The Global Change Assessment Model (GCAM)

JAE EDMONDS FOR THE GCAM TEAM

Asia Integrated Modeling Meeting
Tsukuba, Japan

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U.S. DEPARTMENT OF ENERGY | Office of Science

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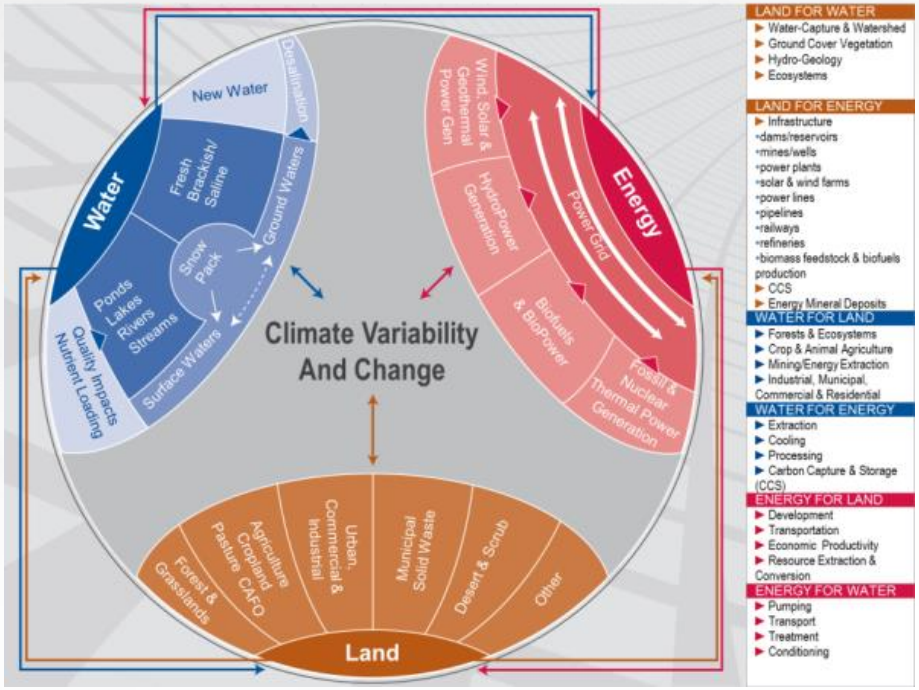
GCAM evolution has always been *PROBLEM DRIVEN and linked to Energy AND Earth System Science.*

GCAM is evolving to address a new set of problems: *climate impacts on the interconnected energy, water and land system in a world that may or may not be simultaneously mitigating GHG emissions, at temporal, spatial, and sectoral scales appropriate to science and decision-support problems.*



GCAM Is Evolving Rapidly

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

- **Produce output products, at appropriate space, time, sectoral, and technological resolutions.**
  - **New problems are emerging that require tools that produce outputs at time scales ranging from days to decades.**
  - **Spatial scales ranging from global to local**
- **Employ high-resolution data inputs as well as those with global coverage;**
- **Reconcile and transform data to appropriate analytical scales,**
- **Employ interoperable modules and models to facilitate research at problem-appropriate scales.**

GCAM TODAY

The Core Element of the Global Change Assessment Model (GCAM)

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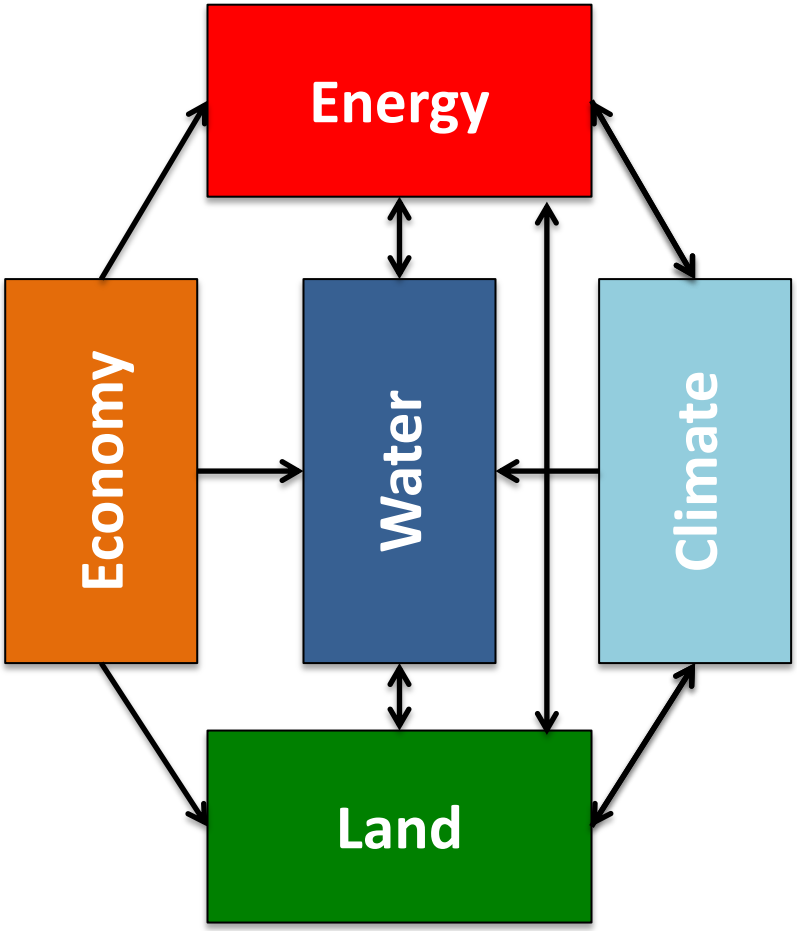

- GCAM is a **global integrated assessment model**, with regional and local resolutions
- GCAM links **Economic**, **Energy**, **Land-use**, **Water** and **Climate** systems
- Technology-rich model
- Emissions of 16 greenhouse gases and short-lived species: CO_2, CH_4, N_2O, halocarbons, carbonaceous aerosols, reactive gases, sulfur dioxide. At global, regional and 0.5° resolution.
- Land use, land use change, and land cover. At global, regional and 0.5° resolution.
- Runs through **2100** in **5-year time-steps.**

GCAM's Adaptive Spatial Resolution

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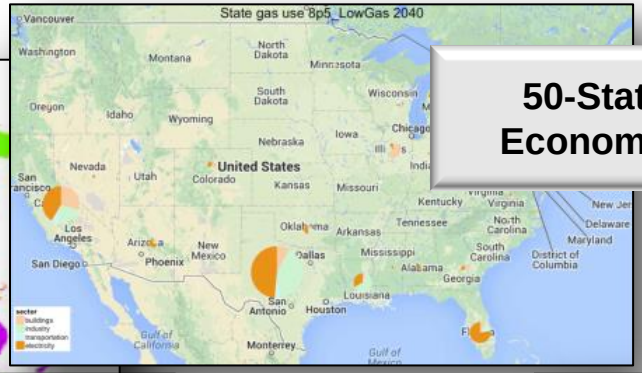
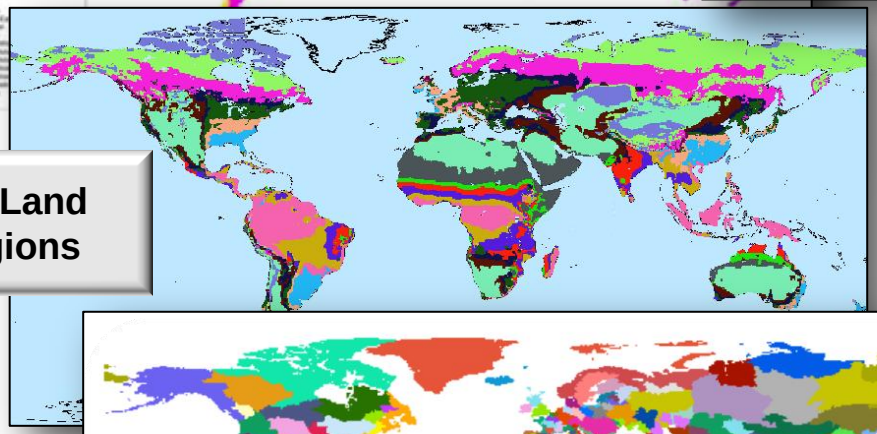
32 Energy Economy Regions

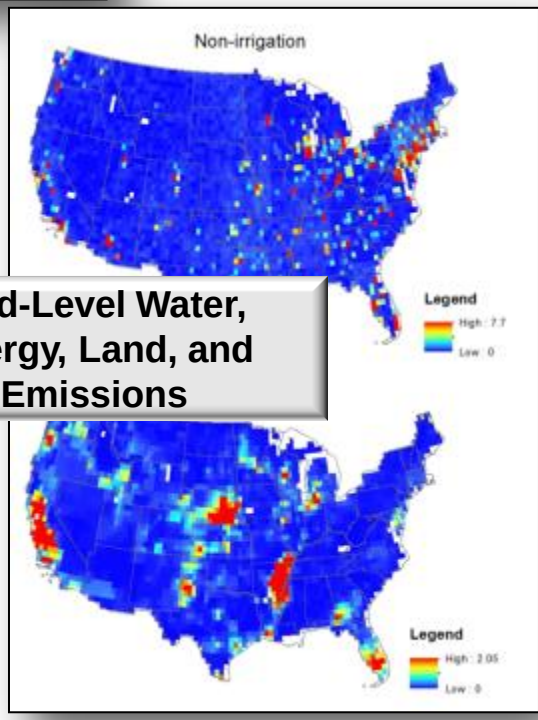


50-State Energy Economy Regions



283 Land Regions

233 Water Basins



Grid-Level Water, Energy, Land, and Emissions

GCAM is a community model

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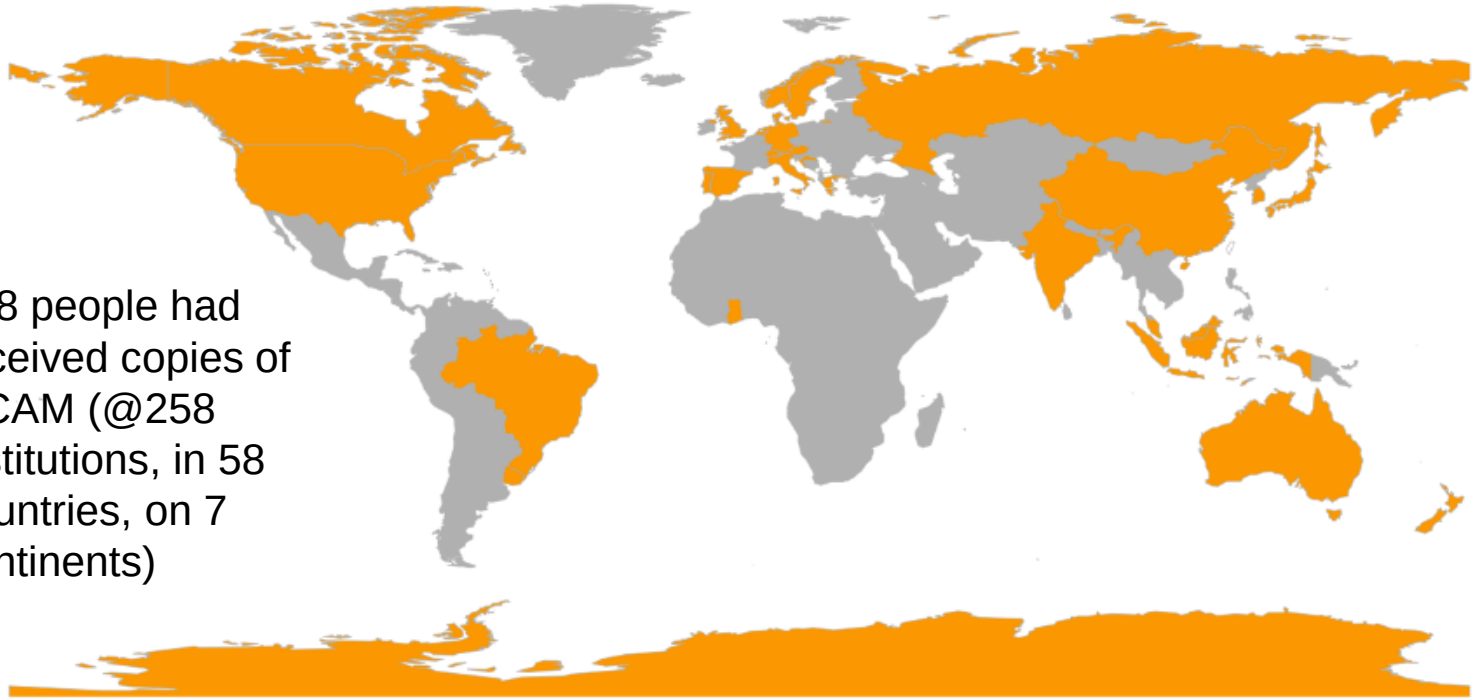
- GCAM has a large and growing community of users.
- GCAM annual meeting brings users together to collaborate and network.

http://www.globalchange.umd.edu/models/gcam/download/



418 people had received copies of GCAM (@258 institutions, in 58 countries, on 7 continents)

GCAM documentation: wiki.umd.edu/gcam/

Recent Development: The First Version of a New Community Climate Emulator-Hector

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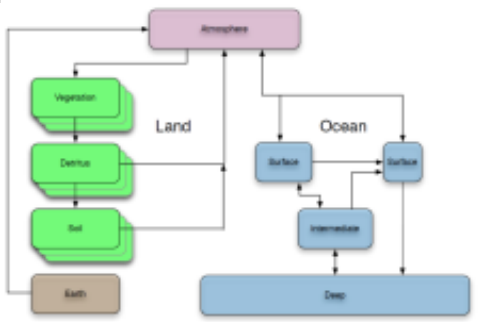
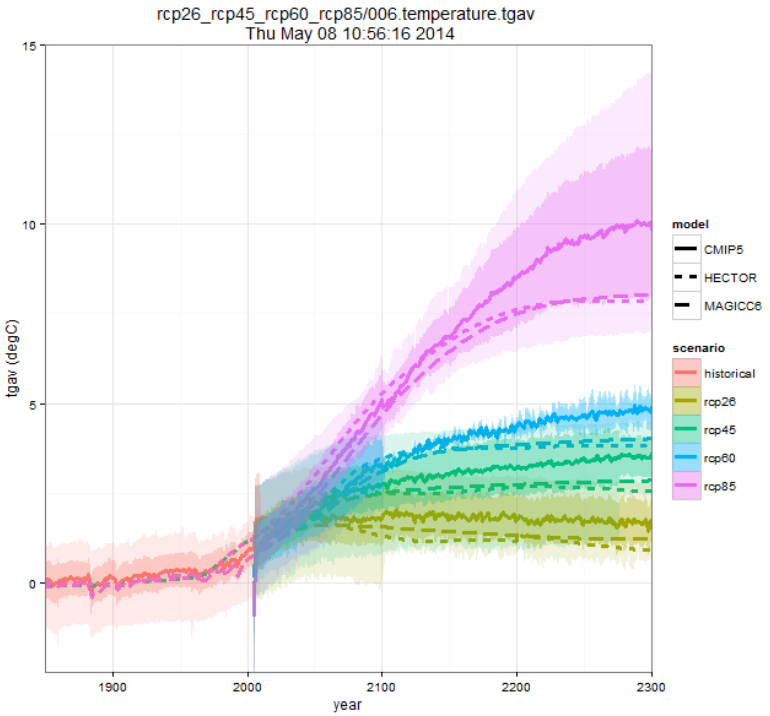
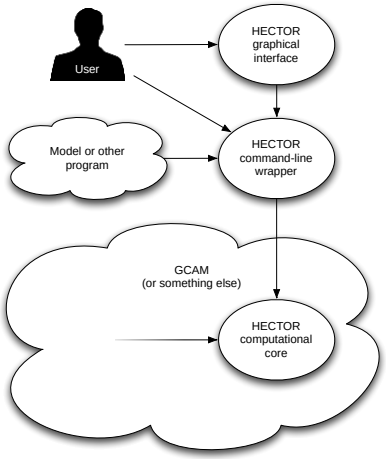
- *Fast-executing* newly developed global climate and carbon cycle model
- *Open source* and community oriented
- Capable of replicating some outputs of more complex models
- Being expanded to facilitate research on energy-water-land interactions and integrated impacts within GCAM



Fast, flexible emulation CMIP5 global to biome-scale outputs



Modular, open-source C++ codebase. Central coupler enforces message passing and unit checking.



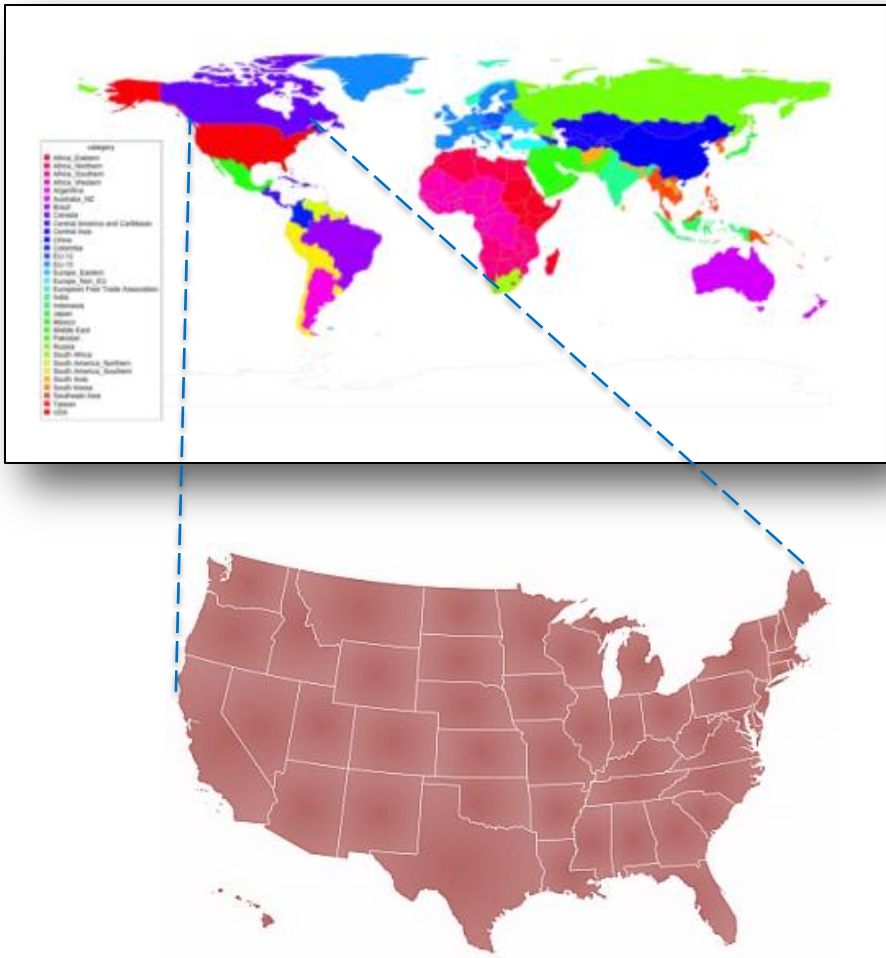
Adding sub-national detail to GCAM facilitates coupling with sector models

To facilitate coupling with detailed sector models, we have added subnational detail to GCAM (version name: GCAM-USA):

- 50-state (+DC) climate-dependent building energy
- 50-state (+DC) electricity generation mix
- Increased spatial and technological resolution for agriculture and land use
- Water supply and demand at major watershed scale

The rest of the model operates normally, thus providing global constraints and context (i.e., GCAM-USA is GCAM)

Stand-alone GCAM with 32 Global Geopolitical Regions



GCAM-USA: Subnational Detail

GCAM-USA Electricity: Results

2050 Electricity supply mix in Gulf Coast states

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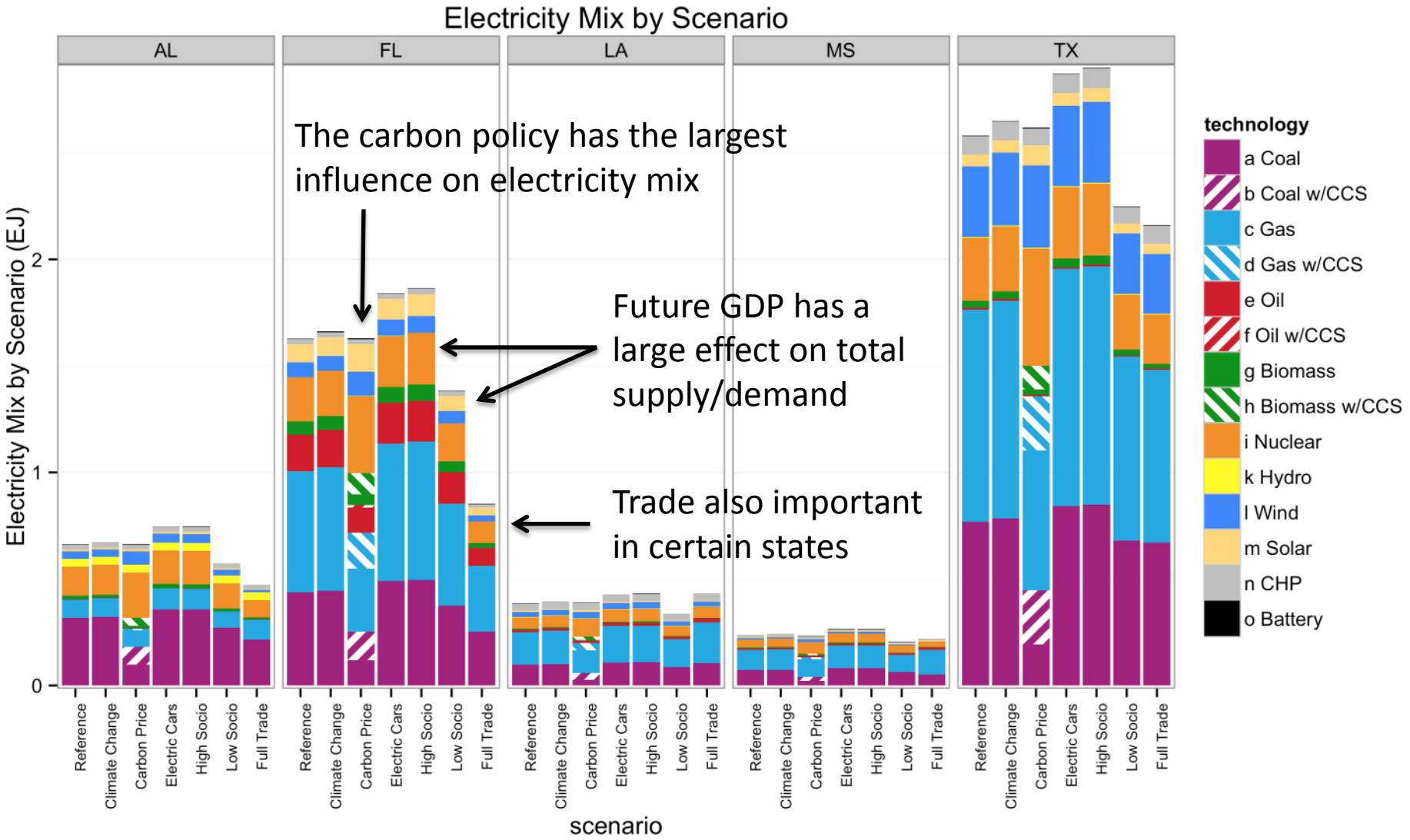

Coupling to Other Models, e.g. the BEND Model, allows research at finer space and time scales

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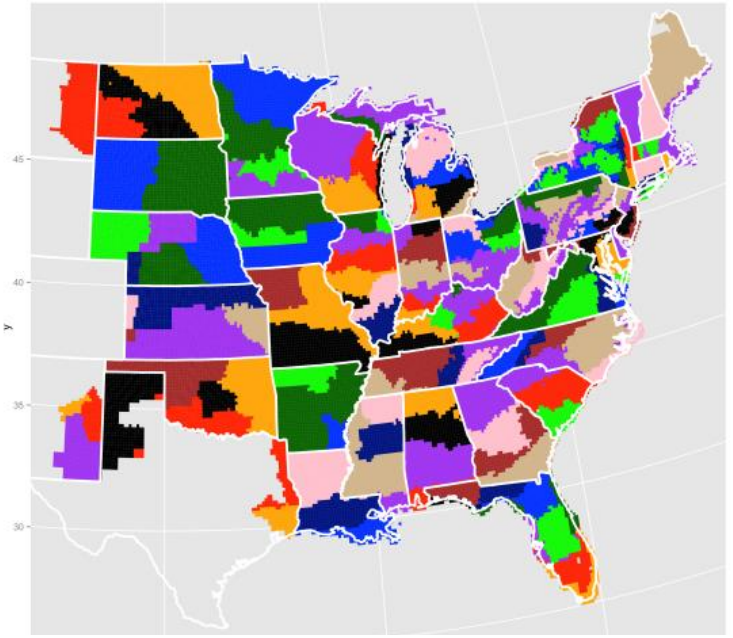
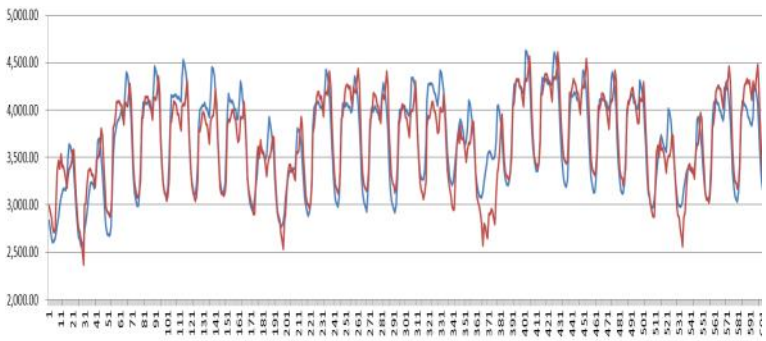
The Building Energy Demand (BEND) simulates climate-dependent building energy demand at high spatial, temporal, and technological resolution

- Combines DOE's EnergyPlus model (for individual buildings) with a geostatistical analysis of regional climate, population, and building types and technologies
- Resolution as fine as 1/8 degree (~12 km); results can be aggregated to any geographic region (e.g., utility zone)
- Uses GCAM input (population-driven floor space growth, technology turnover) to drive future building stock changes
- Uses RESM or other hourly weather/climate input (9 variables!) to simulate changes in building energy demand
- Can also be used to model demand response, smart charging, etc.



Climate similar regions in the Eastern Interconnection

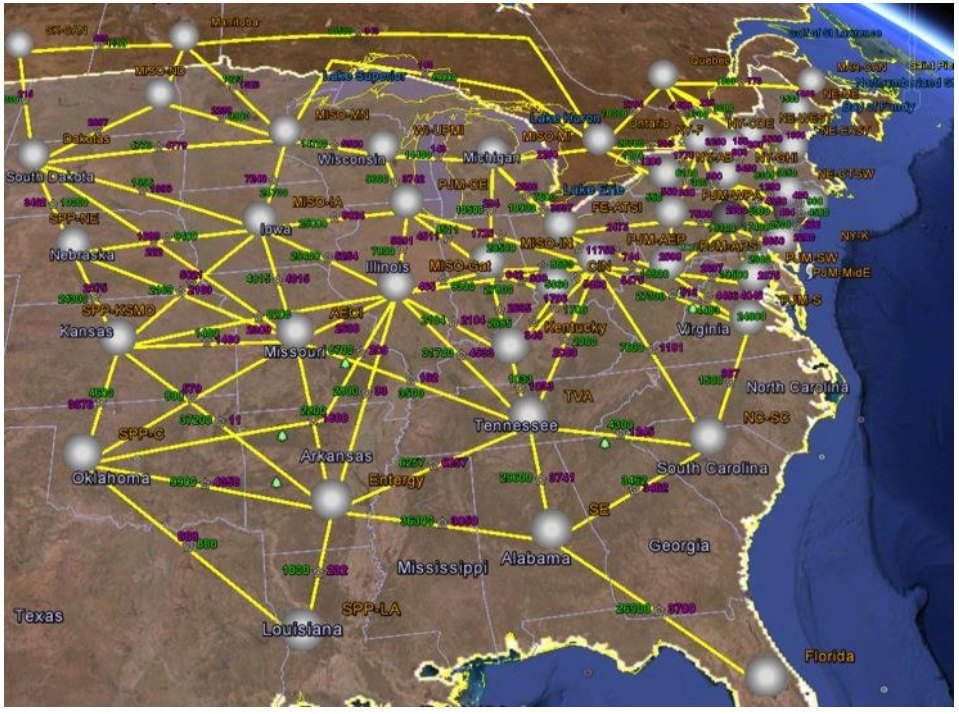


Sample BEND output/validation for a single utility zone

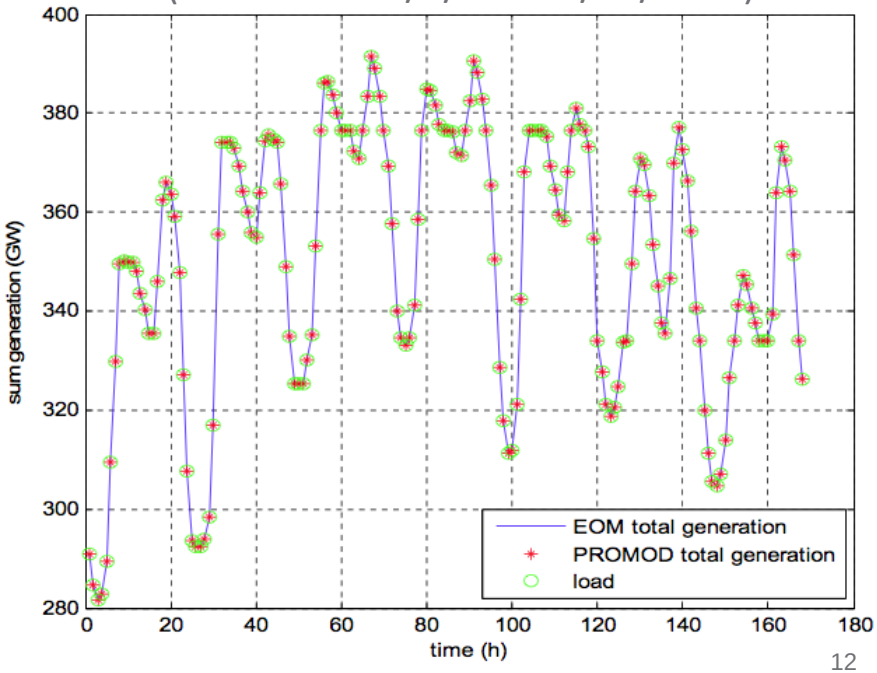
Electricity Operations Model (EOM)

- Hourly Unit Commitment with zonal transmission constraints
- Unique capability: Hourly climate-dependent capacity rating (can account for air temperature and cooling water availability)
- Open source; Validated against PROMOD

Validation for Eastern Interconnection



Good agreement with PROMOD
(Simulation: 1/4/2004-1/10/2004)



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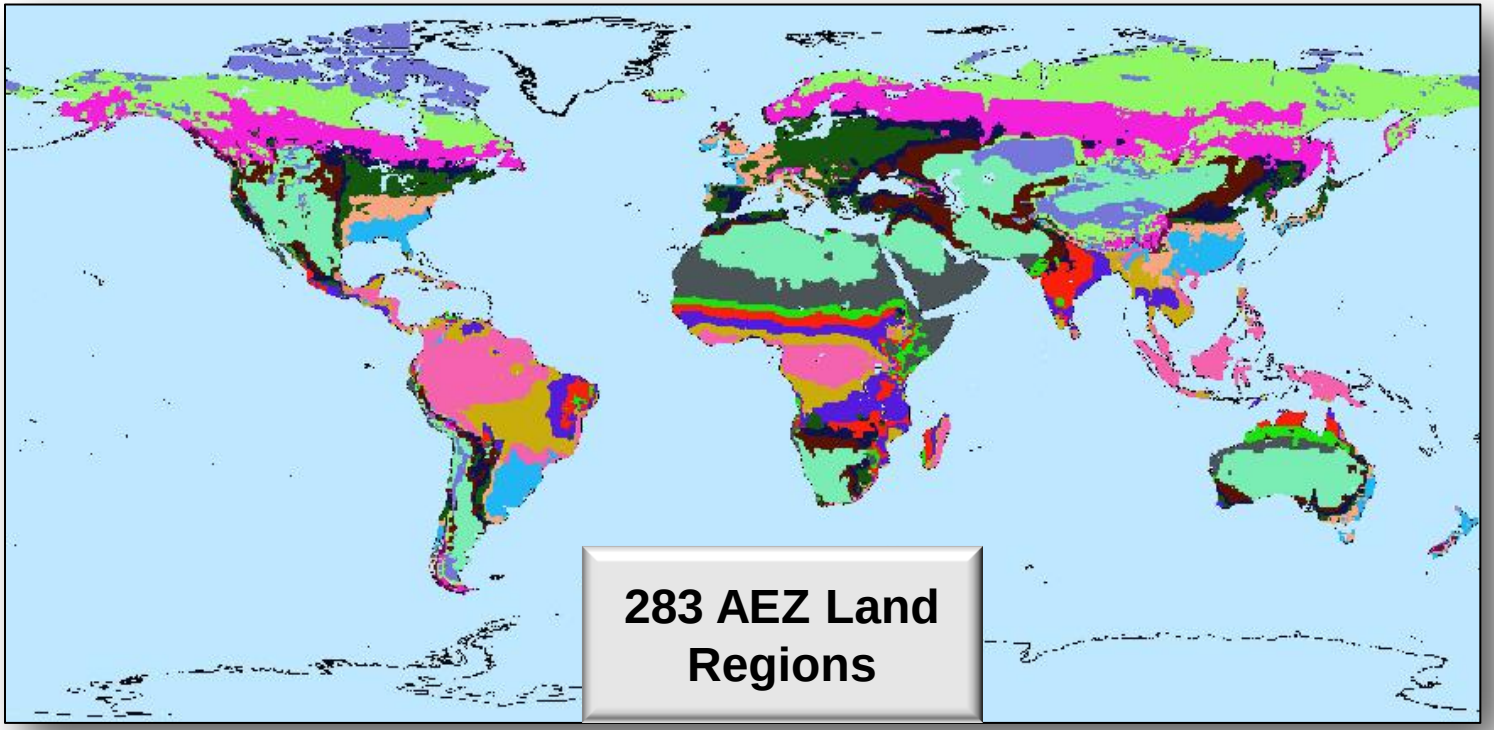
Recent developments in representing land systems and processes

AGRICULTURE AND LAND USE

Core GCAM land regions

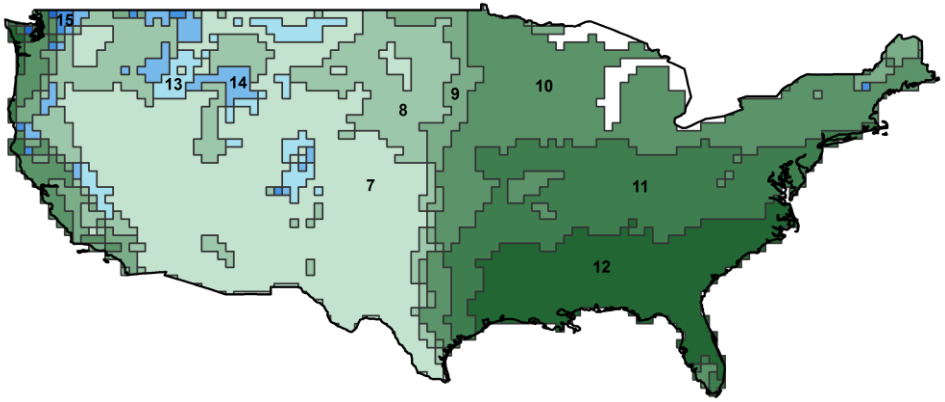
- While core GCAM has 283 AEZs, many problems require finer spatial resolution



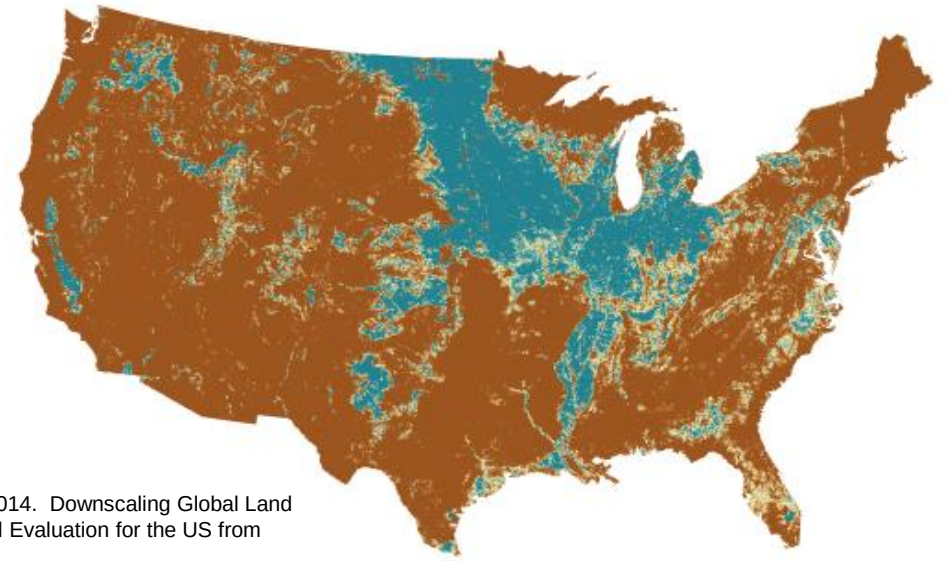
GCAM land cover decisions occur at 283 region resolution, but results are available at 0.05° resolution

- 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

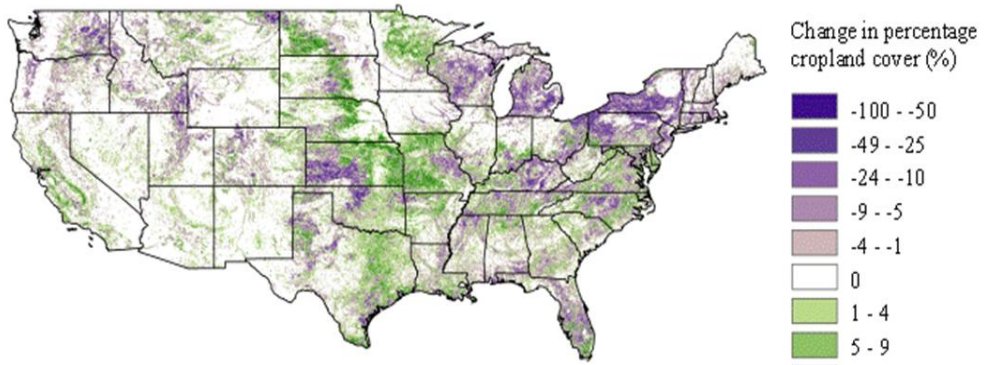


Source: Tristram O. West, Yannick Le Page, Maoyi Huang, Julie Wolf, and Allison M. Thomson. 2014. Downscaling Global Land Cover Projections from an Integrated Assessment Model for Use in Regional Analyses: Results and Evaluation for the US from 2005 to 2095. Accepted for Publication in *Environmental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

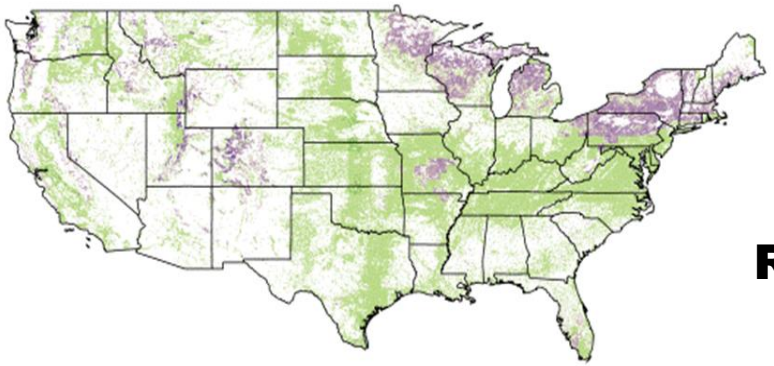
As we develop and incorporate new capability, we are evaluating its performance.

- 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

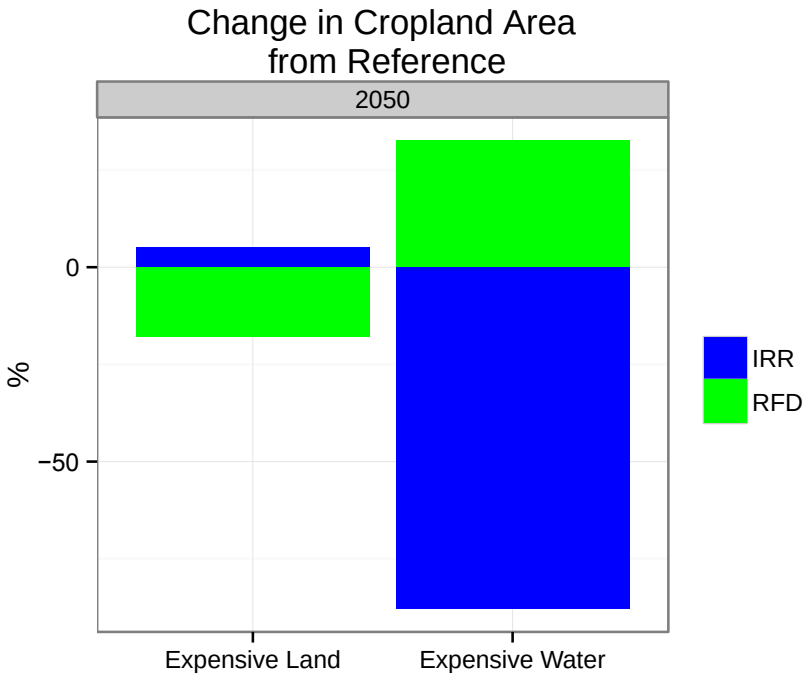


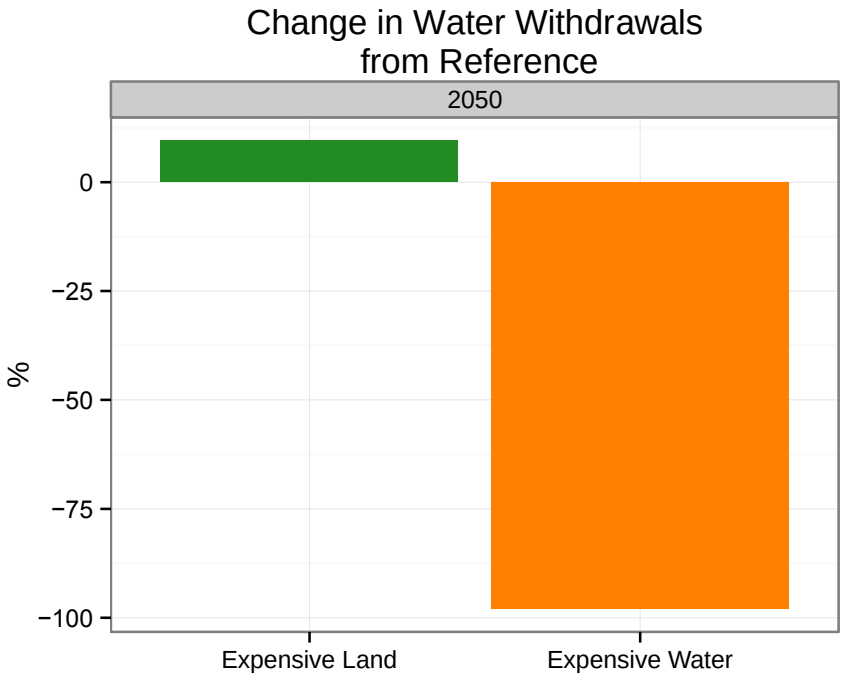
R^2 = 0.83

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*.

GCAM has evolved to include intensification and irrigation (a major fresh water demand)

- Allocation between irrigated & rainfed depends on economics.
- Profit rate for each will depend on yield, cost of production, and carbon price (if applicable)
  - Yields are higher for irrigated crops.
  - Costs are higher for irrigated crops.
  - Carbon implications are lower for irrigated crops.





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

GCAM NOW INCLUDES WATER

GCAM Global Water Supplies

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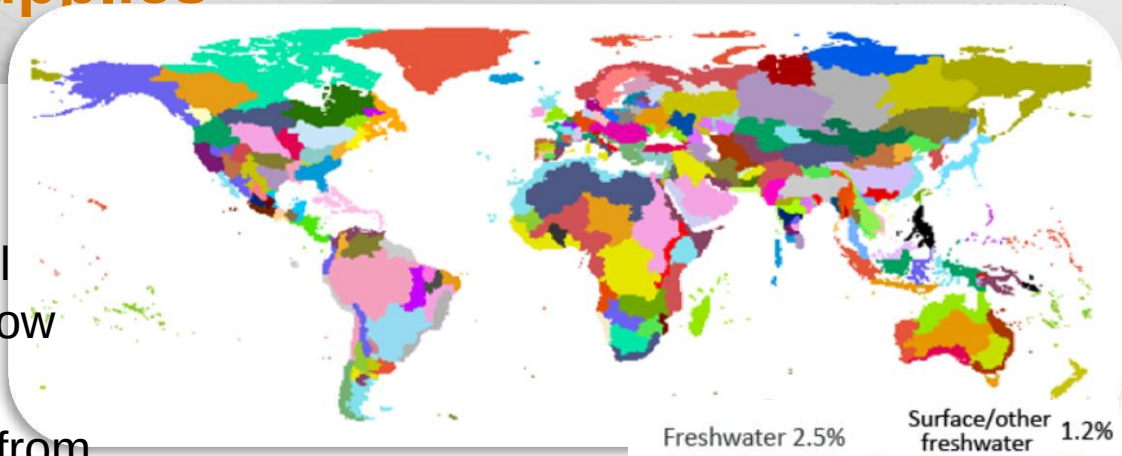
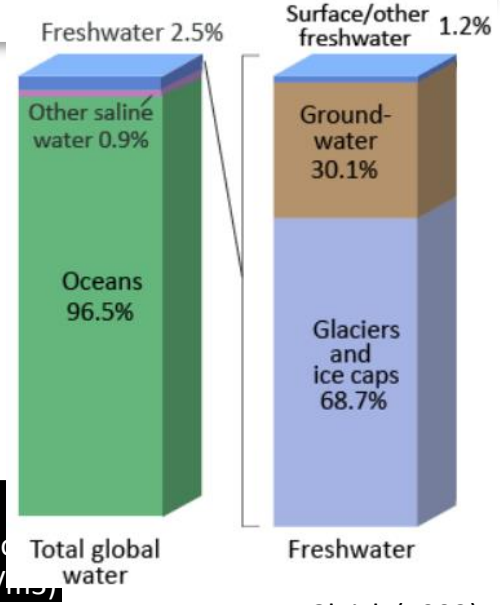


1. Renewable
   - 233 basins global
   - Macro-scale hydrologic model emulates runoff and stream flow (1901-2100)
   - Requires climate information from GCMs as inputs
2. Non-renewable (fossil) groundwater
   - Depletable resources
   - Supply curves by GCAM region
   - Cost of groundwater pumping increases with depth following the work of Zhu et al., (2007)
3. Desalinated water
   - Constant cost per unit water



Gleick (1993)

Desalination water source	Global Share (%)	Global Cost ($/m3)	US Share (%)	US Cost ($/m3)
Sea	56%	1	7%	1
Brackish	24%	0.6	51%	0.6
River	9%	0.6	26%	0.6
Waste water	6%	0.6	9%	0.6
Pure	5%	0.6	7%	0.6
Brine	0%	-	0%	-
SUM	**100%**	**0.824**	**100%**	**0.628**

Wangnick/GWI (2005)
Zhou & Tol (2005)

GCAM Global Water Demands

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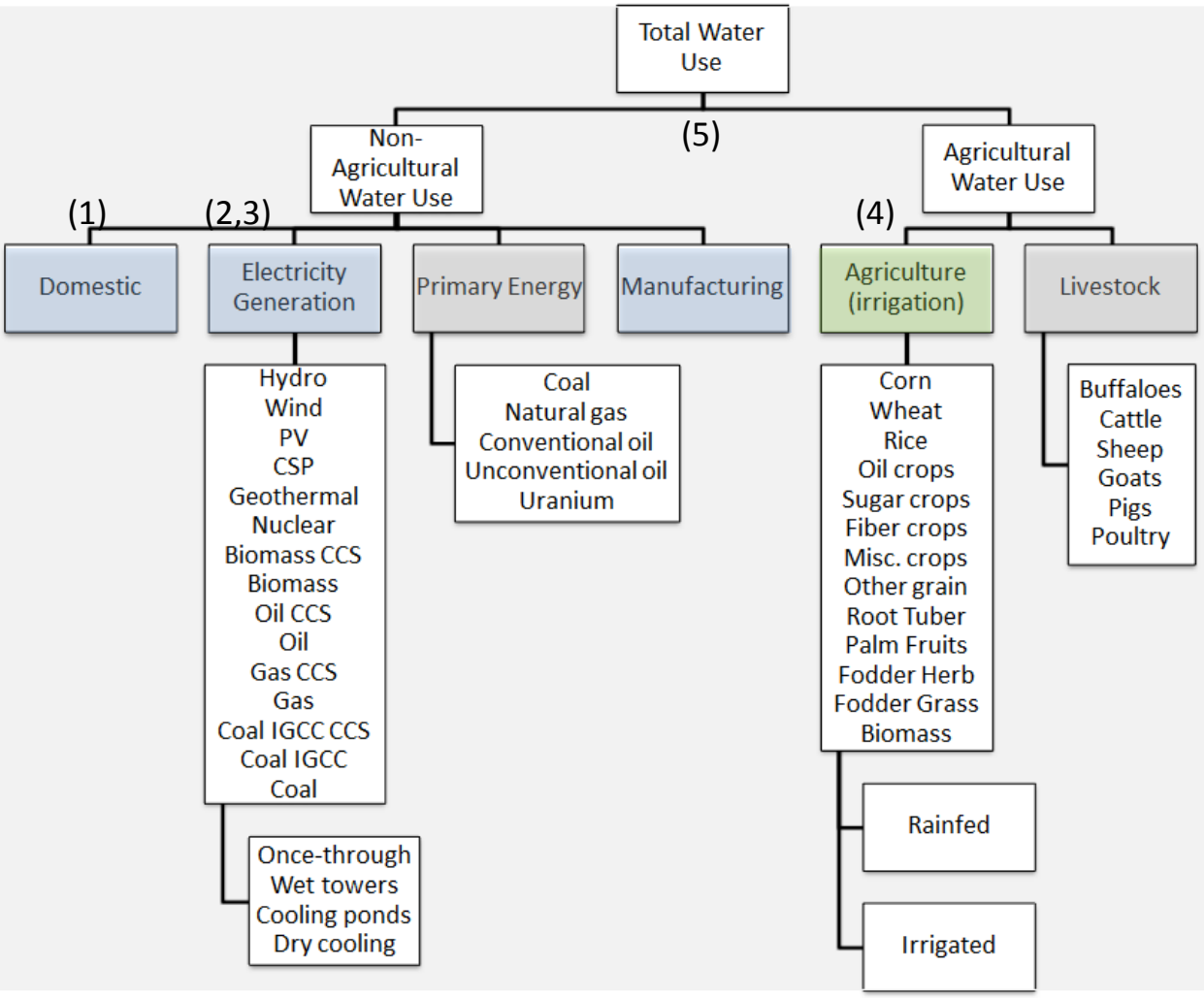

- Technologically detailed representation of water demand sectors
- Tracks water demands for several sectors, subsectors, and technologies
- Tracks water demands at various spatial scales (regions, state, agro-ecological zones)
- **Tracks both annual withdrawal and consumptive water use**
- Endogenously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

(1) Hejazi et al. (2013). Hydrological Sciences Journal.
(2) Kyle et al. (2013). International Journal of Greenhouse Gas Control.
(3) Davies et al. (2013). Advances in Water Resources.
(4) Chaturvedi et al. (2013). Mitigation and Adaptation Strategies for Global Change.
(5) Hejazi et al. (2014). Technological Forecasting and Social Change

14 GCAM Regions | 151 AEZ scale | US (50-state)

Climate change will affect hydropower generation

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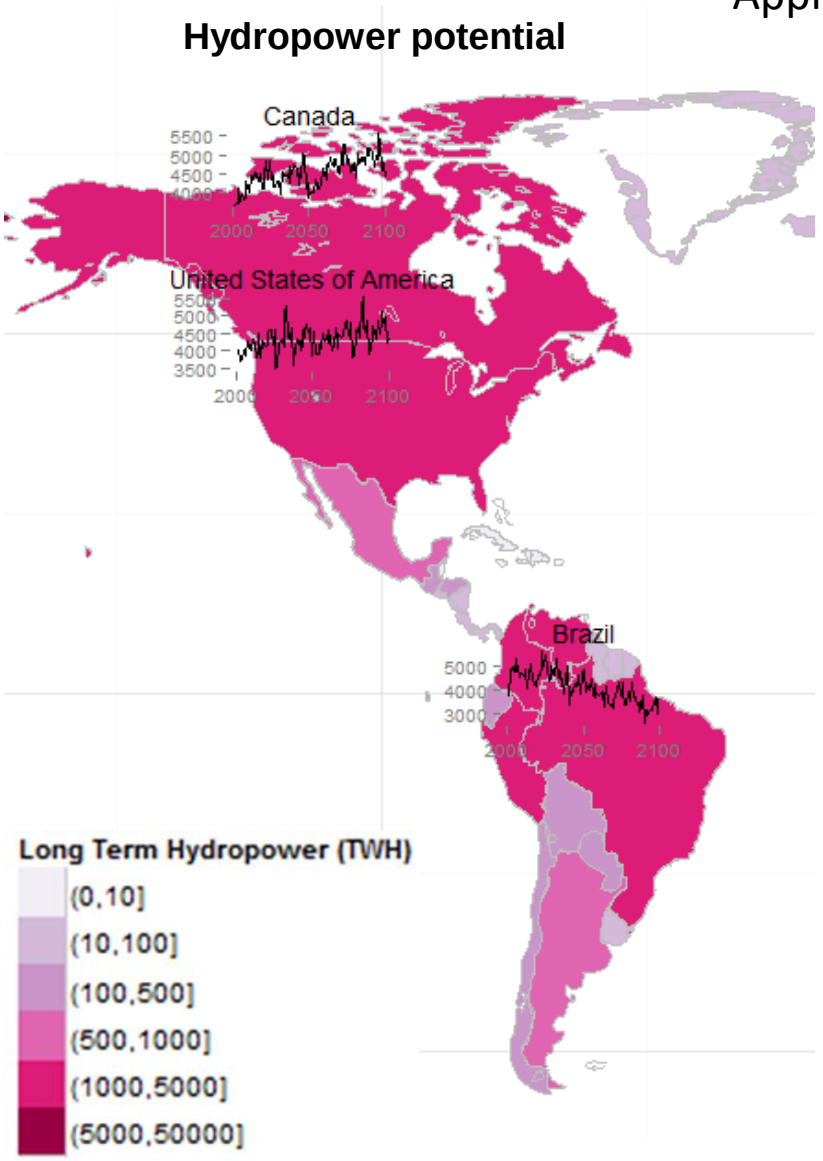
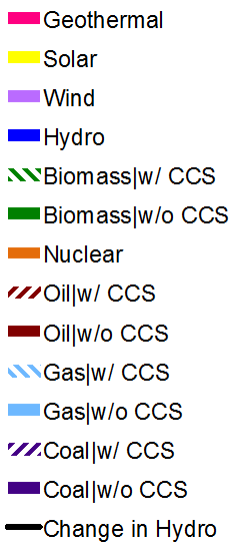
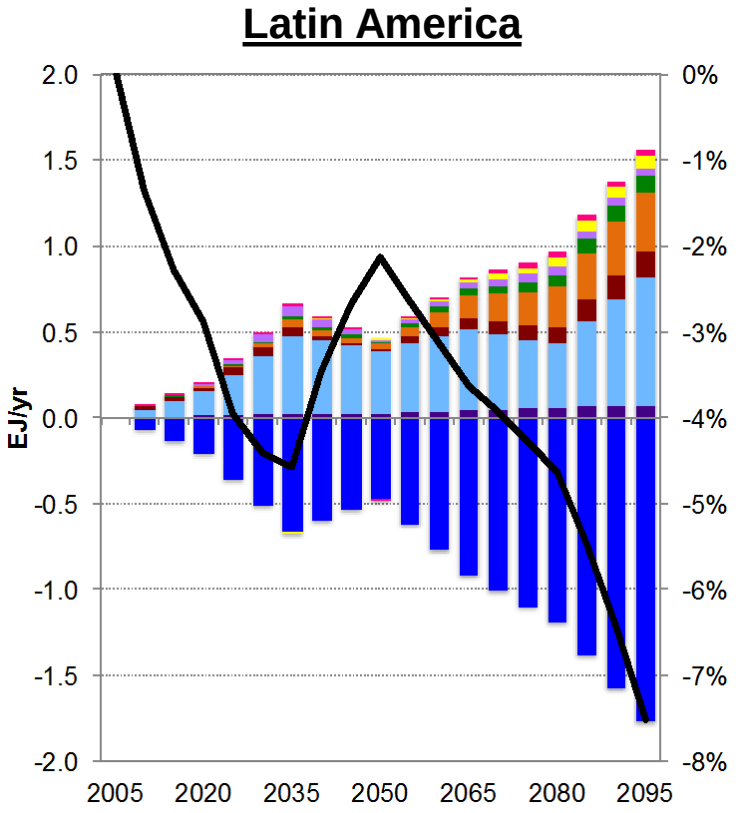
Application using HadCM3







Positive values mean an increase in electricity generation when impacts are considered

Humans play a larger role in water scarcity in 93% of the basins (89% of total land)

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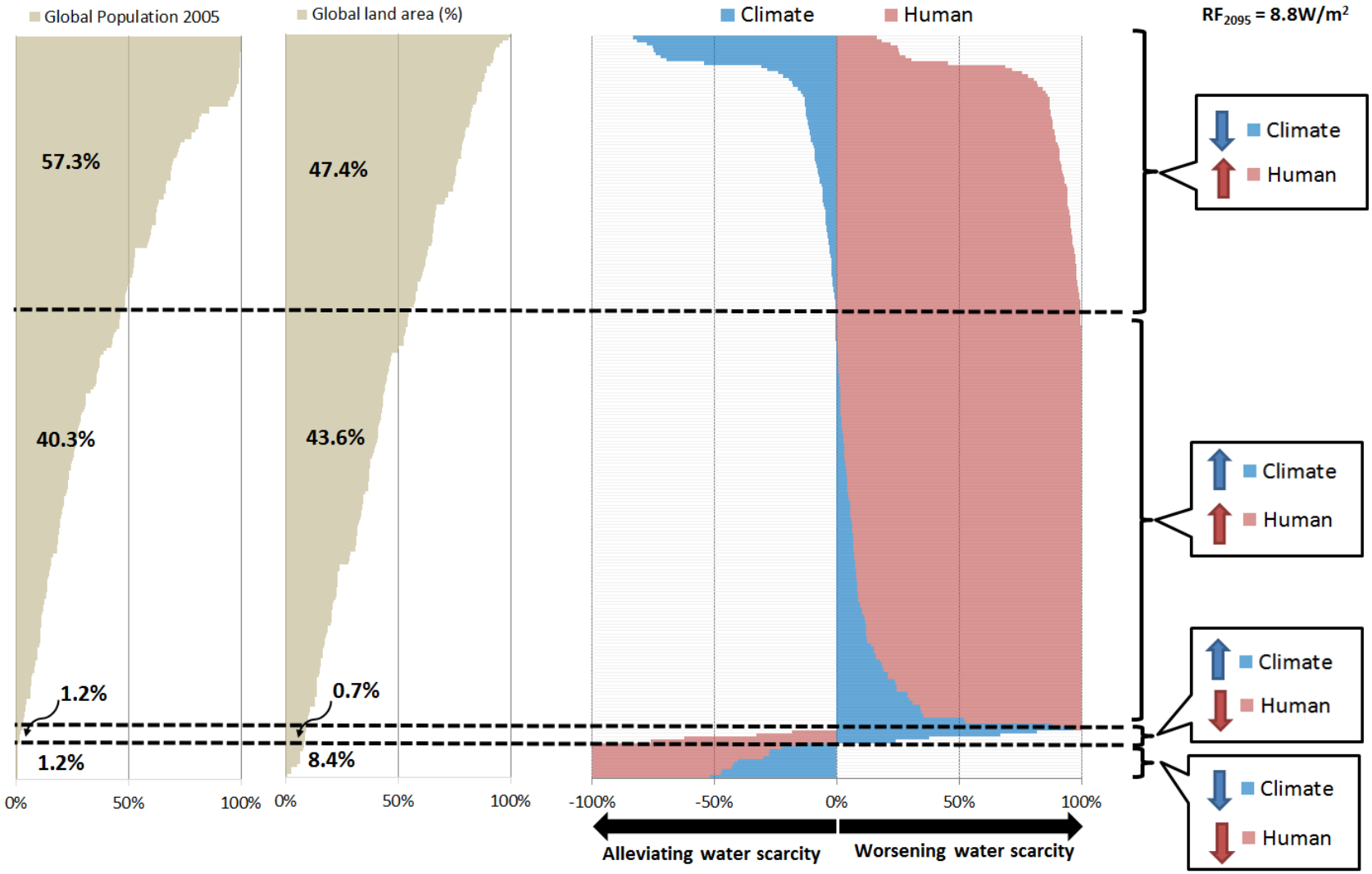
No policy (8.8 W/m^2 by year 2100)



Water demands and availability are now reconciled in GCAM, i.e. Limits in water availability have consequences.

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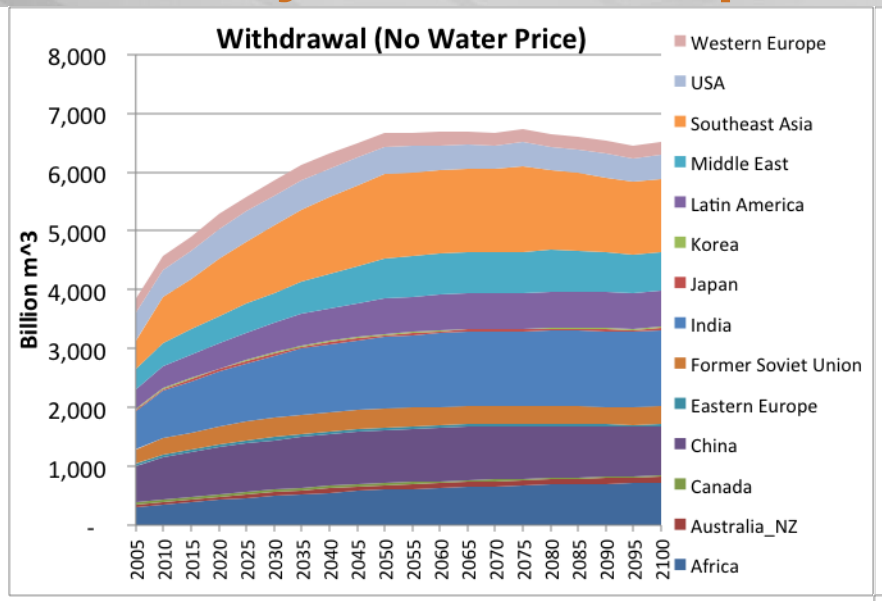
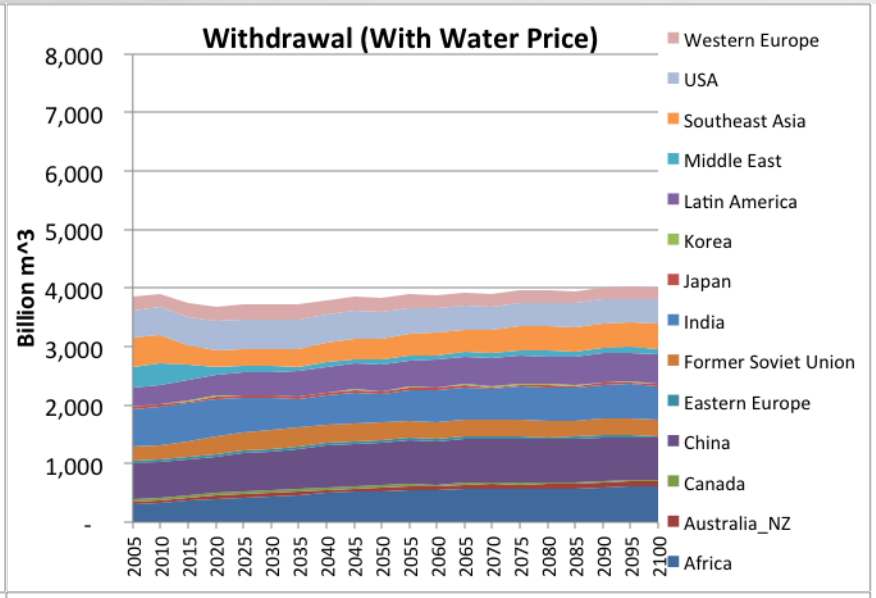
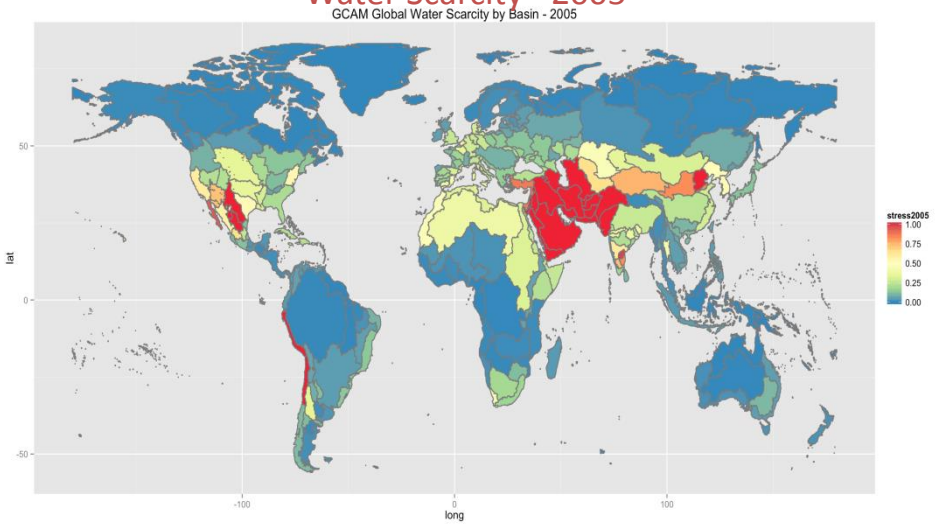
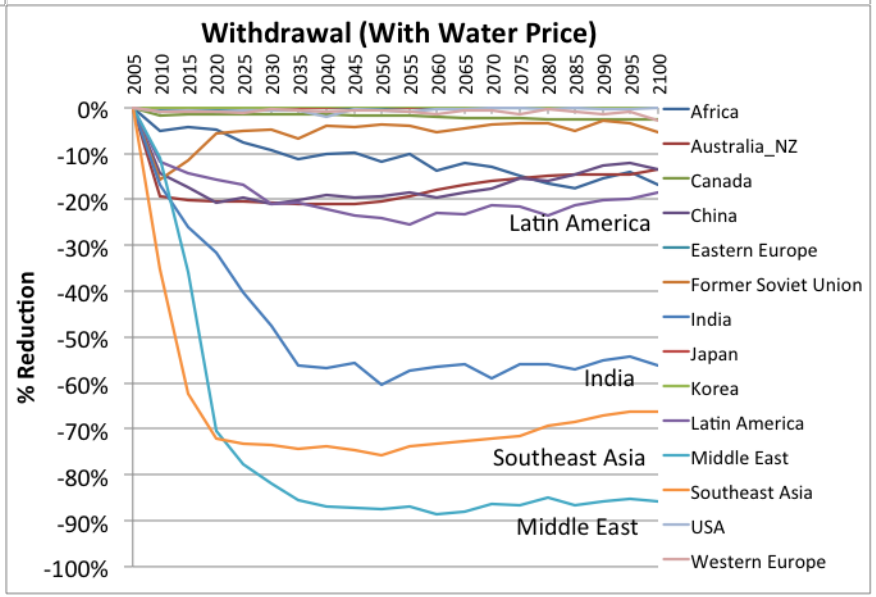


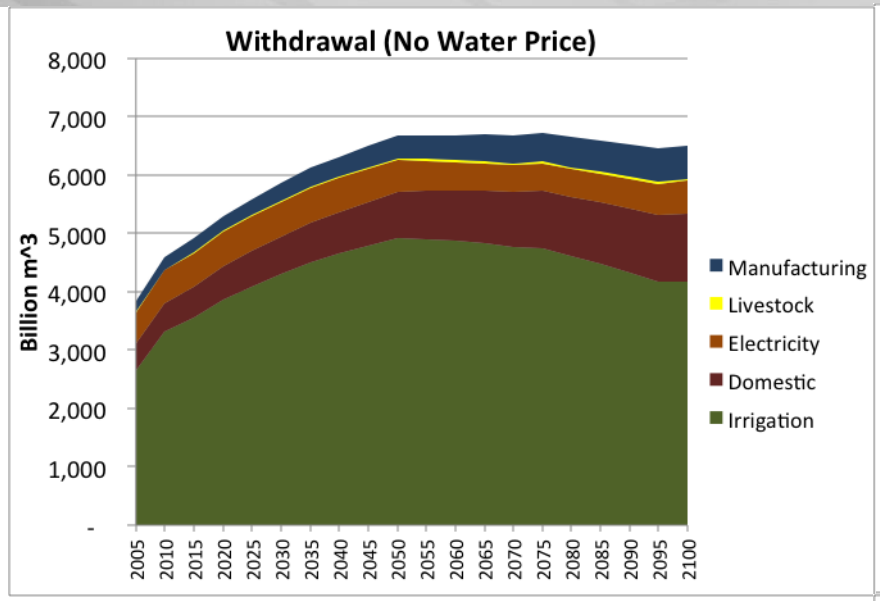


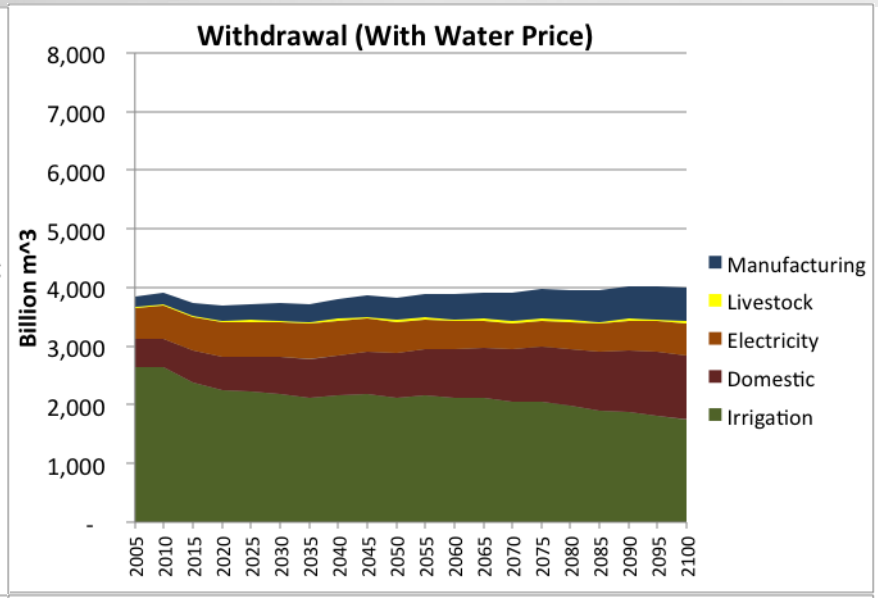
Water Scarcity - 2005

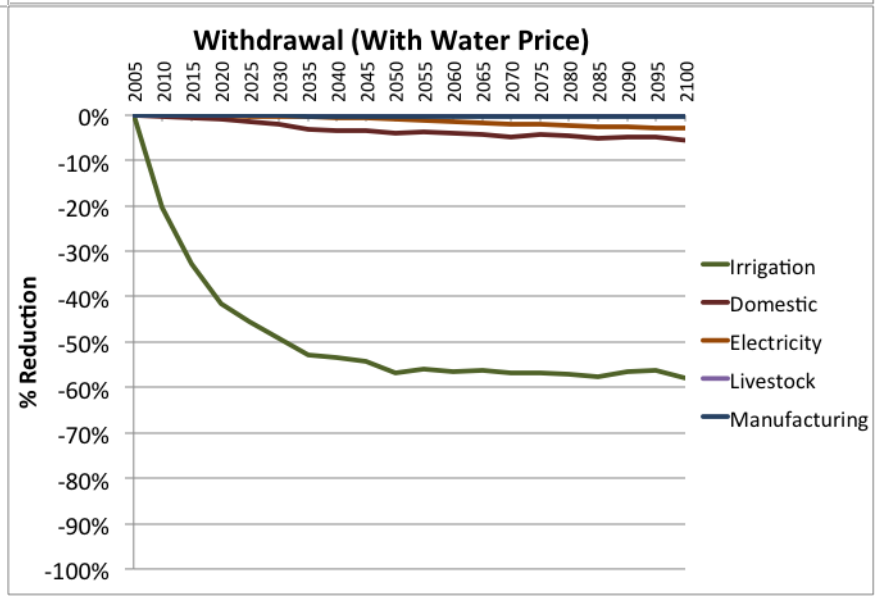




Agricultural demands are most affected by scarcity when GCAM uses a shadow price







2050: Regional Changes in ECONOMICALLY EFFICIENT Crop Production with Water Limits by AEZ

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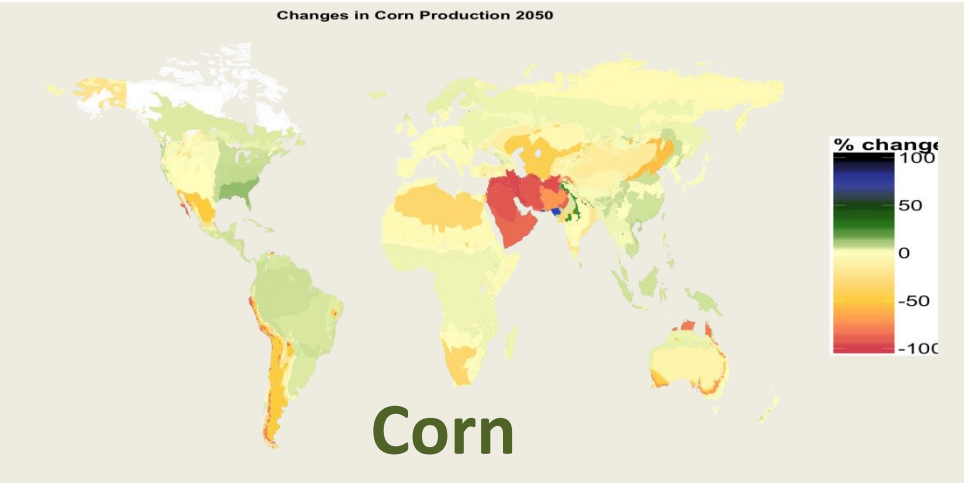

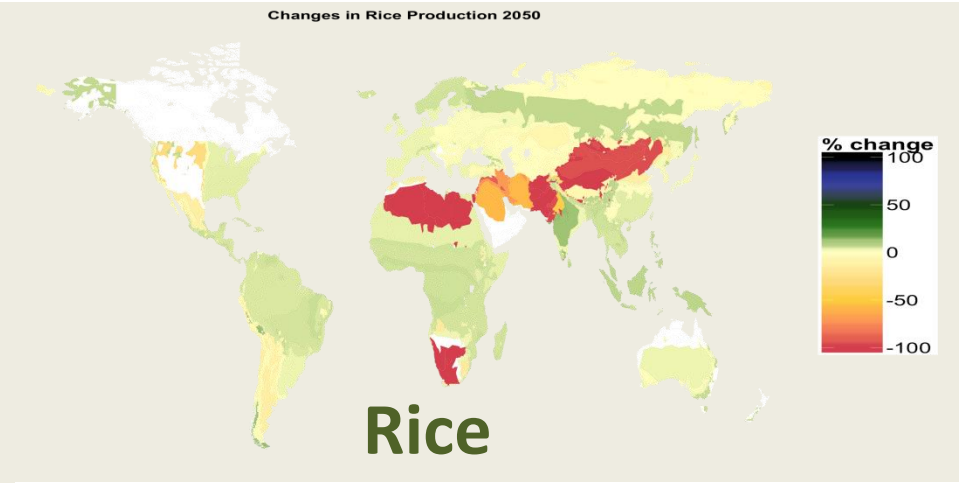

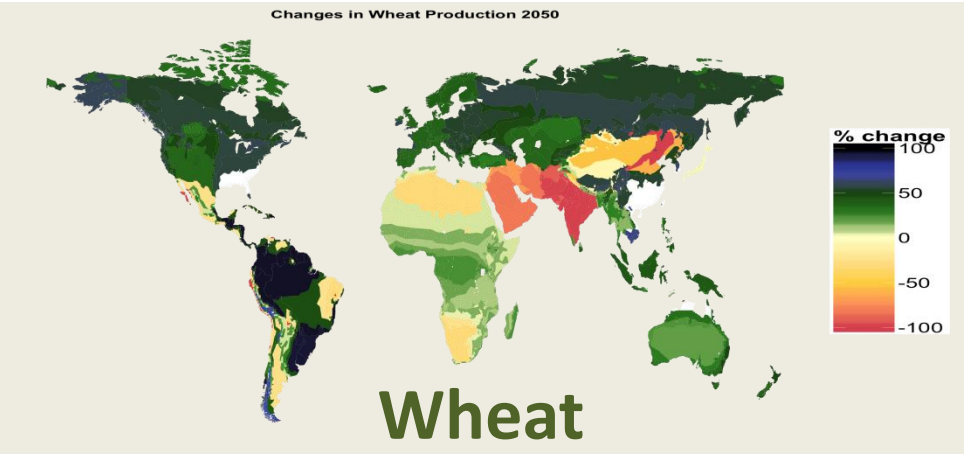

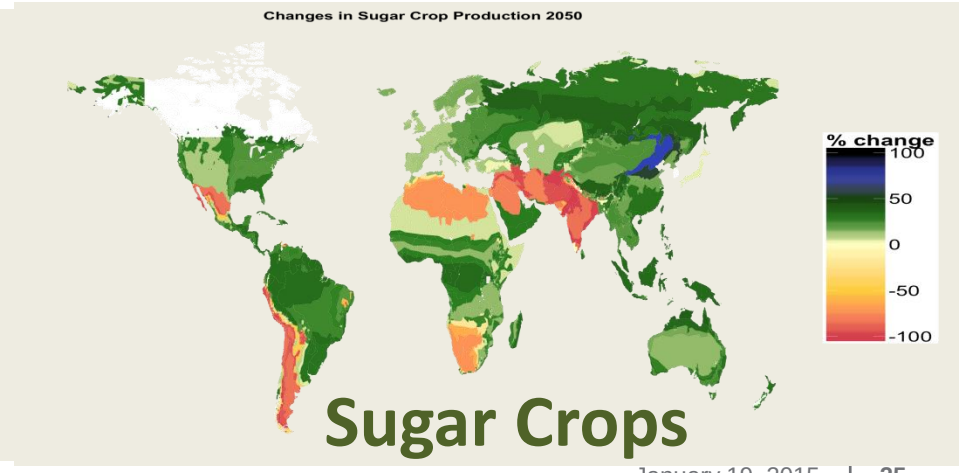

FUTURE DIRECTIONS

Looking to the Future

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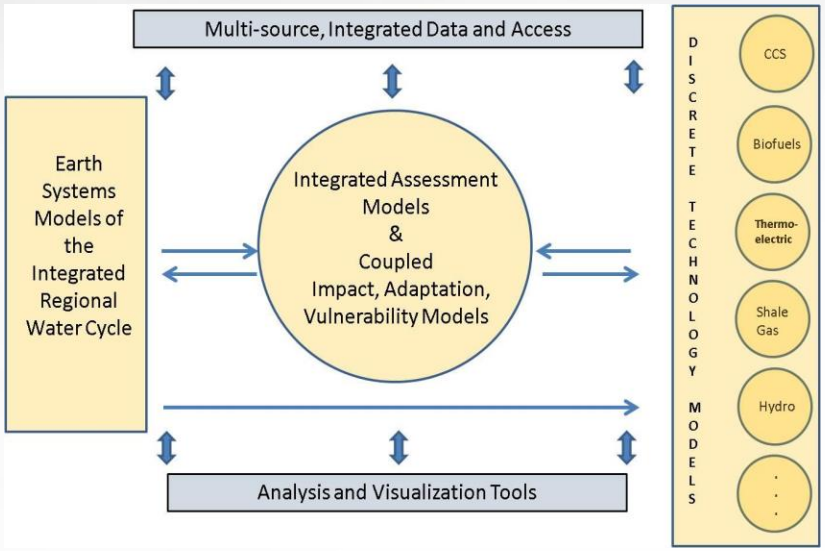
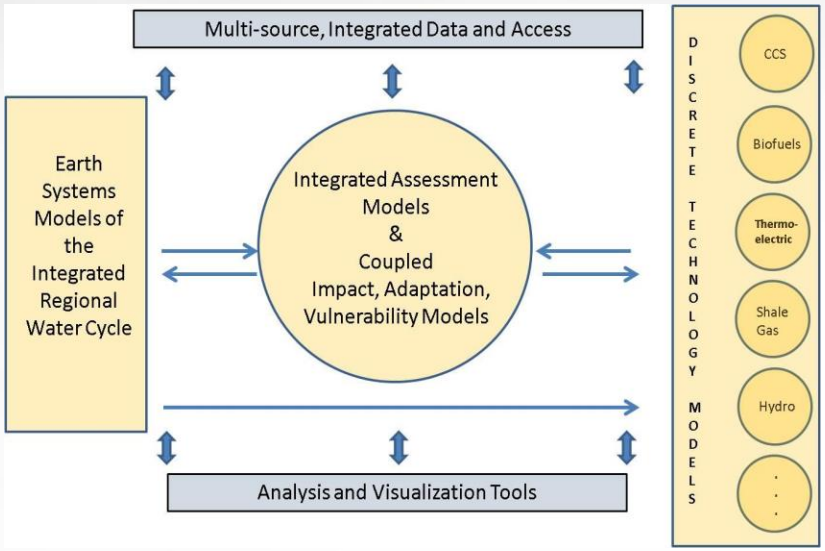
GCAM development will continue to be PROBLEM DRIVEN—E.g. climate impacts on the energy-water-land nexus.



Looking to the Future

GCAM development will continue to be PROBLEM DRIVEN—E.g. climate impacts on the energy-water-land nexus.

- **High-resolution input data**
  - Multiple sources
  - Reconciled data products
  - Multiple scales (appropriate to the problem at hand)
- **GCAM model modules**
  - Interoperable (appropriate to the problem at hand)
  - Utilization of GCAM's telescopic design to examine problems at a variety of resolutions—Space, Time, Sectors, Technologies
  - Connection to infrastructure models
  - Energy, water, land physical and economic system closure.



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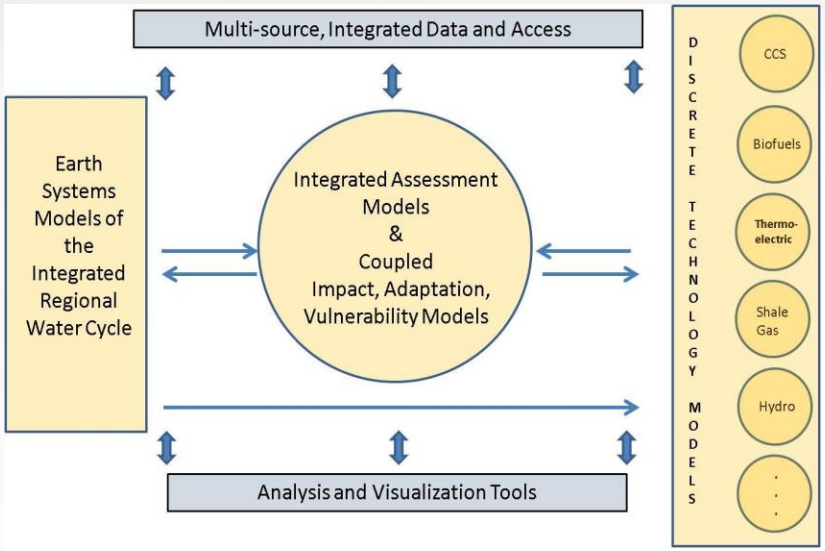

- ***GCAM's unique contribution remains INTEGRATION—the provision of insights from interactions between human and biogeophysical systems that would not otherwise be available from traditional independent disciplinary research alone.***

DISCUSSION