

The Future of Integrated Assessment Modeling

JAE EDMONDS

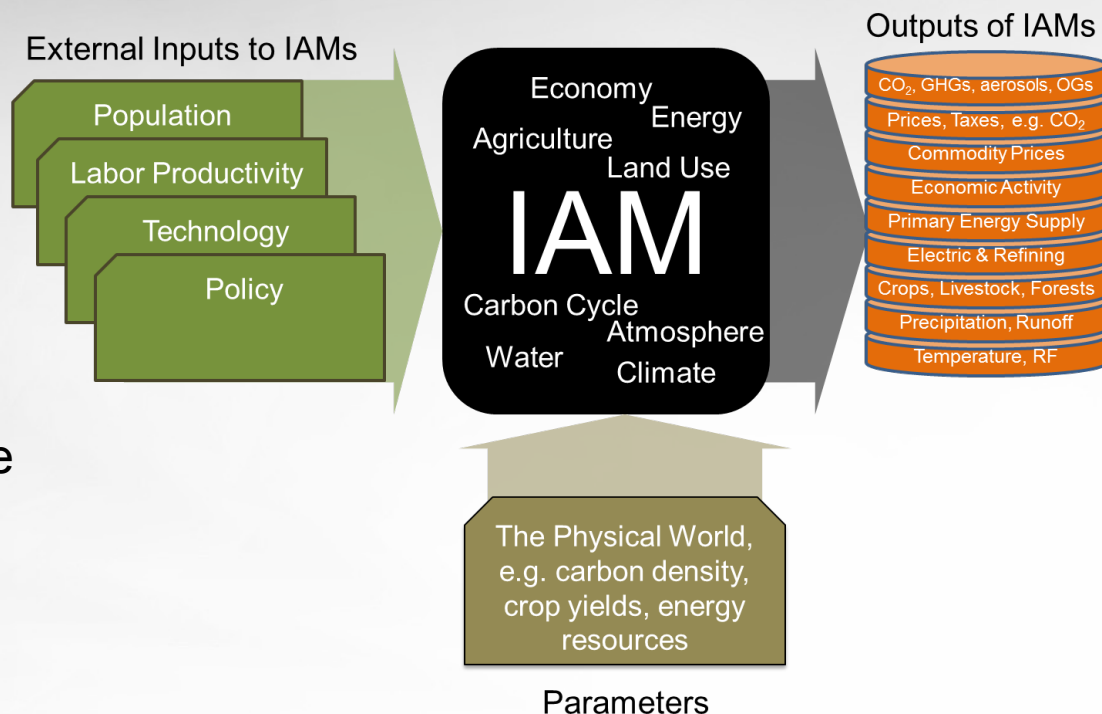
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Integrated Assessment Models (IAMs)

IAMs integrate human and physical Earth system climate science.

- IAMs capture interactions between complex and highly nonlinear systems. IAMs provide insights that would be otherwise unavailable from disciplinary research.
- IAMs provide other climate scientists with information about human systems such as GHG emissions, land use and land cover, but increasingly other features such as demographics, technology, and income.



IAMs provide science-based decision support tools.

- IAMs support national, international, regional, and private-sector decisions.

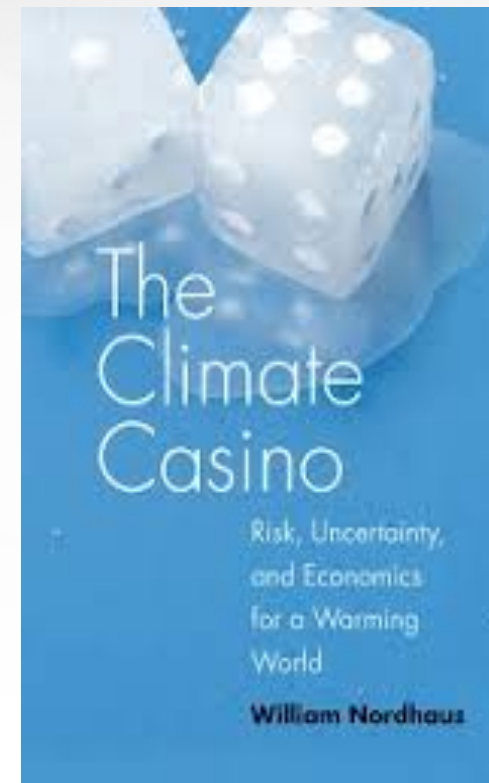


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IAMs come in three sizes: DICE, Medium and RCP-class

- ▶ DICE Class models are highly aggregated, have a relatively small number of equations, and were originally built to address climate change as a cost-benefit problem.



RCP-class

► RCP-class models were built to better understand human-system interactions with the larger biogeophysical and biogeochemical world.

- Provide all of the information that state-of-the-art physical Earth system models need as drivers (GHGs, SLS, LU, LC).
- They are built by interdisciplinary teams and contained detailed process representation of the physical world, e.g. water balance model, graded wind resources, population distribution, buildings, etc.
- Physical system models that range from simple highly parameterized models such as MAGICC to state-of-the-art Earth system models such as CESM.
- Explicit representations of technologies.
- They have been the workhorses for community scenario development and analysis of emissions mitigation.
- Beginning to incorporate climate impacts and adaptation for specific systems, e.g. agriculture, water, forestry, buildings energy.

RCP-Class Models

AIM

Asia Integrated Model



GCAM

Global Change Assessment
Model



IGSM

Integrated Global System Model



IMAGE

The Integrated Model to Assess
the Global Environment



MESSAGE

Model for Energy Supply
Strategy Alternatives and their
General Environmental Impact



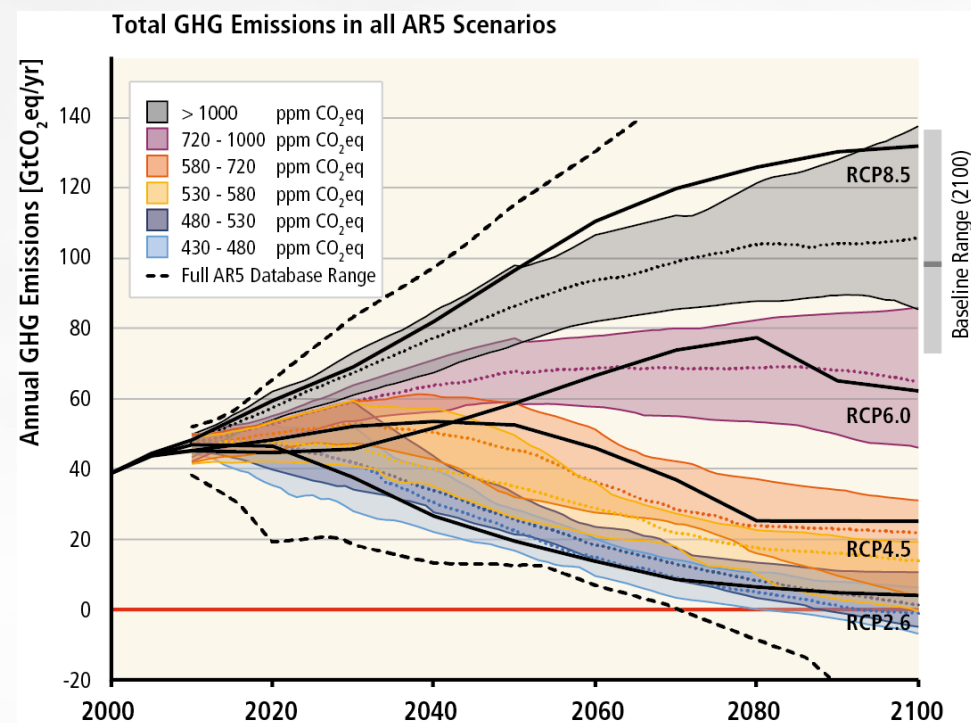
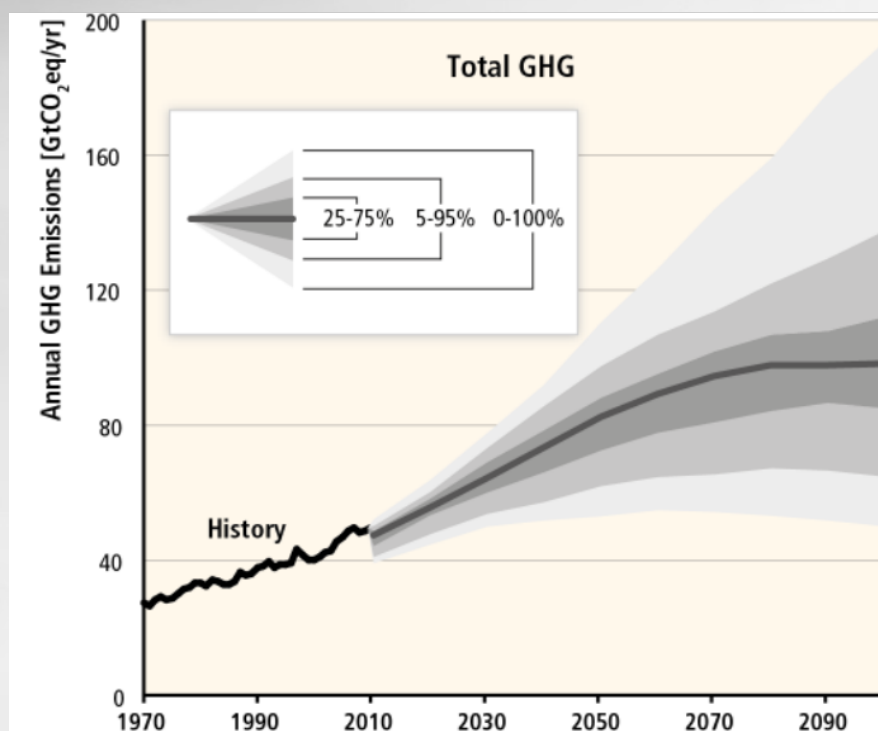
REMIND

Regionalized Model of
Investments and Technological
Development

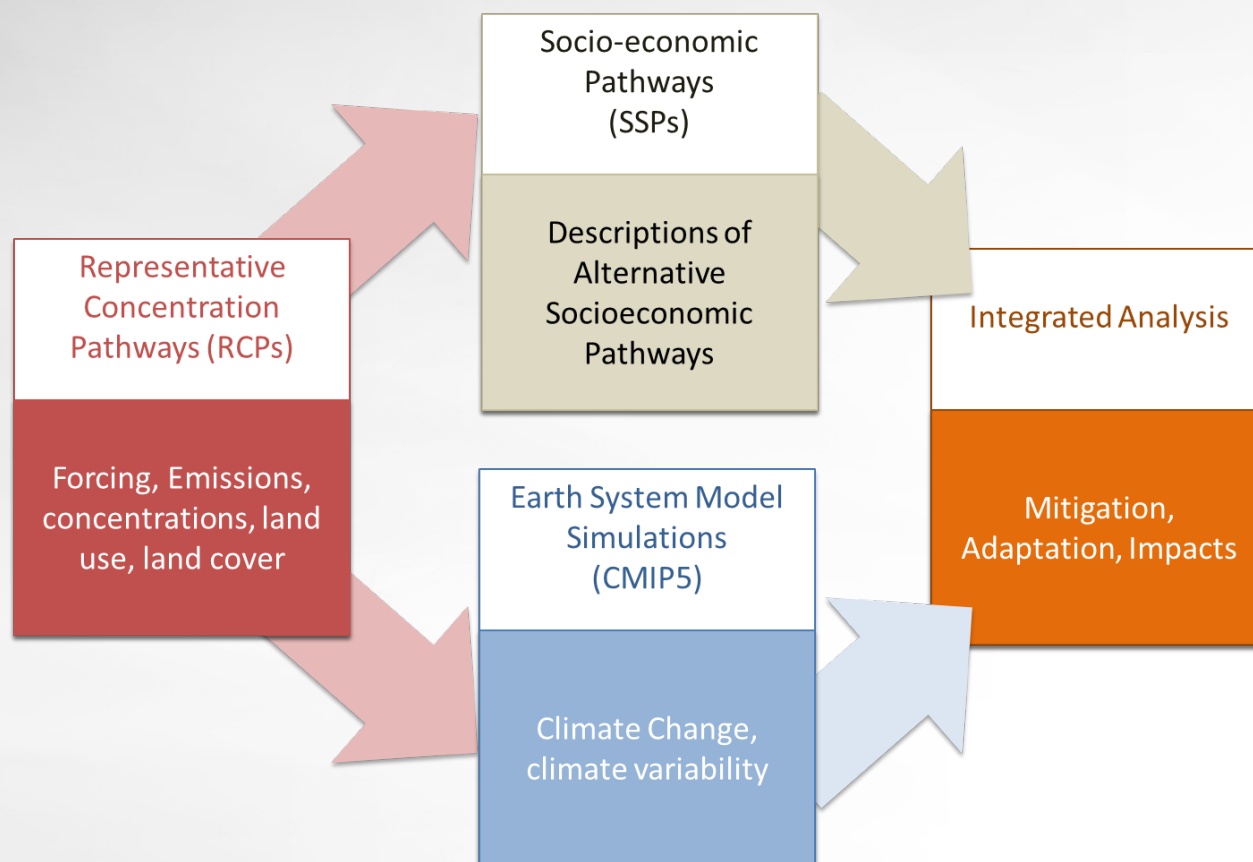


A traditional role of IAMs has been a source of information about anthropogenic emissions and emissions mitigation

Global GHG Emissions

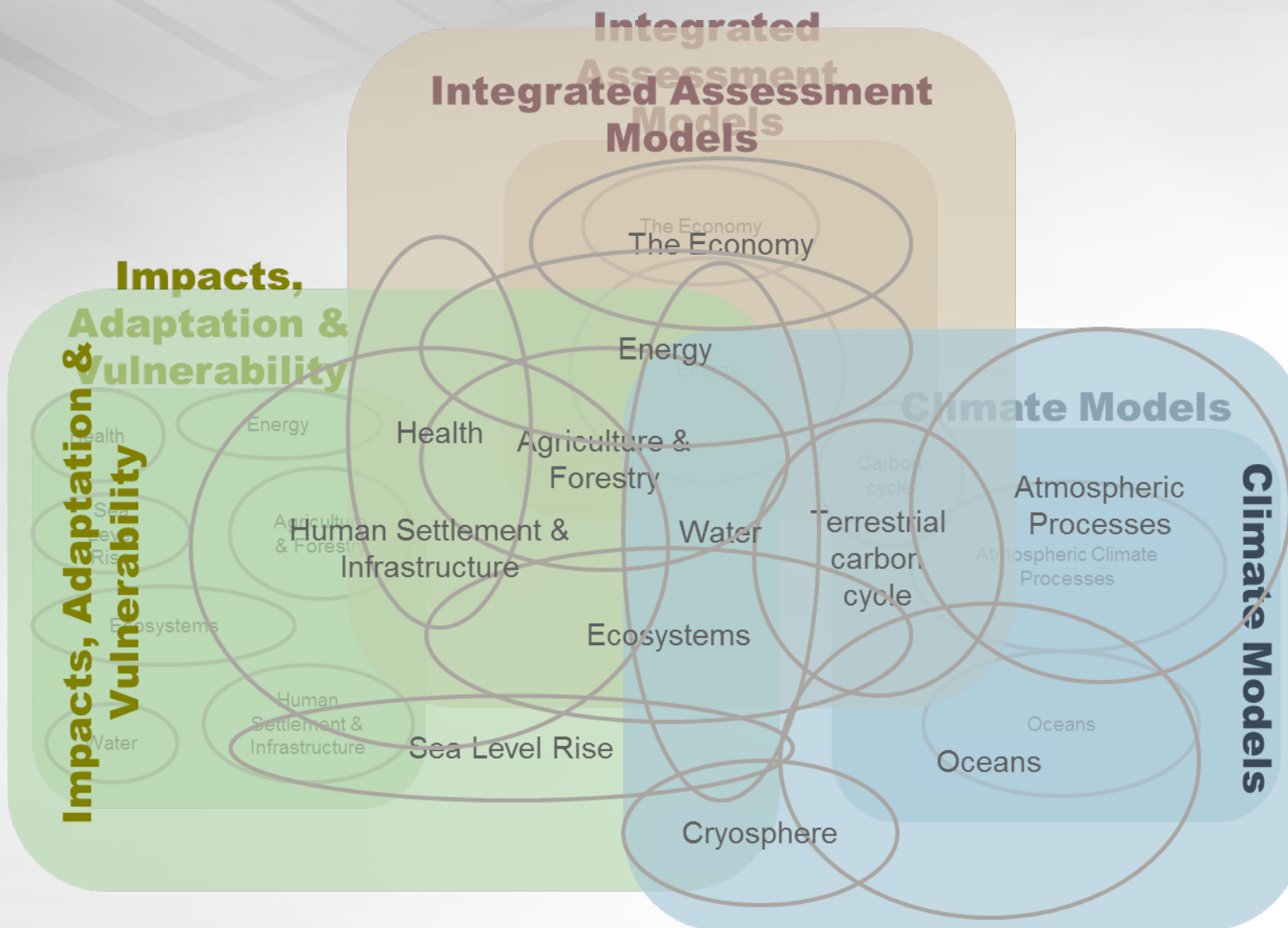


But IAMs are moving to provide information to a broader climate science community with 5 new reference scenarios designed around the needs of the IAV community—and much of it designed here at the AGCI



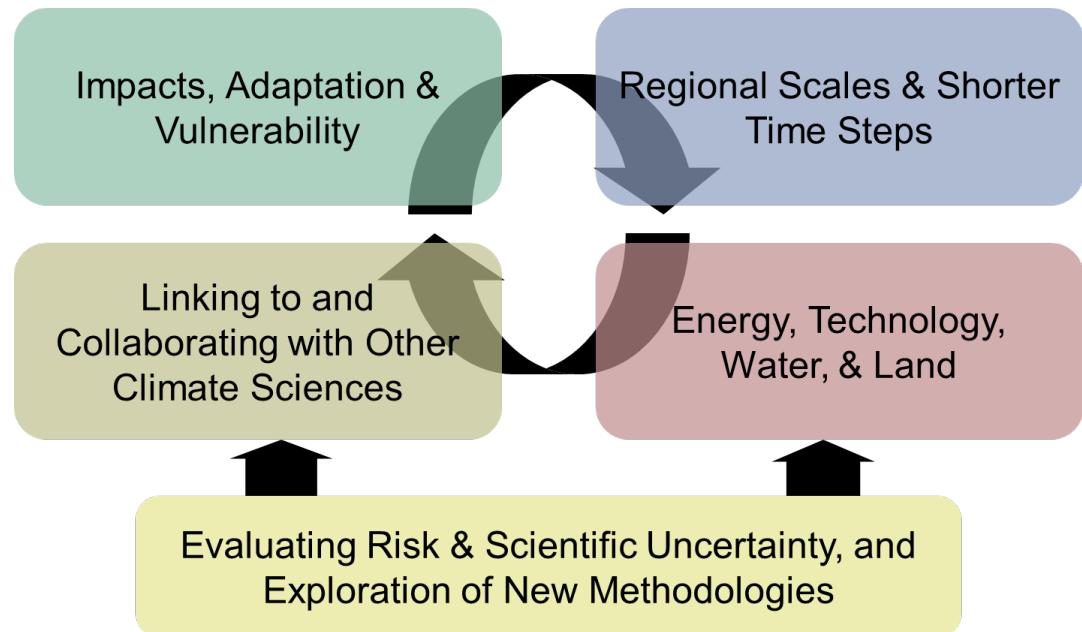
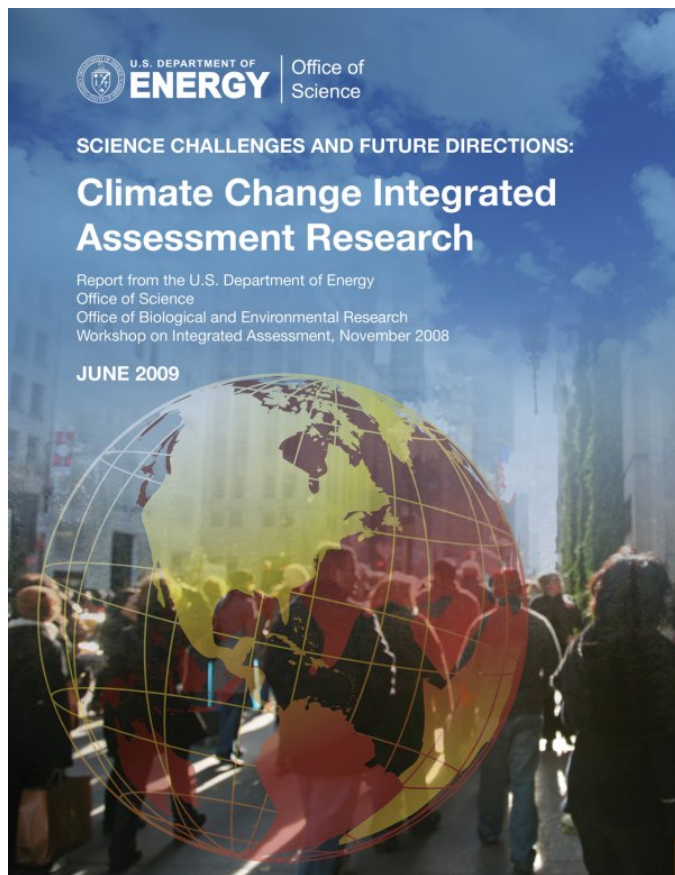
After Moss, Edmonds, et al. (2010)

Growing overlap in climate research communities



IAMs are moving to address new problems

U.S. emphasis on five themes



Many of the cutting edge developments for IAMs feature advances in more than one of these domains.



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GCAM'S FUTURE DIRECTIONS

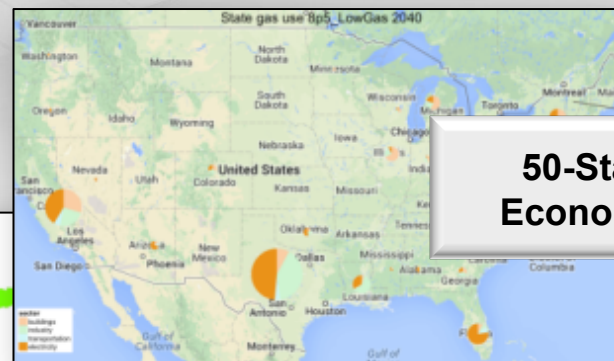
GCAM Is Rapidly Evolving

GCAM has evolved to become a modeling system with multiple interoperable modules, temporal and spatial scales, and modes of application in response to evolving challenges.

Tackling new problems such as **climate impacts on the **energy-water-land nexus** means that GCAM has evolved to:**

- ▶ **Employ high-resolution data inputs,**
- ▶ **Reconcile and transform data to appropriate analytical scales,**
- ▶ **Employ interoperable modules and models, and**
- ▶ **Produce output products, at appropriate space, time, sectoral, and technological resolutions.**

GCAM is a Multi-scale Model With Adaptive Resolution

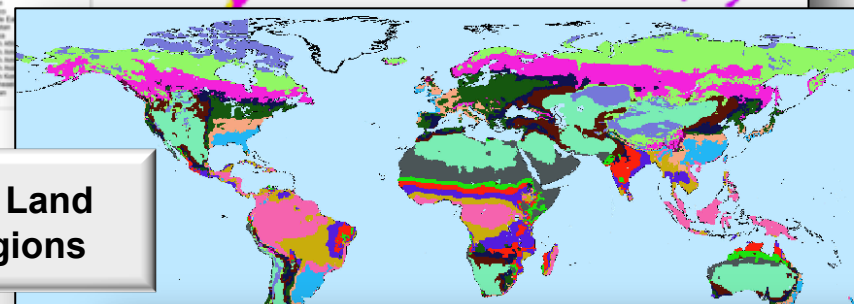


**50-State Energy
Economy Regions**

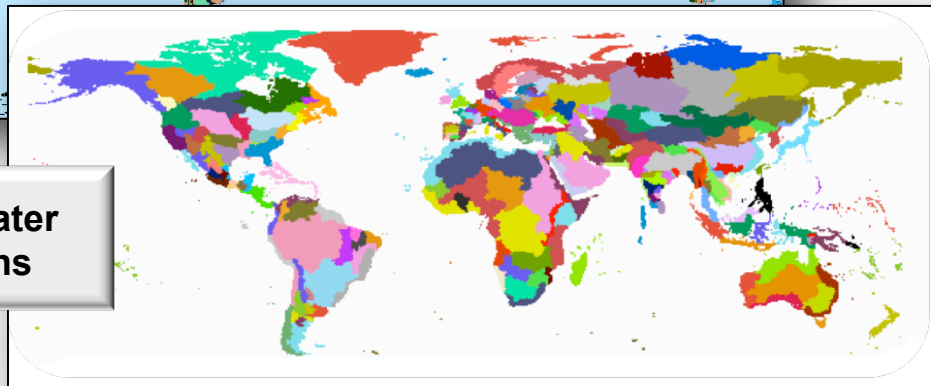
**32 Energy
Economy
Regions**



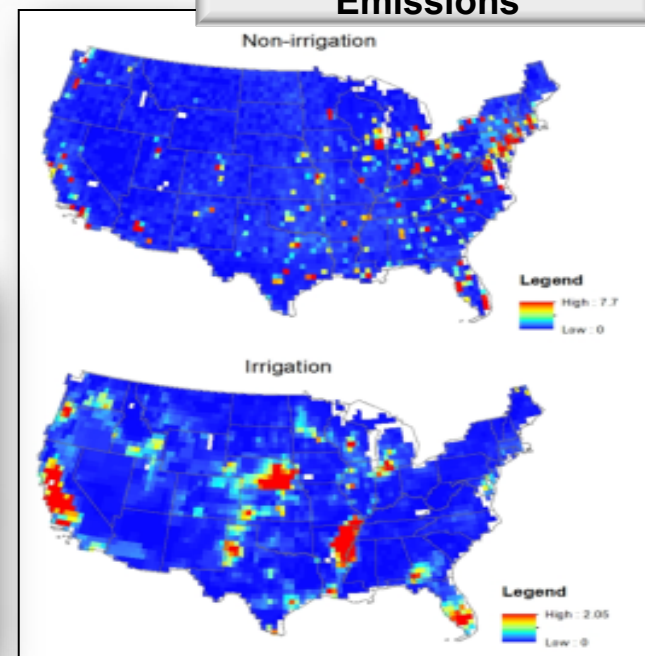
**283 Land
Regions**



**233 Water
Basins**



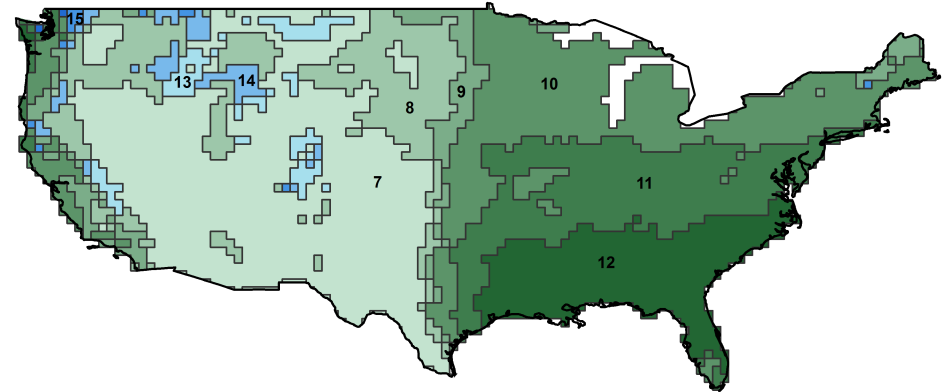
**Grid-Level Water,
Energy, Land, and
Emissions**



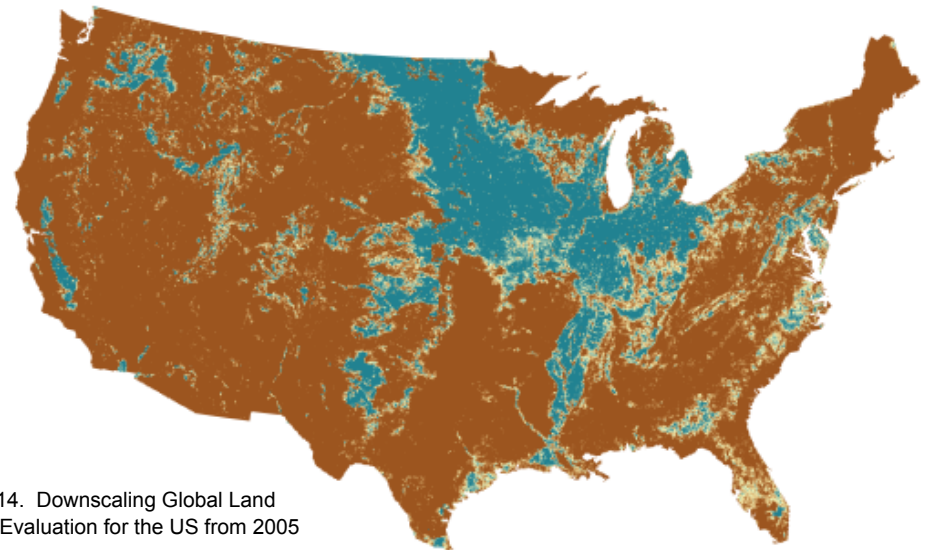
GCAM land cover decisions occur at 283 region resolution, but results are available at 0.05° resolution

- ▶ Economic decisions about land are made at a 283 region resolution globally (9 regions in the USA).
- ▶ However, land cover data is output at 0.05° x 0.05° resolution.
- ▶ Transition from economic regions to spatial scale considers factors like proximity to existing agricultural areas and conversion types.
- ▶ We are expanding this modeling to include land suitability and protected lands.

9 AgLU Economic Regions in the USA



Cropland area in 2005 at a 0.05° Resolution





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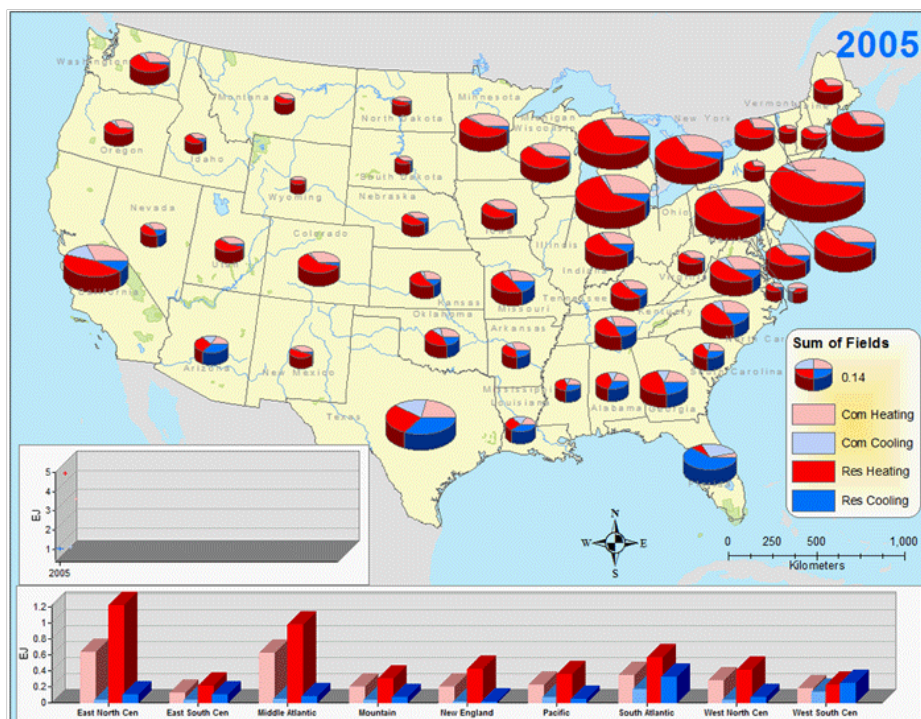
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GCAM ENERGY, AGRICULTURE AND LAND USE

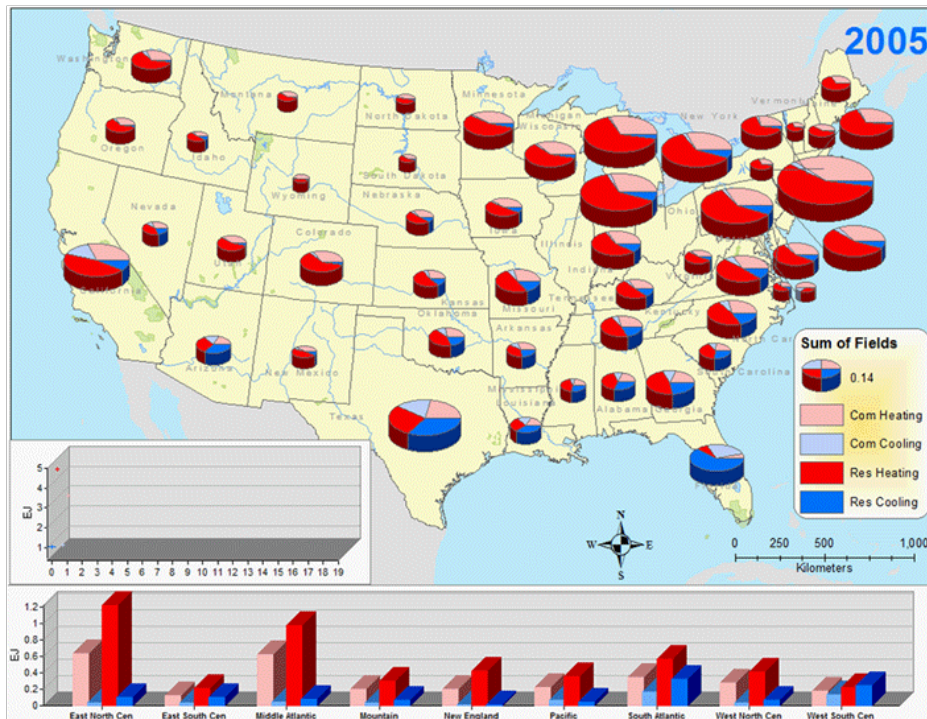
Regional and 'Local' Climate Change Feedbacks on Energy

Climate Impacts on Building Energy Use

Fixed Climate



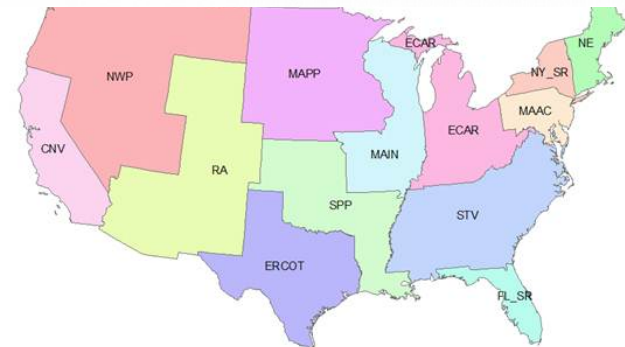
A2 Climate



Source: Zhou Y, L Clarke, J Eom, G Kyle, P Patel, S Kim, J Dirks, E Jensen, Y Liu, J Rice, L Schmidt, T Seiple. 2013. "Modeling U.S. State Building Energy Use and Climate Change Impact." *Applied Energy* 113:1077-1088 .

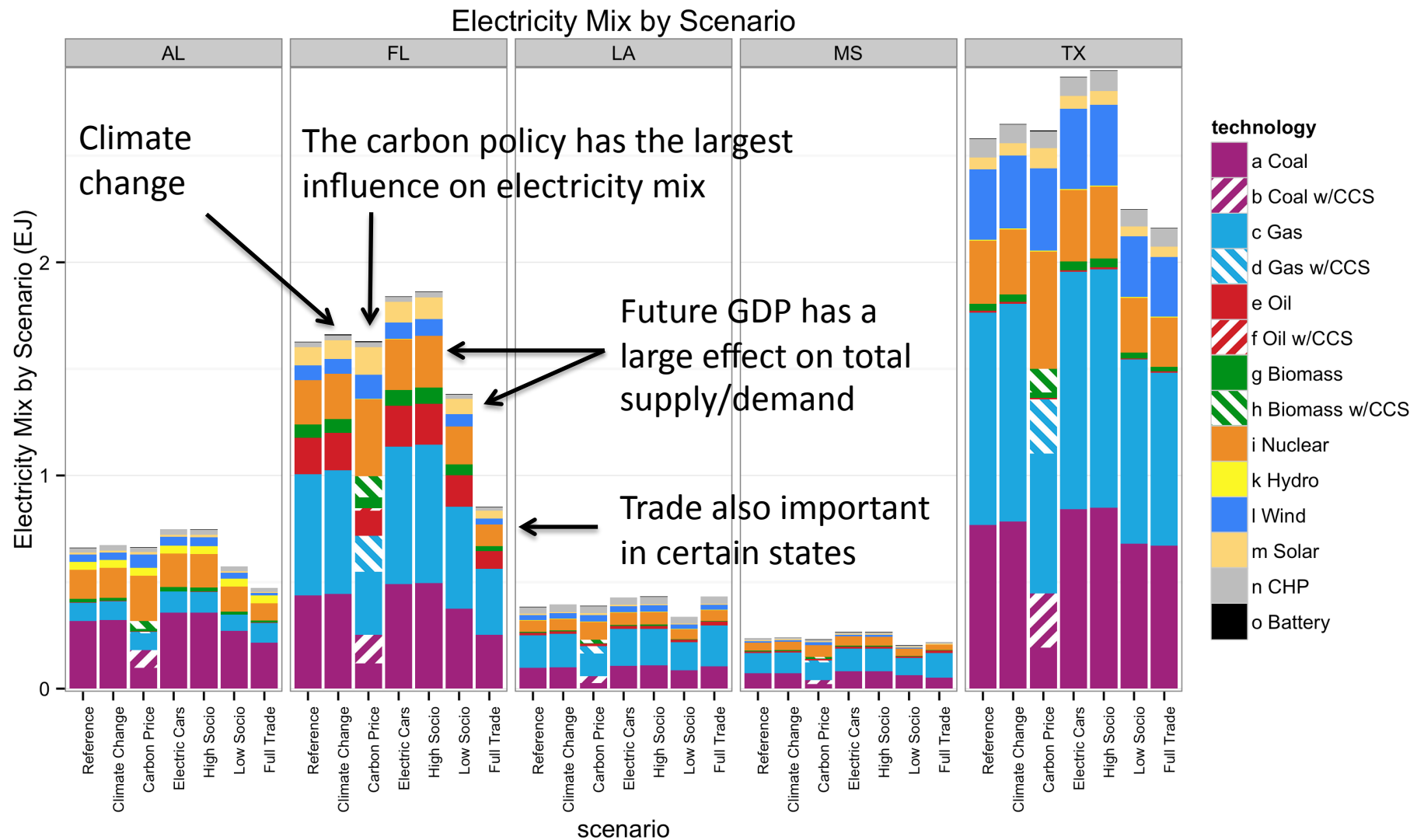
GCAM now examines state-level issues and interactions, all set in the larger global context

- ▶ Every state produces and consumes electricity according to the usual drivers (population, GDP, technology, etc.)
- ▶ There is a set of regional markets based on NEMS, and states can trade electricity within their markets
- ▶ Trade between markets can be fixed at base year levels or loosened up to roughly approximate the effects of increased transmission capacity, market changes, etc.
- ▶ GCAM still provides additional global constraints and context



GCAM-USA Electricity: Results

2050 Electricity supply mix in Gulf Coast states



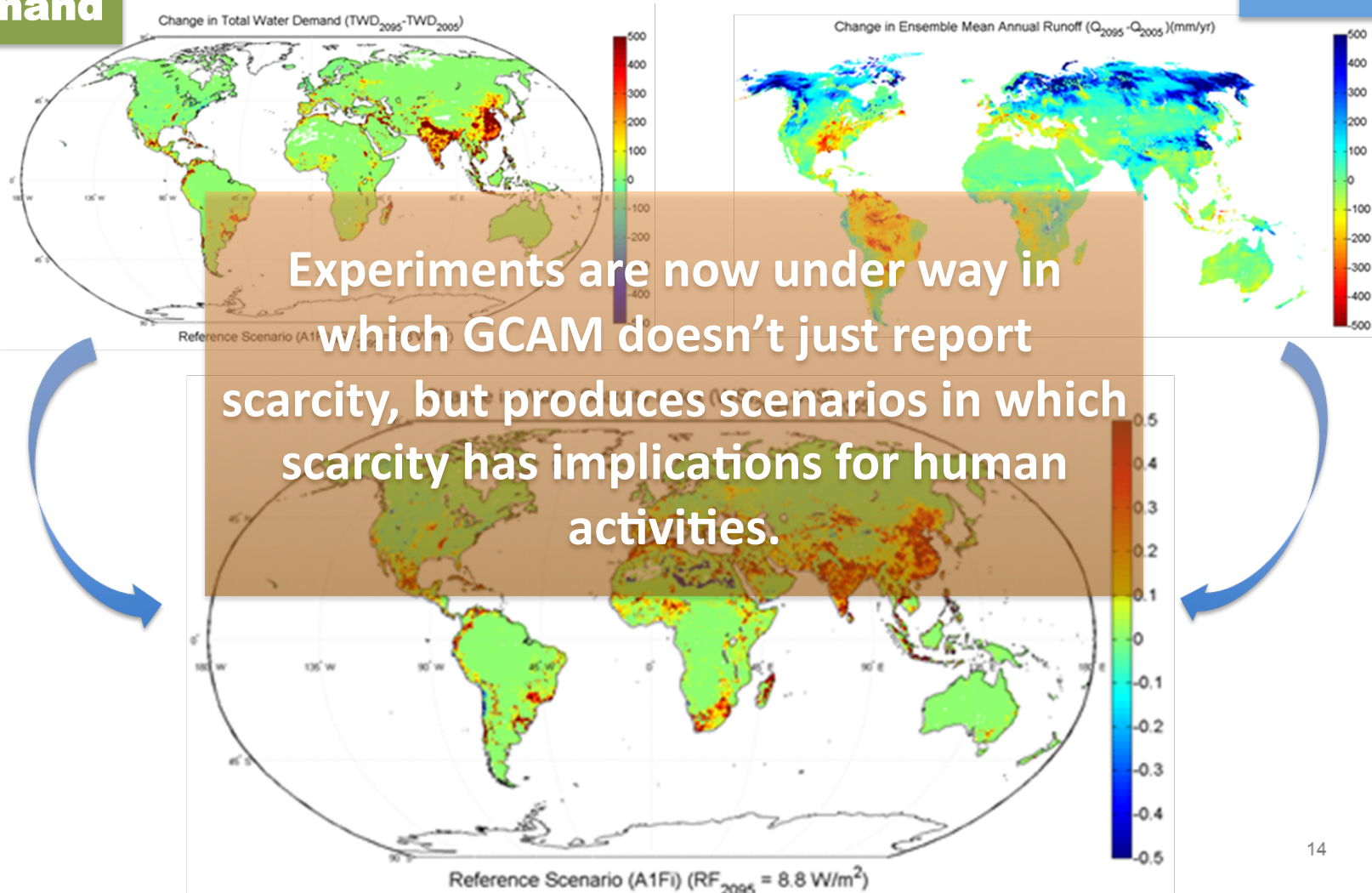
Hydrology using climate model outputs to assess stream-flow, river routing, and river management to assess energy system impacts

GCAM ENERGY, LAND AND WATER

How do growing demands & changes in water supply from climate change affect water scarcity?

Δ Demand

Δ Runoff



14

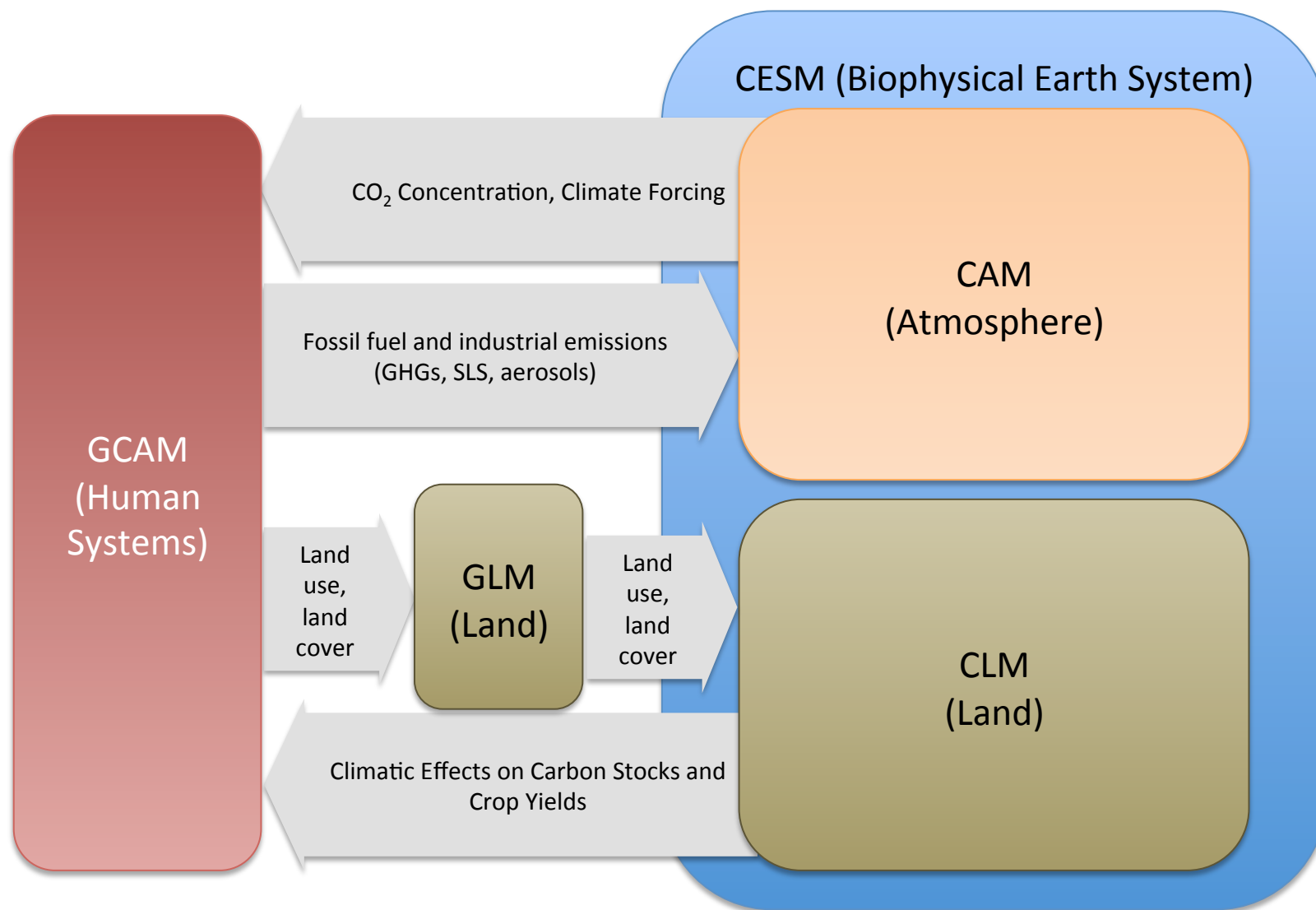
Change in Scarcity

Source: Hejazi et al. (2013). Integrated assessment of global water scarcity over the 21st century: Global water supply and demand under extreme radiative forcing, Hydrology and Earth System Sciences Discussion, 10, 3327–3381, doi:10.5194/hessd-10-3327-2013.

Coupling GCAM human systems (energy & land use) to CESM

IESM

The iESM Model Components



Three iESM Experiments to test implications of two-way coupling—does it matter?

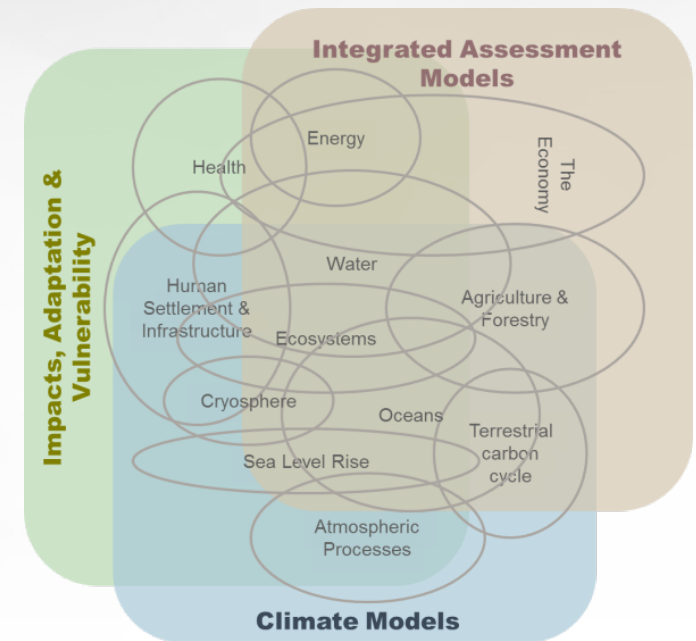
- ▶ **Experiment 1—Two-way terrestrial system coupling (Are energy and/or land-use systems different under two-way terrestrial system coupling?)**
 - **Experiment:** Run a coupled GCAM-CESM system with RCP 4.5 carbon tax and compare the coupled and uncoupled outputs.
 - **Scientific insight:** *Coupling terrestrial systems is harder than it looks. The CMIP5 method employed by the CESM contained errors requiring new methods and code to address.*
 - **Scientific insight:** **PRELIMINARY RESULT** *The RCP 4.5 terrestrial carbon cycle is different with 2-way coupling, with more bioenergy, lower crop prices, and redistributed carbon pools.*

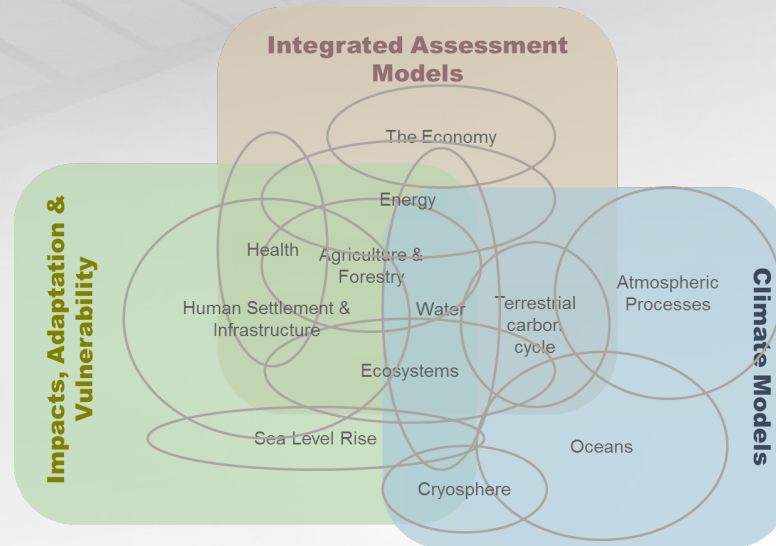
One of the most impressive accomplishments of the project was getting a highly interdisciplinary team of researchers to speak the same language.

The field of integrated assessment modeling is changing rapidly

- ▶ IAMs will continue to provide
 - Decision support tools for emissions mitigation analysis of policy, and
 - Drivers for the climate science community

- ▶ IAMs will exhibit substantial growth in new areas to address new problems
 - IAV: Both providing the new SSPs, but also being part of IAV research
 - Energy-water-land system interactions,
 - Finer spatial and temporal resolution,
 - Greater interaction between scientific disciplines, and
 - Understanding uncertainty, and risk management.





DISCUSSION

Backup Slides

Three climate research communities

Integrated Assessment
Models
IAMs



Human systems
Drivers of Climate Change

Physical Earth System
Models
ESMs



Physical systems
Climate change

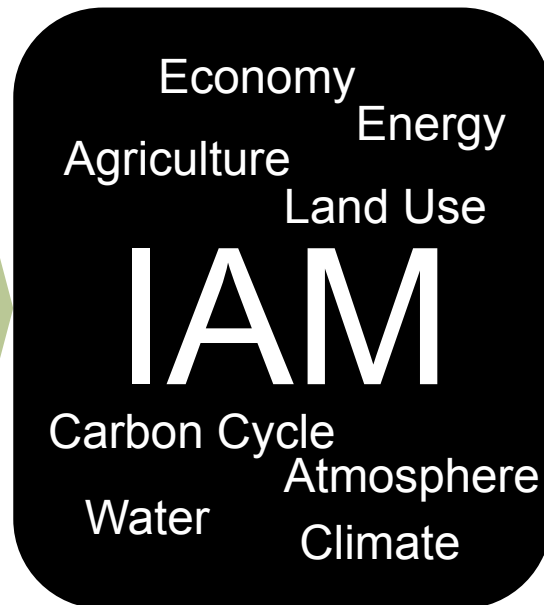
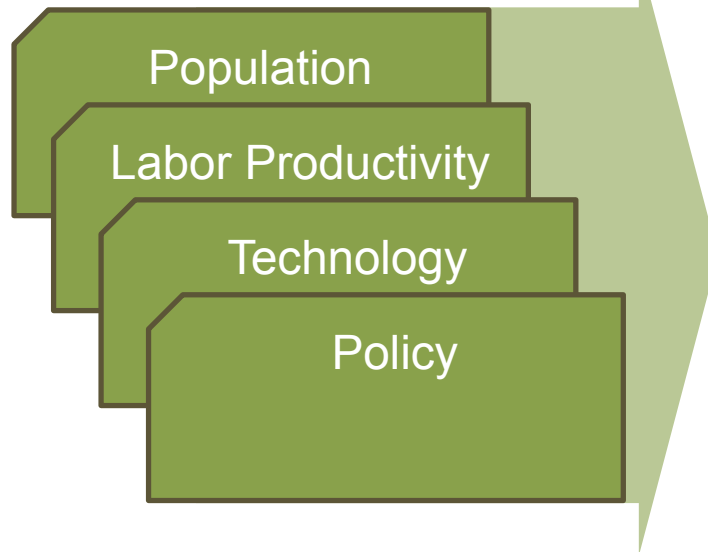
Impacts, Adaptation,
and Vulnerability
IAV



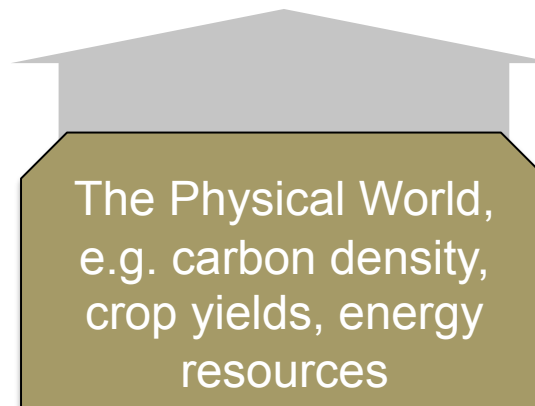
Human systems
Impacts & adaptation

Inputs and Outputs in GCAM

External Inputs to IAMs



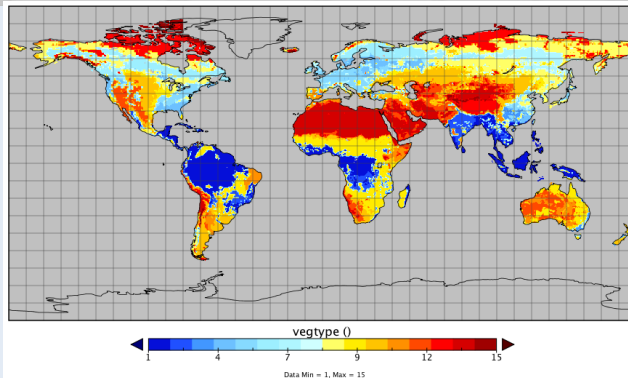
Outputs of IAMs



Parameters

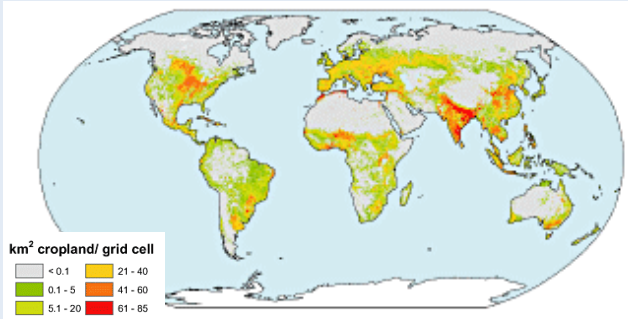
GCAM also incorporates high resolution input data as appropriate to the problem at hand

Potential Vegetation



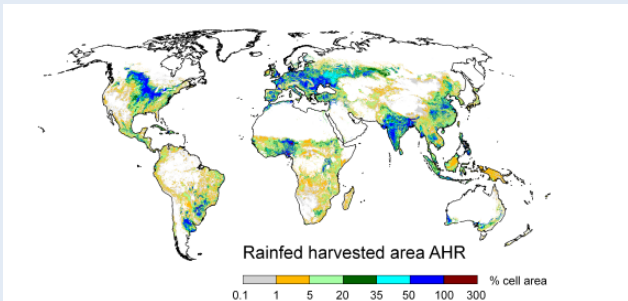
Source: Ramankutty, N., and J.A. Foley (1999). Estimating historical changes in global land cover: croplands from 1700 to 1992, Global Biogeochemical Cycles 13(4), 997-1027.

Cropland area

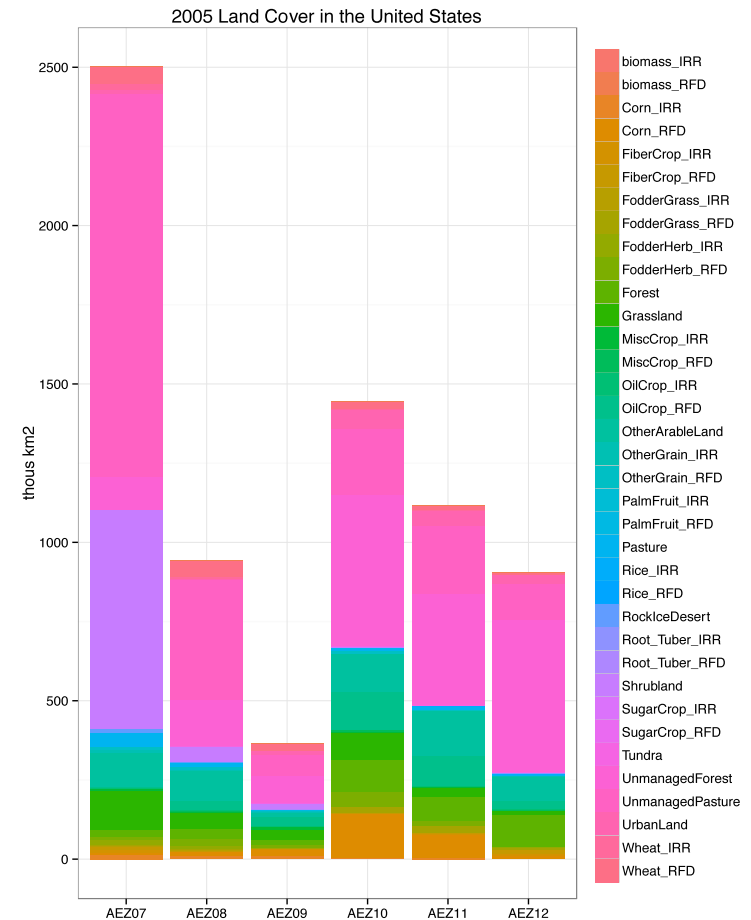


Source: Klein Goldewijk, K., A. Beusen, M. de Vos and G. van Drecht (2011). The HYDE 3.1 spatially explicit database of human induced land use change over the past 12,000 years, Global Ecology and Biogeography 20(1): 73-86.

Rainfed area



Source: Portmann, F. T., Siebert, S. & Döll, P. (2010): MIRCA2000 – Global monthly irrigated and rainfed crop areas around the year 2000: A new high-resolution data set for agricultural and hydrological modeling, Global Biogeochemical Cycles, 24, GB 1011, doi:10.1029/2008GB003435.

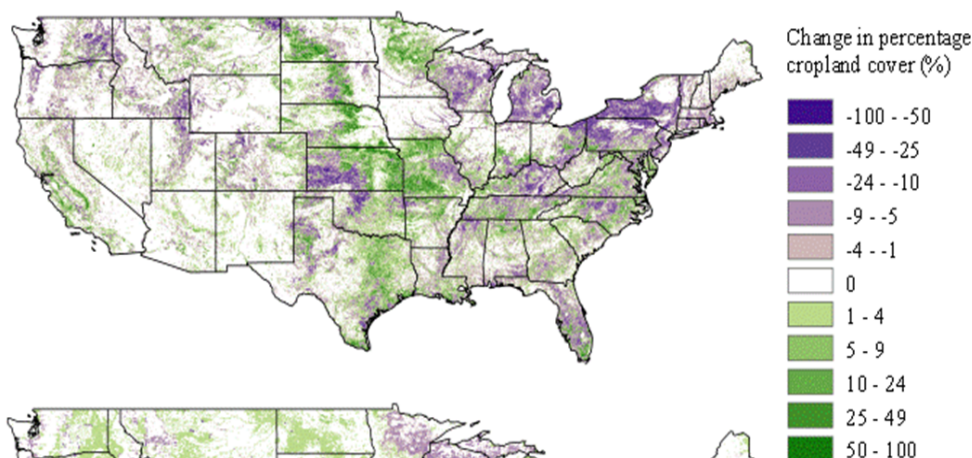


- ▶ We also produce reconciled data products in the process of incorporating data into GCAM.

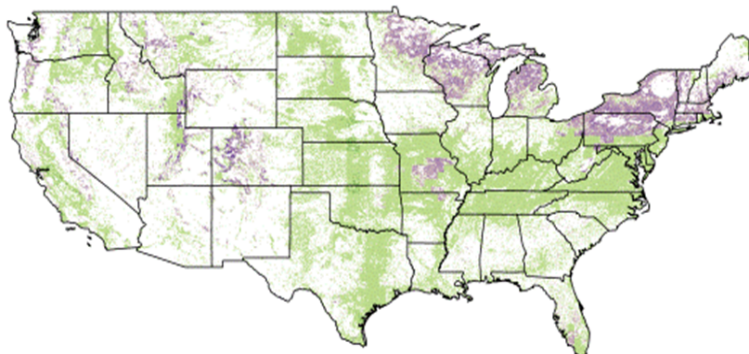
As we develop and incorporate new capability, we are evaluating its performance.

- ▶ Correlation between crop PFT land cover in the native 2010 MODIS **land cover** and the 2010 land GCAM RCP 4.5 was $r^2=0.98$.
- ▶ Correlation between the **cropland difference maps** representing only those grid cells that changed, was $r^2=0.83$.

**Cropland
Change
MODIS 2005-
MODIS 2010**



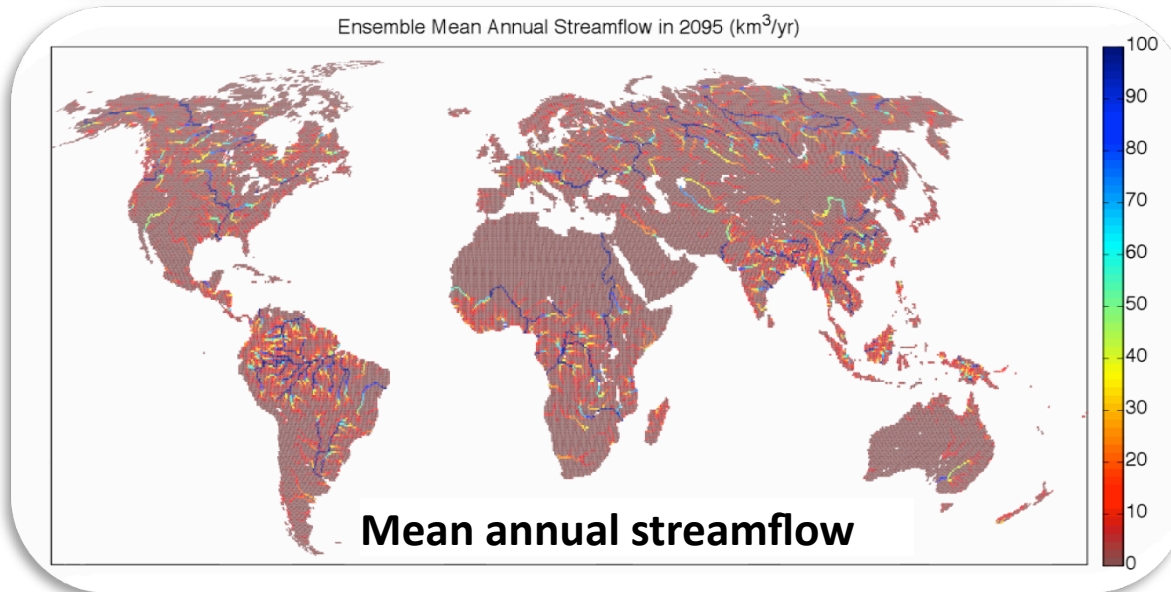
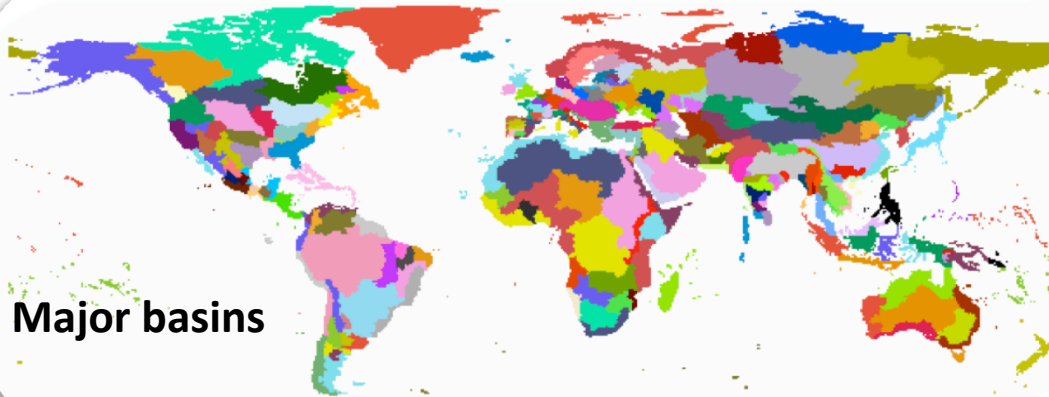
**Cropland
Change
MODIS 2005-
GCAM 2010**



$R^2 = 0.83$

Source: Tristram O. West, Yannick Le Page, Maoyi Huang, Julie Wolf, and Allison M. Thomson. 2014. Downscaling Global Land Cover Projections from an Integrated Assessment Model for Use in Regional Analyses: Results and Evaluation for the US from 2005 to 2095. Accepted for Publication in *Environmental Research Letters*.

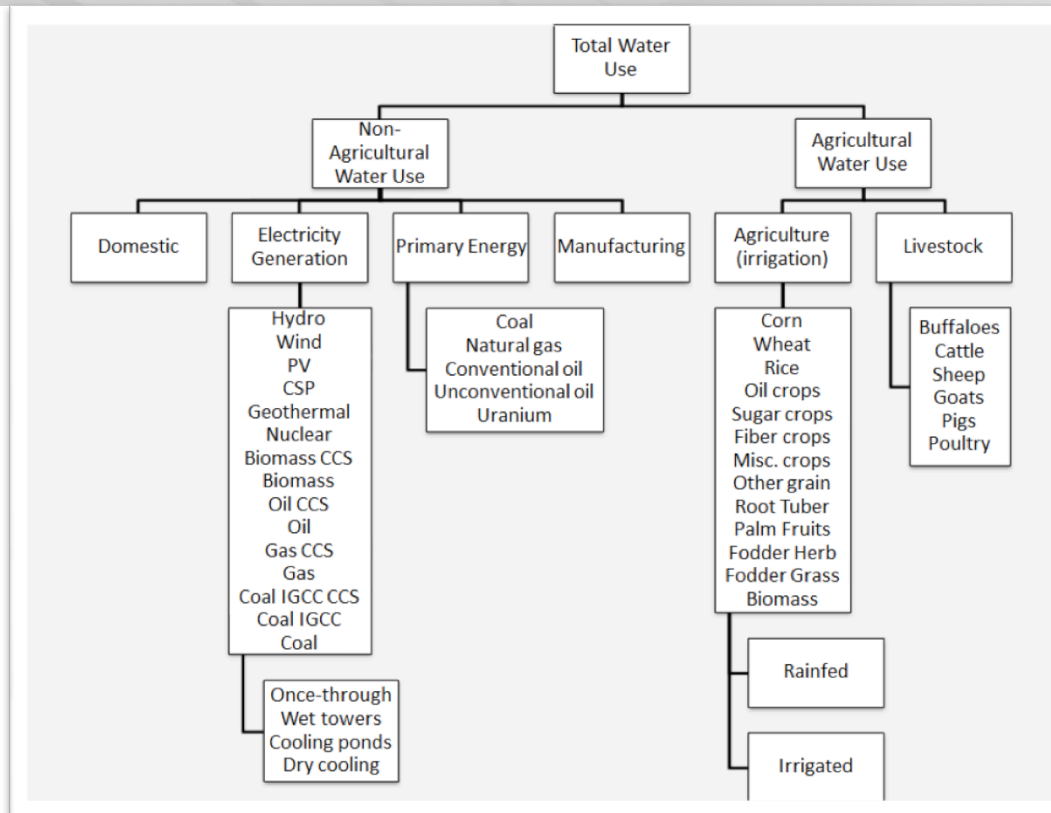
The GCAM Global Hydrologic Model



- ▶ GCAM has a macroscale global hydrologic model
- ▶ Modified River Transport Model scheme
- ▶ Simulates runoff and streamflow (1901-2100)
- ▶ Requires climate information from GCMs as inputs
- ▶ 233 basins globally
- ▶ 18 basins in the US consistent with the USGS WRRs
- ▶ Monthly temporal scale
- ▶ 0.5x0.5 degree spatial resolution

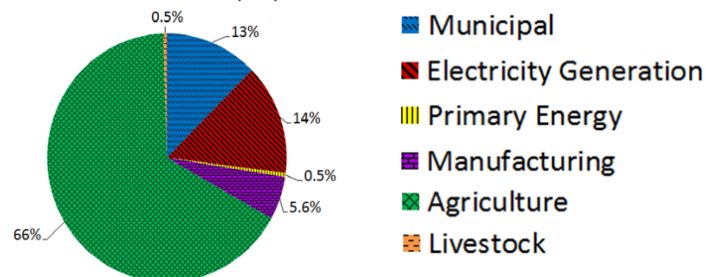
Toward understanding the implications of **climate change impacts** on **water** availability and on **energy and land** decisions in GCAM

How much water do humans demand for energy and food?

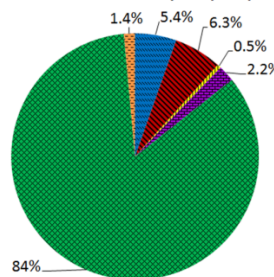


- ▶ Technologically detailed representation of water demand sectors
- ▶ Tracks water demands for several sectors, subsectors, and technologies
- ▶ Tracks water demands at various spatial scales (regions, state, agro-ecological zones)
- ▶ Tracks both annual withdrawal and consumptive water use
- ▶ Endogenously incorporated in GCAM

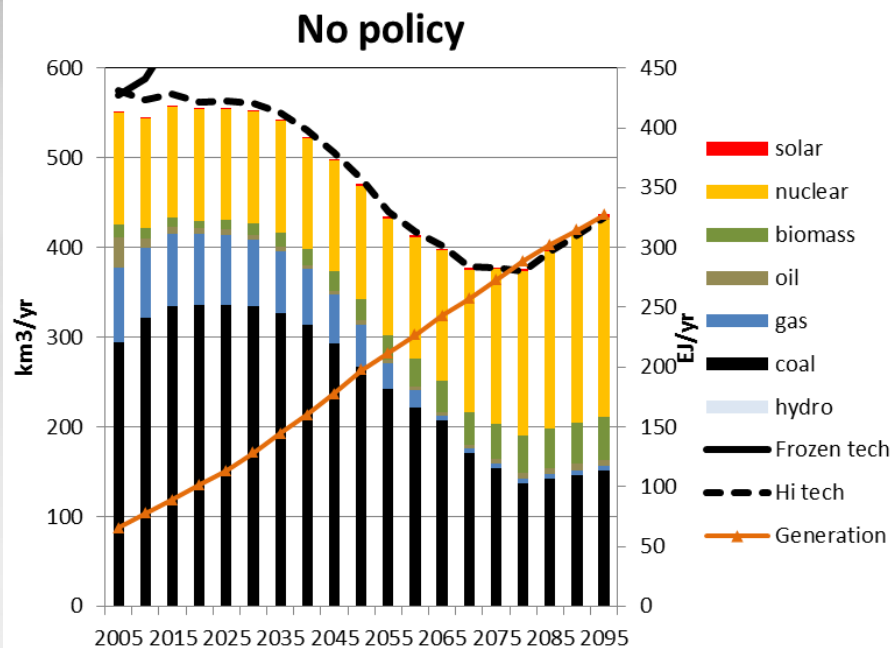
Global Water Withdrawals (2005)



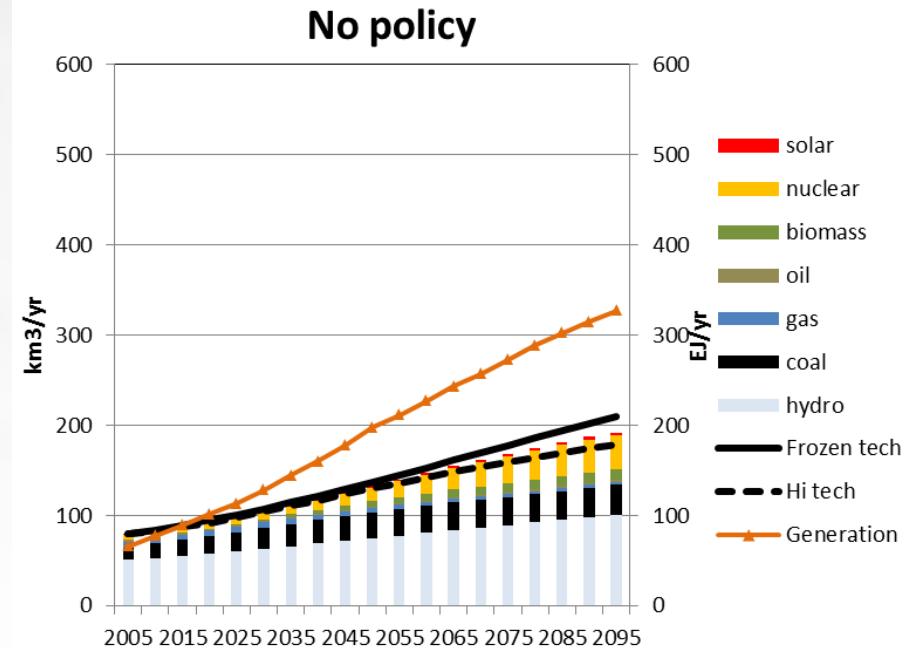
Global Water Consumption (2005)



Global water withdrawal and consumption in a reference scenario with increasing deployment of cooling towers in power generation



Withdrawal



Consumption