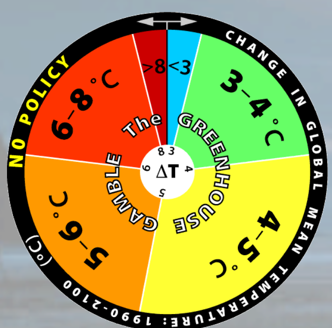
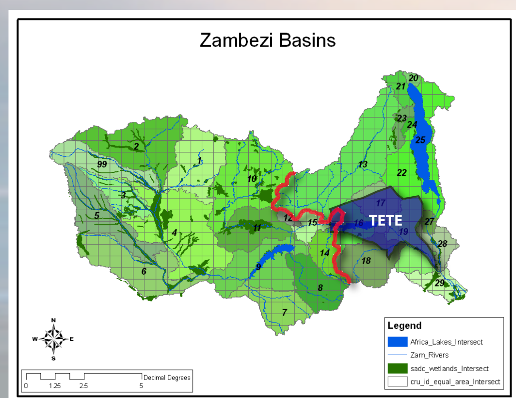
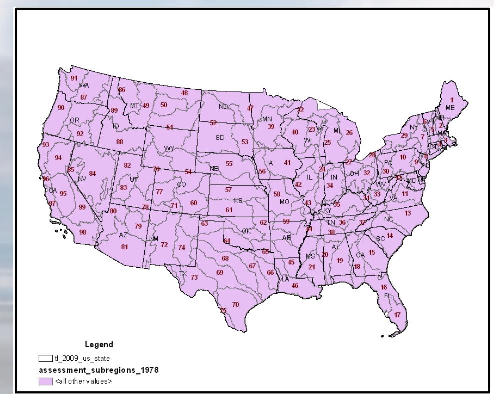
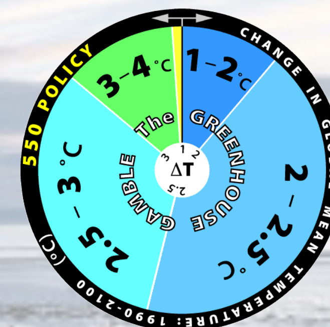
Water Resource Assessment in an Integrated Framework of the Human and Earth Systems
"A Tale of Two Countries and Their Basins"

C. Adam Schlosser, Ken Strzepek, Elodie Blanc, Jake Jacoby, Arthur Gueneau, Xiang Gao, Andrei Sokolov, Sergey Paltsev, Sebastian Rausch, Sirein Awadalla, Channing Arndt, Charles Fant, Sherman Robinson, James Thurlow, John Reilly









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MIT JOINT PROGRAM ON THE SCIENCE AND POLICY of GLOBAL CHANGE

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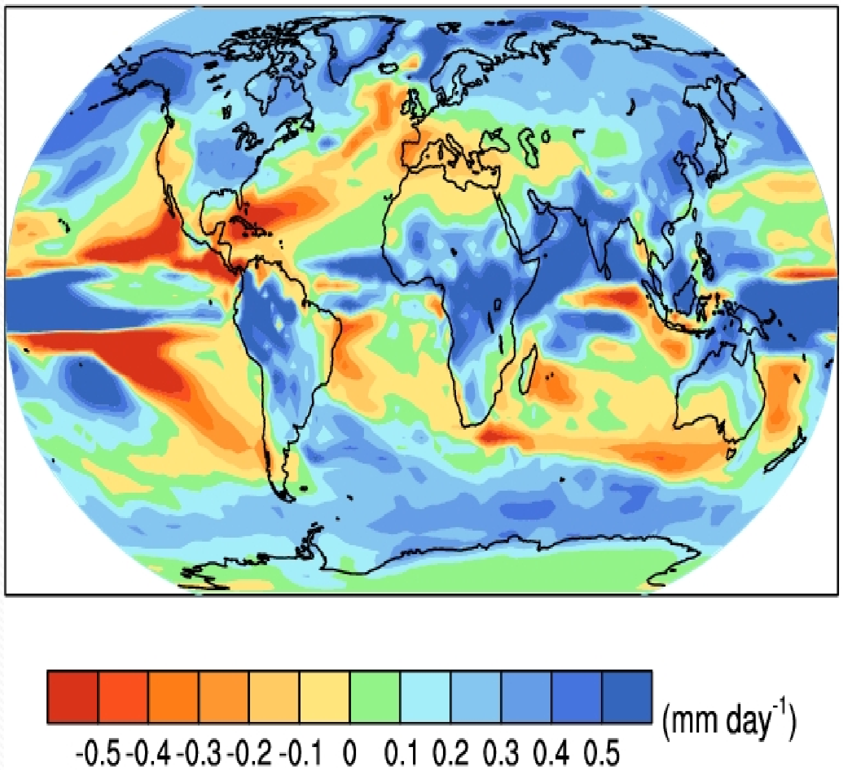
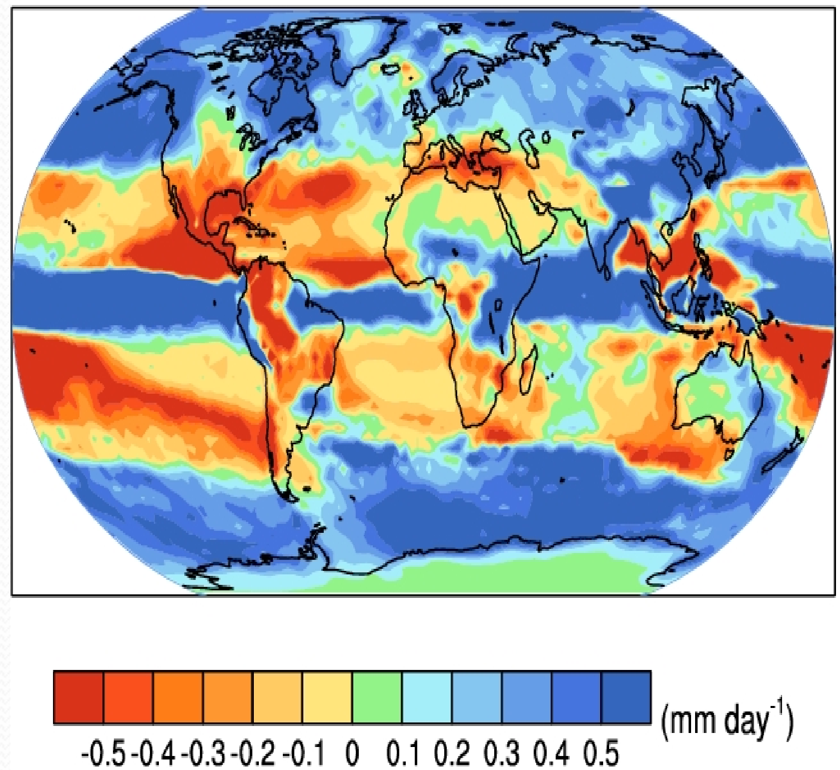
Uncertainty in Regional Change

Simulated Precipitation Change in 21st Century: A1B Scenario
Opposing Climate Model Results at the Regional Scale

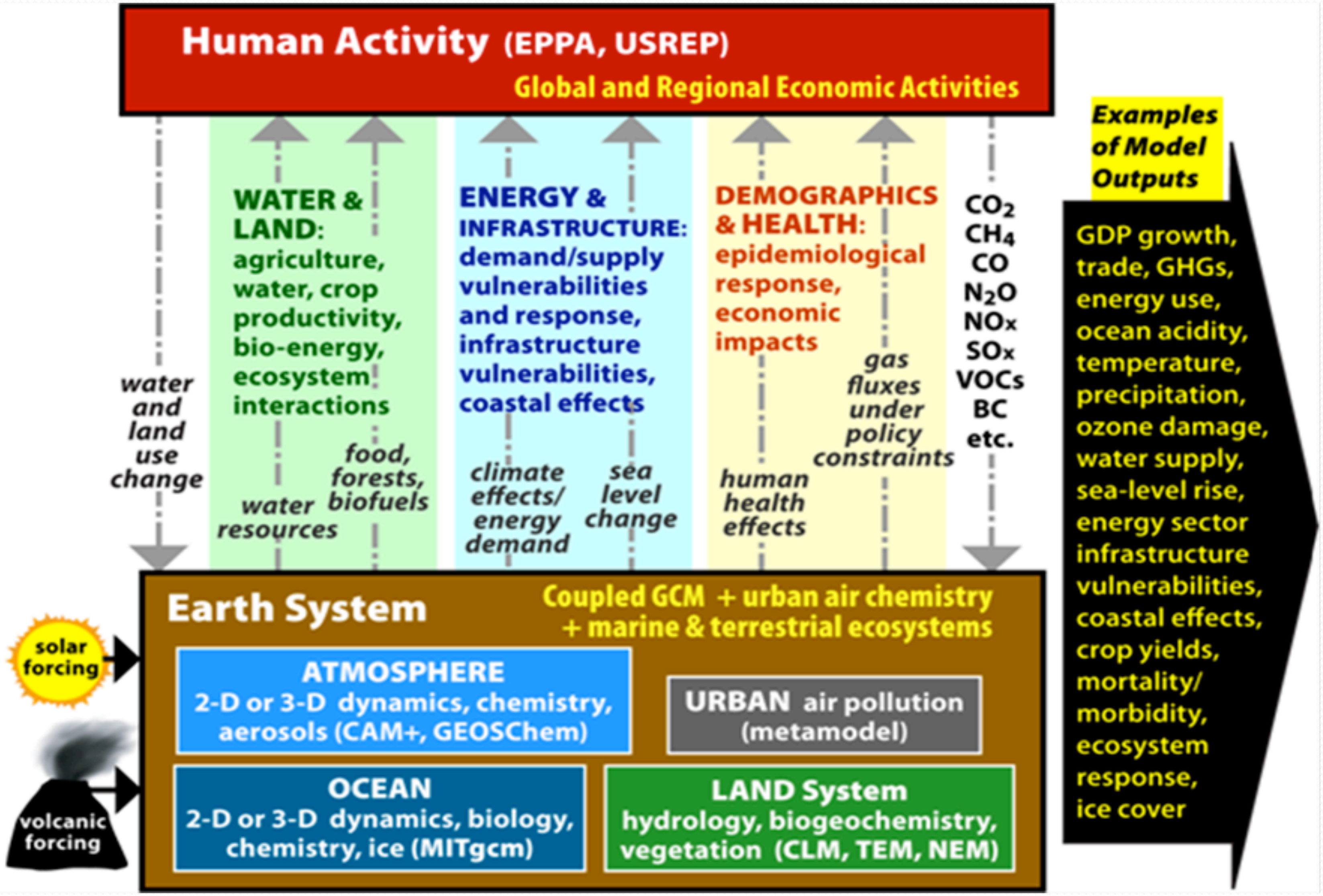




HOW CAN WE PREPARE WHEN REGIONAL CHANGES DIFFER IN SIGN?

The MIT Integrated Global Systems Model (IGSM) An Integrated Assessment Model (IAM)

(IGSM2: Sokolov et al., 2005, JP Tech. Report #124 EPPA: Paltsev et al. 2005, JP Tech. Report #125
Land: Schlosser et al., 2007 JP Tech Report #147 Ocean: Dutkiewicz et al., 2005, JP Tech. Report #122)



IGSM Scenarios

(Sokolov et al., 2009, and Webster et al., 2009)

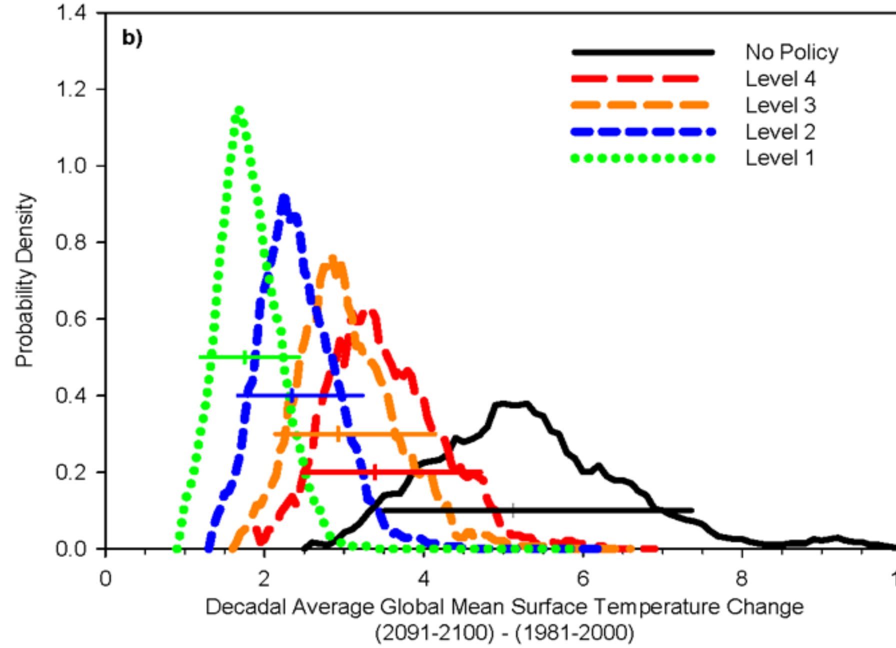
No Policy (Reference):

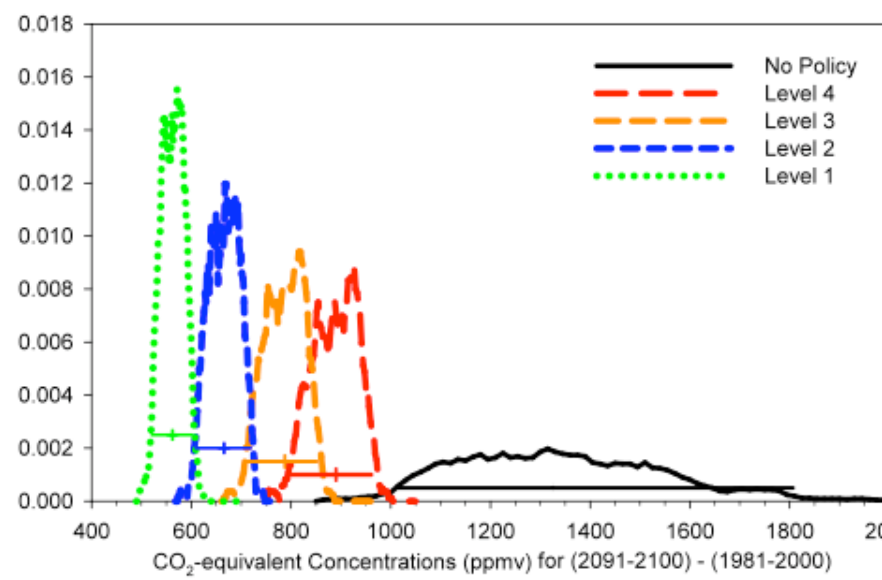
- Climate & EPPA samples

Policy Scenarios:

Representative Concentration Pathways (RCPs)

- U.S. CCSP Level 4
- U.S. CCSP Level 3
- U.S. CCSP Level 2
- U.S. CCSP Level 1



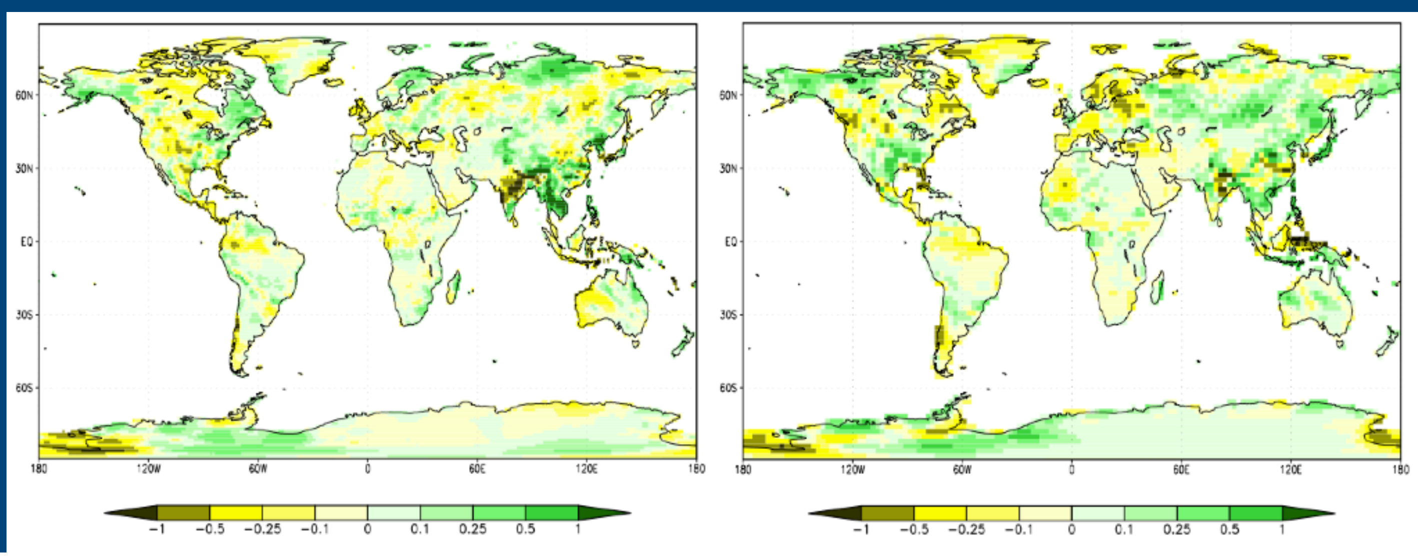


CHARACTERIZING REGIONAL CLIMATE-CHANGE UNCERTAINTY IN THE IGSM: A HYBRID APPROACH

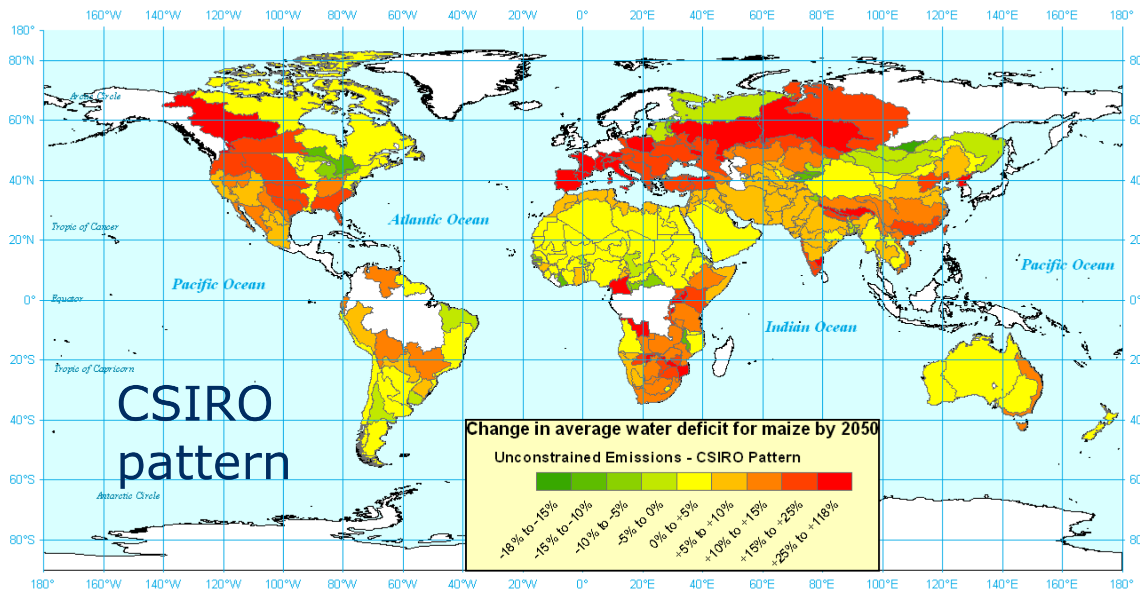
SCHLOSSER ET AL., 2012

$$V_{x,y}^{IGSM} = \left(C_{x,y} + \frac{dC_{x,y}}{dT_{Global}} * \Delta T_{Global}^{IGSM}\right) * \overline{V}_{y}^{IGSM}$$

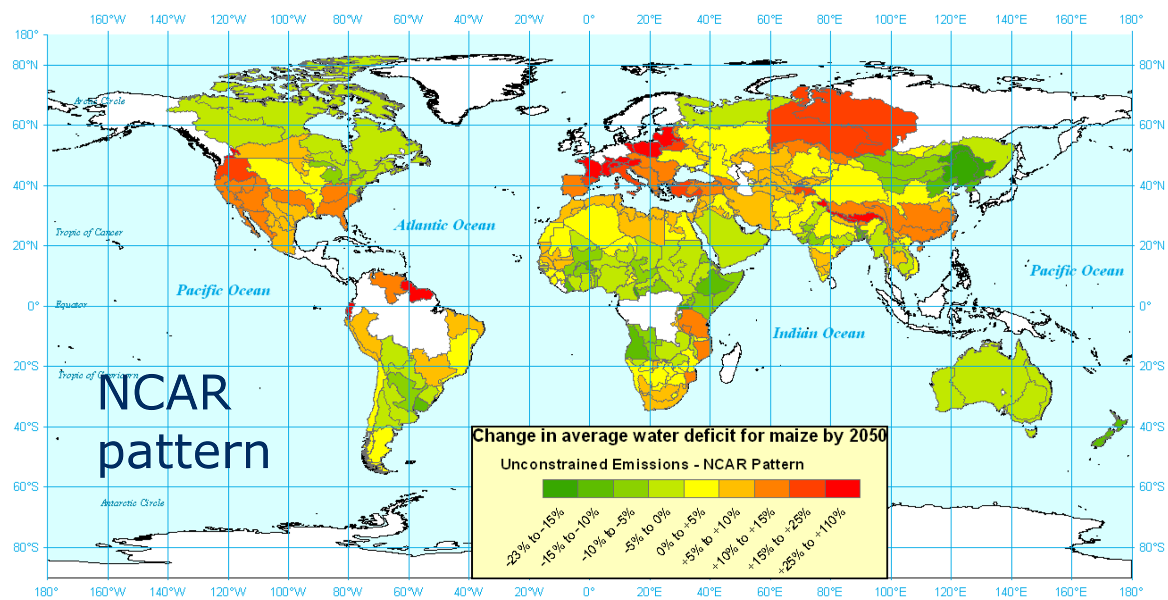
$\frac{dC_{x,y}}{dT_{Global}}$: The change of transformation coefficient at CO_2 doubling normalized by global temperature difference between the doubled CO_2 and the 20th century, based on the IPCC AR4 archive (~17 GCMs).



Changes in Crop Irrigation Demand in 2050



Uncertainty in regional climate changes lead to dramatically different consequences for agricultural water demand.

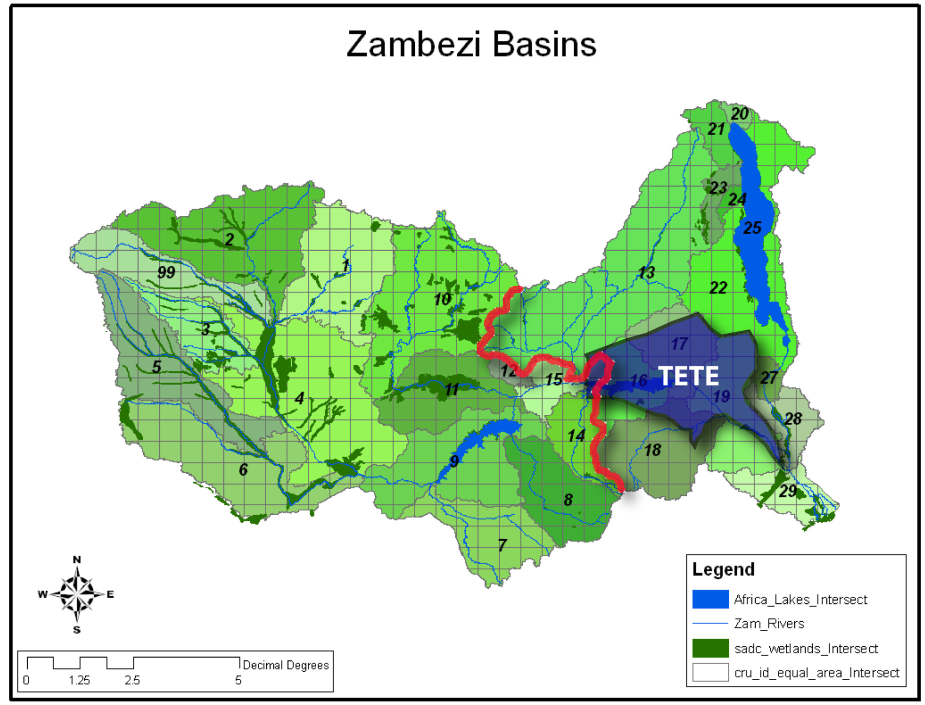


Simulations with CliCrop (Fant et al., 2012) in the IGSM framework

MIT JOINT PROGRAM SCIENCE POLICY GLOBAL CHANGE

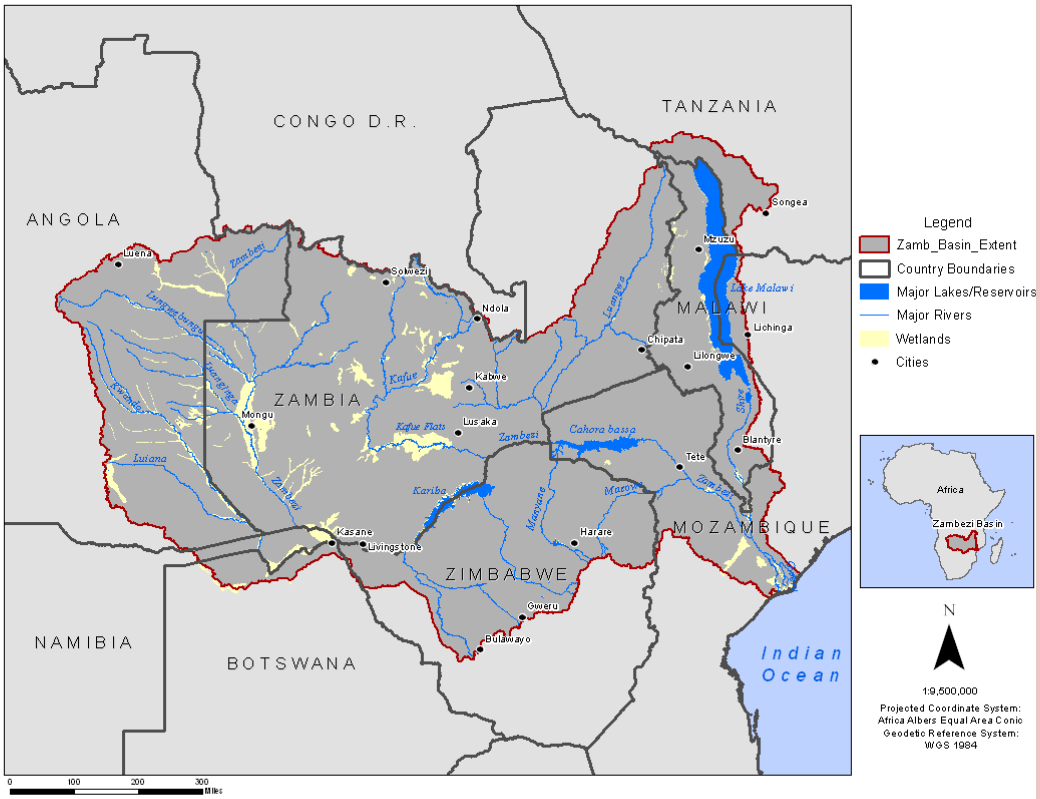
Quantifying the Likelihood of Regional Climate Change and their Impacts: Zambezi River Basin

Quantify the climate-change risk of the greater Zambezi River Basin, by covering the range of uncertainty in the global and regional climate response as well as emissions under climate policies.



C. Adam Schlosser (MIT), Ken Strzepek (MIT), Channing Arndt (WIDER), Charles Fant (WIDER), Sherman Robinson (IFPRI), James Thurlow (WIDER), Xiang Gao (MIT), Arthur Gueneau (MIT), Sergey Paltsev (MIT), and Andrei Sokolov (MIT)

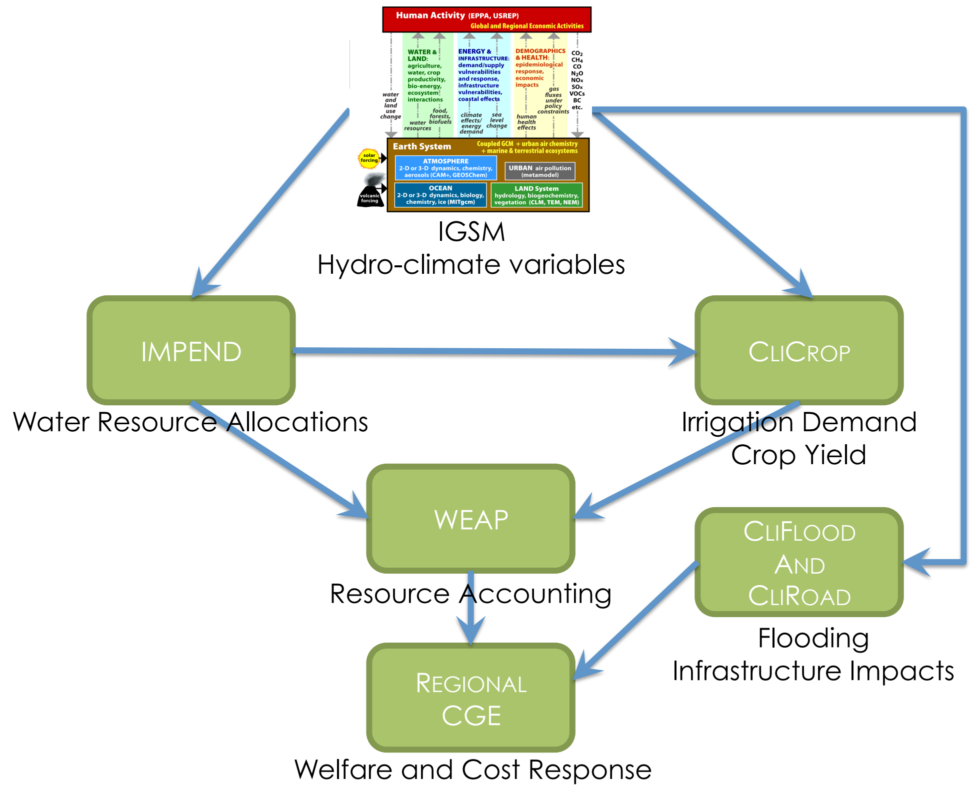
Zambezi River Basin

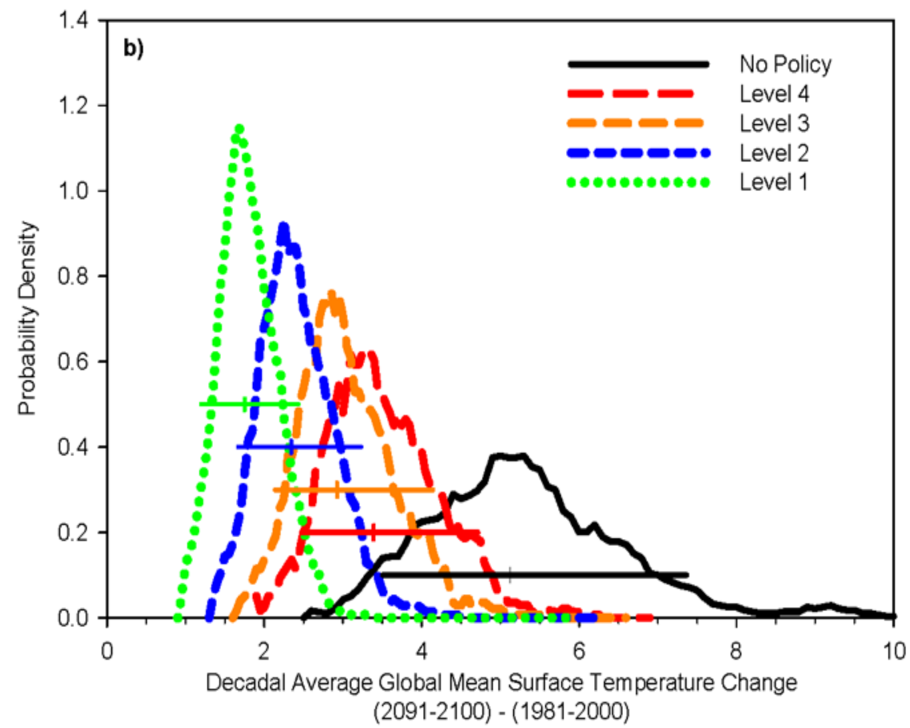


From "Assessment of the Impacts of Climate Change on *Multi-Sector Investment Opportunities* in the Zambezi River Basin" IEc Report, June 2011
K. Strzepek, B. Boehlert, A. McCluskey, W. Farmer, J. Neumann, M. Fuchs

- Land area of 1.37 million km^2
- 4th largest basin on the continent after the Congo, Nile and Niger basins.
- Spans portions of eight countries: Angola, Namibia, Botswana, Zimbabwe, Zambia, Tanzania, Malawi, and Mozambique.
- The total population in the basin is 30 million, with over 85% in Malawi, Zimbabwe and Zambia, 25% of total living in major urban areas.
- The main economic activities throughout the basin include fisheries, mining, agriculture, tourism, and manufacturing.

Model Framework: Regional CGE model forced by impacts from Integrated Global Systems Model (IGSM) projections

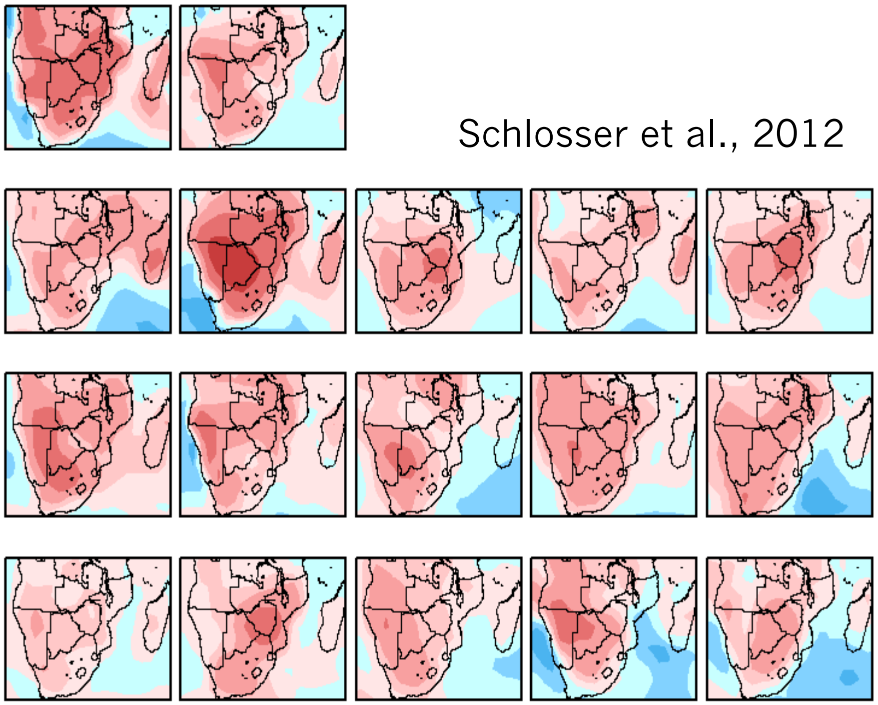




The chain of models are applied to the greater Zambezi basin. A computable general equilibrium model of Mozambique is forced by impacts from differing climate outcomes. The CGE model incorporates impacts on crop yields, hydropower production, sea level rise, and infrastructure (especially roads) due to flooding and changes in maximum temperature and precipitation.

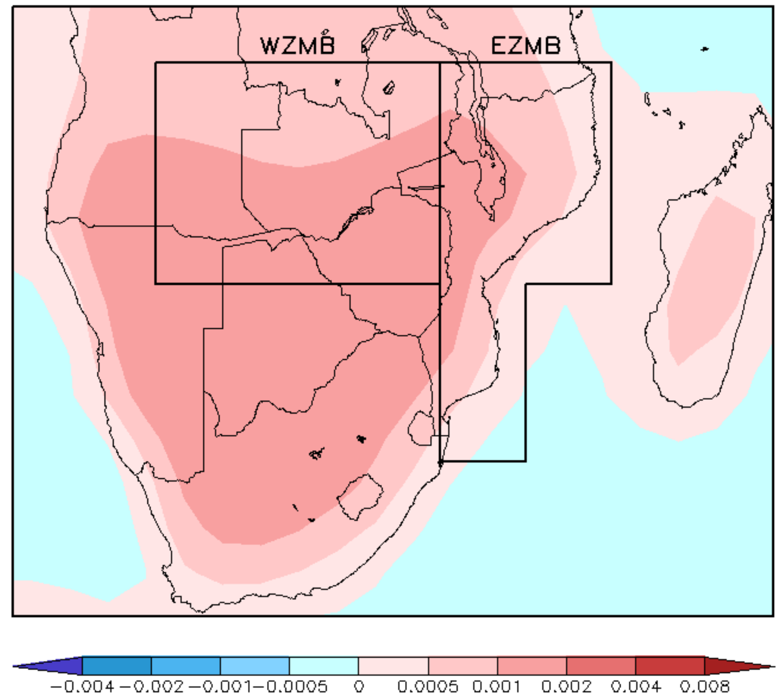
Regional Climate-Change Kernels: DJF Surface-Air Temperature

AR 4 Models



Schlosser et al., 2012

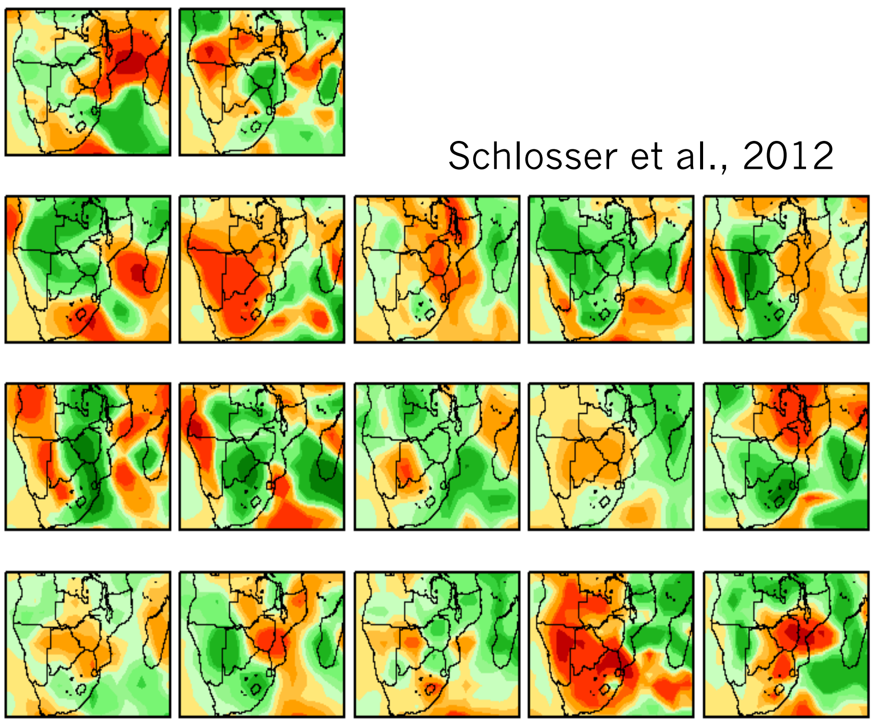
AR4 Model Mean



Climate-change pattern kernels from the IPCC AR4 climate models used to construct hybrid climate-change distributions from the IGSM. Shown are the relative changes in DJF surface-air temperature in response to a unit global temperature increase as a result of anthropogenic greenhouse emissions.

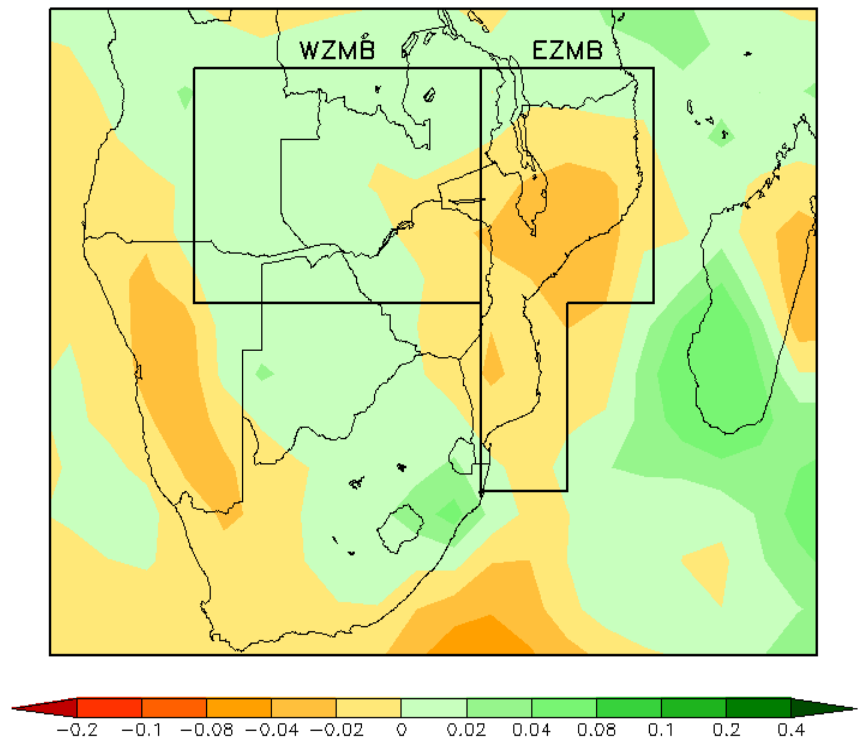
Regional Climate-Change Kernels: DJF Precipitation

AR 4 Models



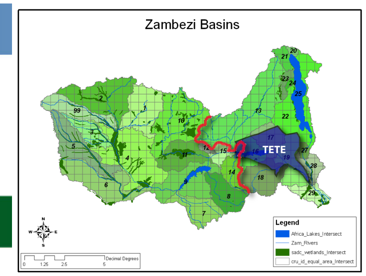
Schlosser et al., 2012

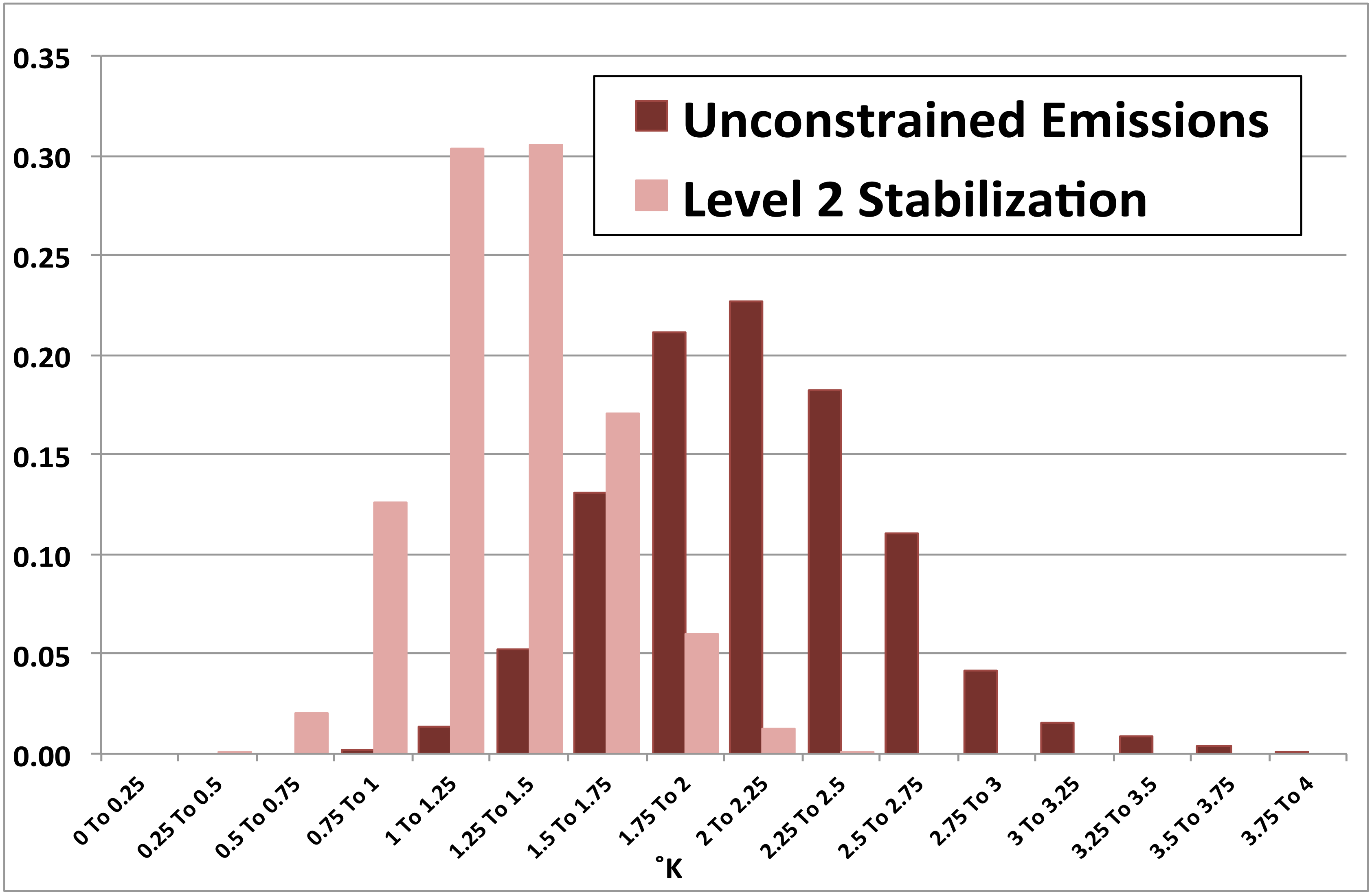
AR4 Model Mean



Climate-change pattern kernels from the IPCC AR4 climate models used to construct hybrid climate-change distributions from the IGSM. Shown are the relative changes in DJF precipitation in response to a unit global temperature increase as a result of anthropogenic greenhouse emissions.

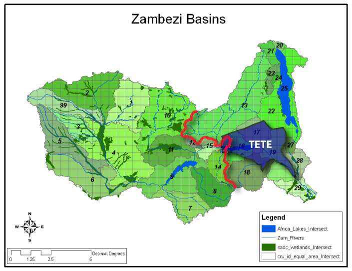
Western Zambezi Frequency Distributions
2050 Decadal Average Surface-Air Temperature Change: SON

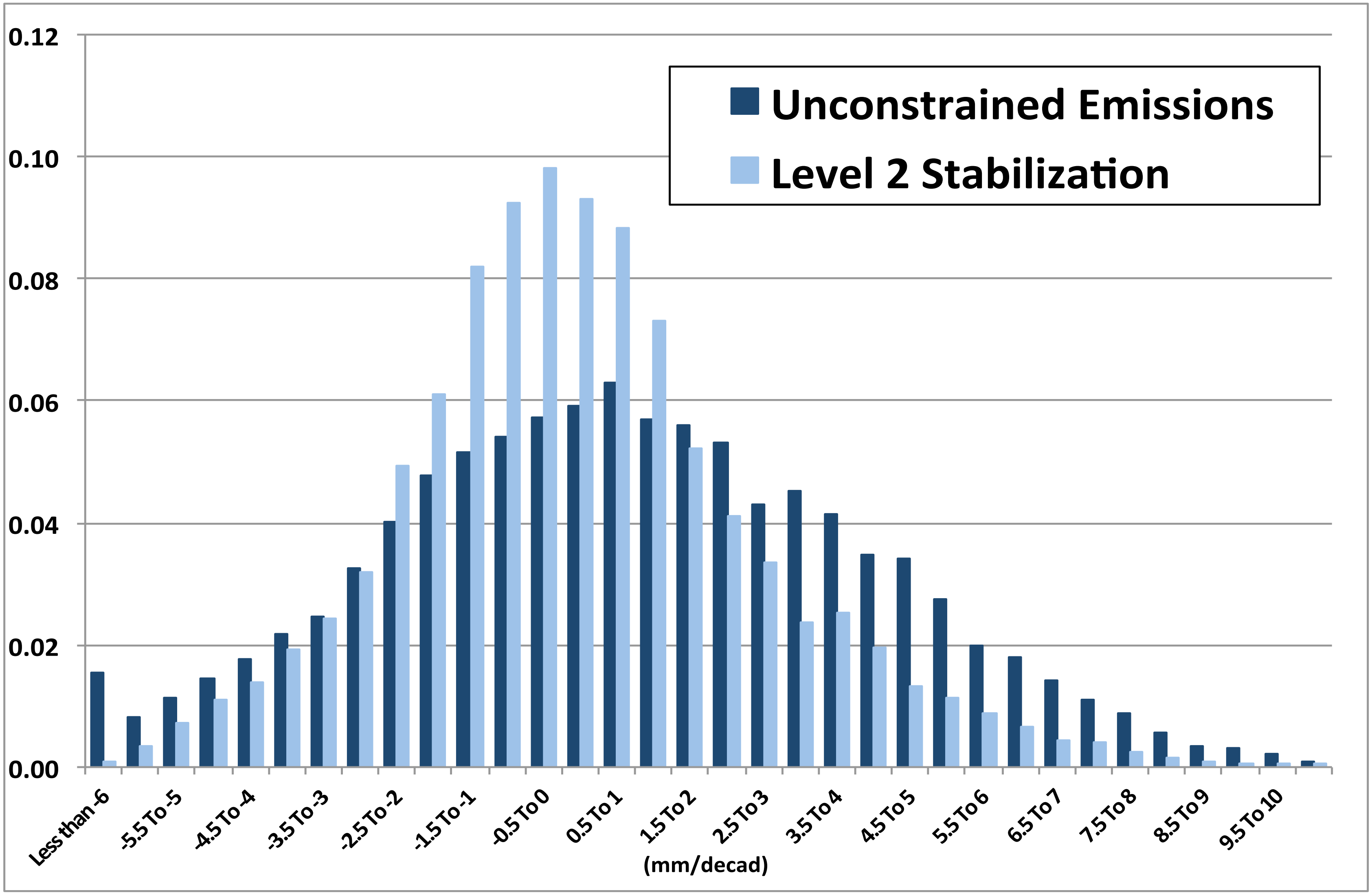




Schlosser et al., 2011

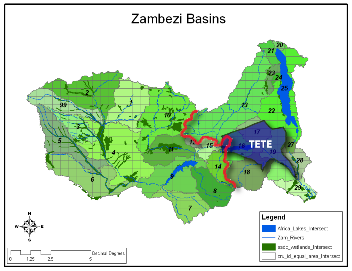
Eastern Zambezi Frequency Distributions
2050 Decadal Average Precipitation Change: DJF

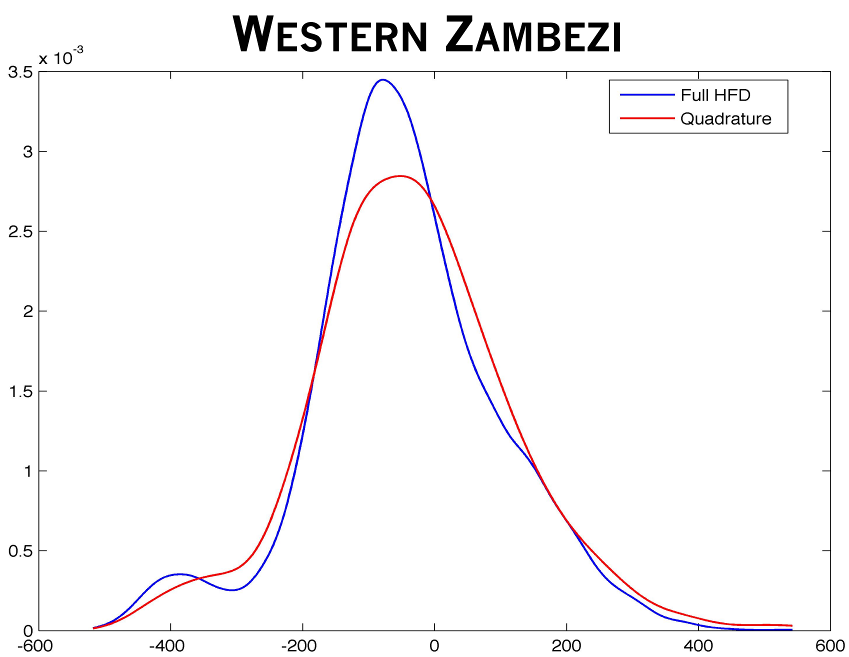


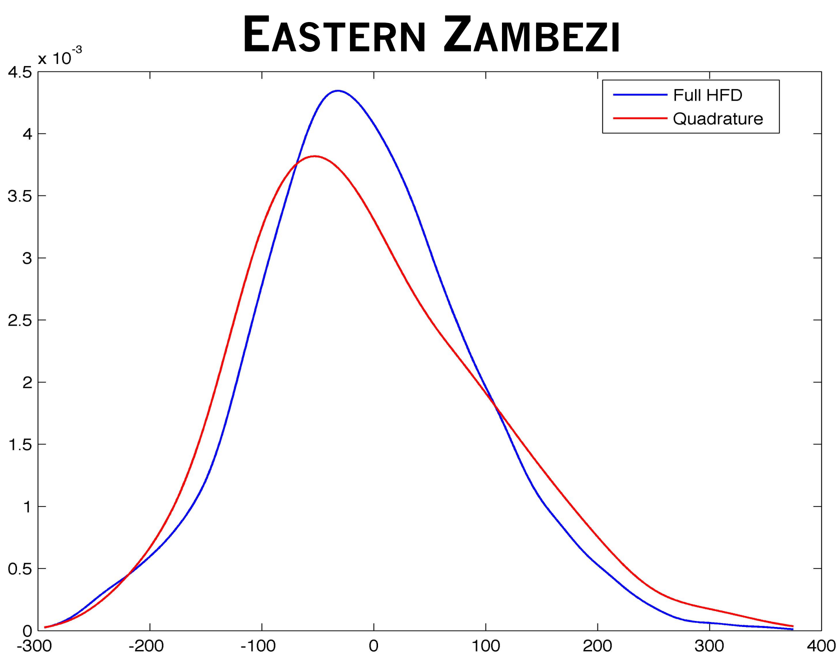


Schlosser et al., 2011

Projections in Hydrologic Change: Runoff in 2050

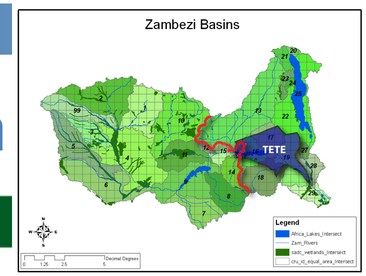


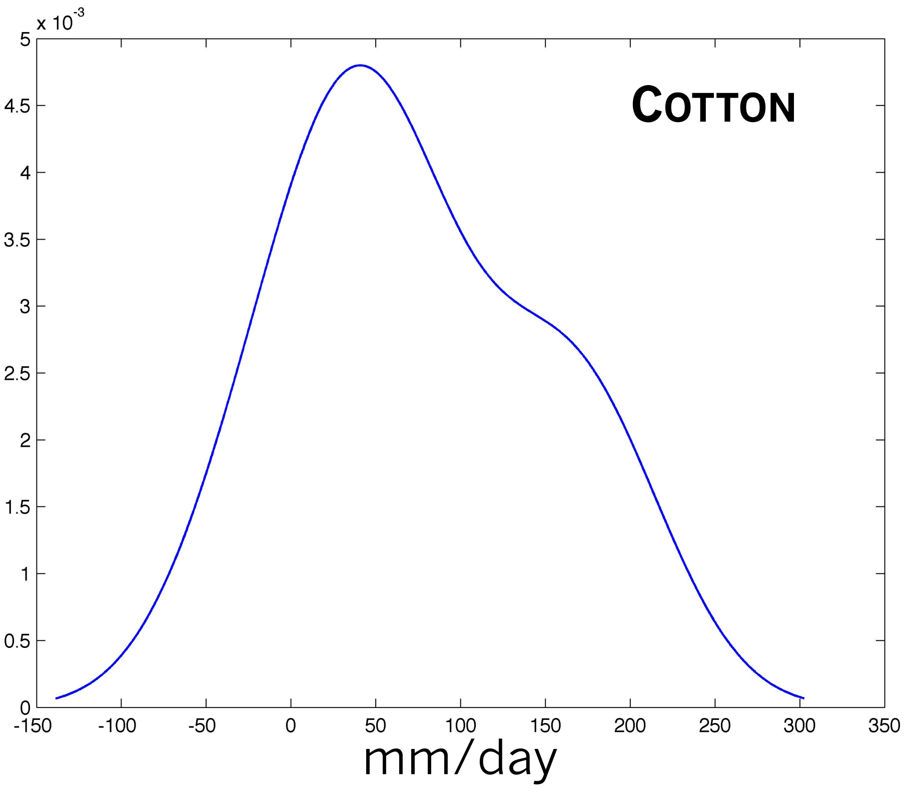


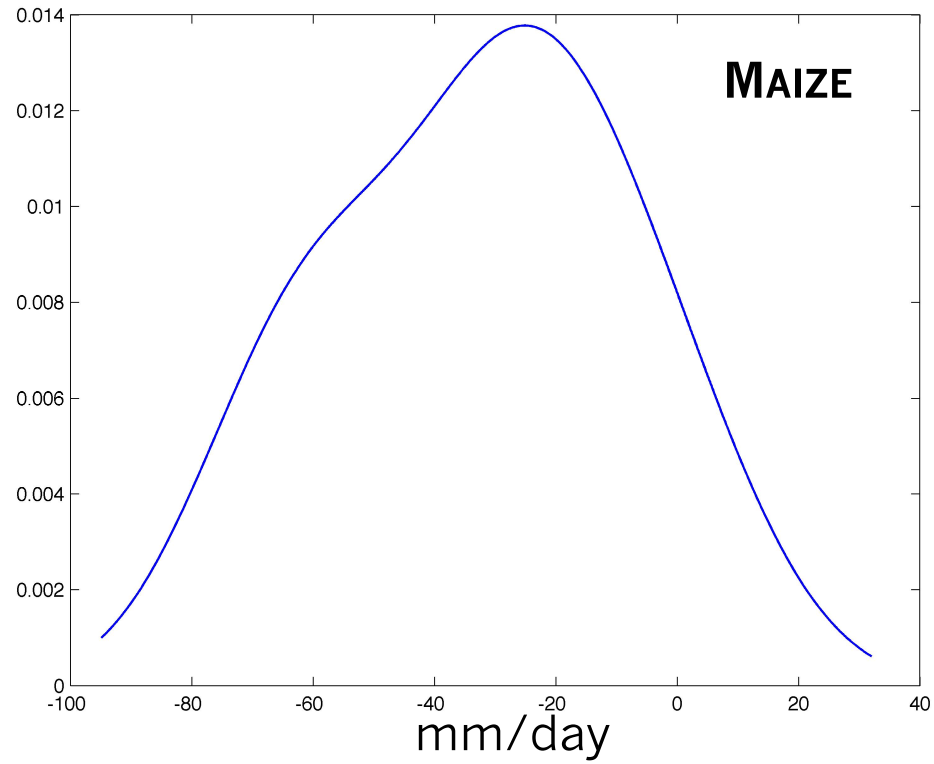


Frequency distributions of decadal averaged changes (2050-2000) in runoff (mm/year) for the eastern (right panel) and western (left panel) Zambezi basins. Results shown for unconstrained-emission pathway. The blue curve is the result of the full HFD ensemble, the red curve shows the result from the reduce sampling of the ***Gaussian quadrature reduction*** (Arndt et al., 2006).

Change in Irrigation Demand in 2050: Tete Region







Frequency distributions of decadal averaged changes (2050-2000) in irrigation demand (mm/year) for a selected province (Tete) and crops. The results are based on a Gaussian Quadrature sampling of the HFDs (Schlosser et al., 2011) for the unconstrained emission IGSM scenario (Sokolov et al., 2009).

Dynamic Computable General Equilibrium (DGCE) Model Features

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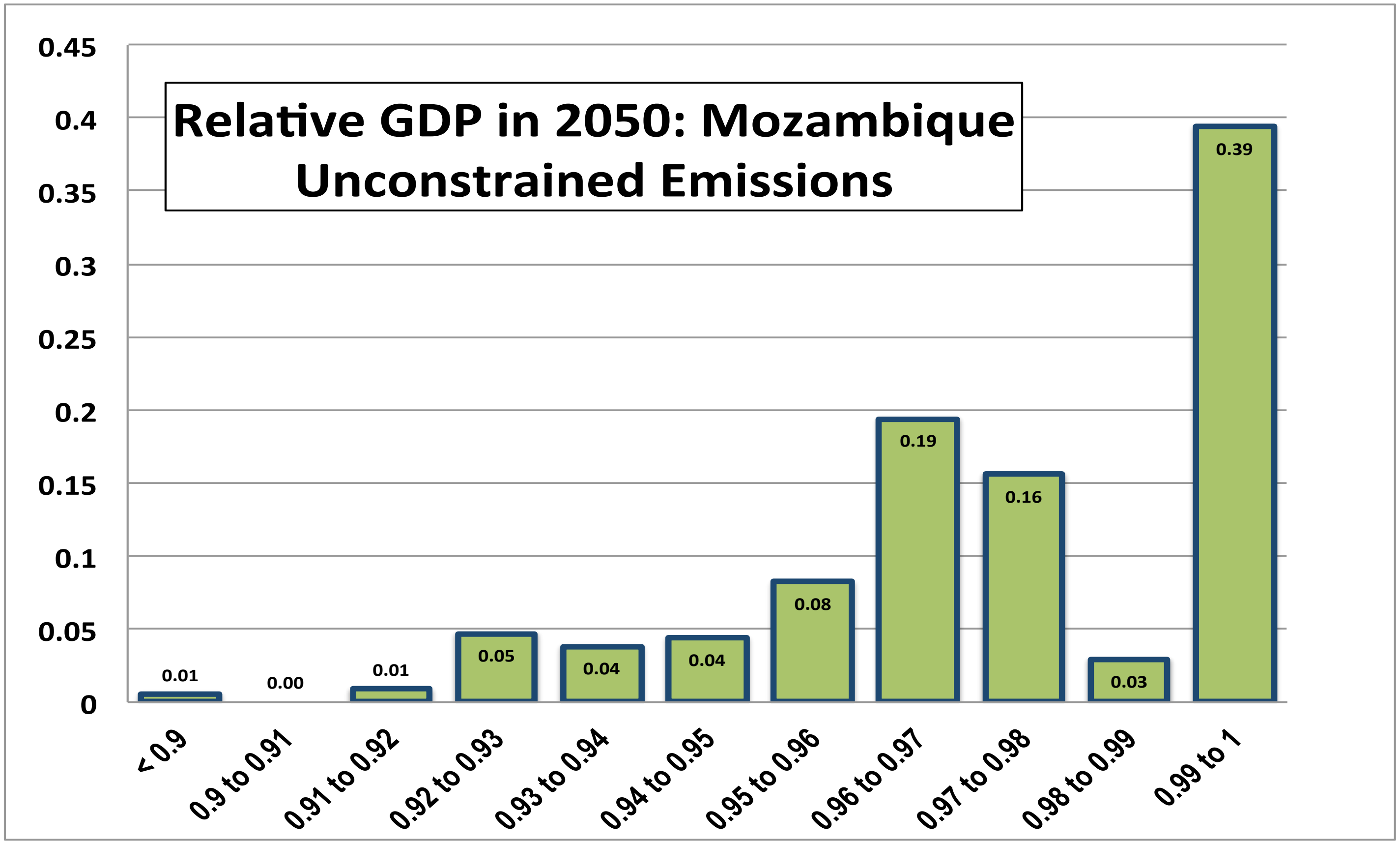
- 30 SECTORS: INCLUDES ELECTRICITY, TRANSPORT, AND TEN AGRIC. SUBSECTORS.
- 37 PRODUCTION FACTORS: THREE TYPES OF LABOR (EDUCATION: PRIMARY, SECONDARY, AND TERTIARY AND SUB-DIVIDED BETWEEN RURAL AND URBAN ZONES), CAPITAL, AGRIC. LAND AND CAPITAL, FISH/LIVESTOCKS.
- CLIMATE CHANGE AFFECTS ECONOMIC GROWTH AND WELFARE VIA FOUR PRINCIPAL MECHANISMS.
  - ***PRODUCTIVITY CHANGES IN RAIN-FED AGRICULTURE*** AFFECT AMOUNT OF RESOURCES THAT SHOULD BE DEVOTED TO EACH CROP GIVEN THEIR RELATIVE PROFITABILITY (I.E., 'ENDOGENOUS ADAPTATION').
  - ***FLUCTUATIONS IN HYDROPOWER*** PRODUCTION (FROM IMPEND).
  - ***LENGTH OF REGIONAL ROAD NETWORKS*** AFFECT THE RATE OF PRODUCTIVITY GROWTH. SHORTER ROAD NETWORK LOWERS TRANSPORT PRODUCTIVITY AND INCREASES THE COST OF MOVING GOODS.
  - ***EFFECTS OF SEA-LEVEL RISE AND TROPICAL CYCLONES*** BY REDUCING THE TOTAL AMOUNT OF CULTIVABLE LAND IN EACH REGION BY THE LAND INUNDATION ESTIMATES. SEPARATE ESTIMATES ARE ALSO MADE FOR REDUCTIONS IN PRIVATE PHYSICAL CAPITAL AND ROAD INFRASTRUCTURE.
- CAPTURE ANNUAL CHANGES IN PHYSICAL AND HUMAN CAPITAL ACCUMULATION AND TECHNICAL CHANGE.

EXAMPLE: IF CLIMATE CHANGE REDUCES AGRICULTURAL OR HYDROPOWER PRODUCTION IN A GIVEN YEAR, IT ALSO REDUCES INCOME, WHICH IN TURN REDUCES SAVINGS. THIS REDUCTION IN SAVINGS DISPLACES INVESTMENT AND LOWERS PRODUCTION POTENTIAL. SIMILARLY, HIGHER ROAD MAINTENANCE COSTS IMPLY LESS INFRASTRUCTURE INVESTMENT AND SHORTER ROAD NETWORKS BOTH NOW AND IN THE FUTURE.

Relative Change in Real GDP: Mozambique



15% OF THE DISTRIBUTION RESULTS IN AT LEAST A 5% REDUCTION IN GDP

Most economic outcomes result on the more favorable end of the distribution with some outcomes close to the level that would be attained with no climate and weather variability at all. Nevertheless, the left tail of the distribution is long and thus pointing to the potential for some decidedly unfavorable outcomes. More detailed analysis is merited.

U.S. WATER RESOURCE ASSESSMENT IN THE MIT INTEGRATED FRAMEWORK

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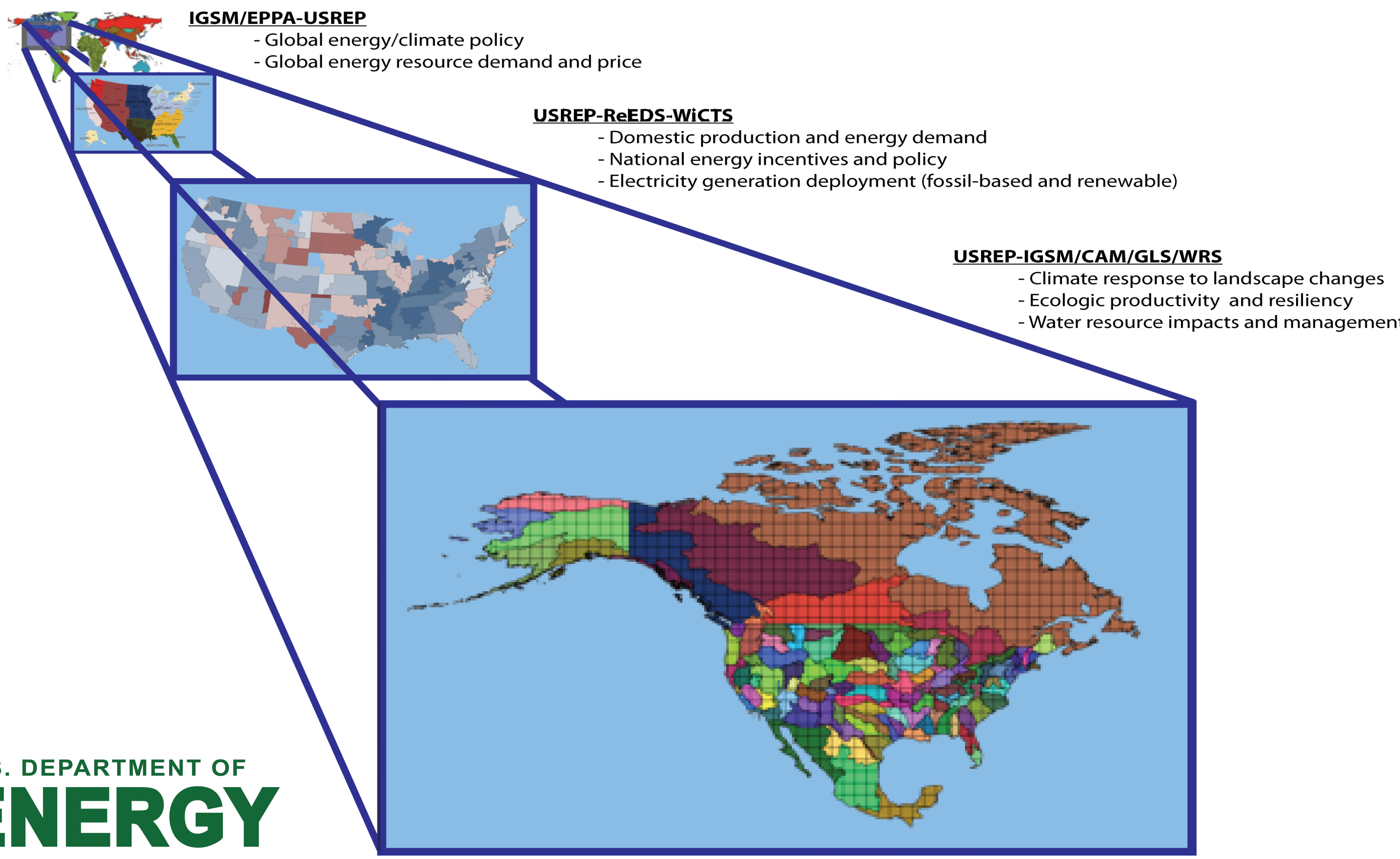
C. Adam Schlosser, Ken Strzepek, Elodie Blanc, Jake Jacoby, Arthur Gueneau, Xiang Gao, Andrei Sokolov, Sebastian Rausch, Sirein Awadalla, Charles Fant, Bilhuda Rasheed, Sergey Paltsev, and John Reilly



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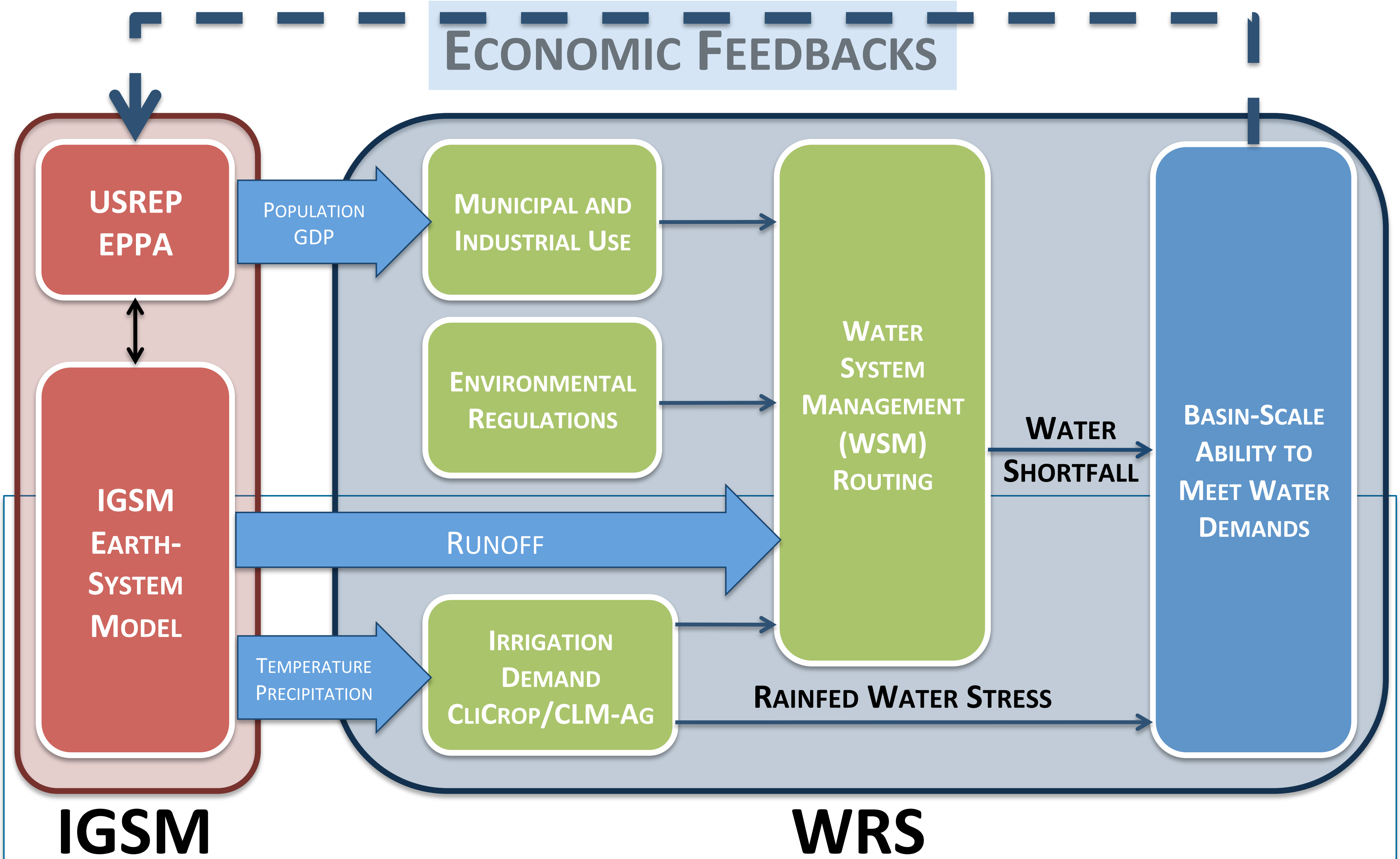
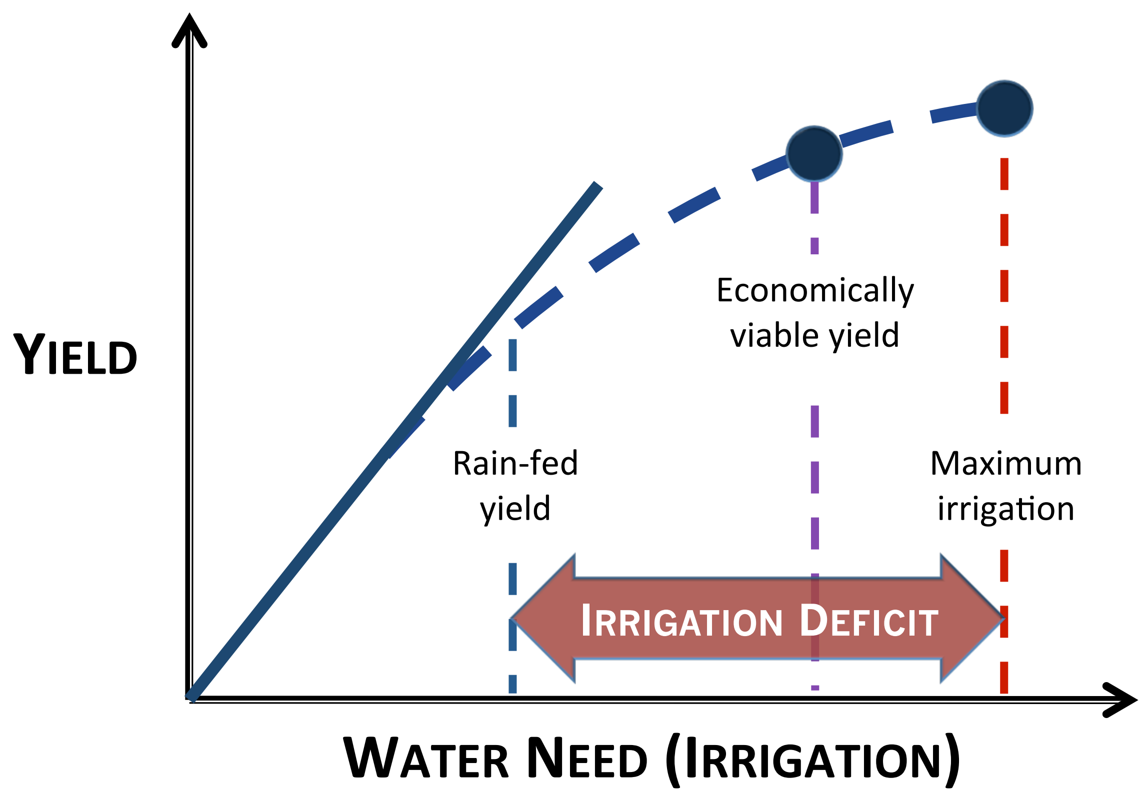
IGSM links to a Water-Resource System (WRS)



The Economics and Climate of Irrigation

INTRODUCE "J-FACTOR"

$$J = \frac{\text{Actual Irrigation}}{\text{Maximum Irrigation}}$$



Crops	J	Observations
forage	0.488***	1,570
pasture	0.406***	2,564
cotton	0.488***	284
grains	0.643***	154
groundnuts	0.336***	134
maize	0.925***	1,036
pulses	0.995***	151
rice	0.463***	108
sorghum	0.410***	200
soybeans	0.902***	569
sugarbeets	0.956***	60
wheat	0.398***	458
vegetables	1.166***	1,210
potatoes	0.969***	239
berries	1.307***	668
orchard	0.584***	925
other	1.301***	3,082

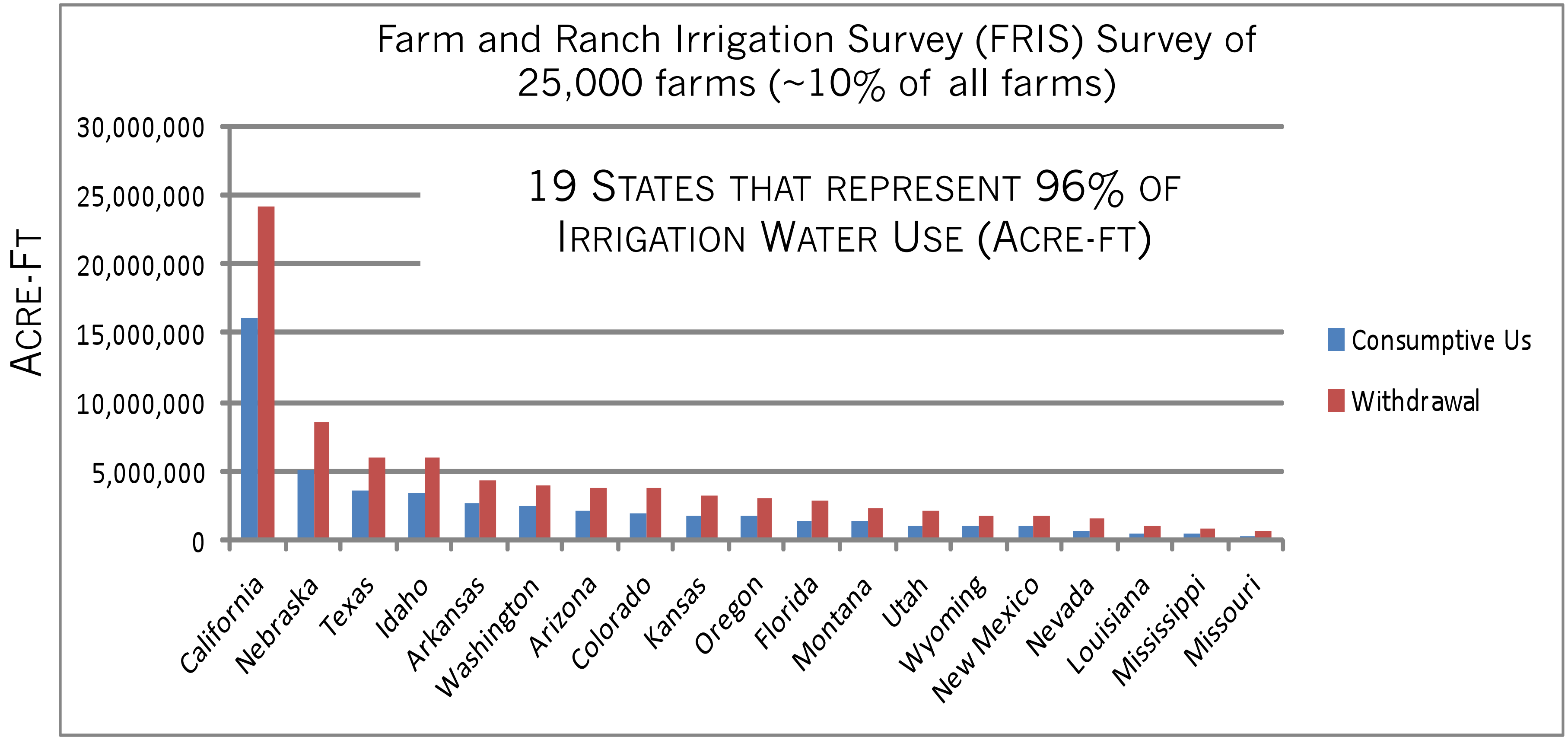
BY DEFAULT - CROP MODEL (CLICROP OR CLM-AG) DESCRIBES BIOPHYSICAL SHORTAGE OF WATER FOR A GIVEN CROP ("IRRIGATION DEFICIT")

Efficiency: Withdrawal vs. Consumptive Use

- Drip Irrigation: 90%
- Micro-irrigation: 78%
- Sprinklers: 65%
- Surface: 52%

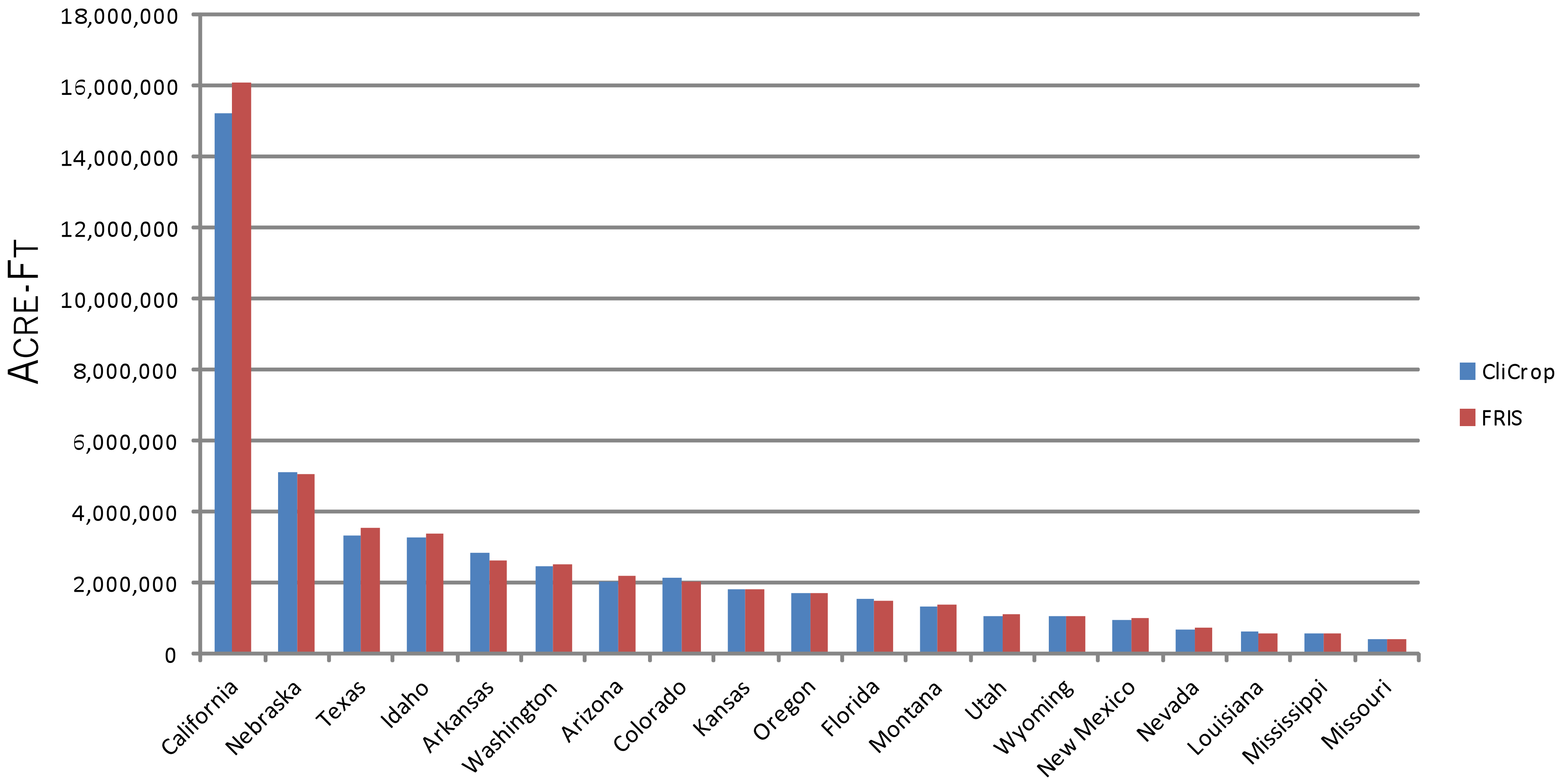
Kenny, 2004

Calculate average state efficiency based on crop type.

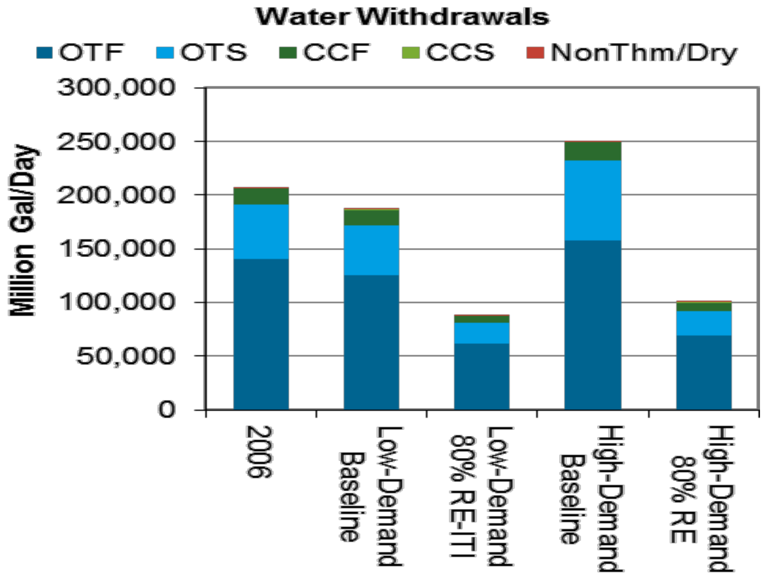


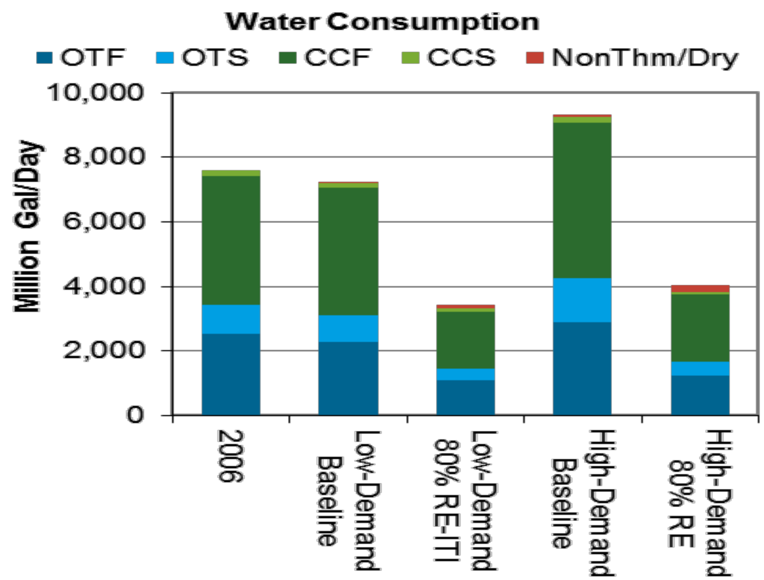
Evaluation: CliCrop versus FRIS for 2003

FRIS consumptive use = 51.4 Million Acre-ft
CliCrop with J-factor = 50.3 Million Acre-ft

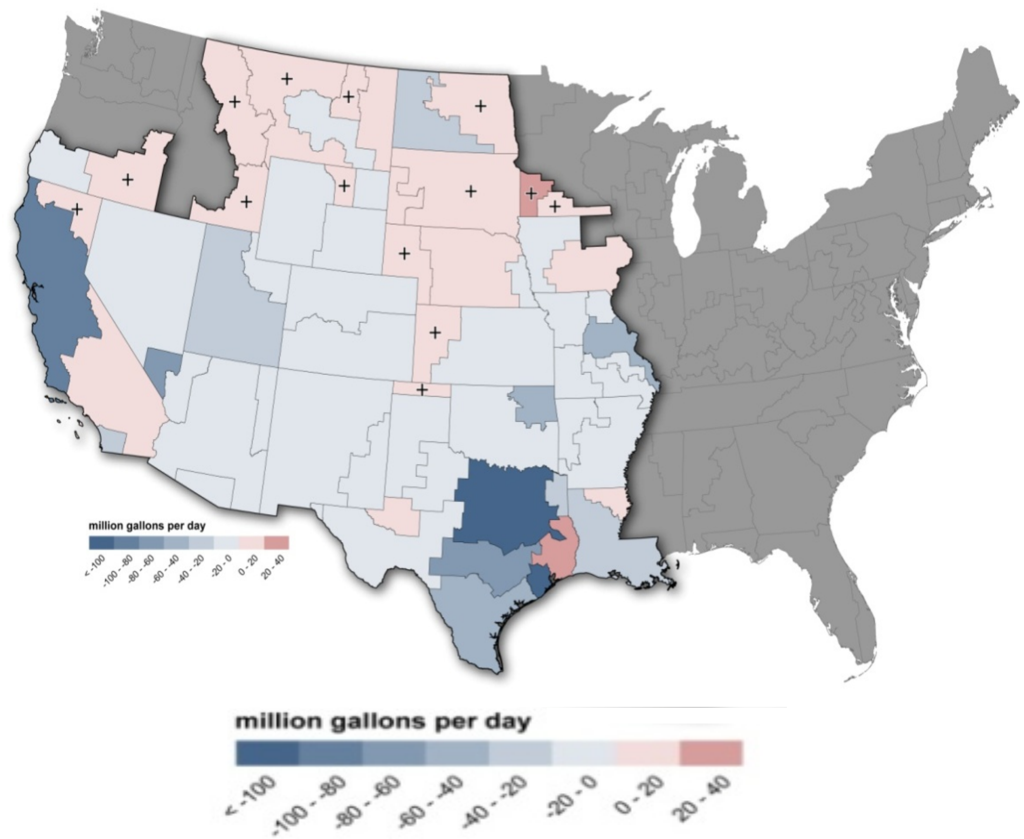


Renewable Energy Deployment: Cool Water Savings



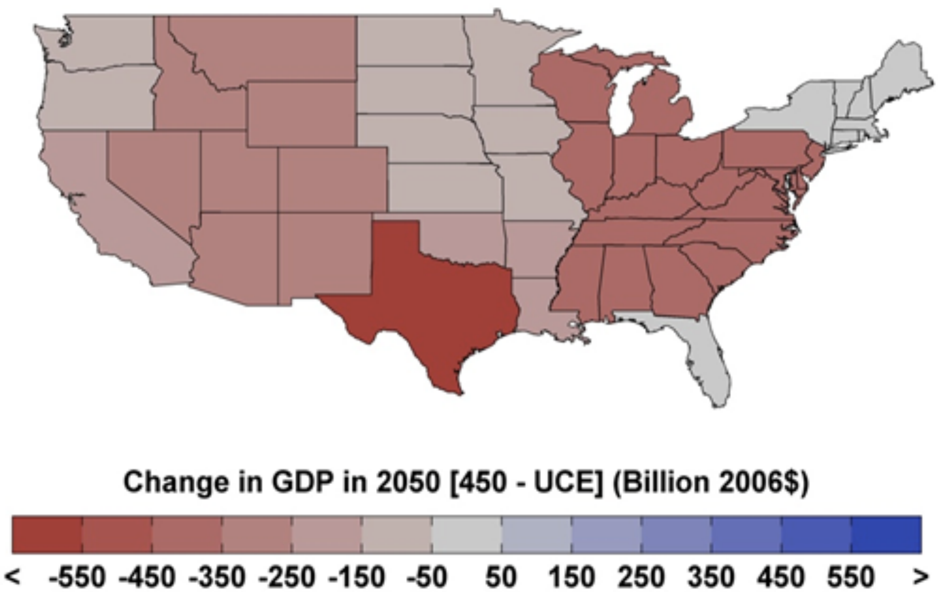


Change in 2050 water consumption between *80% RE Cost-H* and *(Low-Demand) Baseline Scenarios*

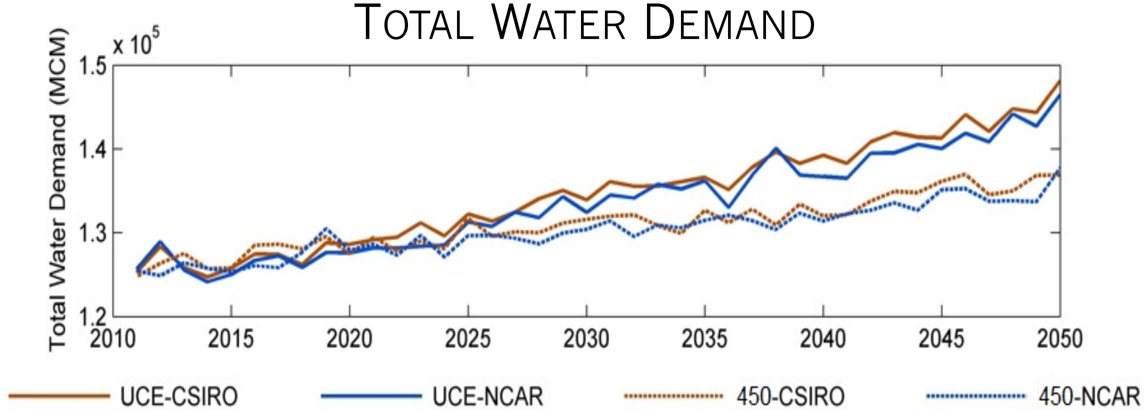


NREL (2012) and Strzepek et al. (2012)

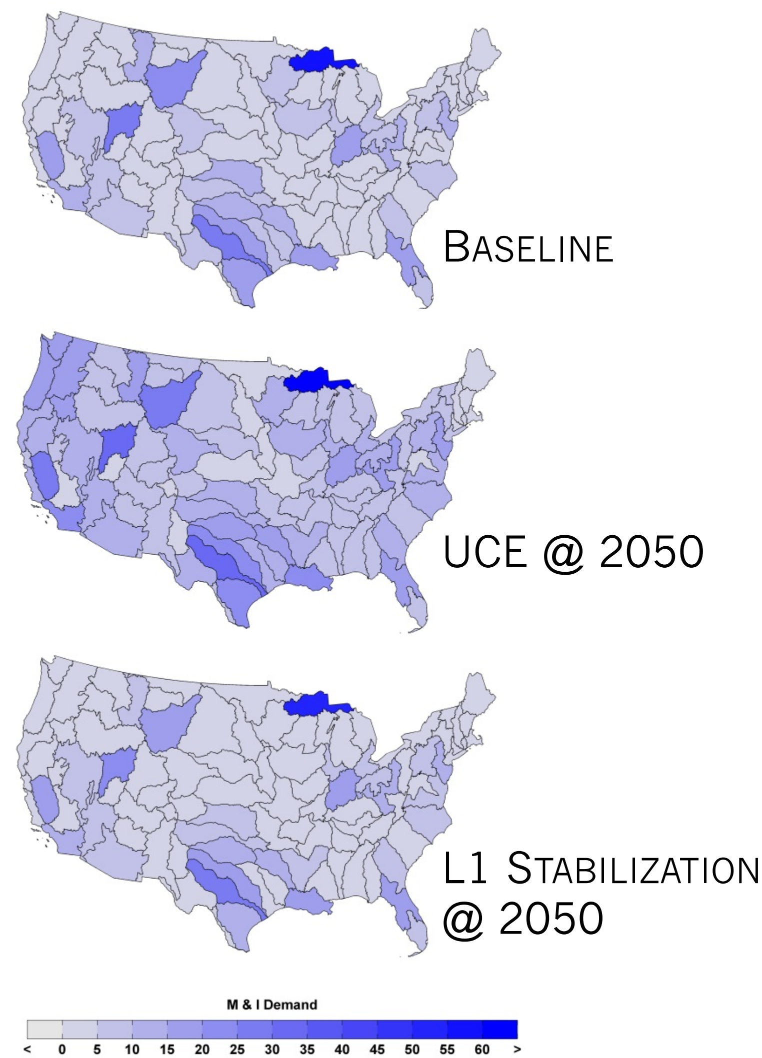
Changes in Economic Drivers and Water Demand to 2050



Total Water Demand



Mining Water Demand



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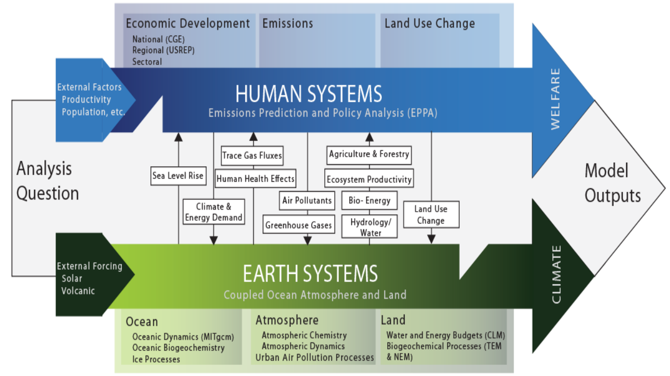

- **The integrated framework provides a linked assessment tool for water management in an "ideal" predictive situation.**
- **In its current configuration, IGSM-WRS describes "potential use".**
- **Through coupled econometric feedbacks, a more robust assessment of water demand can be tracked.**
- **Technologies, efficiencies, J-factors assumed to be stationary.**
- **Downscaling method will be further refined to consider higher-order expansions as well as information from regional climate models (and AR5 model results).**

THANK YOU

Research was supported by the U.S. Department of Energy (DOE-BER-CCRD-IA and DOE-NREL), the National Science Foundation, National Aeronautics and Space Administration, and the Corporate and Foundation Sponsors of the MIT Joint Program on the Science and Policy of Global Change.