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

LUMIP
Land Use Change

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, Julia Pongratz, Sonia Seneviratne, Elena Shevliakova

with input from many Earth System Modeling, Integrated Assessment Modeling, and historical land use communities

https://cmip.ucar.edu/lumip

… with significant impacts on water (e.g., 70% of water withdrawals for agriculture) and energy fluxes

Regionally, land-use and land-cover change has been as impactful on surface climate as GHGs

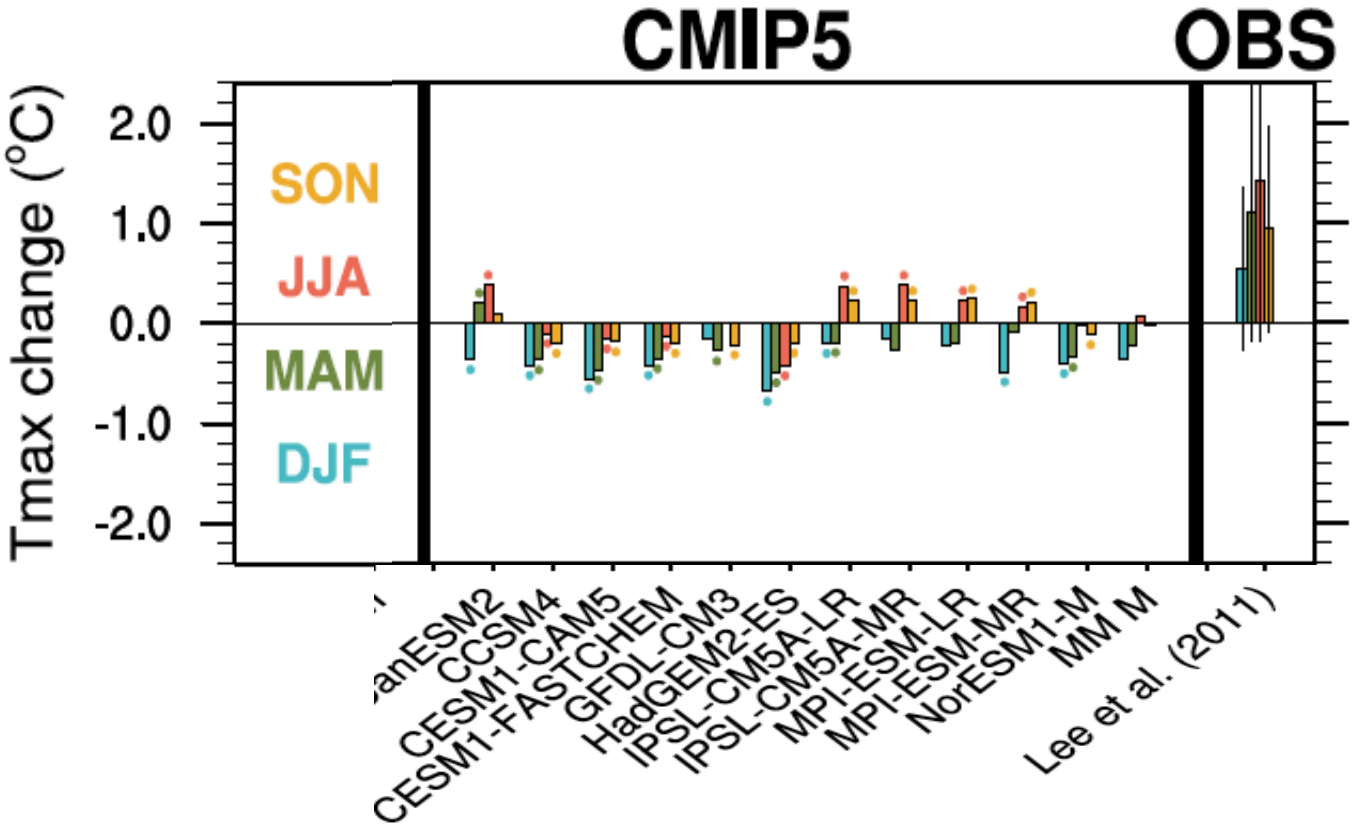
… and on direct carbon emissions (~1/3 of direct historic C emissions - 195 ± 45 PgC - from land use)

… with significant impacts on water (e.g., 70% of water withdrawals for agriculture) and energy fluxes

Regionally, land-use and land-cover change has been as impactful on surface climate as GHGs

… and indirect carbon emissions (e.g., the Loss of Additional Sink Capacity)

Models do not agree with obs estimates or each other on sign or amplitude of LULCC impact

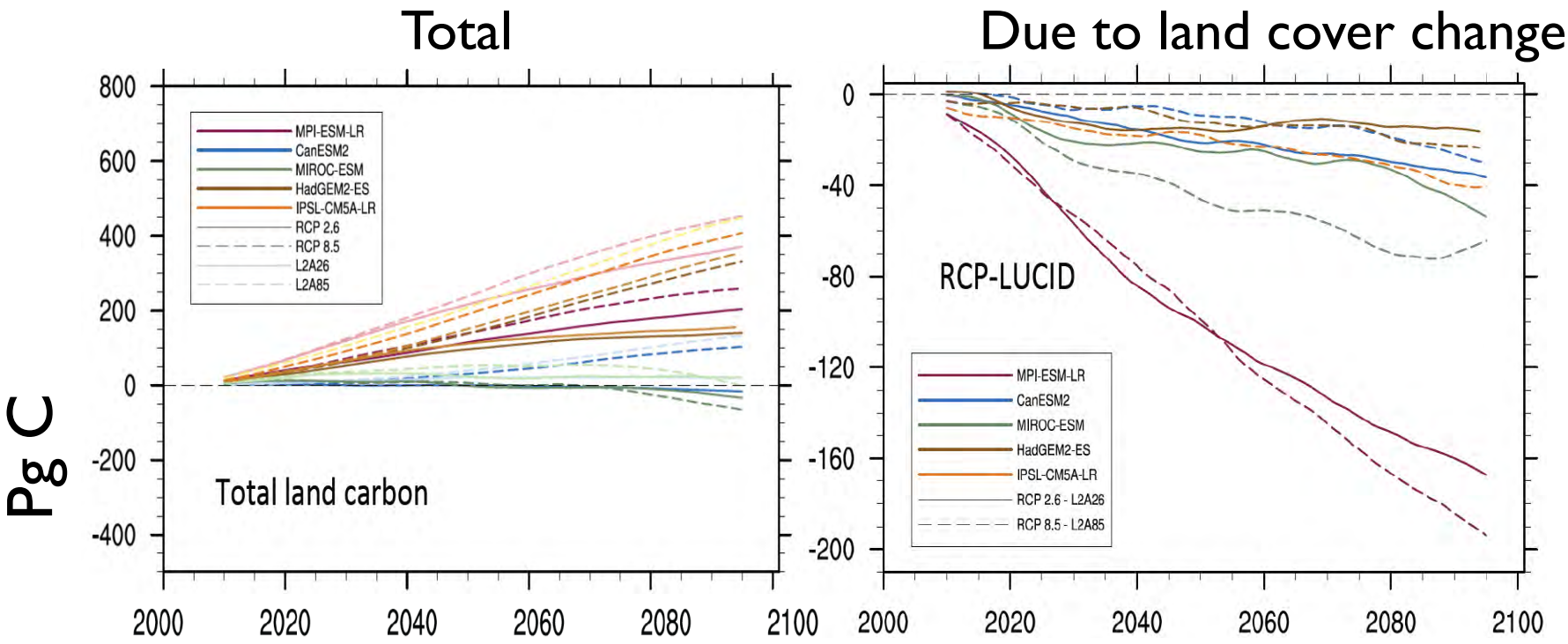


Model and obs estimates do not agree on amplitude (or even sign) of land-cover change impact on Ts

Lejeune et al., 2017

Nor do they agree with respect to the impact of LULCC on terrestrial carbon cycle

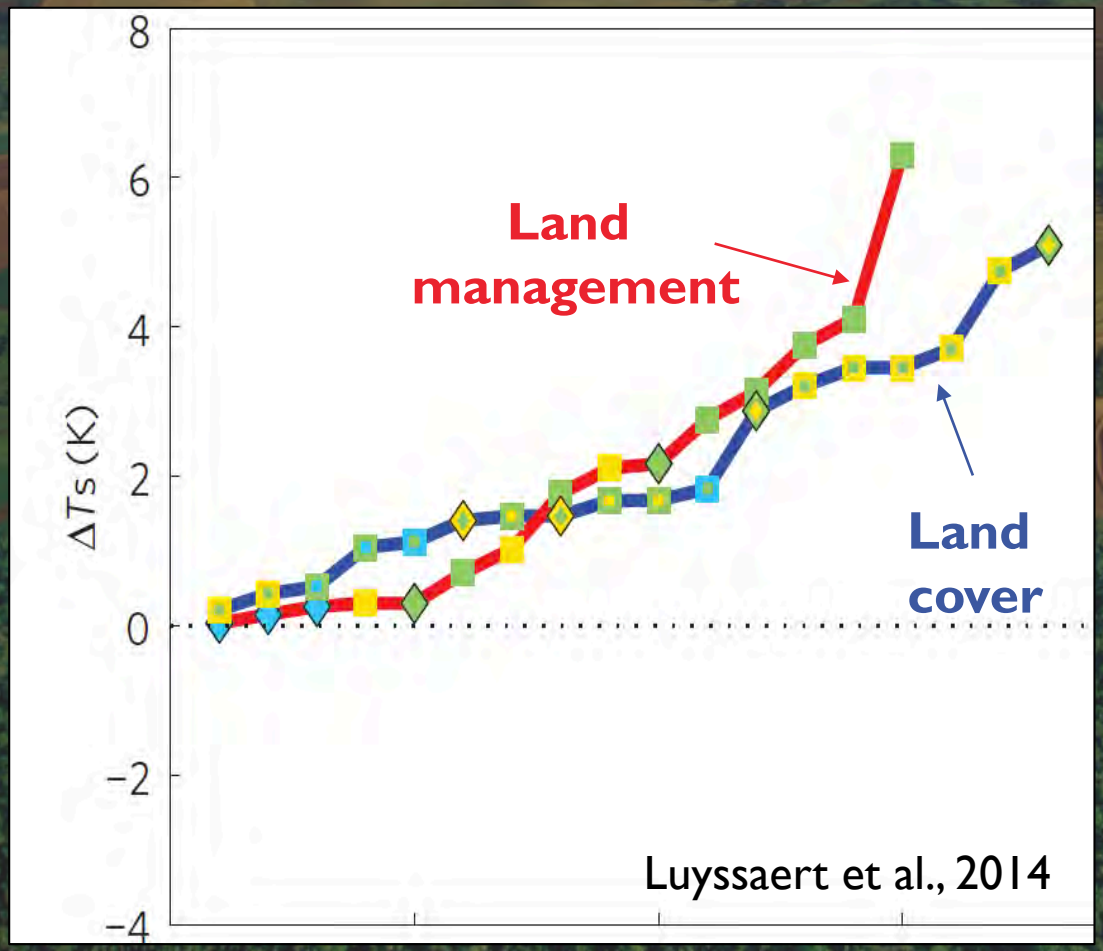
Changes in land carbon storage



- Disparity across CMIP5 models in terms of LCC impact on C, even in scenario where prescribed LCC was relatively small (RCP8.5)
- And, many CMIP5 models represent land use simplistically (w/o wood harvest, crop management, irrigation, fertilization, shifting cultivation)
- Indirect C impacts as big or bigger than direct (Mahowald et al. 2016)

Brovkin et al.., J. Clim. 2013

Land management and land-cover change have impacts on surface temperature of similar magnitude



Paired Tower sites

since 1993

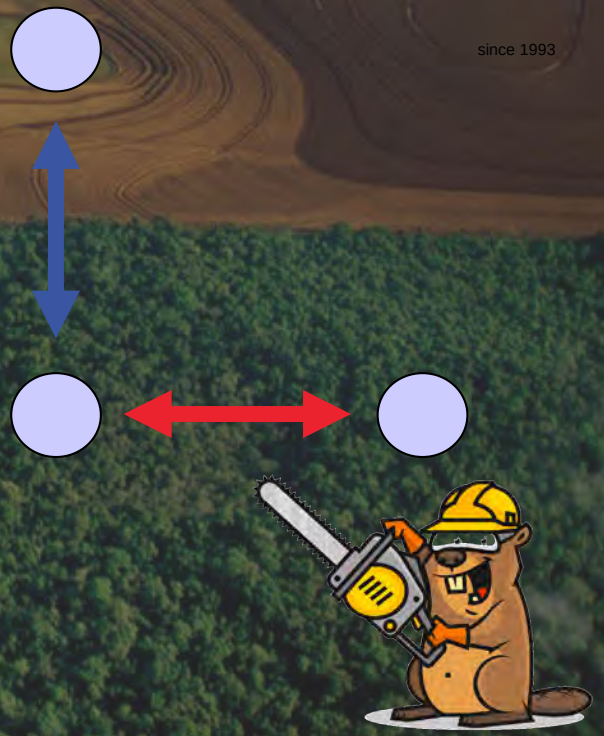
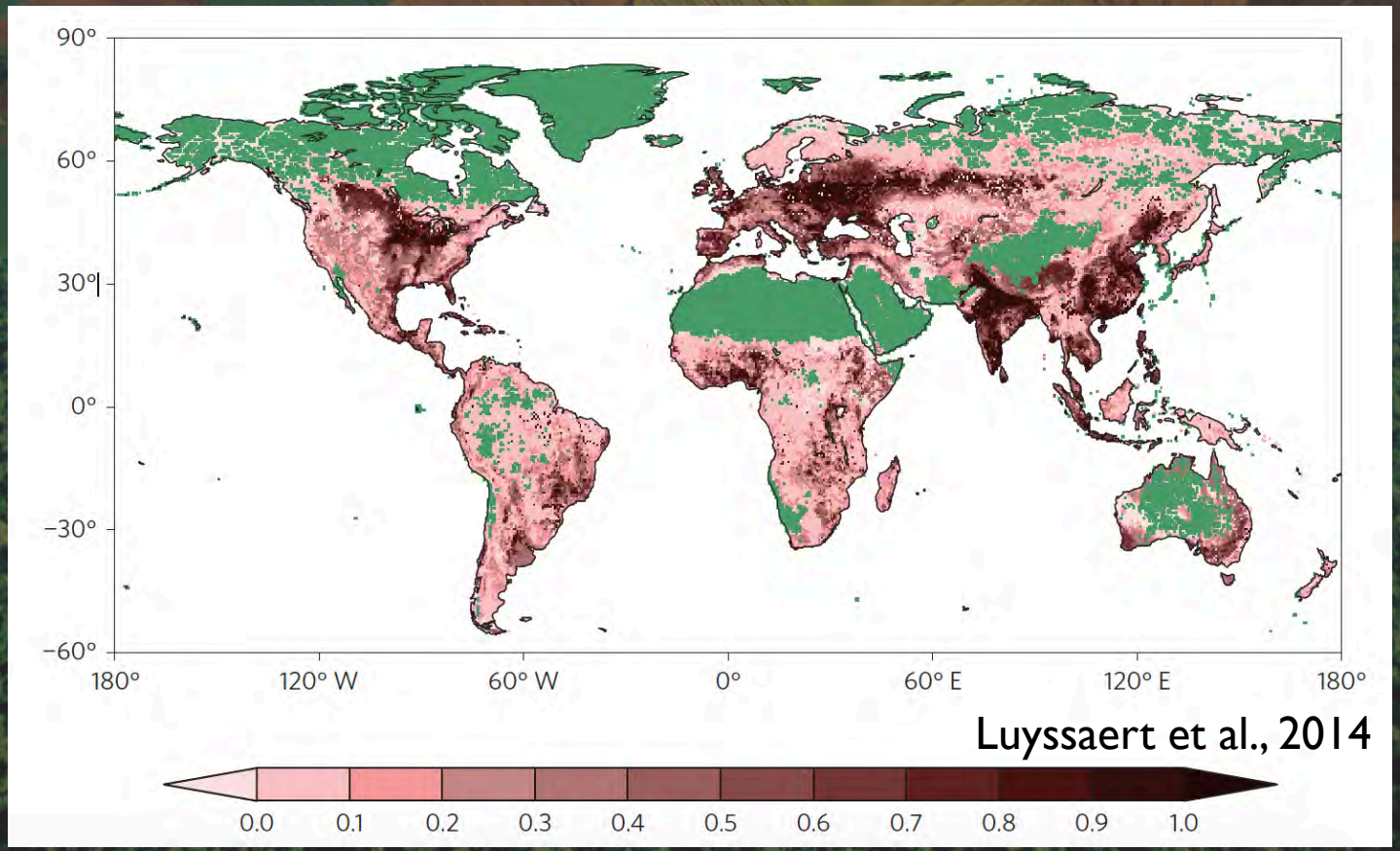


Image: Frans Lanting/Robert Harding Picture Library

Most of the land in the world is being managed

- ~25% non-ice land area undergone anthropogenic land-cover change
- Additional ~50% non-ice land area under some form of land management

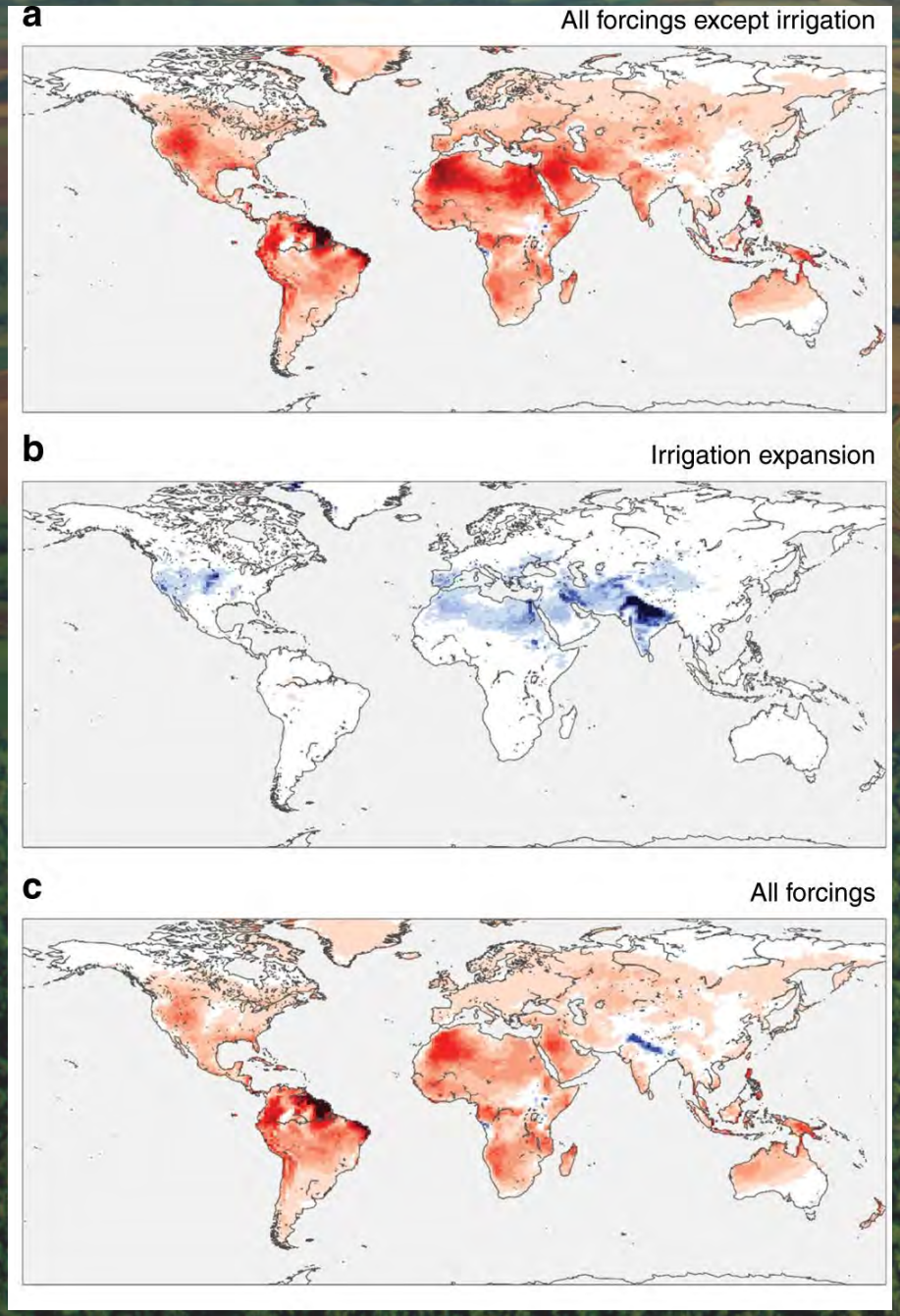


Land-use intensification

- Due to predicted increases in global population and affluence, demand for land-based food and fiber is likely to surge during coming decades
- Expansion of management into relatively untouched regions may satisfy part of growing demand
- … but, land-use intensification will necessarily play a decisive role
- Land management will likely be a required mitigation tool to reach 1.5 or 2C targets

since 1993

Image: Frans Lanting/Robert Harding Picture Library



nature communications

Article | Open Access | Published: 15 January 2020

Warming of hot extremes alleviated by expanding irrigation

Wim Thiery ✉, Auke J. Visser, Erich M. Fischer, Mathias Hauser, Annette L. Hirsch, David M. Lawrence, Quentin Lejeune, Edouard L. Davin & Sonia I. Seneviratne

since 1993

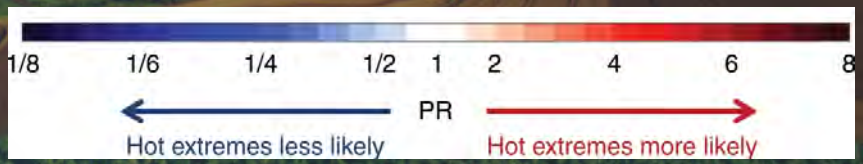
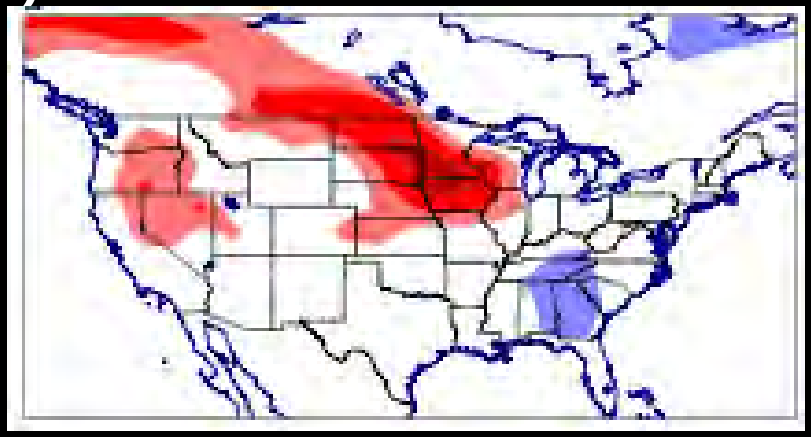


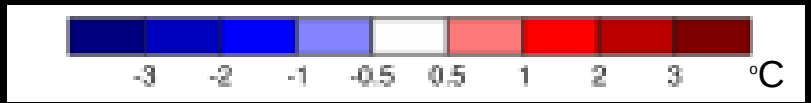
Image: Frans Lanting/Robert Harding Picture Library

Impact of cover crops on winter climate

Change in Winter Surface Temperature (°C)

Tall, Sparse:
LAI = 1
Height = 50 cm

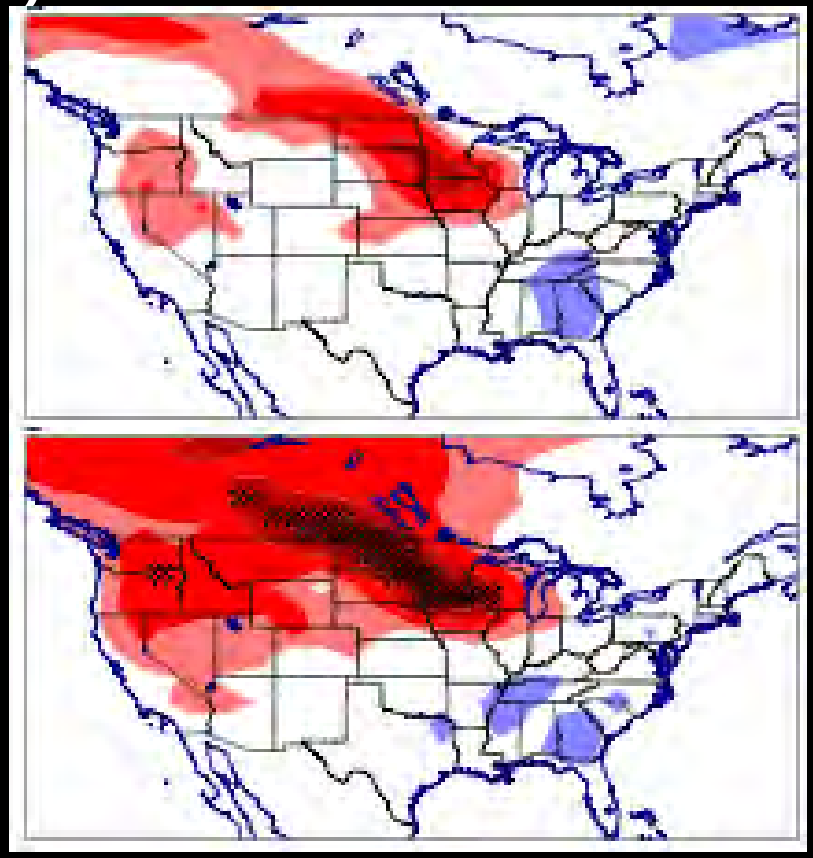




Change in Winter Surface Temperature (°C)

Tall, Sparse:
LAI = 1
Height = 50 cm

Tall, Leafy:
LAI = 4
Height = 50 cm

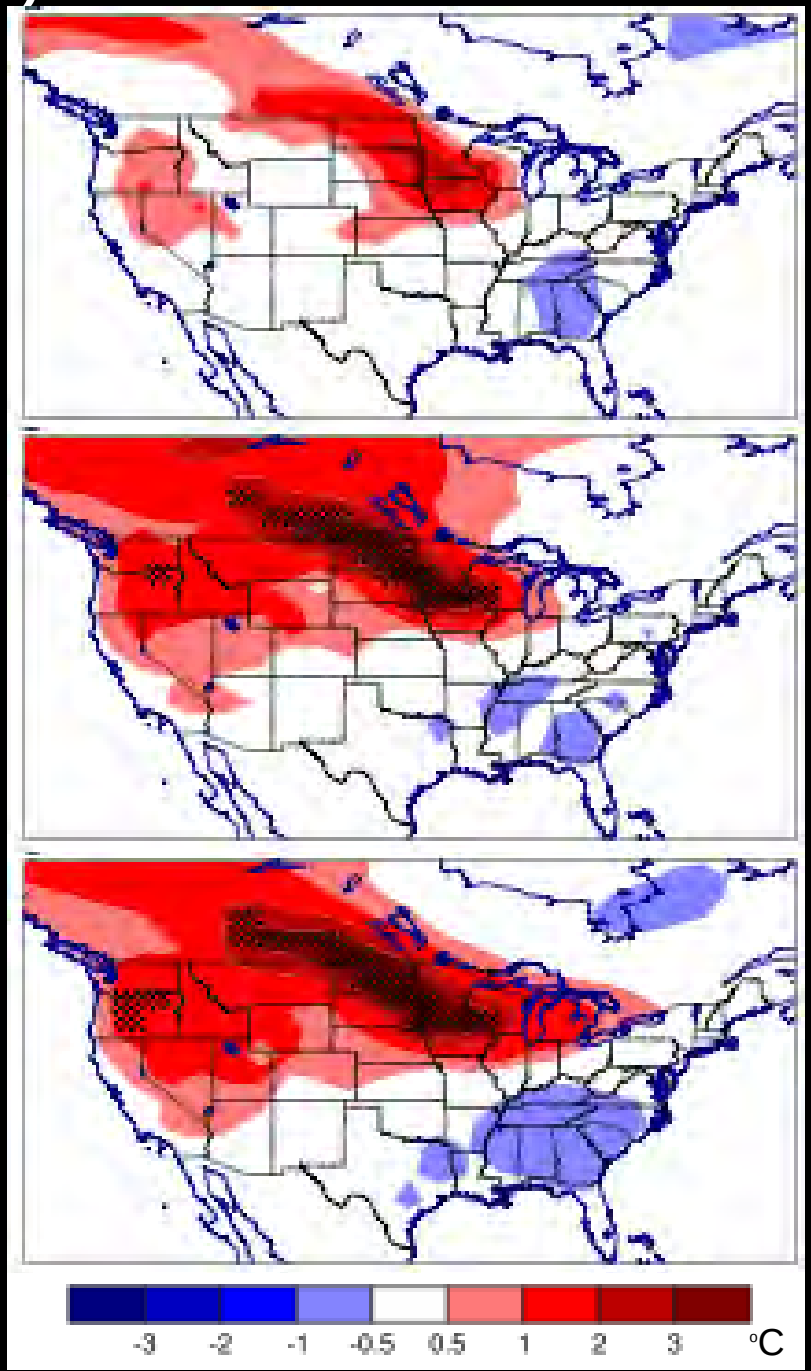


Change in Winter Surface Temperature (°C)

Tall, Sparse:
LAI = 1
Height = 50 cm

Tall, Leafy:
LAI = 4
Height = 50 cm

Short, Leafy:
LAI = 4
Height = 10 cm



LUMIP Goals and Activities

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
- Impacts from land-cover change vs land management
- Modulation of land use impact on climate by land-atmosphere coupling strength (LS3MIP)
- Modulation of global CO_2 fertilization by LULCC
- Direct vs indirect carbon consequences of LULCC
- *Total radiative forcing from LULCC*
- *Scale issues*
- *Fragmentation of forests*

CMIP6 Questions: How does Earth System respond to forcing?

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

LUMIP Goals and Activities

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?

- Update land use datasets and define new model output requests, including subgrid variables on land use tiles
- Design a set of experiments that isolate, quantify, and understand land use and land management effects on climate
- Coordinate analyses and develop new metrics to assess/quantify model performance with respect to land use impacts on climate

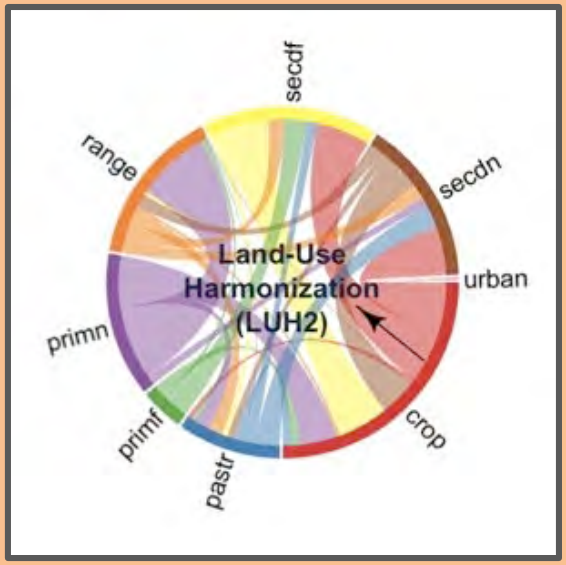
Land Use Harmonization Dataset (LUHv2)

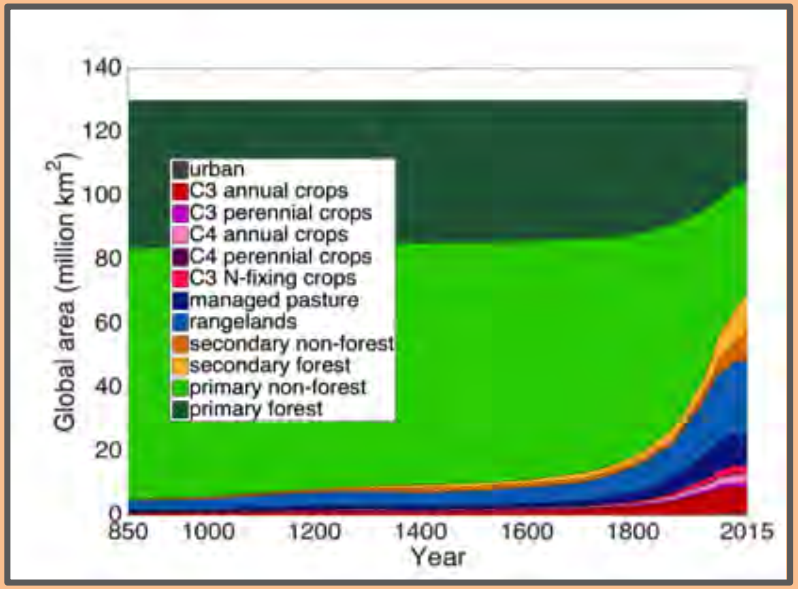
Hurtt et al., in review

0.25° resolution
850 to 2100

New History

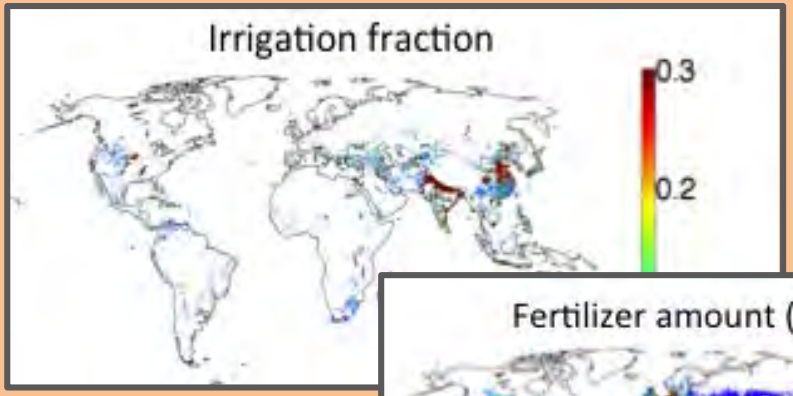
Hyde 4-based
Landsat F/NF constraint
Multiple crop types (5)
Multiple pasture types (2)
Updated forest cover/
biomass
Updated wood harvest
Updated shifting cultivation

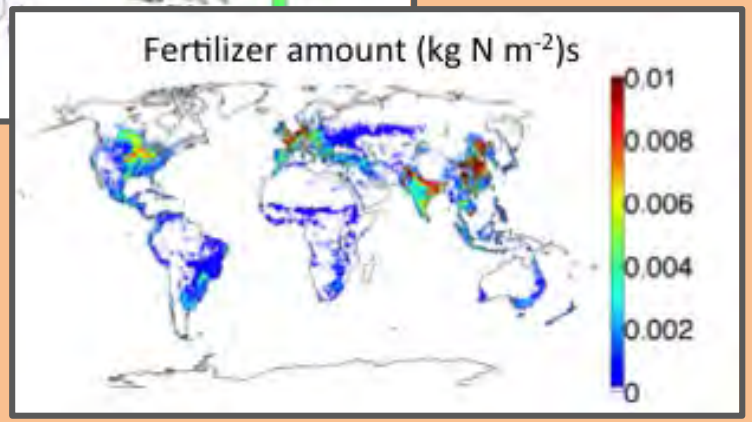




New Management Layers

<u>Agriculture</u>
% cropland irrigated
% cropland flooded
% cropland fertilized (industrial)
Industrial Fertilizer application rates
% cropland for biofuels
Crop rotations



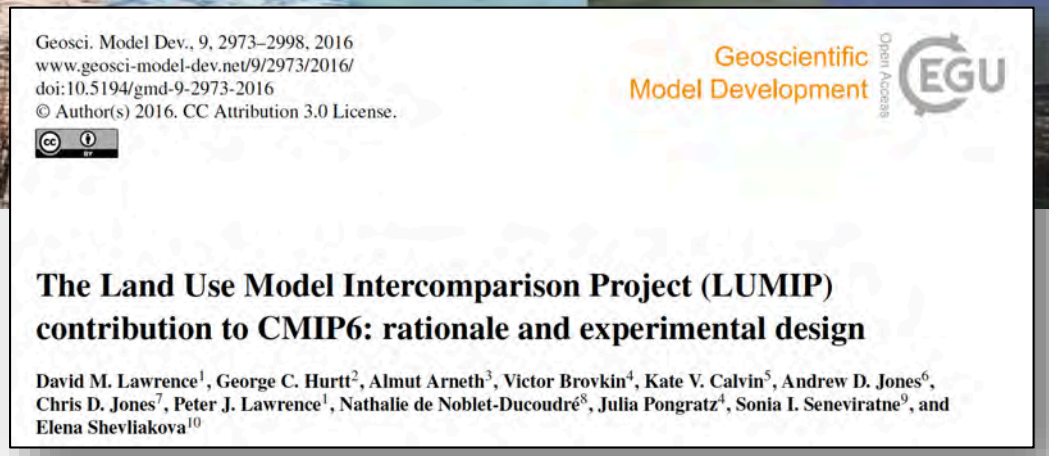


<u>Wood Harvest</u>
% used for industrial products
% used for commercial biofuels
% used for fuelwood

Supported by DOE-SciDAC

The LUMIP Experimental Design

Clarifications/corrections at https://cmip.ucar.edu/lumip



Geosci. Model Dev., 9, 2973–2998, 2016
www.geosci-model-dev.net/9/2973/2016/
doi:10.5194/gmd-9-2973-2016

Geoscientific Model Development
Open Access
EGU

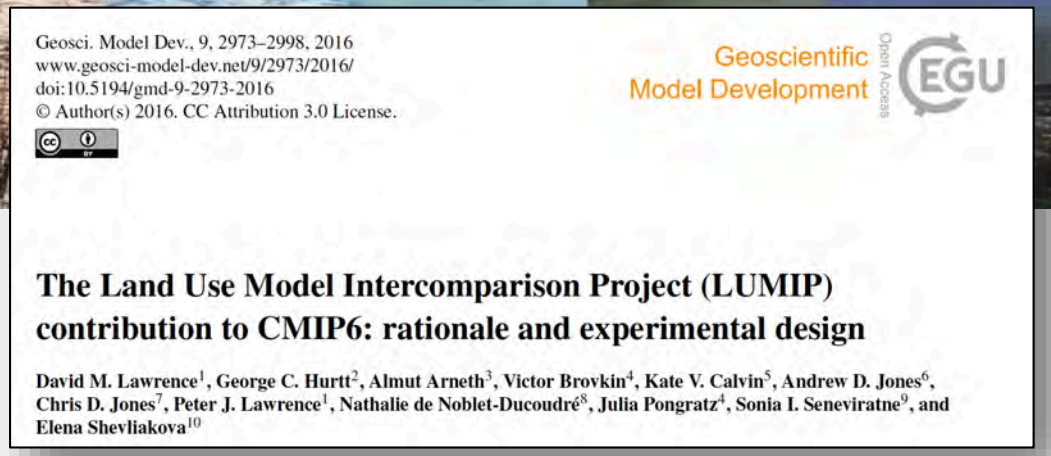
The Land Use Model Intercomparison Project (LUMIP) contribution to CMIP6: rationale and experimental design

David M. Lawrence[1], George C. Hurtt[2], Almut Arneth[3], Victor Brovkin[4], Kate V. Calvin[5], Andrew D. Jones[6], Chris D. Jones[7], Peter J. Lawrence[1], Nathalie de Noblet-Ducoudré[8], Julia Pongratz[4], Sonia I. Seneviratne[9], and Elena Shevliakova[10]

Tier 1

- Idealized deforestation (10 million km2 removal of forest over 50 years)
- Historical no land use change (coupled and land-only)

The LUMIP Experimental Design


Geosci. Model Dev., 9, 2973–2998, 2016
www.geosci-model-dev.net/9/2973/2016/
doi:10.5194/gmd-9-2973-2016

Geoscientific Model Development
Open Access
EGU

The Land Use Model Intercomparison Project (LUMIP) contribution to CMIP6: rationale and experimental design

David M. Lawrence[1], George C. Hurtt[2], Almut Arneth[3], Victor Brovkin[4], Kate V. Calvin[5], Andrew D. Jones[6], Chris D. Jones[7], Peter J. Lawrence[1], Nathalie de Noblet-Ducoudré[8], Julia Pongratz[4], Sonia I. Seneviratne[9], and Elena Shevliakova[10]

Clarifications/corrections at https://cmip.ucar.edu/lumip

Tier 1

- Idealized deforestation (10 million km2 removal of forest over 50 years)
- Historical no land use change (coupled and land-only)
- Alternative land use scenarios for projection periods (concentration and emissions-driven) – e.g., use SSP1-2.6 land use in SSP3-7 simulation

Tier 2

- Additional ensemble members (historical, idealized deforest, SSPs)
- Land management factorial (land-only)

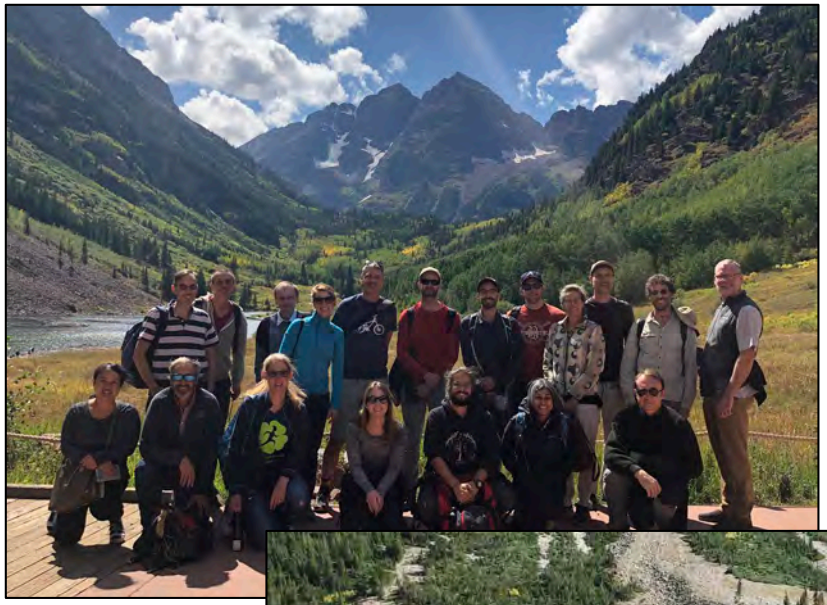
LUMIP Simulations available on ESGF
(as of Friday, December 6)

https://pcmdi.llnl.gov/CMIP6/ArchiveStatistics/esgf_data_holdings/LUMIP/index.html

model	# of experiments	deforest-globe	esm-ssp585-ssp126Lu	hist-noLu	land-cCO2	land-cClim	land-crop-noFert	land-hist	land-hist-altStartYear	land-noFire	land-noLu	ssp126-ssp370Lu	ssp370-ssp126Lu
# of models	54	5	4	6	3	2	1	7	3	1	6	8	8
BCC-CSM2-MR	7	155	156	156				41			41	150	154
CESM2	11	1230	180	1301	172	172	172		24	172	161	1301	1307
CMCC-ESM2-SR5	2							139			139		
CNRM-CM6-1	1							153					
CNRM-ESM2-1	9	334		334	151	151		229	152		151	333	332
CanESM5	4	342	342									343	343
GFDL-ESM4	7		61	60				29	31		31	65	64
GISS-E2-1-G	1							795					
IPSL-CM6A-LR	7	1366		1884	163			208			205	456	458
MIROC-ES2L	2											255	255
UKESM1-0-LL	3			716								178	178

LUMIP workshop – Aspen Global Change Institute

Impacts of Land Use and Land Management on Earth System Evolution, Biogeochemical Cycles, Extremes and Inter-Sectoral Dynamics, September 16-20, 2019



Sessions on:

- State of knowledge of historic LULCC, impacts on climate and biogeochemical cycles
- Progress reports and planning on LUMIP analyses
- Connections with multi-sector dynamics and societal impacts including implications of land use/land management on water and food security

ASPEN GLOBAL CHANGE INSTITUTE

U.S. DEPARTMENT OF ENERGY

NOAA

NASA

LUMIP Analysis Plans

Access from LUMIP webpage (cmip.ucar.edu/lumip)

LUMIP simulations will be available to anyone who registers for access to CMIP6 data. Below is a list of planned analysis projects. Please add your proposed analysis following the format provided. We recommend that you try to work with other research groups with similar analysis interests to develop projects that are complementary and that minimize overlap. The LUMIP leads are happy to help organize.

Resources

Full list of CMIP6 experiments:

http://rawgit.com/WCRP-CMIP/CMIP6_CVs/master/src/CMIP6_experiment_id.html
(search for LUMIP to get list of specific LUMIP experiments)

LUMIP experimental description paper:

http://www.geosci-model-dev.net/9/2973/2016/

Project Title: Climate response to idealized deforestation

Project participants: Victor Brovkin (victor.brovkin@mpimet.mpg.de), David Lawrence, et al.

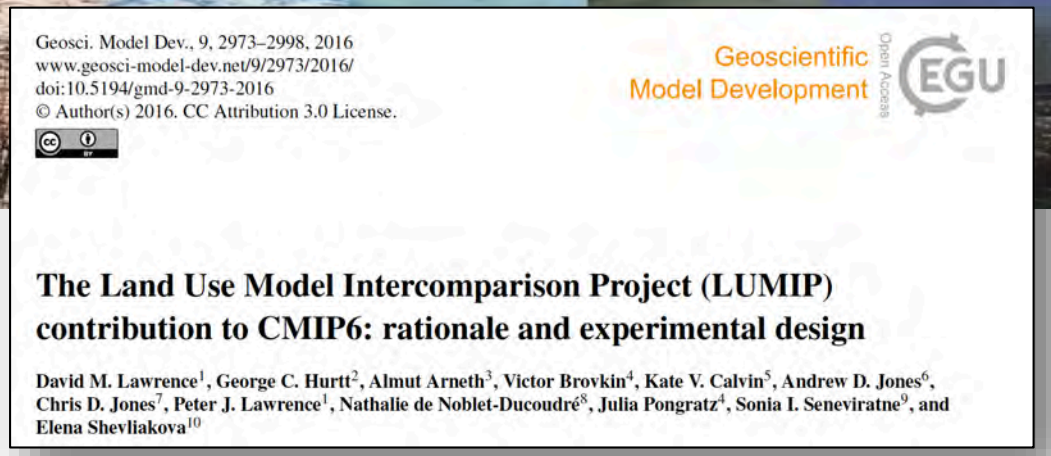
LUMIP / CMIP6 simulations used: deforest-globe, piControl

Brief Project Description: Assess global and regional temperature and precipitation response across models to idealized deforestation. Data from piControl will be used to establish internal variability.

25+ analysis plans (papers) have been registered

The LUMIP Experimental Design

Clarifications/corrections at https://cmip.ucar.edu/lumip



Geosci. Model Dev., 9, 2973–2998, 2016
www.geosci-model-dev.net/9/2973/2016/
doi:10.5194/gmd-9-2973-2016

Geoscientific Model Development
Open Access
EGU

The Land Use Model Intercomparison Project (LUMIP) contribution to CMIP6: rationale and experimental design

David M. Lawrence[1], George C. Hurtt[2], Almut Arneth[3], Victor Brovkin[4], Kate V. Calvin[5], Andrew D. Jones[6], Chris D. Jones[7], Peter J. Lawrence[1], Nathalie de Noblet-Ducoudré[8], Julia Pongratz[4], Sonia I. Seneviratne[9], and Elena Shevliakova[10]

Tier 1

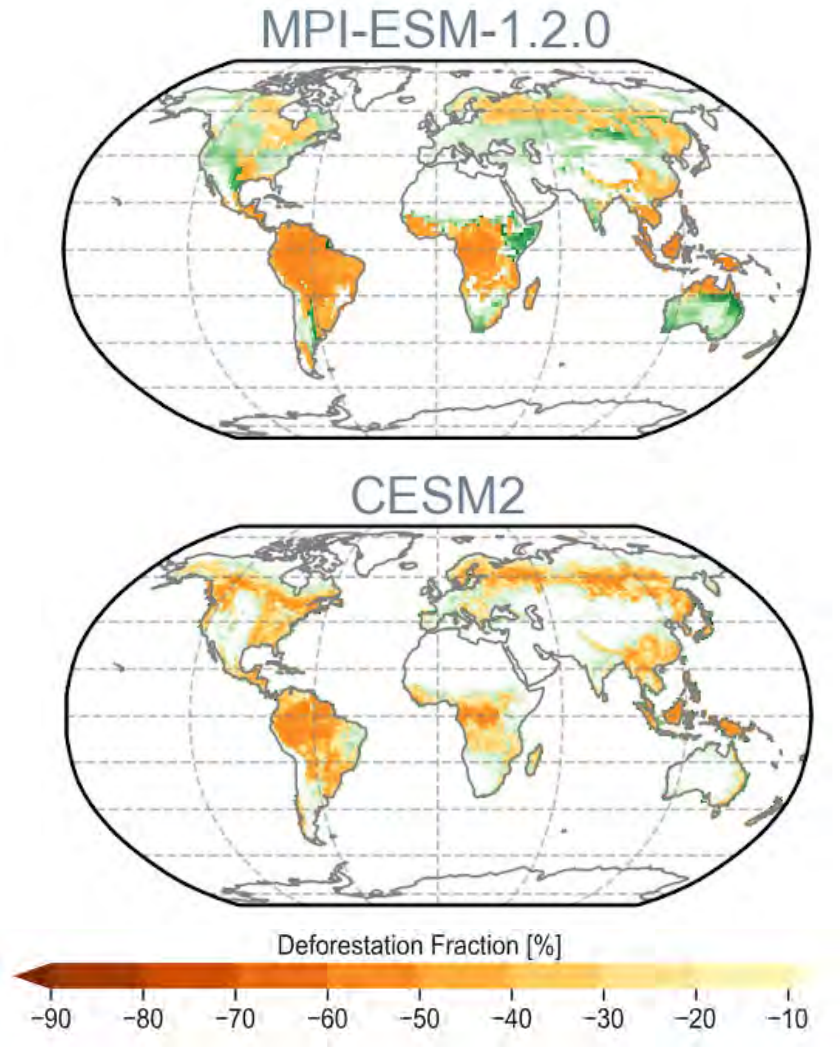
- **Idealized deforestation (10 million km^2 removal of forest over 50 years)**
- Historical no land use change (coupled and land-only)
- Alternative land use scenarios for projection periods (concentration and emissions-driven) – e.g., use SSP1-2.6 land use in SSP3-7 simulation

Tier 2

- Additional ensemble members (historical, idealized deforest, SSPs)
- Land management factorial (land-only)

Climate response to Idealized Deforestation (deforest-globe)

deforest-globe: Remove 10 million km2 of forest over 50 years from top 20% forested cells

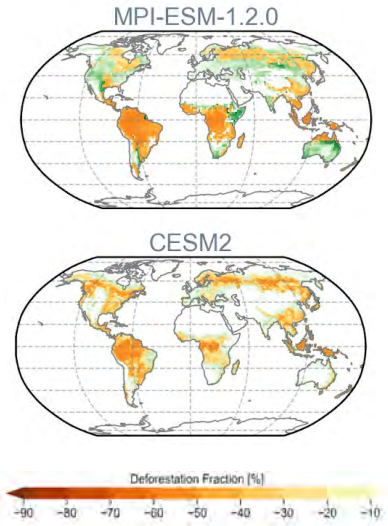


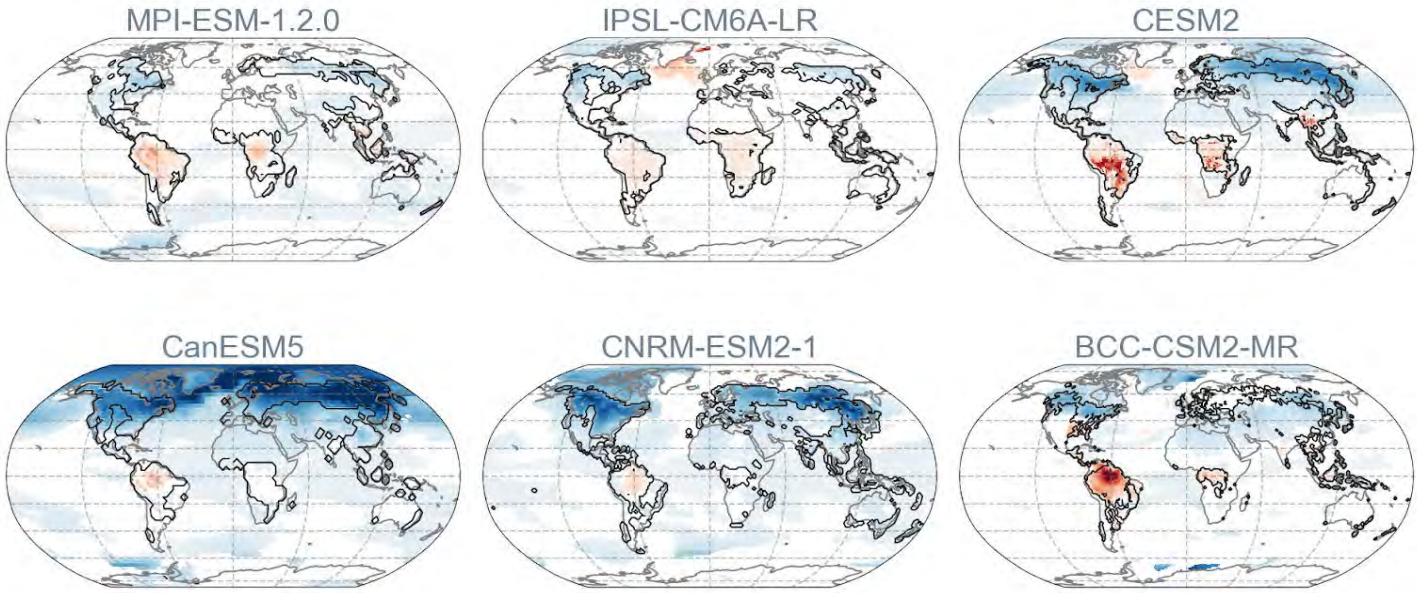
Reasonably similar deforestation patterns across models

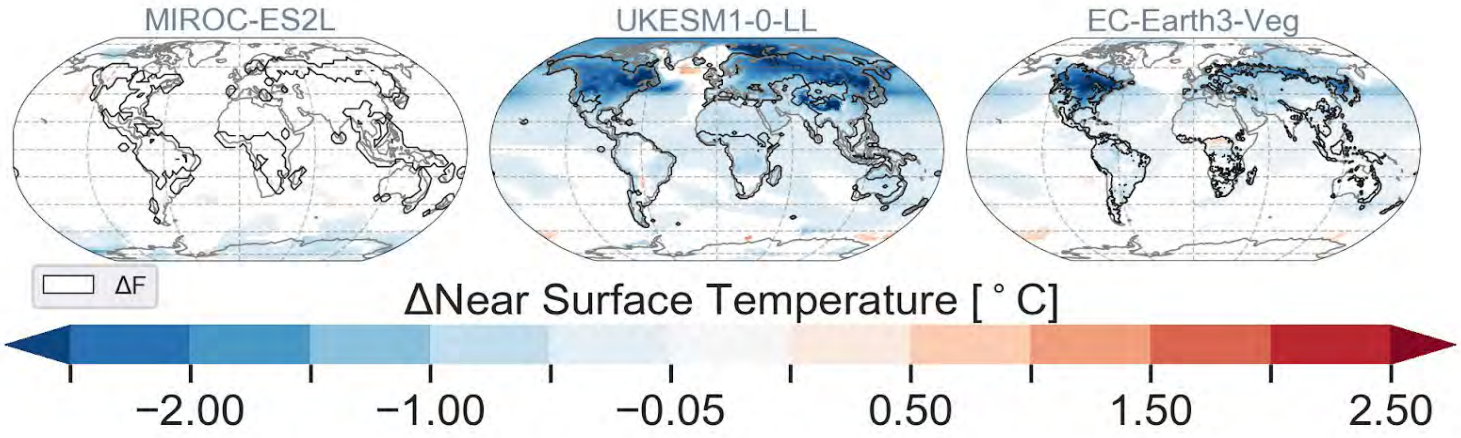
Boysen et al., in prep

Climate response to Idealized Deforestation

deforest-globe: Remove 10 million km^2 of forest over 50 years from top 20% forested cells





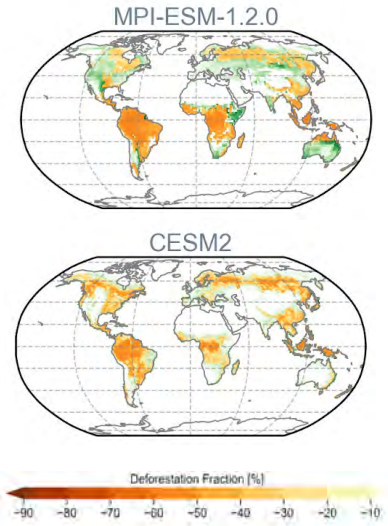


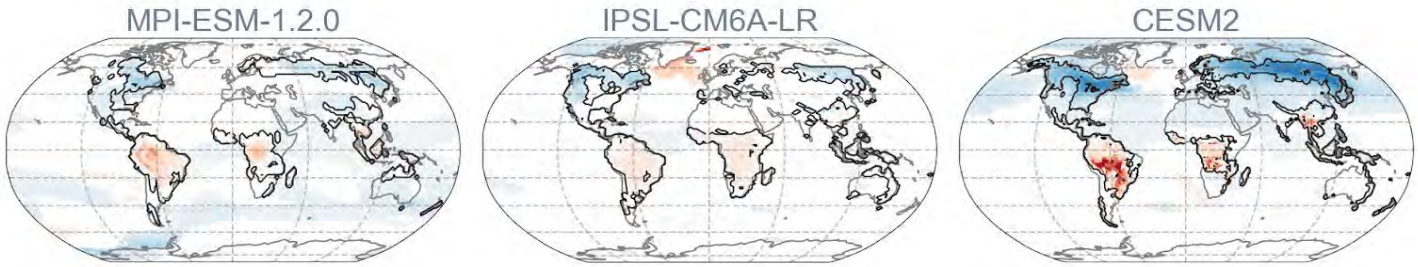
- Broad agreement of cooling across boreal forests
- Most (but not all) models show warming in the Tropics

Boysen et al., in prep

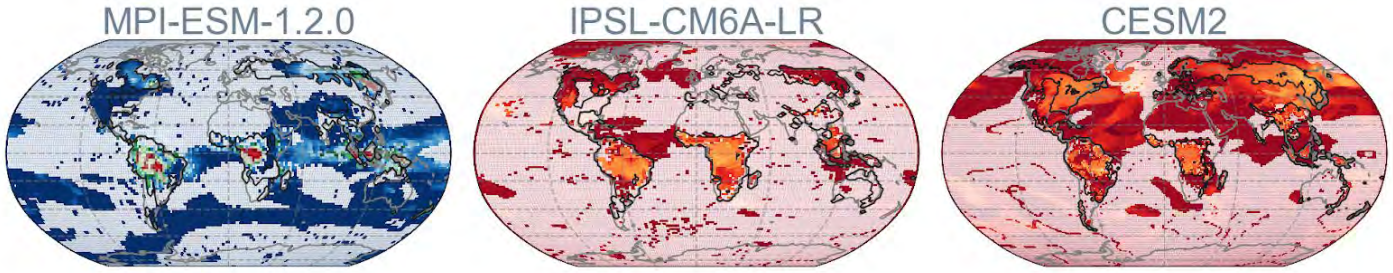
Climate response to Idealized Deforestation (deforest-globe)

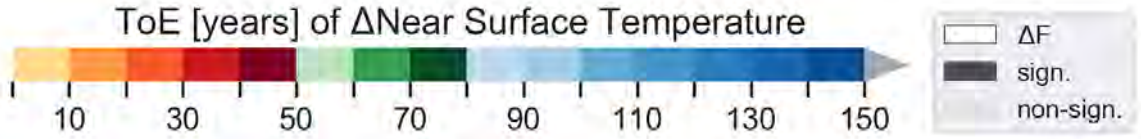
deforest-globe: Remove 10 million km2 of forest over 50 years from top 20% forested cells





Time of signal Emergence

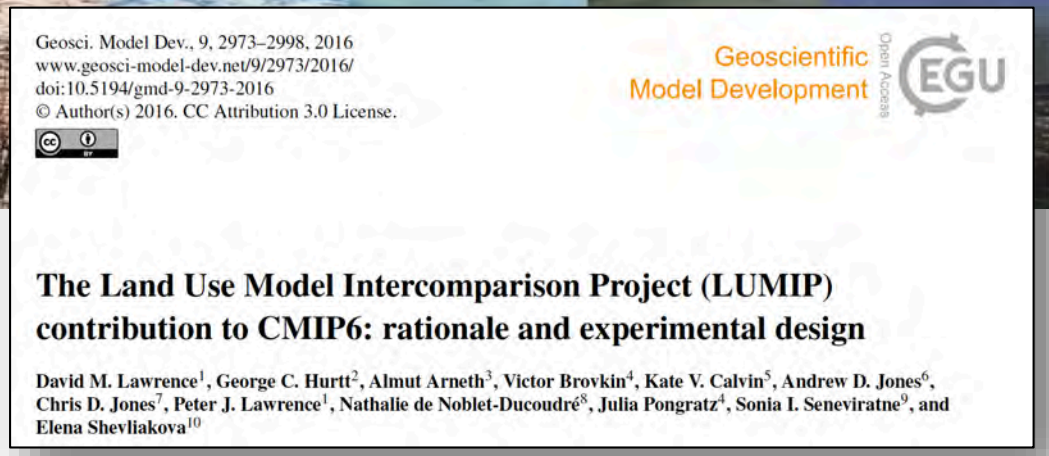




Boysen et al., in prep

The LUMIP Experimental Design

Clarifications/corrections at https://cmip.ucar.edu/lumip



Geosci. Model Dev., 9, 2973–2998, 2016
www.geosci-model-dev.net/9/2973/2016/
doi:10.5194/gmd-9-2973-2016

Geoscientific Model Development
Open Access
EGU

The Land Use Model Intercomparison Project (LUMIP) contribution to CMIP6: rationale and experimental design

David M. Lawrence[1], George C. Hurtt[2], Almut Arneth[3], Victor Brovkin[4], Kate V. Calvin[5], Andrew D. Jones[6], Chris D. Jones[7], Peter J. Lawrence[1], Nathalie de Noblet-Ducoudré[8], Julia Pongratz[4], Sonia I. Seneviratne[9], and Elena Shevliakova[10]

Tier 1

- Idealized deforestation (10 million km^2 removal of forest over 50 years)
- **Historical no land use change (coupled and land-only)**
- Alternative land use scenarios for projection periods (concentration and emissions-driven) – e.g., use SSP1-2.6 land use in SSP3-7 simulation

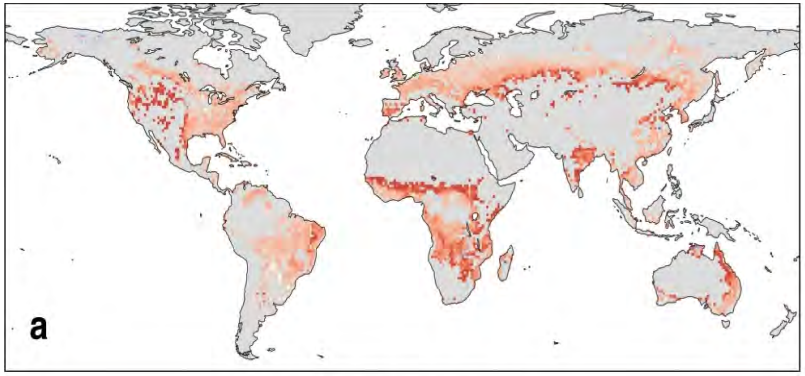
Tier 2

- Additional ensemble members (historical, idealized deforest, SSPs)
- Land management factorial (land-only)

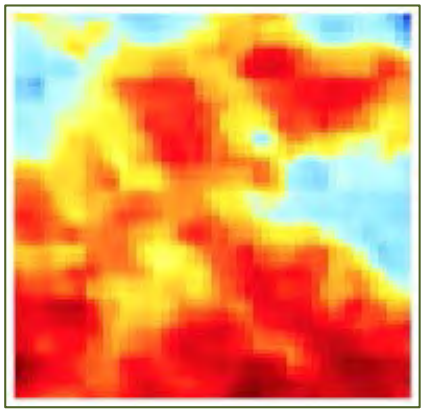
Evaluating and understanding model responses to land-cover change

"Space-for-change method"

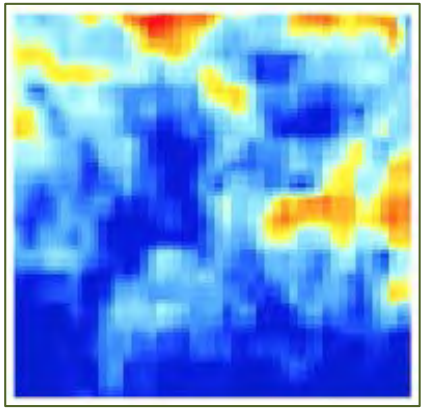
△Ts, max (MODIS, JJA)

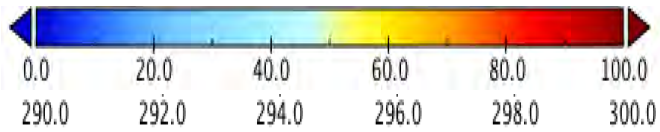


MODIS Ts



Tree cover %

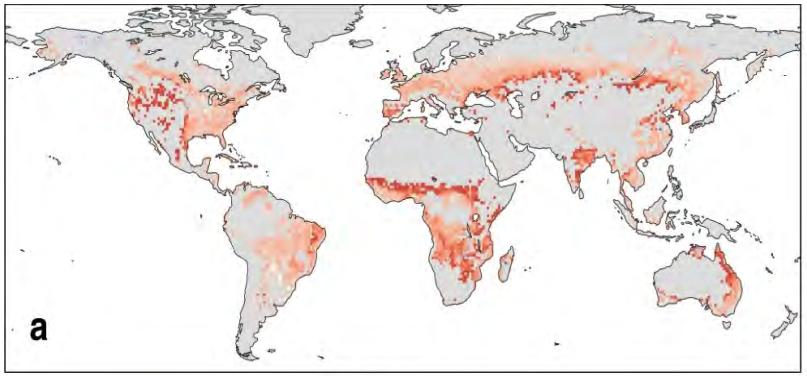




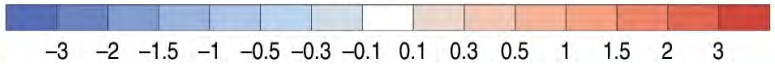
Chen and Dirmeyer, 2020

Observational estimate vs coupled model response to global deforestation in CESM

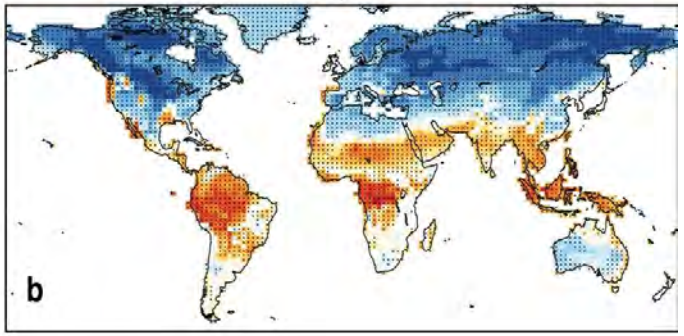
△Ts, max (MODIS, JJA)



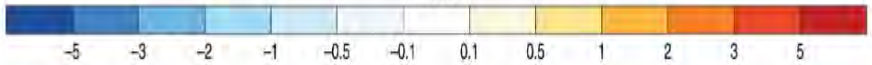
△Ts / △DF Sensitivity of LST (K %$^{-1}$*10)



Coupled (CAM/CLM)



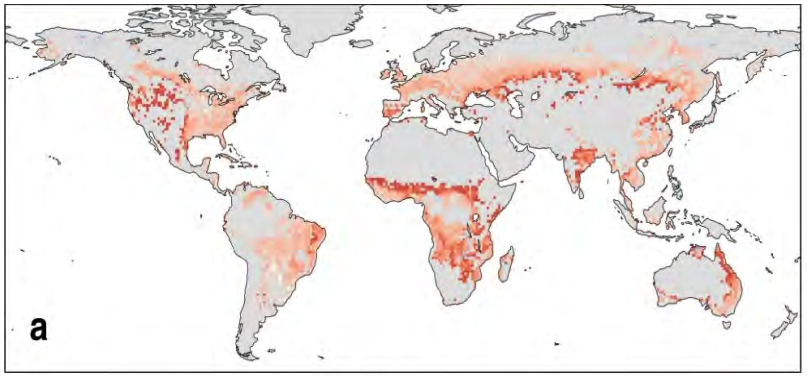
ΔLST (K)



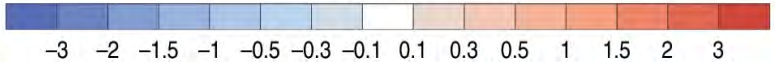
Chen and Dirmeyer, 2020

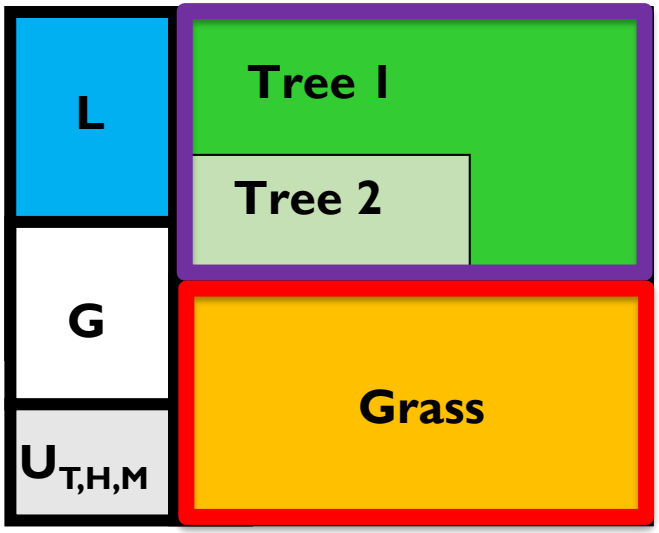
Observational estimate vs coupled model response to global deforestation in CESM

△Ts, max (MODIS, JJA)



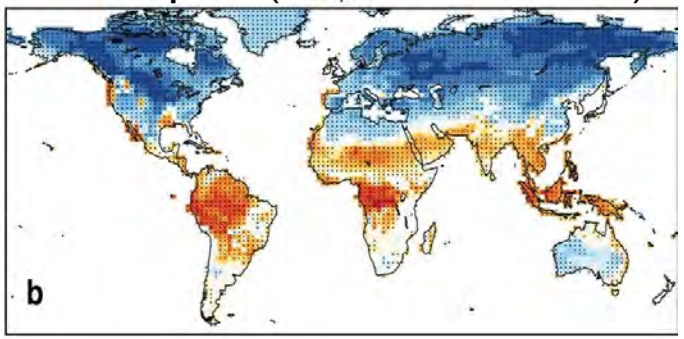
△Ts / △DF Sensitivity of LST (K $\%^{-1}$*10)



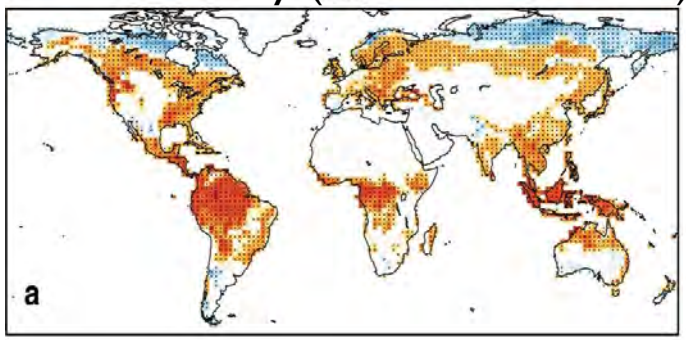


Chen and Dirmeyer, 2020

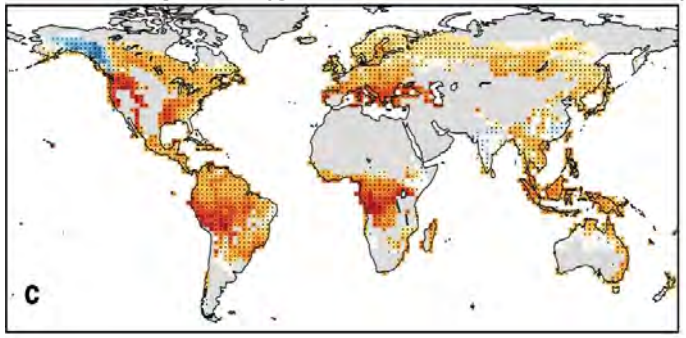
Coupled (deforest – control)



Land-only (deforest – control)

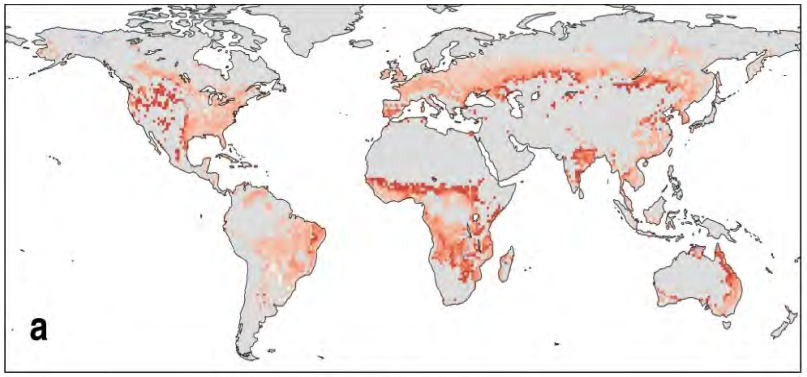


Coupled (grass – tree, deforest)

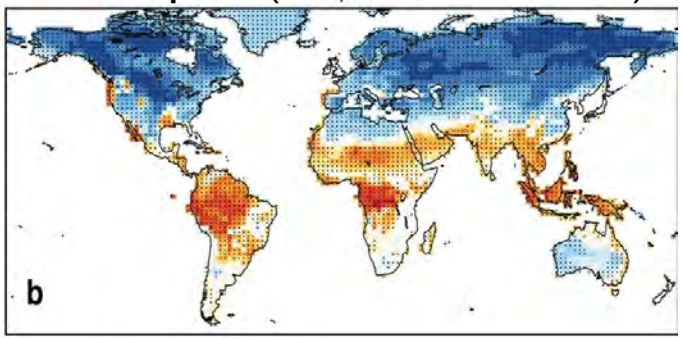


Observational estimate vs coupled model response to global deforestation in CESM

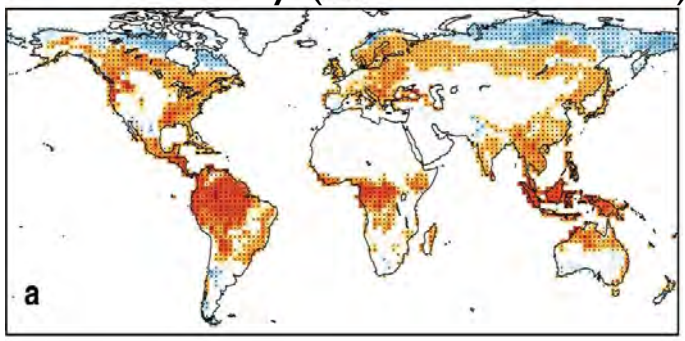
△Ts, max (MODIS, JJA)



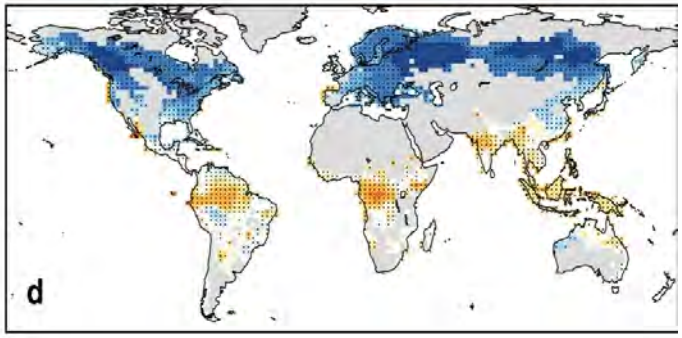
Coupled (deforest – control)



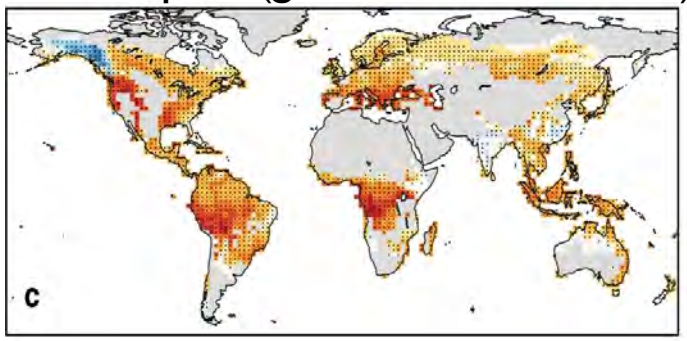
Land-only (deforest – control)



Coupled
(tree deforest – tree control)



Coupled (grass – tree, deforest)

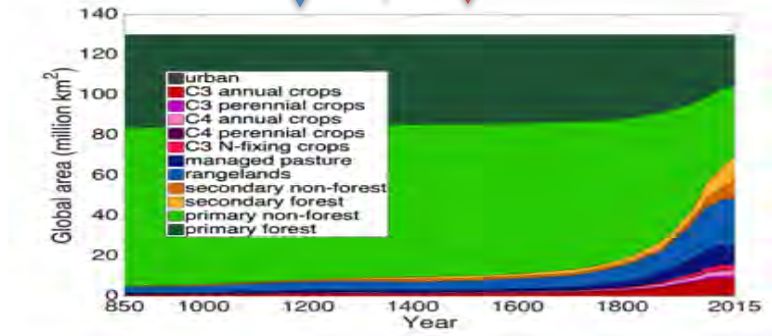


No LULCC experiments: Historic period 1850-2014
Coupled and land-only

All Forcings

CMIP6 Historical

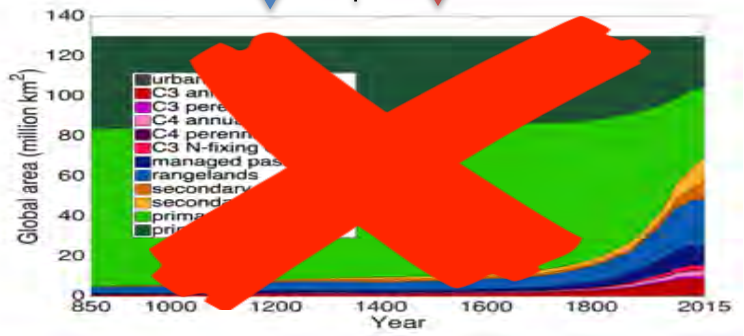
Land-only Historical

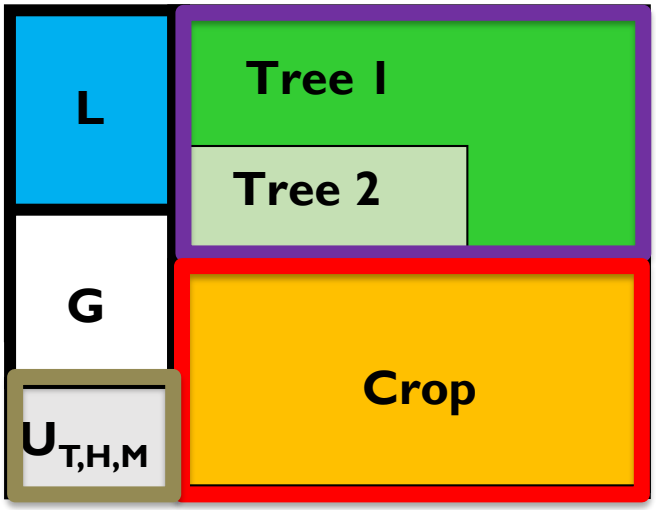


No LULCC

CMIP6 Historical

Land-only Historical

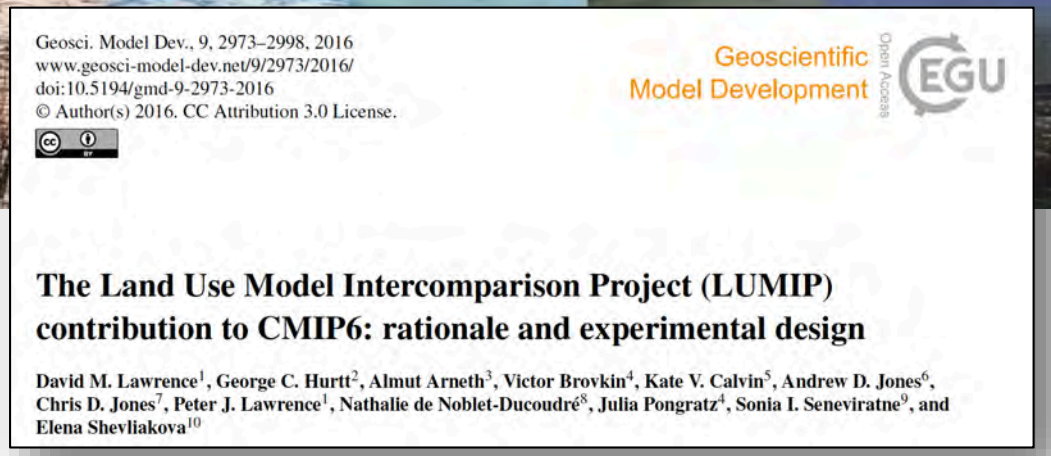




Multi-model exploration in LUMIP

- Availability of coupled/land-only no LULCC experiments as well as subgrid land use data
- Do models disagree due to land response to deforestation or due to atmospheric feedbacks?

The LUMIP Experimental Design


Geosci. Model Dev., 9, 2973–2998, 2016
www.geosci-model-dev.net/9/2973/2016/
doi:10.5194/gmd-9-2973-2016

Geoscientific Model Development
Open Access
EGU

The Land Use Model Intercomparison Project (LUMIP) contribution to CMIP6: rationale and experimental design

David M. Lawrence[1], George C. Hurtt[2], Almut Arneth[3], Victor Brovkin[4], Kate V. Calvin[5], Andrew D. Jones[6], Chris D. Jones[7], Peter J. Lawrence[1], Nathalie de Noblet-Ducoudré[8], Julia Pongratz[4], Sonia I. Seneviratne[9], and Elena Shevliakova[10]

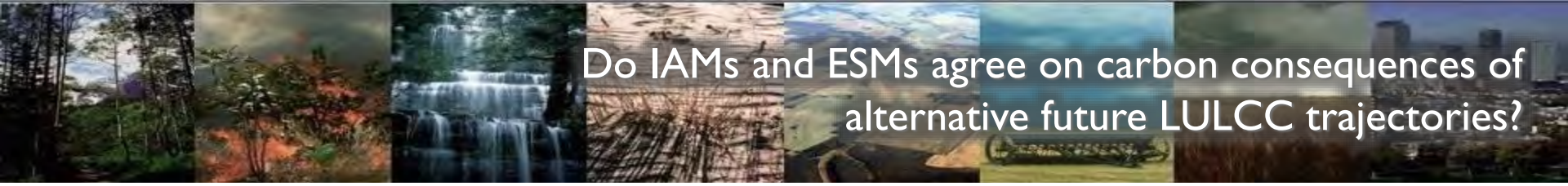
Clarifications/corrections at https://cmip.ucar.edu/lumip

Tier 1

- Idealized deforestation (10 million km^2 removal of forest over 50 years)
- Historical no land use change (coupled and land-only)
- **Alternative land use scenarios for projection periods (concentration and emissions-driven) – e.g., use SSP1-2.6 land use in SSP3-7 simulation**

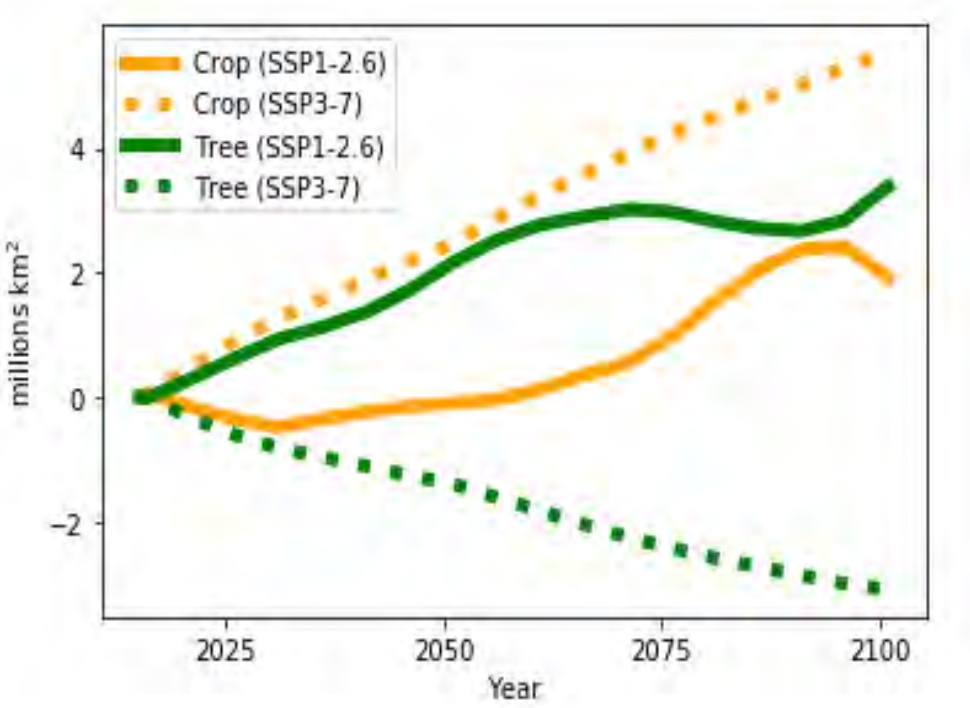
Tier 2

- Additional ensemble members (historical, idealized deforest, SSPs)
- Land management factorial (land-only)



Do IAMs and ESMs agree on carbon consequences of alternative future LULCC trajectories?

Land-cover trajectories for SSP1-2.6 and SSP3-7

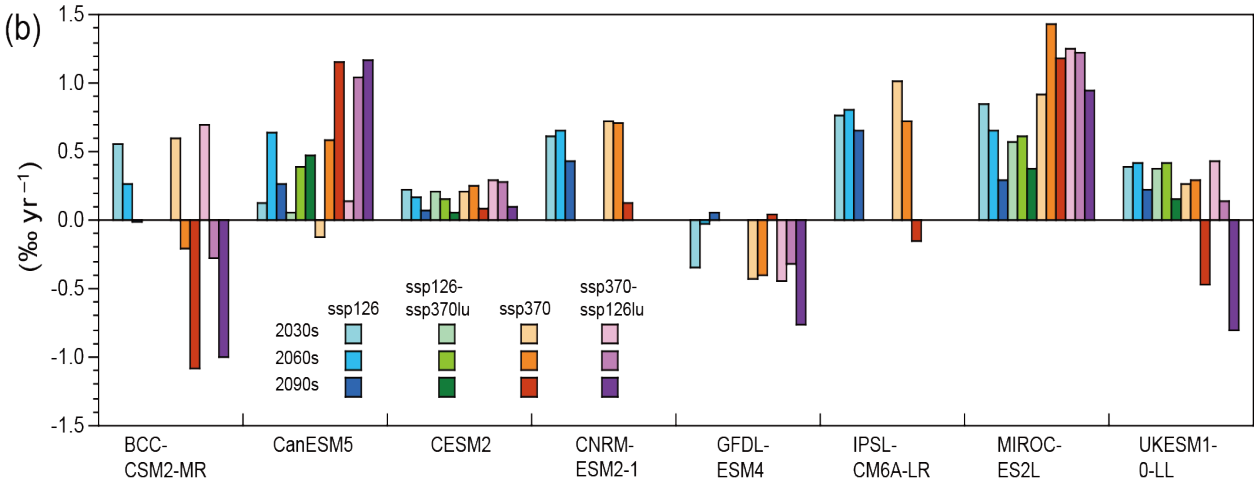


SSP1-2.6 (———)
Sustainability – Taking the Green Road (Low challenges to mitigation and adaptation)

SSP3-7 (▪▪▪▪▪▪)
Regional Rivalry – A Rocky Road (High challenges to mitigation and adaptation)

Soil carbon sequestration simulated in the LUMIP models (Implications for the 4 per 1000 initiative)

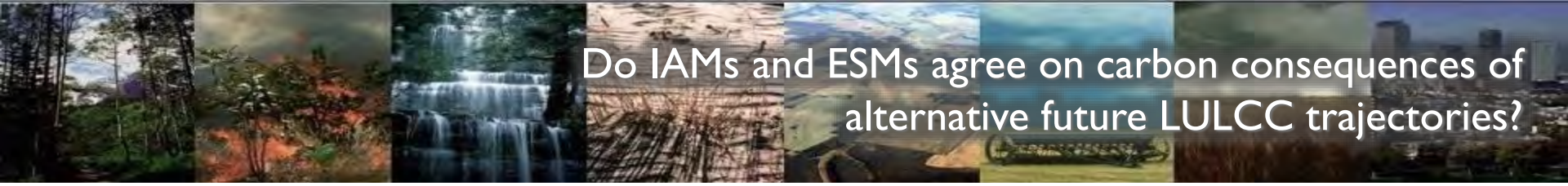
% yr^{-1} change in soil carbon stocks



ESM	ssp126-ssp370Lu – ssp126 (Pg C)	ssp370-ssp126Lu – ssp370 (Pg C)
BCC-CSM2-MR		9.1
CanESM5	-17.4	26.3
CESM2	-4.2	9.3
GFDL-ESM4		-4.3
MIROC-ES2L	-7.0	1.2
UKESM1-0-LL	4.6	-14.1

- Models don't agree on implications of alternative LULCC trajectories
- Weak indication that afforestation (SSP1-2.6) drives increased soil carbon stocks and deforestation (SSP3-7) results in decreased soil carbon stocks, though not all models agree

Ito et al., submitted



Do IAMs and ESMs agree on carbon consequences of alternative future LULCC trajectories?

C Impact of SSP1-2.6Lu vs SSP3-7Lu

IAM projections of accumulated land C

IMAGE SSP1-2.6 : +27 Pg C

AIM SSP3-7: -98 Pg C

+125 Pg C

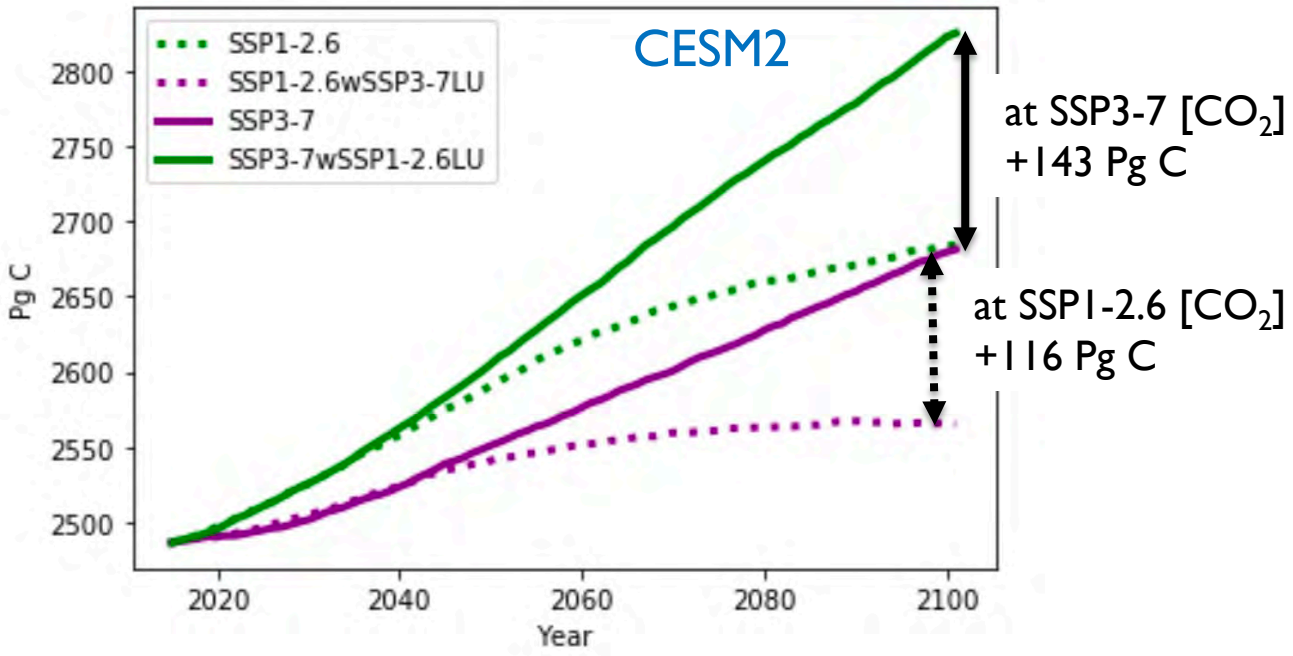
Impact of SSP1-2.6Lu vs SSP3-7Lu

IAMs +125 Pg C

CESM2 +143 Pg C at SSP3-7 [CO_2]

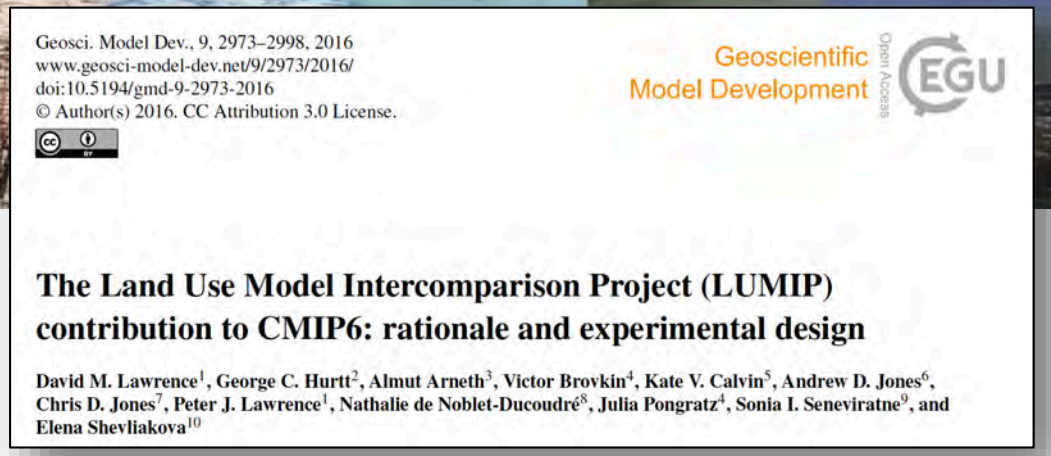
+116 Pg C at SSP1-2.6 [CO_2]

Good news: Model is broadly consistent with IAM expectations, other models?



Lawrence et al., in prep

The LUMIP Experimental Design


Geosci. Model Dev., 9, 2973–2998, 2016
www.geosci-model-dev.net/9/2973/2016/
doi:10.5194/gmd-9-2973-2016

Geoscientific Model Development
Open Access
EGU

The Land Use Model Intercomparison Project (LUMIP) contribution to CMIP6: rationale and experimental design

David M. Lawrence[1], George C. Hurtt[2], Almut Arneth[3], Victor Brovkin[4], Kate V. Calvin[5], Andrew D. Jones[6], Chris D. Jones[7], Peter J. Lawrence[1], Nathalie de Noblet-Ducoudré[8], Julia Pongratz[4], Sonia I. Seneviratne[9], and Elena Shevliakova[10]

Clarifications/corrections at https://cmip.ucar.edu/lumip

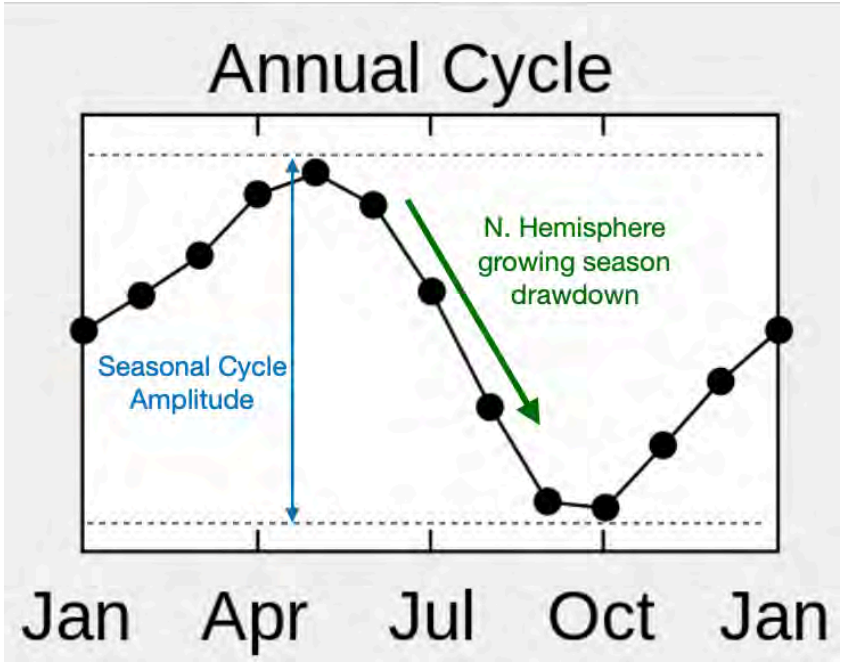
Tier 1

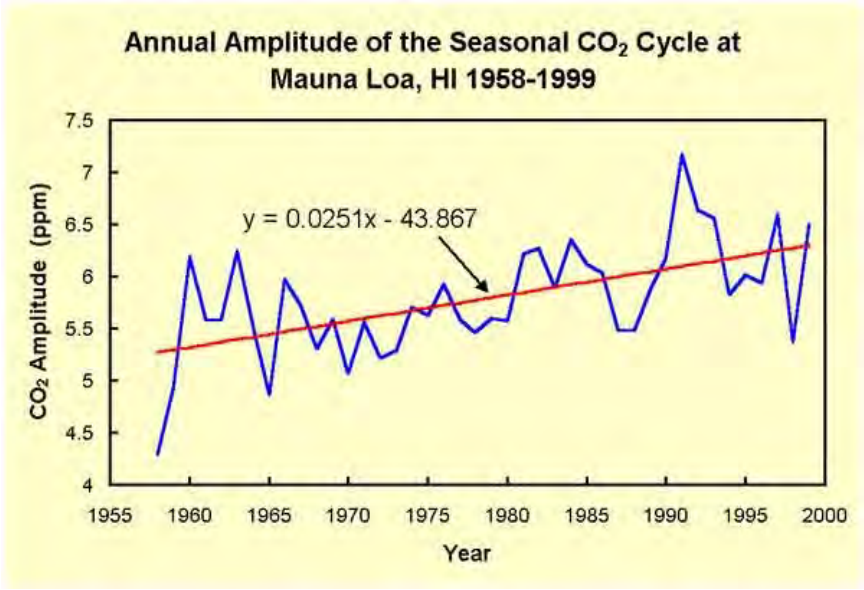
- Idealized deforestation (10 million km^2 removal of forest over 50 years)
- Historical no land use change (coupled and land-only)
- Alternative land use scenarios for projection periods (concentration and emissions-driven) – e.g., use SSP1-2.6 land use in SSP3-7 simulation

Tier 2

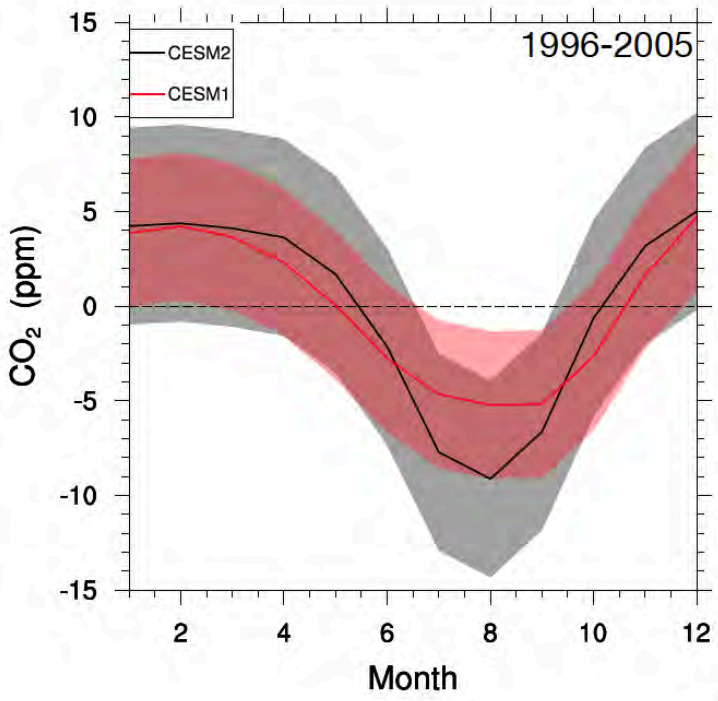
- Additional ensemble members (historical, idealized deforest, SSPs)
- **Land management factorial (land-only)**

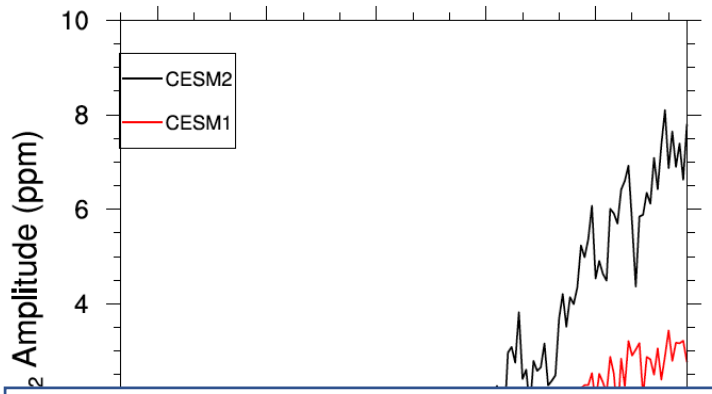
Trends in amplitude of CO_2 annual cycle





CO_2 annual cycle and trend in CESM version





- Amplitude of annual cycle was weak in CESM1 and showed weaker growth than observed
- Both features improved in CESM2

Managed crops

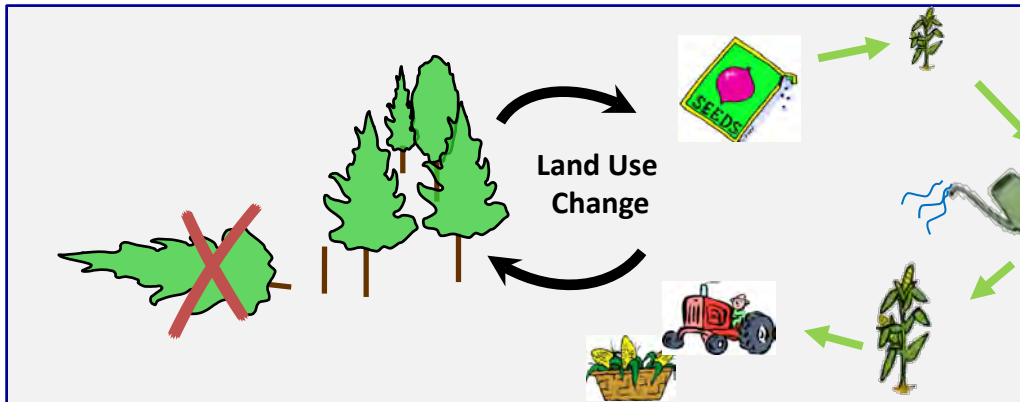
Planting, harvesting, fertilizing, irrigating

* *Temperate and tropical varieties*

Land-only land management experiment

Set of land-only historic (1850 – 2014) simulations with one-at-a-time modification of particular aspects of land management

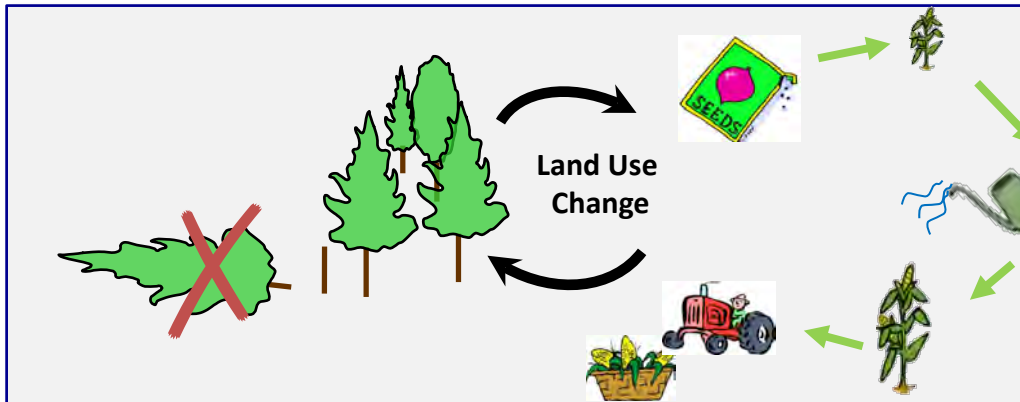
1 Land historical all management
2 Year 1700 instead of 1850 start
3 No LULCC change
4 Alternate land use histories
5 No shifting cultivation
6 Crop and pasture as unmanaged grassland
7 Crops with crop model but no irrigation/fertilization
8 No irrigation
9 No fertilization
10 No wood harvest
11 No grazing on pastureland
12 No human fire ignition/suppression
13 Constant 1850 CO_2
14 Constant 1850 climate



Land-only land management experiment

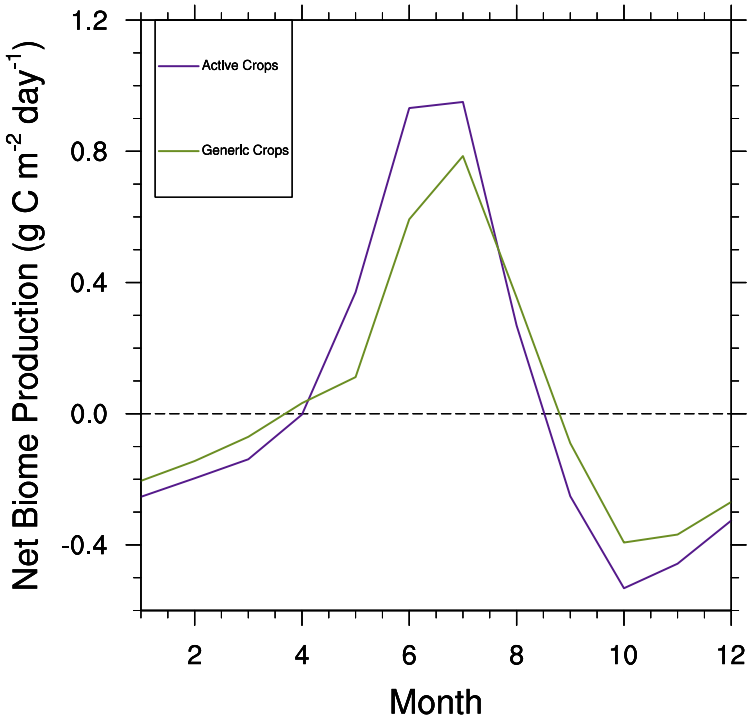
Set of land-only historic (1850 – 2014) simulations with one-at-a-time modification of particular aspects of land management

1 **Land historical all management**
2 Year 1700 instead of 1850 start
3 No LULCC change
4 Alternate land use histories
5 No shifting cultivation
6 **Crop and pasture as unmanaged grassland**
7 Crops with crop model but no irrigation/fertilization
8 **No irrigation**
9 **No fertilization**
10 No wood harvest
11 No grazing on pastureland
12 No human fire ignition/suppression
13 **Constant 1850 CO_2**
14 **Constant 1850 climate**



Crops increase amplitude of Net Biome Production (NBP) annual cyc
Analysis of land management factorial simulation

Community Land Model (CLM5)



Managed crop

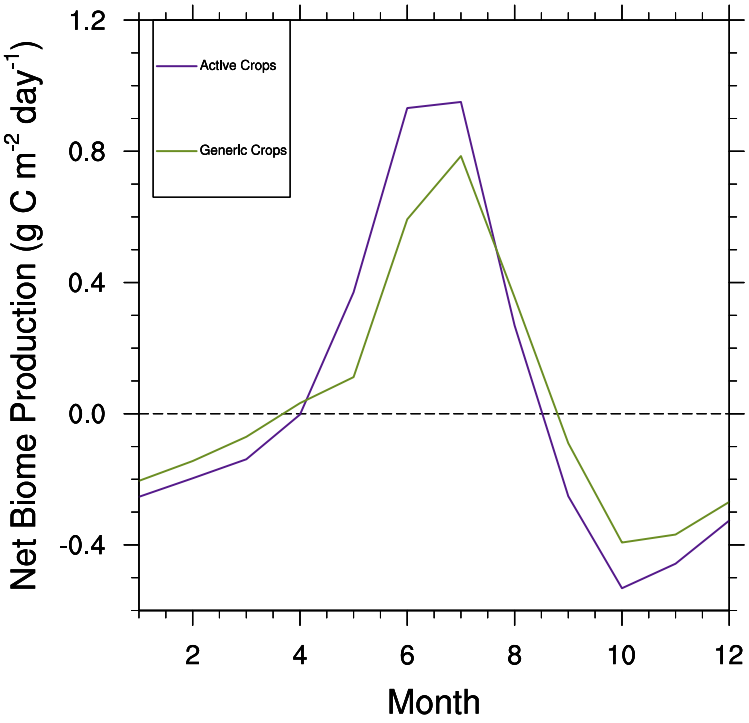
Planted, harvested, irrigated, fertilize

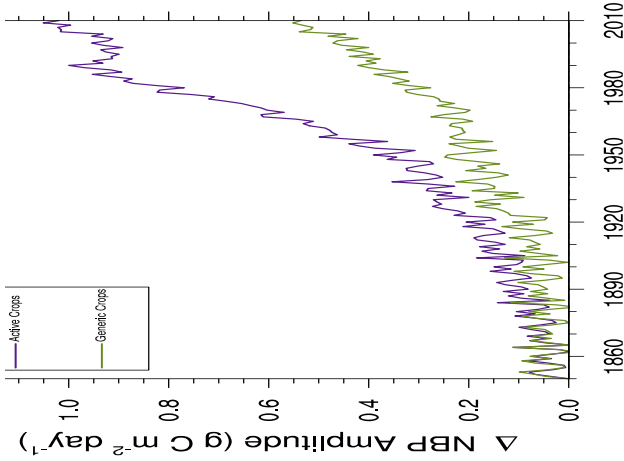
Crop as grassland

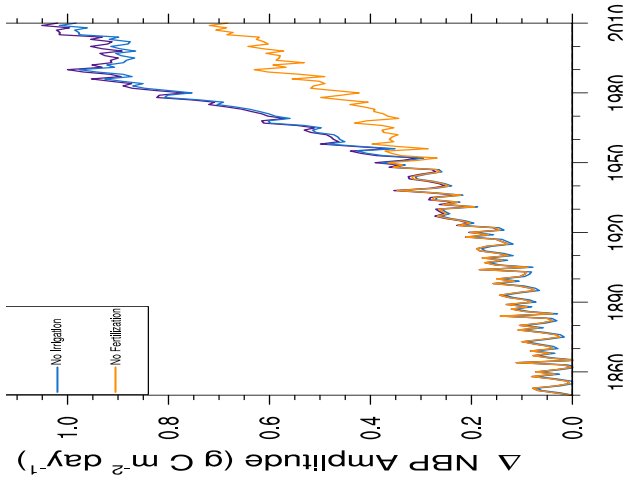
Function as C3 grass

Crops increase amplitude of Net Biome Production (NBP) annual cyc
Analysis of land management factorial simulation

Community Land Model (CLM5)







- Explicit crop representation results in 20% larger amplitude relative to generic crops
- NBP (which impacts atm CO_2) annual amplitude increases twice as much with managed crops by 2010
- Increasing crop area and introduction of industrial fertilizer

- LUMIP simulations from a range of ESMs are complete and available through CMIP6 data portals
- Many planned analyses are underway and are beginning to yield new scientific insight
- If interested in participating, please either contact paper leads or register your own interest for a topic that is not yet planned

LUMI
Land Use Change