Proposed Land-Use Harmonization Priorities and Strategy For CMIP6 (LUMIP)- 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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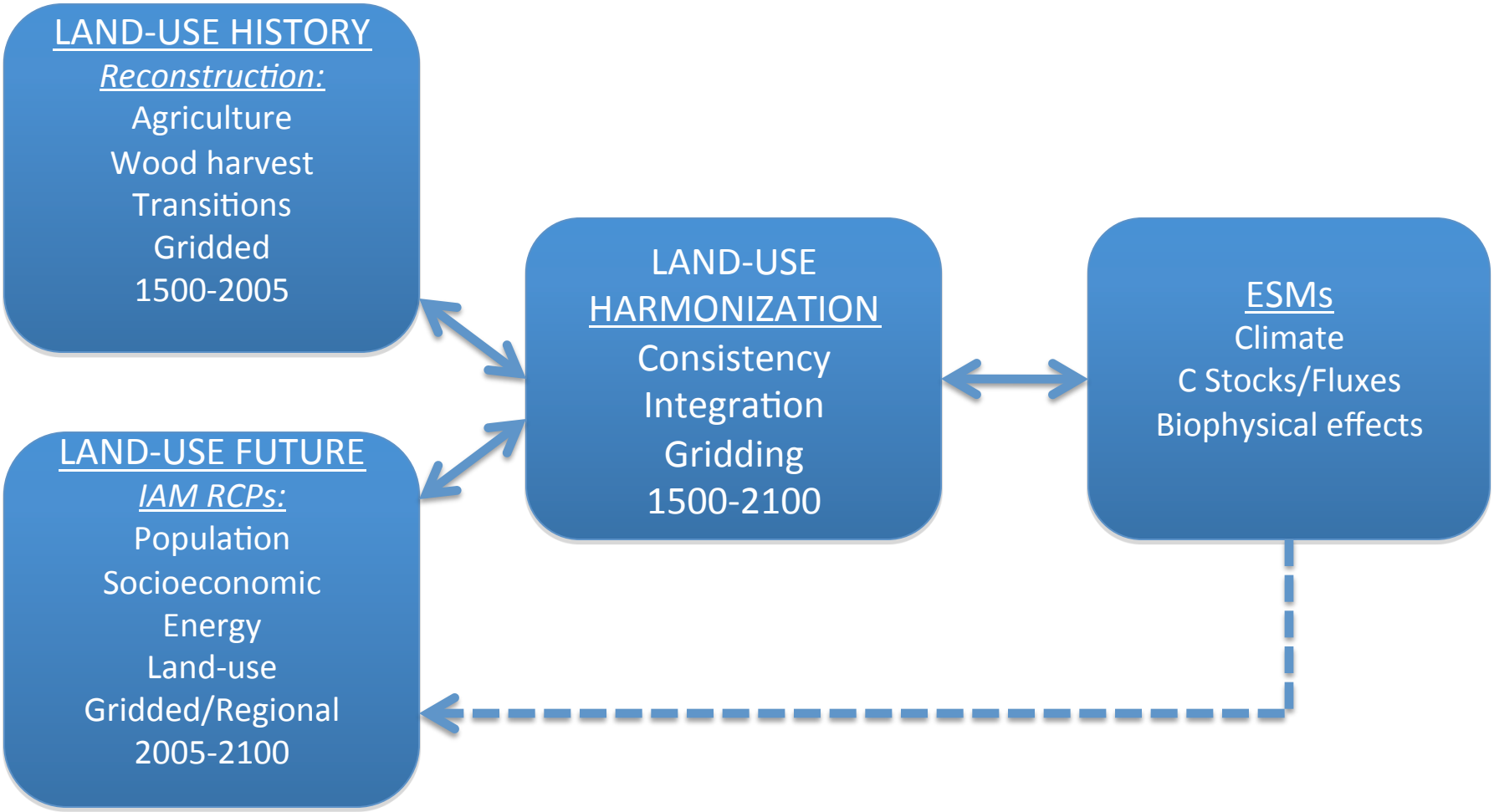
https://www2.cgd.ucar.edu/research/mips/lumip

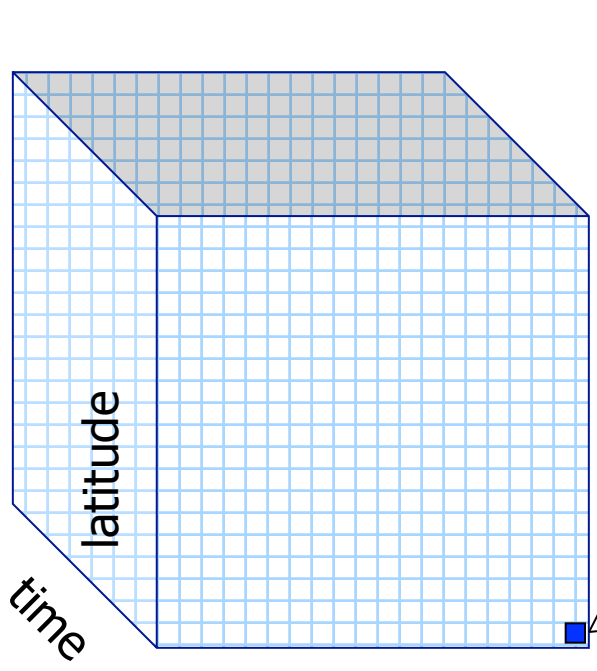
AGCI Meeting
Aspen
August 6, 2014

CMIP5 Scheme (Land-use)



Hurtt et al. (2009, 2011)

Mathematical Structure

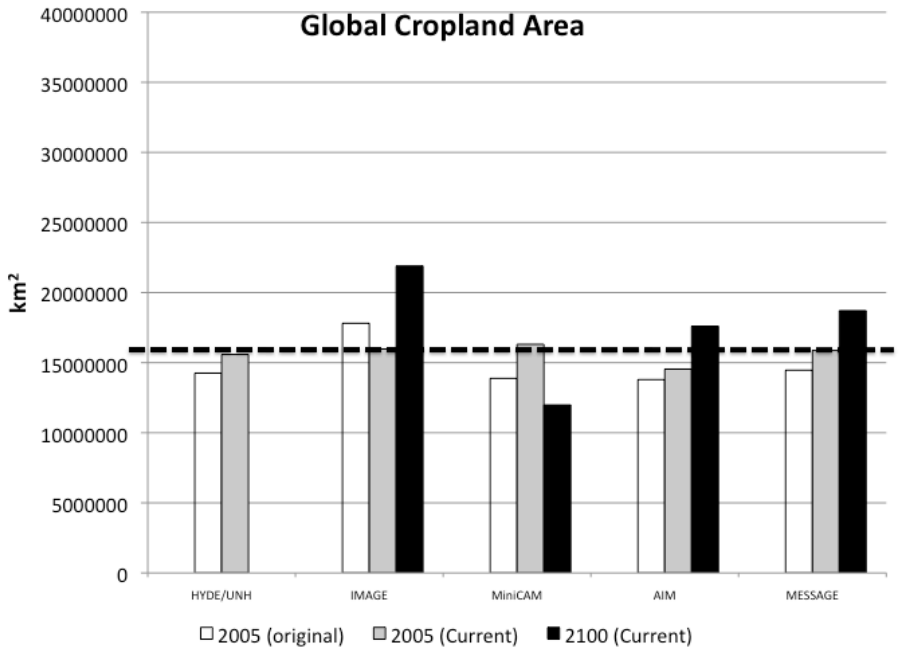


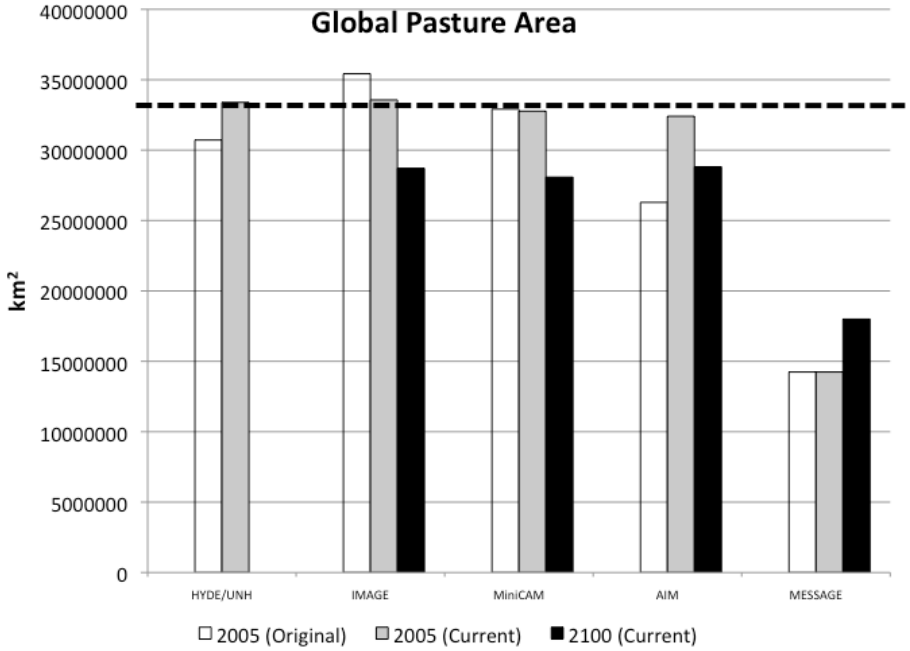
$$\boldsymbol{l}(x,y,t+1) = \mathbf{A}(x,y,t)\,\boldsymbol{l}(x,y,t)$$

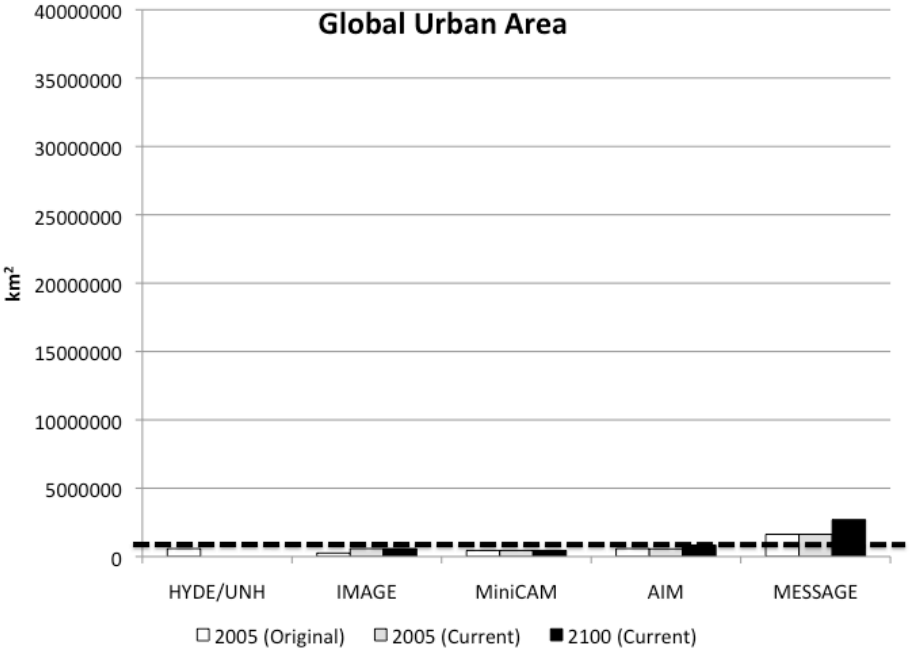
$$\begin{bmatrix} l_1 \\ l_2 \\ l_3 \\ \dots \end{bmatrix}_{t+1} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & \dots \\ a_{21} & a_{22} & a_{23} & \dots \\ a_{31} & a_{32} & a_{33} & \dots \\ \dots & & & \dots \end{bmatrix} \begin{bmatrix} l_1 \\ l_2 \\ l_3 \\ \dots \end{bmatrix}_{t}$$

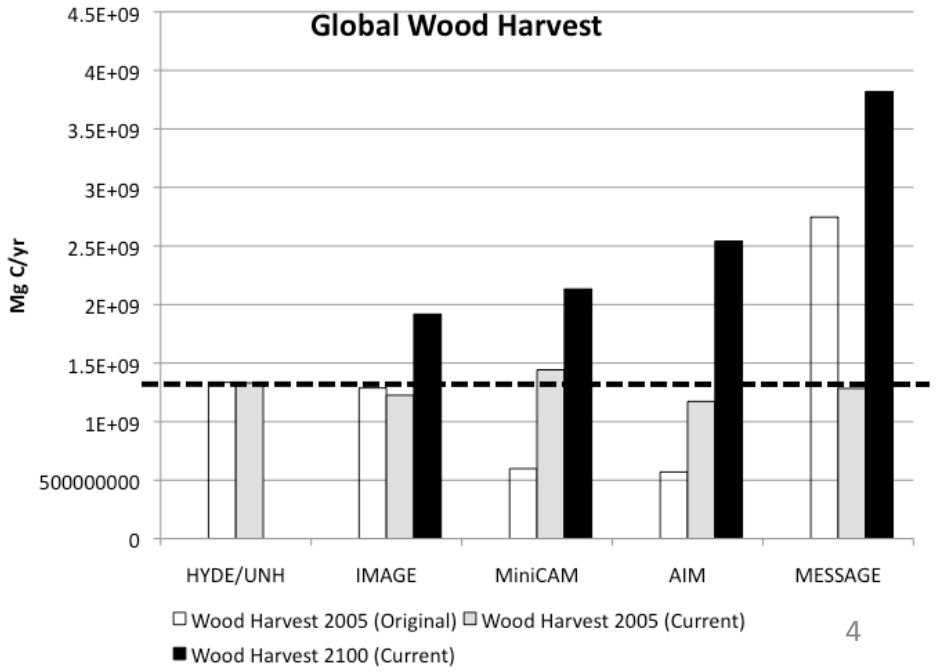
Global, 0.5°x0.5°, 400y, 4D:
~10^9 unknowns!

after Hurtt et al. (2006)


Global Cropland Area
km²
40000000
35000000
30000000
25000000
20000000
15000000
10000000
5000000
0
HYDE/UNH
IMAGE
MiniCAM
AIM
MESSAGE
2005 (original)
2005 (Current)
2100 (Current)


Global Pasture Area
km²
40000000
35000000
30000000
25000000
20000000
15000000
10000000
5000000
0
HYDE/UNH
IMAGE
MiniCAM
AIM
MESSAGE
2005 (Original)
2005 (Current)
2100 (Current)

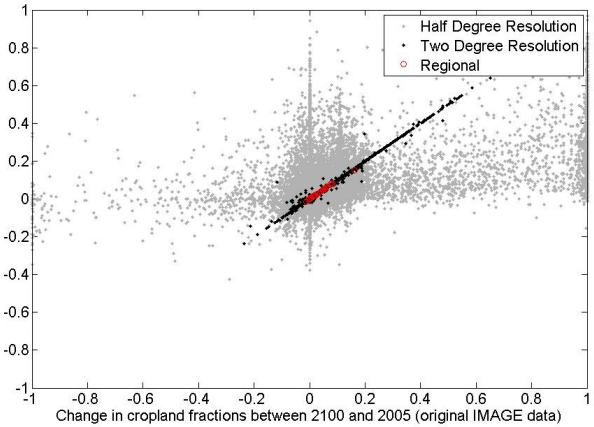

Global Urban Area
km²
40000000
35000000
30000000
25000000
20000000
15000000
10000000
5000000
0
HYDE/UNH
IMAGE
MiniCAM
AIM
MESSAGE
2005 (Original)
2005 (Current)
2100 (Current)

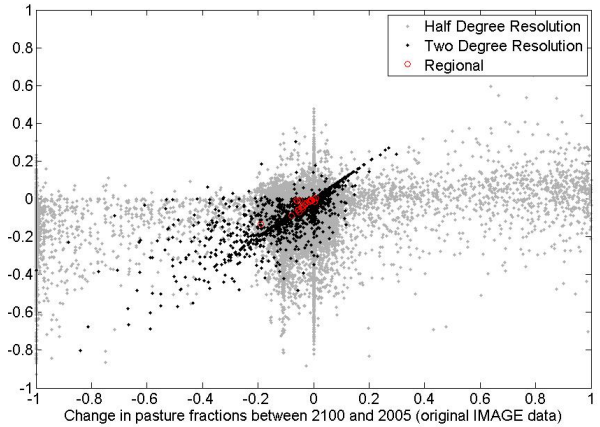

Global Wood Harvest
Mg C/yr
4.5E+09
4E+09
3.5E+09
3E+09
2.5E+09
2E+09
1.5E+09
1E+09
500000000
0
HYDE/UNH
IMAGE
MiniCAM
AIM
MESSAGE
Wood Harvest 2005 (Original)
Wood Harvest 2005 (Current)
Wood Harvest 2100 (Current)

crop

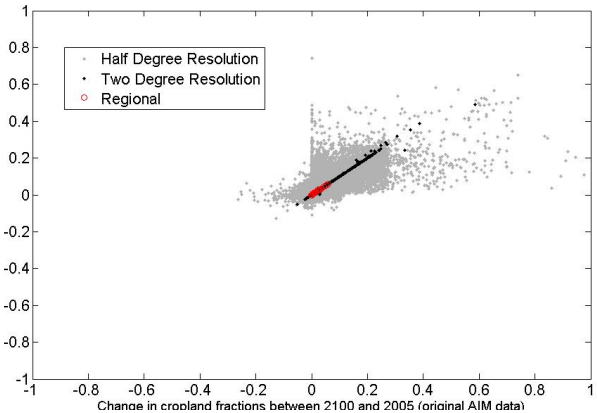
pasture

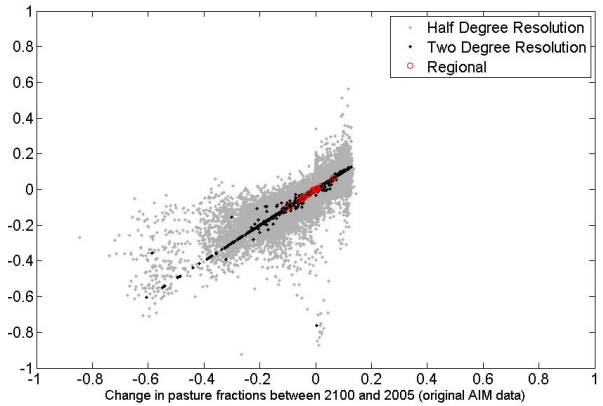
IMAGE



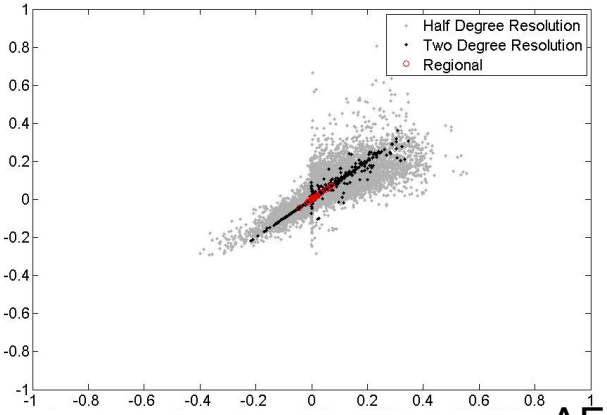


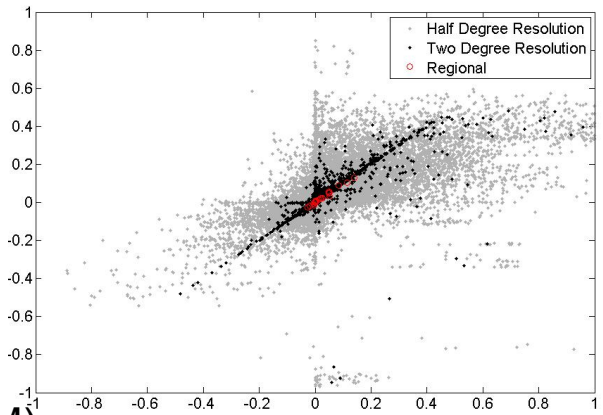
AIM





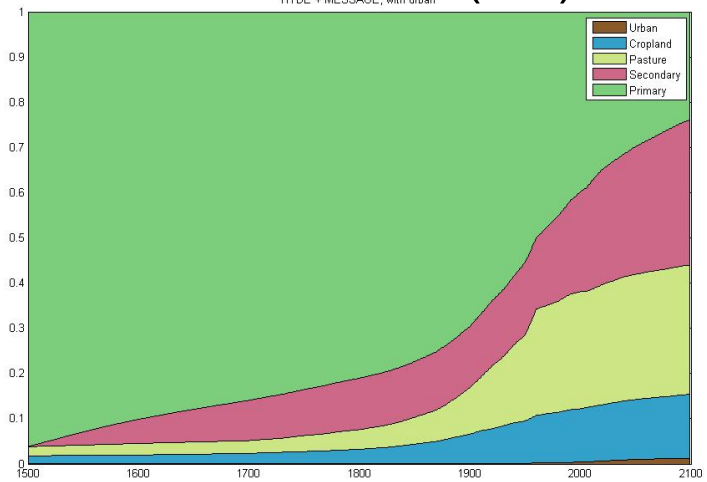
MESSAGE



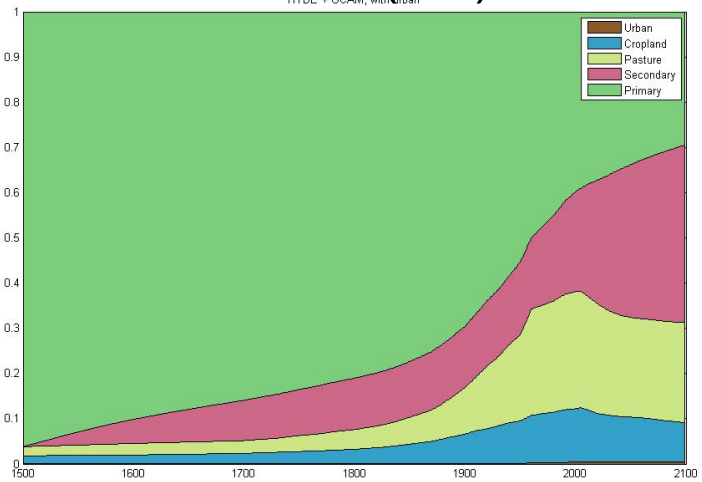


ΔF (IAM)

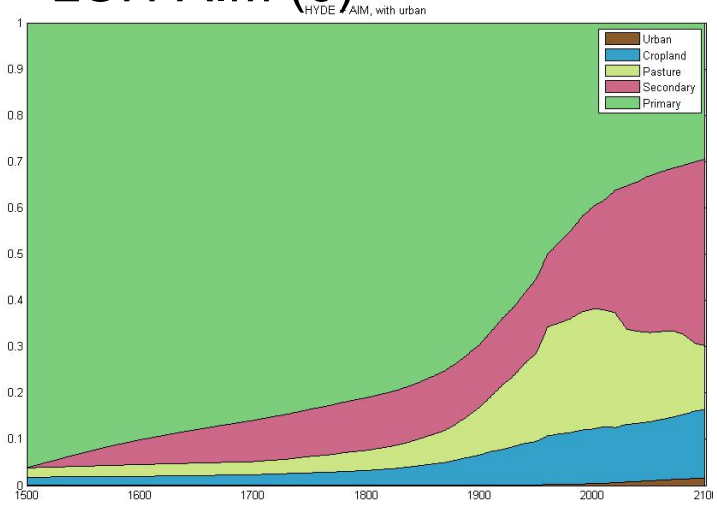
LUH-MESSAGE (8.5)



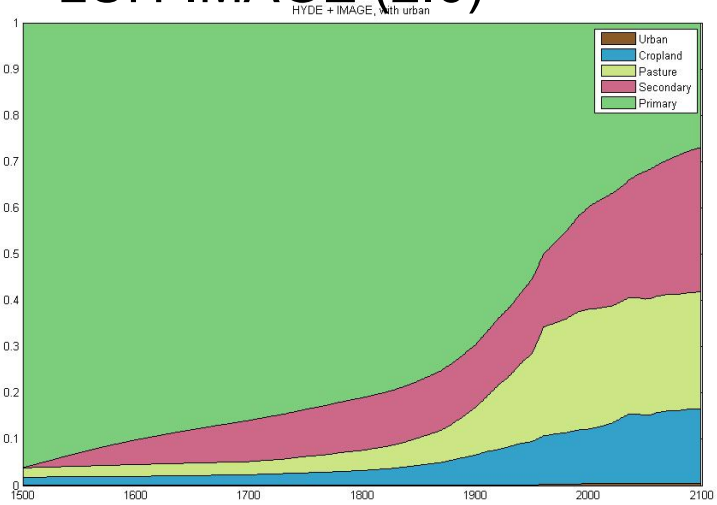
LUH-GCAM (4.5)



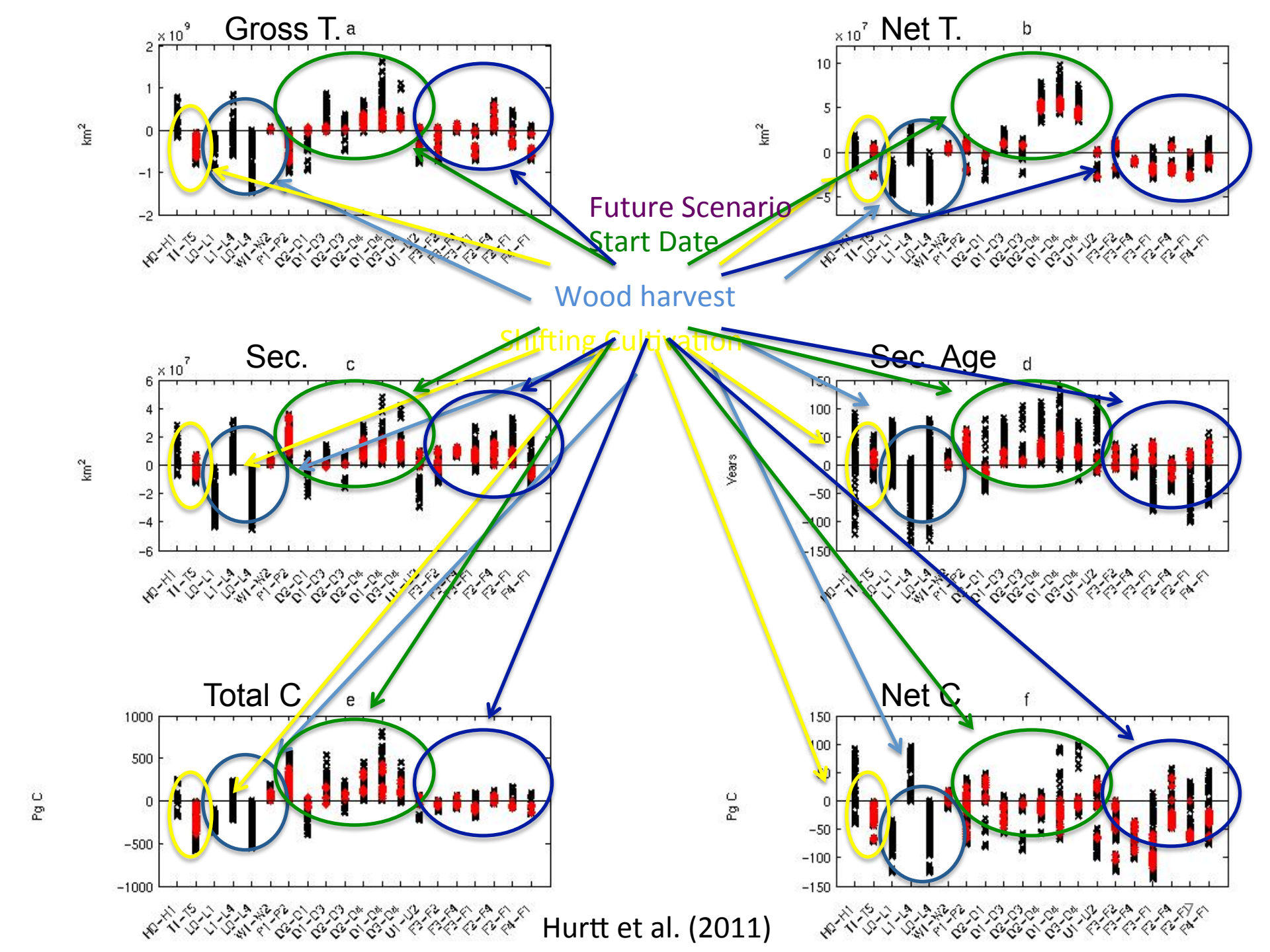
LUH-AIM (6)



LUH-IMAGE (2.6)

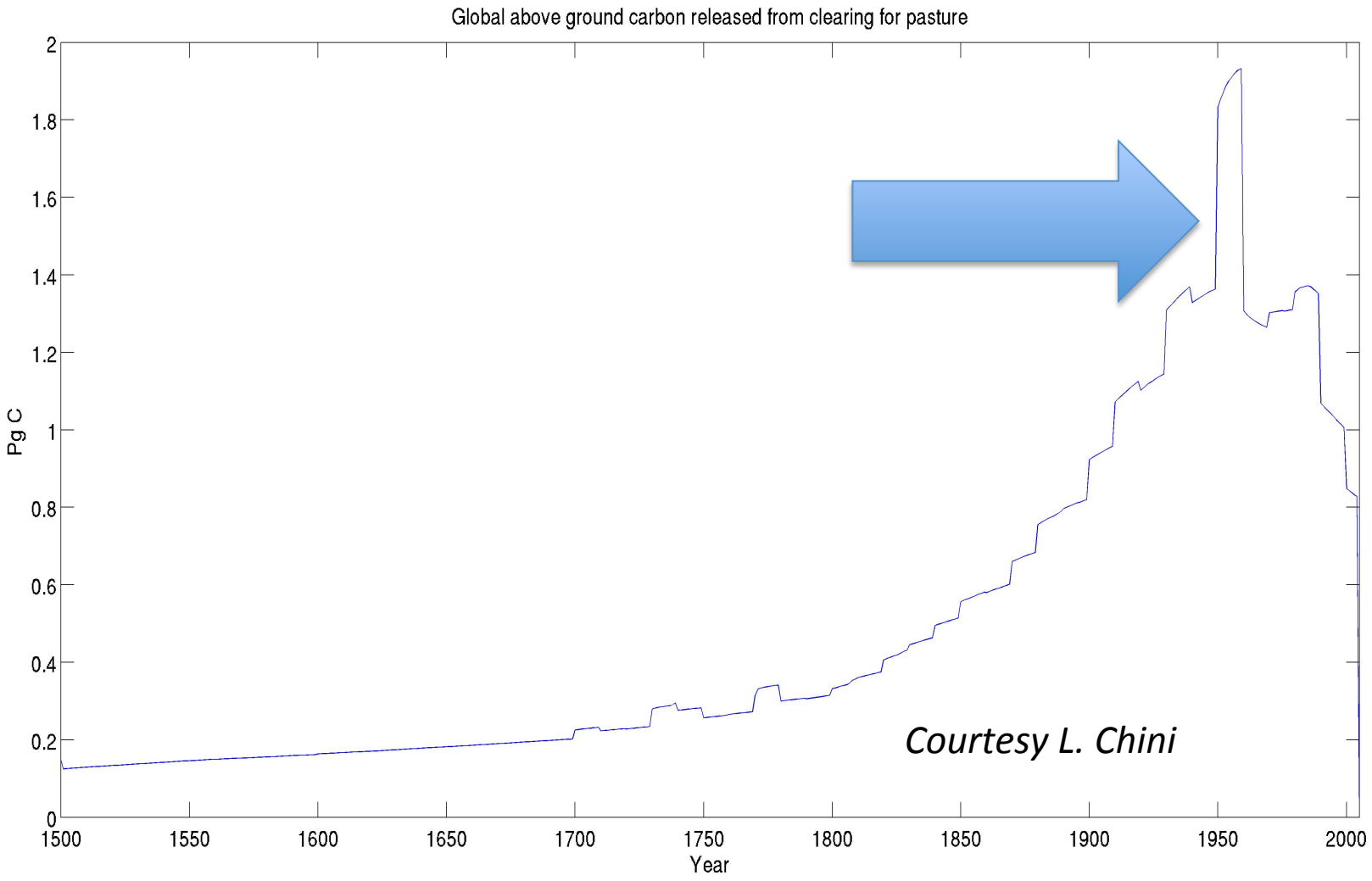


Hurtt et al. 2011



Hurtt et al. (2011)

Simulated Atmospheric CO_2



LUMIP Major Science Questions

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

Land Use Data Standardization CMIP6 (Draft)

- Updated land-use history
  - Pasture anomaly correction, new enhanced historical reconstruction, Landsat F/NF gross transitions 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
- Output
  - Revisit CMIP5 variables
  - Add reporting by tile

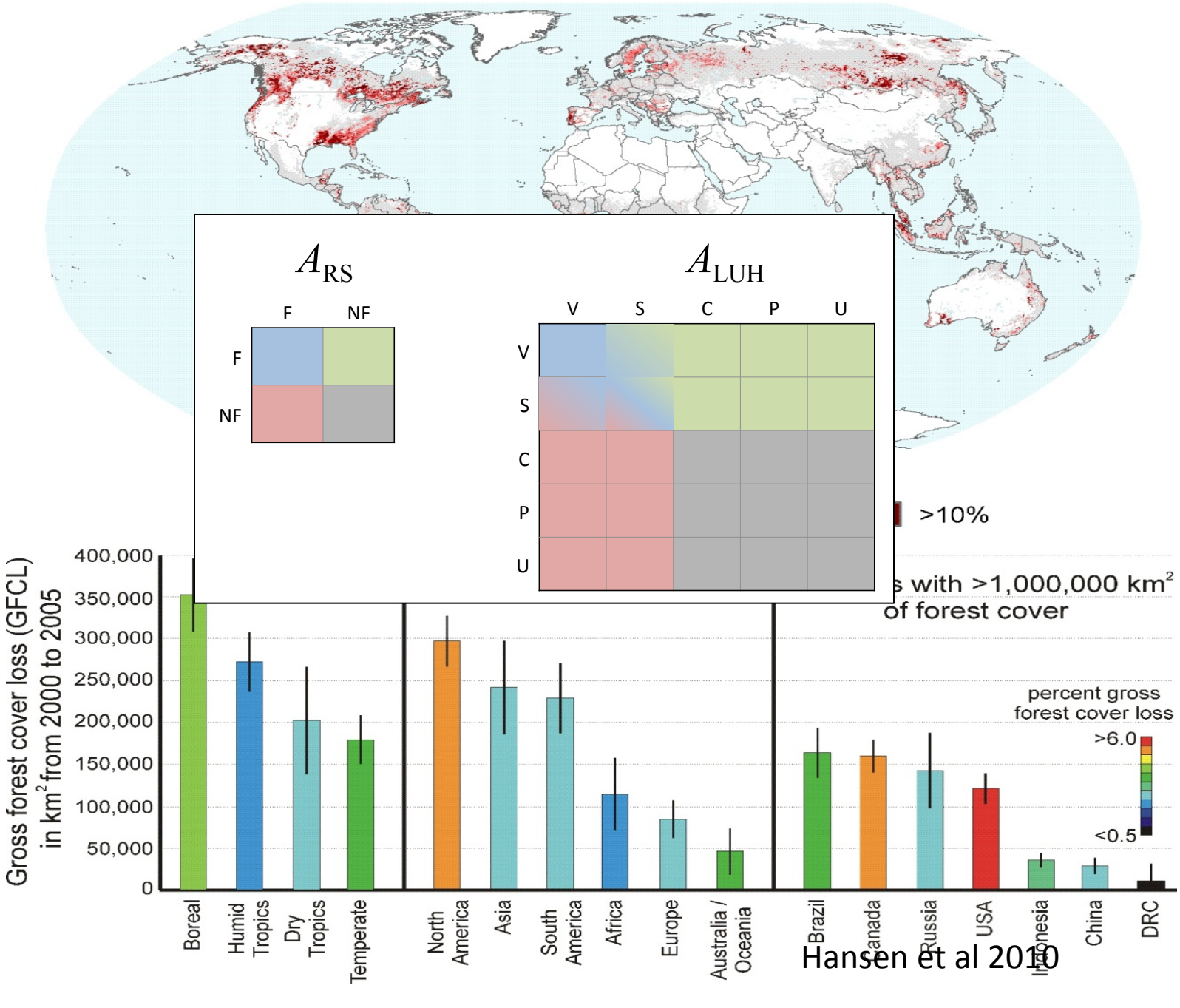
Harmonization Variables

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***
- ***Biofuel Mgt***
- ***Transitions?***
- ***Narrative?***
- ***….?***



Hansen et al 2010

LUH2 Land-cover Classes (Proposed)

- F/NF transitions based on Landsat
- *PFTs using widely used classification (IGBP)*
  - *ENL, EBL, DNL, DBL, and mixed forests*
  - *Closed and open Shrublands, savanna*
  - *Grassland, pasture*
  - *Urban*
  - *Croplands*
- *Crop functional types (CFTs)*
  - *C4*
  - *C3 perennial*
  - *C3 annual*
  - *N fixers*
  - *Rice*
- Align with IAMs and ESMs
- Advance implementation

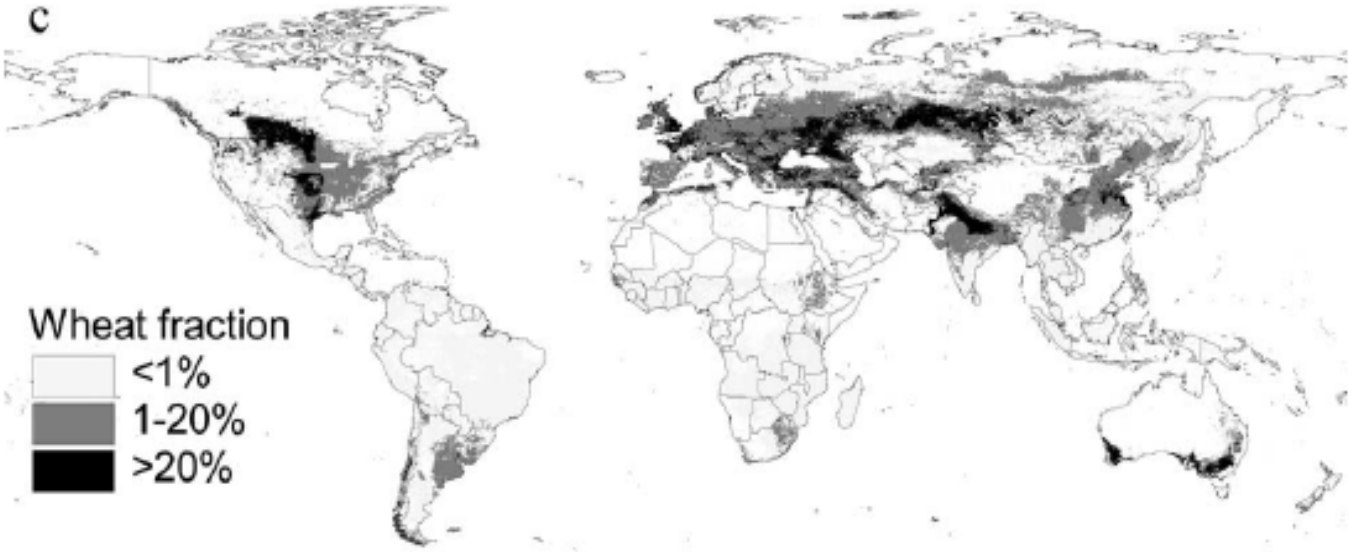
Table 1. Land cover types.

IGBP	GLM3	GCAM	CLM
ENL Forest	ENL Forest	Unmanaged forest*	ENL Tree –temperate
		Managed forest*	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	C3 arctic grass
		Unmanaged pasture	C3 grass
		Pasture	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	Temperate corn
		Fodder grass/herb*	Tropical corn
		Sugar crops*	Sugar cane
		Other grain*	
		Biomass*	
		Miscellaneous/other*	
	C3 perennial	Palm fruit	
		Jatropha	
		Willow	
		Eucalyptus	
		Sugar crops*	
	C3 annual	Wheat	Spring wheat
		Other grain*	Winter wheat
		Root/tuber	Barley
		Oil crops*	Winter barley
		Fodder grass/herb*	Rye
		Fiber crops*	Winter rye
		Biomass*	Cotton
		Miscellaneous/other*	
	N-fixers	Fodder herb*	Soy
		Oil crops*	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

Leff et al. (2004)

Global maps of 18 major crops at 5-minute resolution (e.g., wheat→) based on cropland map of Ramankutty & Foley (1998) and mid-1990s agricultural census data.



Leff et al (2004) crop	mid-1990s area (km^2)	% of total	FAO 2004 % of total
Wheat	4,028,000	22.5	16.0
Maize	2,271,000	12.7	11.3
Rice	1,956,000	10.9	11.4
Barley	1,580,000	8.8	4.0
Soybeans	927,000	5.2	5.5
Pulses	794,000	4.4	4.8
Cotton	534,000	3.0	2.4
Sorghum	501,000	2.8	3.0
Potatoes	501,000	2.8	1.5
Millet	331,000	1.8	2.7
Sunflower	290,000	1.6	1.6
Rye	288,000	1.6	0.7
Rapeseed (canola)	283,000	1.6	1.9
Sugarcane	265,000	1.5	1.4
Groundnuts (peanuts)	247,000	1.4	1.8
Cassava	235,000	1.3	1.2
sugarbeets	154,000	0.9	0.4
Oil palm	72,000	0.4	0.7
Other	2,664,000	14.9	27.7

How might these be aggregated to simplify & generalize?

What is *other*?

FAO: 157 other 'major' crops

Developing global mean crop-type physiological parameterizations

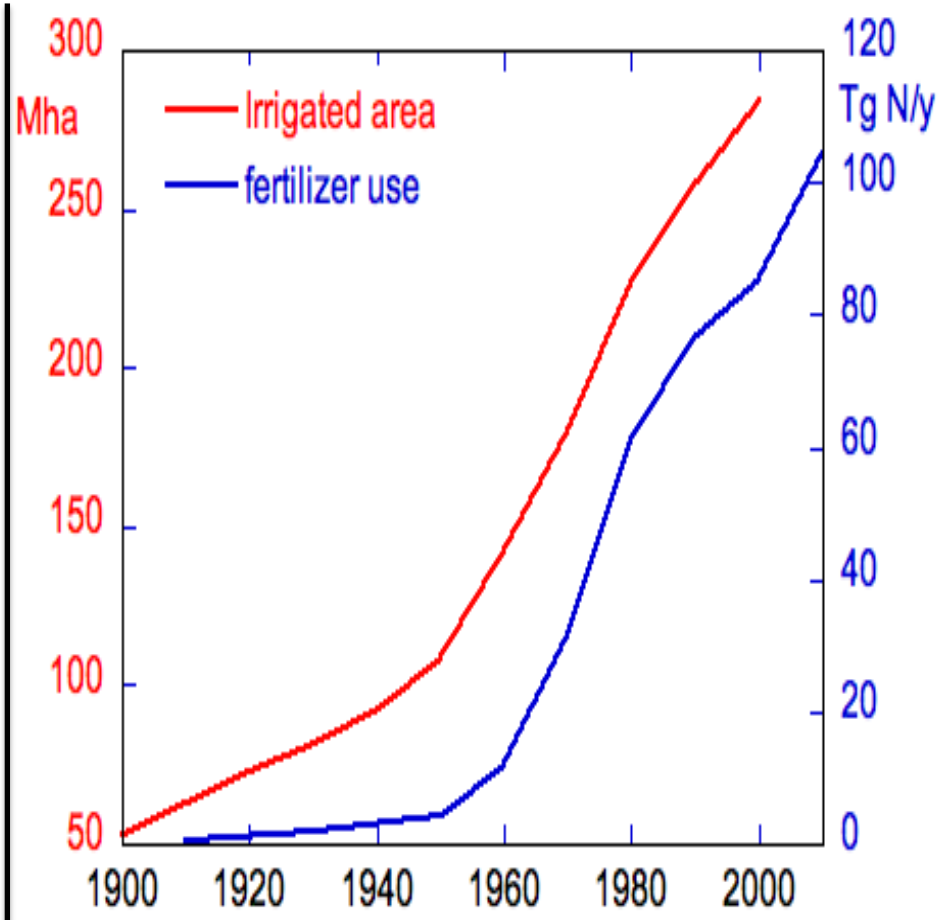
1. We acquired crop physiological parameters from the DNDC model for major crops (thirteen C3-annuals, three C3 N-fixers, three C3-perennials, three C4-annuals).
2. We calculated area-weighted averages to get mean global crop parameters.

Basic global mean crop parameters

	C3 annual	C3 N-fixing	C3 perennial	C4 annual	units
total biomass	5000	3800	8400	16000	kg C/ha
Grain %	39	29	41	27	%
Shoot %	43	46	40	39	%
Grain C:N	23	14	39	91	--
Shoot C:N	59	34	42	110	--
Root C: N	46	33	45	110	--
Max. height	0.7	0.5	3.2	1.7	m
Max root depth	1.0	1.5	1.3	1.0	m
Max. LAI	4.0	3.0	4.2	4.7	m2/m2
Water required	250	220	260	160	kg H_2O/kg C
Heat required	1800	2300	--	2900	°C-days
Max. psn rate	42	38	49	63	kg CO_2/ha/h

LUH2 Management (Proposed)

- Focus on Largest Forceings
  - Harvest
  - Fertilizer
  - Irrigation
  - Biofuel/CCS
  - *Tillage*
  - *Forest Plantations*
  - *Pasture Mgt intensity*
- Harmonize management forceings with land-use/land-cover patterns
- Align with IAMs and ESMs
- Advance Implementation

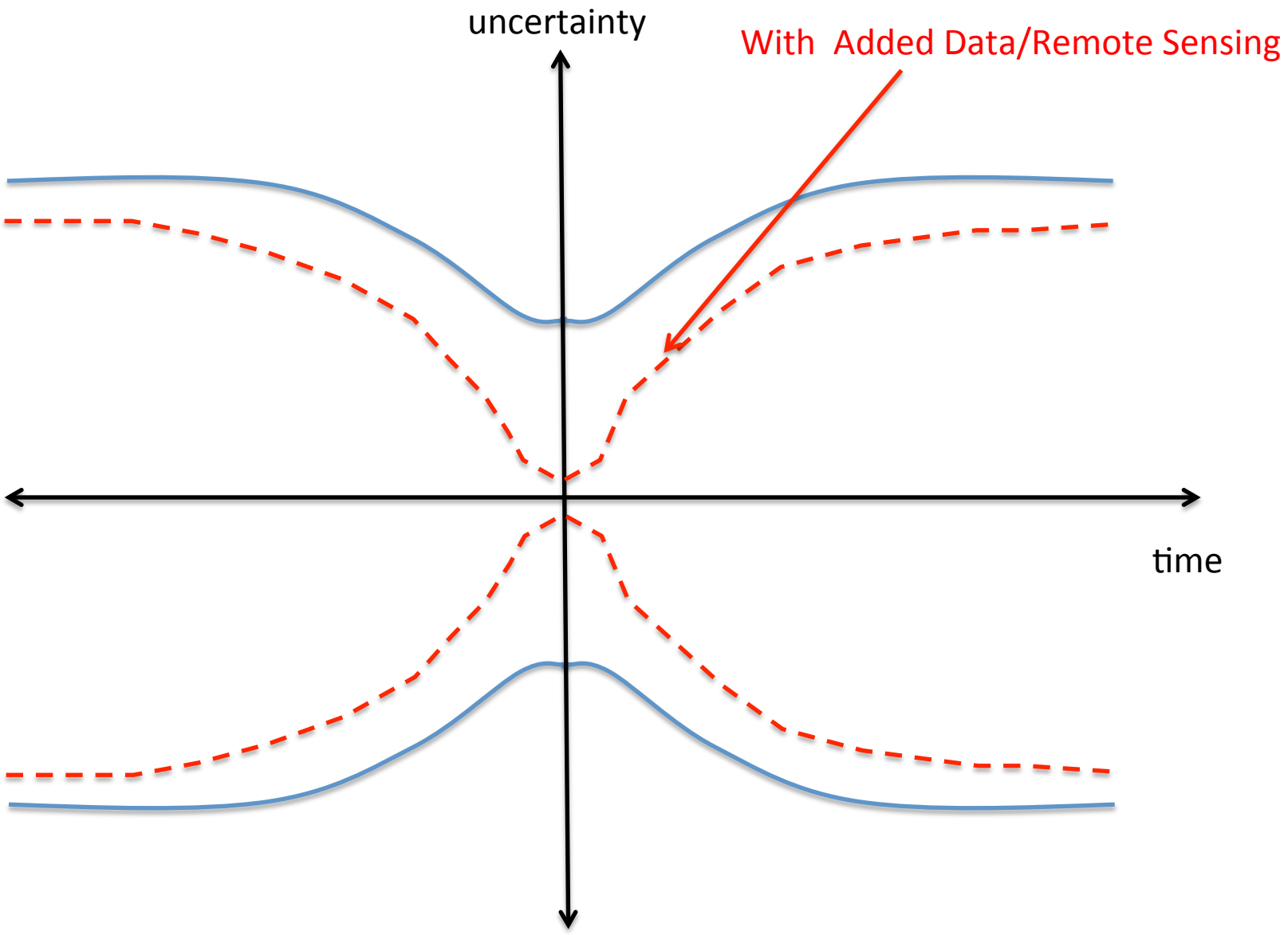


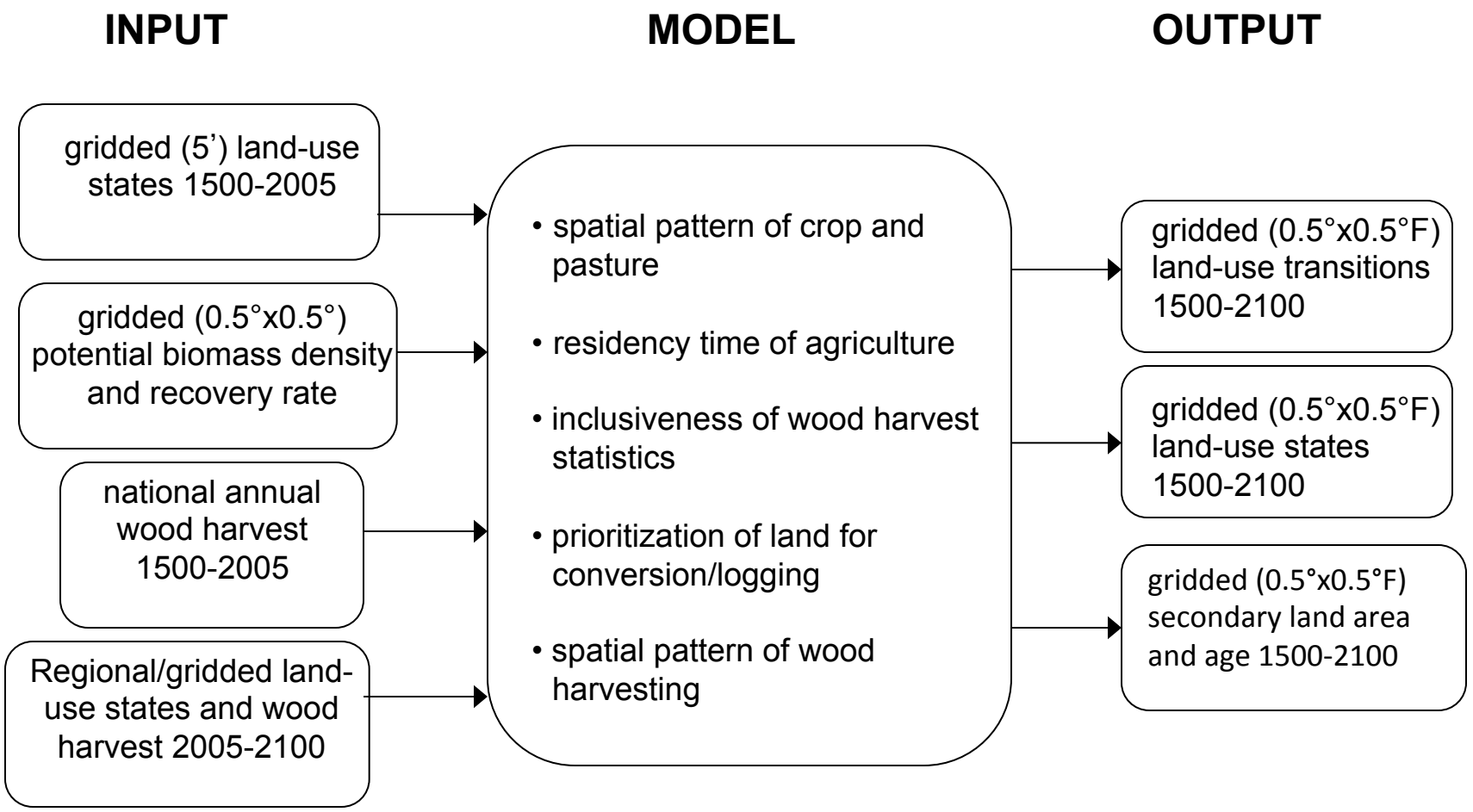
Global irrigated area 1900-2000 (Freydank & Siebert 2008) and global N fertilizer use 1900-2010 (Smil 2001; IFA 2014).

Land-use Harmonization CMIP6 Steps (Proposed)

- Updated land use history
  - Pasture anomaly, new Hyde, Landsat F/NF*, PFTs, N Fert, Irrig, Crop type*
- IAM-History harmonization
  - Same variables as last time
  - +F/NF, *N Fert, Irrig, Crop type, Biofuel type and Mgt*
  - Global. *Regional?*
- Land-use Harmonization beta release
  - including sensitivity analysis
  - Including best use guidelines
- Review and Testing by IAMs and ESMs
- Land-use Harmonization final
- Support implementation and use in ESMs

PARKING LOT


uncertainty
With Added Data/Remote Sensing
time



Hurtt et al. (2009, 2011)

Diagnostics

Diagnostic	Reference data	Hurtt 2006	LUHa
Percentage of land surface impacted by human land-use activities 1700-2000 (C+P+S)		42-68%	57.5%
Total secondary land increase 1700-2000		10-44 x 10^6 km^2	26 x 10^6 km^2
Percentage of secondary land increase 1700-2000 that is forested		50%	51%
Percentage of secondary land generated by wood harvest and shifting cultivation (permanent agriculture generated the rest)		70-90%	83.5%
Wood harvest (including slash) 1850-1990	106 Pg (Houghton 1999)*; 82 Pg (FAO)	77 Pg	82 Pg
Wood clearing for agriculture 1850-1990	149 Pg (Houghton 1999)	105-158 Pg	170 Pg
Area of forested land in shifting cultivation fallow (2000)	4.42 x 10^6 km^2 (FAO)	4.56-6.19 x 10^6 km^2	3.7 x 10^6 km^2
Rates of clearing land in shifting cultivation	0.6-0.09 x 10^6 km^2/yr (Rojstaczer et al. 2001)	0.48-0.65 x 10^6 km^2/yr	0.58 x 10^6 km^2/yr
Percentage of US Forests that are secondary (2000)		94-99%	100%
Mean age of Eastern US Secondary Forests (2000)	38yrs *	71 yrs	63 yrs
Total gross transitions (2000)		1.6 x 10^6 km^2/yr	2.0 x 10^6 km^2/yr
Total net transitions (2000)		0.17 x 10^6 km^2/yr	0.19 x 10^6 km^2/yr
Global Cropland Area (1990)		12.1 x 10^6 km^2	15.1x 10^6 km^2
Global Pasture Area (1990)		25.8 x 10^6 km^2	33.1 x 10^6 km^2
Global Primary Land Area (1990)		57.7 x 10^6 km^2	58.4 x 10^6 km^2

Hurtt et al. (2009, 2011)

Land Experiments – Prioritization/Coordination (DRAFT)

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

Experiment Name	Tier	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	Hyungjun 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	Requres LND_HIST	Hyungjun 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 Arneth, 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 paricular 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	

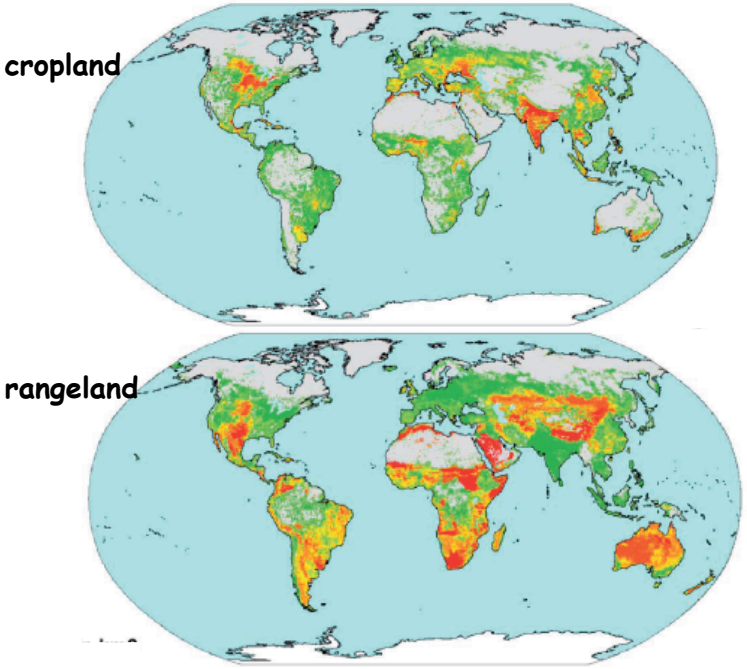
What we learned (CMIP5+)?

- Enabled first global model emission driven projections of both 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

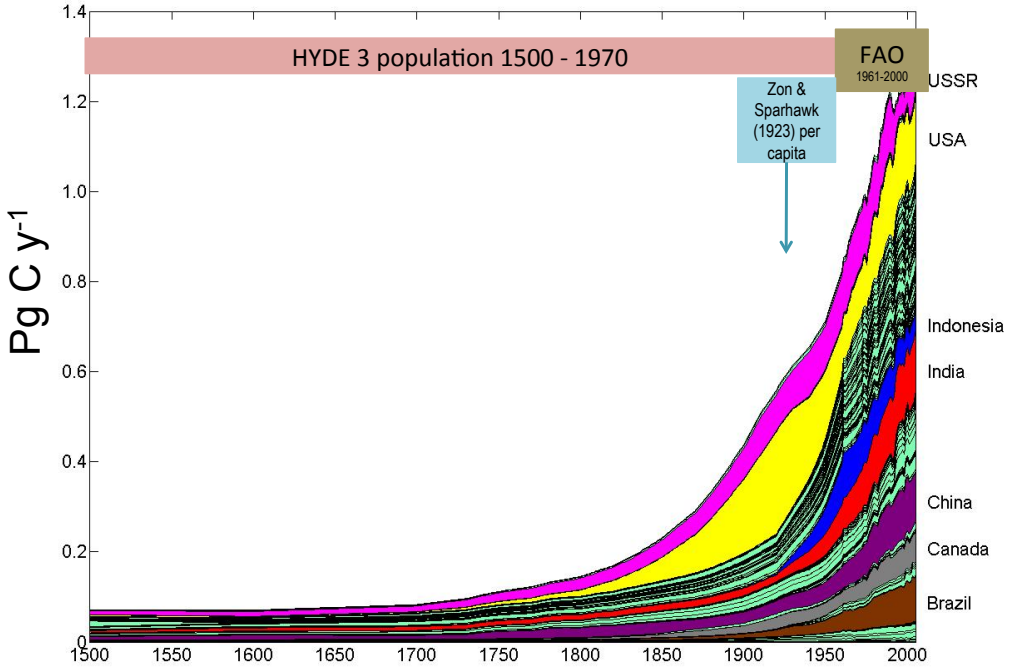
Priorities for CMIP6 (Land Use)

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

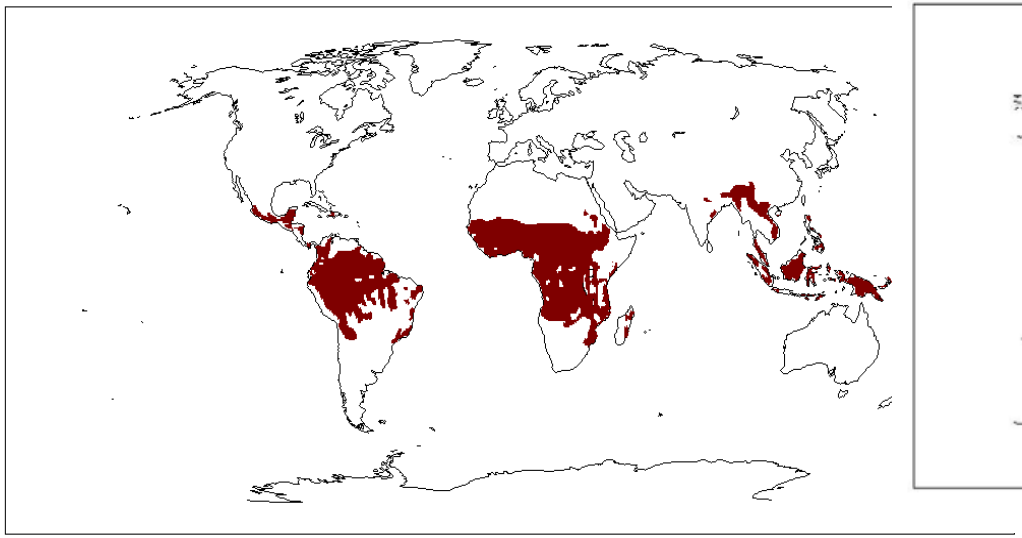
HYDE 3: Cropland & rangeland in 2000 (Klein Goldewijk

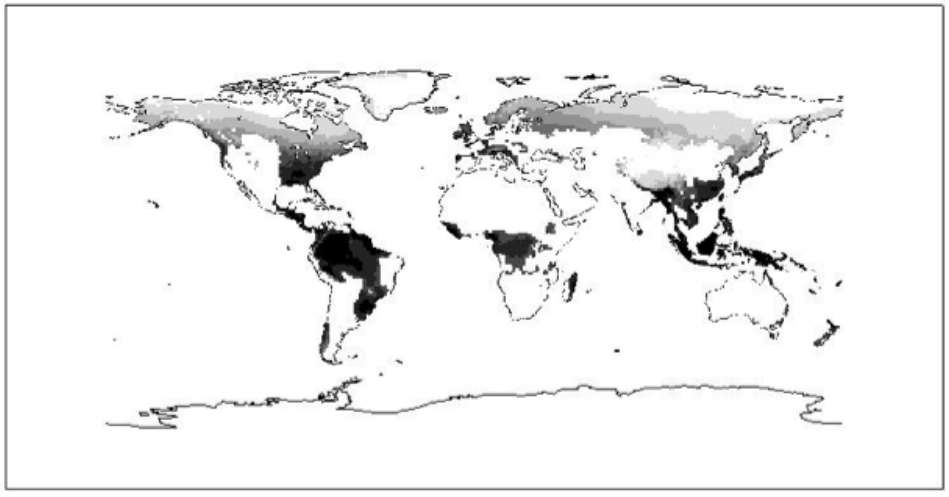


Global wood harvest by country, 1500-2005 (Pg C y^{-1})



Hurtt et al. 2006; revised





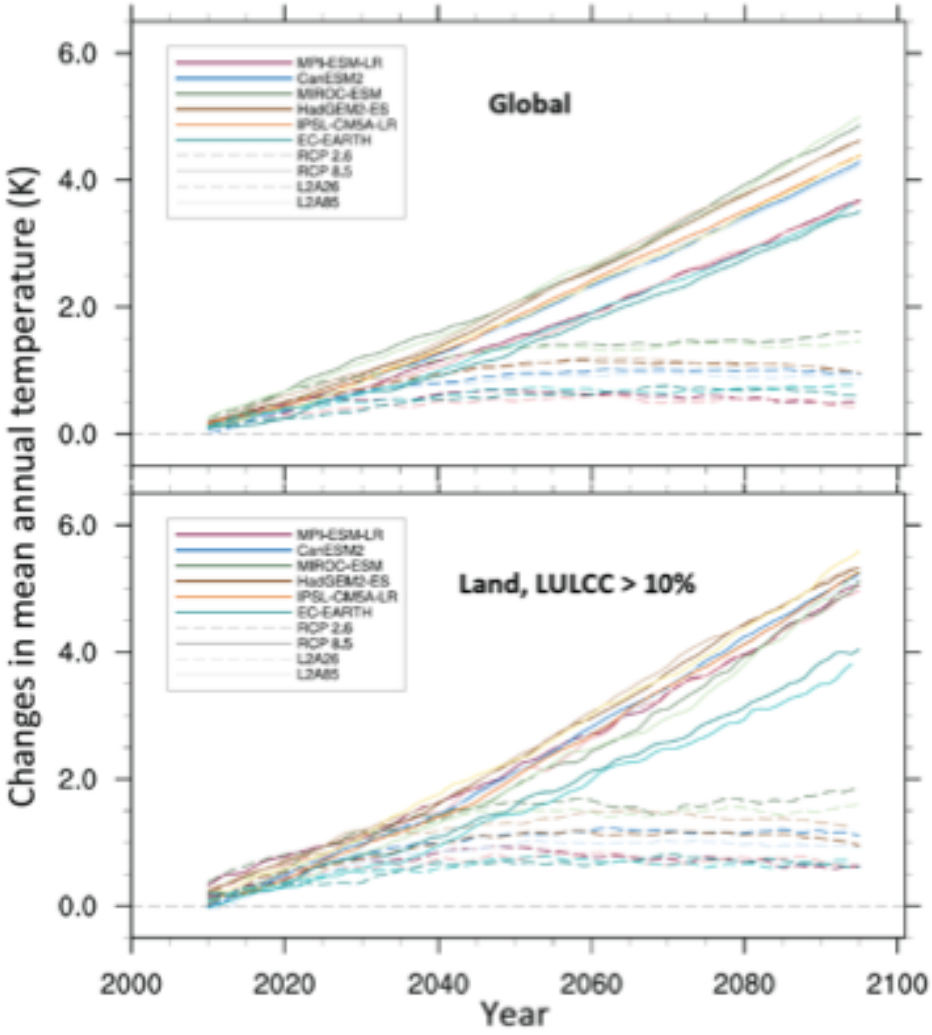


Figure 4. 10-yr moving average of changes relative to year 2006 in annual near-surface air temperature, K, averaged for ensemble simulations globally (top) or for land grid cells where LULCC exceeded 10% of cell area (bottom). Bold and dashed lines are for 2.6 and 8.5 scenarios, dark and light colors are for RCP and LUCID experiments, respectively.

Brovkin et al (2013)

Table 2. Brief description of models participated in the LUCID-CMIP5 simulations

ESM	CanESM2	EC-Earth	HadGEM2-ES	IPSL-CM5A-LR	MIROC-ESM	MPI-ESM-LR
Atmosphere/land resolution	~2.8°	~1.1°(T159)	~1.6°	3.75°x1.90° (T39)	~2.8° (T42)	~1.9°(T63)
Land surface component	CTEM	HTESSEL	JULES	ORCHIDEE	SEIB-DGVM	JSBACH
Number of PFTs	9	15	5	13	13	12
Dynamic vegetation	No	No	Yes	No	Yes	Yes
Fire module	No	No	No	Yes	No	Yes
Crop PFT	Yes	Yes	No	Yes	No[1]	No[2]
Pasture PFT	No	No[3]	Yes	No[3]	Yes	Yes
Wood harvest	No	No	No	No	No	Yes
Usage of land-use transitions (Hurtt et al. 2011)	No	Yes	No	No	Yes	Yes
Ensemble members, RCP26/L2A26	3/3	1/1	3/3	-	1/1	3/2
Ensemble members, RCP85/L2A85	3/3	1/1	3/3	3/1	1/1	3/2
ESM reference	(Arora et al. 2011)	(Hazeleger et al. 2012; Weiss et al. 2012)	(Collins et al. 2011; Jones et al. 2011; Martin et al. 2011)	(Dufresne and Co-authors 2013)	(Watanabe et al. 2011)	(Giorgetta and al. 2013; Reick et al. 2013)

[1] Uses grasses PFT parameters for crops, but harvested annually
[2] Crops differ from grasses in parameters of photosynthesis and phenology
[3] Pastures are implicitly accounted

Brovkin et al (2013)

- Land use is the human use of the land.
- Land cover is the physical material at the surface of the earth.
- Important to keep these separate, to drive process-based models, and attribute results.

Table 3. Differences between RCP and LUCID simulations in annual mean climate characteristics averaged for land regions with LULCC exceeding 10%. Only statistically significant results ($p<0.05$) are presented.

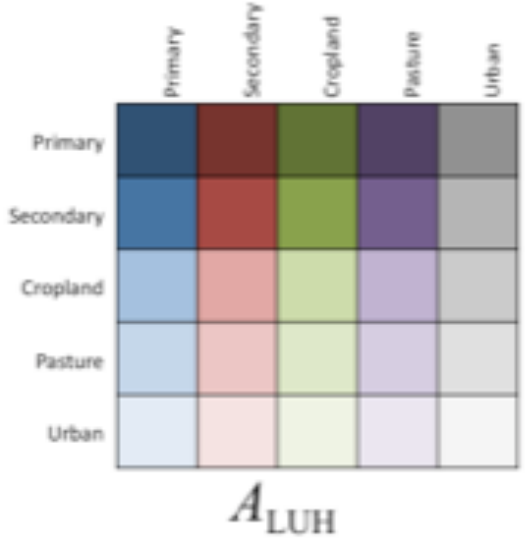
Model	Scenario	Surface air temperature [K]	Precipitation (mm/day)	Albedo (×100)	Available energy (W m^{-2})	Latent heat flux (W m^{-2})
CanESM2	2.6	0.11	-	-	0.5	-
	8.5	0.10	-	0.03	0.6	-
EC-Earth	2.6	-	-	0.33	-	
EC-Earth	8.5	-	-	0.32	-1.4	-0.5
HadGEM2-ES	2.6	-0.08	-0.05	0.59	-1.2	-1.0
	8.5	-0.09	-0.04	0.35	-0.6	-
IPSL-CM5A-LR	8.5	-	-	0.39	-1.7	-
MIROC-ESM	2.6	-	-	0.15	-	-2.3
	8.5	-0.23	-	0.02	-	-2.8
MPI-ESM-LR	2.6	-	-0.02	0.73	-1.6	-0.7

Table 4. Estimated biogeochemical effect of land-use changes

Model	RCP scenario	Cumulative net land-use emissons, PgC, year 2100	Transient climate sensitivity to emissions, K/TtC, (Gillett et al. 2013)	Estimated global annual temperature increase, K, year 2100
CanESM2	2.6	39	2.365	0.09
	8.5	34		0.08
HadGEM2-ES	2.6	19	2.105	0.04
	8.5	25		0.05
IPSL-CM5A-LR	8.5	37	1.585	0.06
MIROC-ESM	2.6	65	2.151	0.14
	8.5	62		0.13
MPI-ESM-LR	2.6	175	1.604	0.28
	8.5	205		0.33

Brovkin et al (2013)

New Consistent Land-cover Harmonization

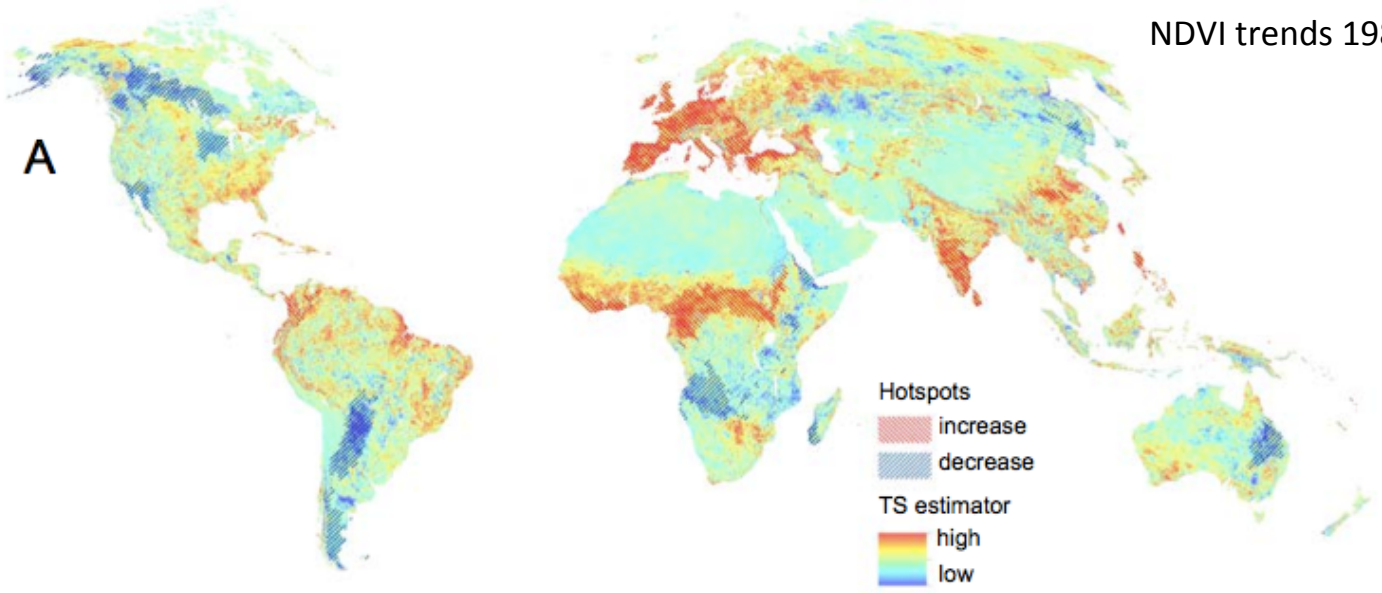


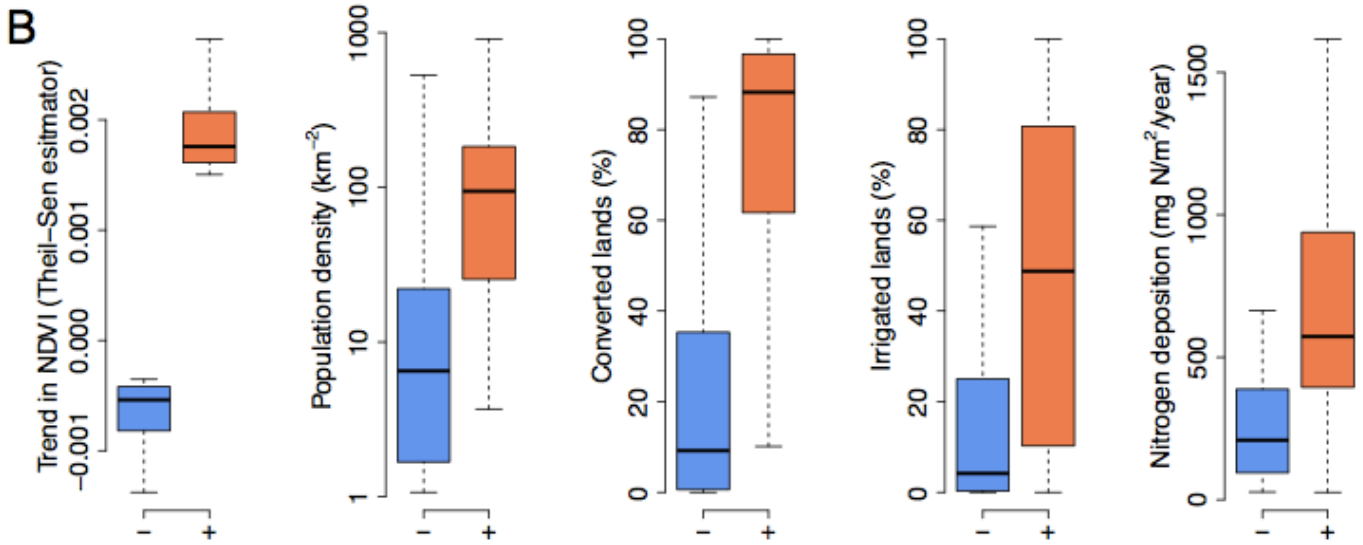
A_{LUH}

A_{LUH2}

Importance of Management Effects

NDVI trends 1981-2010

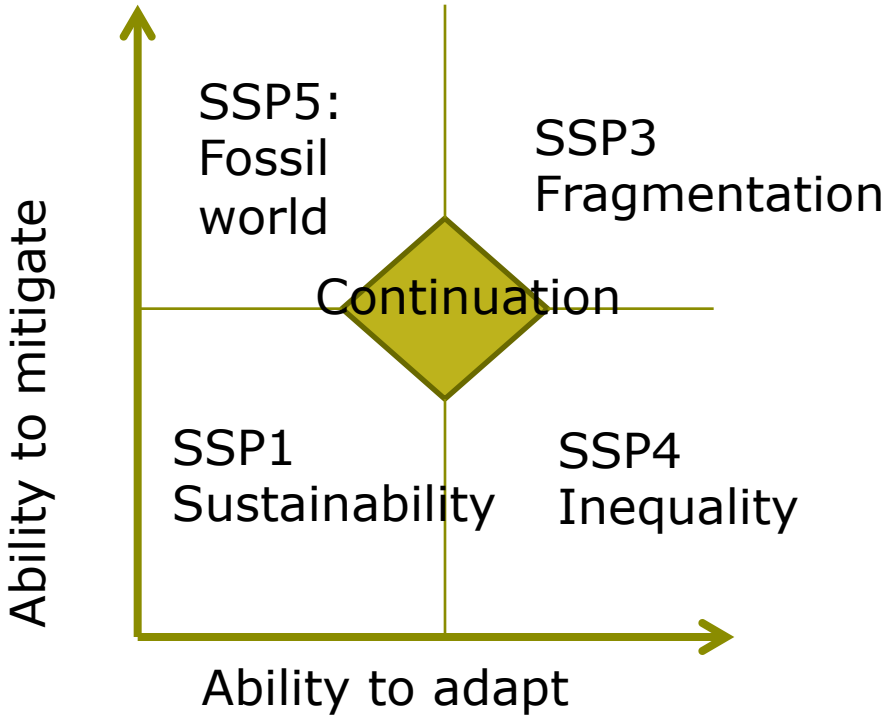




Mueller et al. 2014

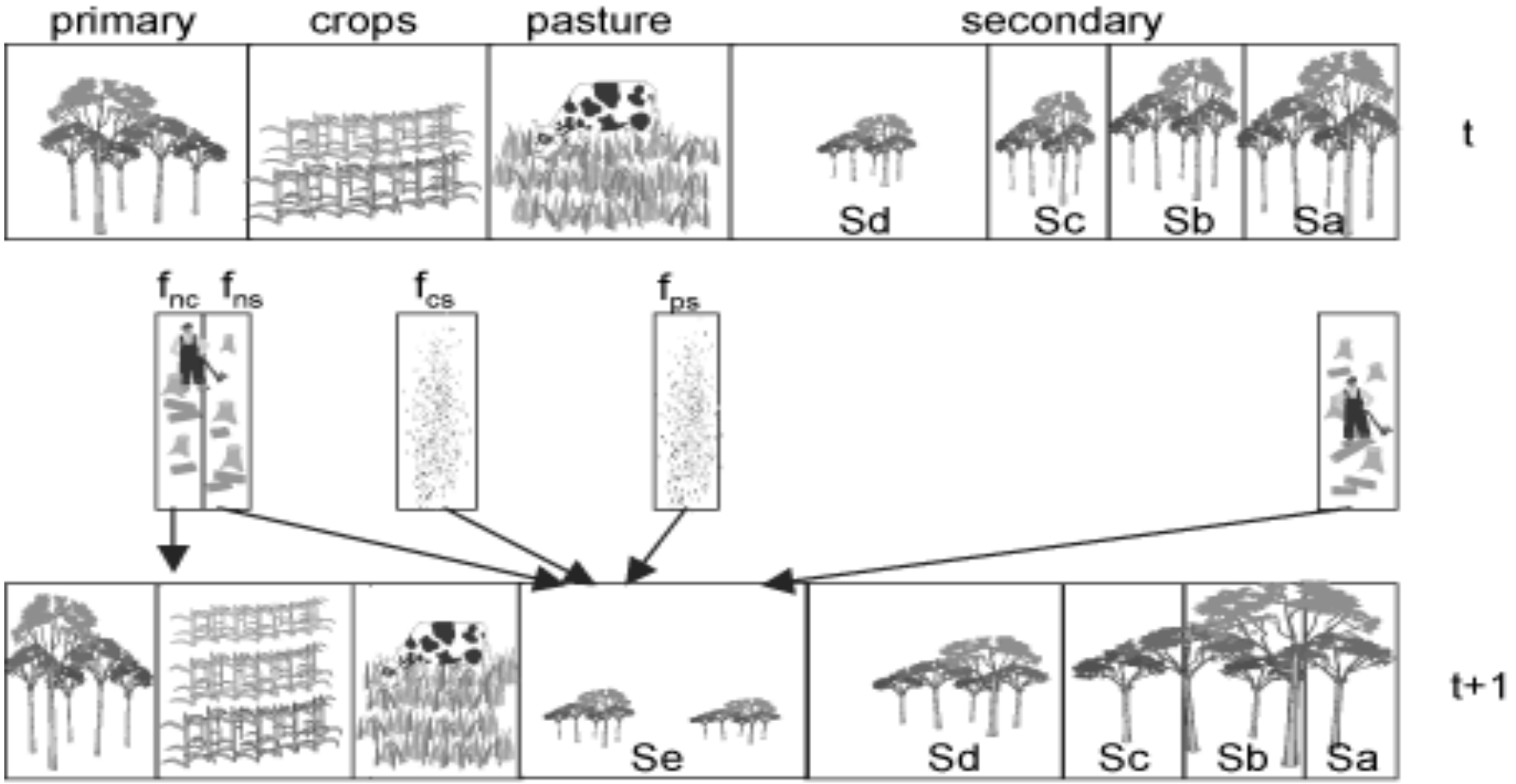
Development and Use of New Scenarios

SSPs



O'Neill et al. 2011, van Vuuren 2012

LM3V is designed to diagnose and predict the land-use sink/source.

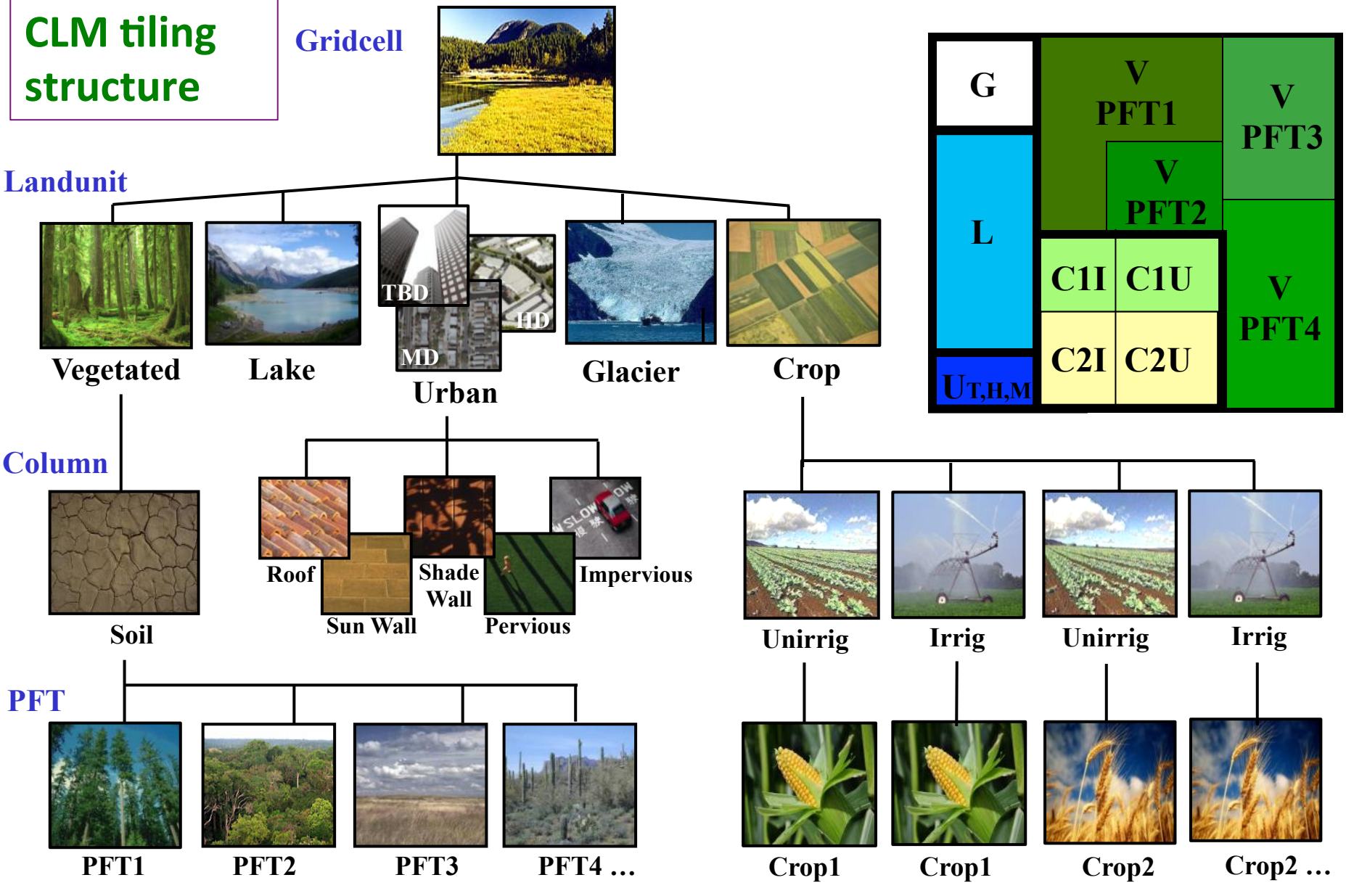


An example of land transitions in LM3V: fraction of natural forest f_{nc} is cut to clear land for cropland; fraction f_{ns} is cut and left to re-grow; fraction of cropland f_{cs} and pasture f_{ps} are abundant; and fraction f_{ss} of a secondary forest is harvested. After transitions, the area of natural, cropland, pasture and harvested secondary tiles are updated and a new secondary tile Se is formed.

Shevliakova et al. (2009)

Issue: Subgrid data as default for CMIP

CLM tiling structure



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