Resolution, Process Representations, and Probabilistic Methods

Improvements to the MIT Integrated Global Systems Model

John Reilly
Joint Program on the Science and Policy of Global Change
Massachusetts Institute of Technology

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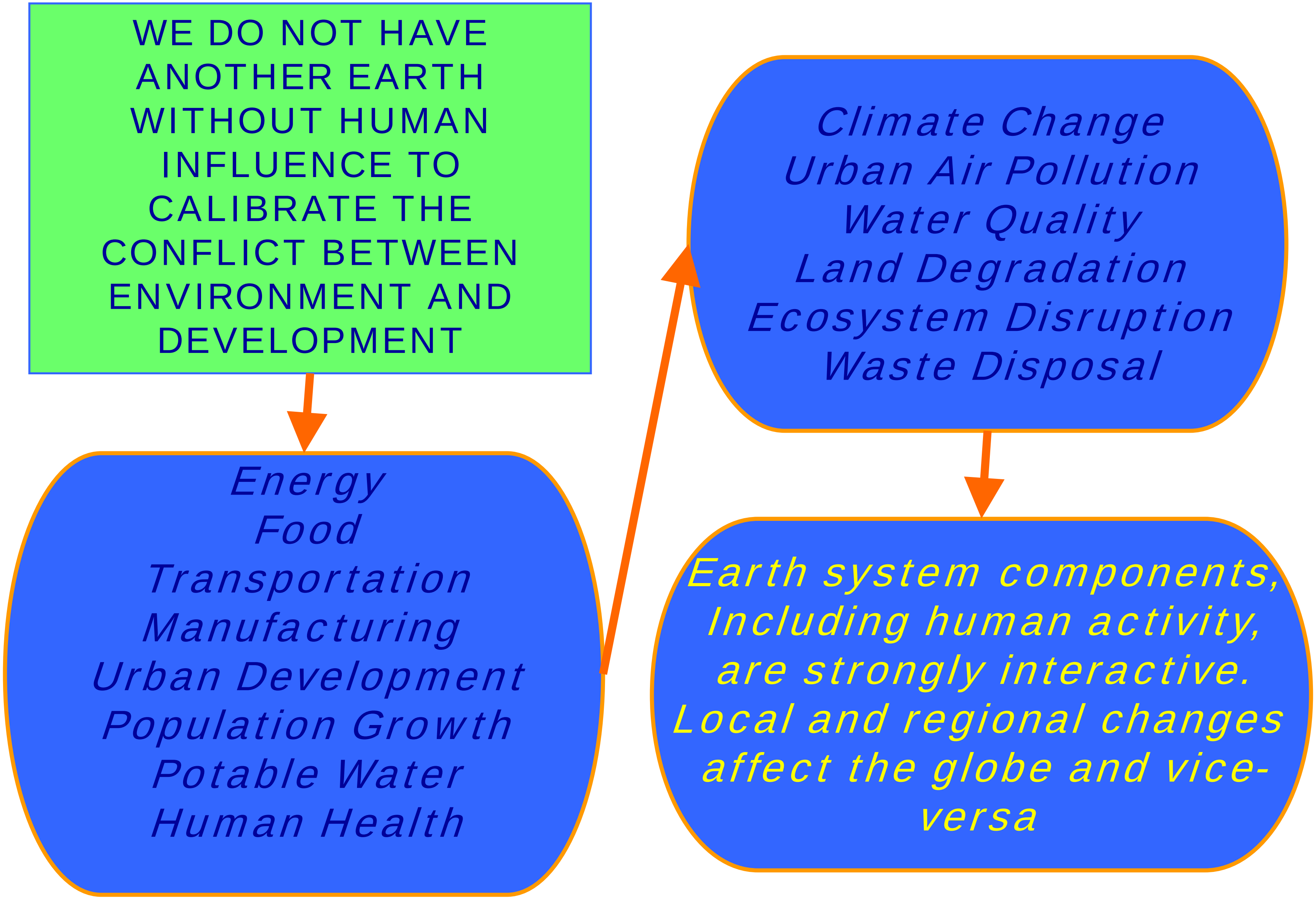
jreilly@mit.edu
http://globalchange.mit.edu/

To Review: WHY DO WE NEED EARTH SYSTEM MODELS?



WE DO NOT HAVE ANOTHER EARTH WITHOUT HUMAN INFLUENCE TO CALIBRATE THE CONFLICT BETWEEN ENVIRONMENT AND DEVELOPMENT

Energy
Food
Transportation
Manufacturing
Urban Development
Population Growth
Potable Water
Human Health

Climate Change
Urban Air Pollution
Water Quality
Land Degradation
Ecosystem Disruption
Waste Disposal

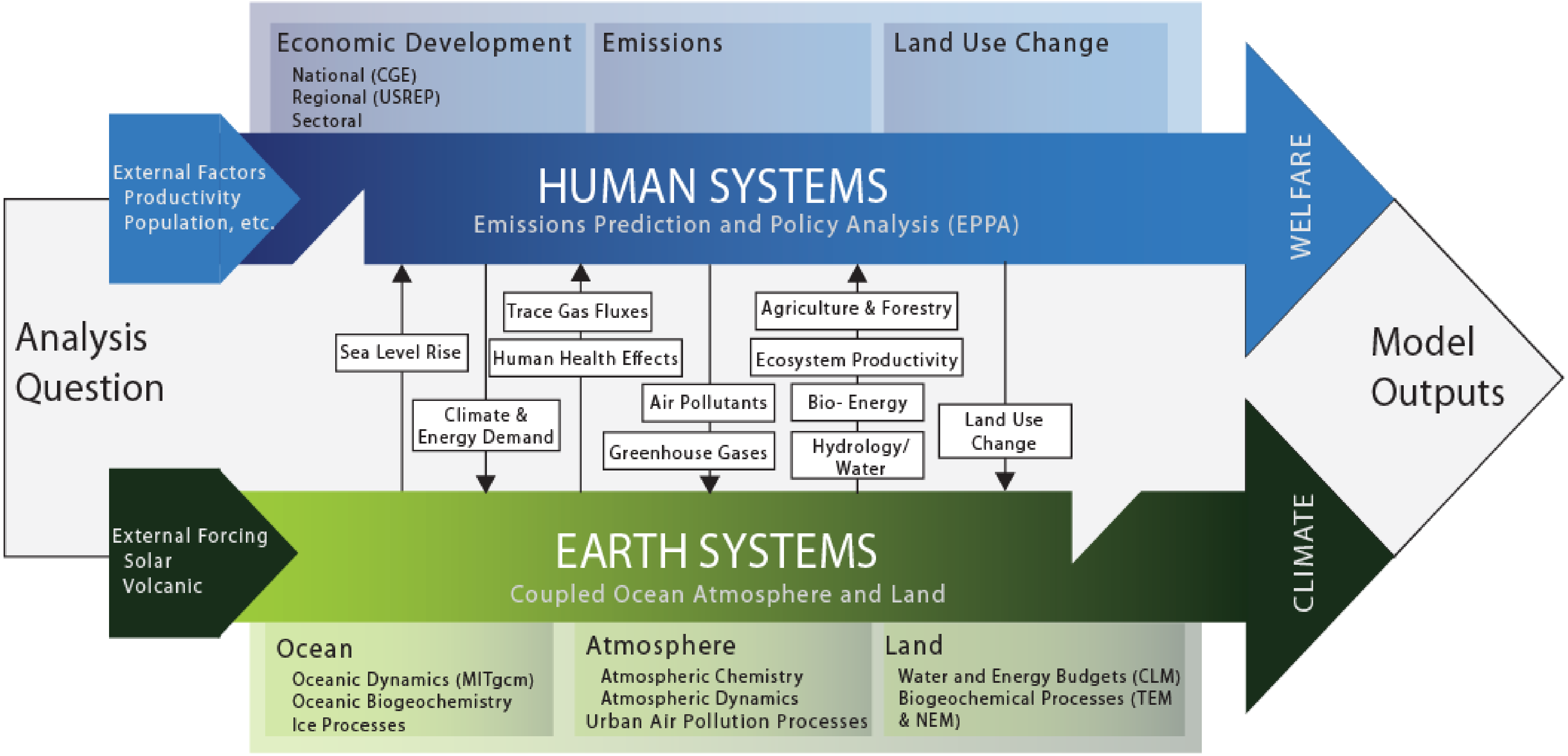
Earth system components, Including human activity, are strongly interactive. Local and regional changes affect the globe and vice-versa

TO FORECAST CLIMATE CHANGE AND DEVELOP SOUND RESPONSES, WE NEED TO:
COUPLE THE HUMAN & NATURAL COMPONENTS OF THE EARTH SYSTEM.
SUCH INTEGRATED ASSESSMENTS HAVE MANY ADDITIONAL POTENTIAL BENEFITS.

- Dynamics of complex interactions among natural and human systems
- Objective assessment of uncertainty in economic and climate projections
- Quantitative evaluation of mitigation and adaptation technologies and options
- Understanding connections to other environmental issues (e.g. air pollution, biodiversity, agriculture, energy, water quality)

MIT IGSM: An earth system model with the flexibility to include more or less spatial detail as the research question dictates

The Integrated Global Systems Model



Economic Development
National (CGE)
Regional (USREP)
Sectoral

Emissions

Land Use Change

External Factors
Productivity
Population, etc.

HUMAN SYSTEMS
Emissions Prediction and Policy Analysis (EPPA)

WELFARE

Analysis Question

Sea Level Rise

Trace Gas Fluxes

Human Health Effects

Climate & Energy Demand

Air Pollutants

Greenhouse Gases

Agriculture & Forestry

Ecosystem Productivity

Bio- Energy

Hydrology/ Water

Land Use Change

Model Outputs

External Forcing
Solar
Volcanic

EARTH SYSTEMS
Coupled Ocean Atmosphere and Land

CLIMATE

Ocean
Oceanic Dynamics (MITgcm)
Oceanic Biogeochemistry
Ice Processes

Atmosphere
Atmospheric Chemistry
Atmospheric Dynamics
Urban Air Pollution Processes

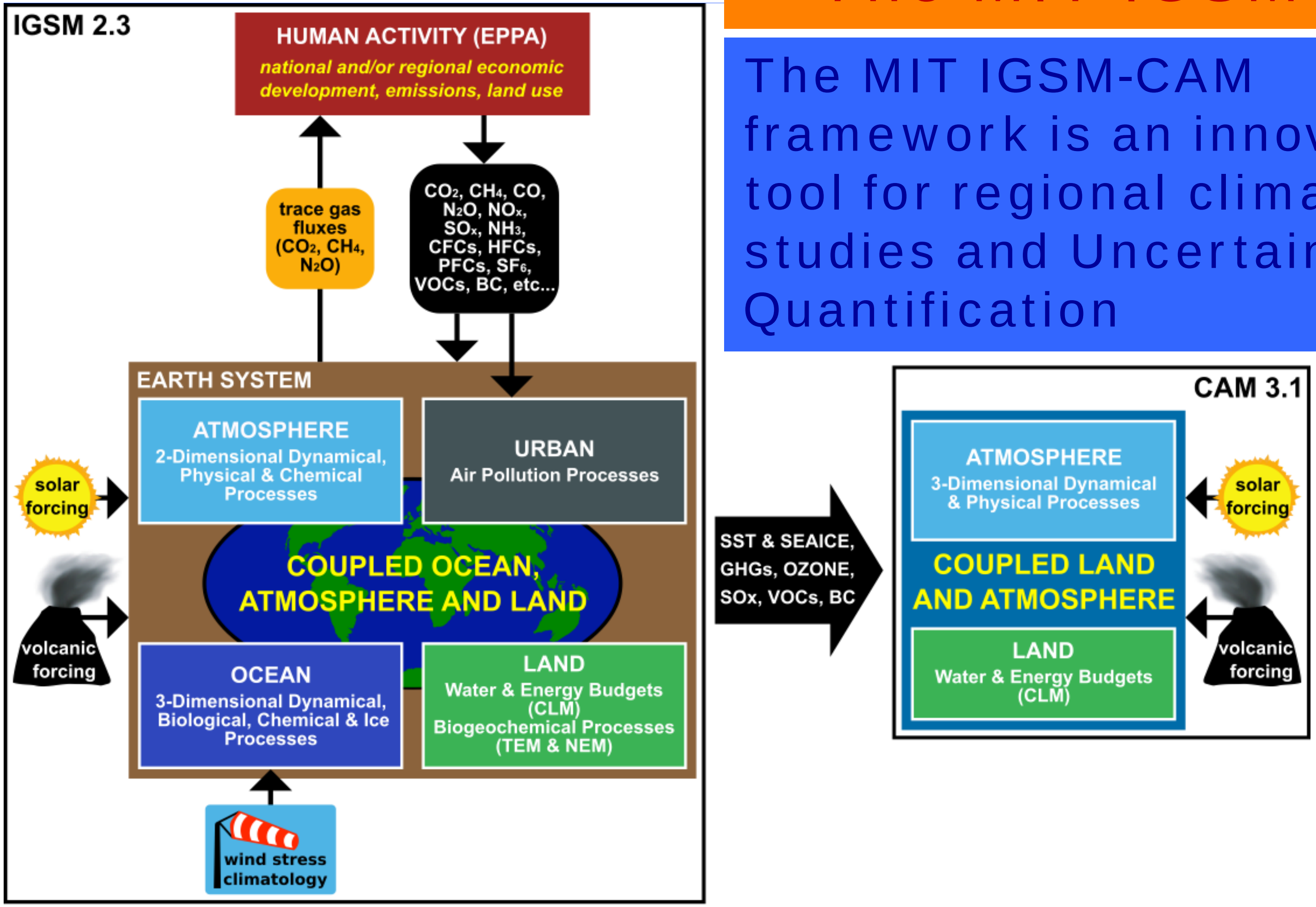
Land
Water and Energy Budgets (CLM)
Biogeochemical Processes (TEM & NEM)

Highlight of Recent Improvements

- Include capability to use full 3-D atmosphere
- Methods to estimate conditional likelihoods of future outcomes with greater resolution.
- Improved urban air chemistry
- High resolution ocean modeling and ocean effects
- Greater technological detail in modeling the economy
- Dynamically link
  - economy and terrestrial vegetation
  - air pollution processes, human activity and the economy
  - Hydrology, water resource management and the economy

The MIT IGSM-CAM

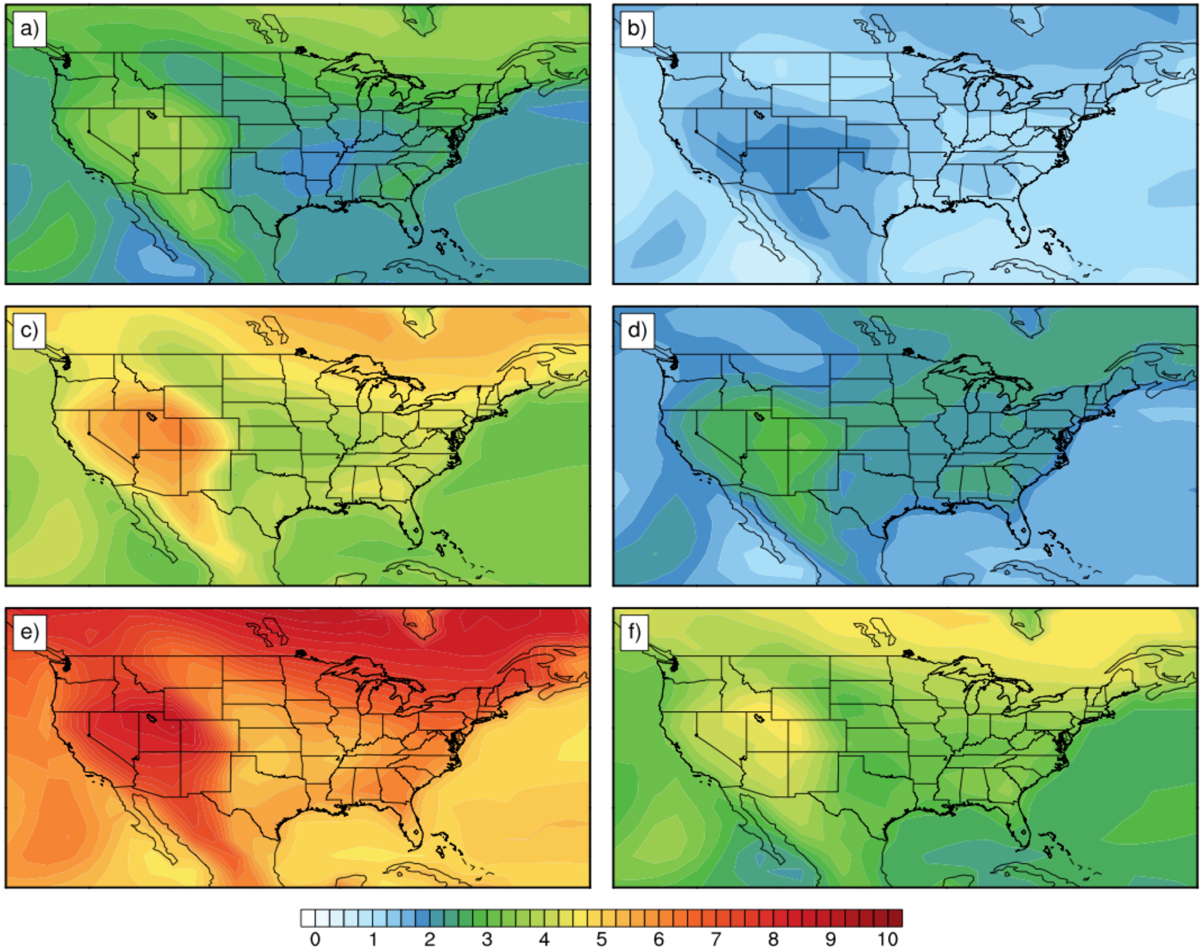
The MIT IGSM-CAM framework is an innovative tool for regional climate studies and Uncertainty Quantification



The MIT IGSM-CAM framework links the MIT IGSM with

- The NCAR CAM3.1 (3D global atmospheric model)
- The NCAR CLM3.0 (land surface model)

Uncertainty Quantification



Unconstrained Emissions

Stabilization at 660 ppm CO_2eq

Low
Climate
Response

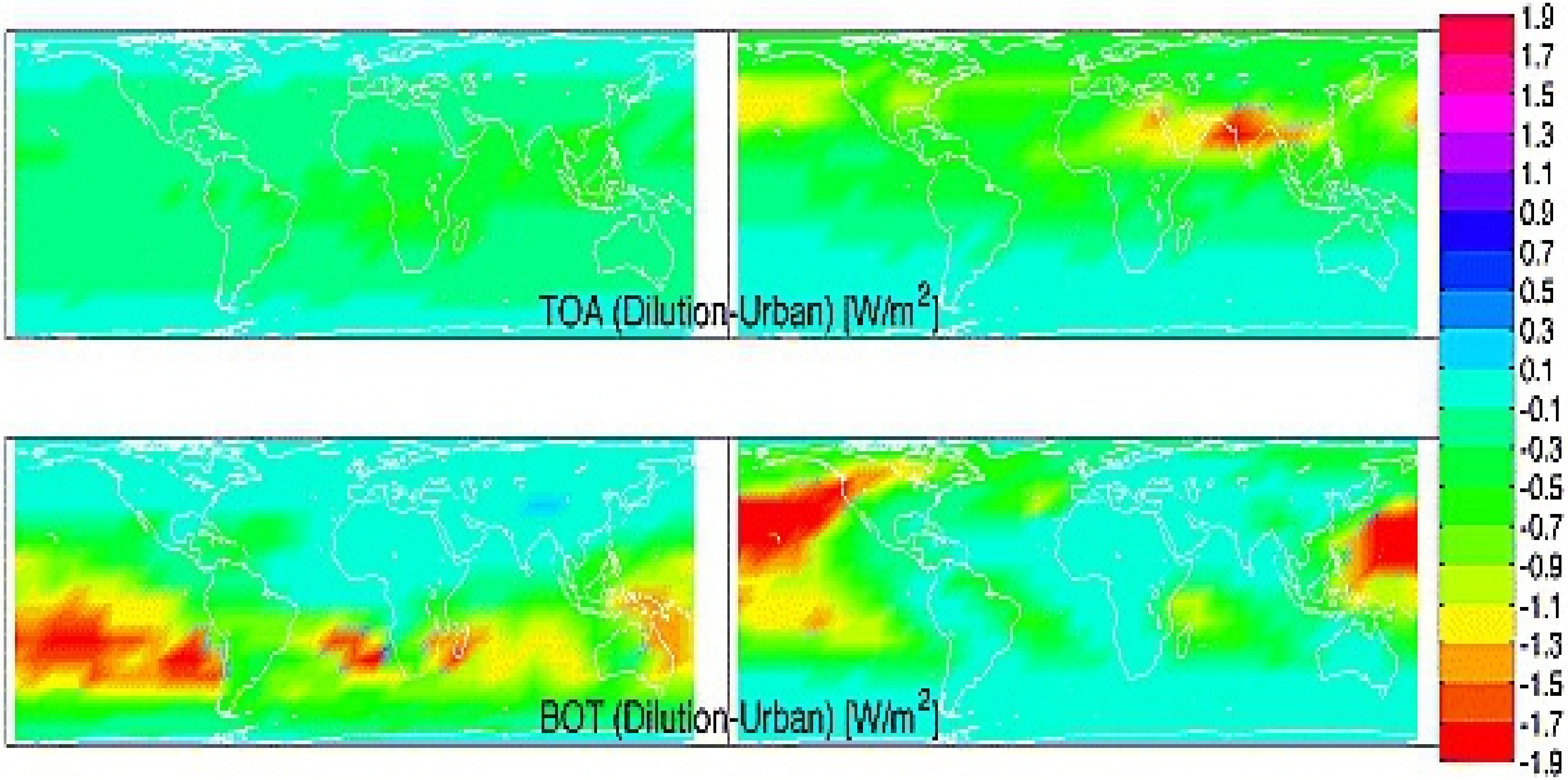
Median
Climate
Response

High
Climate
Response

Changes in surface air temperature (in deg C), 1980-1999 to 2080-2099; Low and High response reflect approximately 90% uncertainty bounds.

More detail See Monier, et al. Poster—Also see, Schlosser et .al. Uncertainty Quantification Session

Urban processing of emissions shows smaller cooling effect of aerosols at top and bottom of the atmosphere

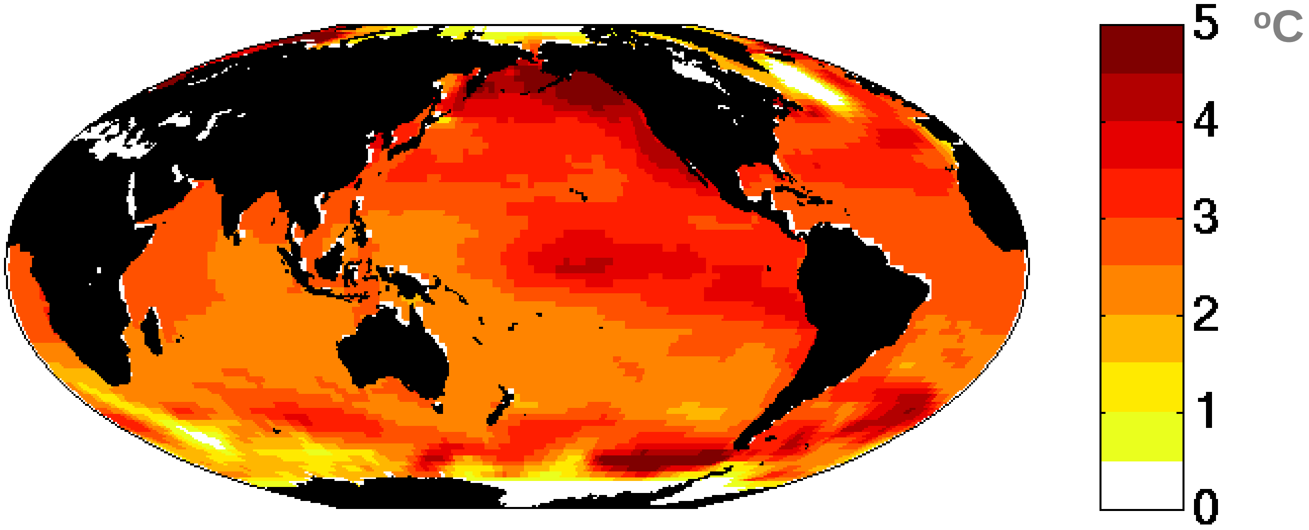


The absolute bias (Dilution - Urban) of ignoring urban processing for TOA and BOT

Cohen, J. B., R. G. Prinn, and C. Wang (2011), The impact of detailed urban-scale processing on the composition, distribution, and radiative forcing of anthropogenic aerosols, GRL 38

Oceans threatened by warming

- Ocean surface probably had warmed by about 0.5°C over last 200 years
- How warm will it be in the future?



Simulated Change in ocean surface temperature (2100-2000)

"Business as usual" emissions scenario using IGSM:

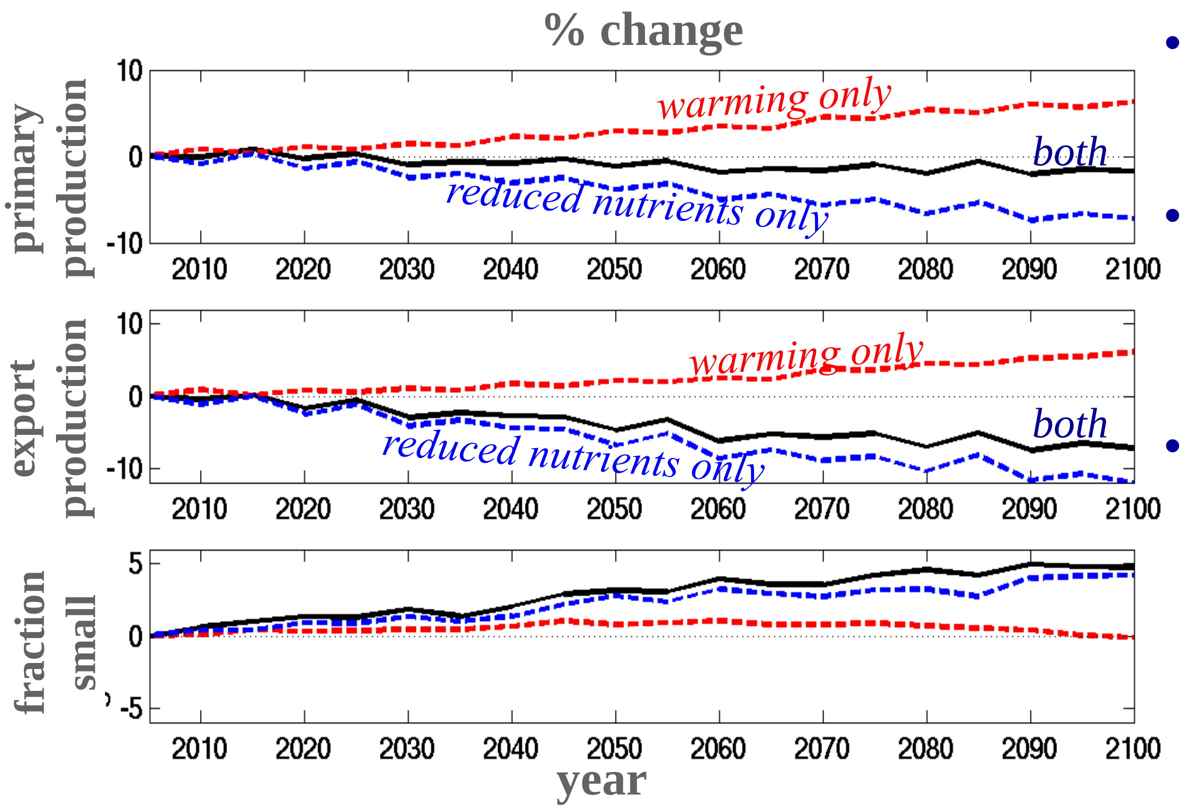
by 2100: atmospheric pCO2 is 1300ppmv

global surface air temperatures up 5°C

Dutkiewicz, Scott, Follows, 2011

… Changes in mixing and circulation

- **Increased stratification, reduced overturning circulation**
- **Decreased supply of nutrient to surface sunlight layers**



- **reduced nutrients, reduced production**

- **counteracts increase from warming**

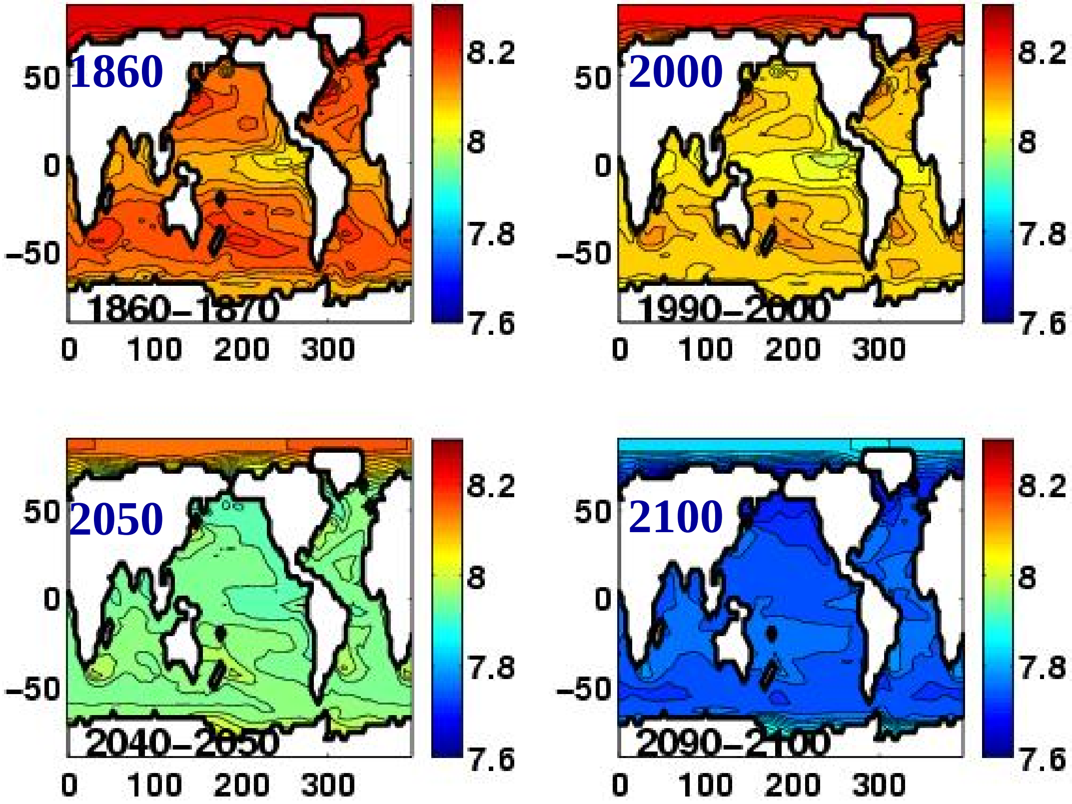
- **lower nutrients favors small recycling plankton: less export of carbon to depth**

Numerical Simulations

Dutkiewicz, Scott, Follows, 2011

…and acidification

- Ocean has absorbed about 1/3 anthropogenic CO_2
- Higher carbon leads to increased in acidity (lower pH)



"business as usual" projection

Surface pH

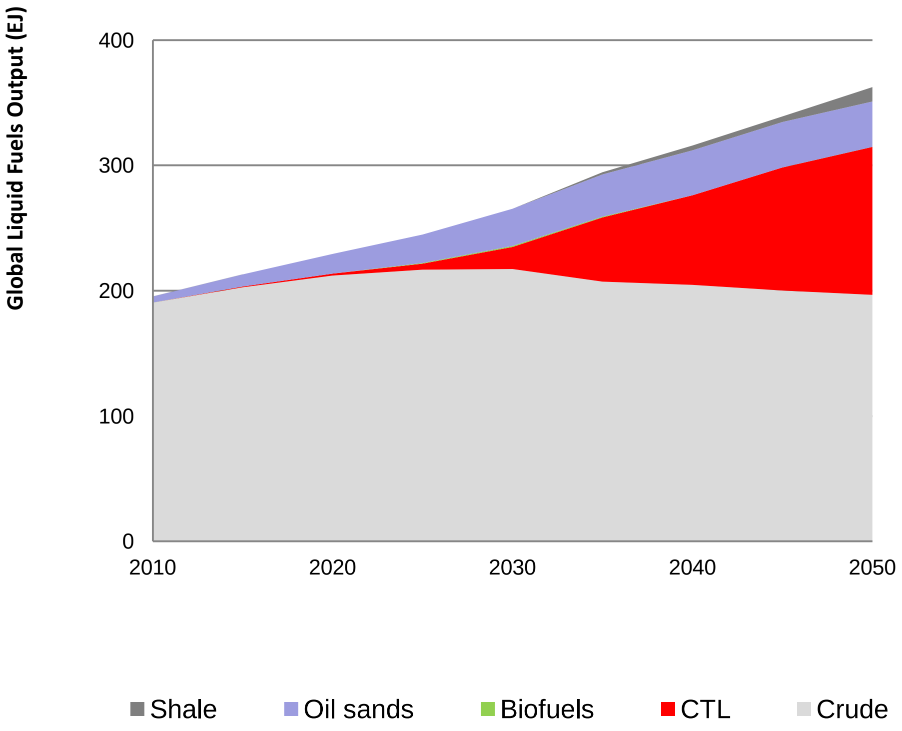
alkaline>7
neutral=7
acidic<7

Numerical Simulation: IGSM

Dutkiewicz et al, 2005

Stephanie Dutkiewicz
http://ocean.mit.edu/~stephd

Representation of multiple liquid fuels and “peak” oil.



- Oil sands and heavy oils, coal to liquids (CTL), shale oil, biofuels are more to much more carbon intensive then crude.
- Resources are abundant to super-abundant.
- Even if process CO_2 emissions are captured and stored the fuels themselves are no better than gasoline or diesel.

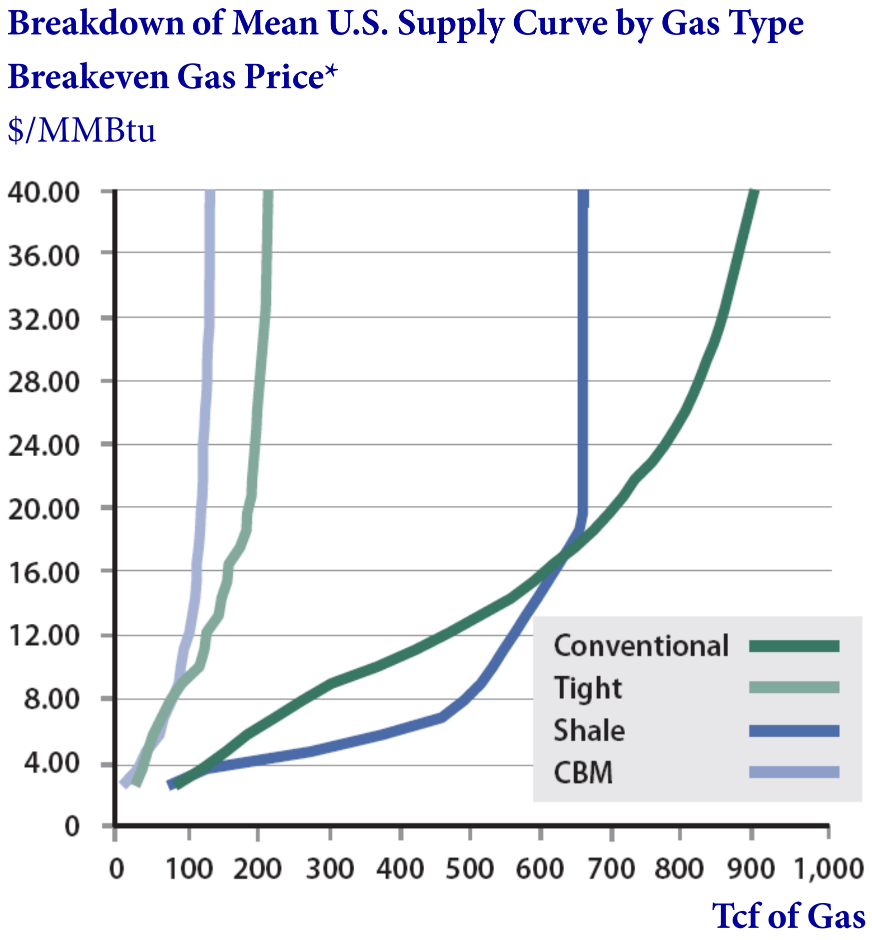
U.S. Gas Supply Cost Curve

From: MIT Future of Natural Gas Study

- Advances in technology have significantly expanded the economic resource base for gas.

- Waiting in the wings—methane hydrates which are super abundant.

- Gas is less carbon intensive and cleaner than oil or coal but gas is a bridge to a lower carbon future, not the answer.



Breakdown of Mean U.S. Supply Curve by Gas Type

Breakeven Gas Price*

$/MMBtu

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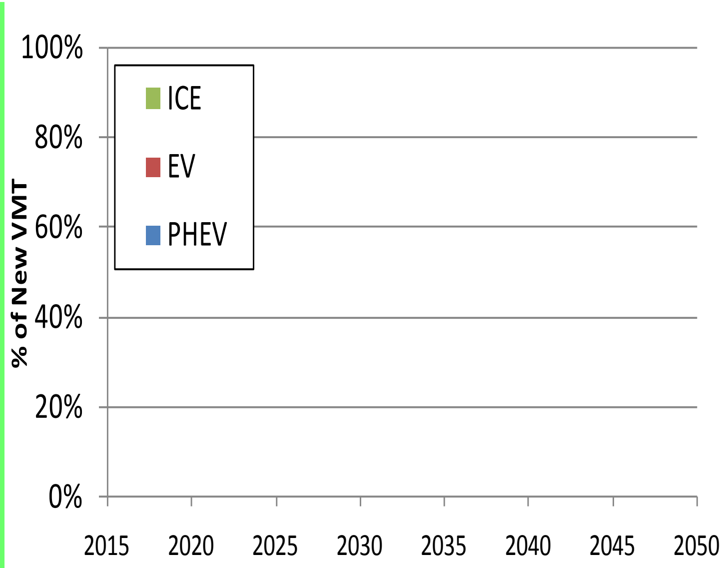
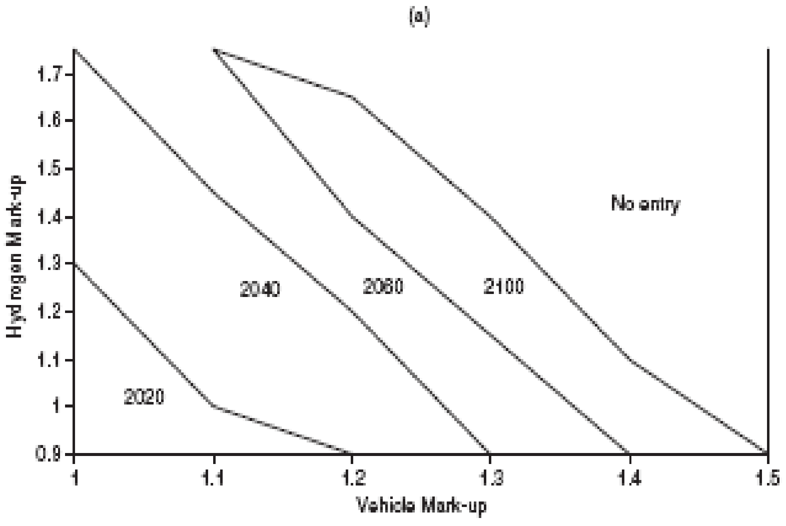
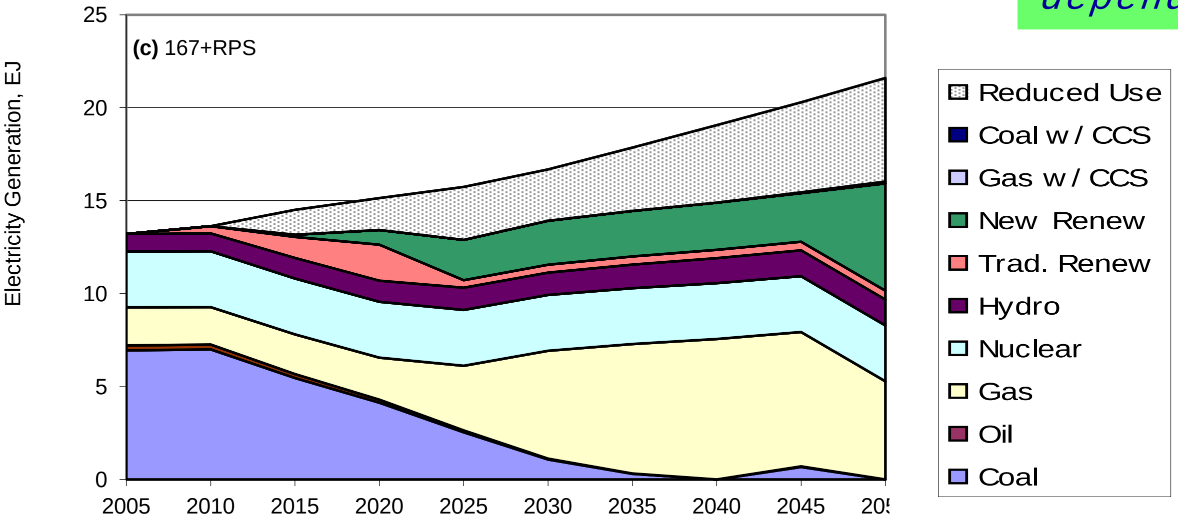
* Cost curves calculated using 2007 cost bases. U.S. costs represent wellhead breakeven costs. Cost curves calculated assuming 10% real discount rate, ICF Hydrocarbon Supply Model

Fleet turnover slows adoption of vehicle options such as PHEV, EVs; adoption also depends on battery cost





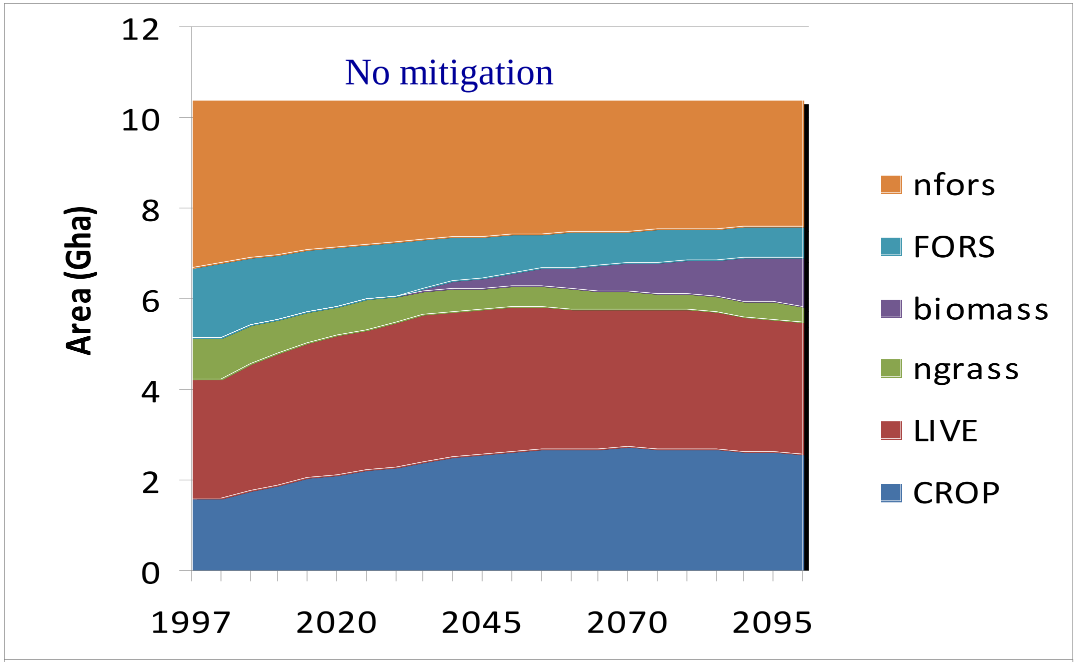
Hydrogen Vehicle entry decade depends on vehicle and fuel cost



Shale Gas resources increase potential role of gas under mitigation scenarios in the US

Expansion of technology options in vehicles, electricity generation, and fuels

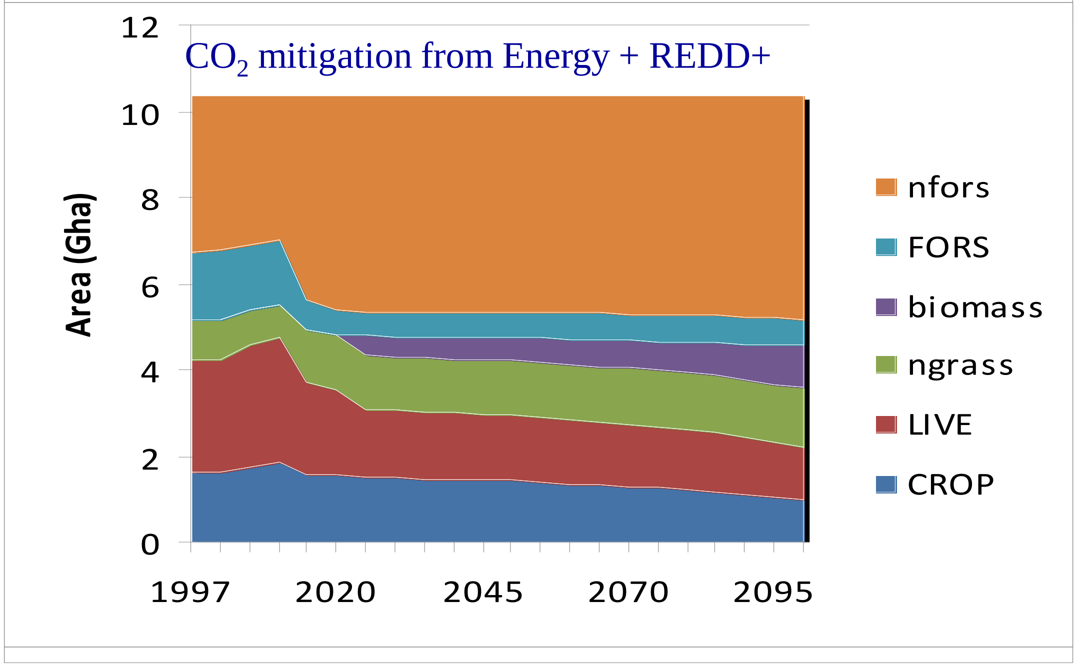
Land Use


No mitigation

Population pressure climate and ozone increases demand for cropland and pasture.

Biomass enters after 2040.

Natural and managed forests shrink by more than 1 billion hectares.


CO_2 mitigation from Energy + REDD+

Biomass energy starts earlier and expands more.

Pricing carbon in land results in immediate push to reforest and return to natural grassland.

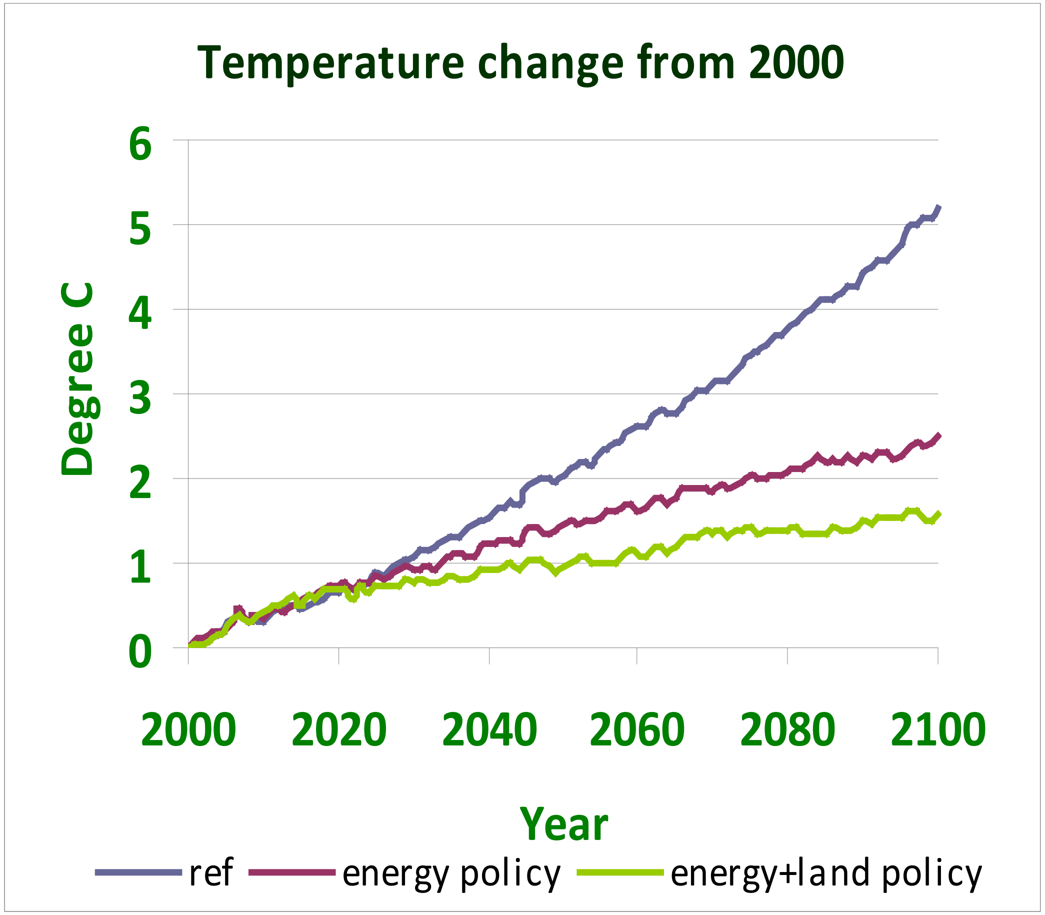
All other land uses squeezed.

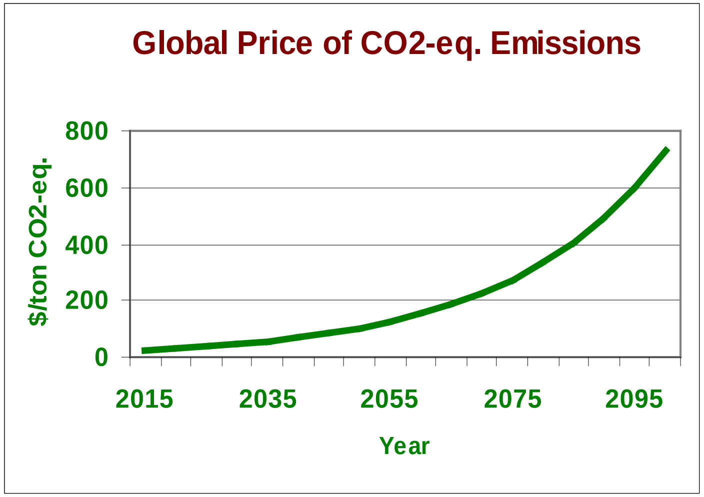
Why does reforestation squeeze out biofuels?

Climate Effects

Managing of land use makes it nearly possible to stay under the 2 C from preindustrial Copenhagen goal—adding 0.6° C for pre-2000—with all IFs.

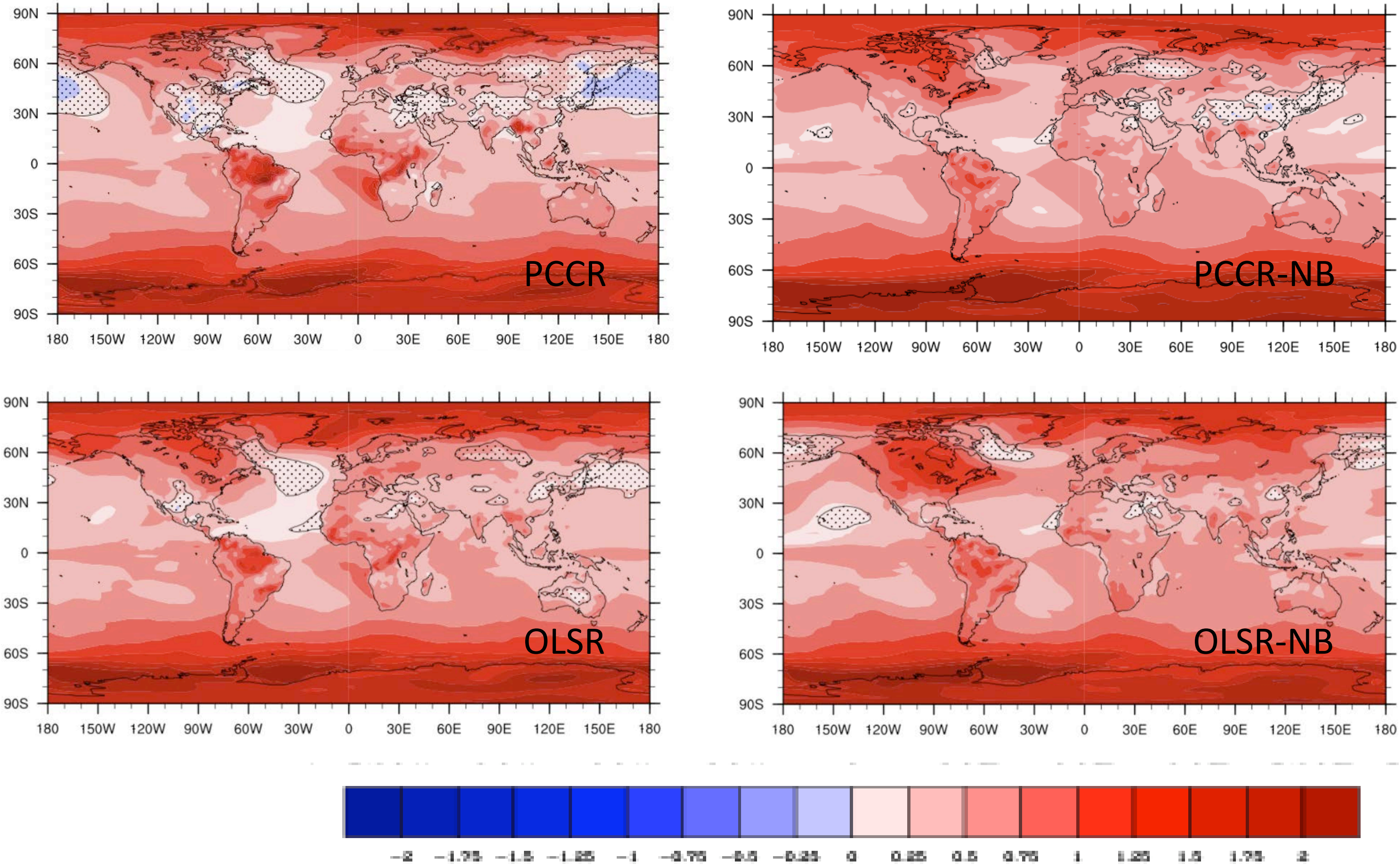
Land use carbon avoids 1.0 C of warming through 2100.





*Effects of Land Cover Change on Surface-**Air Temperature (˚C)***

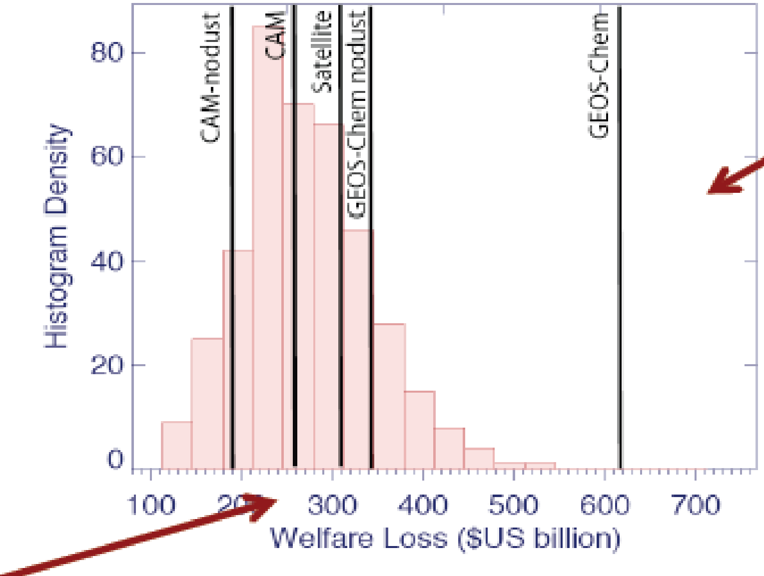
2050-1990 Trace-Gas Forcing and 2050-1990 Land Cover Change



Hallgren et al. presentation by Schlosser later today

Uncertainties in epidemiology and economics are substantial but range of estimates of concentrations from different models are as large or larger.

Monte Carlo analysis of PM2.5 health impacts and related costs: relative uncertainties in different global PM2.5 estimates, compared with uncertainty in health and economic variables



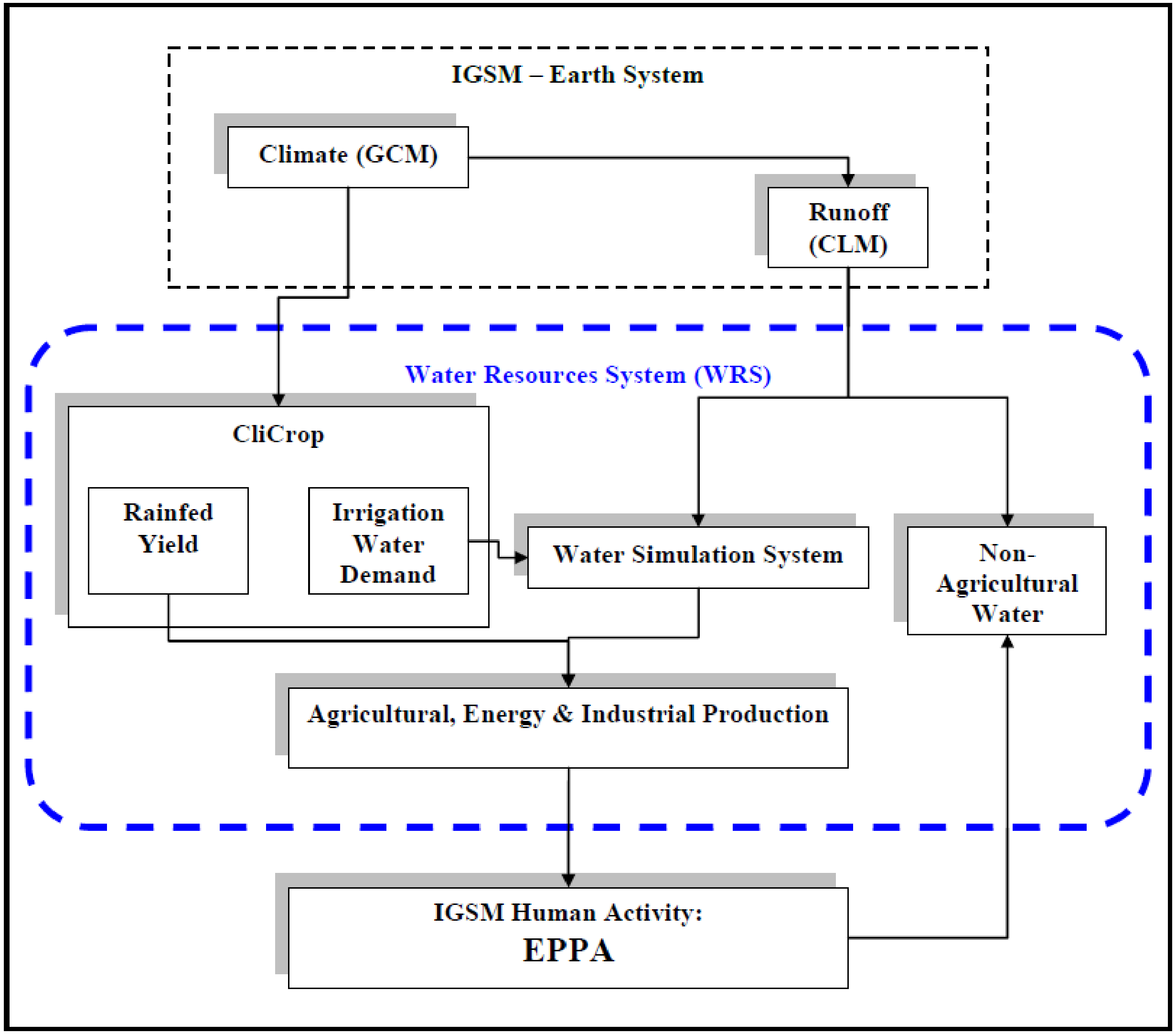
Black vertical lines: calculated cost for different PM2.5 estimates/models, holding health/ economic functions constant

Pink: uncertainty range spanned by health/ economic uncertainty, with selected PM2.5 estimate (satellite product) held constant

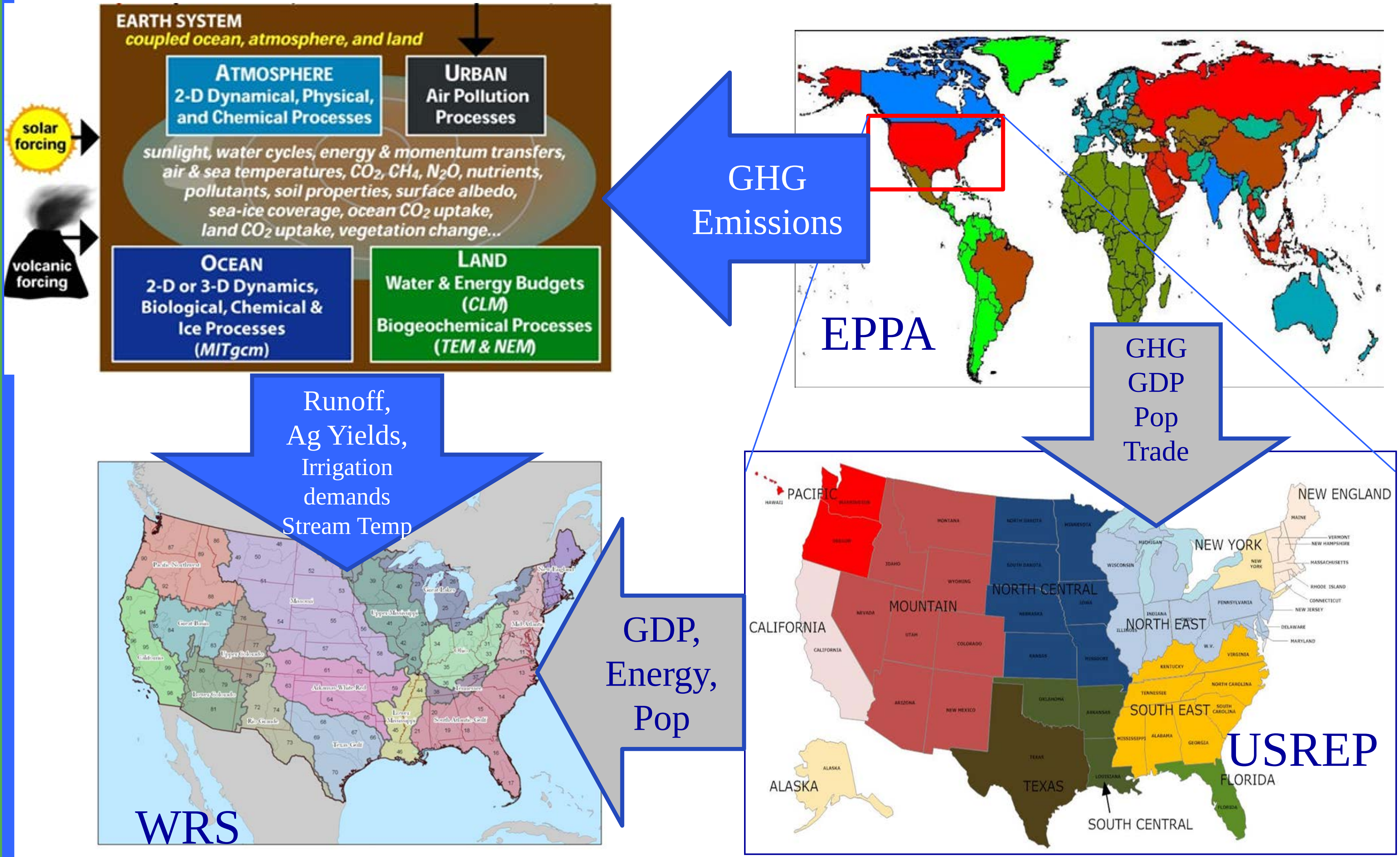
Bottom line: atmospheric modeling contributes substantially to overall uncertainty!

[Selin et al., to be submitted to Atmopsheric Environment]

Water in IGSM



From Global Scale to regions and Water basiins



EARTH SYSTEM
coupled ocean, atmosphere, and land

ATMOSPHERE
2-D Dynamical, Physical, and Chemical Processes

URBAN
Air Pollution Processes

sunlight, water cycles, energy & momentum transfers, air & sea temperatures, CO_2, CH_4, N_2O, nutrients, pollutants, soil properties, surface albedo, sea-ice coverage, ocean CO_2 uptake, land CO_2 uptake, vegetation change...

OCEAN
2-D or 3-D Dynamics, Biological, Chemical & Ice Processes
(*MITgcm*)

LAND
Water & Energy Budgets
(*CLM*)
Biogeochemical Processes
(*TEM & NEM*)

GHG
Emissions

EPPA

GHG
GDP
Pop
Trade

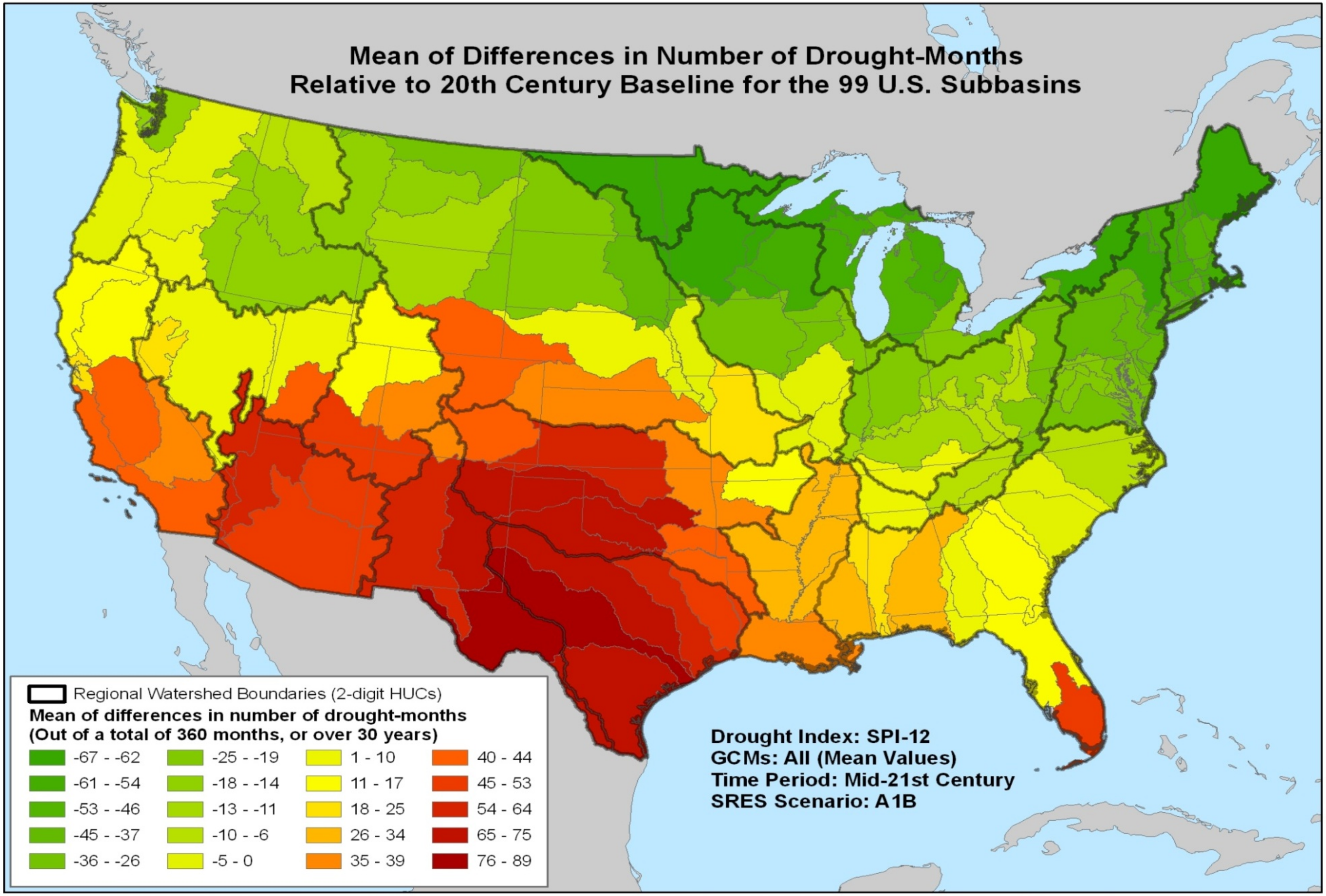
USREP

GDP,
Energy,
Pop

Runoff,
Ag Yields,
Irrigation
demands
Stream Temp

WRS

Example: Change in Months with Drought Stress for CLM-WRS driven by Mean of GCMS for SRES A1B



Mean of Differences in Number of Drought-Months Relative to 20th Century Baseline for the 99 U.S. Subbasins

Drought Index: SPI-12
GCMs: All (Mean Values)
Time Period: Mid-21st Century
SRES Scenario: A1B