



Land use, water, and carbon in the integrated Earth System Model (iESM)

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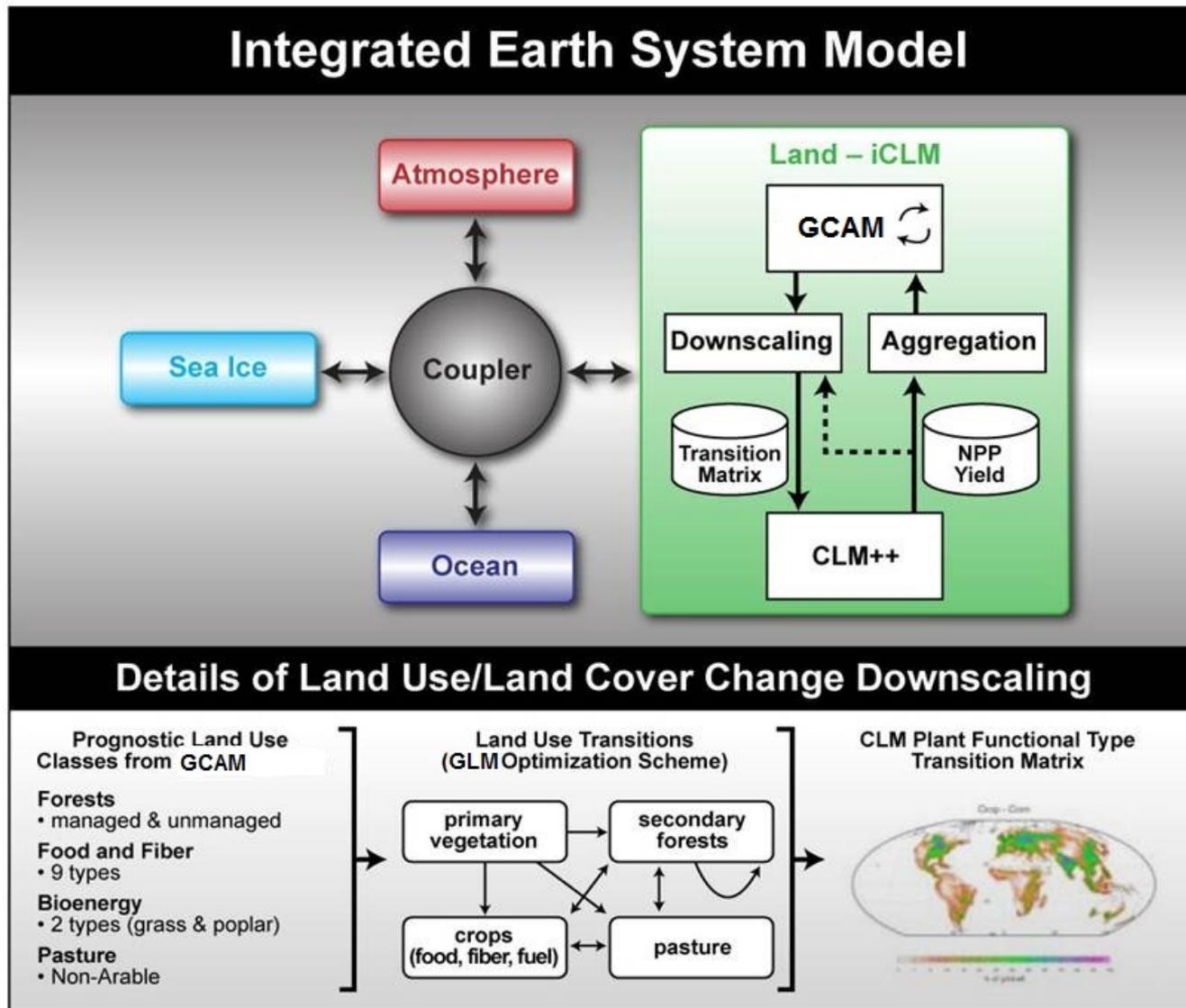
Three Major Objectives

- ▶ Task 1: Create a first generation integrated Earth System Model (iESM) with both the human components of an IAM and a physical ESM
- ▶ Task 2: Further develop components and linkages within the iESM and apply the model to improve our understanding of the coupled physical, ecological, and human system
- ▶ Task 3: Add realistic hydrology, including freshwater demand, allocations and demands to hold stocks of water as well as representation of freshwater availability from surface water, ground water, and desalinization.

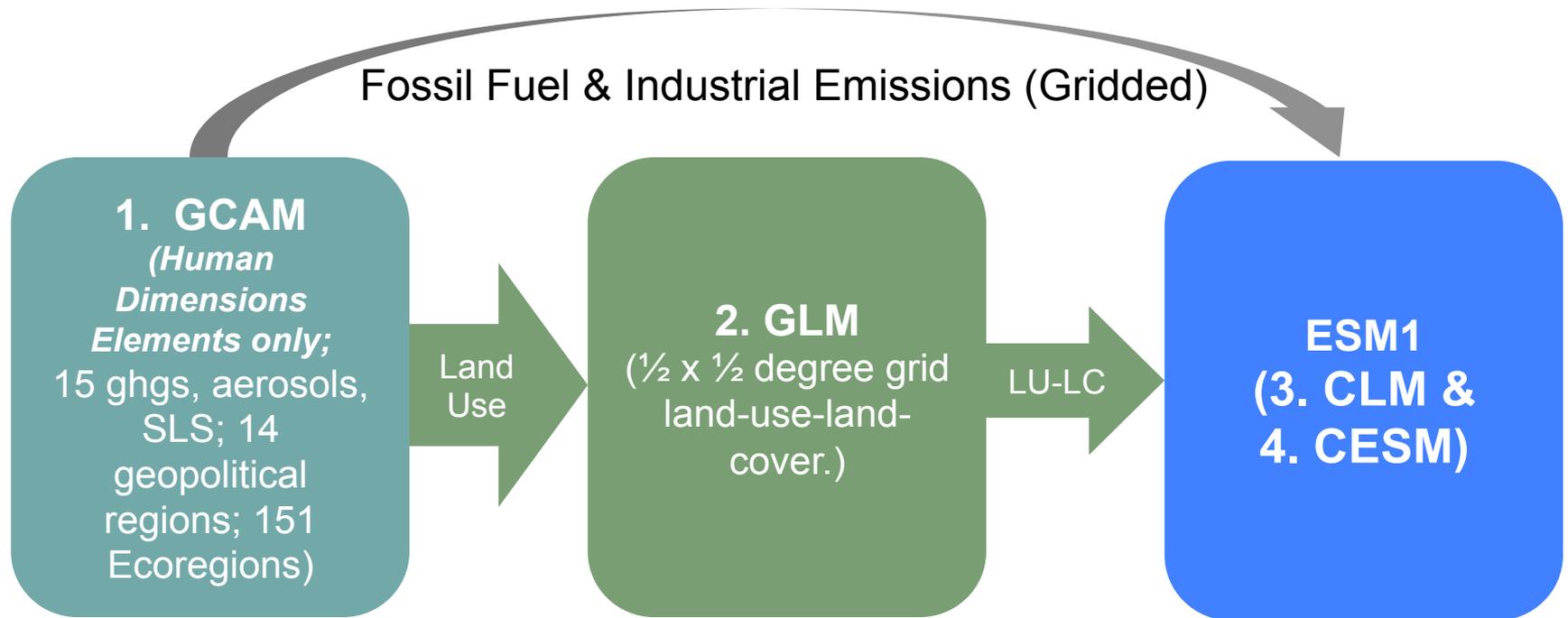
Why Is This So Important?

- ▶ ***In the present world emissions mitigation analysis is undertaken under the assumption that the climate is not changing.*** E.g. crop yields are unchanged, water resources are unchanged, and energy systems don't have to cope with a changing climate.
- ▶ ***Climate impacts analysis is undertaken with the assumption that no resources are being diverted to address climate change.*** E.g. no land is being used for reforestation, no land is being used to grow bioenergy, and energy prices are unchanged.
- ▶ ***The changes in behavior of the coupled climate-energy-land modeling system are significantly different than in the un-coupled models.***
Modeling the system as a unit materially changes our understanding of the evolution of the physical climate system
- ▶ The development of an iESM means that **fully consistent analysis** of potential future climate change, emissions mitigation options, and impacts and adaptation options will be possible.

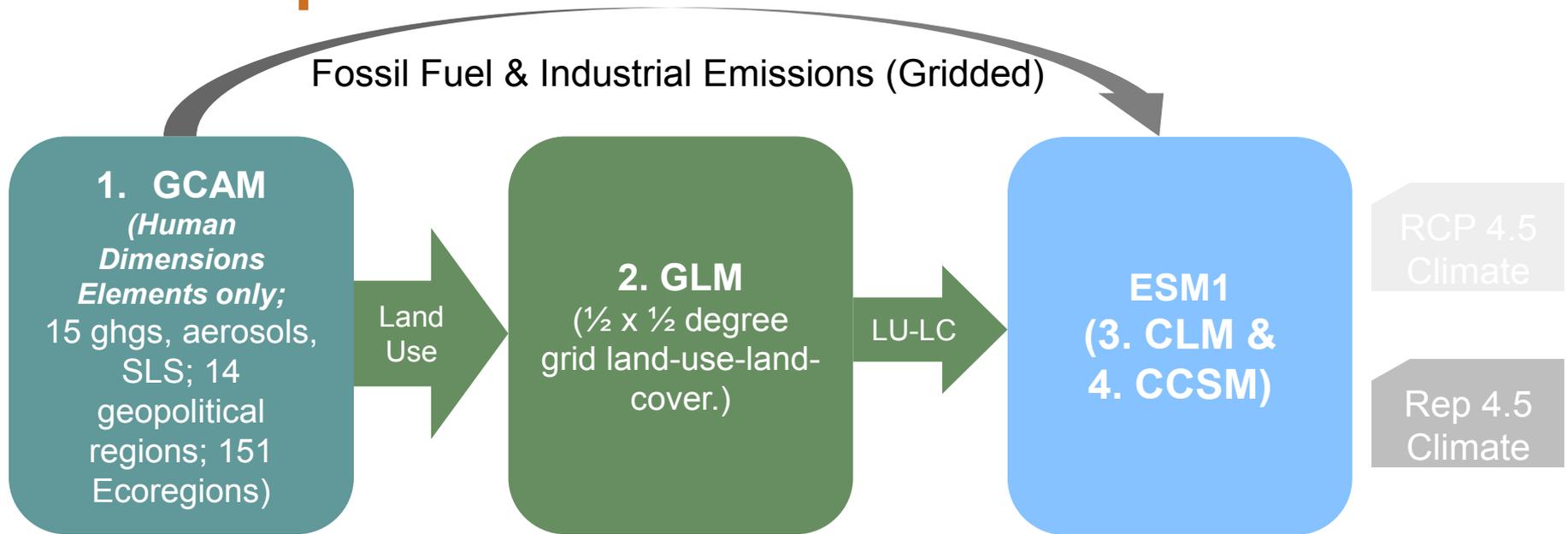
iESM Schematic



Four Modeling Systems: GCAM, GLM, CLM, & CCSM

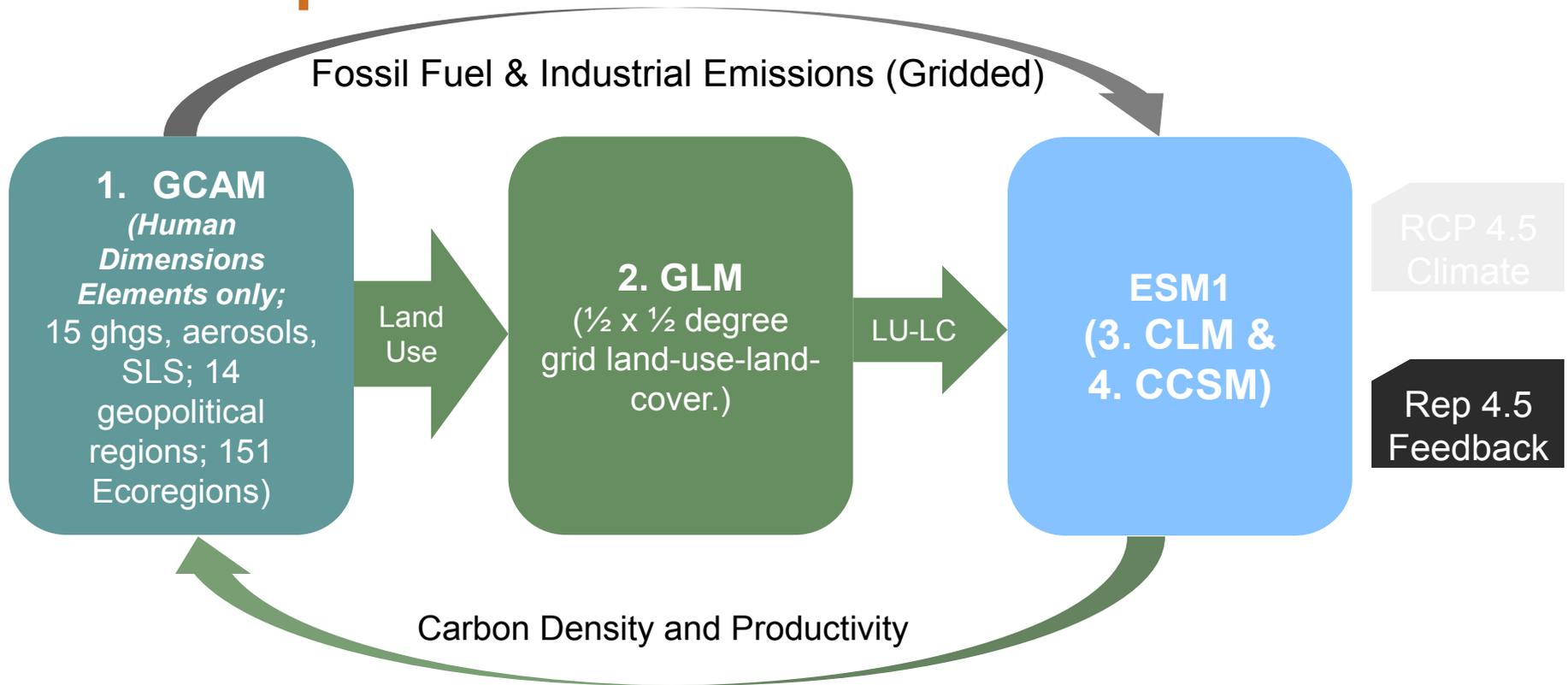


Two Experiments



- ▶ **Experiment 0:** Compare two cases
 - RCP 4.5
 - An RCP 4.5 replication Wm^{-2} scenario without terrestrial mitigation.
- ▶ (Sneaker-net).

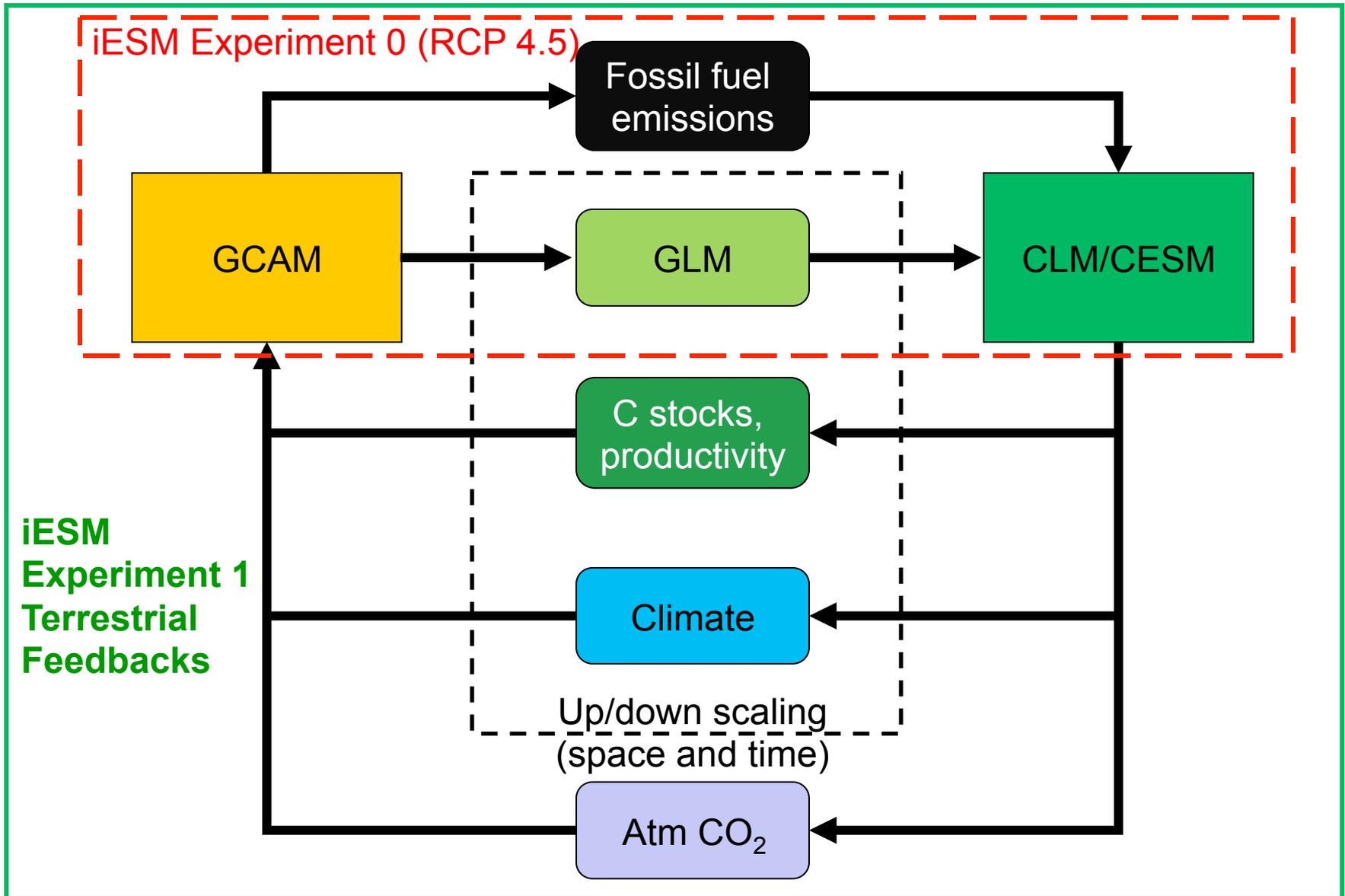
Two Experiments



► **Experiment 1: RCP 4.5, with feedback from the CLM-CCSM calculations**

- 15-year time steps;
- Lagged adjustment:
- **Sneaker-net.**

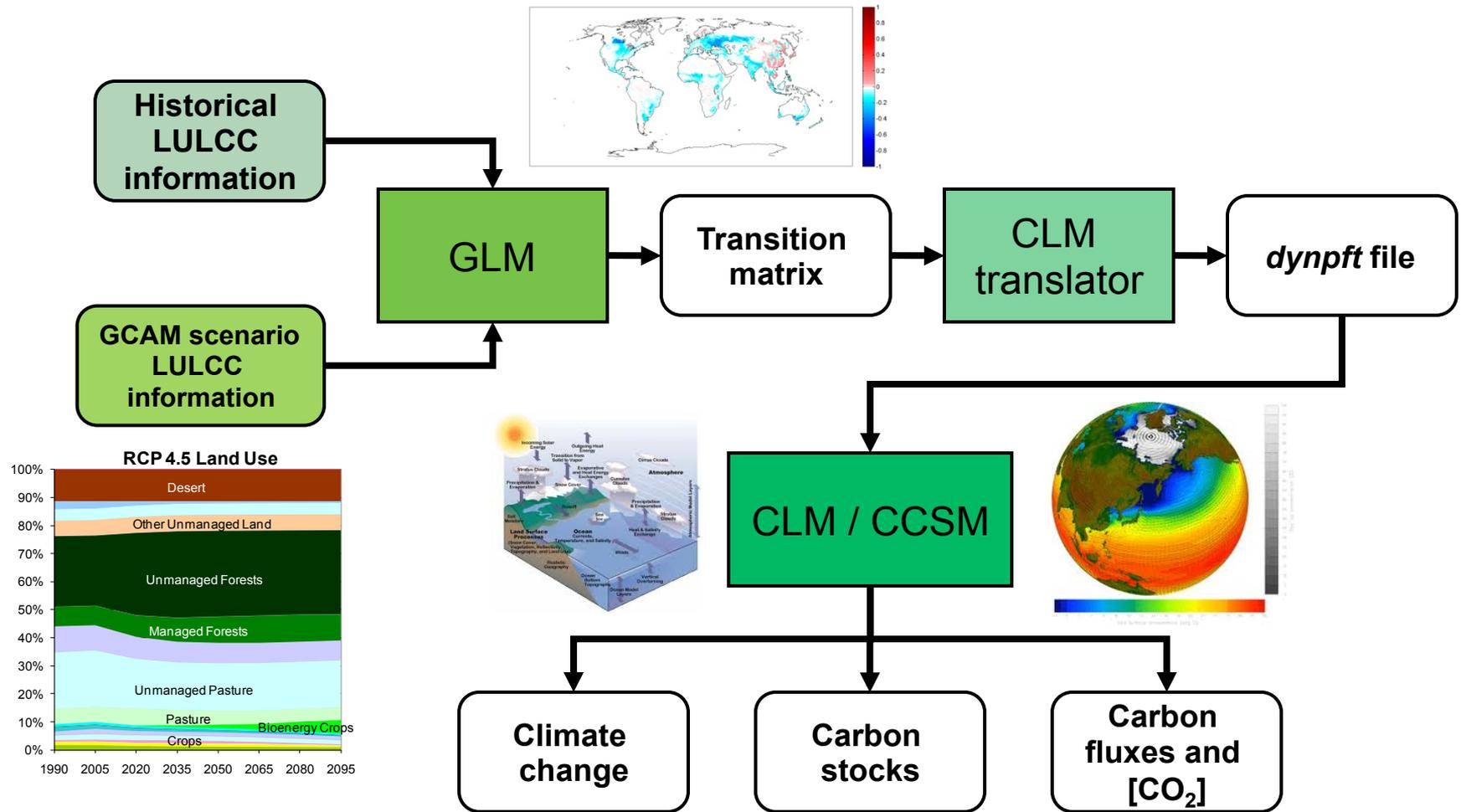
iESM multi-phase coupling strategy



iESM Experiment 0: Bioenergy Scenarios with the Simplest One-Way Coupling

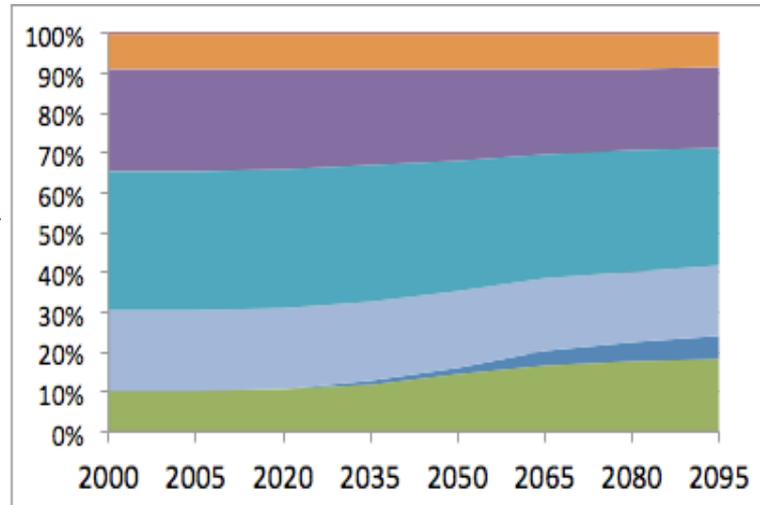
- ▶ GCAM to GLM to CESM
- ▶ Does the one-way pass of information replicate the original RCP4.5 simulation done in CMIP5?
- ▶ If we now add a different policy scenario, but keep the same concentration pathway, does the evolution of the climate system differ?
- ▶ What happens when we replicate the approach of the Wise et al. Science paper?
 - RCP4.5 – carbon price on all carbon (UCT)
 - RCP4.5 – carbon price ONLY on fossil carbon (FFCT)

Experiment 0 Work Flow

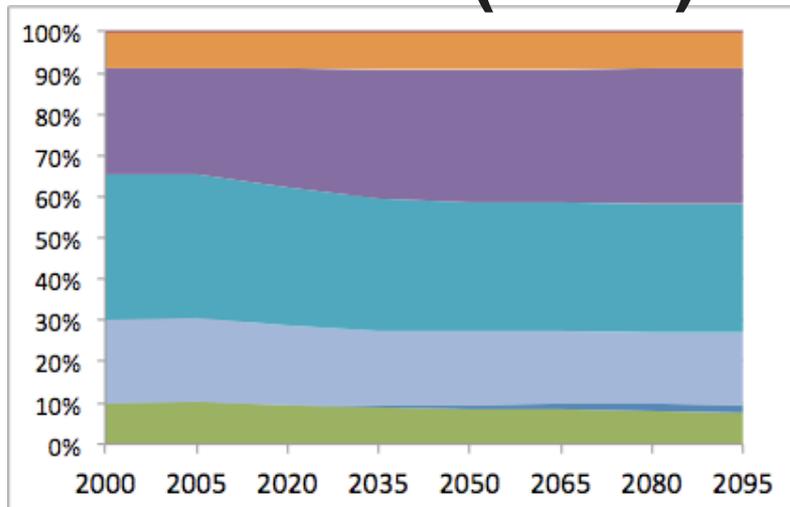


RCP 4.5 and a Replication without terrestrial mitigation policy

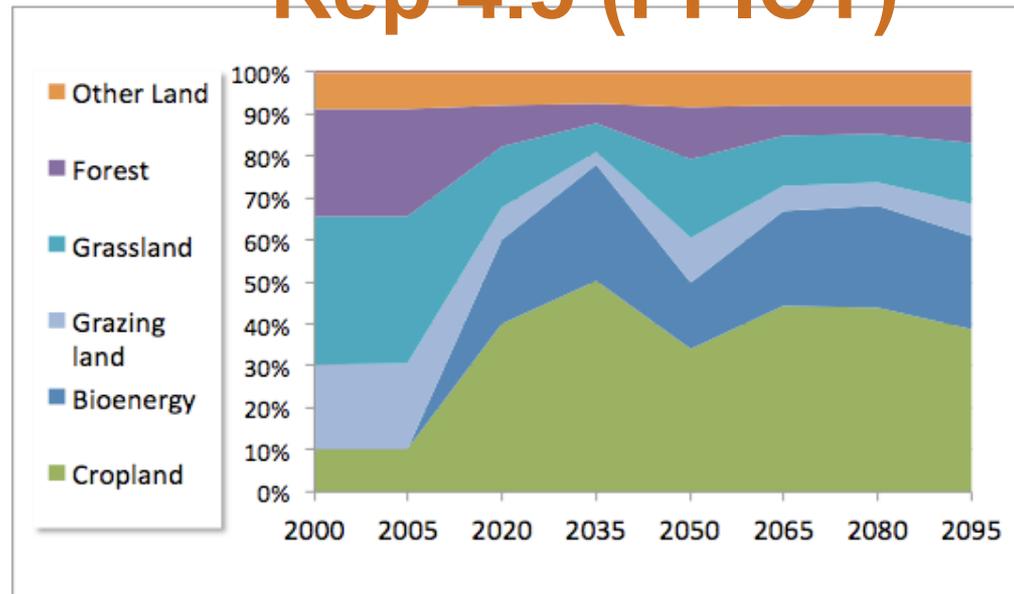
No Policy



RCP4.5 (UCT)

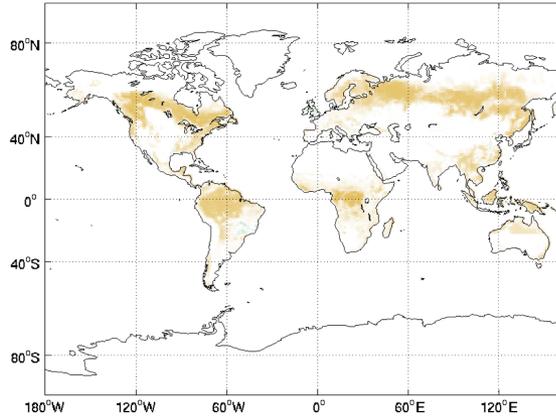


Rep 4.5 (FFICT)

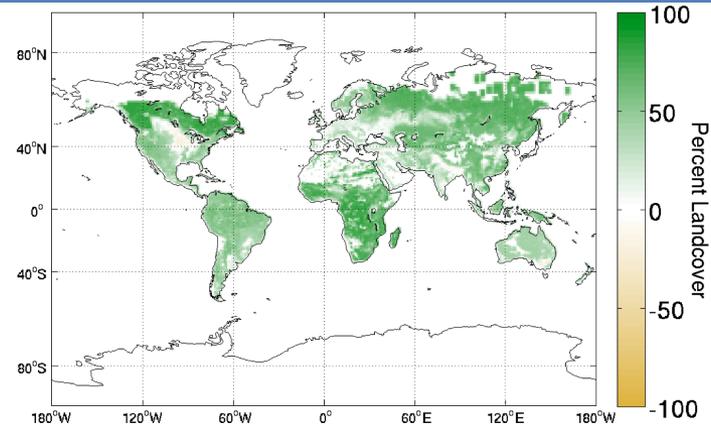


Change in Landcover under the RCP4.5 FFICT Scenario

FFICT: Change in Forest Cover



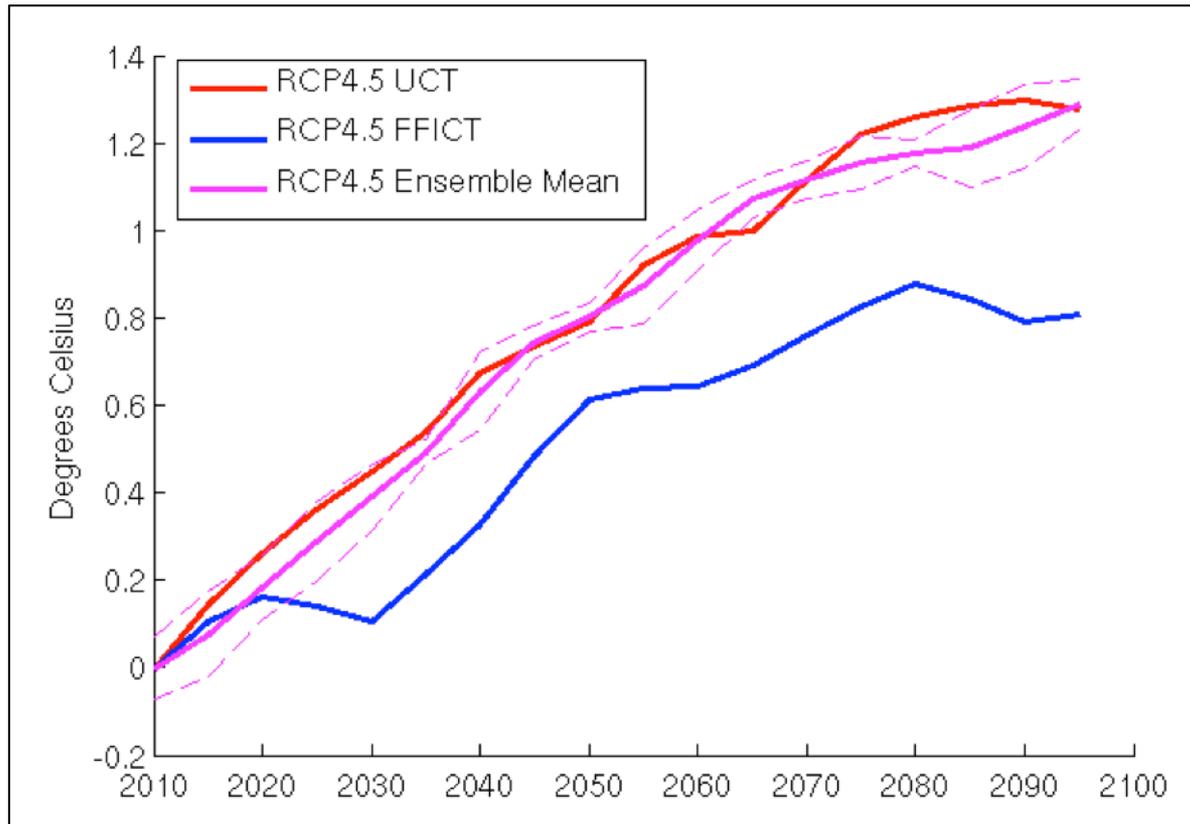
FFICT: Change in Crop Cover



Jones et al, 2012

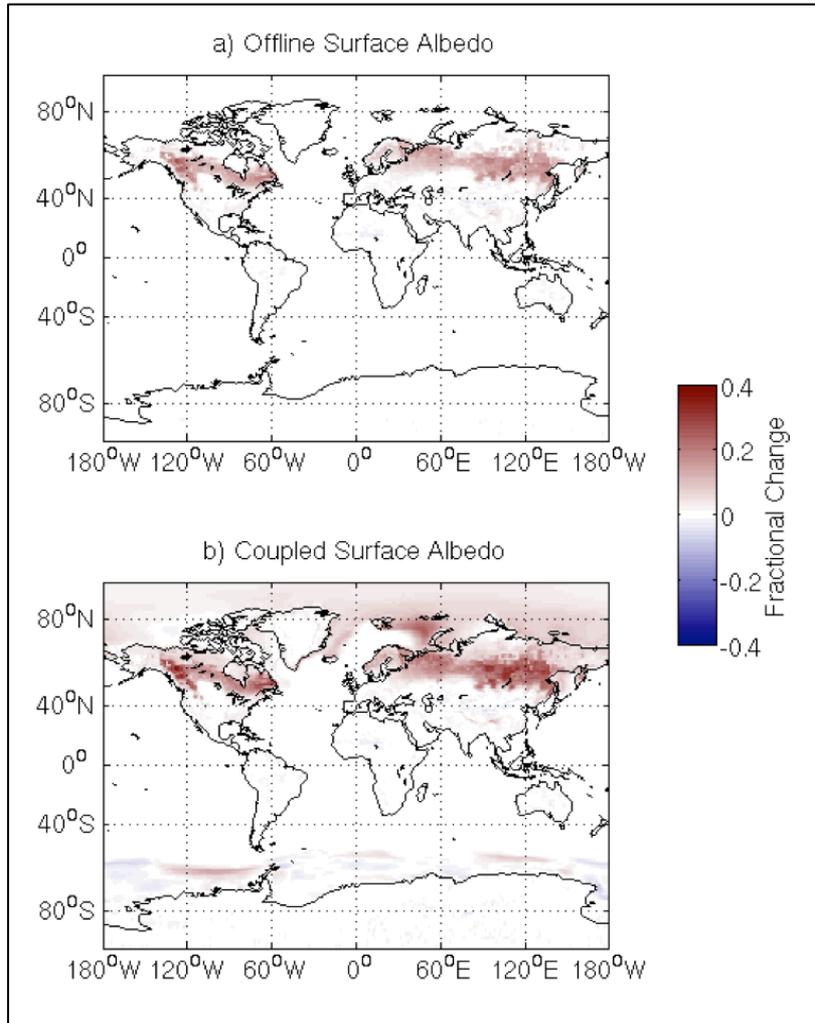
Change in Landcover from
2005 to 2100

Effect of Land cover scenario on global mean temperature

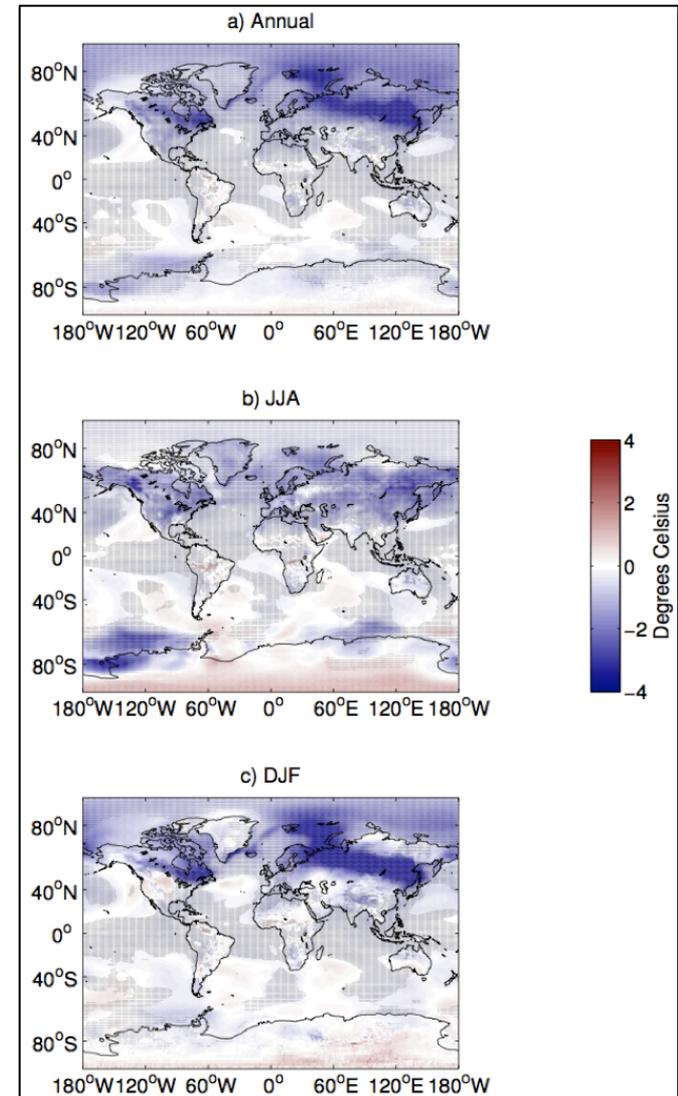


Jones et al, 2012

Link between albedo and temperature

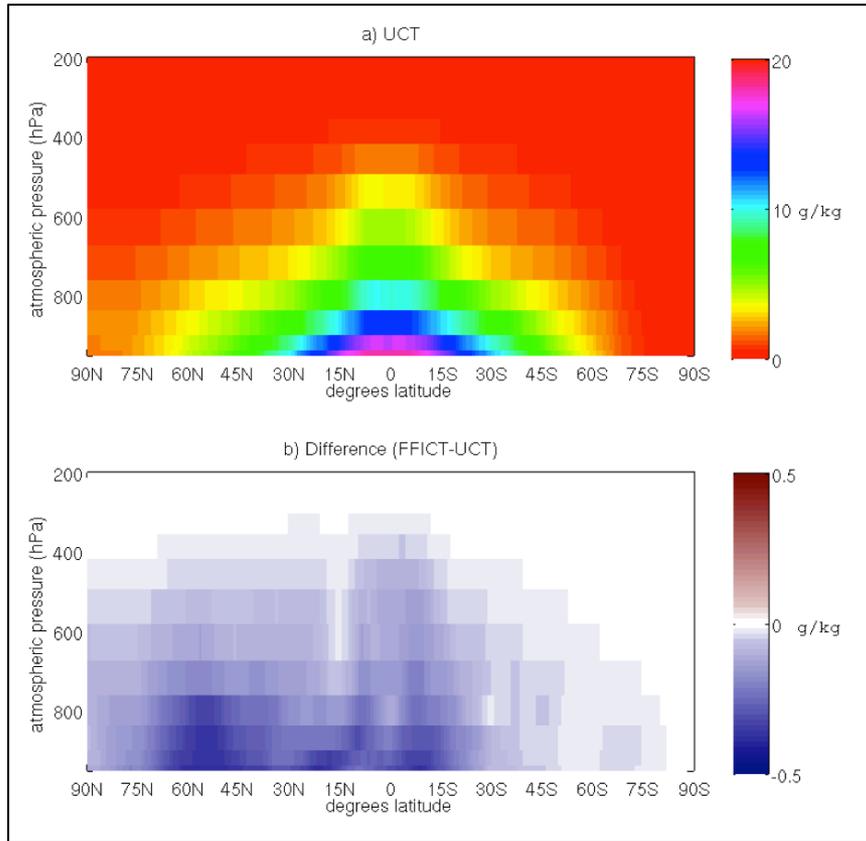


Jones et al, 2012

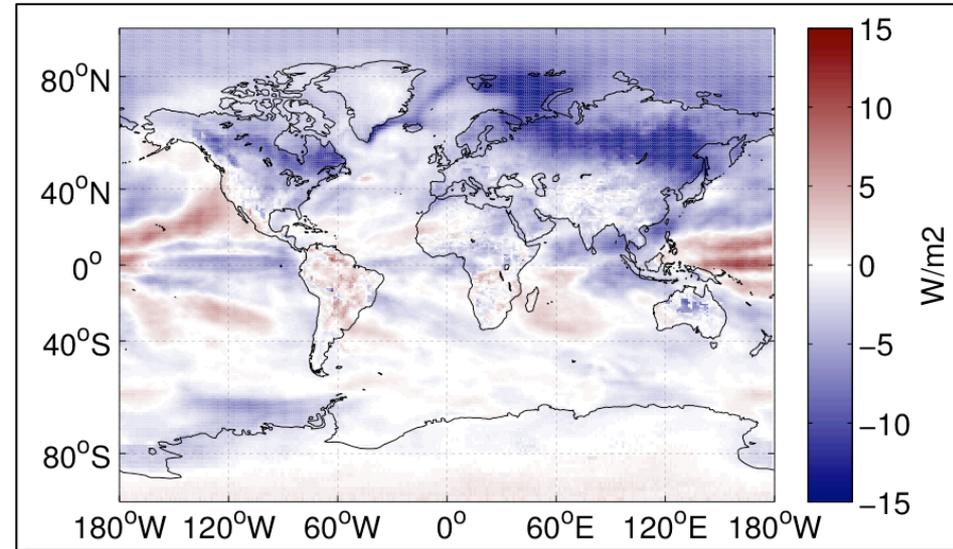


Jones et al, 2012

Linkage of water vapor and greenhouse effect



Jones et al, 2012



Jones et al, 2012

Major Findings of Experiment 0

- ▶ The two scenarios have the **same radiative forcing from GHGs**.
- ▶ Yet they are **substantially different** in the evolution of the climate: the equivalent of 1.5 W/m^2 , or about 0.5°C global annual average.
- ▶ **We can replicate RCP 4.5** with a one way pass of information.
- ▶ But it is also true that **the actual policy chosen matters** – in this case the very large land-use change associated with FFICT.
- ▶ **Radiative forcing by GHGs is not a complete metric** for evaluating the evolution of the climate system

Experiment 1:

Simplest possible feedback from CESM(CLM) to GCAM

- **Send maps of carbon density, by PFT, from CLM to GCAM**
- **GCAM updates internal carbon densities based on changes from CLM**
- **GCAM regenerates RCP, including new LULCC trajectory, based on updated carbon densities.**

Experiment 1:

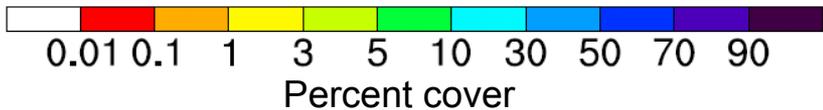
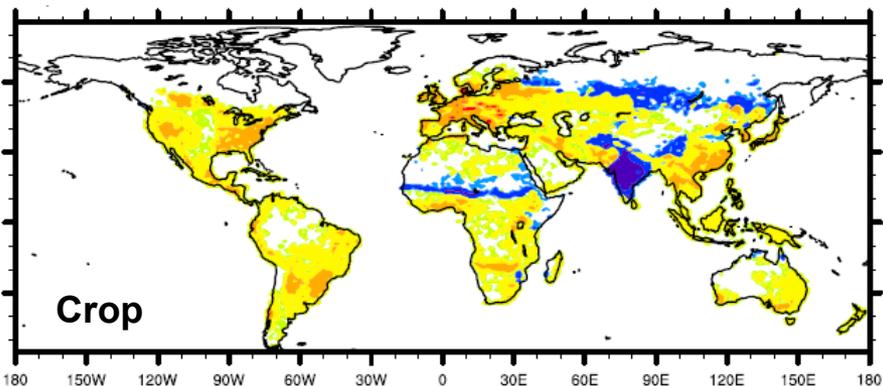
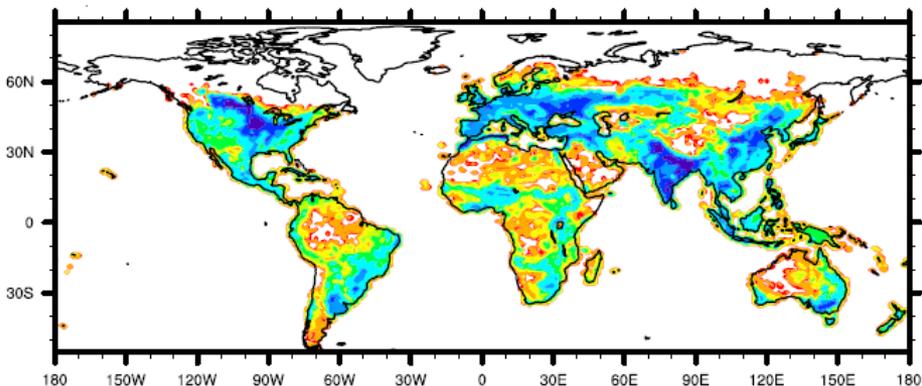
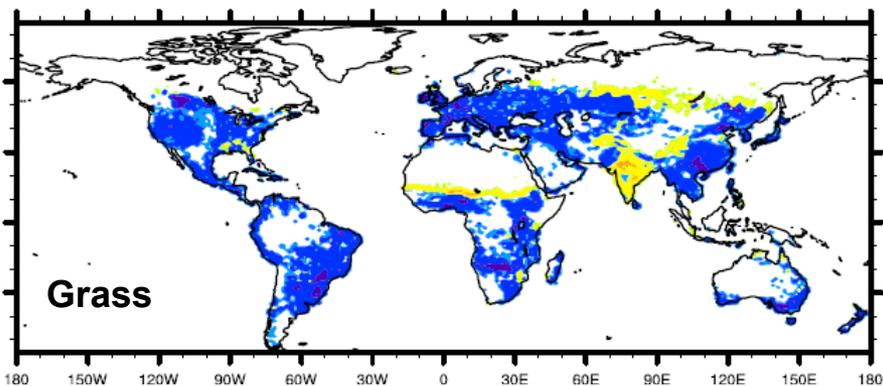
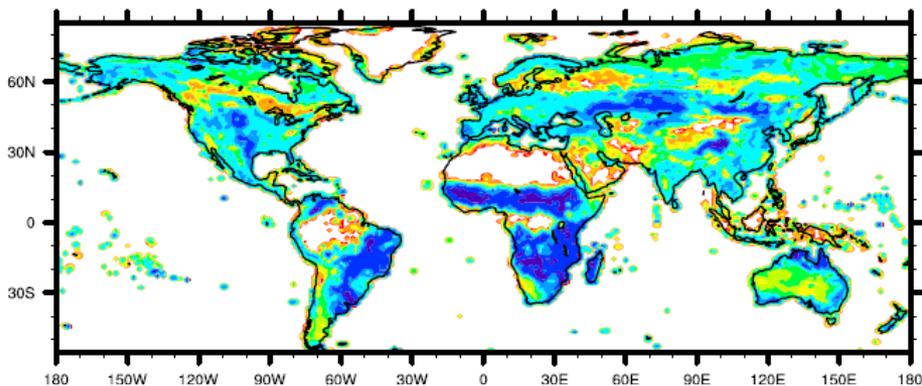
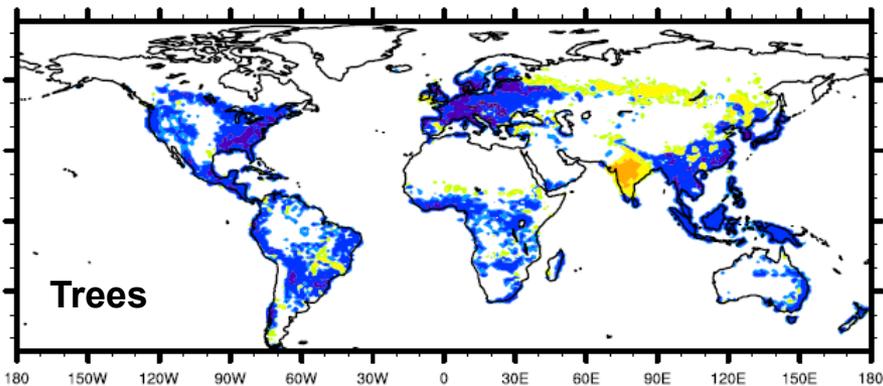
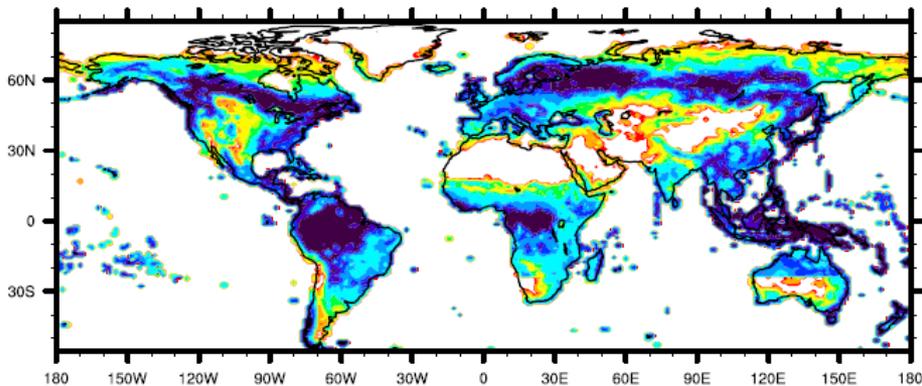
A few other details...

- **15-year time step, first departure from control occurs in period 2020-2034.**
- **Feedback modifies spatial/temporal pattern of GCAM carbon density as integration proceeds, but doesn't modify baseline carbon cycle.**
- **GLM has its own internal carbon density representation, which is not being modified in this experiment.**

Translation of GCAM/GLM coupling response to CLM vegetation types

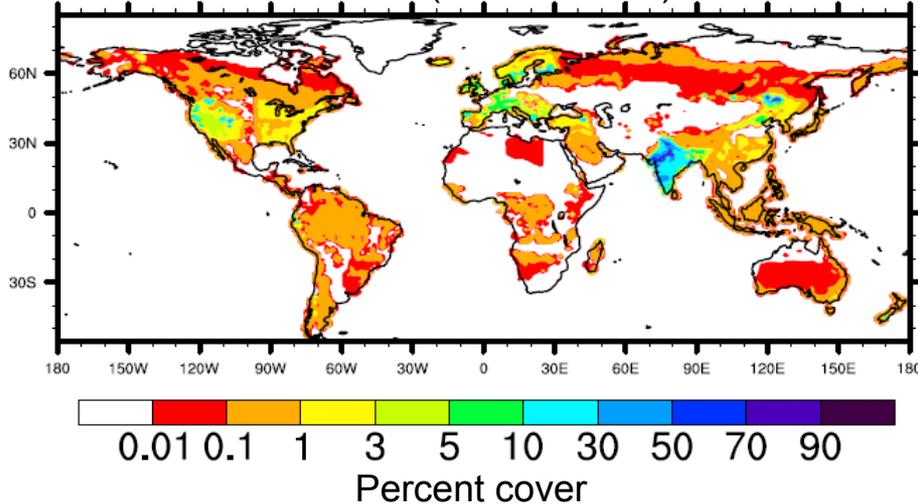
Control (2020 to 2034)

Expt 1 – Control (2020 to 2034)

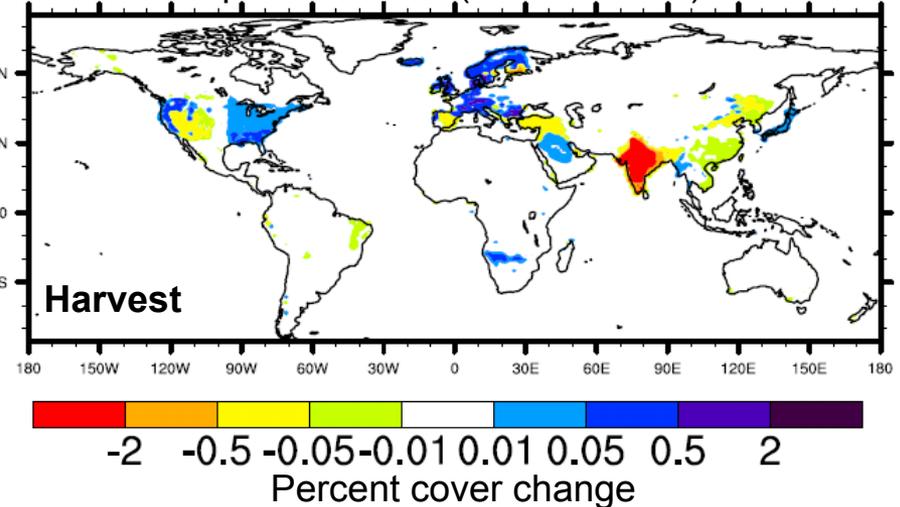


Translation of GCAM/GLM coupling response to CLM harvest

Control (2020 to 2034)



Expt 1 – Control (2020 to 2034)

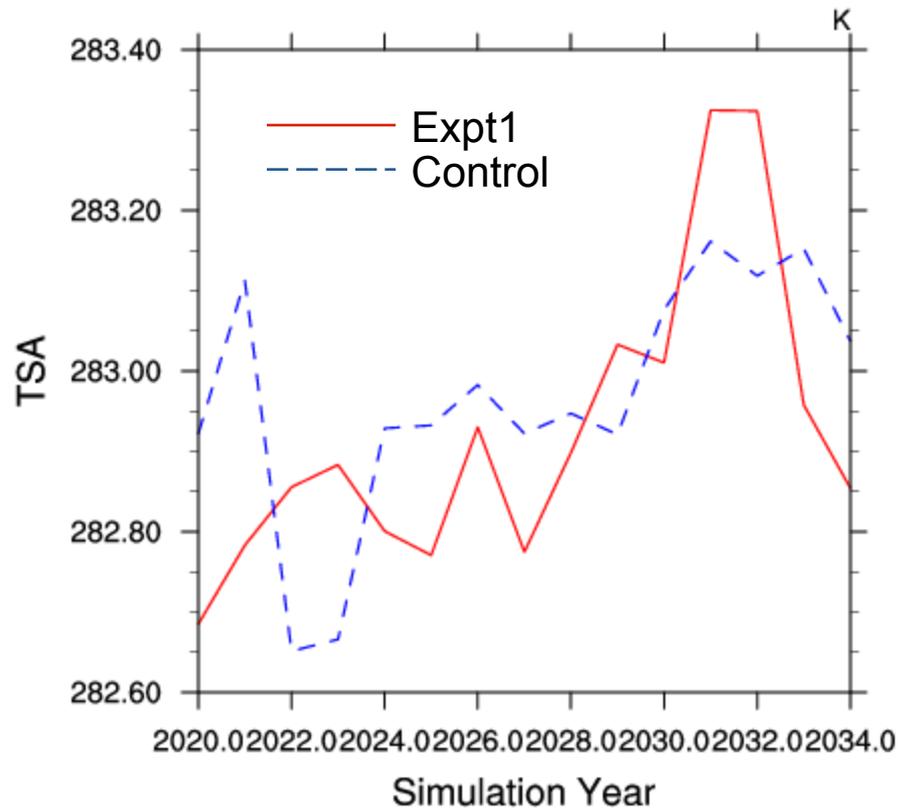


Summary of coupling influence on CLM forcing:

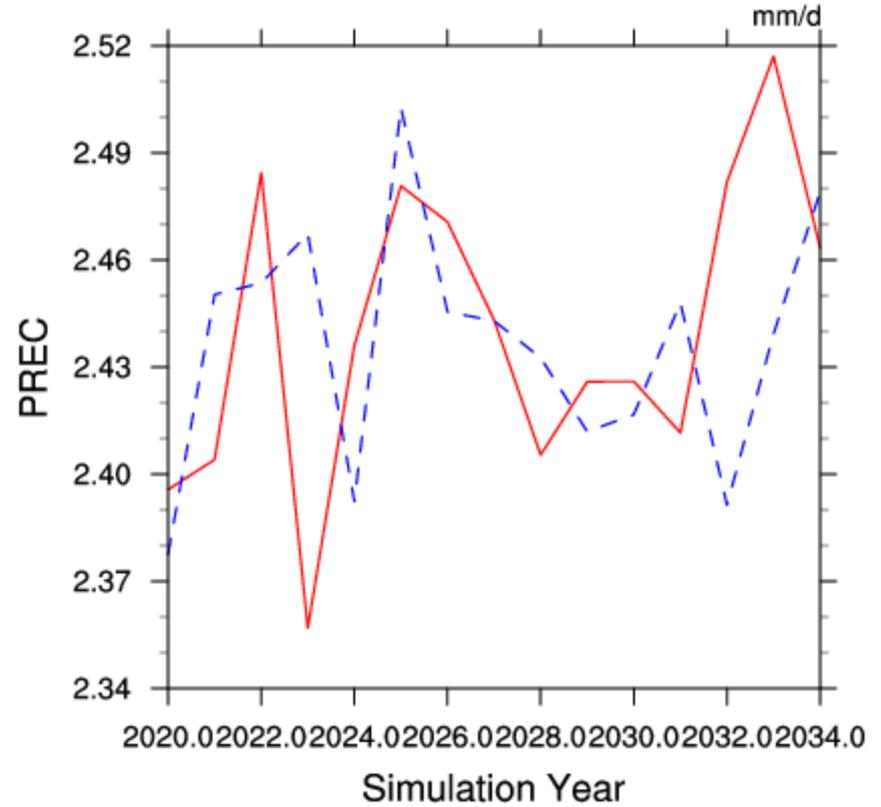
- Tree cover higher
- Grass cover higher
- Crop cover lower
- Pattern reversed for Sahel, India, southern boreal forest in Asia
- Regional modifications to harvest rate

CLM/CESM response to Expt 1 coupling (2020-2034)

2m air temperature

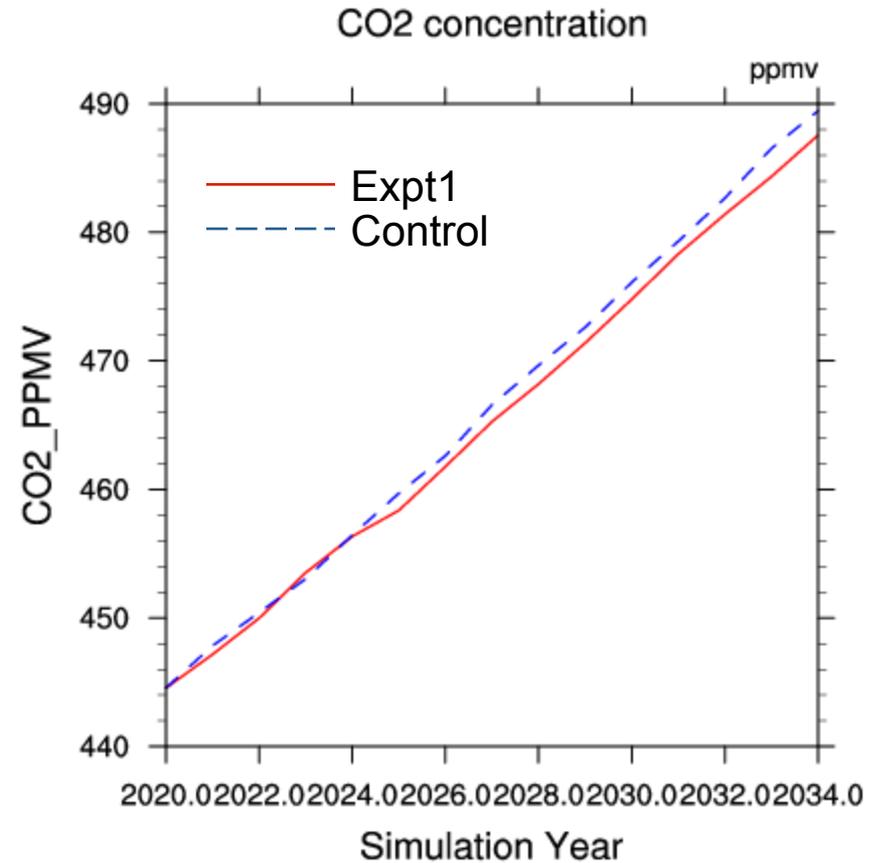
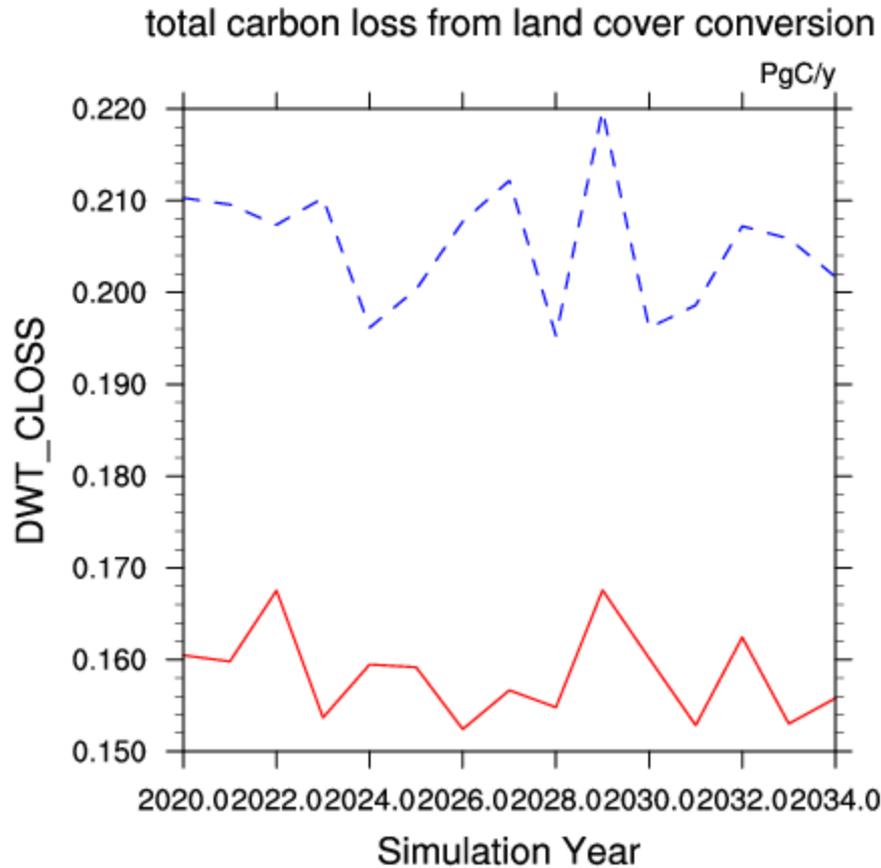


ppt: rain+snow



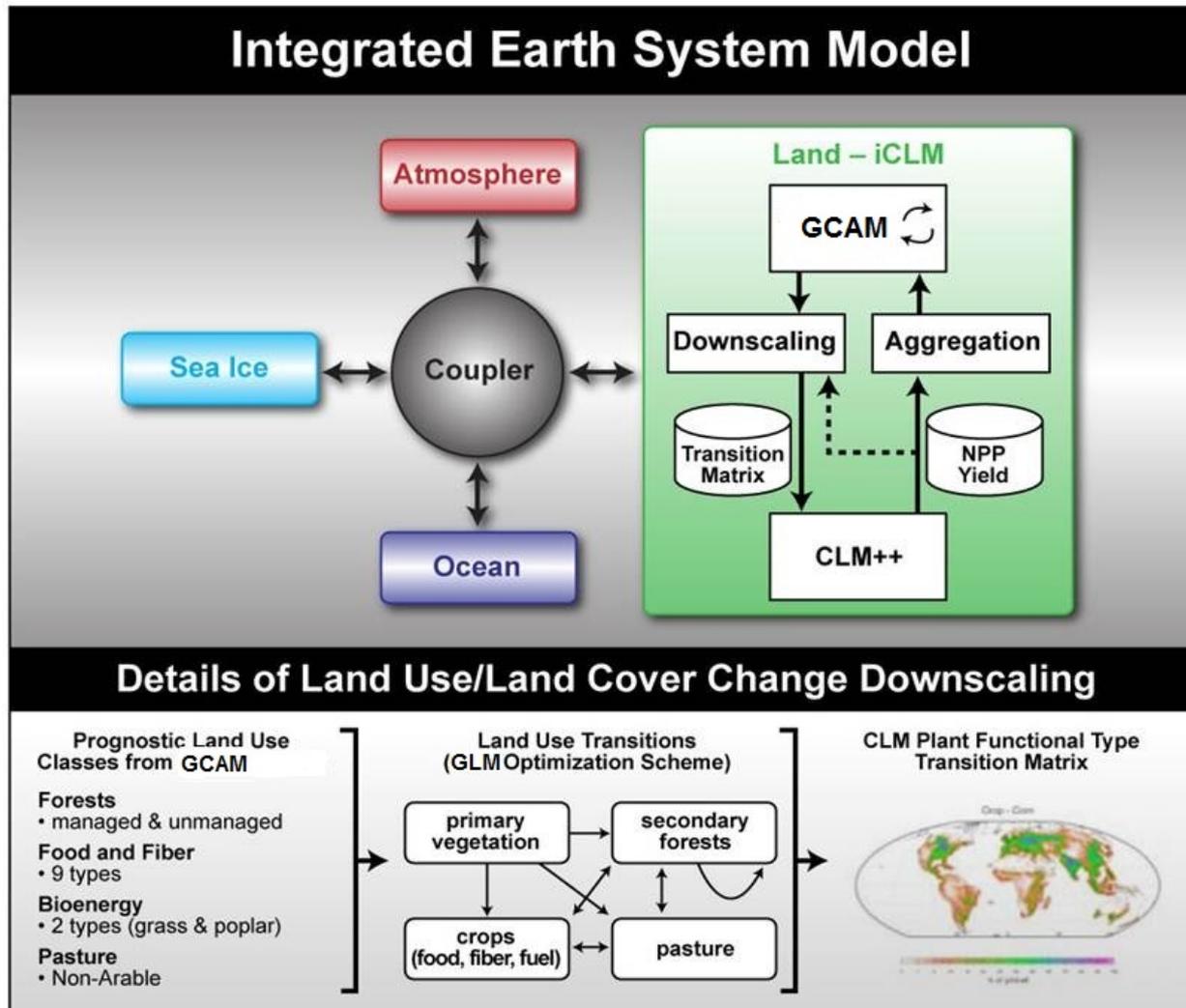
No climate signal after first coupling time step

CLM/CESM response to Expt 1 coupling (2020-2034)

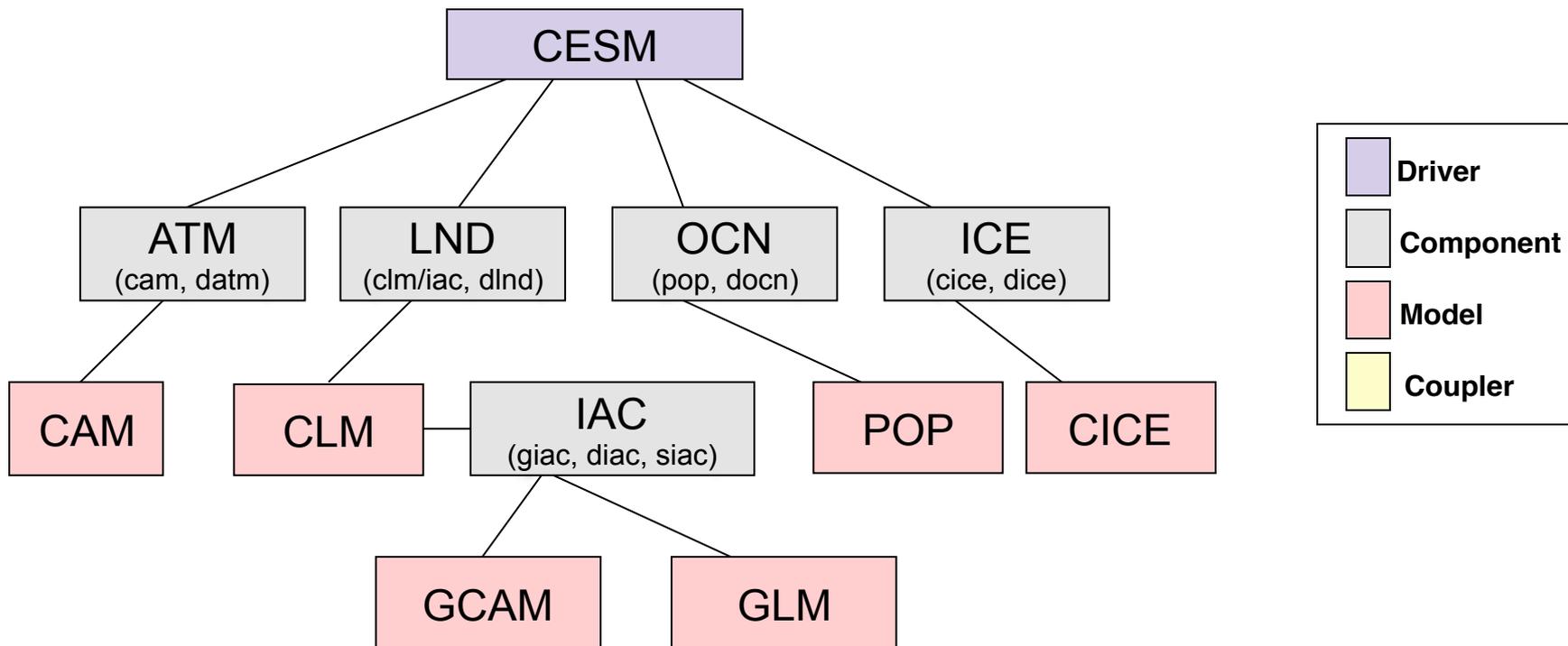


Clear signal in land cover change flux
emerging signal in atmospheric CO₂ concentration.

iESM Coupling Status



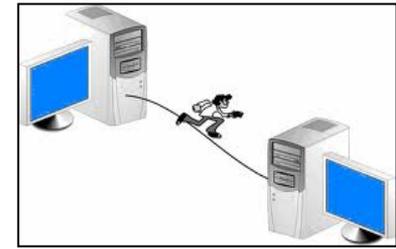
First Generation iESM



Status:

- iESM code is written.
- iESM code is running at NERSC.
- Validation against sneaker-net version of experiment 1.1 is underway.

Sneaker Net Implementation



- run GCAM at JGCRI
 - => regional land use change
- run matlab script at JGCRI
 - => 1/2 degree land use change
- run GLM at JGCRI
 - => 1/2 degree land cover change
- run PL code at ORNL
- run mksurfdat at ORNL
 - => clm surface dataset on clm grid
- run CESM at ORNL
 - => carbon stocks on clm grid
- run 01_pft_to_grid_h1.ncl at JGCRI
- run sneaker.r at JGCRI
 - => carbon stocks on gcam grid

Issues:

- Diversity of languages



- Large amount of effort to conduct this relay race



- Human effort scales directly with coupling frequency.

Active Coupling Implementation

run CESM

call Ind_run()

⇒ carbon stocks on gcam grid

call gcam()

⇒ regional land use change

call gcam2glm()

⇒ 1/2 degree land use change

call glm()

⇒ 1/2 degree land cover change

call glm2clm() ! (mksurfdt)

⇒ clm surface dataset on clm grid (to file)

call clm()

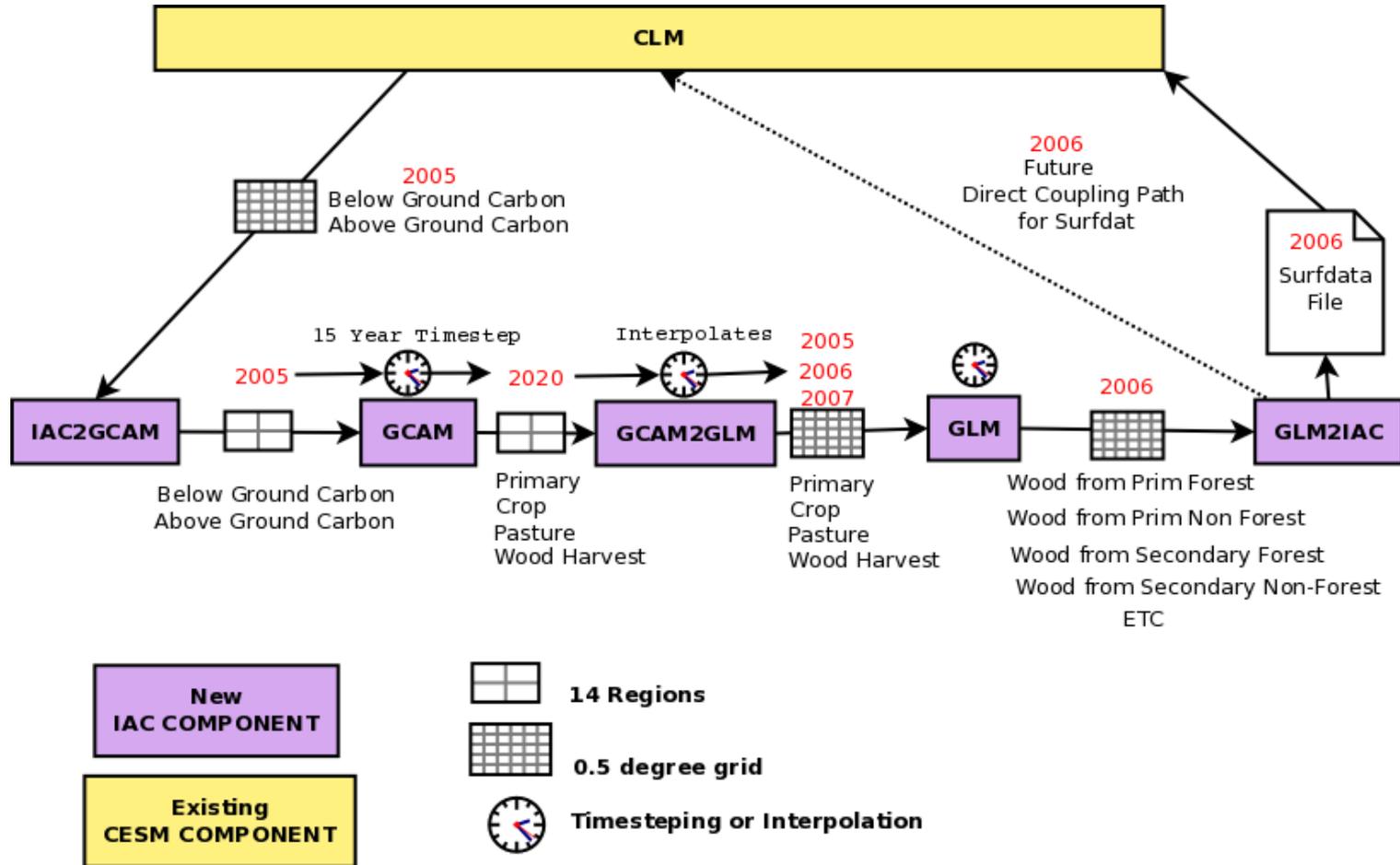
⇒ carbon stocks on clm grid

call clm2gcam

⇒ carbon stocks on gcam grid



iESM Coupling: Emulation of Sneaker-net Coupling



Status:

- We emulate sneaker-net using 15-year timesteps.

Emulation of pasture distributions using iESM

Status:

- We can reproduce the distributions of pasture to 1 part in 100,000.

Overview of plans through 2014

▶ Remainder of 2012

- Experiments
 - Complete Experiment 1
 - Validate iESM code with Experiment 1
 - Meeting of working group on experiments to plan next phase
- Model development
 - Integrate emissions coupling process into iESM
 - Scoping of RTB integration into CESM
- Model testing
 - Test CESM feedbacks to GCAM buildings sector

▶ Goals for 2013-2014

- Integrate GCAM and CESM (RTB) water models
- Explore the consequences of the basic science uncertainties in CESM for energy systems in GCAM
- Further develop and explore carbon cycle coupling with iESM
- Additional experiments with a wider range of climate, mitigation and sustainability scenarios.

Acknowledgements to the Project Team

- ▶ PNNL – JGCRI: Ben Bond-Lamberty, Kate Calvin, Jae Edmonds, Mohamad Hejazi, Tony Janetos, Sonny Kim, Page Kyle, Pralit Patel, Allison Thomson, Marshall Wise, Yuyu Zhou
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- ▶ UMD: George Hurtt, Louise Chini



Discussion

