Land-Use Harmonization for CMIP5 and Priorities for CMIP6

George C. Hurtt
University of Maryland
gchurtt@umd.edu

Kathy Hibbard
PNNL
Kathy.hibard@pnnl.gov

David Lawrence
NCAR
dlawren@ucar.edu

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Questions

- What are the combined biogeochemical and biogeophysical effects of land-use change on Earth System dynamics (past-future)?

- How can data from multiple time periods, sources, quantities etc. best be combined into a common coherent product to satisfy community modeling needs?
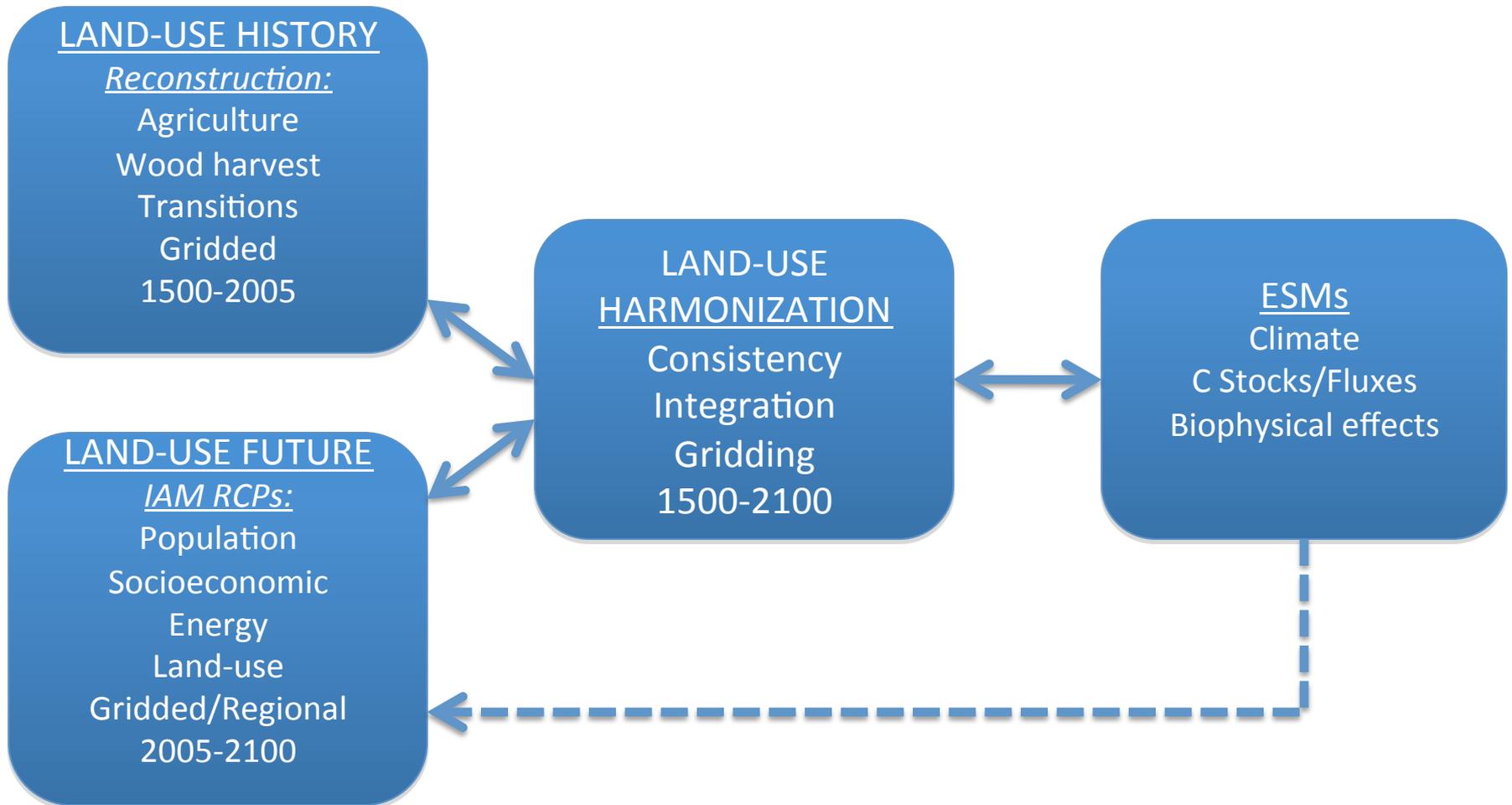
Scientific Approach
- **Data**
- **Detection and mapping of changes**
- **Attribution of causes of change**
- **Field cal/val**
- **Experiments**
- **Input data for models**
- **Model development, parameterization**
- **Model initialization, projections, testing**
- **MIPs, DiPS,…**

FOCUS AND ASK AGAIN

Proposed AR5 Scheme (Land-use)

LAND-USE HISTORY
Reconstruction:
Agriculture
Wood harvest
Transitions
Gridded
1500-2005

LAND-USE FUTURE
IAM RCPs:
Population
Socioeconomic
Energy
Land-use
Gridded/Regional
2005-2100

LAND-USE HARMONIZATION
Consistency
Integration
Gridding
1500-2100

ESMs
Climate
C Stocks/Fluxes
Biophysical effects

Hurtt et al. (2009)

Collaborators

- Louise P. Chini[1]
- Steve Frolking[2]
- Richard Betts[3]
- Johannes Feddema[4]
- Guenther Fischer[5]
- Justin Fisk[1]
- Kees Klein Goldewijk[6]
- Kathy Hibbard[9]
- Richard Houghton[8]
- Anthony Janetos[9]
- Chris Jones[3]

- Georg Kindermann[5]
- Tsuguki Kinoshita[10]
- Keywan Riahi[5]
- Elena Shevliakova[11]
- Steve Smith[9]
- Elke Stehfest[6]
- Allison Thomson[9]
- Peter Thornton[12]
- Detlef van Vuuren[6]
- Yingping Wang[13]

(1) University of Maryland (2) University of New Hampshire (3) Met Office Hadley Centre, Germany (4) University of Kansas (5) International Institute for Applied Systems Analysis and Graz University of Technology, Austria (6) Netherlands Environmental Assessment Agency (7) National Center for Atmospheric Research (8) Woods Hole Research Center (9) Pacific Northwest National Laboratory—Joint Global Change Research Institute (10) National Institute for Environmental Studies, Japan (11) Princeton/GFDL (12) Oak Ridge National Lab (13) CSIRO, Australia
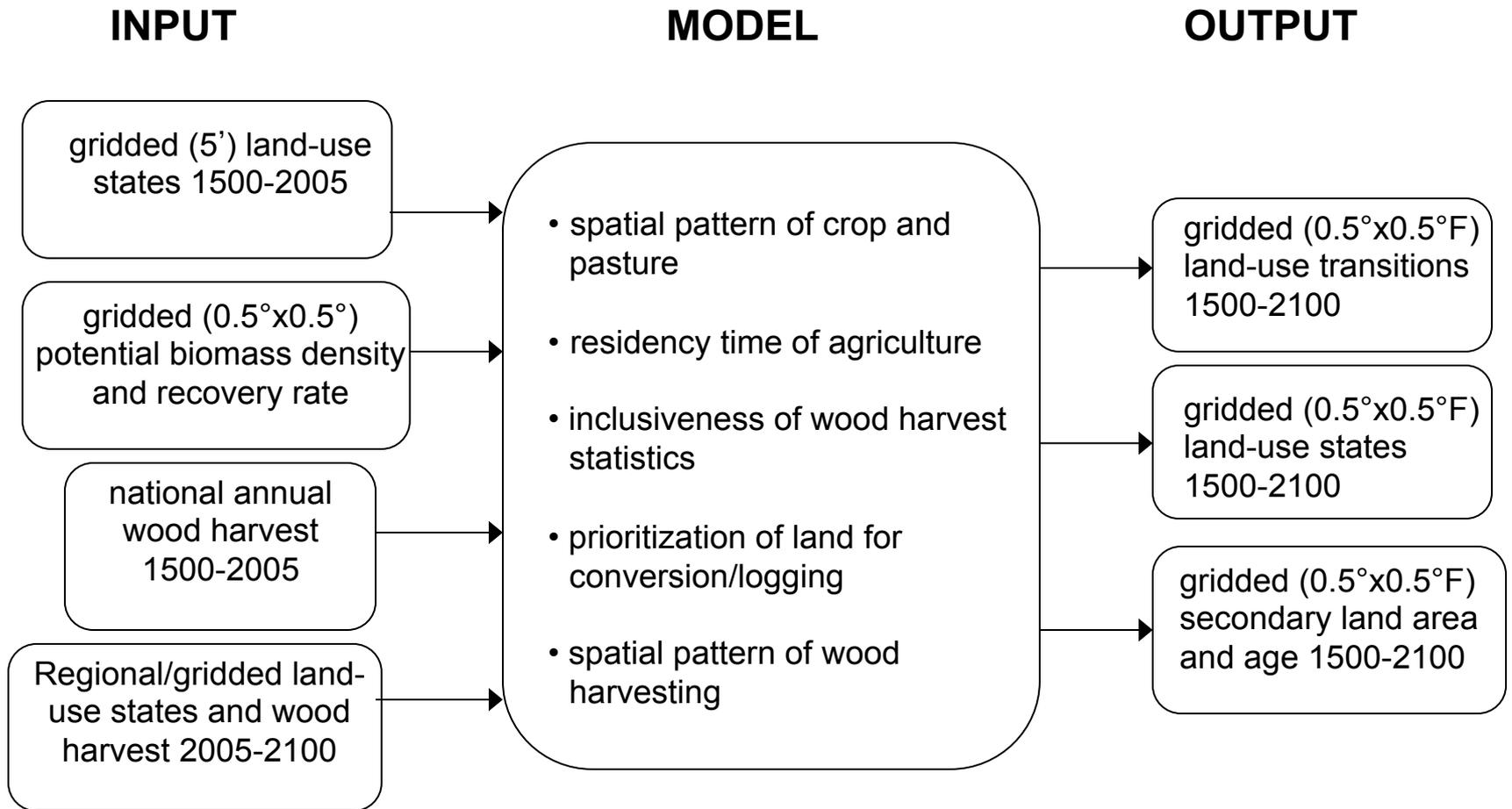
Harmonization Steps

- Develop consensus land-use history reconstruction

- Minimize differences between end of historical reconstruction and beginning of future projections

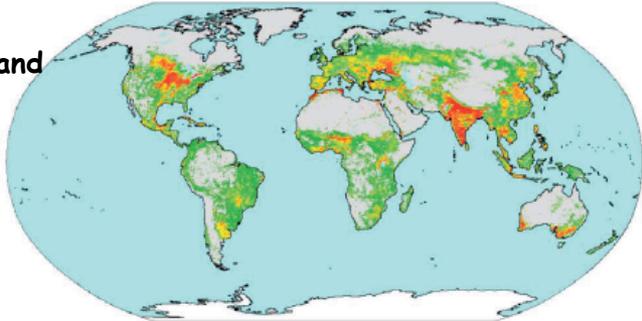- Preserve as much information from IAMs on future as possible

Hurtt et al. (2009, 2011)

Mathematical Structure

$$l(x,y,t+1) = A(x,y,t)\, l(x,y,t)$$

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

Global, 0.5°x0.5°, 600y, 5D:
~10^9 unknowns!

Hurtt et al. (2006, 2011)

INPUT

MODEL

OUTPUT

gridded (5') land-use states 1500-2005

gridded (0.5°x0.5°) potential biomass density and recovery rate

national annual wood harvest 1500-2005

Regional/gridded land-use states and wood harvest 2005-2100

- spatial pattern of crop and pasture

- residency time of agriculture

- inclusiveness of wood harvest statistics

- prioritization of land for conversion/logging

- spatial pattern of wood harvesting

gridded (0.5°x0.5°F) land-use transitions 1500-2100

gridded (0.5°x0.5°F) land-use states 1500-2100

gridded (0.5°x0.5°F) secondary land area and age 1500-2100

Hurtt et al. (2009, 2011)

Global wood harvest by country, 1500-2005 (Pg C y⁻¹)
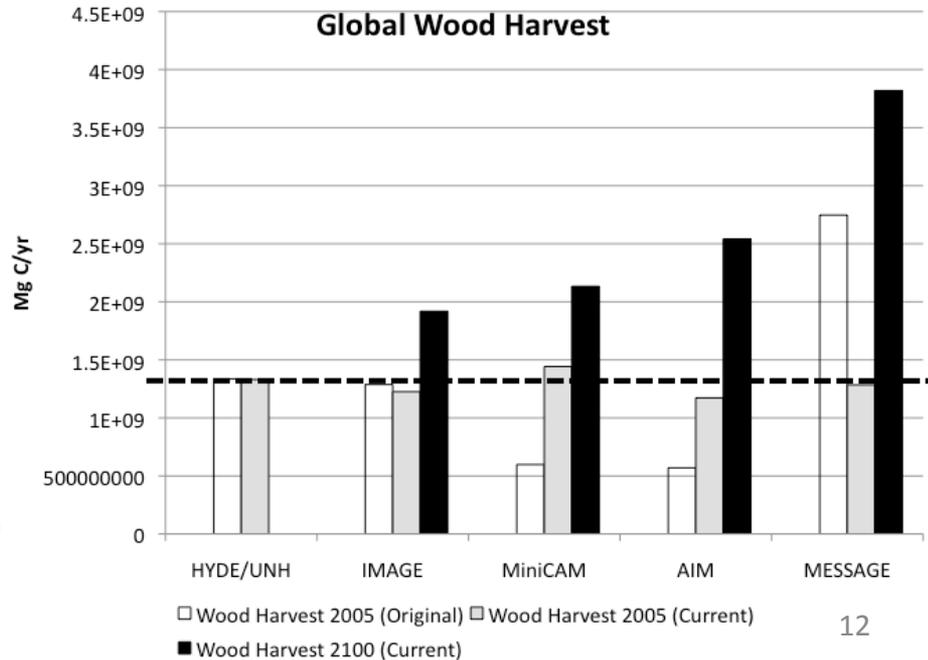
cropland

rangeland
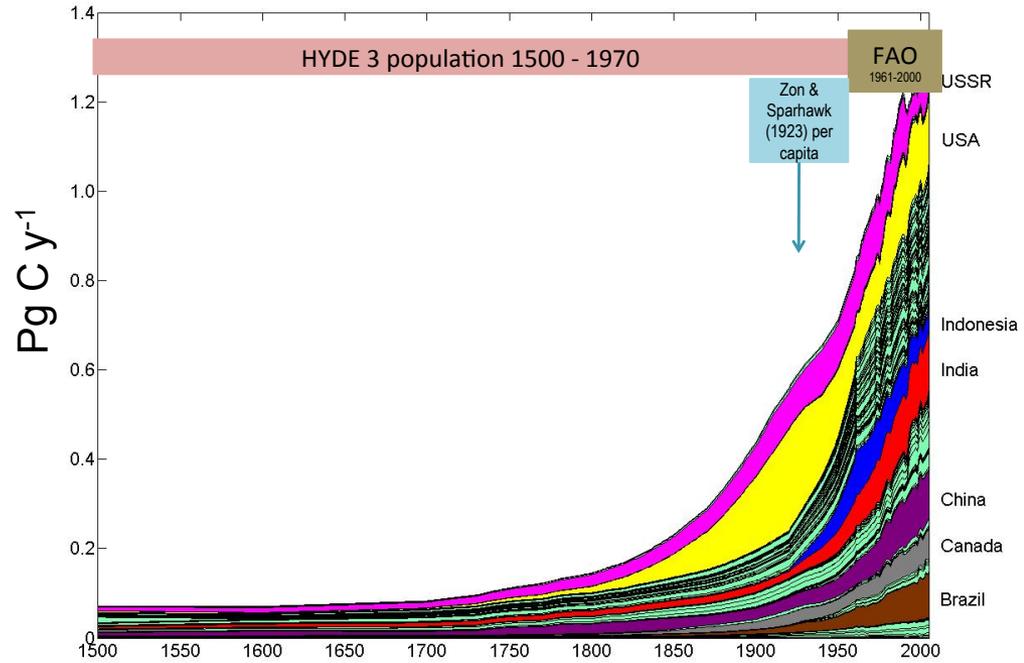
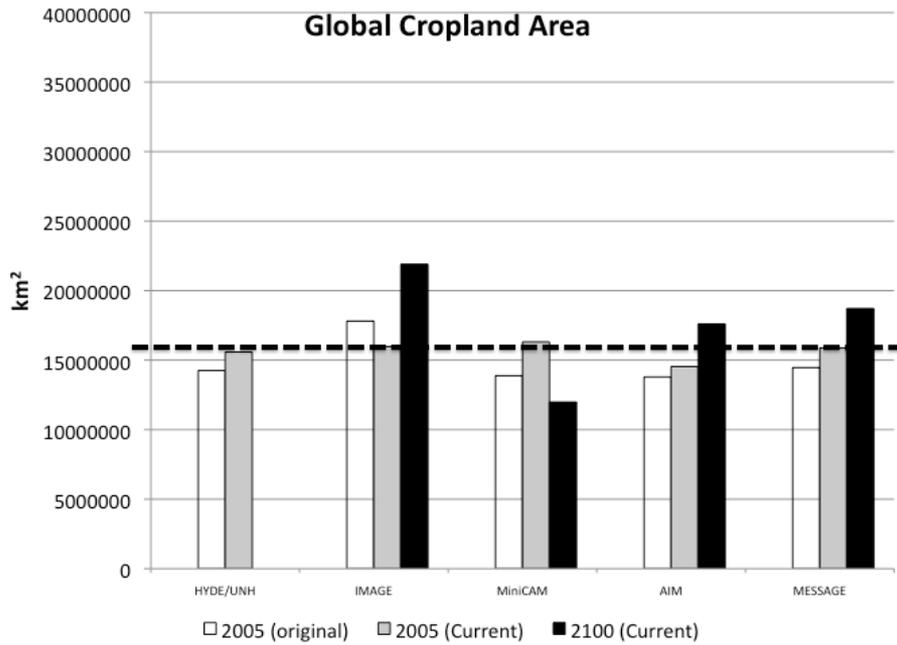

Hurtt et al. 2006; revised

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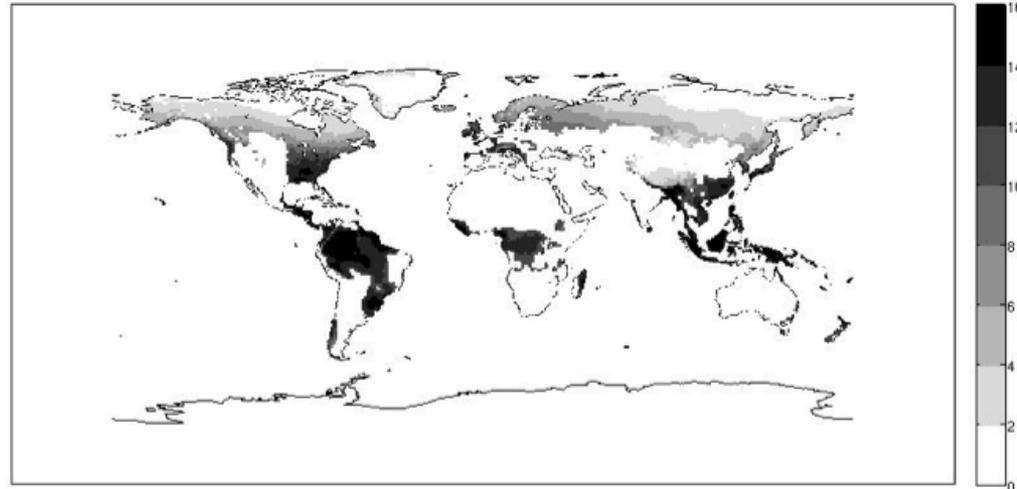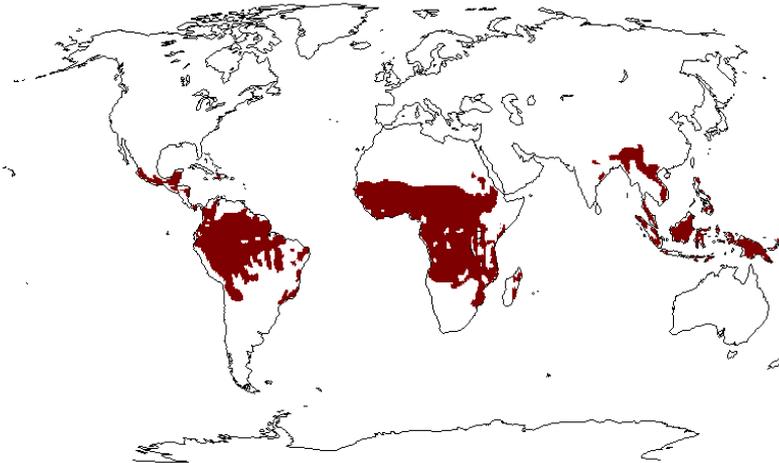
Diagnostics

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)

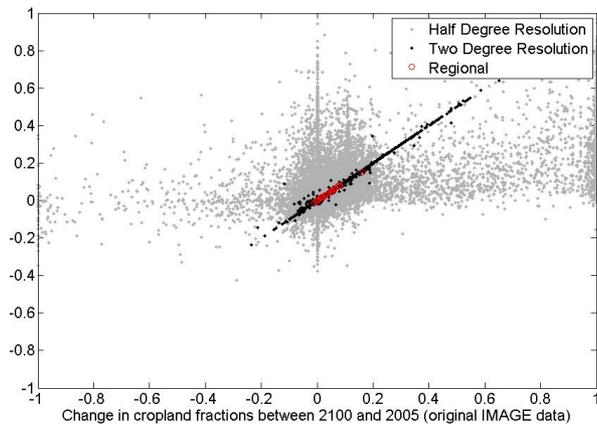# Representative Concentration Pathways (RCPs)

IAM	RCP	Radiative Forcing	Concentration	Pathway Shape
MESSAGE	8.5	>8.5 W/m^2 in 2100	> ~1370 CO_2-eq in 2100	Rising
AIM	6	~6 W/m^2 at stabilization after 2100	~850 CO_2-eq at stabilization after 2100	Stabilization without overshoot
MiniCAM	4.5	~4.5 W/m^2 at stabilization after 2100	~650 CO_2-eq at stabilization after 2100	Stabilization without overshoot
IMAGE	2.6	Peak at ~3 W/m^2 before 2100 and then declines to 2.6 W/m^2 by 2100	Peak at ~490 CO_2-eq before 2100 and then decline	Peak and decline

Moss et al. (2008) "Towards New Scenarios for Analysis of Emissions, Climate Change, Impacts, and Response Strategies". IPCC, Geneva.
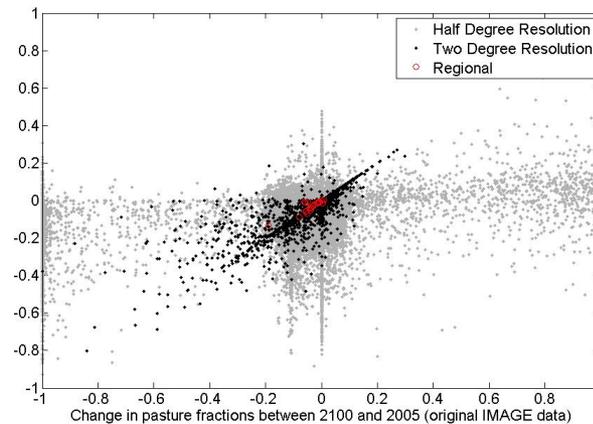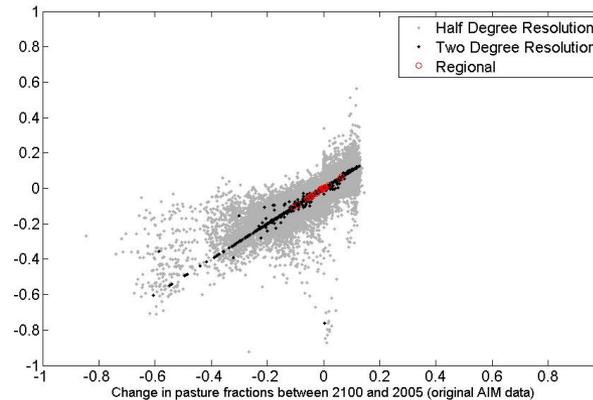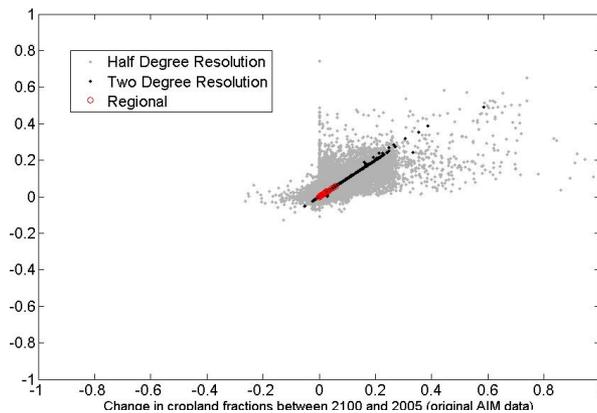
Global Cropland Area

km²

□ 2005 (original)   ▨ 2005 (Current)   ■ 2100 (Current)

HYDE/UNH   IMAGE   MiniCAM   AIM   MESSAGE

Global Pasture Area

km²

□ 2005 (Original)   ▨ 2005 (Current)   ■ 2100 (Current)

HYDE/UNH   IMAGE   MiniCAM   AIM   MESSAGE

Global Urban Area

km²

□ 2005 (Original)   ▨ 2005 (Current)   ■ 2100 (Current)

HYDE/UNH   IMAGE   MiniCAM   AIM   MESSAGE

Global Wood Harvest

Mg C/yr

□ Wood Harvest 2005 (Original)   ▨ Wood Harvest 2005 (Current)
■ Wood Harvest 2100 (Current)

HYDE/UNH   IMAGE   MiniCAM   AIM   MESSAGE
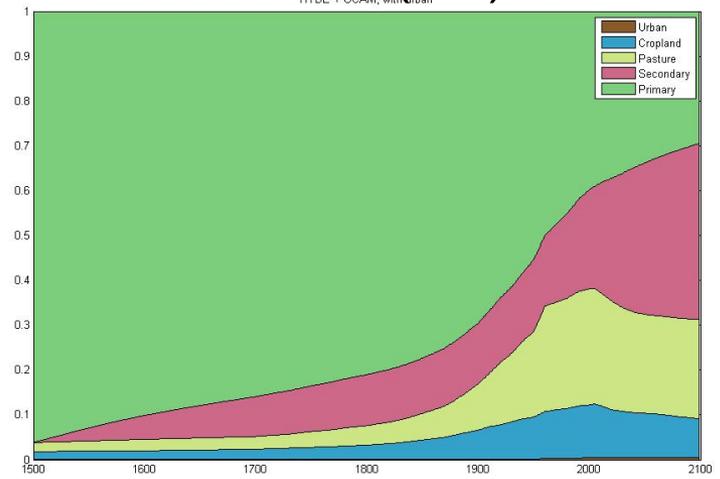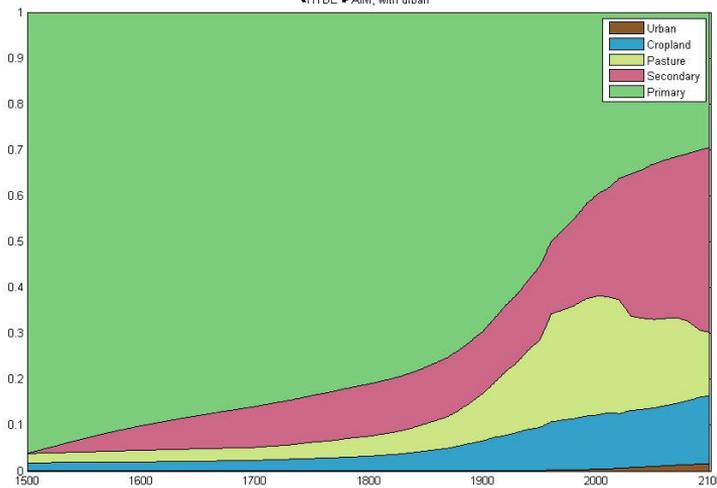
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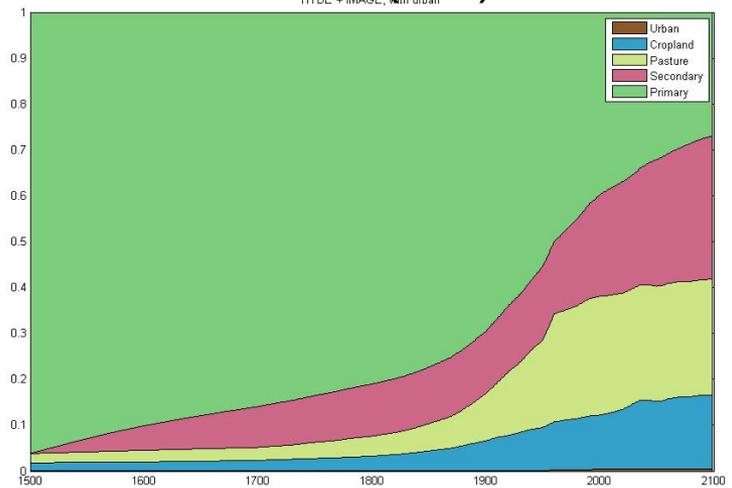crop   pasture

IMAGE

AIM

MESSAGE

ΔF (LUH)

ΔF (IAM)

LUH-MESSAGE (8.5)

LUH-GCAM (4.5)

LUH-AIM (6)

LUH-IMAGE (2.6)

Hurtt et al. 2011

| Model factor	Number of Cases: Description
H: Historical land-use reconstruction	3: HYDE 3.0, "No Data", None
T: Residence time of agricultural land	2: Shifting cultivation, no shifting cultivation
L: Wood harvest history reconstruction	3: No wood harvest, FAO wood harvest reconstruction, "No Data"
W: Land-conversion wood clearing tallied as harvest to satisfy annual wood harvesting	2: Included 100%, not included
P: Priority for land-use transitions	2: Primary, secondary
D: Historical start date	4: 1500, 1700, 1850, 2005
U: Urban land use included	2: Included, not included
F: Future land-use projections	4: AIM, GCAM, IMAGE, MESSAGE

Total number of simulations = 1664

Gross T. a — Net T. b — Sec. c — Sec. Age d — Total C e — Net C f
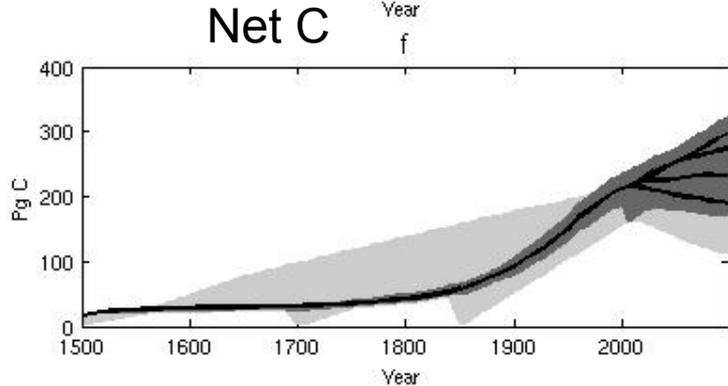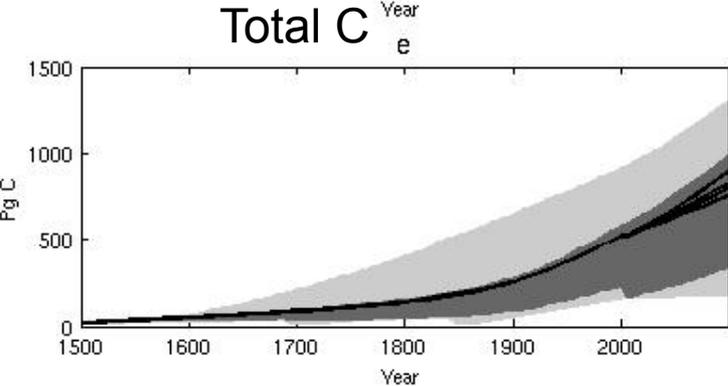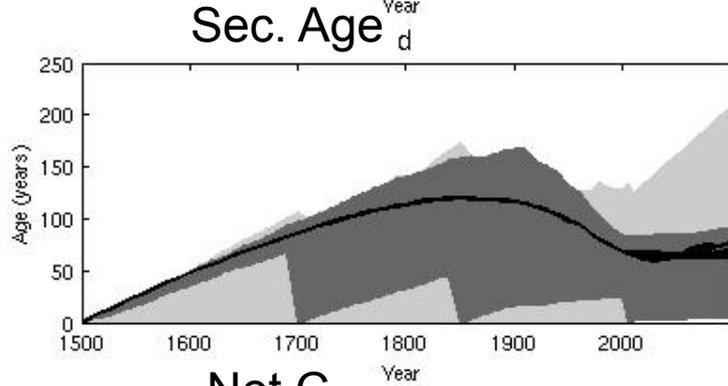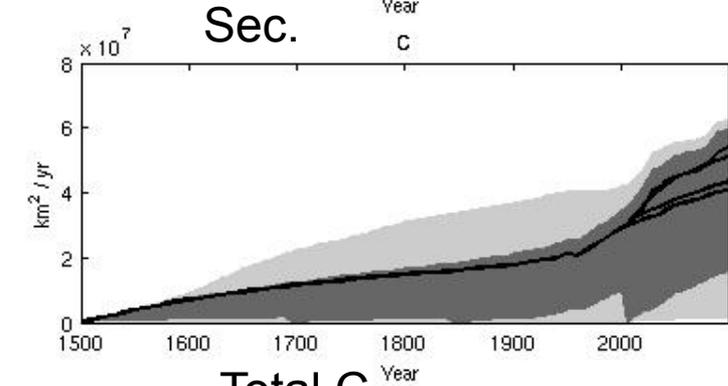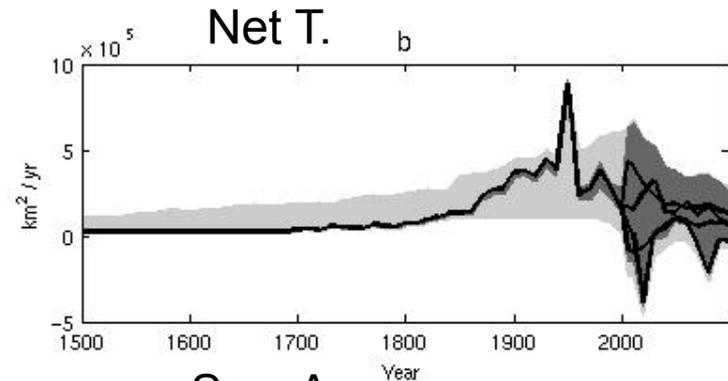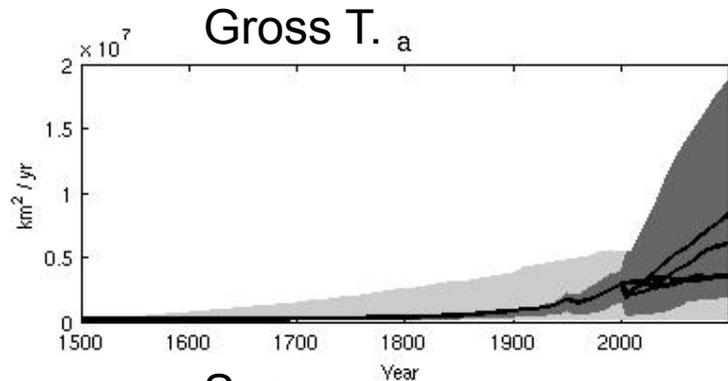
--- Focal case
--- Data-based
--- All

Hurtt et al. (2011)   16

Hurtt et al. (2011)
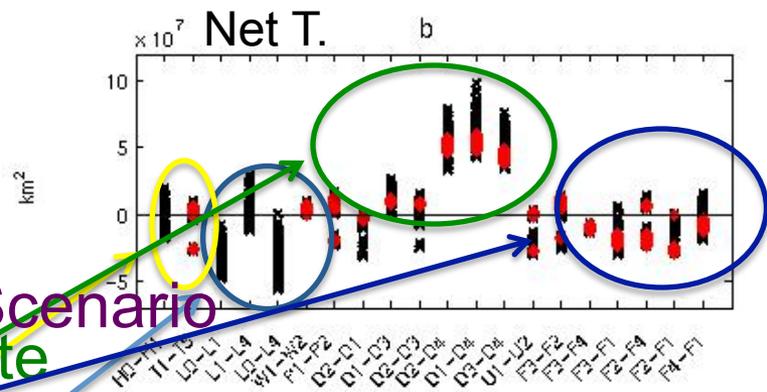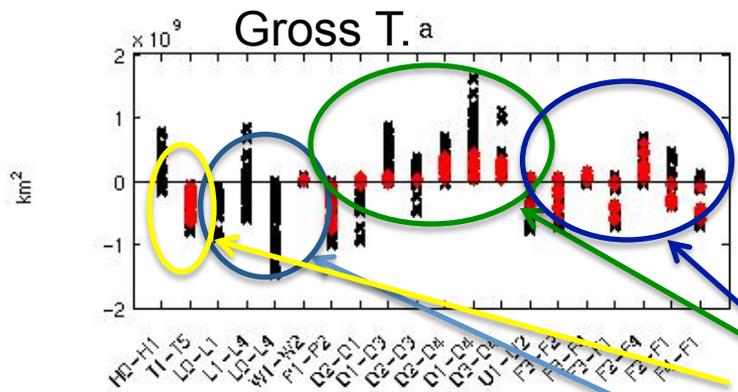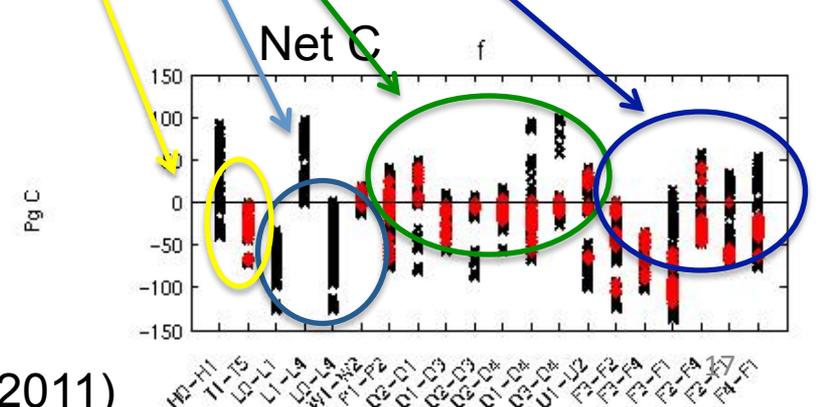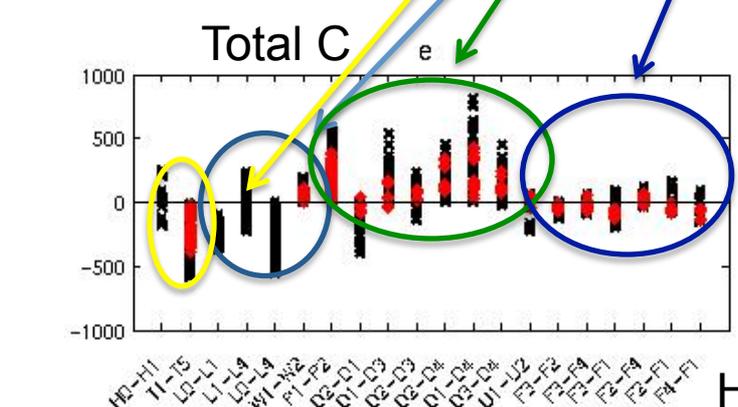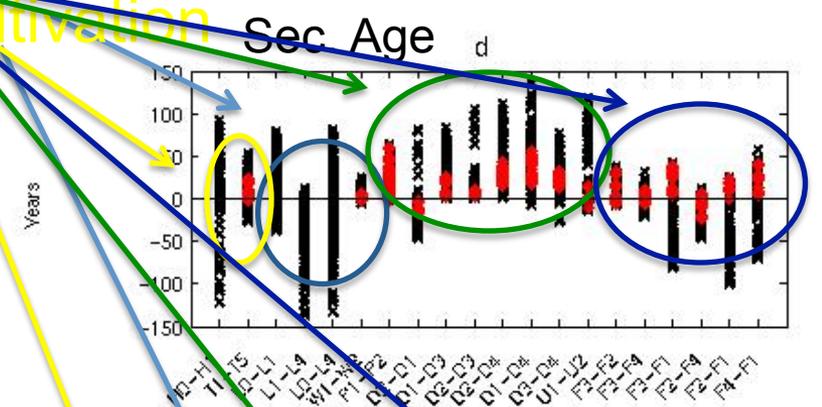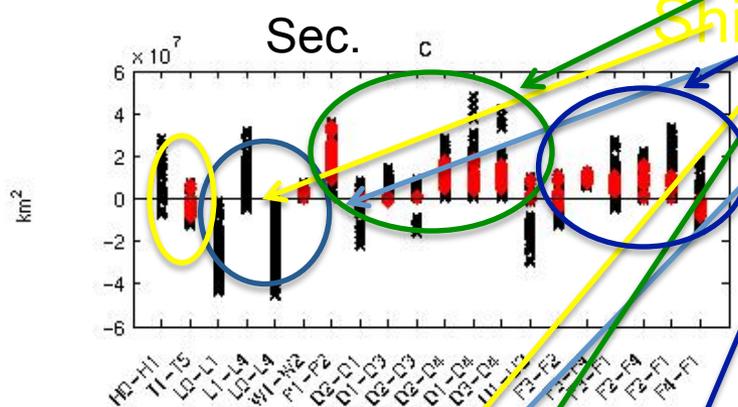
Figure 4. 10-yr moving average of changes relative to year 2006 in annual near-surface air temperature, K, averaged for ensemble simulations globally (top) or for land grid cells where LULCC exceeded 10% of cell area (bottom). Bold and dashed lines are for 2.6 and 8.5 scenarios, dark and light colors are for RCP and LUCID experiments, respectively.

Brovkin et al (2013)

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

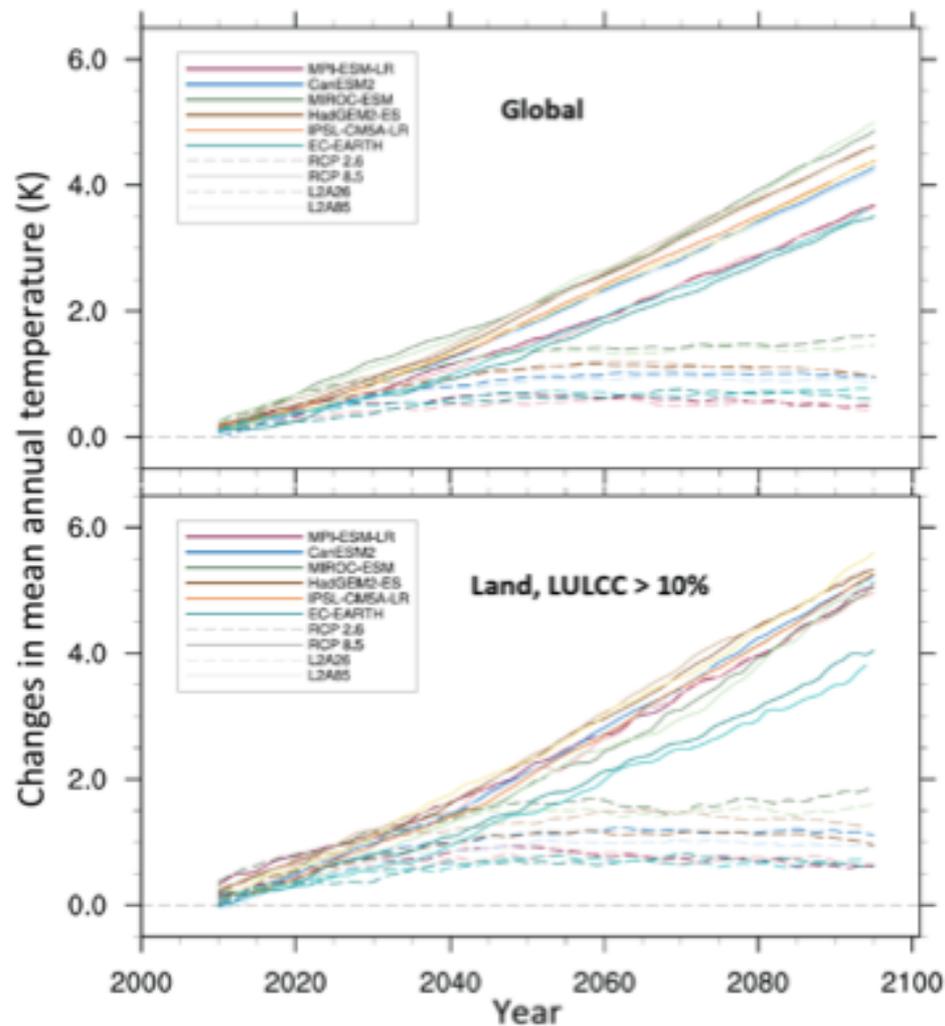| ESM	CanESM2	EC-Earth	HadGEM2-ES	IPSL-CM5A-LR	MIROC-ESM	MPI-ESM-LR
Atmosphere/land resolution	~2.8°	~1.1°(T159)	~1.6°	3.75°x1.90° (T39)	~2.8° (T42)	~1.9°(T63)
Land surface component	CTEM	HTESSEL	JULES	ORCHIDEE	SEIB-DGVM	JSBACH
Number of PFTs	9	15	5	13	13	12
Dynamic vegetation	No	No	Yes	No	Yes	Yes
Fire 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)

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

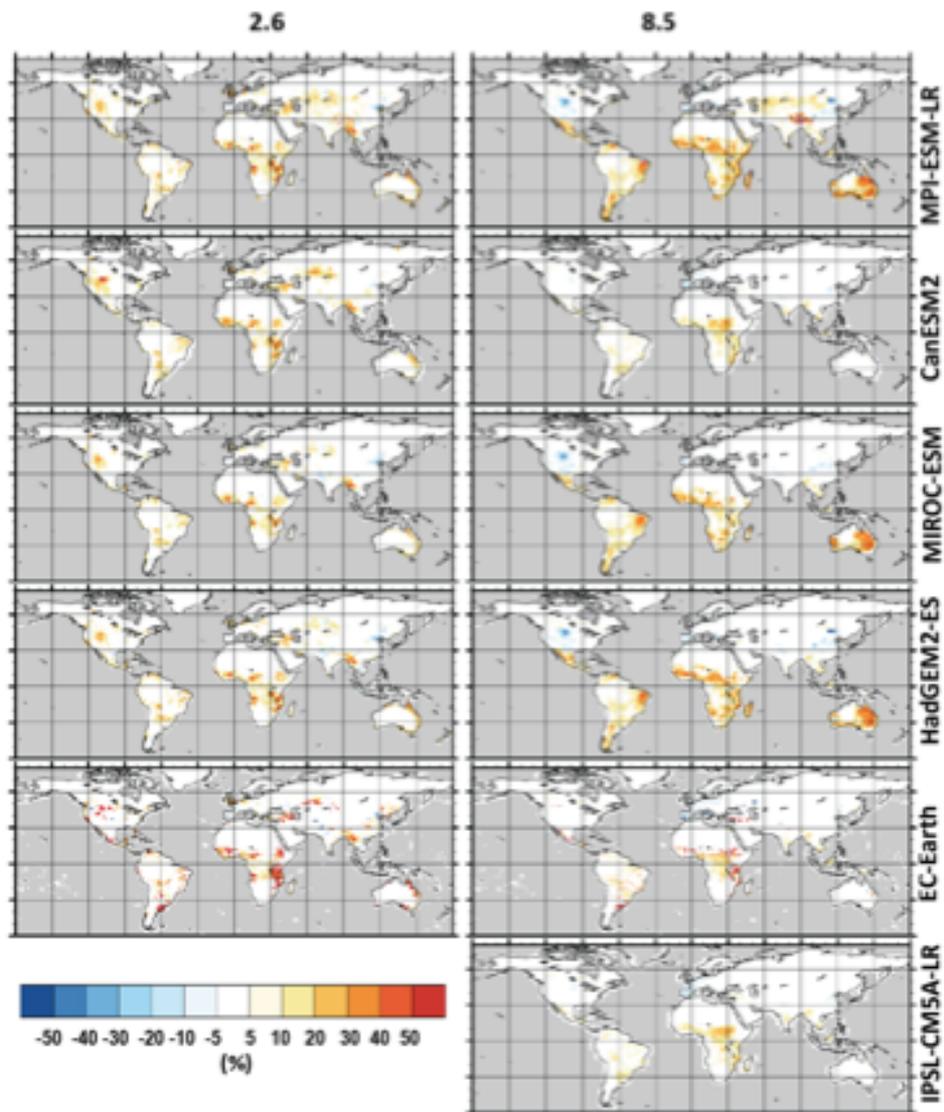| Model	RCP scenario	Cumulative net land-use emissons, PgC, year 2100	Transient climate sensitivity to emissions, K/TtC, (Gillett et al. 2013)	Estimated global annual temperature increase, K, year 2100
CanESM2	2.6	39	2.365	0.09
	8.5	34		0.08
HadGEM2-ES	2.6	19	2.105	0.04
	8.5	25		0.05
IPSL-CM5A-LR	8.5	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)

Figure 2. Maps of changes in total crop and pasture fraction (%) in the RCP26 (left) and RCP85 (right) simulations between 2006 and 2100 for all LUCID-CMIP5 models. The fractions are specific for each model due to different interpretation of land-use change scenarios by land surface models.

Brovkin et al (2013)

Summary/Conclusions

- Virtually all ESMs either now track, or are developing capacity to track, gridded land-use changes. The strategy developed for AR5 is a nascent approach for harmonizing land-use information across multiple data sources, models, and scenarios. The resulting science is promising and still unfolding.

- The next generation of these studies is poised to advance in a more advanced and integrated fashion on all major fronts, and prepare for the next generation studies and of fully integrated models (e.g. iESMs+). SESYNC 2013-15, Aspen 2013, iLEAPS-IMCES Amsterdam 2013, Special issue of GBC 2014,...

- **Next:**

1) Improve models. Models differ widely in treatment of LULCC, and this leads to important differences in projections related to processes and process detail incl.

2) Improve data. Utilize more data to improve land-use transitions (e.g. wood harv., shifting cultivation, carbon); harmonize corresponding major effects of transitions, and mgt. practices   (e.g. fert., irrig., harvest, tillage, biofuel, fate);

3) Improve process/qs. Std. data usage; augment parallel process esp. to account for biophysical effects of land-use; consider new scenarios that add more normative considerations up front; even more coordination & robust process.

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