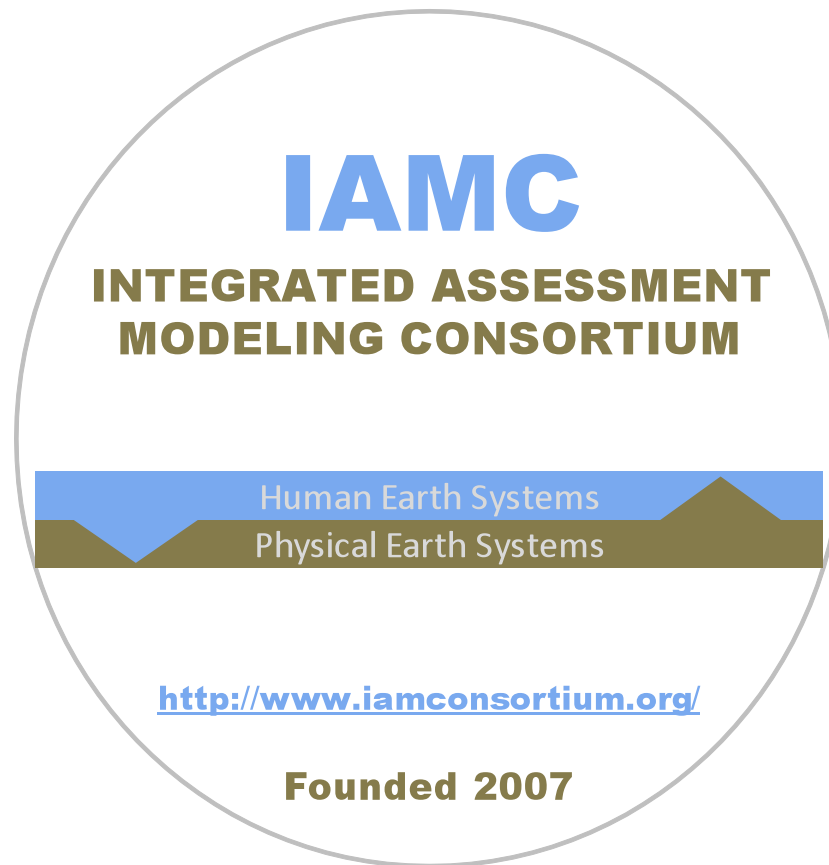
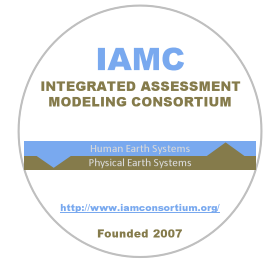


Integrated Earth System Modeling (iESM)



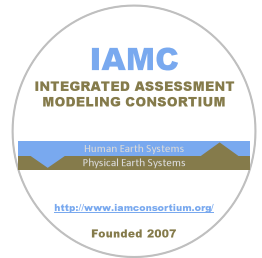
October 28, 2010



Thanks to my colleagues for help in preparing this presentation

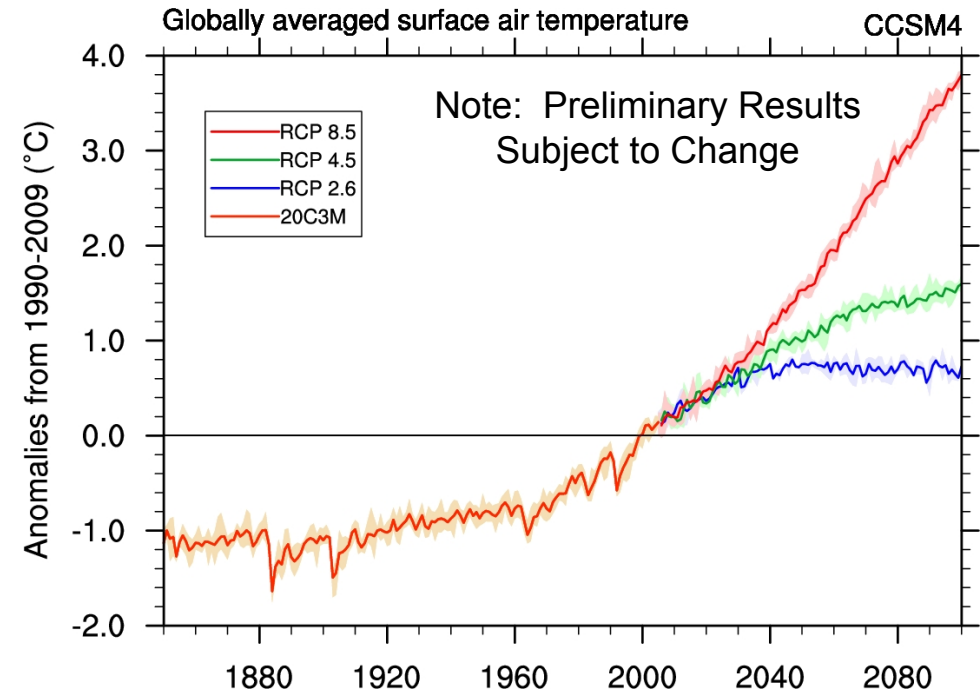
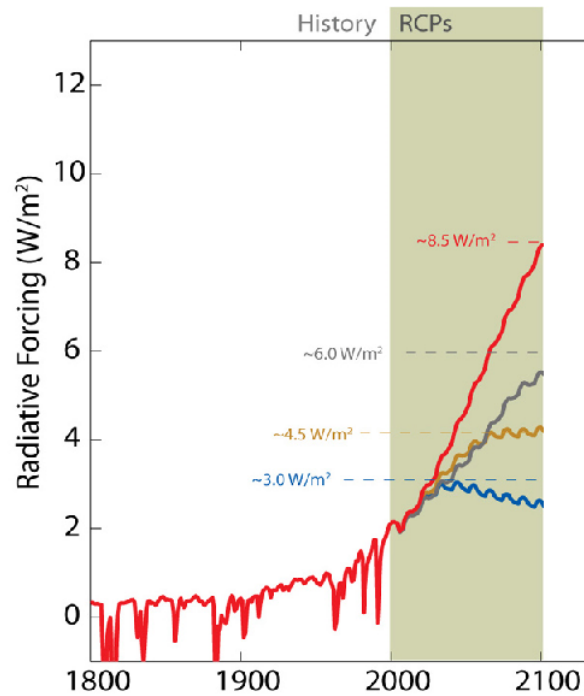
- Mikiko Kainuma
 - Brian O'Neill
 - John Reilly
 - Keywan Riahi
- Detlef van Vuuren

Integrated Earth System Models



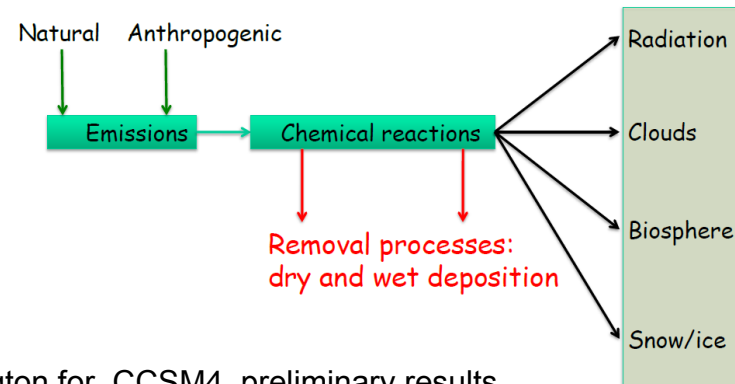
- **The idea of an iESM grows out of two lines of research:**
 - Climate modeling
 - Integrated assessment modeling
- **Climate modeling**
 - GCM (general circulation model)
 - AOGCM (atmosphere-ocean GCM)
 - ESM (Earth system model—an AOGCM + terrestrial processes)
 - iESM (an ESM + human system models)
- **Integrated assessment modeling**
 - IAMs—Sophisticated human Earth system modeling + reduced form ESM
 - iESM—IAM run inside a state-of-the-art ESM.

Traditional One-Way Coupling



GHG Emissions and Concentrations from IAMs

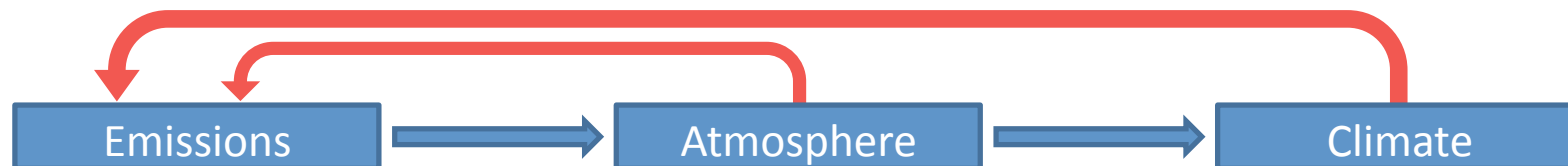
- Greenhouse gases: CO_2 , CH_4 , N_2O , CFCs, HFC's, PFC's, SF_6
- Emissions of chemically active gases: CO , NO_x , NH_3 , VOCs
- Derived GHG's: tropospheric O_3
- Emissions of aerosols: SO_2 , Black Carbon (BC), Organic Carbon (OC)
- Land use and land cover



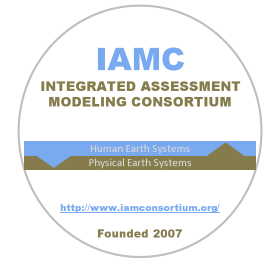
Thanks to Warren Washington for CCSM4 preliminary results.

Motivation

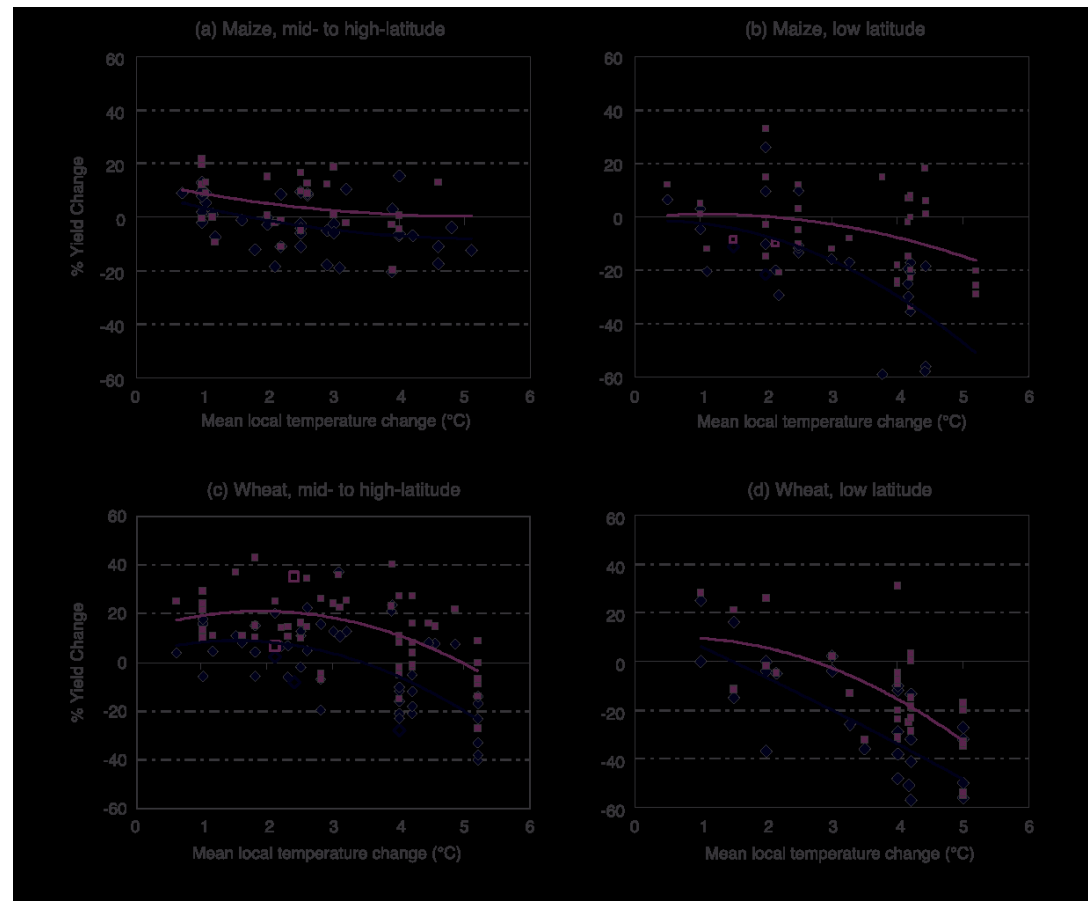
- ***In many IAMs, emissions mitigation analysis is undertaken under the assumption that the climate is not changing.*** E.g. crop yields are unchanged, water resources are unchanged, and energy systems don't have to cope with a changing climate.
- ***Most climate impacts analysis is undertaken with the assumption that no resources are being diverted to address climate change.*** E.g. no land is being used for carbon storage, no land is being used to grow bioenergy, and energy prices are unchanged.
- 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.



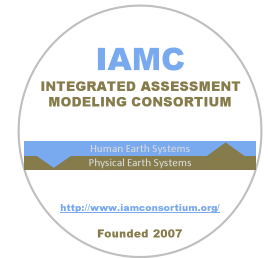
Why Might More Complete Linkage Be Different?



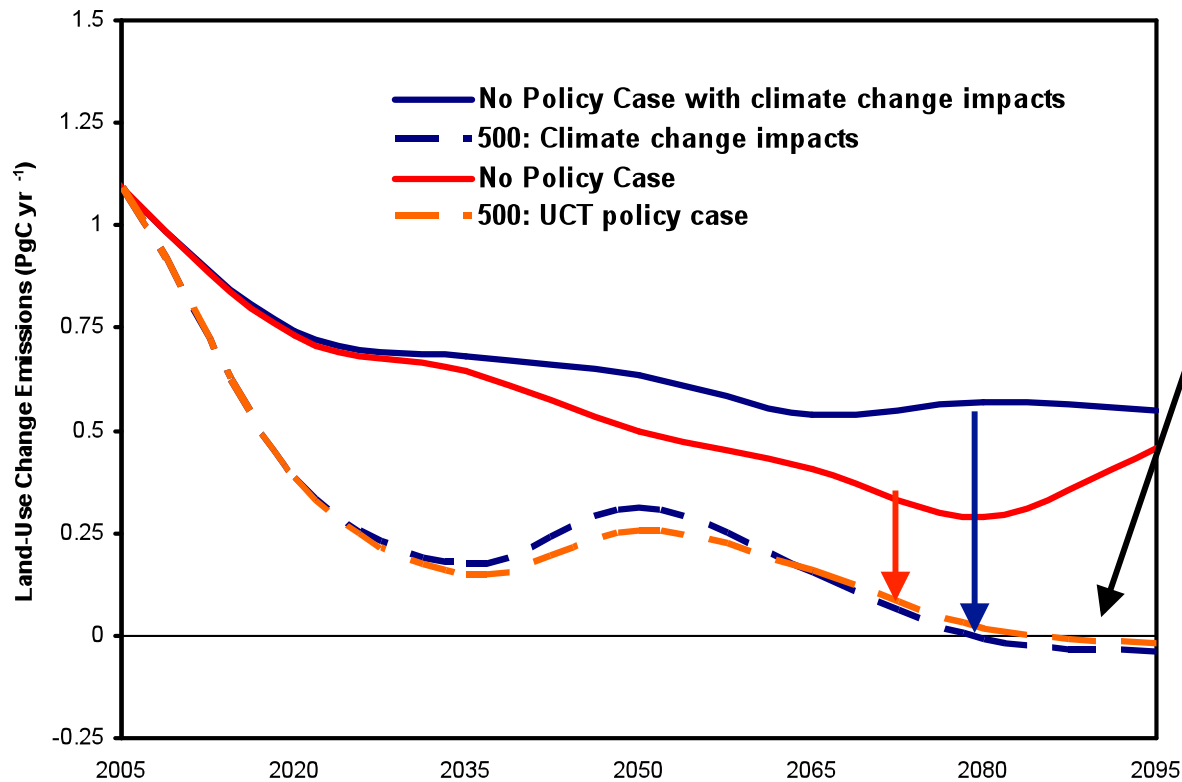
- An experiment with GCAM
- Two scenarios—reference and 550 ppm CO₂ stabilization.
- Climate feedbacks to crops based on IPCC AR4 WG2 process model numerical experiments.



Climate mitigation policies reduce future land-use change emissions

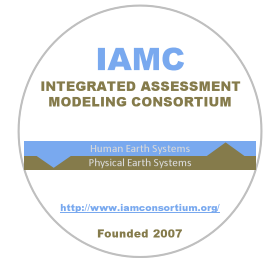


- Employed MAGICC-SENGEN to generate climate scenarios.



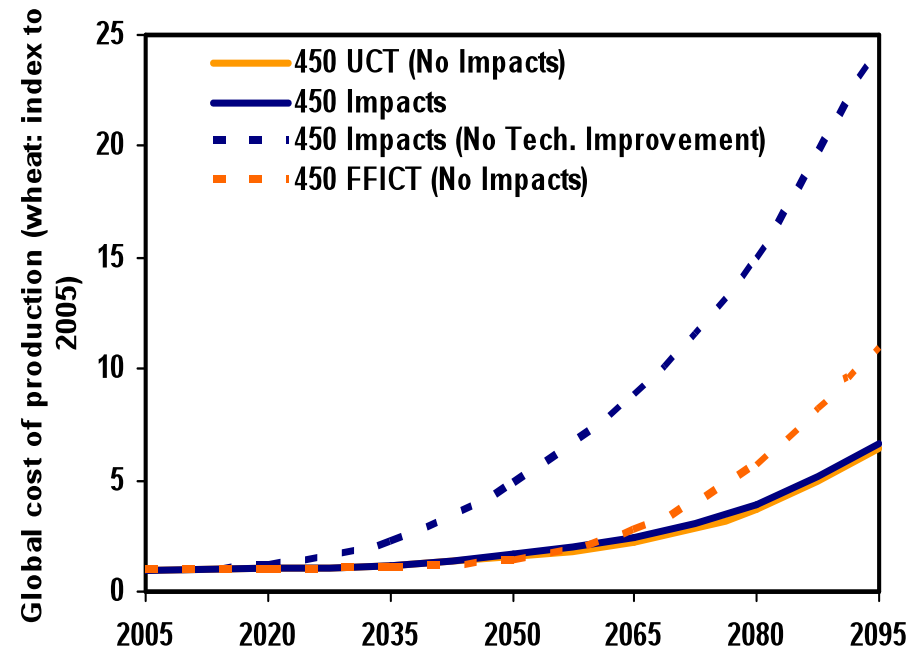
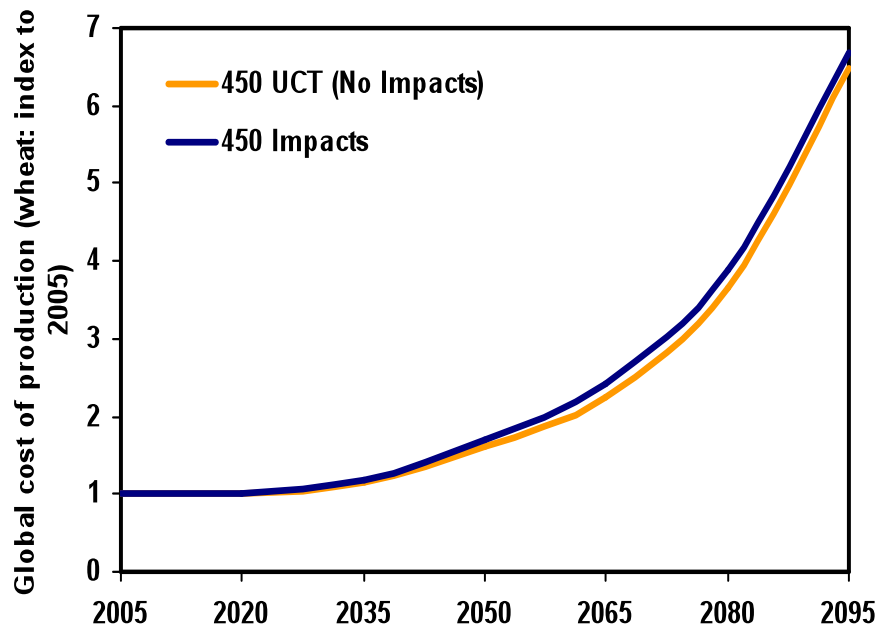
By 2095, ILUC emissions go negative with climate policy cases

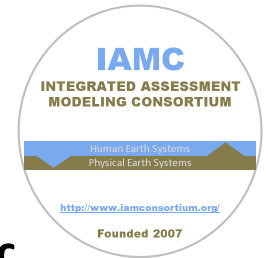
Global cost of food production



Climate impacts exert some upward pressure on crop price

That upward pressure is magnified if technology or carbon pricing achievements are not realized.



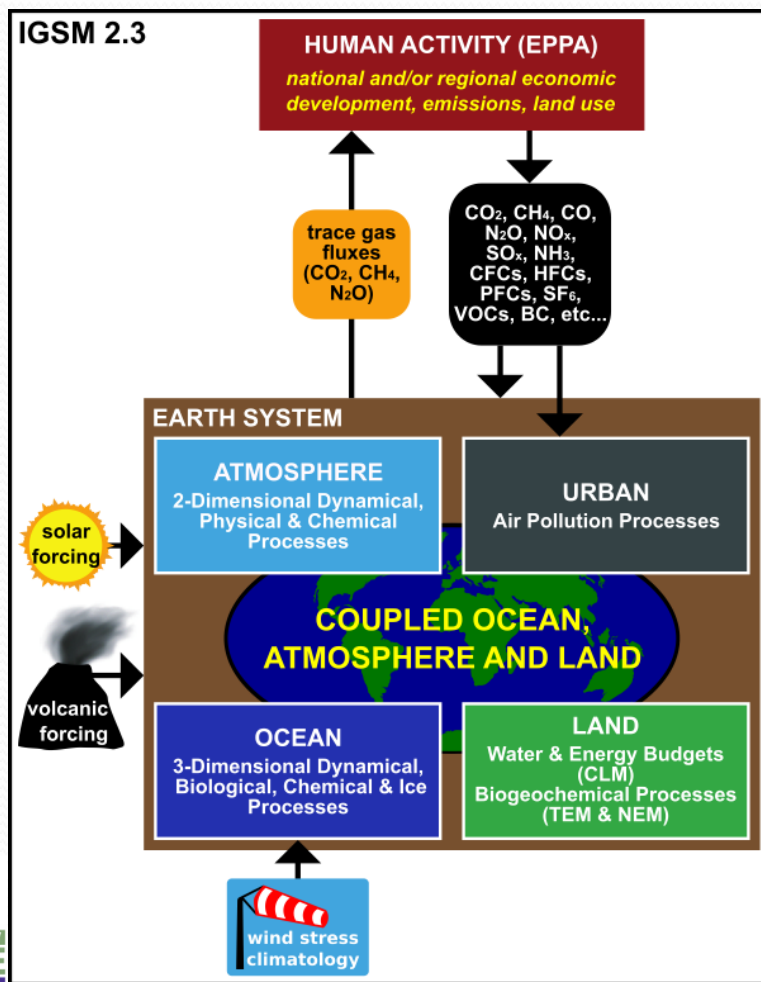


Work Going On In the Community

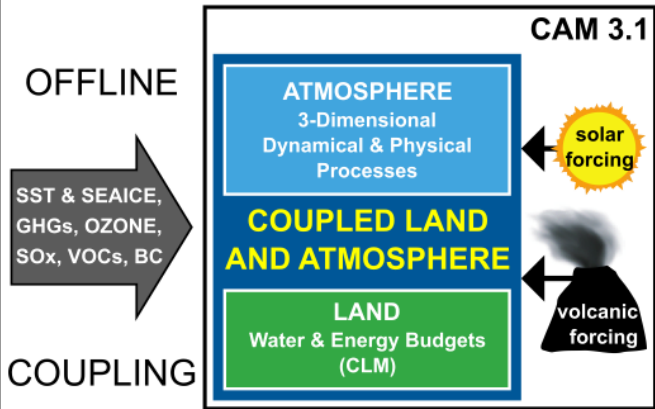
- **MIT-IGSM team**—working with National Center for Atmospheric Research (NCAR).
- **NCAR**—developing a project to link HD IA components to the CESM (Brian O’Neill).
- **PBL-IMAGE team**—working with Oak Ridge National Laboratory (ORNL); the Fr. CNRM-CM3 team; and European climate modelers.
- **IIASA MESSAGE team**—potentially developing a collaboration with the Goddard Institute for Space Studies (GISS).
- **PNNL-GCAM team**—working with the Lawrence Berkeley National Laboratory (LBNL) and ORNL.

IGSM Framework with 3-D Climate Capabilities

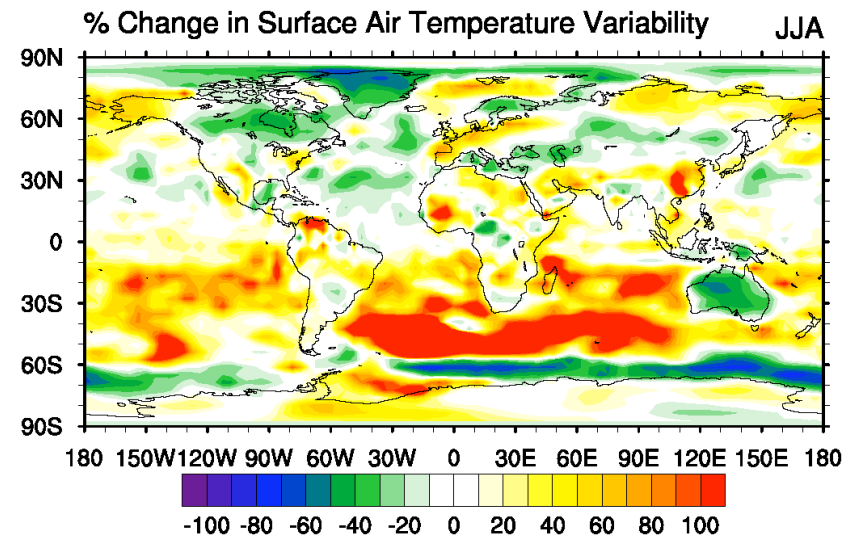
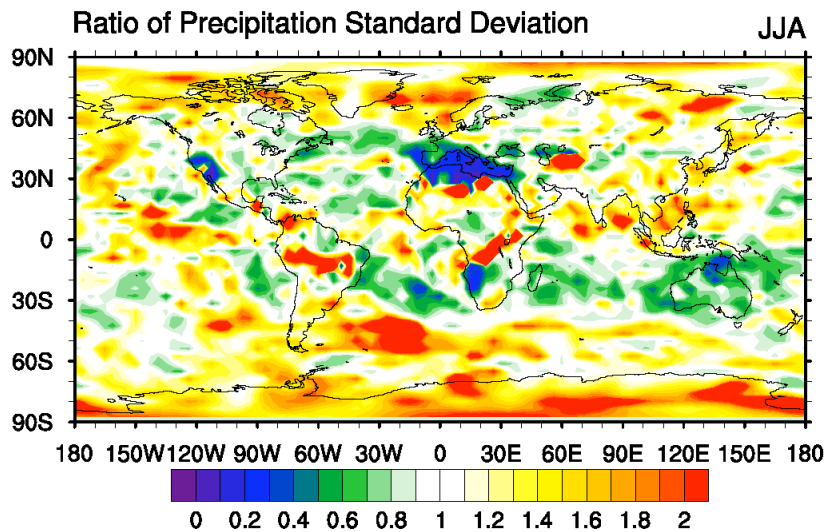
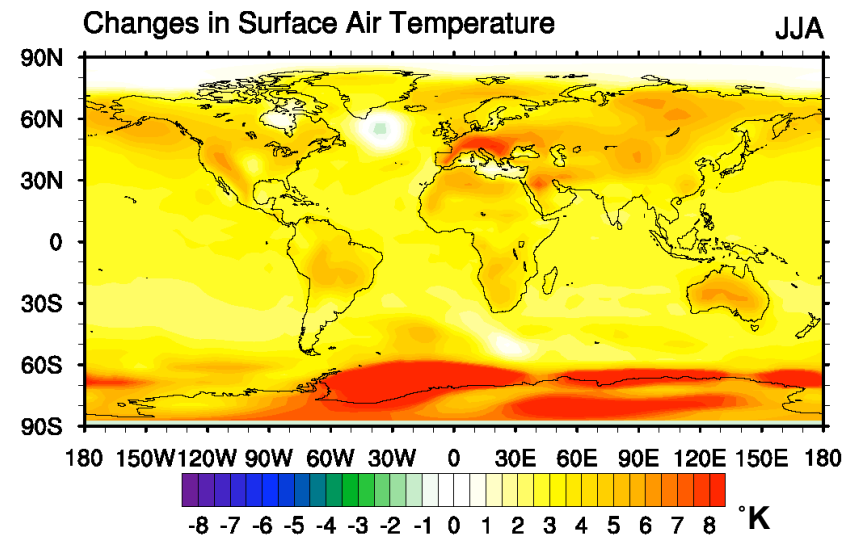
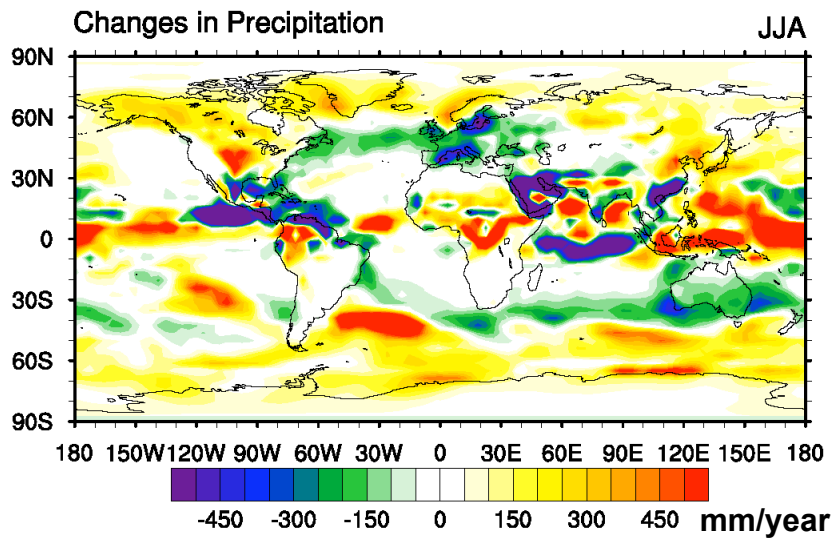
CAM is the atmosphere-climate component of CCSM4=CESM1



- Two Simulation modes with the Community Atmospheric Model (CAM):**
- CAM with mixed-layer, slab ocean model
 - CAM forced with IGSM2.3 SSTs, sea-ice, and trace gas concentrations.



No Policy Response of CAM-IGSM

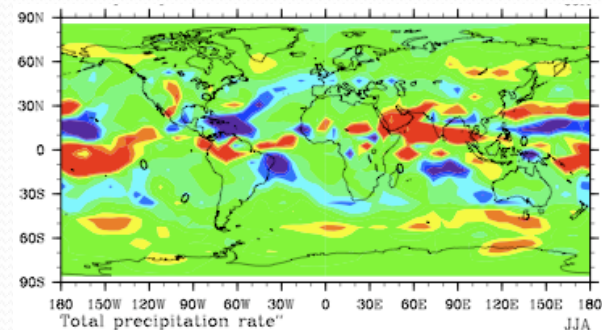
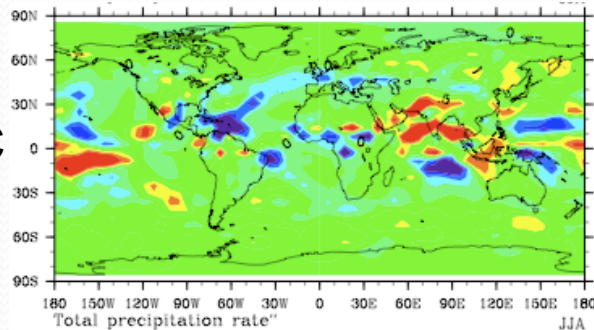


Change in JJA Decadal Average Precipitation (mm/day) End of 21st Century Minus End of 20th Century

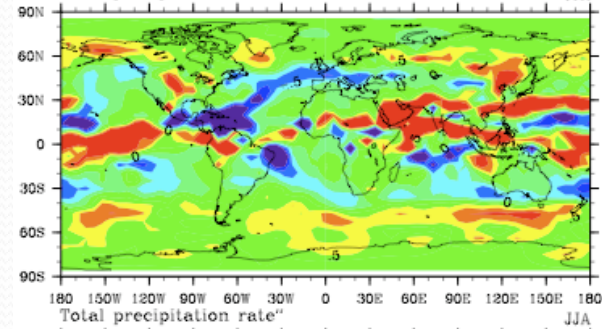
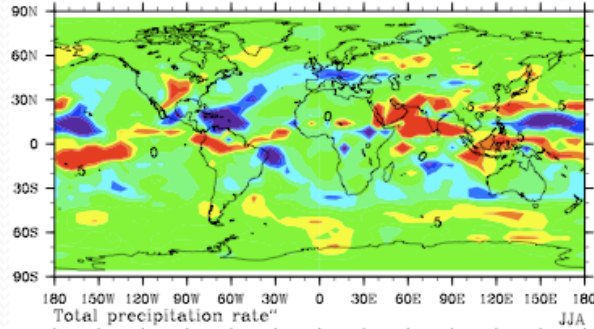
Level 1 Stabilization

No Policy

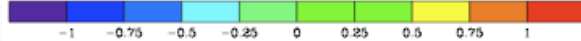
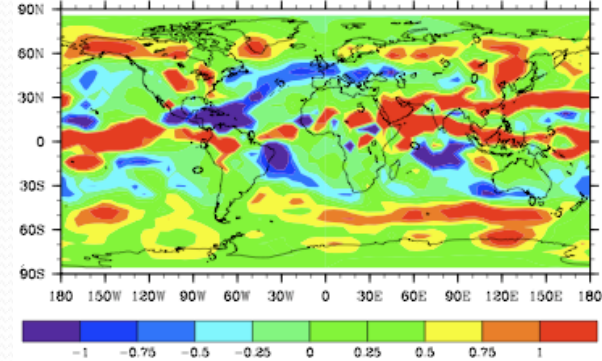
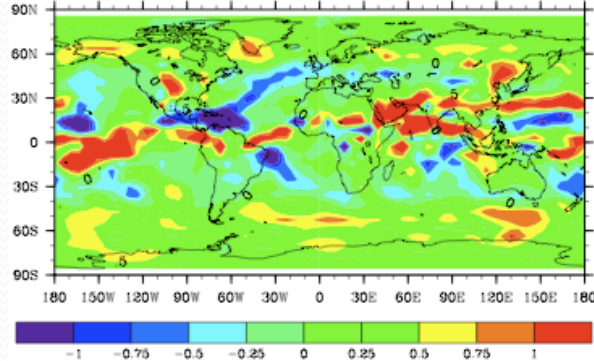
$C_s = 1.7^\circ\text{C}$



$C_s = 2.6^\circ\text{C}$



$C_s = 4.2^\circ\text{C}$



PBL Activities



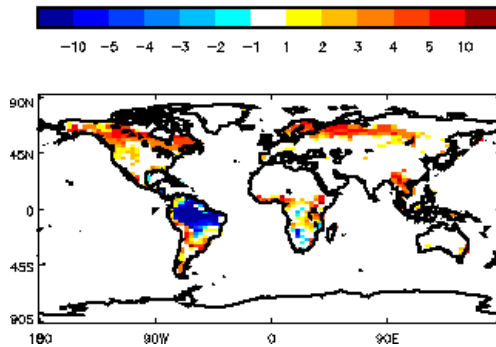
- Climate impacts (crop yields, carbon cycle, vegetation) included in IMAGE itself via MAGICC+pattern scaling
- IMAGE land use module has already been integrated into the French GCM (CNRM-CM3).
- COMBINE project: explore feedbacks via soft links with 10 European climate modeling teams, e.g. Hadley, Max Plank.
- Developing an interface between IMAGE and the Community Land Model (CLM)—a collaboration with the ORNL.
- Collaboration to develop soft and hard links with the EC Earth ESM (Netherlands).



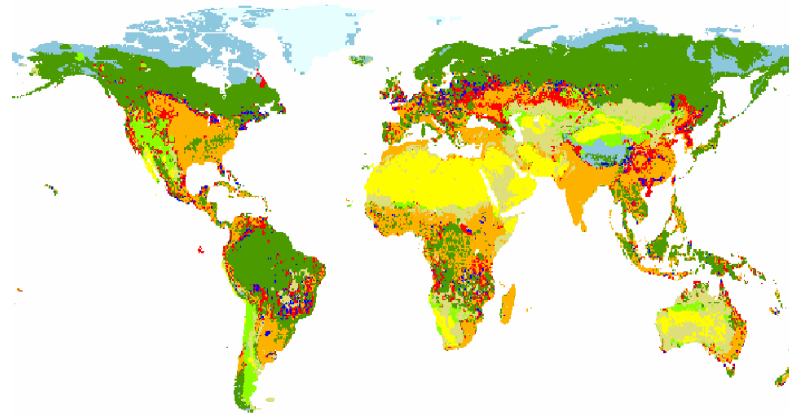
EC-Earth IMAGE project



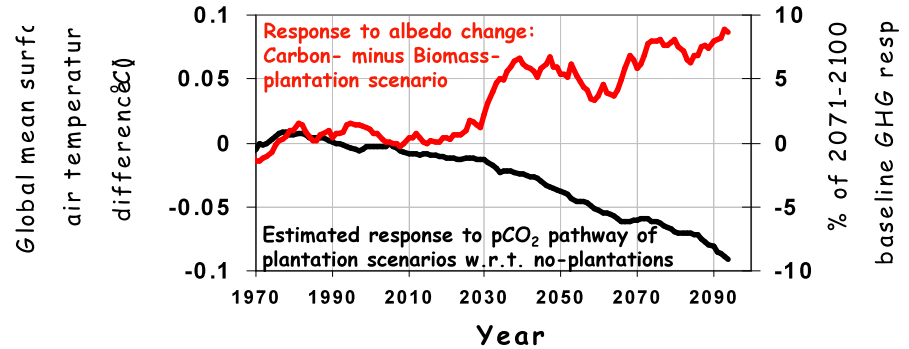
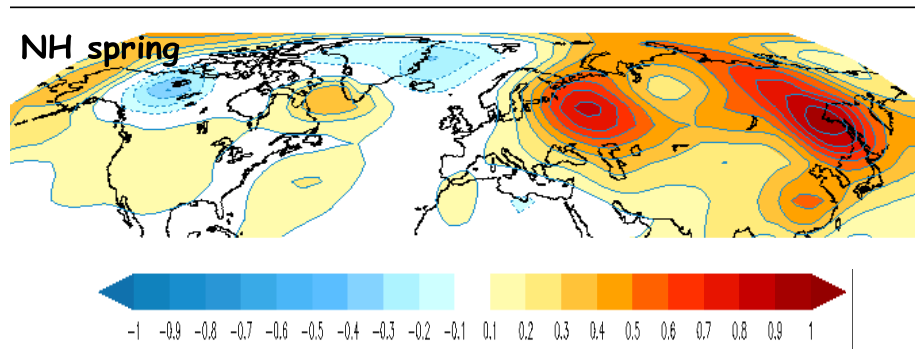
Land use consistent with temperature?



Cox et al. [2000].

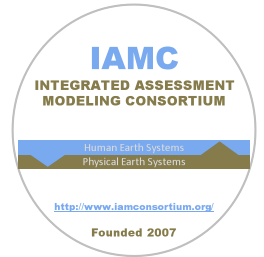


Impact of processes (Albedo) not taken into account in IMAGE



Schaeffer et al

The PNNL, ORNL and LBNL iESM Collaboration



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



Approach

▶ Four state of the art modeling systems:

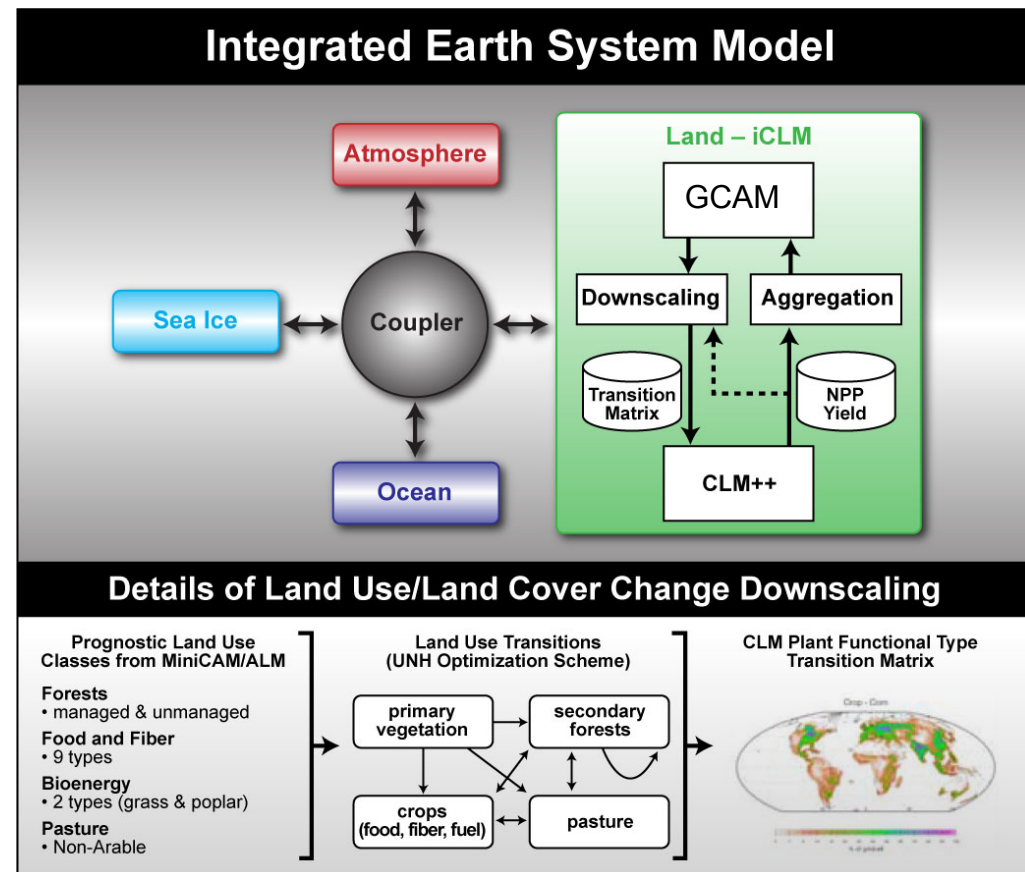
▶ **GCAM1**

▶ **CLM4**

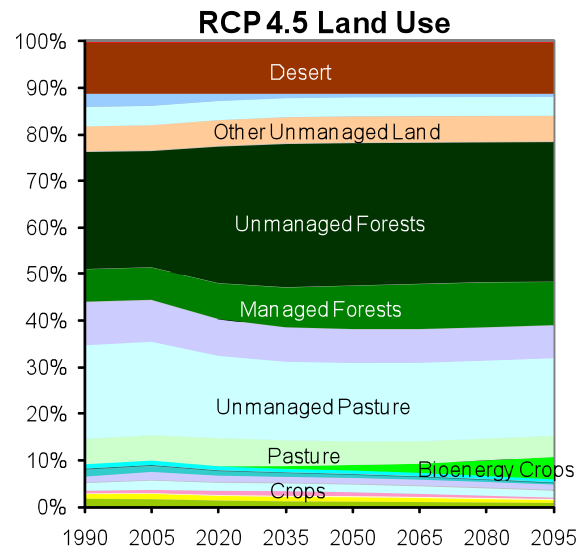
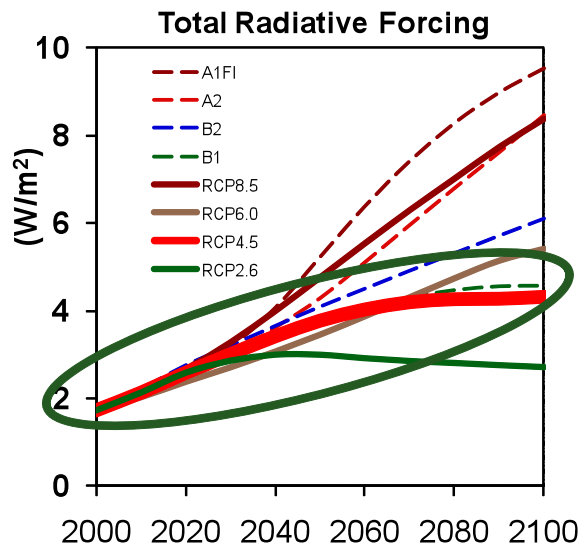
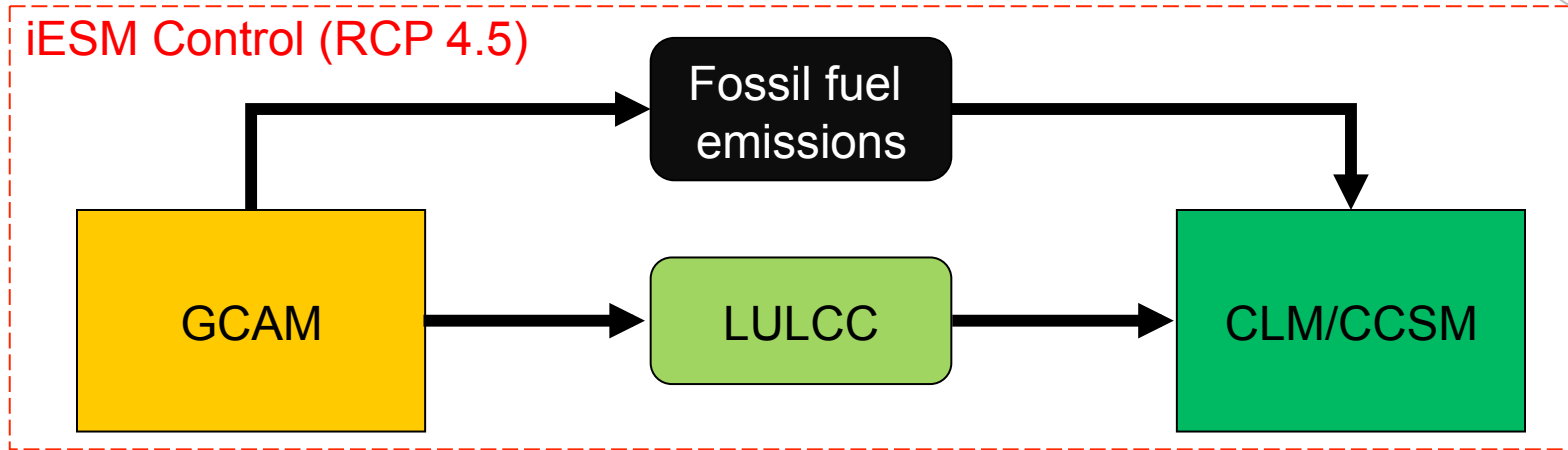
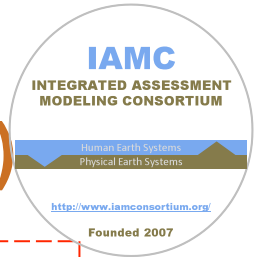
▶ **GLM1**

▶ **CCSM4**

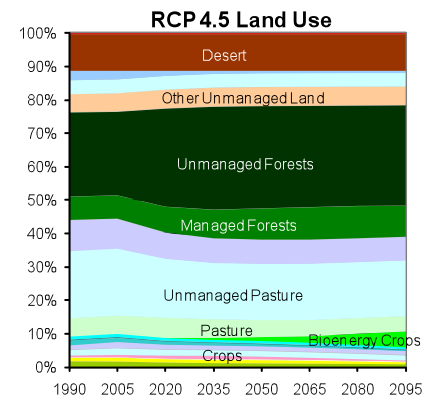
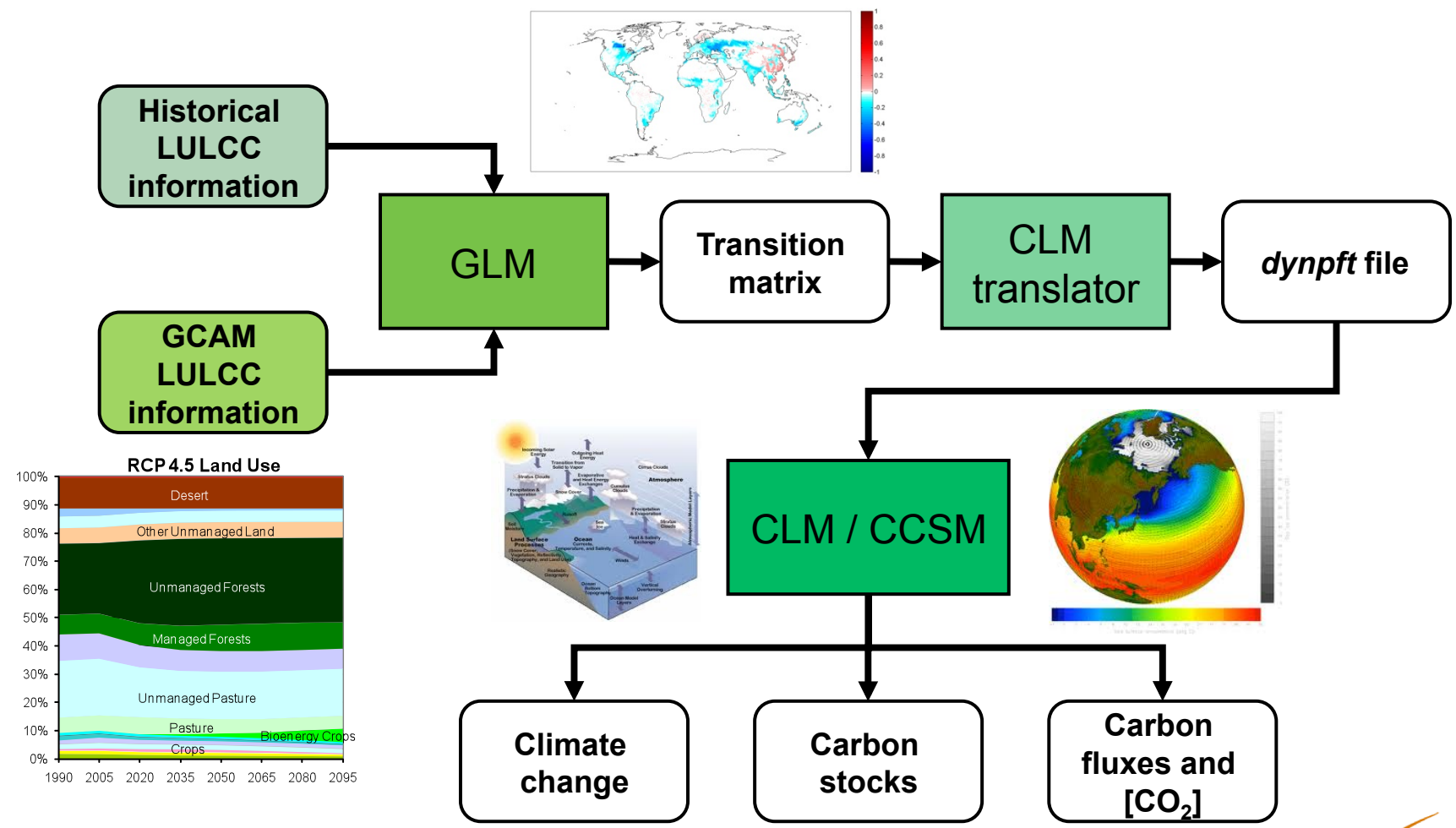
▶ Run inside
CCSM4
(CESM1)



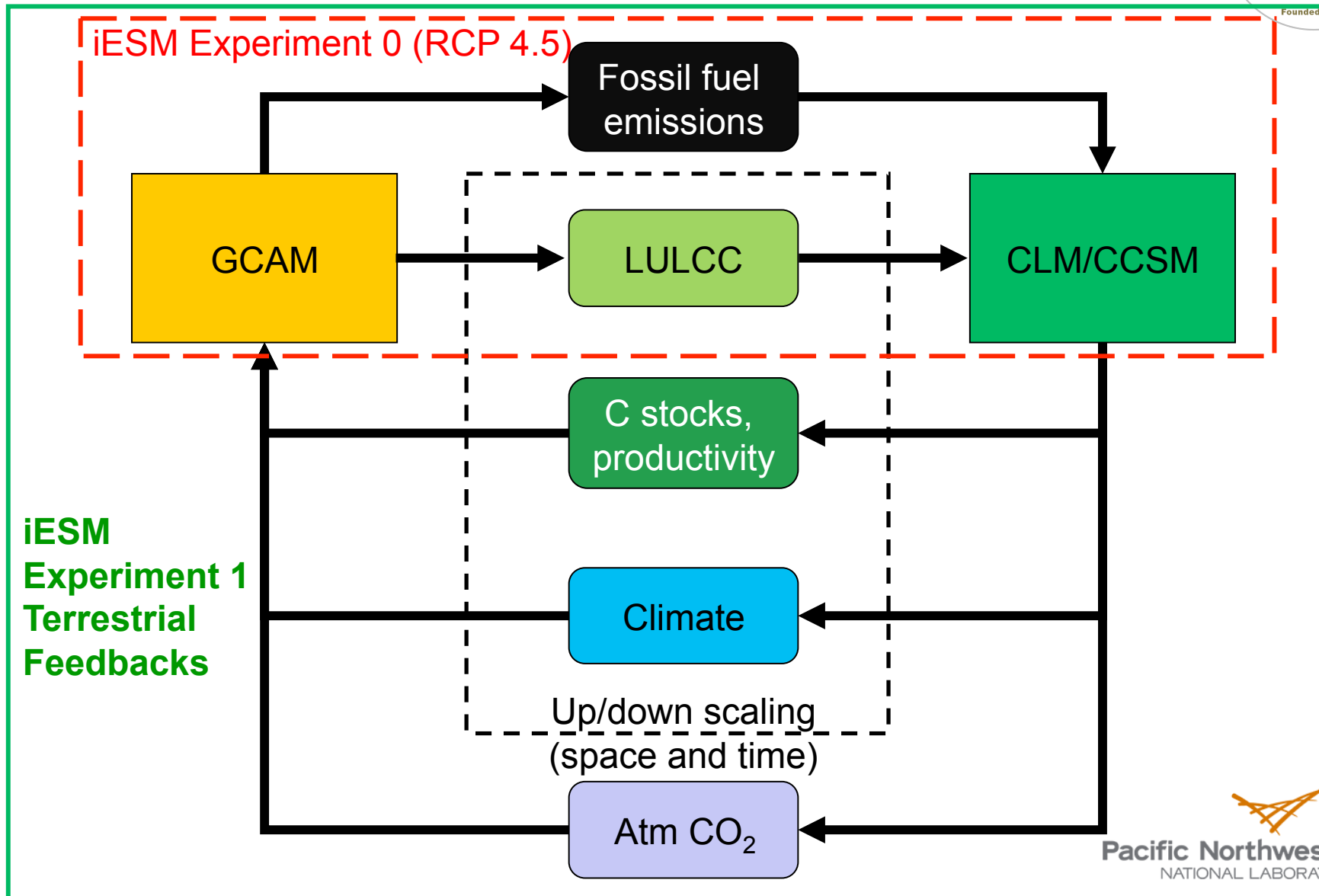
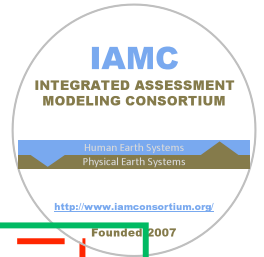
iESM Experiment 0: Traditional One Way Coupling, but Endogenous to CCSM4 (ESM1)

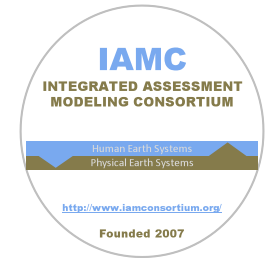


THE CLM: Initial One-way Coupling: LAND USE AND LAND COVER CHANGE (iESM Control experiment)



iESM multi-phase coupling strategy





Time Line for the First Two Experiments

- ▶ Present State of Development—All models running within CCSM4.
- ▶ January 1—Experiment 0
- ▶ March 31—Experiment 1

DISCUSSION