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

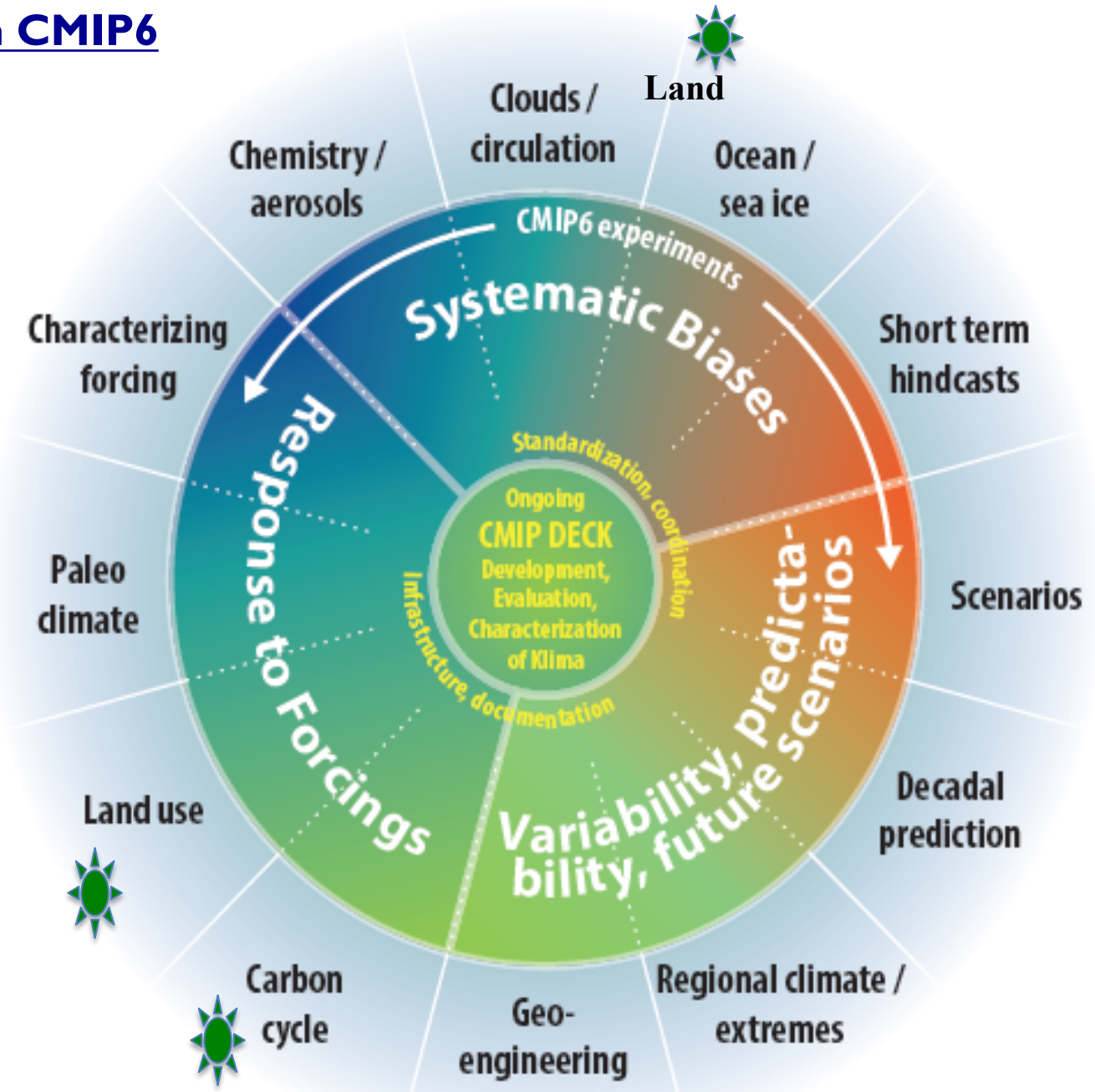
with input from many from Earth System Modeling, Integrated Assessment Modeling, and historical land use communities

https://cmip.ucar.edu/lumip

Terrestrial Processes in CMIP6

Collection of coordinated activities to assess land role in climate and climate change

- **Land Only** simulations forced with obs historical climate
- **Land Use = LUMIP** land use forcing on climate, biogeophysics and biogeochemistry with policy relevance
- **Carbon Cycle = C4MIP** land biogeochemical feedbacks on climate change
- **Land = LS3MIP** land systematic biases and biogeophys feedbacks including soil moisture and snow feedbacks



Adapted from Meehl et al., EOS, 2014

History and timeline

- 2013 Summer: Concept at CMIP6 AGCI meeting
- 2014 Summer: LUMIP proposal development at GEWEX workshop and Hamburg meeting
- 2014 August: AGCI Joint-MIP workshop (ScenarioMIP, AerchemMIP, LUMIP)
- 2014 September: LUMIP proposal submitted to CMIP6 panel
- 2016 LUMIP GMD paper published
- 2017 Sept: Final versions of LUH2 datasets for Historical and SSPs released
- 2018 through 2019: Model simulations
- 2018 Fall: joint LUMIP, C4MIP, LS3MIP meeting
- 2019 Fall: LUMIP-AGCI meeting to present/discuss papers/analysis
- 2019 December 31: Deadline for paper submission for IPCC AR6
- 2021 IPCC AR6

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
- 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 Major Activities

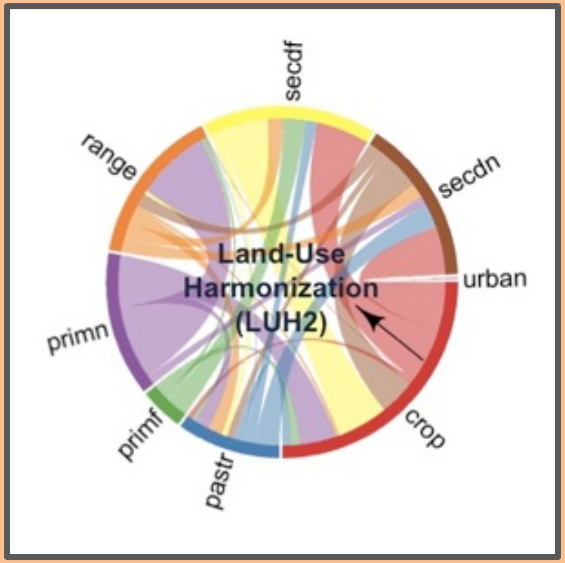
- **Data standardization**
  - Update and enhance historical and future land-use data sets, passing maximum amount of common information between relevant communities (Obs historical, Integrated Assessment Models, Earth System Models)
  - Data output: new variables, subgrid land-use tile variables

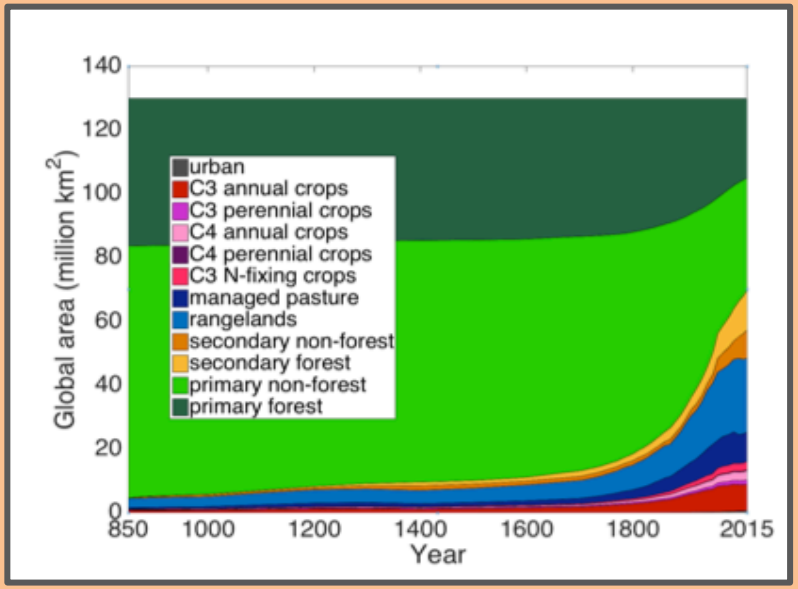
- **Model metrics and diagnostics**
  - Synthesis activity to document existing metrics of LULCC impact on climate
  - Develop new metrics to assess/quantify model performance with respect to land use impacts on climate

- **Model experiments**
  - Experiments designed to isolate, quantify, and understand land use and land management effects on climate and biogeochemical cycles

Land Use Harmonization Dataset (LUHv2)

0.25° resolution
850 to 2100



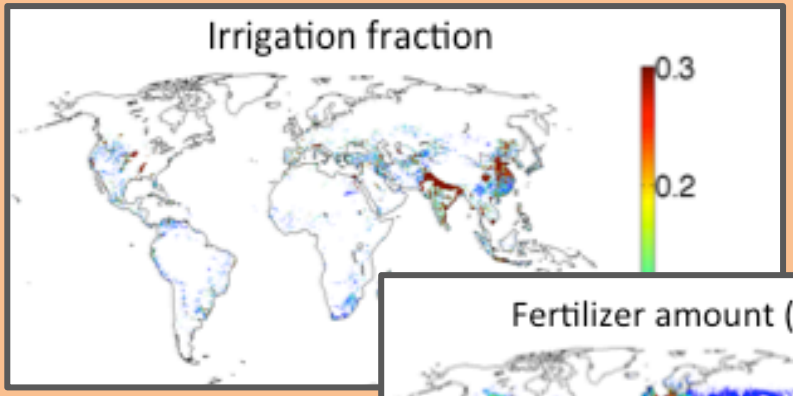


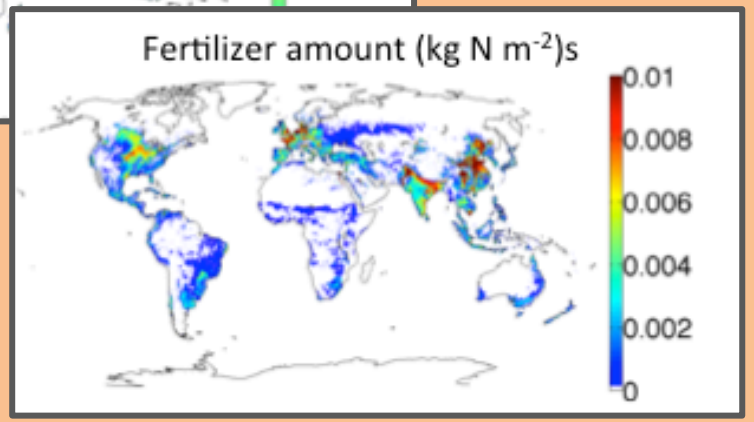
New History

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



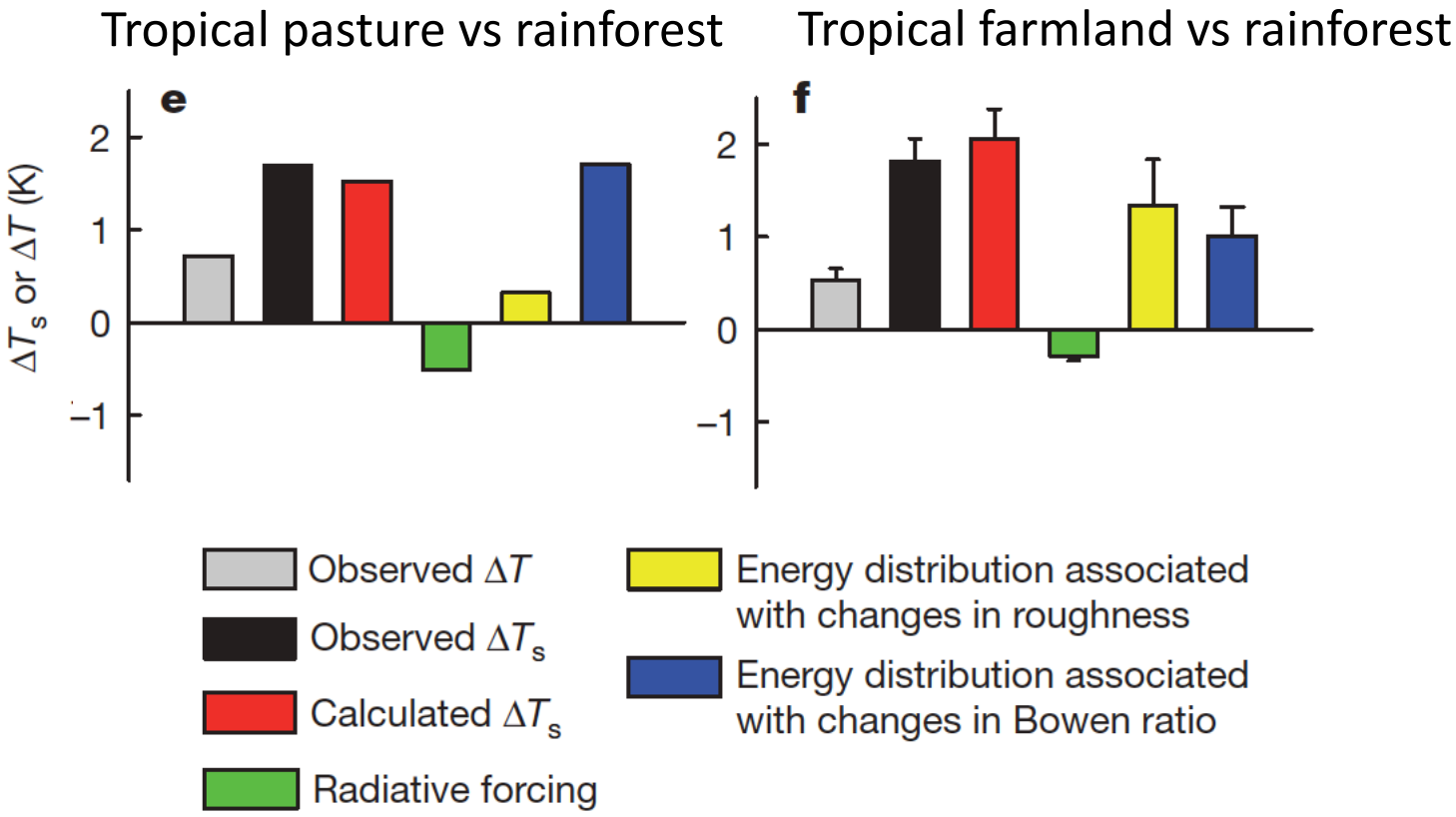


<u>Wood Harvest</u>
% used for industrial products
% used for commercial biofuels
% used for fuelwood

Supported by DOE-SciDAC

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



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

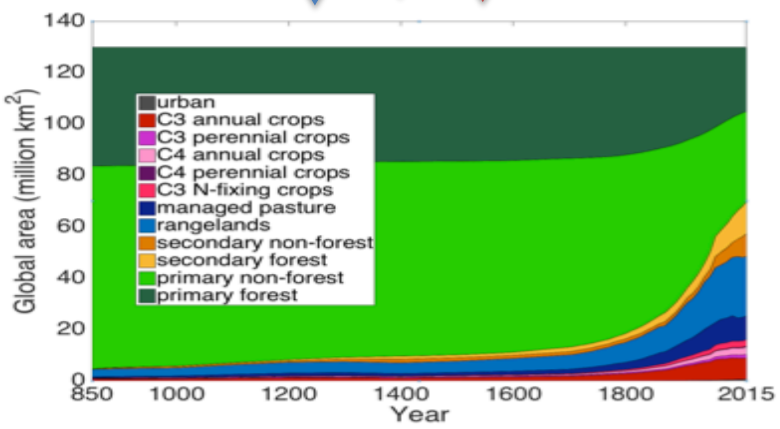
- Idealized deforestation (10 million km2 removal of forest over 50 years)
- Historical no land use change (coupled and land-only)

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

- Assess impact of LULCC in historical period for water, carbon, energy fluxes and climate (C4MIP, LS3MIP)
- Assess land-only vs coupled 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)

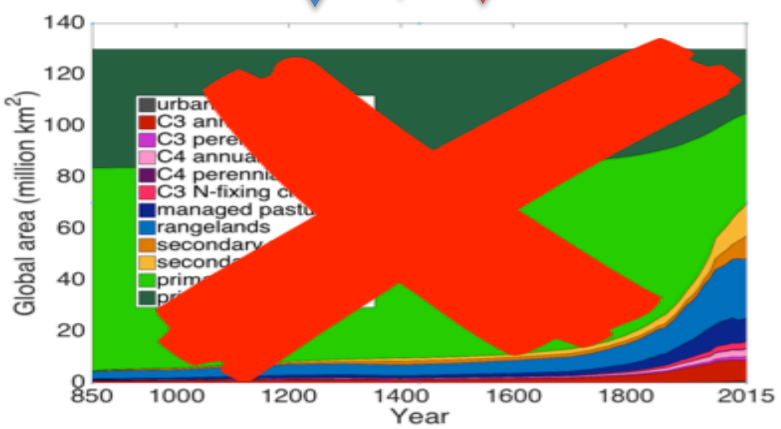
CMIP6 Historical

Land-only Historical



CMIP6 Historical

Land-only Historical



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

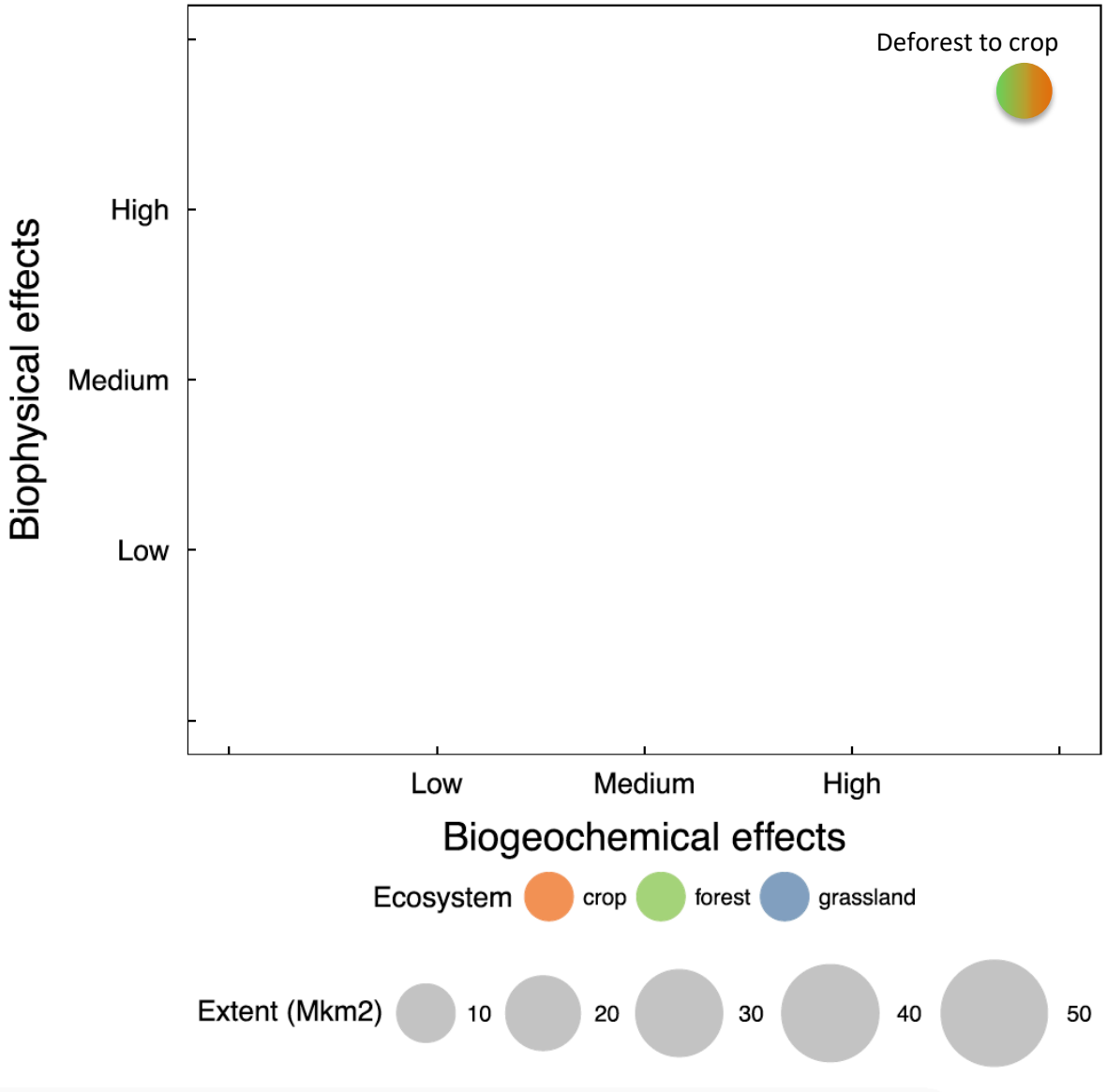
Tier 1

- 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)

Land-only land management experiments

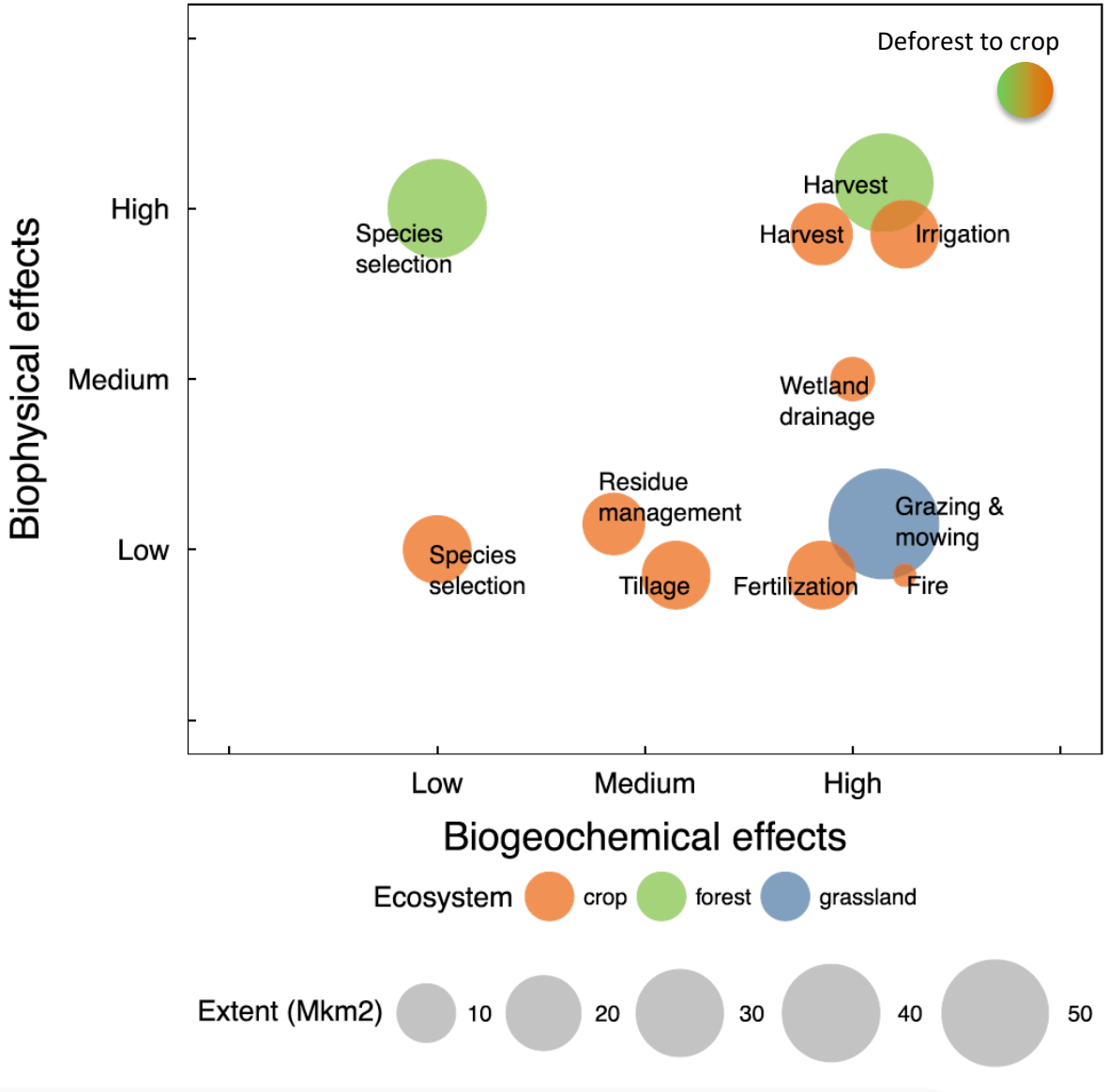


~25% non-ice land area undergone anthropogenic land-cover change

~80% non-ice land area under land management

Erb et al., GCB, 2016

Land-only land management experiments



~25% non-ice land area undergone anthropogenic land-cover change

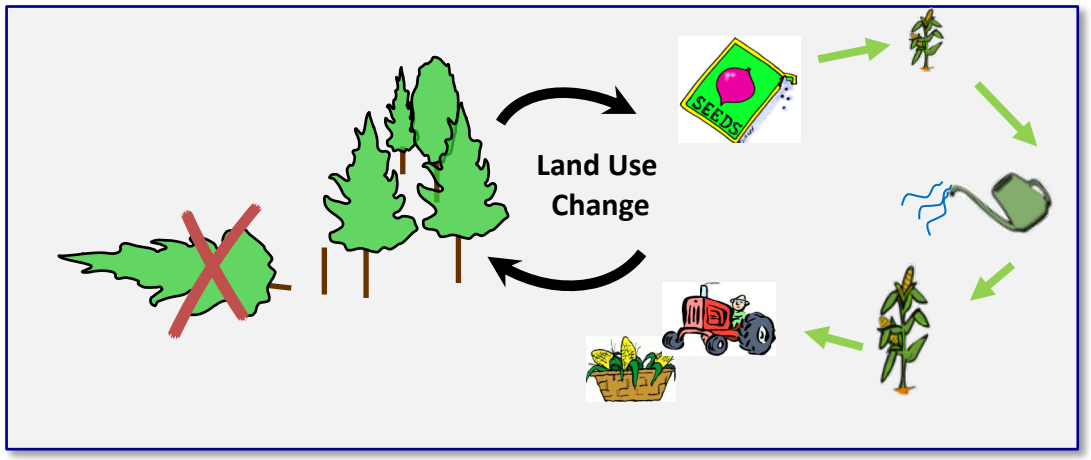
~80% non-ice land area under land management

Erb et al., GCB, 2016

Land-only land management experiments

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

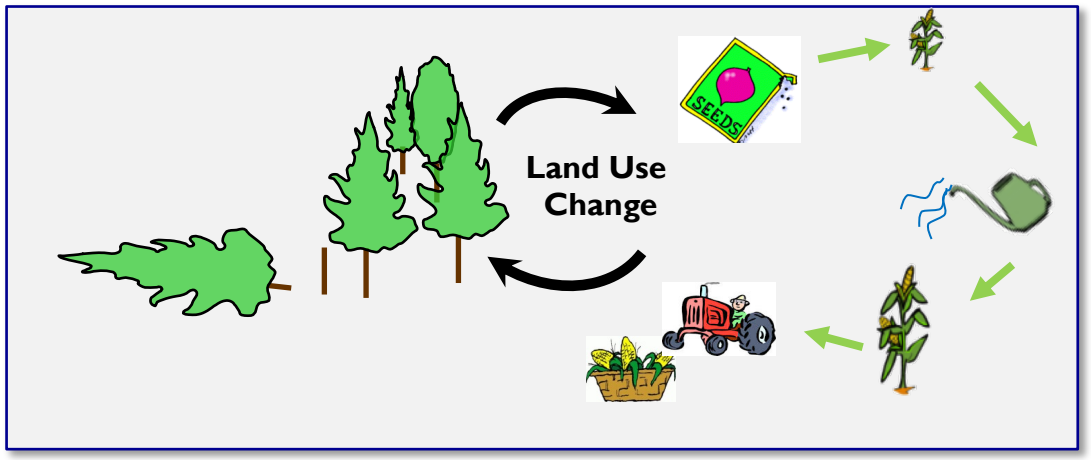


Lawrence et al., 2016

Land-only land management experiments

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

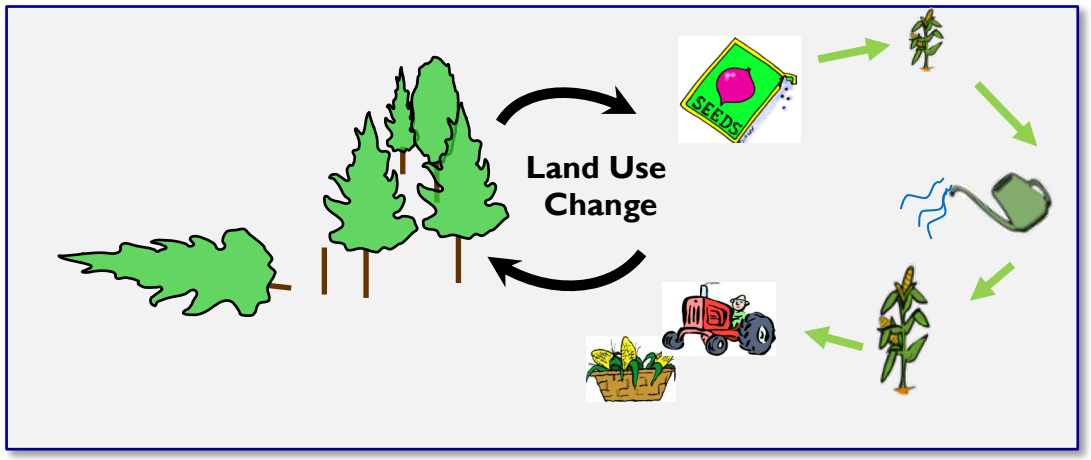


Lawrence et al., 2016

Land-only land management experiments

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

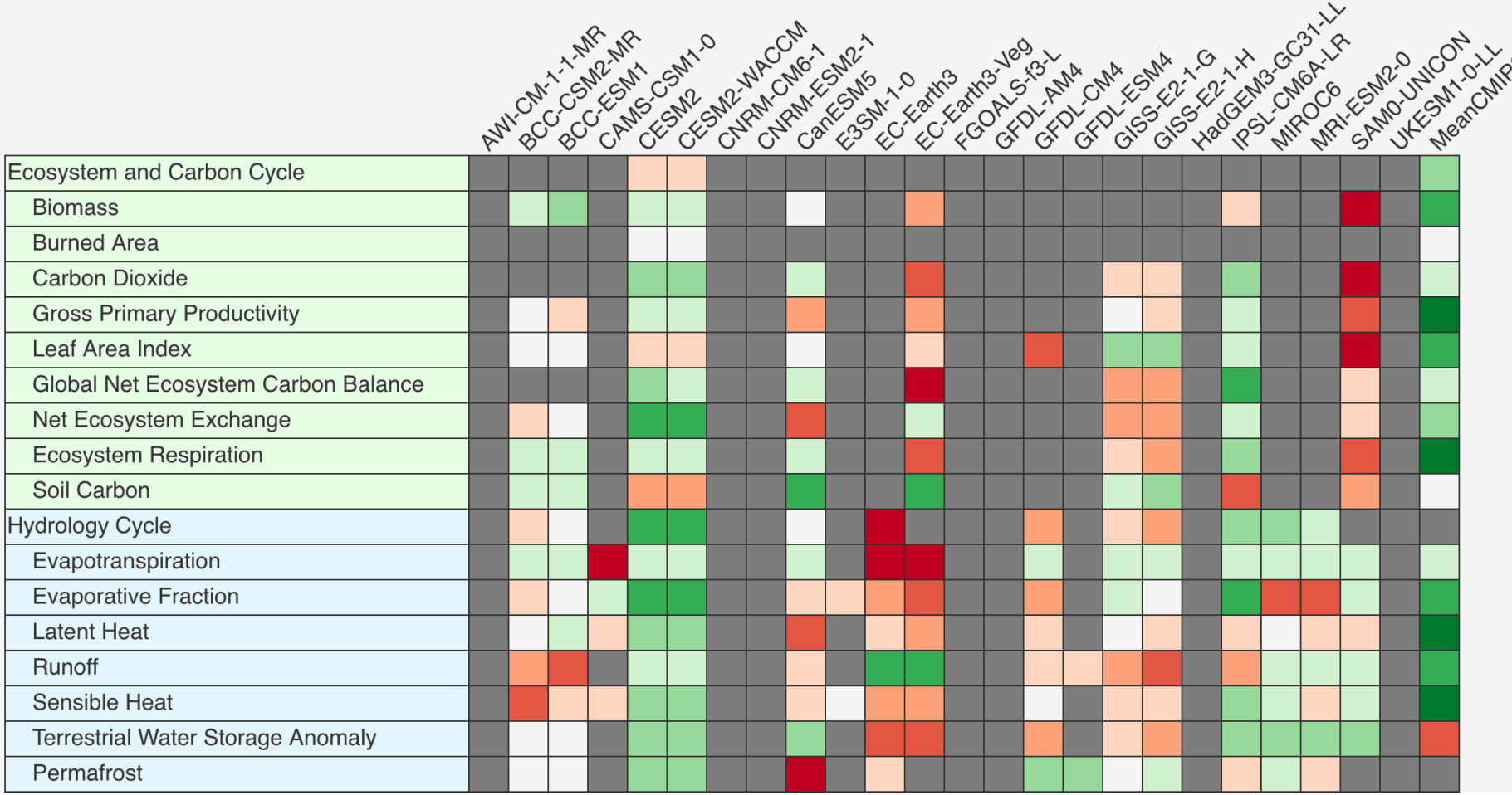


Lawrence et al., 2016

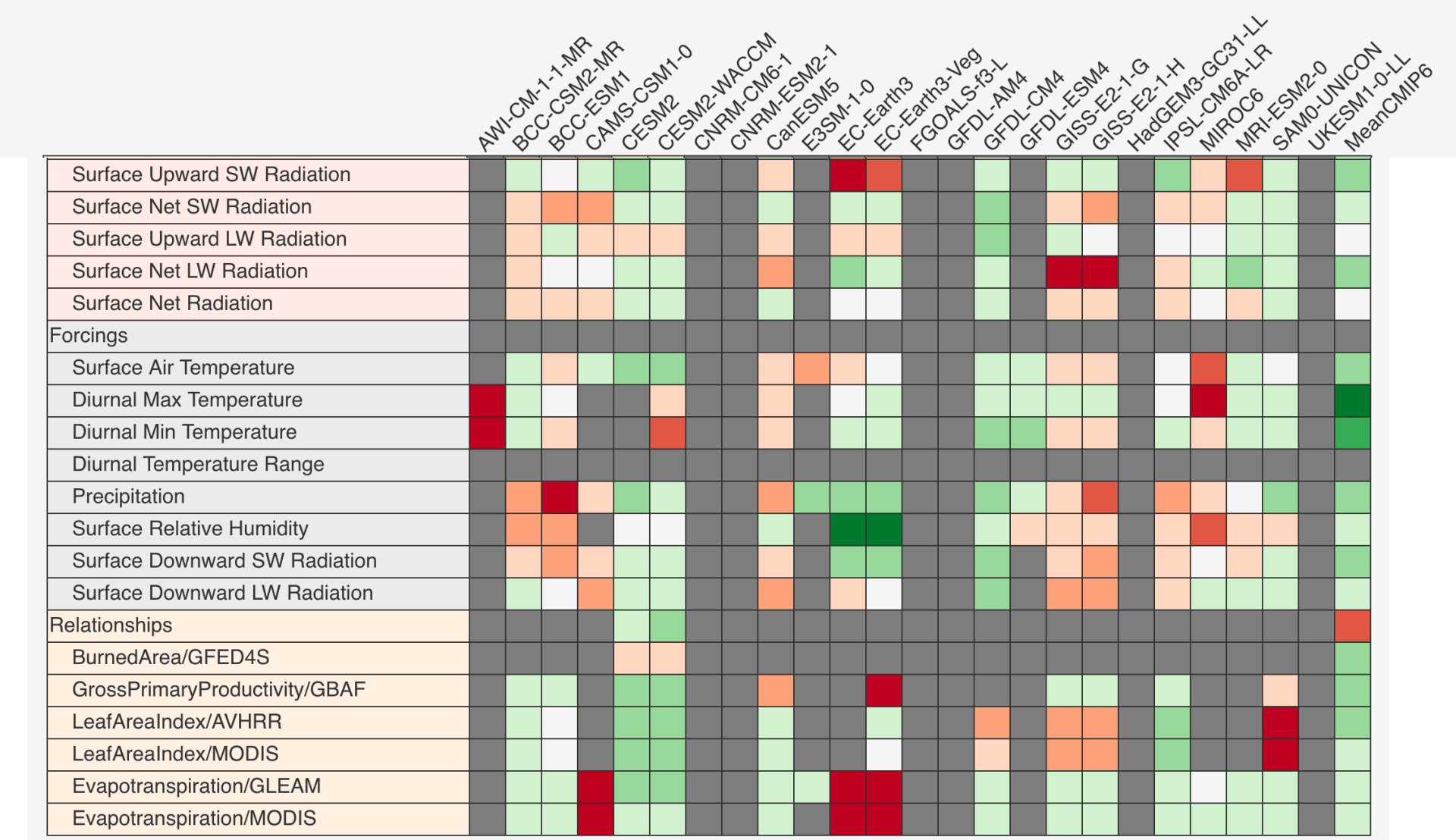
LUMIP Simulations available on ESGF
(as of Friday, September 13)

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	31	5	3	4	1	1	1	5	1	1	2	3	4
BCC-CSM2-MR	7	156	157	157				41			41	151	155
CESM2	11	370	179	1298	172	172	172		24	172	161	427	427
CNRM-CM6-1	1							153					
CNRM-ESM2-1	3	334		334				95					
CanESM5	4	342	342									8	8
GISS-E2-1-G	1							825					
IPSL-CM6A-LR	3	1369		1888				176					
UKESM1-0-LL	1												165

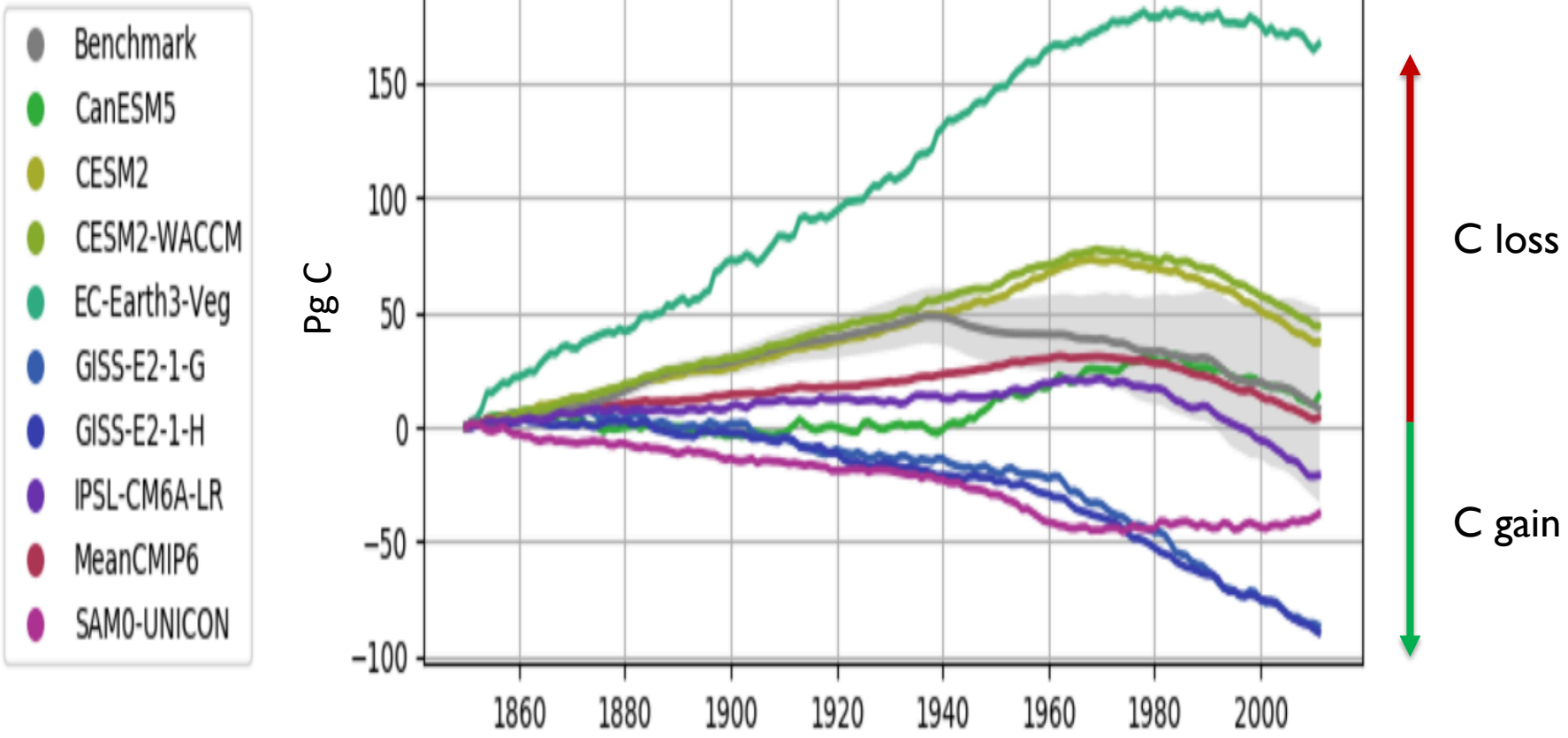
CMIP6 ILAMB results (PRELIMINARY!!!!)



CMIP6 ILAMB results (PRELIMINARY!!!!)



Accumulated terrestrial carbon accumulation



LUMIP Analysis Plans

docs.google.com/document/d/1YWmSJqg5bGG7QVdEUfqolFQkJ6SjK2nXABXyteQv_yU/edit

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.

Registered LUMIP Analysis Projects

- Climate response to idealized deforestation

Lena Boysen (lena.boysen@mpimet.mpg.de), Victor Brovkin (victor.brovkin@mpimet.mpg.de), David Lawrence, et al.

- Benchmarking LUMIP models

Edouard Davin (edouard.davin@env.ethz.ch), David Lawrence, Sanjiv Kumar, et al.

- Potential of targeted land use/land management as mitigation tool

Dave Lawrence (dlawren@ucar.edu), George Hurtt, and LUMIP SSG

- Detection and attribution of LULCC influences on historical trends in climate extremes

Wim Thiery (wim.thiery@env.ethz.ch), David Lawrence, Annette Hirsch, Edouard Davin, Sonia Seneviratne and LUMIP simulation contributors

- Projections of climate extremes under different LULCC scenarios

Annette Hirsch (annette.hirsch@env.ethz.ch), David Lawrence, Wim Thiery, Edouard Davin, Sonia Seneviratne and LUMIP simulation contributors

- Coupled versus uncoupled impacts of historical land use change

Peter Lawrence (lawrence@ucar.edu), David Lawrence, Sanjiv Kumar and others

Registered LUMIP Analysis Projects

- Simulated historical land-use emissions

Andy Wiltshire (andy.wiltshire@metoffice.gov.uk); Anna Harper (a.harper@exe.ac.uk); Eddy Robertson (eddy.robertson@metoffice.gov.uk); Chris Jones (chris.d.jones@metoffice.gov.uk)

- Regional land-use emissions and detection limits

Julia Pongratz (julia.pongratz@lmu.de); Victor Brovkin (victor.brovkin@mpimet.mpg.de); Lena Boysen (lena.boysen@mpimet.mpg.de); Eddy Robertson (eddy.robertson@metoffice.gov.uk)

- Global carbon budget

Julia Pongratz (julia.pongratz@lmu.de); Victor Brovkin ; Lena Boysen; Pierre Friedlingstein; Pep Canadell; Chris Jones and others

- Pasture in the global water and carbon cycles and its climatic feedbacks

Akihiko Ito (NIES: itoh@nies.go.jp), Tomohiro Hajima (JAMSTEC), et al.

- Impacts of historical and projected land-use change on global soil carbon stock

Akihiko Ito (NIES: itoh@nies.go.jp), Tomohiro Hajima (JAMSTEC), et al.

Goals for the meeting

From the Workshop Prospectus

- Advance international research on impacts of land use and land management on climate, carbon emissions, and extremes as well as the impact of LULCC on important societal issues such as food, water, and energy security
- The stimulus for meeting is availability of new CMIP6 ESM simulations which have been designed to provide the most advanced assessment to date of the potential impacts of LULCC on climate

Specific Goals

- Synthesize current understanding of impacts of LULCC on climate and biogeochemistry
- Document / transfer information on LULCC representation in CMIP6 ESMs
- Advance LUMIP-related manuscripts in advance of IPCC paper deadline (Dec. 31, 2019)
- Identify intersections and opportunities for research into regional LULCC implications / tradeoffs for energy systems, food security, water scarcity, water quality, biodiversity, and adaptation
- Others?

CMIP | Coupled Model Intercomparison Project past • present • future

Search

LUMIP | Land Use Model Intercomparison Project

cmip.ucar.edu/lumip
LUMIP google group

LUMIP

LUMIP HOME

LUMIP | LAND USE MODEL INTERCOMPARISON PROJECT

- LUMIP Simulations Protocol Paper - Published September 2, 2016
- LUMIP Simulations FAQ and Discussion - Follow link for updated protocols, clarification, and discussion onfLUMIP simulations
- LUMIP Analysis Planning - Follow link to register analysis plans and to coordinate with other research groups
- LUMIP Land-Use Tile Output Variables - Updated November 8, 2016

OVERVIEW

Human land-use activities have resulted in large changes to the biogeochemical and biophysical properties of the E activities are likely energy. CMIP5 achi climate, for the firs (past-future) in cou gridded land-use da projections from In Results indicate tha complex to warrant

PRIMARY CONTA

- George Hurtt (gc
- Dave Lawrence (

SCIENTIFIC STEE

Almut Arneth (KIT), Jones (Hadley Cent (Max Planck), Sonia

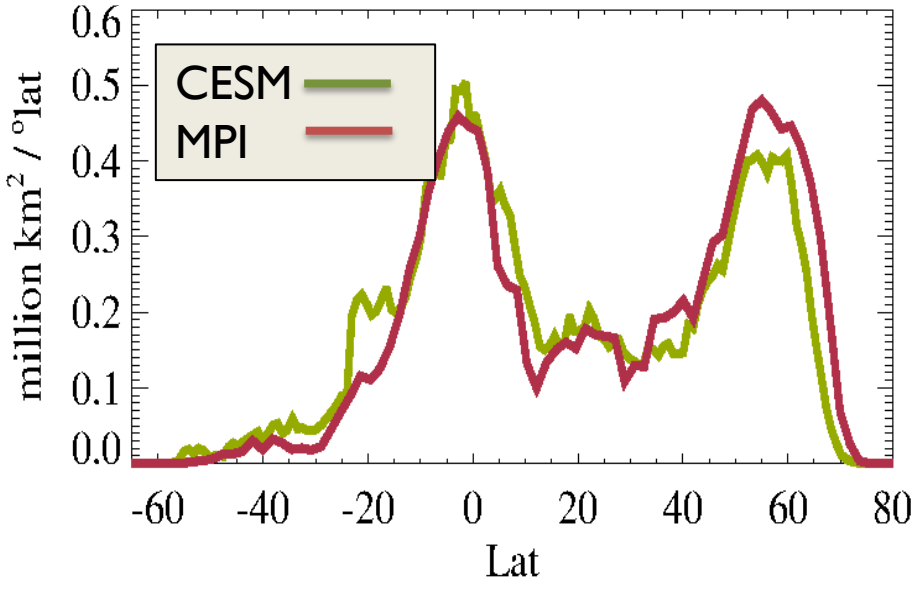
Geosci. Model Dev., 9, 2973–2998, 2016
www.geosci-model-dev.net/9/2973/2016/
doi:10.5194/gmd-9-2973-2016

Geoscientific Model Development
Open Access
EGU

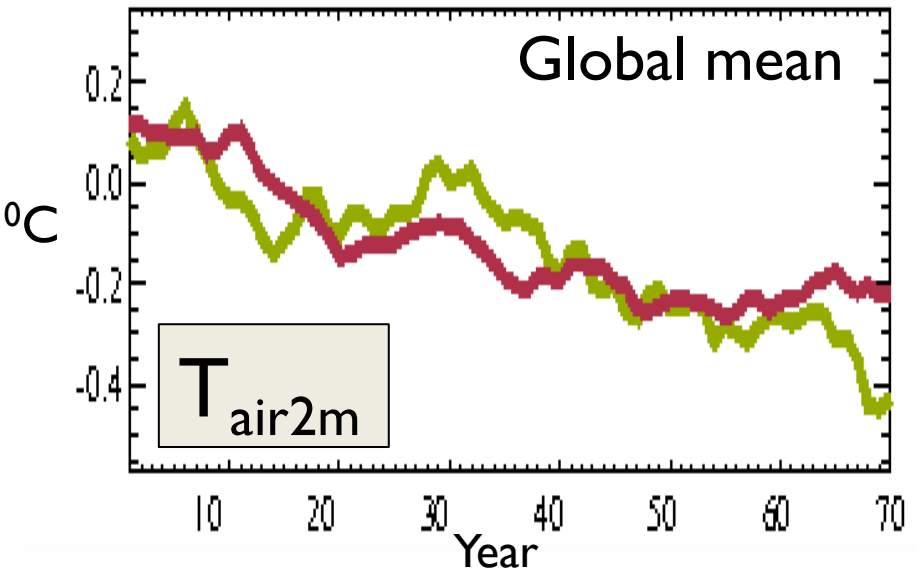
The Land Use Model Intercomparison Project (LUMIP) contribution to CMIP6: rationale and experimental design

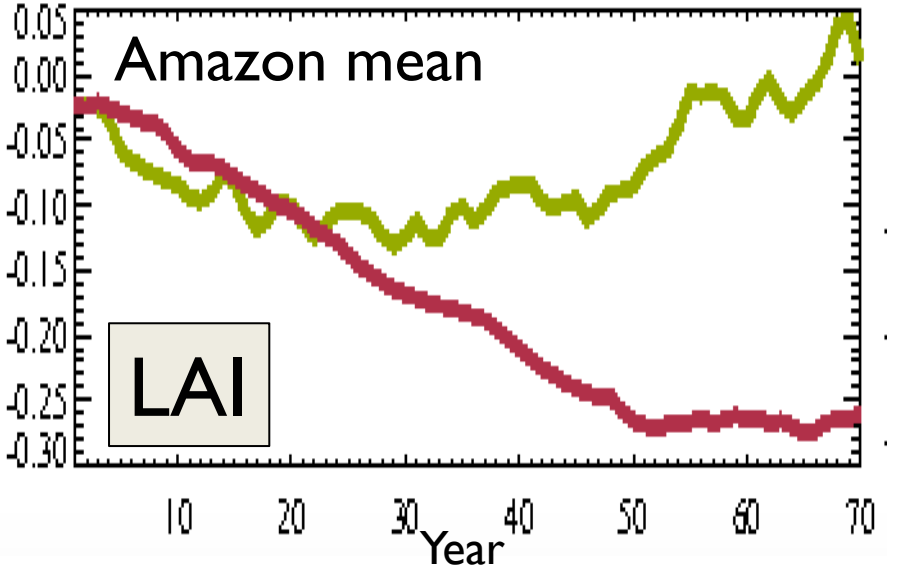
David M. Lawrence[1], George C. Hurtt[2], Almut Arneth[3], Victor Brovkin[4], Kate V. Calvin[5], Andrew D. Jones[6], Chris D. Jones[7], Peter J. Lawrence[1], Nathalie de Noblet-Ducoudré[8], Julia Pongratz[4], Sonia I. Seneviratne[9], and

Idealized deforestation (GCM, Tier 1)



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





LUMIP / ScenarioMIP ESM simulations
Projection period (2015-2100)

	Land-Use Scenario		
Main Scenario	**SSP1-2.6 Afforest**	**SSP3-7 Deforest**	**SSP5-8.5 Weak Deforest**
SSP1-2.6	**ScenarioMIP** Conc.-driven		
SSP3-7		**ScenarioMIP** Conc.-driven	
SSP5-8.5			**C4MIP** Emissions-driven

	Land-Use Scenario		
Main Scenario	**SSP1-2.6 Afforest**	**SSP3-7 Deforest**	**SSP5-8.5 Weak Deforest**
SSP1-2.6	**ScenarioMIP** Conc.-driven	**LUMIP** Conc.-driven	
SSP3-7	**LUMIP** Conc.-driven	**ScenarioMIP** Conc.-driven	
SSP5-8.5			**C4MIP** Emissions-driven

Biogeophysical climate impacts of LULCC; assess land management for regional climate mitigation

Assess how impact of LULCC differs at different climate change and CO_2 levels

	Land-Use Scenario		
Main Scenario	**SSP1-2.6 Afforest**	**SSP3-7 Deforest**	**SSP5-8.5 Weak Deforest**
SSP1-2.6	**ScenarioMIP** Conc.-driven	**LUMIP** Conc.-driven	
SSP3-7	**LUMIP** Conc.-driven	**ScenarioMIP** Conc.-driven	
SSP5-8.5	**LUMIP** Emissions-driven		**C4MIP** Emissions-driven

Biogeophysical climate impacts of LULCC; assess land management for regional climate mitigation

Assess how impact of LULCC differs at different climate change and CO_2 levels

Full effects of LULCC through both biogeophys and biogeochem processes

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

Lut variables are included in latest CMOR tables versions

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

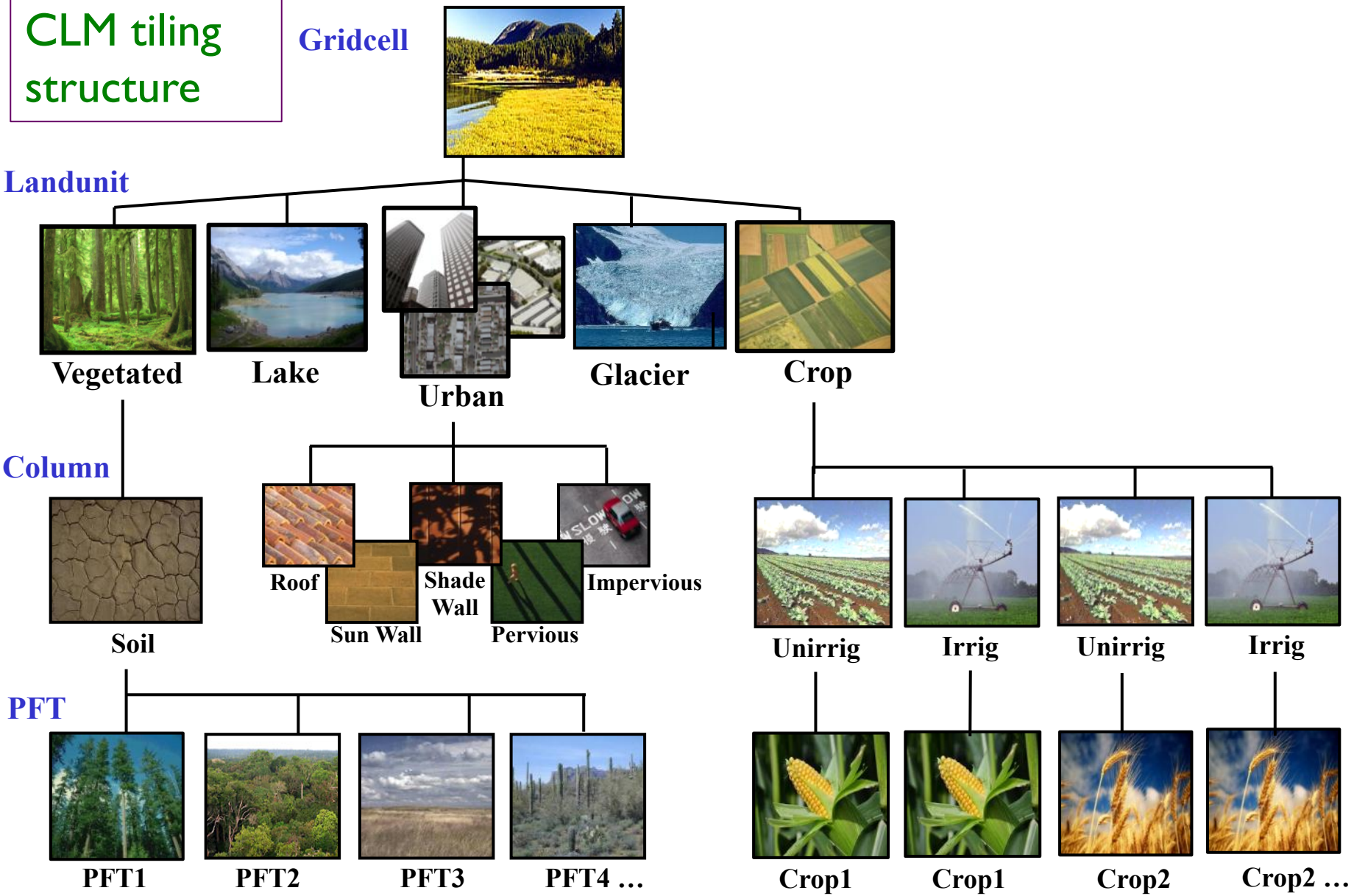
Biogeophysical variables
tasLut – near-surface air temperature
hussLut – near-surface specific humidity
hflsLut – latent heat flux
hfssLut – sensible heat flux
rsusLut – surface upwelling shortwave (albedo)
laiLut – leaf area index

Bigoechemical 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

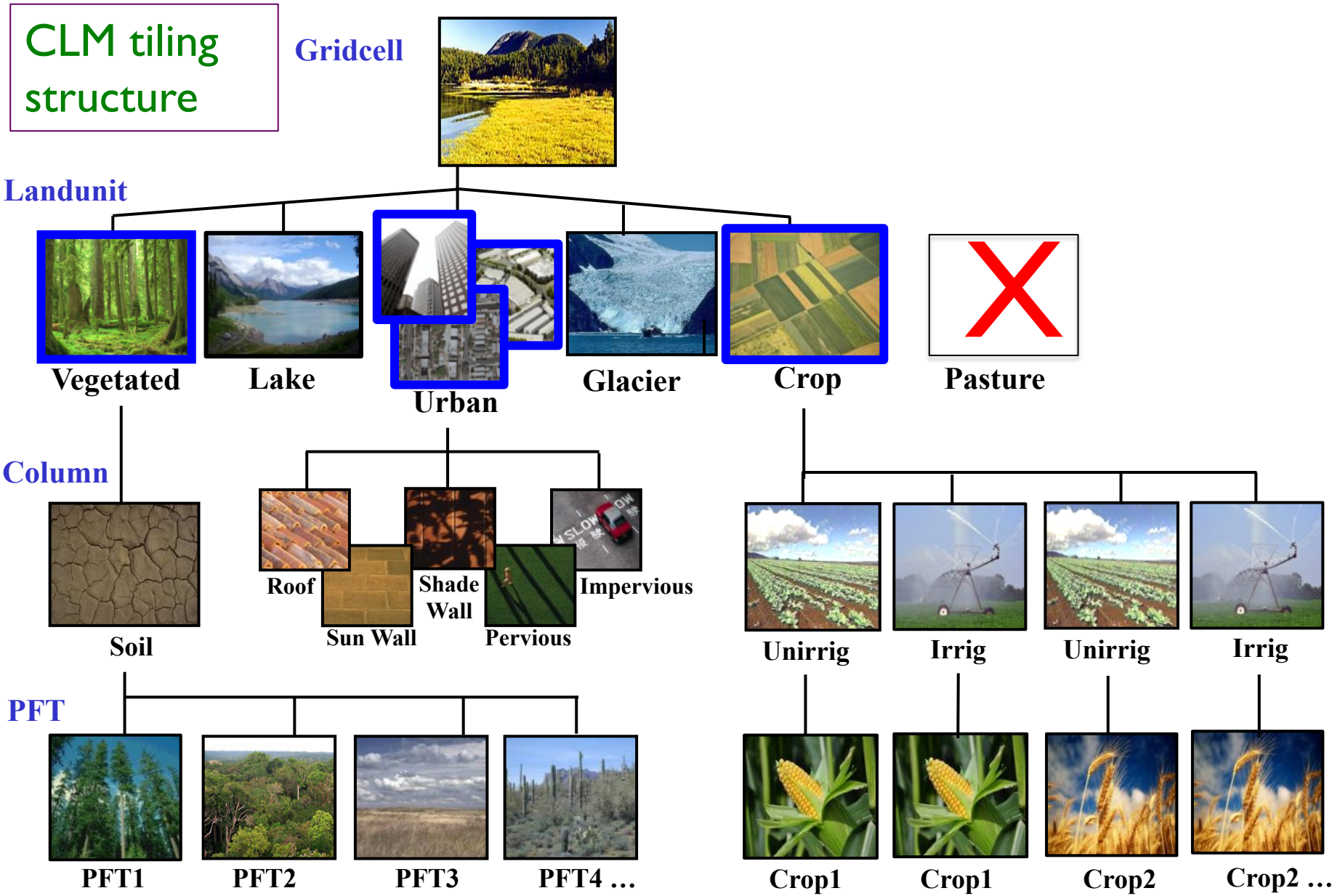
LULCC fraction changes
fracInLut – fraction transferred into land-use type
fracOutLut – fraction transferred out of LUT

Example aggregation onto Land-Use Tiles for CLM

CLM tiling structure



Example aggregation onto Land-Use Tiles for CLM



Useful webpages

- C4MIP/LUMIP modeling group plans https://docs.google.com/spreadsheets/d/1AVZTNHcZME5xr0_hMbhvZY6z4twk3o3GHMz2Di3ZUN0/edit#gid=383139377

- ESGF CMIP6 data holdings https://pcmdi.llnl.gov/CMIP6/ArchiveStatistics/esgf_data_holdings/

- CMIP6 output tables https://docs.google.com/spreadsheets/d/14bVnGtQpvK5XnaUn8IctuBTSnSWxDFZbwGYmd0K6GAI/edit#gid=1530995877

CMIP6_TABLES_v06.xlsx

File Edit View Insert Format Data Tools Add-ons Help Last edit was made on July 26 by Keith Lindsay

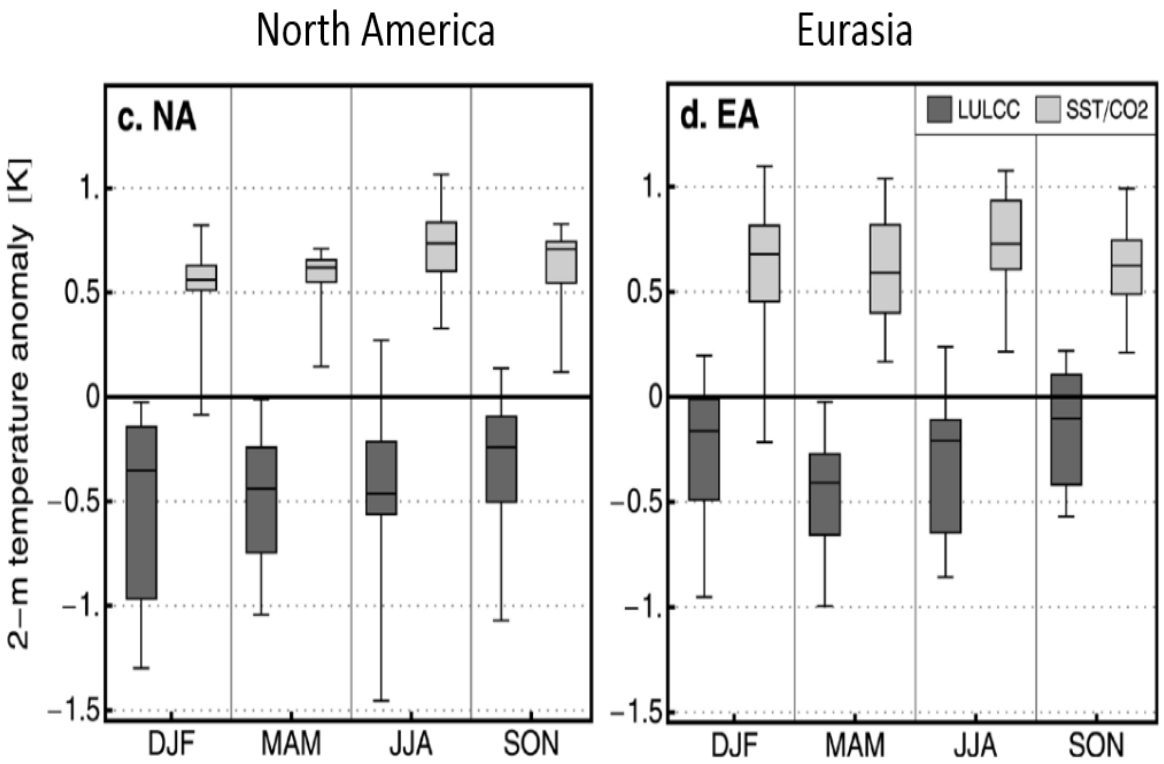
100% $ % .0 .00 123 Calibri 24

fx Emon

	A	B	C	D	E	F
1	**Emon**					
2	**Variable**	**Description**	**Units**	**Frequency**	**Dimensions**	**Modeling Realm**
110	fracLut	Percentage of grid cell for each land use tile: End of year values (not annual mean); note that percentage should be reported as percentage of land grid cell (example: frac_lnd = 0.5, frac_ocn = 0.5, frac_crop_lnd = 0.2 (of land portion of grid cell), then frac_lut(crop) = 0.5*0.2 = 0.1) cell_methods:area: mean where land over all_area_types time: mean cell_measures:area: areacella positive:	%	mon	time|landUse|longitude|latitude	land
111	gppGrass	gross primary production on grass tiles: Total GPP of grass in the gridcell cell_methods:area: time: mean where natural_grasses (comment: mask=grassFrac) cell_measures:area: areacella positive:	kg m-2 s-1	mon	time|longitude|latitude	land
112	gppLut	gross primary productivity on land use tile: "Production of carbon" means the production of biomass expressed as the mass of carbon which it contains. Gross primary production is the rate of synthesis of biomass from inorganic precursors by autotrophs ("producers"), for example, photosynthesis in plants or phytoplankton. The producers also respire some of this biomass and the difference is "net_primary_production". "Productivity" means production per unit area. The phrase "expressed_as" is used in the construction A_expressed_as_B, where B is a chemical constituent of A. It means that the quantity indicated by the standard name is calculated solely with respect to the B contained in A, neglecting all other chemical constituents of A. cell_methods:area: time: mean where landuse cell_measures:area: areacella positive:	kg m-2 s-1	mon	time|landUse|longitude|latitude	land
		gross primary production on Shrub tiles: Total GPP of shrubs in the gridcell cell_methods:area: time: mean where shrubs (comment:				

EdayZ Efx Emon EmonZ Esubhr Eyr IfxAnt IfxGre ImonAnt ImonGre

… as highlighted by LUCID …



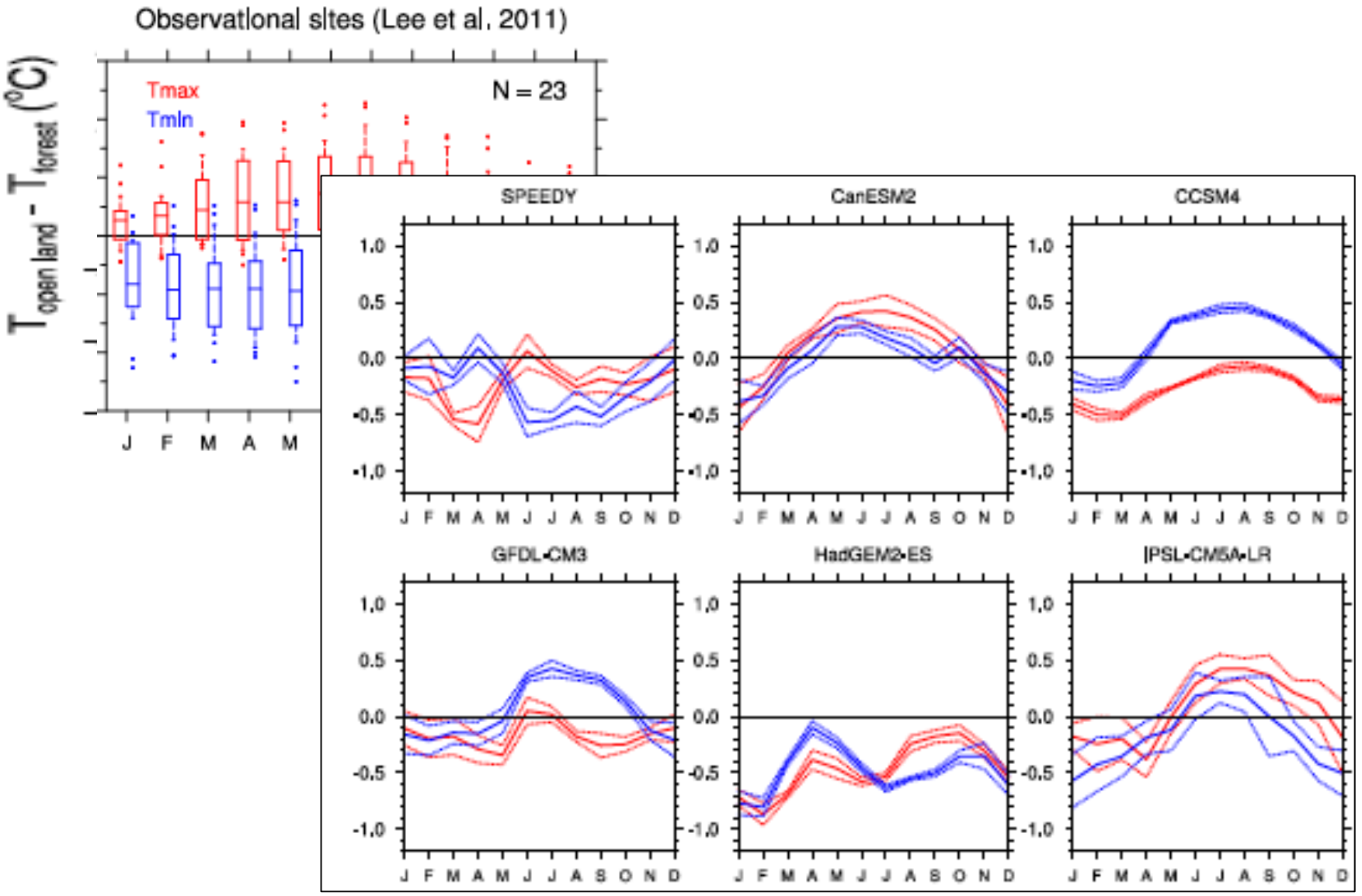
CO_2 + SST + SIC forcing leads to warming

LULCC leads to cooling

- 30-50% of variation in land-use climate signal attributed to differences in specified land use change
- Uncertainty in LULCC impact on T larger than for CO_2
- Models do not agree on sign of impact on evapotranspiration
- Models ignore relevant processes, e.g. irrigation

de Noblet-Ducoudré et al. 2012, Boisier et al. 2012

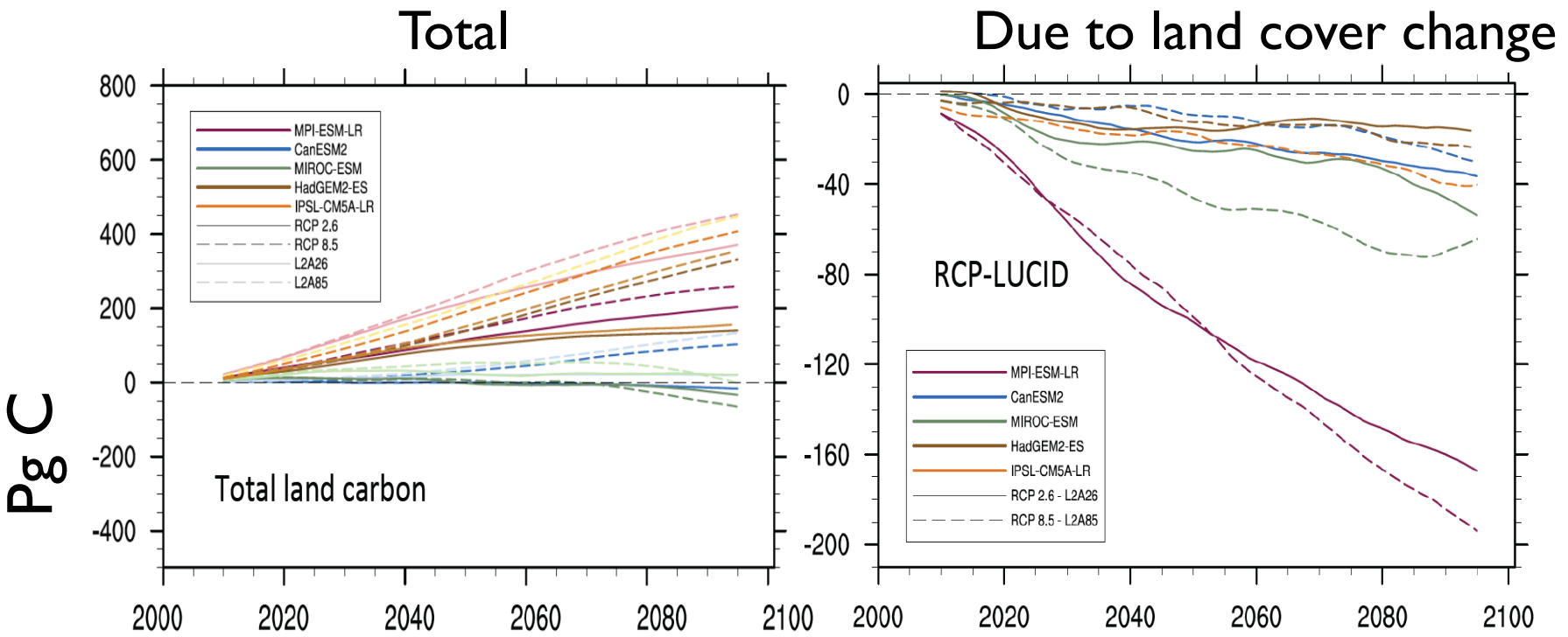
… and more recently
Daytime versus nighttime response to deforestation



Lejeune et al., J. Clim, 2017

… and with respect to the carbon cycle (LUCID-CMIP5)

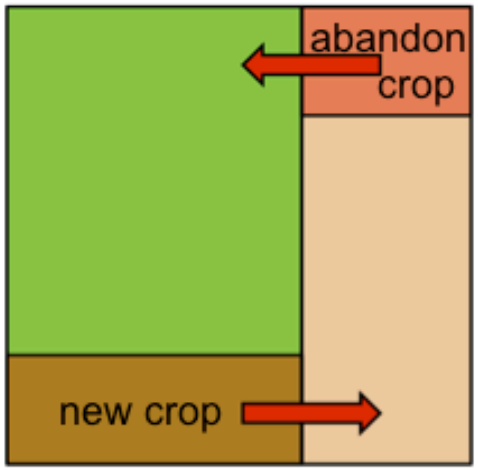
Changes in land carbon storage



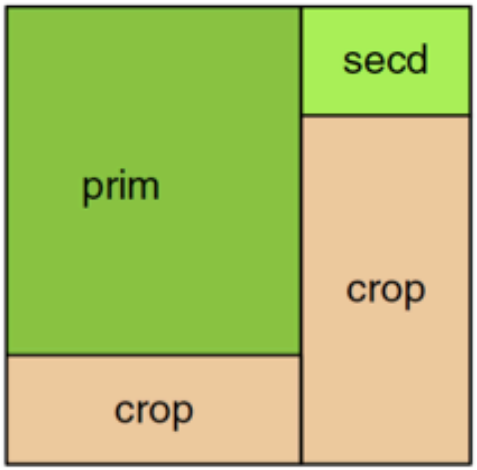
- Disparity across CMIP5 models in terms of LCC impact on C, even in scenario where prescribed LCC was relatively small (RCP8.5)
- And, many CMIP5 models represent land use simplistically (w/o wood harvest, crop management, irrigation, fertilization, shifting cultivation)
- Indirect C impacts as big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

Brovkin et al.., J. Clim. 2013

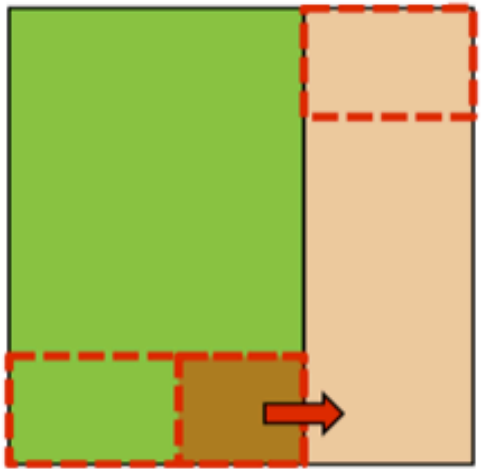
Shifting cultivation



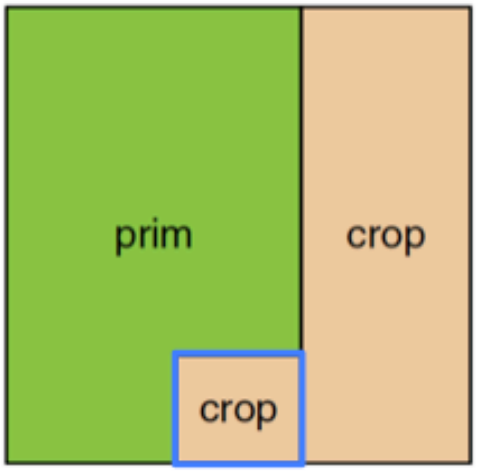
shifting cultivation
(gross LU transition)



state after gross transition



without shifting cultivation
(net LU transition)



state after net transition

LUMIP Goals

Deliberate enhancement of rainfall using desert plantations

Oliver Branch and Volker Wulfmeyer

PNAS first published September 3, 2019 https://doi.org/10.1073/pnas.1904754116