A Few Recent Results from the Program on Integrated Assessment Model Development, Diagnostics, and Inter-comparison (PIAMDDI)

Presentation to: **Biological and Environmental Research Advisory Council**
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Outline

- Introduction to Integrated Assessment
- Introduction to PIAMDDI
- Recent Highlights From PIAMDDI
- Q&A

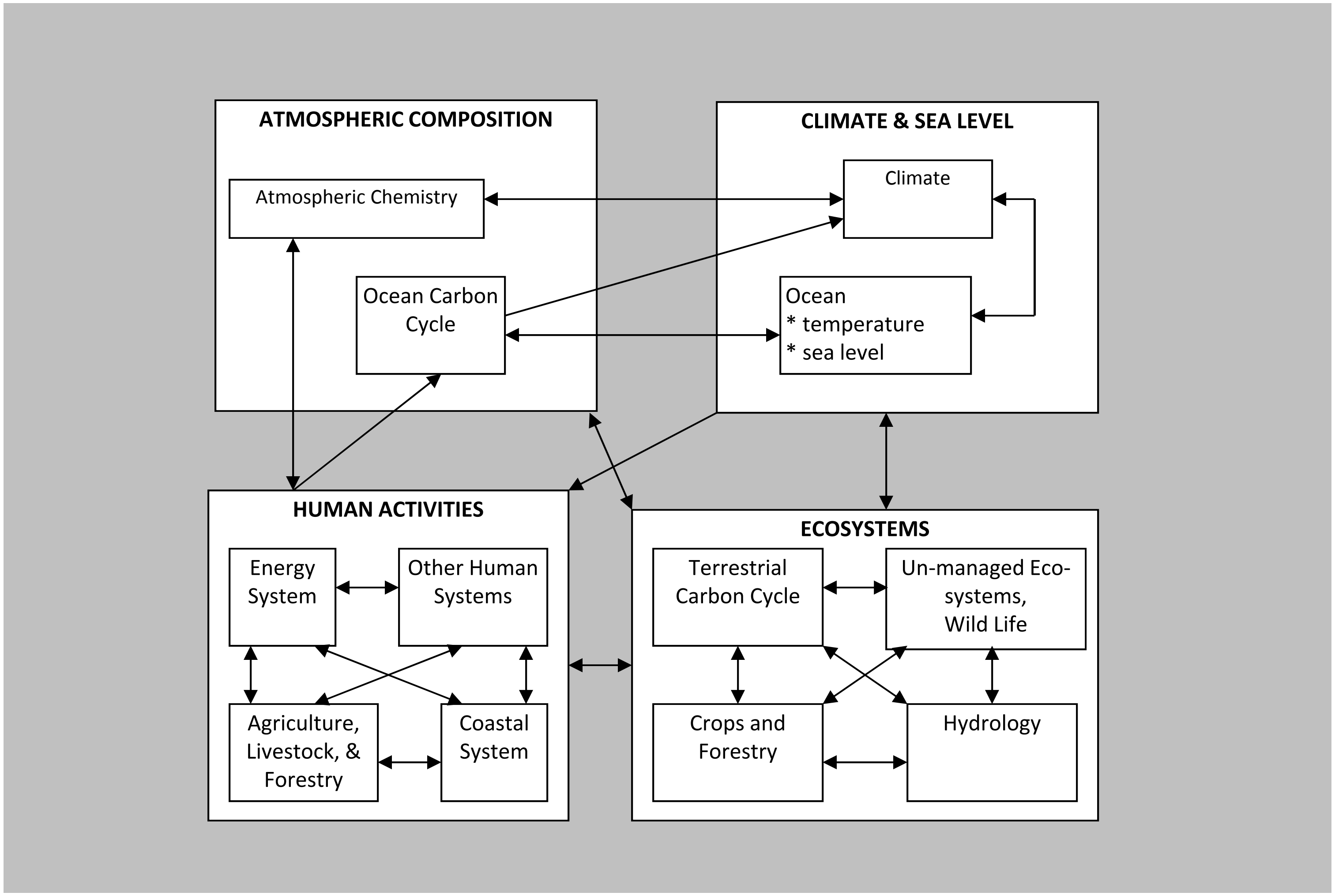
What is Integrated Assessment of Climate Change?

- Many definitions of IA for many purposes (climate change is just one application area)
- Could include any analysis involving two or more major earth system components including at least one natural and one human component
- Can be done with or without models
- Most “formal” IAMs cover as much of the global earth system as possible

Why Integrate?

- Understand complicated interactions and feedbacks among components
- Develop information and insights not available from individual disciplinary models
- Focus in on where and at what scale major interactions between components can occur

Integrating Components



Basic Concepts of Integrated Assessment

- Ocean/Atmosphere/Atmospheric Chemistry
  - Conservation of momentum
  - Conservation of mass
  - Conservation of energy
  - Chemical Reactions
- Eco-systems
  - Photo-synthesis
  - Conservation of mass
  - Conservation of energy
  - Bio-Geo-Physical-Chemical Processes
- Socio-economic System
  - Birth and Death
  - Resource allocation, optimization and market equilibrium
  - Technology change and choice
  - Investment and economic growth

Some Things We Find in Social Sciences, But Not in Physics, Chemistry or Biology

- Humans have:
  - Preferences (possibly changing over time)
  - Expectations (certainly changing over time)
  - Ability to adapt
  - The ability to make contingent decisions
- These characteristics may lead to differences in:
  - Framing questions
  - Modeling systems
  - Integrating models
  - Assessing models

Integrated Assessment Models (IAMs)

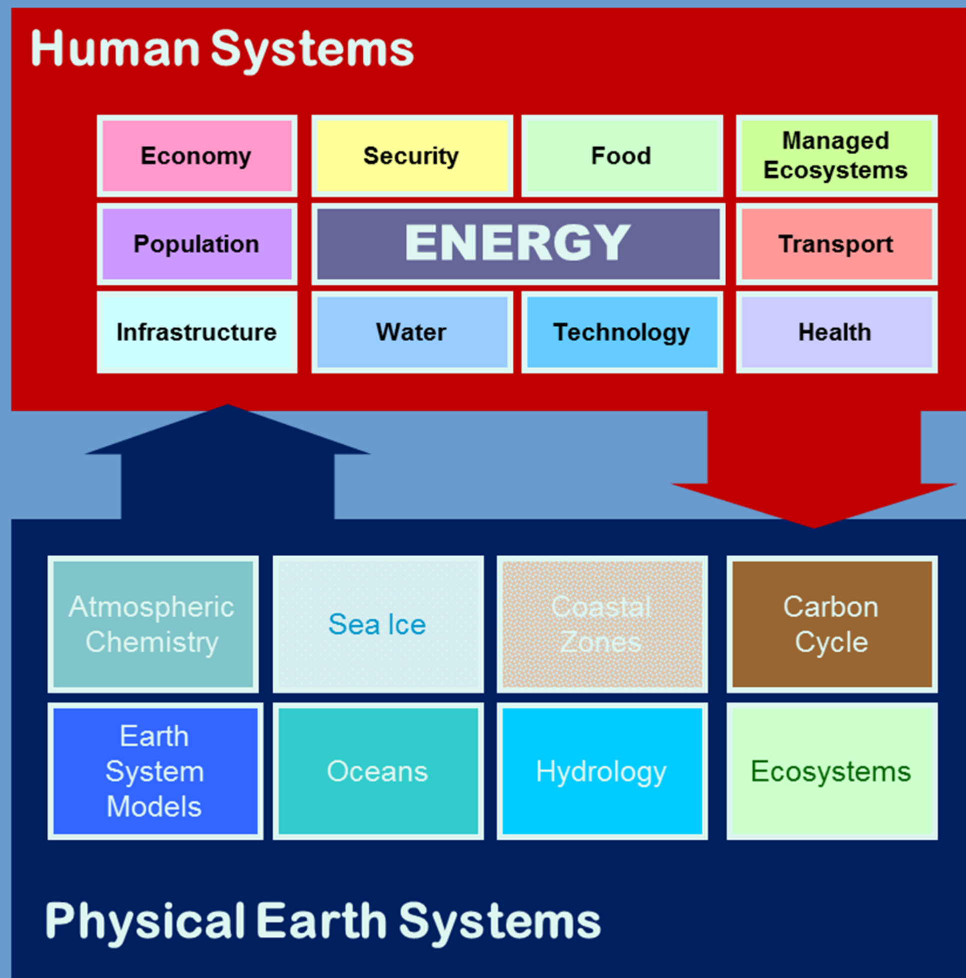
IAMs integrate human and natural Earth system climate science.

- IAMs capture interactions between complex and highly nonlinear systems. IAMs provide insights that would be otherwise unavailable from disciplinary research.
- IAMs provide physical science researchers with information about human systems such as GHG emissions, land use and land cover.

IAMs provide important, science-based decision support tools.

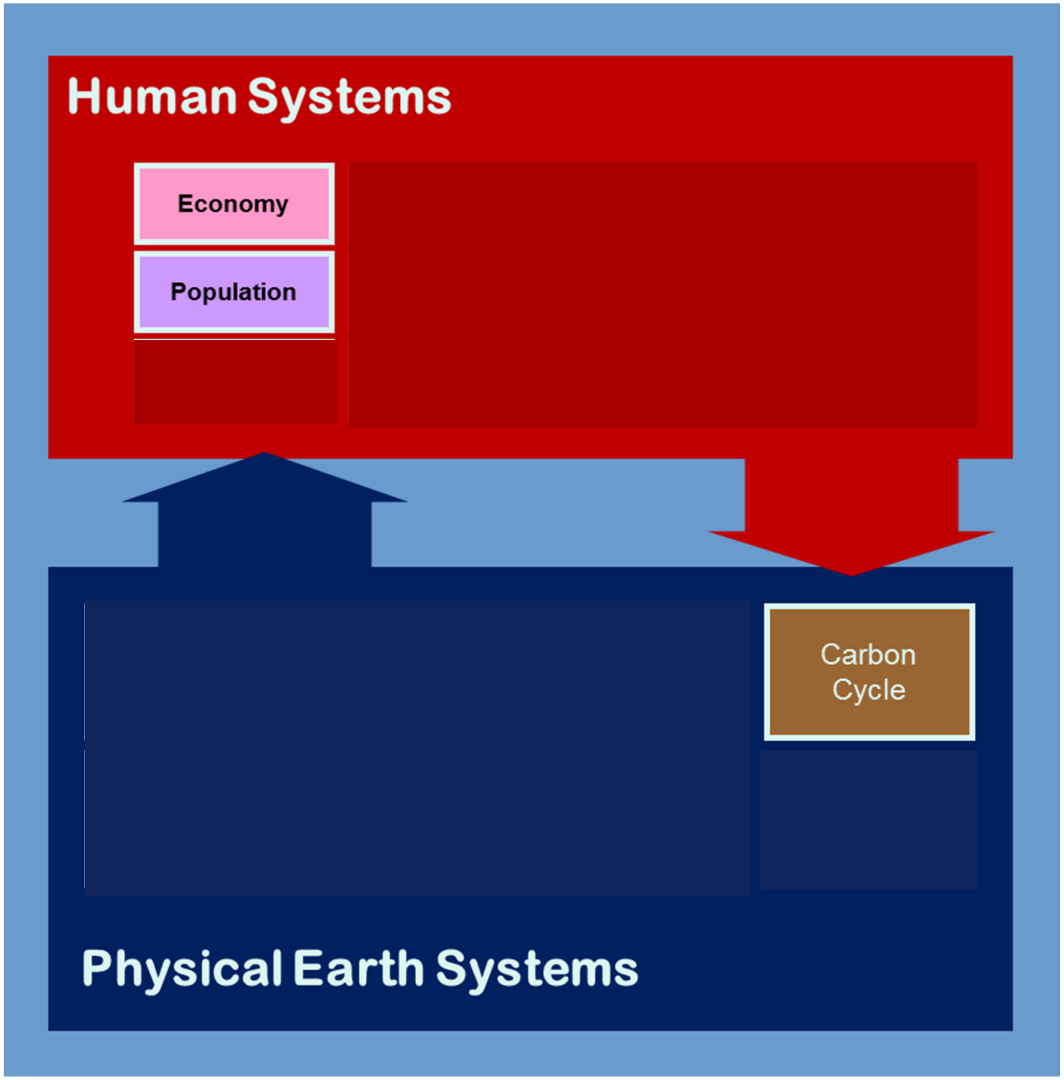
- IAMs support national, international, regional, and private-sector decisions.

From: Calvin, O'Neill and Sue Wing, DOE Climate-Energy Workshop October 24, 2014.



- Some integrated assessment models (e.g., DICE, PAGE, FUND) have focused on cost-benefit analysis. That is, weighing the costs of mitigation against the costs of inaction.

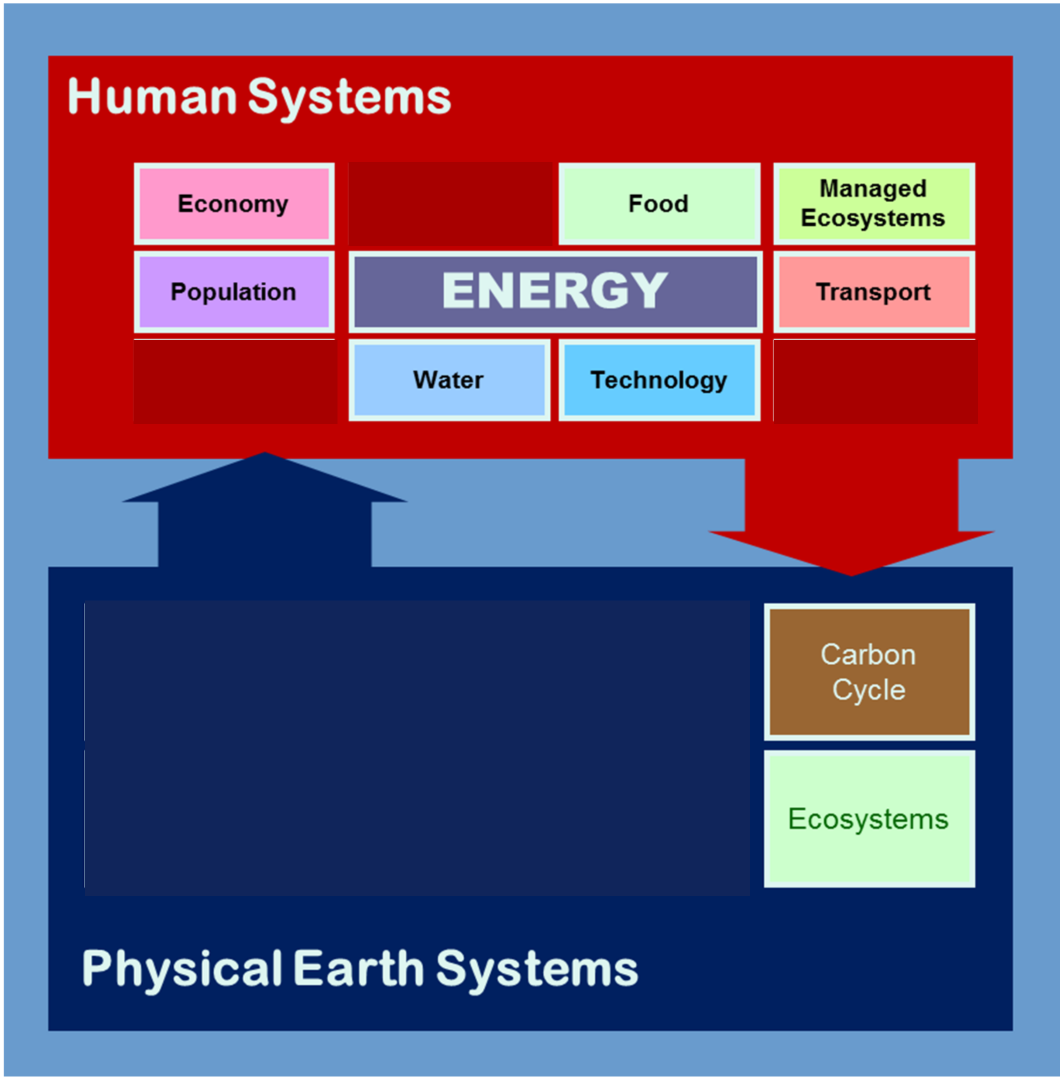
- These models have very simple representations of the economy, but incorporate *all* potential feedbacks from the climate to the human system.



From: Calvin, O'Neill and Sue Wing, DOE Climate-Energy Workshop October 24, 2014.

- Other integrated assessment models (e.g., IGSM, GCAM, MESSAGE, IMAGE, MERGE) have focused on cost-effectiveness analysis. That is, quantifying the transition pathways and costs associated with stabilizing climate at a pre-defined level.

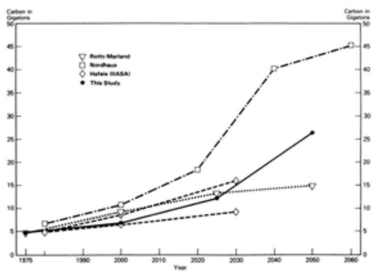
- These models have more complex representations of different components of the economy (e.g., energy, agriculture), but have largely excluded feedbacks from the climate to the human system.



From: Calvin, O'Neill and Sue Wing, DOE Climate-Energy Workshop October 24, 2014.

1980's

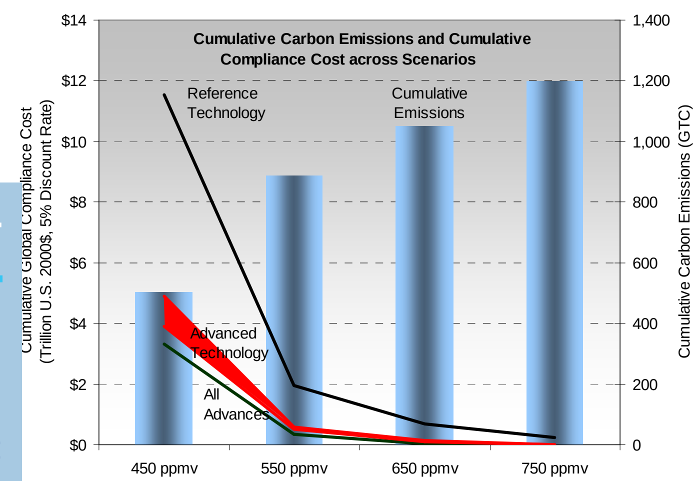
Projections of emissions and concentrations



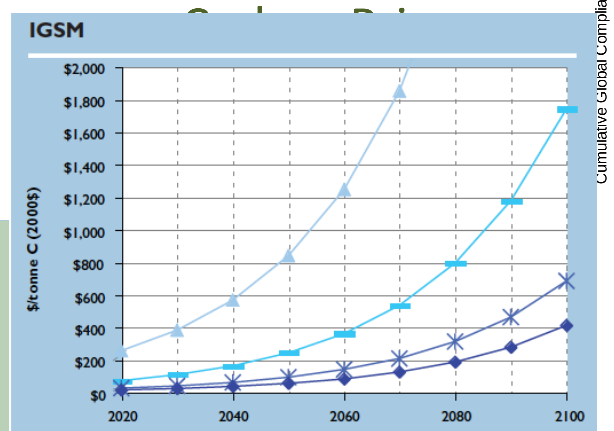
ENERGY-ECONOMY-climate

1990's through 2000's

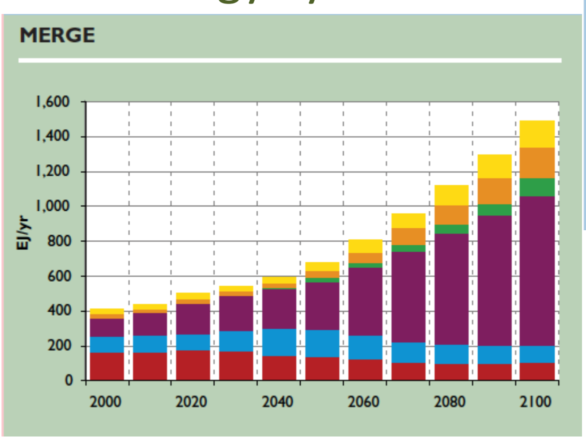
Energy, Technology, and Mitigation



Value of Technology



Energy Systems

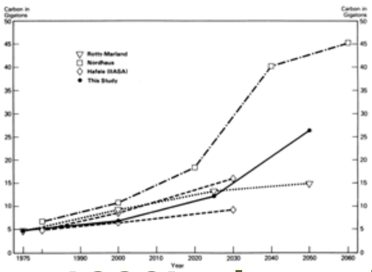


From: Calvin, O'Neill and Sue Wing, DOE Climate-Energy Workshop October 24, 2014.

ENERGY-ECONOMY-land-climate

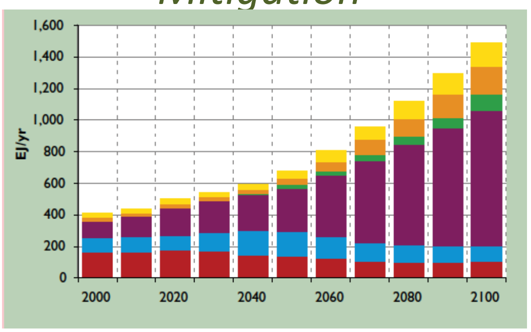
1980’s

Projections of emissions and concentrations



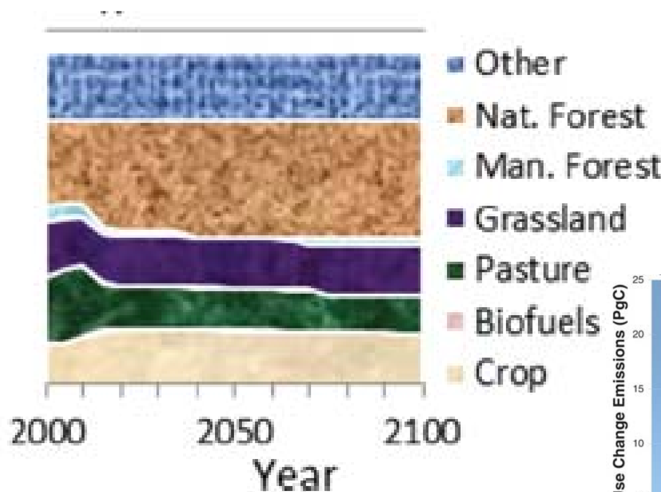
1990’s through 2000’s

Energy, Technology, and Mitigation



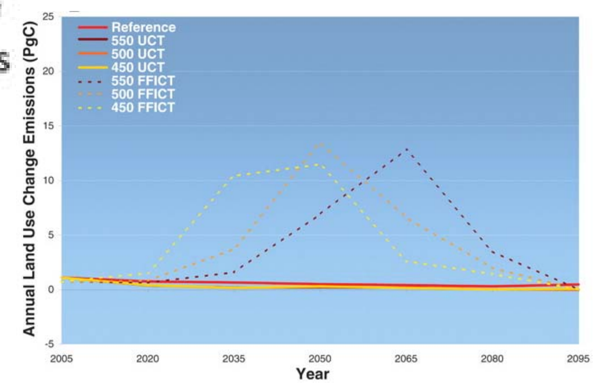
2000’s

Mitigation and land use



Crop production and land surface changes

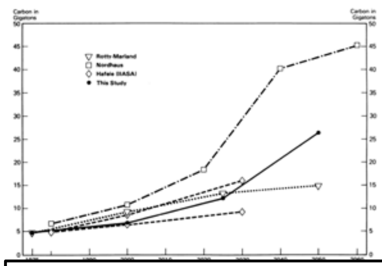
Land Use Change Emissions



From: Calvin, O’Neill and Sue Wing, DOE Climate-Energy Workshop October 24, 2014.

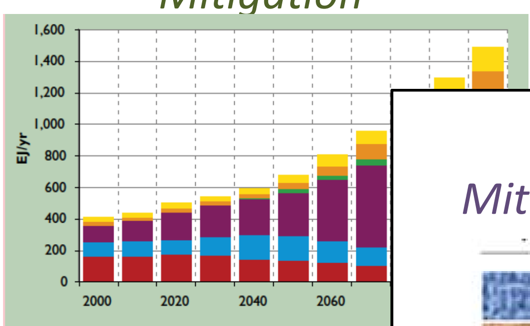
1980's

Projections of emissions and concentrations



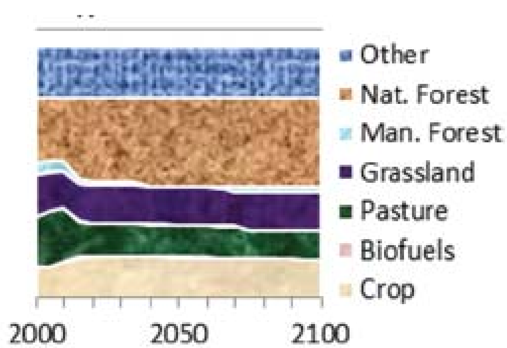
1990's through 2000's

Energy, Technology, and Mitigation



2000's

Mitigation and land use



ENERGY-ECONOMY-LAND-WATER-CLIMATE

TODAY

Integrating Impacts, adaptation, and vulnerability

From: Calvin, O'Neill and Sue Wing, DOE Climate-Energy Workshop, October 24, 2014.

PIAMDDI

- Who are we?
  - A transdisciplinary network of researchers engaging in empirically driven research that provides valuable tools and insights to the IAM community and other global change research communities (e.g. ESM ,IAV, Agric., etc.)

- What is our role in the IAM community?
  - Given the diversity and orientation of the research group, we don't favor any one approach—instead embracing the need for "horses for courses"
  - We strive to be a group of researchers who evaluate alternative approaches in a consistent and balanced way (i.e, we are inter-disciplinary "honest brokers")
  - We bring together a team of researchers considered experts in their fields that serve or could serve as advisors to the IAM community and other GC communities.

PIAMDDI

- What is our goal?
  - An overarching research goal is to improve the way feedbacks and interactions are captured in IAMs.
  - There are a number of approaches to accomplish this objective, and PIAMDDI is investigating all of them:
    (1) Direct coupling of models;
    (2) Emulators of more complex ESM and IAV models that can be coupled with IAMs;
    (3) Pattern scaling, dynamical downscaling, statistical emulations to be incorporated directly into IAMs;
    (4) Integration and translational tools for facilitating the flow of information across models.
  - Uncertainty quantification, model diagnostics and inter-comparison cross-cut all of these research projects

Progress in Each Of These Areas Requires Parallel Efforts In:

- Basic research
- Research co-ordination
  - DOE PI Meetings/BERAC
  - Across multiple disciplines and team members
  - Our own PI meetings including reps. from LLNL, LBNL, JGCRI, MIT, EPRI
  - Outreach and communication accomplished through global networks
    - IAMC, WCRP, IAV, DMUU, AEA, INFORMS
      - » AMPERE/LIMITS/ROSE (EU), ADVANCE(EU), PESETA (EU), LCS (Japan), LAMP (EPA-JGCRI)
    - Energy Modeling Forum MIPs
    - Global disciplinary research networks, NBER, GTAP, ETSAP, IEW, etc.
    - US Agencies
    - EU/ROW Agencies
- Model diagnostics and validation
  - Collaborations with PCMDI/CMIP5-6/ADVANCE, etc.
  - New focus on hind casting
- And these three types of activities need to be tightly coordinated within and between the four research areas

SOME RESULTS:
EARTH SYSTEM COMPONENT MODEL EMULATION AND DOWNSCALING

More Basic concepts
Sources of uncertainty/differences

- Forcing

  GHG emissions scenario (e.g. B1, A1B, A2, 4 RCPs)

  Ozone, sulfate aerosols, land use, black carbon …

- Response

  Model differences

  Different physics, parameterizations, resolution …

- Internal (Unforced) Variability

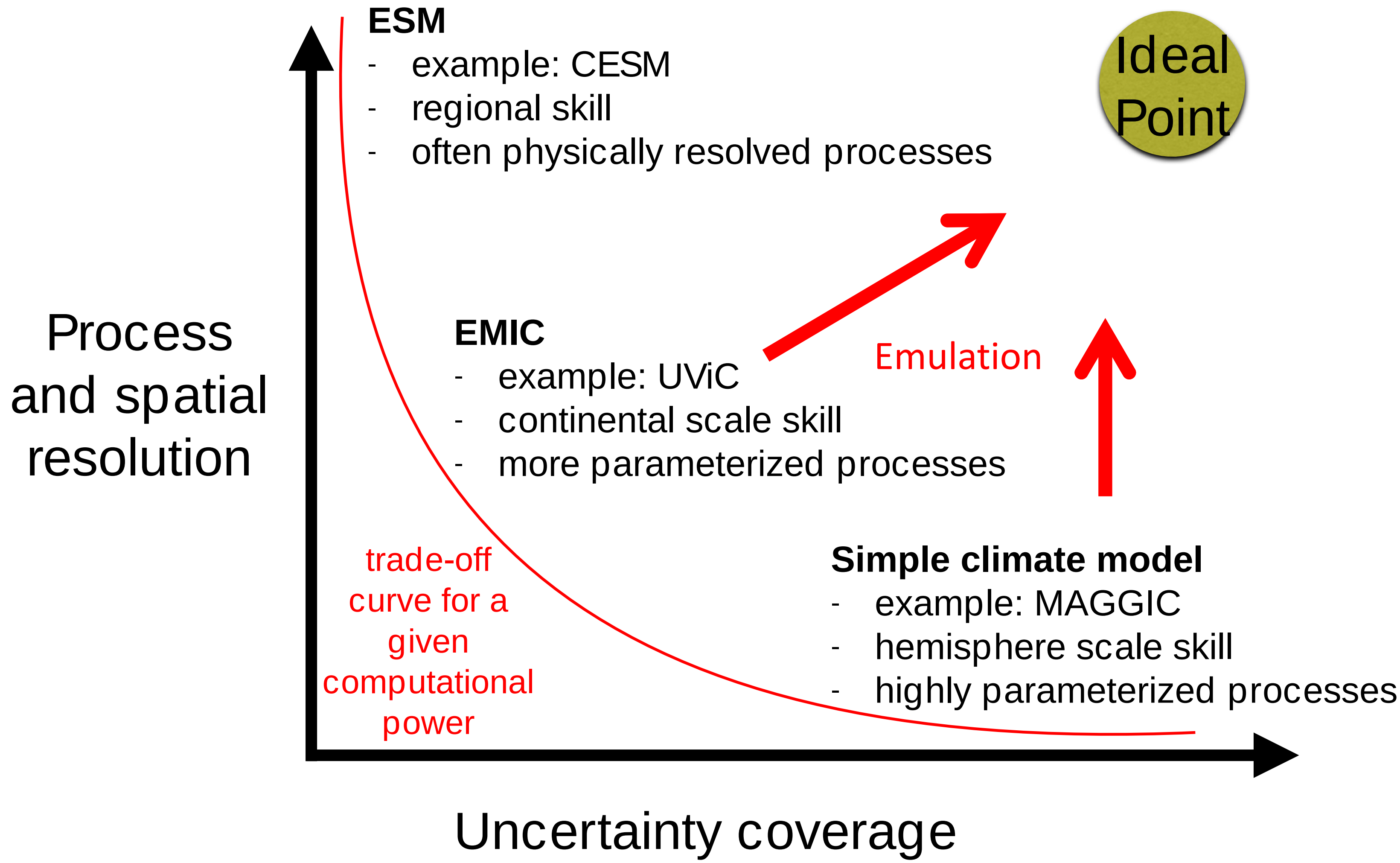
  Atmosphere

  Ocean

  Coupled atmosphere-ocean system

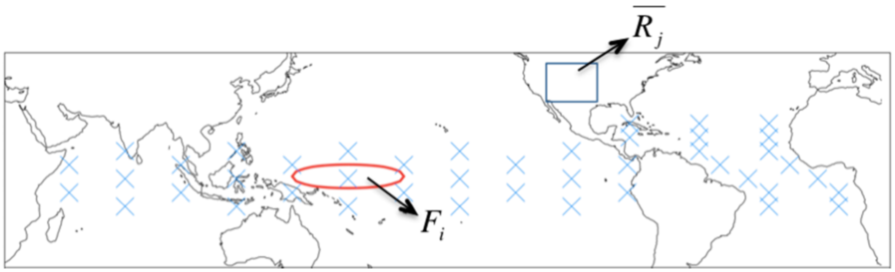
Deser & Phillips (2014, ASP Colloquim)

Even More Basic Concepts: Emulation can facilitate the information exchange between a suite of model complexities.



Keller et al (in prep)

Can Global Teleconnection Operators be used to estimate regional climate changes driven by sea surface temperature changes?

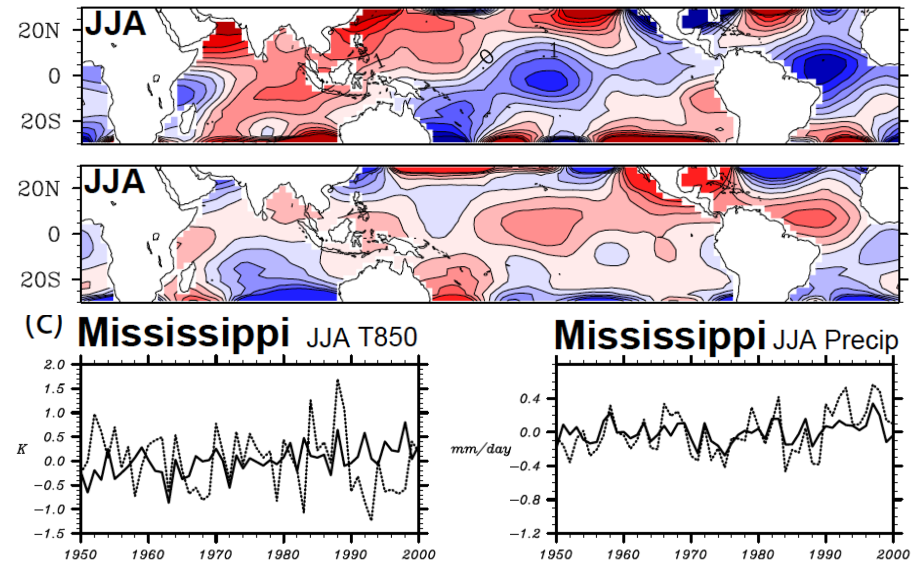


Global Teleconnection Operator, K_{ij},
Sensitivity of regional climate change as estimated from an ensemble-mean response, R_j, to a localized ΔSST forcing, F_i:

$$\overline{R_j} = K_{ij} \cdot F_i + \varepsilon$$

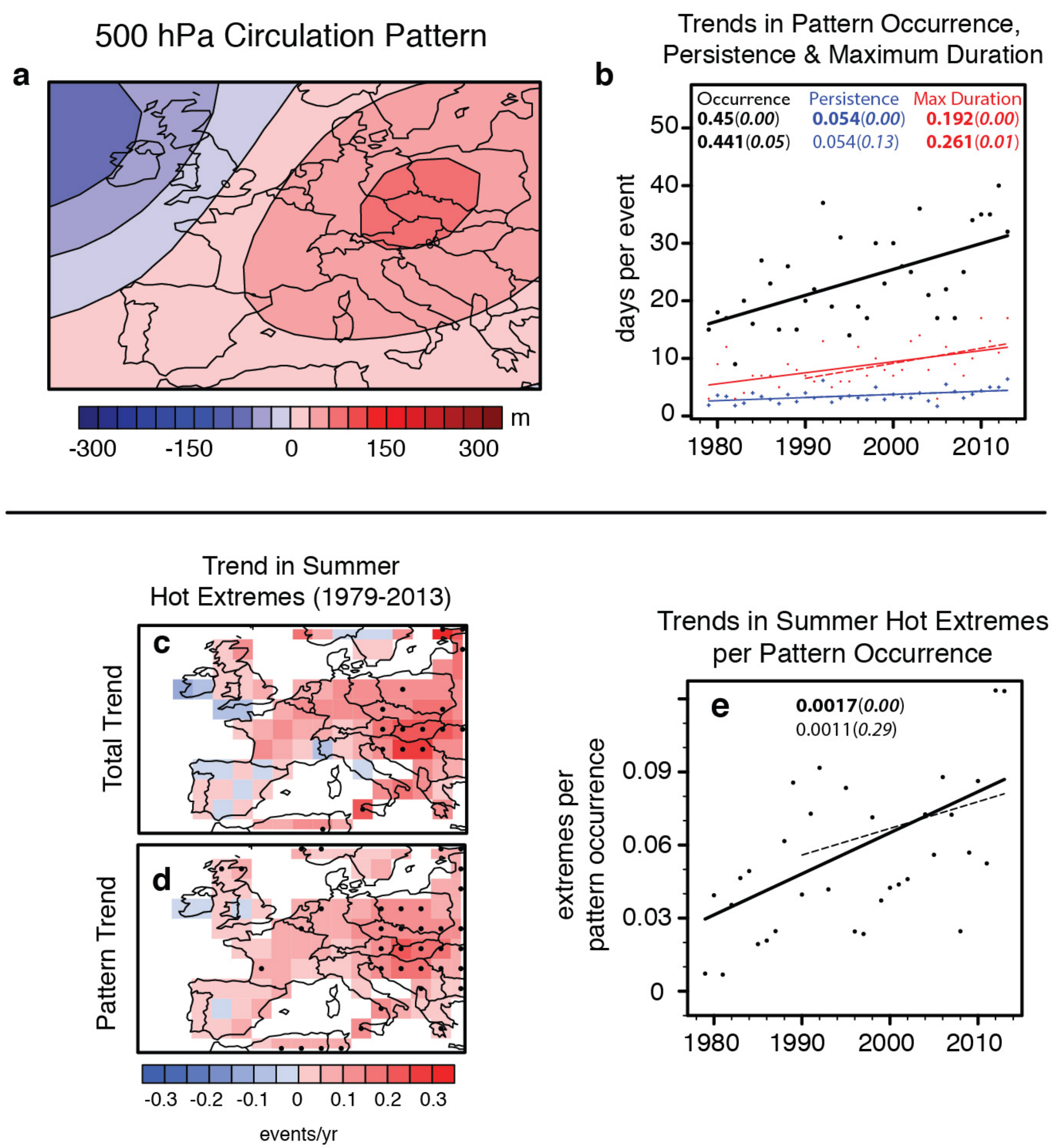
Estimation Method Developed in:
Li, Forest, & Barsugli (2012, JGR, doi:10.1029/2011JD017186)

Application to Mississippi River Basin



(top) Sensitivity of T850 and Precip in basin to SST anomaly location
(bottom) Reconstructed T850 and Precip using observed SST changes from 1950-2000
Tsai, Forest, and Wagener (2014, Clim. Dyn.)

Application Papers:
Sensitivity of Regional Dust Emissions to SST: Hoffman, Forest, & Li (2014, JGR, doi:10.1002/2014JD021682)
Regional River Basin Hydrology: Tsai, Forest, & Wagener (2014, Clim. Dyn., doi:10.1007/s00382-014-2449-1)
NAO/PNA Variability driven by SST changes: Li & Forest (2014, J. Climate, doi:10.1175/JCLI-D-14-00231.1)



Horton et al., provisionally accepted by Nature

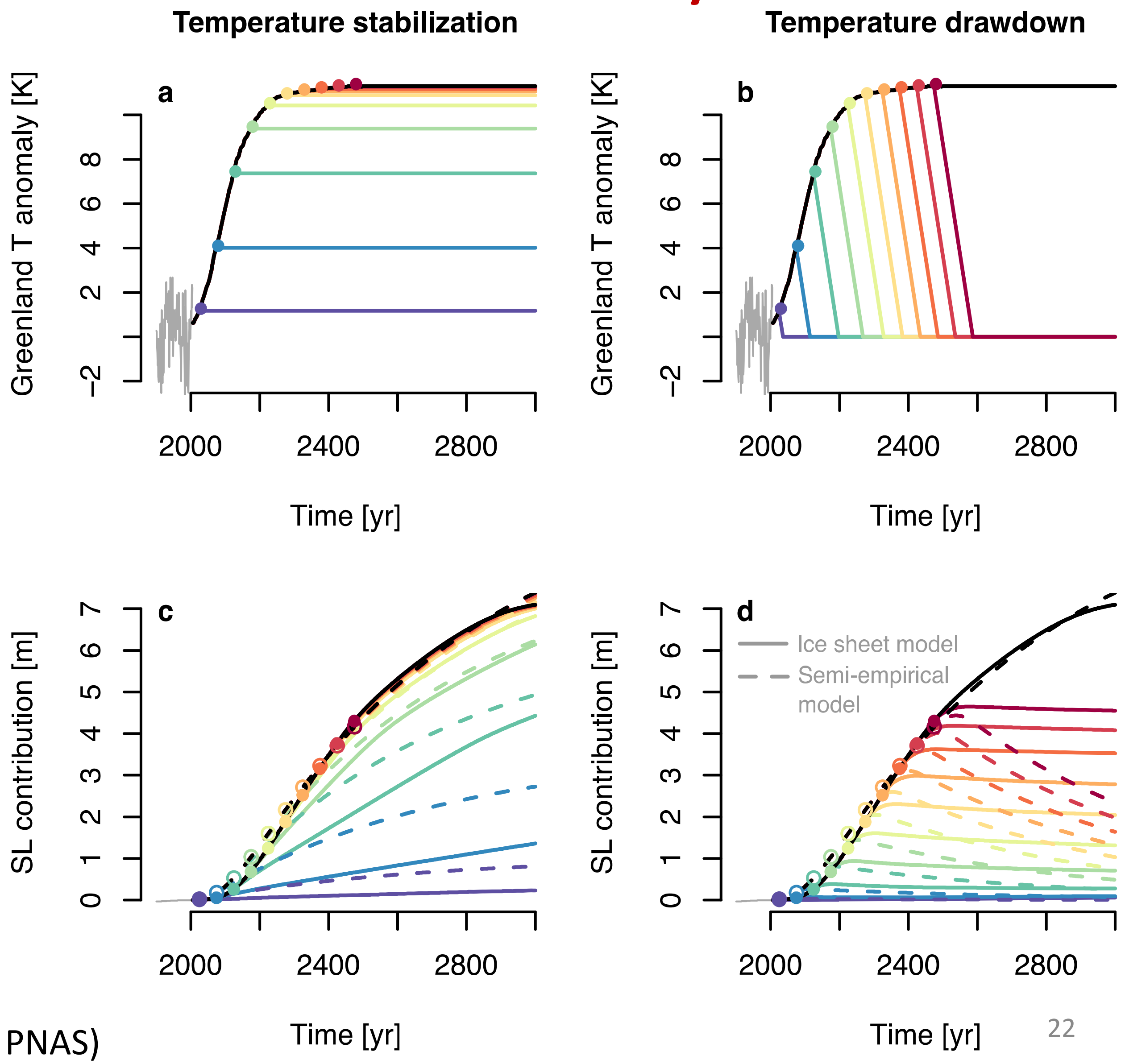
What causes observed changes in extreme temperature occurrence?

- driven in part by changes in atmospheric pattern occurrence
- and in part by extent of extremes within region when pattern occurs

Do Simple Ice Sheet Models Capture Important Irreversibility's

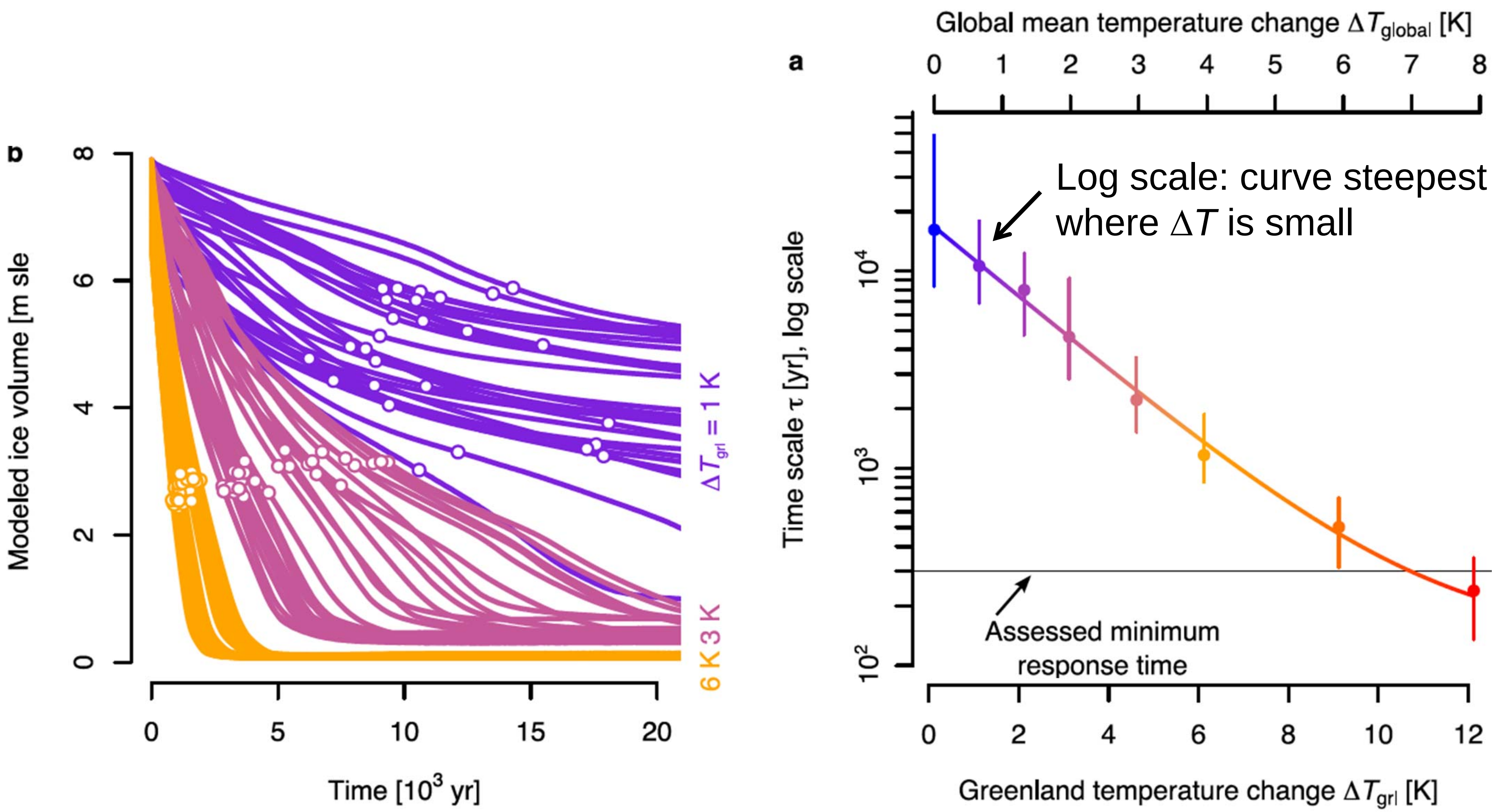
Simple physical feedbacks render geoengineering inefficient to reverse sea-level rise due to a Greenland Ice Sheet melting.

Semi-empirical models used in IAMs typically miss this point.



Applegate and Keller (in review, PNAS)

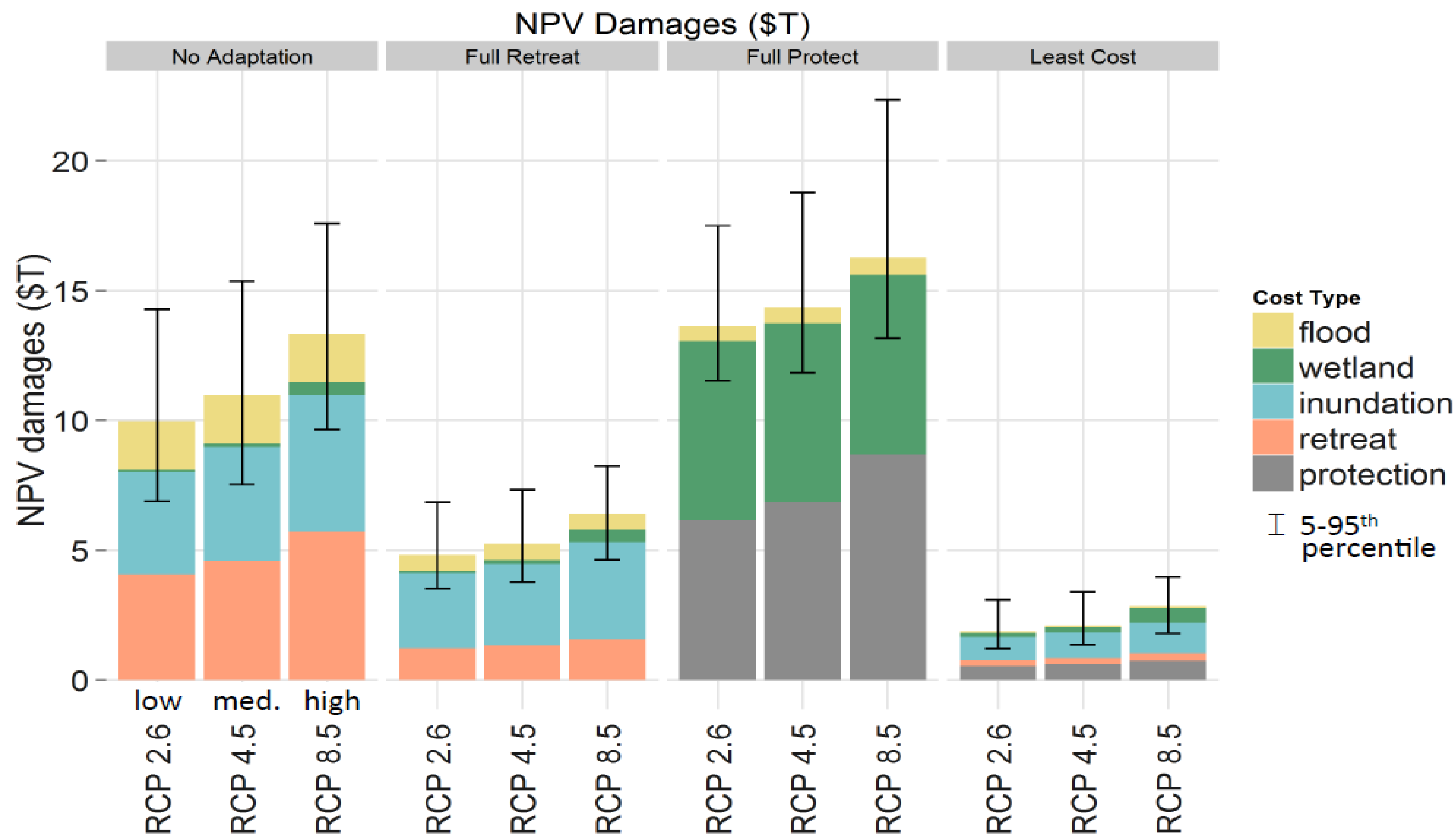
Does the Greenland Ice Sheet response speed up with increasing forcing?



Applegate, Parizek, Nicholas, Alley, and Keller (Climate Dynamics, 2014)

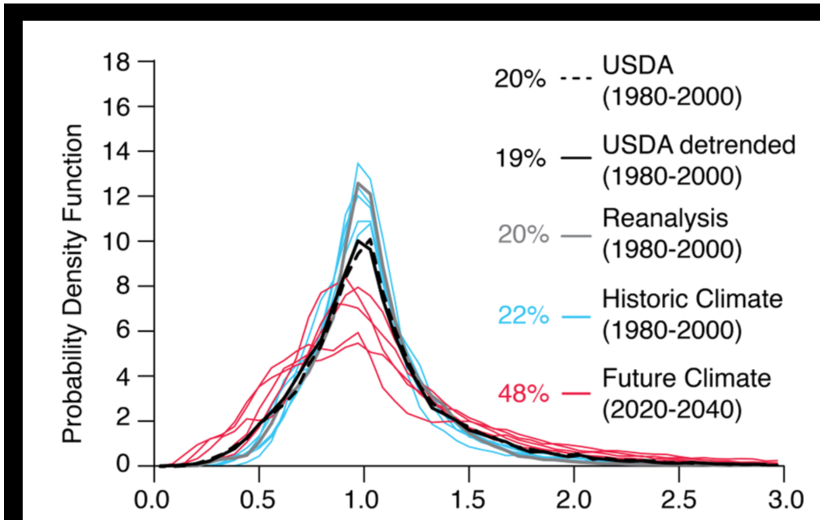
Can Adaptation Reduce the Cost of Sea Level Rise?

CIAM results: Adaptation can reduce global discounted costs by factor of five



Diaz, Delavane: Poster at 2015 American Geophysical Union Annual Meeting, Dec., 2014.

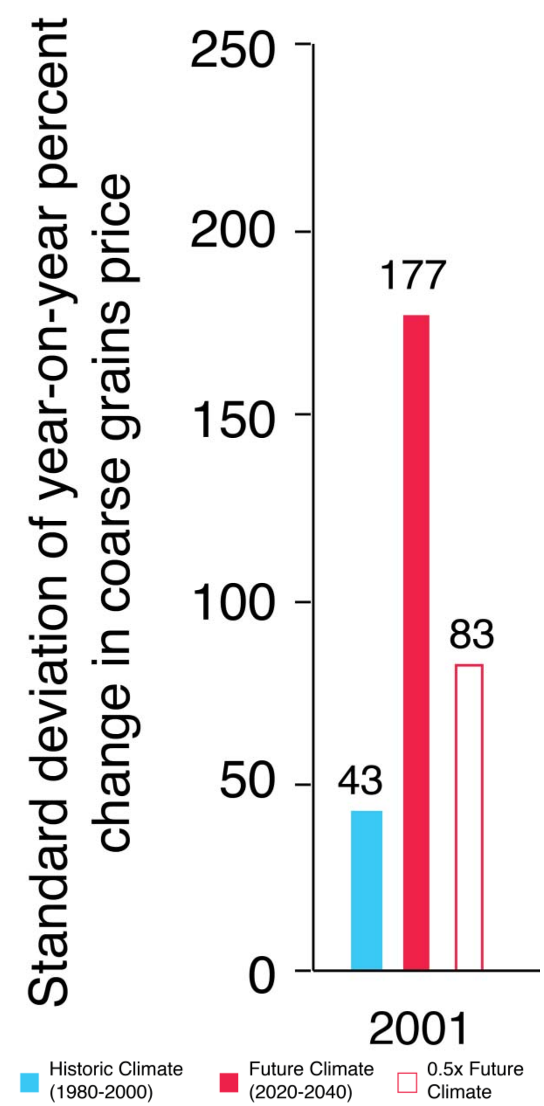
SOME RESULTS:
INTEGRATED CLIMATE CHANGE IMPACTS ASSESSMENT



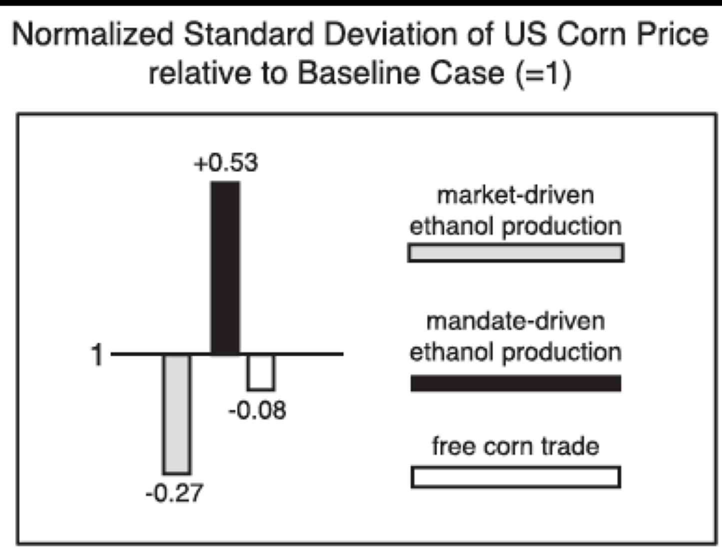
Diffenbaugh et al., 2012

Additional 1˚C of global warming increases occurrence of extreme heat, which leads to ~2x change in volatility of U.S. corn yields

2x increase in corn yield volatility causes 4x increase in corn price volatility

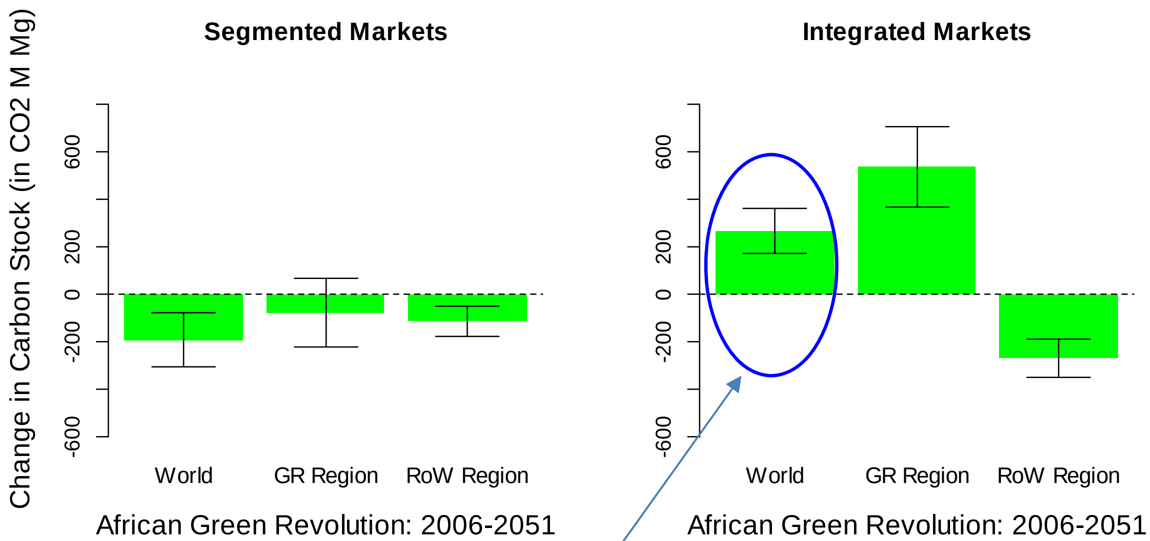


Diffenbaugh et al., 2012



mandate-driven ethanol production exacerbates corn price volatility, but market-driven integration reduces volatility

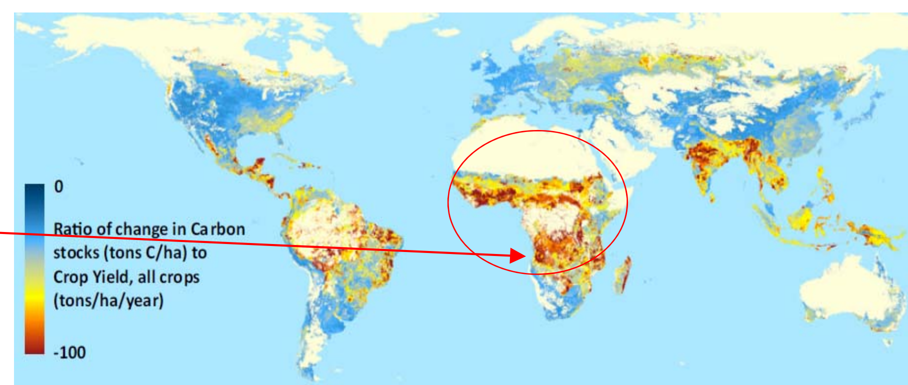
Future integration of world markets changes the GHG consequences of Green Revolutions



Hertel, Ramankutty and Baldos, "Global market integration increases likelihood that a future African Green Revolution could increase crop land use and CO2 emissions" *PNAS*, 2014

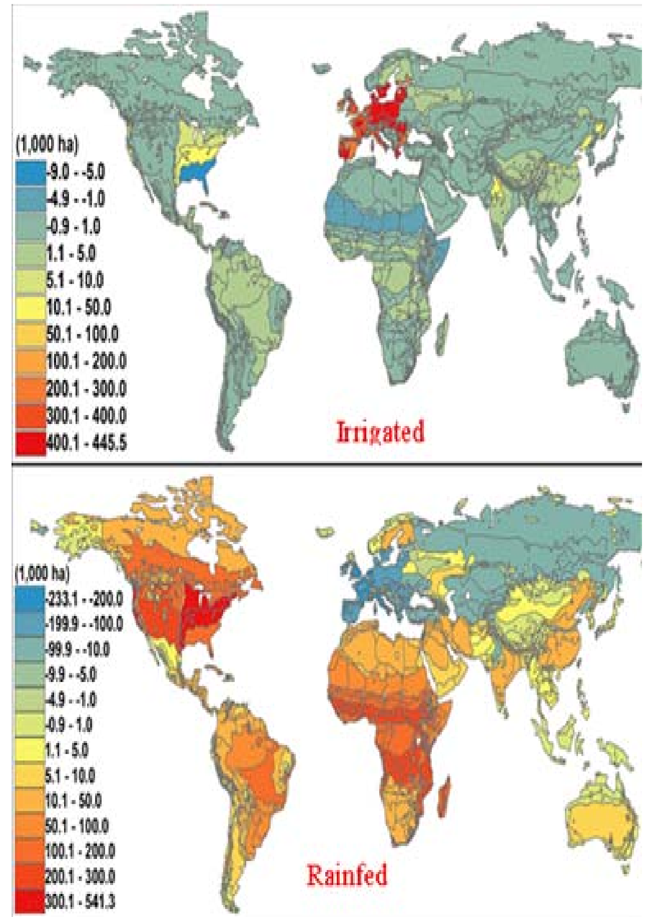
Prospective African *GR is unambiguously emissions increasing* when markets are integrated

This finding is driven by the ***low relative emissions efficiency in African agriculture***



Will constraints on irrigation expansion shape future patterns of land use & associated GHG emissions

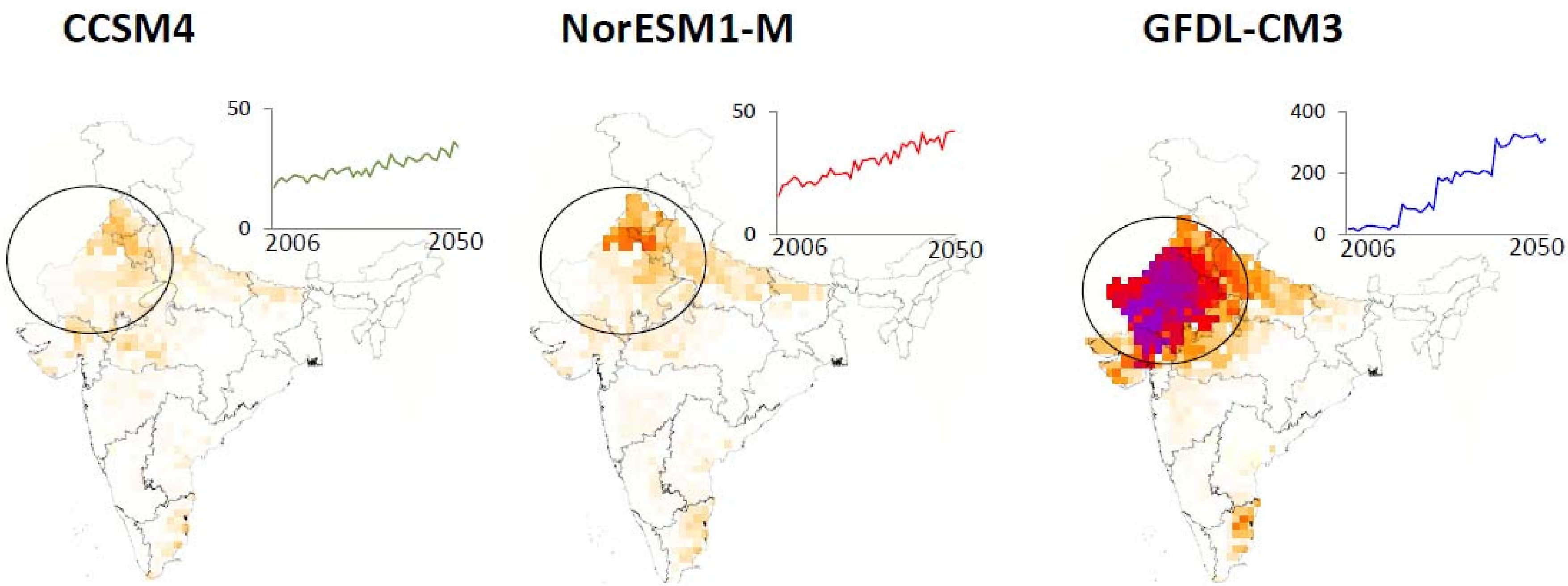
- **Irrigated area accounts for 40% of crop output, world-wide:**
  - Crop yields: irrigated > rainfed
  - Carbon/ha: rainfed >> irrigated
- **When irrigation expansion is constrained in water scarce regions, rainfed area expands:**
  - Average yields are lowered
  - Tend to expand in more carbon rich AEZs
- **Under US ethanol-driven cropland expansion, including irrigation constraint boosts GHG emissions by 25%!!**

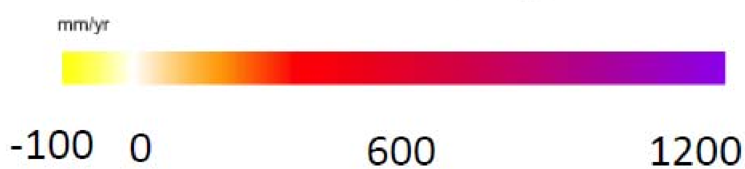


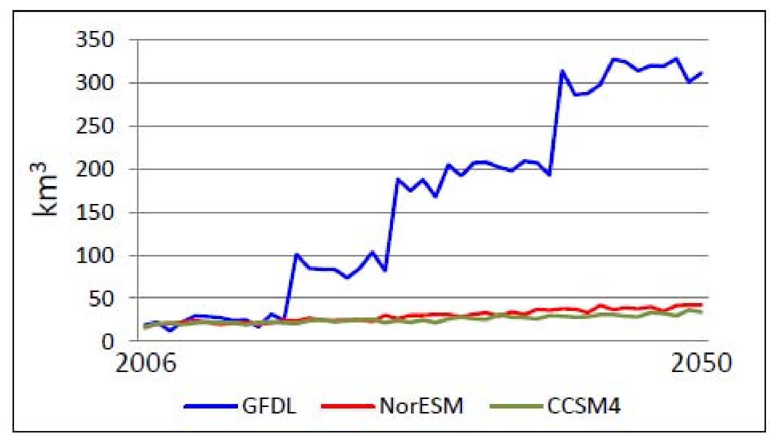
Constrained Case

Taheripour, Hertel and Liu (2013)

Preliminary Results: Δ Unsustainable Mined Groundwater [Dry Season]



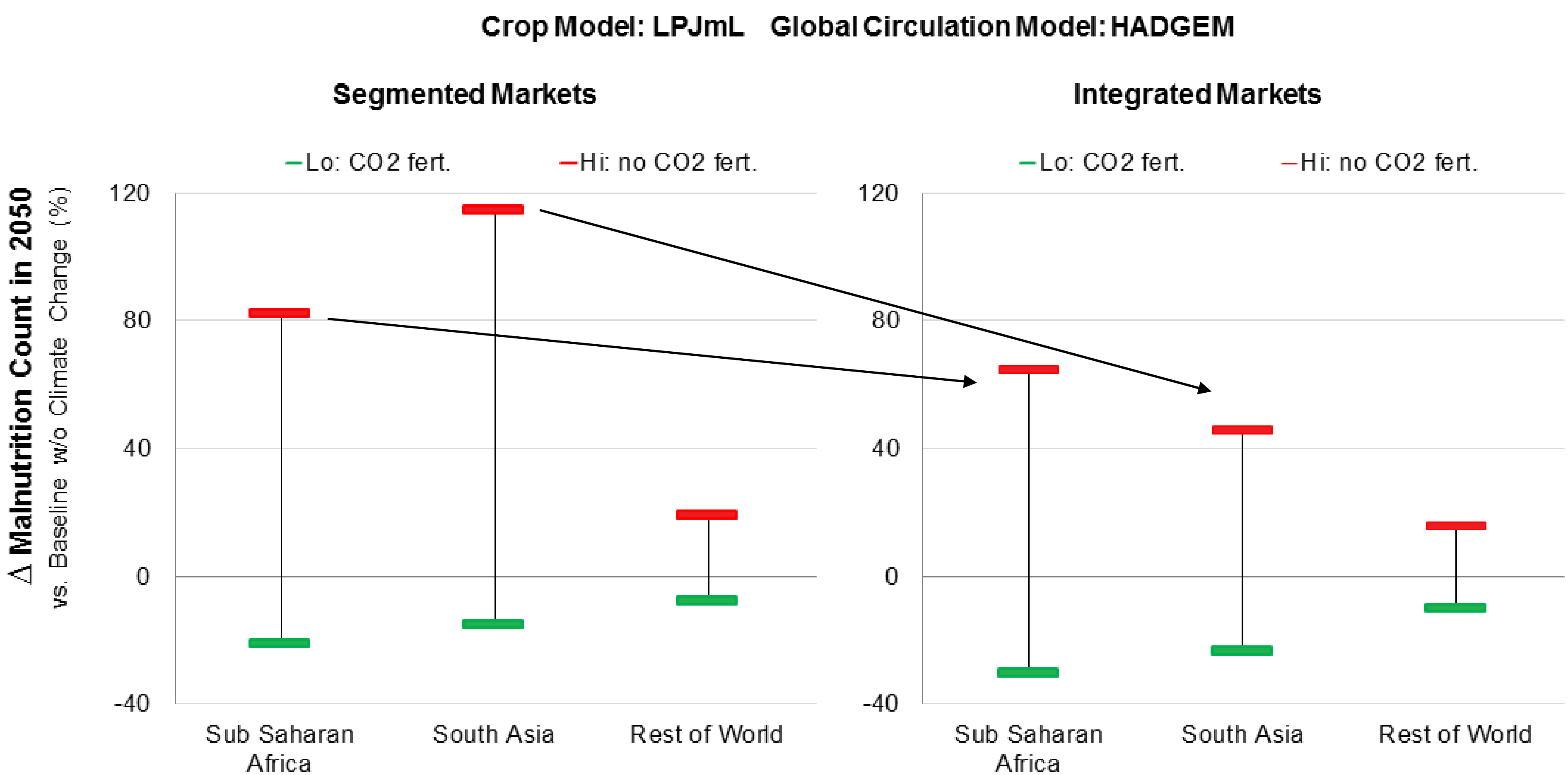




* Δ = 2040-2049 minus 2006-2015.

Grogan, Zaveri, Fisher-Vanden, Frolking, Wrenn, Nicholas (2014).

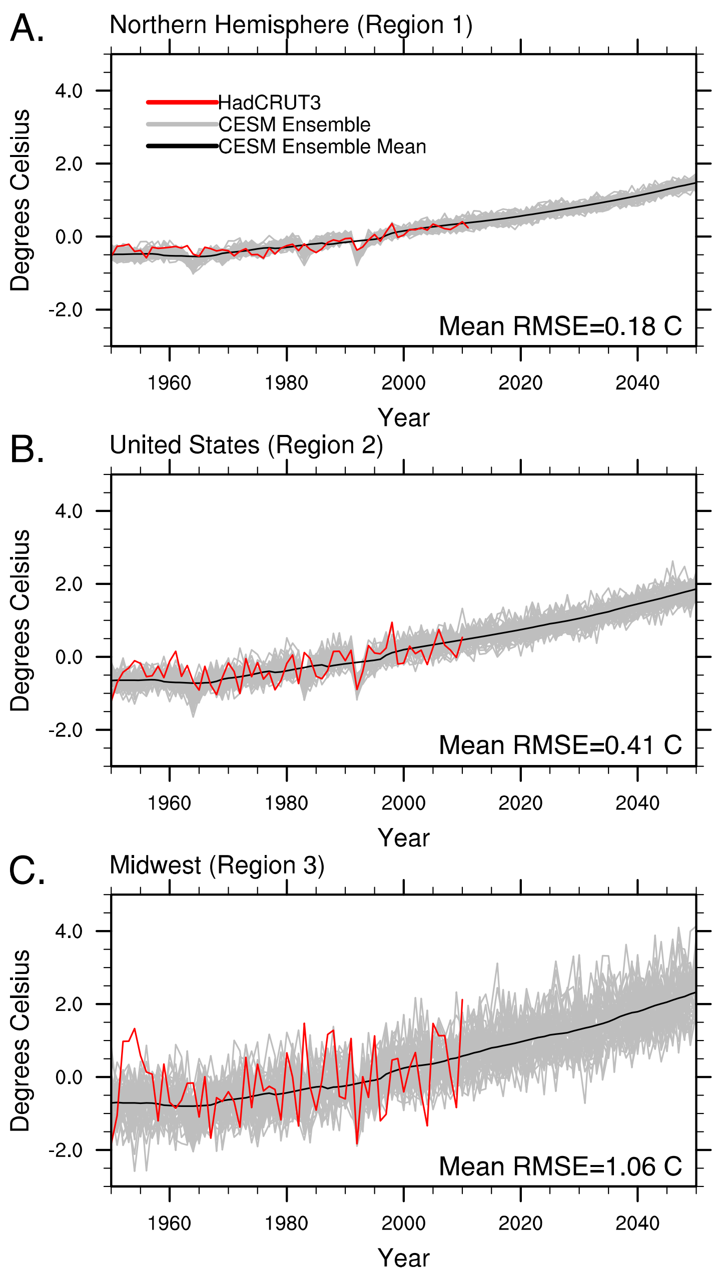
Will International market integration moderate the most severe nutritional impacts of climate change?



Uris Baldos and Thomas Hertel, "The role of international trade in managing food security risks from climate change" *Food Security* (in press)

SOME RESULTS:
UNCERTAINTY AND DIAGNOSTICS

Summer Mean Temperature



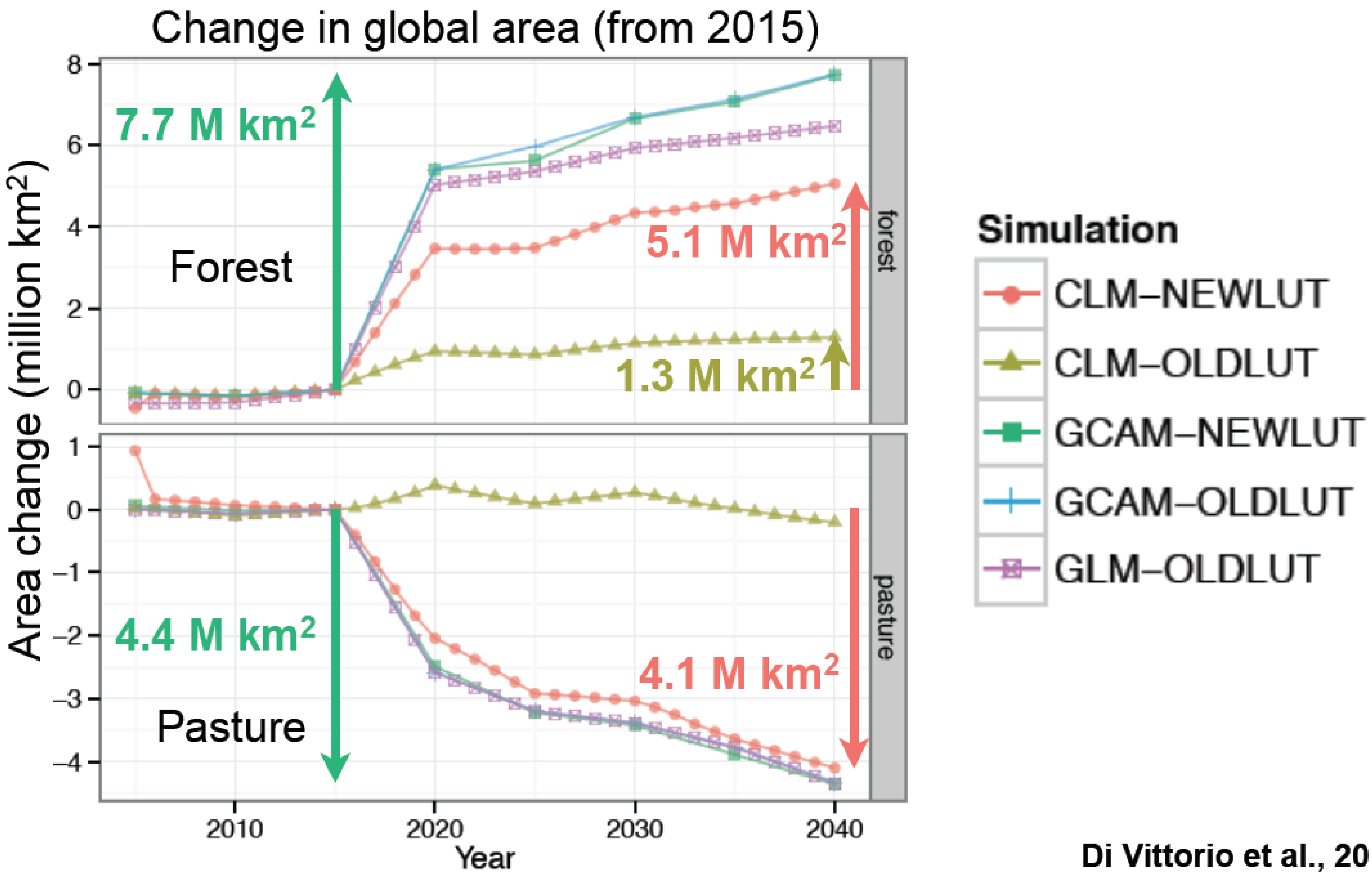
- We use CESM to sample the effect of unforced variability in the coupled ocean-atmosphere-land system on regional climate

- The ensemble exhibits considerable skill in simulating inter-annual climate variability, and it captures key statistical characteristics of temp/precip extremes

- Results point to new model diagnostics based on variability and extremes that can be used to evaluate model skill, quantify decision-relevant uncertainty, and inform regional impacts analyses

Sriver R. L., Forest C. E., and Keller K. (2015), In review at Geophysical Research Letters

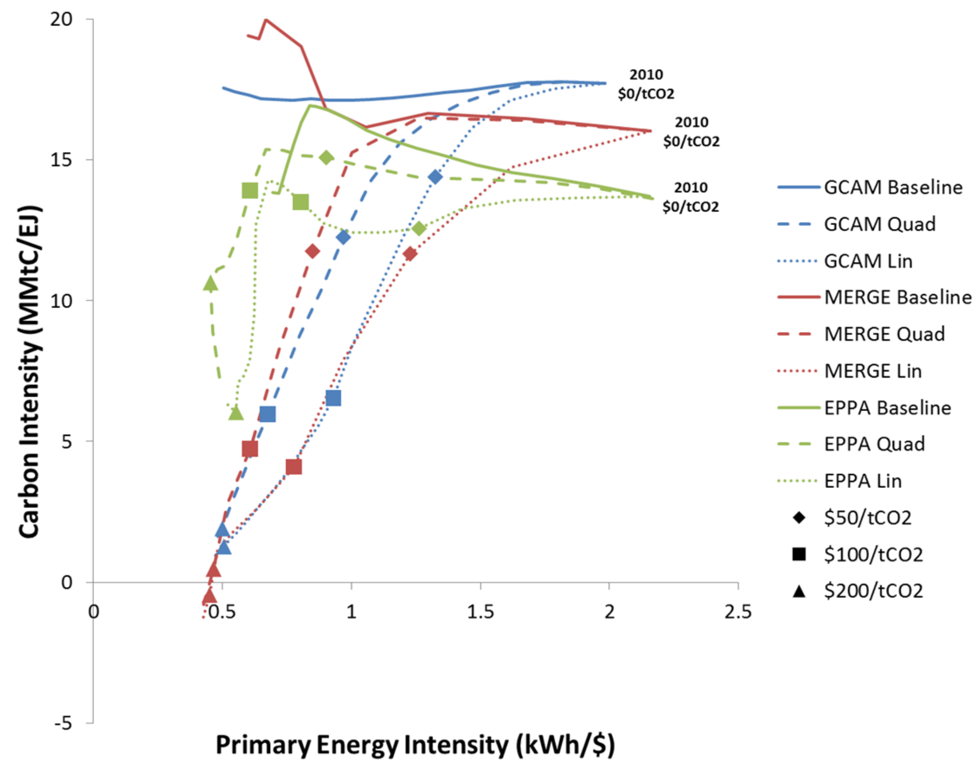
Land cover inconsistencies across IAMs and ESMs can alter the global carbon cycle



Di Vittorio et al., 2014

How do energy and carbon intensities in IAMs adjust to carbon constraints?

- First note that each model assumes different states at the beginning of the runs
- MERGE anticipates future Changes
- EPPA shows almost no reduction in carbon intensity until the price reaches $200, then suddenly switches to all carbon reduction



Source: Wilkerson, et al., 2015.

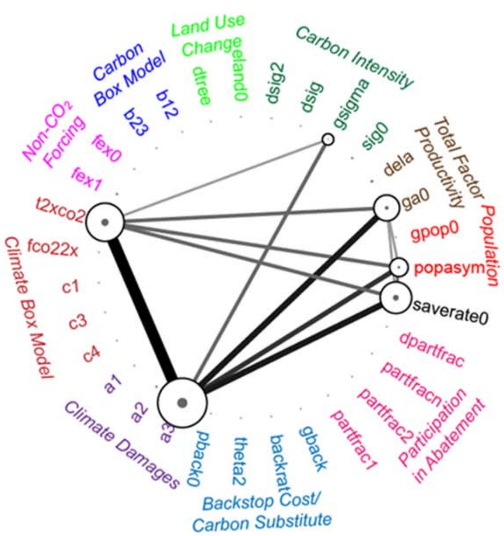
Do sensitivities of outputs from IAMs differ by scenario?

Identifying Parametric Controls and Dependencies in Integrated Assessment Models using Global Sensitivity Analysis

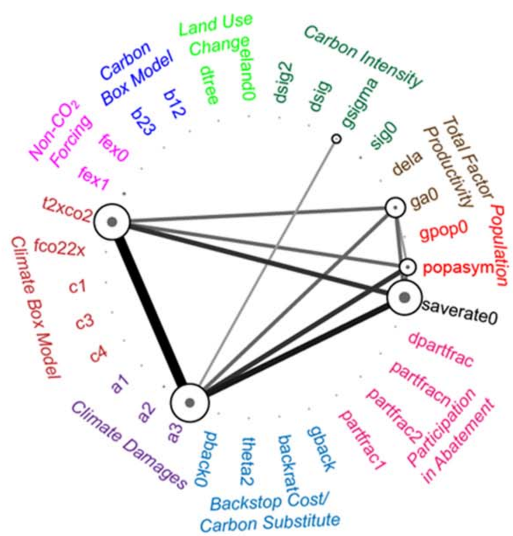
Butler, M., Reed, P.M., Fisher-Vanden, K., Keller, K., and Wagener, T.
Environmental Modelling & Software, v59, pages 10-29, 2014
http://www.sciencedirect.com/science/article/pii/S1364815214001327#

Butler, M., Reed, P.M., Fisher-Vanden, K., Keller, K., and Wagener, T.
Climatic Change, v127, no(3-4), pages 463-474, 2014
http://link.springer.com/article/10.1007%2Fs10584-014-1283-0#

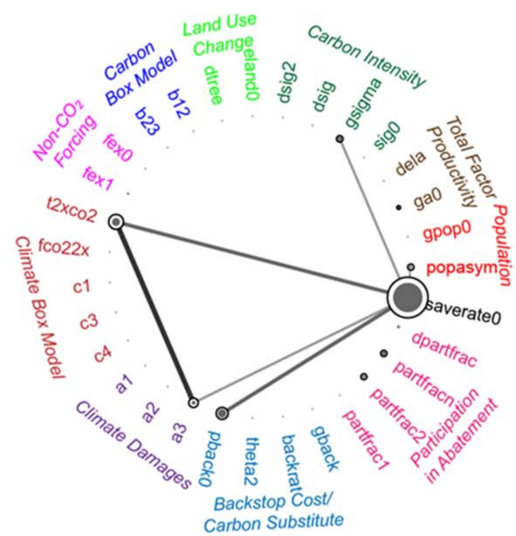
BAU

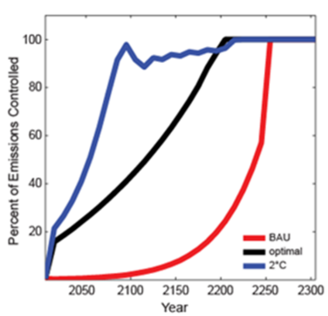


Optimal



2 °C





NPV Total Cost Comparisons in Trillions of 2005 USD

	BAU	Optimal	2°C	2xCO2
Deterministic	2.0	1.7	2.2	1.8
Ensemble Median	4.2	4.1	6.3	4.5
90th Percentile	17.3	12.2	15.3	12.1
95th Percentile	27.5	17.2	19.4	16.2

Modeling Uncertainty in Integrated Assessment Models of Global Climate Change

Nordhaus and Gillingham (PIs), Yale University
Participating modelers: John Reilly (MIT), David Anthoff (Berkeley), Geoff Blanford (EPRI), Haewon McJeon (JGCRI)

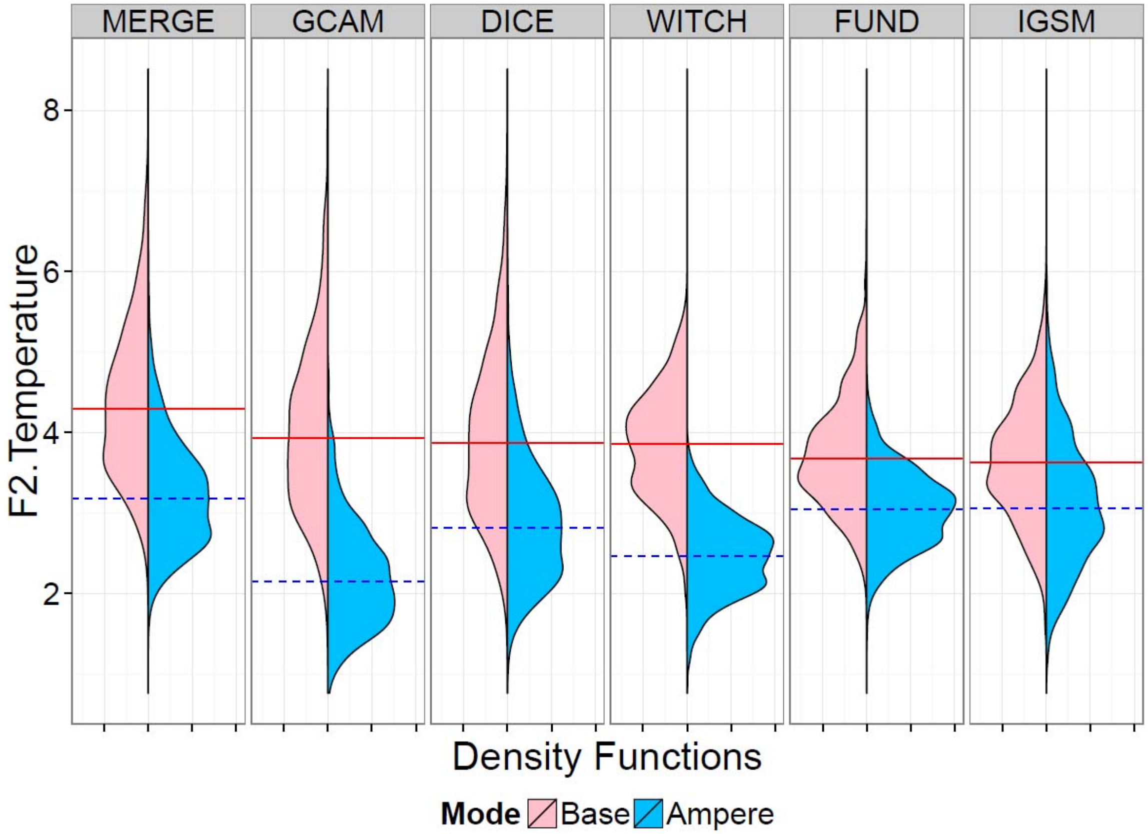
- Uncertainty in the results of integrated assessment models of climate change is pervasive and has critical policy relevance

- This project brings together six large-scale models used for climate change policy: MERGE, GCAM, WITCH, DICE, FUND, and IGSM.

- We examine uncertainty in three key variables that can be harmonized across models: population, GDP, and climate sensitivity

- Each model is run 5 x 5 x 5 times using a grid of the three variables as inputs. We fit a surface response function to the results.

- Using developed PDFs of the three variables, we run a Monte Carlo to estimate the output distributions.



Violin diagrams showing preliminary results for the distribution of temperature change above pre-industrial in 2100 for each of the 6 models. *Base* refers to modeler's baseline and *Ampere* refers to a carbon tax scenario implemented on the modeler's baseline.

Thank You

Questions?