



The integrated Earth System Model (iESM)

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Science gaps in 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.**
- ▶ Tighter integration of IAMs and ESMs could provide **fully consistent analysis** of potential future climate change, emissions mitigation options, and impacts and adaptation options will be possible.



Motivation for integrating IAMs and ESMs

- ▶ *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**
- ▶ *Prototype:* **Initial release of an iESM built on CESM**



Mitigation



Adaptation



Technology pathways

Primary science questions for iESM

- ▶ Is the present CMIP5 “parallel process” approach **good enough**?
- ▶ **Will human activities affect local and regional climate** on scales that matter?
- ▶ **Will climate change itself affect human decision making** (energy use, land-use, water use) in ways that feed back to local, regional and global climate forcing?

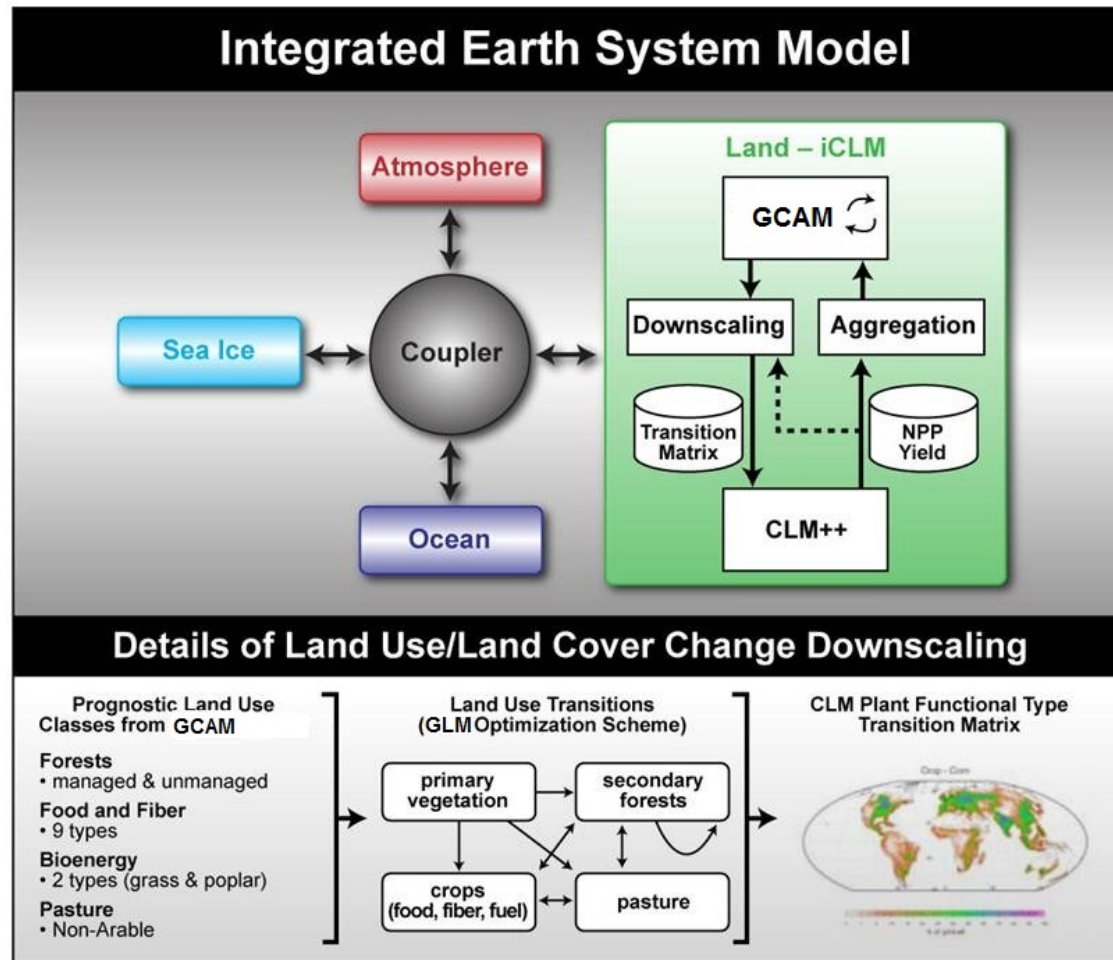


Three major objectives of iESM project

- ▶ **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.



iESM schematic



Foundations for iESM are:

- Global Change Assessment Model (GCAM):
- Global Land Model (GLM):
- Community Earth System Model (CESM):

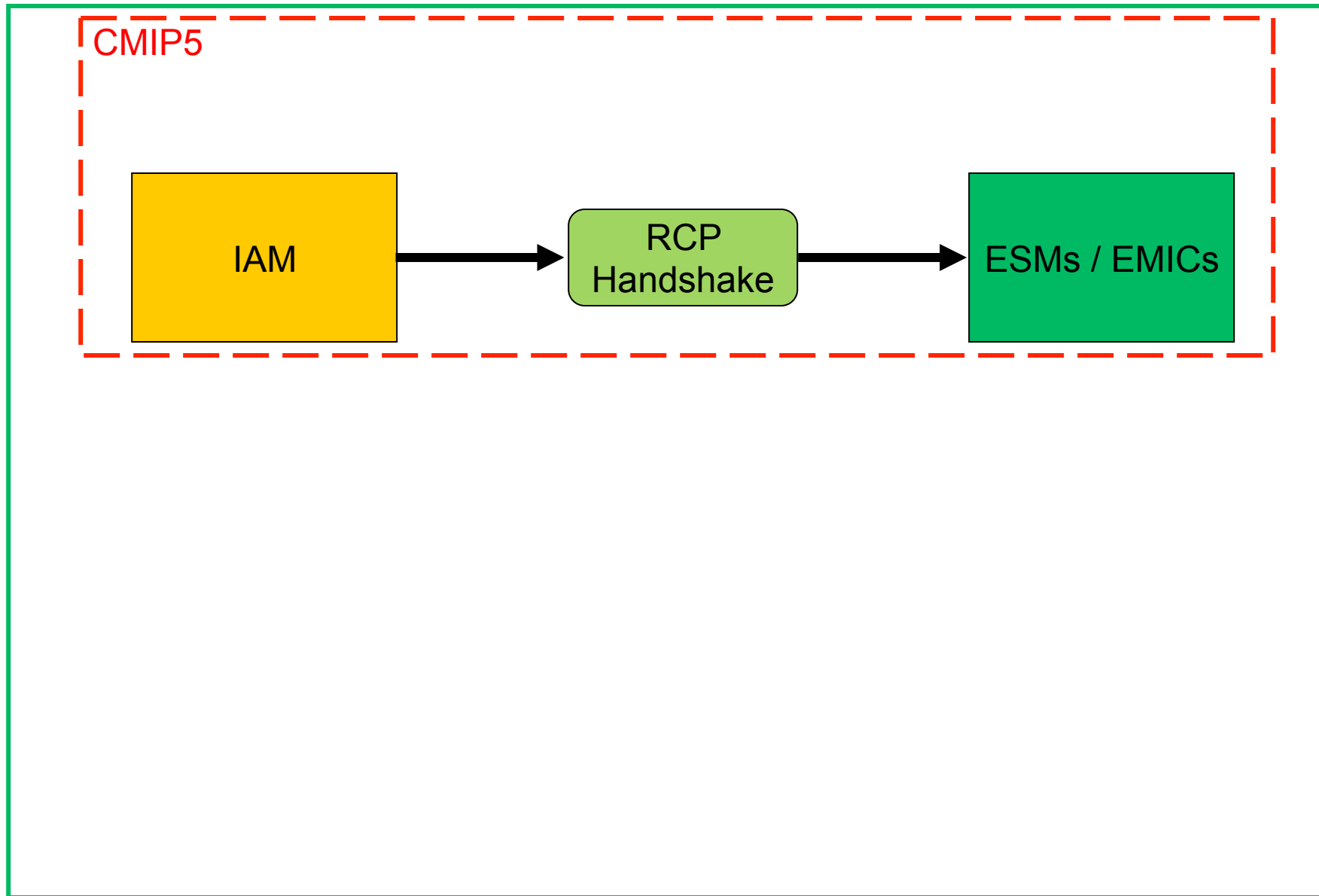
Applications:

RCP 4.5

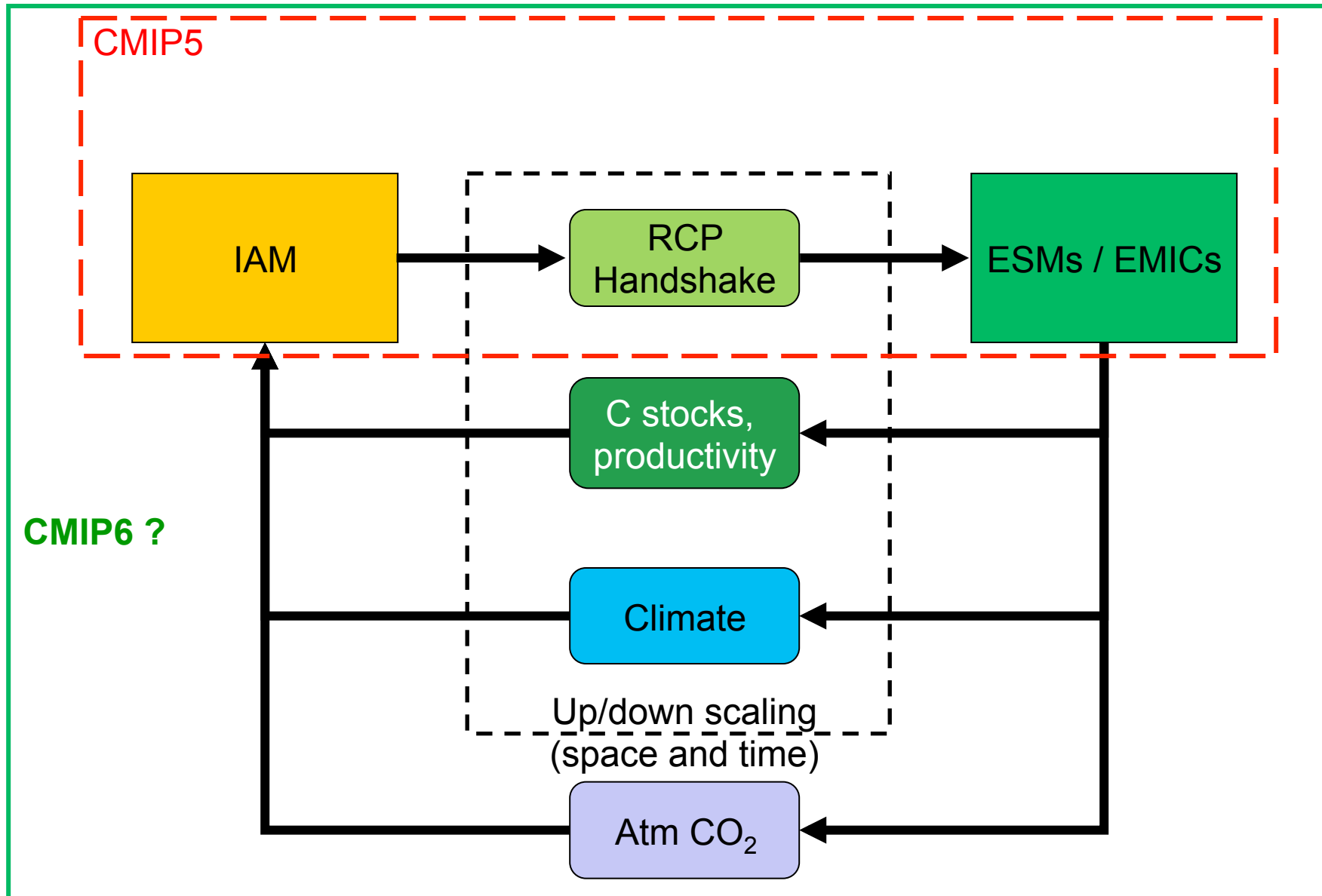
Land-use in AR5

IPCC simulations

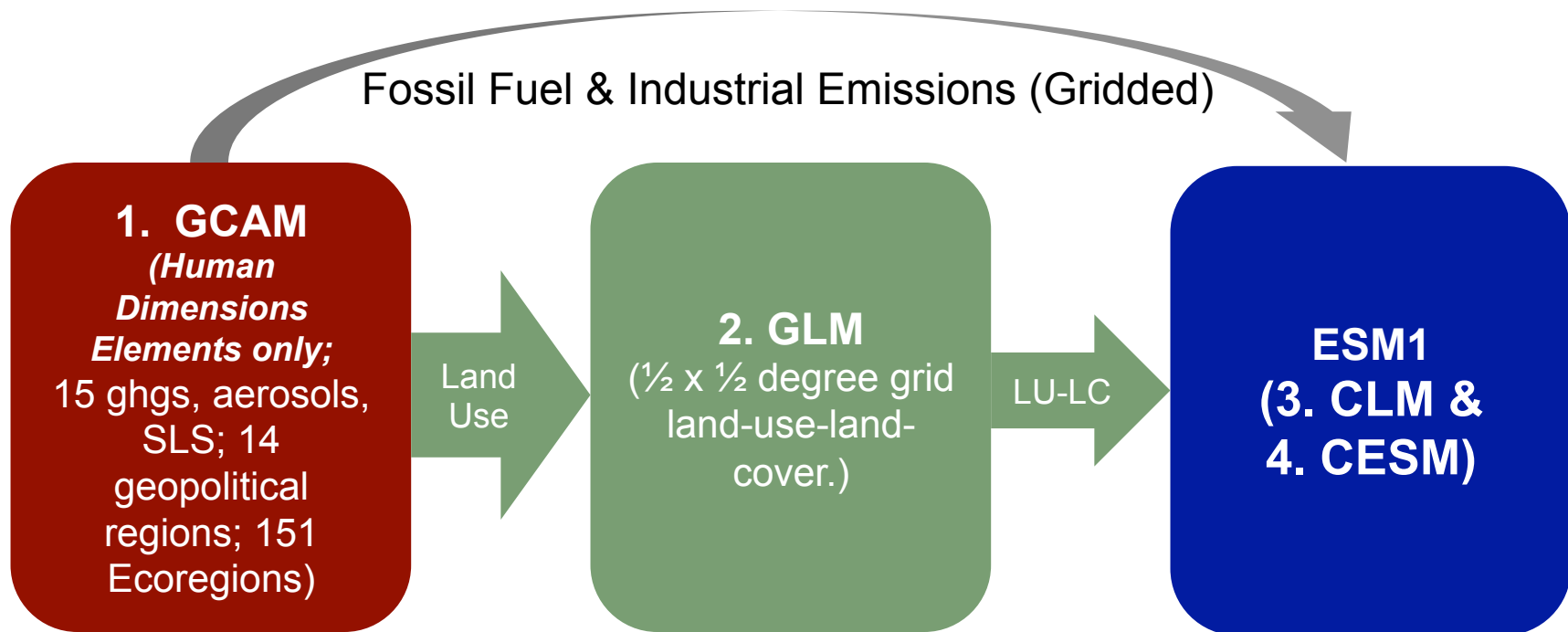
Multi-phase coupling of IAMs and ESMs / EMICs



Feedback coupling of IAMs and ESMs / EMICs?

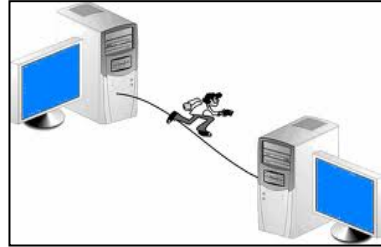


iESM links 4 models: GCAM, GLM, CLM, & CESM



Transition to fully coupled implementation

“Sneaker Net” Version



Issues:

- Diversity of languages



- Large amount of effort to conduct this relay race



- Human effort scales directly with coupling frequency.

Automated and Integrated Version



Advantages:

- Unified Implementations

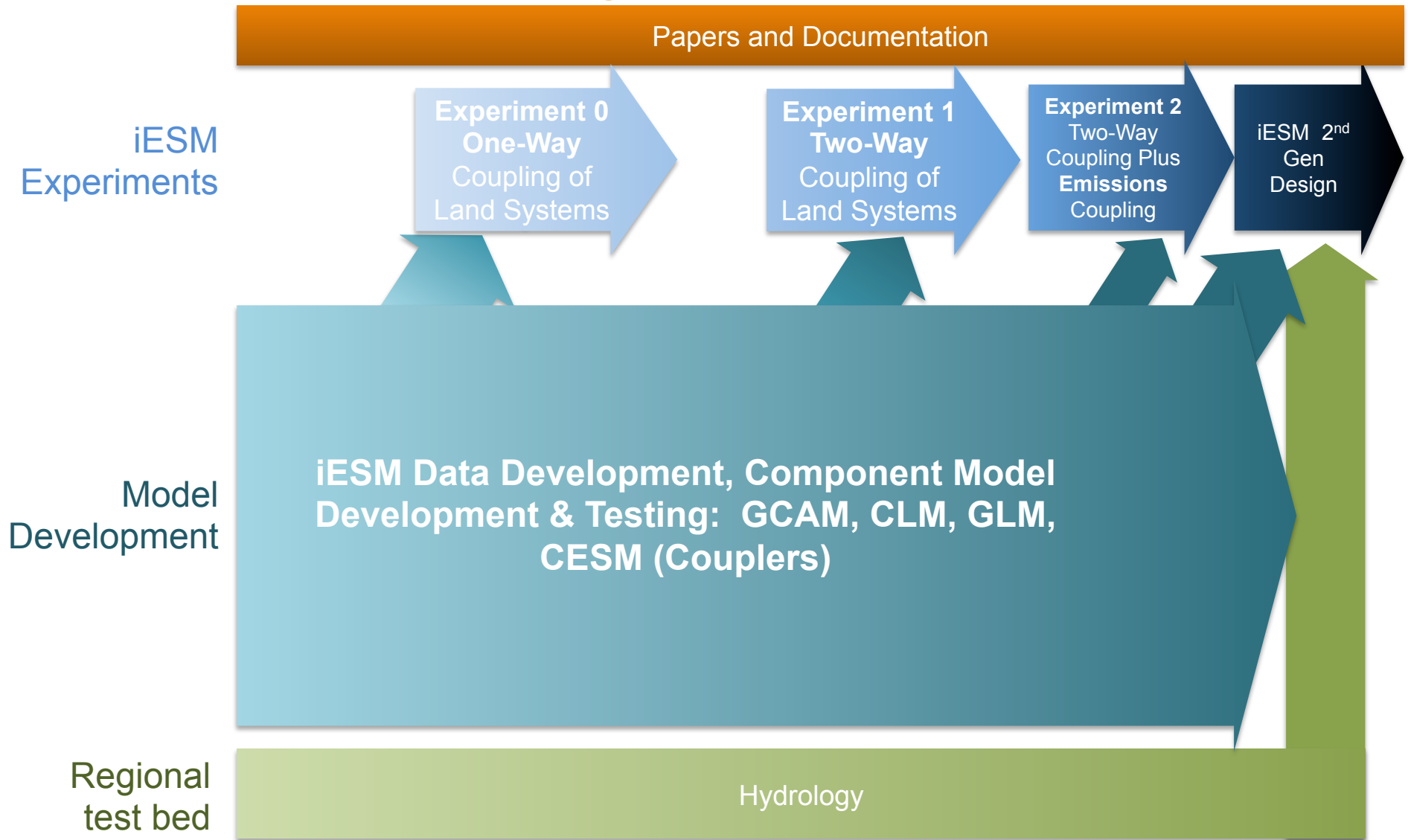


- Long-time integrations handled by CESM system.

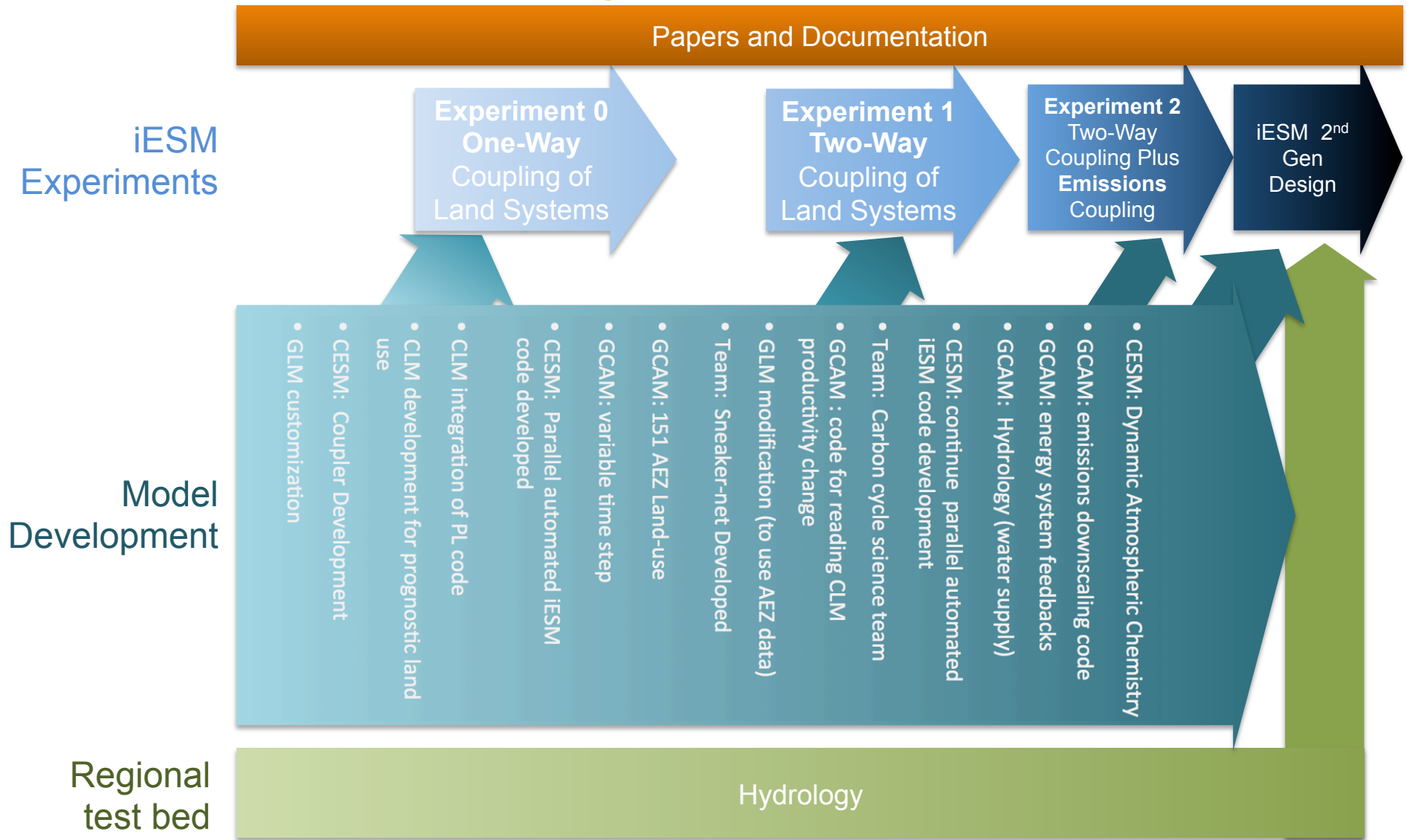
Community Earth System Model **CESM**

- Researcher's time freed for devising new experiments.

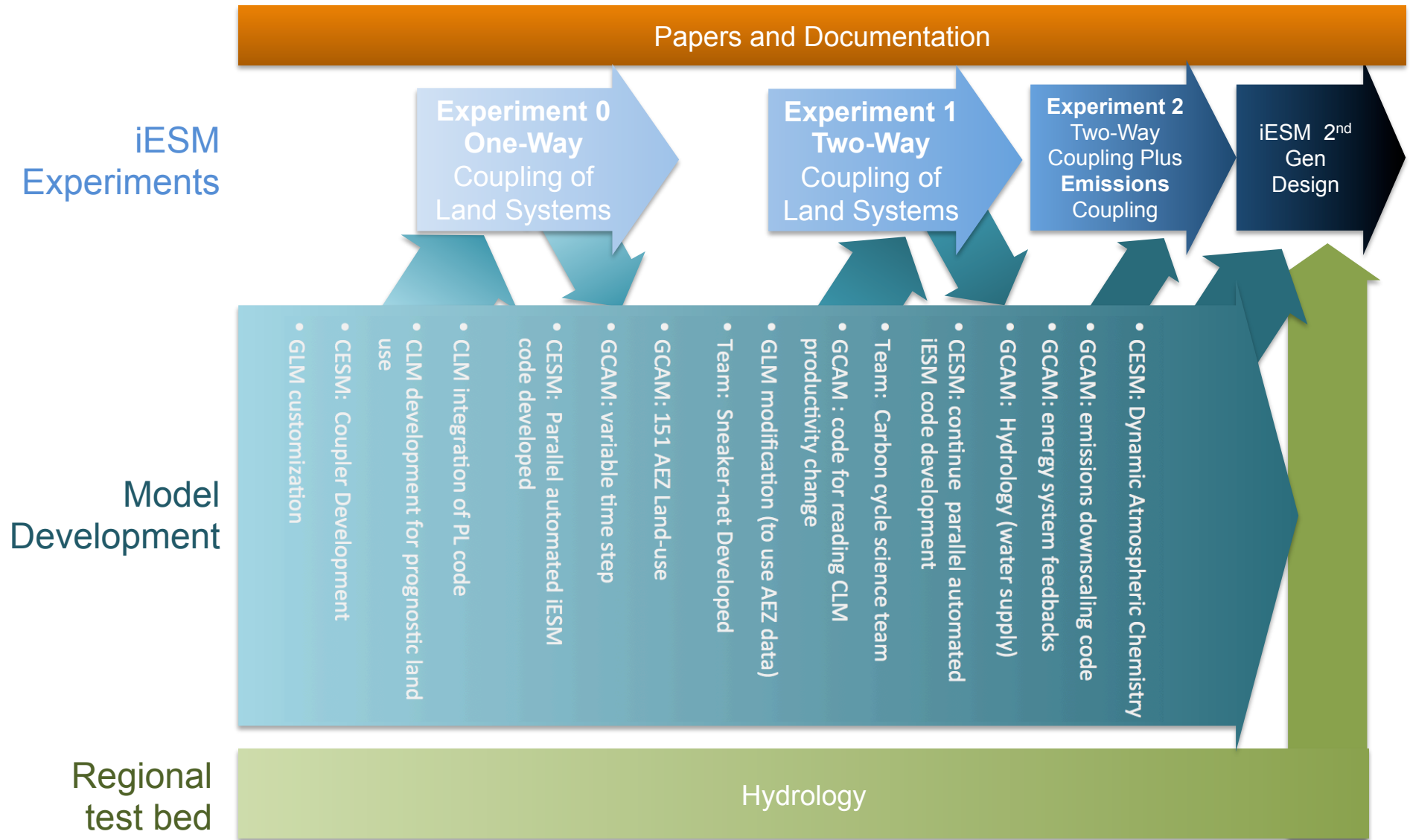
iESM Project—Data Development, Component Model Development & Testing



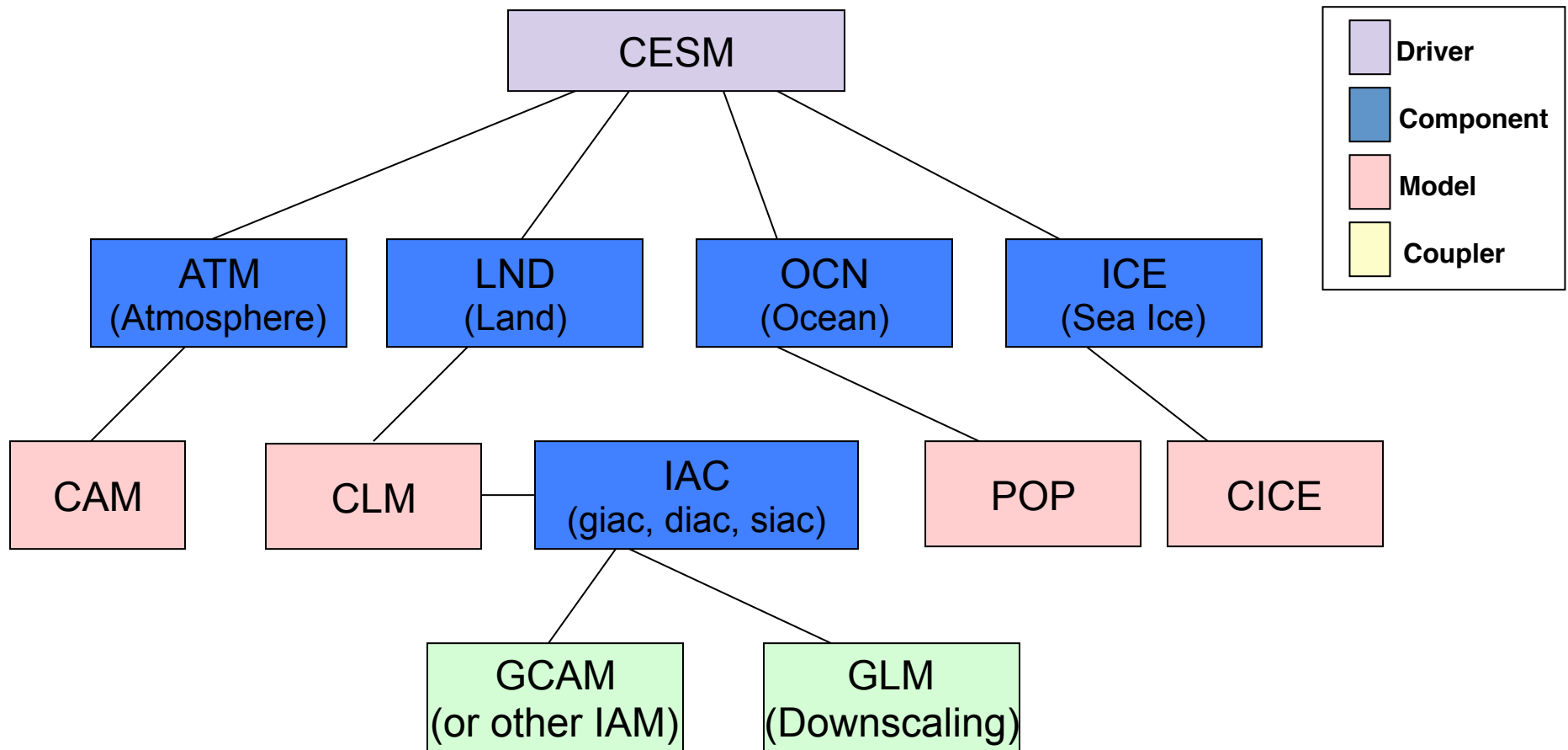
iESM Project—Data Development, Component Model Development & Testing



iESM Project—lessons from each experiment feed back to inform model development

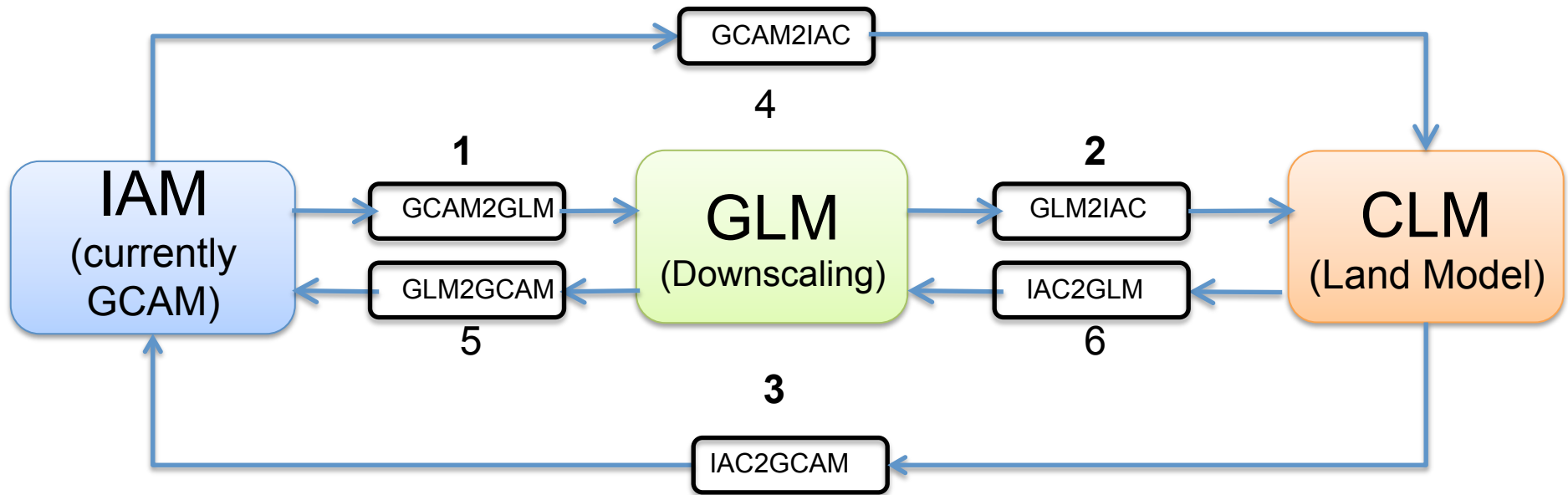


Current iESM Coupling Implementation



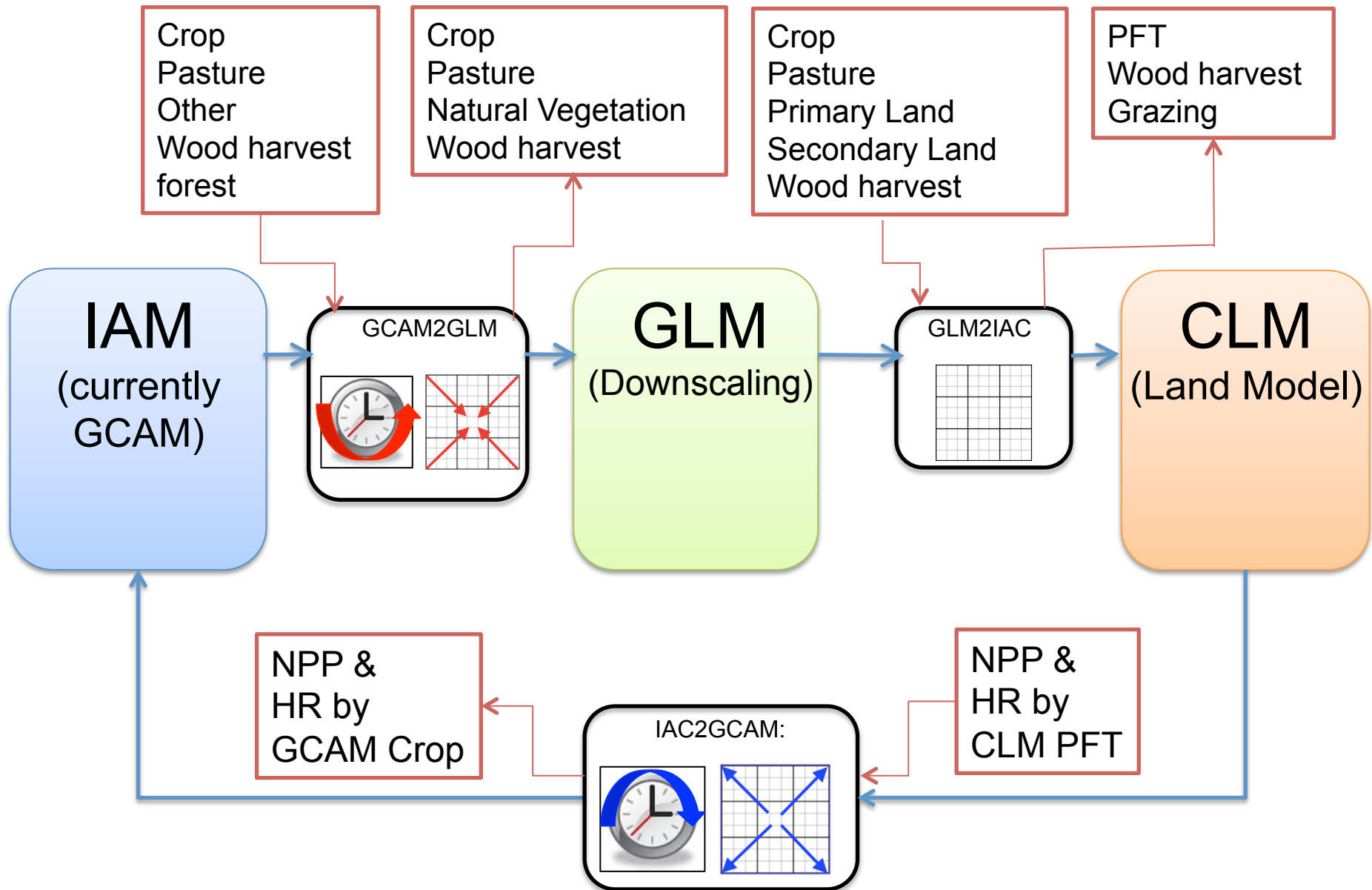
iESM is implemented using the existing infrastructure of CESM.

The iESM Coupling Diagram

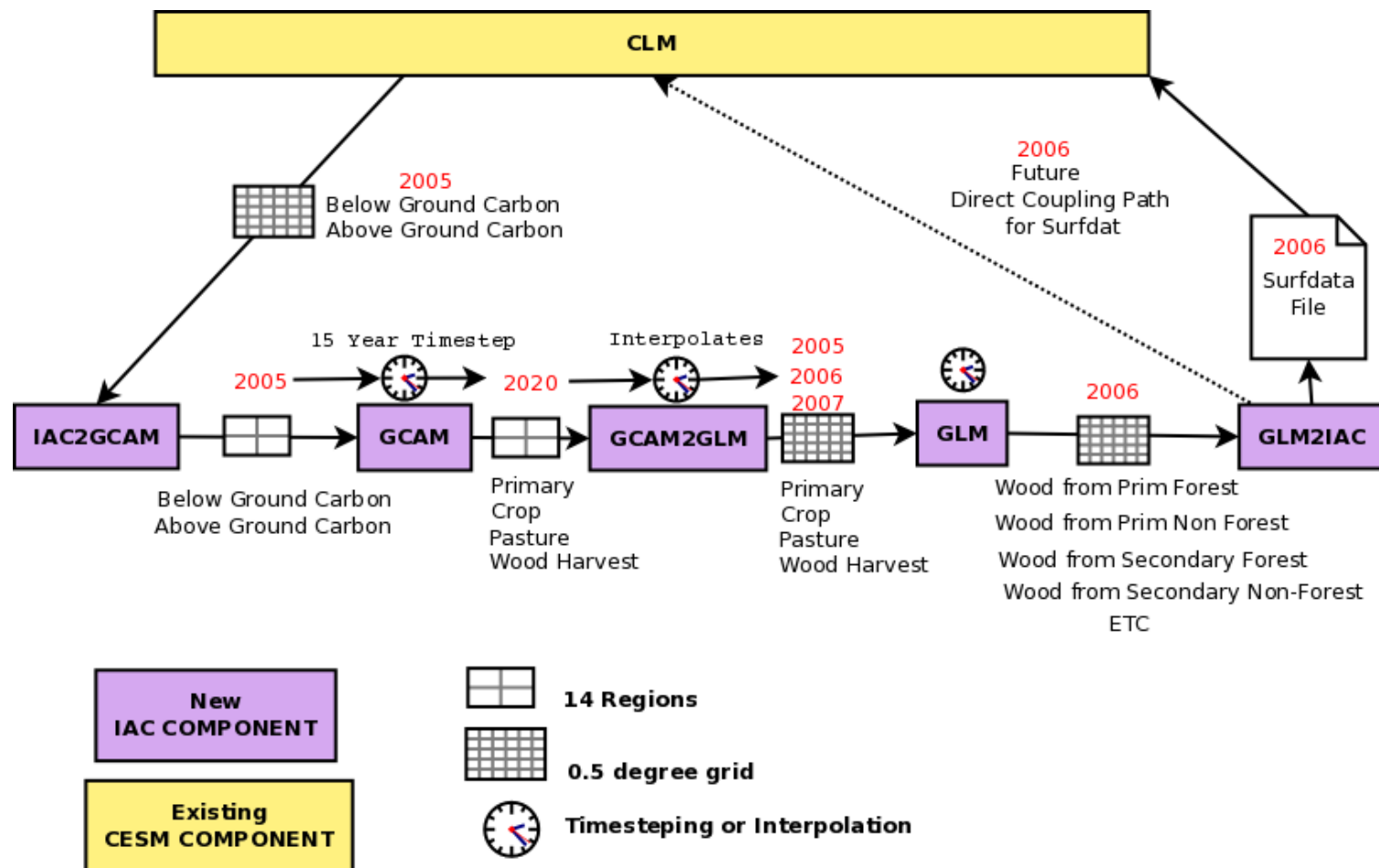


Coupler	Input	Output	Status
1	IAM	Downscaling	Running
2	Downscaling	Land Model	Running
3	Land Model	IAM	Running
4	IAM	Land Model	Coded
5	Downscaling	IAM	Coded
6	Land Model	Downscaling	Coded

The iESM Information Exchange

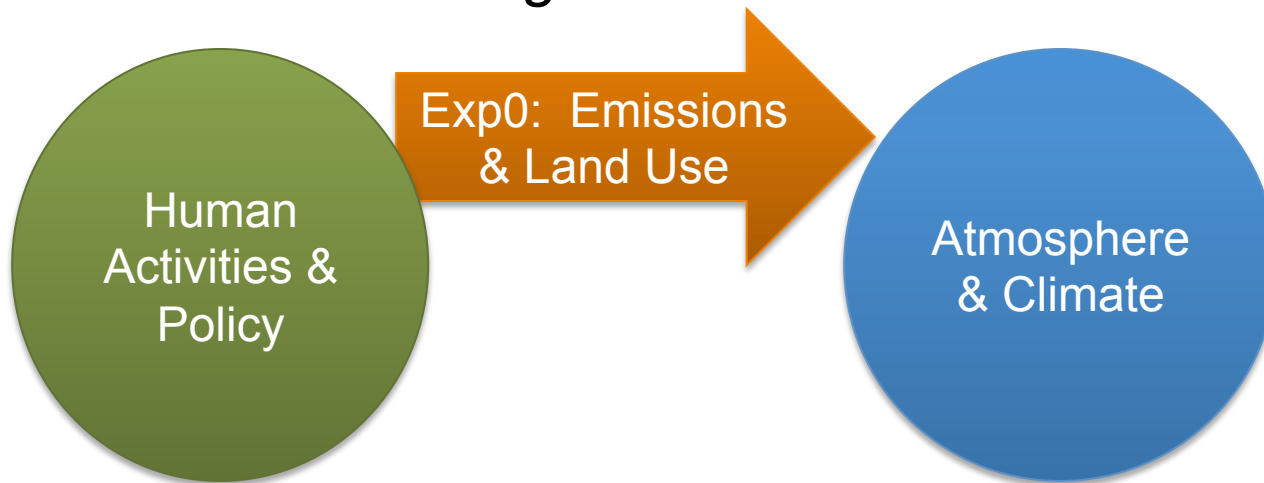


iESM Coupling: The time stepping procedures



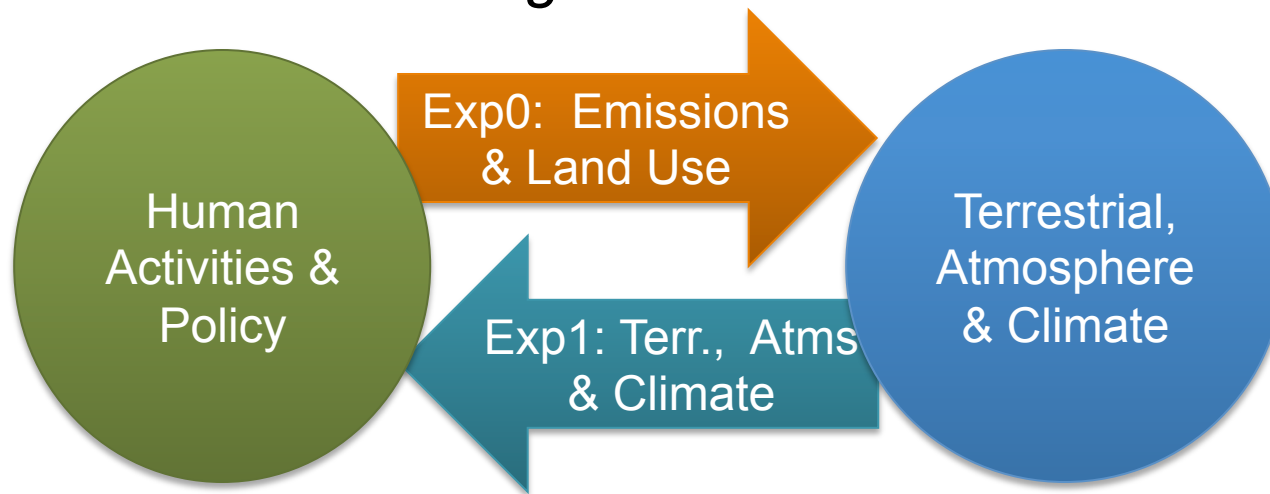
Two major experiments

- ▶ **Experiment 0:** One-way coupling
- ▶ **Scientific Question:** *How much difference does land-use emissions mitigation policy make for near-term and long-term climate change?*



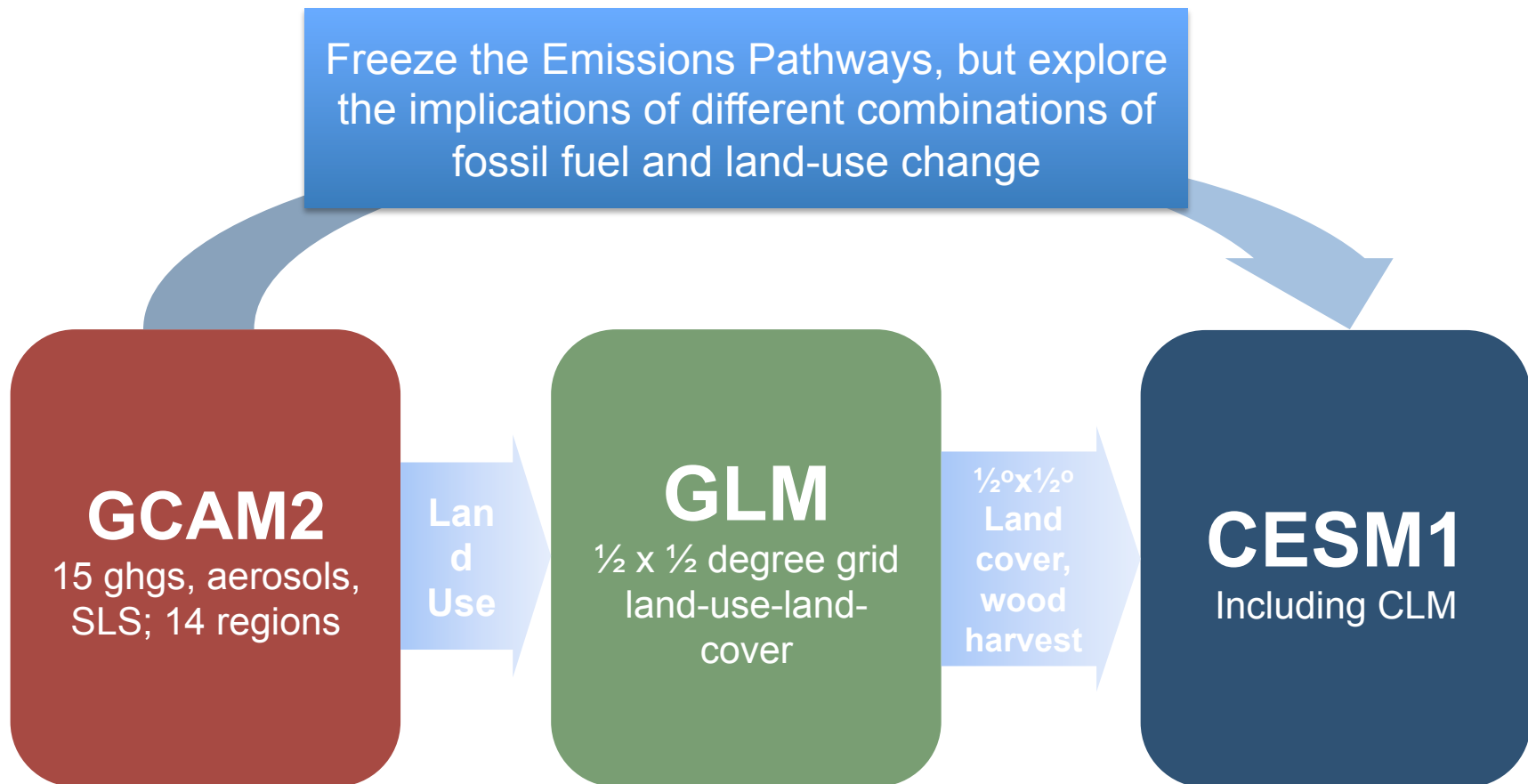
Three major experiments: Two complete

- ▶ **Experiment 0:** One-way coupling
- ▶ **Scientific Question:** *How much difference does land-use emissions mitigation policy make for near-term and long-term climate change?*



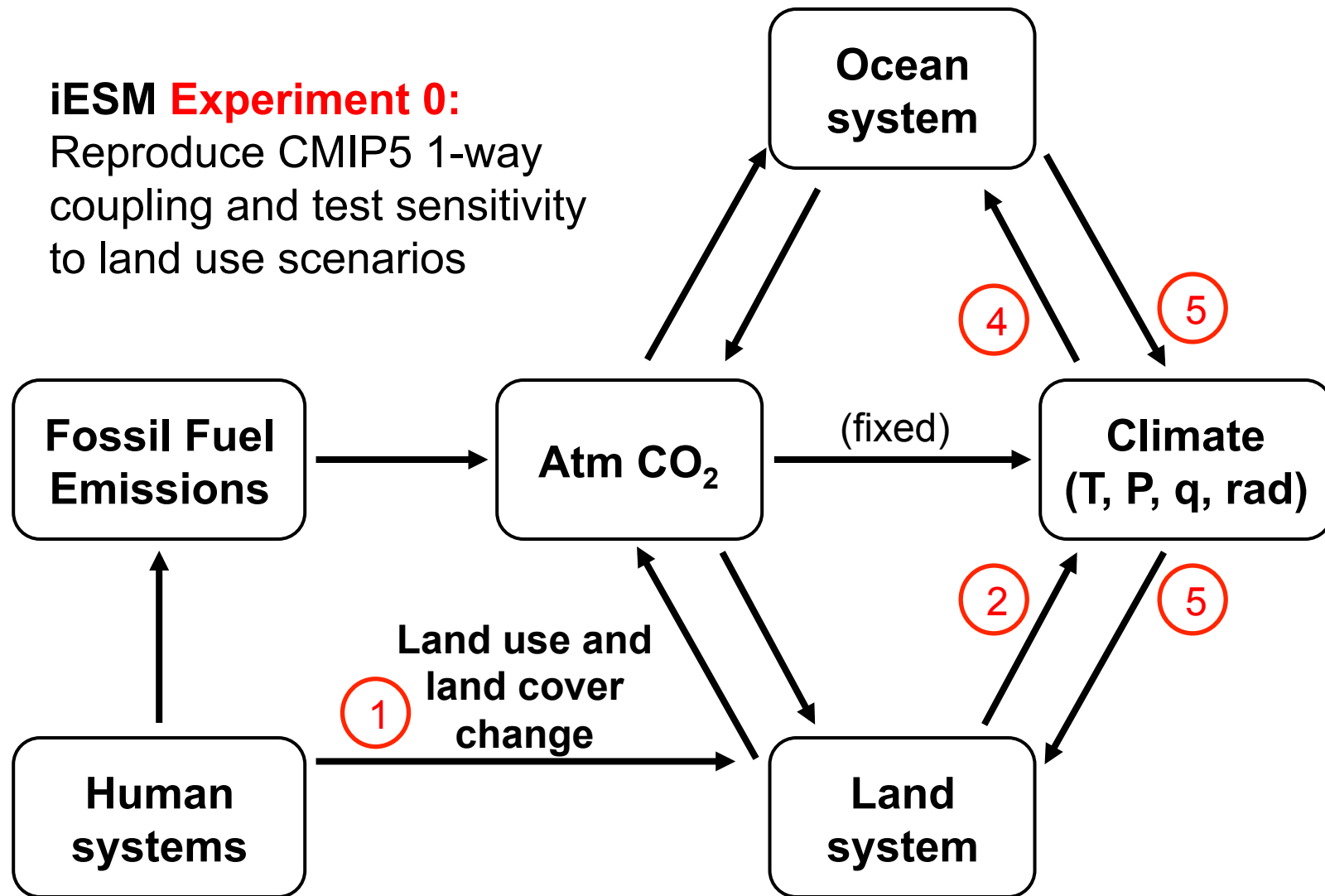
- ▶ **Experiment 1:** Two-way coupling of the land-use components
- ▶ **Scientific Question:** *How much difference does atmosphere and climate change make for crop yields and land use?*

Research Design and Model Coupling in the iESM: Experiment 0

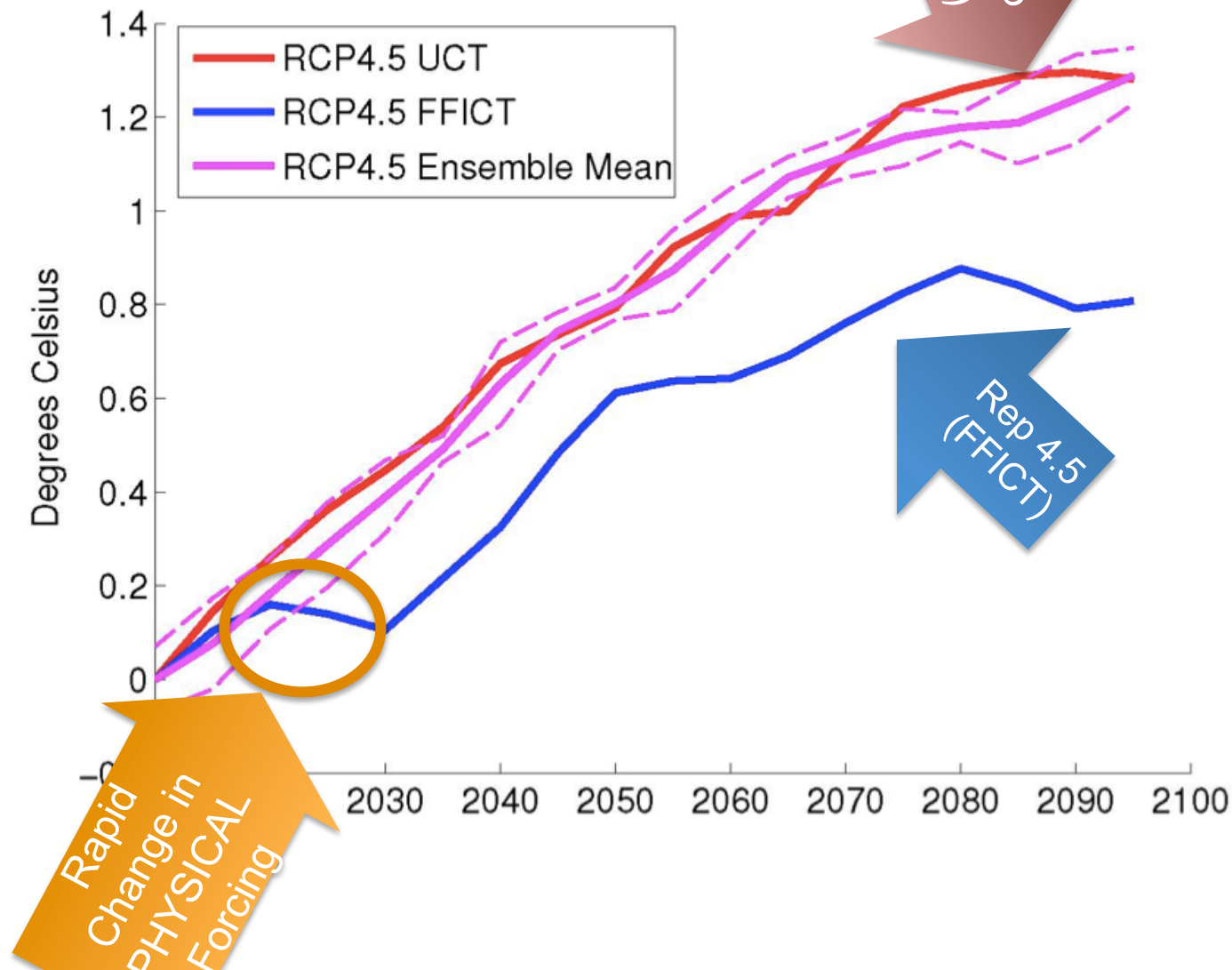


iESM Experiment 0:

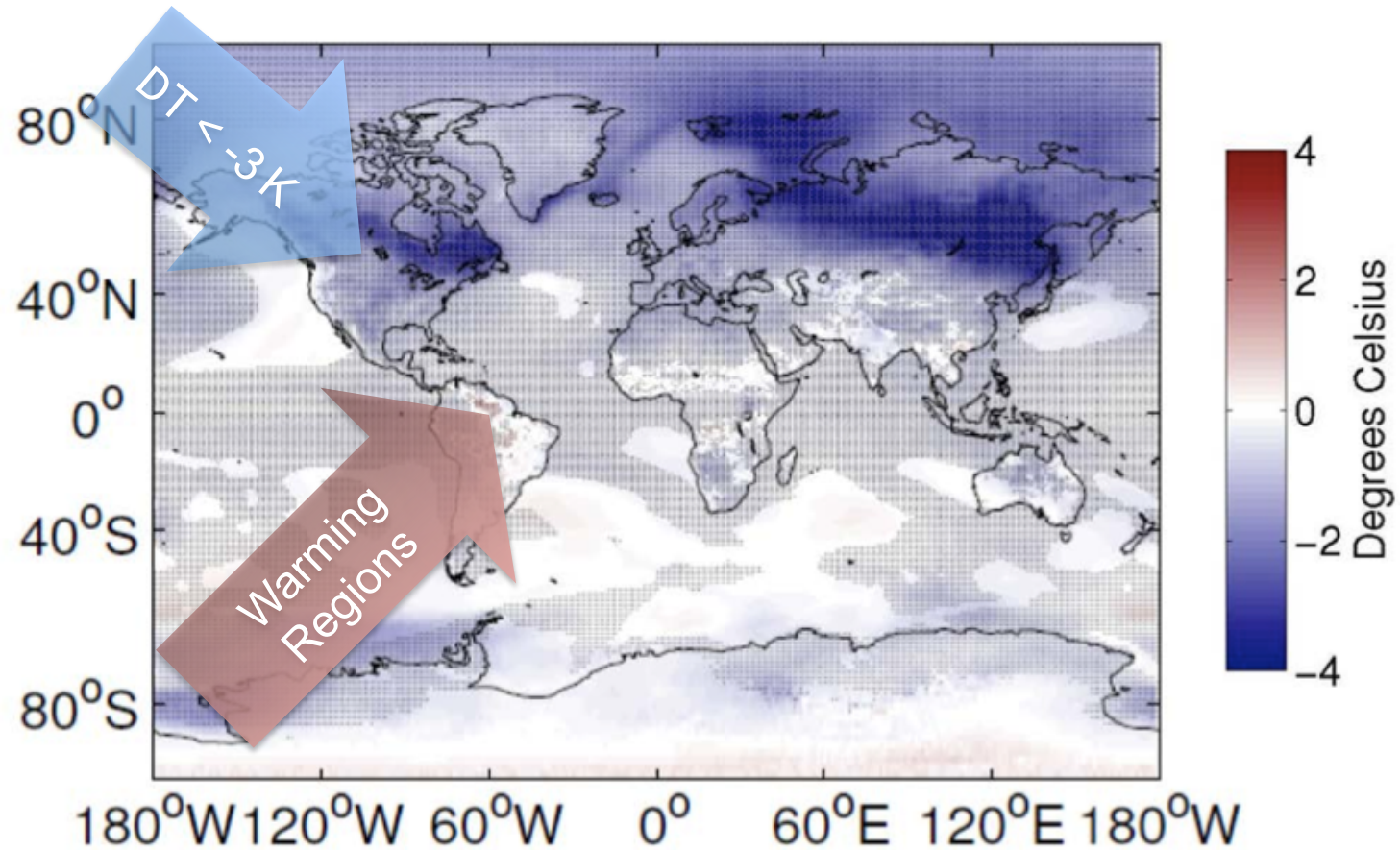
Reproduce CMIP5 1-way coupling and test sensitivity to land use scenarios



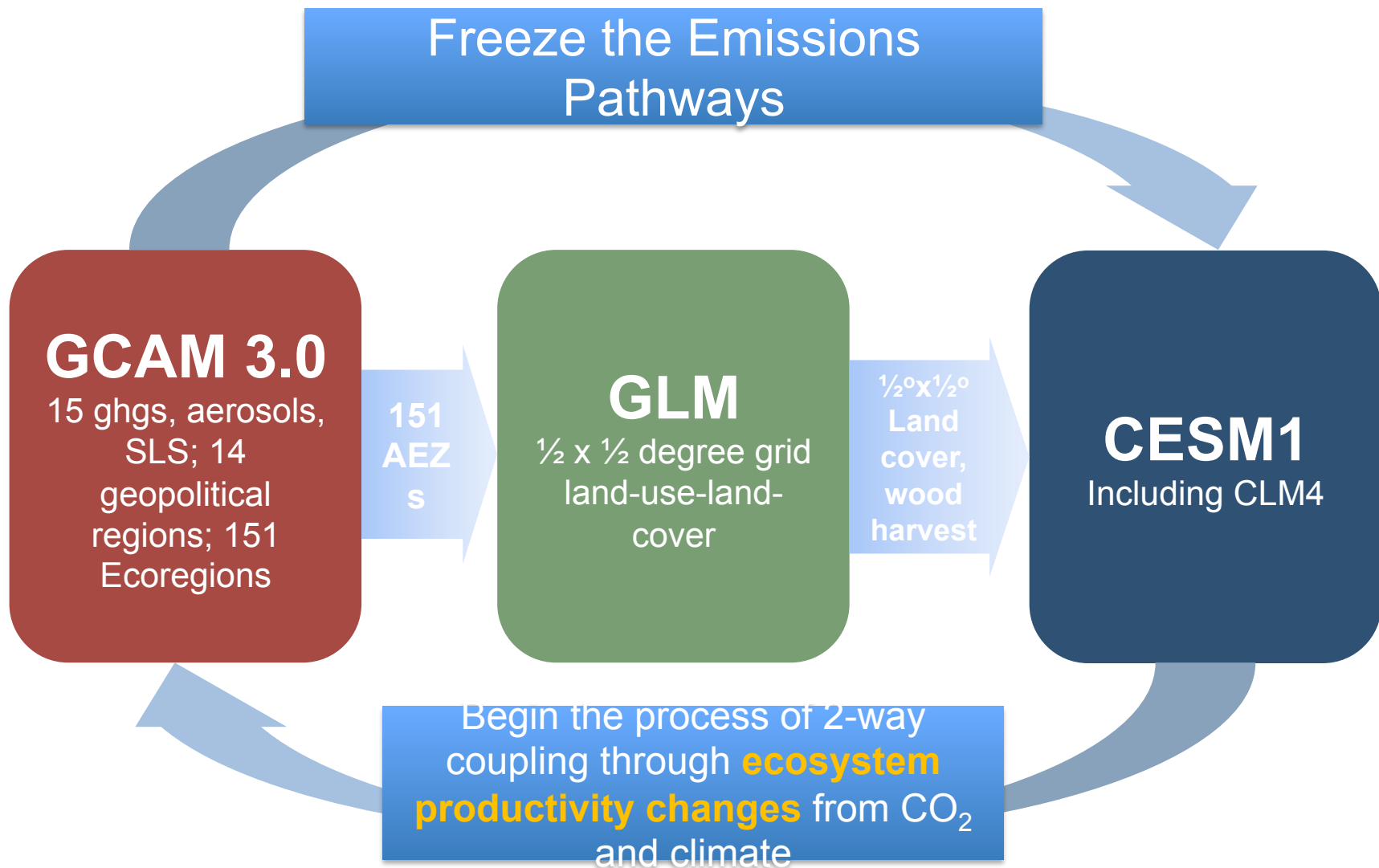
Experiment 0: Land use effect on global mean temperature



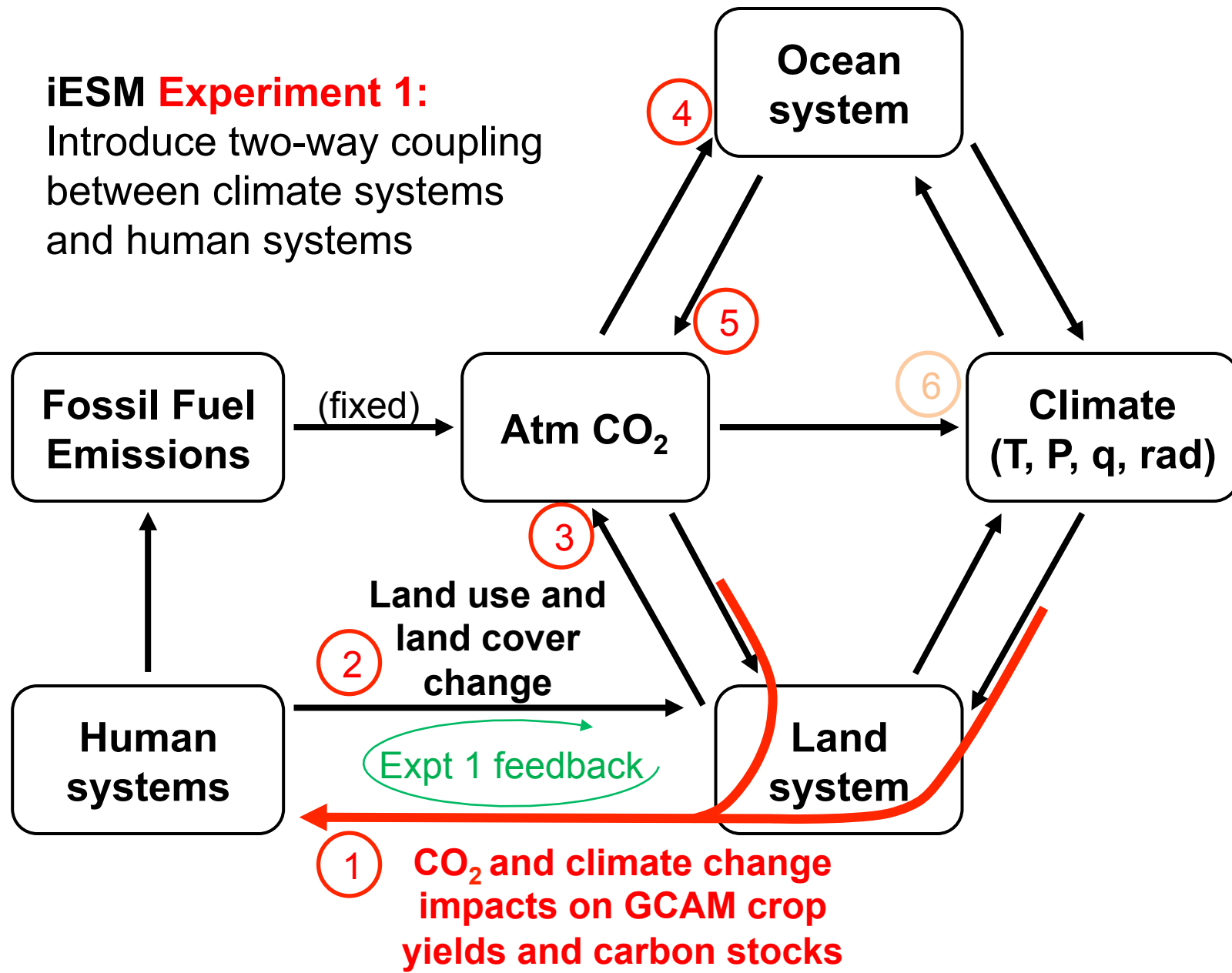
Experiment 0: Land use effect on regional temperature



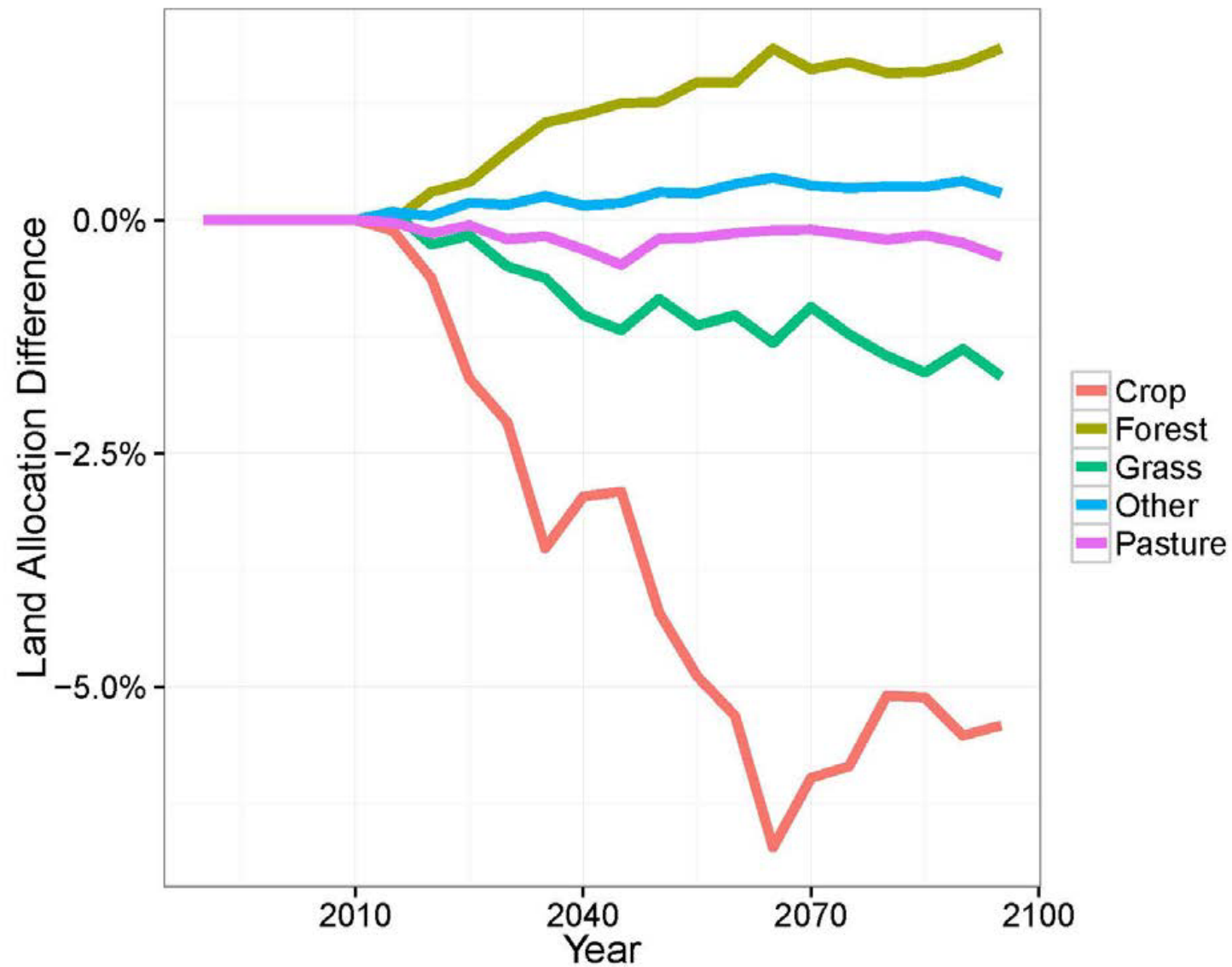
Research Design and Model Coupling in the iESM: Experiment 1



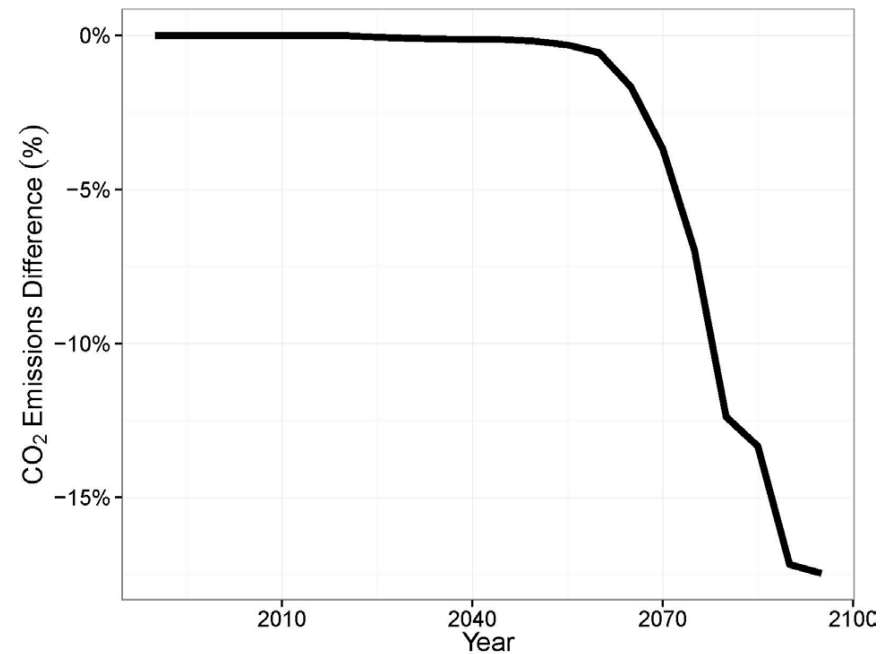
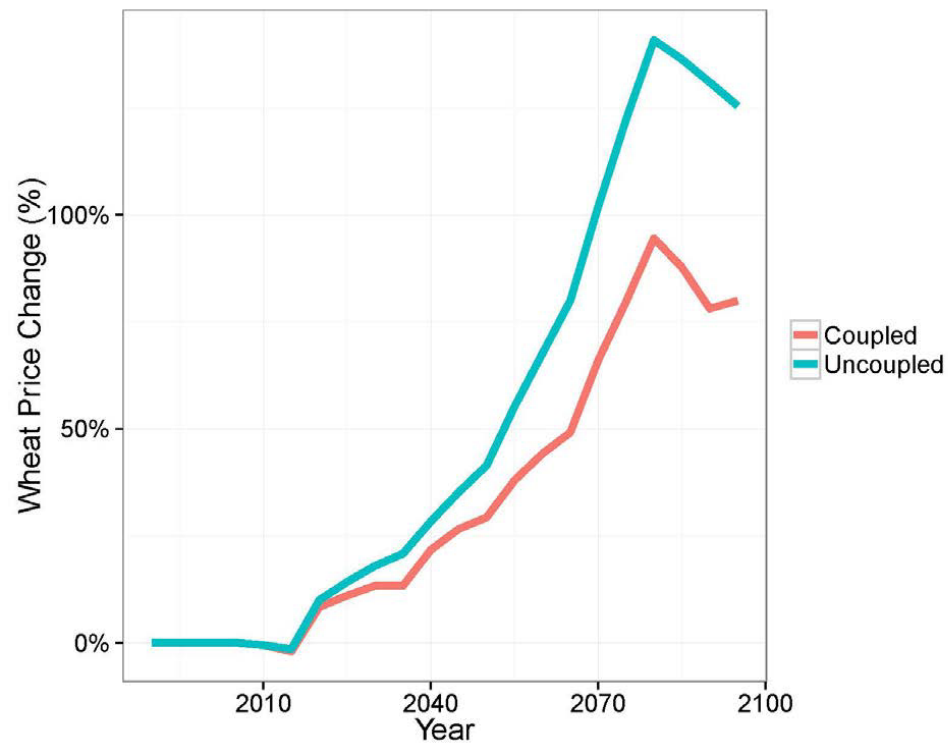
Introduce two-way coupling between climate systems and human systems



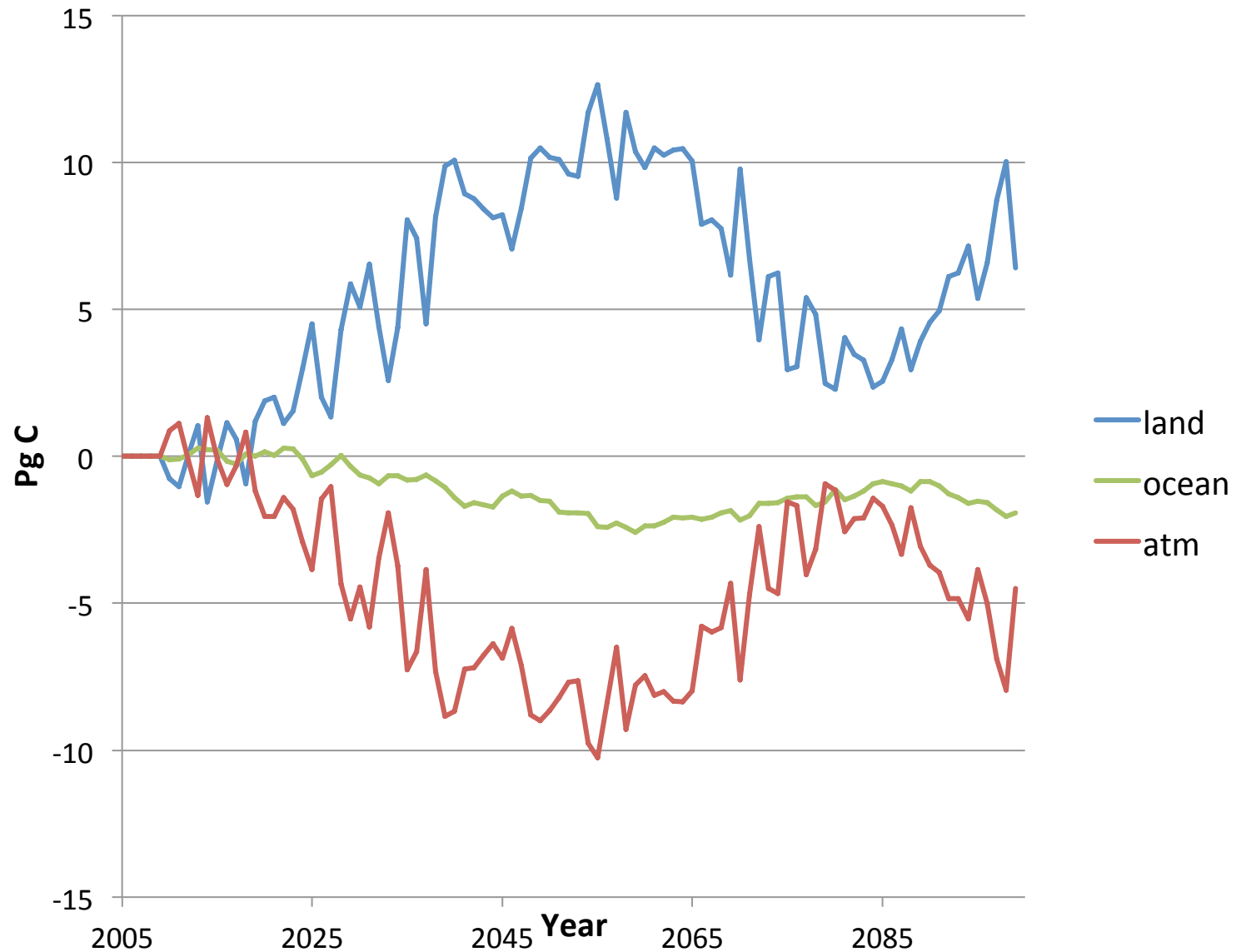
Experiment 1: Feedback changes land allocation



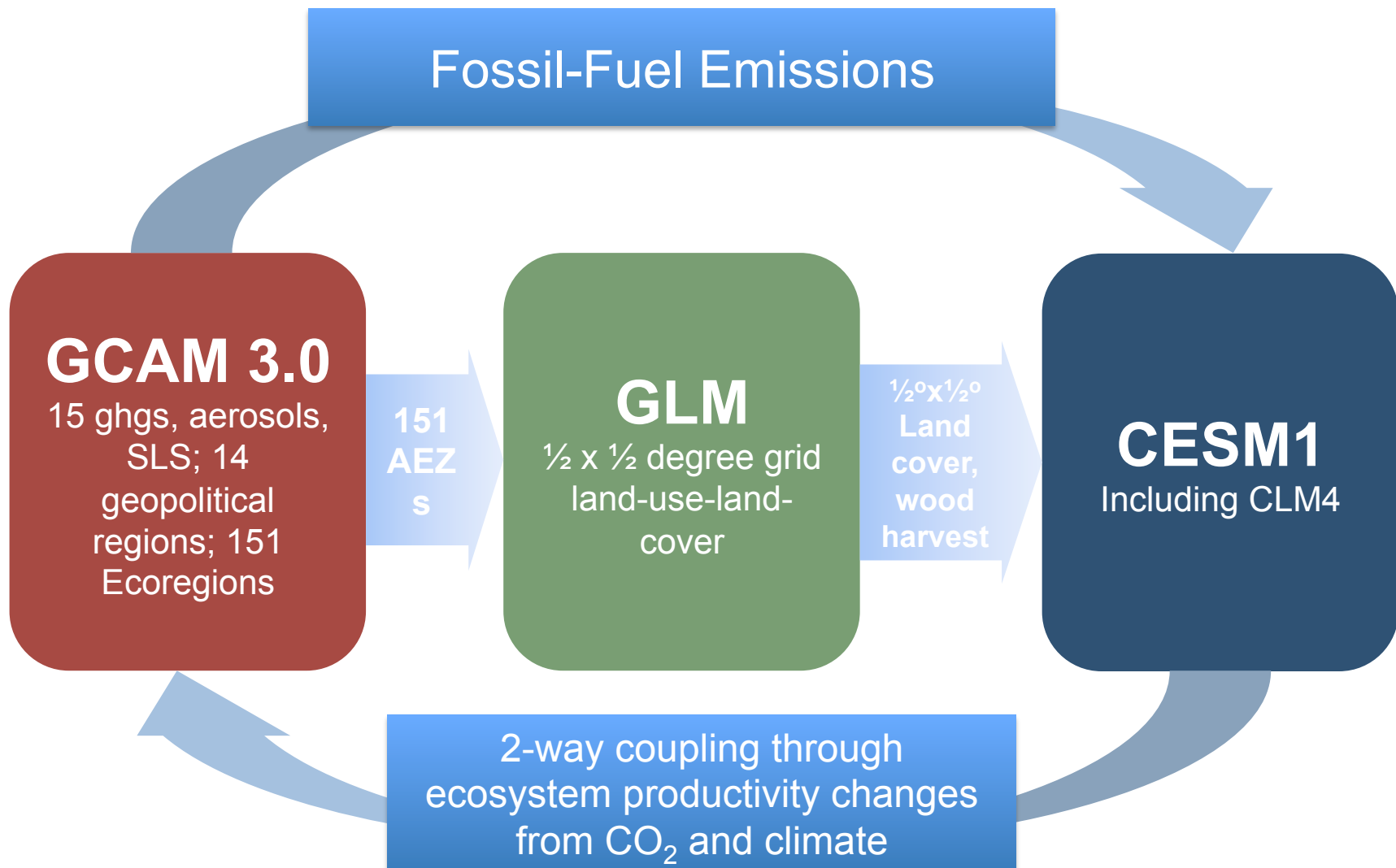
Experiment 1: Feedback alters commodity prices and fossil fuel emissions



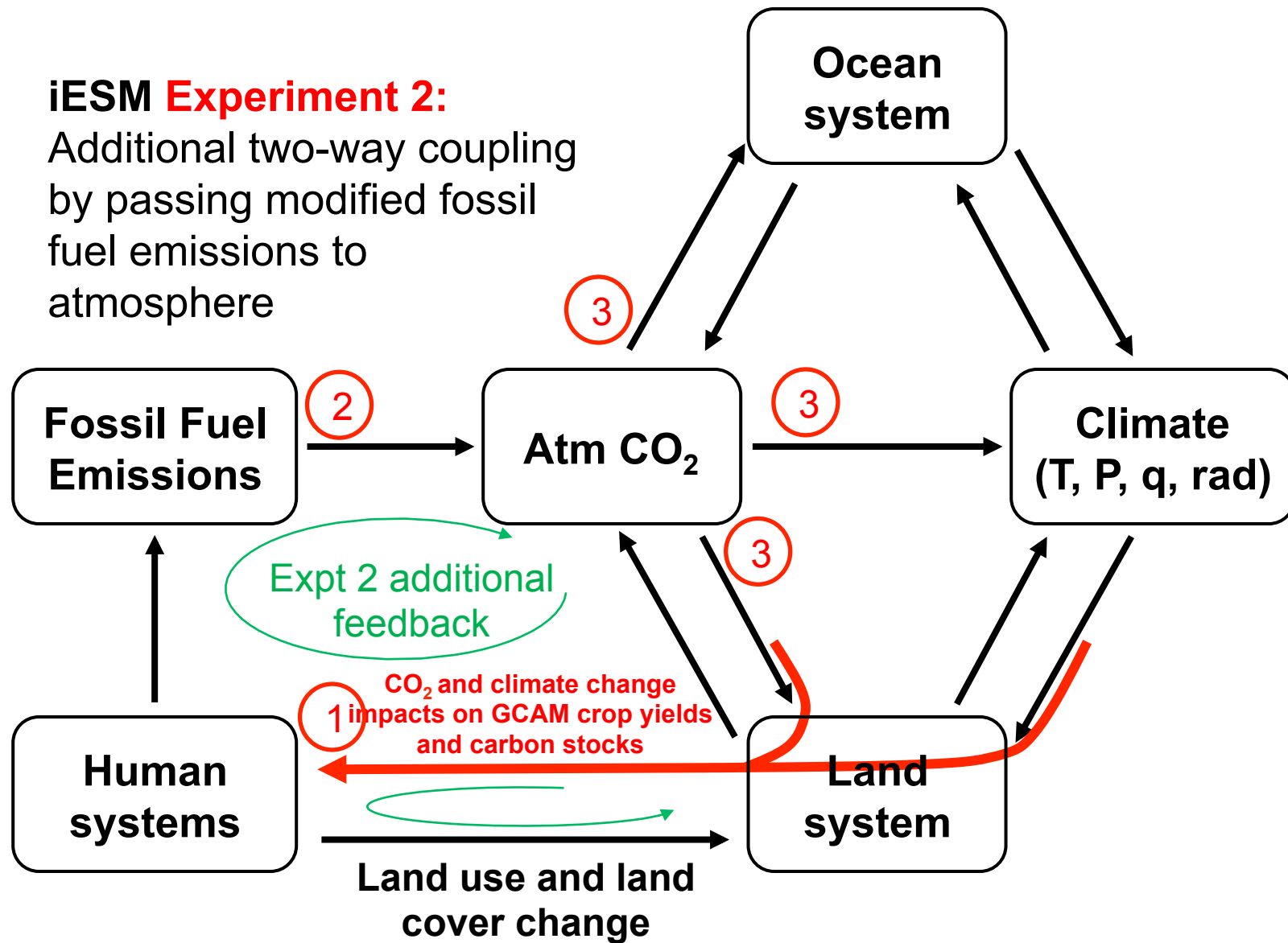
Experiment 1: Feedback alters global carbon cycle



Research Design and Model Coupling in the iESM: Experiment 2



Additional two-way coupling
by passing modified fossil
fuel emissions to
atmosphere



Primary science questions for iESM

- ▶ Is the present CMIP5 “parallel process” approach **good enough**?

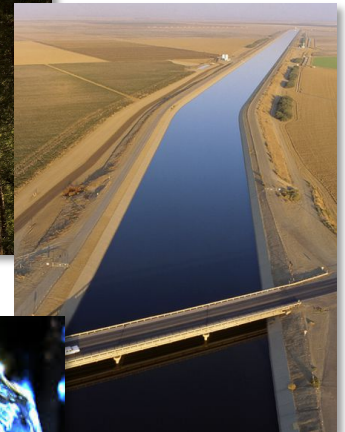
Process could be improved to treat significant effects of LULCC, feedbacks...

- ▶ **Will human activities affect local and regional climate** on scales that matter?

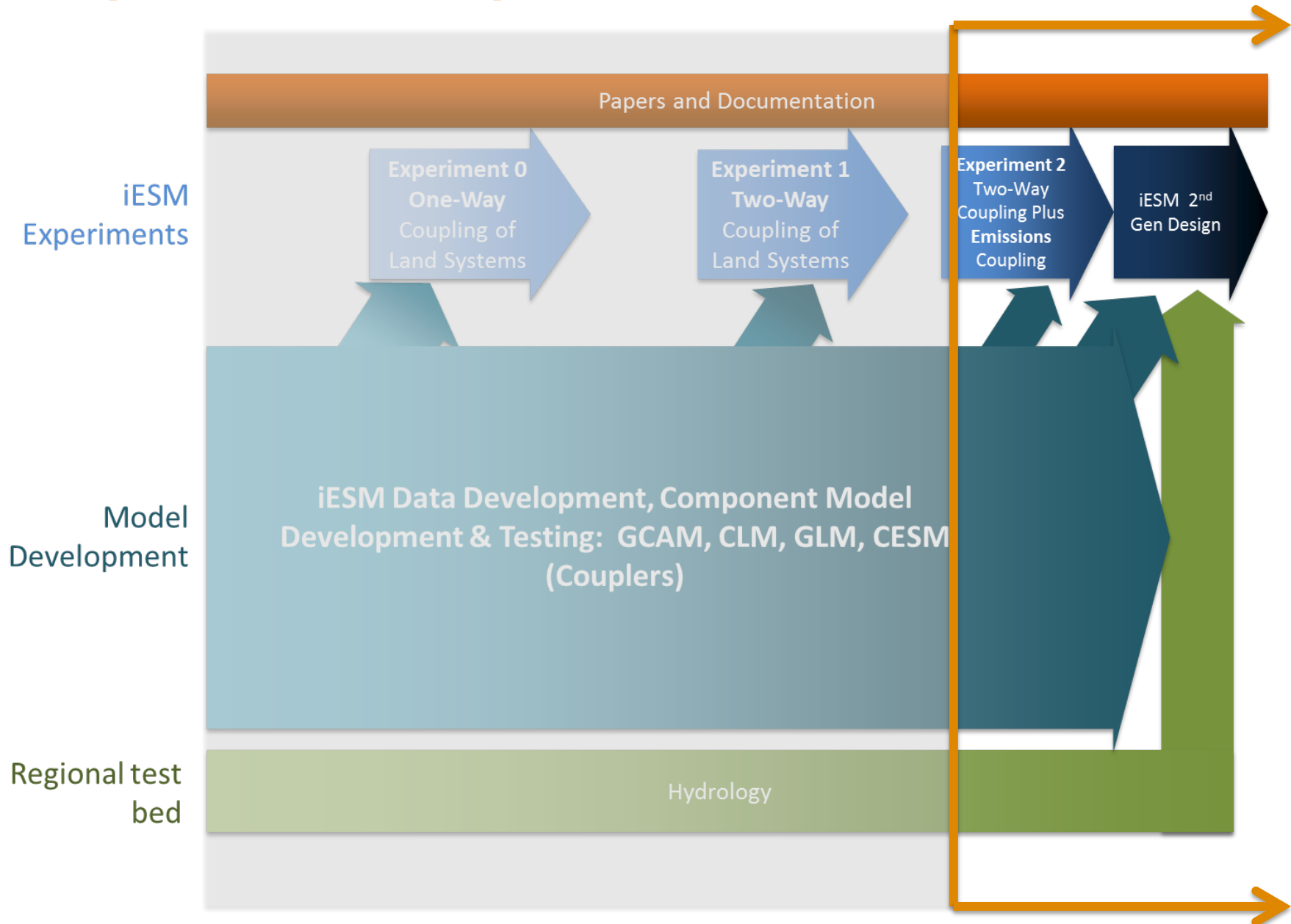
Of course – iESM amplifies regionality.

- ▶ **Will climate change itself affect human decision making**
(energy use, land-use, water use)
in ways that feed back to local, regional and global climate forcing?

Yes, and these affects are non-negligible.

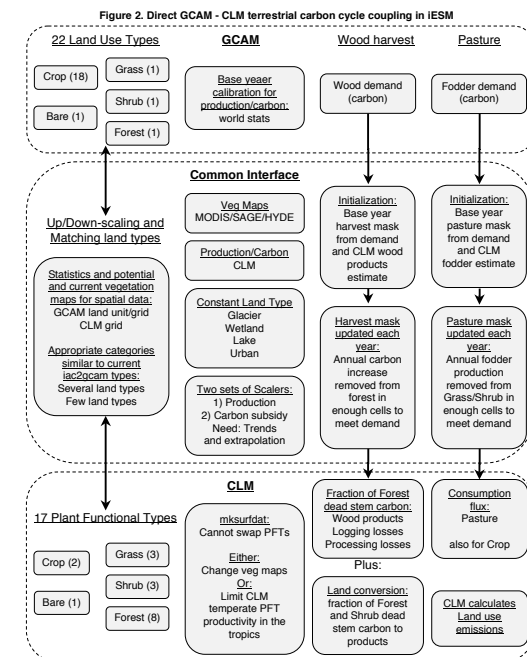
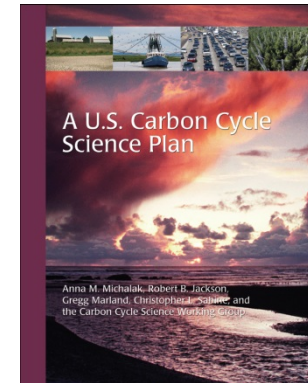
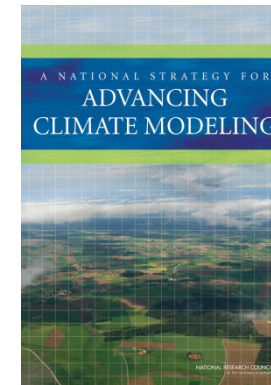


Proposed next steps for iESM



Unification of the Carbon Cycle

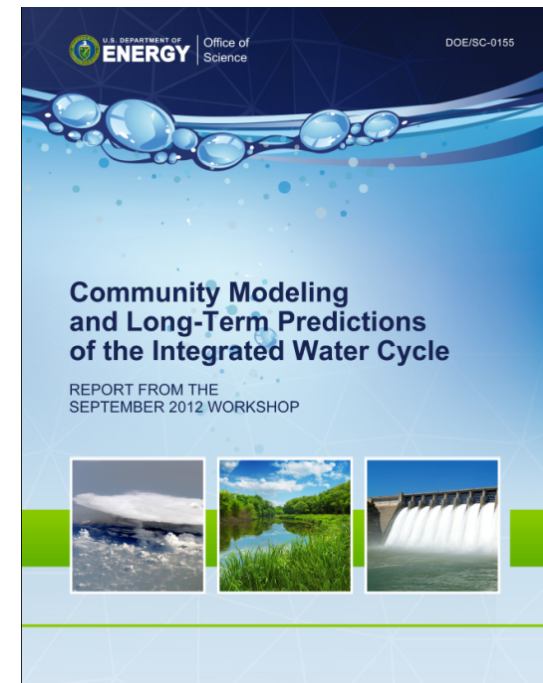
- ▶ Grand Challenge: Develop a **Unified Carbon Cycle** that brings the GCAM land-use fully within a DOE supported Earth System Model.
- Expand the set of PFTs in the terrestrial system model.
- Expand and match PFTs in GCAM
- Reconcile (match?) spatial scales in GCAM and the terrestrial system model
- Directly pass information about carbon and productivity to GCAM from the terrestrial system model.
- Directly pass information about land use and land cover from GCAM to the terrestrial system model.
- Develop convergence criteria for consistency.



Present iESM carbon cycle coupling

Integration of the Coupled Hydrological Cycle

- ▶ Grand Challenge: Fully integrate physical climate and **Hydrology** from biogeophysical Earth systems into human Earth systems decision making particularly regarding energy, land and water use.
- Pass hydrologic information directly from the terrestrial system model to the GCAM
- Reconcile (match?) spatial scales in GCAM and the terrestrial system model
- Reconcile land use decision making with hydrologic decision making—
simultaneously clear agriculture, land, and energy markets with water basin availability.
- Directly pass information about water use (consumption, withdrawals, and storage) back to the terrestrial system model.
- Develop convergence criteria for consistency.



Opportunities afforded by further integration

- ▶ **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.***



Questions?

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