



Integrated Earth System Models: Next Generation Tools for Exploring Water-Land-Energy Interactions

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Motivation and development of iESMs

- ▶ *Opportunities:* **Build unified framework for water/energy/climate**
- ▶ *Possible solution:* **Unite IA and climate in single framework**
- ▶ *Potential upsides:* **Quick “look-see”, inclusion of feedbacks, and stronger IA foundations**
- ▶ *Trial of iESM:* **Land-use and land-cover change (LULCC)**
- ▶ *Results:* **Simulation spread from diverse LULCC forcing under same RCP**
- ▶ *Future roll-out:* **Next steps in iESM development**

Three major objectives of iESM project

- ▶ **Create a first generation integrated Earth System Model (iESM)** with both the human components of an IAM and a physical ESM
- ▶ Develop linkages within the iESM and apply the model to improve **our knowledge of coupled physical, ecological, and human system**
- ▶ Add hydrology and water demand, allocation, and availability to IA.



Mitigation



Adaptation



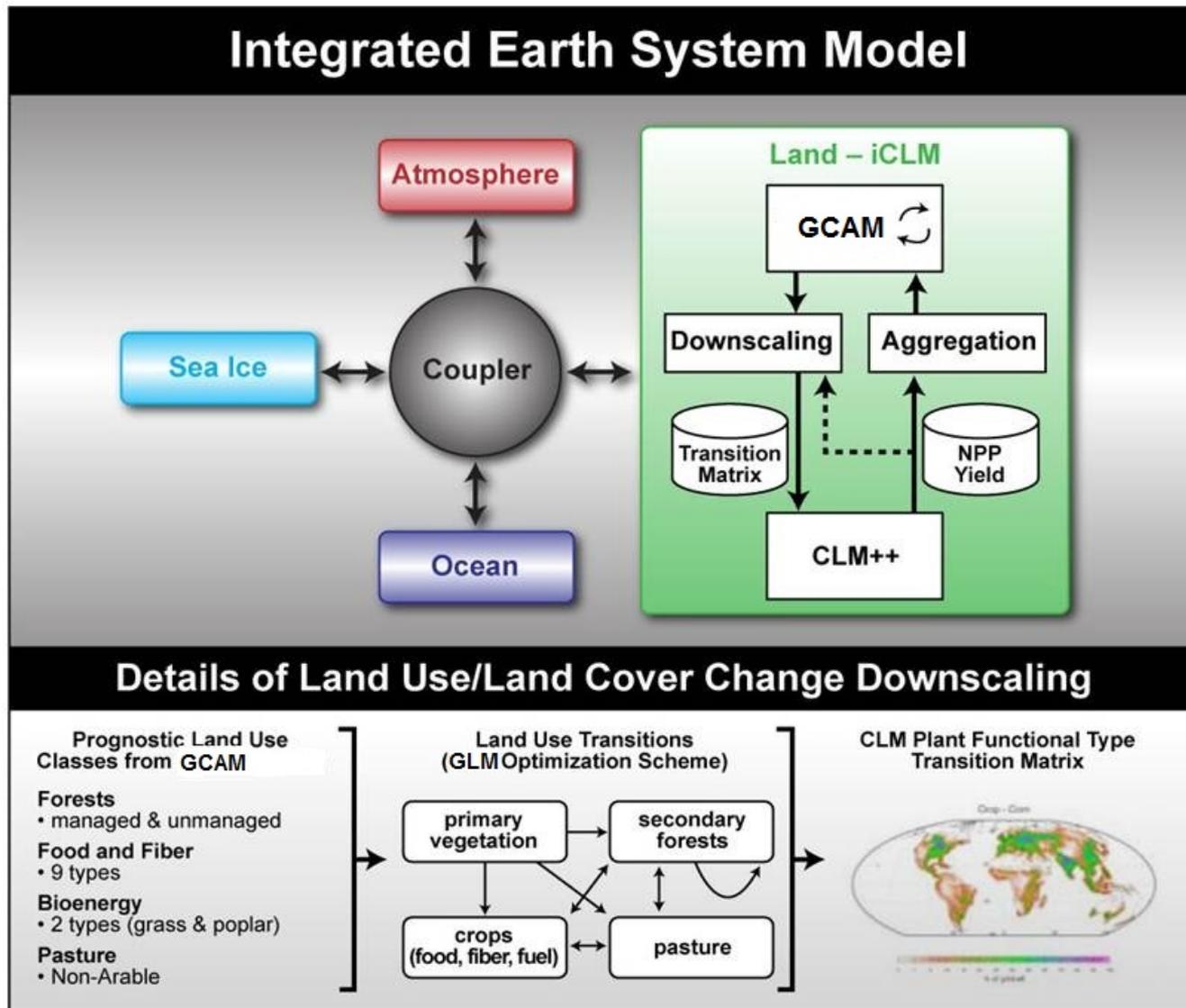
Technology pathways

How would iESM change current paradigm?

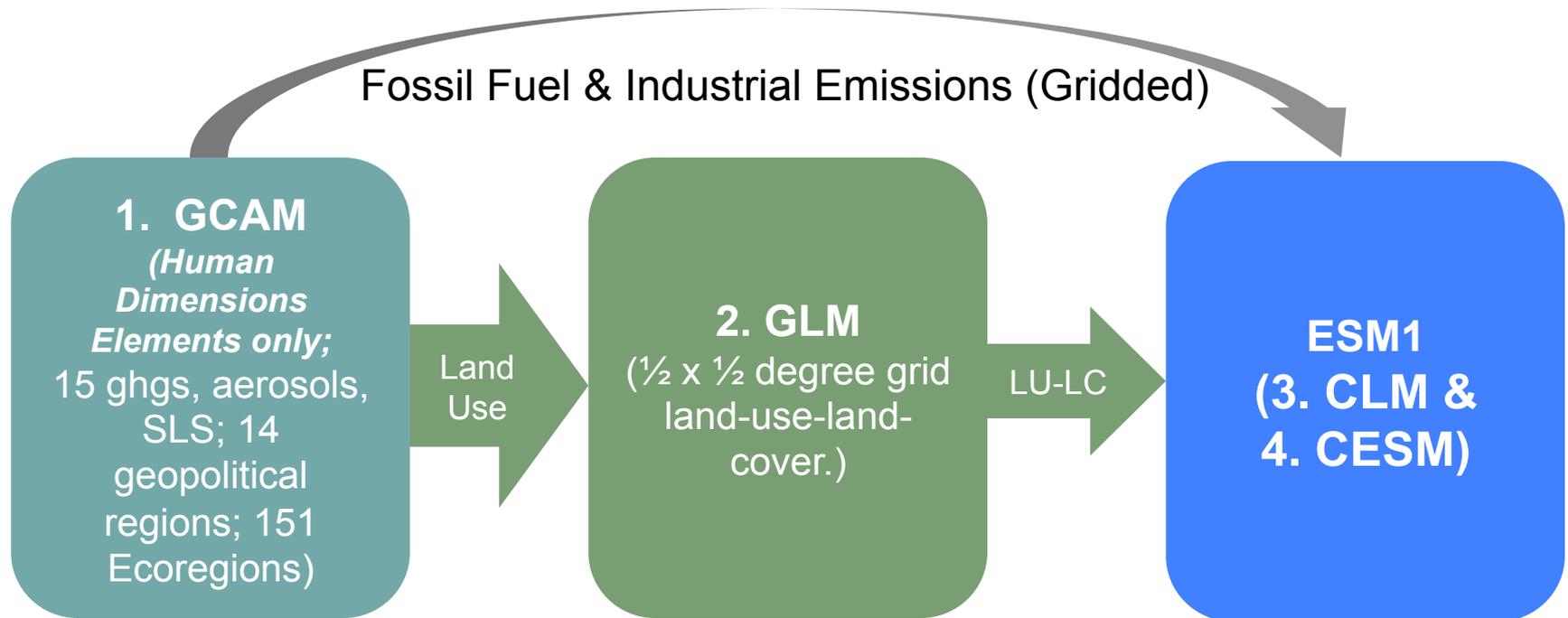
- ▶ In the present world, emissions mitigation analysis is undertaken under the assumption that **the climate is not changing**.
- ▶ Climate impacts analysis is undertaken with the assumption that **no resources are being diverted to address climate change**.
- ▶ **Changes in response of the coupled climate-energy-land model are significantly different than in the un-coupled models.**
- ▶ 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.



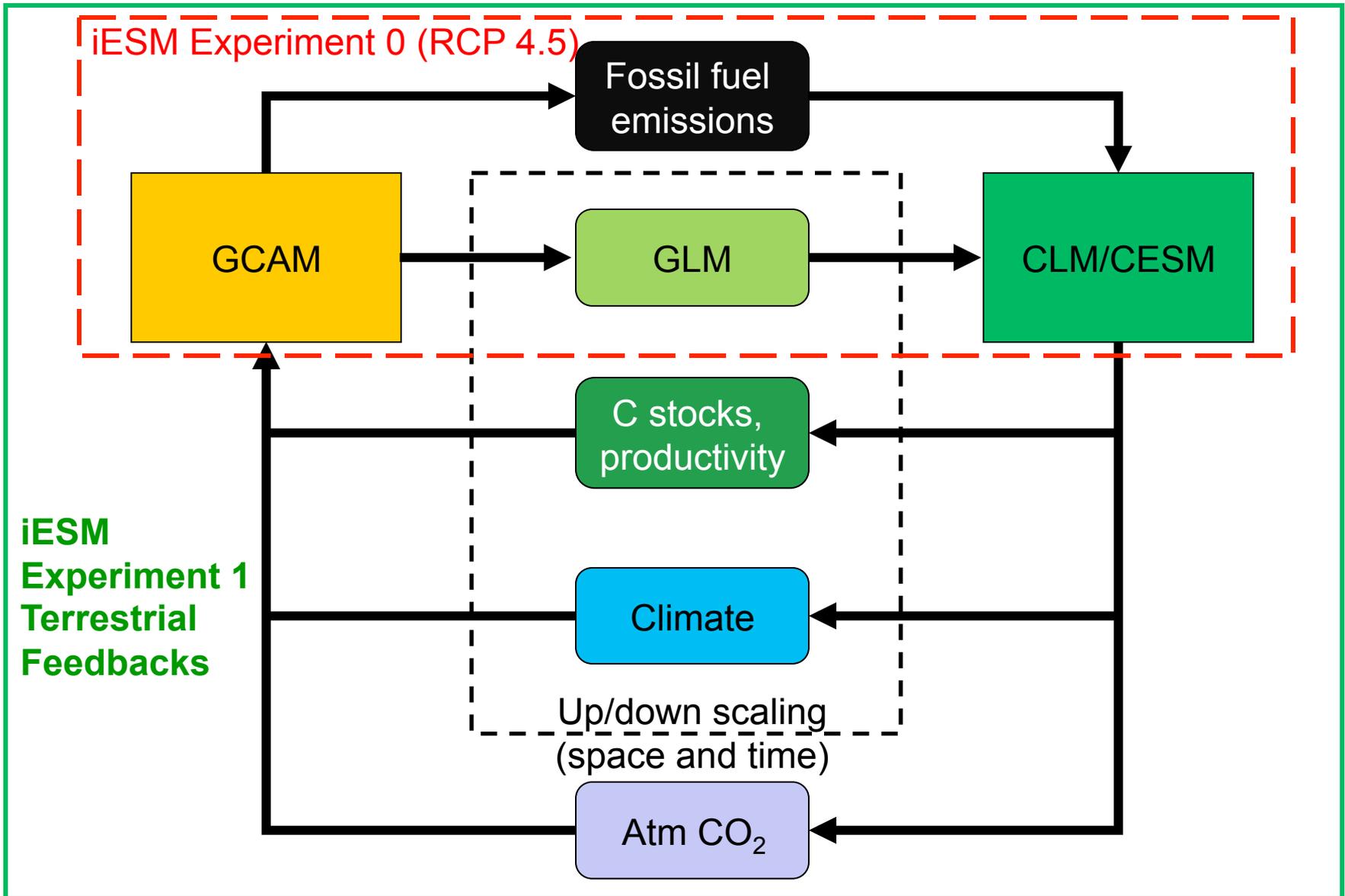
iESM schematic



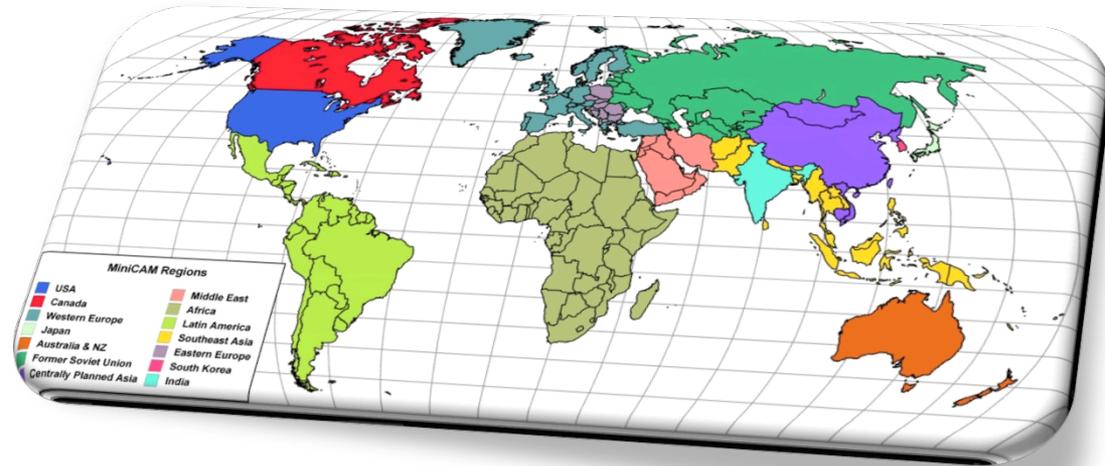
iESM links 4 models: GCAM, GLM, CLM, & CCSM



iESM multi-phase coupling strategy

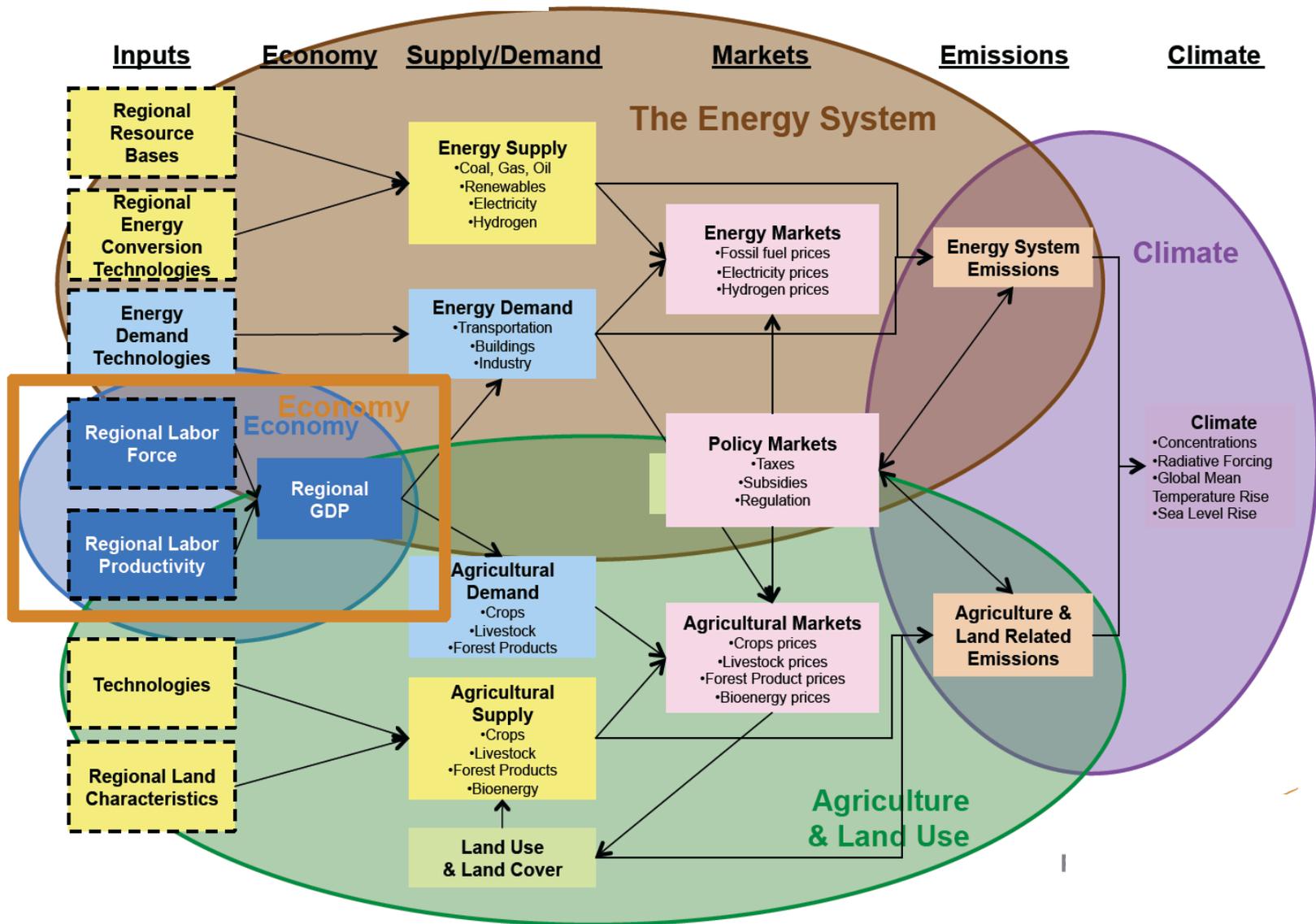


GCAM RCP 4.5 Characteristics

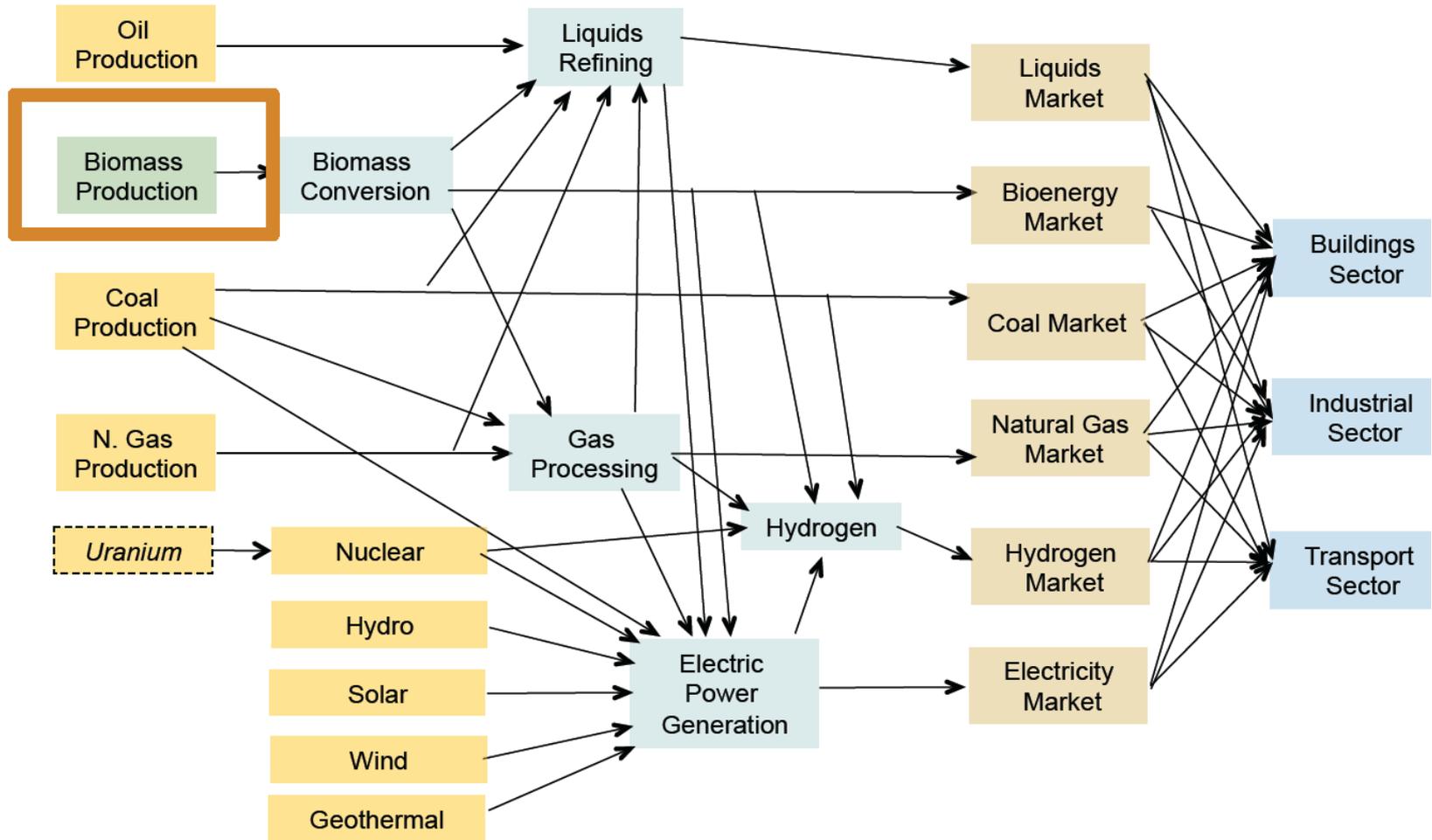


- ▶ **Regional Details:**
 - *Regional Scope:* Global
 - *Number of Sub-Regions:* 14
- ▶ **Time Step:** 15 years
- ▶ **Time Frame:** 1990 to 2095
- ▶ **Model Type:** Dynamic Recursive
- ▶ **Equilibrium Type:** Market Equilibrium
- ▶ **Underlying Computing Framework:** Object Oriented (C++)

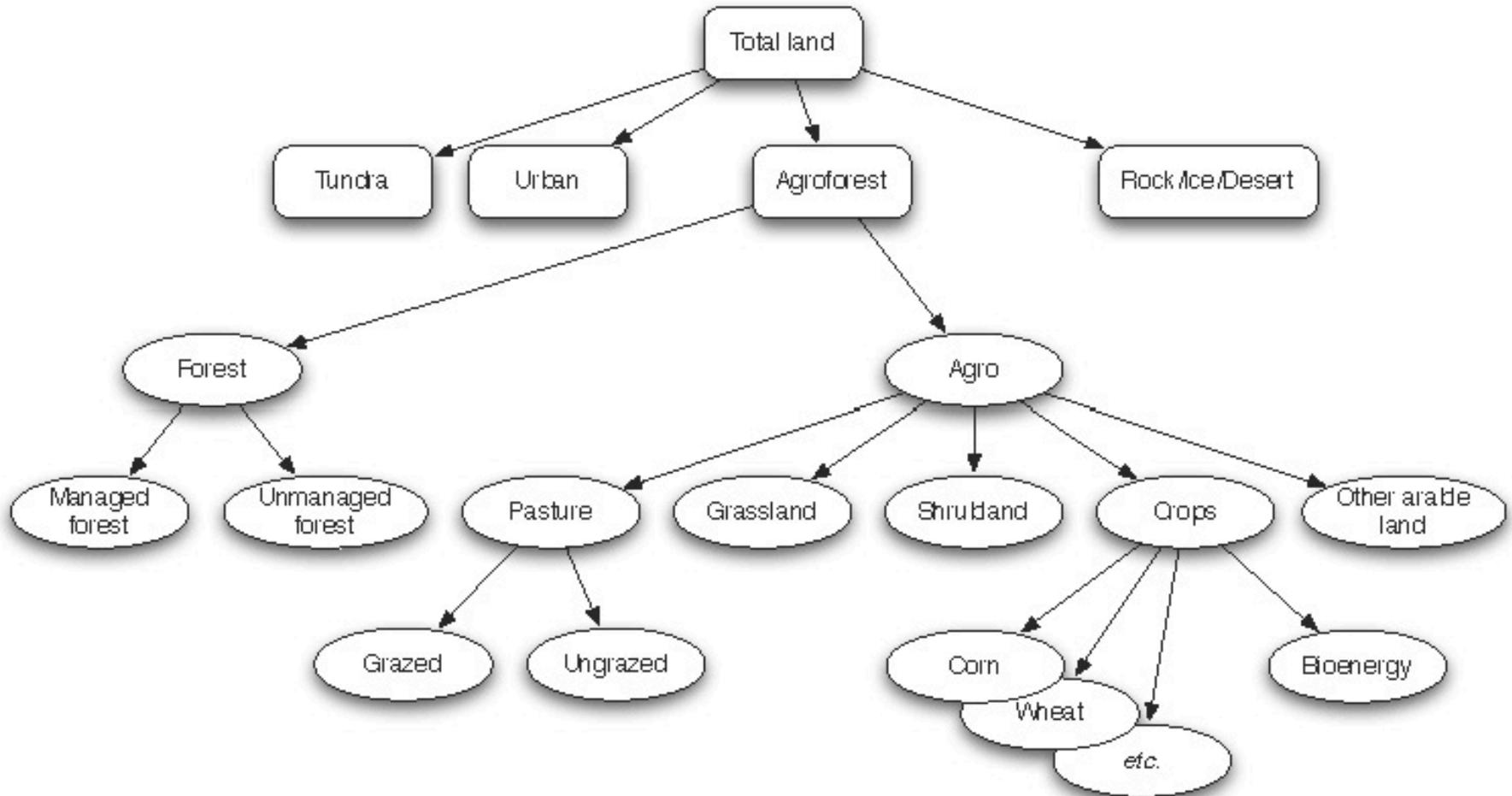
Schematic and data flow of GCAM



Role of biofuels in GCAM's energy markets



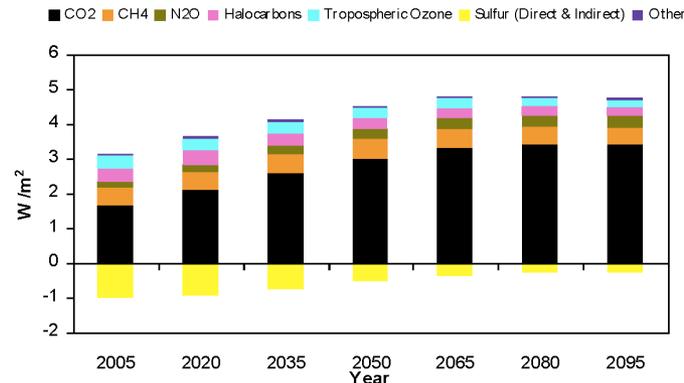
Action of the markets on LULCC



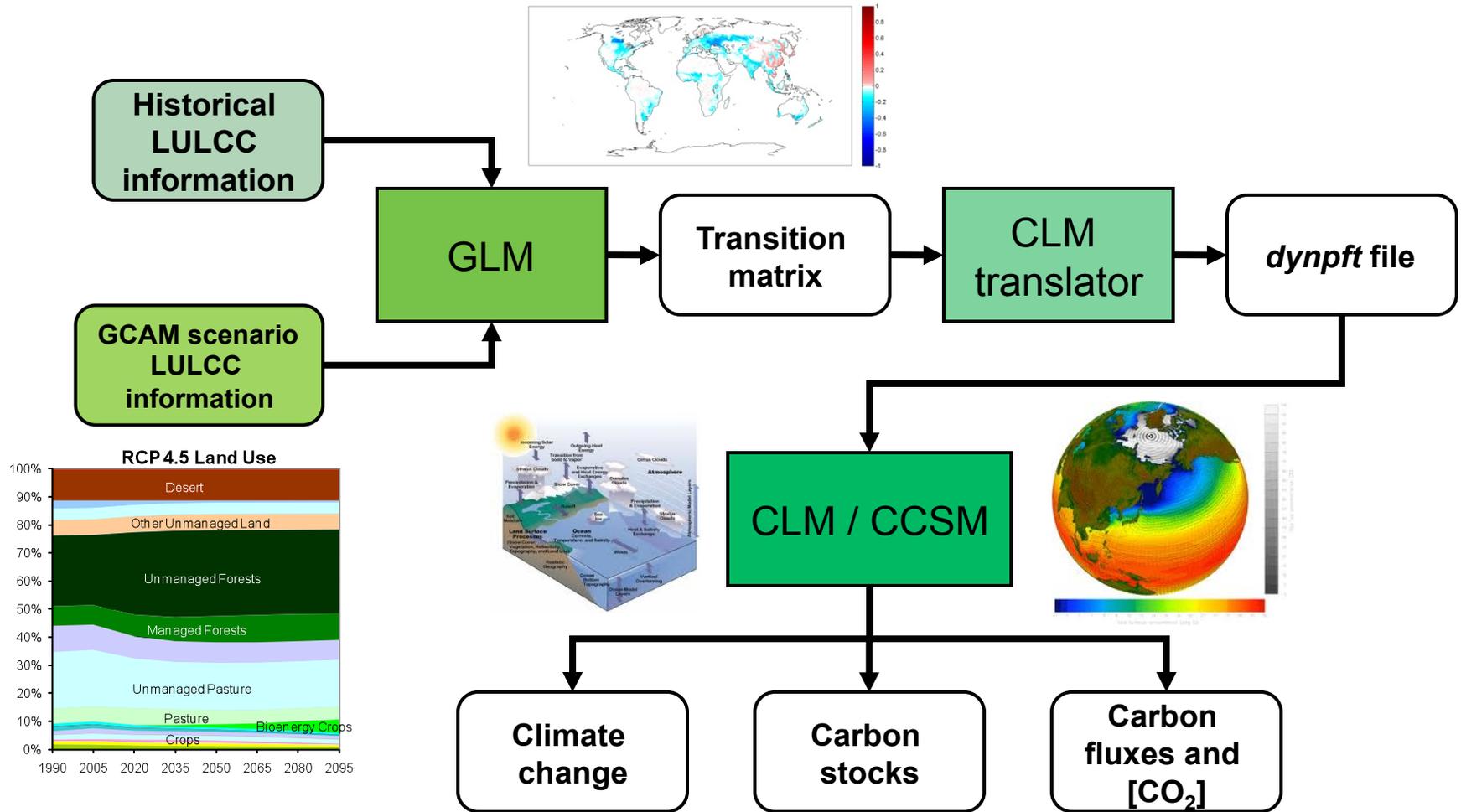
**GCAM Land allocation based on profitability
(representative structure shown here)**

iESM experiment 0: *Bioenergy scenarios with one-way coupling*

- ▶ *Information flow:* IA to downscaling to Earth System Model
- ▶ *Sanity check:* Does the one-way pass of information replicate the original RCP4.5 simulation done in CMIP5?
- ▶ *Policy sensitivity:* For different policy but same concentration pathway, does the evolution of the climate system differ?
- ▶ *Experiment 0:* Contrast two pathways:
 - ▶ RCP4.5 – carbon price on all carbon (UCT)
 - ▶ RCP4.5 – carbon price ONLY on fossil carbon (FFICT)

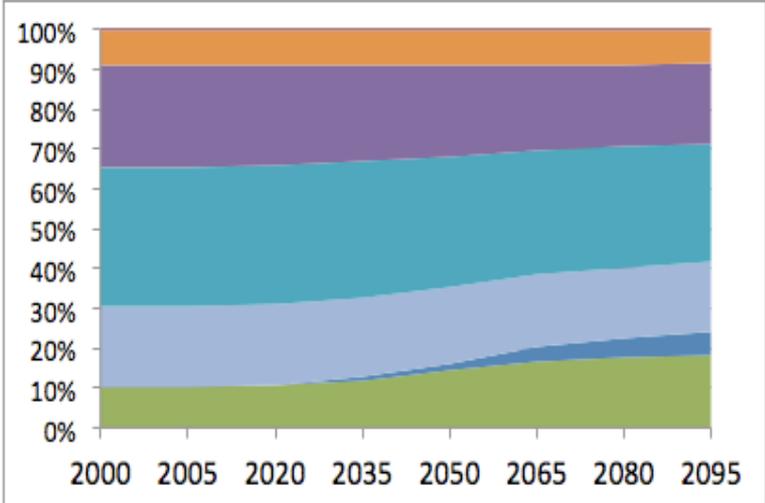


Experiment 0 work flow

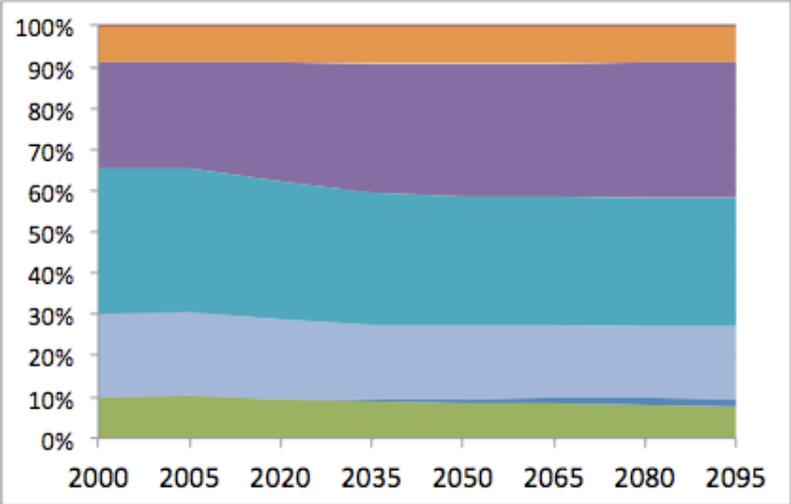


RCP 4.5 and a version without terrestrial mitigation

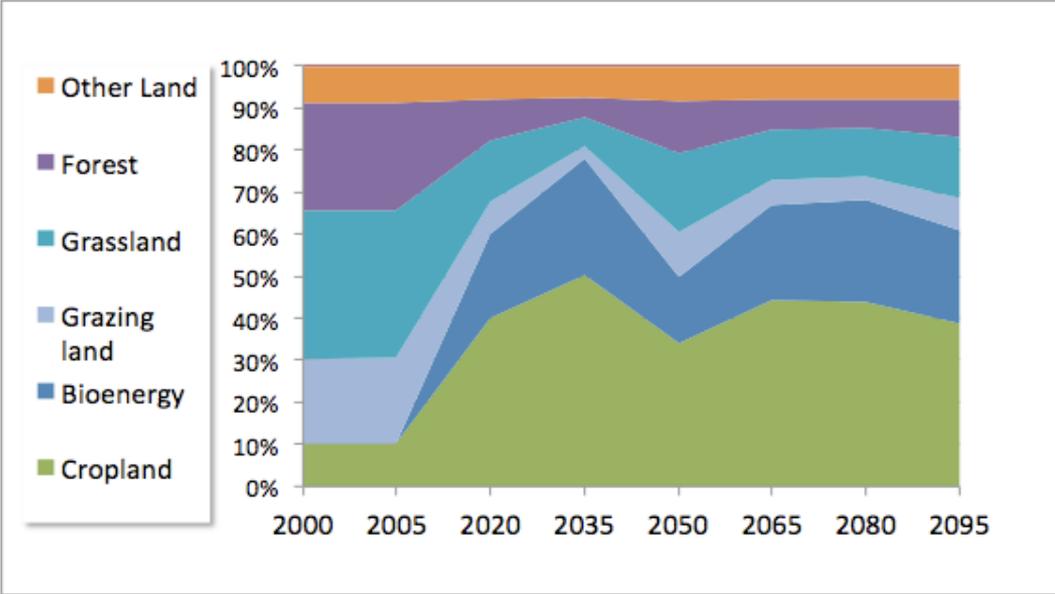
No Policy



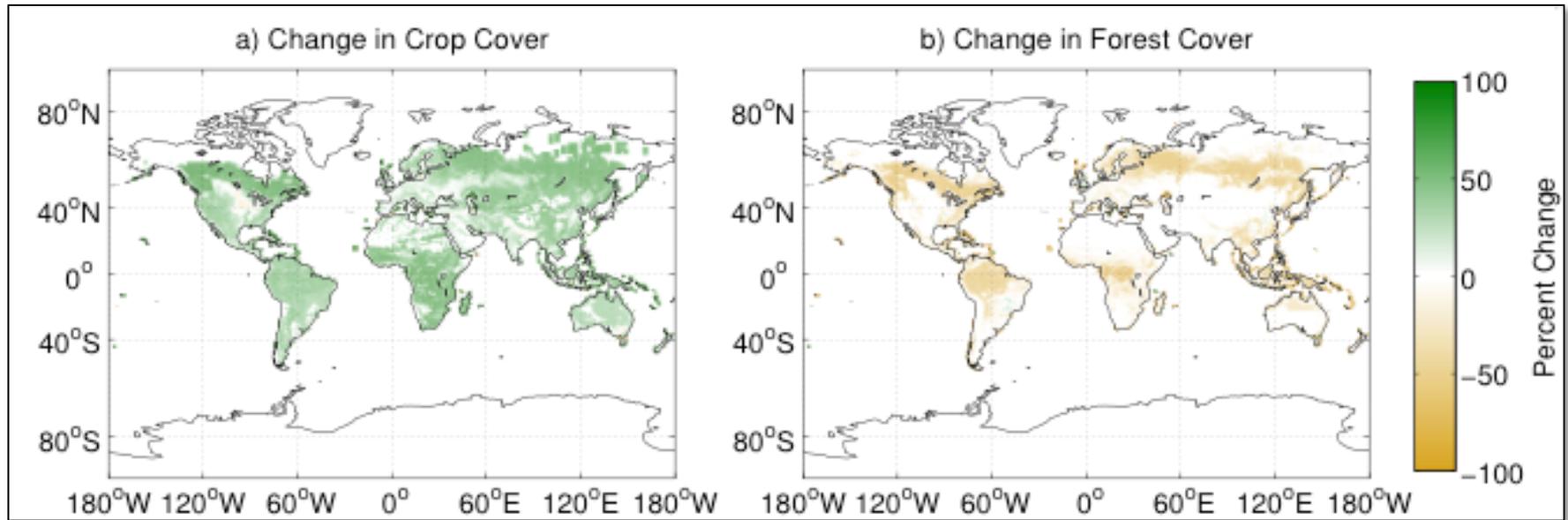
RCP4.5 (UCT)



Rep 4.5 (FFICT)



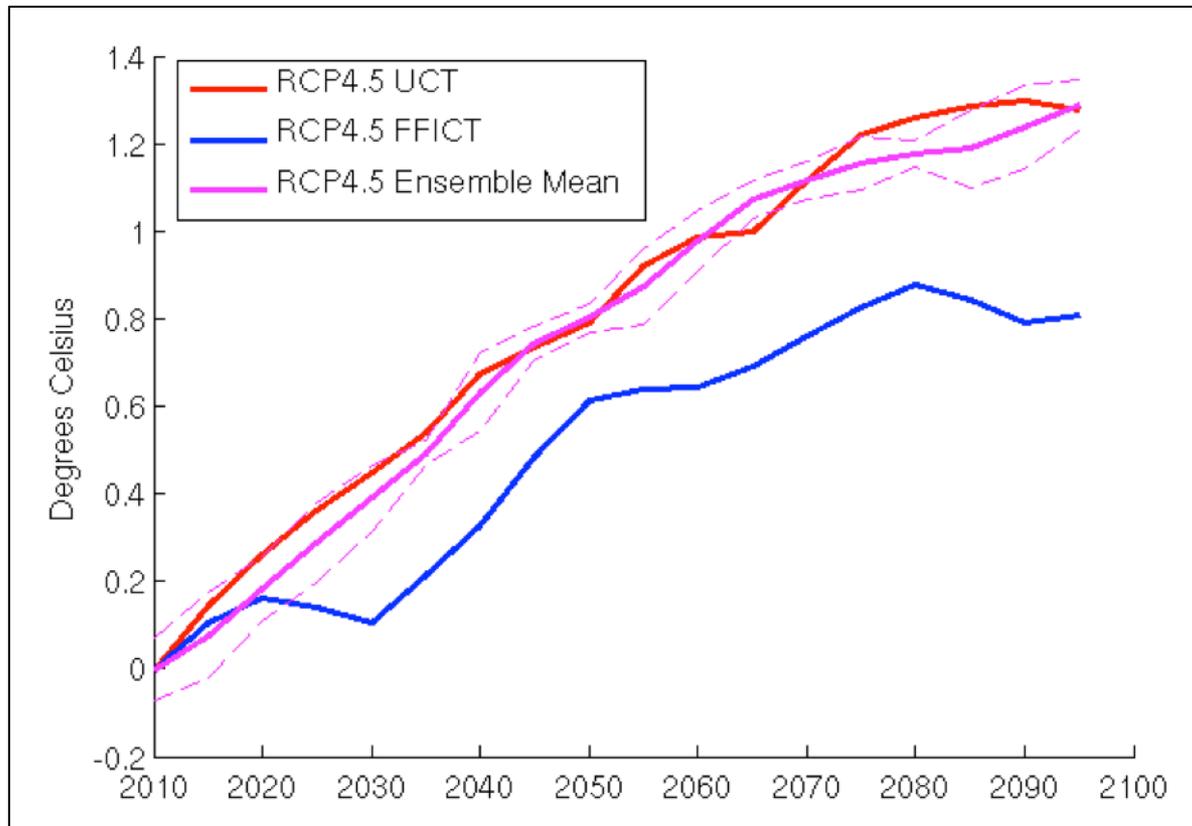
Land cover change in the RCP4.5 FFICT scenario



Jones et al, 2012

In many regions, biofuels displace up to 50% of forests in latter 21st C.

Land cover scenario effects on global temperature

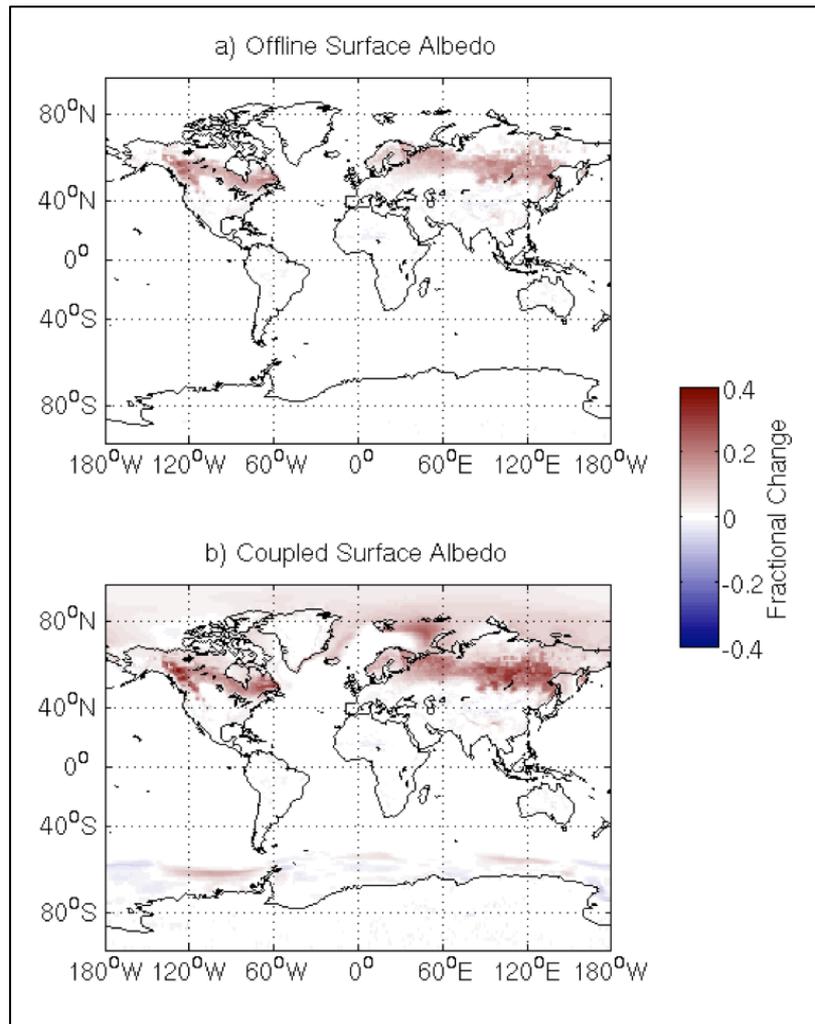


Jones et al, 2012

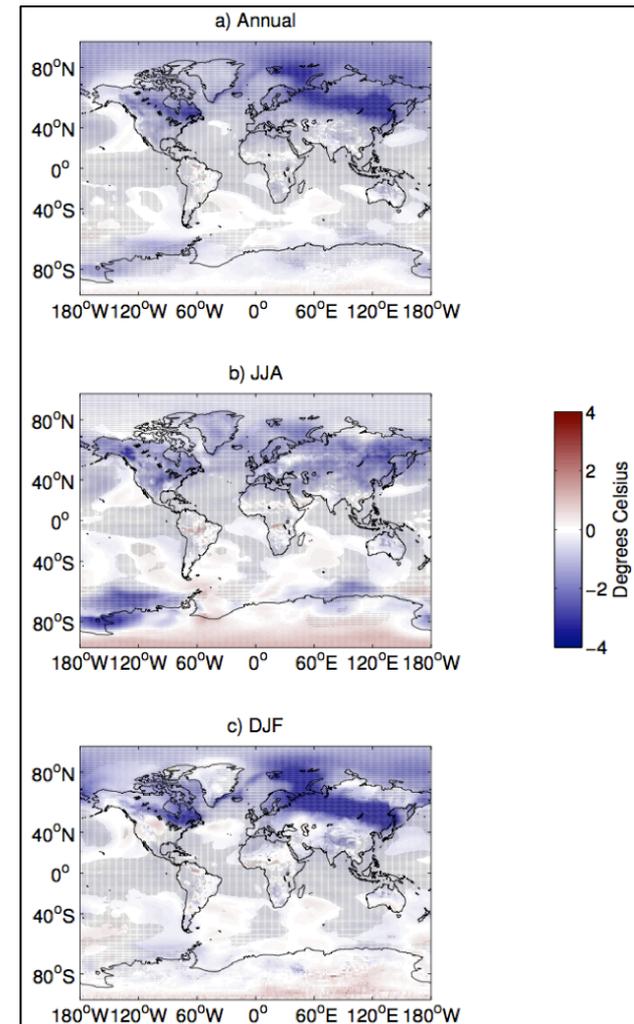
Temperature changes by 0.5°C despite same LLGHGs and aerosols.

Link between albedo and temperature

Albedo

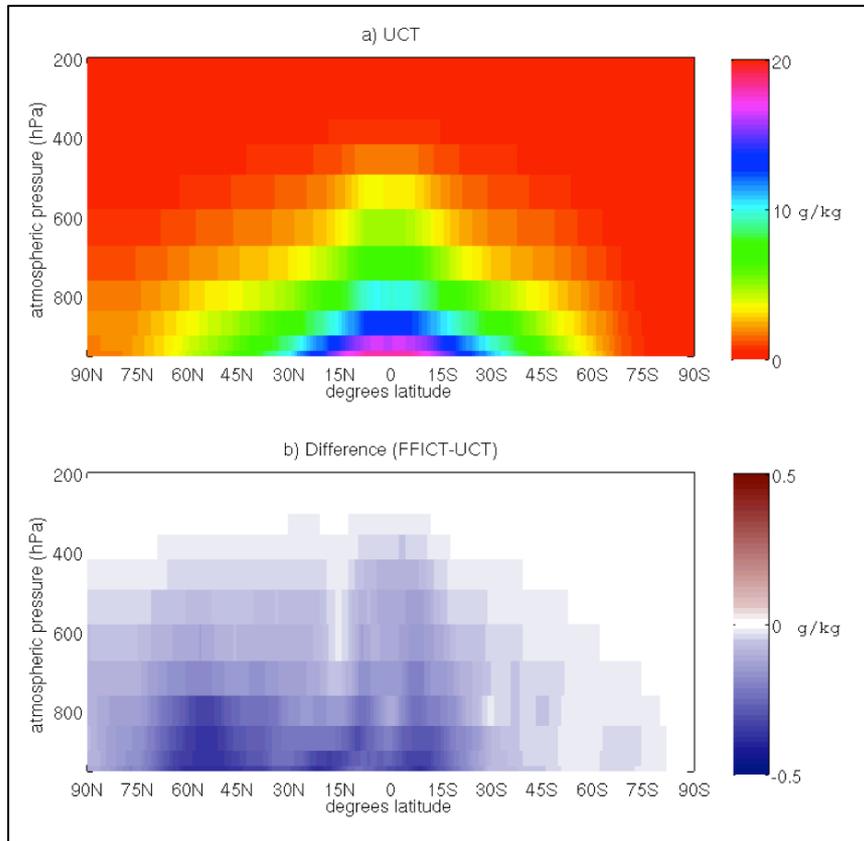


Temperature



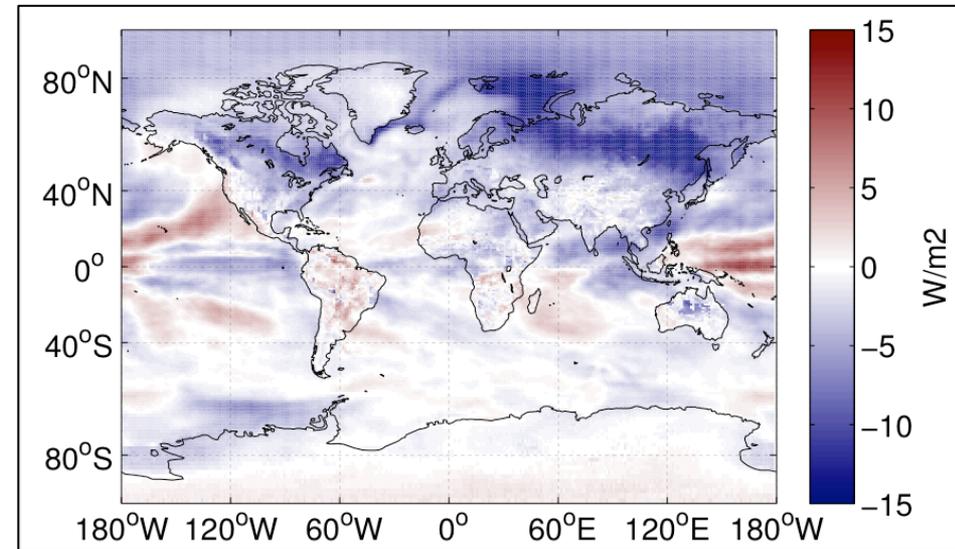
Linkage of water vapor and greenhouse effect

Water Vapor



Jones et al, 2012

Greenhouse Effect

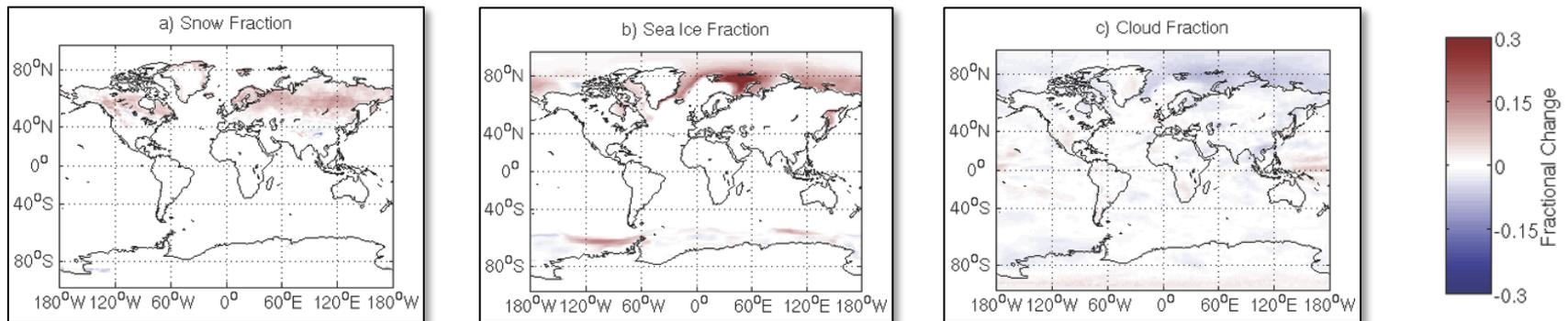


Jones et al, 2012

- ▶ Water vapor is lower in FFICT run.
- ▶ GHG effect is reduced by 1.5 W/m².

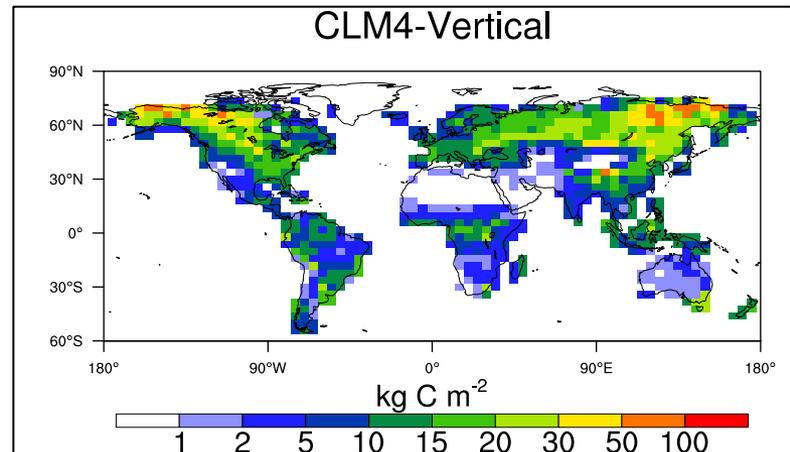
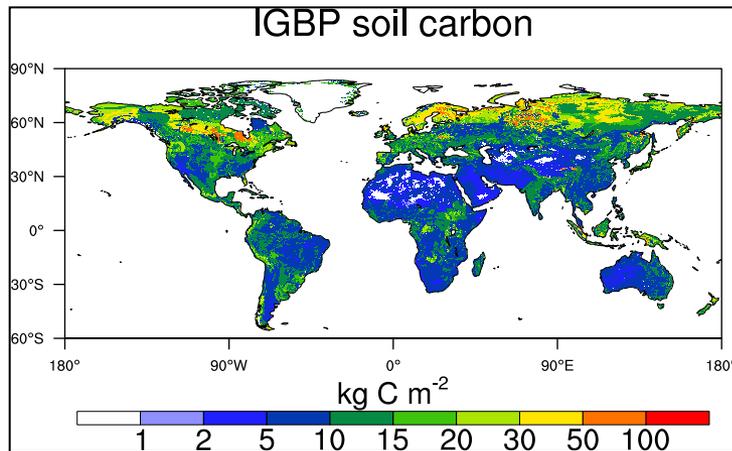
Major findings of experiment 0

- ▶ 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



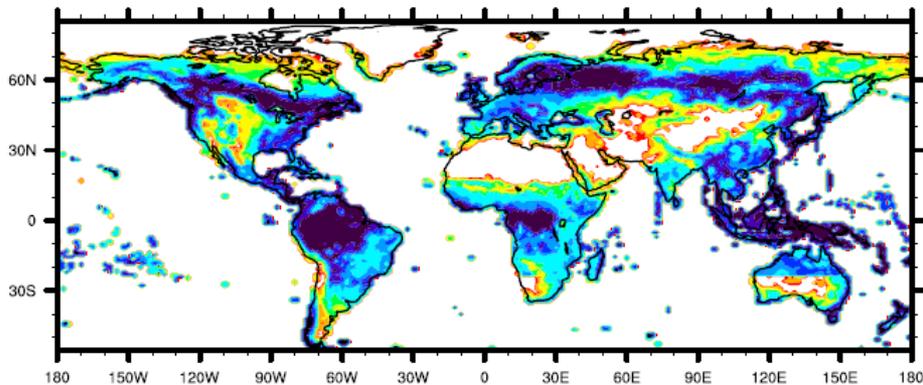
Experiment 1: Simplest possible feedback from CESM to GCAM

- ▶ Send maps of carbon density, by plant type, from CLM to GCAM.
- ▶ GCAM updates its carbon densities based on changes from CLM.
- ▶ GCAM recreates RCP, with new LULCC path, based on carbon densities.

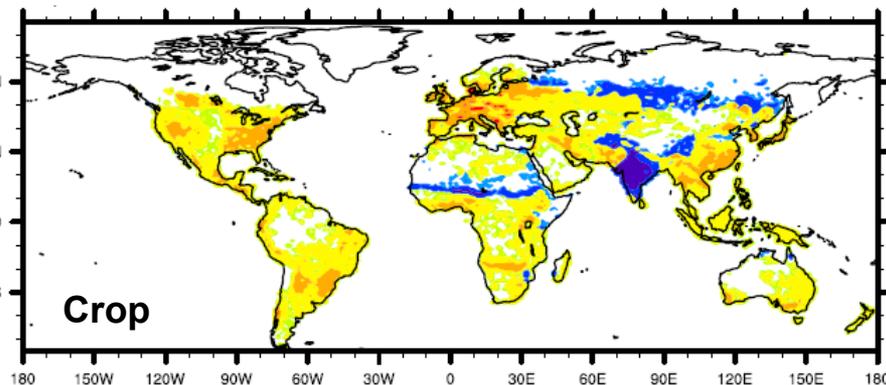
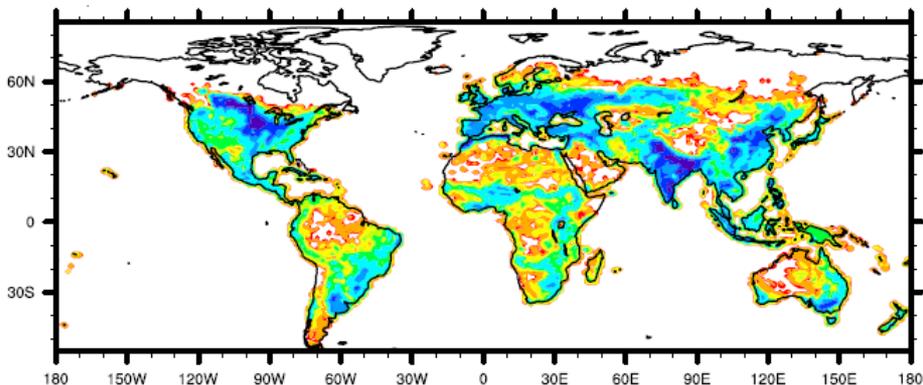
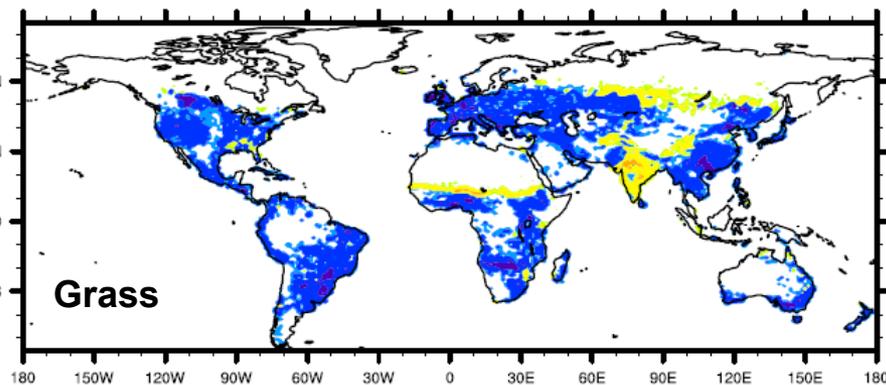
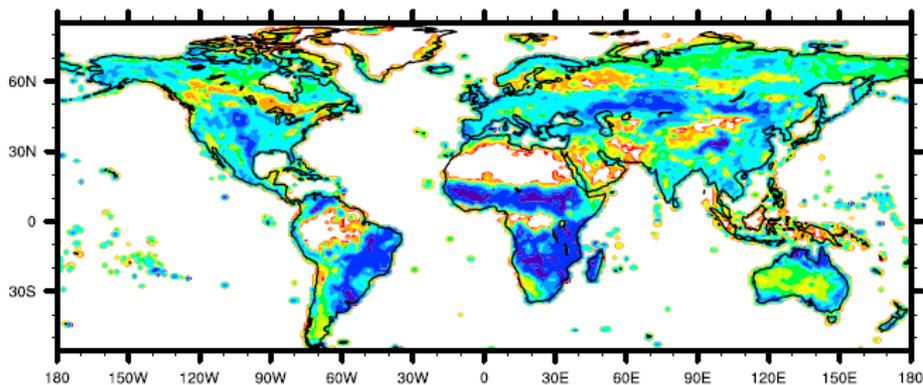
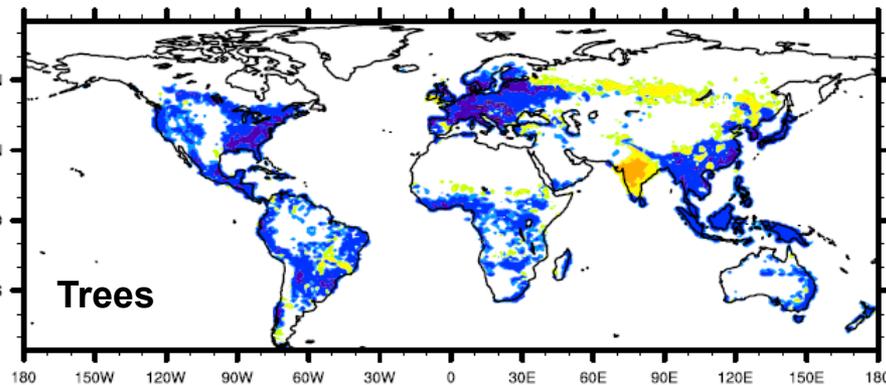


Translation of GCAM/GLM response into CLM vegetation types

Control (2020 to 2034)

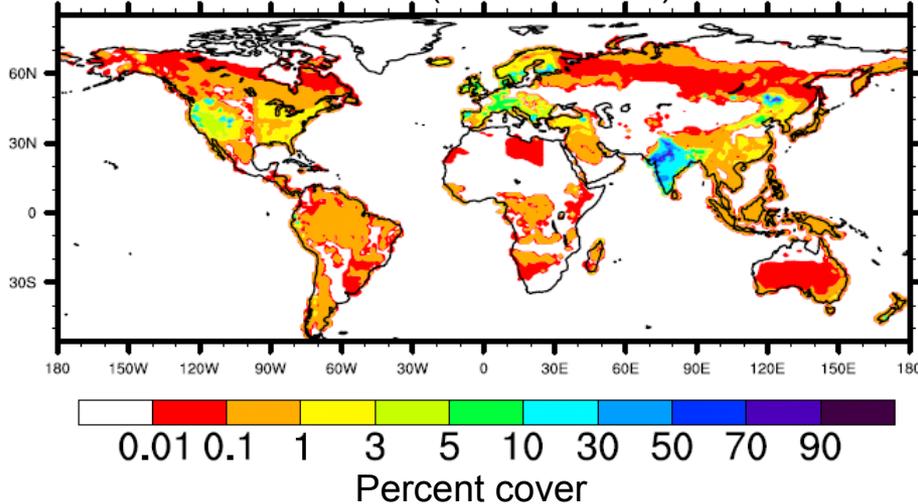


Expt 1 – Control (2020 to 2034)

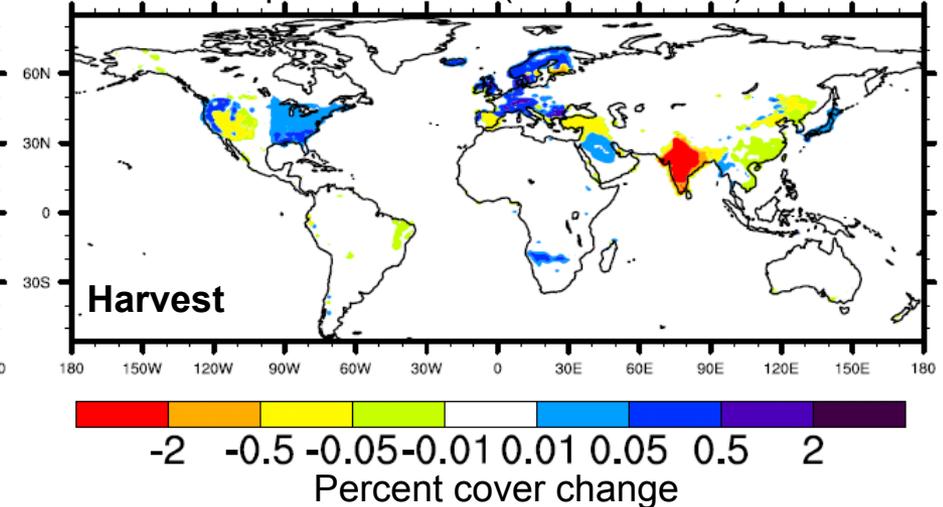


Translation of GCAM/GLM coupling response to CLM harvest

Control (2020 to 2034)



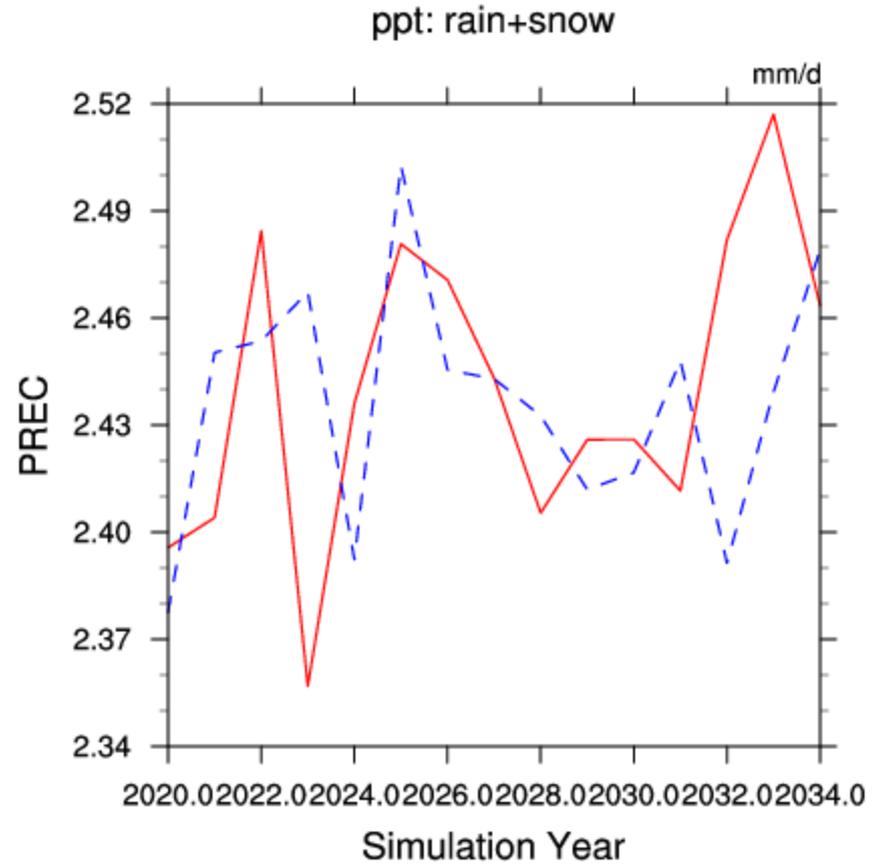
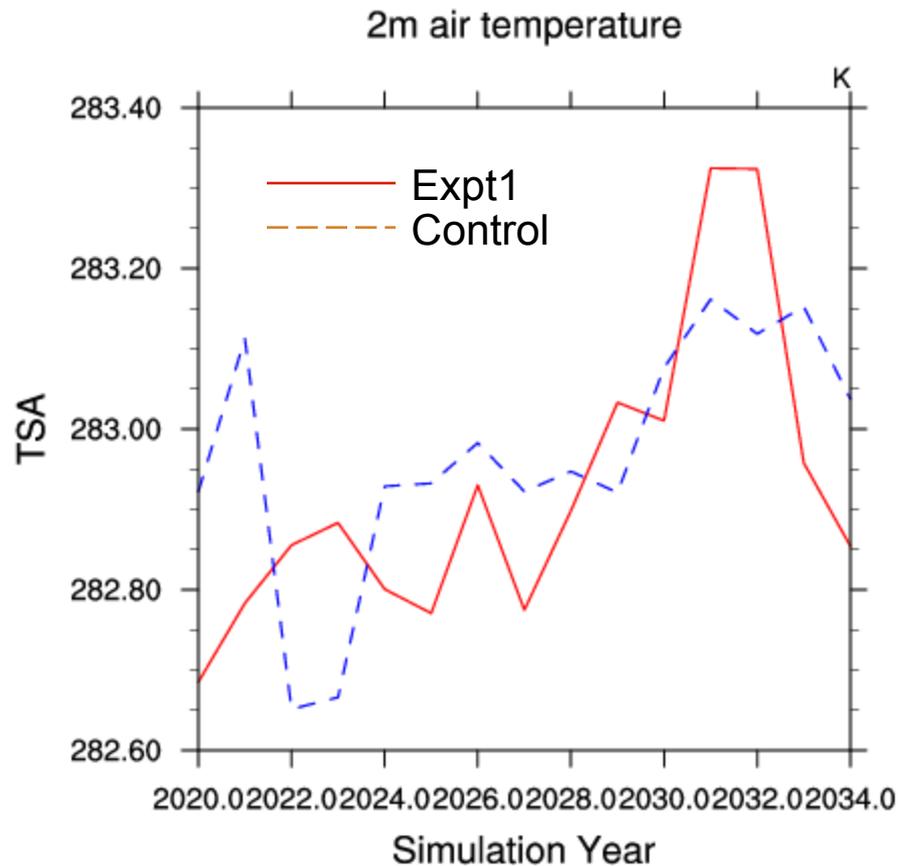
Expt 1 – Control (2020 to 2034)



Summary of coupling influence on CLM forcing:

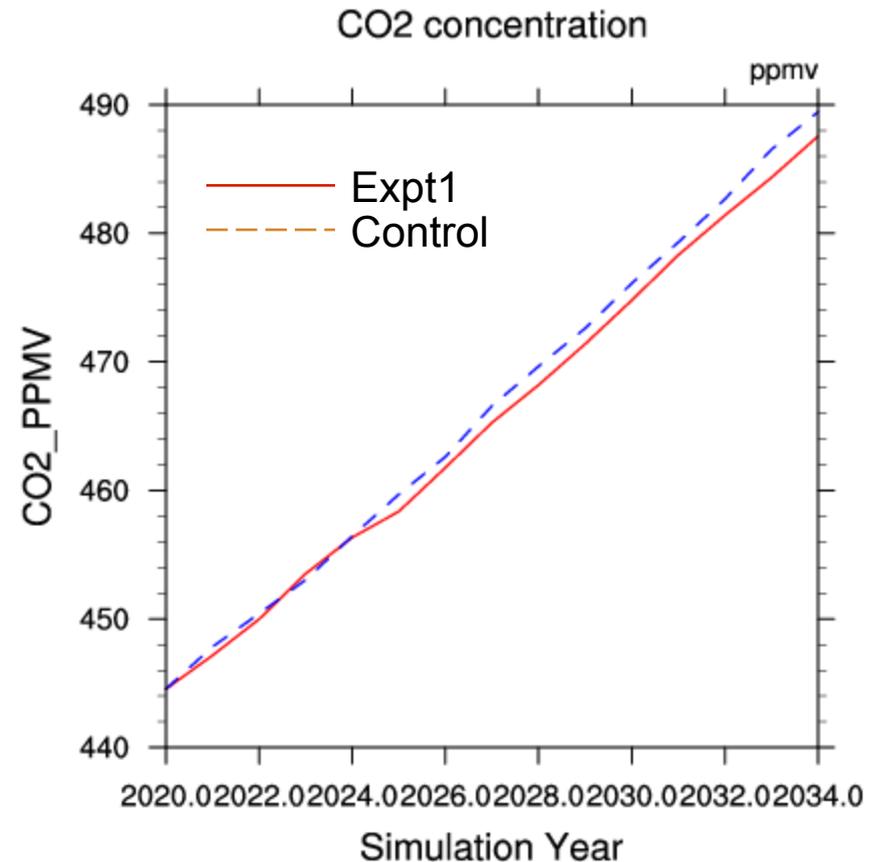
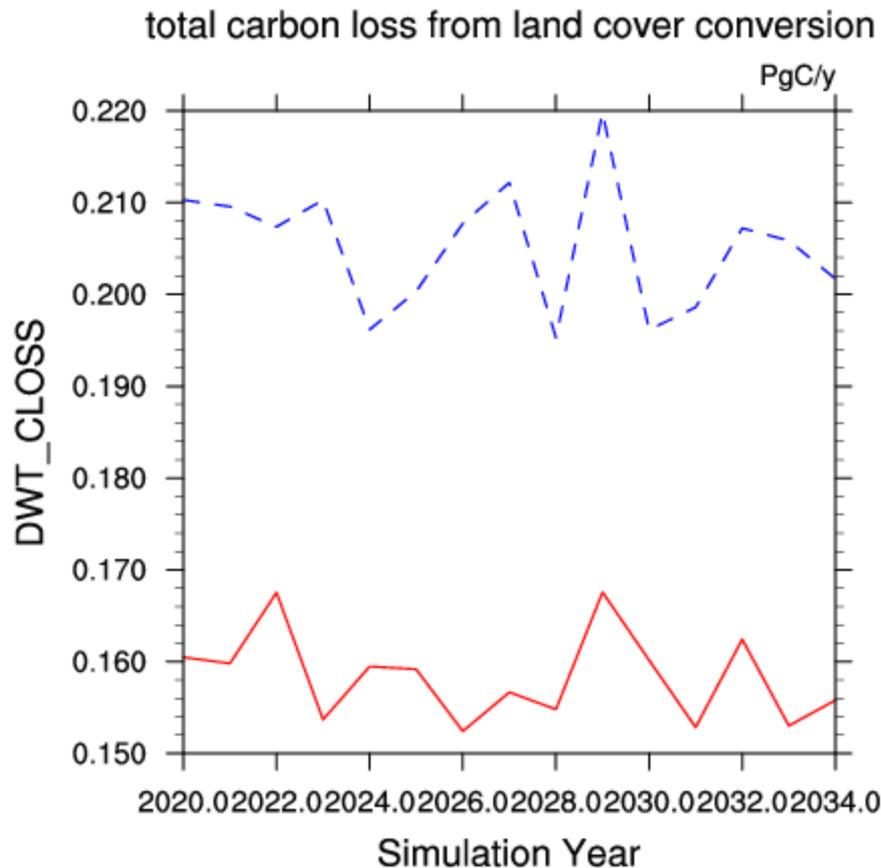
- ▶ Tree cover higher
- ▶ Grass cover higher
- ▶ Crop cover lower
- ▶ Pattern reversed for Sahel, India, and forests in Asia
- ▶ Regional modifications to harvest rate

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



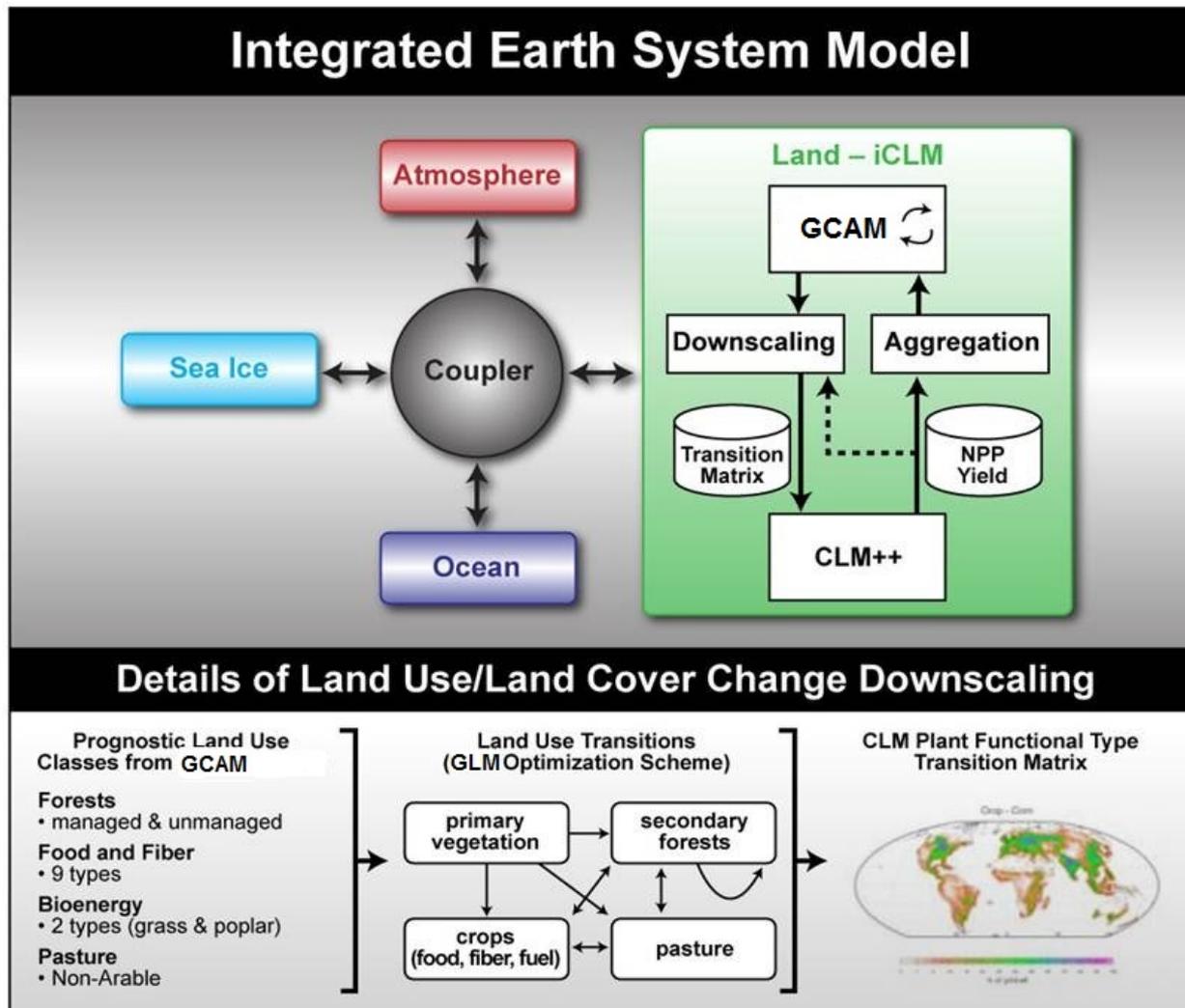
No climate signal after first coupling time step

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

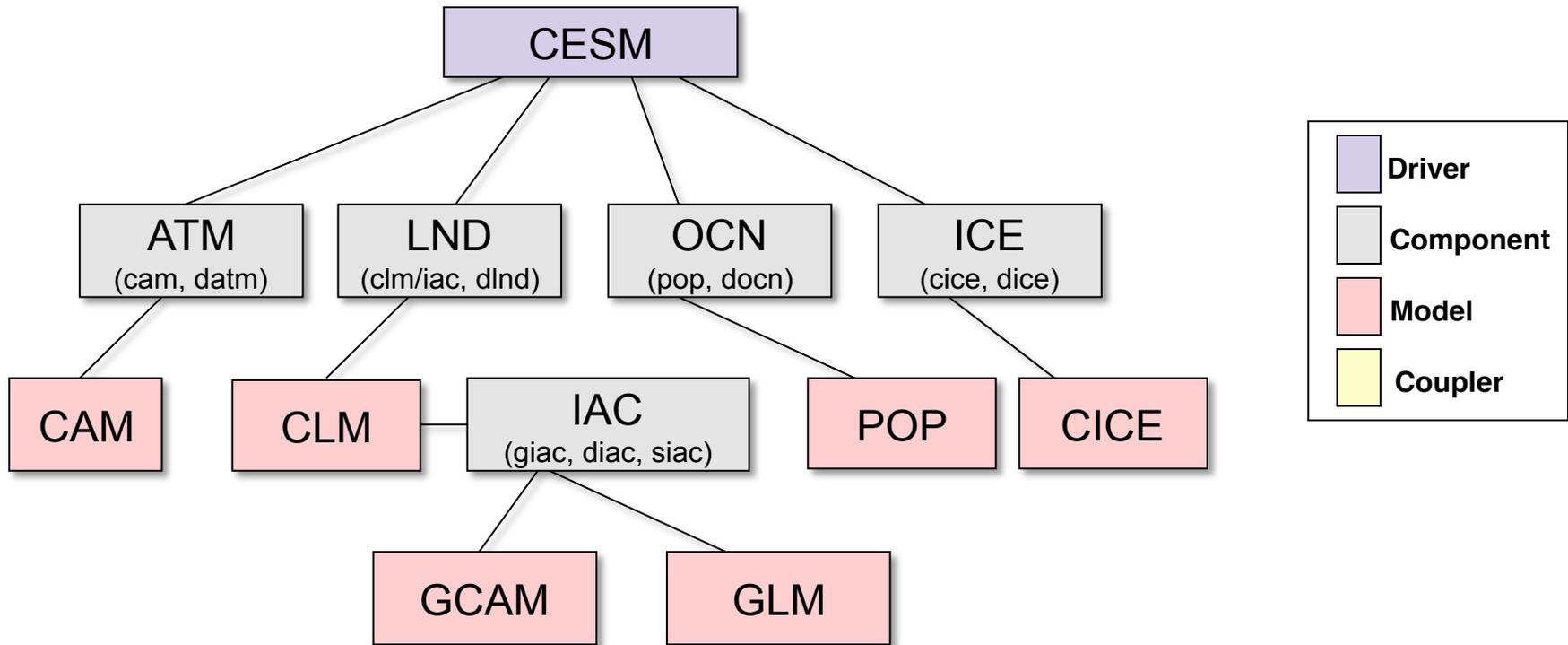


Clear signal in land cover change flux
emerging signal in atmospheric CO₂ concentration.

iESM coupling status



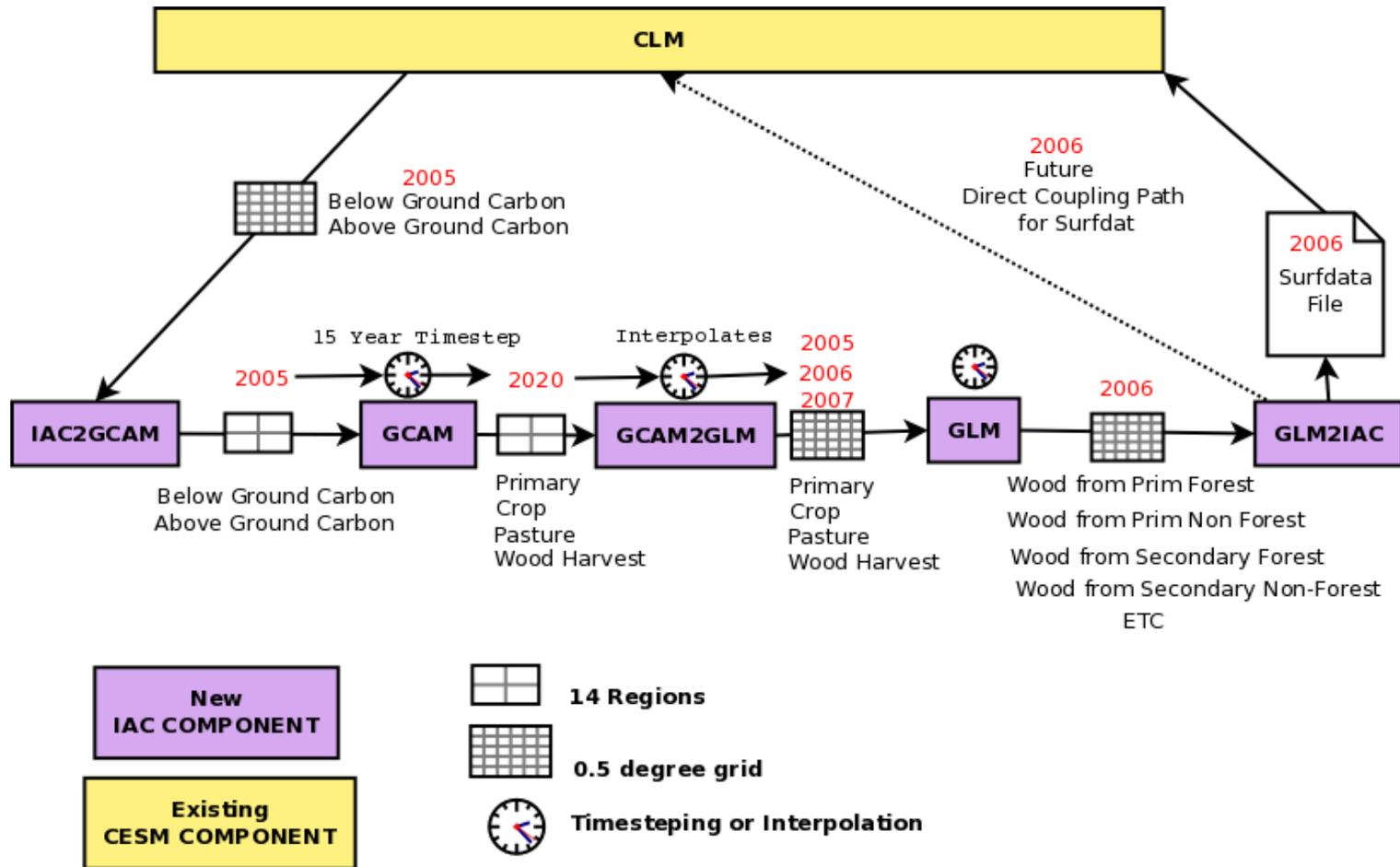
First generation iESM



Status:

- ▶ iESM code is written.
- ▶ iESM code is running at JGCRI, ORNL, and NERSC.
- ▶ Internal consistency of c-cycle under development.

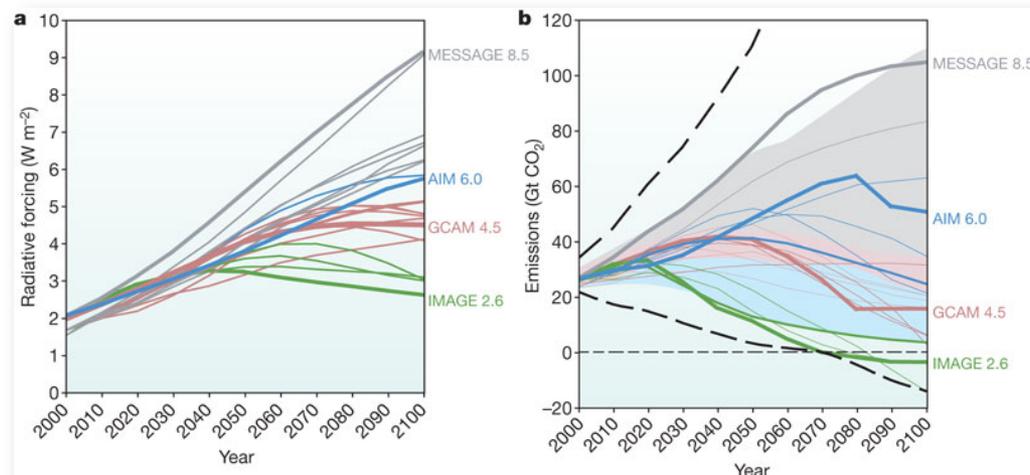
iESM coupling:



Our framework can handle the disparate space/time scales in IA and climate models.

Next steps for the integrated Earth System Model

- ▶ **Proof-of-concept experiments of extensibility to other IAMs** that conform to the RCP “handshake” protocol.
- ▶ Friendly-use release to CESM Societal Dimensions Working Group and **global climate community**.
- ▶ Extensions underway to handle forcings besides LULCC: **full RCP complement of LLGHGs, aerosols, etc.**



Moss et al, 2010

Opportunities afforded by iESM

- ▶ **Immediate** tests of climate impacts for future scenarios.
- ▶ Tool to enable “no regrets” scenario/path development.
- ▶ Advances in internally consistent treatment of water, energy, and climate in mitigation pathways.
- ▶ Quantification of impacts of feedbacks and interactions ***that are yet to be treated under current protocols and yet could be significant on mitigation timescales.***