

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

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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>

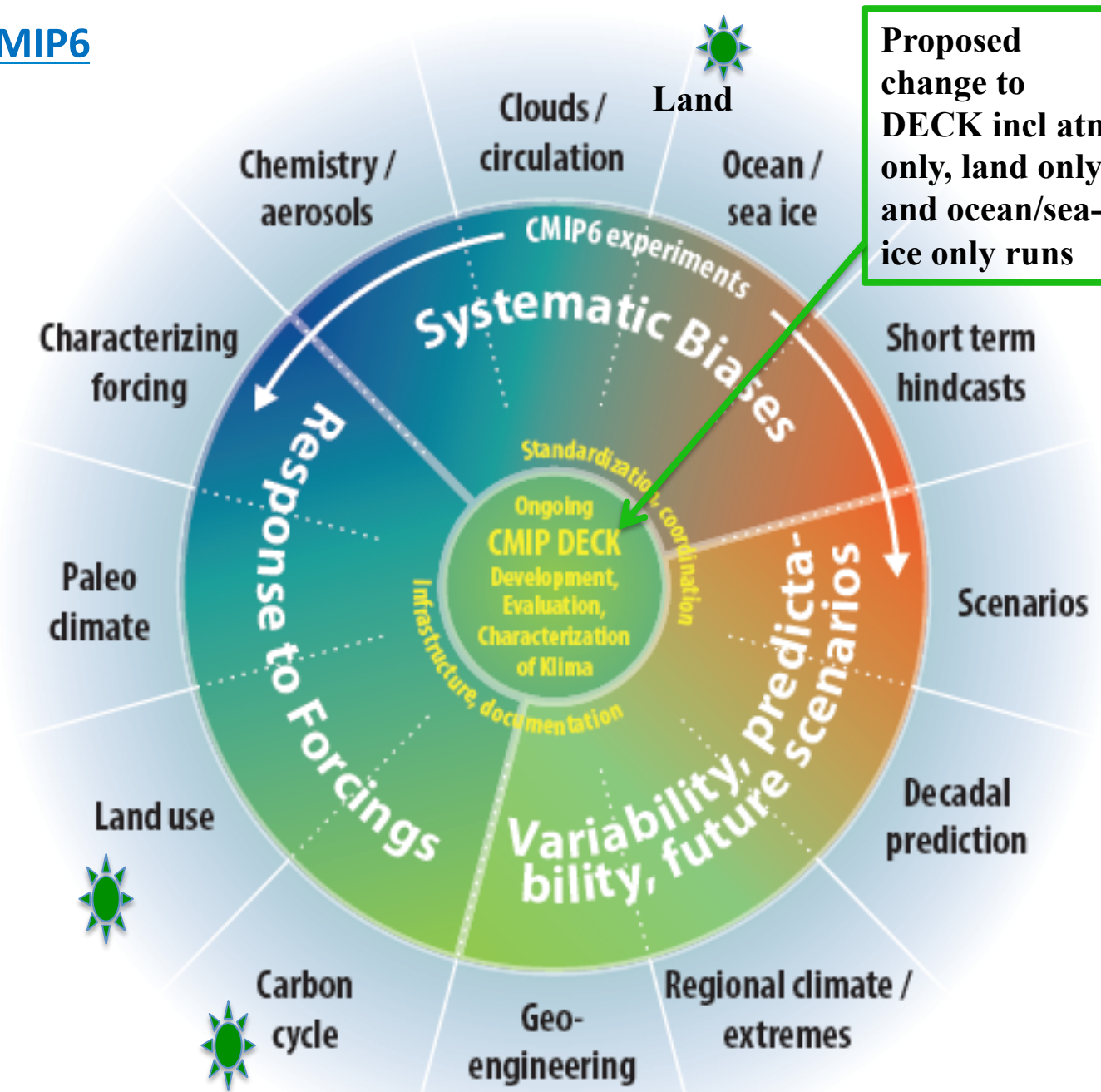
LUMIP Timeline

- 2013 Summer: Concept
- 2013 Fall: CMIP Proposal, WGCM Briefing
- 2014 Spring: GLP Meeting, Workshop 1
- 2014 July 17-18: GEWEX – Biogeophysics
- 2014 July 21-22: Hamburg – Biogeochemistry
- 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



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

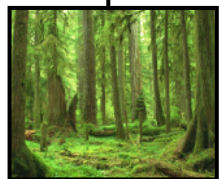
Task: Develop subgrid data archiving for selected key variables as default for CMIP

CLM tiling structure

Gridcell



Landunit



Vegetated



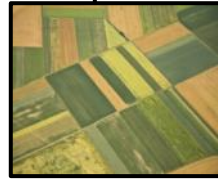
Lake



Urban



Glacier



Crop

Column



Soil



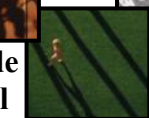
Roof



Sun Wall



Shade Wall



Pervious



Impervious

PFT



PFT1



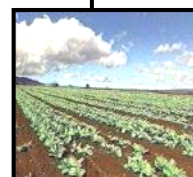
PFT2



PFT3



PFT4 ...



Unirrig



Irrig



Unirrig



Irrig



Crop1



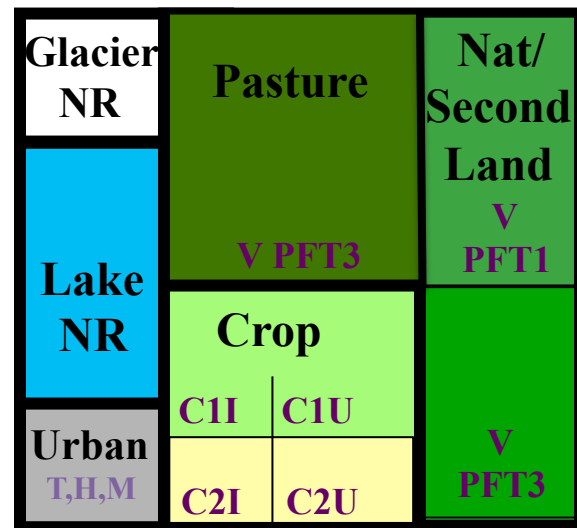
Crop1



Crop2



Crop2 ...

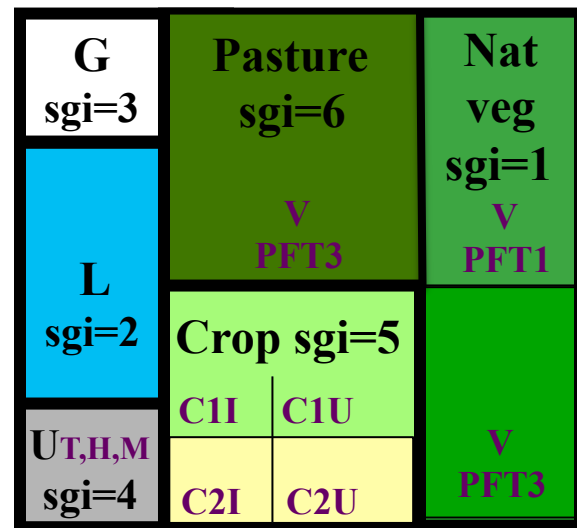


Task: Develop subgrid data archiving for selected key variables as default for CMIP

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

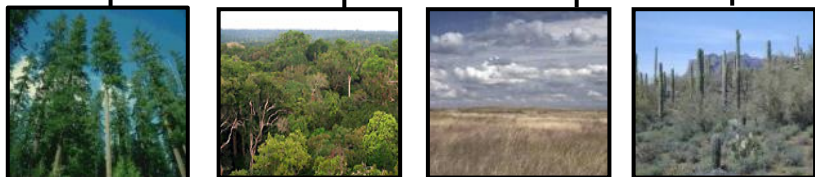
gpp_sg – gross primary productivity
npp_sg – net primary productivity
nee_sg – net ecosystem exchange (or NEP)
cSoil_sg – carbon mass in soil pool
cVeg_sg – carbon mass in vegetation
cLitter_sg – carbon mass in litter pool



pp



Unirrig Irrig Unirrig Irrig



PFT1 PFT2 PFT3 PFT4 ...



Crop1 Crop1 Crop2 Crop2 ...

CL
str

Land

V

Colu

PFT

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 historical and future land cover/use change on climate relative to other forcings

Draft experimental design (Phase 1)

Experiment	Description	Period
Process understanding	Idealized experiments designed to assess biogeophysical role of land cover change on climate	
CPL_1%DF	Idealized 1% or 2% per year deforestation, once global deforest, continue run for 50 to 100 years (Tier 1)	1850-????
LND_DF, ATM_DF, CPL_DF	Land, atm, cpl simulations with some set of tropical, boreal, or temperate deforestation (defined by LUC4C/LUCID?) (Tier 3?)	1980-2010

Draft experimental design (Phase 1)

Land cover versus land management change (Tier 2)	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?)
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LND_allmanage	All land cover/use/management features for each particular model turned on; 1700 start; transient CO ₂ , N-dep, aerosol dep, etc.
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LND_1850spin	All management simulation with land use change starting at 1850 (testing impact of pre-1850 land use)
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LND_noLULCC	LND_allmanage except no land use change
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LND_grasscrop	LND_noLULCC but w/ LULCC with 'grassland' crop/pasture
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LND_gross_vs_net	LND_grasscrop except with net transitions instead of gross
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LND_fire	LND_grasscrop with human fire management
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LND_woodharv	LND_grasscrop or LND_fire with wood harvest
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LND_pasture	LND_grasscrop but with grazing on pastureland (???)
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LND_crop	LND_grasscrop but with crop area utilizing prognostic crop model
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LND_crop-irrig	LND_crop with realistic transient irrigated area
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LND_crop-irrig-fert	LND_crop-irrig with realistic transient fertilization
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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 same land model configuration as used in coupled simulations; transient land cover and land management, CO ₂ , N-dep, aerosol dep forced with historical climate (land only sim)	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 (Tier 3?), no human impact	1850-2014 (3 ens for conc runs)
CPL_landpolicy_fut	Additional land use change scenario with strongly different land use to the control (see next slide); 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 (Tier 2?)	2015-2100 (# ens?)

Draft Experimental Design (Phase 2)

Land use change impact on future climate

RCP3.7

RCP7

**ScenarioMIP
(Tier 1)**

SSP1

SSP3

LUMIP (Tier 1)

Deforest_sens
SSP1
w/ SSP3-7
land use

Afforest_sens
SSP3
w/ SSP1-3.7
land use

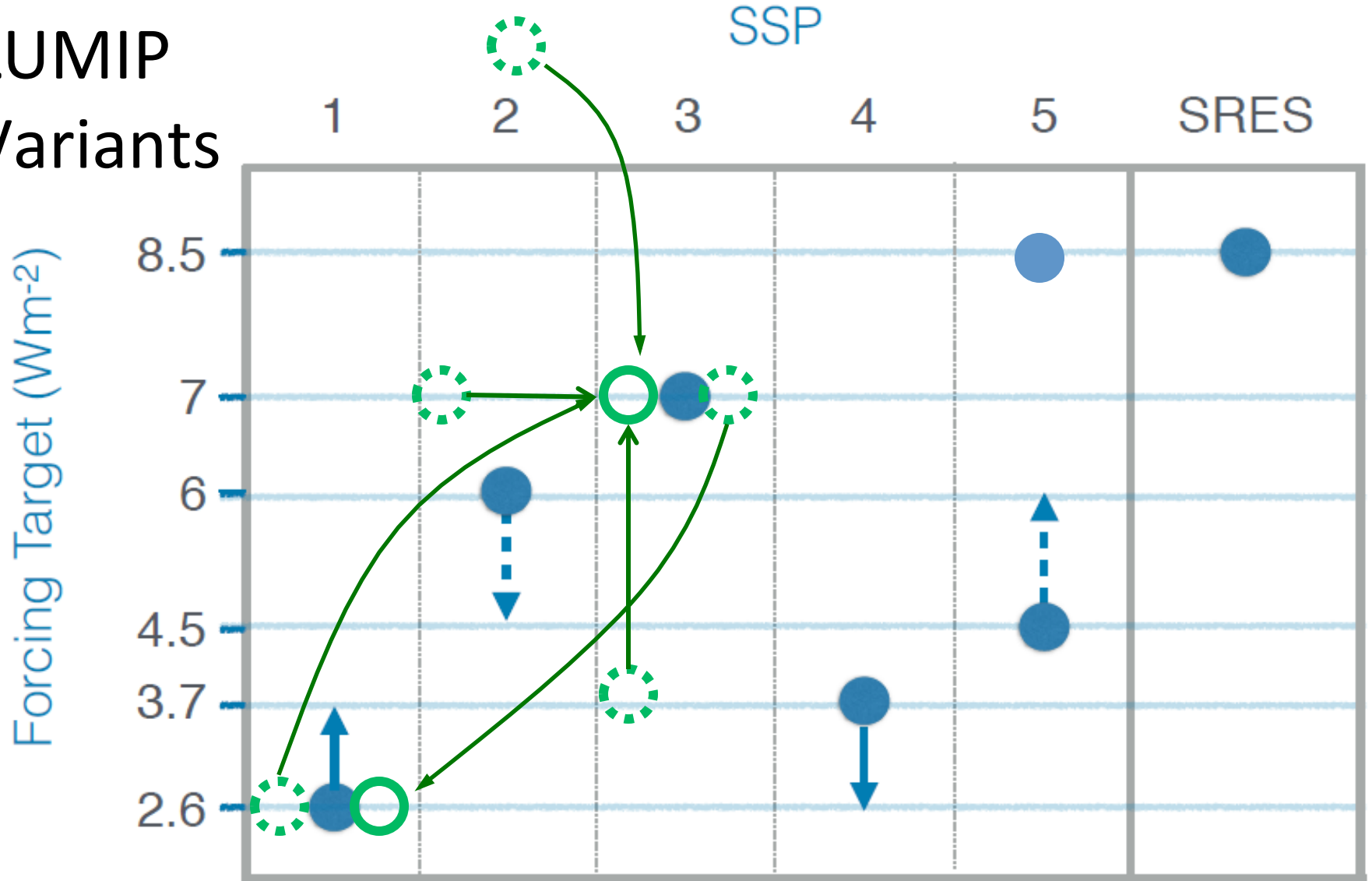
LUMIP (Tier 2)



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



 LUMIP scenario variant
 LUMIP component

 Permutation 1
 Permutation 2

Draft Experimental Design (Phase 2)

Experiment	Description	Period
Effects of climate change on land use and land use change		
iESM	???	

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 driven 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)

Notes: All simulations assume that land model is run with prognostic carbon cycle

Experiment Name	Tie r	Experiment Description	Configuration	Years	# Ens	CMIP6 MIP	Coord/use with/by other MIPs	Responsible group	Science questions, science purpose	Comments	Contact	Cost
LND_ALLFORCE_hist	1	Historical land only simulation including transient land cover/use, CO2, etc	LND	1850-2014	1	Land only	LUMIP, C4MIP, LSMIP	GSWP3, TRENDY	Assess systematic biases in land model	Should be part of DECK	Hyunjin Kim	
LND_noLULCC_hist	1	Historical land only simulation with land use held at 1850; no human activity	LND	1850-2014	1	LUMIP	C4MIP, D&A?	GSWP3, TRENDY	Assess land use change impact on historic water, energy, carbon fluxes; Benchmark land model response to LULCC	Requires LND_HIST	Hyunjin Kim	
LND_ALLFORCE_fut	3	Future land only simulation forced with several projected climate trajectories	LND	2015-2100	?	LSMIP	LUMIP, C4MIP, ScenarioMIP	GSWP3, ISI-MIP	Assess land response to climate change across land models; Impact studies	How many climate projections (# of ESM projections, # of scenarios)?		
CPL_1%DF	1	Idealized 1% or 2% (TBD) global deforestation with all other forcings held constant	CPL	50 or 100 years + 50 years at global deforest	1	LUMIP		LUCID?	Assess coupled model response to land cover change in idealized setting; Identify what amount of deforestation required to see signal relative to noise	Starts from some point in pre-industrial control ; extension of 50+ years so that can also look at equilibrium response; compare to pre-industrial control	Dave Lawrence, Victor Brovkin	
LND_DF, ATM_DF, CPL_DF	3	Paired idealized timeslice control and deforestation experiments for specific regions (tropical, boreal, temperate?, TBD)	LND, ATM, CPL	1980-2010	?	LUMIP		LUC4C, LUCID	Idealized experiments designed to assess response to land cover change in specific regions	Specific regions TBD, based on preliminary work in LUC4C	Almut Arneht, Nathalie de Noblet-Ducoudre	
LND_COVER/MANAGE	2	Factorial set of land only experiments with increasingly realistic treatment of land management	LND	1850-2014	1	LUMIP	ScenarioMIP	LUMIP	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	Exact expts TBD, but including grasscrop, wood harvest, pasture, crop, crop-irrigation, crop-irrigation-fertilization; possibly could be extended to 2100 as in LND_FUT	Dave Lawrence, George Hurtt	
CPL_ALLFORCE_hist_conc	1	Standard all forcing historical simulation	CPL	1850-2014	5+	DECK						
CPL_ALLFORCE_hist_emis	1	All forcings historical emission driven	CPL	1850-2014	?	C4MIP?	LUMIP	C4MIP				
CPL_noLULCC_hist_conc	1	Same as CPL_ALLFORCE_hist_conc but with land cover held at 1850, no human activity;	CPL	1850-2014	3	LUMIP	D&A, C4MIP	LUMIP	Assess biogeophysical impact of historic land use change on climate and extremes	Requires CPL_ALLFORCE_hist_conc		
CPL_noLULCC_hist_emis	2	Same as CPL_ALLFORCE_hist_emis but with land cover held at 1850, no human activity	CPL	1850-2014	?	LUMIP	C4MIP	LUMIP	Assess total impact (biogeophysical and biogeochemical) of historic land use change; along with paired concentration runs, can assess biogeophysical vs biogeochemical impact of land use change	Requires CPL_ALLFORCE_hist_emis		
CPL_ALLFORCE_fut_emis	1	All forcing future scenarios, emissions driven	CPL	2015-2100	?	C4MIP?	ScenarioMIP, LUMIP	C4MIP				
CPL_landpolicy_fut_emis	1	Additional land mitigation policy scenarios for a particular RF scenario, keep all GHG the same, only change land use; emissions driven runs if possible	CPL	2015-2100	?	LUMIP	ScenarioMIP	LUMIP	Evaluate how future possible land use trajectories for a particular RF target affect climate regionally and globally	Depends on outcome of ScenarioMIP; which future scenarios?; do for just one scenario with multiple ensemble members?; Envision 3 land use trajectories for a particular RF scenario (e.g., standard, hi deforestation, hi afforestation)		
CPL_noLULCC_fut_emis	2	Same as CPL_ALLFORCE_fut except with land use held constant at 2015 levels; done for one or more scenarios?; emissions driven if possible	CPL	2015-2100	?	LUMIP	ScenarioMIP	LUMIP	Evaluate impact of projected land use change on climate	How should human activity such as fire suppression, ignition, wood harvest be treated?	Victor Brovkin	

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

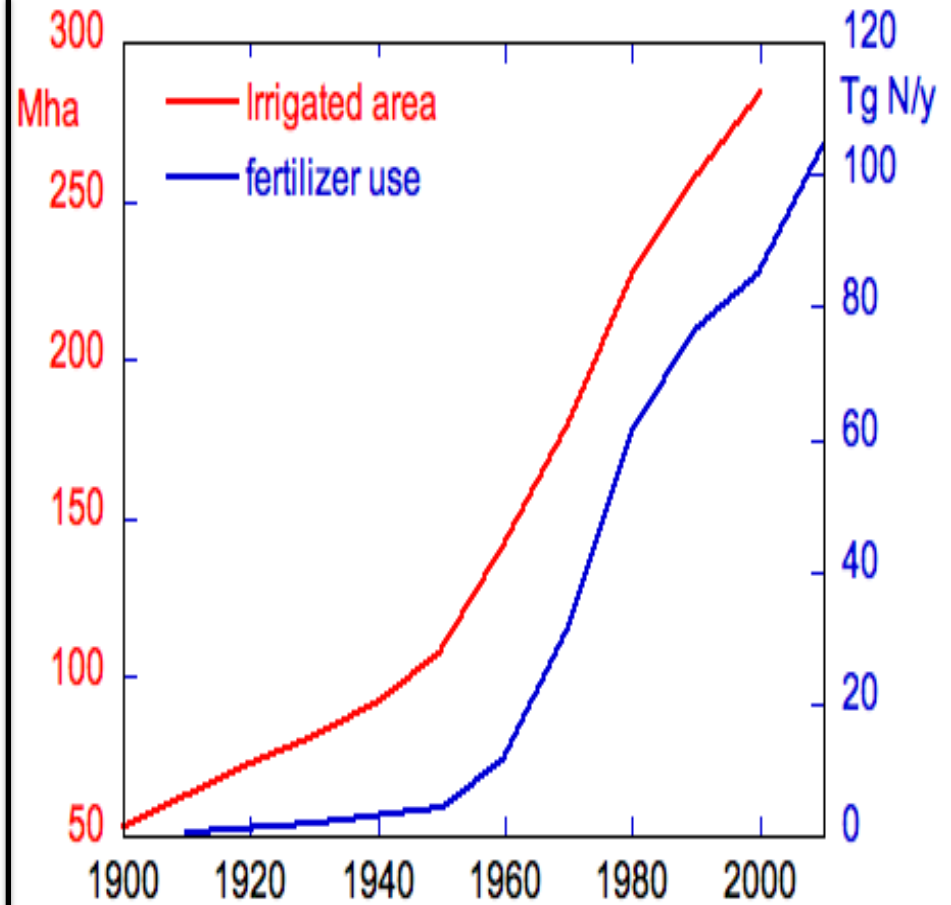
Table 1. Land cover types.

IGBP	GLM3	GCAM	CLM
ENL Forest	ENL Forest	Unmanaged forest* Managed forest*	ENL Tree –temperate ENL Tree –boreal
EBL Forest	EBL Forest		EBL Tree –tropical EBL Tree –temperate
DNL Forest	DNL Forest		DNL Tree –boreal
DBL Forest	DBL Forest		DBL Tree –tropical DBL Tree –temperate DBL Tree –boreal
Mixed forest	Mixed forests		(tiled grid cell)
Closed shrub	Closed shrub	Shrub	EBL shrub–temperate
Open shrub	Open shrub		DBL shrub–temperate
Woody savanna	Woody savanna		DBL shrub–boreal
Savanna	Savanna		
Grassland	Pasture	Grassland Unmanaged pasture Pasture	C3 arctic grass C3 grass C4 grass
wetlands	wetlands	Tundra	C3 arctic grass
Urban	Urban	Rock ice desert	urban
Cropland/natural		Urban	(tiled grid cell)
Snow/ice	Ice/water		ice
Barren			barren
Croplands	C4	Corn Fodder grass/herb* Sugar crops* Other grain* Biomass* Miscellaneous/other*	Temperate corn Tropical corn Sugar cane
	C3 perennial	Palm fruit Jatropha Willow Eucalyptus Sugar crops*	
	C3 annual	Wheat Other grain* Root/tuber Oil crops* Fodder grass/herb* Fiber crops* Biomass* Miscellaneous/other*	Spring wheat Winter wheat Barley Winter barley Rye Winter rye Cotton
	N-fixers	Fodder herb* Oil crops*	Soy Tropical soybean
	Rice	Rice	rice

* GCAM crop categories cannot always be classified into a single CLM or GLM PFT. These will be disaggregated following the proportion of each PFT within the GCAM categories in the base year, and assuming it constant in the future. For example, sugar crops include both sugar cane (C4) and beet root (C3) in known proportion in the base year.
E: evergreen; D: deciduous; NL: needleleaf; BL: broadleaf

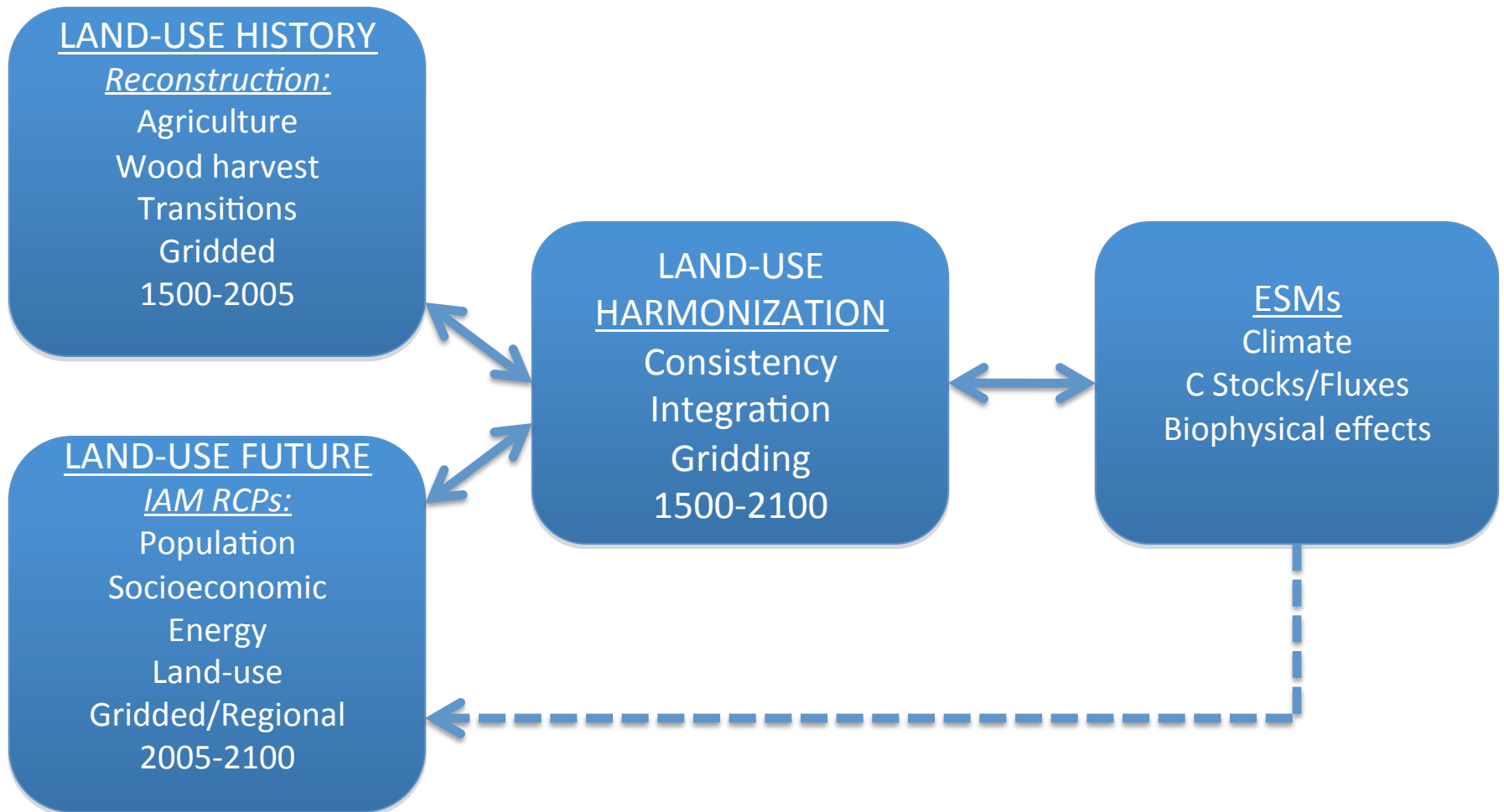
LUH2 Management (Proposed)

- 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)



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