Development and Early Results from an Integrated Earth System Model (iESM)

Tony Janetos, Jae Edmonds, Peter Thornton, Bill Collins

DOE Climate and Earth System Modeling PI Meeting

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Office of Science
U.S. DEPARTMENT OF ENERGY

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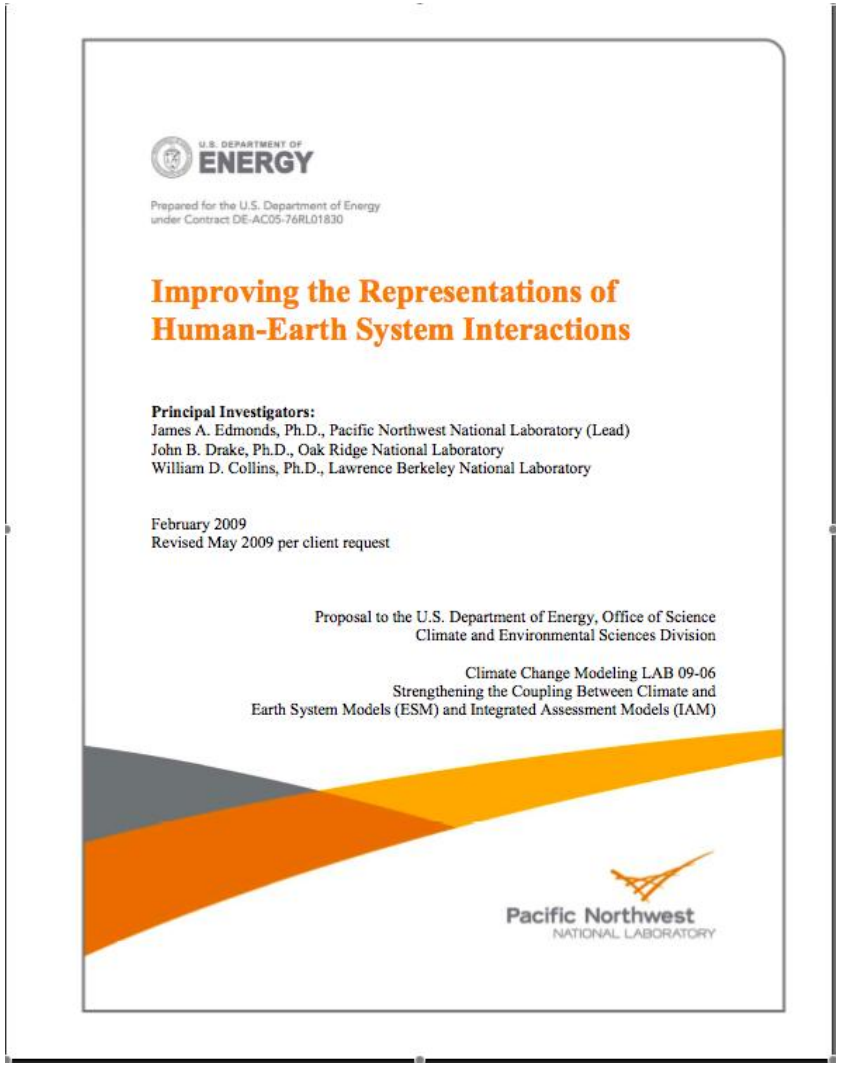

U.S. DEPARTMENT OF ENERGY

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Improving the Representations of Human-Earth System Interactions

Principal Investigators:
James A. Edmonds, Ph.D., Pacific Northwest National Laboratory (Lead)
John B. Drake, Ph.D., Oak Ridge National Laboratory
William D. Collins, Ph.D., Lawrence Berkeley National Laboratory

February 2009
Revised May 2009 per client request

Proposal to the U.S. Department of Energy, Office of Science
Climate and Environmental Sciences Division

Climate Change Modeling LAB 09-06
Strengthening the Coupling Between Climate and
Earth System Models (ESM) and Integrated Assessment Models (IAM)

Pacific Northwest
NATIONAL LABORATORY

Three Primary Tasks

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

Why Is This So Important?

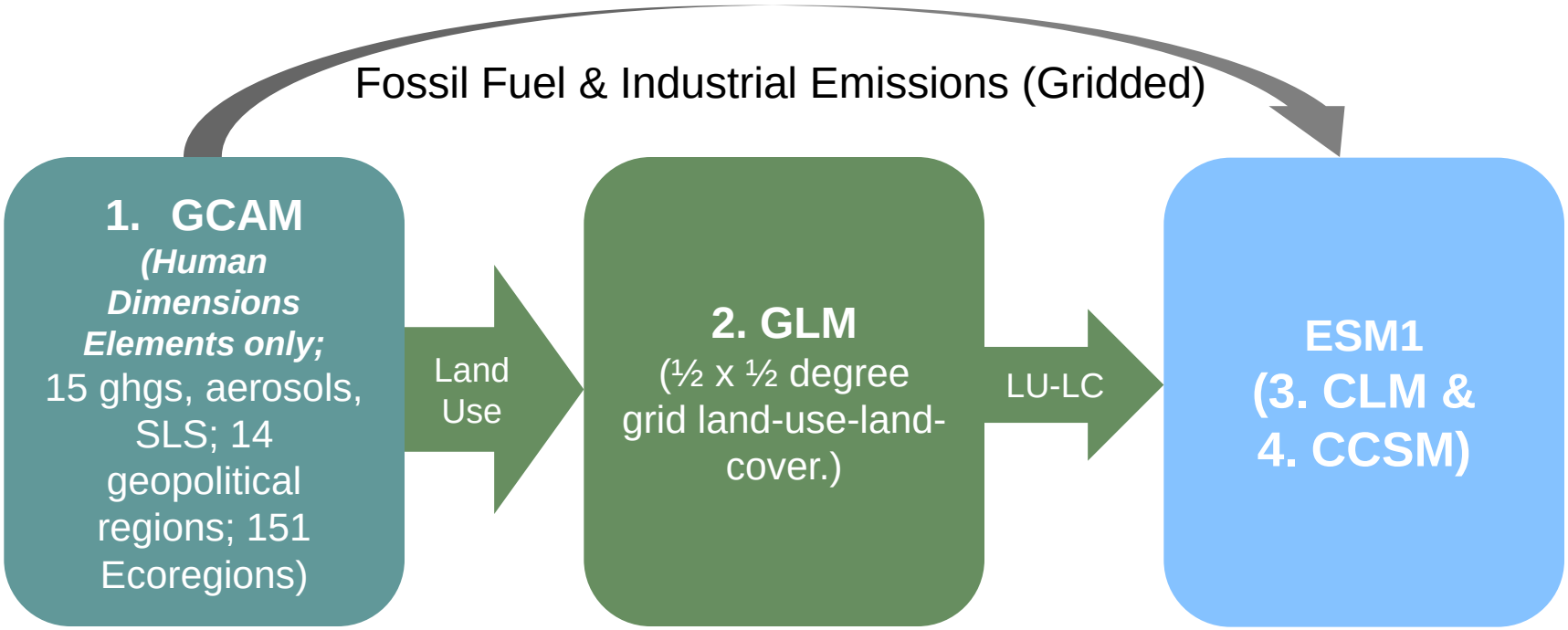
- ***In the present world emissions mitigation analysis is undertaken under the assumption that the climate is not changing.*** E.g. crop yields are unchanged, water resources are unchanged, and energy systems don't have to cope with a changing climate.

- ***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.

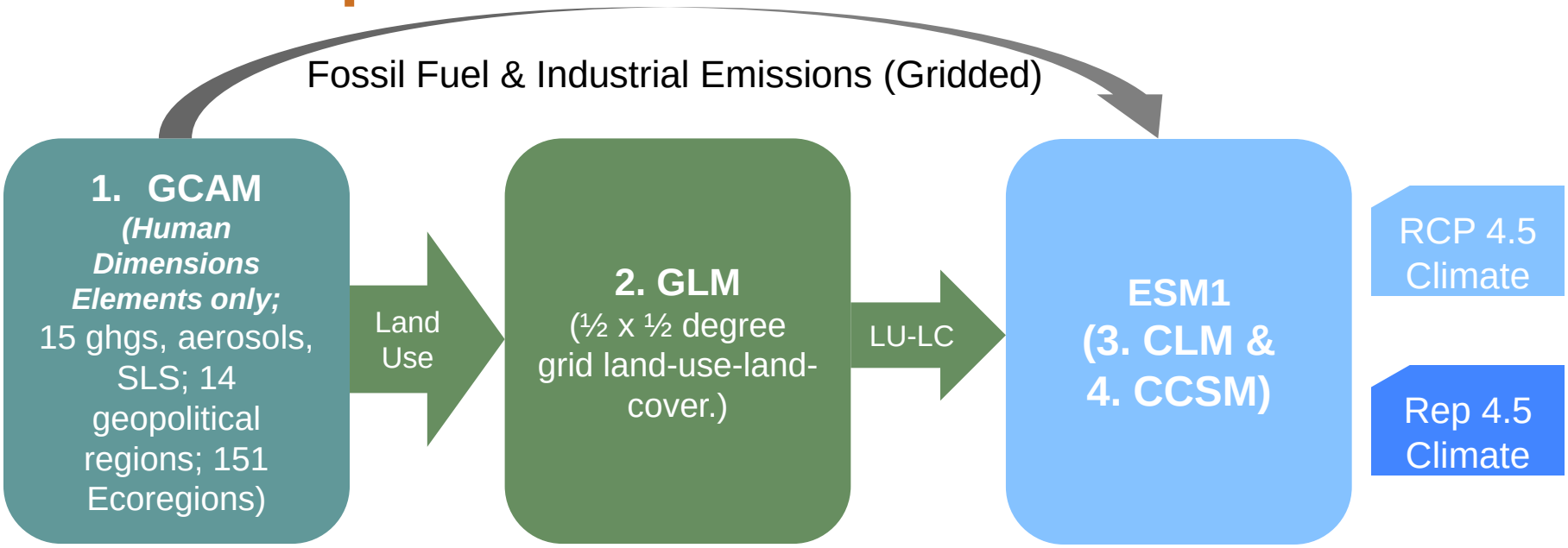
- ***Climate simulations are done under specified land-cover/land-use changes (if any)***, e.g. no land is being used for bioenergy, reforestation, feeding an additional 3-4 billion people, and energy use is only considered indirectly via emissions.

- 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.

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

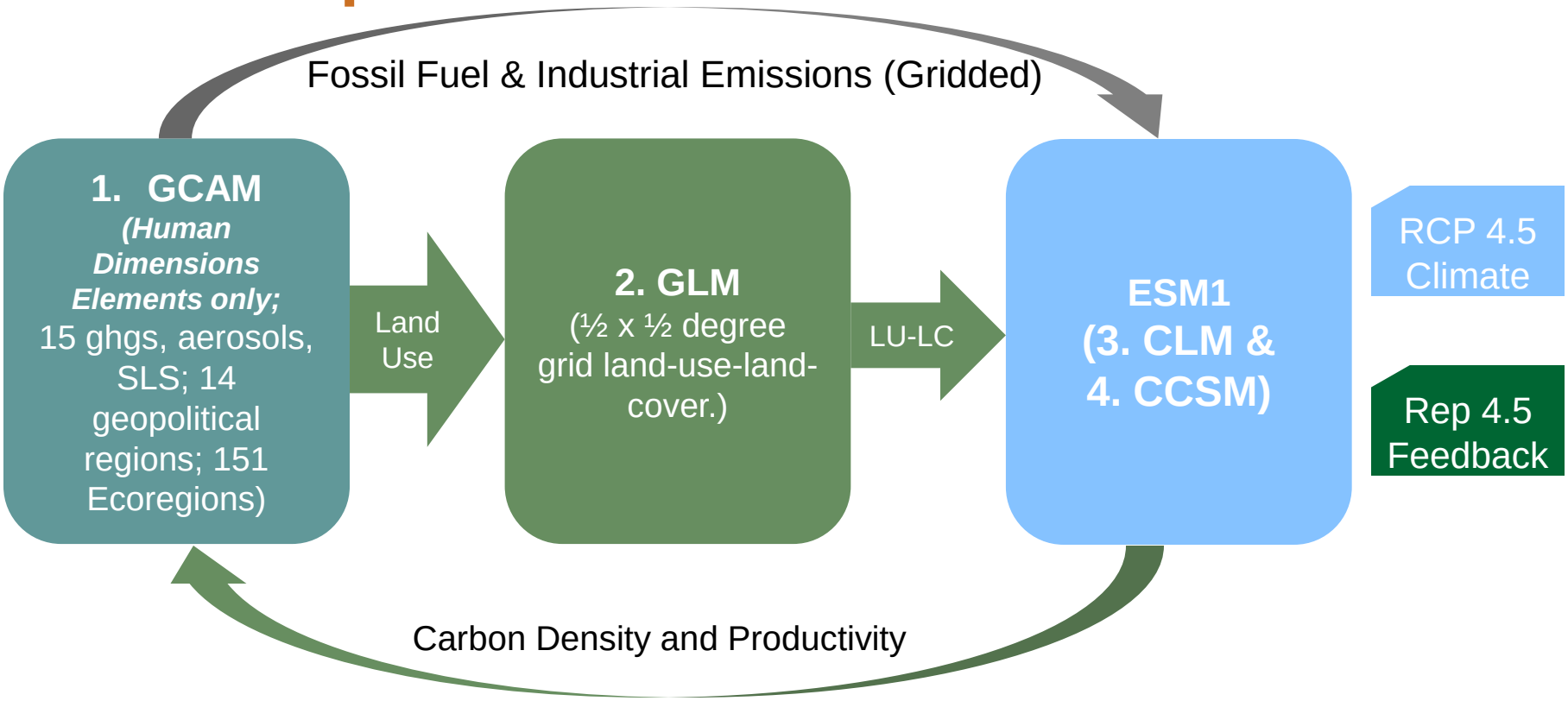


Three Experiments



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

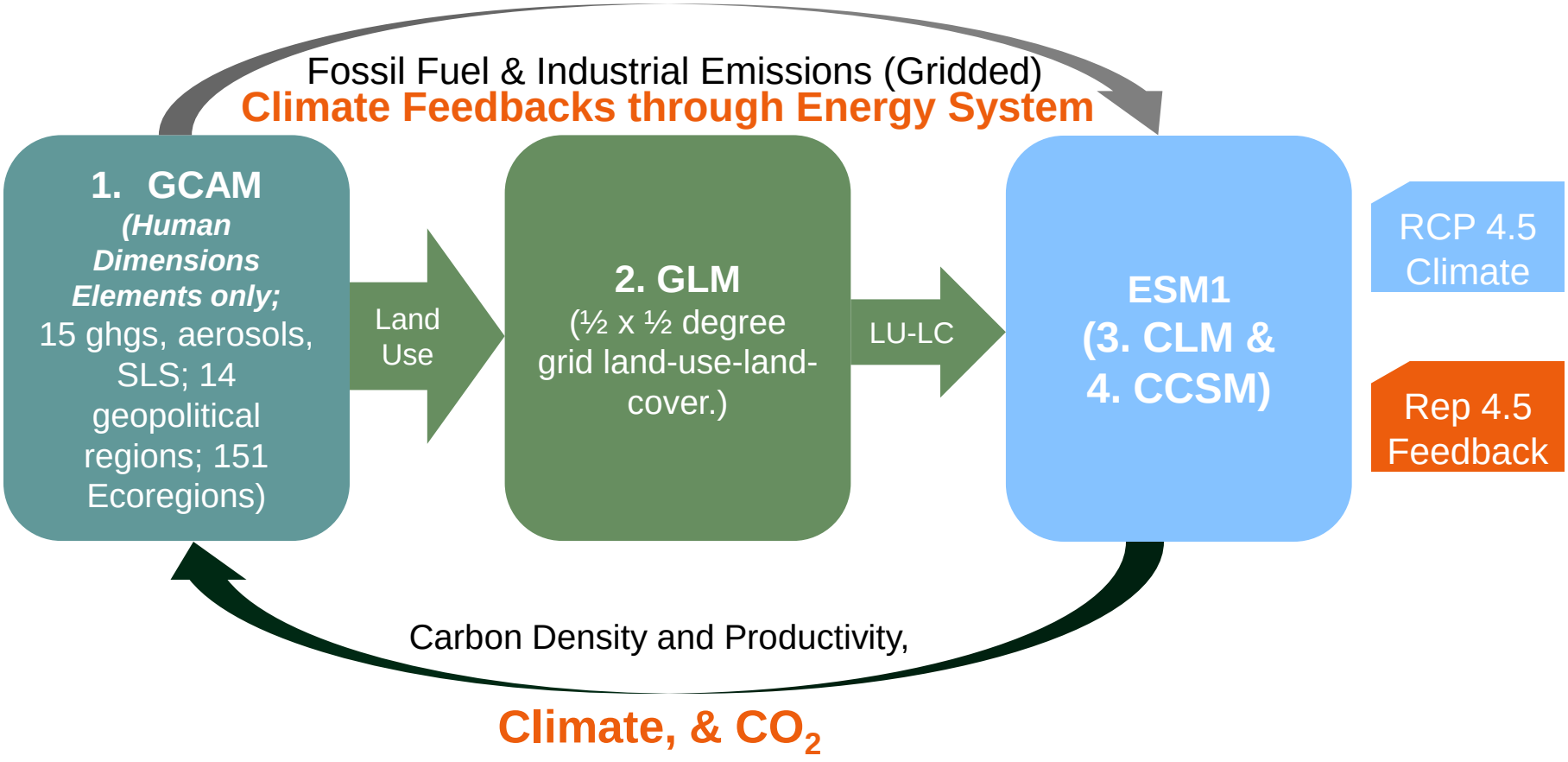
Three Experiments



- **Experiment 1:** RCP 4.5, with feedback from the CLM-CCSM calculations
  - 15-year time steps;
  - Lagged adjustment:
  - **Sneaker-net.**

Three Experiments

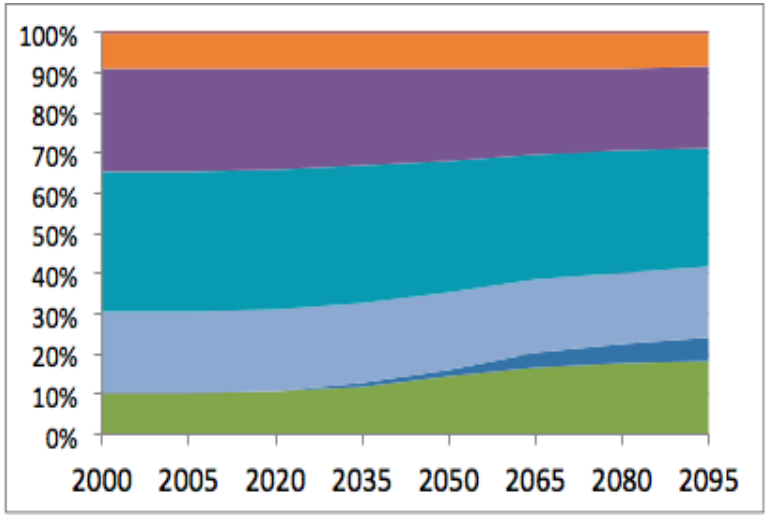
- **Experiment 2:** RCP 4.5, with FULL feedback from the CLM-CCSM calculations
  - **FULLY Integrated**



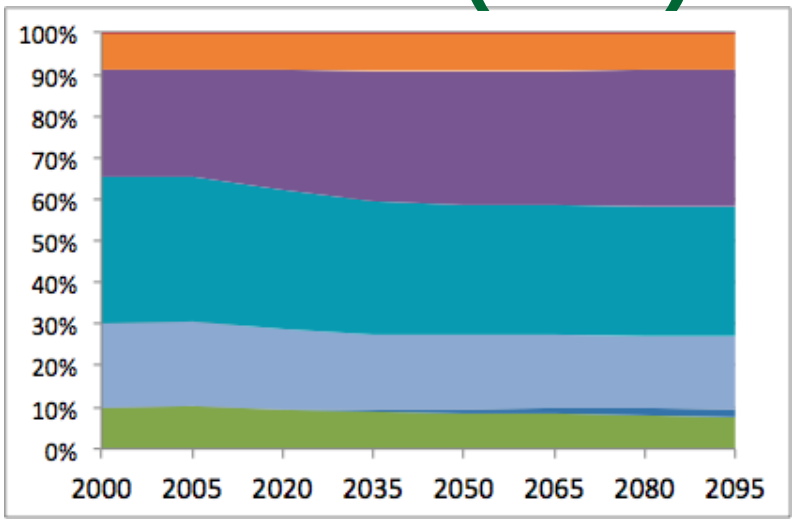
EXPERIMENT 0

RCP 4.5 and a Replication without terrestrial mitigation policy

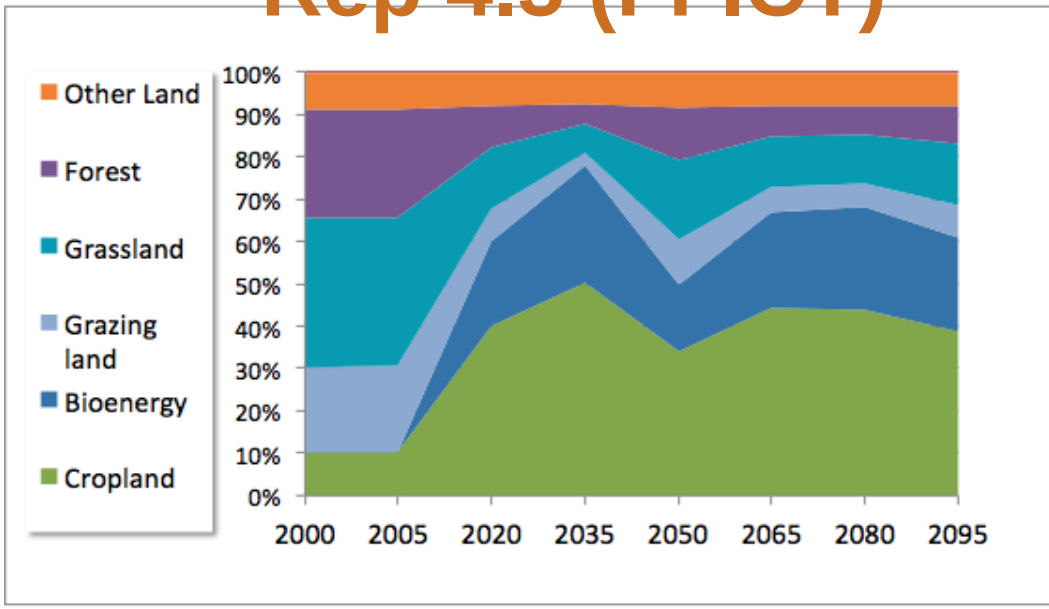
No Policy



RCP4.5 (UCT)

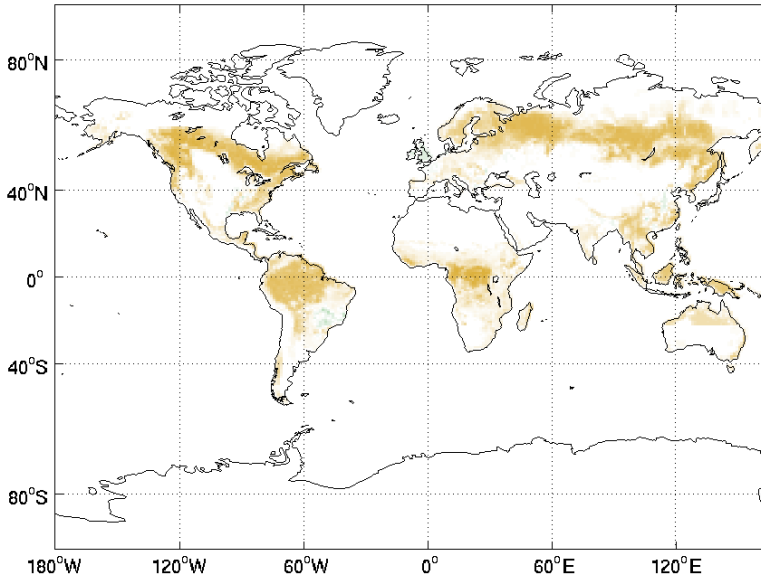


Rep 4.5 (FFICT)

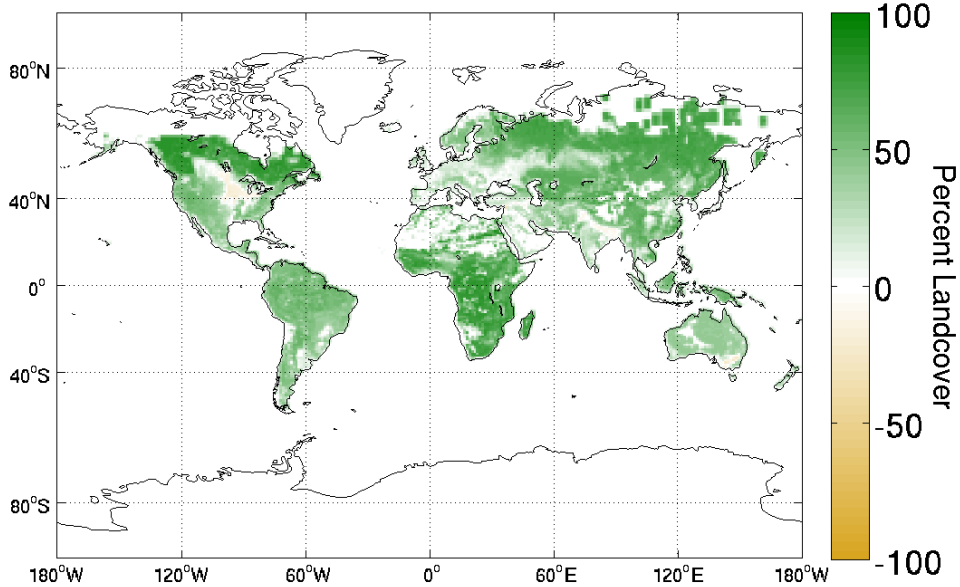


Experiment 0: GLM downscaling Rep 4.5 FFICT

FFICT: Change in Forest Cover

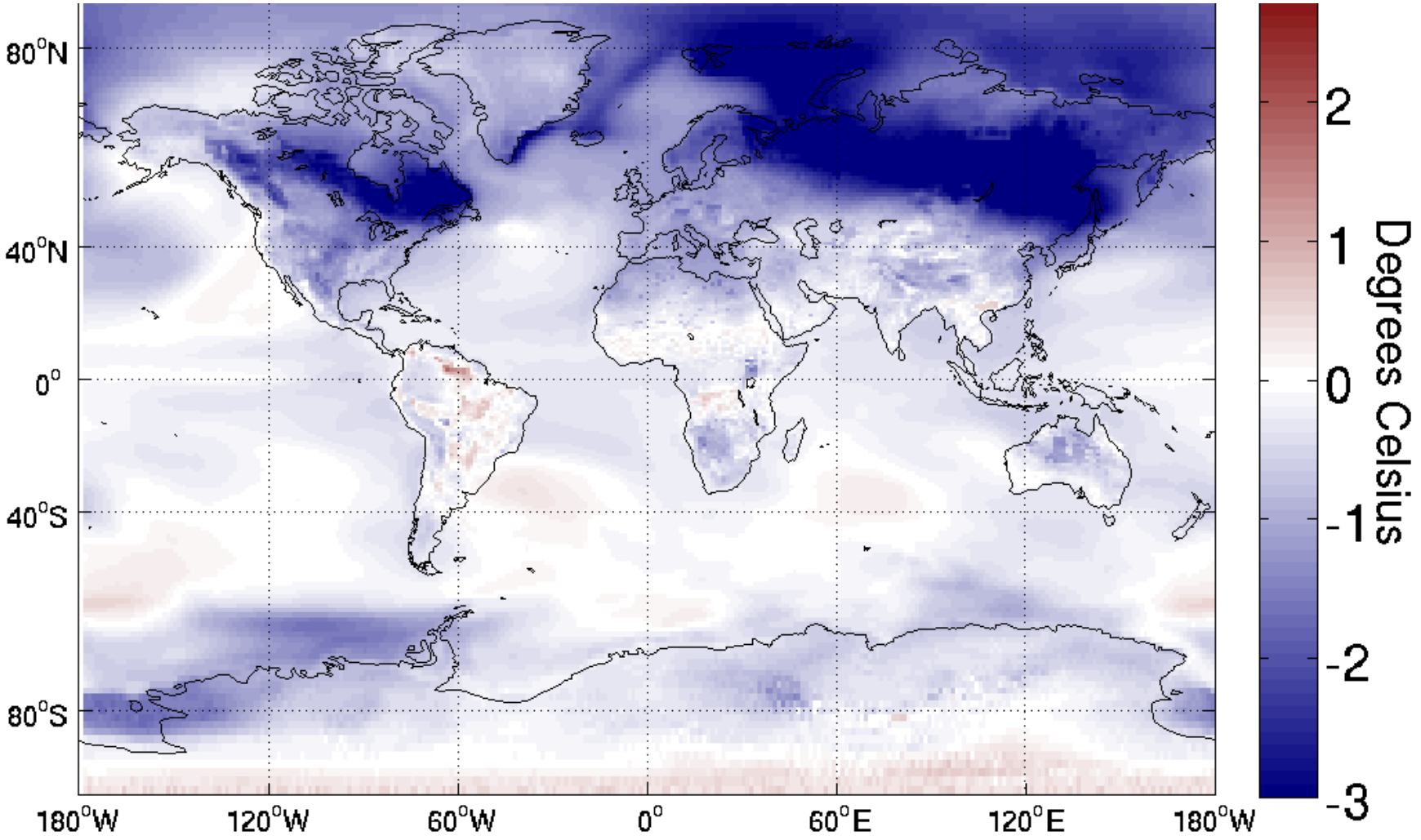


FFICT: Change in Crop Cover

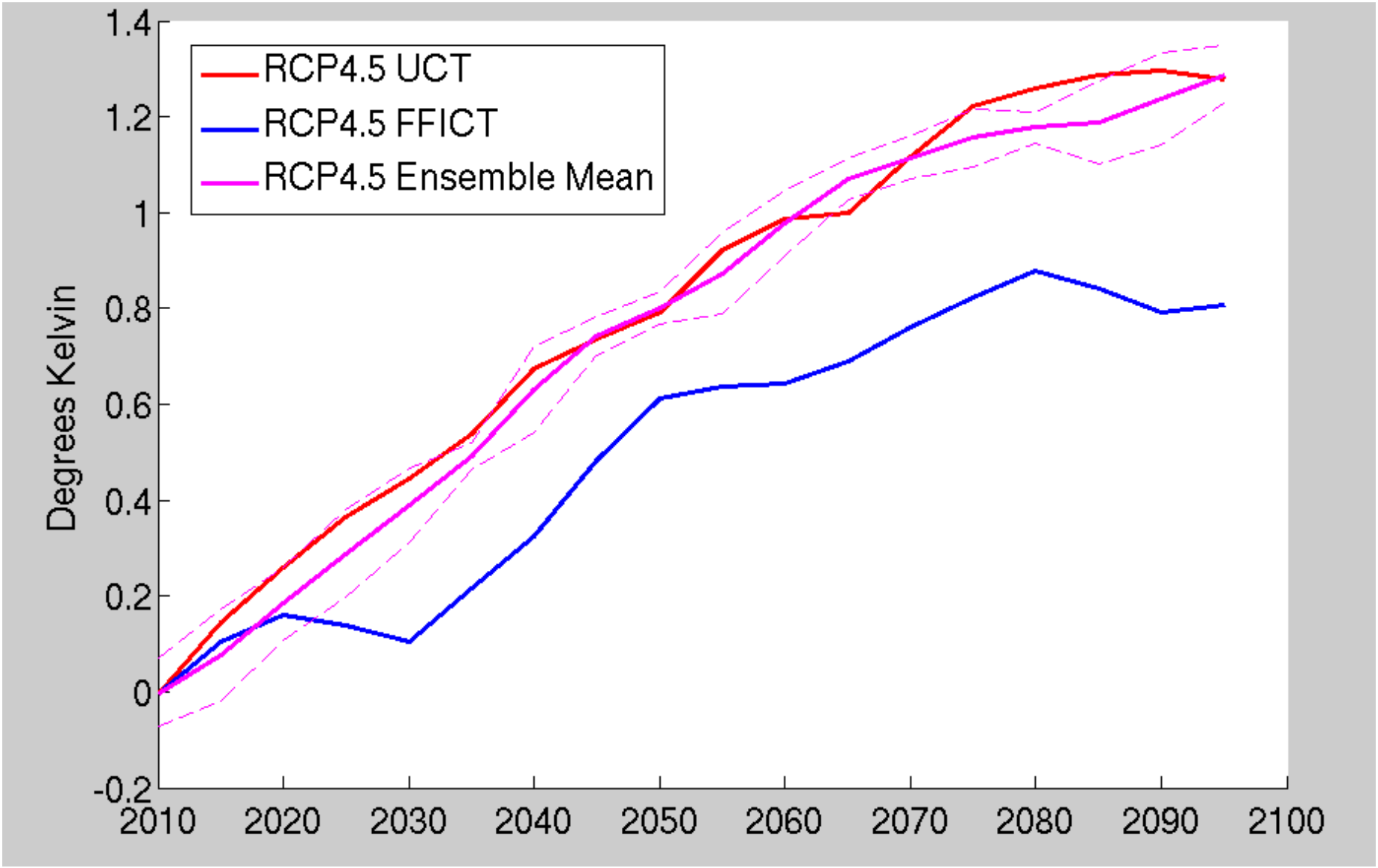


Change in Landcover from 2005 to 2100

Temperature Difference Rep4.5 – RCP 4.5
Decadal Mean 2090-2100



Global Mean Temperature Change



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:

Team

- **ORNL: Xiaoying Shi, Jiafu Mao, Peter Thornton (CLM/CESM)**
- **PNNL: Ben Bond-Lamberty, Allison Thomson, Kate Calvin, Yuyu Zhou, Pralit Patel (GCAM)**
- **UMD: Louise Chini, George Hurtt (GLM)**

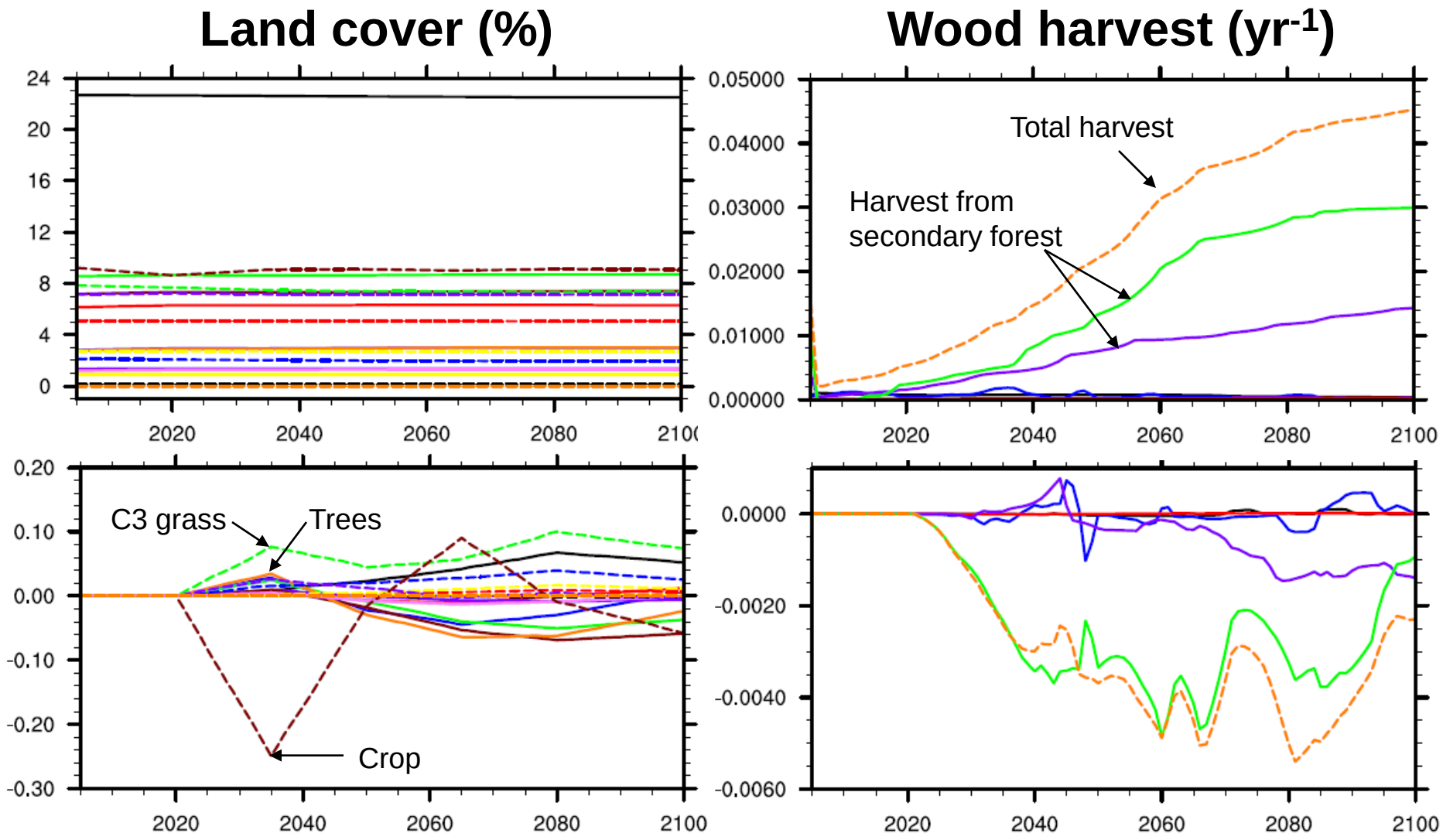
Experiment 1:

A few other details…

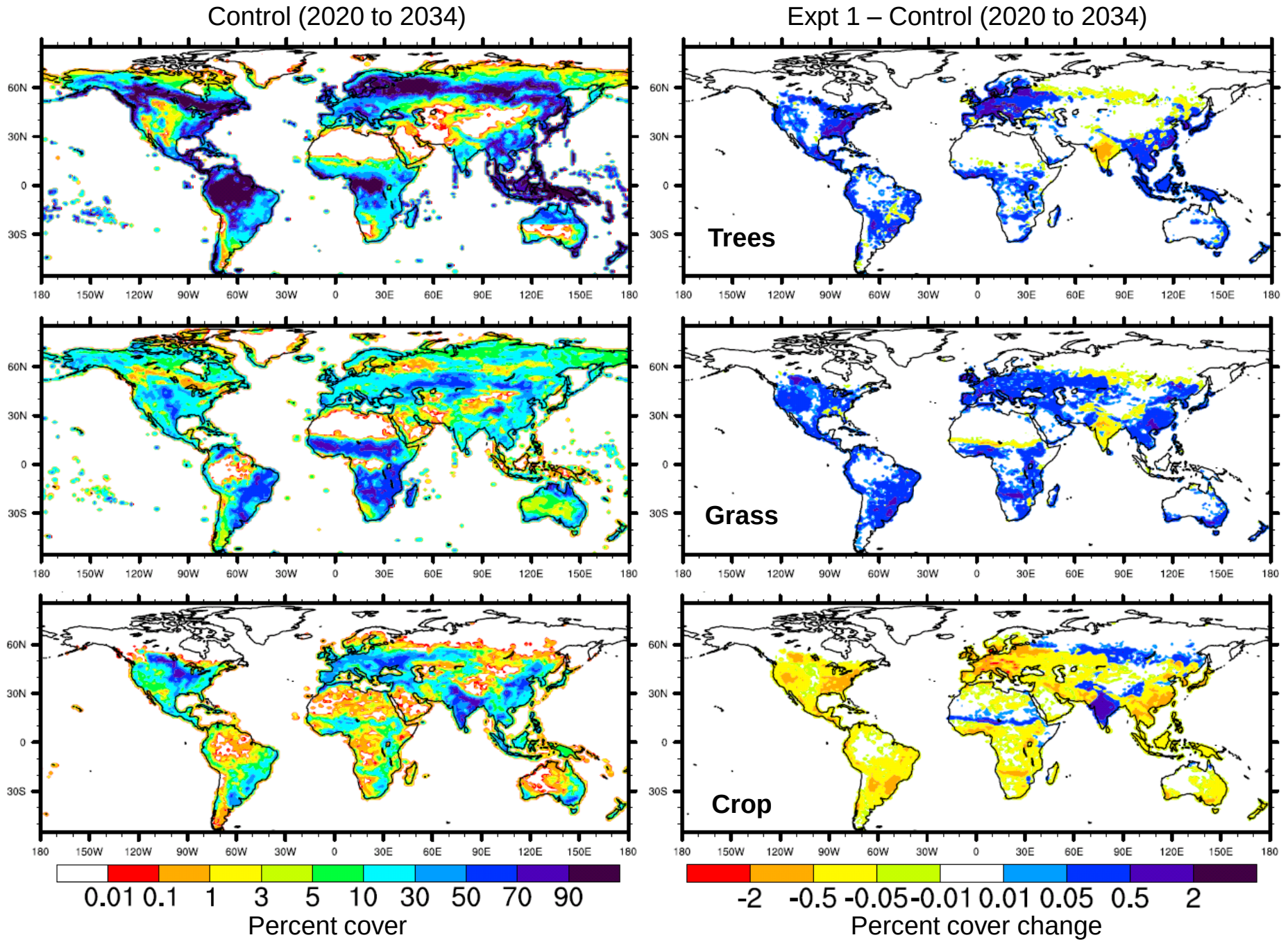
- **15-year time step, first departure from control occurs in period 2020-2034.**
- **Feedback modifies spatial/temporal pattern of GCAM carbon density as integration proceeds, but doesn't modify baseline carbon cycle.**
- **GLM has its own internal carbon density representation, which is not being modified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

Initial influence of Expt 1 feedback:

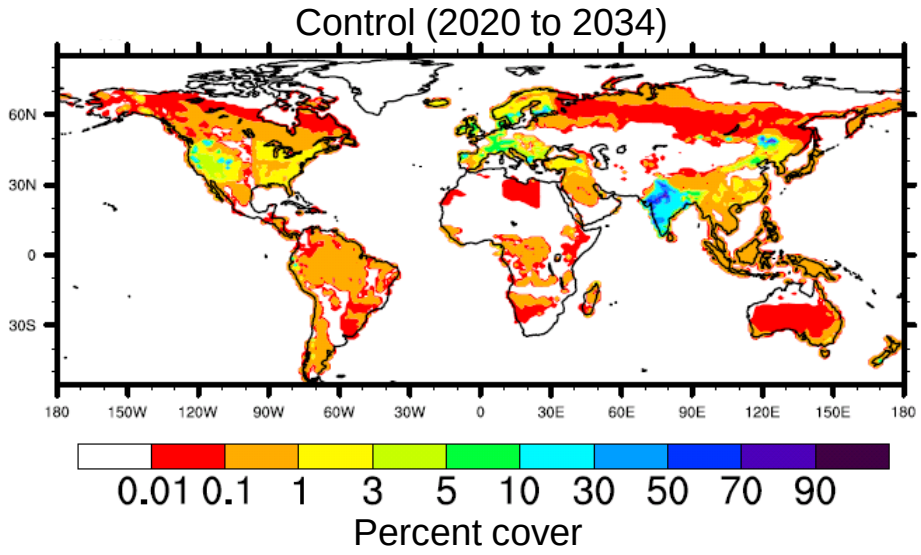
Control (top), Expt1-Control (bottom)

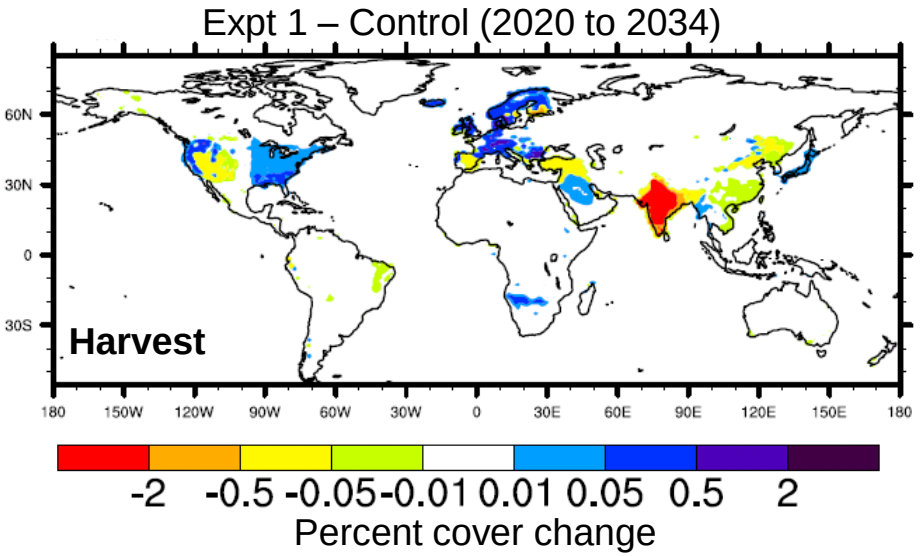


Translation of GCAM/GLM coupling response to CLM vegetation types



Translation of GCAM/GLM coupling response to CLM harvest



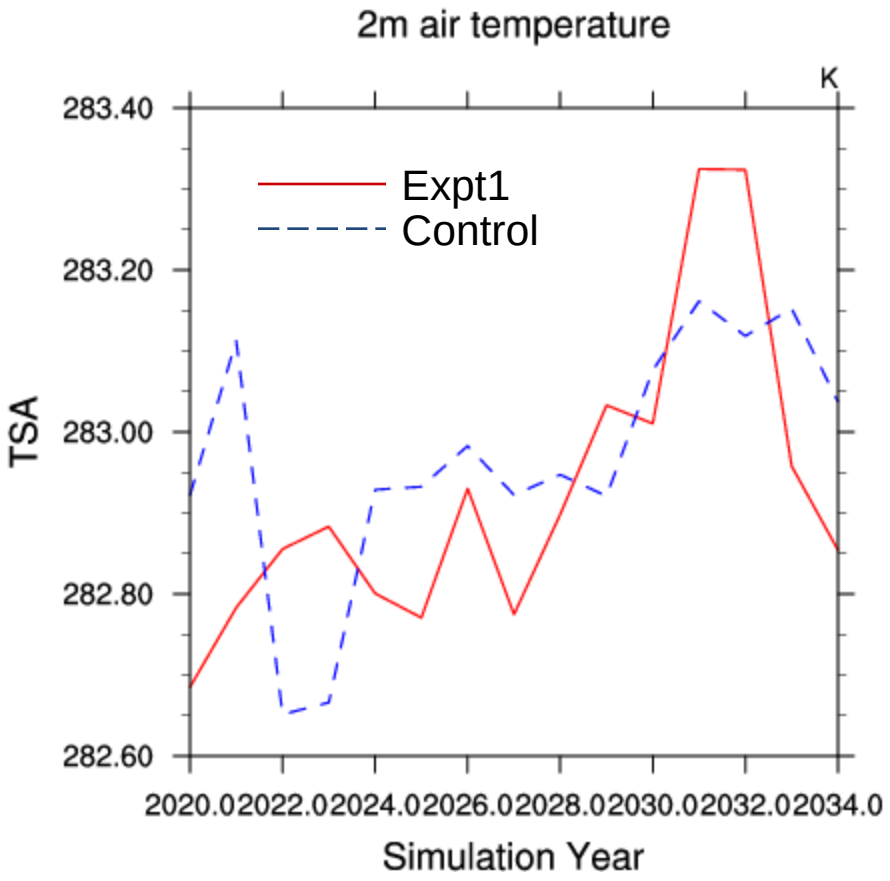


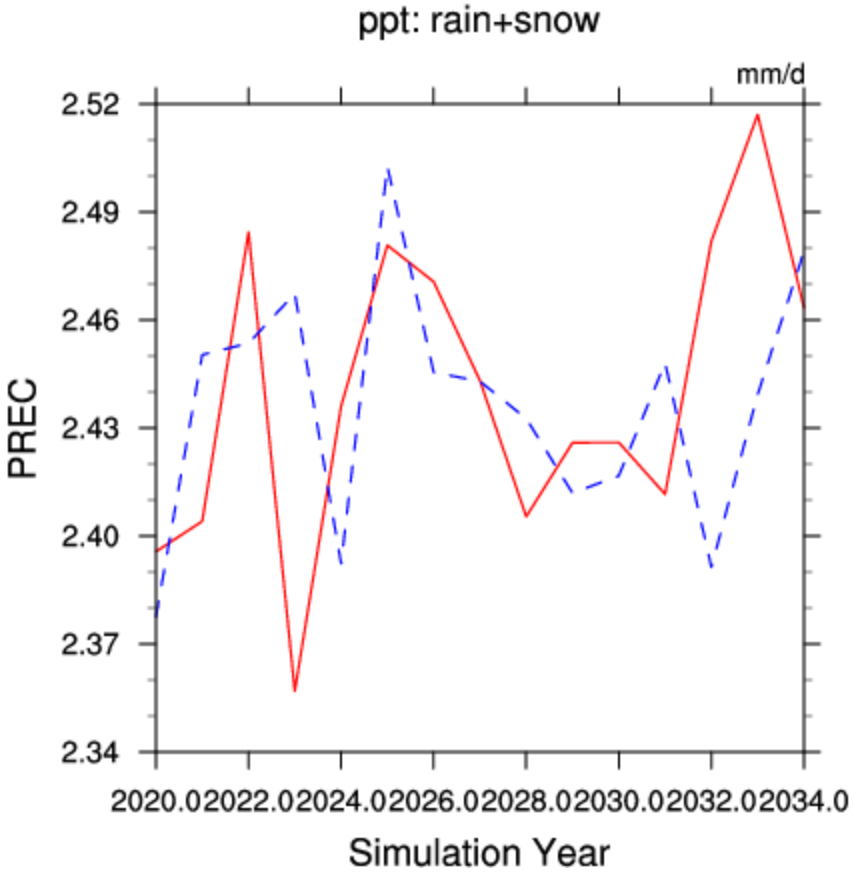
Summary of coupling influence on CLM forcing:

- 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)

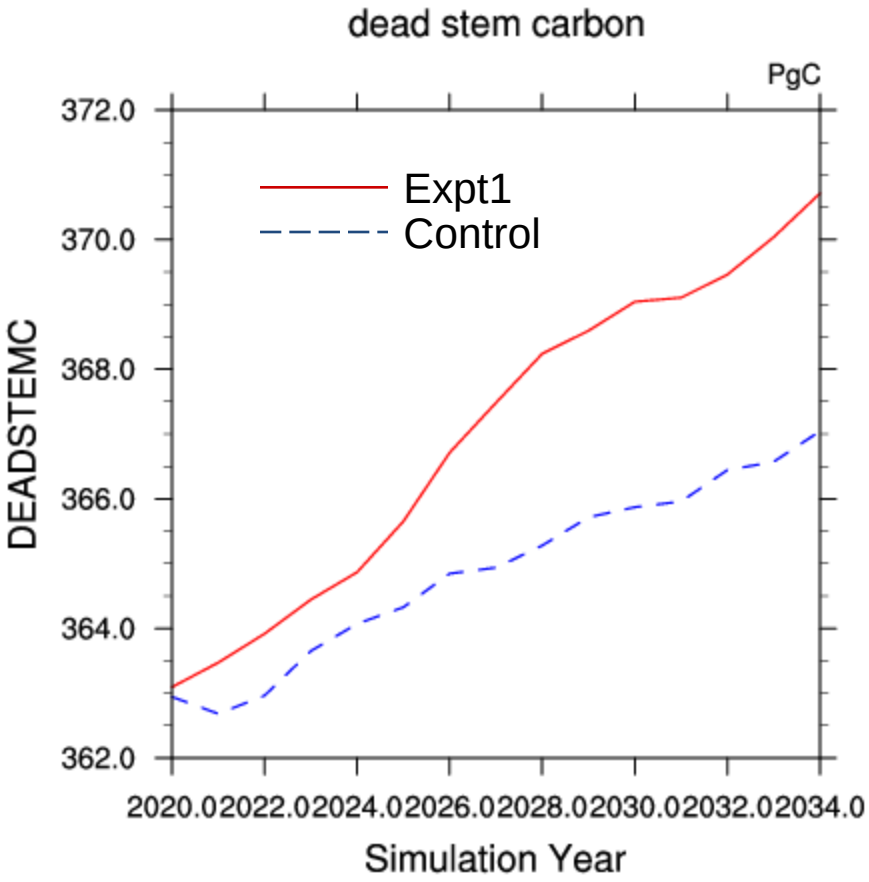


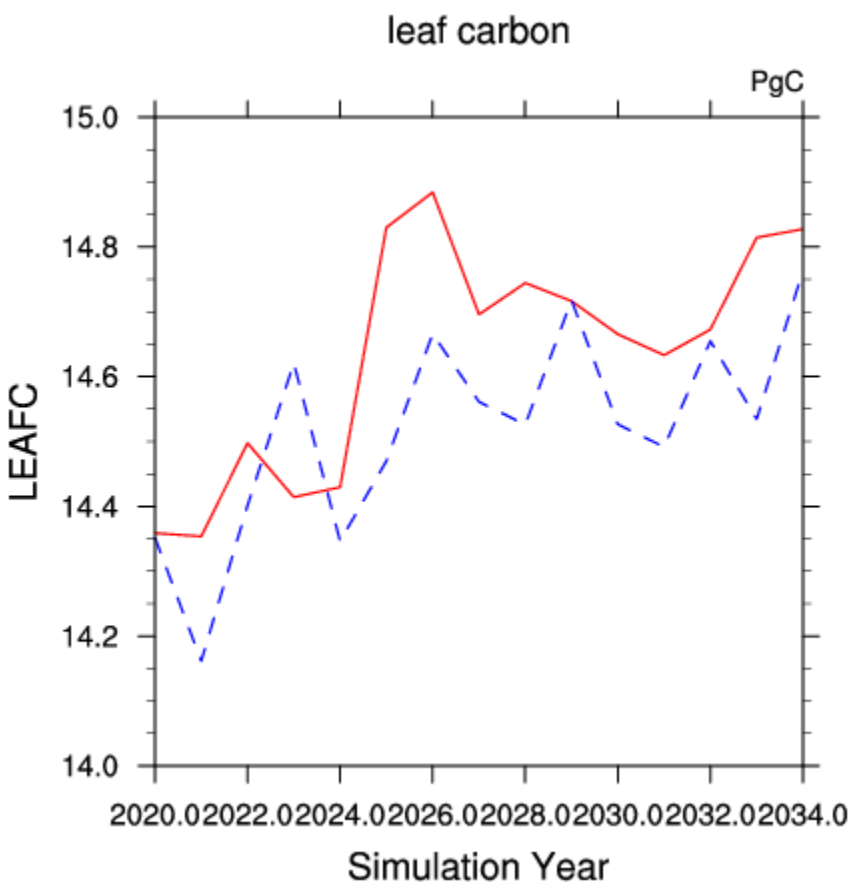


No climate signal after first coupling time step

CLM/CESM response to Expt 1 coupling

(2020-2034)

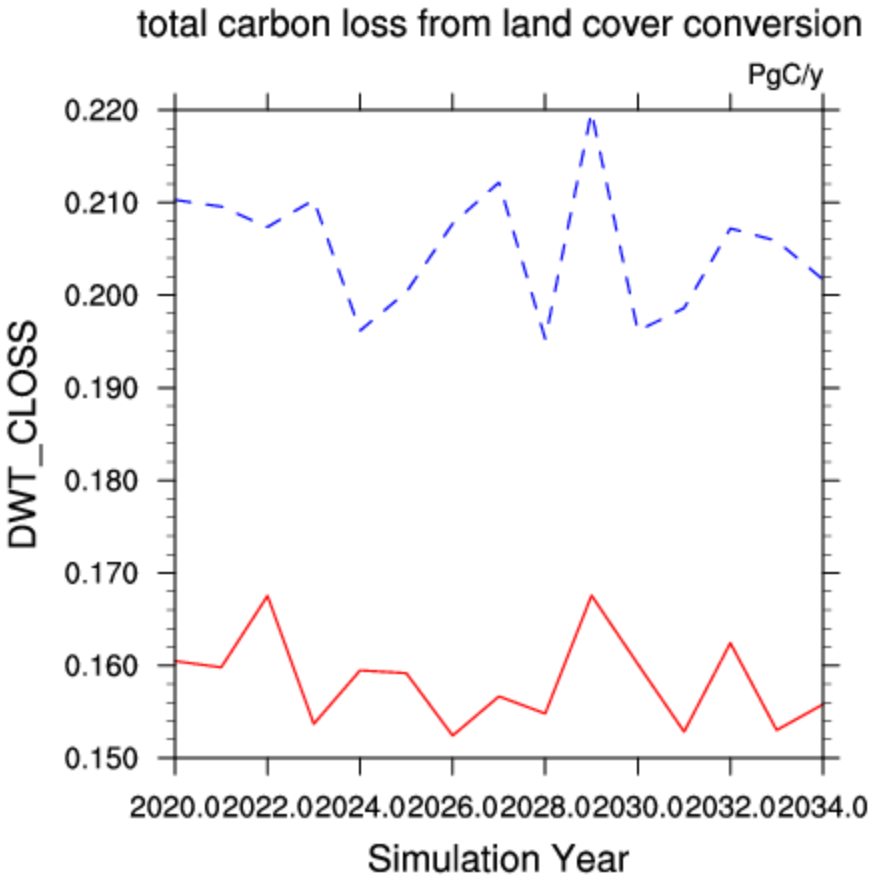


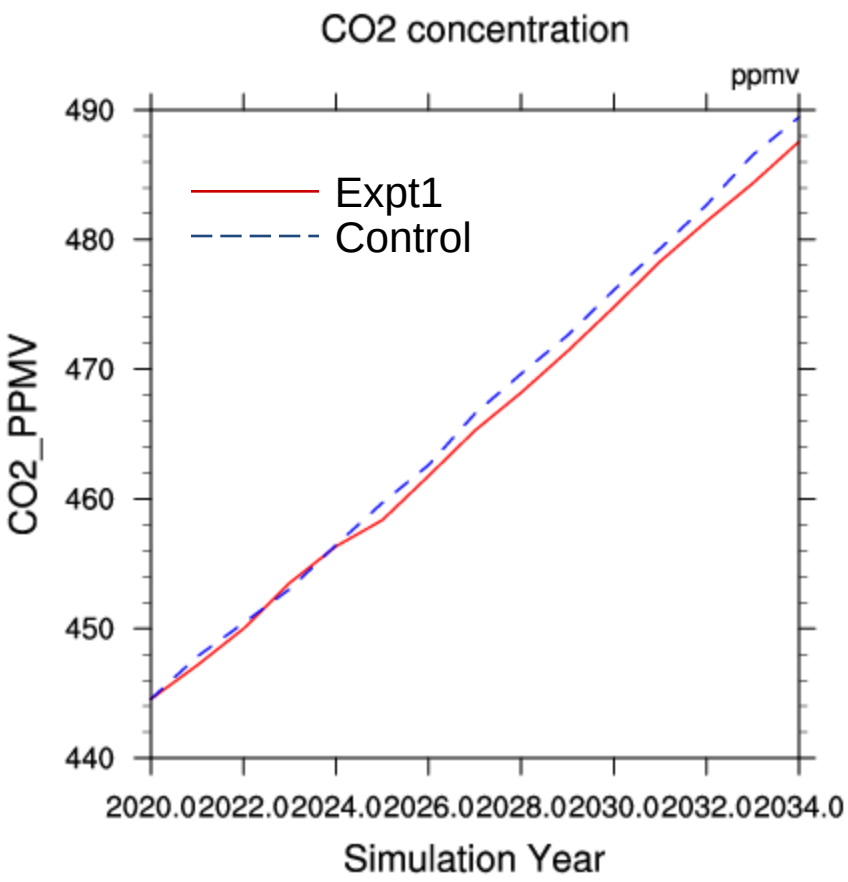


Clear signal in woody carbon stock,
emerging signal in leaf carbon.

CLM/CESM response to Expt 1 coupling

(2020-2034)



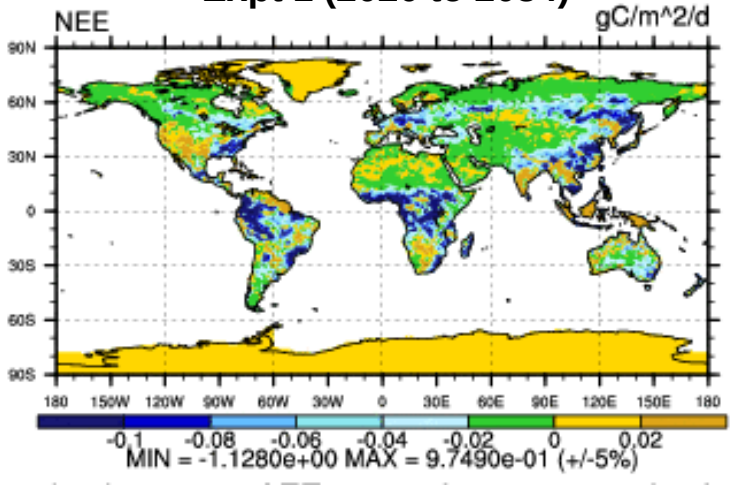


Clear signal in land cover change flux
emerging signal in atmospheric CO_2 concentration.

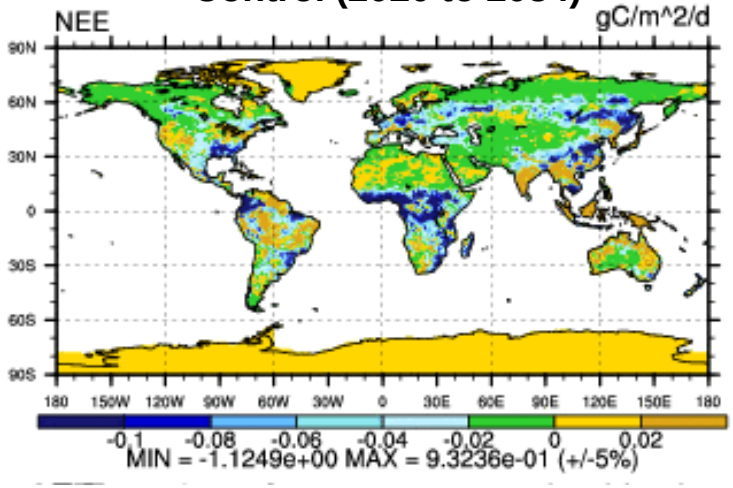
CLM/CESM response to Expt 1 coupling: NEE

(2020-2034)

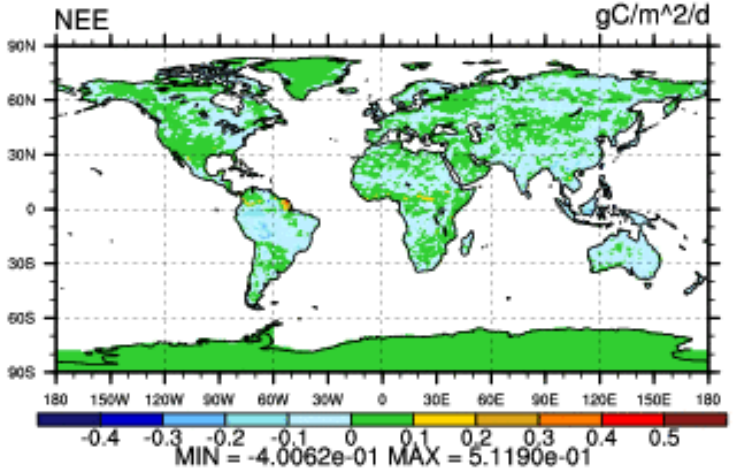
Expt 1 (2020 to 2034)

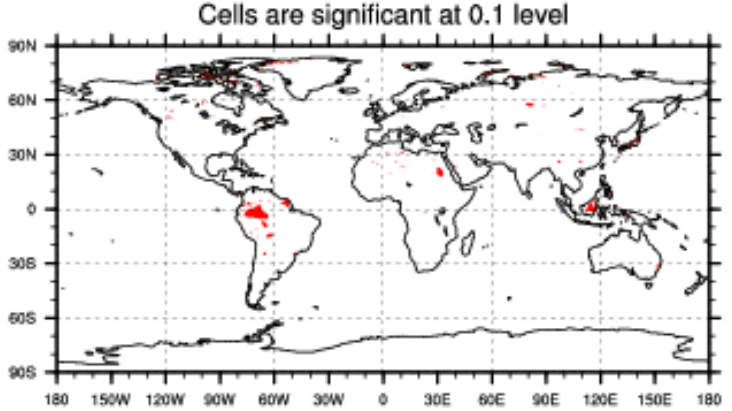


Control (2020 to 2034)



Expt 1 - Control (2020 to 2034)





Climate system internal variation still dominates NEE signal

Adding Integrated Assessment to CESM: Progress and prospects

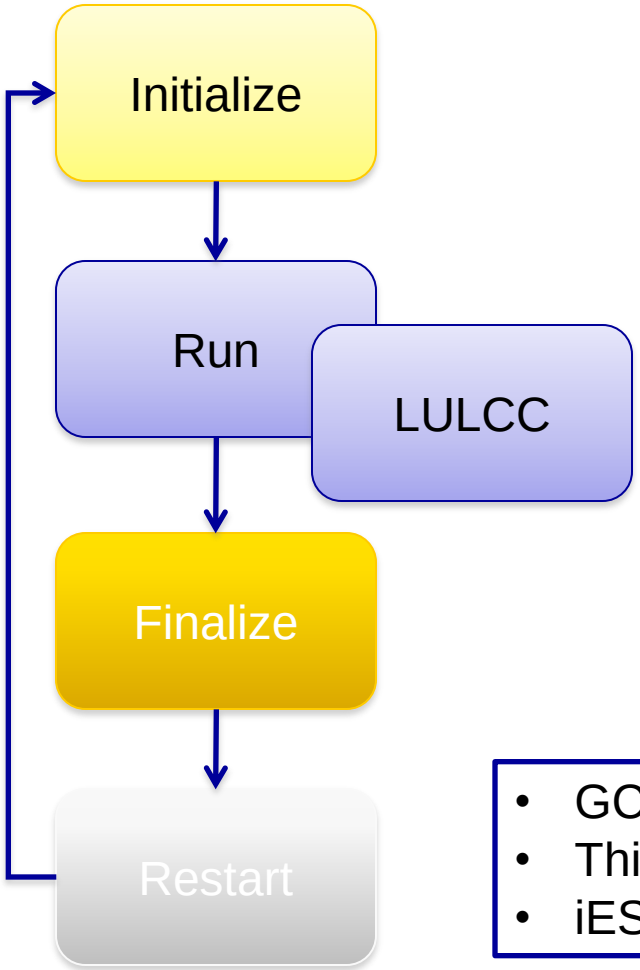
William Collins, co-PI, UCB and LBL

With contributions from the rest of the iESM team led by
Jae Edmonds, PI, JGCRI
Peter Thornton, co-PI, ORNL

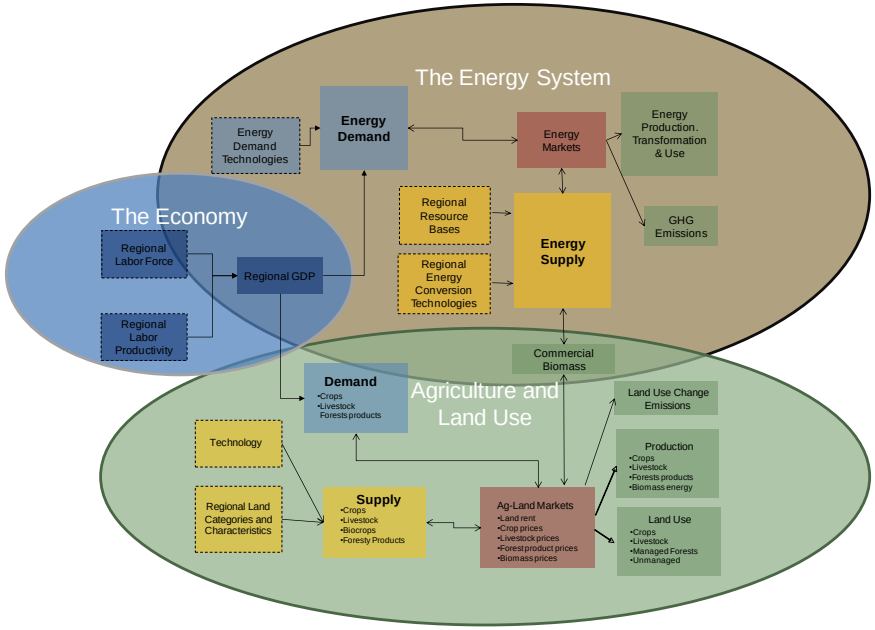
CESM STM Meeting
September 19-22, 2011
Boulder, Colorado

Goals of Integration of GCAM and CCSM

GCAM Interfaces for CCSM



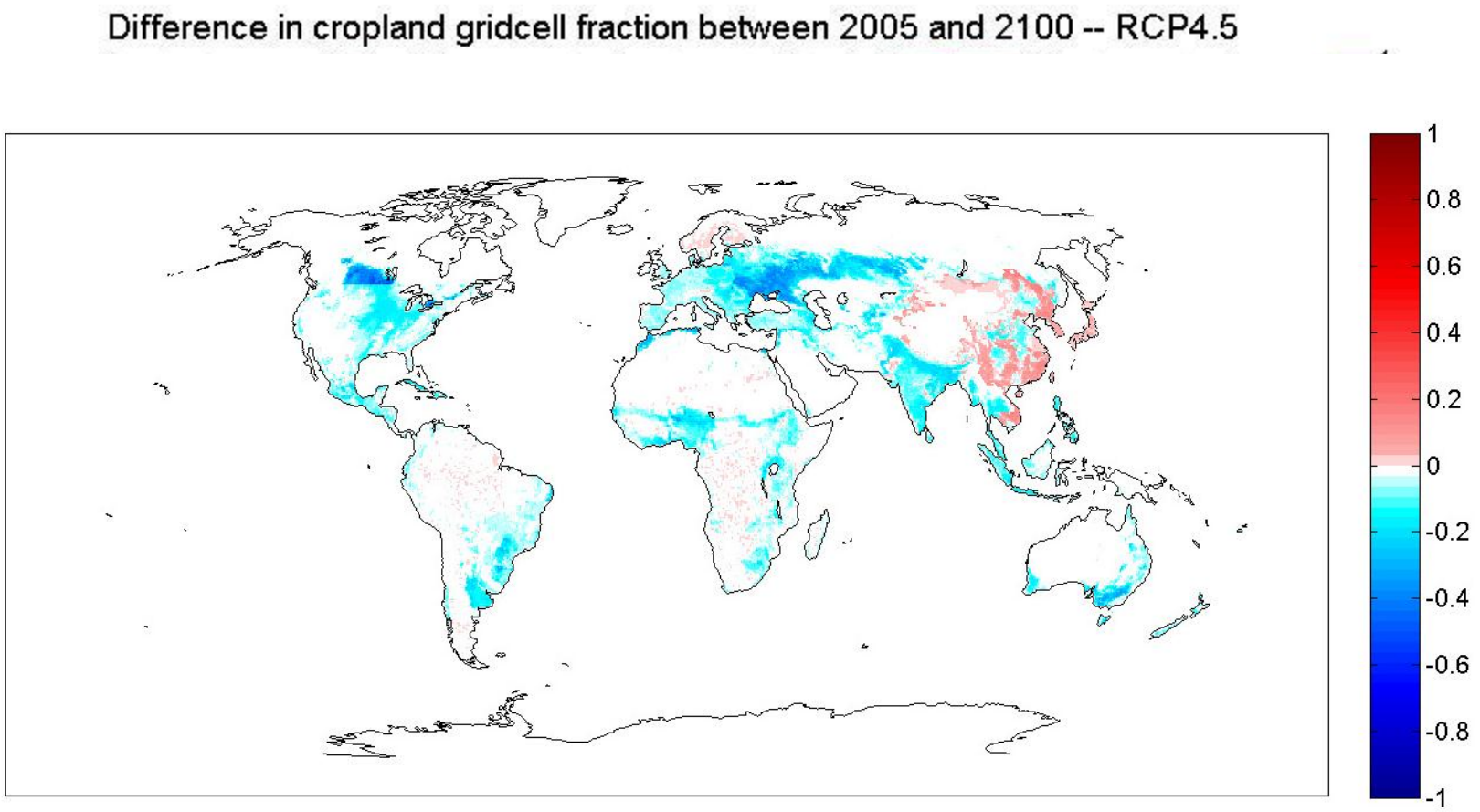
GCAM Human Earth System Structure



- GCAM and GLM can operate stand-alone or coupled.
- This flexibility is integrated with GCAM and GLM codes.
- iESM can track latest versions of GCAM and GLM.

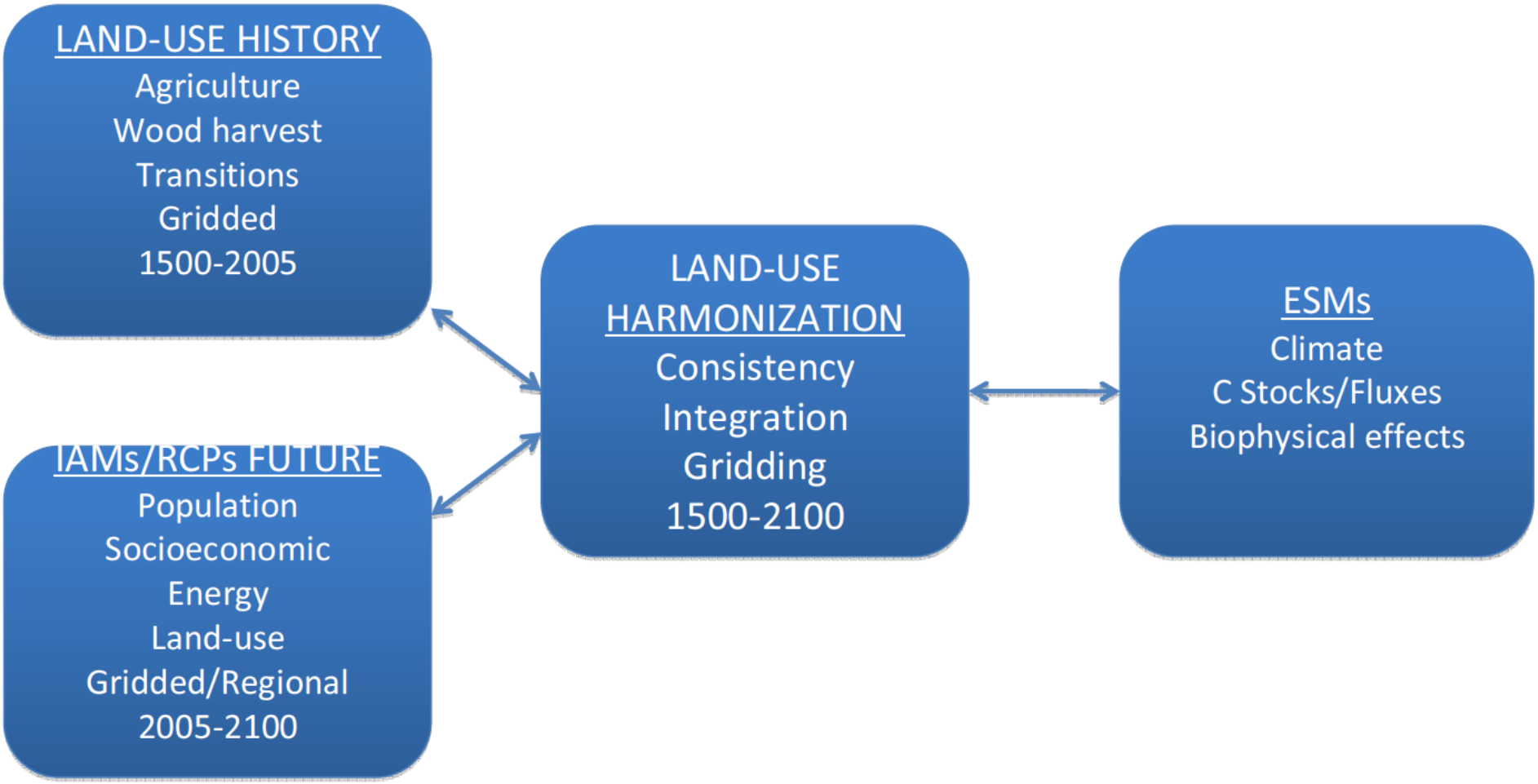
Down-scaling algorithms for land cover:

GCAM regions to CLM grid points

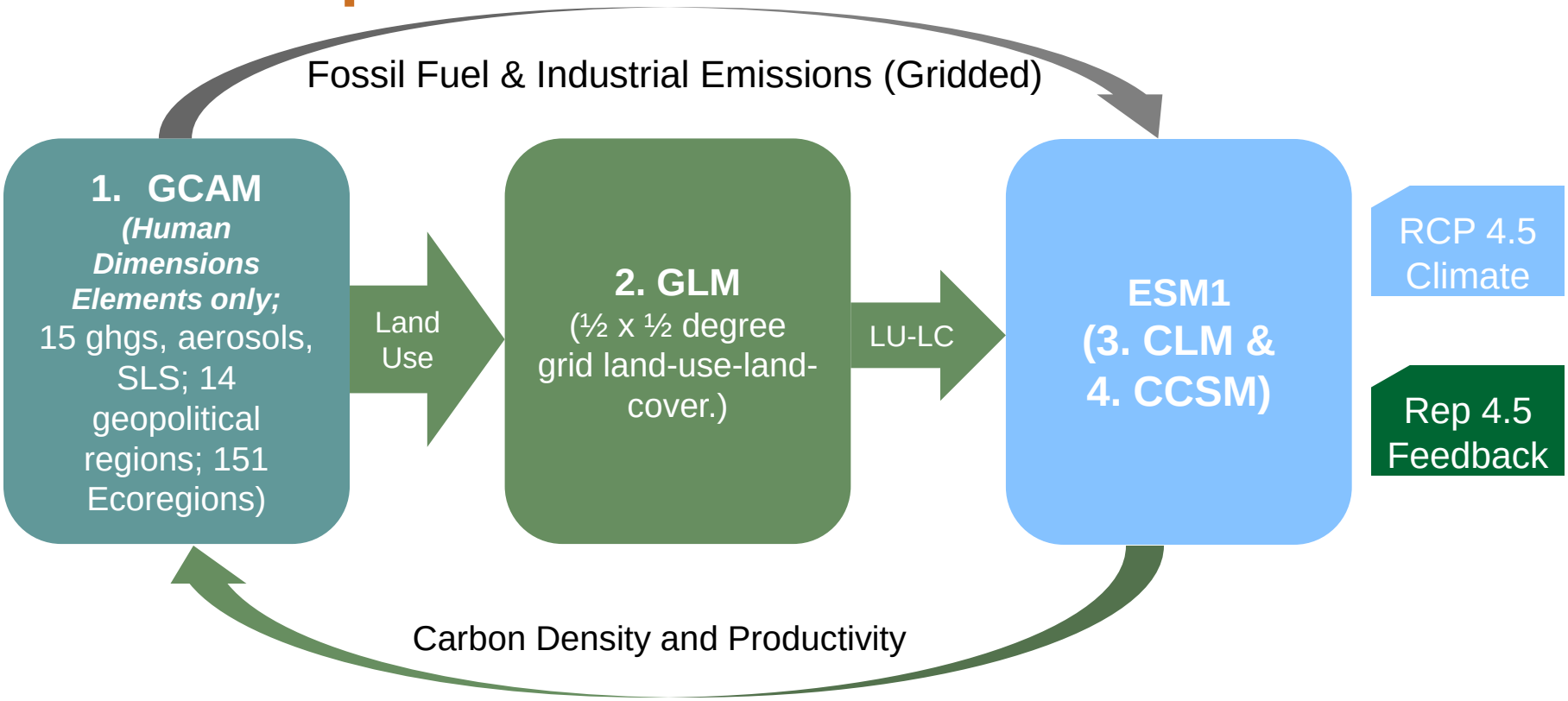


Thon

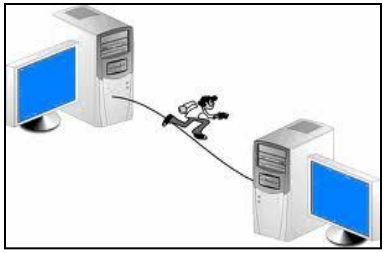
Downscaling via the Global Land Model



Three Experiments



- **Experiment 1:** RCP 4.5, with feedback from the CLM-CCSM calculations
  - 15-year time steps;
  - Lagged adjustment:



Sneaker Net Implementation

run GCAM at JGCRI
=> regional land use change
run matlab script at JGCRI
=> ½ degree land use change
run GLM at JGCRI
=> ½ 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 lnd_run()

=> carbon stocks on gcam grid

call gcam()

=> regional land use change

call gcam2glm()

=> ½ degree land use change

call glm()

=> ½ degree land cover change

call glm2clm() ! (mksurfdt)

=> clm surface dataset on clm grid (to file)

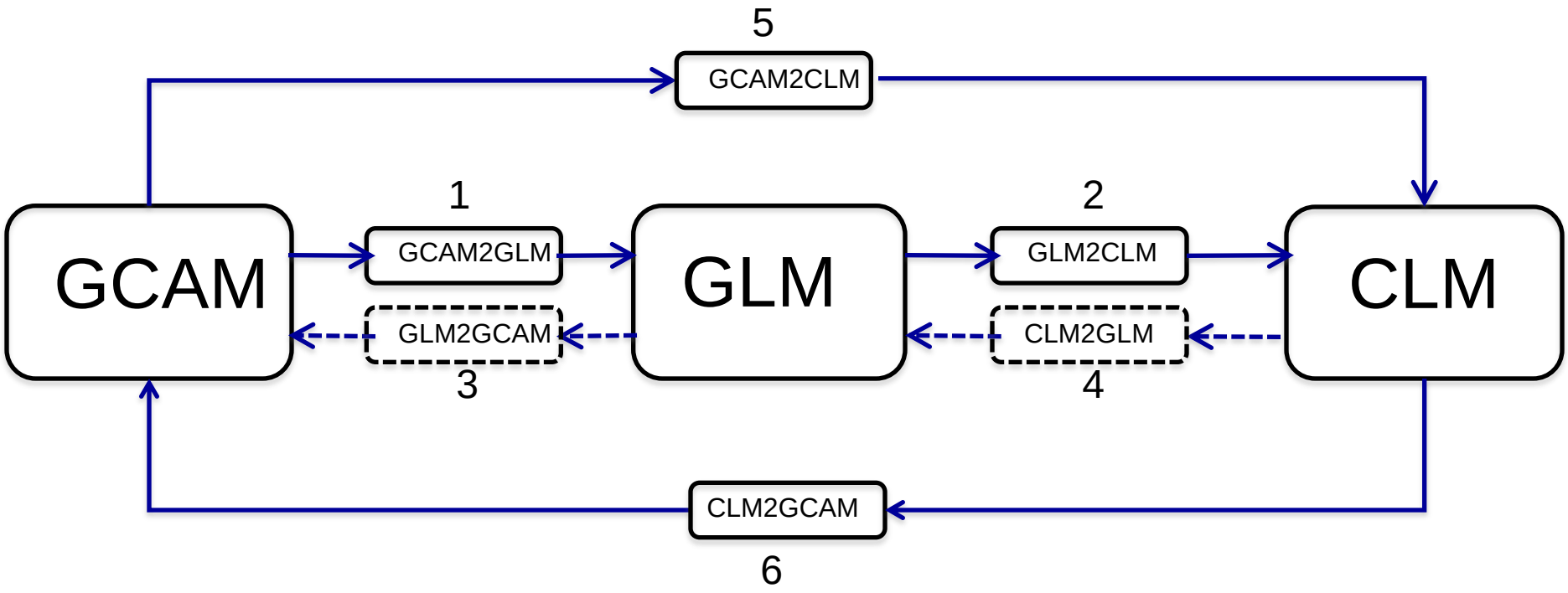
call clm()

=> carbon stocks on clm grid

call clm2gcam

=> carbon stocks on gcam grid

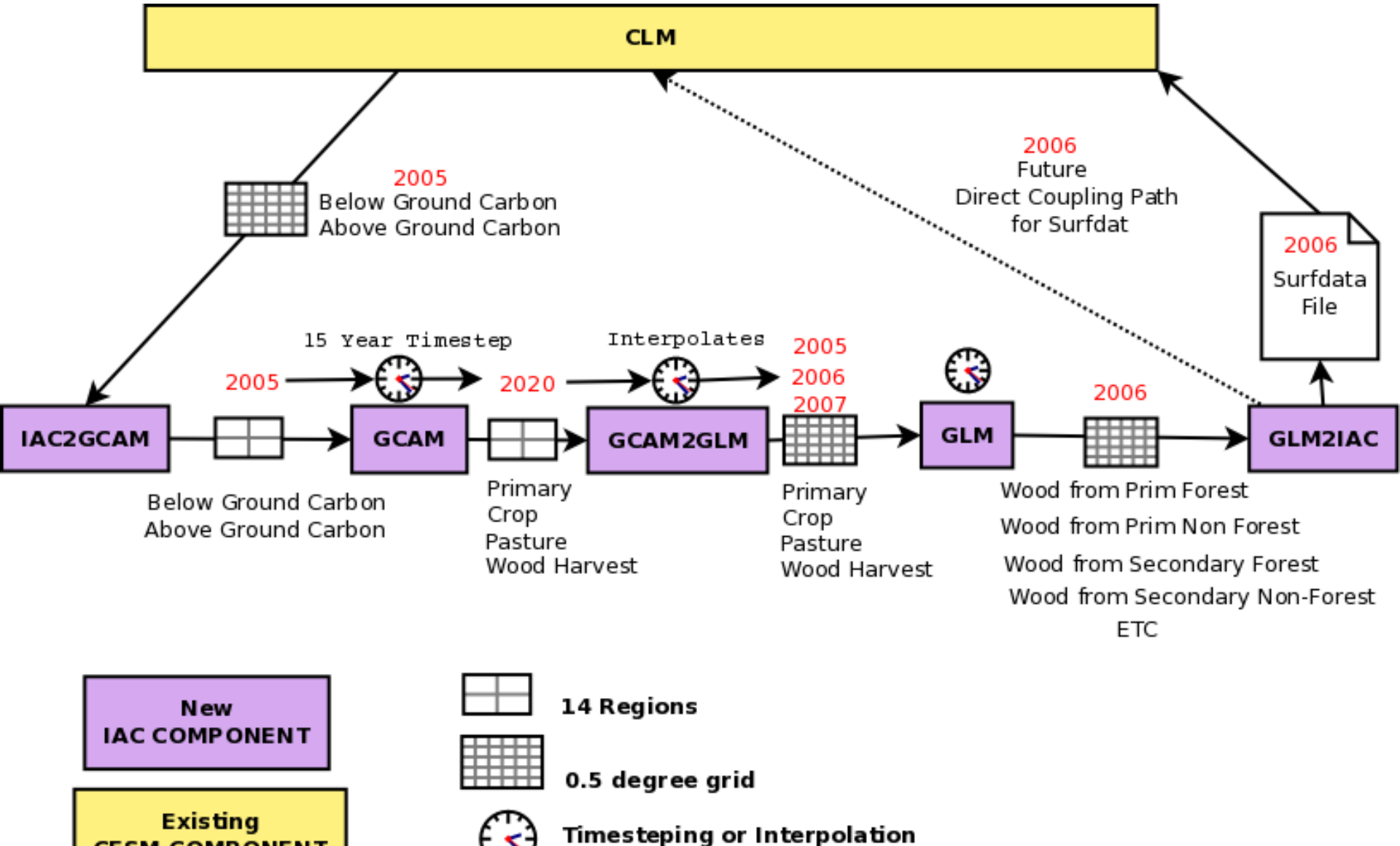
The iESM Coupling Diagram



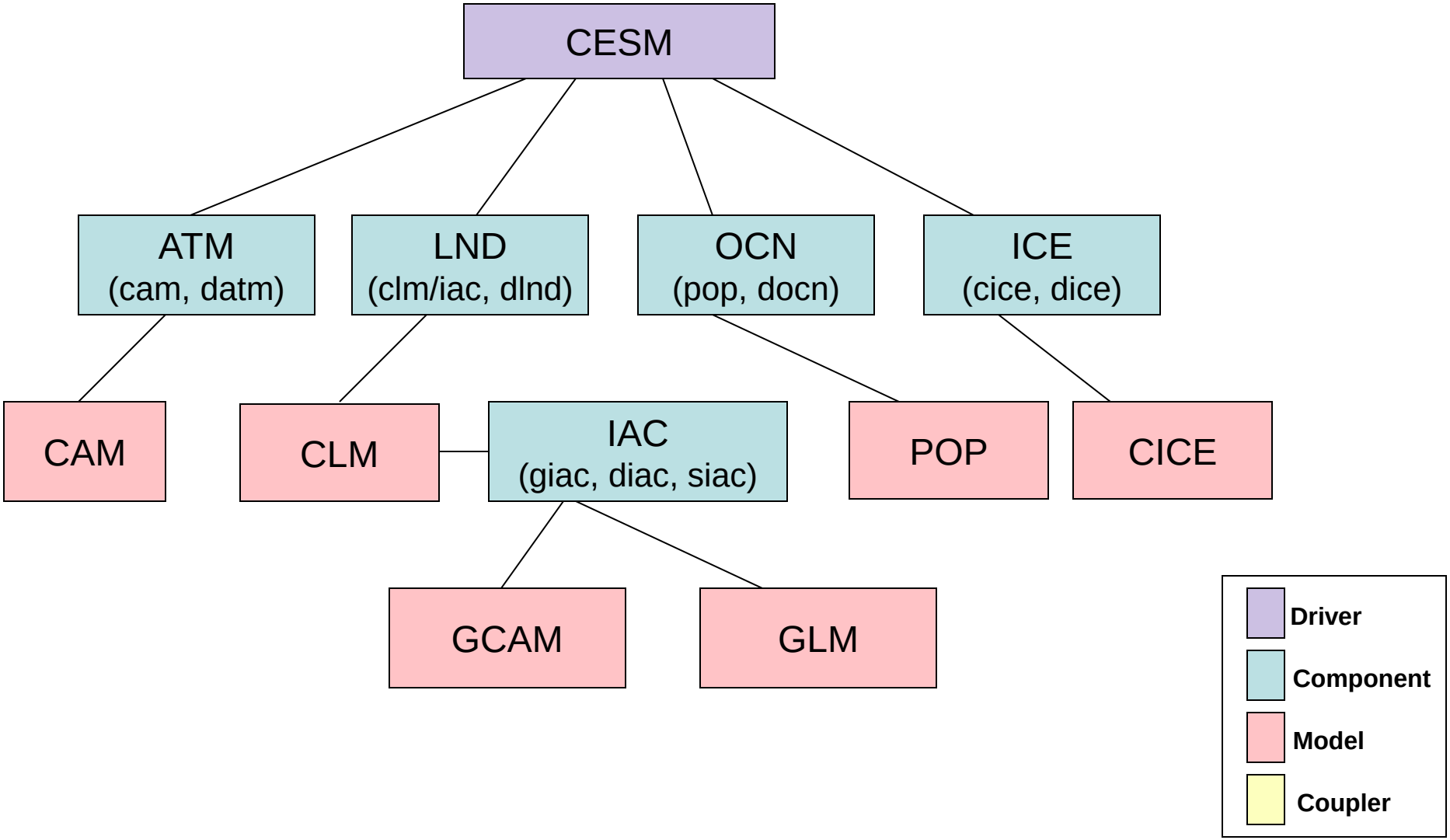
Couplers:
1) GLM Matlab Code
2) PL + mksurfdat
3) Nothing (yet)
4) mapping (nothing yet)
5) scalar coupling (?)
6) GCAM averaging tool

NOTE: Couplers may map spatially, time average, and/or derive new fields

iESM Coupling



Current iESM Coupling Implementation Schematic



Status of coupled iESM integration

- Technical goal is to integrate a leading IAM with CESM.
- We ensure “dual use” of IAM components for maximum extensibility.
- Framework could be used for other IAMs.
- We will attempt first coupled experiments this fall.
- We will provide this system to the CESM community.

- Scientific goal is to understand the two-way interactions between
  mitigation measures and climate change.
- Starting point: introduce feedbacks into RCP 4.5 framework.

Conclusions

- The iESM project is still under way, and some preliminary results are beginning to emerge.

- Experiment 0: The non-CO2 climate effects of land use and landcover change can be significant on global scales. Current metrics based on radiative forcing may not be adequate to describe these changes.

- Experiment 1: Even though it represents a modest level of coupling, is showing significant impact on carbon stocks, and an emerging influence on CO_2 concentration.


The Beginning. . .
"Louis, I think this is the beginning of a beautiful friendship." Casablanca, 1942.