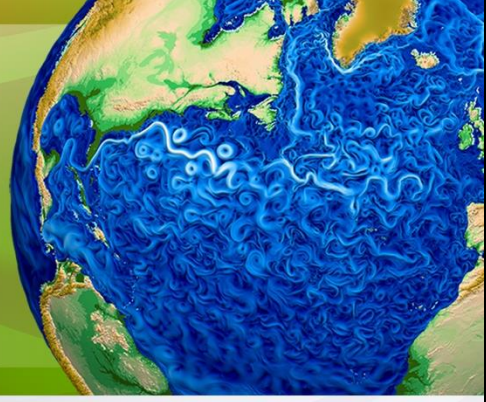
E3SM
Energy Exascale
Earth System Model



Modeling the Influence of Land Use and Land Cover Change (LULCC)

Atul Jain

Shijie Shu & Xiaoming Xu

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Collaborators
Katherine Calvin, Xiaojuan Yang, Dan Ricciuto & Gautam Bisht

Acknowledgements
DOE (No. DE-SC0016323)

U.S. DEPARTMENT OF ENERGY

Overall Objective of our E3SM Project

- Improve our understanding of the dynamics and drivers of LULCC
  - Improve our understanding of the impacts of LULCC dynamics on the quantities and pathways of land carbon and nitrogen fluxes

Motivation

nature COMMUNICATIONS

ARTICLE

DOI: 10.1038/s41467-018-05340-z OPEN

Land-use emissions play a critical role in land-based mitigation for Paris climate targets

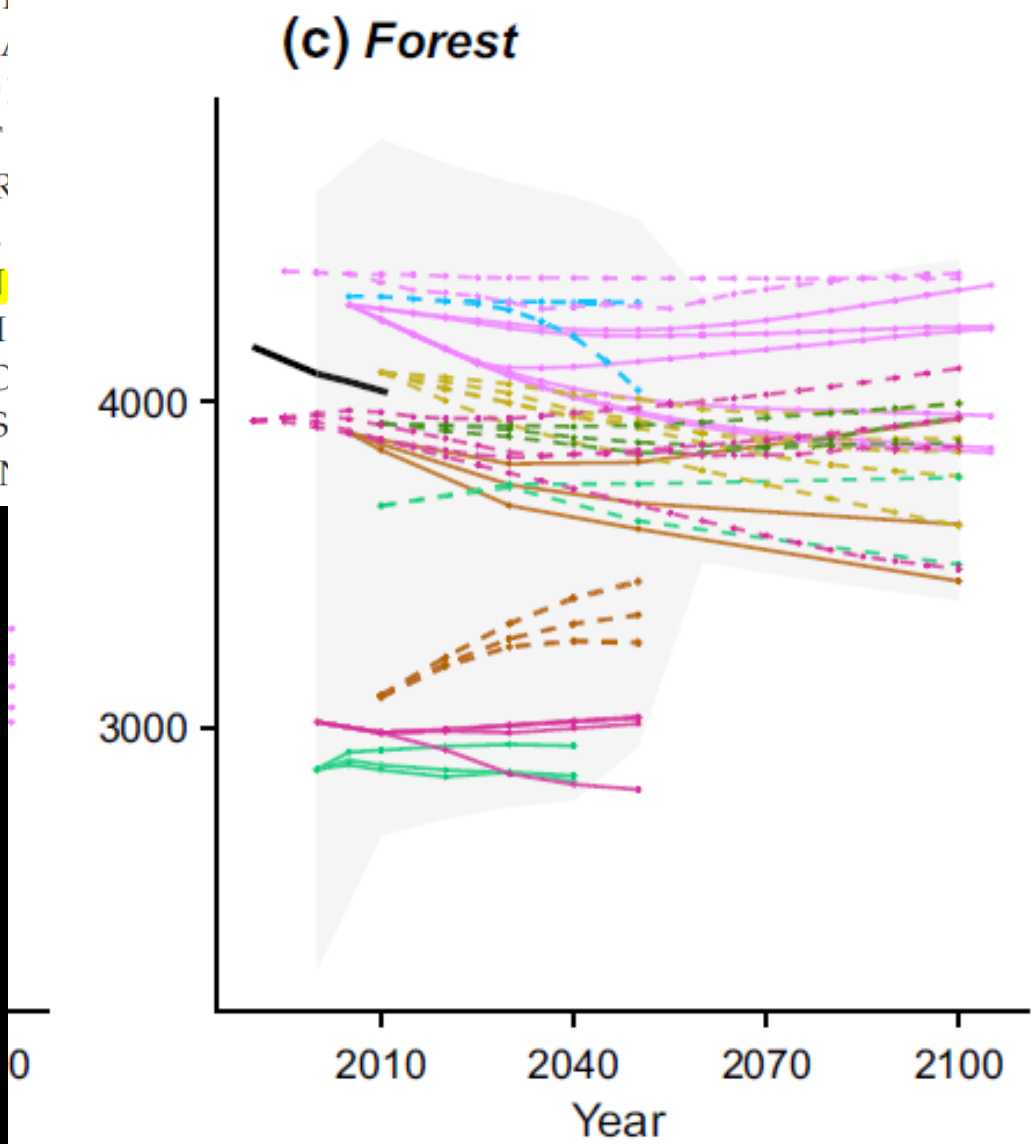
Anna B. Harper[1], Tom Powell[2], Peter M. Cox[1], Joanna House[3], Chris Huntingford[4], Timothy M. Lenton[2], Stephen Sitch[2], Eleanor Burke[5], Sarah E. Chadburn[1,6], William J. Collins[7], Edward Comyn-Platt[4], Vassilis Daioglou[8,9], Jonathan C. Doelman[8], Garry Hayman[4], Eddy Robertson[5], Detlef van Vuuren[8,9], Andy Wiltshire[5], Christopher P. Webber[7], Ana Bastos[10,11], Lena Boysen[12], Philippe Ciais[11], Narayanappa Devaraju[11], Atul K. Jain[13], Andreas Krause[14], Ben Poulter[15] & Shijie Shu[13]

NATURE COMMUNICATIONS | (2018)9:2938 | DOI: 10.1038/s41467-018-05340-z | www.nature.com/naturecommunications

Global Change Biology (2016), doi: 10.1111/gcb.13447

Assessing uncertainties in land cover projections

PETER ALEXANDER[1,2], REINHARD PREST
CLAUDIA BARANZELLI[5], FILIPE BATIST
KATHERINE CALVIN[7], NICOLAS DENDO
ROBERT DUNFORD[10,11], KERSTIN ENGST
SHINICHIRO FUJIMORI[13], PAULA A. HAR
PETR HAVLIK[14], SASCHA HOLZHAUER[1],
CHRIS JACOBS-CRISIONI[5], ATUL K. JAIN
CARLO LAVALLE[5], TIM LENTON[17], JIAYI
ALEXANDER POPP[15], TOM POWELL[17], RC
ELKE STEHFEST[9], JEVGENIJS STEINBUKS
MARSHALL A. WISE[7] and MARK D. A. ROUI



Project Accomplishments

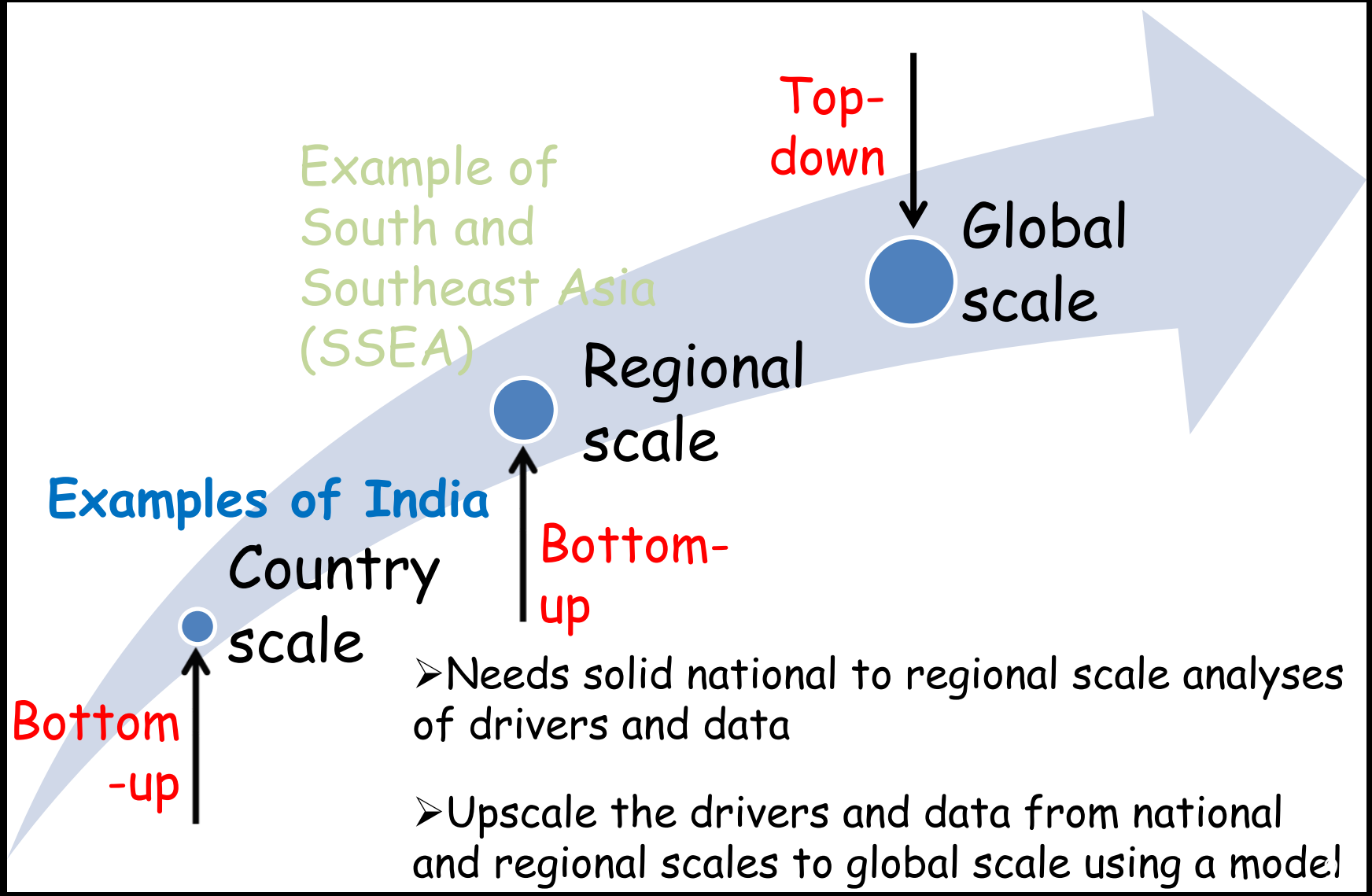
- Improve the historical LULCC data (1850-2015)
  - Use satellite and socioeconomics and biophysical driver data in combination with statistical and machine learning algorithms.
  - Global-Scale Spatial Dynamic Allocation Model (SDAM)
- Study the impacts of LULCC on BGC and BGP using ELM for the period 1850-2015
- Coupled GCAM model output for socio-economic data and biophysical data with SDAM to make projections of LULCC at 0.5 deg resolution over the period 2016-2100.
  - RCP 6.0-SSP4 and RCP 3.4-SSP4

Project Accomplishments (cont.)

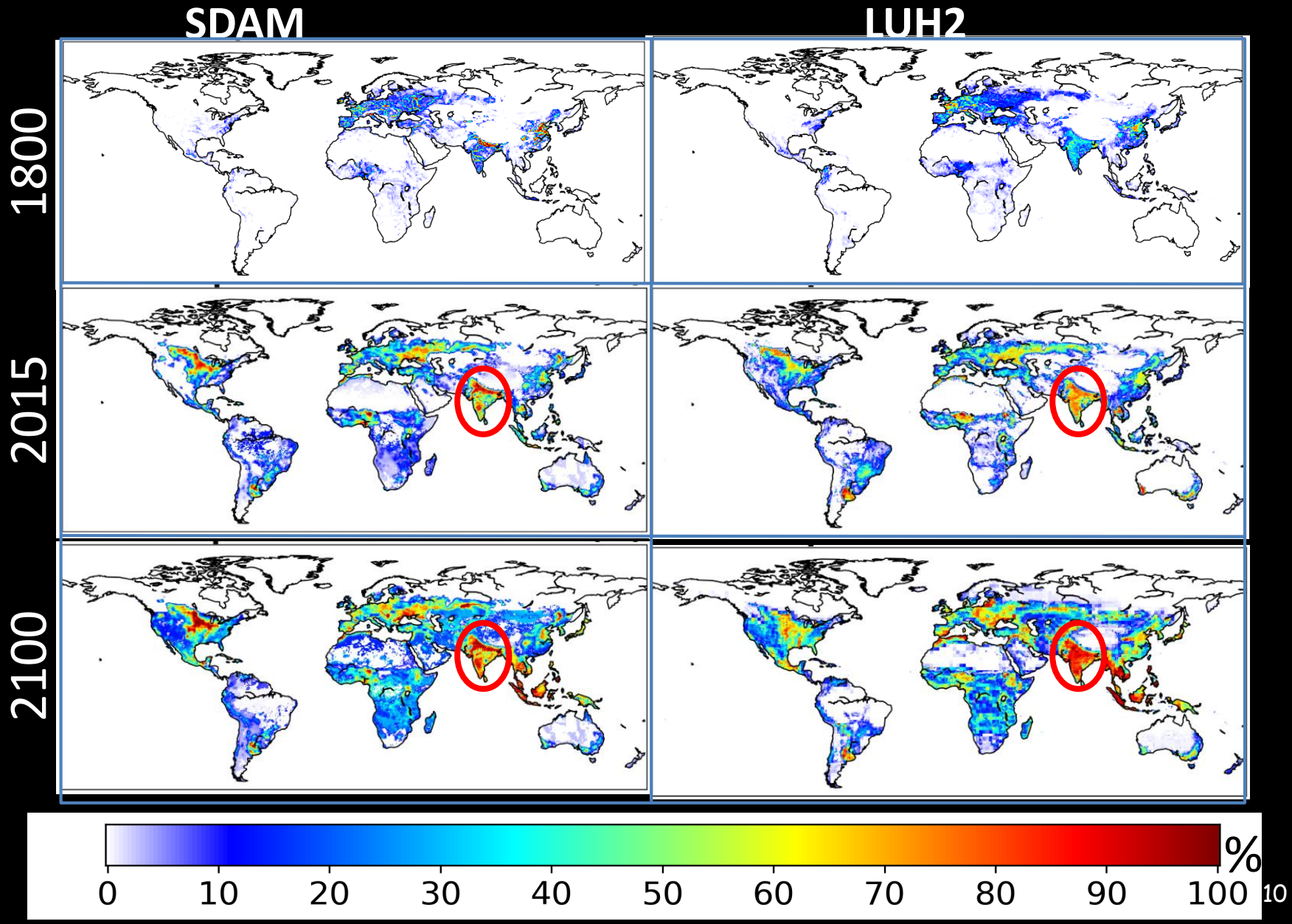
- Implemented mosaic-based (patch) approach in ELM to calculate soil properties at a grid scale
- Identified issues with soil decomposition rates used in ELM, but not made any modifications in ELM

Improving the LULCC for historical time (1850 -2015) and developing future scenarios (2016-2100)

LUC Drivers and Data at Global Scale - Mix of top-down and bottom-up approaches

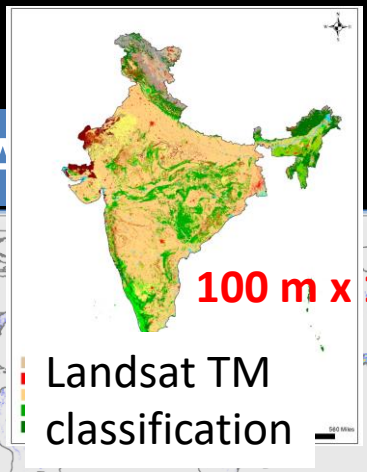


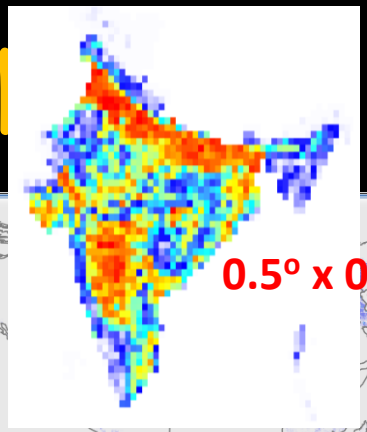
Results: Cropland

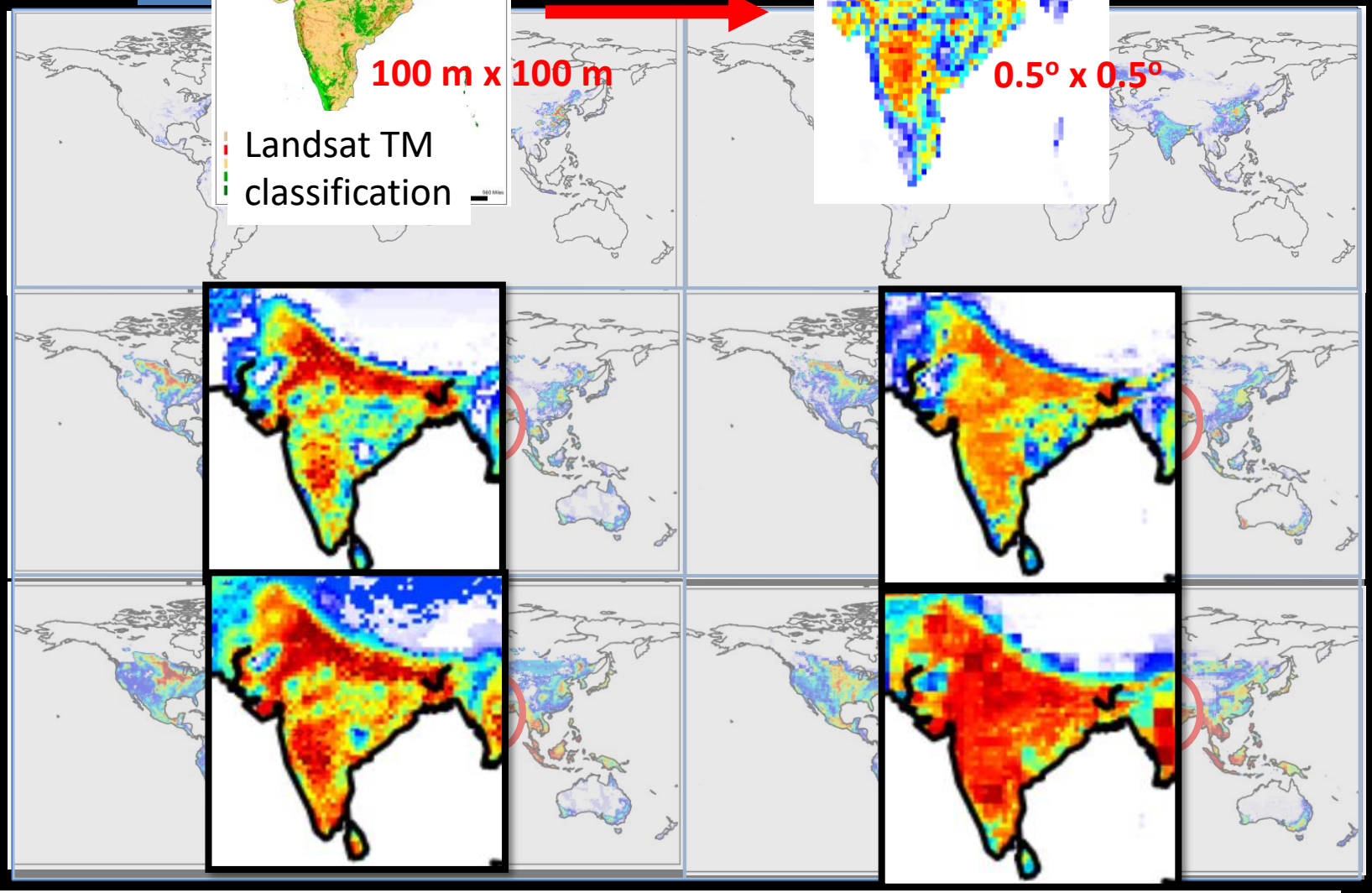


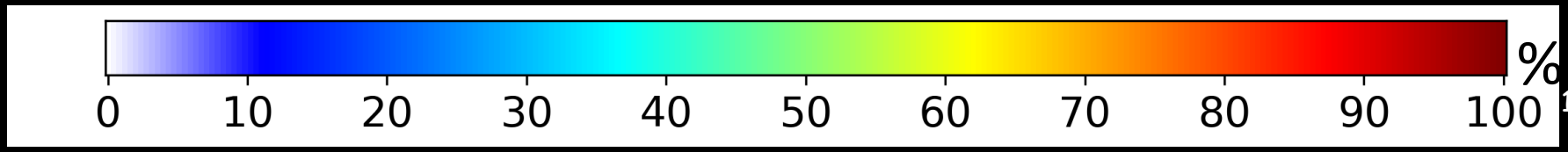
ts: Crop

ISA

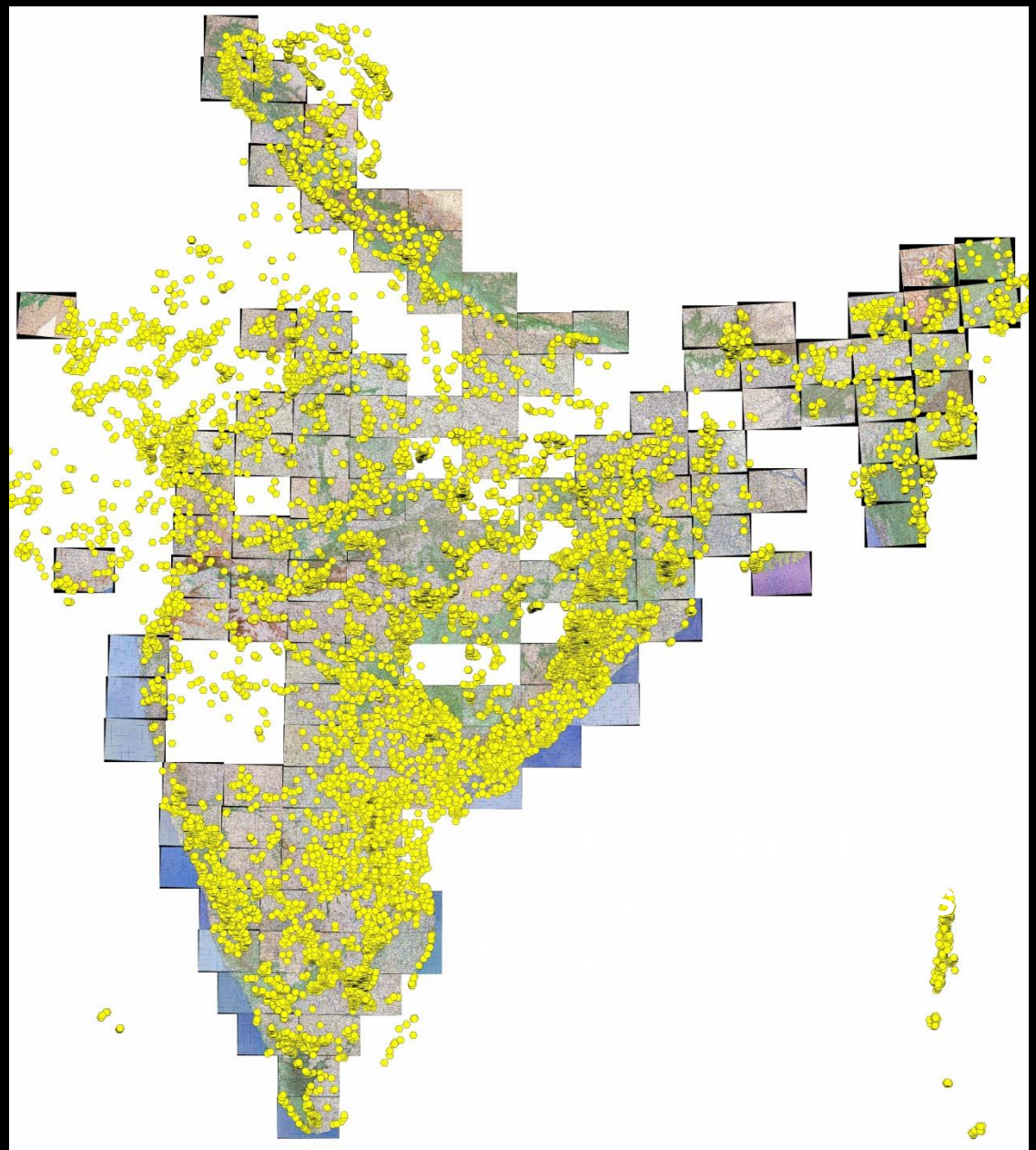

100 m x 100 m
Landsat TM
classification


0.5° x 0.5°

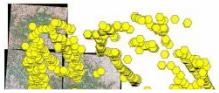

2015
2100


0
10
20
30
40
50
60
70
80
90
100
%

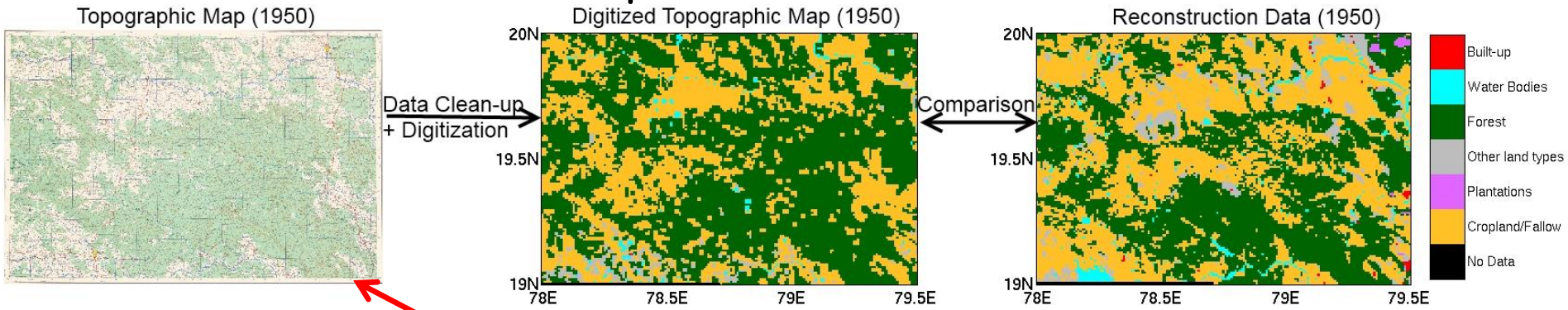
Validation: How good are the reconstructed maps?

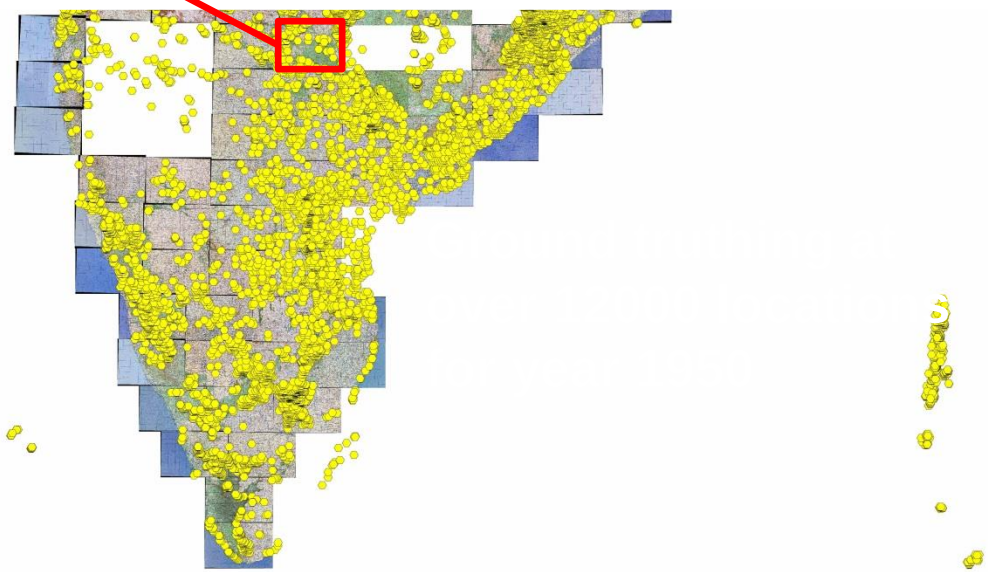


Validation: How good are the reconstructed maps?



Pattern validation: an example

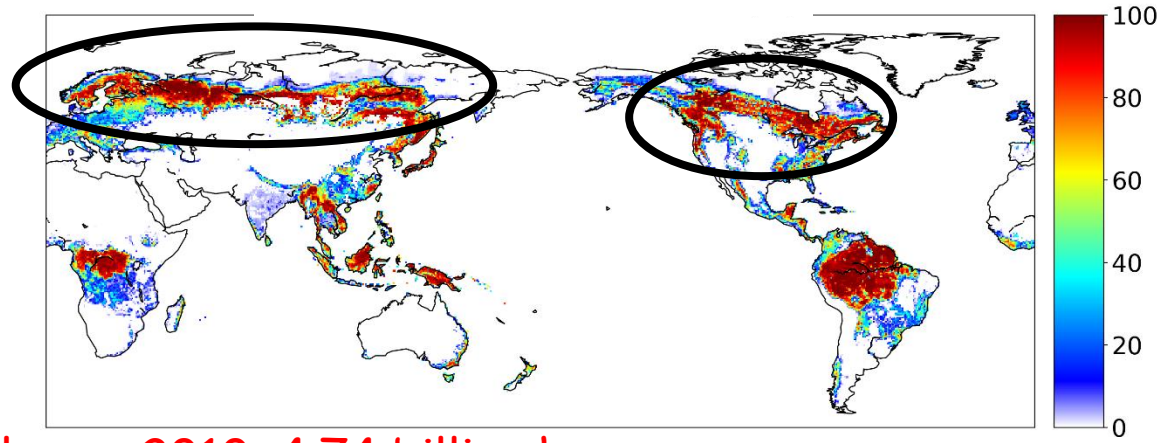




Grid level Forest Fractions based on two data sets (2010)

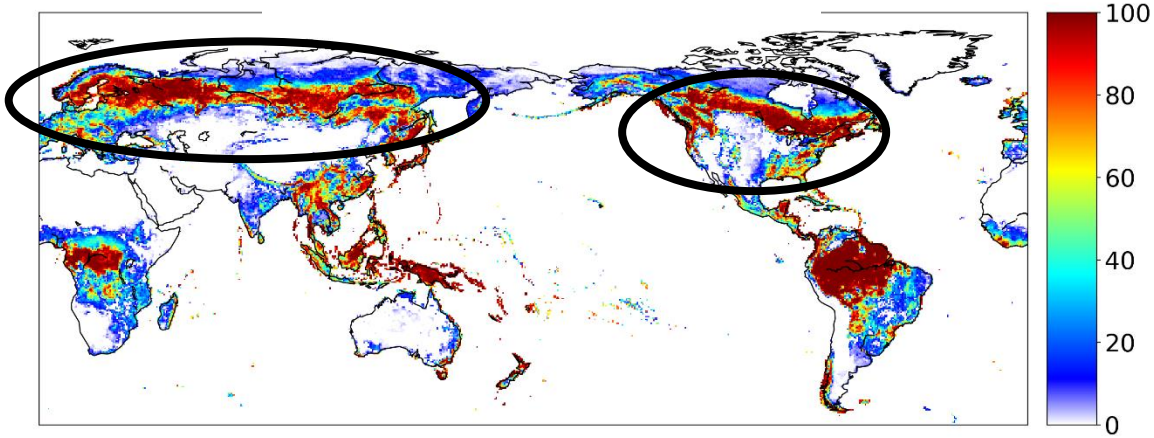
Total area 2010: 2.91 billion ha

SDAM



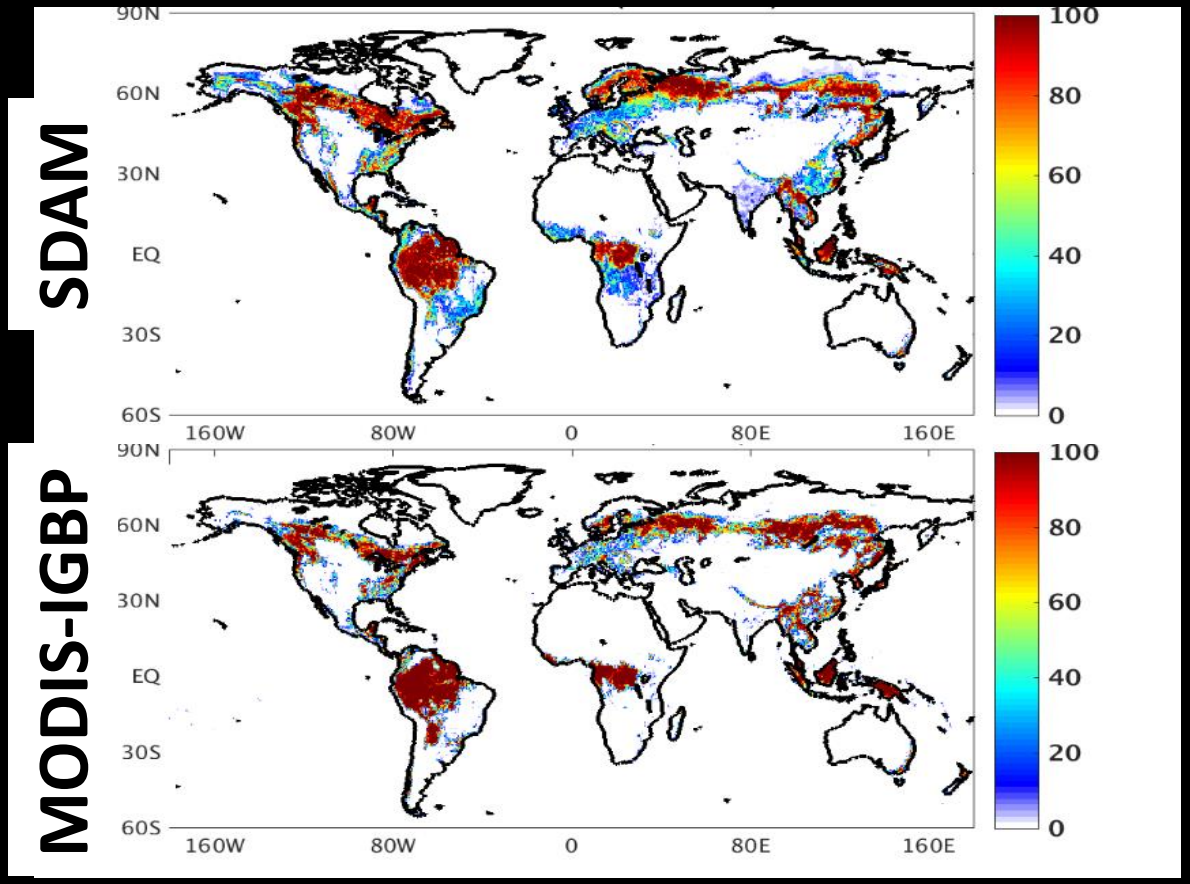
Total area 2010: 4.74 billion ha

LUH2



Results: Forest

SDAM was evaluated with the MODIS and other satellite maps and ground-based data



Bottom-up Approach: Regional Scale Modeling of LUC

DOI: 10.1111/gcb.14611

PRIMARY RESEARCH ARTICLE

WILEY Global Change Biology

Quantifying the biophysical and socioeconomic drivers of changes in forest and agricultural land in South and Southeast Asia

Xiaoming Xu[1] | Atul K. Jain[1] | Katherine V. Calvin[2]

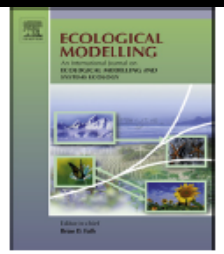
Top-down Approach: Global Scale Modeling of LUC

ELSEVIER

Contents lists available at ScienceDirect

Ecological Modelling

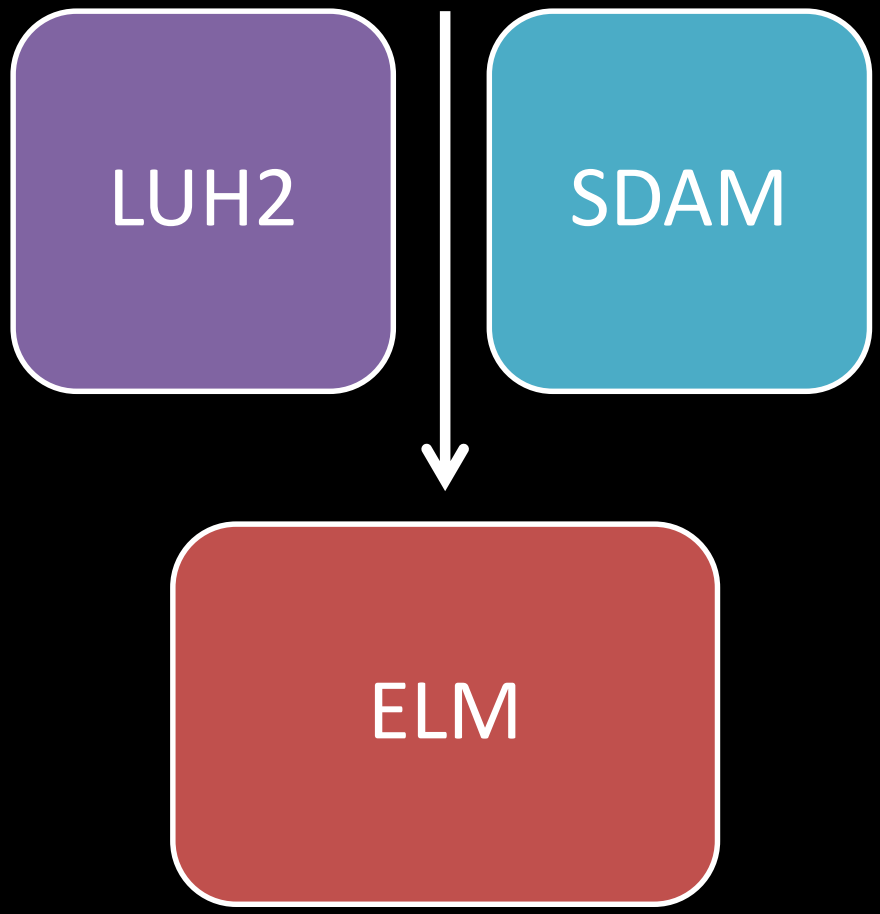
journal homepage: www.elsevier.com/locate/ecolmodel



Spatial modeling of agricultural land use change at global scale

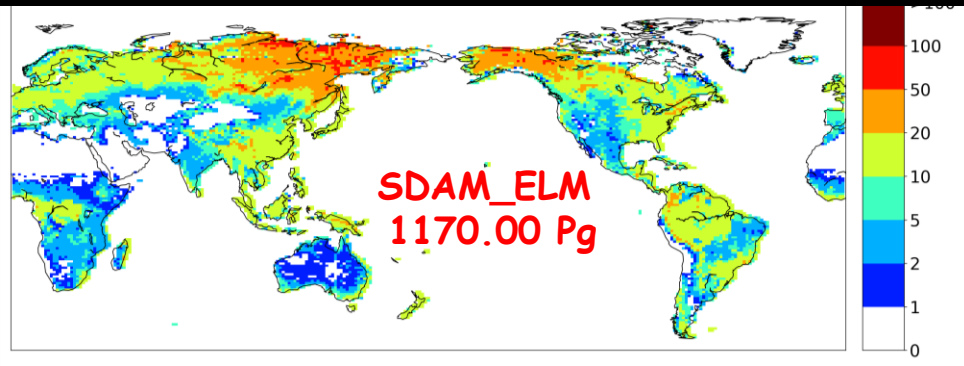
Prasanth Meiyappan[a,*], Michael Dalton[b], Brian C. O'Neill[c], Atul K. Jain[a,**]

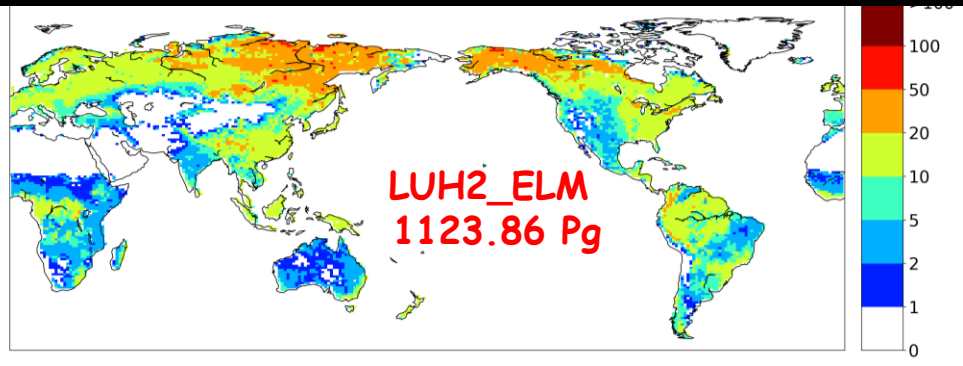
Studying the Impacts of LULCC (1850-2010)



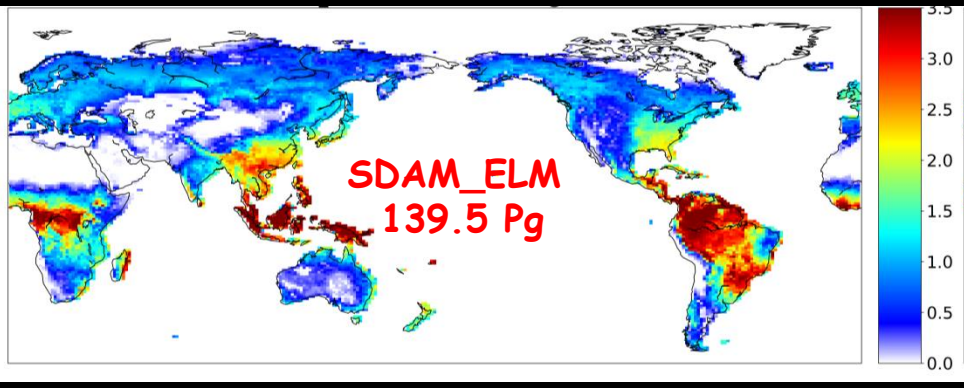
(Compared results for Soil Carbon and GPP)

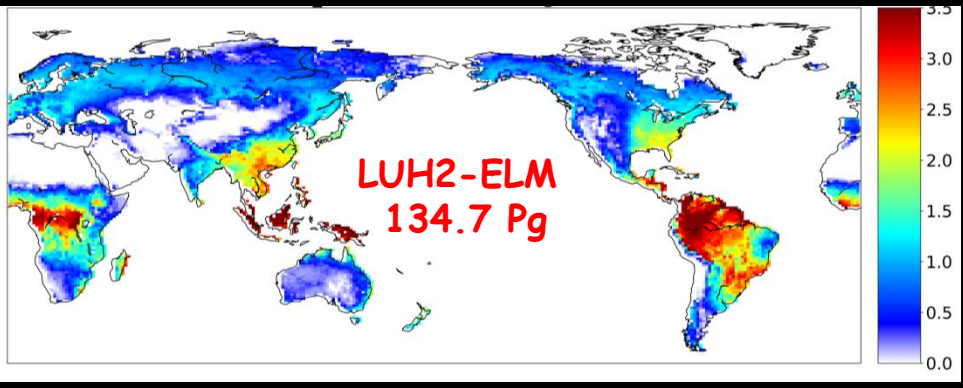
ELM runs for SOC (2010)



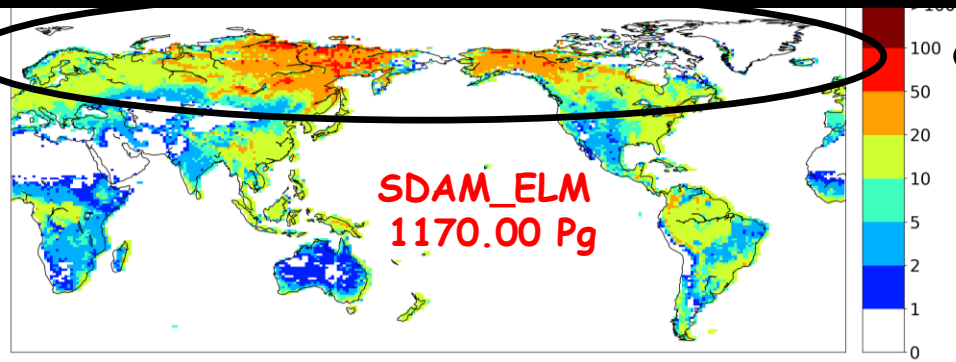


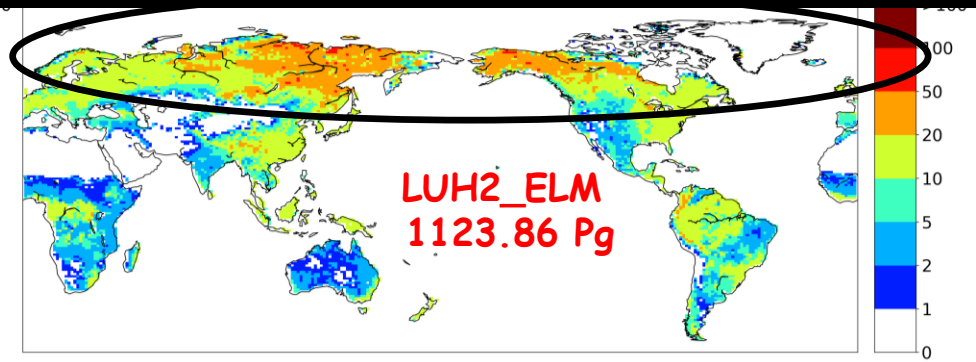
ELM runs for GPP (2010)



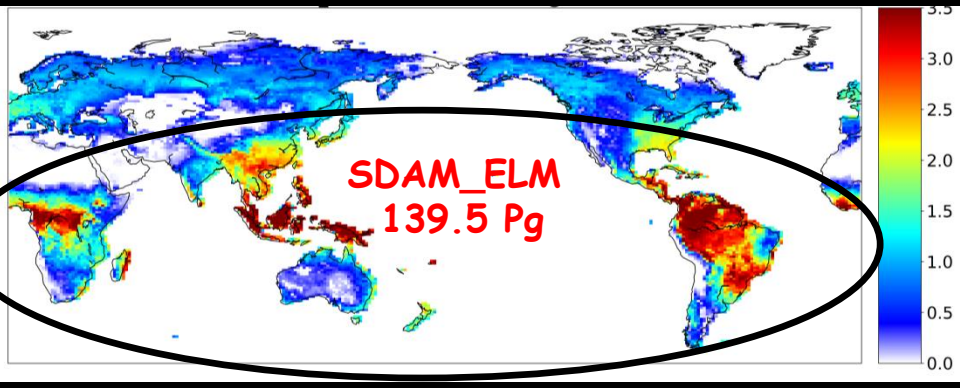


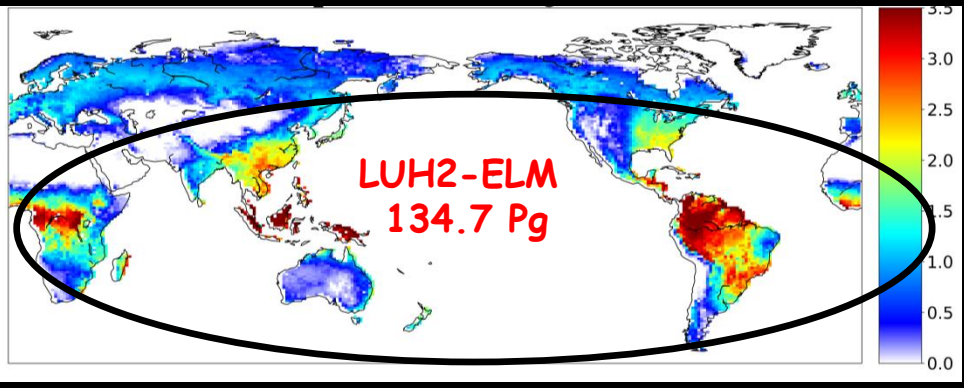
ELM runs for SOC (2010)



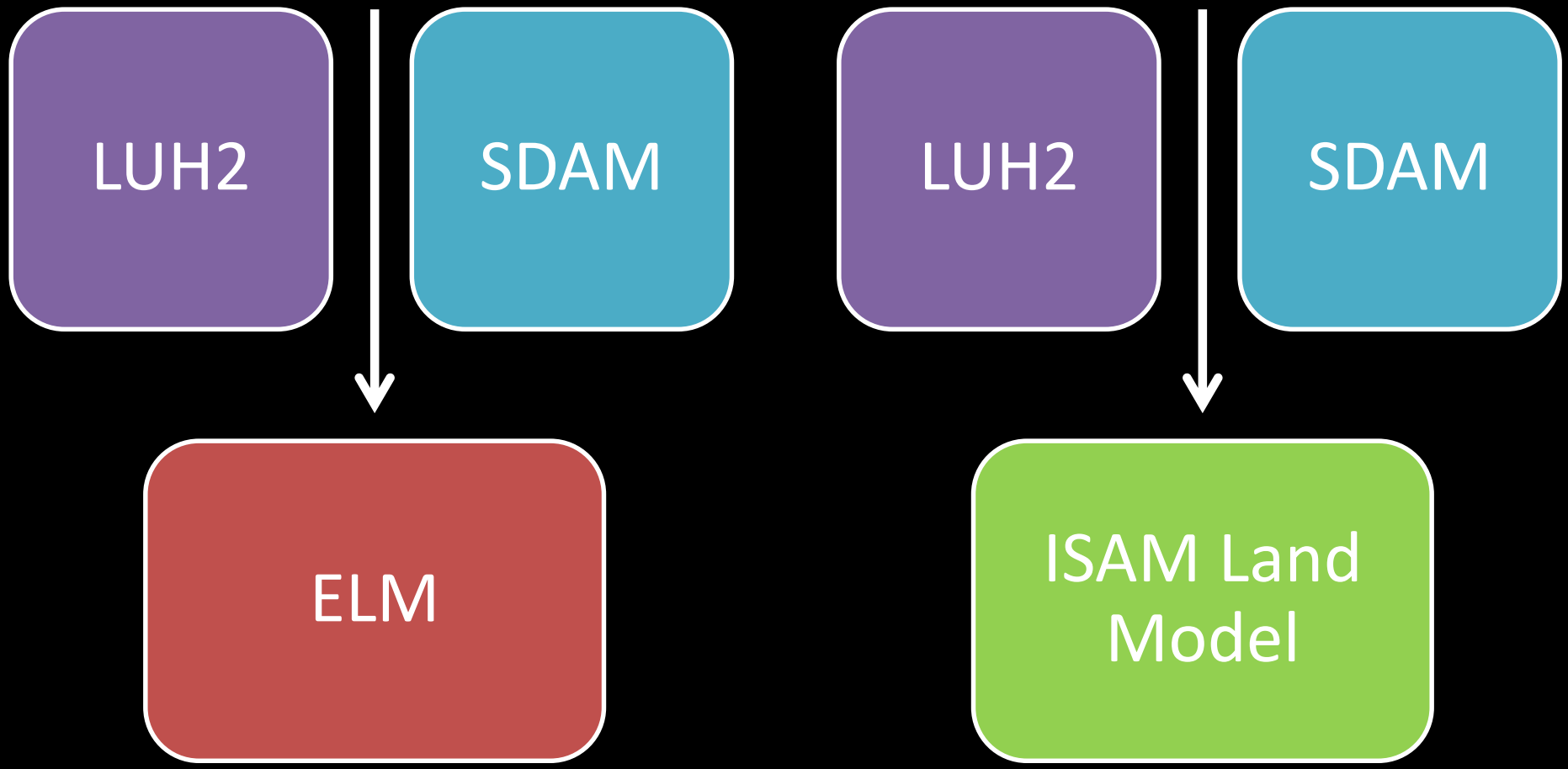


ELM runs for GPP (2010)





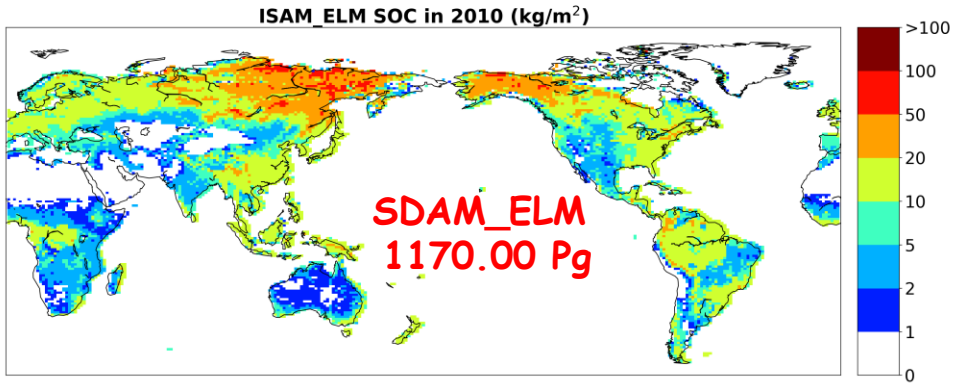
Studying the Impacts of LULCC (1850-2010)

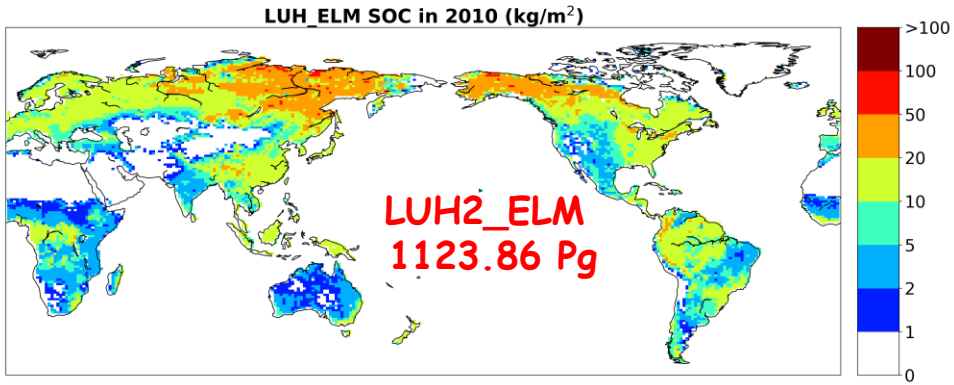


(Compared results for Soil Carbon and NBP)

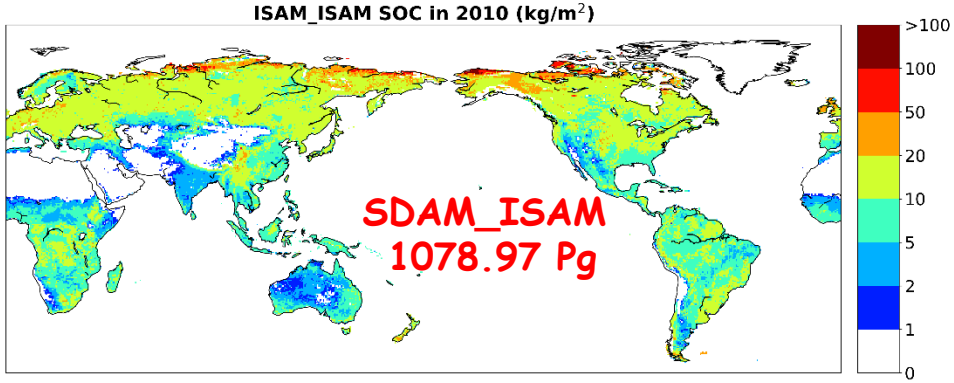
ELM and ISAM runs for SOC (2010)

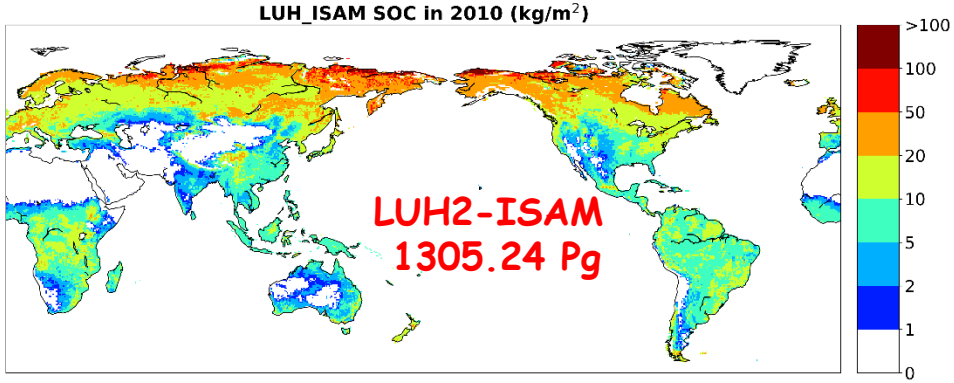
ELM Model Runs





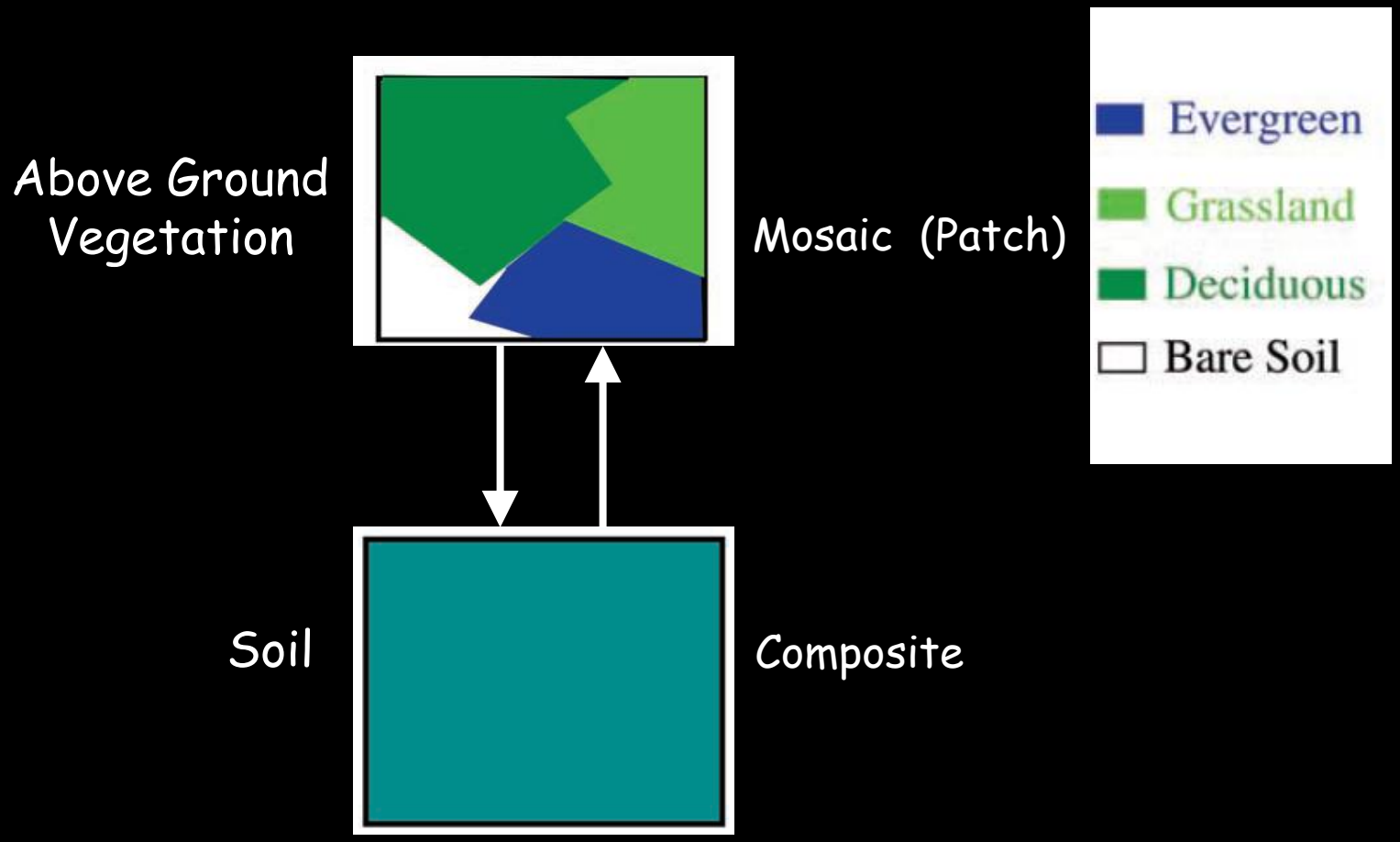
ISAM Model Runs



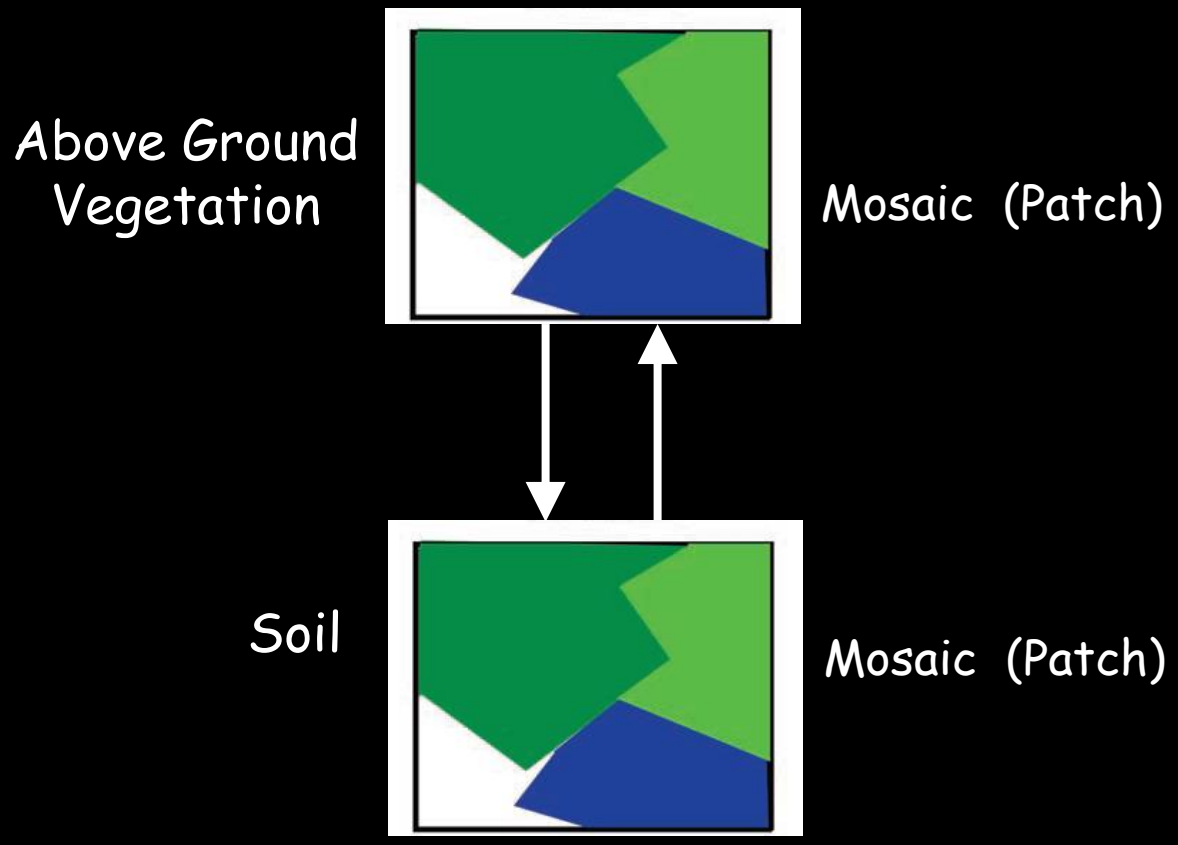


Model Structure Differences

ELM Aggregation Approach for BGC at a Grid Level



ISAM Aggregation Approach for BGC at a Grid Level



ISAM Aggregation Approach for BGC/BGP at a Grid Level

Above Ground Vegetation

Mosaic (Patch)

Implemented mosaic structure in ELM to calculate the soil properties

Soil

Mosaic (Patch)

We Ran Two Different Version of ELM at a Fluxnet Forest Site

- We consider the US-Me2 Fluxnet boreal forest site. We performed 260 years of accelerated decomposition (AD) spin-up and another 200 years of normal spin-up.
  - 100% Forest
  - 50% Forest and 50% Grass

Above ground vegetation and Soil Carbon for Two different Versions of ELM (100% Forest Case)

	Above Ground Veg.	Soil
	gC/m^2	gC/m^2
Original Version	8294	3.5m: 29540
Extended Version	8300	3.5m: 29583

Above ground vegetation and Soil Carbon for Two different Versions of ELM (50% Forest and 50% Grass Case)

	Above Ground Veg.	Soil
	gC/m^2 (% Change)	gC/m^2 (% Change)
Original Version	1893	3.5m: 11400
Extended Version	1523 (-20%)	3.5m: 13184 (16%)

Home Take Message

- Accurate land use and land cover change dynamics is important for the calculations of carbon and other fluxes.
- Blow ground processes are important for accurately simulating the nutrient limitations and LULCC effects

Thank You

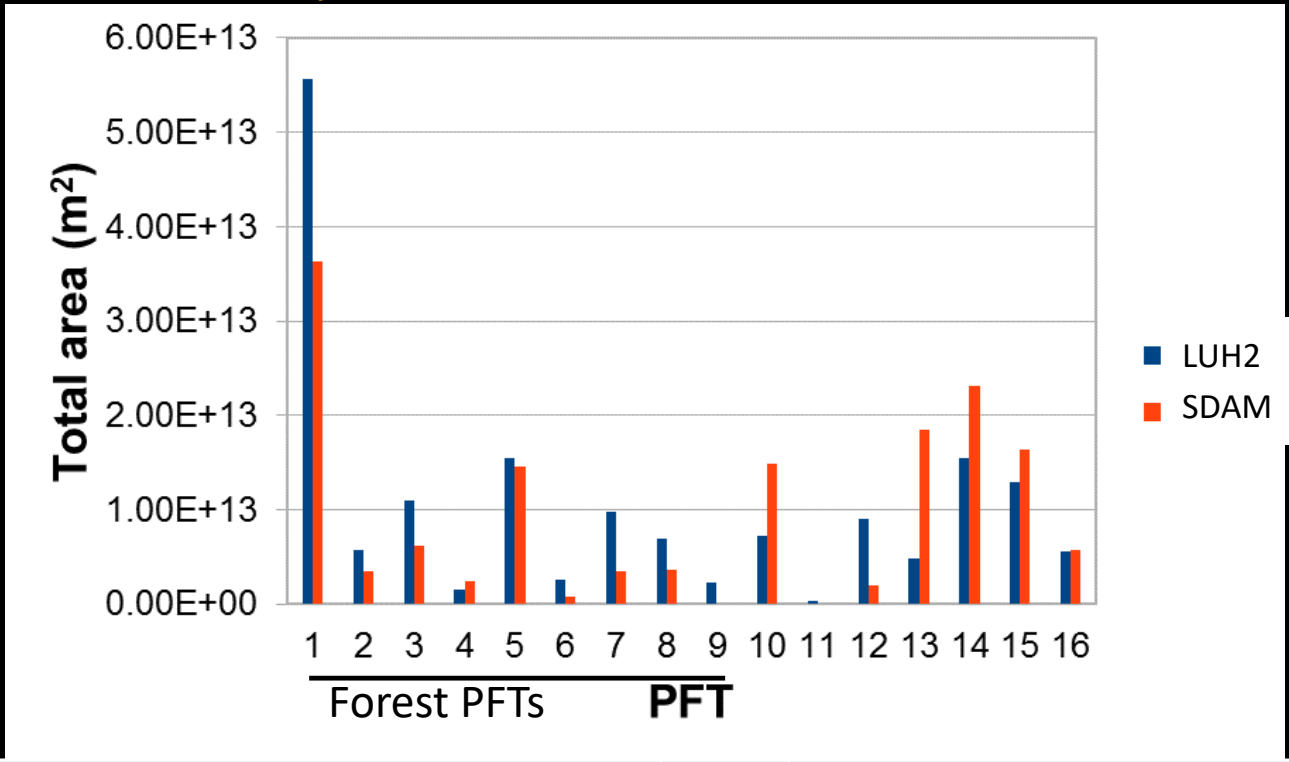
Model settings

Options	Settings	Note
ELM model branch	dmricciuto/elm/cplbypass_memfix	Coupler bypassed version
AD spin-up settings	➢ C and N coupled ➢ Relative Demand (RD) approach for C and N competition ➢ Convergent trophy cascade (CTC) approach for SOC dynamics ➢ CO2 and N deposition set to 1850	ICB1850CNRDCTCBC_ad_spinup
Normal spin-up settings	➢ C, N and P coupled ➢ RD approach for C, N and P competition ➢ CTC approach for SOC dynamics ➢ CO2 and N deposition set to 1850	ICB1850CNPRDCTCBC
Other options	➢ Vertically-resolved soil – on ➢ Explicit (de)nitrification – on ➢ Crop module – off ➢ Methane module – off	
Working environment	Cori-KNL, interactive job with 1 node	

Running the ELM Land Model

- Branch: dmricciuto/elm/cplbypass_memfix (Coupler bypass)
- Compset:
  - ICB1850CNRDCTCBC (ad-spinup, P cycle turned off, coupler bypass mode)
  - ICB1850CNPRDCTCBC (normal spinup, P cycle on, coupler bypass mode)
  - ICB20TRCNPRDCTCBC (transient, P cycle on, coupler bypass mode)
- Climate forcing: GSWP3
- Surface data with the ISAM-HYDE data: /global/cscratch1/sd/sshu3/LC_4_e3sm/surfdata_0.9x1.25_simyr1850_c181008.nc
- LULCC time series data: /global/cscratch1/sd/sshu3/LC_4_e3sm/landuse.timeseries_0.9x1.25_hist_simyr1850-2005_c181008.nc
- With the help from Gautam Bisht, Xiaojuan Yang & Dan Ricciuto

PFT areas based on two data sets for 2001-2010



1	Wasteland	9	Broadleaf deciduous tree – boreal
2	Needleleaf evergreen tree – temperate	10	Broadleaf evergreen shrub – temperate
3	Needleleaf evergreen tree - boreal	11	Broadleaf deciduous shrub – temperate
4	Needleleaf deciduous tree – boreal	12	Broadleaf deciduous shrub – boreal
5	Broadleaf evergreen tree – tropical	13	C3 arctic grass
6	Broadleaf evergreen tree - temperate	14	C3 grass
7	Broadleaf deciduous tree – tropical	15	C4 grass
8	Broadleaf deciduous tree – temperate	16	Crop

Uncertainties in parameterization of BGC and BGP

Decomposition Rates

- Decomposition rates and turnover time are not PFT specific, which could also make large impact on the SOC
  - ISAM decomposition rates are calibrated based on the litter bag study and using the ^{14}C profiles