Adaptation in the Face of Inherent Uncertainty in Climate and Socioeconomic Futures

Perspectives/Directions in the MIT Joint Program on the Science and Policy of Global Change

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Vision and Goals

We explore the interplay between our global environment, economy and human activities, and the potential impact of policies intended to stabilize these relationships.

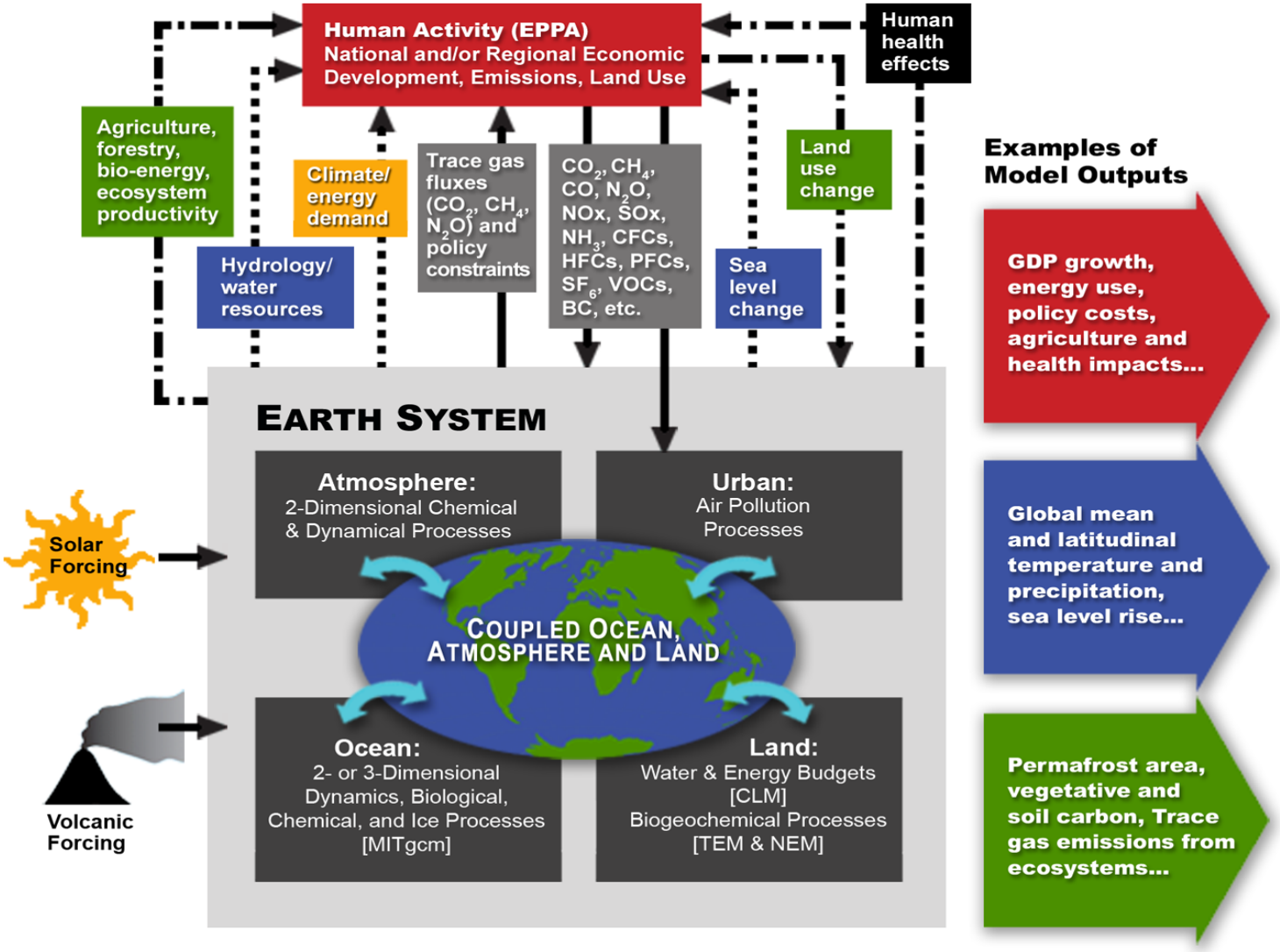
We depend on support of an international consortium of nearly 30 major companies, 7 USA Federal Agencies and 1 Foundation.

Our Goals:

- Discover new interactions among natural and human climate system components
- Objectively assess uncertainty in economic and climate projections
- Critically and quantitatively analyze environmental management and policy proposals
- Improve methods to model, monitor and verify greenhouse gas emissions and climatic impacts
- Understand complex connections among the many forces that will shape our future

THE MIT INTEGRATED GLOBAL SYSTEM MODEL (IGSM)

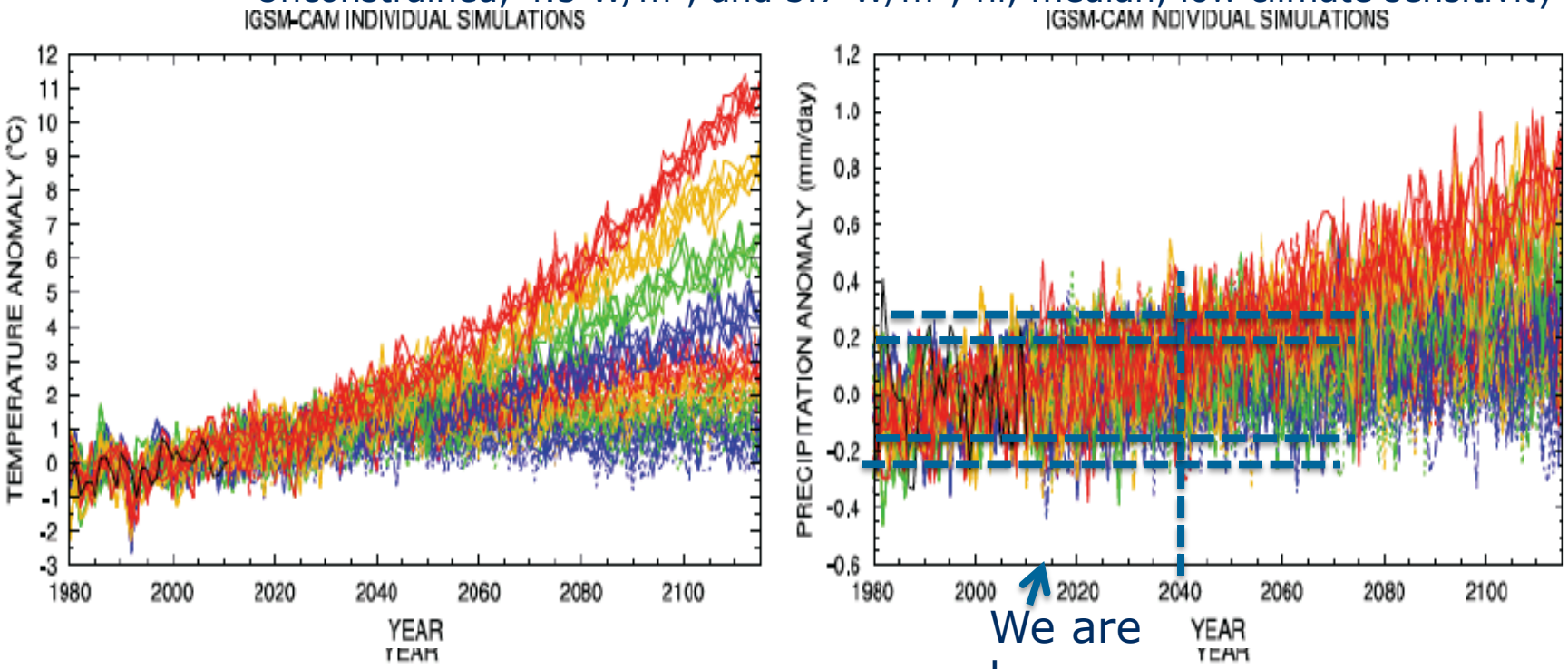
Earth and Human System Links



The adaptation challenge: climate is noisy

US mean Temperature (left) and Precip. (right)

Unconstrained, 4.5 W/m^2, and 3.7 W/m^2; hi, median, low climate sensitivity



When we talk of climate change we tend to think of smoother change or distant future where alternatives are distinct:

- if we believe that we will reduce emissions we can rule out larger changes
- but little evidence we will actually avoid them

Either way the near-term outlook is rife with uncertainty and variability.

But numerous forces affecting agriculture

- meeting the worlds growing and changing demand for food as population and income increase;
- adapting to environmental changes that affects agriculture, such as climate change, tropospheric ozone, aerosol haze, and soil degradation;
- other competition for land and water to meet energy, recreation, and urbanization needs;
- Altering agricultural practices to meet a variety of environmental constraints such as reduced soil erosion and run off of nutrients into streams, lakes, and coastal areas, and reduced greenhouse gas emissions;
- Local agriculture will face continued competitive pressures from an increasingly globalized agricultural markets;
- changes in technology;
- the "industrialization" of agriculture

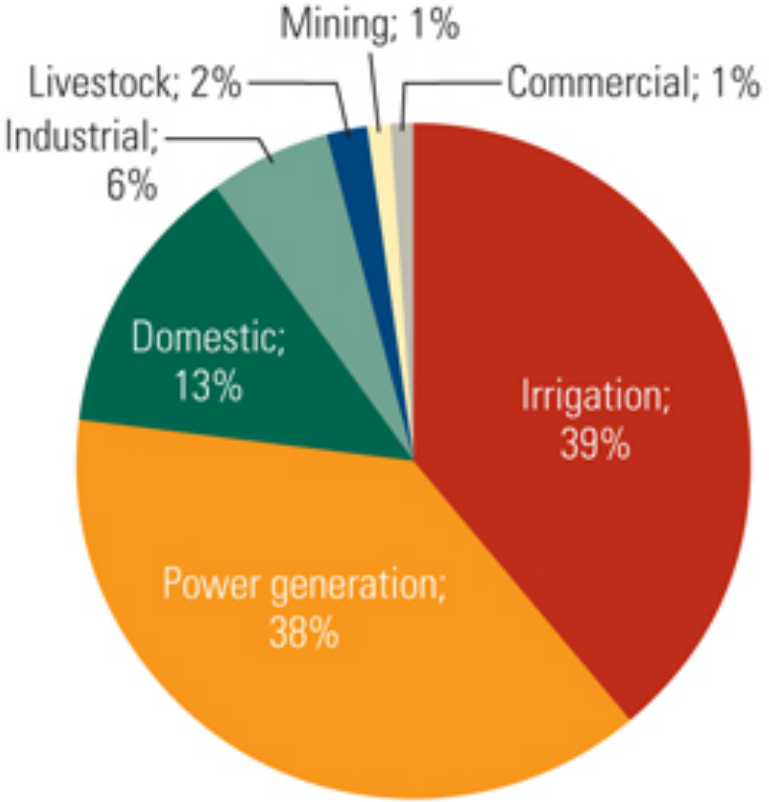
Will these increase agricultural and forestry sustainability, or make it more difficult to achieve?

And links to water and energy

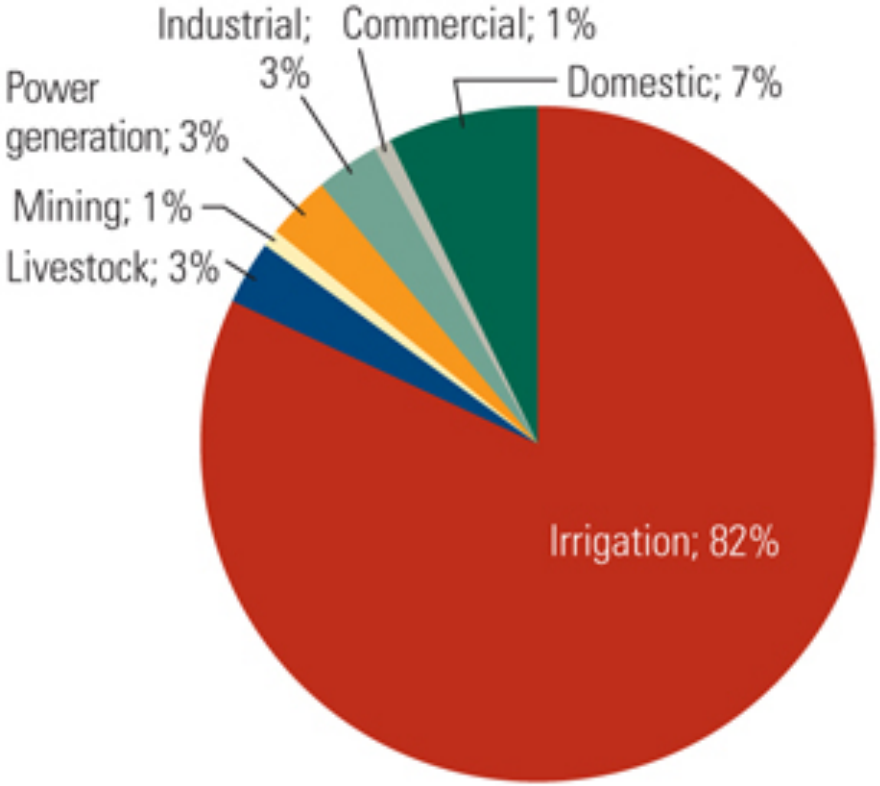
- Climate change will bring rising temperatures and shifts in precipitation, river runoff and soil moisture
- Much of world population water is stressed now.
  - ✓ .8 b. lack clean water
  - ✓ 2.4 b. without sanitation
  - ✓ 1.3 b. with no electricity
- Food demands will add pressures
  - ✓ Production may need to rise by 70% by 2050
  - ✓ 40% of cereal output is from irrigated land
- Growth in water demand in many regions as incomes, populations rise and concern about freshwater ecosystem…and e.g., biofuels, power plant cooling

UN, 2013

Withdrawals vs. Consumption (e.g. US)

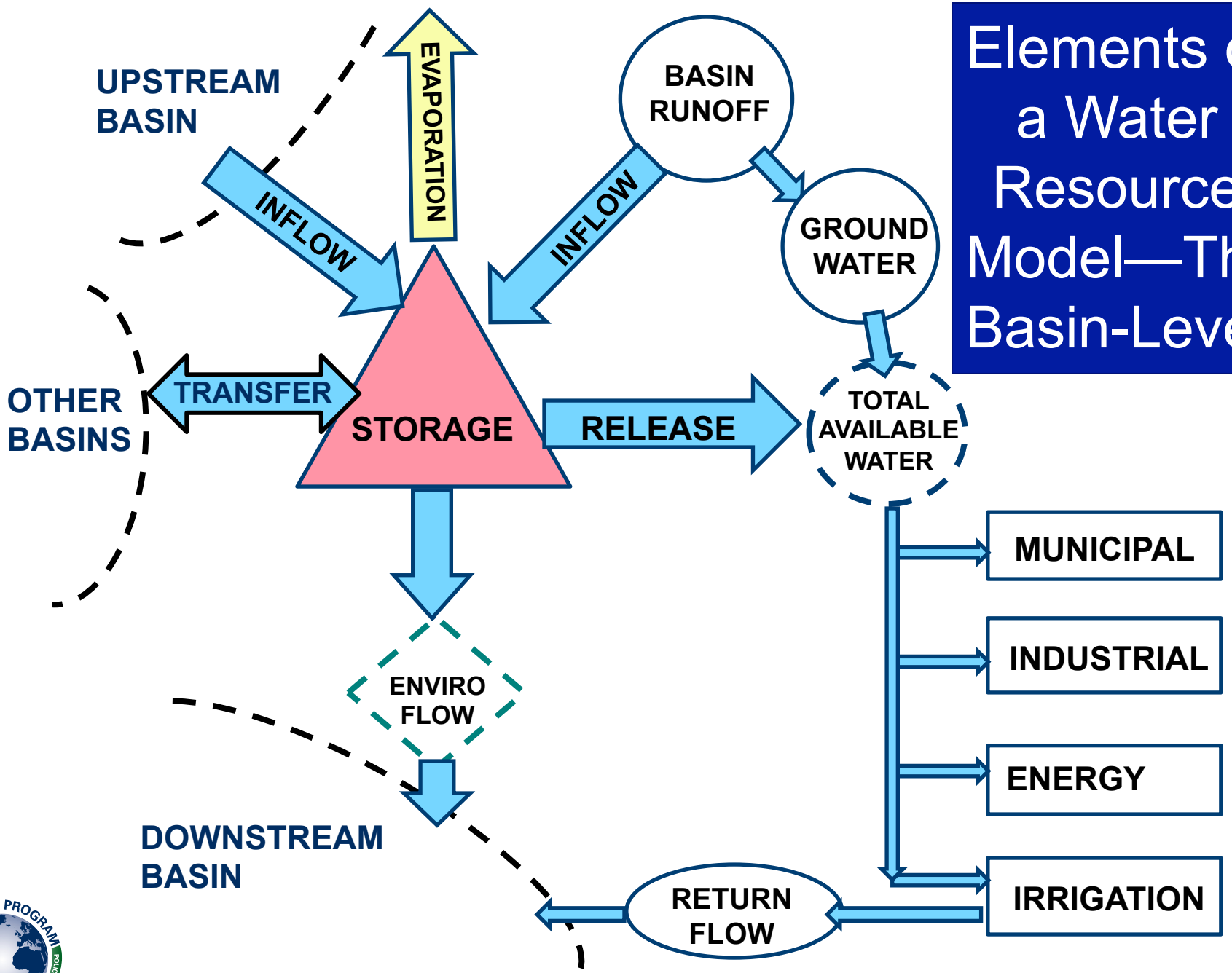


Freshwater withdrawal



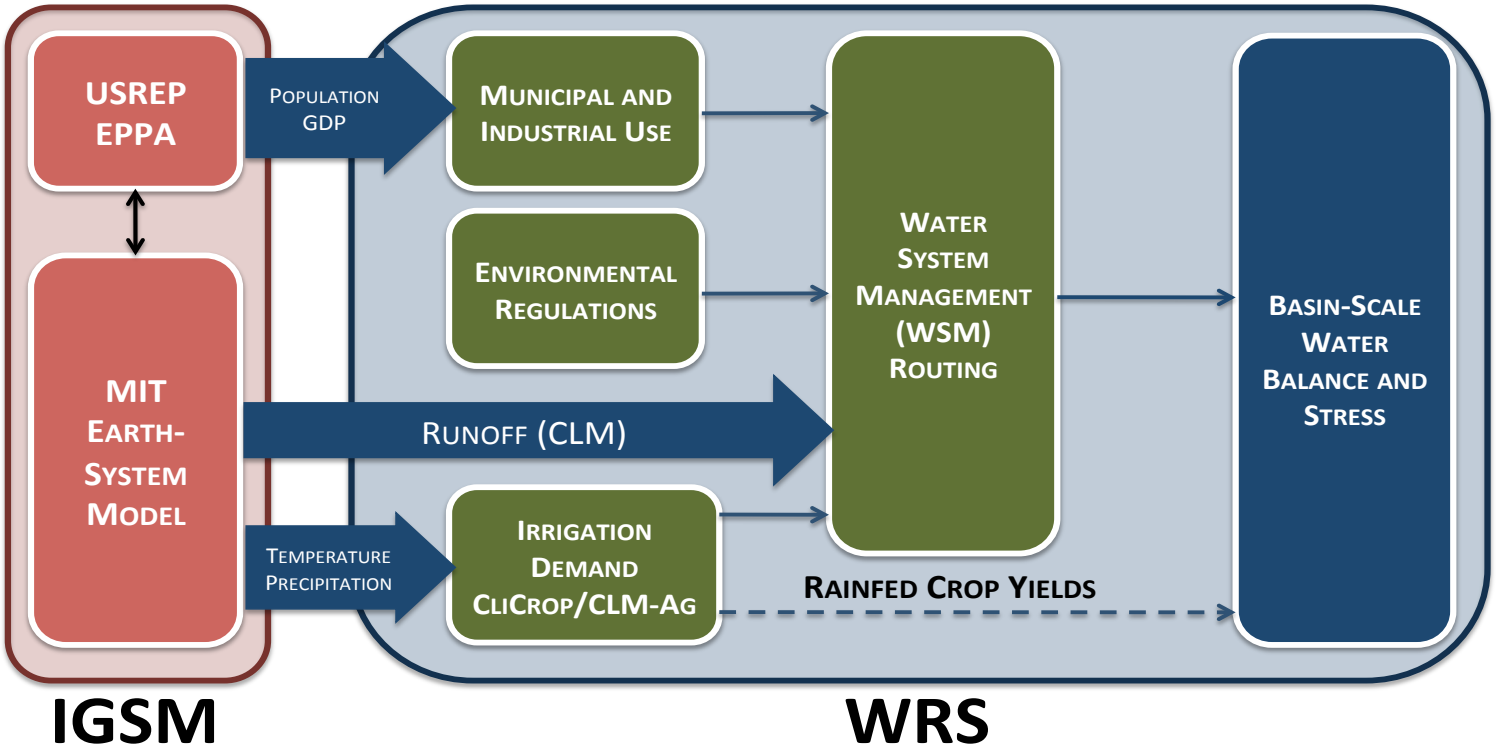
Freshwater consumption

Elements of a Water Resource Model—The Basin-Level

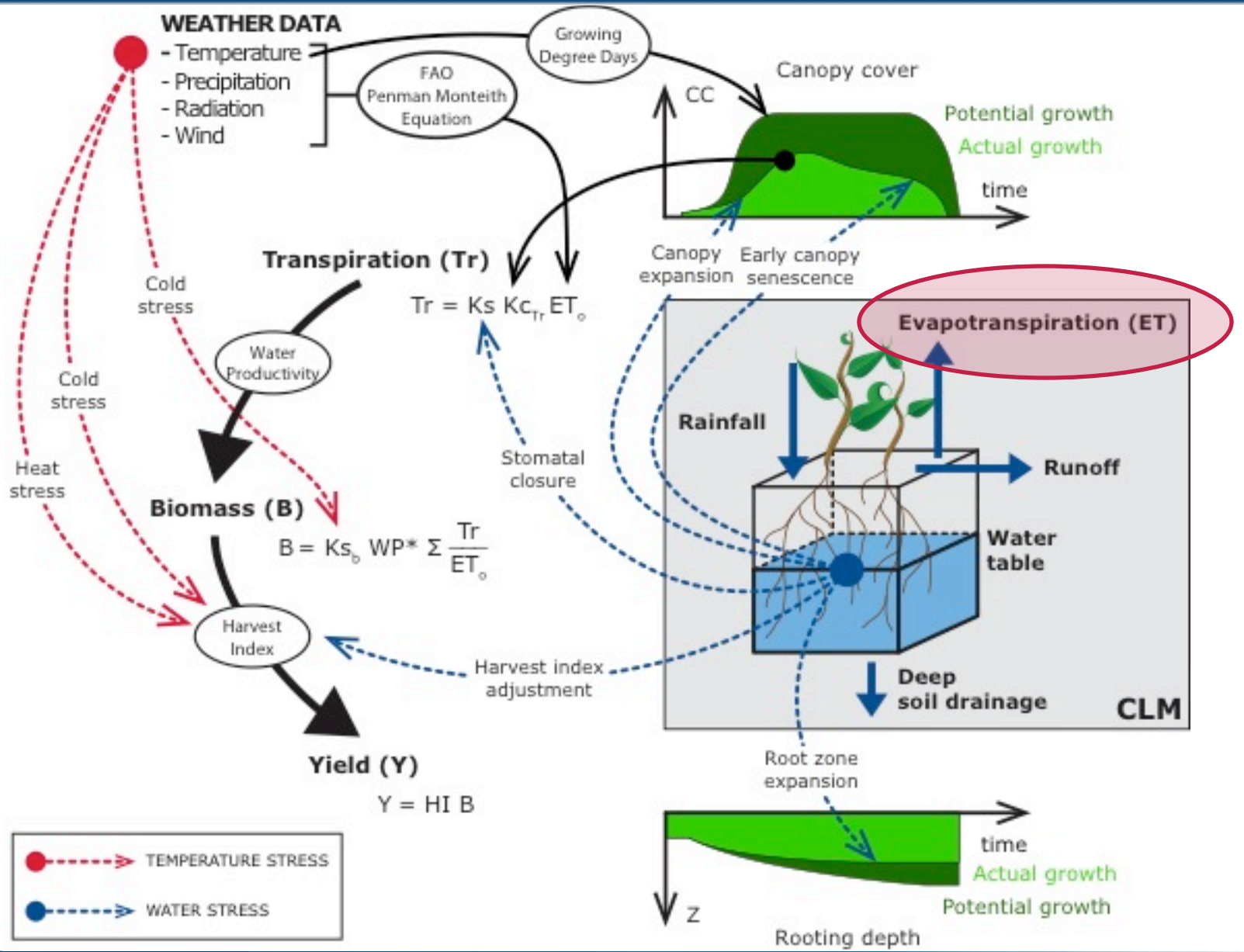


MIT-JP Basic Water Resource System model

- Considers changes in availability by water basin
- Models demand from all sectors & environmental flows
- Extend analysis to represent uncertainty in climate and growth
- Goal
  - Screen larger basins for potential water stress—hand-off to others with more detailed models analysis of the region
  - Link to other components of the MIT



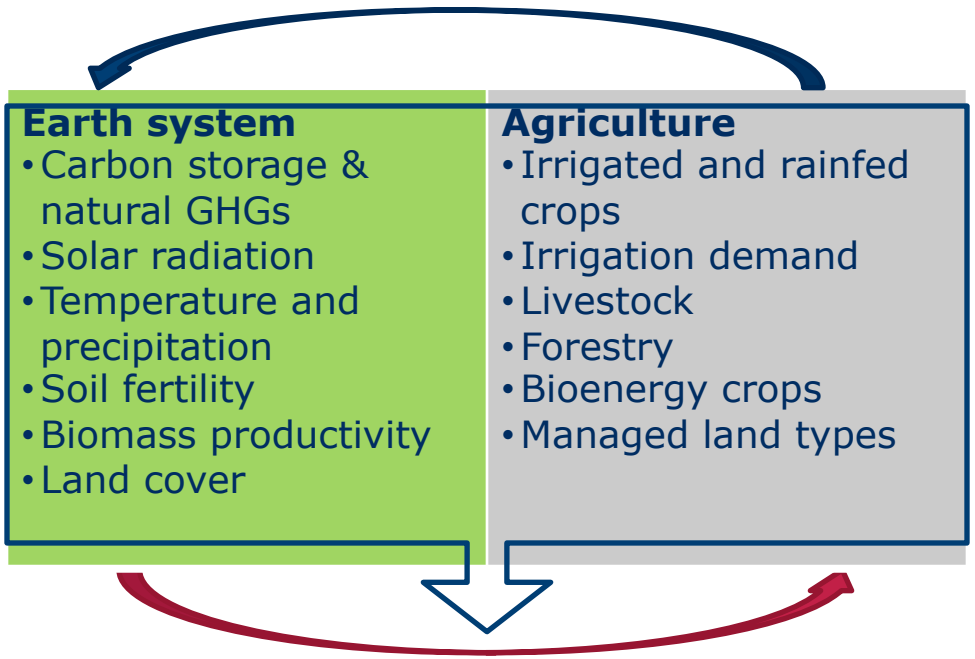
Elements of Crop-Water model



MIT-IGSM Vision for a fully elaborated linked water-agriculture model

Drivers of agriculture and earth system change
- Econ & Pop Growth, Diets, Policies

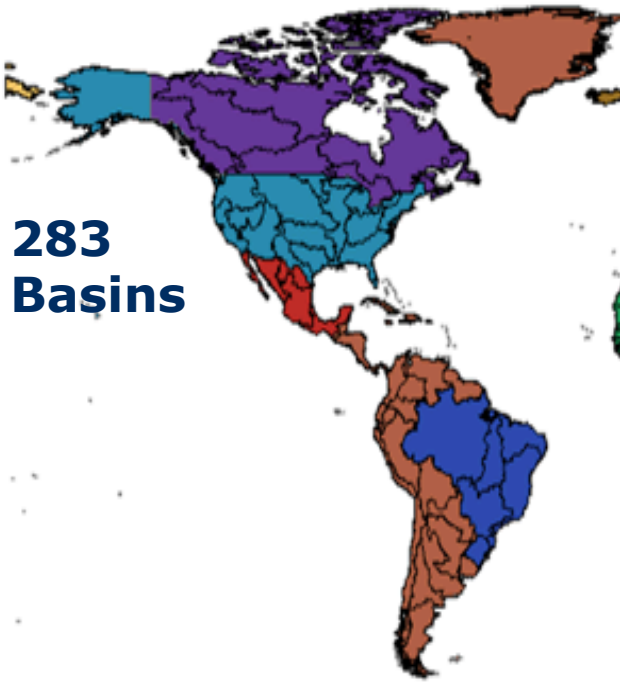
Natural processes: biogeochemical cycle, hydrological cycle, plant growth, atmosphere and ocean circulation

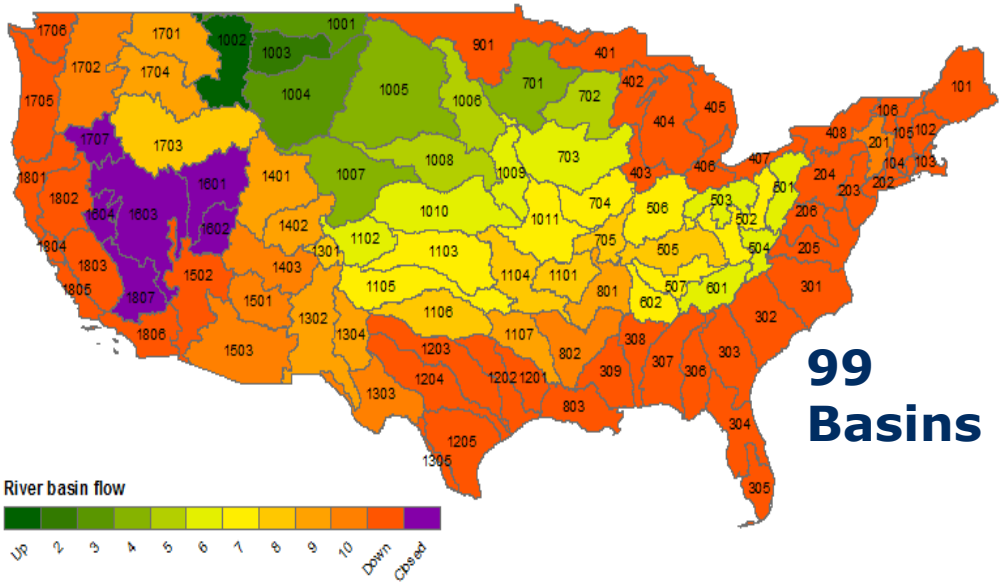


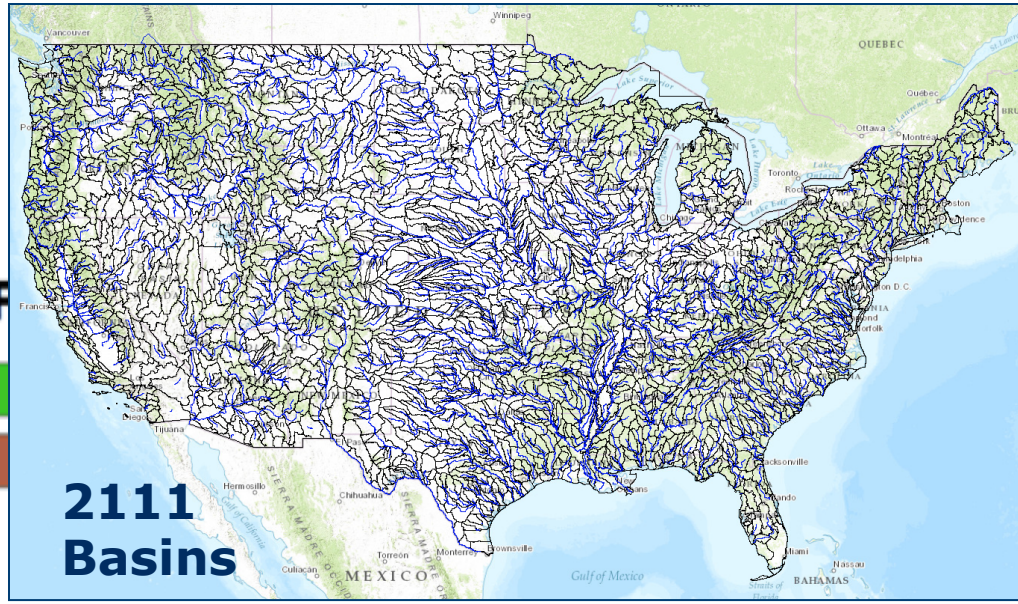
Human processes: Agricultural practices, land allocation, water allocation and storage, supply and demand interactions, international trade

Questions we hope to address
- How will climate change and policies affect yields?
- How will water be used?
- What types of crops will be grown and where?
- Will there be deforestation?

The Downscaling Task





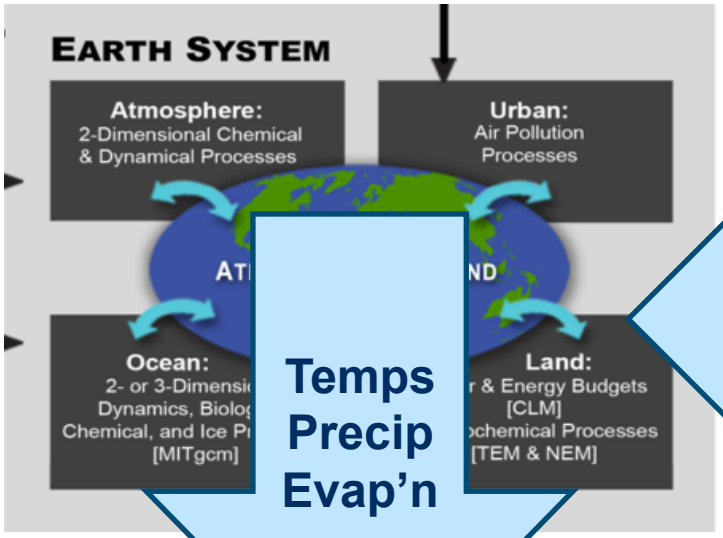


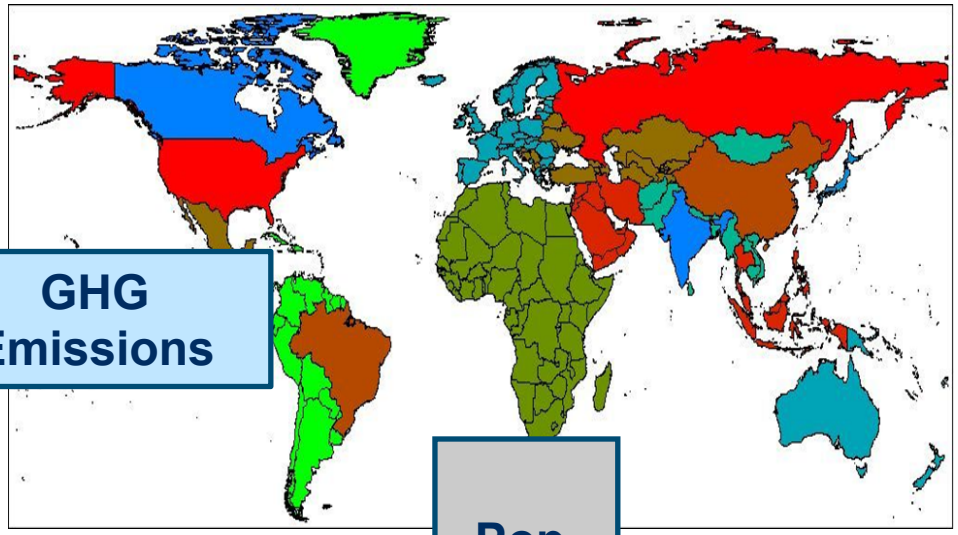
EPR

RUS REA MES JPN

USA ROE MEX LAM

Integrating the Components





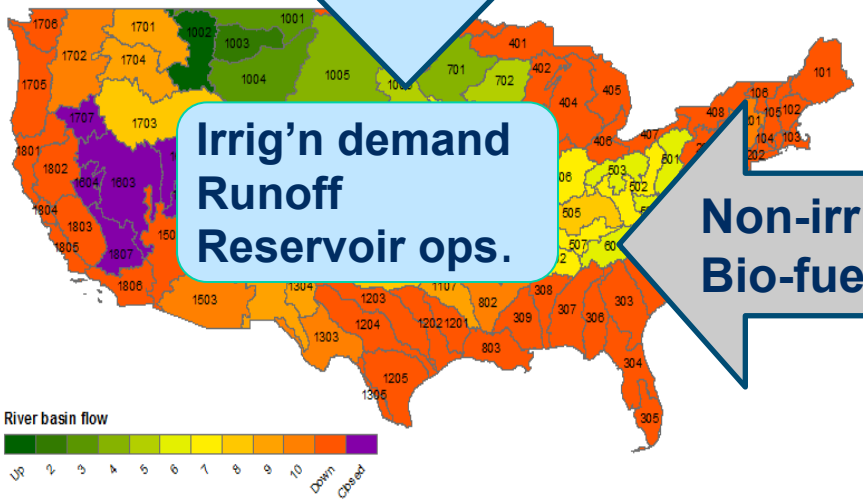
GHG Emissions

Temps
Precip
Evap'n

Pop.
GDP
Policy
Trade

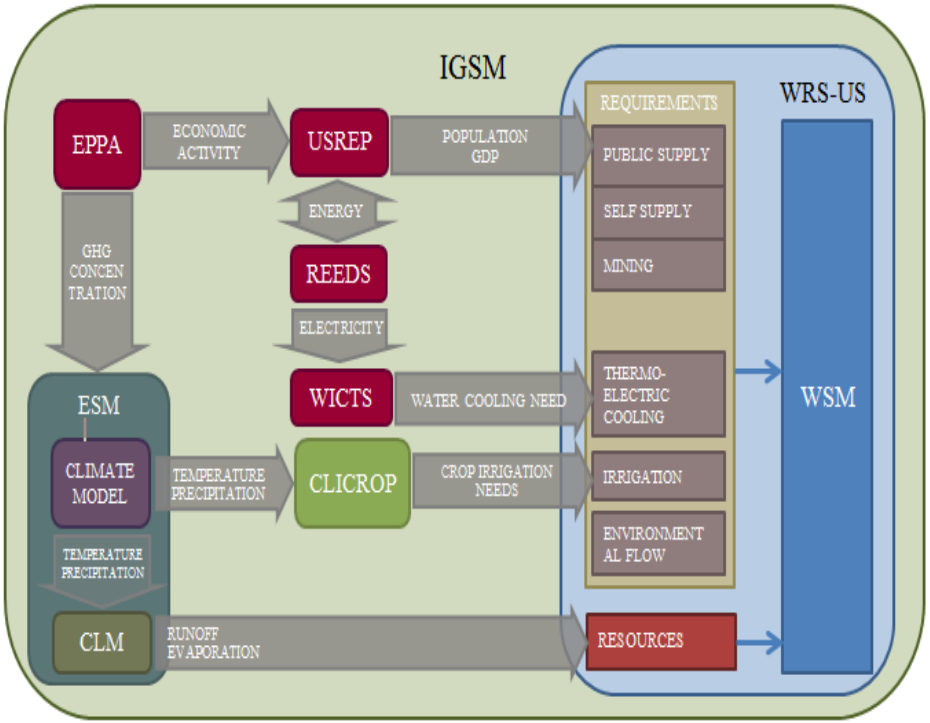
Irrig'n demand
Runoff
Reservoir ops.

Non-irrig'n demands
Bio-fuels, etc.

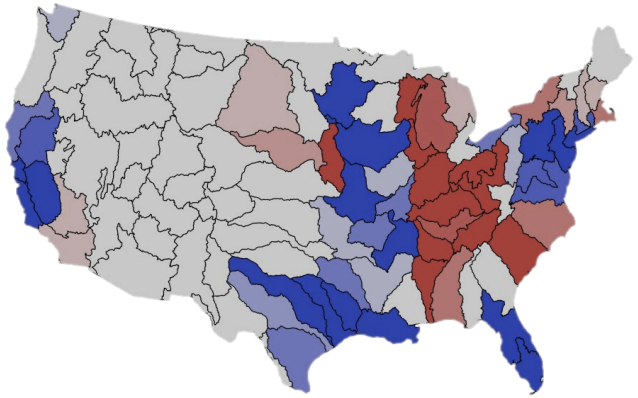


Regional Focus: United States

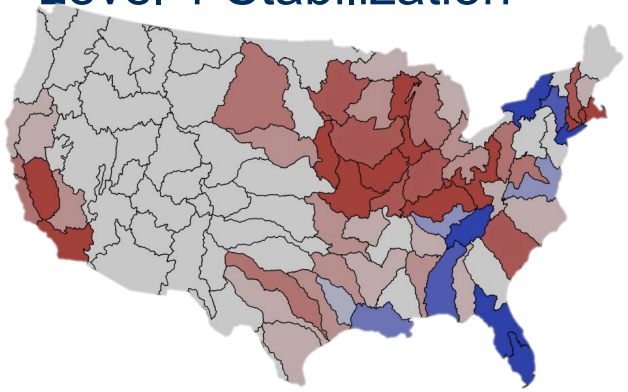
IGSM-WRS-US



Unconstrained Emission



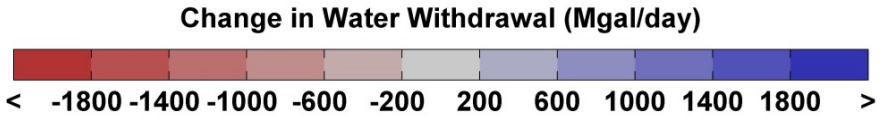
Level 1 Stabilization



Why less with mitigation?

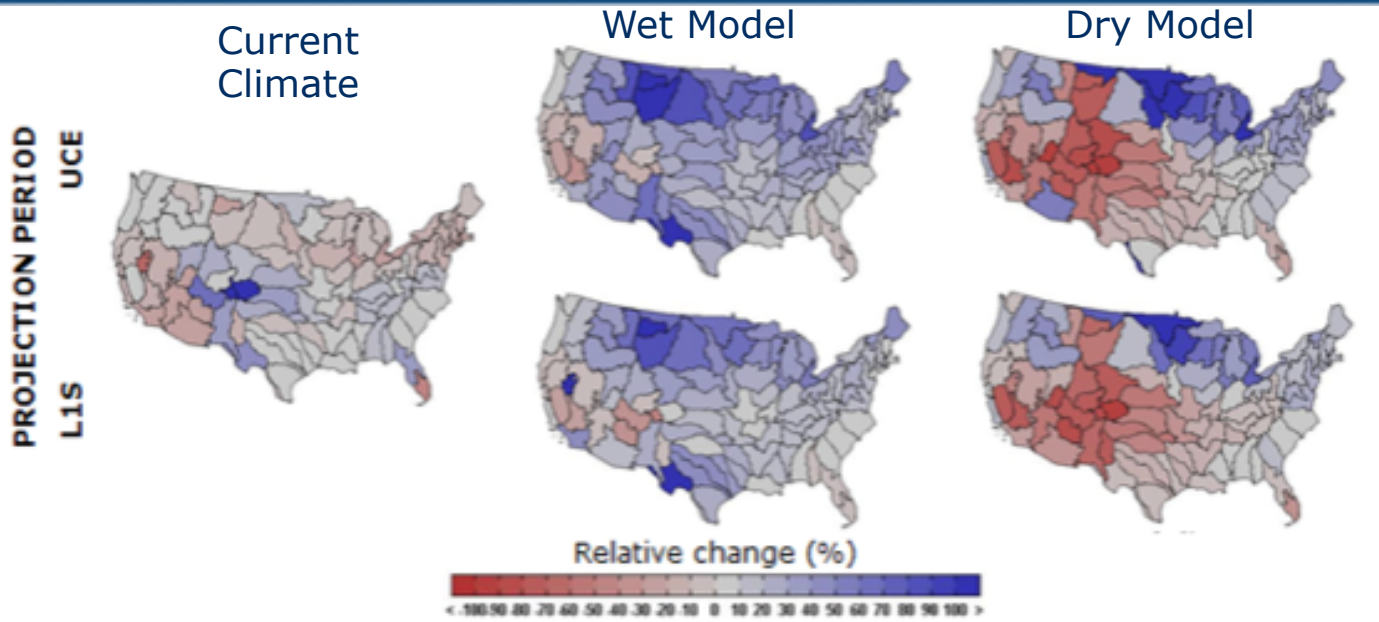
- Lower electric demand
- Shift coal to gas
- More renewables

Change in Cooling Withdrawal (Mgal/day)

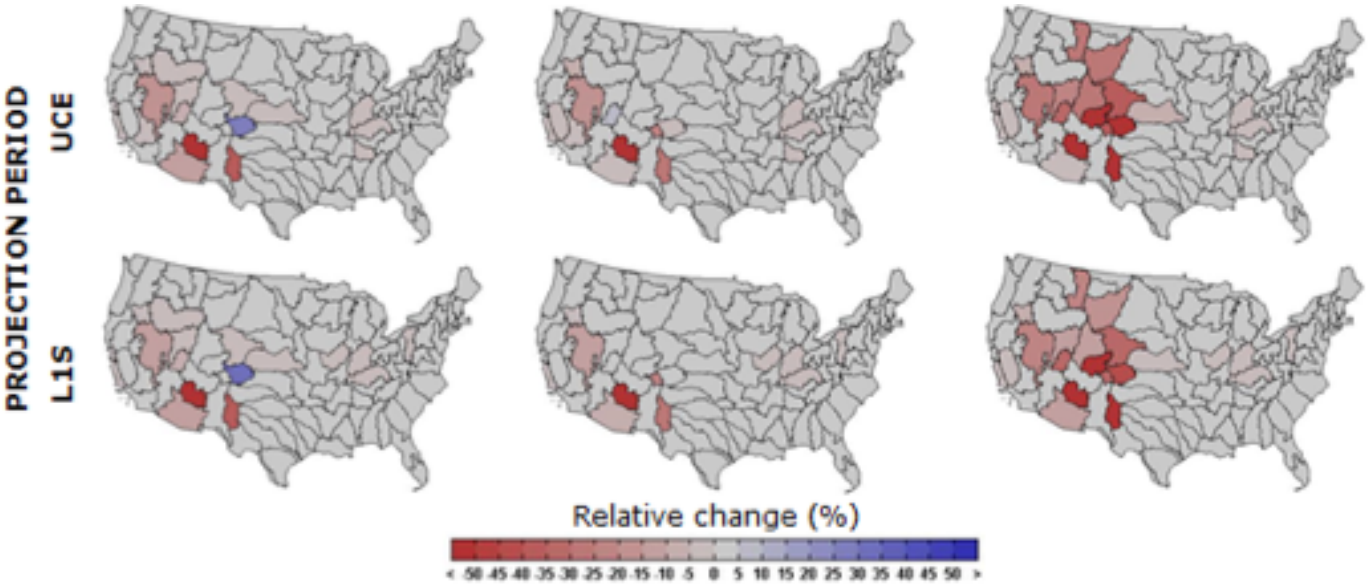


Projected Changes to 2050

Runoff



Water Stress



U.S. Powerplant Cooling Analysis

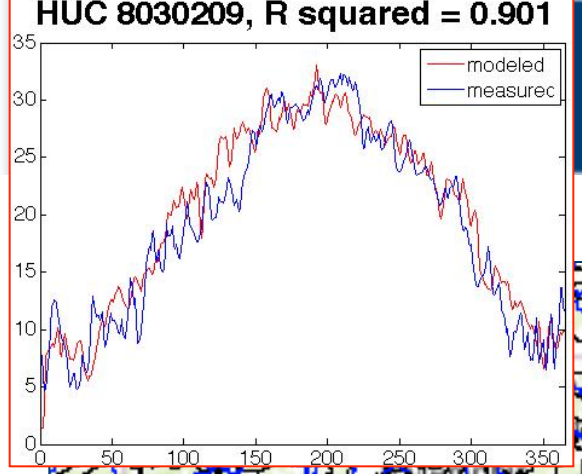
- The task
  - ✓ Model river temperature at 8-digit HUC scale
  - ✓ Evaluate water analysis using historical data
  - ✓ Incorporate power plant details
  - ✓ Explore cooling problems with climate change

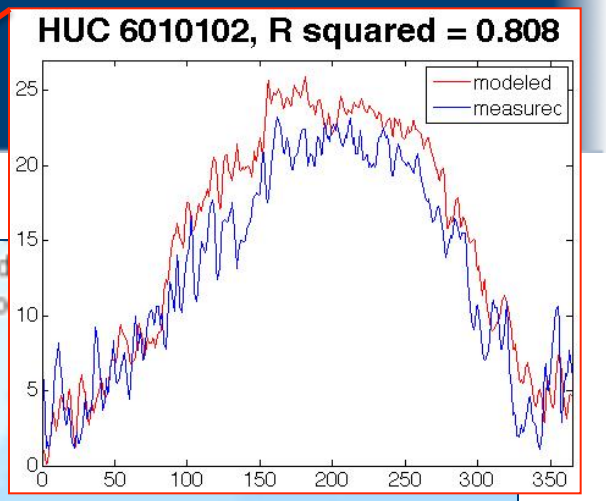
- Preliminary analysis of 2050 conditions
  - ✓ Temperatures from IGSM projection
  - ✓ Streamflow from IGSM-WRS-USA projection
  - ✓ Calculate days of power production lost per year due to mixing zone or temperature violations

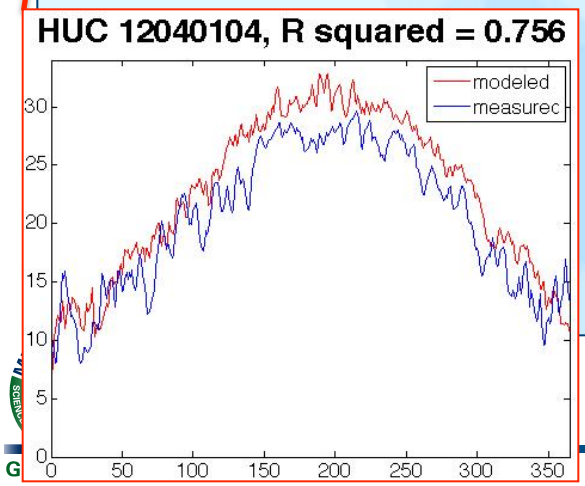
Environmental Conflict with Cooling

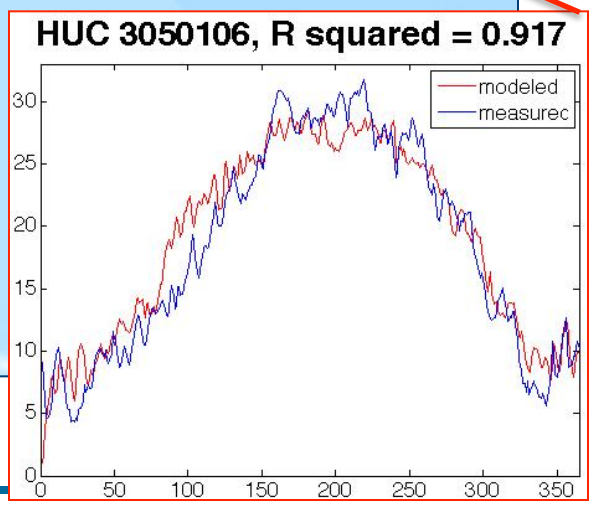
- **Europe, summer of 2003**. Spain shut down its reactors while France and Germany allowed some to operate and shut down others.
- **Illinois, Minn., July 29 to Aug. 2, 2006**. Prairie Island (Minn.) plant had to reduce output by 54%.
- **Southeast U.S, Aug. 5-12, 2008**. All three TVA Browns Ferry reactors idled to prevent overheating of the Tennessee River.
- **France, July 2009**. Almost a third of nuclear generating capacity lost due to discharge limits.
- **Southeast U.S., July, August 2011**. To meet discharge limits the TVA reduced power at Browns Ferry to about 50 percent of capacity

Model Test

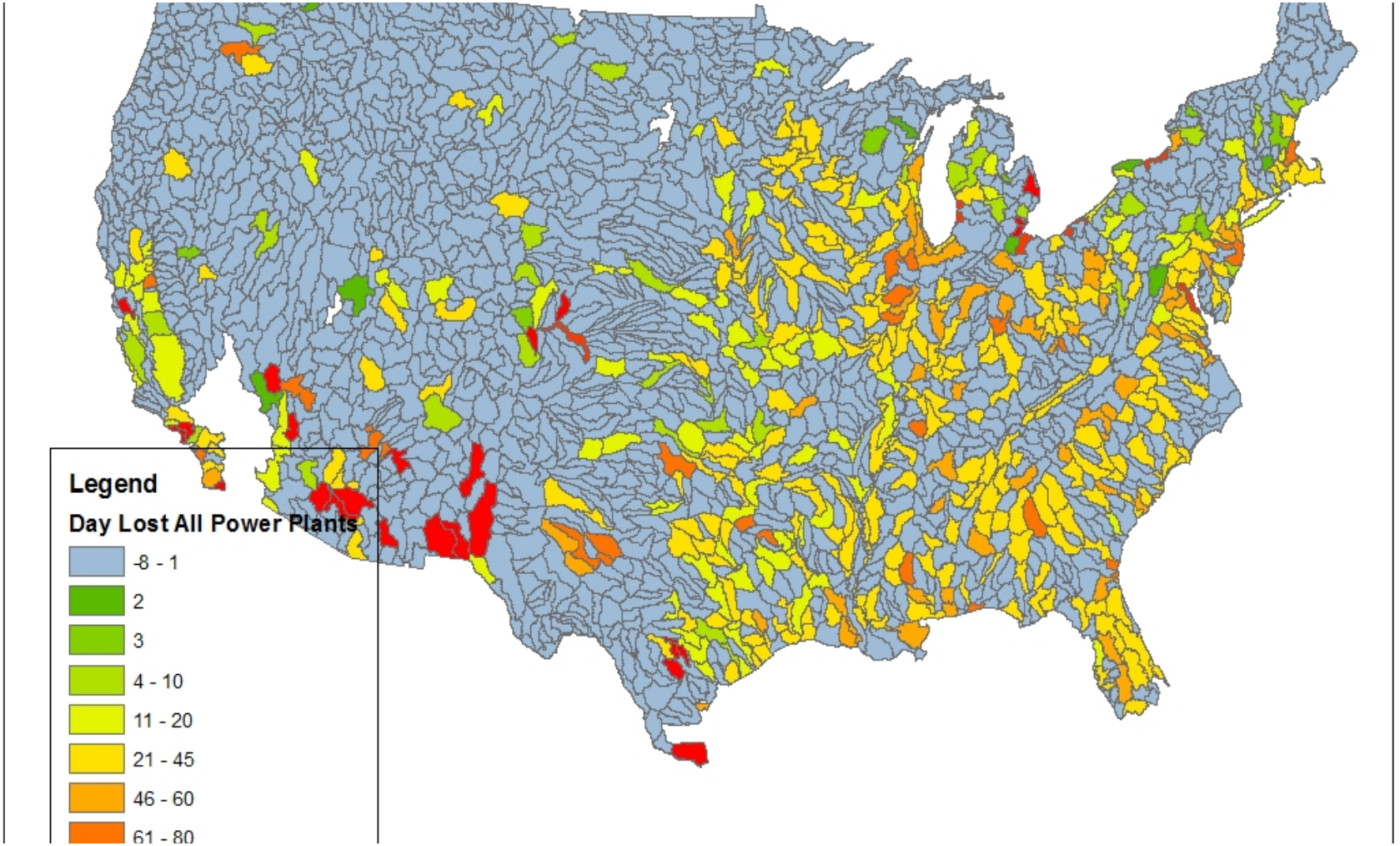

HUC 8030209, R squared = 0.901
modeled
measurec


HUC 6010102, R squared = 0.808
modeled
measurec


HUC 12040104, R squared = 0.756
modeled
measurec

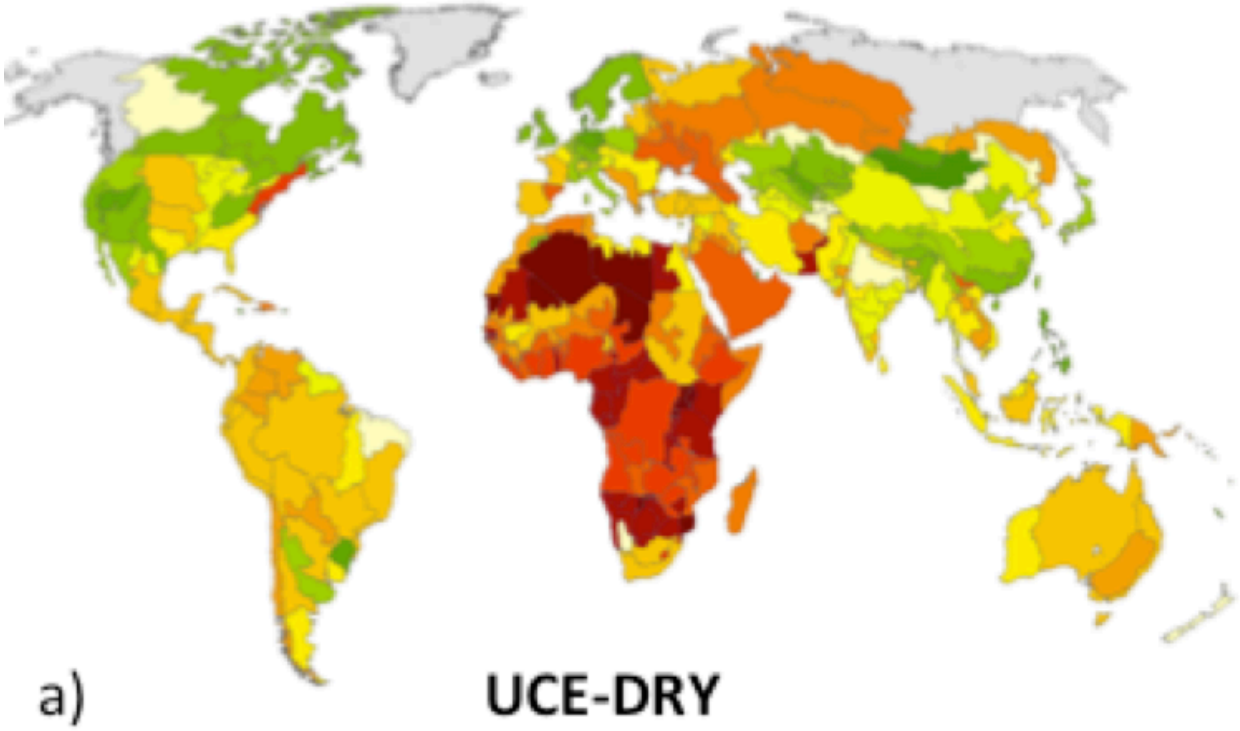

HUC 3050106, R squared = 0.917
modeled
measurec

Days of Lost Generation in 2050

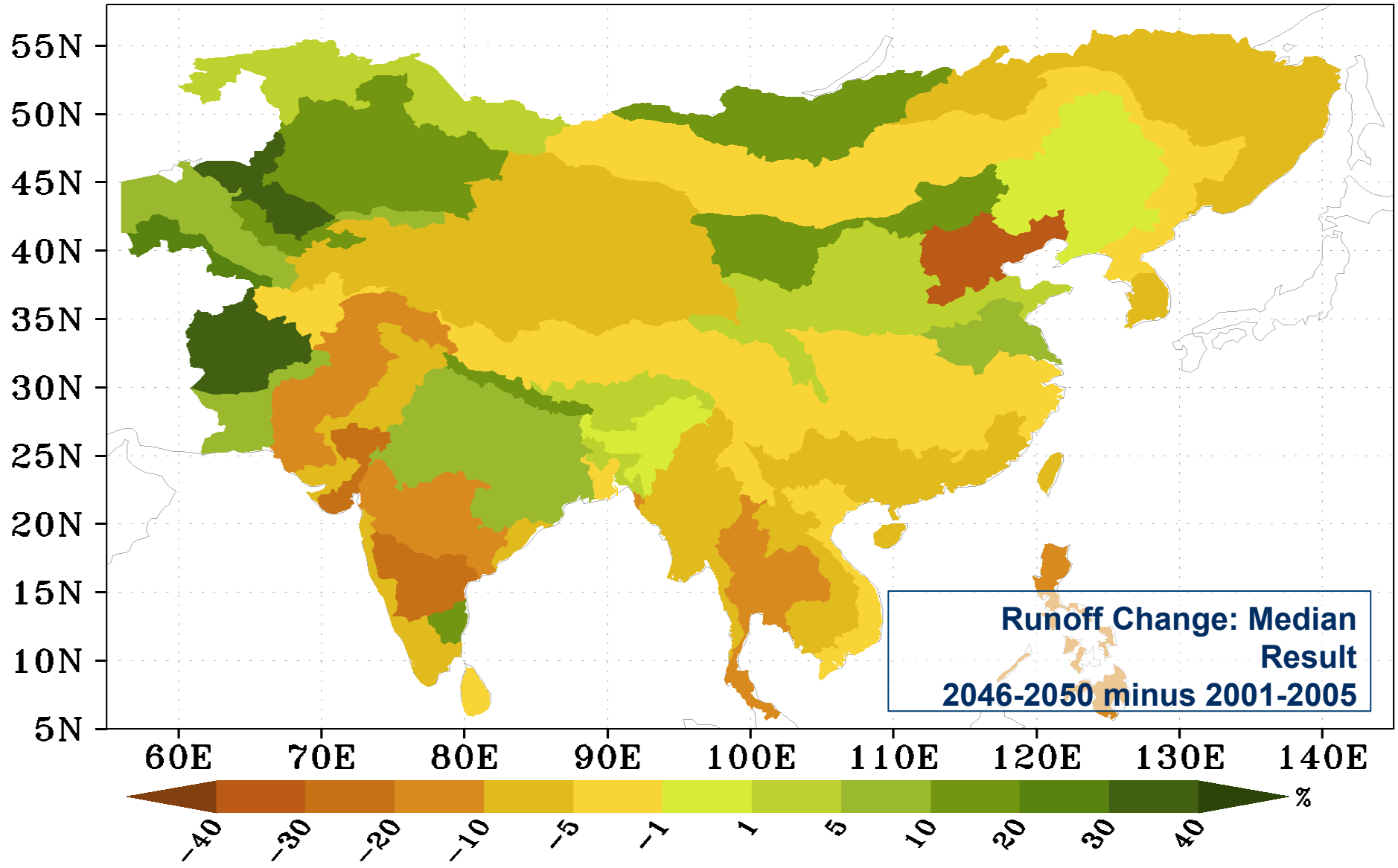


Projection of 2050 Global Water Stress

- Overly stressed population nearly doubles by 2050
- 80% of overly stressed population now is in developing countries
- In developing countries economic growth is the primary driver of stress

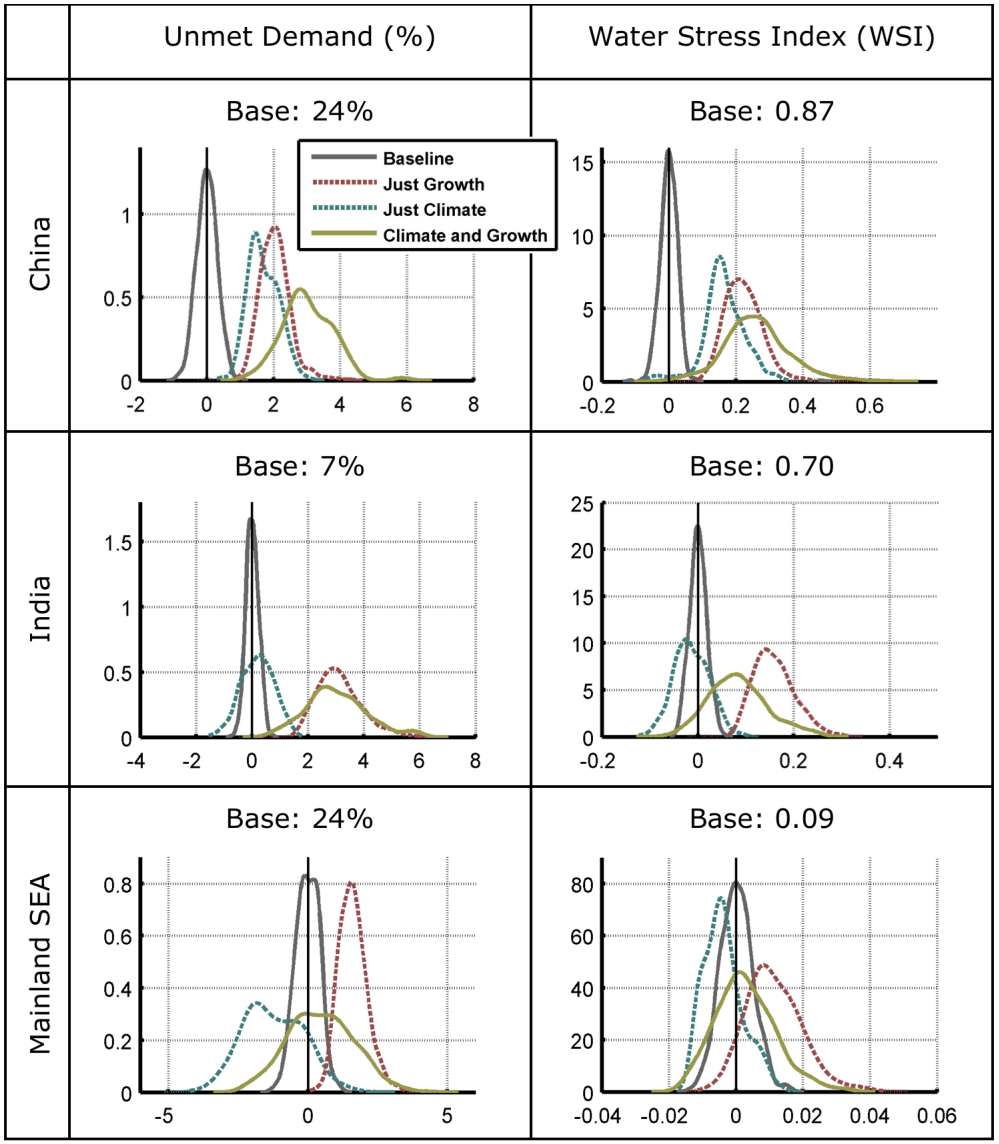


Uncertainty: South & East Asia

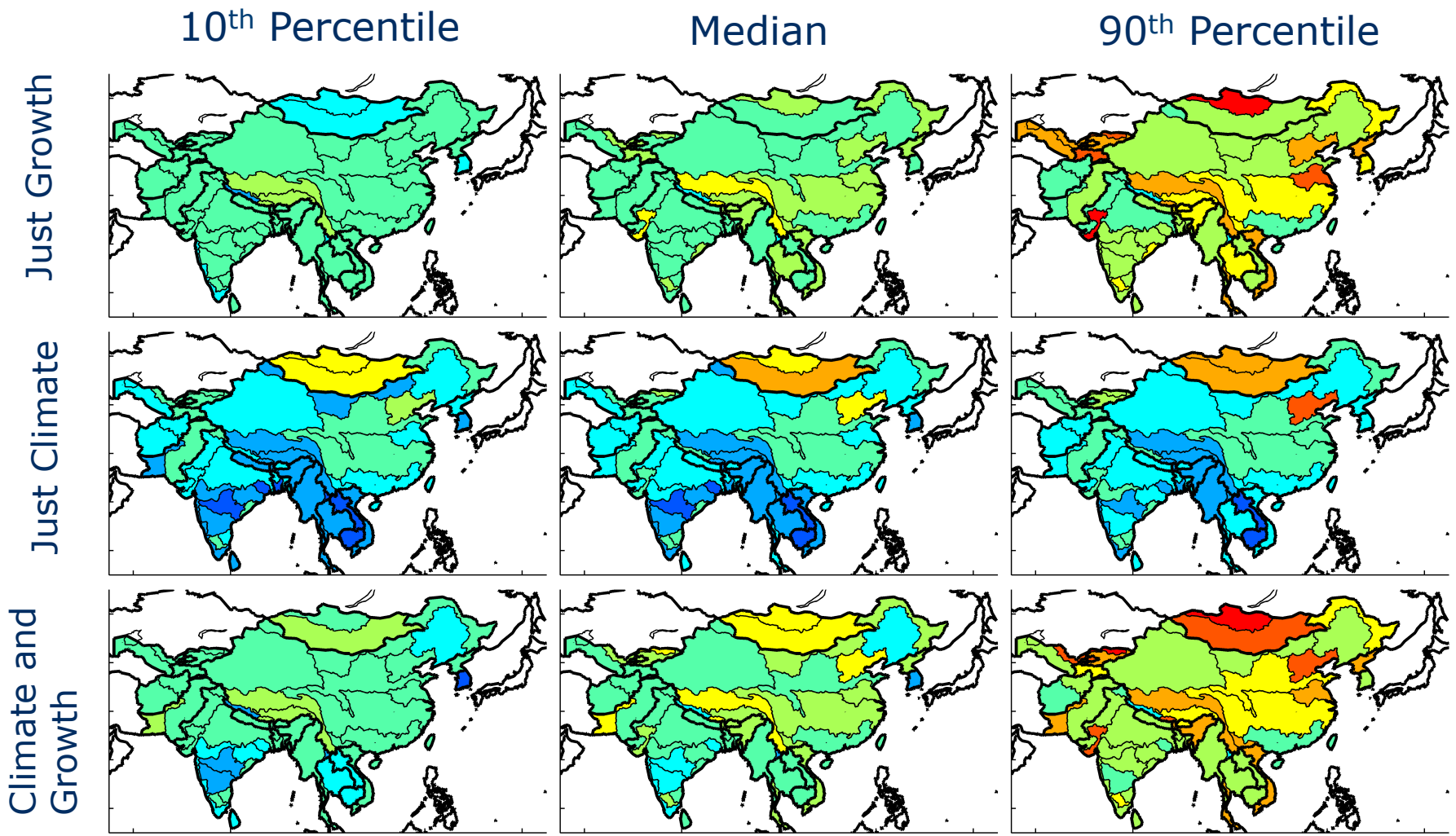


Changes in Southeast Asia ASR Unmet Demand and Water Stress (WSI)

Plots show changes in decadal averaged (2040-50) unmet demand (%) and water stress index (unitless) aggregated over political boundaries and weighted by population.

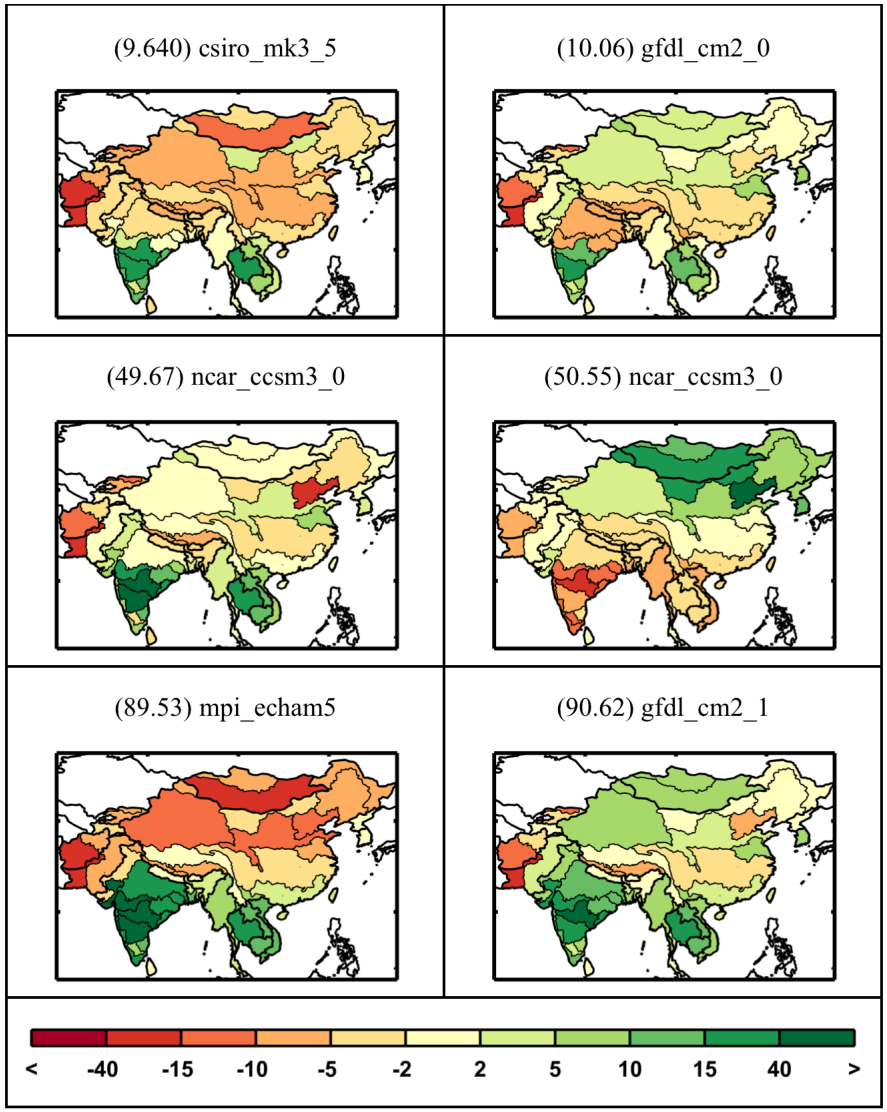


WSI: Change from Baseline



Examples of runoff change (in %) around the 10th percentile, median, and 90th percentile

Patterns from different GCMS are much different even for relatively dry or wet (or median) scenarios for the South and East Asia as a whole.



Not quite 10th percentile

Not quite median

Not quite 90th percentile

Climate, CO_2 Concentrations, and Changes in Land Carbon Storage

- Land policy gets us another ½ degree of avoided warming.
- Not much difference between the no biofuels and biofuels policy.
- With land incentives, land is a major sink.
- The climate policy also helps largely because we need less land for crops because of less environmental (ozone) damage.

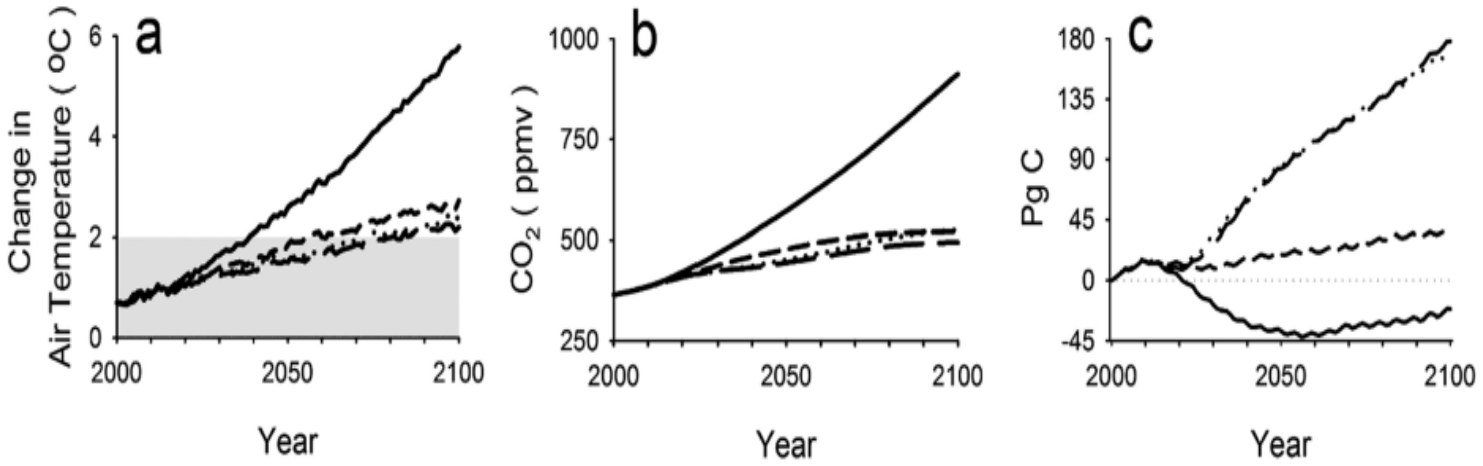
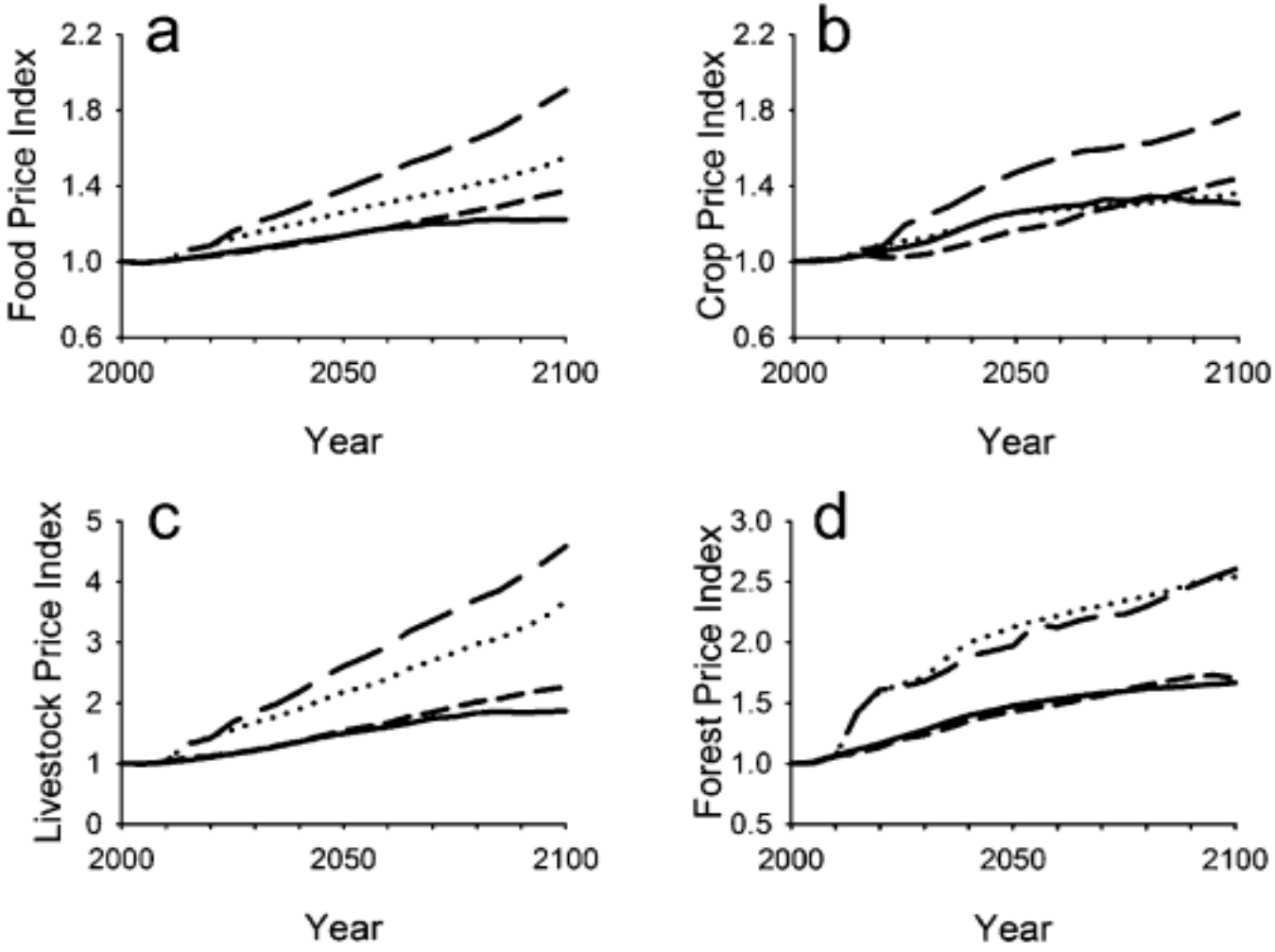


Figure 2. Changes in global mean temperature from preindustrial level (a), atmospheric carbon dioxide (CO_2) concentrations (b), and changes in cumulative land carbon fluxes (c) over the 21st century for different climate/energy policies: *No-Policy* (solid line), *Energy-Only* (short dashed line), *Energy+Land* (long dashed line), and *No-Biofuel* (dotted line). The shaded area in (a) represents the temperature goal of 2 °C above preindustrial of the Copenhagen agreement. Positive values in (c) represent net terrestrial carbon sequestration, while negative values represent net loss of terrestrial carbon to the atmosphere.

Big Effects on Food Prices When Land Carbon Priced



Surprising result:
No-policy and energy only about the same.

Less environmental damage w/ energy policy, but higher energy and GHG control costs offset benefit to crops.

Energy+Land has big price impacts. w/o biofuels some pressure off.

Solid: no-policy
Dots: No biofuels

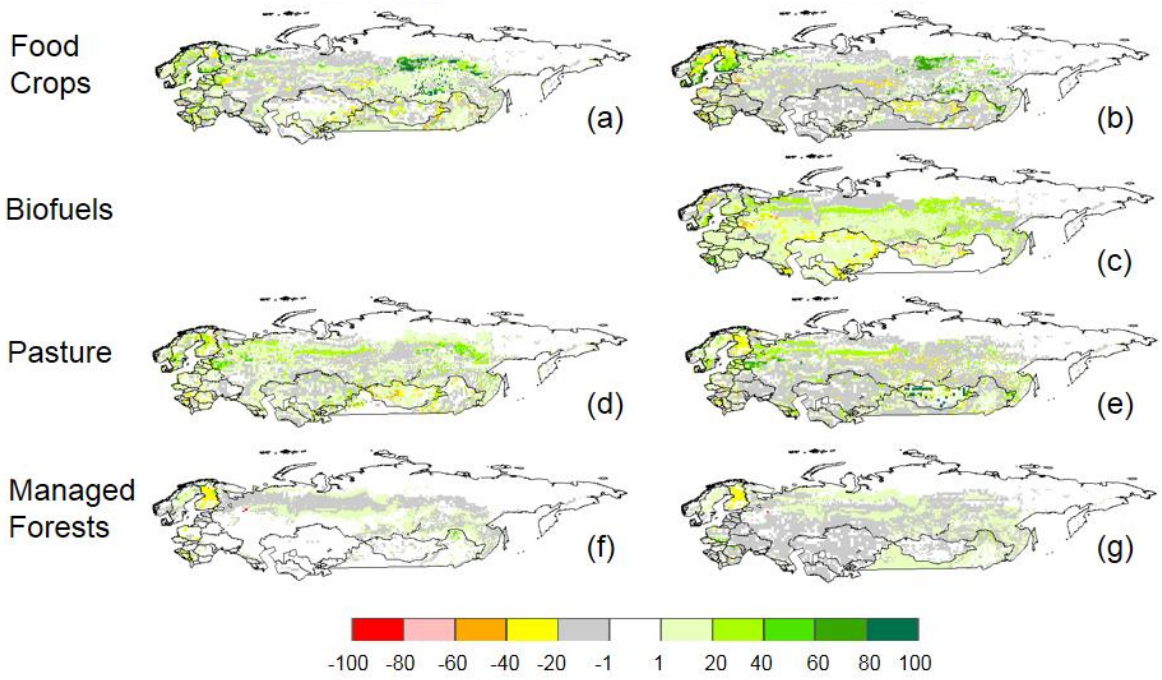
Short Dash: Energy-Only
Long Dash:Energy+ Land

Impact of Vegetation Shifts on Land Use and Wildfire

Objective: Estimate how vegetation shifts and changes in the rate and intensity of wildfire caused by climate change impact the amount of land available for cultivation.

Approach: The EPPA Model is coupled to a terrestrial ecosystem model. This is used to evaluate two scenarios: (1) An emissions stabilization scenario where the cultivation of biofuels is encouraged, and (2) A business as usual scenario.

Impact: In both scenarios, tundra shrinks, opening more land for cultivation. In the business as usual scenario, much of this land is used for food production. In the stabilization scenario less land becomes available for cultivation. Large parts of Northern Eurasia may become drier and more susceptible to wildfires, potentially making them less suitable for cultivation.



Effect of vegetation shifts on the distribution of crops at the end of the 21st century (percent). Left shows business as usual scenario, right shows stabilization scenario.

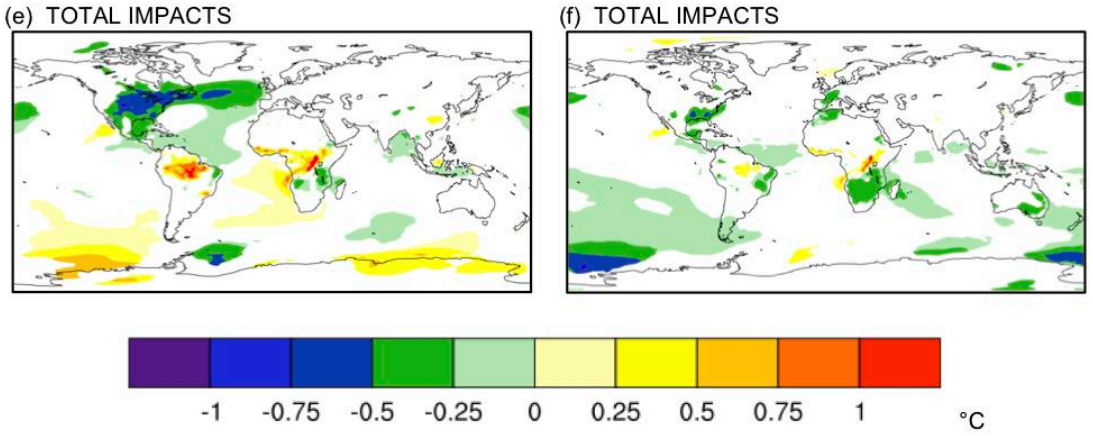
Kicklighter, D.W., Y. Cai, Q. Zhang, E.I. Parfenova, S. Paltsev, A.P. Sokolov, J.M. Melillo, J.M. Reilly, N.M. Tchebakova and X. Lu, 2014: Potential Influence of climate-induced vegetation shifts on future land use and associated land carbon fluxes in Northern Eurasia, Environmental Research Letters, 9(2014): 035004, doi: 10.1088/1748-9326/9/3/035004.

Climate Impacts of Large-Scale Biofuels Expansion

Objective: Investigate how land-use policies and economic factors influence where and how biofuel crops are planted, the ramifications for land-use change and greenhouse gas emissions, and how these influence climate.

Approach: This study uses the DOE-supported IGSM to model the climate effects of two global biofuels programs—one that allows conversion of natural areas to meet the increased demand for land, and a second that encourages more intense use of existing managed land, and restricts deforestation.

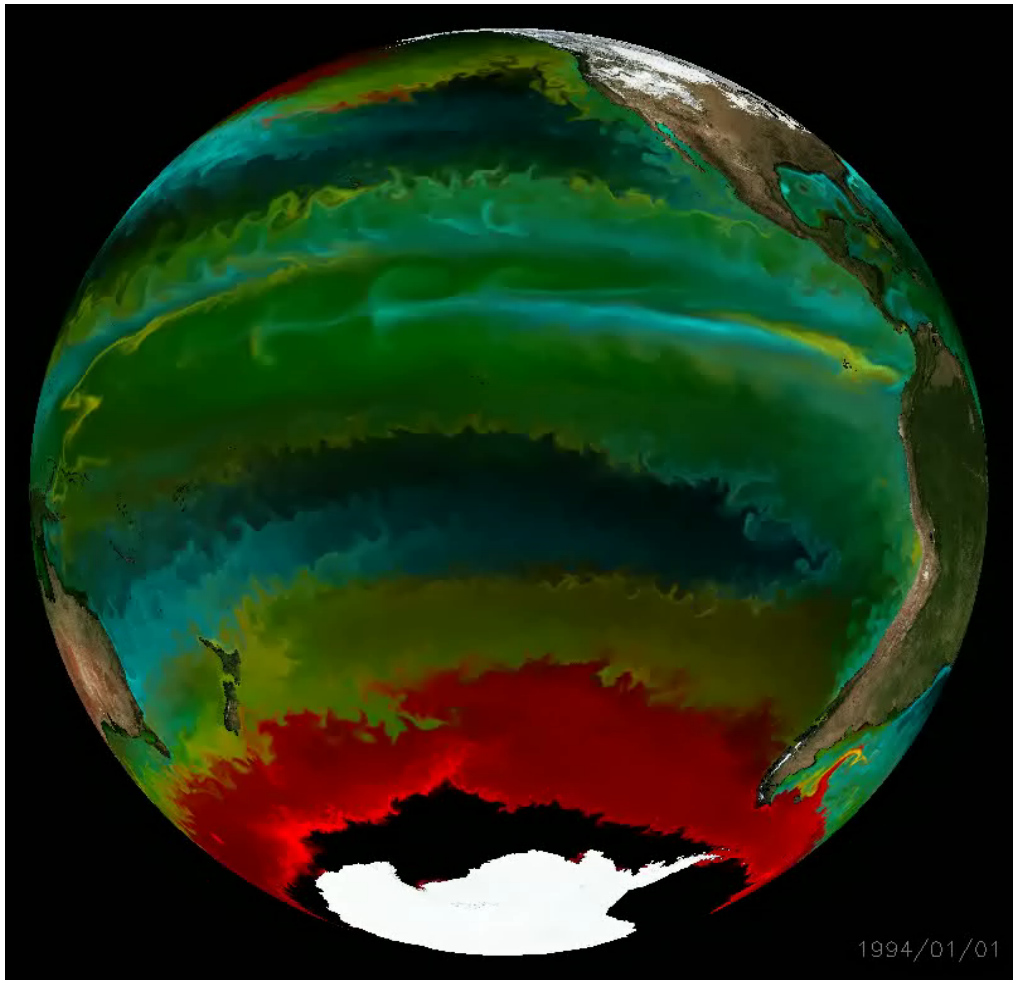
Impact: Increased biofuel crop cultivation has a negligible effect on global temperature. More substantial regional warming will occur, with up to 1.5 °C warming in the Amazon Basin and Central Africa. This effect is stronger in the first case examined which allows conversion of forests into crop land. The effect is less pronounced in the second case, when deforestation is limited.



Total temperature change in (e) the first case examined, and (f) the second case examined.

Hallgren, Willow, C. Adam Schlosser, Erwan Monier, David Kicklighter, Andrei Sokolov and Jerry Melillo, 2013: Climate Impacts of Large-Scale Biofuels Expansion, Geophysical Research Letters, 40(8): 1624–1630.

Seasonal Phytoplankton



Dominant phytoplankton types during 1994-1998 from a high-resolution ocean and ecosystem model.

Red: diatoms (big, need silica)
Yellow: other big phytoplankton,
Green: Prochlorococcus-like (small, cannot use NO_3)
Cyan: other small phytoplankton.

The model contains flow fields from 1994-1998 (ECCO2), inorganic nutrients, 78 species of phytoplankton, zooplankton and particulate and dissolved organic matter.