



# Advancing our understanding of the impacts of historic and projected land use in the Earth System



## The Land Use Model Intercomparison Project (LUMIP)

Chairs: David Lawrence (NCAR) and George Hurtt (University of Maryland)

SSG: Almut Arneth, 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

<https://cmip.ucar.edu/lumip>

# LUMIP Goals

What are the effects of land use and land-use change on climate and biogeochemical cycling (past-future)?

What are the impacts of land management on surface fluxes of carbon, water, and energy and are there regional land-management strategies with promise to help mitigate against climate change?

- Fossil fuel vs. land use change
- Biogeochemical vs. biogeophysical impact of land use
- Land cover vs. land management impacts
- Modulation of land use impact on climate by land-atmosphere coupling strength (LS3MIP)
- Modulation of global CO<sub>2</sub> fertilization by land use

CMIP6 Questions: How does Earth System respond to forcing?

WCRP Grand Challenge: Biospheric forcings and feedbacks ,  
Water Availability, Climate Extremes

# LUMIP Major Activities

- **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: new variables, subgrid land-use tile variables
- **Model experiments**
  - Experiments designed to isolate, quantify, and understand land use and land management effects on climate
- **Model metrics and diagnostics**
  - Develop metrics to assess/quantify model performance with respect to land use impacts on climate
  - Synthesis activity to collect existing metrics

# LUMIP/LU Forcing Timeline

- 2013 Summer: Concept, Aspen AGCI
- 2014 July-August: GEWEX, Hamburg, Aspen meetings
- 2014 September: LUMIP proposal to CMIP submitted
- 2015 January: Prototype Land-use dataset released (v0.1)
- 2015 July: CMIP6 Endorsement
- 2015 October: WGCM/CMIP6/LandMIP workshops
- 2016 January: Historic land-use dataset released (LUH2\_v1.0)
- 2016 March: GMD papers submitted
- 2016 September: GMD paper published
- 2016 October: LUH2\_v2.0h released

# LUMIP Experimental Design

## Overall Approach:

Two parts: 1) idealized simulations, 2) realistic simulations

Tiered prioritization of experiments

Includes coupled and land-only simulations (520 yrs Tier 1 GCM/ESM)

## Part 1 Idealized model experiments:

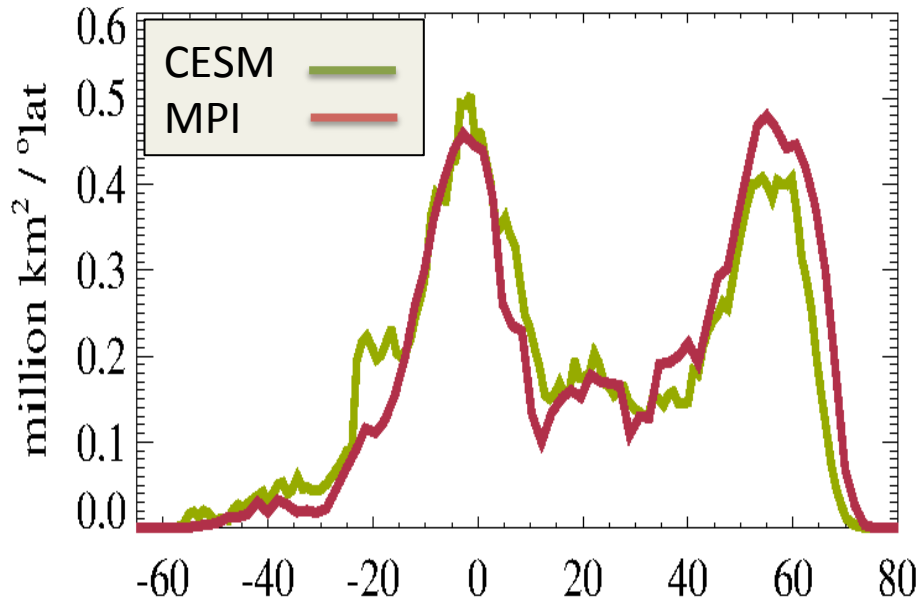
Improve process understanding/assessment of how models represent impact of changes in land state on climate;

Quantify model sensitivity to potential land cover and land management changes

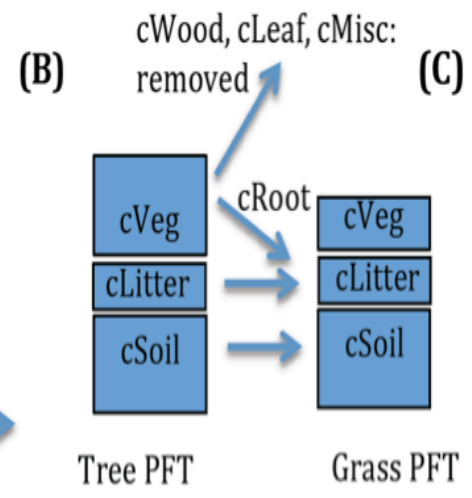
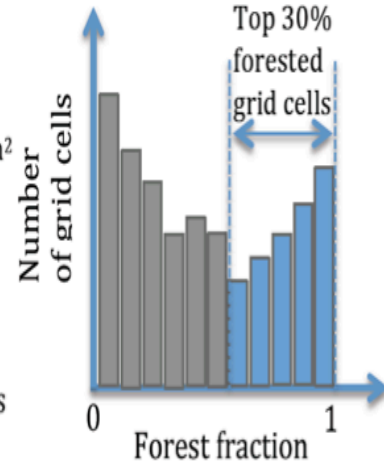
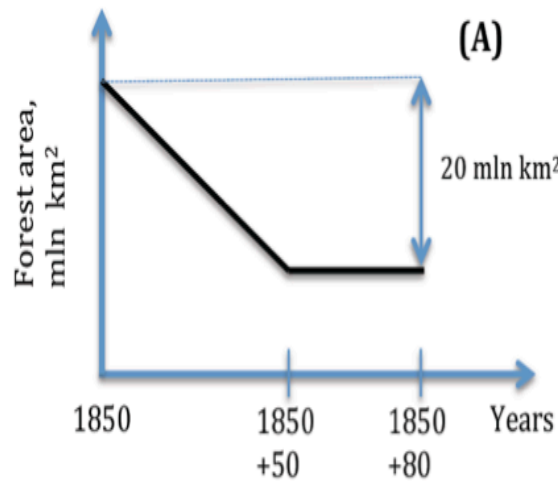
## Part 2 Realistic model experiments:

Isolate the role of historical and future land cover/use change on climate relative to other forcings, assess potential for climate mitigation through land use

# Idealized global deforestation GCM (Tier 1)



- Remove 20 million km<sup>2</sup> forest over 50 years from top 30% forest area grid cells, starting from 1850 control
- Controlled assessment of coupled model response to deforestation



## Historic period No LULCC experiments GCM and land-only (Tier 1)

- Assess impact of LULCC in historical period for water, carbon, energy fluxes and climate (C4MIP, LS3MIP)
- Assess land model response to historic LULCC (LS3MIP)
- Assess how land-atmosphere coupling strength modulates climate, weather, extremes response to LULCC (LS3MIP)
- Relevant for detection and attribution (DAMIP)

Built off of and compared to CMIP6 historical

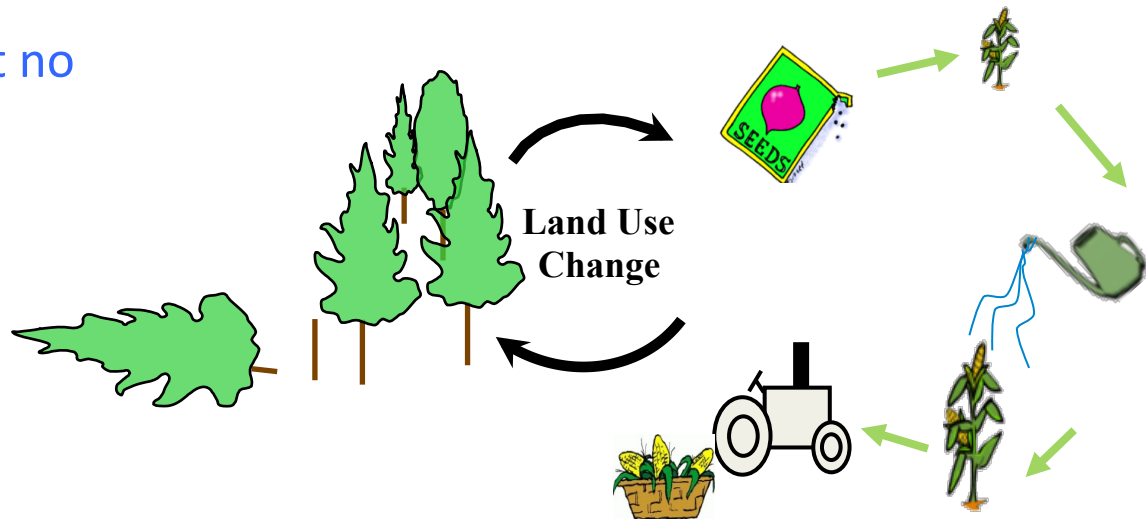
Long pre-industrial control will be utilized in signal-to-noise analysis

**NOTE:** Guidance as to definition of “No LULCC” provided in LUMIP GMID paper, but implementation will be model dependent; contact LUMIP SSC with questions

# Land cover change vs land management experiments (Phase 1, Tier 2)

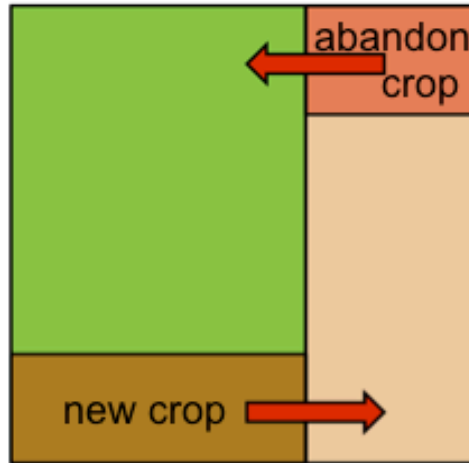
Set of land-only historic simulations (variants of LMIP-Hist) with one-at-a-time modification of particular aspects of land management; Evaluate impact of land use on fluxes of water, energy, and carbon

- ① Year 1700 instead of 1850 start
- ② No LULCC change
- ③ Alternate land use histories
- ④ No shifting cultivation
- ⑤ Crop and pasture as unmanaged grassland
- ⑥ Crops with crop model but no irrigation/fertilization
- ⑦ No irrigation
- ⑧ No fertilization
- ⑨ No wood harvest
- ⑩ No grazing on pastureland
- ⑩ No human fire ignition/suppression
- 11 Constant 1850 CO<sub>2</sub> (N dep?)
- 12 Constant climate

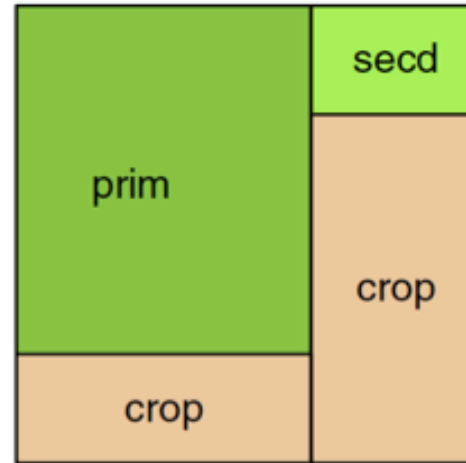




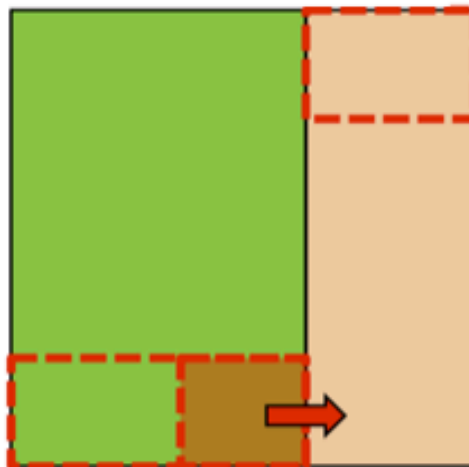
# Shifting cultivation



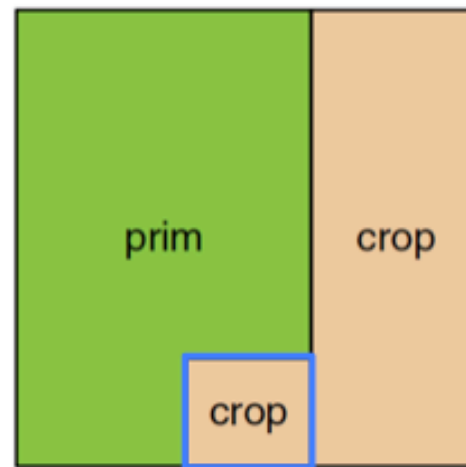
shifting cultivation  
(gross LU transition)



state after gross transition



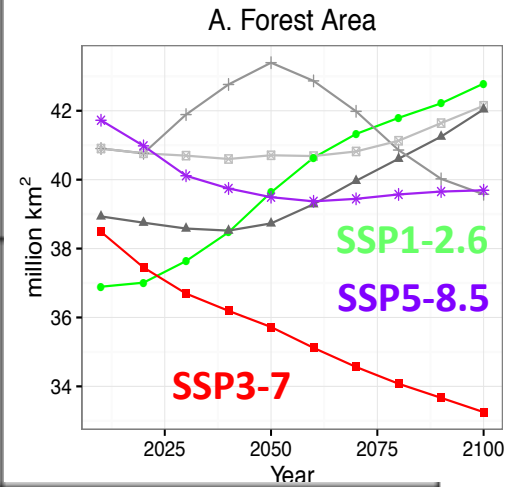
without shifting cultivation  
(net LU transition)



state after net transition

# Land use change impact on future climate expts

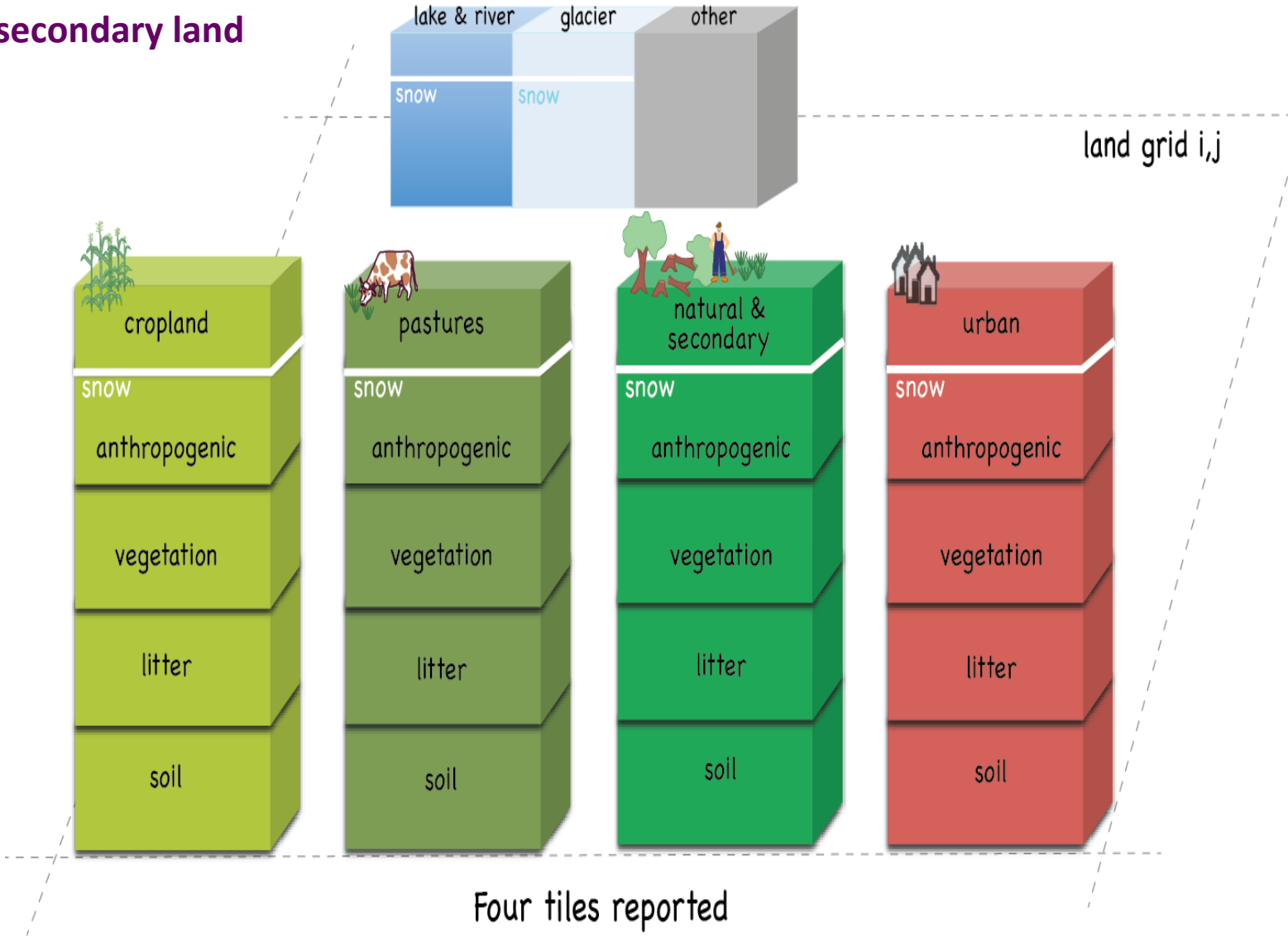
	Land-Use Scenario		
Main Scenario	SSP1-2.6	SSP3-7	SSP5-8.5
SSP1-2.6	<b>ScenarioMIP</b> Conc.-driven	<b>LUMIP</b> Conc.-driven	
SSP3-7	<b>LUMIP</b> Conc.-driven	<b>ScenarioMIP</b> Conc.-driven	
SSP5-8.5	<b>LUMIP</b> Emissions-driven		<b>C4MIP</b> Emissions-driven <b>ScenarioMIP</b> Conc.-driven



# Subgrid land-use tile data request

LUMIP is requesting sub-grid information for four sub-grid categories (i.e., tiles) for selected variables to permit more detailed analysis of land-use induced surface heterogeneity. The four categories are:

- (1) Primary and secondary land
- (2) Cropland
- (3) Pastureland
- (4) Urban



# Subgrid land-use tile data request

LUMIP is requesting sub-grid information for four sub-grid categories (i.e., tiles) for selected variables to permit more detailed analysis of land-use induced surface heterogeneity. The four categories are:

**(1) Primary and secondary land**

**(2) Cropland**

**(3) Pastureland**

**(4) Urban**

## LUMIP LUT vars requested for following expts

- **CMIP6 Historical (coupled and land-only)**
- **ScenarioMIP**
- **C4MIP scenario expts**
- **LUMIP**

## STATUS

**New variable names and area\_types have been proposed to CF-conventions mailing list and are under discussion**

## Selected Subgrid Variables (not the full list, see [LUMIP website](#))

### **Biogeophysical variables**

tasLut – near-surface air temperature

hussLut – near-surface specific humidity

hflsLut – latent heat flux

hfssLut – sensible heat flux

rsusLut – surface upwelling shortwave (albedo)

laiLut – leaf area index

### **Biogeochemical variables, carbon stocks/fluxes**

gppLut – gross primary productivity

nppLut – net primary productivity

cSoilLut – carbon mass in soil pool

cVegLut – carbon mass in vegetation

cLitterLut – carbon mass in litter pool

### **LULCC fraction changes**

fracInLut – fraction transferred into land-use type

fracOutLut – fraction transferred out of LUT

# Example aggregation onto Land-Use Tiles for CLM

**CLM tiling structure**

**Gridcell**



**Landunit**



**Vegetated**



**Lake**



**Urban**



**Glacier**



**Crop**

**Column**



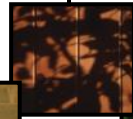
**Soil**



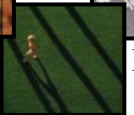
**Roof**



**Sun Wall**



**Shade Wall**



**Pervious**



**Impervious**



**Unirrig**



**Irrig**



**Unirrig**



**Irrig**

**PFT**



**PFT1**



**PFT2**



**PFT3**



**PFT4 ...**



**Crop1**



**Crop1**



**Crop2**

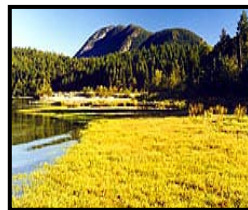


**Crop2 ...**

# Example aggregation onto Land-Use Tiles for CLM

**CLM tiling structure**

**Gridcell**



**Landunit**



**Vegetated**



**Lake**



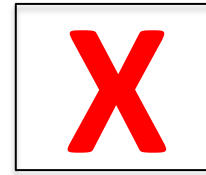
**Urban**



**Glacier**



**Crop**



**Pasture**

**Column**



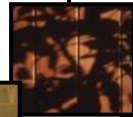
**Soil**



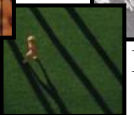
**Roof**



**Sun Wall**



**Shade Wall**



**Pervious**



**Impervious**



**Unirrig**



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**Unirrig**

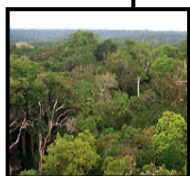


**Irrig**

**PFT**



**PFT1**



**PFT2**



**PFT3**



**PFT4 ...**



**Crop1**



**Crop1**



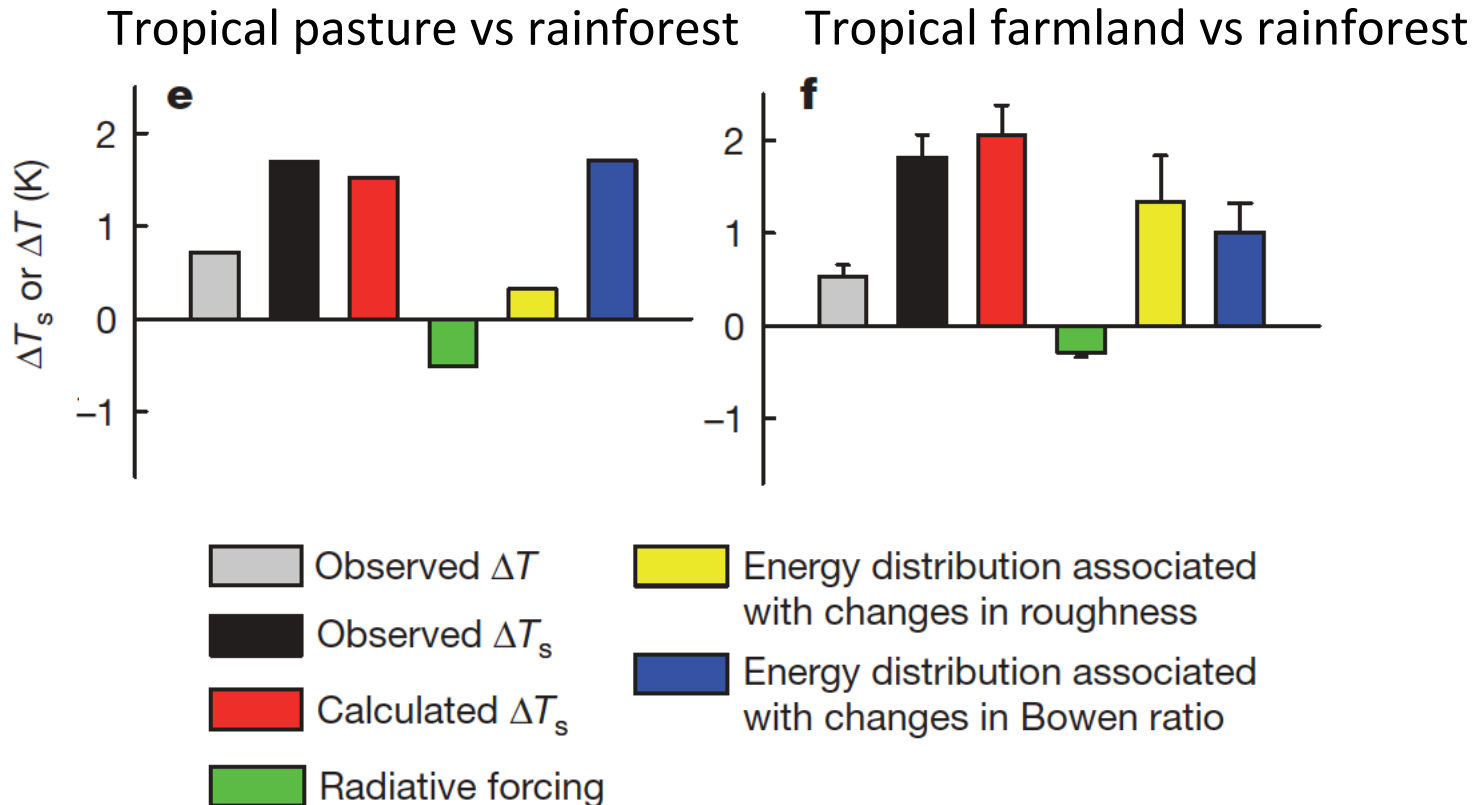
**Crop2**



**Crop2 ...**

# Land Use Metrics and Diagnostics

- Task: Develop/collect set of metrics to assess/quantify model performance with respect to land use impacts on climate
- Synthesis activity/paper of existing metrics (Edouard Davin has initiated for biogeophysics)



## LUMIP | Land Use Model Intercomparison Project

## LUMIP

[Home](#)

## LUMIP HOME

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### LUMIP | LAND USE MODEL INTERCOMPARISON PROJECT

- [LUMIP Proposal to CMIP Panel](#) - Updated June 10, 2015
- [Proposed LUMIP Experiments List for CMIP6](#) - see **Experiments** tab and look for LUMIP
- [LUMIP New Variables List for CMIP6](#) - see **New variables** tab
- [Land Use Harmonization \(LUH2 v0.2\) README](#) - September 9, 2015
- [Land Use Harmonization \(LUH2 v0.1\) README](#) - January, 2015

### LUMIP GOOGLE GROUP

We will update the LUMIP community on simulations and datasets and make plans for analysis through this google group. To sign up, click [here](#)

### OVERVIEW

Human land-use activities have resulted in large changes to the biogeochemical and biophysical properties of the Earth surface, with resulting implications for climate. In the future, land-use activities are likely to expand and/or intensify further to meet growing demands for food, fiber, and energy. CMIP5 achieved a qualitative scientific advance in studying the effects of land-use on climate, for the first time explicitly accounting for the effects of global gridded land-use changes (past-future) in coupled carbon-climate model projections. Enabling this advance, the first consistent gridded land-use dataset (past-future) was developed, linking historical land-use data, to future projections from Integrated Assessment Models, in a standard format required by climate models. Results indicate that the effects of land-use on climate, while uncertain, are sufficiently large and complex to warrant an expanded activity focused on land-use for CMIP6.

### PRIMARY CONTACTS

- George Hurtt ([gchurtt@umd.edu](mailto:gchurtt@umd.edu), U. Maryland)
- Dave Lawrence ([dlawren@ucar.edu](mailto:dlawren@ucar.edu), NCAR)

### SCIENTIFIC STEERING COMMITTEE

Almut Arneth (KIT), Victor Brovkin (Max Planck), Kate Calvin (PNNL), Andrew Jones (LBNL), Chris Jones (Hadley Centre), Peter Lawrence (NCAR), Nathalie de Noblet Ducoudré (IPSL), Julia Pongratz (Max Planck), Sonia Seneviratne (ETH-Zurich), Elena Shevliakova (GFDL)

### LUMIP

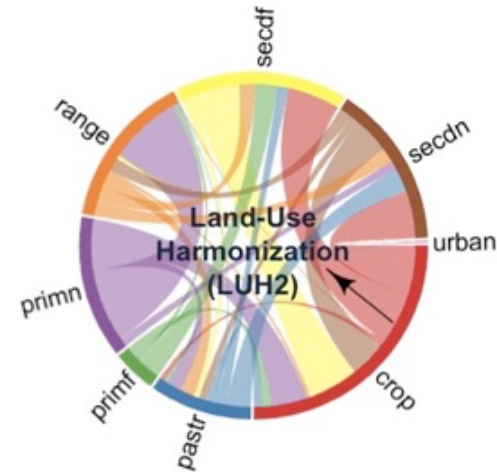
- [LUMIP Home](#)
- [Experimental Protocols](#)
- [Timeline & Meetings](#)

<https://cmip.ucar.edu/lumip>



# LUMIP/LU Forcing Timeline

- 2016 (autumn) through 2018: Model simulations
  - Ideally, groups would run land-only simulation first and benchmark simulated/imposed land cover time series
  - Also preferred that groups run the idealized deforestation expt early
- 2016 December: LUH2 harmonized datasets for SSPs released ???
- 2017 Begin analysis (coordination through LUMIP SSG)
- 2017 Land-use change impacts metrics/benchmarks synthesis papers
- 2018 Spring: possible joint LUMIP, C4MIP, LS3MIP meeting
- 2018 Summer: possible LUMIP meeting to present/discuss papers/analysis
- 2021 IPCC AR6?



G. Hurtt  
D. Lawrence

# Land-use Forcing

**FUTURES:** In progress now (6). Finalizing input datasets from IAMs, generating draft harmonized datasets, reviewing and iterating with each IAM teams as needed, monthly with all IAM teams.

**HISTORICAL: LUH2 v2h Release (10/14/16):** The updated release of the historical land-use forcing dataset (LUH2 v2h) covers the period 850-2015 and corrects all known issues and notices identified with the previous version (LUH2 v1.0h). This dataset replaces the previously released dataset (LUH2 v1.0h). This product is the result of a series of prototypes released previously, uses the established data format, and will connect smoothly to gridded products for the future. Additional 'High' and 'Low' historical products in development.

**Data Availability:** <http://luh.umd.edu> (available), CMIP (in progress)

**LUMIP:** Paper published (Lawrence et al 2016), Kickoff telecon October 26, 2016.

# Acknowledgements

**DOE-SciDAC:** Louise Chini (UMD), Steve Frolking (UNH), Ritvik Sahajpal (UMD), Matt Hansen (UMD), Dave Lawrence (NCAR), Peter Lawrence (NCAR), Peter Thronton (DOE), Bill Collins (LBL), Andy Jones (LBL), Jay Edmonds (JGCRI), Kate Calvin (JGCRI), Kees Klein Goldewijk (PBL)

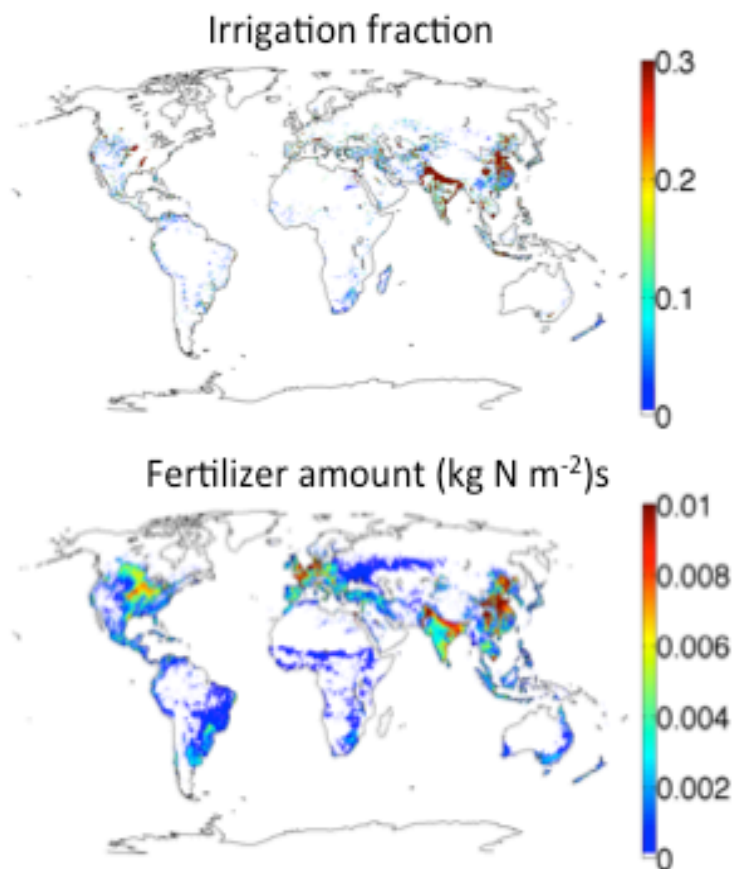
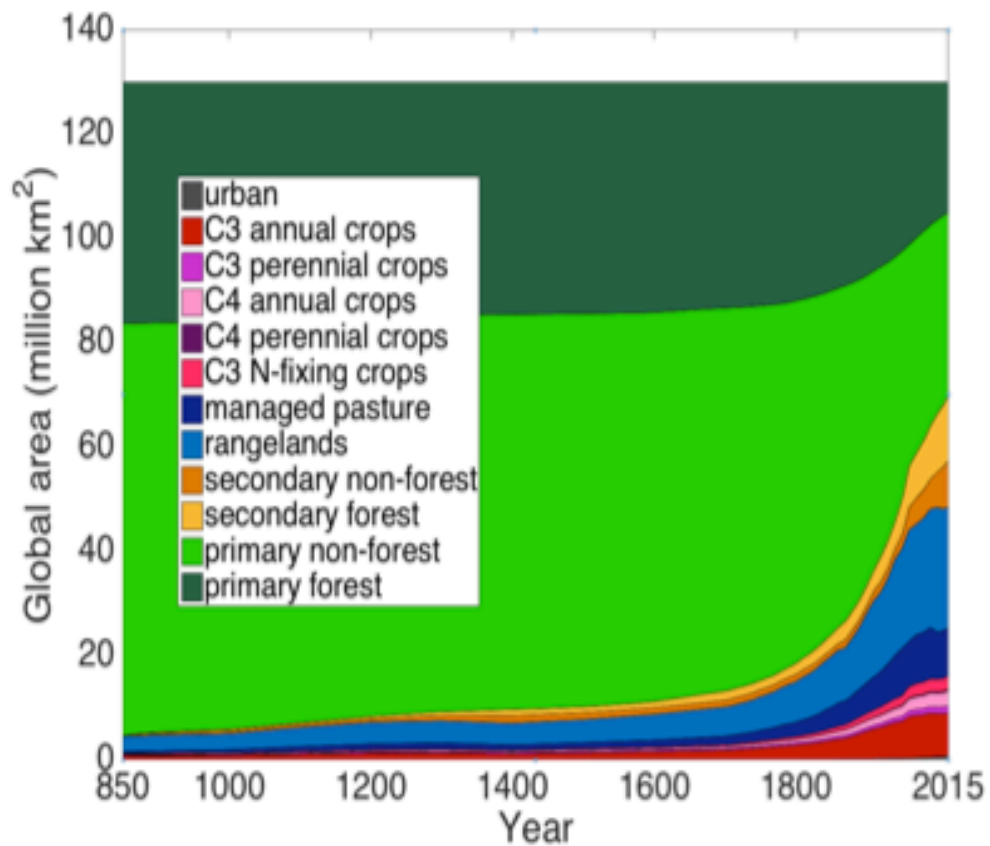
**LUMIP-SSG:** Dave Lawrence (NCAR), Almut Arneth (KIT), Victor Brovkin (MPI), Kate Calvin (JGCRI), Andy Jones (LBL), Chris Jones (UKMO), Peter Lawrence (NCAR), Nathalie de Noblet-Ducoudré (IPSL), Julia Pongratz (MPI), Sonia Seneviratne (ETH), Elena Shevliakova (GFDL)

**Other:** Ole Mertz (KU), Andreas Christensen (KU), Justin Fisk (UMD), Andreas Heinemann (UBE), Johann Jungclaus (MPI), Jed Kaplan (EPFL), Fernando Sedano (UMD)

# LUH2 Major Attributes for CMIP6

- LUH2 v2h (historical update) released October 14, 2016
- Updated Common history Reference, + High and low\* cases
- Multiple harmonized futures, CMIP6 ScenarioMIP (6), Added 1.5 degree cases\* (6)
- Spatial domain, Global
- Spatial resolution, 0.25 x 0.25 degree
- Temporal domain, 850-2100 (850-2300\*)
- Temporal resolution, annual
- 12 possible land-use states including separation of Primary and Secondary natural vegetation into Forest and Non-forest sub-types, Pasture into Managed Pasture and Rangeland, and Cropland into multiple crop functional types (C3 annual, C3 perennial, C4 annual, C4 perennial, N fix)
- >100 possible land-use transitions per grid cell per year, including crop rotations, shifting cultivation, ag changes, wood harvest
- Updated static basemaps, historical inputs, shifting cultivation estimates
- F/NF (LandSat) constraints
- Gridded agriculture management layers including irrigation, fertilizer, tillage\*, and biofuel management
- Partitioning of woof harvest fuel/non-fuel
- Expanded Diagnostic Package

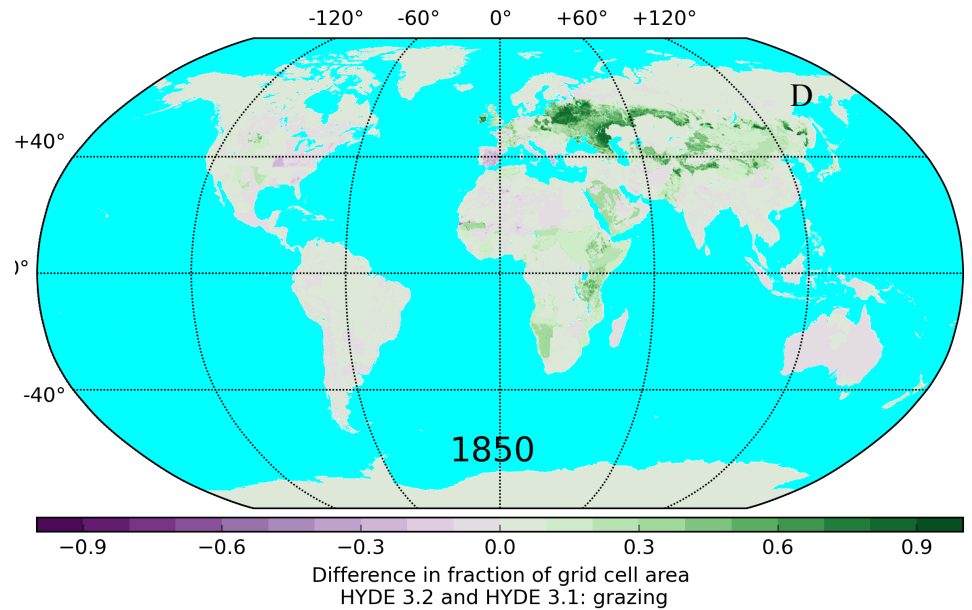
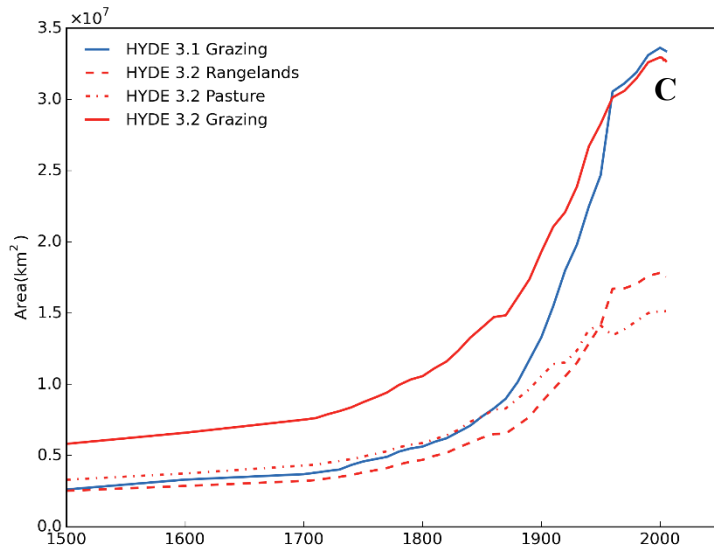
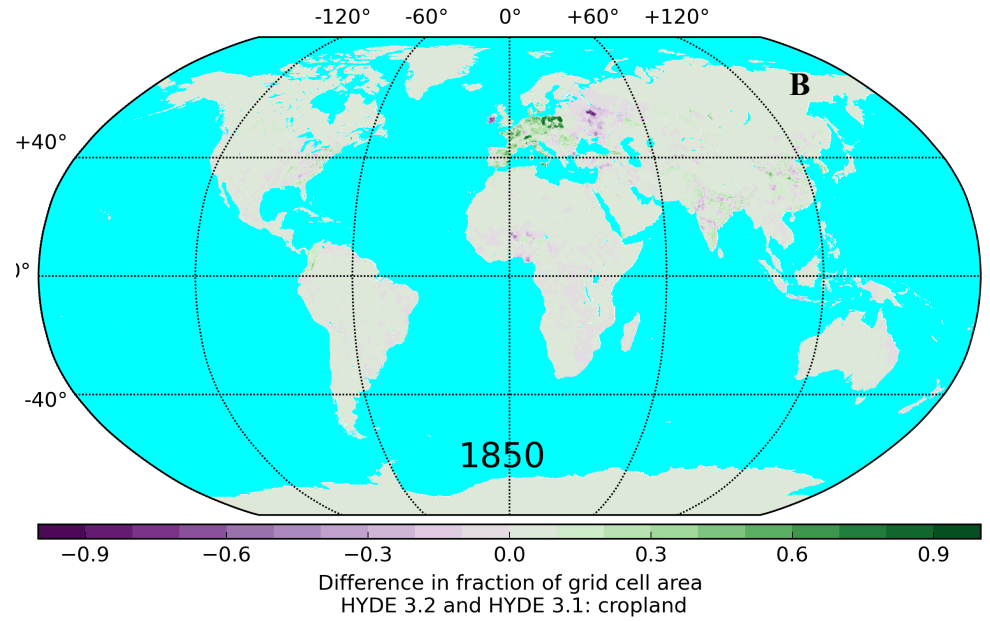
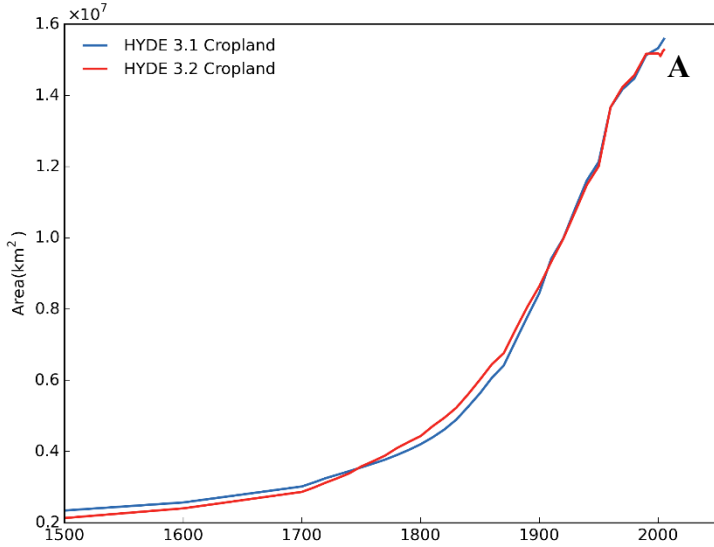
**>50x CMIP5 data**



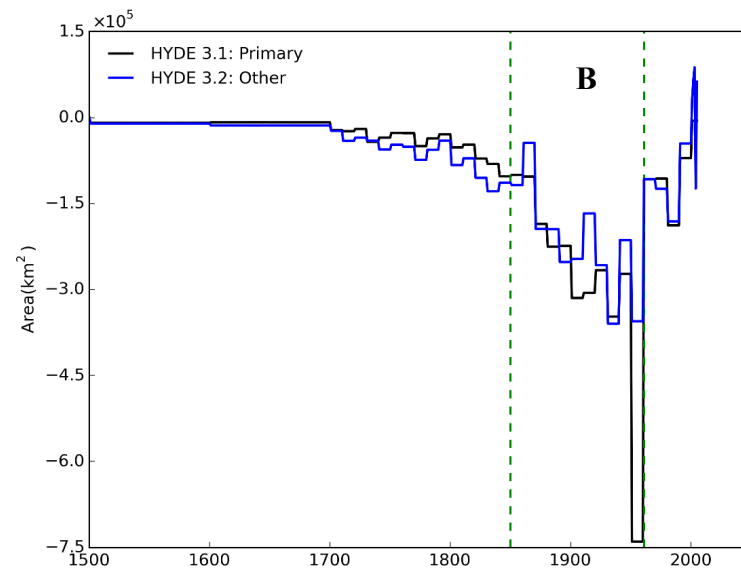
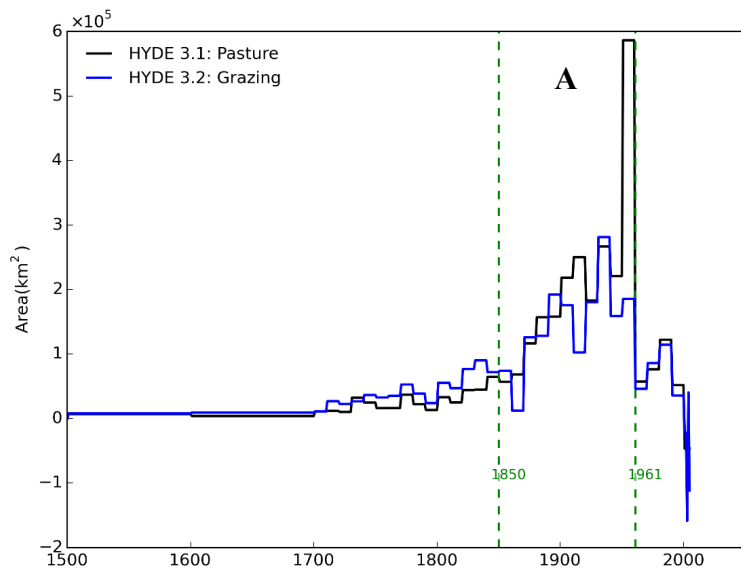
LUH2 v1.0h (April 29, 2016)

Lawrence et al 2016

# Global Agricultural Area: HYDE 3.2\* and HYDE 3.1

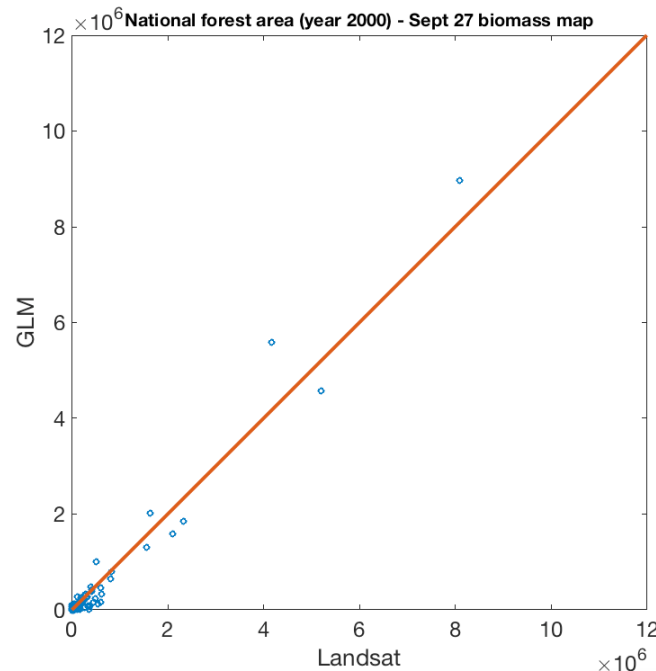


# Annual Changes in Global Agricultural Area: HYDE 3.2\* and HYDE 3.1



# Expanded Diagnostic Package (Tabular, Examples 65)

	Diagnostic	Time-period	Region	LUH2_v2h	LUH2_v1.0h	Hurtt 2011 (LUH1)	Hurtt 2006	Units	Reference data
1	* Total Cropland area	1990	Global	15.17	15.17	15.13	12.1	10 <sup>6</sup> km <sup>2</sup>	
2	* Total Pasture area	1990	Global	32.72	32.72	33.11	25.8	10 <sup>6</sup> km <sup>2</sup>	
3	* Primary land area	1990	Global	56.15	55.7	54.57	57.7	10 <sup>6</sup> km <sup>2</sup>	
4	Total gross transitions	2000	Global	1.86	1.85	2.90	0.55 - 4.2	10 <sup>6</sup> km <sup>2</sup>	
5	Total net transitions	2000	Global	0.23	0.22	0.17	0.0 - 0.17	10 <sup>6</sup> km <sup>2</sup>	
12	* Median secondary forest mean age	2015	Global	43.78	37.18	n/a	n/a	years	30 - 40 years, Ben Poulter, NACP 2013
18	Secondary land increase	1700 - 2000	Global	13.18	12.25	17.19	10.0-44.0	10 <sup>6</sup> km <sup>2</sup>	
24	Agricultural land undergoing shifting cultivation	2000	Global	0.32	0.32	0.58	0.48-0.65	10 <sup>6</sup> km <sup>2</sup> /yr	Andreas, Ole personal communication: 0.3
27	* Total wood clearing	850 - 1990	Global	356.16	336.97	336.97	n/a	n/a	Pg C
37	* Forest area	2015	Global	37.21	36.68	n/a	n/a	10 <sup>6</sup> km <sup>2</sup>	Sexton, 2016: 32.1-41.4
44	* Fertilizer use	2012	Global	106.60	105.89	n/a	n/a	Tg N/yr	Zhang, 2016: 100
45	* Irrigated area	2003	Global	2.51	2.51	n/a	n/a	10 <sup>6</sup> km <sup>2</sup>	FAO: 2.77
50	* Plant total biomass on all lands	Potential	Global	718.11	749.94	731.0545424		Pg C	Kucharik, 2000: 557.4; Sitch, 2003: 923; Pan, 2013: 772
52	* Plant AGB on pantropical forest lands	2007 - 2008	Pantropical	184.23	177.87	176.6110458		Pg C	Avitabile, 2016: 187.5
59	* Plant total biomass on all lands	2005	Global	434.31	422.35	439.8956451		Pg C	Pan, 2013: 393.4, (annualreviews.org, Table 2)

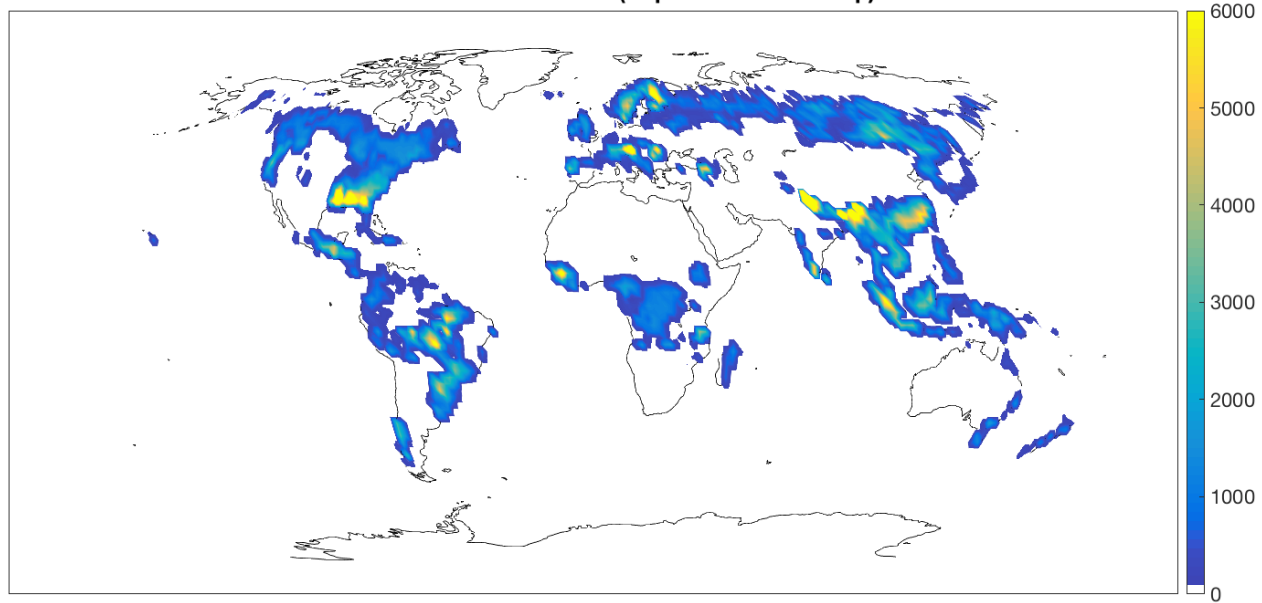


LUH2 v2h (Oct 14, 2016)

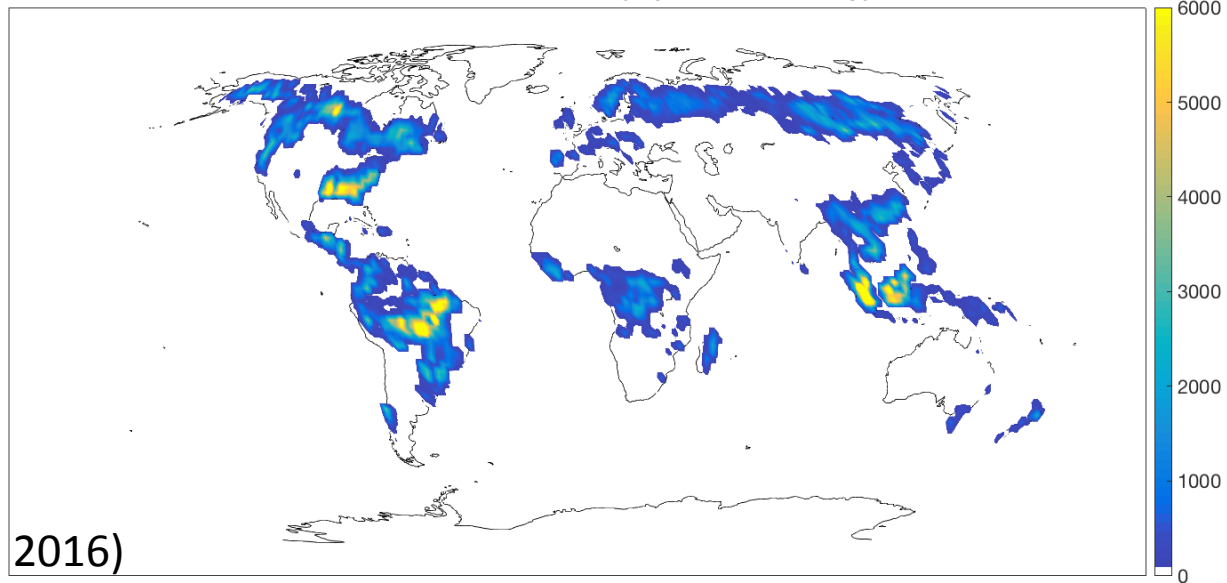


# Expanded Diagnostic Package

GLM forest loss 2000-2012 (Sept 27 biomass map)



Landsat forest loss 2000-2012 (Sept 27 biomass map)



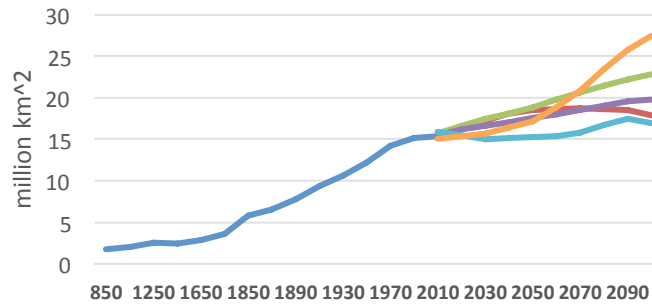
# Future Scenarios (ScenarioMIP)

**Table 2.** ScenarioMIP experimental design.

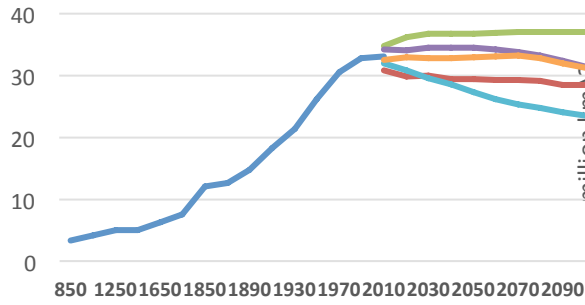
Scenario name	Forcing category	2100 forcing <sup>1</sup> (W m <sup>-2</sup> )	SSP	Use by other MIPs <sup>2</sup>
Tier 1 <sup>3</sup>				
SSP5-8.5	High	8.5	5	C <sup>4</sup> MIP, GeoMIP, ISMIP6, RFMIP
SSP3-7.0	High	7.0	3	AerChemMIP, LUMIP
SSP2-4.5	Medium	4.5	2	VIACS AB, CORDEX, GeoMIP, DAMIP, DCPD
SSP1-2.6	Low	2.6	1	LUMIP
Tier 2				
Additional 21st century scenarios				
SSP4-6.0	Medium	5.4	4	GeoMIP
SSP4-3.4	Low	3.4	4	
SSP5-3.4-OS	Overshoot	3.4	5	
SSPa-b	Low	Around or below 2.0	1 (prelim.)	
Ensembles <sup>4</sup>				
SSP3-7.0	Nine-member ensemble	7.0	3	AerChemMIP, LUMIP
Extensions				
SSP5-8.5-Ext	Long-term extension	8.5	5	C <sup>4</sup> MIP, ISMIP6, GeoMIP
SSP5-3.4-OS-Ext	Long-term extension	3.4	5	
SSP1-2.6-Ext	Long-term extension	2.6	1	

# Pre-harmonization Comparison LUH2 and IAMs

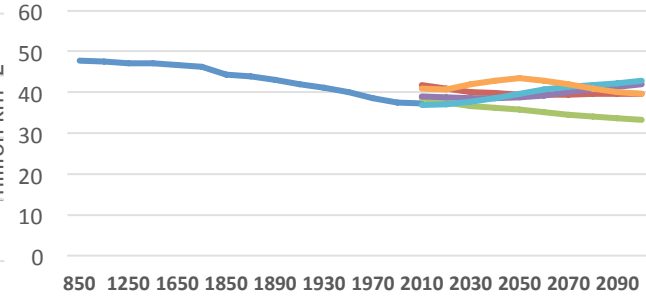
## Cropland area



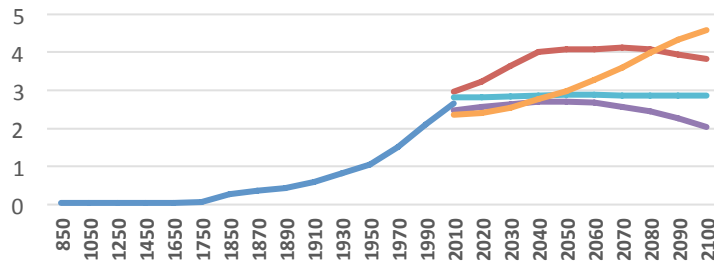
## Pasture area



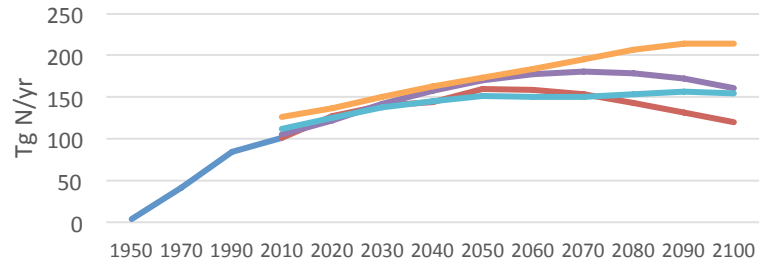
## Forest area



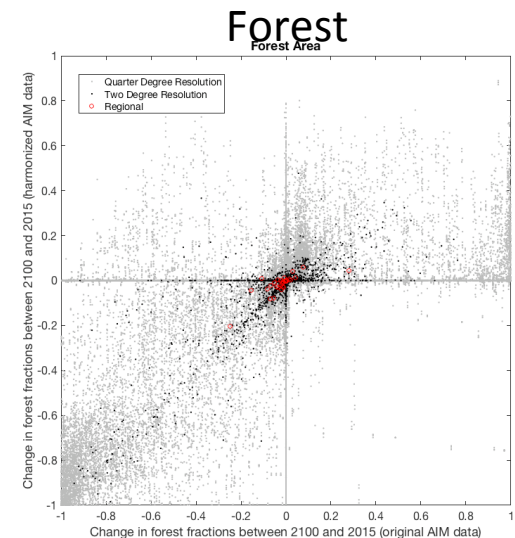
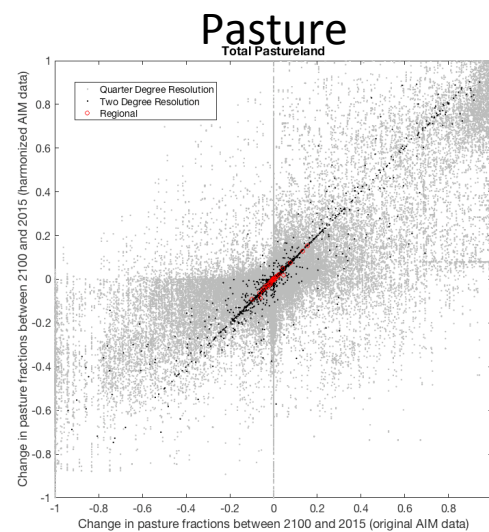
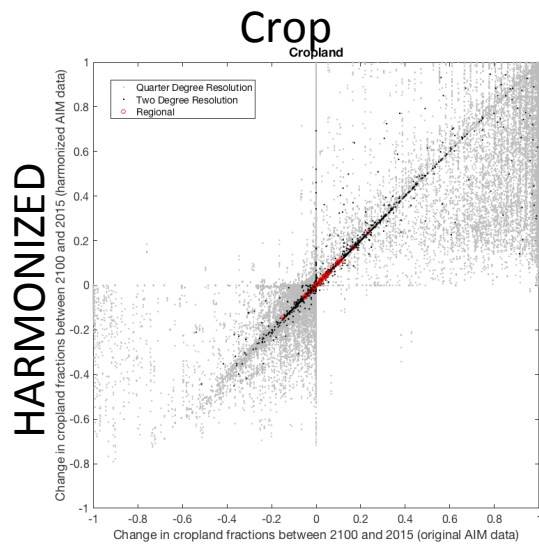
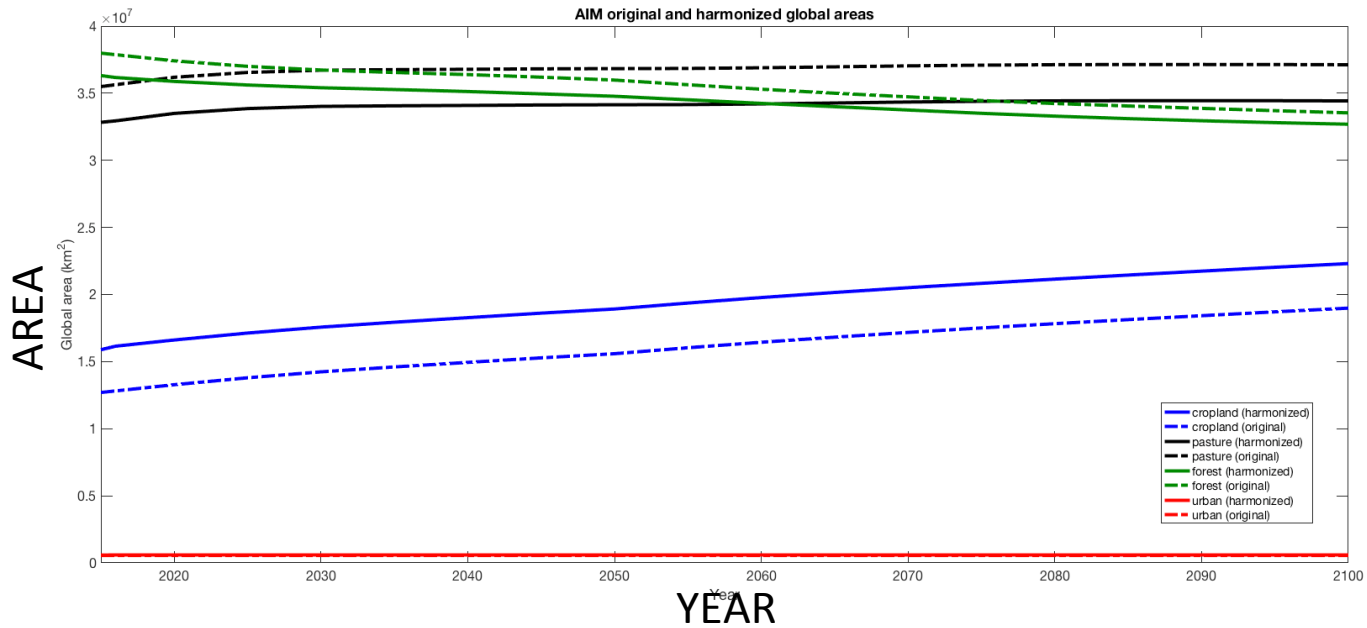
## Irrigated area



## N Fertilizer usage



# Draft Harmonization (SSP3-7 AIM)



IAI

IAI

IAI

# Land-Use Harmonization 2 (CMIP6)

## New History

- Hyde 3.2 based
- Landsat F/NF
- Multiple crop types (5)
- Multiple pasture types (2)
- Updated Forest Cover/B
- Updated Wood harvest
- Updated Shifting Cultivation
- Extended time domain (850-2015)

## New Future Scenarios

Six futures, SSP-based

## New Resolution

0.25°

## New Transition Matrix

	Pri F	Pri NF	Sec F	Sec NF	C3 Ann	C4 Ann	C3 per	C4 per	C3 N-Fix	Pasture	Rangeland	Urban
Pri F	■	■		■								
Pri NF	■	■	■									
Sec F	■	■	■	■								
Sec NF	■	■	■	■								
C3 Ann	■	■			■							
C4 Ann	■	■				■						
C3 Per	■	■					■					
C4 Per	■	■						■				
C3 N-Fix	■	■							■			
Pasture	■	■								■	■	
Rangeland	■	■								■	■	
Urban	■	■										■

## New Mgt. Layers

### Agriculture

- Fraction of cropland irrigated
- Fraction of cropland flooded
- Fraction of cropland fertilized
- Fertilizer application rates
- Fraction of cropland tilled
- Fraction of cropland for biofuels

### Crop rotations

### Wood Harvest

- Fraction used for industrial products
- Fraction used for commercial biofuels
- Fraction used for fuelwood

~ 50x information content of CMIP5!