Proposal for a Land-Use Model Inter-comparison Project (LUMIP) for CMIP6: Summary

Chairs: George C. Hurtt\(^1\) and David M. Lawrence\(^2\)

SSG: Victor Brovkin, Kate Calvin, Andrew Jones, Chris Jones, Peter Lawrence, Nathalie de Noblet-Ducoudré, Julia Pongratz, Sonia Seneviratne, Elena Shevliakova

with input from many from Earth System Modeling, Integrated Assessment Modeling, and historical land use communities

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https://www2.cgd.ucar.edu/research/mips/lumip
LUMIP Timeline

- 2013 Summer: Concept
- 2013 Fall: CMIP Proposal, WGCM Briefing
- 2014 Spring: GLP Meeting, Workshop 1
- 2014 July 17-18: GEWEX – Biogeophysics
- 2014 July 28-Aug 1: EMF Snowmass Meeting
- 2014 August 5-9: AGCI Aspen Joint-MIP Workshop
- 2014 September 15: LUMIP proposal due
- 2014-2017: Diagnostics, new scenarios, new data sets, experimental design
- 2015 GMD paper
- 2018-2019: Model results and synthesis
- 2020: WG1 AR6 Report published
Terrestrial Processes in CMIP6

Collection of coordinated activities to assess land role in climate and climate change

- **Land Only** simulations forced with obs historical climate (joint GSWP3, TRENDSY, ISI-MIP protocol)
- **Land Use = LUMIP** land use forcing on climate, biogeophysics and biogeochemistry with policy relevance (LUCID)
- **Carbon Cycle = C4MIP** land biogeochemical feedbacks on climate change
- **Land = LSMIP** land systematic biases and biogeophys feedbacks including soil moisture and snow feedbacks

Proposed change to DECK incl atm only, land only and ocean/sea-ice only runs

Adapted from Meehl et al., EOS, 2014
LUMIP Major Science Questions

• What are the effects of land use and land-use change on climate and biogeochemical cycling (past-future)?
• Are there regional land management strategies with promise to help mitigate and/or adapt to climate change?
• What are the effects of climate change on land-use and land-use change?

Additional detailed science questions to get at process level attribution, uncertainty, data requirements, etc.

Particular focus on uncertainty, and separating effects of: fossil fuel vs. land use, biogeochemical vs biogeophysical impact of land use, land cover vs land management impacts.
LUMIP Major Activities

• Model metrics and diagnostics
  – Develop set of metrics to assess/quantify model performance with respect to land use impacts on climate; Synthesis activity/paper of existing metrics to start now
  – A diagnostic protocol developed to quantify related model sensitivities

• Data standardization
  – Repeat and mature land use harmonization process→ enhanced land-use data set for CMIP6, passing maximum amount of common information between relevant communities (Historical, IAMs, ESMs)
  – Provide additional required land management datasets
  – Data output standardization, new variables

• Model experiments
  – Development of efficient model experiments designed to isolate and quantify land use and land management effects
Data Standardization (Draft)

- Updated land-use history
  - Pasture anomaly correction, new enhanced historical reconstruction, Landsat constraint
- New future scenarios
  - Idealized, Realistic
- New land-use AND land-cover harmonizations with Mgt
  - Land-use transitions,
    - F/NF gross transitions, PFT land cover transitions
    - Harvest, Fertilizer, Irrigation, Crop type, Biofuel
- Standardization of data usage
  - more information, clear articulation of best practices, stratified comparisons
Task: Develop subgrid data archiving for selected key variables as default for CMIP
Task: Develop subgrid data archiving for selected key variables as default for CMIP

Preliminary Subgrid Variable List

tas$_{sg}$ – near-surface air temperature
huss$_{sg}$ – near-surface specific humidity
hfls$_{sg}$ – latent heat flux
hfss$_{sg}$ – sensible heat flux
rsus$_{sg}$ – surface upwelling shortwave (albedo)
lai$_{sg}$ – leaf area index
gpp$_{sg}$ – gross primary productivity
npp$_{sg}$ – net primary productivity
nee$_{sg}$ – net ecosystem exchange (or NEP)
cSoil$_{sg}$ – carbon mass in soil pool
cVeg$_{sg}$ – carbon mass in vegetation
cLitter$_{sg}$ – carbon mass in litter pool
Overall Approach:

Two phase design: 1) idealized; 2) realistic simulations

Tiered prioritization of experiments

Phase 1 (Start now) Idealized model experiments designed to:

- Improve process understanding/assessment of how models represent impact of changes in land state on climate;
- Quantify model sensitivity to potential land cover and land management changes. Land cover/land management factors manipulated in simple standard fashion.

Phase 2 Realistic model experiments designed to:

- Isolate the role of historical and future land cover/use change on climate relative to other forcings
<table>
<thead>
<tr>
<th>Experiment</th>
<th>Description</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process understanding</td>
<td>Idealized experiments designed to assess biogeophysical role of land cover change on climate</td>
<td></td>
</tr>
<tr>
<td>CPL_1%DF</td>
<td>Idealized 1% or 2% per year deforestation, once global deforest, continue run for 50 to 100 years (Tier 1)</td>
<td>1850-????</td>
</tr>
<tr>
<td>LND_DF, ATM_DF, CPL_DF</td>
<td>Land, atm, cpl simulations with some set of tropical, boreal, or temperate deforestation (defined by LUC4C/LUCID?) (Tier 3?)</td>
<td>1980-2010</td>
</tr>
</tbody>
</table>
Draft experimental design (Phase 1)

<table>
<thead>
<tr>
<th>Land cover versus land management change (Tier 2)</th>
<th>Assess relative impact of land cover and incrementally more comprehensive land management change on fluxes of water, energy, and carbon; forced with historical observed climate and projected climate anomalies (1700 to 2014 or 2100?)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LND_allmanage</td>
<td>All land cover/use/management features for each particular model turned on; 1700 start; transient CO₂, N-dep, aerosol dep, etc.</td>
</tr>
<tr>
<td>LND_1850spin</td>
<td>All management simulation with land use change starting at 1850 (testing impact of pre-1850 land use)</td>
</tr>
<tr>
<td>LND_noLULCC</td>
<td>LND_allmanage except no land use change</td>
</tr>
<tr>
<td>LND_grasscrop</td>
<td>LND_noLULCC but w/ LULCC with ‘grassland’ crop/pasture</td>
</tr>
<tr>
<td>LND_gross_vs_net</td>
<td>LND_grasscrop except with net transitions instead of gross</td>
</tr>
<tr>
<td>LND_fire</td>
<td>LND_grasscrop with human fire management</td>
</tr>
<tr>
<td>LND_woodharv</td>
<td>LND_grasscrop or LND_fire with wood harvest</td>
</tr>
<tr>
<td>LND_pasture</td>
<td>LND_grasscrop but with grazing on pastureland (???)</td>
</tr>
<tr>
<td>LND_crop</td>
<td>LND_grasscrop but with crop area utilizing prognostic crop model</td>
</tr>
<tr>
<td>LND_crop-irrig</td>
<td>LND_crop with realistic transient irrigated area</td>
</tr>
<tr>
<td>LND_crop-irrig-fert</td>
<td>LND_crop-irrig with realistic transient fertilization</td>
</tr>
</tbody>
</table>
### Draft Experimental Design (Phase 2)

<table>
<thead>
<tr>
<th>Land use change impact on land to atmosphere fluxes of water, energy, carbon (Tier 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LND_allforce</strong></td>
</tr>
<tr>
<td><strong>LND_noLULCC</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Land use change impact on past and future climate (Tier 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CPL_allforce</strong></td>
</tr>
<tr>
<td><strong>CPL_noLULCC_hist</strong></td>
</tr>
<tr>
<td><strong>CPL_landpolicy_fut</strong></td>
</tr>
<tr>
<td><strong>CPL_noLULCC_fut</strong></td>
</tr>
</tbody>
</table>
Draft Experimental Design (Phase 2)
Land use change impact on future climate

<table>
<thead>
<tr>
<th>ScenarioMIP (Tier 1)</th>
<th>RCP3.7</th>
<th>RCP7</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSP1</td>
<td></td>
<td>SSP3</td>
</tr>
<tr>
<td>Deforest_sens SSP1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>w/ SSP3-7 land use</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NoLULCC_sens SSP1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>w/ no LULCC</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| LUMIP (Tier 1) | Deforest_sens SSP1 w/ SSP3-7 land use |
| LUMIP (Tier 2) | Afforest_sens SSP3 w/ SSP1-3.7 land use |
| NoLULCC_sens SSP1 w/ no LULCC |
| NoLULUCC_sens SSP3 w/ no LULCC |

Note that final RCP/SSP combinations in ScenarioMIP TBD; LUMIP scenarios will depend on ScenarioMIP choices; LUMIP targeting wide range in land use trajectory between SSPs; important to be clear that LUMIP simulations (deforest_sens, afforest_sens) are not necessarily policy-relevant
LUMIP Variants
## Draft Experimental Design (Phase 2)

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Description</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Effects of climate change on land use and land use change</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>iESM</td>
<td>???</td>
<td></td>
</tr>
</tbody>
</table>
Near-term LUMIP timeline/tasks

note that all activities are open to any interested parties; send email to George and Dave if you or someone in your group want to get involved

- **LUMIP Proposal**
  - Write / submit LUMIP proposal to CMIP panel, due September 15 (George, Dave, SSG)

- **Model metrics and diagnostics**
  - Synthesis activity to assess existing metrics / model evaluation datasets for land use impact on climate and biogeochemical cycles (???)

- **Data standardization**
  - Develop prototype historic / future harmonized land use dataset for afforestation and deforestation scenario (George, Kate; Jan 2015)
  - Land model groups test/comment on dataset by July 2015
  - Final datasets with full set of scenarios (if ready) provided by Jan 2016
  - Develop prototype tiled data format and revised CMIP variable list; distribute to modeling groups for comment (Dave, Elena, Chris; Sept 2014)

- **Model experiments (Phase 1)**
  - Complete tests of 1%/2% deforestation experiments; report at AGU? (Victor, Dave; Fall 2014)
  - Develop preliminary offline land cover/management expts protocol and complete initial set of experiments (single point?) (Dave, Elena, Peter Lawrence; mid 2015?)
    - What datasets to use for land use, irrigation, fertilization, etc?
Topics for Discussion

- What are the most important scenarios to study in LUMIP?
- What are the largest policy relevant land-use changes contemplated?
- What is the most important information for IAMs to pass to ESMs in support scenarios? (e.g. Land cover change, Biofuels/CCS, Ag. Mgt?)
- When is initial year, and is there an attempt at harmonization across IAMs in that year, what variables, what resolution?
- Spinup?
- Historic no LULCC simulations, emission dirven run? Tier?
- Can we design and execute an effective land-use coupling experiment?
- How can we improve workflow/information flow between History/Obs, ESM, IAM?

- ....
PARKING LOT
IAM-LUH-ESM INFO EXCHG

**CMIP5**
- Crop area
- Pasture area
- Wood harvest carbon
- Urban area*
- Biofuel area*

**CMIP6?**
- Crop area
- Pasture area
- Wood harvest carbon
- Urban area*
- Biofuel area*
- Land cover F/NF
- Land cover PFT
- Fertilizer amt/t
- Irrigation amt/t
- Transitions?
- Narrative?
Model Metrics and Diagnostics (Draft)

- Primary variables: net radiation, evapotranspiration, temperature, precipitation, and land carbon stocks
- Protocol: paired simulations w/wo factor, online and/or offline, range of spatial and temporal scales and domains, ensemble members
- Leverage existing datasets for evaluation from multiple ongoing landmips, supplement as needed
- Development of global benchmark maps for all forcing case
- Development of paired-sites data sets for land-use factor experiments
- ILAMB+LU extension
# Land Experiments – Prioritization/Coordination (DRAFT)

<table>
<thead>
<tr>
<th>Experiment Name</th>
<th>Tier</th>
<th>Experiment Description</th>
<th>Configuration</th>
<th>Years</th>
<th># Ers</th>
<th>CMIP6 MIP</th>
<th>Coord/use with/other MIPs</th>
<th>Responsible group</th>
<th>Science questions, science purpose</th>
<th>Comments</th>
<th>Contact</th>
</tr>
</thead>
<tbody>
<tr>
<td>LND_ALLFORCE_hist</td>
<td>1</td>
<td>Historical land only simulation including transient land cover/use, CO₂, etc</td>
<td>LND</td>
<td>1850-2014</td>
<td>1</td>
<td>Land only</td>
<td>LUMIP, CMIP6, LSIPP</td>
<td>GSW03, TRENDY</td>
<td>Assess systematic biases in land model</td>
<td>Should be part of DECK</td>
<td>Hyungjun Kim</td>
</tr>
<tr>
<td>LND_ALLUucci_hist</td>
<td>1</td>
<td>Historical land only simulation with land use held at 1990; no human activity</td>
<td>LND</td>
<td>1850-2014</td>
<td>1</td>
<td>LUMIP</td>
<td>CMIP6, D&amp;I, CSIPP</td>
<td>GSW03, TRENDY</td>
<td>Assess land use change impact on historic water, energy, carbon fluxes; Benchmark land model response to LUCCE</td>
<td>Requires LND_H57</td>
<td>Hyungjun Kim</td>
</tr>
<tr>
<td>LND_ALLFORCE fut</td>
<td>3</td>
<td>Future land only simulation forced with several projected climate trajectories</td>
<td>LND</td>
<td>2015-2100</td>
<td>?</td>
<td>LUMIP</td>
<td>LUMIP, CMIP6, ScenarioMIP</td>
<td>GSW03, ISIMIP</td>
<td>Assess land response to climate change across land models; impact studies</td>
<td>How many climate projections (W of ESM projections, 50 of scenarios)</td>
<td></td>
</tr>
<tr>
<td>CPL_150F</td>
<td>1</td>
<td>Idealized 1.5°C or 2.0°C (TSQ) global deforestation with all other forcings held constant</td>
<td>CPL</td>
<td>50 or 100 years + 50 years at global deforestation</td>
<td>1</td>
<td>LUMIP</td>
<td>LUOD</td>
<td>Assess coupled model response to land cover change in idealized setting; identify what amount of deforestation is required to see signal relative to noise</td>
<td>Starts from same point in pre-industrial control; extension of 30+ years so that can also look at equilibrium responses; compare to pre-industrial control</td>
<td>Dave Lawrence, Vic Brown</td>
<td></td>
</tr>
<tr>
<td>LND_DF, ATM_DF, CPL_DF</td>
<td>3</td>
<td>Paired idealized timeline control and deforestation experiments for specific regions (tropical, boreal, temperate, TSC)</td>
<td>LND, ATM, CPL</td>
<td>1890-2010</td>
<td>?</td>
<td>LUMIP</td>
<td>LUOC, LUOD</td>
<td>Idealized experiments designed to assess response to land cover change in specific regions</td>
<td>Specific regions TSQ, based on preliminary work in LUCC</td>
<td>Almut Arndt, Nathalie de Noblet-Ducoudre</td>
<td></td>
</tr>
<tr>
<td>LND_COVER/MANAGE</td>
<td>2</td>
<td>Test idealized timeline control and deforestation experiments for specific regions (tropical, boreal, temperate, TSC)</td>
<td>LND</td>
<td>1850-2014</td>
<td>1</td>
<td>LUMIP</td>
<td>ScenarioMIP</td>
<td>LUMIP</td>
<td>Assess relative impact of land cover and incrementally more comprehensive land management change on land to atmosphere fluxes of water, energy, and carbon; forced with historical observed climate</td>
<td>Exact TSQ, but including grasscrop, wood harvest, pasture, crop, crop-irrigation, crop-irrigation-fertilization possibly could be extended to 2100 as in LND_FUT</td>
<td>Dave Lawrence, George Hurtt</td>
</tr>
<tr>
<td>CPL_ALLFORCE hist_conc</td>
<td>1</td>
<td>Standard all forcing historical simulation</td>
<td>CPL</td>
<td>1850-2014</td>
<td>5+</td>
<td>DECK</td>
<td></td>
<td></td>
<td>Assess biomeophysical impact of historic land use change on climate and extremes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CPL_ALLFORCE hist_conc</td>
<td>1</td>
<td>All forcing historical emission driven</td>
<td>CPL</td>
<td>1850-2014</td>
<td>?</td>
<td>CMIP</td>
<td>LUMIP, CSIPP</td>
<td></td>
<td>Assess total impact (biogeophysical and biogeochemical) of historic land use change; along with paired concentration runs, can assess biomeophysical vs biogeochemical impact of land use change</td>
<td>Requires CPL_ALLFORCE_hist_conc</td>
<td></td>
</tr>
<tr>
<td>CPL_ALLFORCE hist_conc</td>
<td>1</td>
<td>Same as CPL_ALLFORCE_hist_conc but with land cover held at 1850, no human activity;</td>
<td>CPL</td>
<td>1850-2014</td>
<td>3</td>
<td>LUMIP</td>
<td>OBA, CMIP</td>
<td></td>
<td>Assess biomeophysical impact of historic land use change on climate and extremes</td>
<td>Requires CPL_ALLFORCE_hist_conc</td>
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<td>CMIP</td>
<td></td>
<td>Assess total impact (biogeophysical and biogeochemical) of historic land use change; along with paired concentration runs, can assess biomeophysical vs biogeochemical impact of land use change</td>
<td>Requires CPL_ALLFORCE_hist_conc</td>
<td></td>
</tr>
<tr>
<td>CPL_ALLFORCE fut_conc</td>
<td>1</td>
<td>All forcing future scenarios, emissions driven</td>
<td>CPL</td>
<td>2015-2100</td>
<td>?</td>
<td>CMIP</td>
<td>ScenarioMIP, LUMIP</td>
<td></td>
<td>Evaluate impact of projected land use change on climate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CPL_alluse hist_conc</td>
<td>1</td>
<td>Additional land mitigation policy scenario for a particular RF scenario, keep all GHG the same, only change land use emissions driven if possible</td>
<td>CPL</td>
<td>2015-2100</td>
<td>?</td>
<td>LUMIP</td>
<td>ScenarioMIP</td>
<td></td>
<td>Evaluate how future potential land use trajectories for a particular RF target affect climate regionally and globally</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CPL_alluse hist_conc</td>
<td>1</td>
<td>Same as CPL_ALLFORCE_hist_conc except with land use held constant at 2015 levels done for one or more scenarios; emissions driven if possible</td>
<td>CPL</td>
<td>2015-2100</td>
<td>?</td>
<td>LUMIP</td>
<td>ScenarioMIP</td>
<td></td>
<td>Evaluate impact of projected land use change on climate</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
What we learned (CMIP5+)?

- Enabled first global model emission driven projections of both CO₂ and climate including effects of spatial land-use changes
- Land-use effects on global climate are generally modest relative to FF, but still important
- Land-use transitions are needed for accurately tracking land cover change resulting from land-use change
- Land-use effects are complex and challenging to diagnose
- Different models implemented standardized land-use data sets differently
- Potentially important impacts, management practices, biophysical effects, policy options, uncertainties, and feedbacks not adequately accounted for in current design
- Substantial opportunities exist to build on CMIP5 approach and improve data and models for CMIP6
Priorities for CMIP6 (Land Use)

1. Repeat and mature the LUH process (more data, more terms, increased resolution, longer period, better communication)
2. Work to standardize products, and usage of products
3. Focus: links between LU change, LC change, C fluxes, Biophys.
4. New emphasis: LU management, policy relevance, uncertainty
5. New scenarios: Esp. SSPs and with added multi-objective considerations
6. Expand RCP-RF definition to include biophysical
7. Joint harmonization of LU emissions and LU changes
8. Diagnose ESMs, IAMs, and IAVs to quantify effective data requirements (resolution, precision, etc)
9. Prepare for fully coupled human-physical models
10. Consider LUMIP
LUH2 Land-cover Classes (Proposed)

- Based on widely used classification (IGBP)
  - ENL, EBL, DNL, DBL, and mixed forests
  - Closed and open Shrublands, savanna
  - Grassland, pasture
  - Urban
  - Croplands

- Add important crop functional types (CFTs)
  - C4
  - C3 perennial
  - C3 annual
  - N fixers
  - Rice

- Align with IAMs and ESMs

- Advance implementation
LUH2 Management (Proposed)

• Focus on Largest Forcings
  • Harvest
  • Fertilizer
  • Irrigation
  • Tillage
  • Biofuel/CCS
  • Forest Plantations
  • Pasture Mgt intensity

• Harmonize management forcings with land-use/land-cover patterns

• Align with IAMs and ESMs

• Advance Implementation

Global irrigated area 1900-2000 (Freydank & Siebert 2008) and global N fertilizer use 1900-2010 (Smil 2001; IFA 2014).
CMIP5 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, 2011)*
Discussion (partial list)

- Spatial resolution
- Temporal resolution
- Time domain
- Updated history
- Land cover details
- Management details
- New future scenarios
- Offline/online testing
- Usage Standardization
- Output Standardization
- Support
- Workflow
- Other...

- Harvest frequency/timing
- Pasture Land cover, Mgt
- Biofuel Map, PFT, Mgt, CCS, F
- Land-use/Fire interactions
- Natural Disturbances