

Challenges of Modeling Energy- Water-Land at the National Scale within the Climate Change Impacts and Risk Analysis Project (CIRA)

Snowmass, CO
July 24th, 2014

Objectives and Drivers



- EPA routinely estimates the impacts and benefits of reducing air pollution in meaningful ways (e.g., avoided premature deaths, respiratory illness, economic loss).
- CIRA project aims to produce analogous estimates for GHG mitigation.
 - To date, EPA and the general climate community have had limited ability to show specific and full range of avoided impacts under GHG mitigation scenarios.
 - Climate change presents unique challenges compared to traditional EPA analyses (e.g., global nature, wide-reaching impacts, long time scales).
 - CIRA complements SCC, but differs in purpose and approach.
- CIRA will develop and communicate credible, robust, and meaningful climate impact and benefit estimates to inform policy.

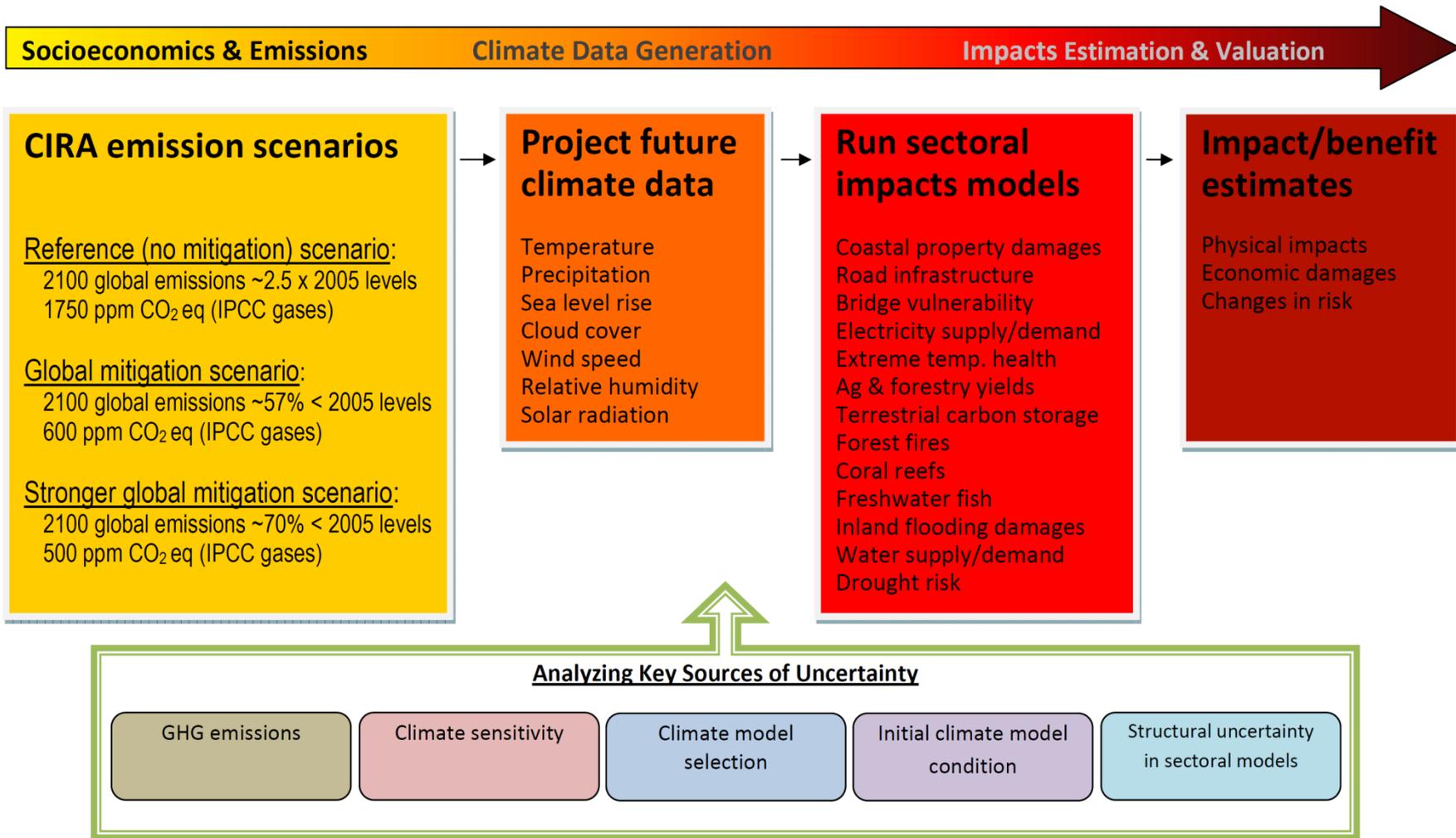


Overview of CIRA



- CIRA is an EPA-led, collaborative modeling effort to analyze how climate change impacts and risks in the U.S. change under different global GHG mitigation scenarios.
 - CIRA describes the costs of inaction (and benefits of mitigation and adaptation) in terms of physical effects, economic damages, and changes in risk.
- CIRA uses *consistent* economic, emission, and climate data to estimate impacts under scenarios with and without GHG mitigation.
 - The project also addresses key sources of uncertainty, including emissions pathway, climate sensitivity, climate projection, and impacts model.
 - The limited number of other comprehensive impact analysis efforts do not emphasize consistency to the same extent as CIRA.
- CIRA examines *regional impacts* in the U.S. across sectors (e.g., water resources, human health, ecosystems, energy) where science is strong and modeling capacity can be leveraged.

Overview of the CIRA Process



Current CIRA Sectoral Models



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CIRA Impact Sector Coverage



- **Human health**
 - Thermal stress (mortality)
 - Air quality
 - Vector-borne disease
 - Extreme event morbidity, mortality
 - Environmental justice / vulnerable populations
 - Thermal stress (labor productivity)
- **Agriculture**
 - Crop yield (U.S.)
 - *Crop yield (global)*
 - *Livestock production*
 - Carbon storage
- **Forests**
 - Change in production
 - Change in CO₂ storage
 - Wildfire
- **Freshwater Resources**
 - Drought
 - Flooding damages
 - Water supply and demand
 - Water quality
- **Ecosystems**
 - Species (coral, freshwater fish, others)
 - Biodiversity
 - Mollusc fishery impacts
 - Other acidification effects
- **Energy**
 - Temperature effects on energy (electricity) supply and demand
 - Precipitation and system effects on hydro power
 - Change in thermo-cooling capacity
 - Climate and system effects on wind and solar generation
 - Other energy system impacts (e.g., extreme event impacts on extraction, transmission, distribution)
- **Infrastructure**
 - Roads and bridges
 - Coastal development
 - Urban drainage
 - Inland property damages from floods
 - Waterways
 - Telecommunication infrastructure
- **Tourism**
 - Coral reef recreation
 - Recreational fishing
 - Other recreation (e.g., winter, boating, birding)
- **Other extreme events**
 - Residual damages post extreme events (e.g., hurricanes)
 - Catastrophic climate change (e.g., ocean circulation shutdown)
 - National security risks (e.g., mass migration)

Key

Existing CIRA capacity

In progress

Not currently in CIRA

General Challenges / Choices within the CIRA Process



Bias Correction Method

Model Availability



CIRA emission scenarios

Reference (no mitigation) scenario:
2100 global emissions ~2.5 x 2005 levels
1750 ppm CO₂ eq (IPCC gases)

Global mitigation scenario:
2100 global emissions ~57% < 2005 levels
600 ppm CO₂ eq (IPCC gases)

Stronger global mitigation scenario:
2100 global emissions ~70% < 2005 levels
500 ppm CO₂ eq (IPCC gases)

Project future climate data

- Temperature
- Precipitation
- Sea level rise
- Cloud cover
- Wind speed
- Relative humidity
- Solar radiation

Run sectoral impacts models

- Coastal property damages
- Road infrastructure
- Bridge vulnerability
- Electricity supply/demand
- Extreme temp. health
- Ag & forestry yields
- Terrestrial carbon storage
- Forest fires
- Coral reefs
- Freshwater fish
- Inland flooding damages
- Water supply/demand
- Drought risk

Impact/benefit estimates

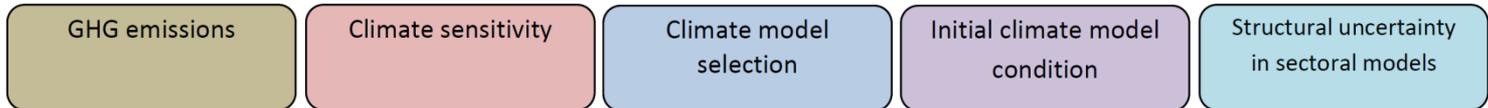
- Physical impacts
- Economic damages
- Changes in risk

Communications

Consistency of Socioeconomic Assumptions

Scenario Selection

Analyzing Key Sources of Uncertainty



Availability of Pattern-Scaled Data

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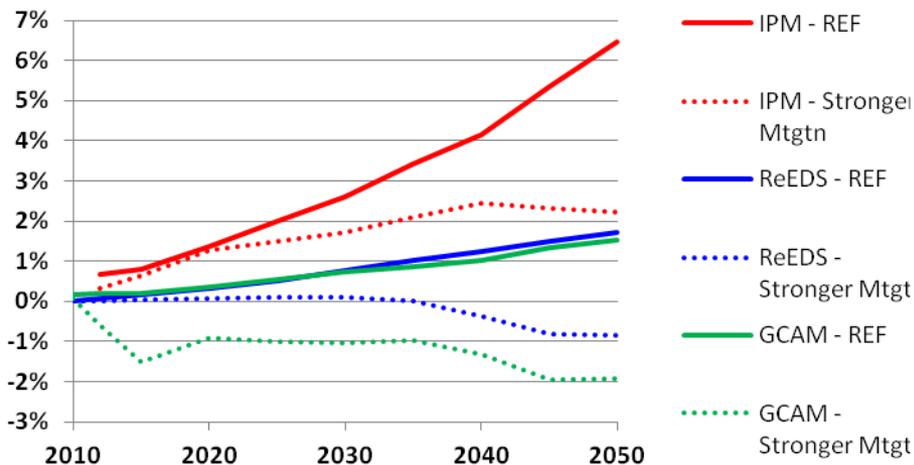


- **Scope**
 - Primarily electric power
 - Change in supply and demand from temperature changes
- **Methodology Overview**
 - Multi-model approach
 - GCAM-USA (heating and cooling demand in buildings)
 - ReEDS (overall electricity demand)
 - IPM (commercial and residential electricity demand)
 - Three different approaches to translating temperature change to change in electricity demand (process-based to econometric)
- **Insights**
 - Minimal differences in translation of temperature change to change in CDD/HDD, yet significant differences in electricity demand
 - Including temperature effects in the baseline changes the relative costs of policy
- **Challenges**
 - Missing non-temperature impacts (i.e., thermo-cooling impacts, hydropower)
 - Need a different set of models to look at operationally disruptive events
 - Limited set of climate scenarios
 - Future challenge – disentangling temperature effects in AEO reference case

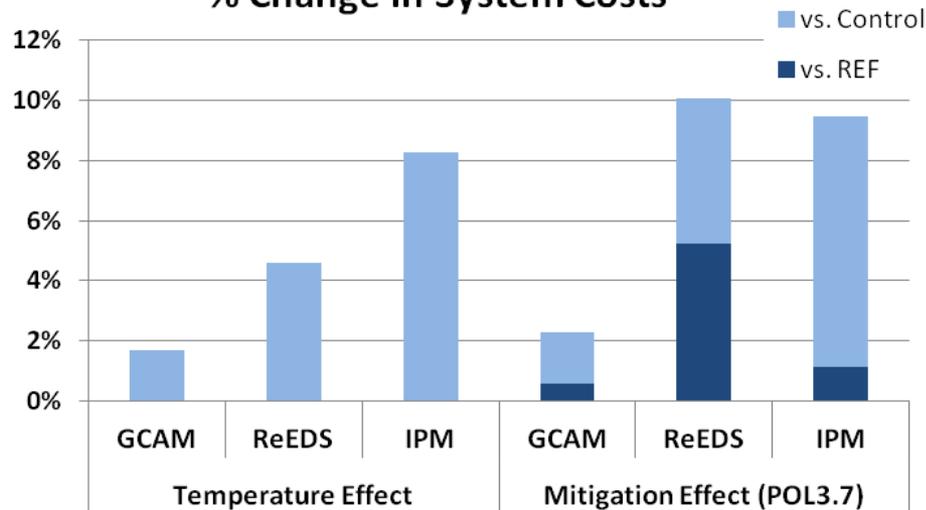
Climate Impacts on Electricity Demand and Supply using multiple models—GCAM, ReEDS, & IPM

- Projected temperature changes increase electricity demand for air conditioning and lower the demand for heating. This effect is frequently omitted from demand projections.
- Electricity demand increases 1.5%–6.5% nationally in 2050 when the air temperature projections from the Reference scenario are included in power sector models (left figure).
- Meeting this additional demand raises power system costs by 1.7%–8.3% across the models (cumulative costs discounted at 3% from 2015–2050, right figure).
- Including temperature effects in baseline scenarios is important. Under the Stronger Mitigation scenario, the change in power system costs from the Reference (0.6%–5.2%) is lower than the change in costs from a Control (2.3%–10.1%) that does not account for temperature effects.

% Change in Elec Demand vs. Control



% Change in System Costs



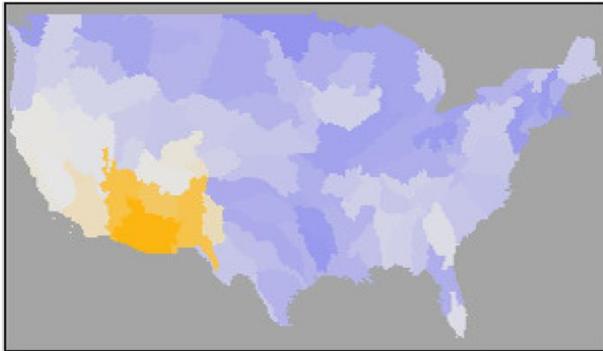
- Temp Effect compares Reference with Control case
- Mitigation Effect compares Stronger Mitigation vs. REF and Control
- System costs include capital, operations, maintenance, and fuel



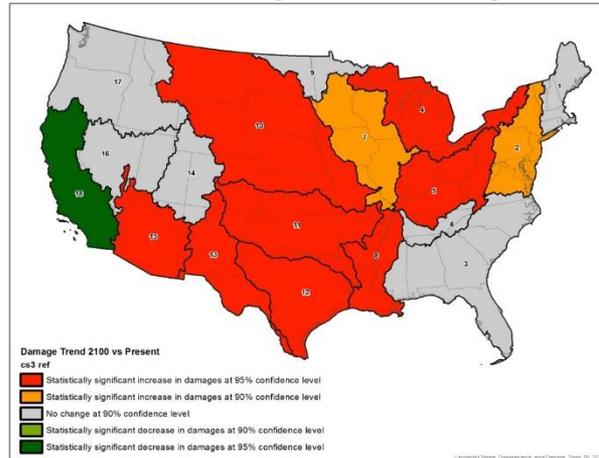
- **Scope**
 - Multi-perspective examination of changes in water resources and impacts
- **Methodology Overview**
 - Multi-model, multi-perspective approach
 - Water supply and demand (US Basin model)
 - Flooding damages (econometric)
 - Drought risk
 - Water quality
 - Water scarcity (GCAM)
- **Insights**
 - Analyzing multiple components of one sector using a consistent set of emission and climate scenarios allows for deeper consideration of potential futures.
- **Challenges**
 - Uncertainty in baseline data (e.g., groundwater supply, water demands from agriculture, municipal, and industrial)
 - Representation of operations and planning at appropriate scale and detail

Using Multiple Metrics Tells a More Complete Story

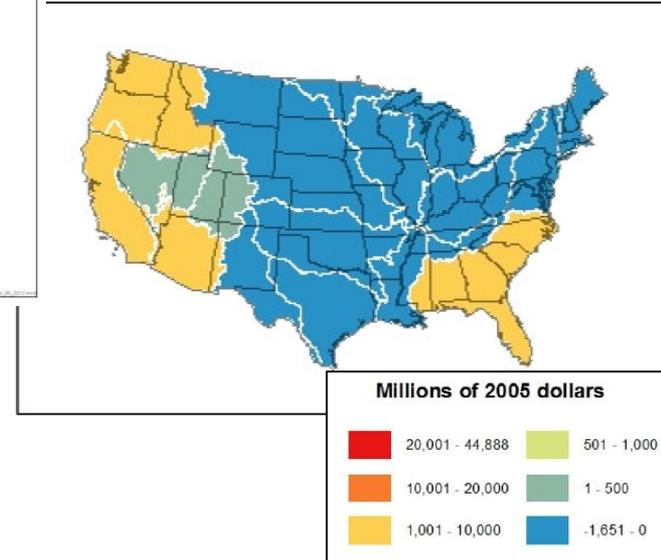
Drought (PDSI)



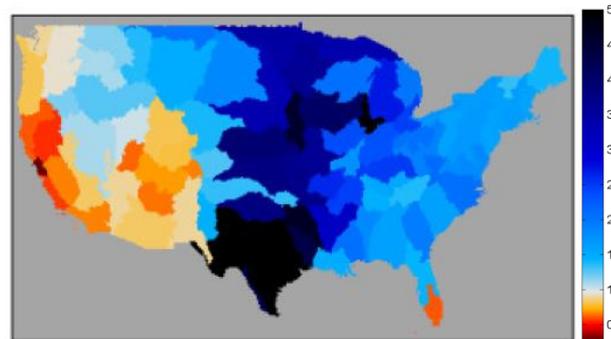
Flooding damages



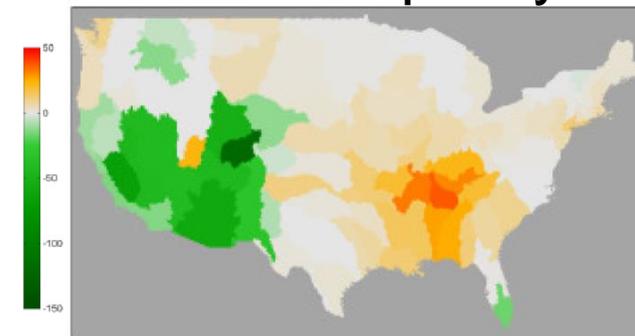
S/D economic model



Runoff



Water quality

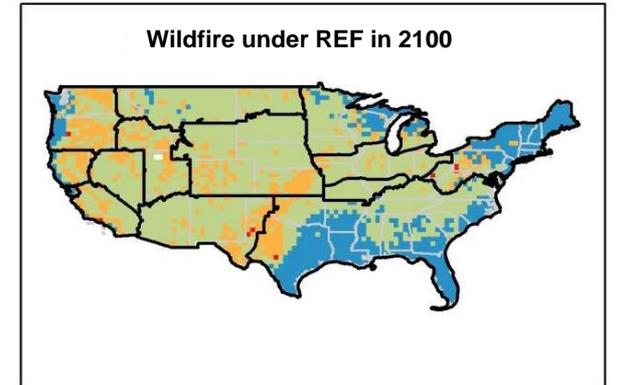
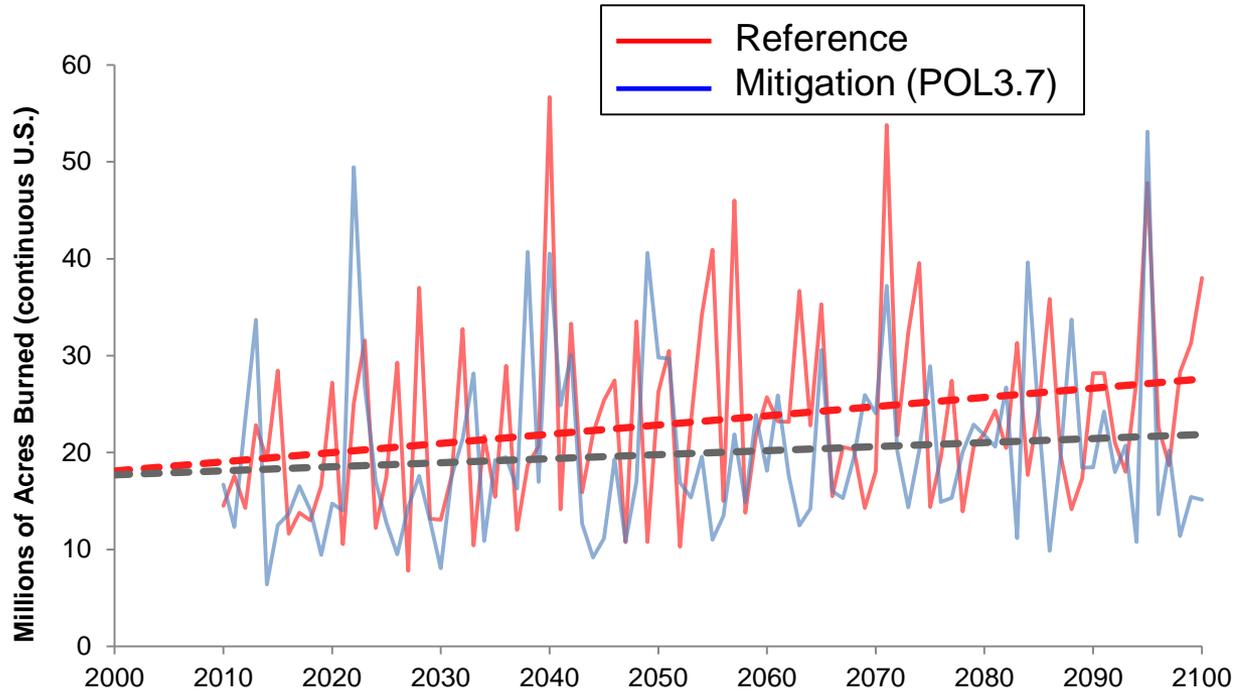


All shown are CIRA REF (3°C CS) in 2100



- Scope
 - Climate impacts on US and global forestry (production, wildfires)
- Methodology Overview
 - Multi-model approach
 - Domestic process model - MC1
 - Global process models - MC2, BioMap
 - Domestic economic model – FASOM (RTI)
 - Global economic model – GTM (tOSU)
- Insights
 - Mitigation reduces wildfire response costs
 - Discounted value of stored carbon under climate policy is \$1.6 trillion
- Challenges
 - Domestic and international models calibrated in different ways, making it difficult to compare results.
 - Pattern-scaled results miss important fluctuations in wildfire incidents

Changes in Wildfire Incidence and Response Costs

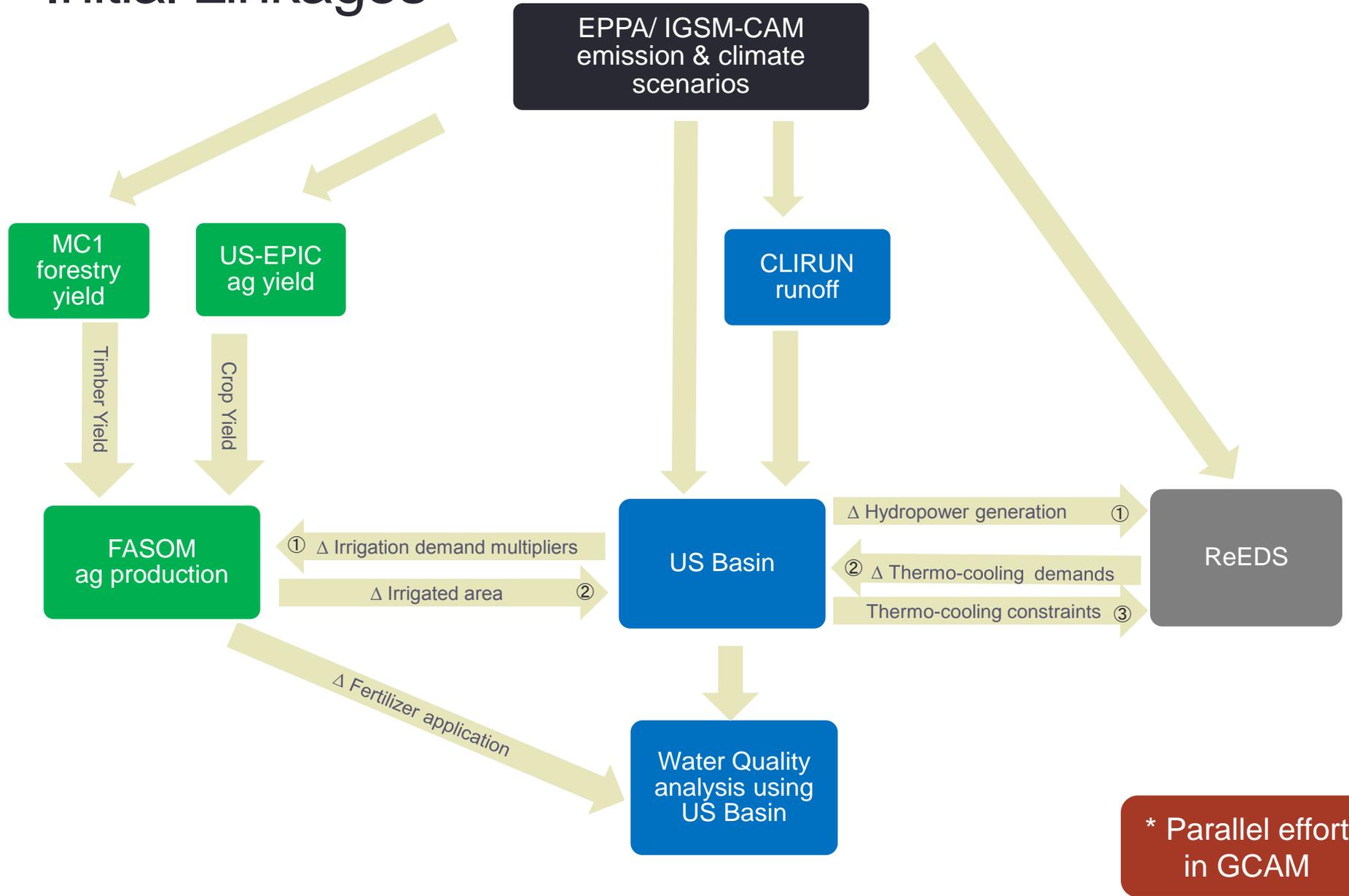


- Implementing the POL3.7 scenario would reduce cumulative acreage burned by wildfires in the continental U.S. between 2011 and 2100 by roughly 303 million acres, relative to the REF scenario.
- The corresponding discounted (3%) monetized estimate of reduced wildfire response costs (i.e., labor, equipment) over this period is \$9.24 billion (2005\$).
- Aggregated results at the national level appear driven by wildfire incidence from a limited number of regions (e.g., Rocky Mountains).



- Scope
 - Changes in US agricultural yields and production
- Methodology Overview
 - Multi-model approach
 - Yield – US-EPIC model (PNNL), CLM-AG (MIT), econometrics (BU)
 - Change in production – FASOM (RTI)
- Challenges
 - Choice of bias correction method
 - Consistency with agricultural productivity in socio-economic scenarios
 - Population, GDP, productivity trends
 - Limited to projections from a single climate model
 - Pattern-scaled climate simulations lack daily variation
 - Interactions with forest sector productivity
 - Analysis does not account for changes in pests
 - Current scenario set is missing high biomass sensitivity

CIRA Water/Energy/ Agriculture Nexus: Initial Linkages



* Parallel effort in GCAM



Planned Efforts

- Consistent socio-economic assumptions across EPPA, ReEDS, FASOM, US Basin
- Informing irrigation supply curves in FASOM with US Basin results
- Using irrigated area and fertilizer application data to inform water quality analysis using US Basin

Challenges

- Current inability to couple ReEDS with US Basin to endogenously account for cooling water constraints in investment decisions
- Spatial resolution of US Basin and lack of data on environmental flow requirements limits strength of conclusions
- Limited to projections from a single climate model
- Limited ability to assess disruptive impacts to power system operation and transmission. Lack infrastructure data and models at appropriate temporal and spatial resolution.

Energy-Water-Land Linkage Take Aways



- Many issues apply to all integrated assessment analyses
 - Maintaining consistent assumptions across models is challenging
 - Appropriately translating parameters from one model to another
 - Learning when spatial and temporal resolution matter to the question at hand
 - Limited resources (people, funding, time) to examine sensitivities and uncertainty space (e.g., emissions pathway, climate sensitivity, climate model, initial conditions, structural parameters in sectoral models)
 - Availability of sectoral models at appropriate resolution
 - Lack data in the water sector on environmental flow requirements
- Some issues are unique to CIRA
 - Pattern scaled climate model data is not available at required temporal resolution
 - Proliferation of sectoral models makes integrated analyses more expensive and complex



- Completing peer-review and publication of 11 papers in a special issue of *Climatic Change* describing CIRA.
 - Papers cover: emissions, carbon cycle, climate projections, climate extremes, water resources, electric power, infrastructure, human health (extr temp.), and ecosystems.
 - Most of the underlying components of CIRA (IA and sectoral models) have already been published in the scientific literature (~30 papers).
- Complete and publish 'in-progress' sectoral analyses: agriculture, forestry, water quality, air quality.
 - Planning an ERL focus issue on CIRA ag/forestry analyses.
 - We welcome other submissions investigating GHG mitigation benefits in these sectors.
- Communicate CIRA results to decision makers and public.

Future Research Directions



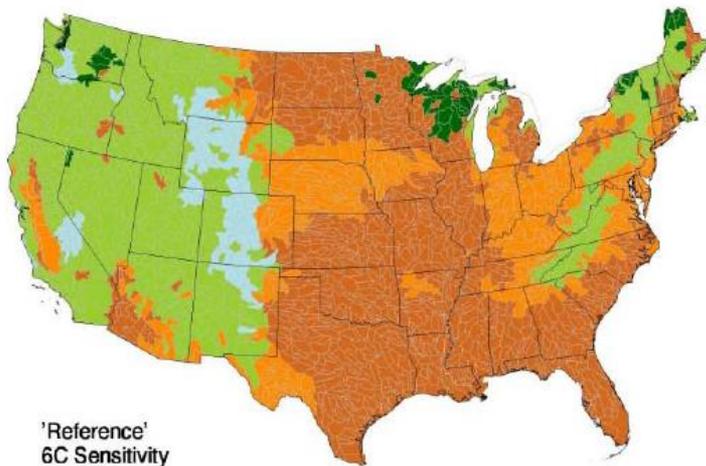
- Run additional mitigation scenarios to develop reduced-form models that analyze 'smaller' (non-global) mitigation levels
 - Radiative forcing targets of 7.4 and 6.0 W/m²
 - Responsive to policy analysis requests
- Assess air quality benefits
- Examine effects on global agriculture and livestock
 - Global EPIC process model and GLOBIOM economic model
- Closing the loop by incorporating climate impacts into reference scenarios within economy-wide models



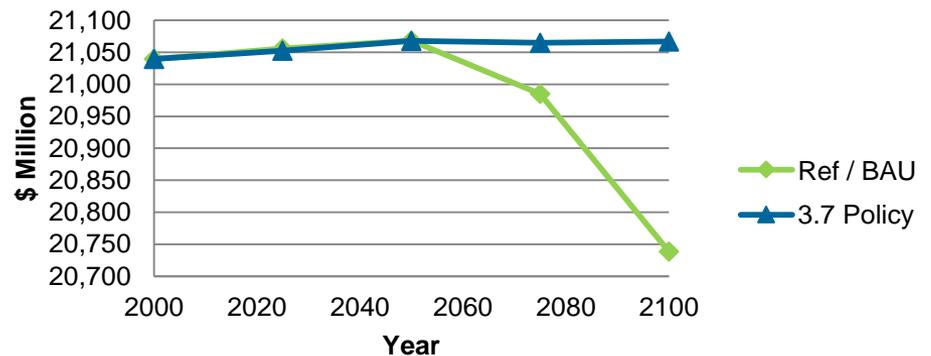
Addendum

Freshwater Recreational Fishing

- Significant changes to the spatial distribution of where fish are today.
- 6.9 million cold water fishing days lost per year by 2100 (6°C sensitivity).
- Mitigation policy avoids \$323M (3°C sensitivity) or \$687M (6°C sensitivity), both discounted at 3%, compared to the reference scenario.

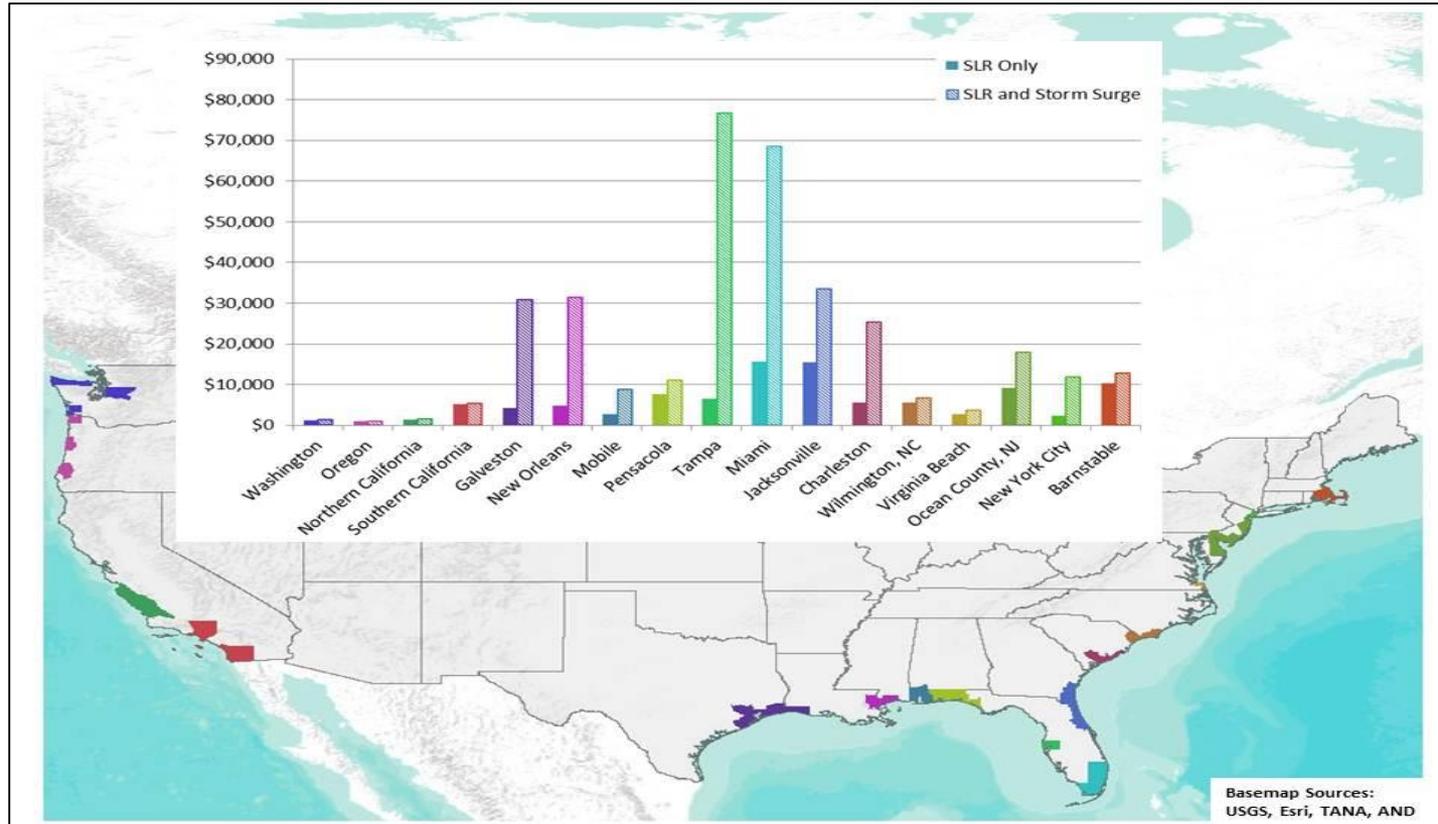


Value of Recreational Fishing, 2000-2100
BAU vs. Pol 3.7



Coastal Property Damages and Adaptation Response Costs

- The cumulative, discounted cost of inaction (no adaptation) in the face of SLR and storm surge through 2100 is estimated at \$4.25 trillion.
- When adaptation is included, the economic impacts through 2100 for the REF are \$85B (for SLR only–140cm) and \$690B (for SLR+storm surge). Mitigation (POL3.7) avoids \$7.5B (SLR only–95cm) or \$20B (SLR+storm surge) of these costs.
- Areas projected to be abandoned have a higher percentage of socially vulnerable populations than areas likely to be protected.



Total costs by 2100 under Reference, discounted at 3% (\$ million)

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Important Limitations and Caveats



- CIRA is a policy analysis tool and different from the comprehensive climate science assessments conducted by IPCC and USGCRP.
- Although some of the sectoral models used can estimate impacts at regional (multi-state) to sub-regional (state to county) scales, none of the CIRA results should be used for local scale vulnerability assessment. The CIRA analyses are specifically designed to answer national-scale impacts and benefits questions.
- CIRA is not currently able to analyze marginal levels of mitigation, and cannot do quick-turnaround analyses of custom scenarios. Work is underway to build capacity in these areas.
- CIRA results likely underestimate the benefits of avoided climate change; there are known impacts that are not currently included, and in many cases, only part of the sectoral impact is being quantified and valued.
- The CIRA climate projections employ a limited number of climate models.
- Adaptation, and its effects on future damages, is modeled differently in each sector – and in some cases not at all.

Key Conclusions



- Global GHG mitigation provides both monetary and risk-reduction benefits in the United States:
 - Implementation of the GHG mitigation policies would prevent or reduce adverse impacts throughout the 21st century compared to the Reference.
- Benefits of GHG mitigation increase over time:
 - Emission scenarios follow similar paths through 2040, but diverge considerably thereafter, generating increasing benefits in most sectors.
- Adaptation can reduce net overall costs:
 - Cost-effective adaptation measures that can substantially reduce impacts under all scenarios, especially in the infrastructure sector.
- Spatial and temporal scale are important:
 - Aggregating nation-wide impacts and damages can miss important regional scale impacts.

CIRA in Context: Complement to SCC



- Both efforts use model-based approaches to estimate mitigation benefits and address climate and model uncertainty, however the approaches differ in important ways:

	CIRA	SCC
Geographic scope	U.S. regional + global	Global
Applicability and usage	<ul style="list-style-type: none"> Significant global action. Informs analysis and helps tell story of benefits of mitigation. 	<ul style="list-style-type: none"> Assess marginal changes in GHG trajectories. Meant to provide a comprehensive metric for benefit-cost analysis. Limited communication tool.
Characterization of impacts	<ul style="list-style-type: none"> Highly specific for U.S. Meaningful physical impacts (e.g., heat mortality, drought, habitat loss). Physical + monetized estimates. 	<ul style="list-style-type: none"> Too aggregated for U.S. specific impacts. Only monetized estimates. Often difficult to see underlying physical impacts.
Coverage of impacted sectors	Detailed U.S.- and sector-specific coverage. A number of known impacts not included (e.g., vector-borne disease, catastrophic events).	Aims to measure economic damages from all impact sectors; in practice models do not capture all important damages.
Approach to impact estimates	Bottom-up modeling: directly modeled at sector level using consistent data, assumptions, and scenarios.	Aggregated damage functions developed from available literature (with inconsistent inputs, data, etc.).

- In the future, results from CIRA's impact analyses may help inform aggregate damage functions used in the SCC models' estimates.

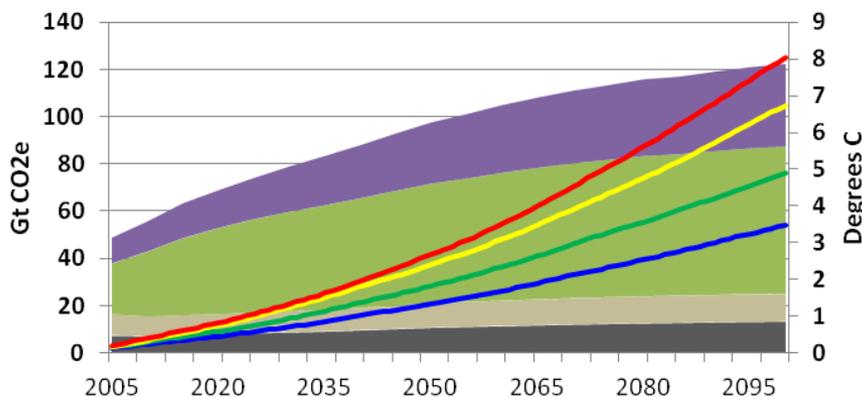
CIRA Global Emissions Scenarios



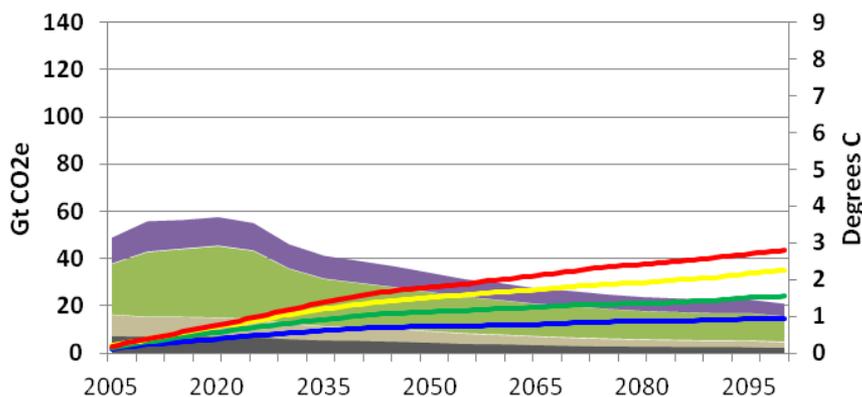
Three global emissions scenarios are used (no explicit assumptions about individual country commitments):

- **Reference scenario (RF 10 W/m² / ≈RCP8.8)**
 - 2100 global emissions ~ 2.5 x 2005 levels
 - 2100 U.S. emissions ~ 1.8x 2005 levels
 - 2100 GHG concentrations (IPCC gases) ~1750 ppm
- **Global mitigation scenario (RF 4.5 W/m² / ≈RCP4.2)**
 - 2100 global emissions ~ 57% below 2005 levels
 - 2100 U.S. emissions ~ 67% below (38% in 2050)
 - 2100 GHG concentrations (IPCC gases) ~ 600 ppm
- **Stronger global mitig. scenario (RF 3.7 W/m² / ≈RCP3.6)**
 - 2100 global emissions ~ 73% below 2005 levels
 - 2100 U.S. emissions ~ 73% below (60% in 2050)
 - 2100 GHG concentrations (IPCC gases) ~ 500 ppm

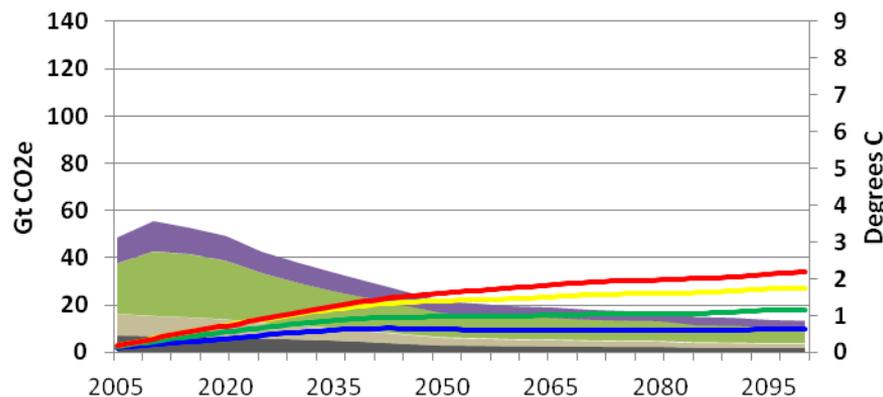
Reference



Mitigation Scenario

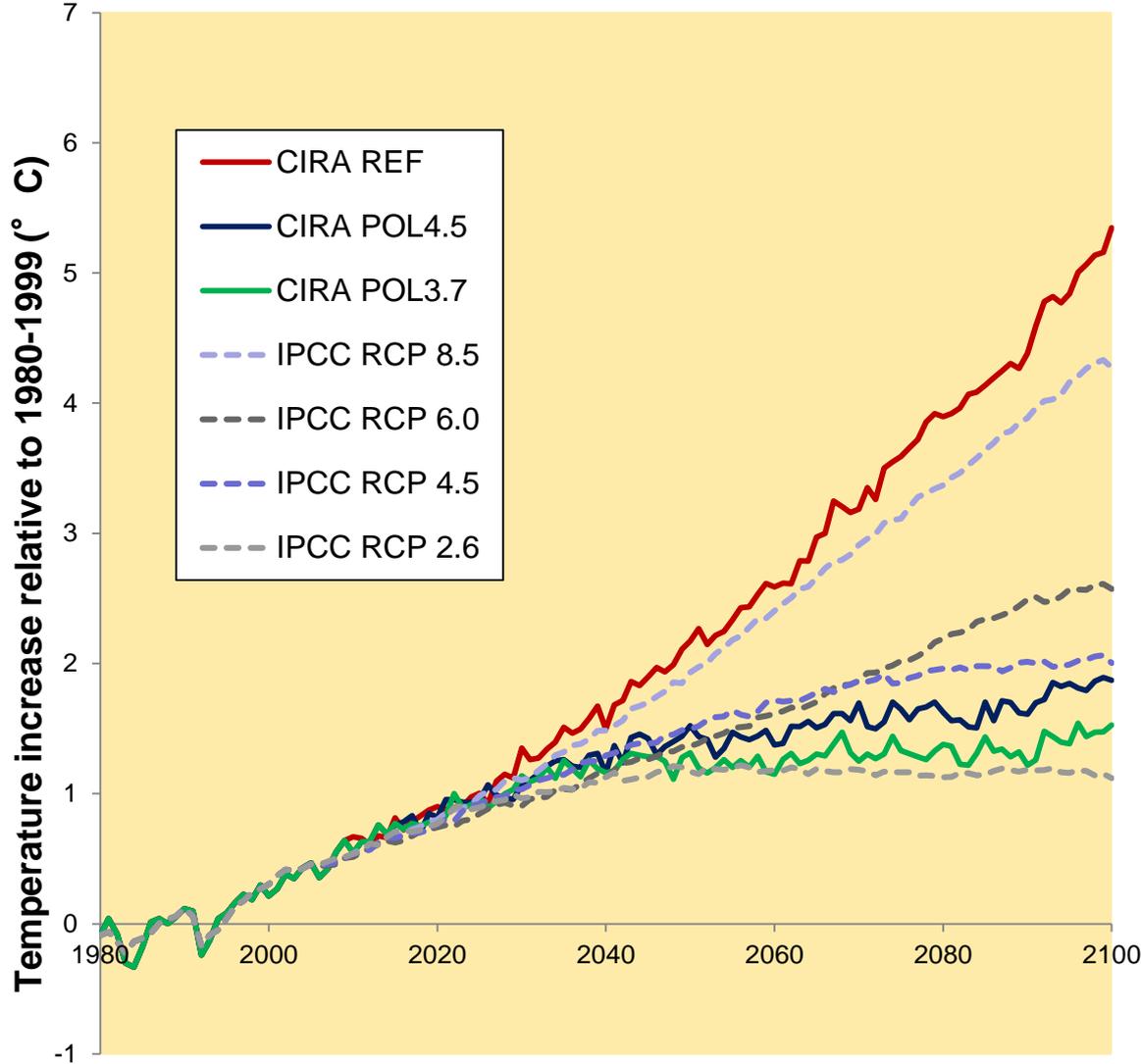


Stronger Mitigation Scenario

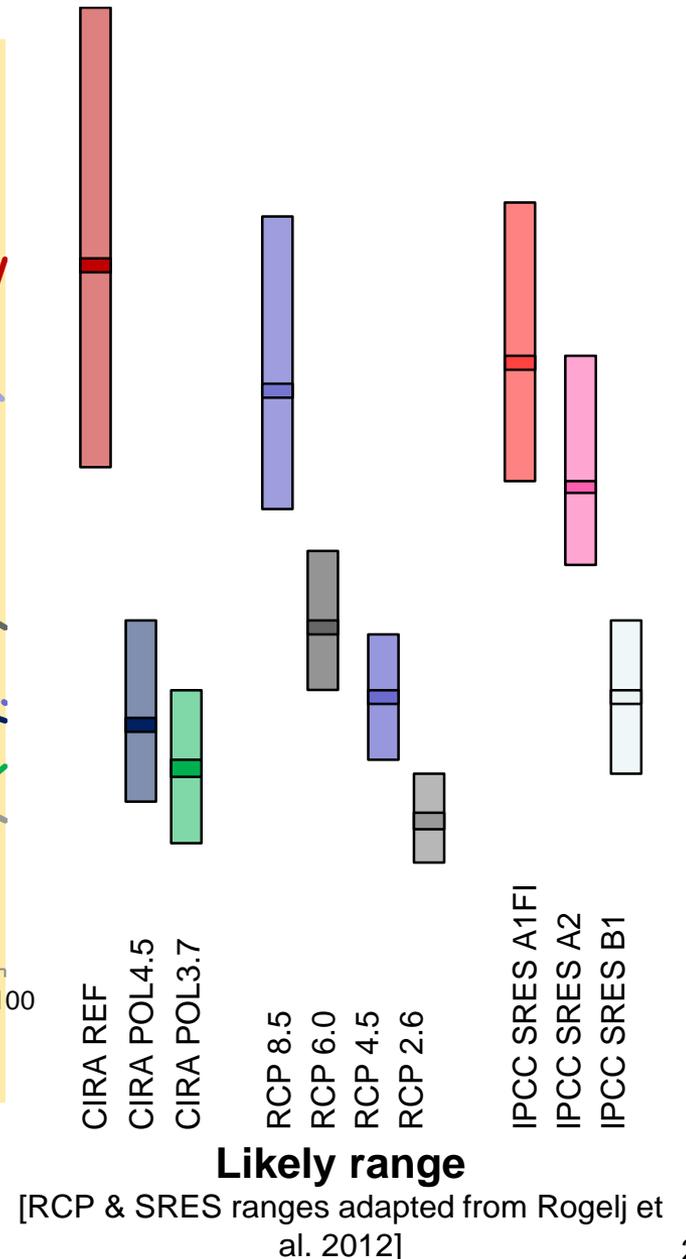


USA
 Other Developed
 Other G-20
 Rest of World
 Temp CS2.0
 Temp CS3.0
 Temp CS4.5
 Temp CS6.0

Emission Scenario Comparison

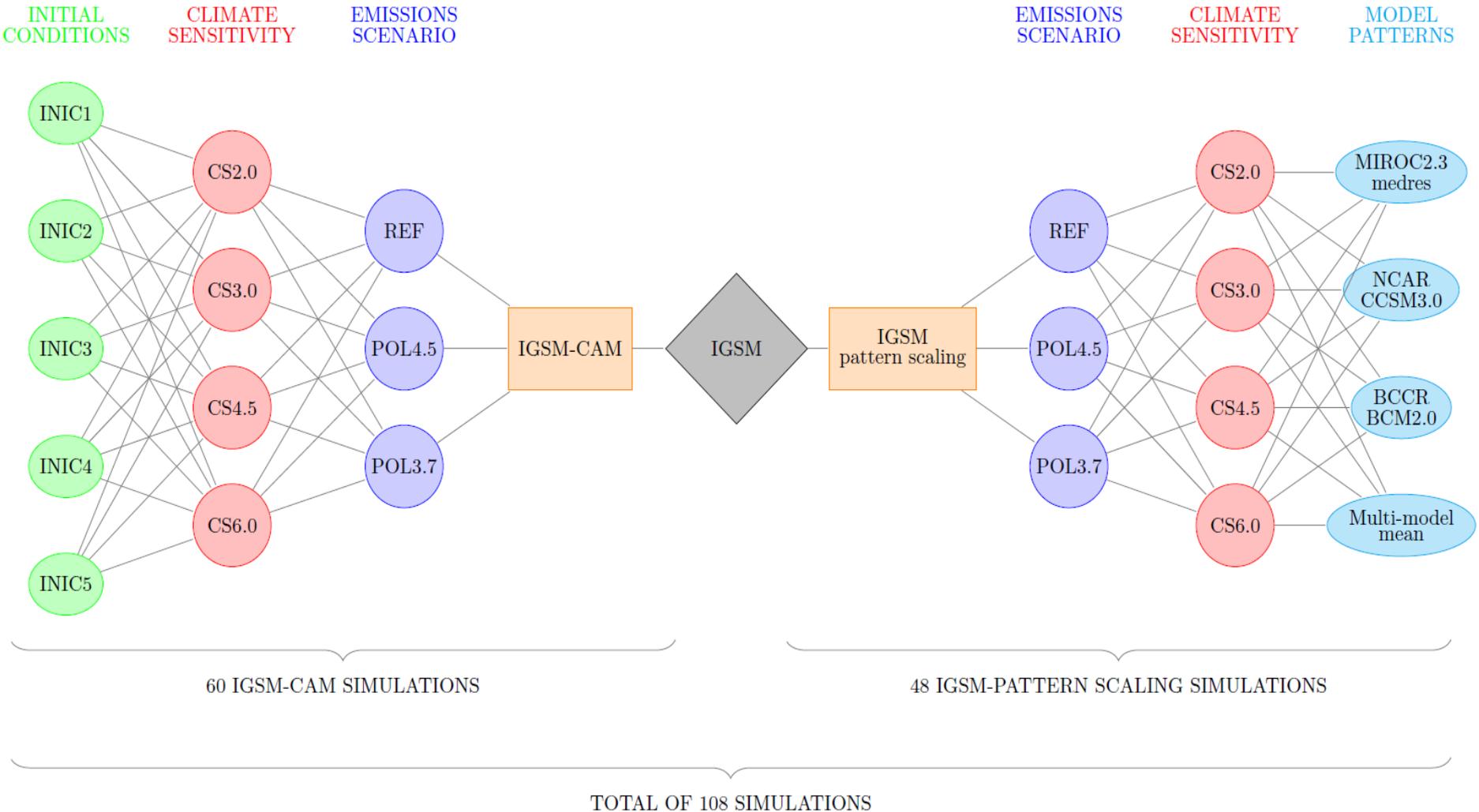


*Likely ranges for CIRA scenarios represent year 2100 values for climate sensitivity 2 and 4.5°C



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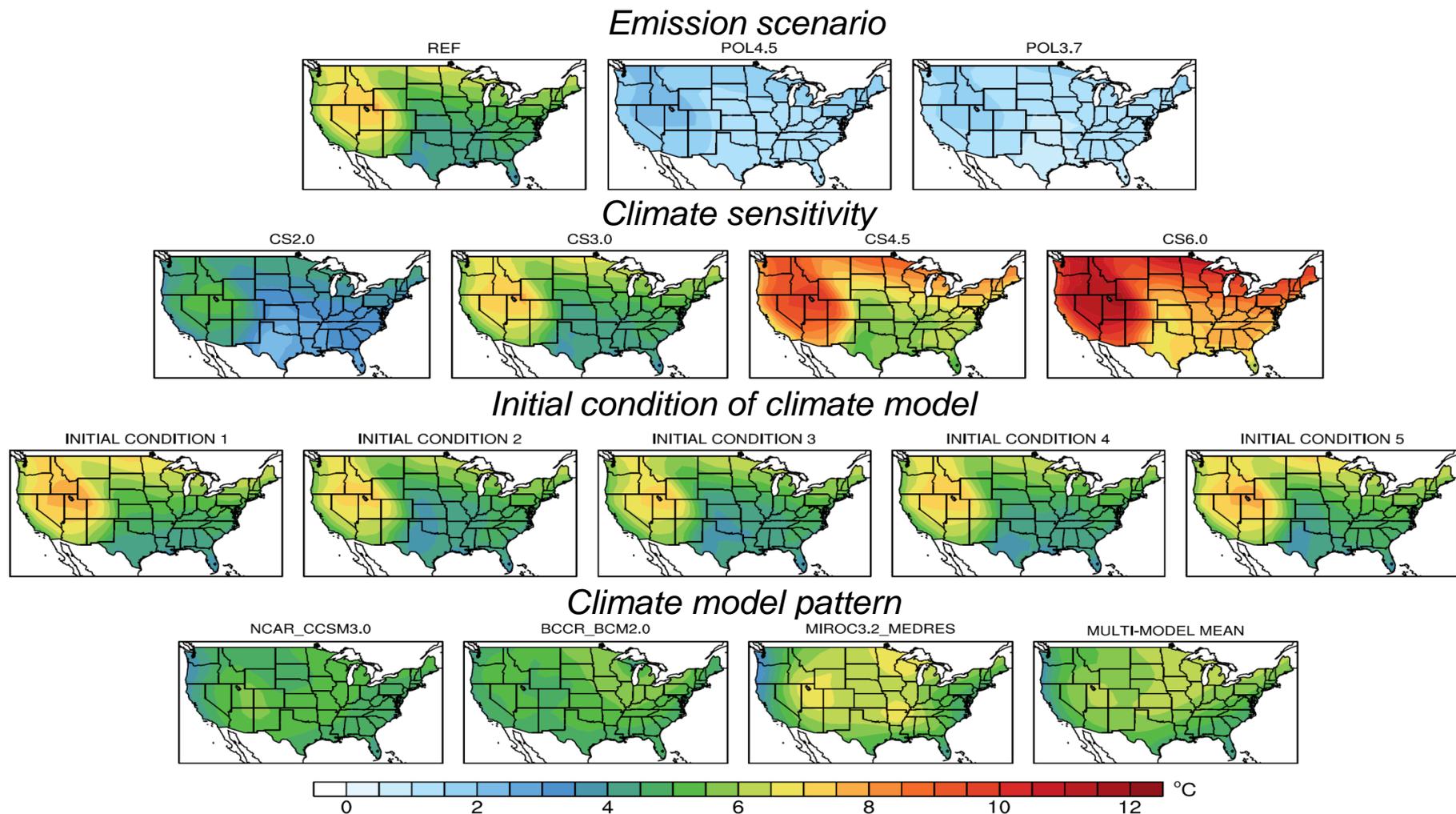
Experimental Design of the CIRA Uncertainty Framework



From: Monier et al. (2014)

Analyzing Key Sources of Uncertainty in Projecting Temperature

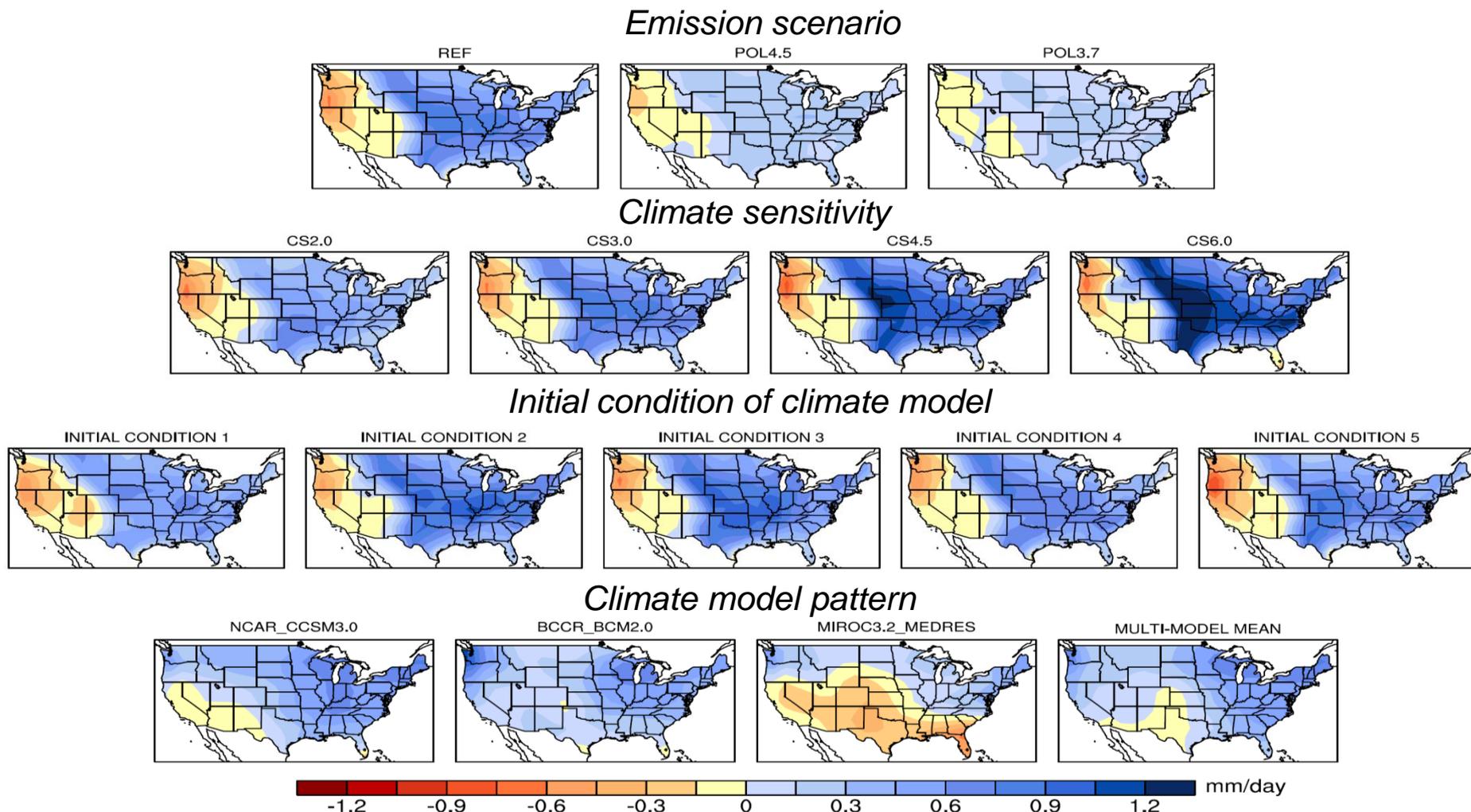
Changes in temperature ($^{\circ}\text{C}$) in 2100 relative to present day



- Both GHG mitigation scenarios greatly reduce warming compared to the reference.
- The different climate sensitivity values show a wide range in the magnitude of future warming.
- Differences between the five initial conditions are less than 1.0°C.
- Different models show relative agreement in magnitude of temperature change, but with different patterns.

Analyzing Key Sources of Uncertainty in Projecting Precipitation

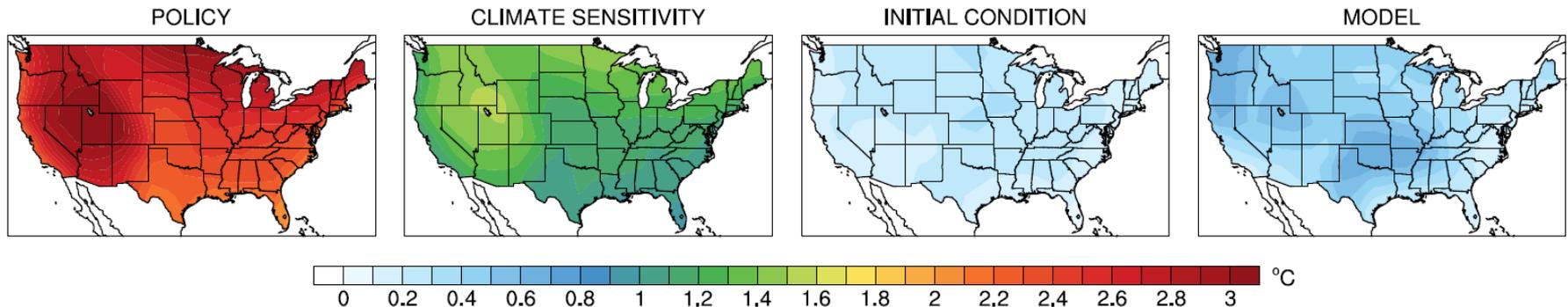
Changes in precipitation (mm/day) in 2100 relative to present day



- Implementation of either policy leads to decreases in the magnitude of precipitation change across U.S.
- The impact of climate sensitivity appears to be strongly localized, while initial conditions have a larger impact on regional precipitation changes than on temperature.
- Climate model pattern shows largest spatial heterogeneity across the U.S.

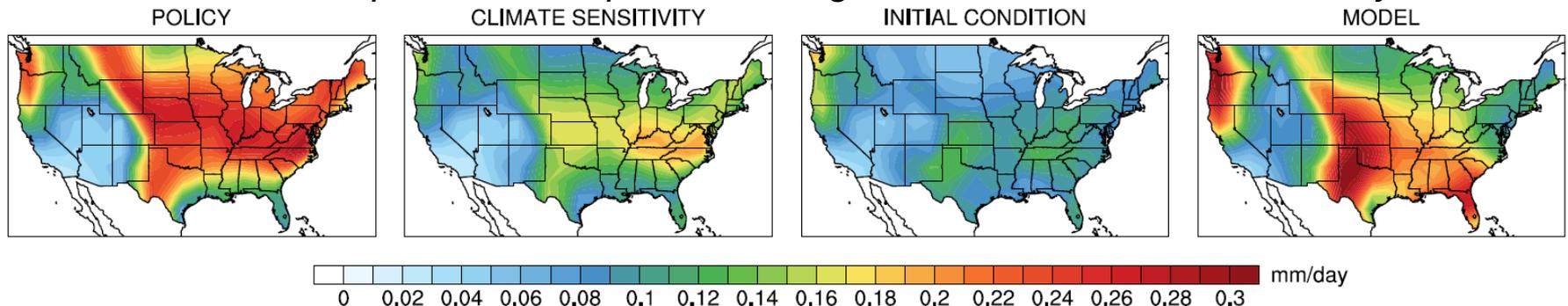
Relative Importance of Uncertainty Sources Analyzed

Mean Spread* of Temperature Change for Each Source of Uncertainty



- The mean spread (1991-2010 mean vs. 2091-2110 mean) displays little spatial heterogeneity. The largest source of uncertainty is the policy (mean spread between 2.0 and 3.0 °C), with the spread from climate sensitivity selection also being substantial (values between 1.0 and 1.7 °C).

Mean Spread of Precipitation Change for Each Source of Uncertainty

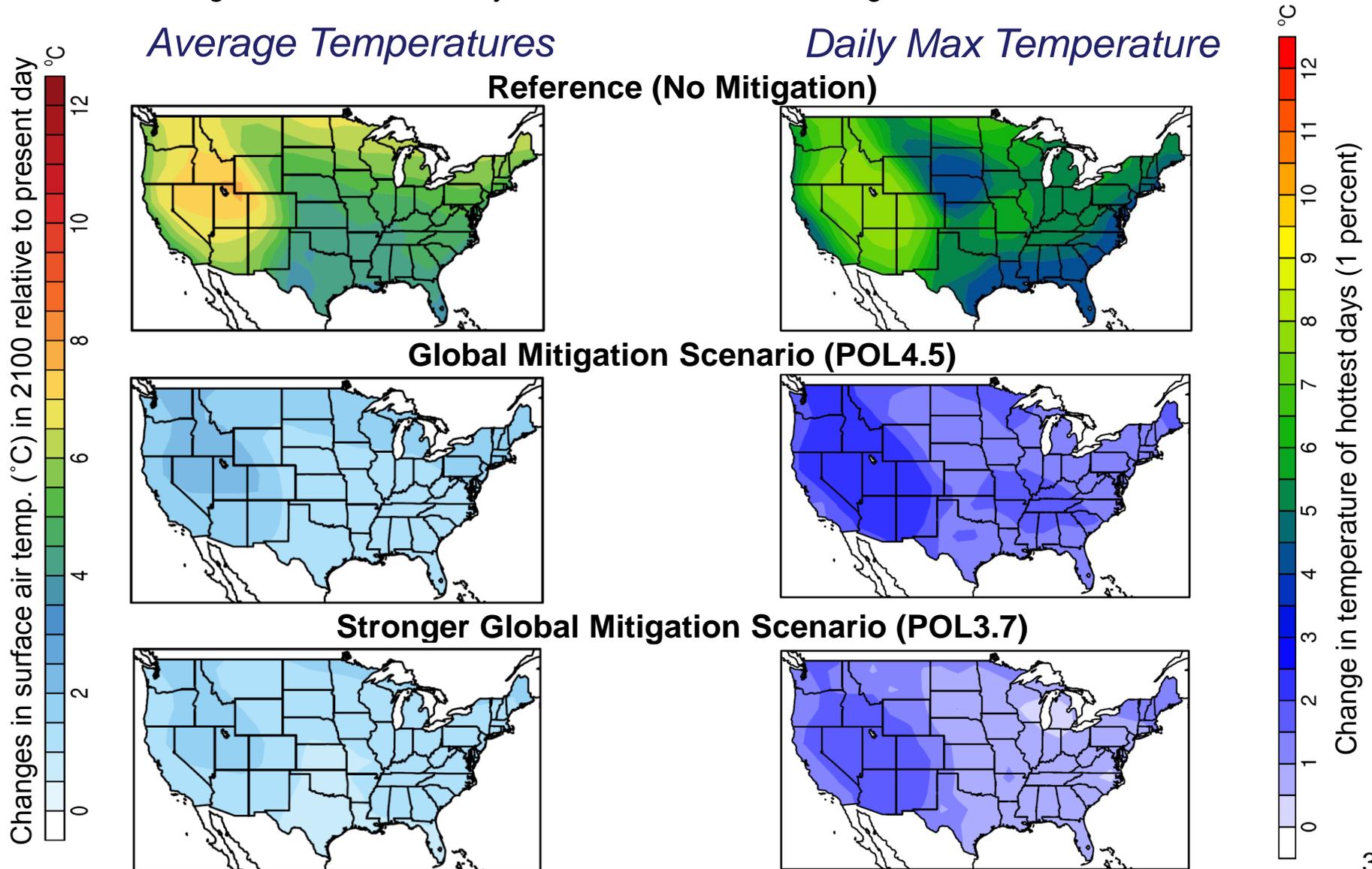


- The mean spread of each source is more heterogeneous. The choice of policy and of models are the largest contributors of uncertainty in precipitation changes, with a mean spread >0.2mm/day in most of U.S.
- A particular feature is the small spread in the Southwest, indicating that this region shows the least amount of uncertainty in precipitation changes.

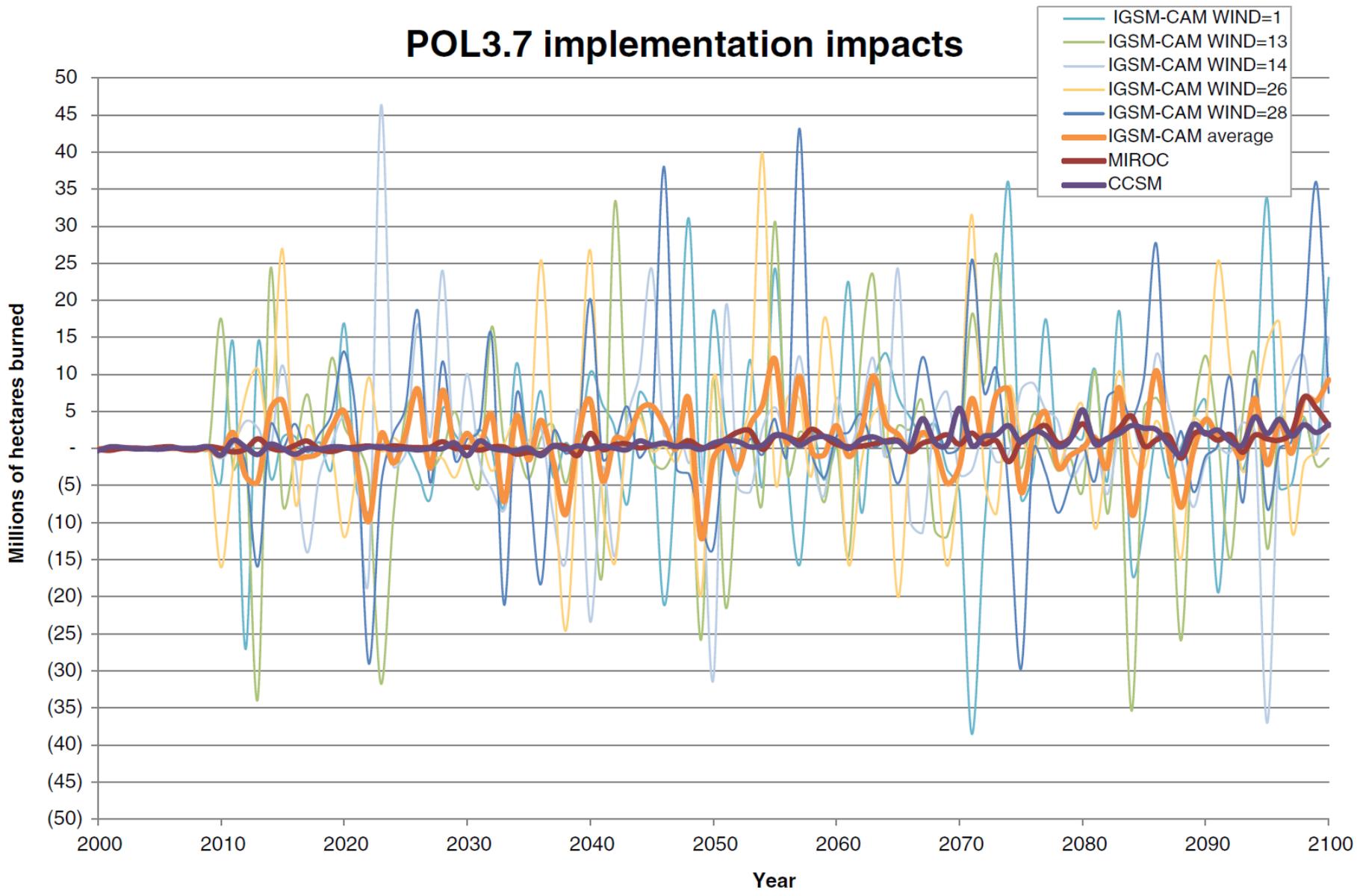
* The mean spread is the S.D. across a source of uncertainty averaged over the other sources of uncertainty.

Changes in Temperature in 2100

- With no mitigation, avg. and extreme temps increase substantially.
- These changes are substantially reduced under both mitigation scenarios.

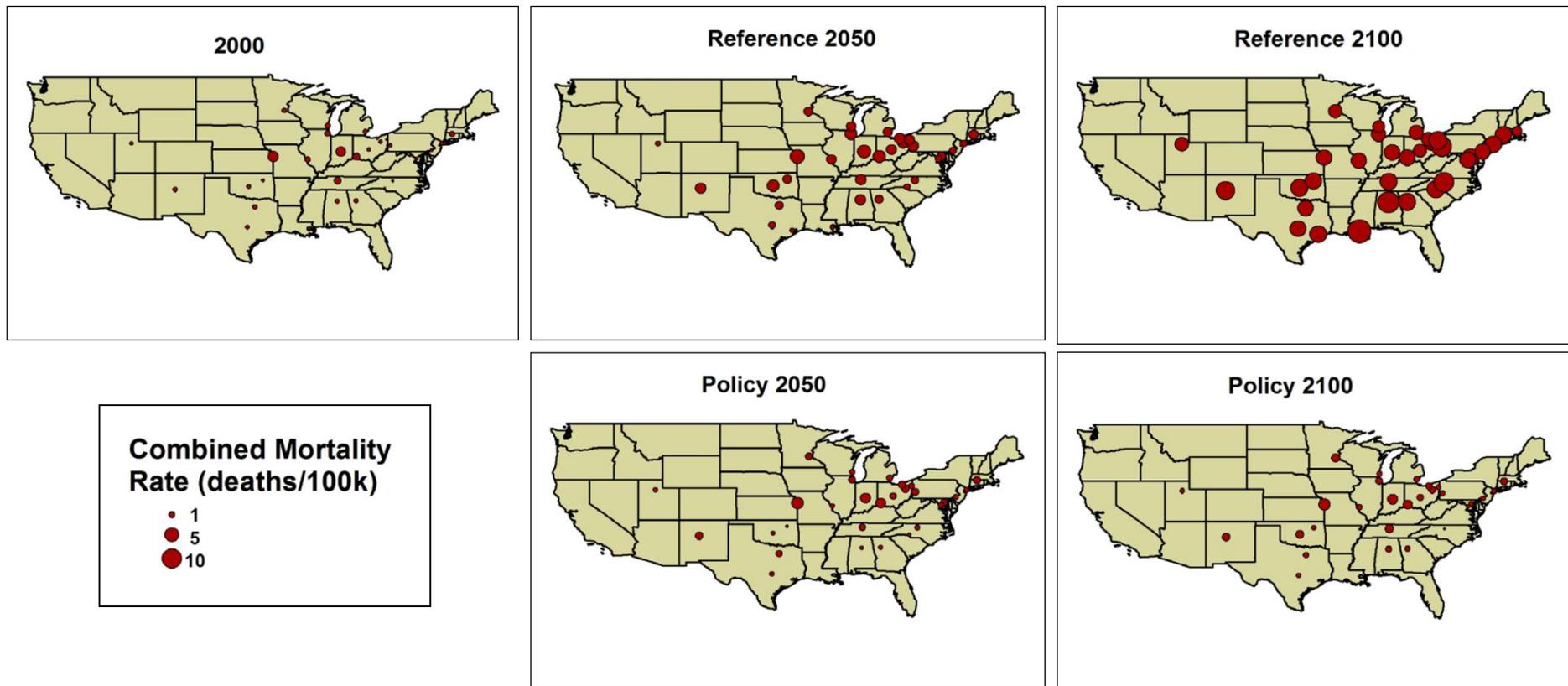


POL3.7 implementation impacts



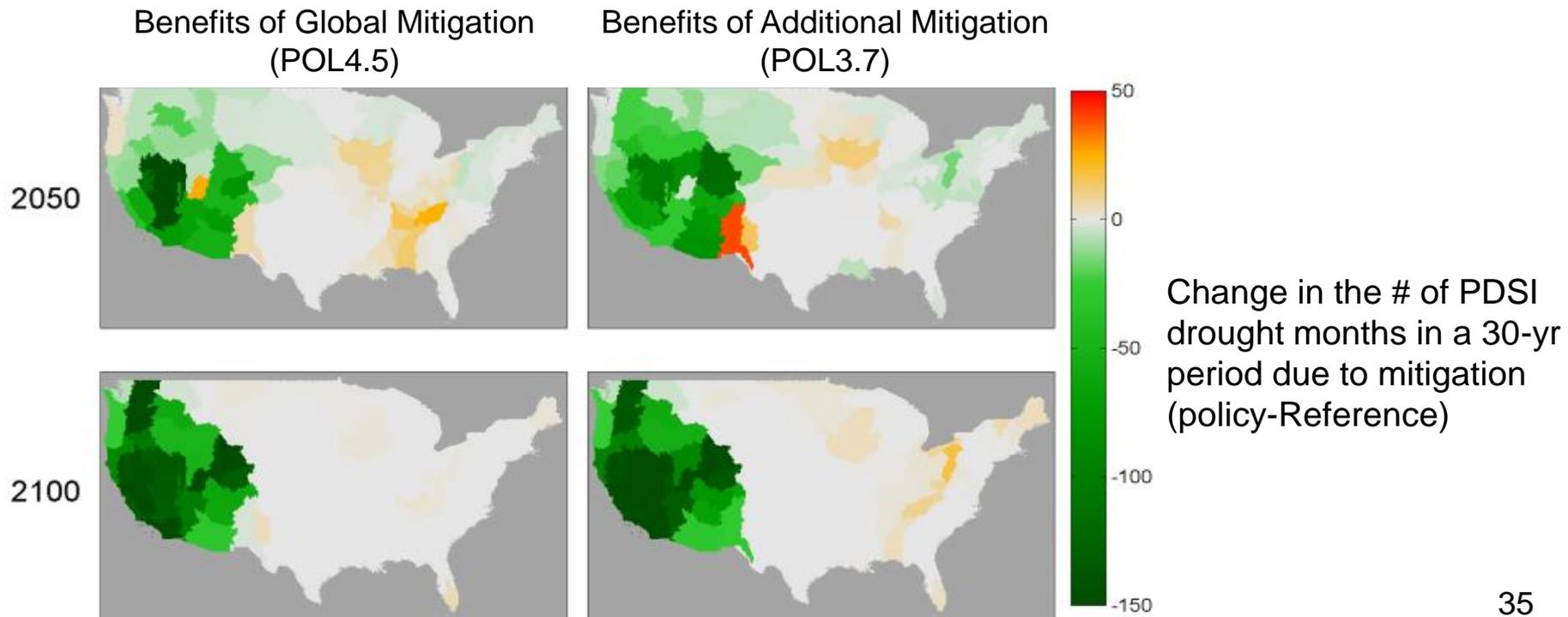
Extreme Temperature Mortality

- Dramatic increase in national projected heat mortality over time; cold mortality continues to diminish.
- Results suggest a considerable annual risk reduction for ETM that grows over time with GHG policy implementation (POL3.7).
- Does not fully consider the effect that adaptation would have in reducing mortality.



Changes in Drought Risk Through 2100

- Drought risk is estimated using the Palmer Drought Severity Index (PDSI, measured by changes in both precipitation and temperature).
- In the figures below, green represents reductions in drought risk associated with the GHG mitigation policies compared to the reference scenario.
- Largest increases in drought frequency under the reference case are in the southwestern U.S., which is also where the largest benefits of mitigation occur.
- Given the 'wetness' of the climate model used, these are likely to be underestimates of impacts/benefits.



Estimated Decline in U.S. Coral Reefs

- GHG mitigation delays Hawaiian coral reef loss compared to the reference.
- The stronger mitigation scenario (POL3.7) avoids ~\$18B (disc. at 3%) by 2100 in lost recreational value for all 3 regions, compared to the reference.
- GHG mitigation provides only minor benefit to coral cover in South Florida and Puerto Rico (*not shown*), as these reefs are already being affected by climate change, acidification, and other stressors.

