# Uncertainty in regional climate projections

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# Outline

1) Objectives

2) Overview of uncertainty in regional climate projections

3) Modeling framework

4) Results

5) Summary and conclusions

# Objective

To investigate the uncertainty in future projections of climate change at the regional level.

Modeling framework is based on:

- integrated economic and climate projections
- a consistent framework for uncertainty in regional climate change

Our focus is on 4 sources of uncertainty in climate projections:

- Emissions projections (policy scenarios)
- Global climate response (climate parameters)
- Natural variability (initial conditions)
- Structural uncertainty/regional patterns of change (multiple models)

# Relevance

What do we mean by “regional” climate projections?

- *At the national to continental scale.*

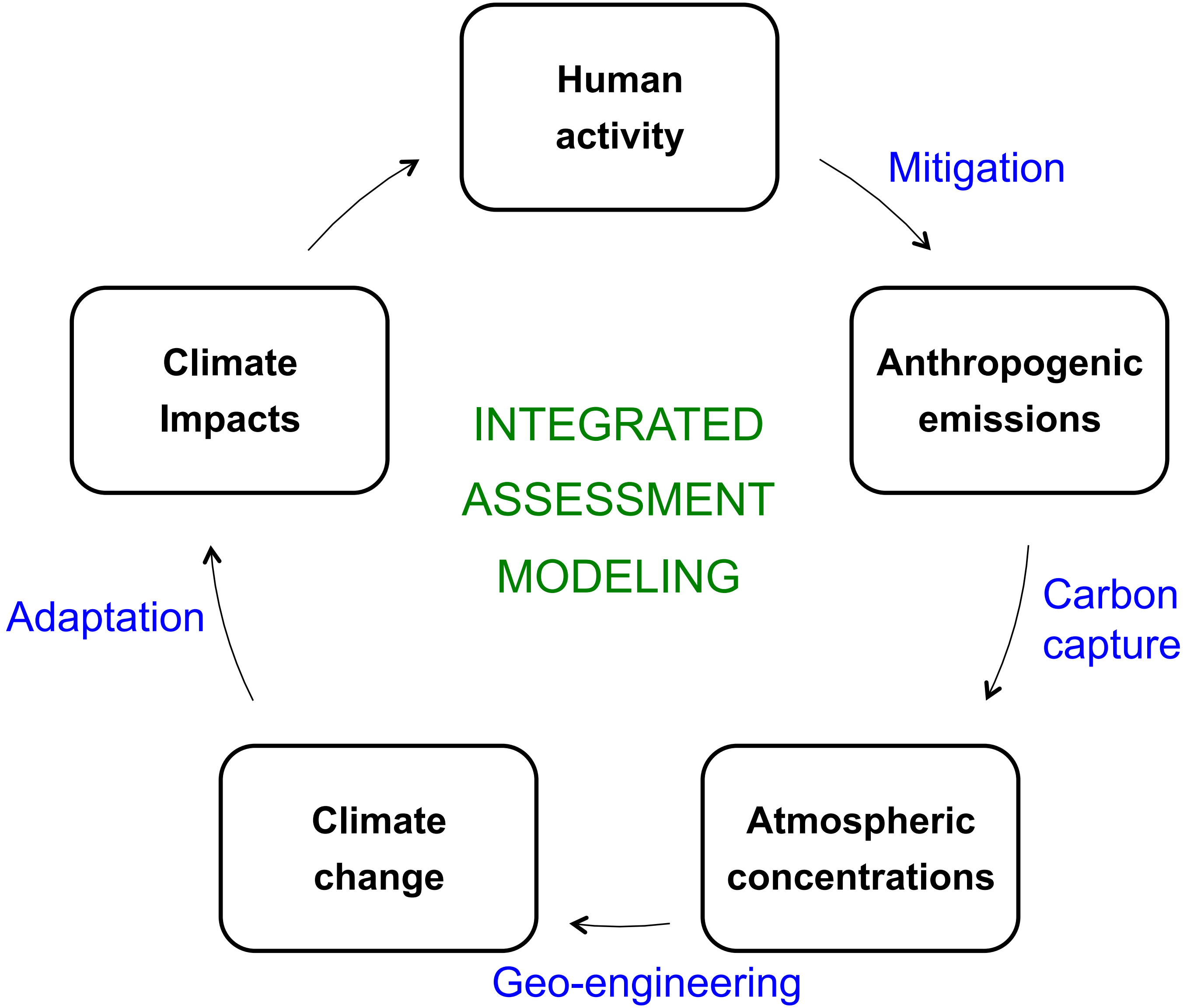
Why is the regional scale important?

- *It’s at the regional scale that climate impacts are felt the most strongly and that decisions about mitigation/adaption are made.*

What do we mean by uncertainty?

- *Differences in climate projections resulting from unknown or uncertain inputs or processes, some irreducible, some that can be narrowed down with increasing knowledge.*

# Integrated Assessment Modeling



# Uncertainty in emissions projections

Projections of future emissions of greenhouse gases and aerosols are highly uncertain because they depend on economic development, societal behavior and political decisions.

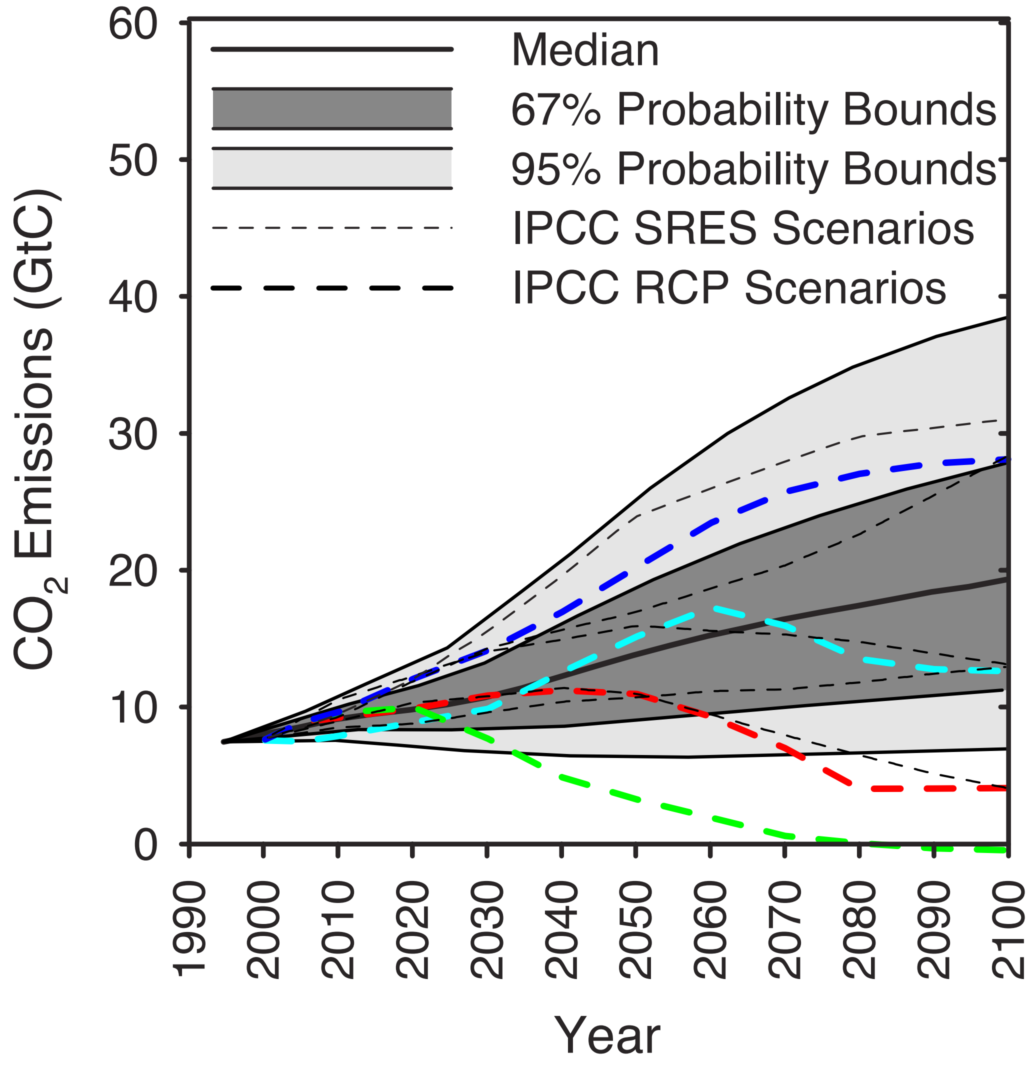
Some of the drivers of emissions that are uncertain include:

- Economic and population growth
- Emergence and costs of new technology
- Implementation of climate policy that could result in the transition to “cleaner” sources of energy

The general approach to examining the impact of the uncertainty in emissions on the climate is scenario based.

At the Joint Program, probabilistic distribution of emissions are derived by sampling over 100 socio-economic and technological parameters for 16 regions covered by the model.

# Uncertainty in emissions projections




Adapted from Webster et al. (2002)

# Uncertainty in climate system response

The climate system response to changes in radiative forcing resulting from changes in greenhouse gas concentrations and aerosol loading is also highly uncertain.

The climate system response is controlled by key climate parameters:

- Climate sensitivity

*Global mean temperature increase for a doubling of CO2 concentrations*

- Strength of aerosol forcing

*How large is the radiative forcing of a particular aerosol loading*

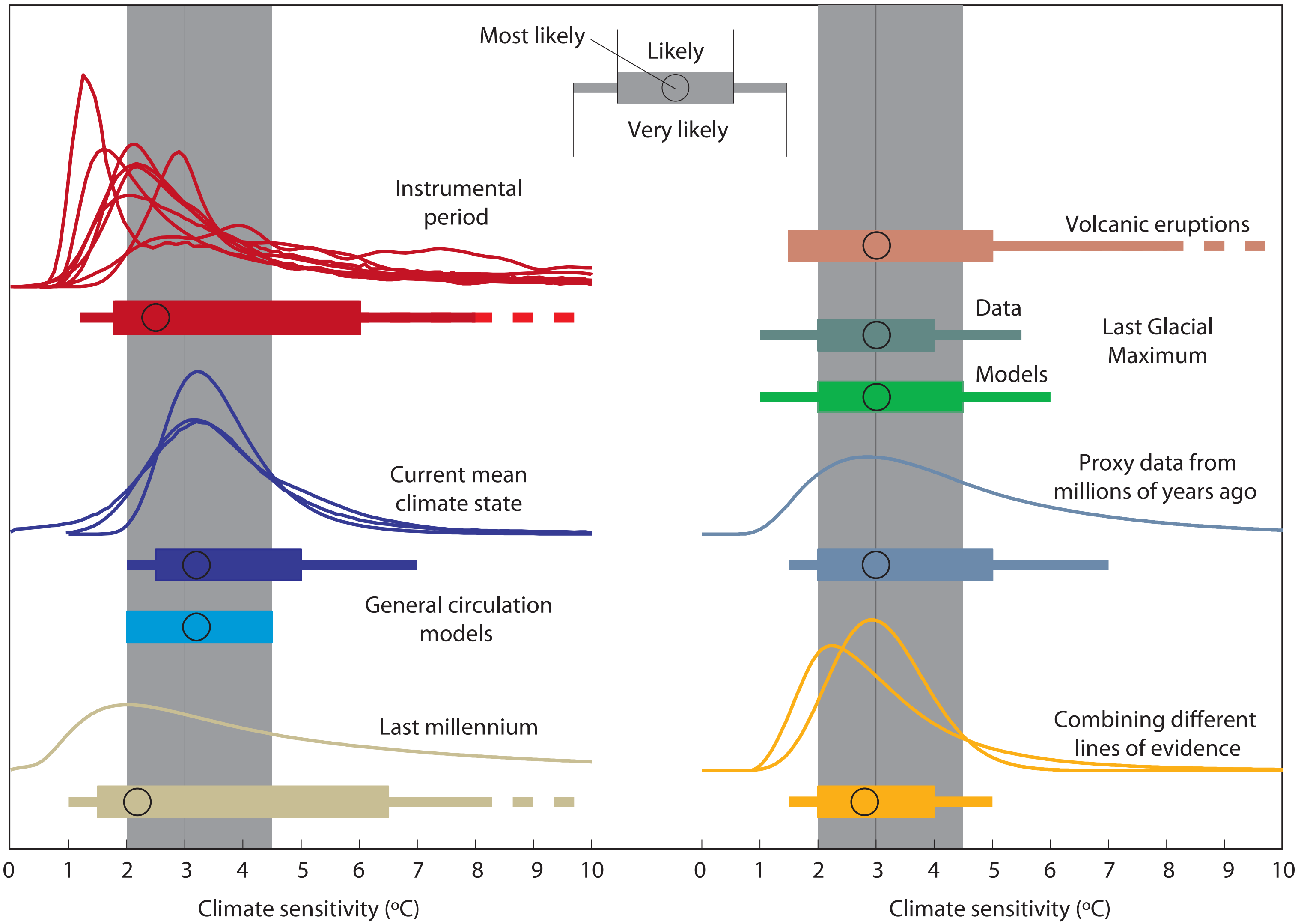
- Ocean heat uptake rate

*Rate at which the ocean uptakes heat from the atmosphere*

At the Joint Program, the general approach relies on computing PDF of climate parameters in order to derive probabilistic projections of future climate change.

# Estimates of climate sensitivity

From Knutti and Hegerl (2008)



# Structural uncertainty

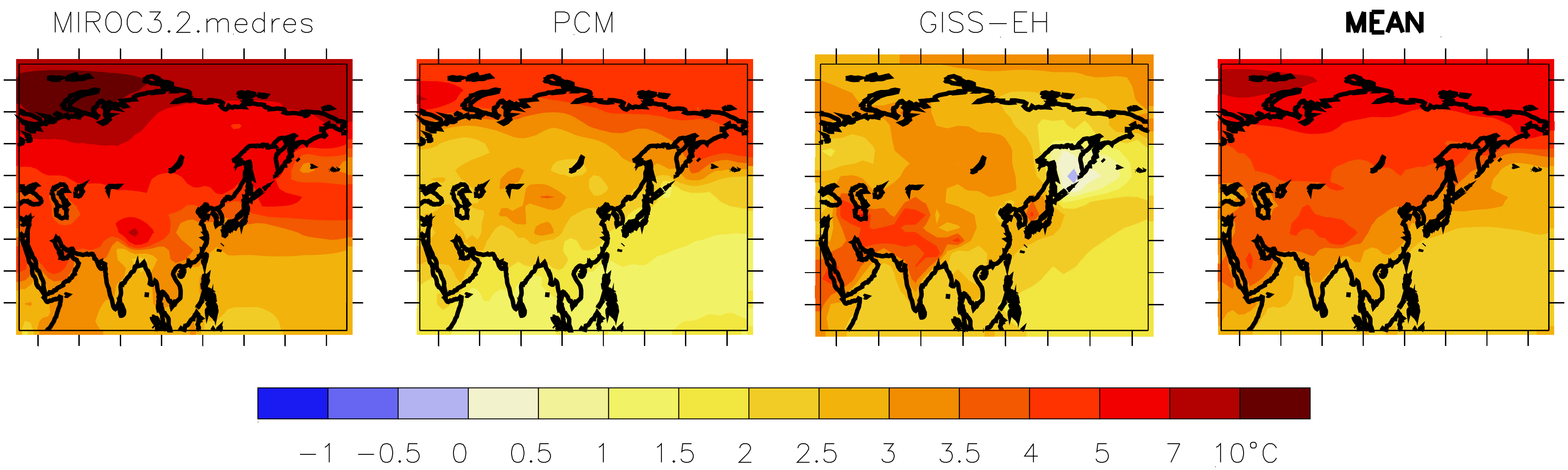
Different climate models have different methods to parameterize particular atmospheric processes (cloud formation, vertical motion within clouds…).

These differences have large impacts on the representation of the mean atmospheric state, as well as on the future projections of key atmospheric variables.

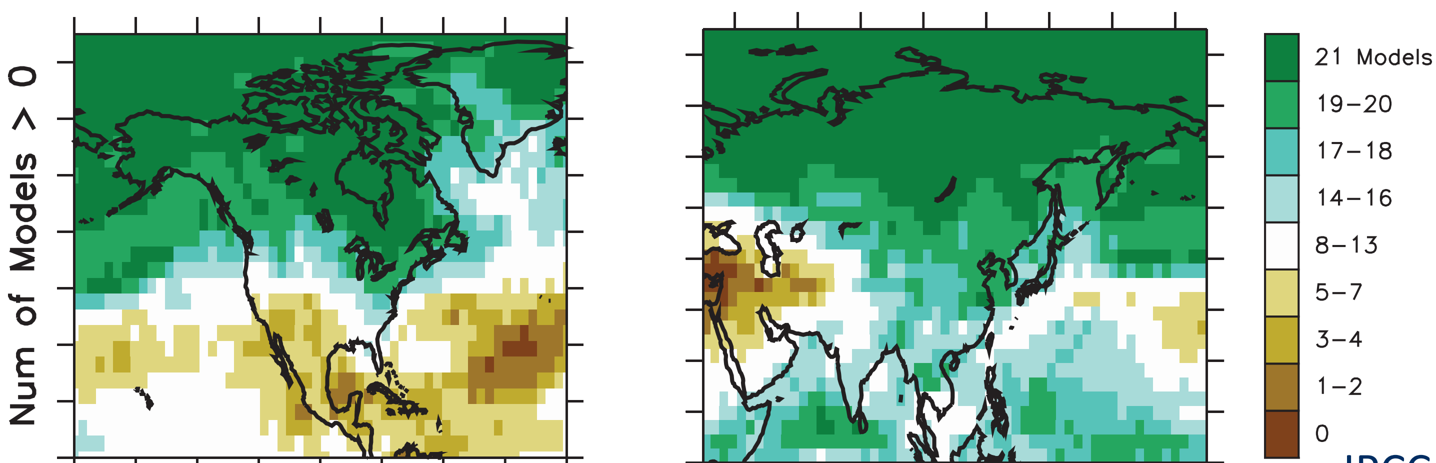
The general approach to examine the role of structural uncertainty on regional climate change is to run multi-model ensemble simulation, like it is done in the various IPCC assessment reports.

# Structural uncertainty

## Annual Mean Surface Air Temperature Response




## Annual Mean Precipitation Response




IPCC AR4 (2007)

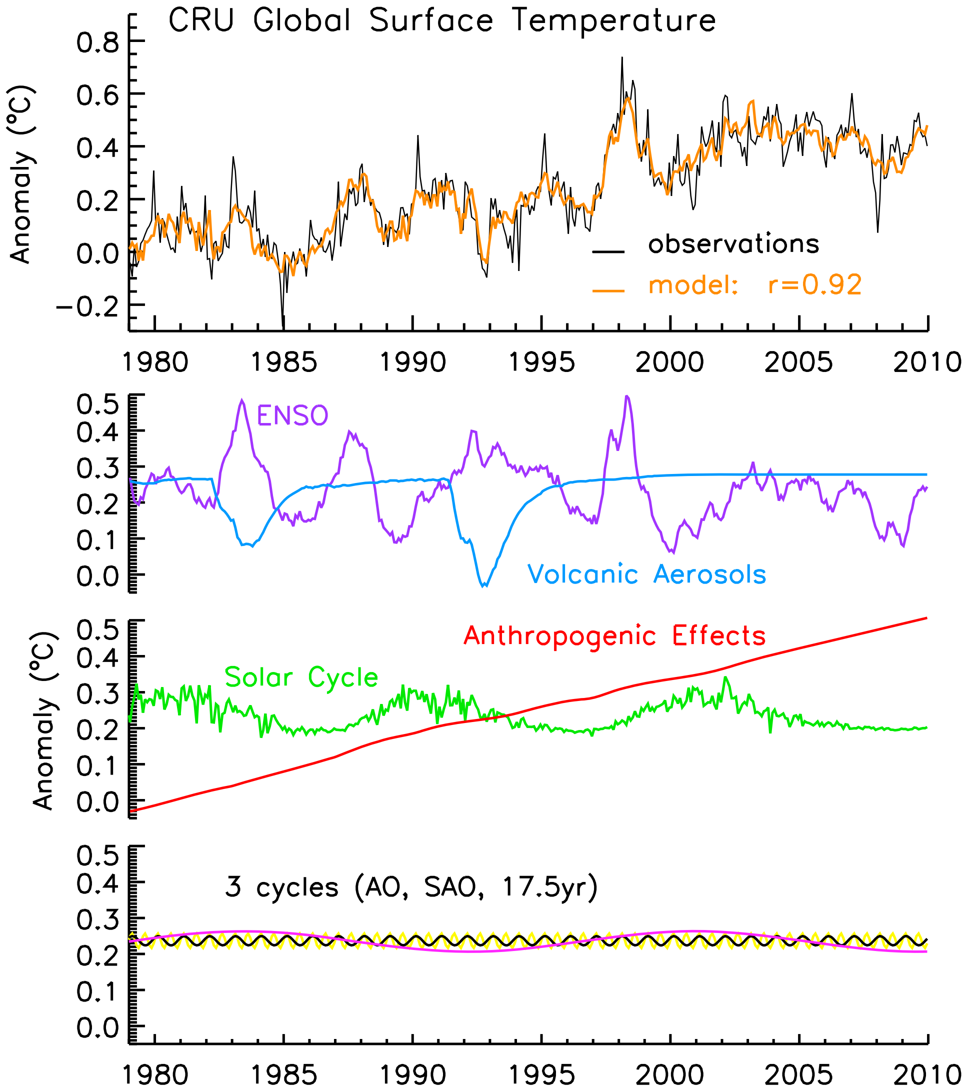
# Uncertainty in natural variability

The atmosphere and ocean systems are chaotic systems that include various modes of variability with different temporal and spatial scales.

The phase of these modes greatly impacts the state of the atmosphere and makes the human signal difficult to extract. These modes of variability have strong teleconnections and impact regional climates worldwide. They can also interact in complex and non-linear ways with the anthropogenic signal, resulting in further uncertainty.

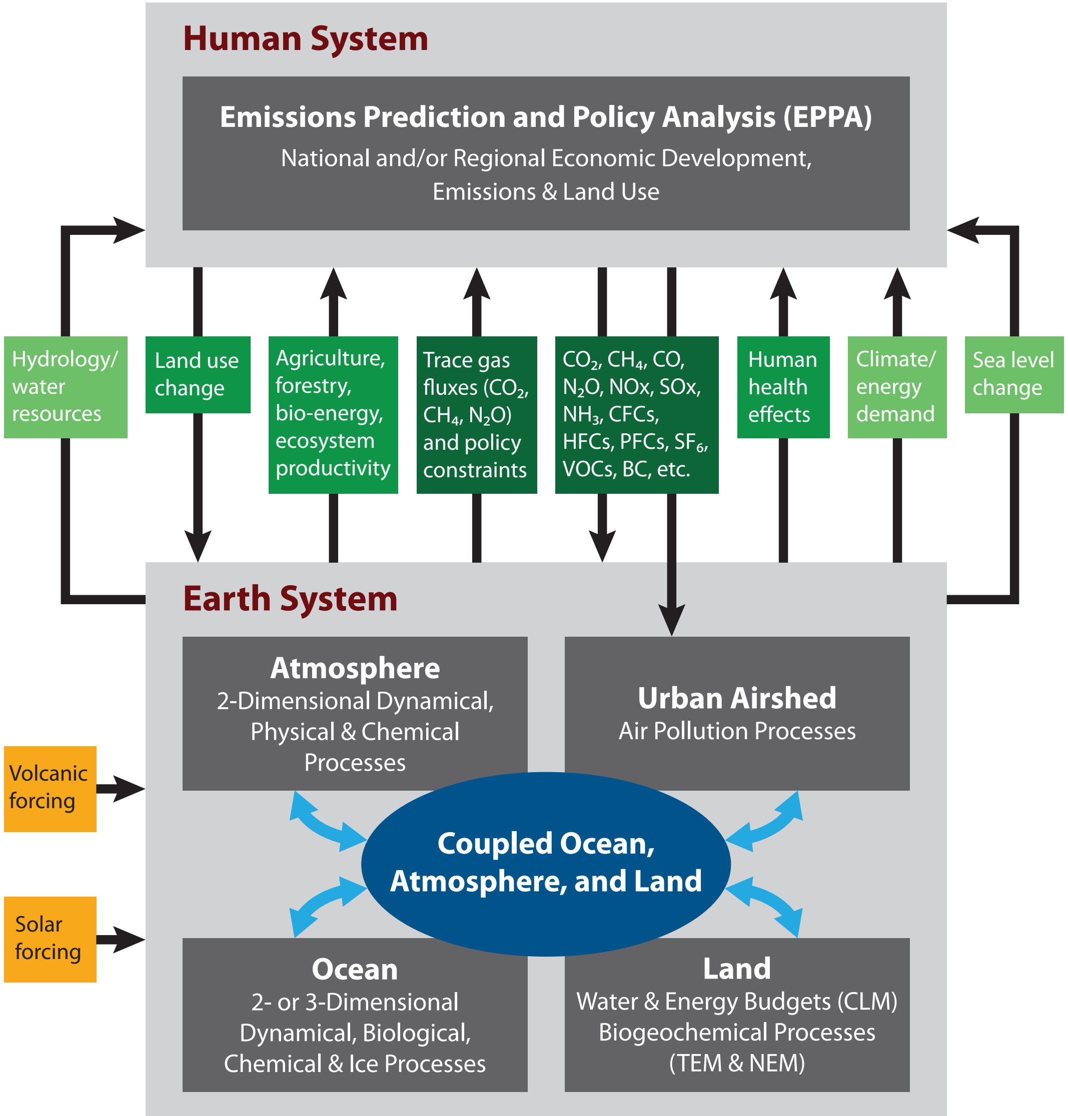
The general approach to take into account the uncertainty in natural variability is to run ensemble simulations with different initial conditions, and therefore different timing/magnitude of these modes of variability.

# Uncertainty in natural variability




Kopp and Lean (2011)

# The MIT Integrated Global System Model




The IGSM is an **integrated assessment model** that couples an earth system model of intermediate complexity to a human activity model.

Flexibility to vary climate parameters (climate sensitivity, ocean heat uptake rate and net aerosol forcing).

Flexibility to analyze uncertainties in emissions resulting from uncertainties intrinsic to the economic model, from parametric uncertainty to uncertainty in future climate policies.

# Regional climate modeling framework

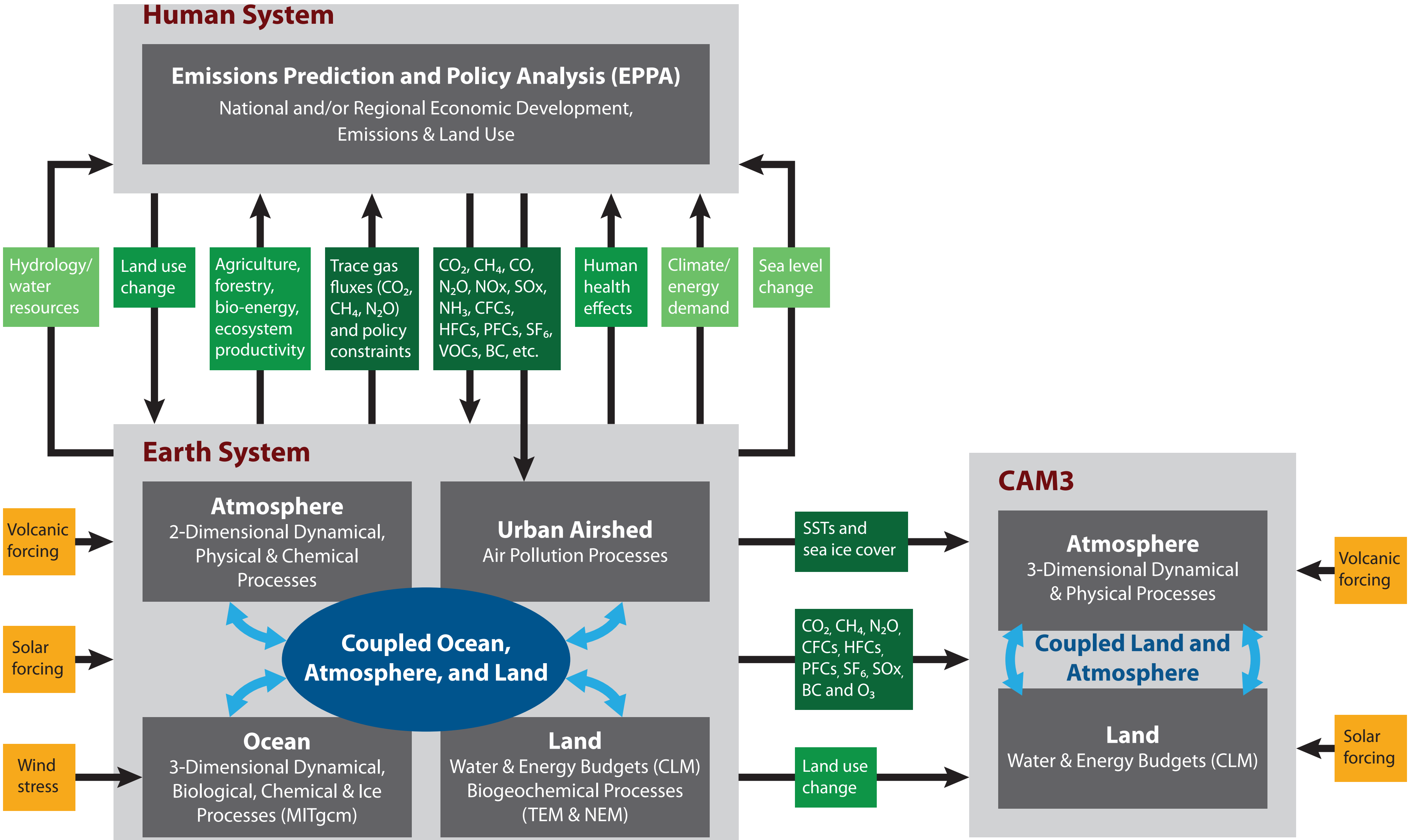
Because the IGSM has a 2D zonal-mean atmosphere,

we use a two-pronged approach to obtain regional changes:

- The MIT IGSM-CAM framework (*Monier et al., 2013*) links the IGSM to the NCAR CAM model, with new modules in CAM to allow climate parameters to be changed to match those of the IGSM. The climate sensitivity of CAM is changed through cloud radiative adjustment method (*Sokolov and Monier, 2012*).

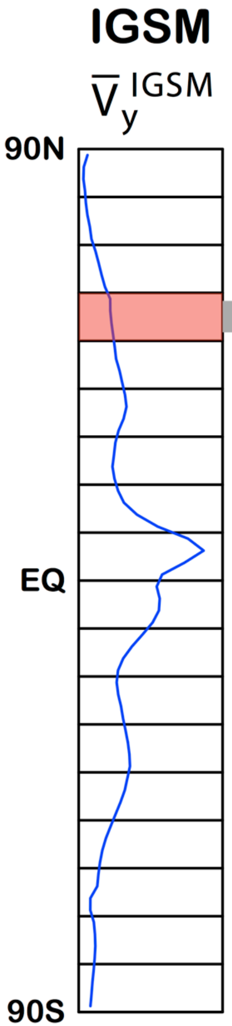
- A pattern scaling method extends the latitudinal projections of the IGSM 2D zonal-mean atmosphere by applying longitudinally resolved patterns from observations and from IPCC AR4 climate models (*Schlosser et al., 2013*).

# IGSM-CAM



Human System
Emissions Prediction and Policy Analysis (EPPA)
National and/or Regional Economic Development, Emissions & Land Use
Hydrology/ water resources
Land use change
Agriculture, forestry, bio-energy, ecosystem productivity
Trace gas fluxes ($CO_2$, $CH_4$, $N_2O$) and policy constraints
$CO_2$, $CH_4$, CO, $N_2O$, NOx, SOx, $NH_3$, CFCs, HFCs, PFCs, $SF_6$, VOCs, BC, etc.
Human health effects
Climate/ energy demand
Sea level change
Earth System
Atmosphere
2-Dimensional Dynamical, Physical & Chemical Processes
Urban Airshed
Air Pollution Processes
Coupled Ocean, Atmosphere, and Land
Ocean
3-Dimensional Dynamical, Biological, Chemical & Ice Processes (MITgcm)
Land
Water & Energy Budgets (CLM) Biogeochemical Processes (TEM & NEM)
Volcanic forcing
Solar forcing
Wind stress
SSTs and sea ice cover
$CO_2$, $CH_4$, $N_2O$, CFCs, HFCs, PFCs, $SF_6$, SOx, BC and $O_3$
Land use change
CAM3
Atmosphere
3-Dimensional Dynamical & Physical Processes
Coupled Land and Atmosphere
Land
Water & Energy Budgets (CLM)
Volcanic forcing
Solar forcing

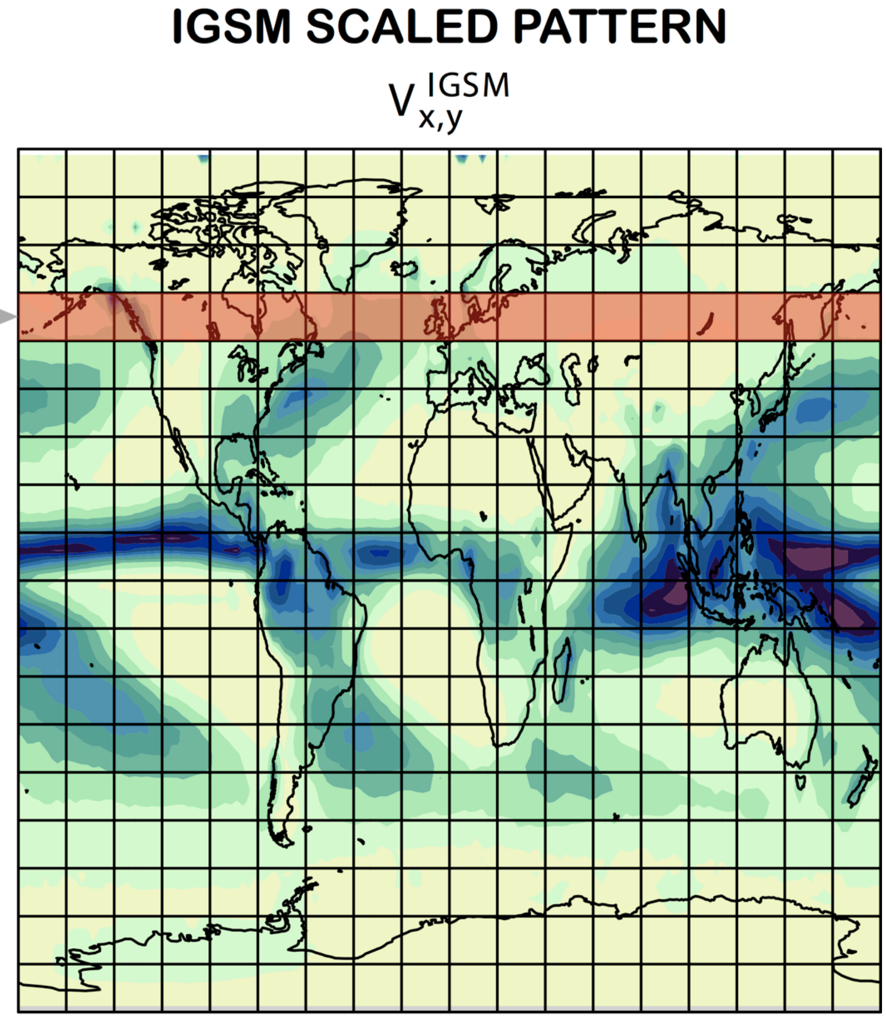
# Pattern scaling method




$$V_{x,y}^{IGSM} = C_{x,y} \cdot \overline{V}_y^{IGSM}$$

$$C_{x,y} = C_{x,y}^{OBS} + \left[ \frac{dC_{x,y}^{AR\,4}}{dT_{Global}} \cdot \Delta T_{Global}^{IGSM} \right]$$

$$C_{x,y}^{(OBS\ or\ AR4)} = \frac{V_{x,y}^{(OBS\ or\ AR4)}}{\overline{V}_y^{(OBS\ or\ AR4)}}$$



# Description of the simulations

9 core simulations with IGSM:

3 emissions scenarios

- REF: Unconstrained emissions, with 8.5 $W/m^2$ in 2100
- POL4.5: Stabilization scenario, with 4.5 $W/m^2$ in 2100
- POL3.2: Stabilization scenario, with 3.2 $W/m^2$ in 2100

3 climate sensitivities (2.0, 3.0, 4.5°C)

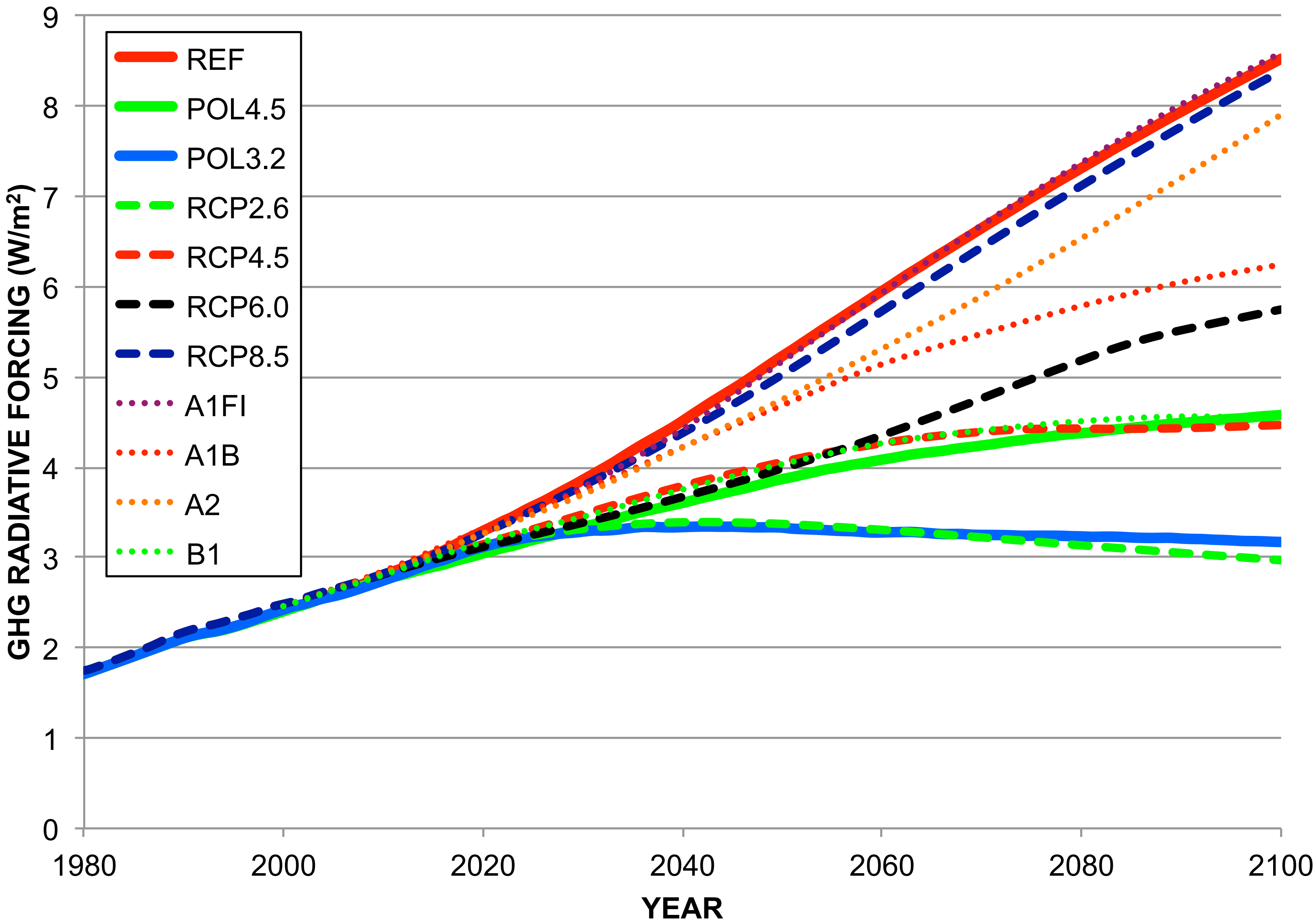
45 IGSM-CAM simulations:

5 different initial conditions for each set of policy/climate parameters

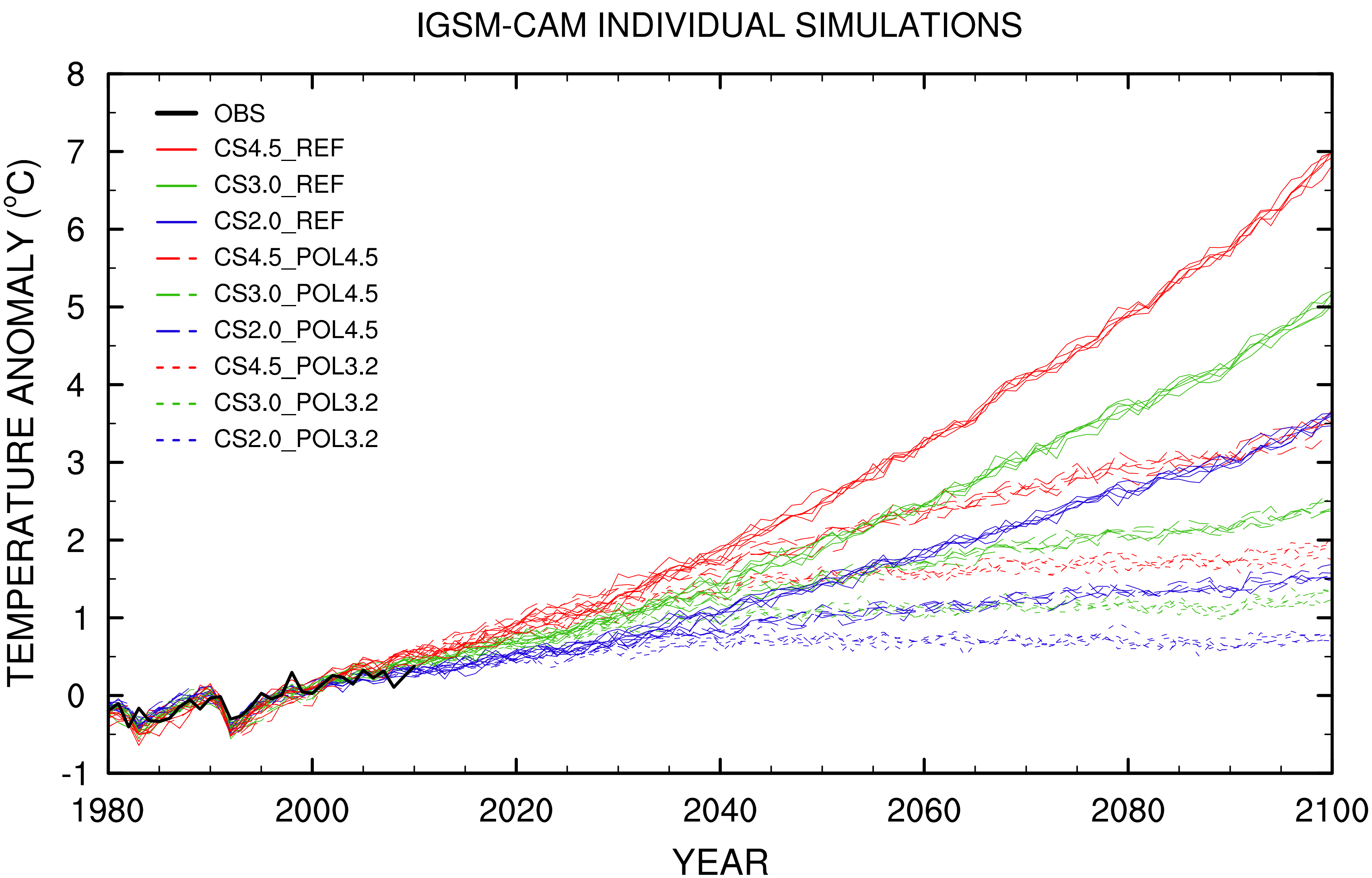
153 pattern scaling of IGSM core simulations

17 IPCC AR4 GCMs

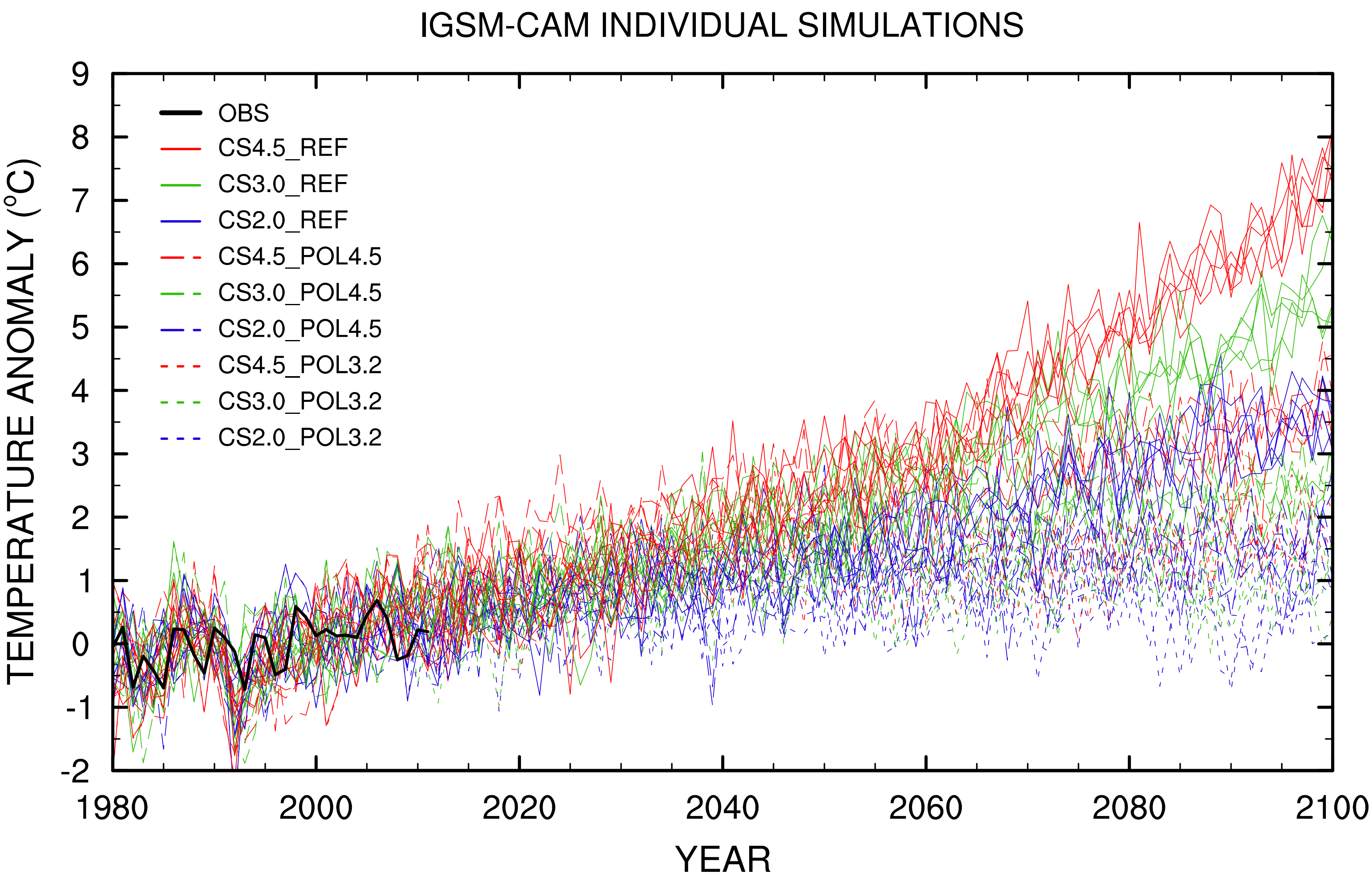
# Greenhouse gas forcing



# Changes in global mean temperature



# Changes in USA mean temperature



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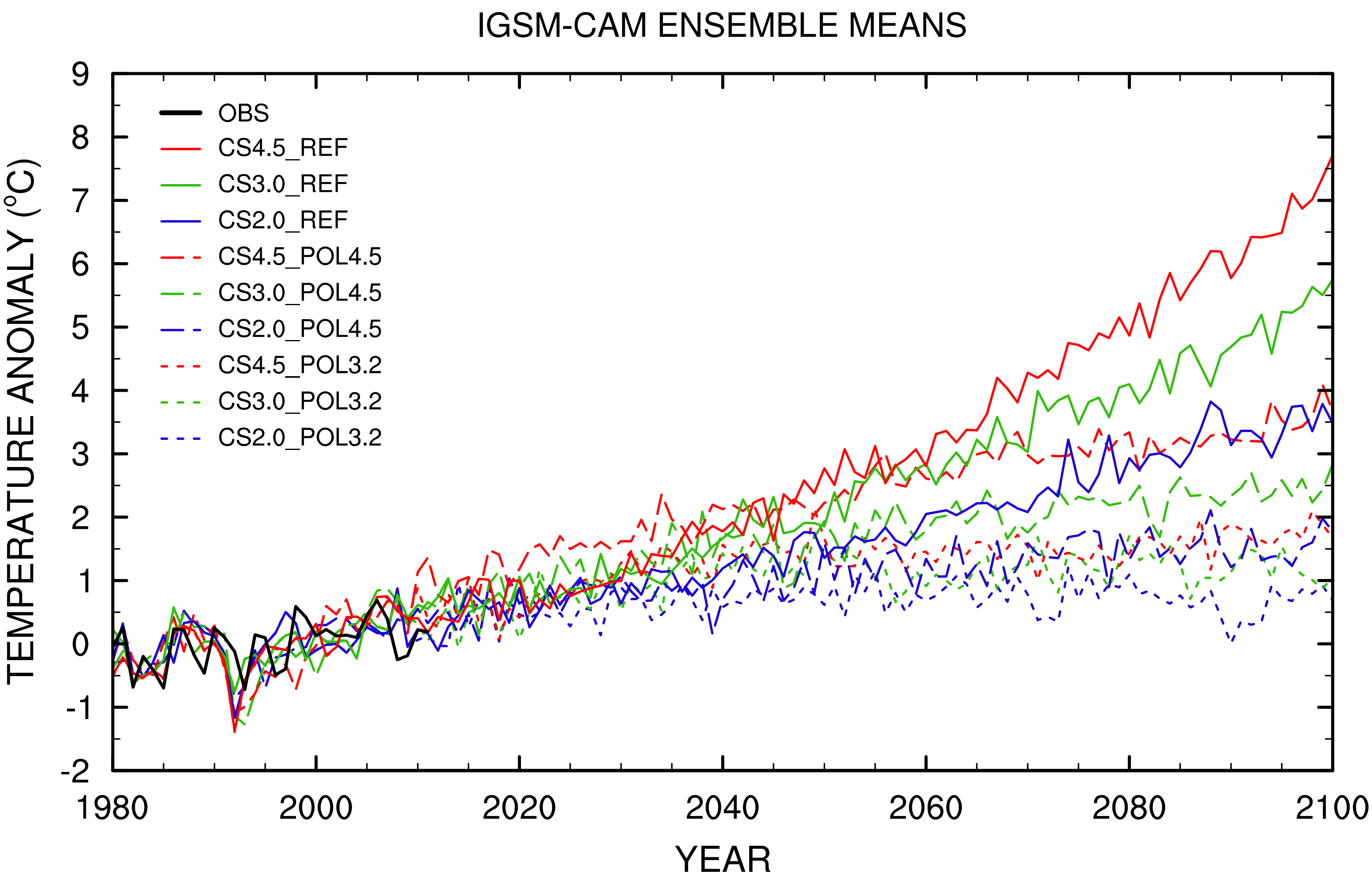
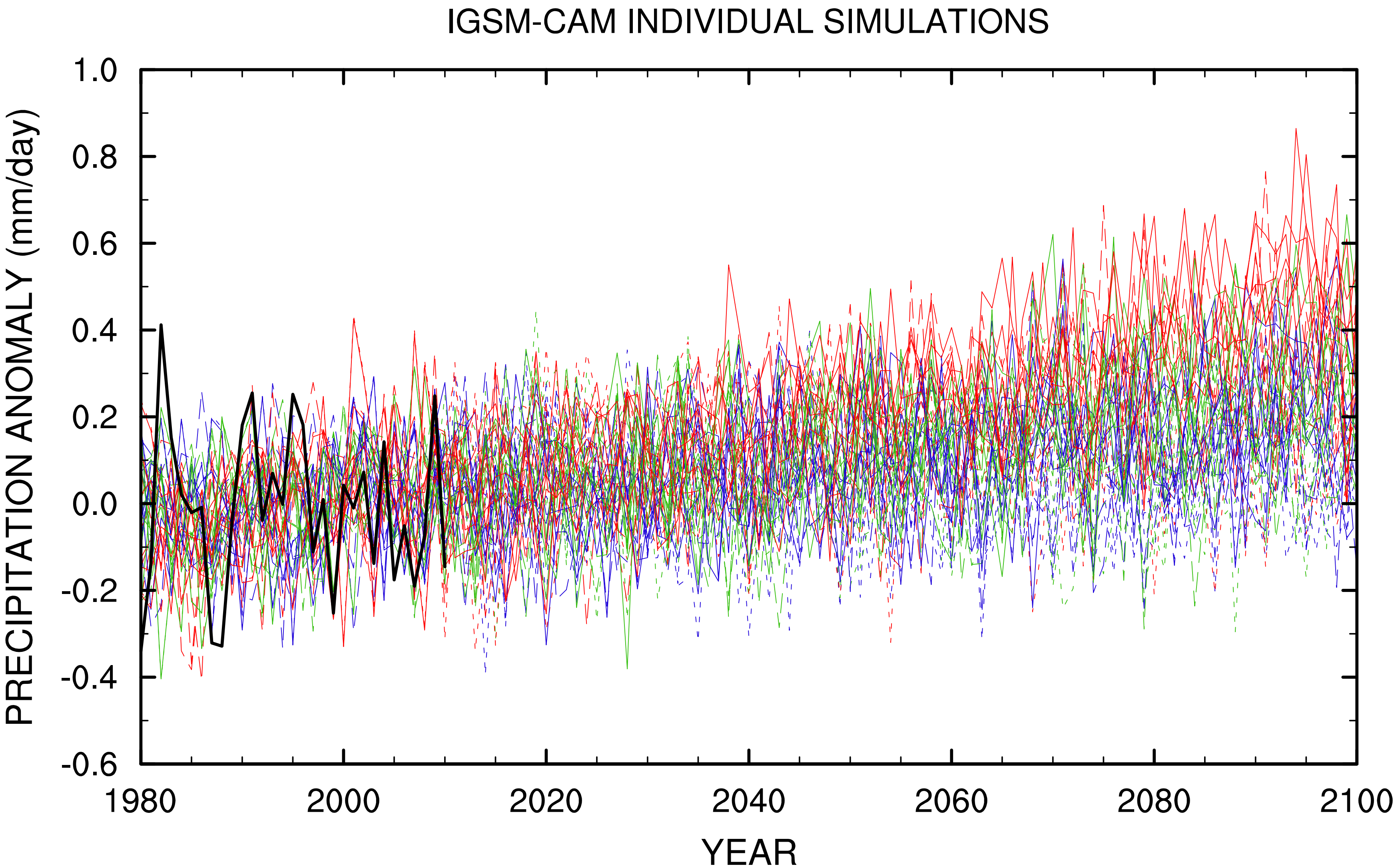
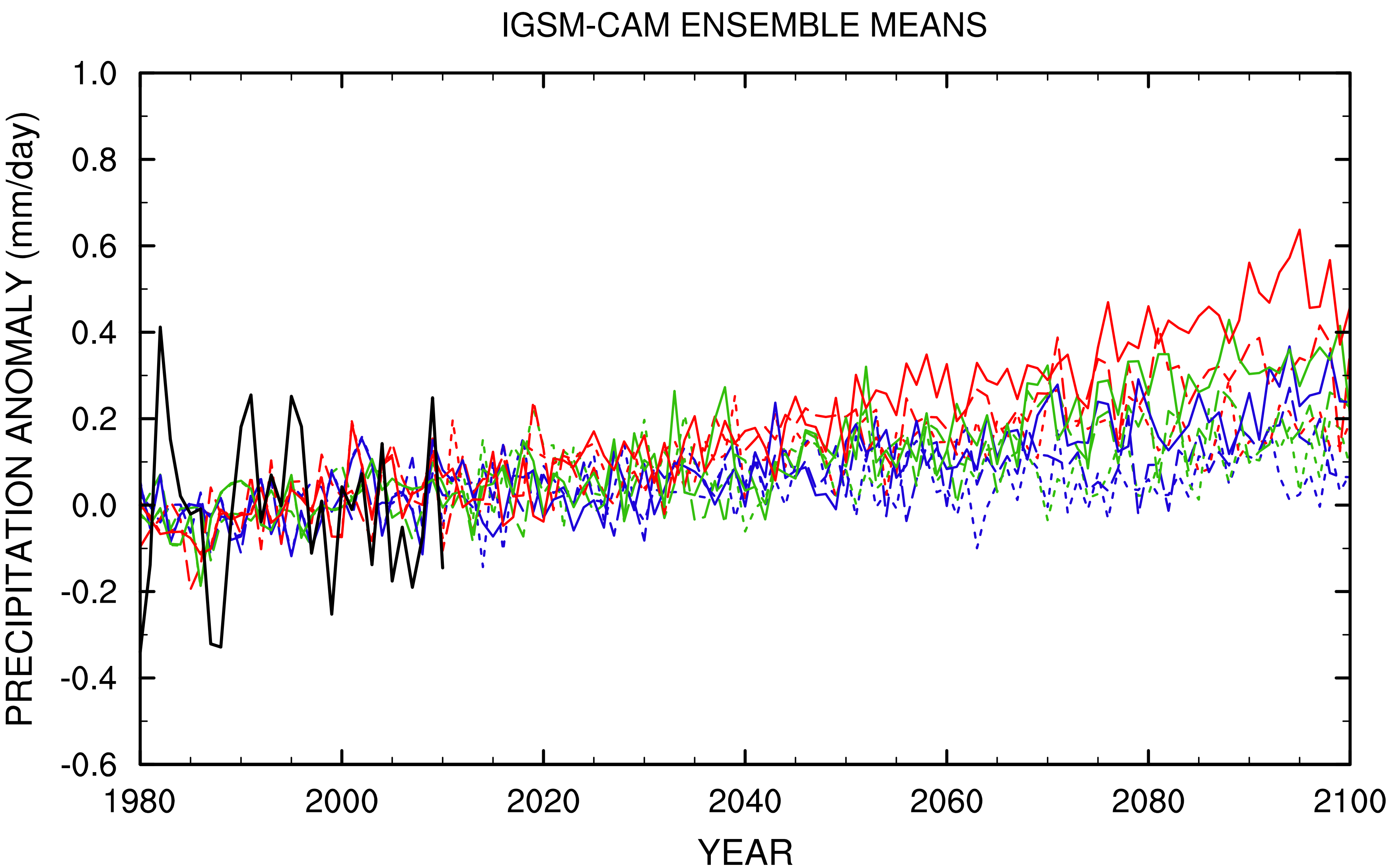


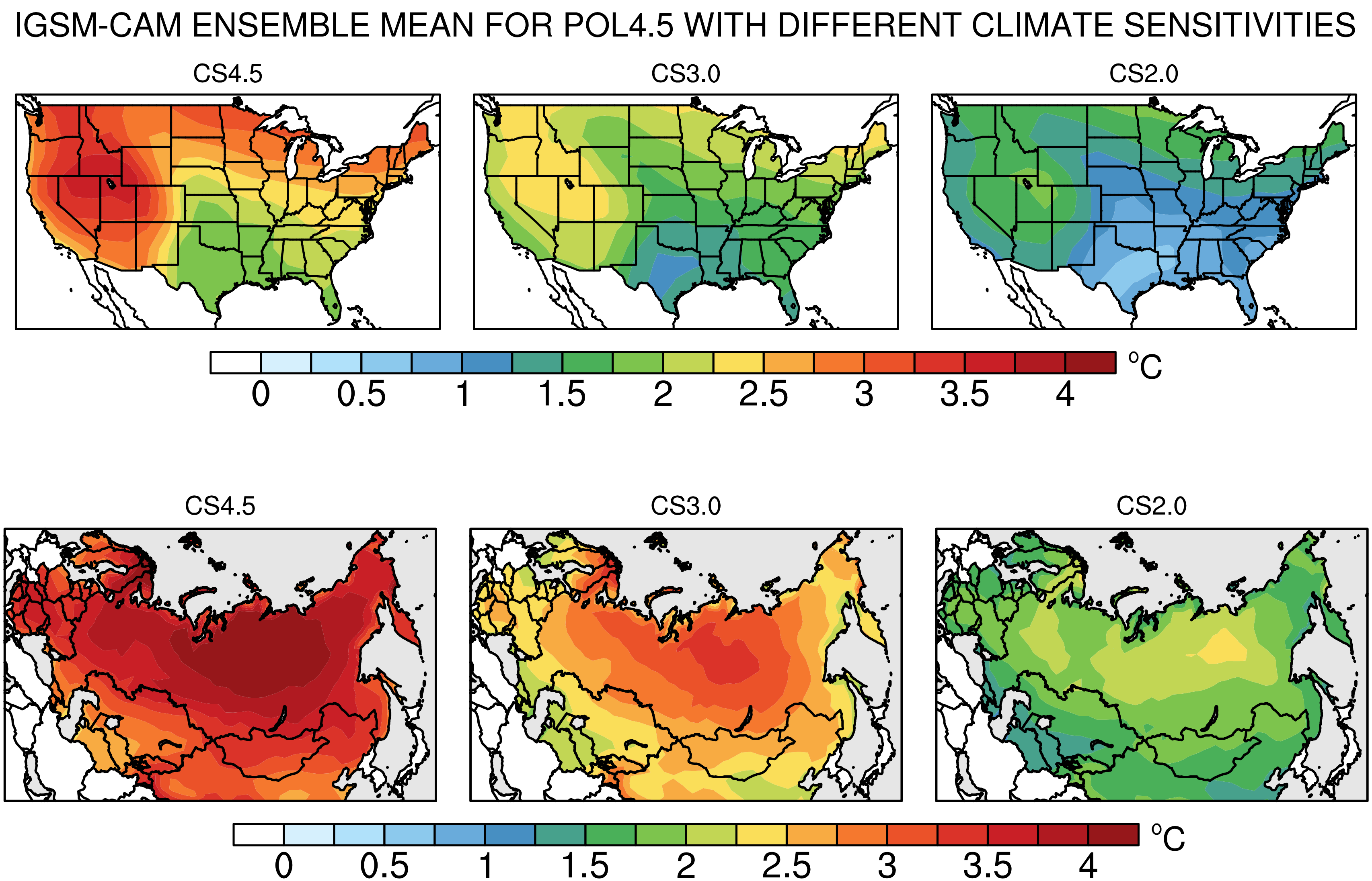
# Changes in USA mean precipitation



# Changes in USA mean precipitation



# Maps of temperature changes (by 2050)



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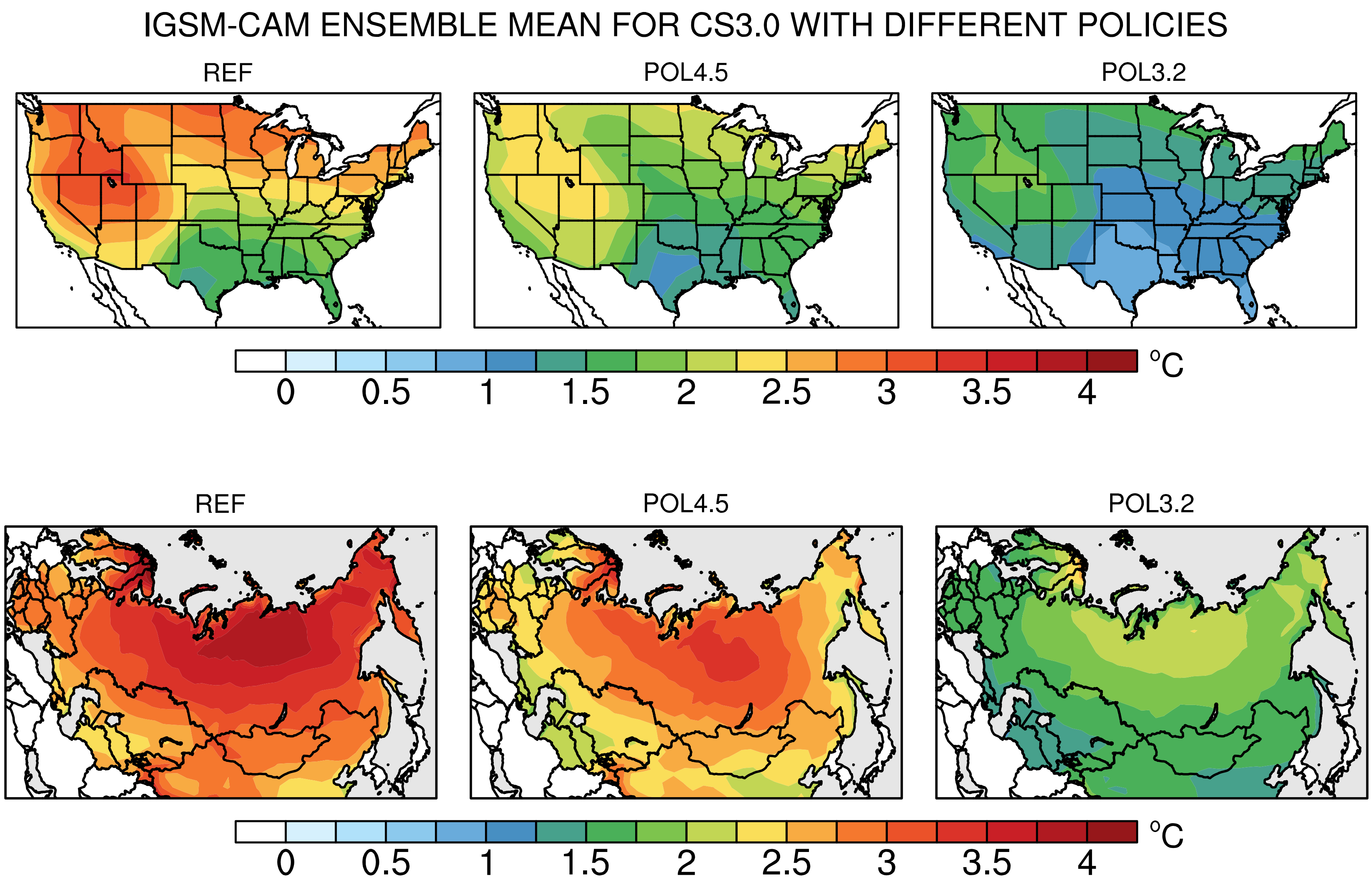

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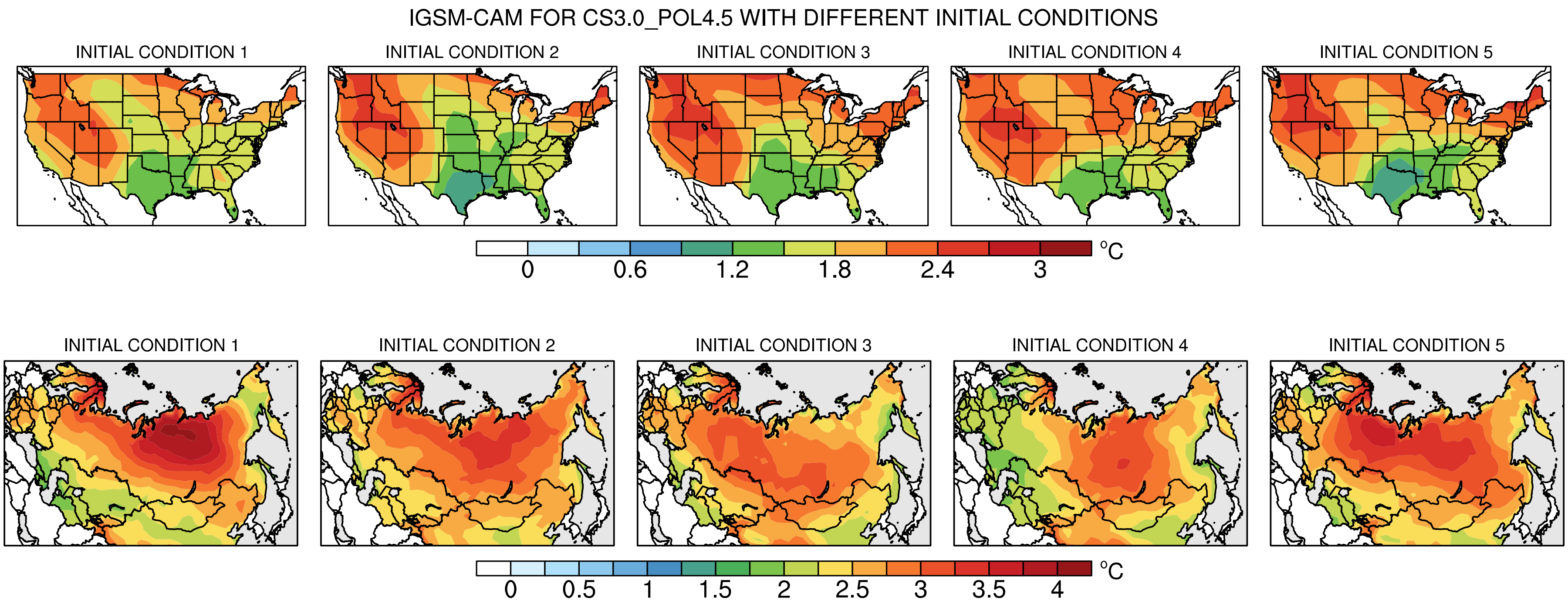

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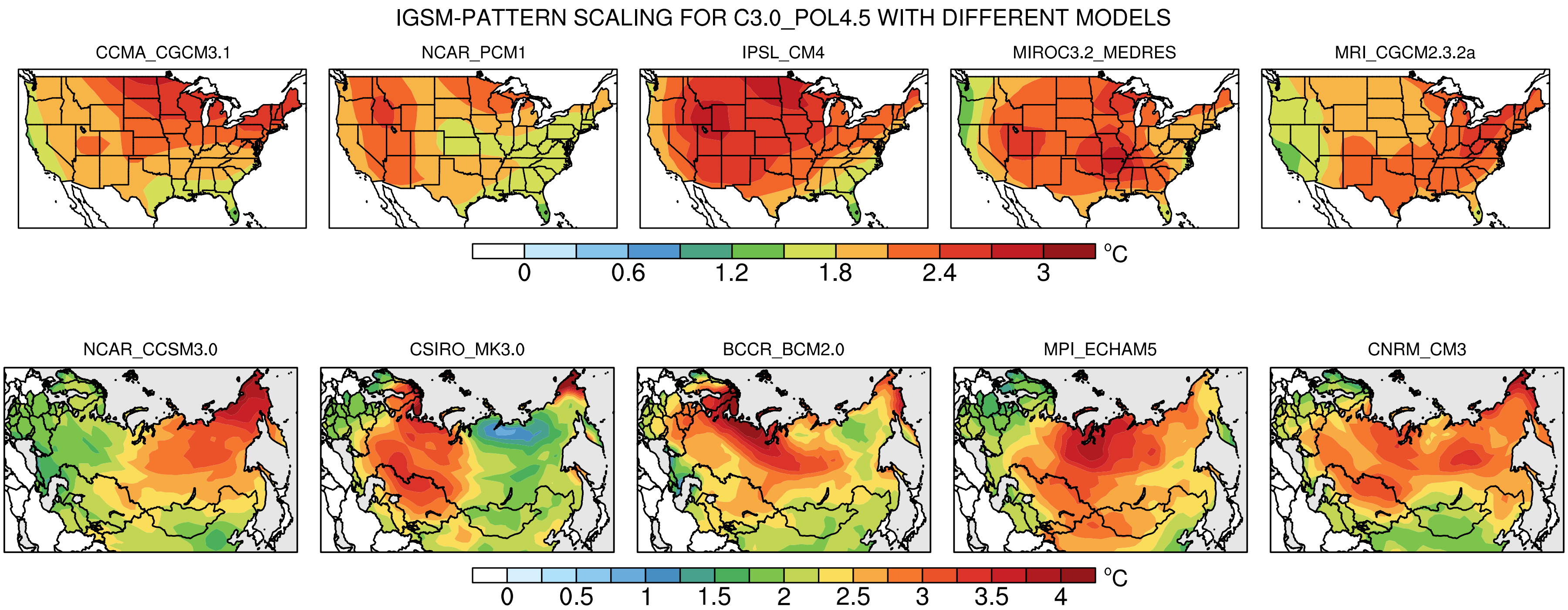
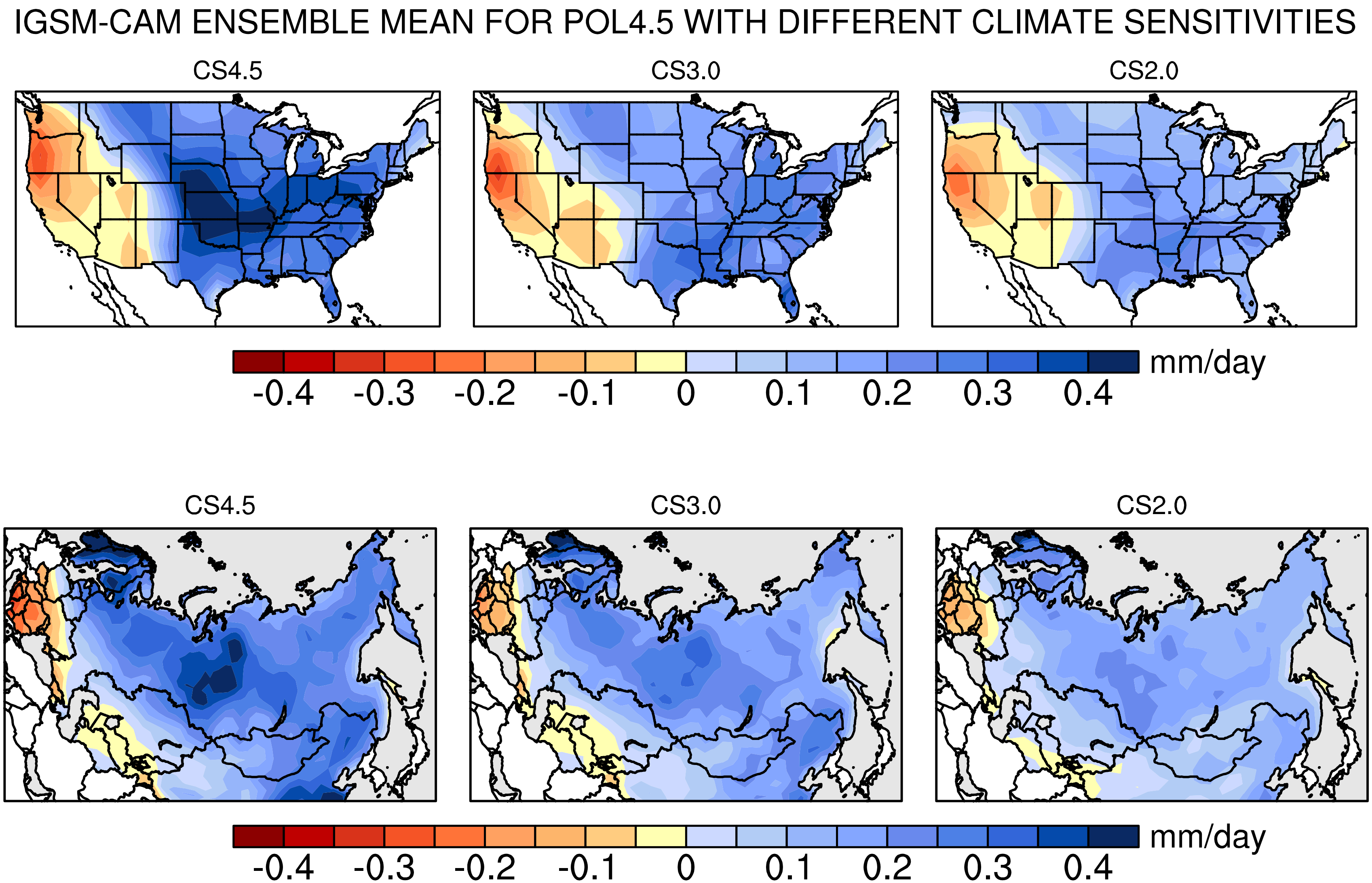


# Maps of precipitation changes (by 2050)



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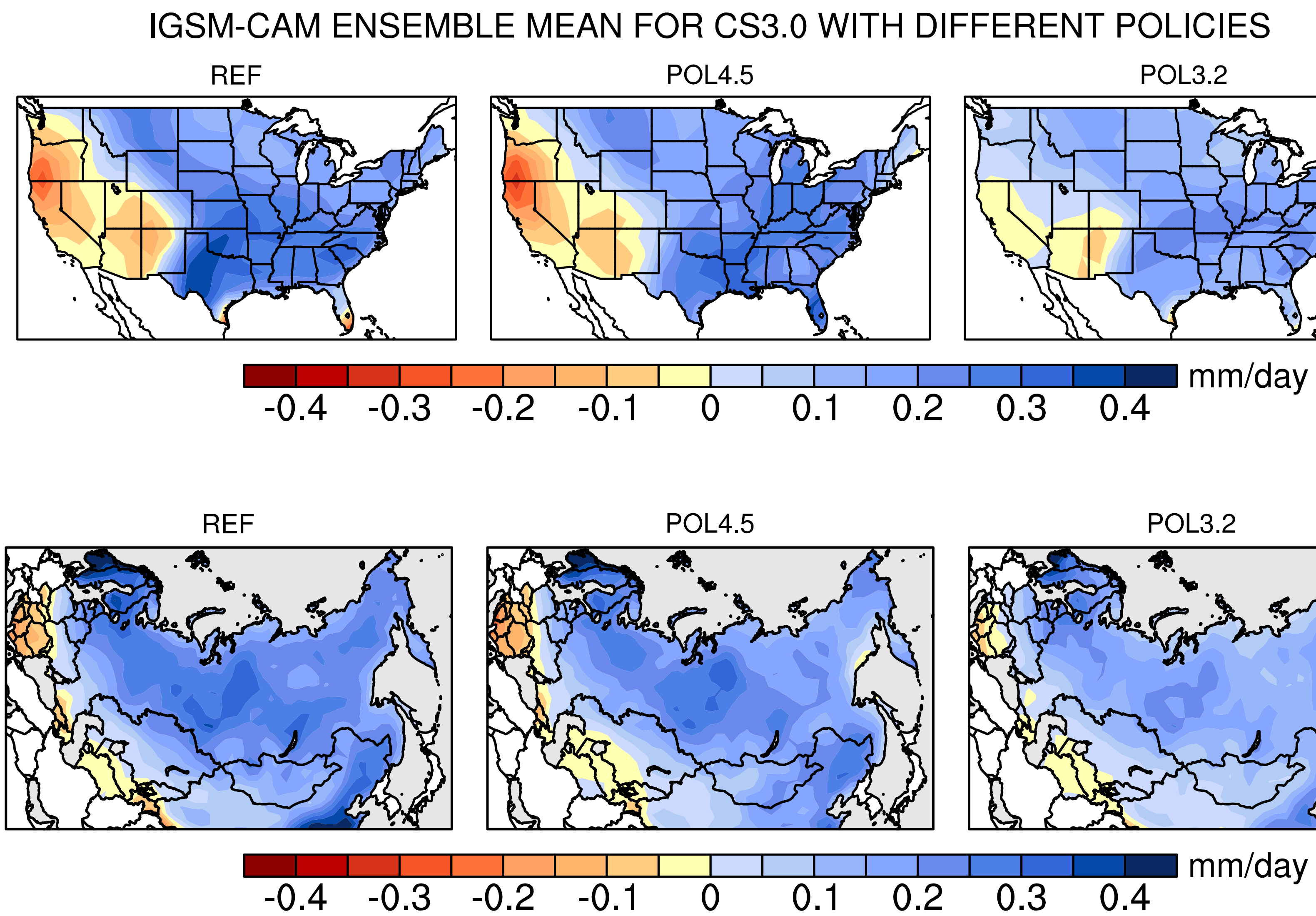

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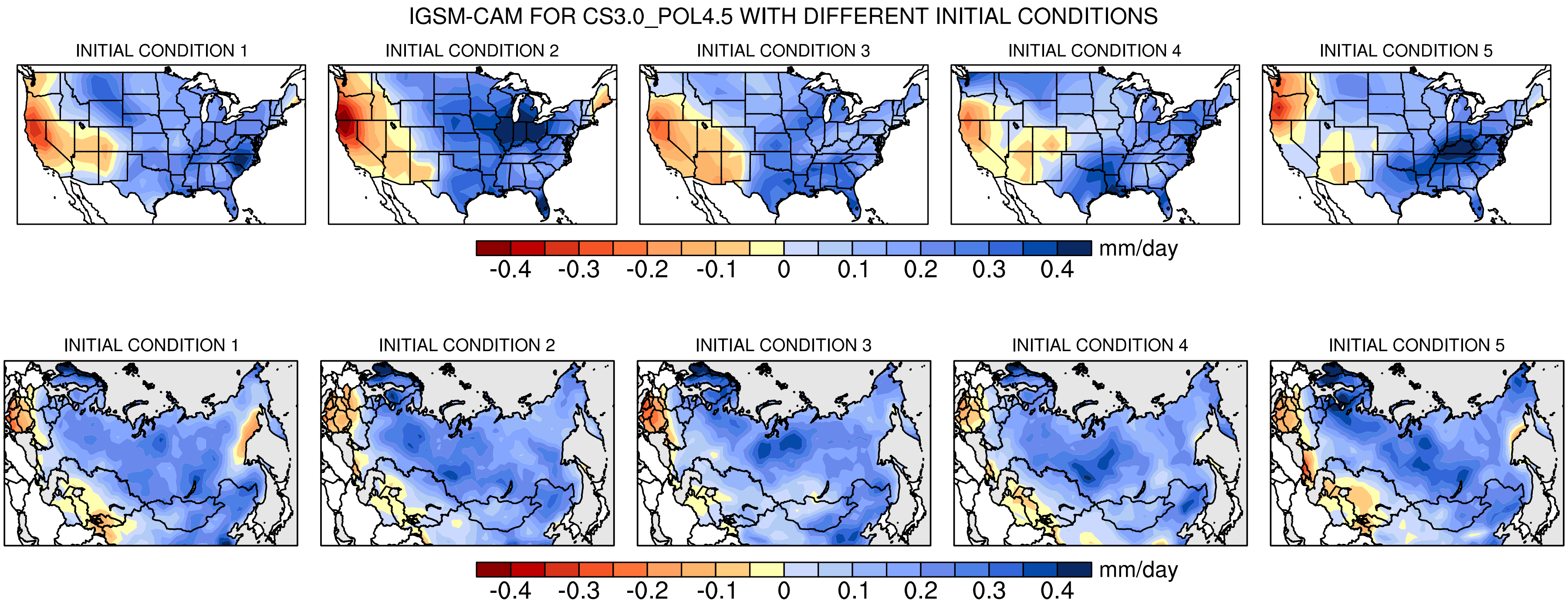

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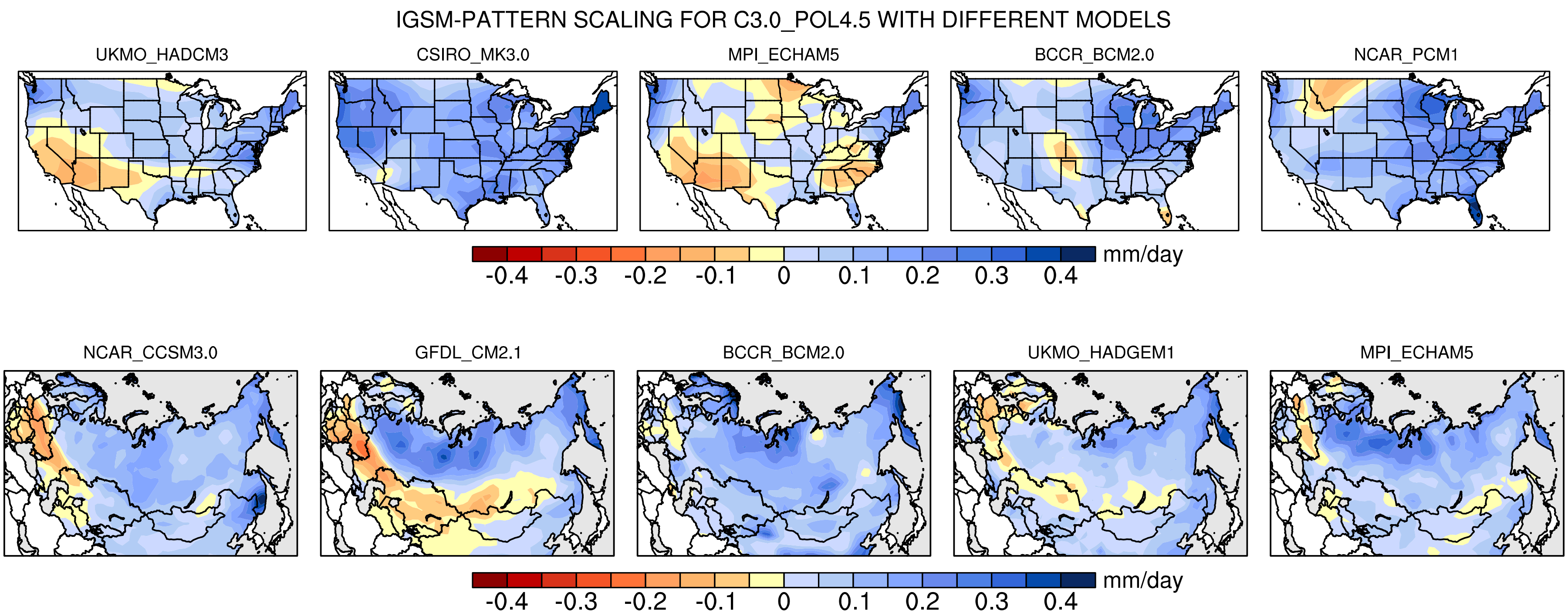
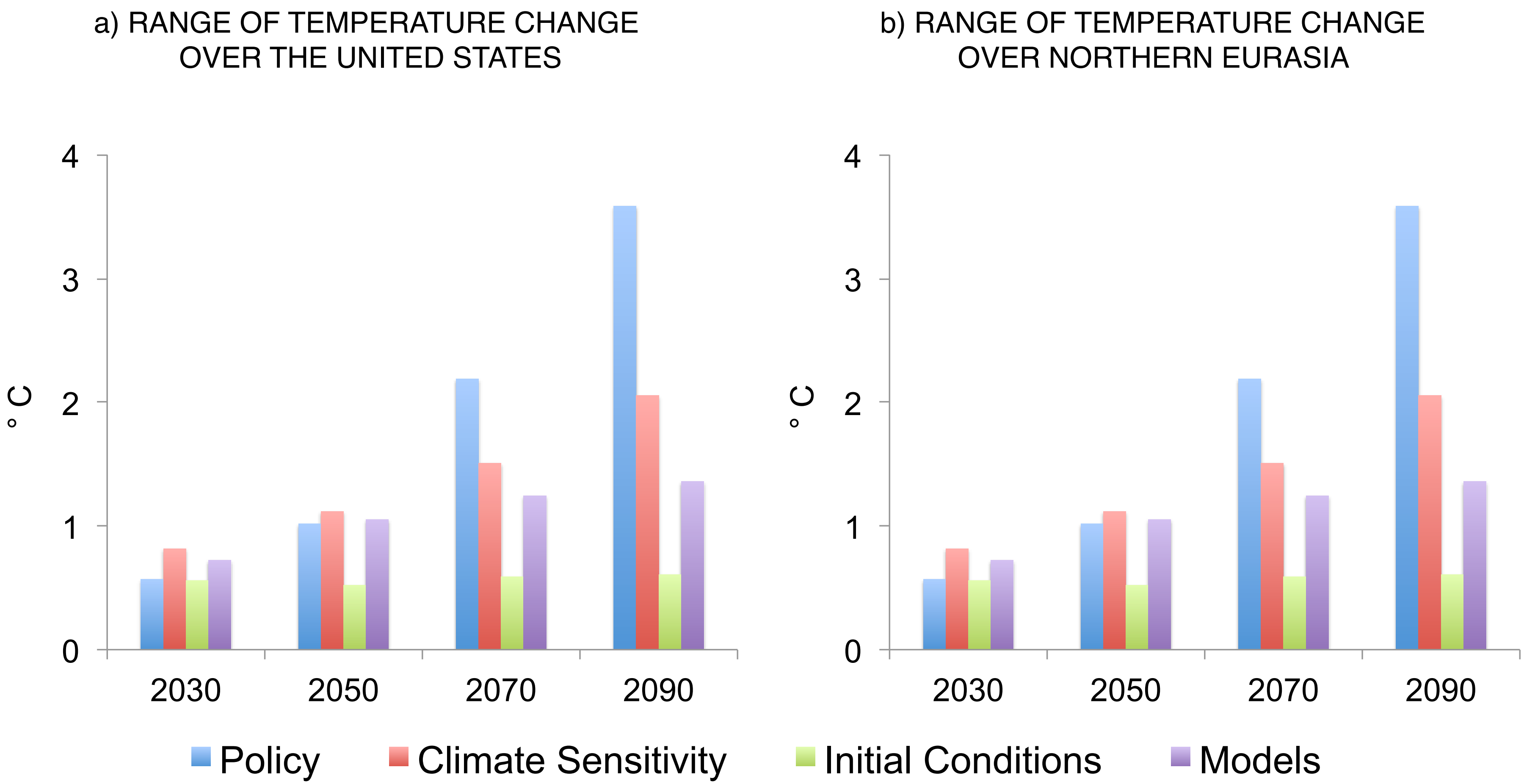


# Impact of source of uncertainty



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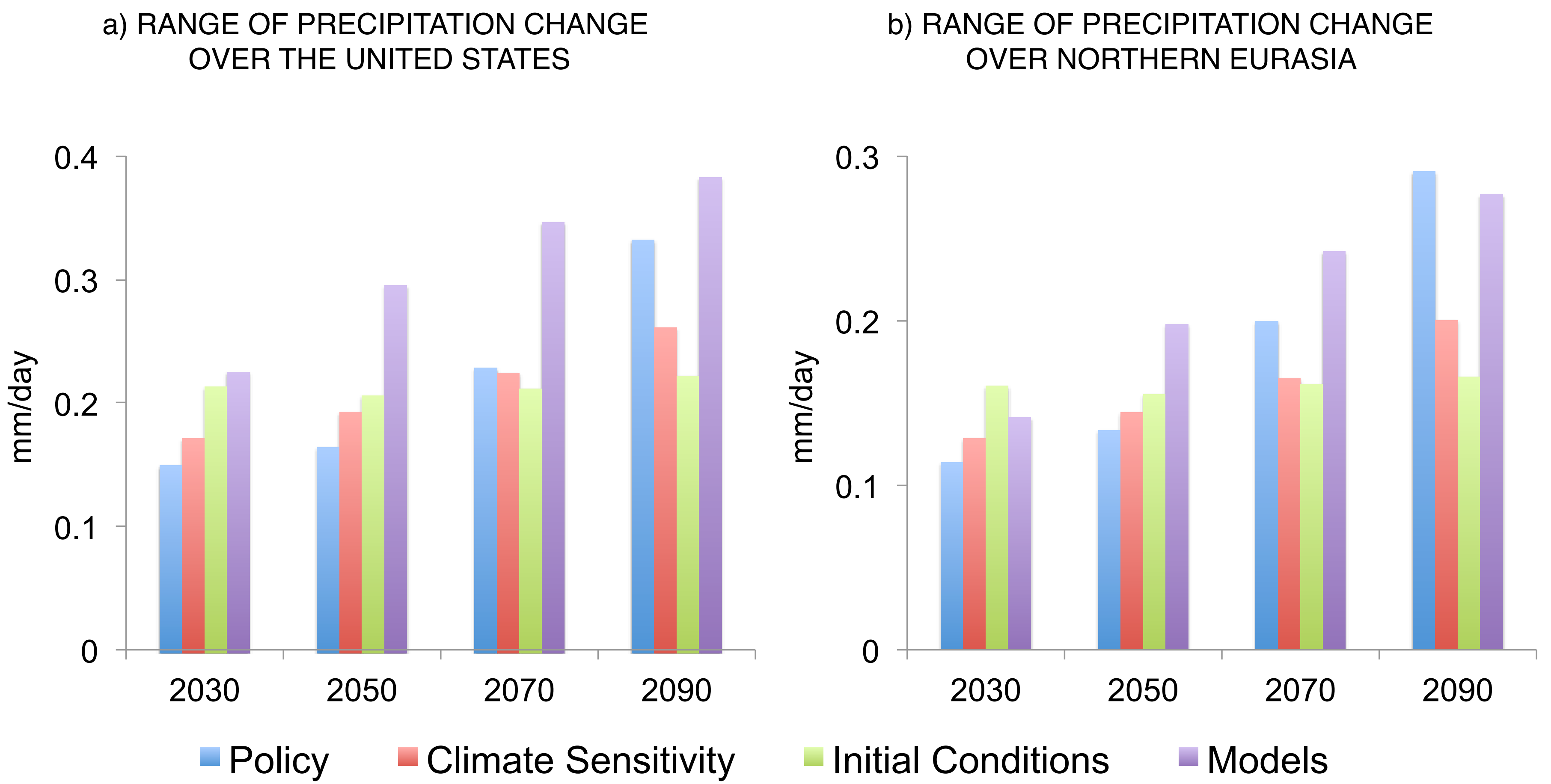

# Conclusions

The modeling framework presented allows multiple sources of uncertainty in regional climate change to be explored:

- Emissions scenarios (policy)
- Global climate response (climate parameters)
- Natural variability (initial conditions)
- Structural uncertainty/regional patterns of change (multiple models)

The simulations show a very large range of future climate change over the United States and Northern Eurasia, in terms of future warming and with different patterns and magnitude of drying and moistening.

The choice of policy is the largest source of uncertainty in future projections of climate change at the regional scale. It is also the only source that society has control over.

# What does this mean for impact studies?

The large uncertainty in projections of future regional climate change drives uncertainty in future climate impacts.

The location and magnitude of maximum warming, the patterns of drying/moistening and magnitude of precipitation changes will significantly impact agriculture productivity, water resources or energy demand projections.

When modeling possible climate impacts to guide decisions on mitigation and/or adaptation, it is important to consider these major sources of uncertainty. It is also useful to identify how they contribute to the uncertainty in climate impacts.

Results from this study (and others like it) guide the Joint Program in its current effort on modeling climate impacts (water resources, crop modeling and energy demand).

# Acknowledgements

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# References

The following articles use the IGSM-CAM and/or IGSM-pattern scaling methods to investigate regional projections of future climate change:


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