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

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SSG: Victor Brovkin, Nathalie de Noblet Ducoudre, Julia Pongratz, Kate Calvin, Elena Shevliakova, Chris Jones

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

EMF Meeting
Snowmass
July 30, 2014
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, TRENDY, 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

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**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 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 biophysical, land cover vs land management.
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 to start now
  – A diagnostic protocol developed to quantify related model sensitivities
  – Development of land use benchmarking data products for evaluation

• Data standardization
  – Repeat and mature land use harmonization process \(\rightarrow\) 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
Issue: Subgrid data as default for CMIP

CLM tiling structure

Gridcell

Landunit

Vegetated

Lake

Urban

Glacier

Crop

Column

Soil

Roof

Sun Wall

Shade Wall

Pervious

PFT

PFT1

PFT2

PFT3

PFT4 ...

Unirrig

Irrig

Unirrig

Irrig

Crop1

Crop1

Crop2

Crop2 ...

PFT

V

PFT1

V

PFT2

C1I

C1U

V

PFT3

C2I

C2U

V

PFT4

UT,H,M

TBD

MD

Unirrig

Irrig

Unirrig

Irrig

Crop1

Crop1

Crop2

Crop2 ...

TBD

MD

TBD

MD

TBD

MD
Model Experimental Design (Draft)

**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 land cover/use change on climate relative to other forcings
# Draft experimental design (Phase 1)

<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>
<tr>
<td>Land cover versus land management change (Tier 2)</td>
<td>Draft experimental design (Phase 1)</td>
<td></td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td>---------------------------------------------</td>
<td></td>
</tr>
<tr>
<td><strong>LND_allmanage</strong></td>
<td>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 (1850-2014, 2100?)</td>
<td></td>
</tr>
<tr>
<td><strong>LND_1850spin</strong></td>
<td>All land cover/use/management features turned on, 1700 start; transient CO₂, N-dep, aerosol dep</td>
<td></td>
</tr>
<tr>
<td><strong>LND_noLULCC</strong></td>
<td>All management simulation with land use change starting at 1850</td>
<td></td>
</tr>
<tr>
<td><strong>LND_grasscrop</strong></td>
<td>LND_allmanage except no land use change</td>
<td></td>
</tr>
<tr>
<td><strong>LND_gross_vs_net</strong></td>
<td>LND_grasscrop but w/ LULCC with ‘grassland’ crop/pasture</td>
<td></td>
</tr>
<tr>
<td><strong>LND_gross_vs_net</strong></td>
<td>LND_grasscrop except with net transitions instead of gross</td>
<td></td>
</tr>
<tr>
<td><strong>LND_fire</strong></td>
<td>LND_grasscrop with fire management</td>
<td></td>
</tr>
<tr>
<td><strong>LND_woodharv</strong></td>
<td>LND_control with wood harvest turned on</td>
<td></td>
</tr>
<tr>
<td><strong>LND_pasture</strong></td>
<td>LND_grasscrop but with grazing ???</td>
<td></td>
</tr>
<tr>
<td><strong>LND_crop</strong></td>
<td>Land use change with crop area utilizing prognostic crop model</td>
<td></td>
</tr>
<tr>
<td><strong>LND_crop-irrig</strong></td>
<td>LND_crop with realistic transient irrigated area</td>
<td></td>
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<tr>
<td><strong>LND_crop-irrig-fert</strong></td>
<td>LND_crop-irrig with realistic transient fertilization</td>
<td></td>
</tr>
</tbody>
</table>
### Draft Experimental Design (Phase 2)

| Land use change impact on land to atmosphere fluxes of water, energy, carbon (Tier 1) |
|---------------------------------|---------------------------------------------------------------|
| **LND_allforce**                | Offline LND with crop, irrigation, fertilization schemes active with transient land cover and land management and CO₂, N-dep, and aerosol dep forced with historical observed climate (LMIP) 1850-2014, 2015-2100? |
| **LND_noLULCC**                 | Same as LND_allforce except with land cover held constant at 1850, no human impact |

| Land use change impact on past and future climate (Tier 1) |
|---------------------------------|---------------------------------------------------------------|
| **CPL_allforce**                | All forcing simulation (DECK, ScenarioMIP) 1850-2100 |
| **CPL_noLULCC_hist**            | Same as ESM_allforce except with land cover/use held constant at 1850, concentration (for DA) and emission driven, no human impact 1850-2014 (3 ens for conc runs)2100? |
| **CPL_landpolicy_fut**          | Additional land mitigation policy scenario with strongly different land use to the control (mid-range RCP scenario); keep all emissions the same as control scenario, only change land use; emissions driven runs if possible 2015-2100 (# ens?) |
| **CPL_noLULCC_fut**             | Future simulation with same RCP scenario with land cover/use held constant at 2014 levels; emissions driven runs if possible 2015-2100 (# ens?) |
## Draft Experimental Design (Track 2)

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Description</th>
<th>Period</th>
</tr>
</thead>
</table>

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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/by 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, CMIP, LSPM</td>
<td>GSWp3, TRENDY</td>
<td>Assess systematic biases in land model</td>
<td>Should be part of DECK</td>
<td>Hyungjin Kim</td>
</tr>
<tr>
<td>LND_NDUCC_hist</td>
<td>1</td>
<td>Historical land only simulation with land use held at 1850; no human activity</td>
<td>LND</td>
<td>1850-2014</td>
<td>1</td>
<td>LUMIP</td>
<td>CMIP, DKKP, LSPM</td>
<td>GSW93, TRENDY</td>
<td>Assess land use change impact on historic water, energy, carbon fluxes; Benchmark land model; response to LUCC</td>
<td>Requires LNDHist</td>
<td>Hyungjin 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>7</td>
<td>LUMIP</td>
<td>LUMIP, CMIP, ScenarioMIP</td>
<td>GSW93, ISIMIP</td>
<td>Assess land response to climate change across land models; impact studies</td>
<td>How many climate projections? (of ESM projections, # of scenarios)?</td>
<td></td>
</tr>
<tr>
<td>CPL_1500F</td>
<td>1</td>
<td>Idealized 1.5° or 2.5° (T2G) global deforestation with all other forcings held constant</td>
<td>CPL</td>
<td>2015-2014</td>
<td>1</td>
<td>LUMIP</td>
<td>LUCID</td>
<td>LUCID</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 response; compare to pre-industrial control</td>
<td>Dave Lawrence, Victor Browkin</td>
</tr>
<tr>
<td>LND_DF, ATM_DF, CPL_DF</td>
<td>3</td>
<td>Pair idealized time-series control and deforestation experiments for specific regions (boreal, temperate, T2G)</td>
<td>LND, ATM, CPL</td>
<td>2015-2014</td>
<td>7</td>
<td>LUMIP</td>
<td>LUCID</td>
<td>LUCID</td>
<td>Idealized experiments designed to assess response to land cover change in specific regions</td>
<td>Specific regions T2G, based on preliminary work in LUCID</td>
<td>Almut Arneth, Nathalie de Noblet-Ducoudré</td>
</tr>
<tr>
<td>LND_COVER/MANAGE</td>
<td>2</td>
<td>Factorial set of land only experiments with increasingly realistic treatment of land management</td>
<td>LND</td>
<td>2015-2014</td>
<td>7</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 expts T2G, but including grasscrop, wood harvest, pasture, crop, crop-irrigation, crop-irrigation-fertilization; possibly could be extended to 2300 as in LND_FUT</td>
<td>Dave Lawrence, George Hunt</td>
</tr>
<tr>
<td>CPL_ALLFORCE_hist_conc</td>
<td>1</td>
<td>Standard all forcing historical simulation</td>
<td>CPL</td>
<td>2015-2014</td>
<td>5</td>
<td>DECK</td>
<td></td>
<td>LUMIP</td>
<td>Assess biophysical 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>Standard all forcing historical deforestation</td>
<td>CPL</td>
<td>2015-2014</td>
<td>7</td>
<td>LUMIP</td>
<td>CMIP, LUMIP</td>
<td>LUMIP</td>
<td>Assess total impact (biophysical and biogeochemical) of historic land use change; along with paired concentration runs, can assess biophysical 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>2015-2014</td>
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<td>CMIP, LUMIP</td>
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<td>Requires CPL_ALLFORCE_hist_conc</td>
<td></td>
</tr>
<tr>
<td>CPL_ALLFORCE_fut_emis</td>
<td>1</td>
<td>All forcing future scenarios, emissions driven</td>
<td>CPL</td>
<td>2015-2100</td>
<td>7</td>
<td>SCENARIO, LUMIP, CMIP</td>
<td>LUMIP</td>
<td>Evaluate how future land use trajectories for a particular RF scenario affect climate regionally and globally</td>
<td>Depends on outcome of ScenarioMIP; which future scenario? do; formalize one scenario with multiple emissions scenarios?; envision 3 land use trajectories for a particular RF scenario (e.g., standard, high deforestation, low deforestation)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CPL_landpolicy_fut_emis</td>
<td>1</td>
<td>Additional land mitigation policy scenarios 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>7</td>
<td>LUMIP</td>
<td>SCENARIO, LUMIP, CMIP</td>
<td>LUMIP</td>
<td>Evaluate how future land use trajectories for a particular RF scenario affect climate regionally and globally</td>
<td>How should human activity such as fire suppression, ignition, wood harvest be treated?</td>
<td></td>
</tr>
</tbody>
</table>
What we learned (CMIP5+)?

- Enabled first global model emission driven projections of both CO$_2$ 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
- Griddded
- 1500-2005

LAND-USE FUTURE

*IAM RCPs:*
- Population
- Socioeconomic
- Energy
- Land-use
- Griddded/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