Land and Water Management in Earth System Models: Opportunities and Challenges

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… 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 as GHGs

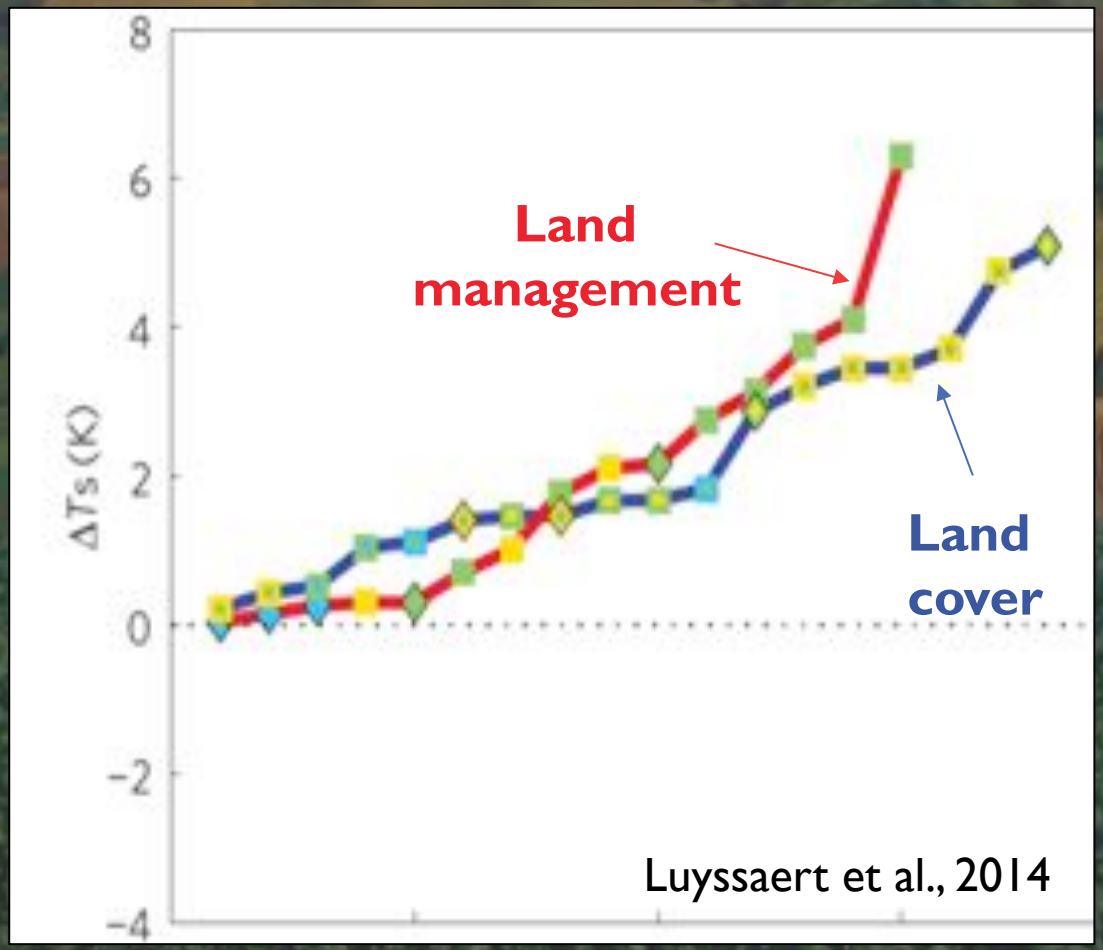
… and on direct carbon emissions (~1/3 of direct historic C emissions - 180 ± 80PgC - from land use)

… 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 as GHGs

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

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



Paired Tower sites

since 1993

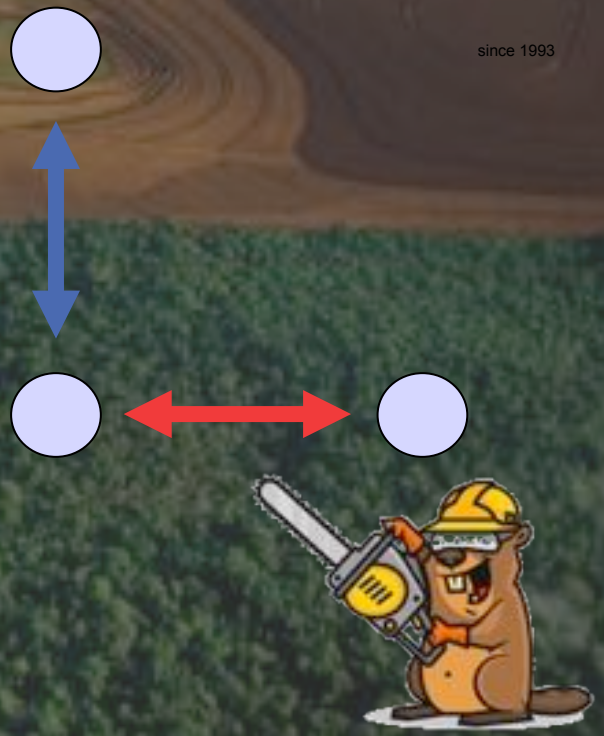
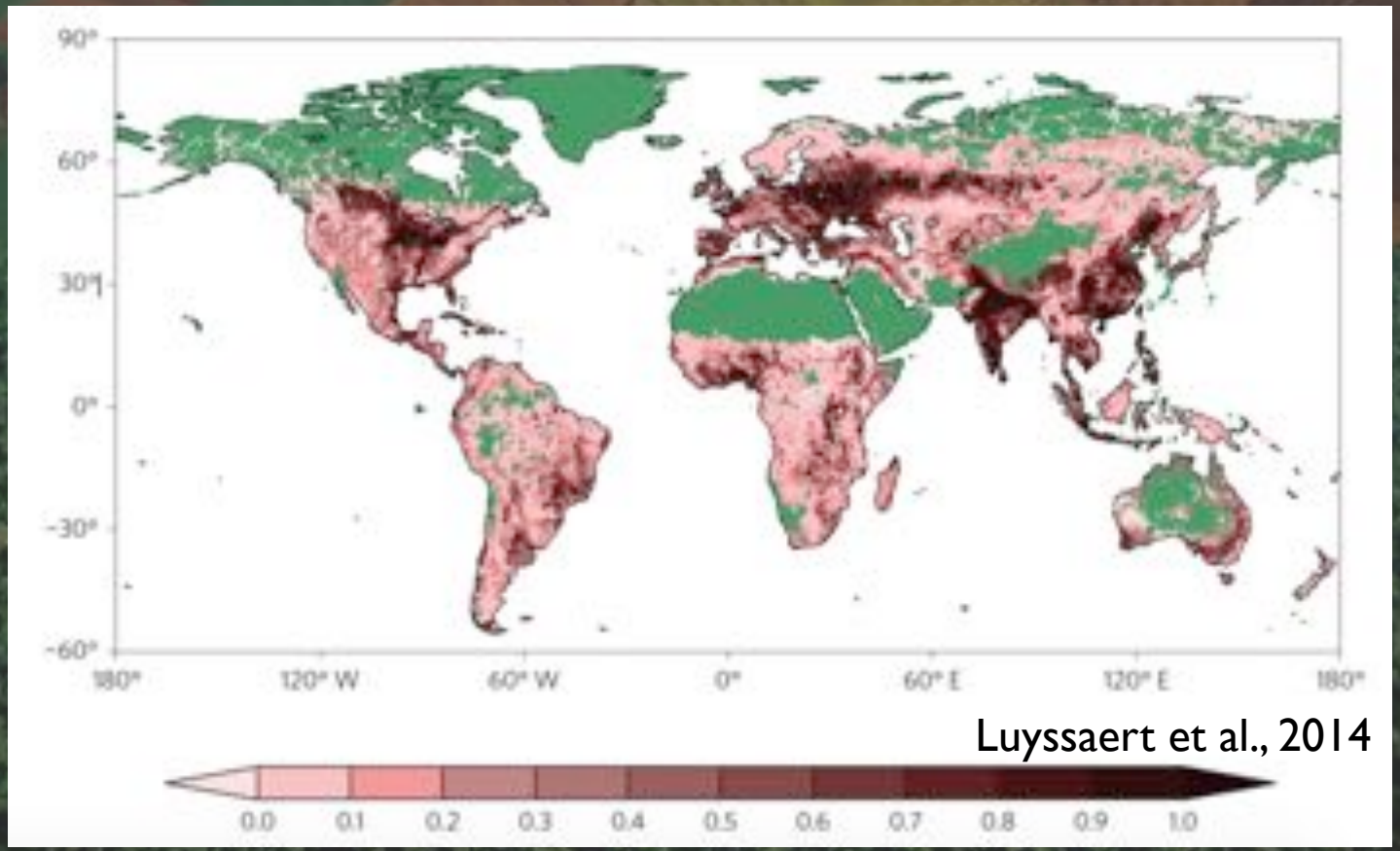


Image: Frans Lanting/Robert Harding Picture Library

Spatial extent of land cover change, land management, wilderness and non-productive area

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



Luyssaert et al., 2014

since 1993

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

Global Change Biology

Research Review | Full Access

Land management: data availability and process understanding for global change studies

Karl-Heinz Erb, Sebastiaan Luyssaert, Patrick Meyfroidt, Julia Pongratz, Axel Don, Silvia Kloster, Tobias Kuemmerle, Tamara Fetzel, Richard Fuchs, ... See all authors

First published: 22 July 2016 | https://doi-org.cuucar.idm.oclc.org/10.1111/gcb.13443

Global Change Biology

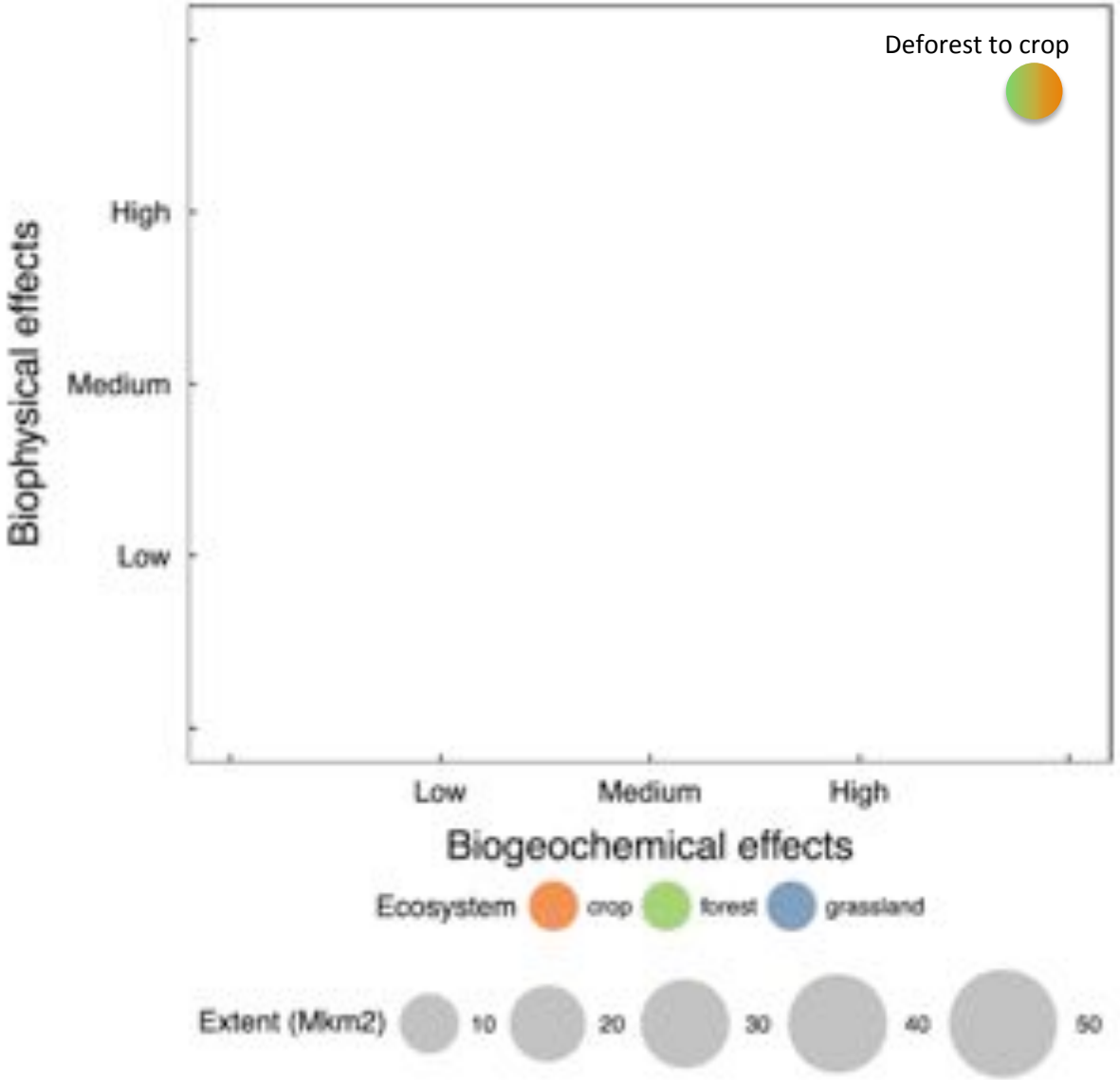
RESEARCH REVIEW

Models meet data: Challenges and opportunities in implementing land management in Earth system models

Julia Pongratz, Han Dolman, Axel Don, Karl-Heinz Erb, Richard Fuchs, Martin Herold, Chris Jones, Tobias Kuemmerle, Sebastiaan Luyssaert, Patrick Meyfroidt, Kim Naudts

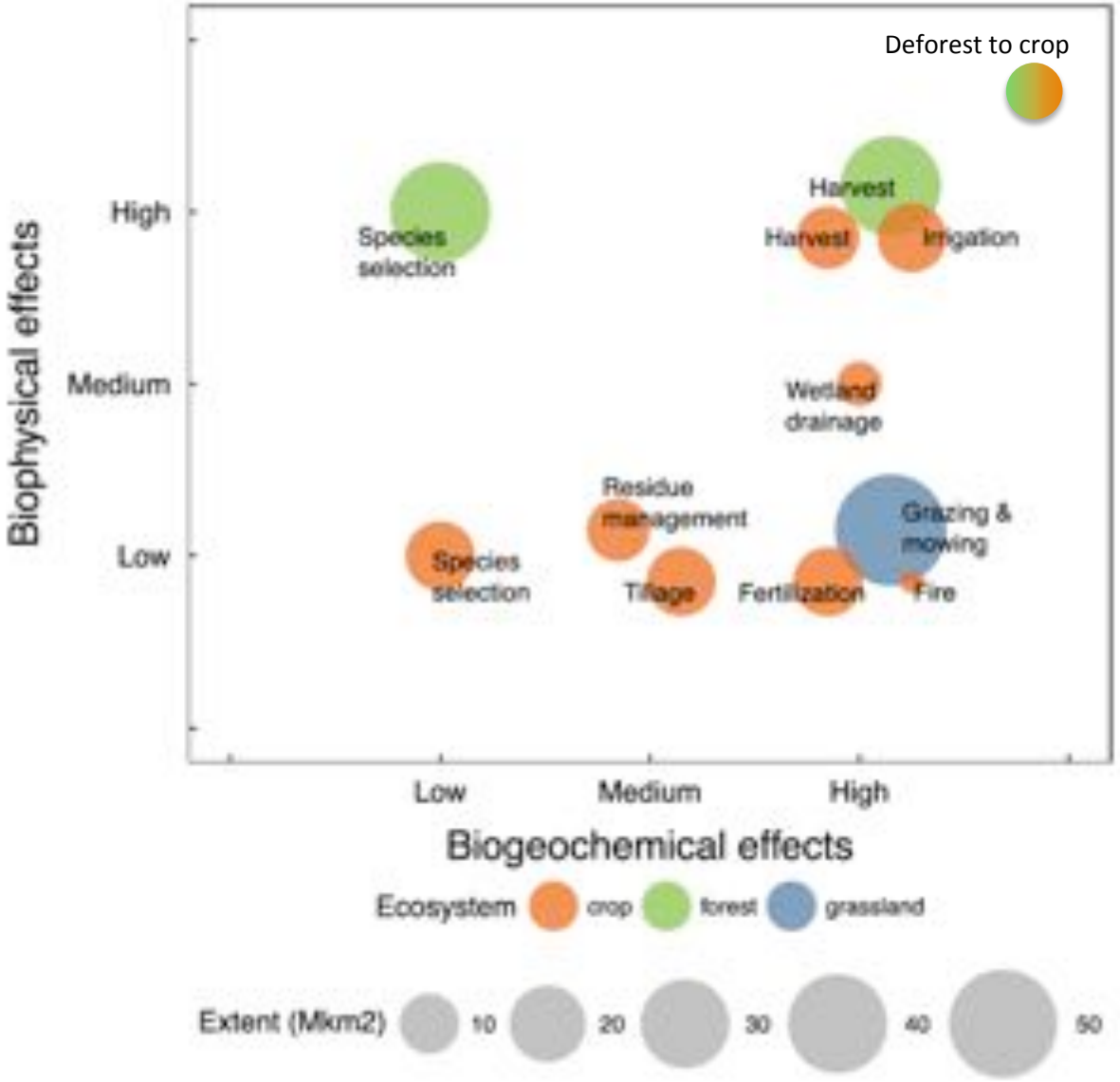
First published: 13 December 2017 | https://doi.org/10.1111/gcb.13988

Synthesis of land management impacts



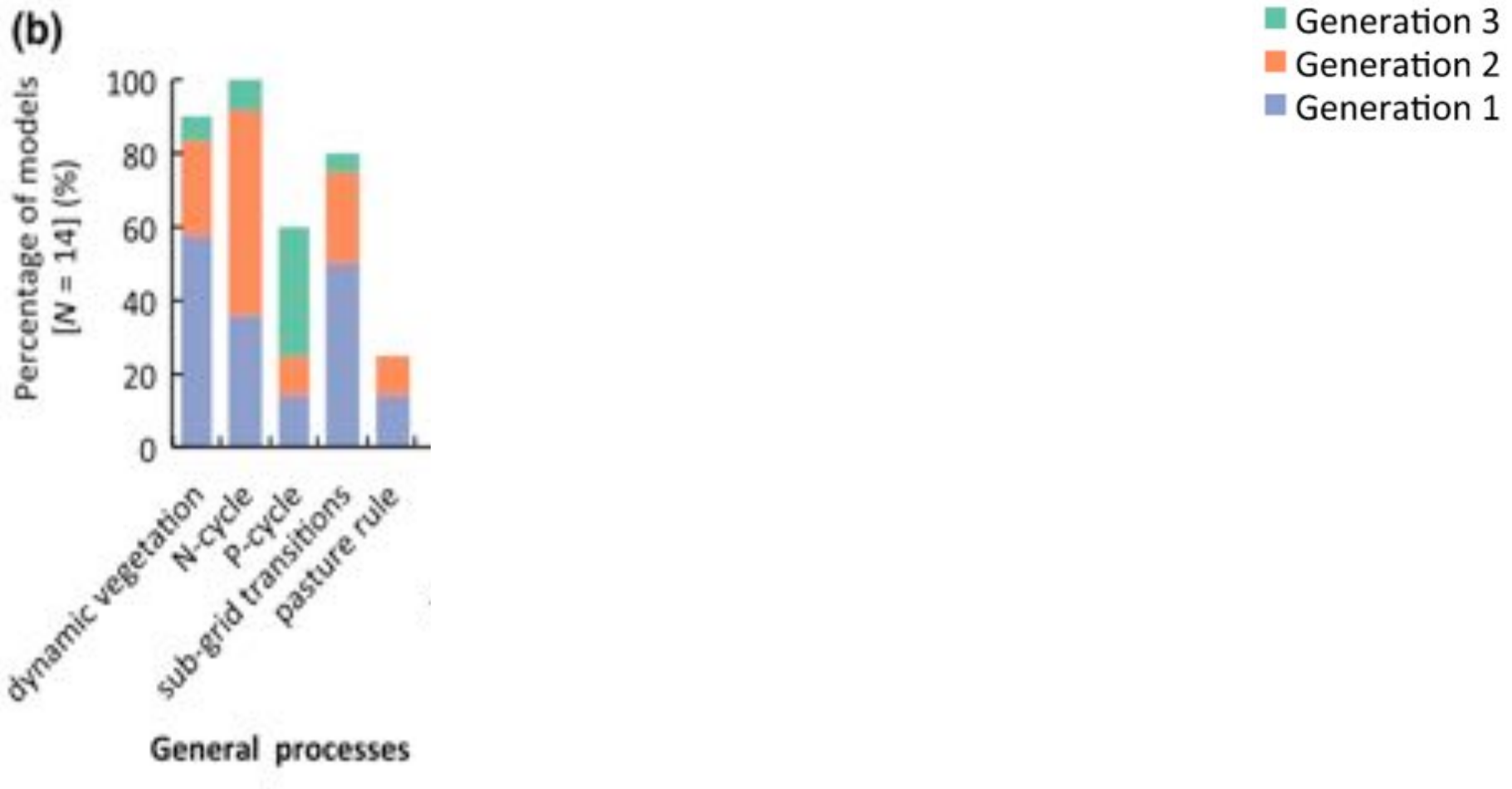
Erb et al., GCB, 2016

Synthesis of land management impacts



Erb et al., GCB, 2016

Survey of modeling groups' progress and plans with respect to implementation of land management

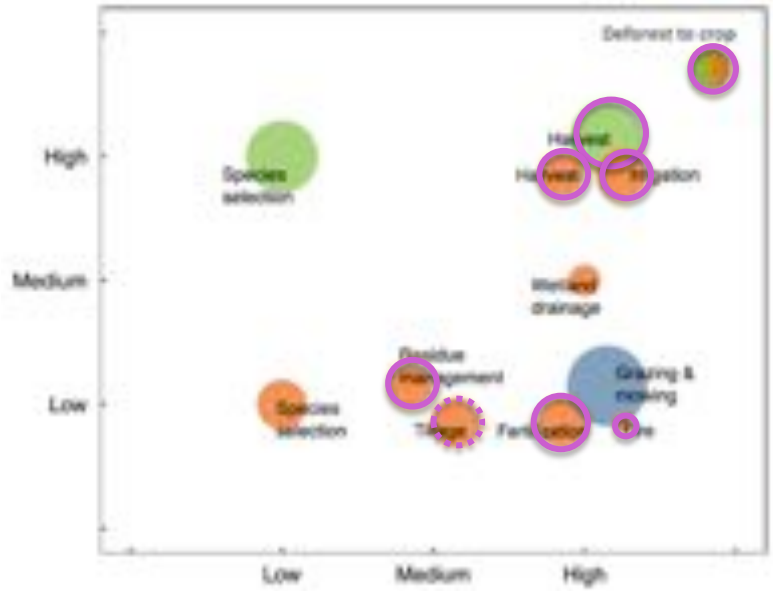


Pongratz et al., GCB, 2018

Land management in Community Land Model (CLM5)

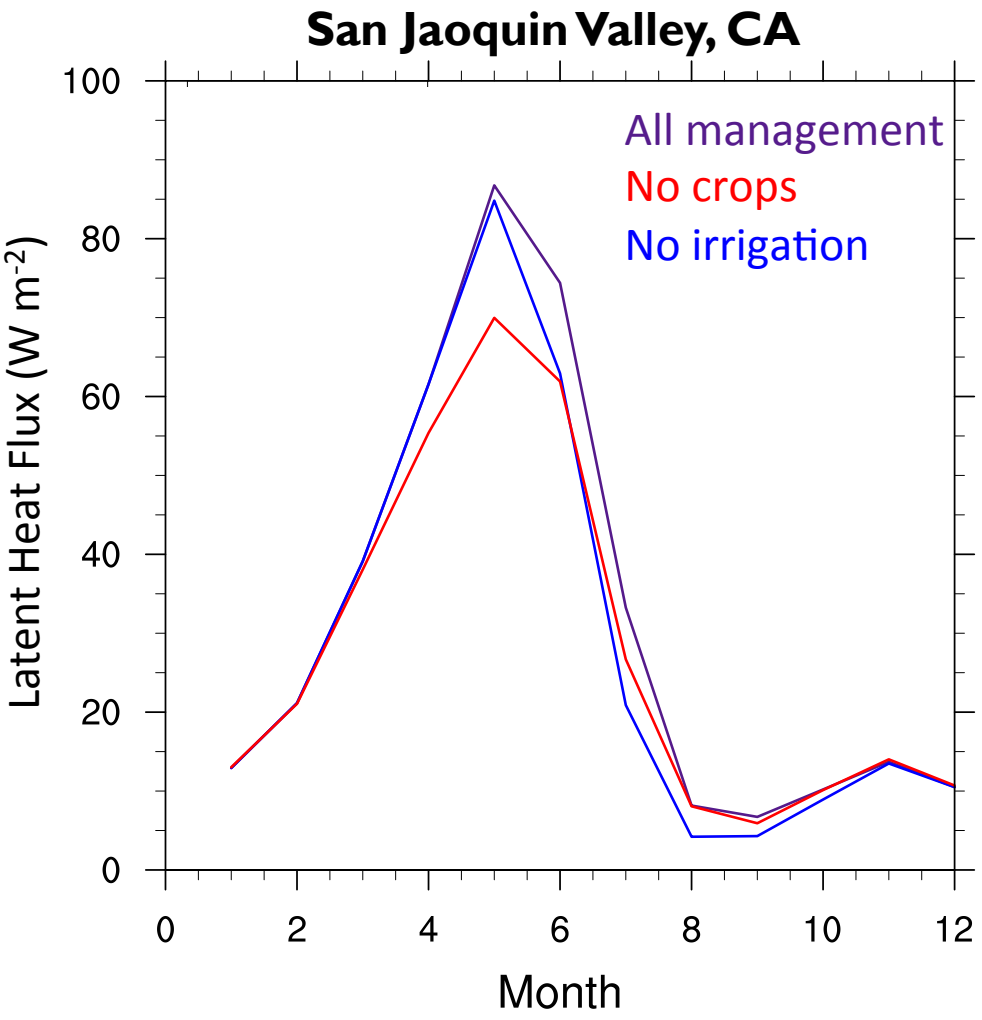
Included in default CLM5

- Global crop model with 8 crop types; planting, grain fill, harvest, residue manage
- Crop irrigation
- Crop Industrial fertilization
- Wood harvest
- Urban environments
- Human fire ignition and suppression



* *Temperate and tropical varieties*

Land-only land management experiments with CLM5

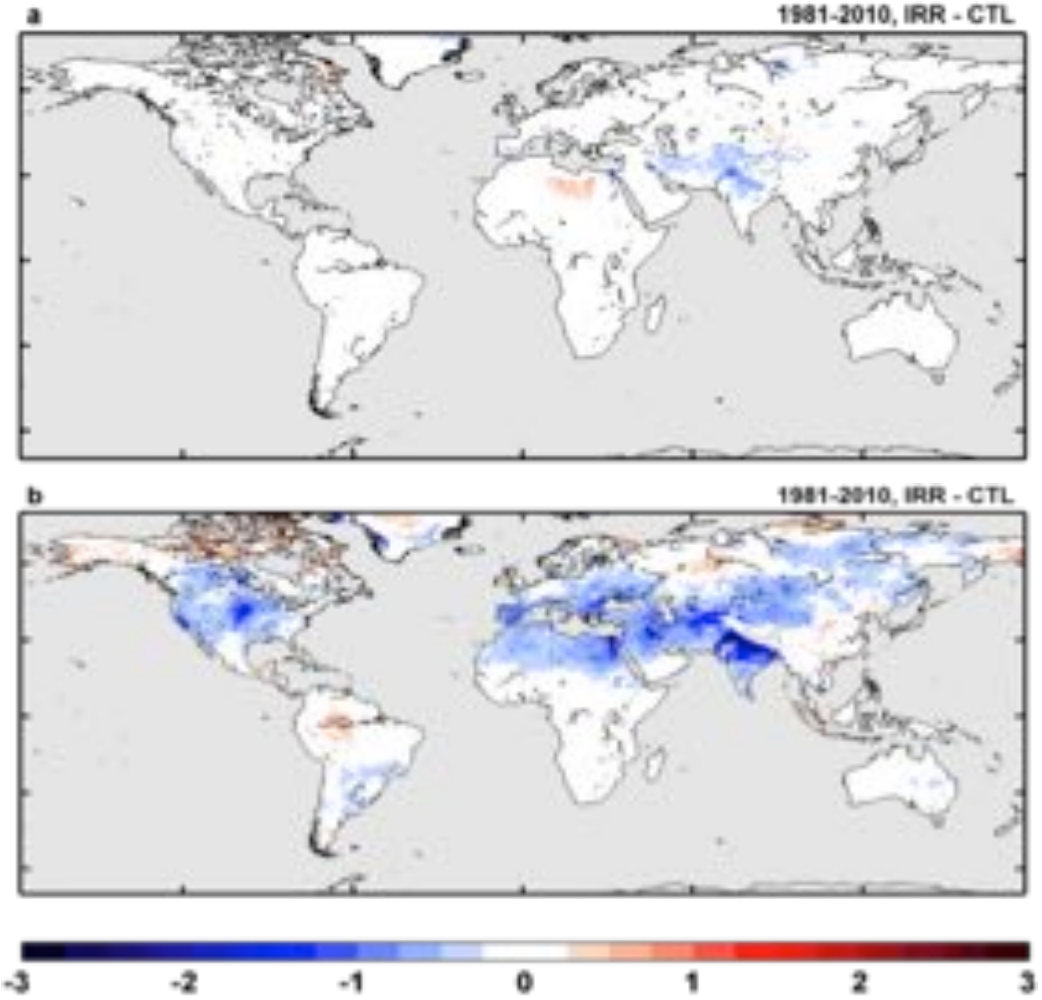


Lombardozzi et al., in prep

Impact of irrigation on climate and extremes

T_{2m}

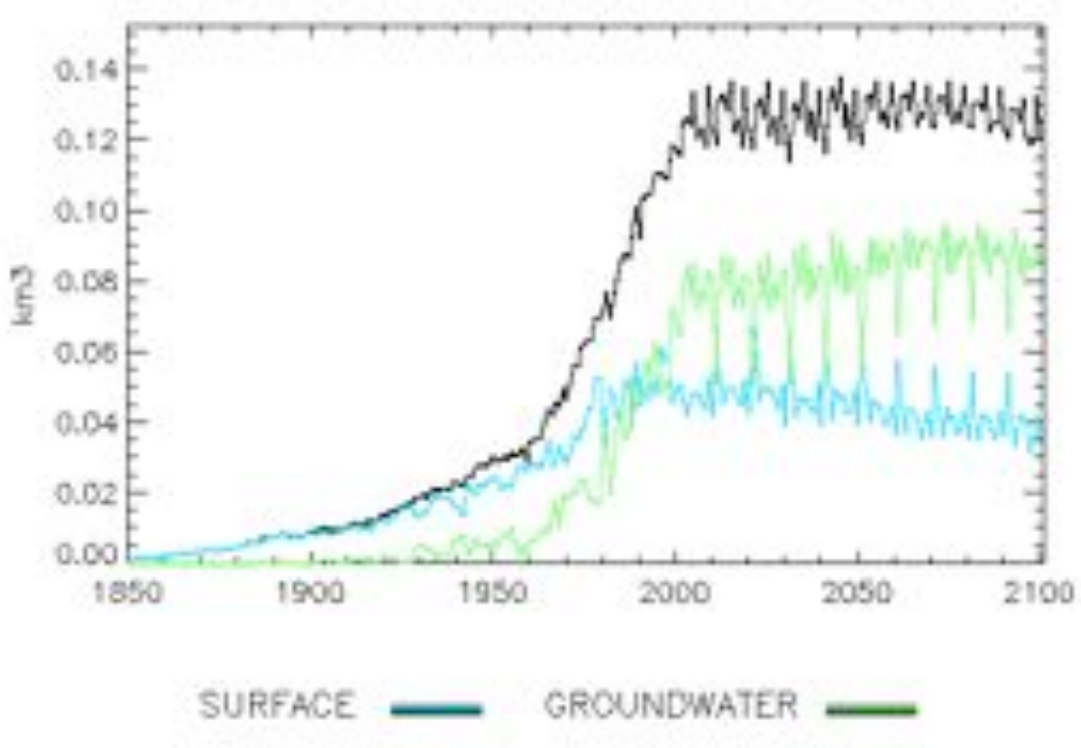
TXx



Thierry et al., JGR, 2017

More realistic treatment of sources of irrigation water

Annual irrigation
Northern India

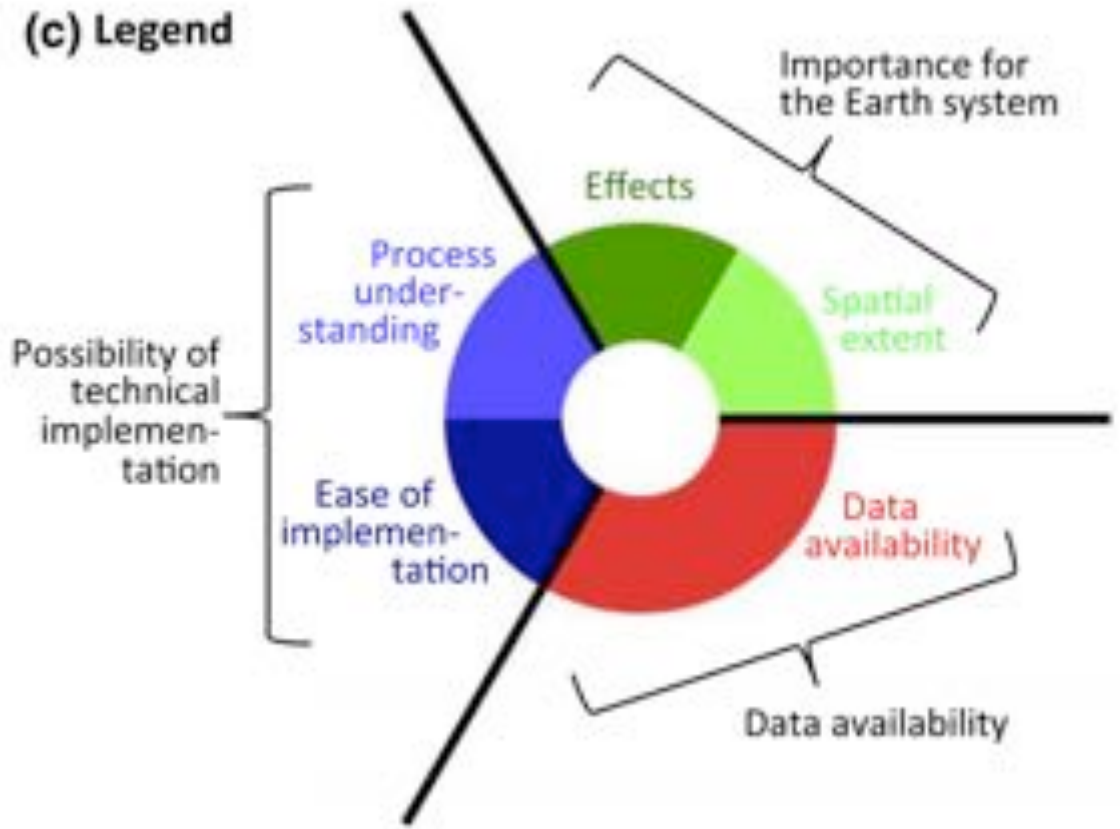


Introduce groundwater pumping

Assess relative withdrawals from surface water versus groundwater

More realistic treatment of sources of irrigation water

Importance and feasibility roadmap

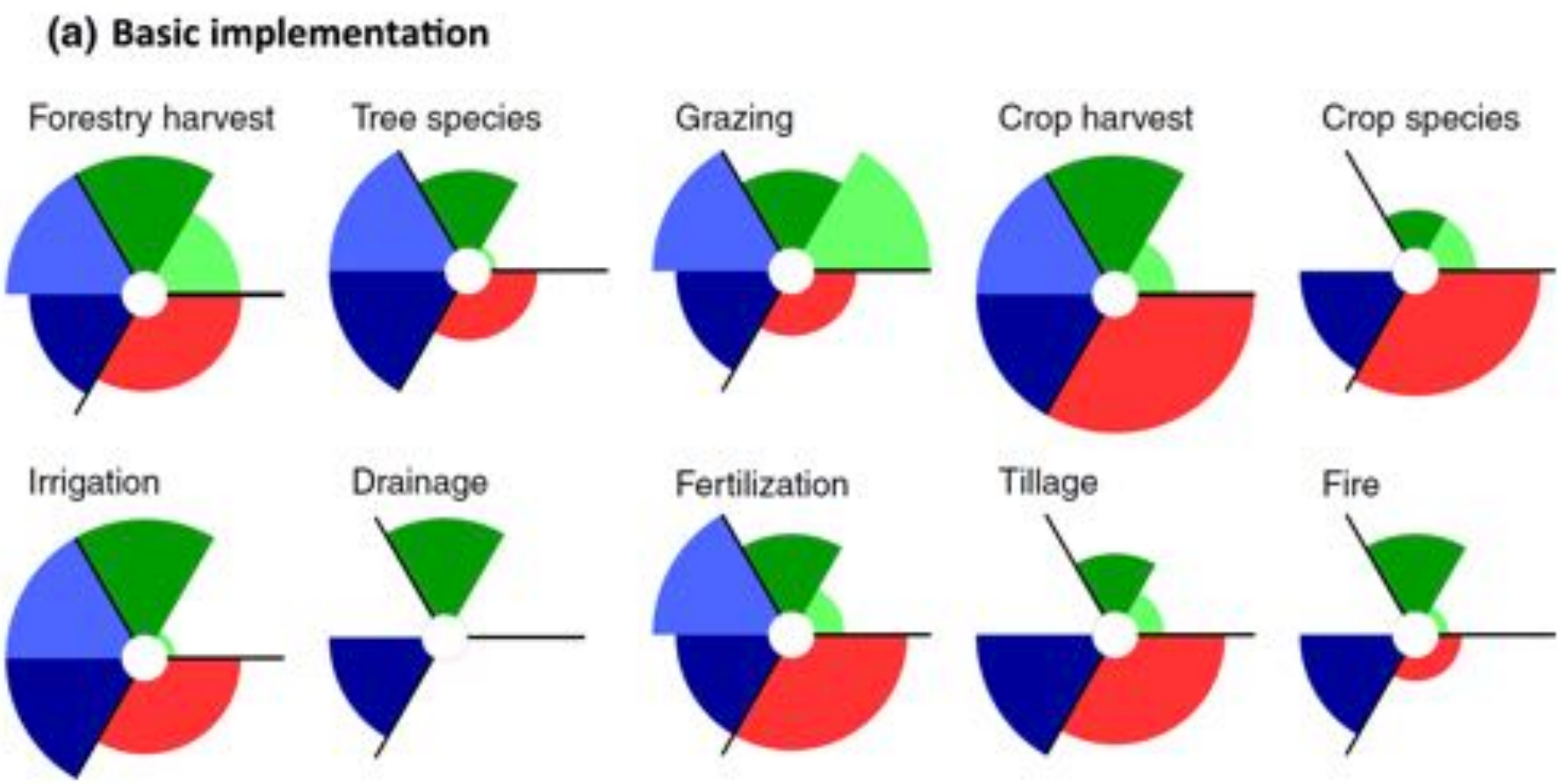


Irrigation (Simple)

Irrigation (Comprehensive)

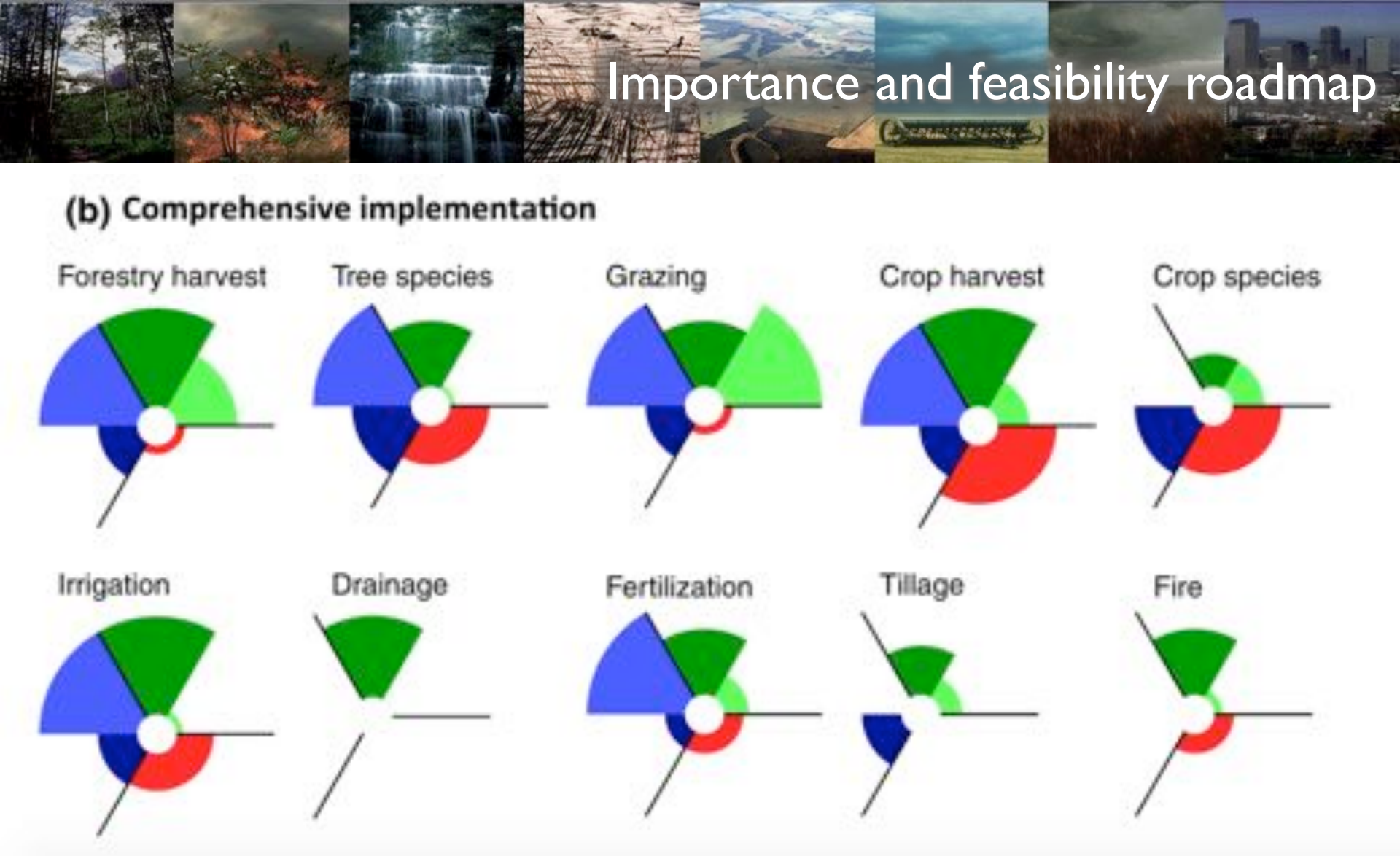
Pongratz et al., GCB, 2018

Importance and feasibility roadmap



Pongratz et al., GCB, 2018

Importance and feasibility roadmap



Pongratz et al., GCB, 2018

So, how do we collectively move forward in the face of all this (relatively new) complexity?

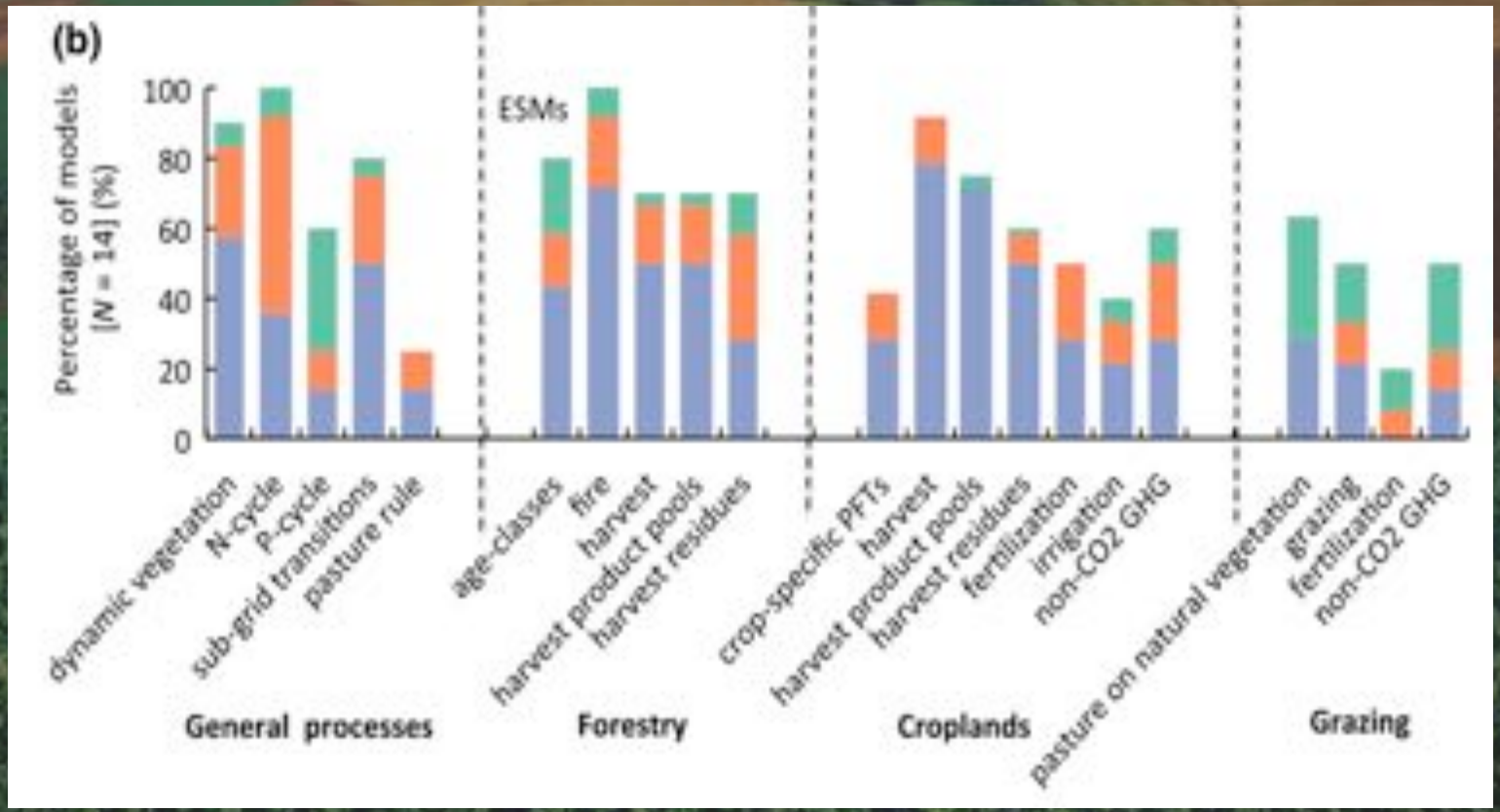
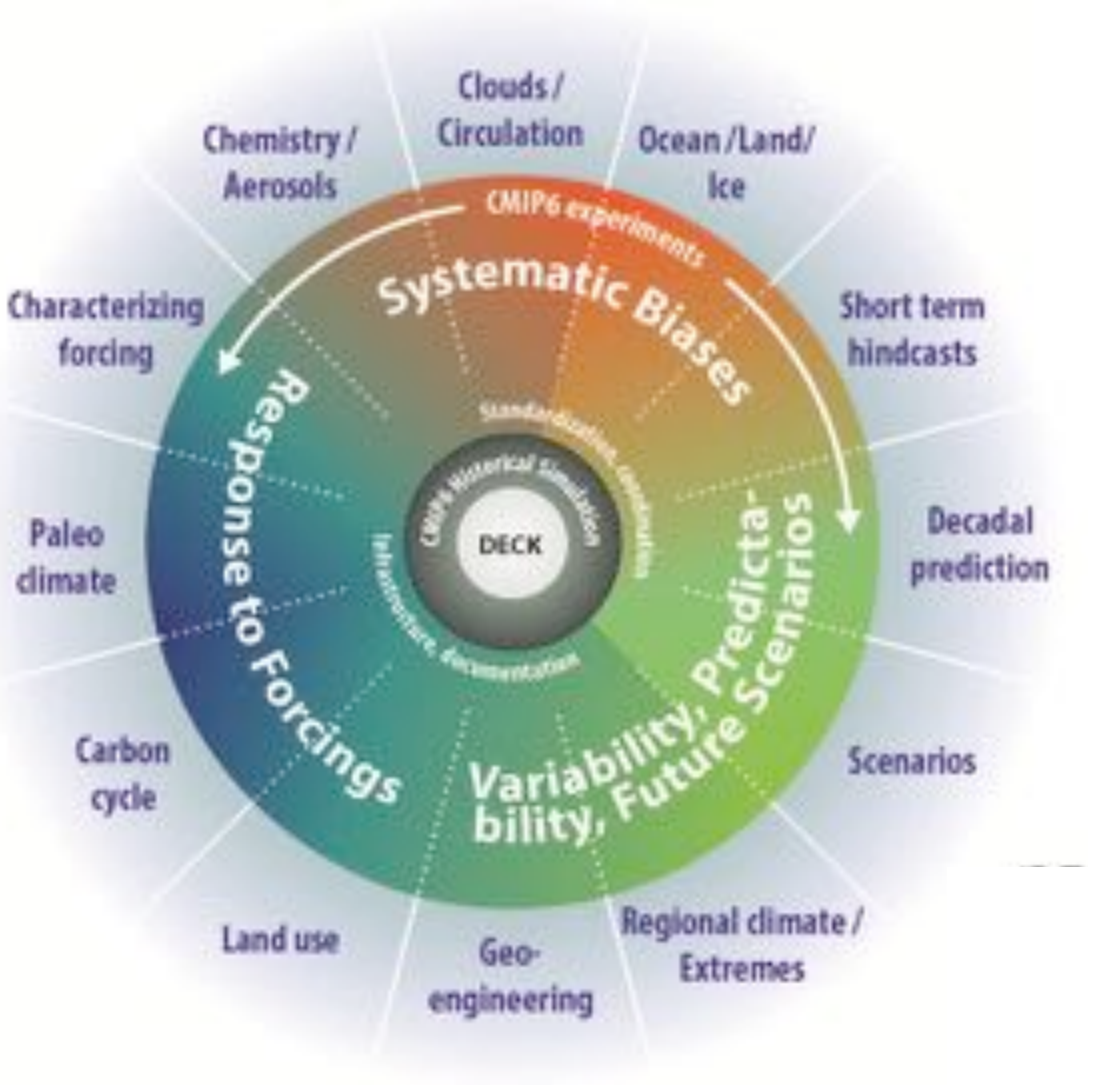


Image: Frans Lanting/Robert Harding Picture Library

Land Use Model Intercomparison Project (LUMIP)

LUMIP
Land Use Change

CMIP6



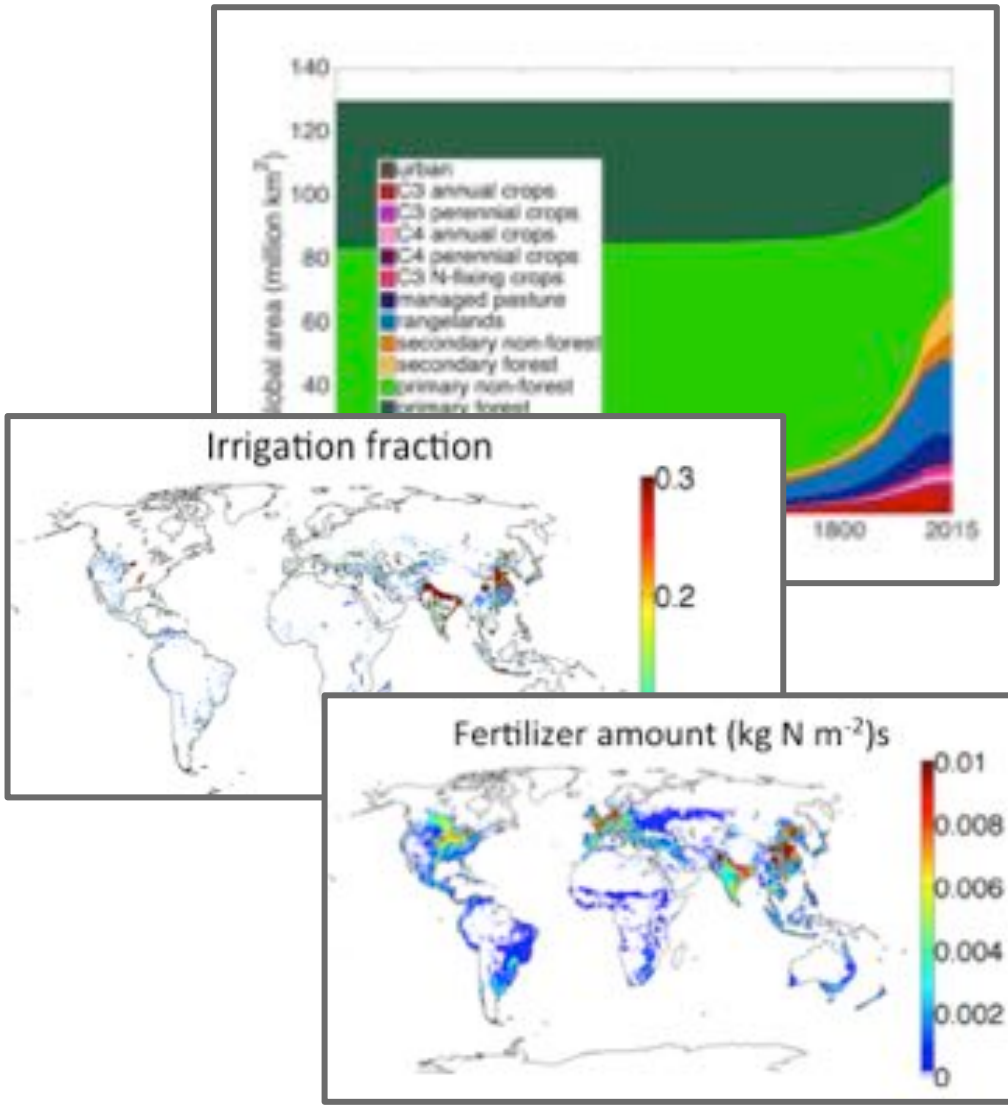
Land Use Harmonization Dataset (LUHv2)

0.25° resolution
850 to 2100 (5 SSPs)

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

Wood Harvest
% used for industrial products
% used for commercial biofuels
% used for fuelwood

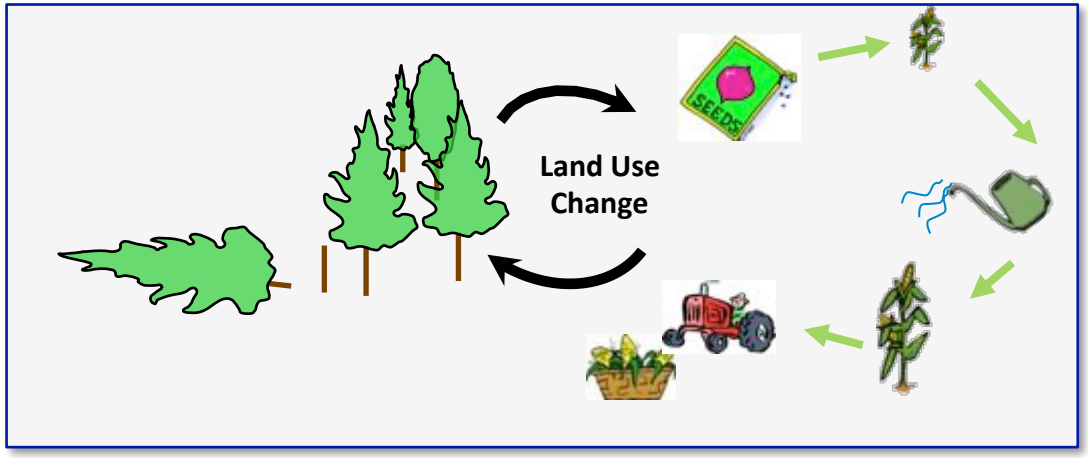


Supported by Hurtt and Lawrence DOE-SciDAC Project

Land Use Model Intercomparison Project
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 (land-hist of LS3MIP)



Lawrence et al., 2016

Land Use Model Intercomparison Project
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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 (land-hist of LS3MIP)**

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

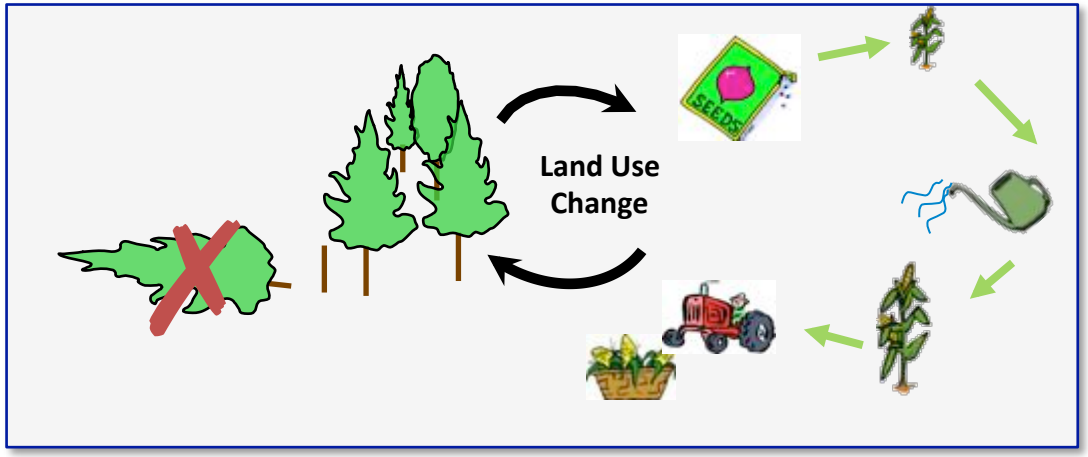
10 No wood harvest

11 No grazing on pastureland

12 No human fire ignition/suppression

13 Constant 1850 CO_2

14 Constant 1850 climate



Lawrence et al., 2016

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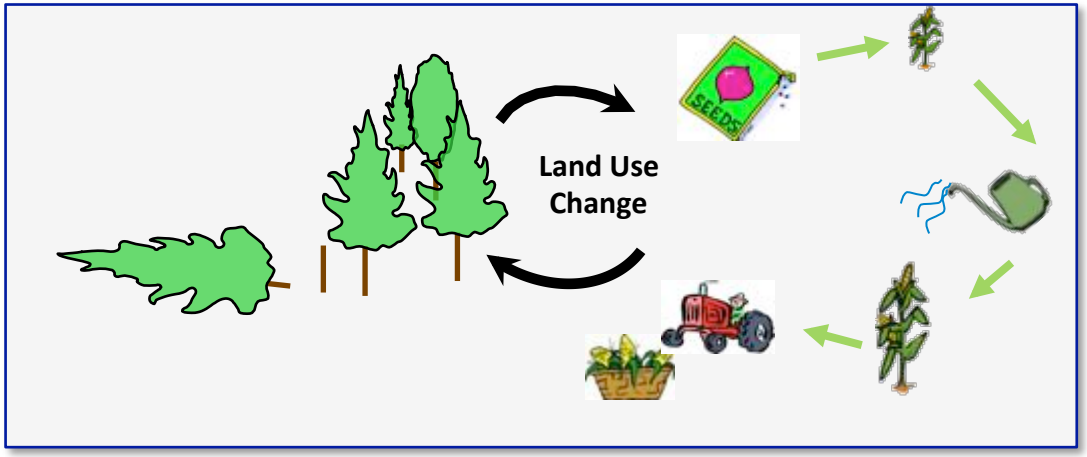
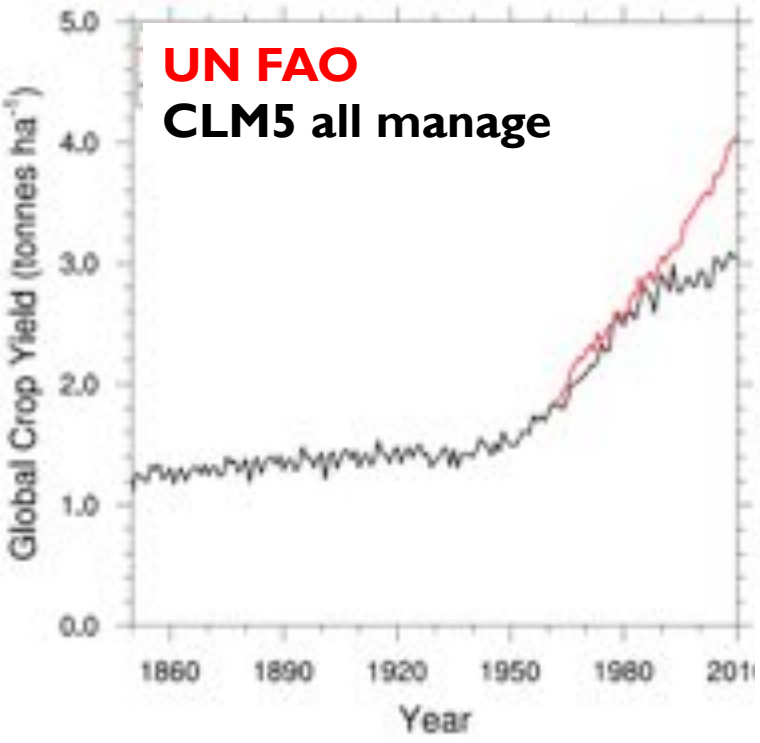
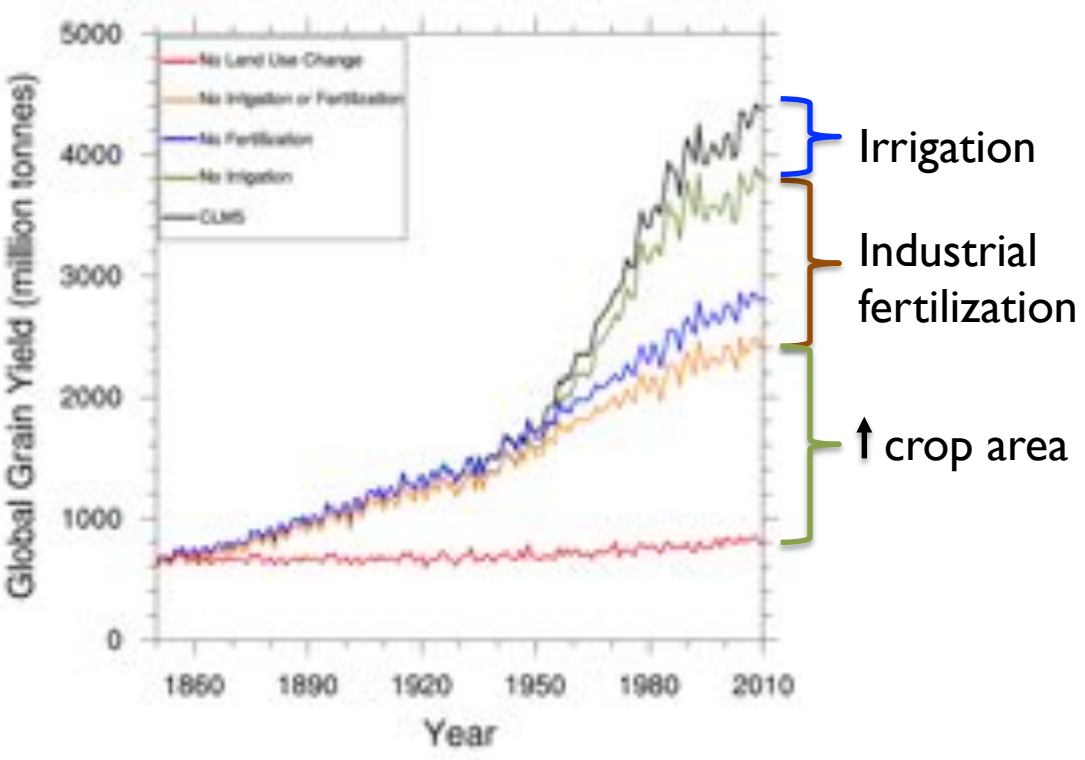


Lawrence et al., 2016

Land-only land management experiments with CLM5

Crop Yield



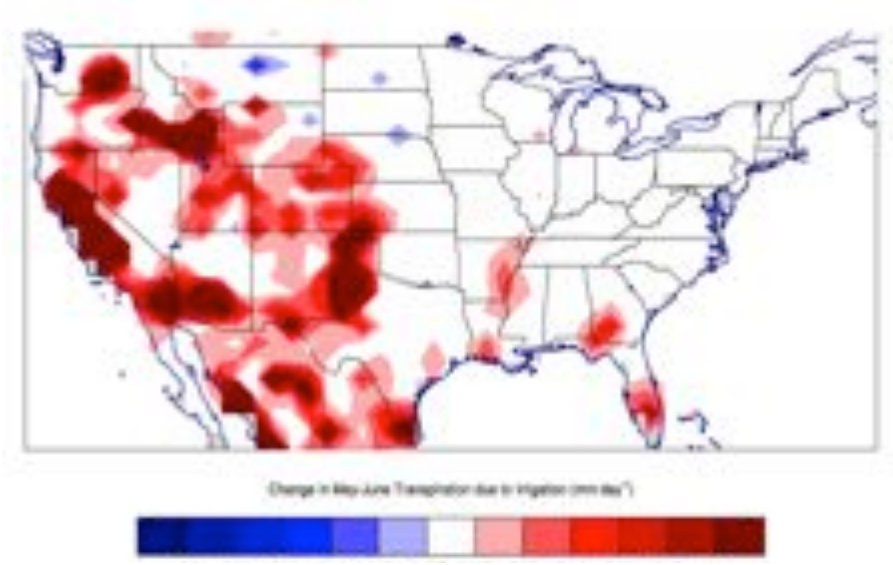


Lombardozzi et al., in prep

Impact of fertilization and irrigation on transpiration (preliminary results)

ΔTranspiration w/ irrigation

land-hist – land-nocropirr



Summary: Prospects for implementation of land management practices in ESMs

Opportunities (Imperatives)

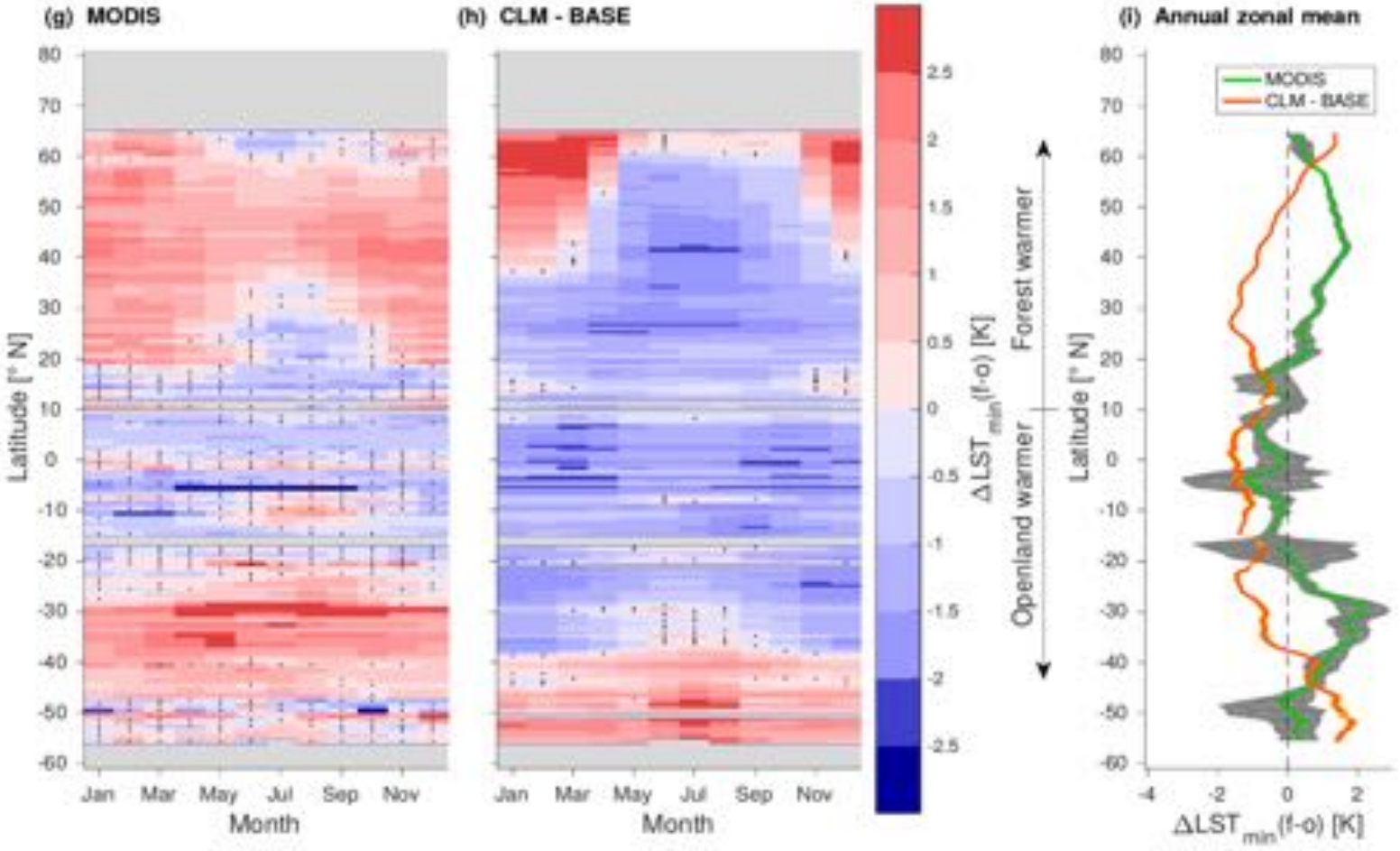
- Land management is pervasive and can strongly impact weather, climate, and biogeochemical cycles
- Land management strategies likely to play key roles in mitigation and adaptation
- Vastly expands research applications
- Embedded physically-based and -consistent impacts models

Challenges

- Lot of work; prioritization
- Input datasets, validation/ assessment datasets since 1993
- Increasing divergence across models
- Increases importance of underlying physical and biological processes
  - Plant physiology
  - Hydrology
  - Land-atmos interactions

Land Surface Temperature

Daily minimum LST

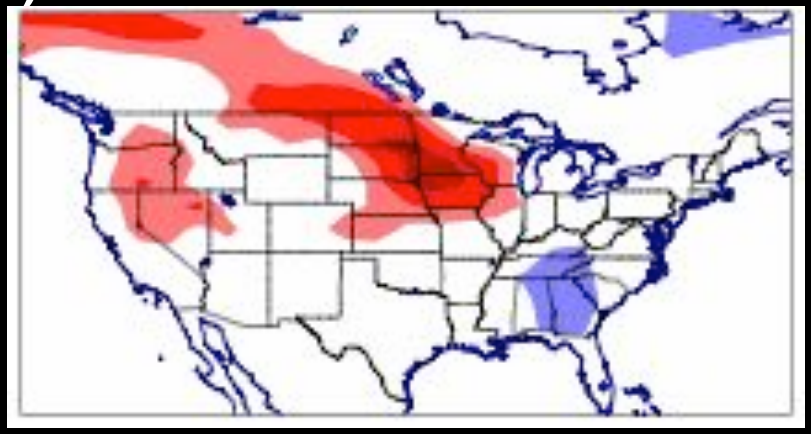


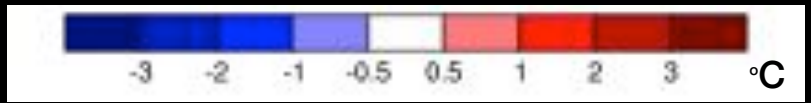
Meier et al. (submitted)


With Cover Crop
No Cover Crop
http://calag.ucanr.edu/Archive/?article=ca.v057n02p48

Change in Winter Surface Temperature (°C)

Tall, Sparse:
LAI = 1
Height = 50 cm

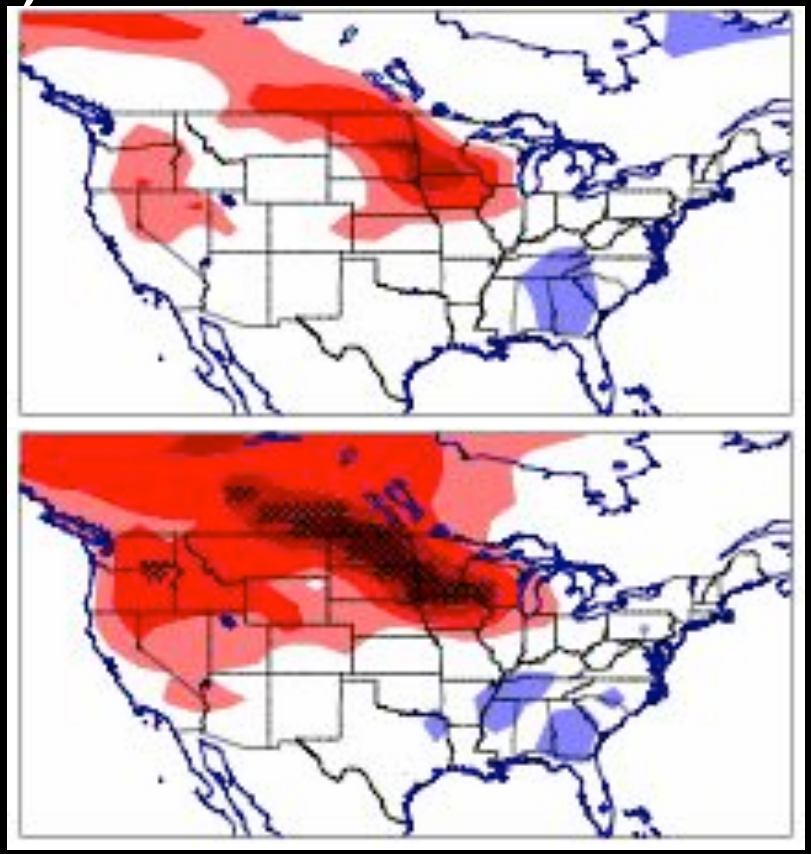


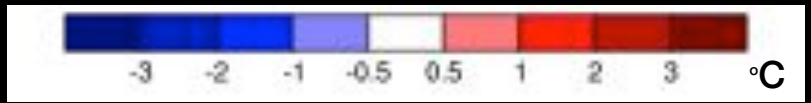


Change in Winter Surface Temperature (°C)

Tall, Sparse:
LAI = 1
Height = 50 cm

Tall, Leafy:
LAI = 4
Height = 50 cm



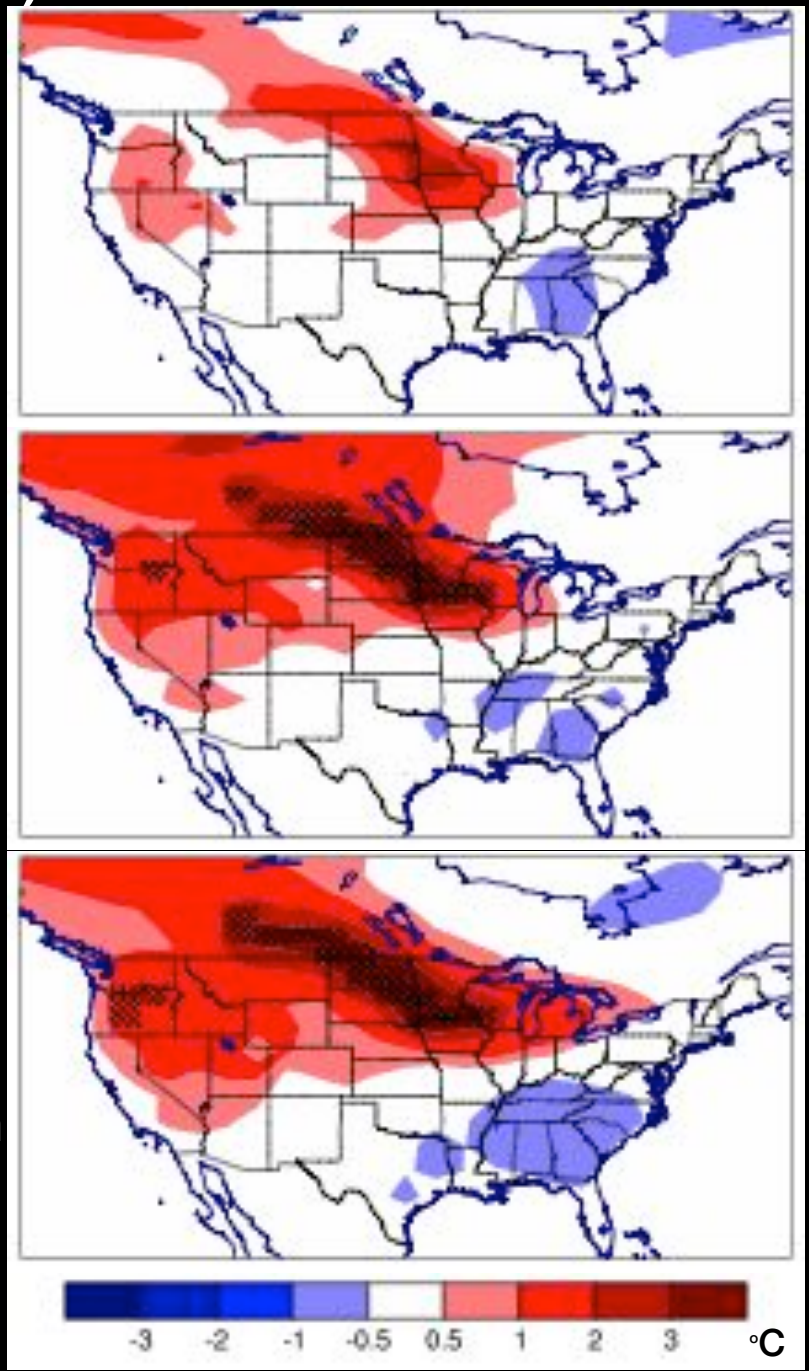


Change in Winter Surface Temperature (°C)

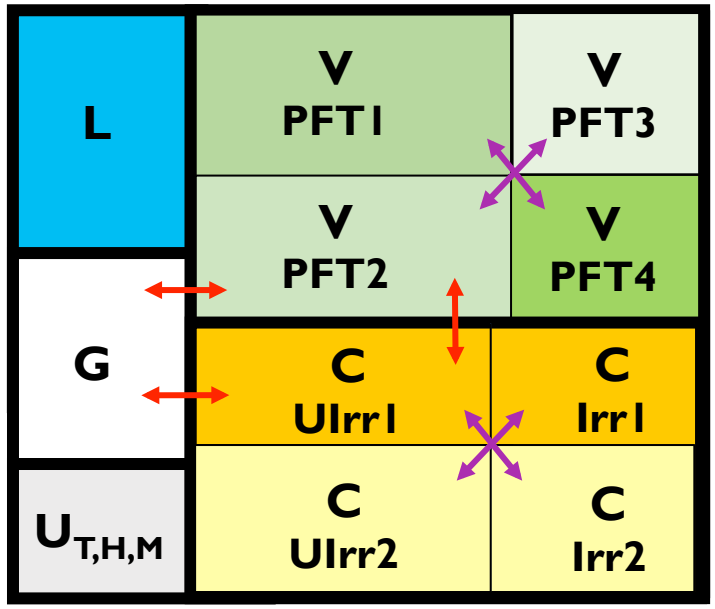
Tall, Sparse:
LAI = 1
Height = 50 cm

Tall, Leafy:
LAI = 4
Height = 50 cm

Short, Leafy:
LAI = 4
Height = 10 cm

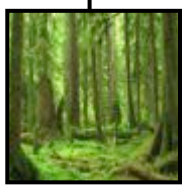


Heterogeneity



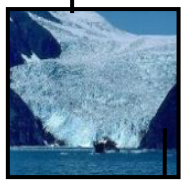
Gridcell

Landunit


Vegetated


Lake

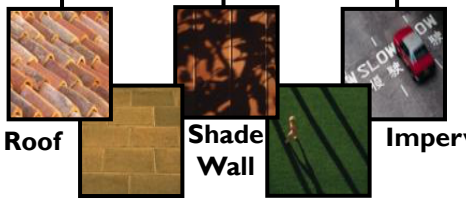
Urban


Glacier


Crop

Column


Soil




Elevation classes


Unirrig


Irrig


Unirrig


Irrig

Patch


PFT1


PFT2


PFT3


PFT4 …

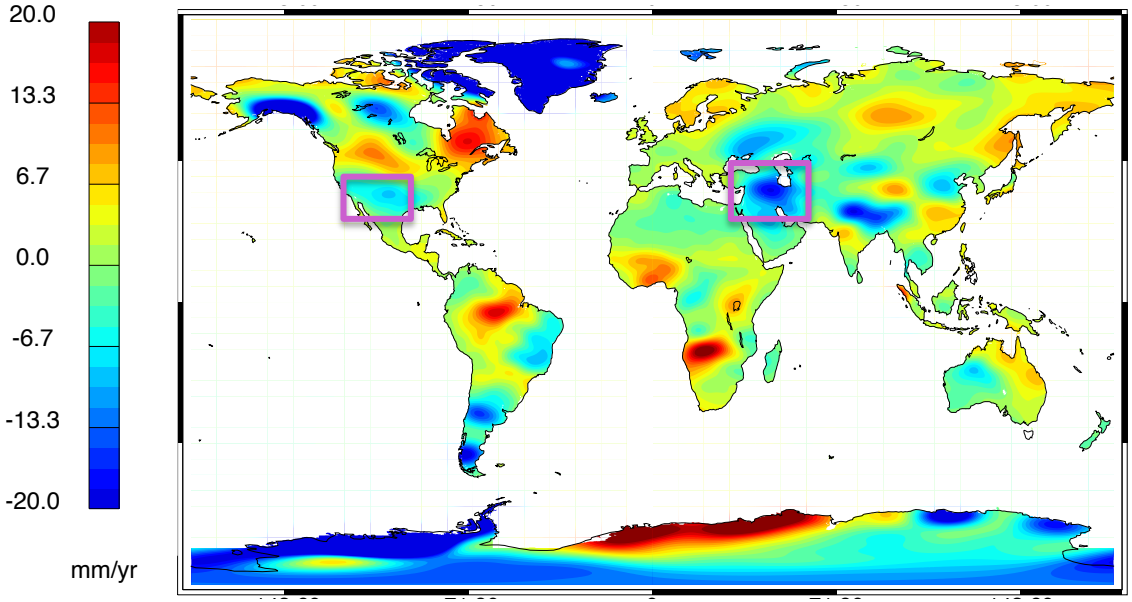

Crop1


Crop1


Crop2

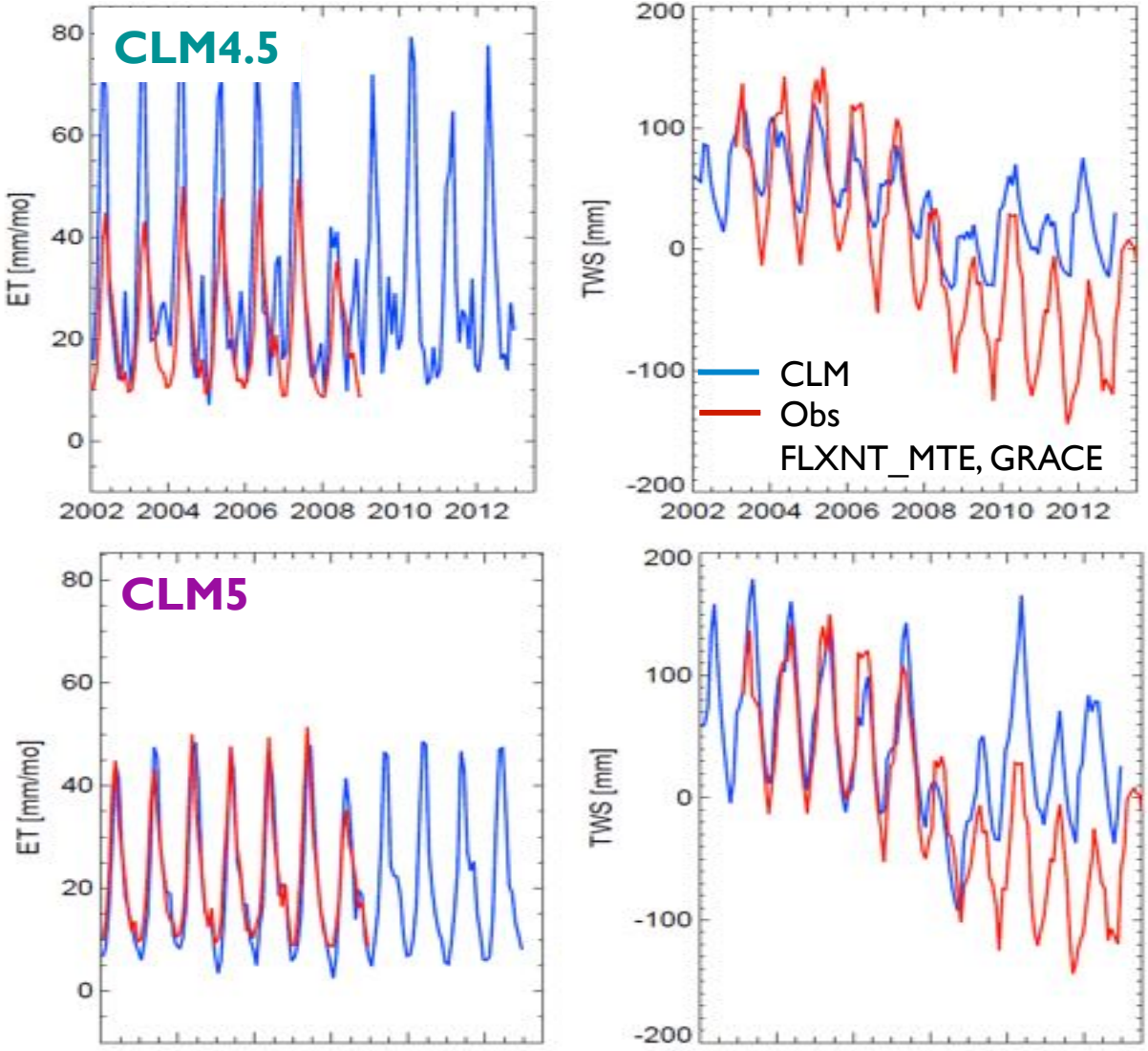

Crop2 …

GRACE trends in Total Water Storage (2003 to 2015)



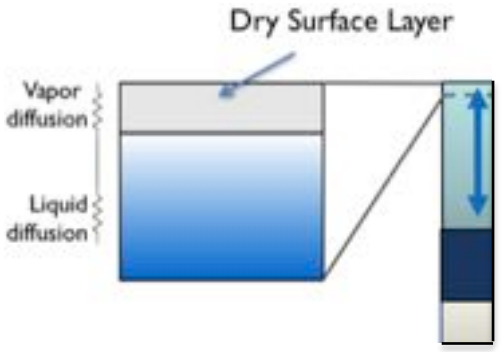
Detecting anthropogenic groundwater withdrawal with CLM

Semi-arid region: Iran



CLM4.5 ET too high after rain → weak annual cycle of water storage

Resolved in CLM5 with 'dry surface layer' parameterization (Swenson and Lawrence, 2014)



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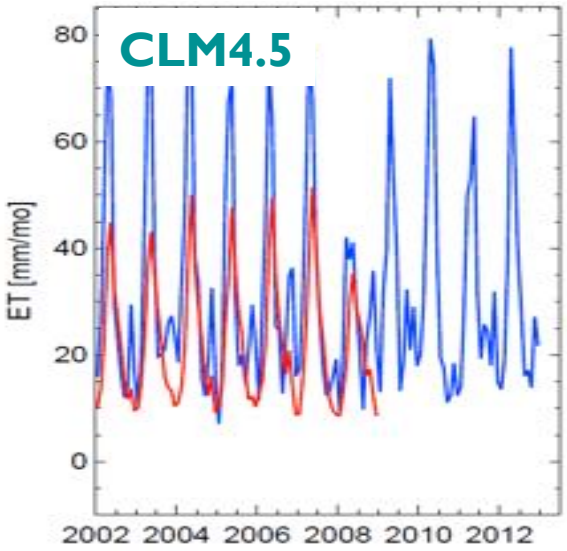

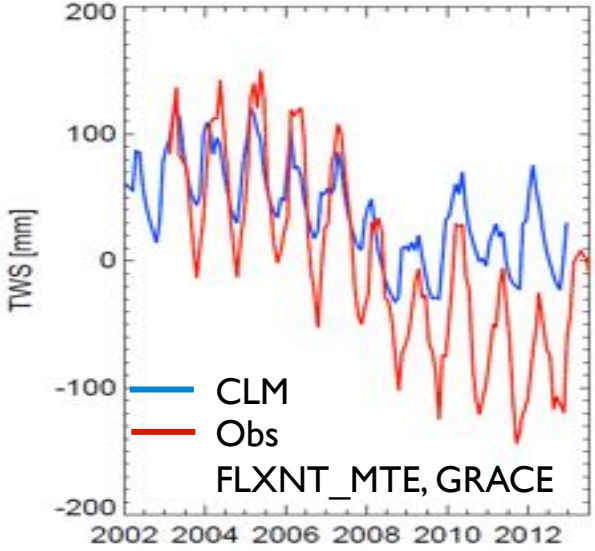

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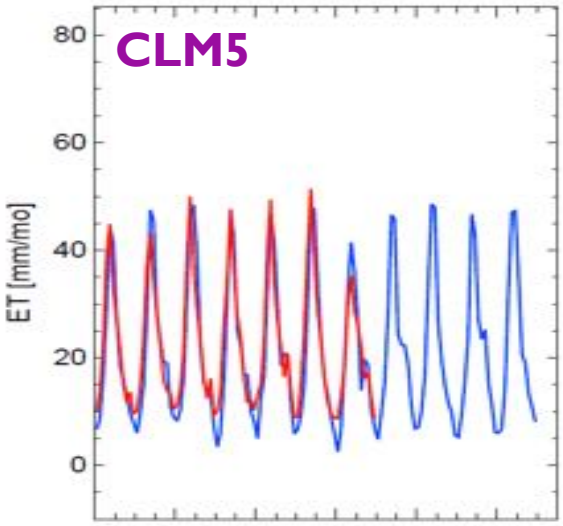
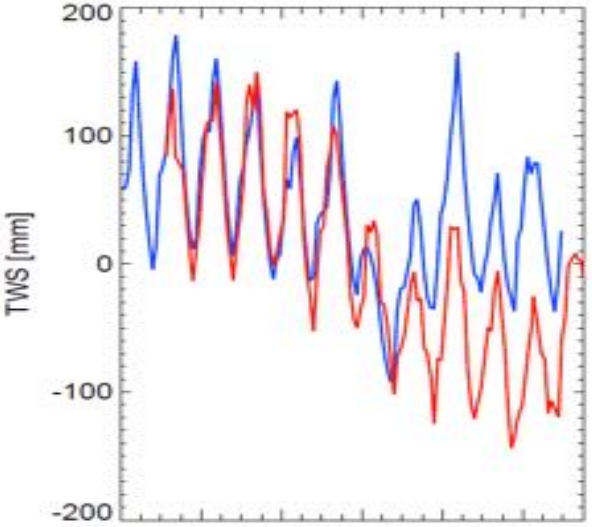
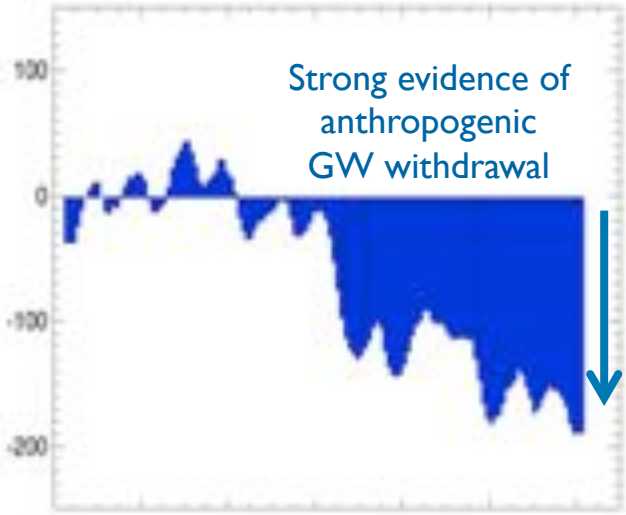


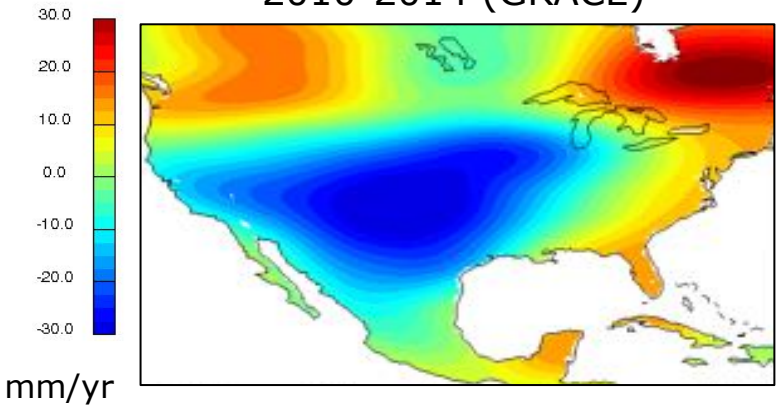


Obs Water Storage – CLM Water Storage



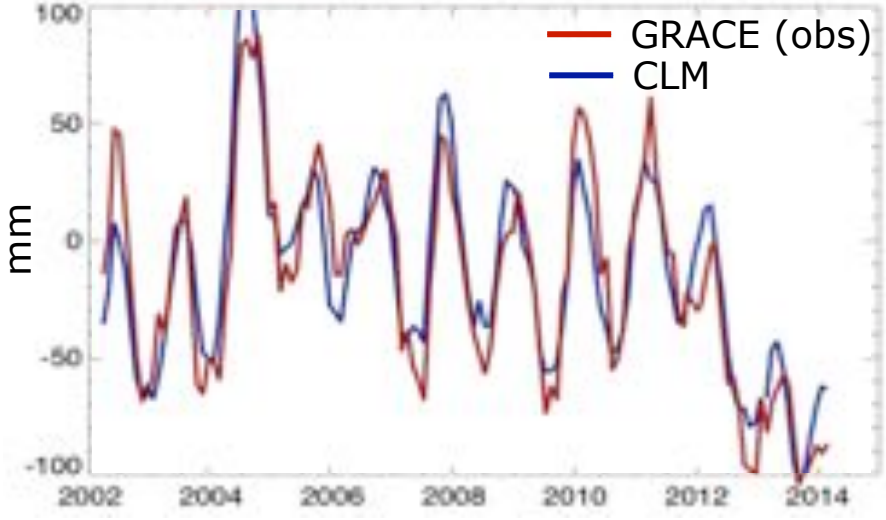
Detecting anthropogenic groundwater withdrawal

Land water storage trend over 2010-2014 (GRACE)

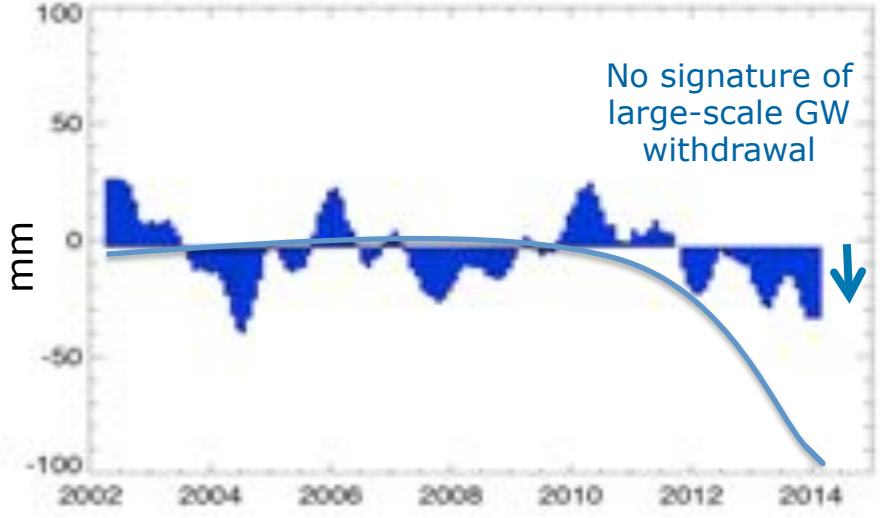


Recent studies suggest that anthropogenic groundwater depletion in **Colorado River basin** during recent drought threatens future water supply

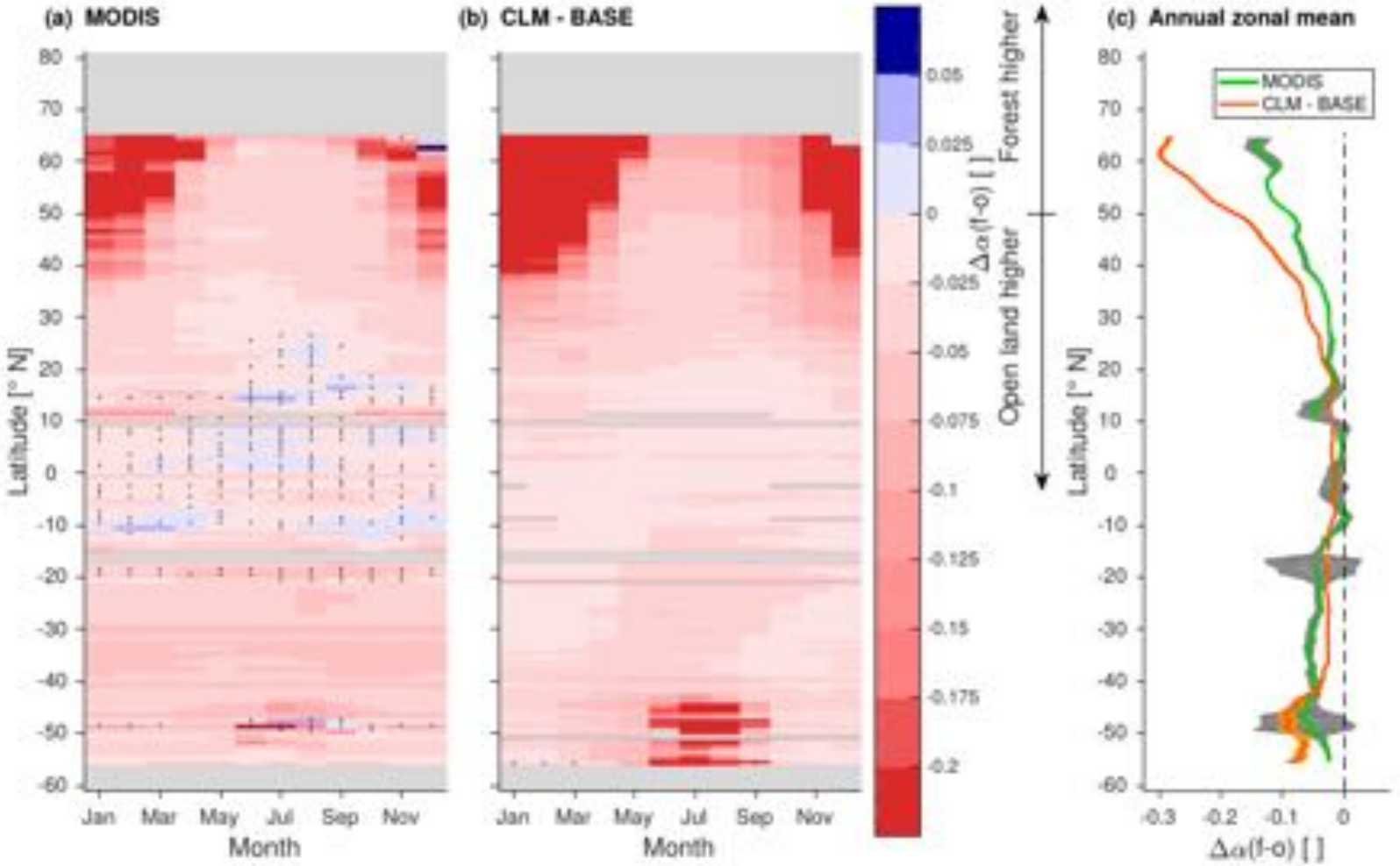
Land Water Storage Anomaly
Colorado River Basin



Obs Water Storage – CLM Water Storage
Colorado River Basin



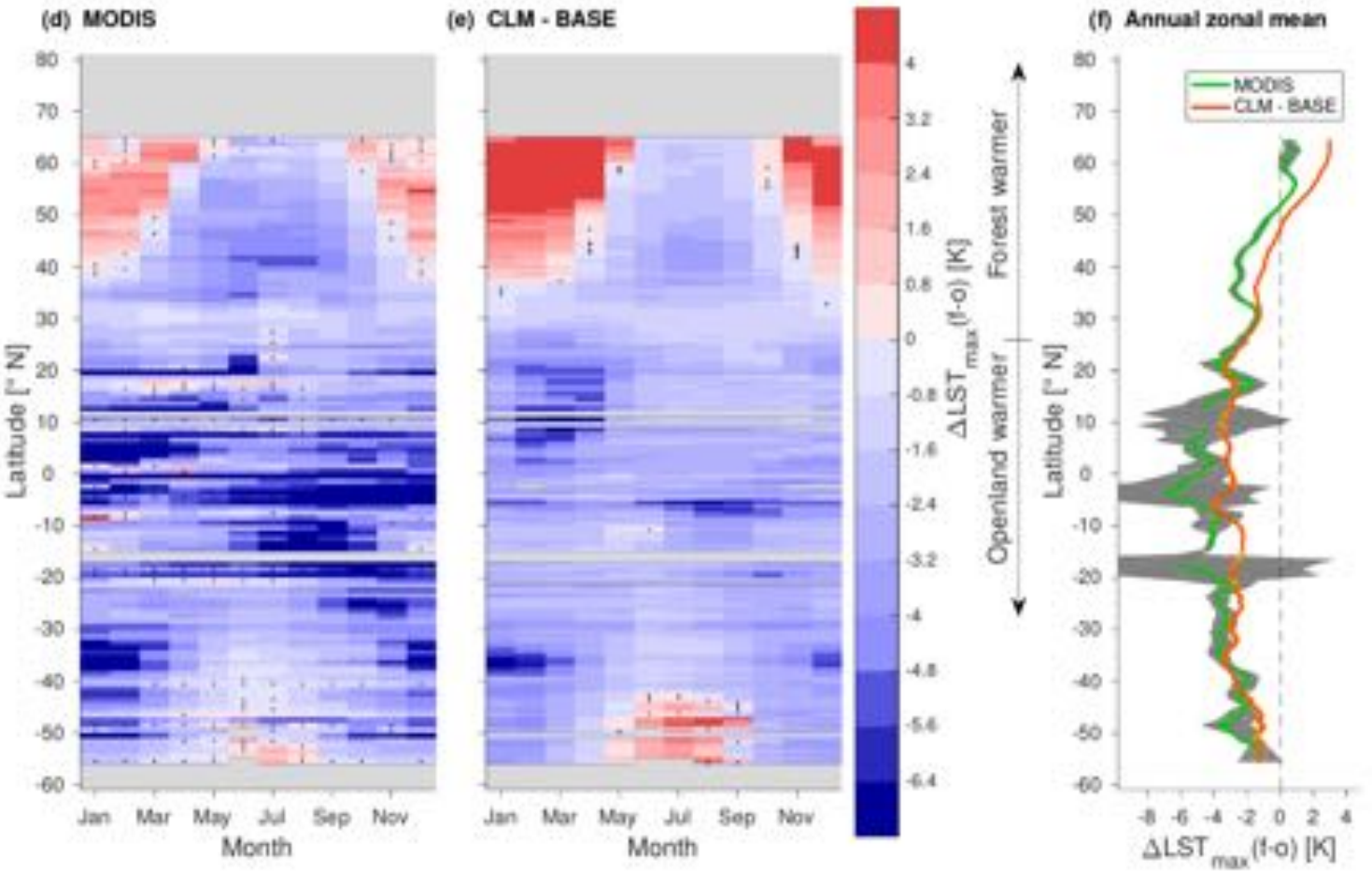
Albedo



Meier et al. (submitted)

Land Surface Temperature

Daily maximum LST



Meier et al. (submitted)

What's next?

Terrestrial Processes in CMIP6

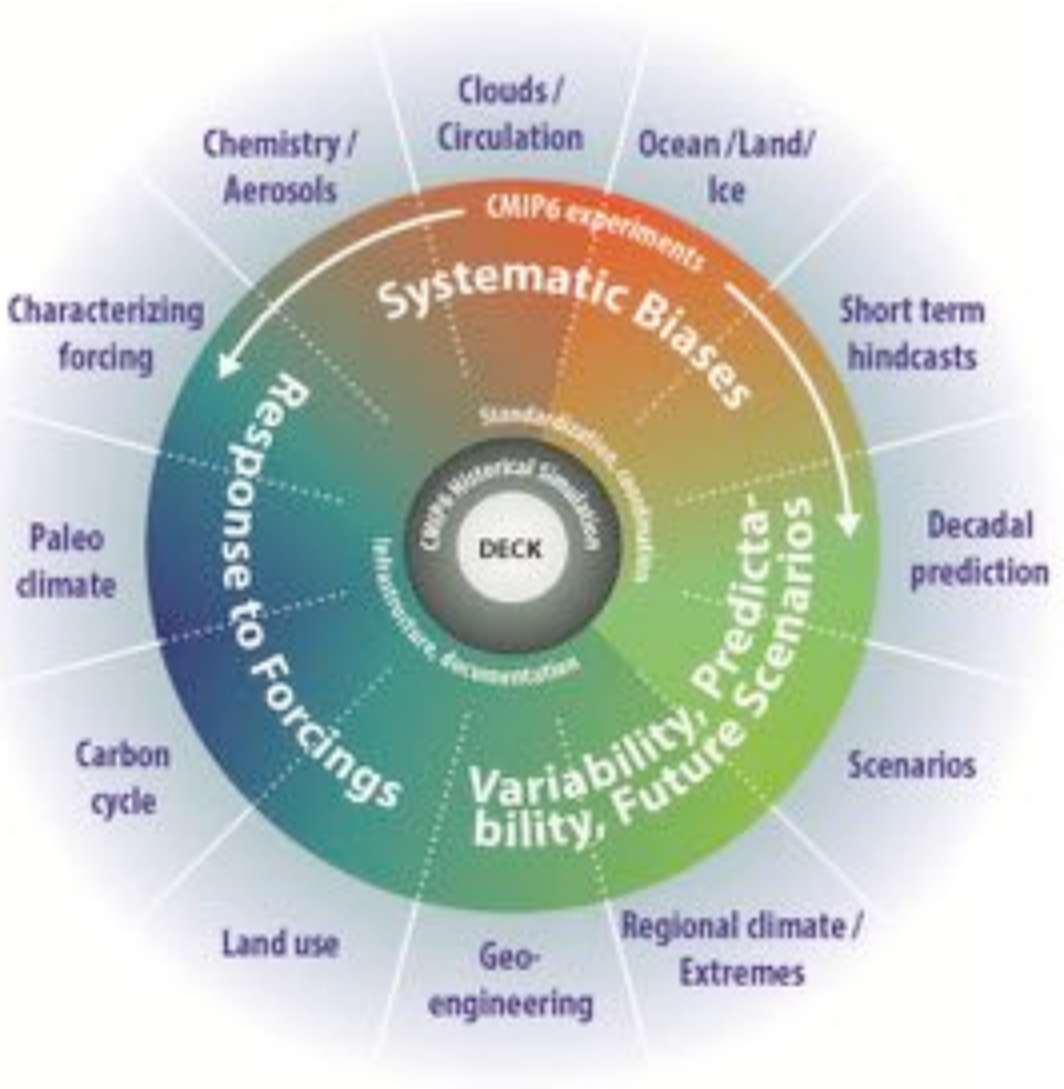
Coordinated activities to assess land role and response to climate and climate change

- **Land-only** simulations forced with obs historical climate, land systematic biases

- **Land Use (LUMIP)**
  land use forcing on climate and carbon, impacts of land management, land management as mitigation

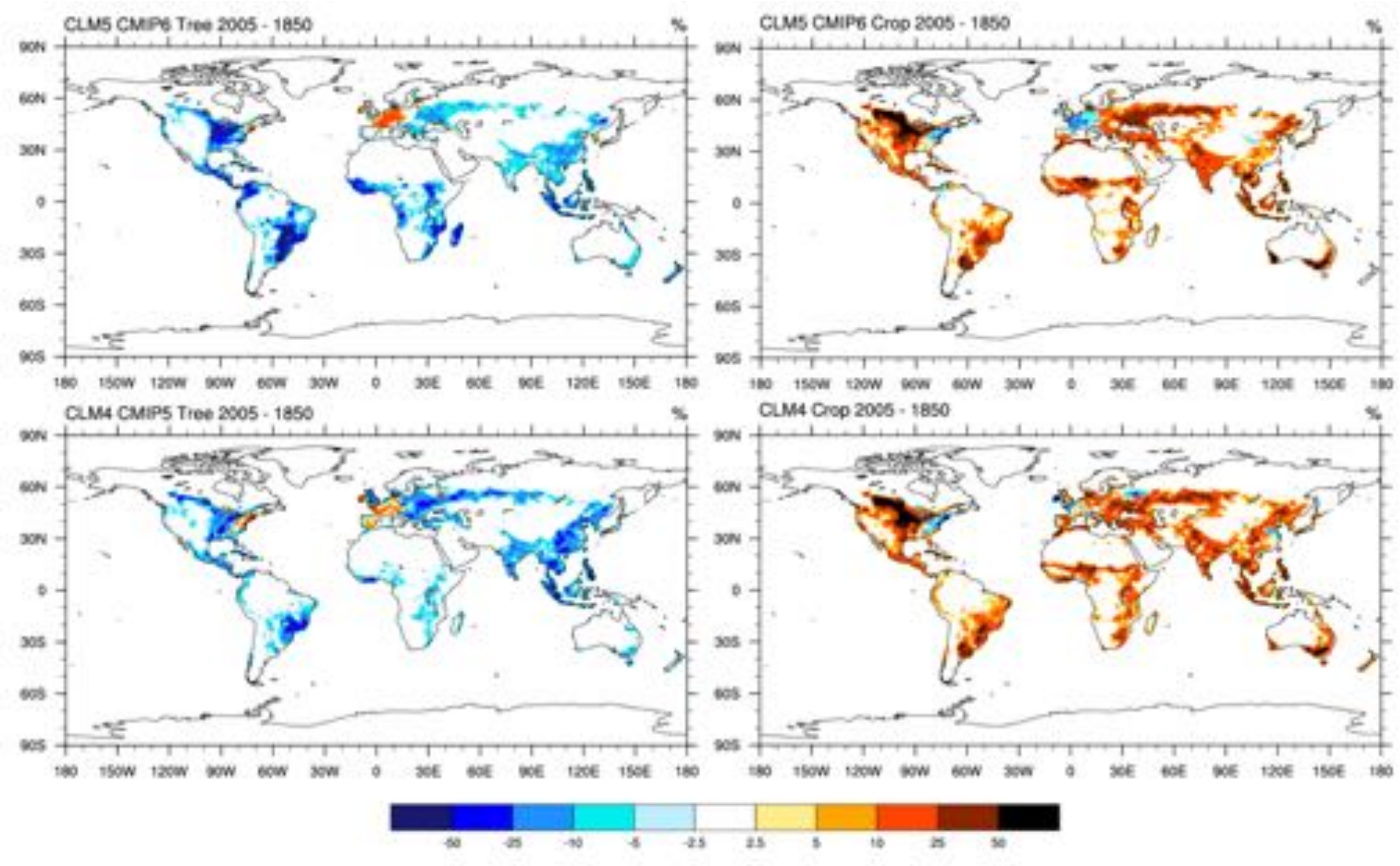
- **Water, Land-atmos (LS3MIP)**
  biogeophys feedbacks including soil moisture and snow feedbacks

- **Carbon (C4MIP)** land biogeochemical feedbacks on climate, permissible emissions



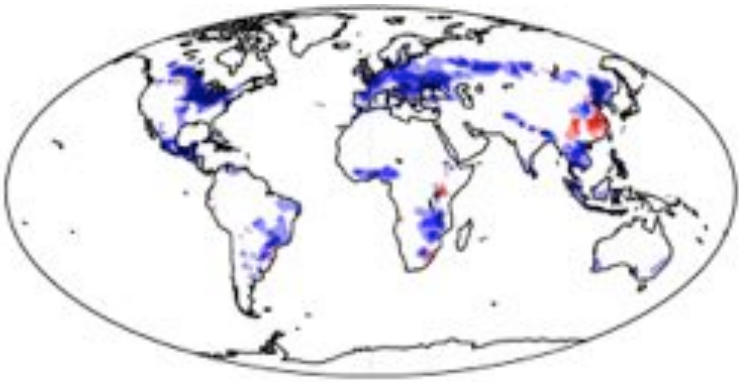
Updated from Meehl et al., EOS, 2014

CLM5 LUMIP vs CLM4 CMIP5 Land Cover in 1850 – 2005

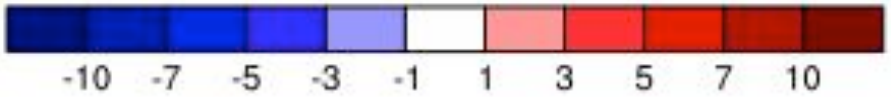


Change[+] in Future Crop Yields

Using a business-as-usual scenario (RCP8.5)



← **Due to future climate***



g C m^{-2}

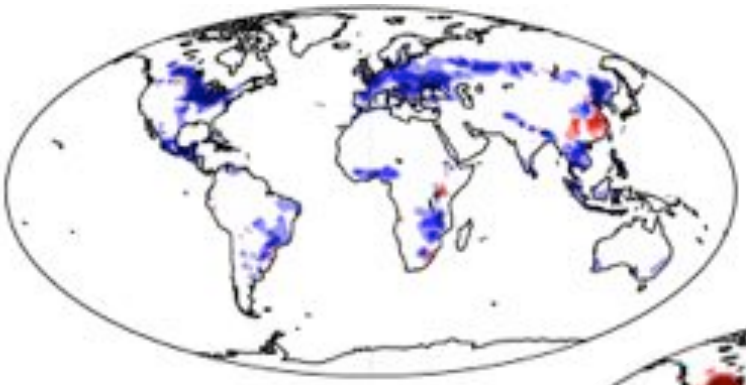
[+] 2100 relative to 2015

[*] temperature & precipitation

Lombardozzi et al. In prep

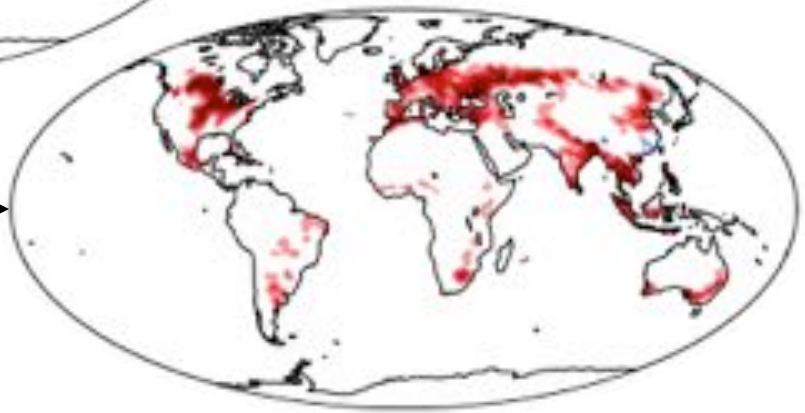
Change[+] in Future Crop Yields

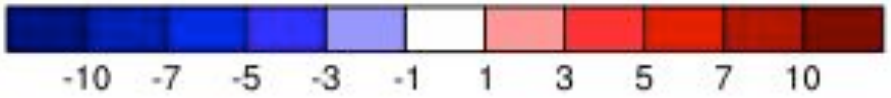
Using a business-as-usual scenario (RCP8.5)



Due to future climate*

Due to future CO_2





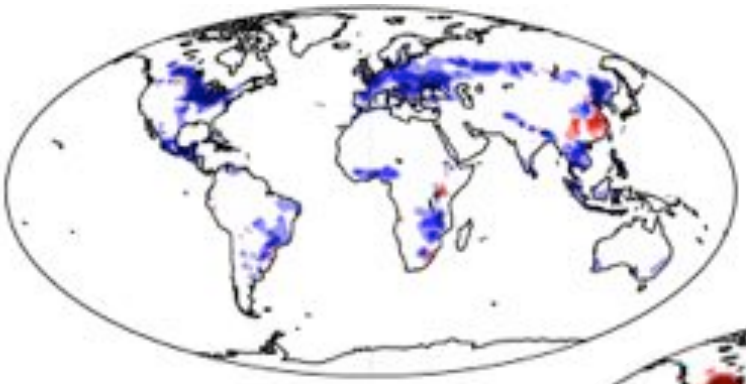
[+] 2100 relative to 2015

[*] temperature & precipitation

Lombardozzi et al. In prep

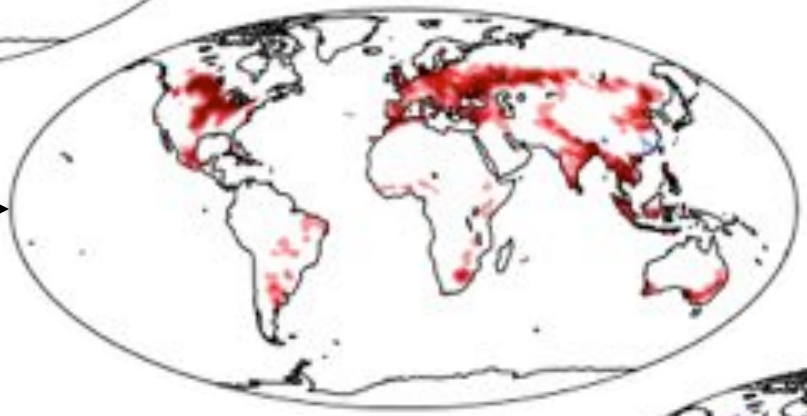
Change[+] in Future Crop Yields

Using a business-as-usual scenario (RCP8.5)

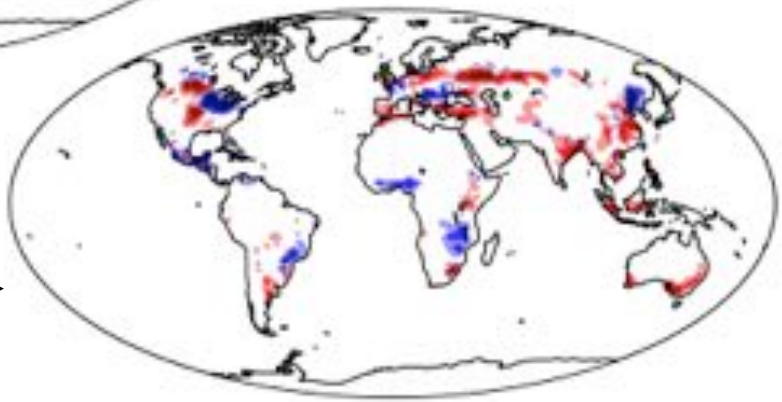


Due to future climate*

Due to future CO_2



Due to the combination of future climate & CO_2



g C m^{-2}

[+] 2100 relative to 2015

[*] temperature & precipitation

Lombardozzi et al. In prep


Management techniques and technological advances are necessary to increase crop yields.
We need to carefully consider the climate feedbacks that management decisions have.

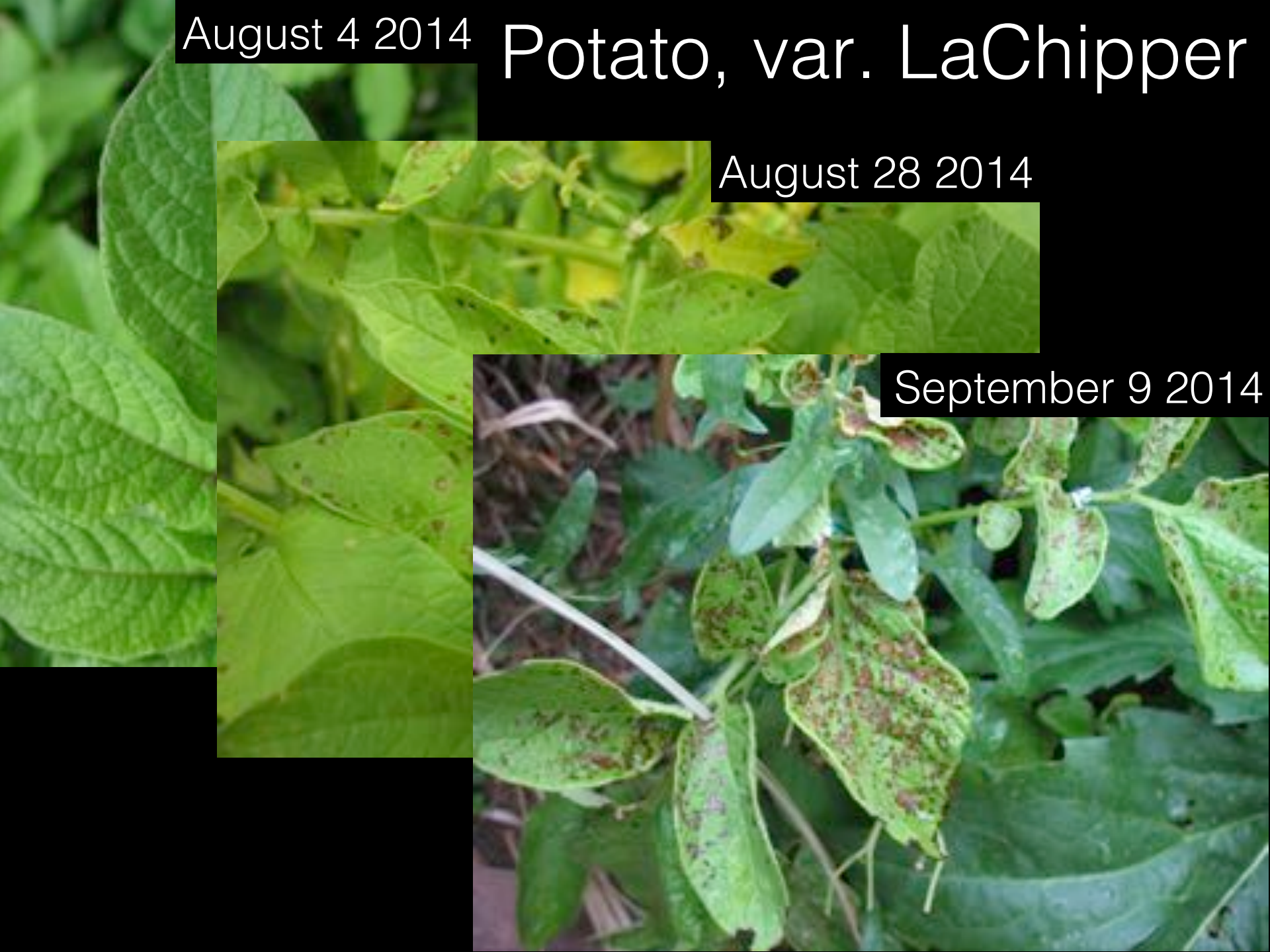
August 4 2014

Potato, var. LaChipper

Potato, var. LaChipper

August 4 2014

August 28 2014


August 4 2014
Potato, var. LaChipper
August 28 2014
September 9 2014