood harvesting

Gridded (0.5°x0.5°F) land-use transitions 1500-2100

Gridded (0.5°x0.5°F) land-use states 1500-2100

Gridded (0.5°x0.5°F) secondary land area and age 1500-2100

Hurtt et al. (2009, 2011)
Mathematical Structure

\[ l(x,y,t+1) = A(x,y,t) \cdot l(x,y,t) \]

Global, 0.5°x0.5°, 600y, 4D: \(~10^9\) unknowns!

\textit{after} Hurtt et al. (2006)
HYDE 3: Cropland & rangeland in 2000 (Klein Goldewijk et al. 2007)

Area (km²) per 5 min. grid

- 0
- < 10
- 10 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- 50 - 60
- > 60

cropland

rangeland
Global wood harvest by country, 1500-2005 (Pg C y⁻¹)

HYDE 3 population 1500 - 1970

FAO 1961-2000

Zon & Sparhawk (1923) per capita

Pg C y⁻¹

1.4

1.2

1.0

0.8

0.6

0.4

0.2

0

1500 1550 1600 1650 1700 1750 1800 1850 1900 1950 2000

Hurtt et al. 2006; revised
## Representative Concentration Pathways (RCPs)

<table>
<thead>
<tr>
<th>IAM</th>
<th>RCP</th>
<th>Radiative Forcing</th>
<th>Concentration</th>
<th>Pathway Shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>MESSAGE</td>
<td>8.5</td>
<td>&gt;8.5 W/m² in 2100</td>
<td>&gt; ~1370 CO₂-eq in 2100</td>
<td>Rising</td>
</tr>
<tr>
<td>AIM</td>
<td>6</td>
<td>~6 W/m² at stabilization after 2100</td>
<td>~850 CO₂-eq at stabilization after 2100</td>
<td>Stabilization without overshoot</td>
</tr>
<tr>
<td>MiniCAM</td>
<td>4.5</td>
<td>~4.5 W/m² at stabilization after 2100</td>
<td>~650 CO₂-eq at stabilization after 2100</td>
<td>Stabilization without overshoot</td>
</tr>
<tr>
<td>IMAGE</td>
<td>2.6</td>
<td>Peak at ~3 W/m² before 2100 and then declines to 2.6 W/m² by 2100</td>
<td>Peak at ~490 CO₂-eq before 2100 and then decline</td>
<td>Peak and decline</td>
</tr>
</tbody>
</table>

Pasture

AIM

ΔF (LUH)

MESSAGE

ΔF (IAM)

Crop

Change in cropland fractions between 2010 and 2005 (original IMAGE data)

Change in pasture fractions between 2010 and 2005 (original IMAGE data)

ΔF (IAM)
<table>
<thead>
<tr>
<th>Model factor</th>
<th>Number of Cases</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>H: Historical land-use reconstruction</td>
<td>3</td>
<td>HYDE 3.0, “No Data”, None</td>
</tr>
<tr>
<td>T: Residence time of agricultural land</td>
<td>2</td>
<td>Shifting cultivation, no shifting cultivation</td>
</tr>
<tr>
<td>L: Wood harvest history reconstruction</td>
<td>3</td>
<td>No wood harvest, FAO wood harvest reconstruction, “No Data”</td>
</tr>
<tr>
<td>W: Land-conversion wood clearing tallied as harvest to satisfy annual wood harvesting</td>
<td>2</td>
<td>Included 100%, not included</td>
</tr>
<tr>
<td>P: Priority for land-use transitions</td>
<td>2</td>
<td>Primary, secondary</td>
</tr>
<tr>
<td>D: Historical start date</td>
<td>4</td>
<td>1500, 1700, 1850, 2005</td>
</tr>
<tr>
<td>U: Urban land use included</td>
<td>2</td>
<td>Included, not included</td>
</tr>
<tr>
<td>F: Future land-use projections</td>
<td>4</td>
<td>AIM, GCAM, IMAGE, MESSAGE</td>
</tr>
</tbody>
</table>

Total number of simulations = 1664
Wood harvest

Hurtt et al. (2011)
Thomson et al. (2010)
iESM Multi-phase Coupling Strategy

iESM Control (RCP 4.5)

Fossil fuel emissions

IMAGE/GCAM

GLM

CLM/CCSM

C stocks, Productivity

Climate

Up/down scaling (space and time)

Atm CO$_2$

Edmonds et al. (2010)
iED

• How can remote sensing and mechanistic ecosystem models be used to improve integrated assessments involving coupled human-forest dynamics?
• What are the opportunities for land-use strategies such as afforestation or woody bioenergy crop production to contribute to stabilization of atmospheric CO$_2$ concentrations?
• What are the linked remote sensing/ecosystem modeling requirements for improving integrated assessments of climate mitigation strategies?
• How could potentially altered disturbance rates affect vegetation, carbon stocks and fluxes, and the development of climate change mitigation strategies?
Fine scale forest change history mapped across the US (Huang, Goward, et al)
Canopy Height - Discrete Return Lidar
Hubbard Brook Experimental Forest

Dubayah et al.
Summary/Conclusions

• Virtually all ESMs either now track, or are developing capacity to track, gridded land-use changes.
• Modeling the effects of land-use in the Earth System requires the treatment of land-use effects consistently in the past, present, and future.
• The strategy described here is a nascent approach for harmonizing land-use transitions across multiple data sources, models, and scenarios.
• Future studies are needed to further constrain land-use reconstructions/models with data, address land mgt., and prepare for the next generation of fully integrated models (e.g. iESMs+).

http://www.iiasa.ac.at
http://luh.unh.edu
Parking Lot
## Comparison with Results from Hurtt et al. 2006

<table>
<thead>
<tr>
<th>Diagnostic</th>
<th>Reference data</th>
<th>Hurtt 2006</th>
<th>LUHa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of land surface impacted by human land-use activities 1700-2000 (C+P+S)</td>
<td></td>
<td>42-68%</td>
<td>57.5%</td>
</tr>
<tr>
<td>Total secondary land increase 1700-2000</td>
<td></td>
<td>10-44 x 10^6 km²</td>
<td>26 x 10^6 km²</td>
</tr>
<tr>
<td>Percentage of secondary land increase 1700-2000 that is forested</td>
<td></td>
<td></td>
<td>50%</td>
</tr>
<tr>
<td>Percentage of secondary land generated by wood harvest and shifting cultivation (permanent agriculture generated the rest)</td>
<td></td>
<td>70-90%</td>
<td>83.5%</td>
</tr>
<tr>
<td>Wood harvest (including slash) 1850-1990</td>
<td>106 Pg (Houghton 1999)*</td>
<td>77 Pg</td>
<td>82 Pg</td>
</tr>
<tr>
<td>Wood clearing for agriculture 1850-1990</td>
<td>149 Pg (Houghton 1999)</td>
<td>105-158 Pg</td>
<td>170 Pg</td>
</tr>
<tr>
<td>Area of forested land in shifting cultivation fallow (2000)</td>
<td>4.42 x 10^6 km² (FAO)</td>
<td>4.56-6.19 x 10^6 km²</td>
<td>3.7 x 10^6 km²</td>
</tr>
<tr>
<td>Rates of clearing land in shifting cultivation</td>
<td>0.6-0.09 x 10^6 km²/yr</td>
<td>0.48-0.65 x 10^6 km²/yr</td>
<td>0.58 x 10^6 km²/yr</td>
</tr>
<tr>
<td>Percentage of US Forests that are secondary (2000)</td>
<td>94-99%</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>Mean age of Eastern US Secondary Forests (2000)</td>
<td>38yrs *</td>
<td>71 yrs</td>
<td>63 yrs</td>
</tr>
<tr>
<td>Total gross transitions (2000)</td>
<td>1.6 x 10^6 km²/yr</td>
<td>2.0 x 10^6 km²/yr</td>
<td></td>
</tr>
<tr>
<td>Total net transitions (2000)</td>
<td>0.17 x 10^6 km²/yr</td>
<td>0.19 x 10^6 km²/yr</td>
<td></td>
</tr>
<tr>
<td>Global Cropland Area (1990)</td>
<td>12.1 x 10^6 km²</td>
<td>15.1 x 10^6 km²</td>
<td></td>
</tr>
<tr>
<td>Global Pasture Area (1990)</td>
<td>25.8 x 10^6 km²</td>
<td>33.1 x 10^6 km²</td>
<td></td>
</tr>
<tr>
<td>Global Primary Land Area (1990)</td>
<td>57.7 x 10^6 km²</td>
<td>58.4 x 10^6 km²</td>
<td></td>
</tr>
</tbody>
</table>

**Hurtt et al. (2011)**
## IAM Data

<table>
<thead>
<tr>
<th>IAM</th>
<th>RCP</th>
<th>Crop and Pasture Data</th>
<th>Wood Harvest Data</th>
<th>Includes Climate Feedbacks for Forest Regrowth?</th>
<th>Biofuel treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>MESSAGE</td>
<td>8.5</td>
<td>Gridded</td>
<td>Gridded</td>
<td>No (only for allocation of crops)</td>
<td>Included in wood harvest</td>
</tr>
<tr>
<td>AIM</td>
<td>6</td>
<td>Gridded</td>
<td>Gridded</td>
<td>No</td>
<td>Included in cropland</td>
</tr>
<tr>
<td>MiniCAM</td>
<td>4.5</td>
<td>Regional</td>
<td>Regional</td>
<td>No</td>
<td>Included in cropland</td>
</tr>
<tr>
<td>IMAGE</td>
<td>2.6</td>
<td>Gridded</td>
<td>Regional</td>
<td>Yes</td>
<td>Included in cropland</td>
</tr>
</tbody>
</table>
Butler (1984)
Hurtt et al. (2011)
Hurtt et al. (2011)
Global area of crop, pasture, primary, and secondary land (10^6 km^2)

- revised wood harvest
- revised shifting cult.
- 0.5° x 0.5°
- HYDE 3
- 1500-2000

Assume secondary = 0