Projecting Energy and Climate for the 21st Century: The MIT Integrated Global System Model

MIT JOINT PROGRAM
SCIENCE
POLICY
GLOBAL CHANGE

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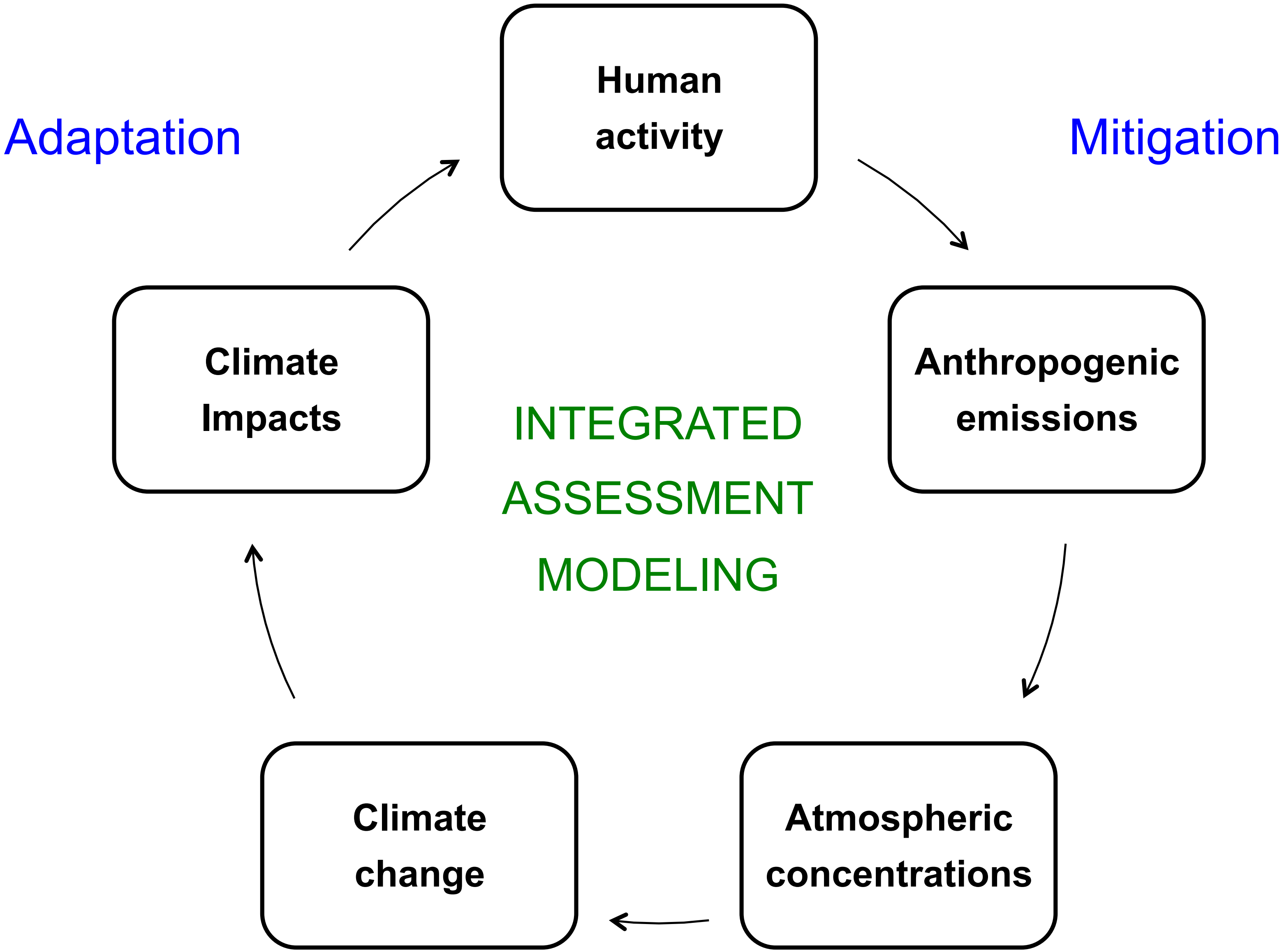
Massachusetts Institute of Technology

USEA
United States Energy Association

Briefing at U.S. Energy Association

Washington, DC
June 30, 2015

BROADER CONTEXT



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- Natural variability
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- *Land use land cover change*
  - *Interaction between climate impacts on ecosystem productivity and socio-economic assumptions (agriculture, forestry…)*

EMISSIONS PROJECTIONS

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- Economic and population growth
- Emergence and costs of new technology
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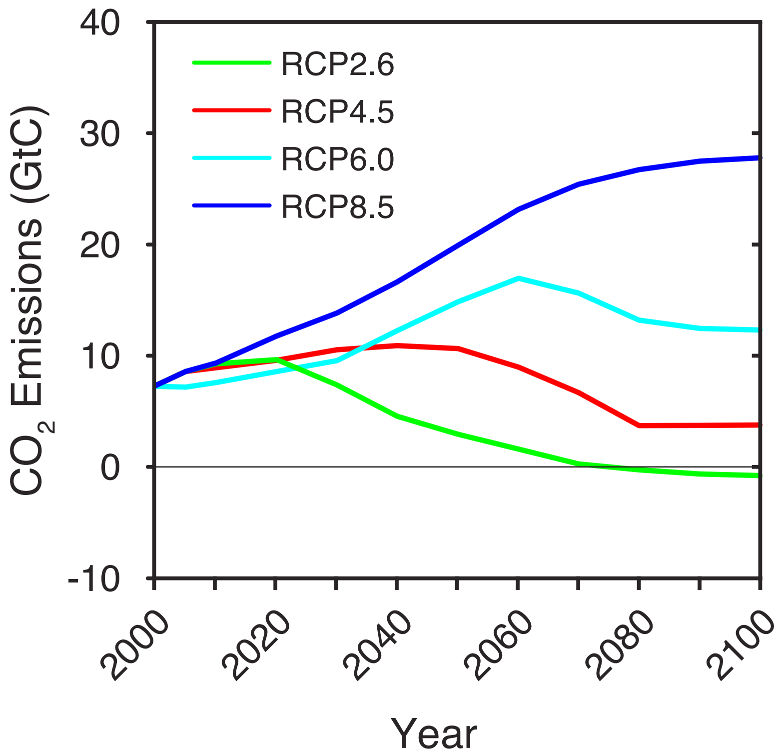
used as far back as IPCC FAR (1990)



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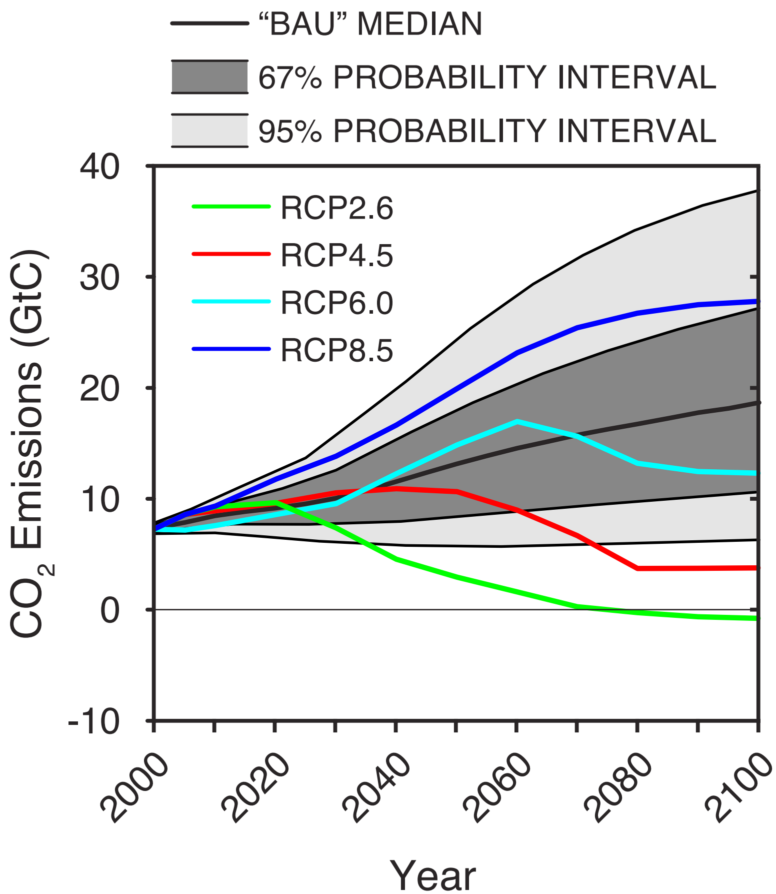
Alternative:

Probabilistic distributions of emissions derived by sampling socio-economic and technological parameters for each region covered by the economic model.



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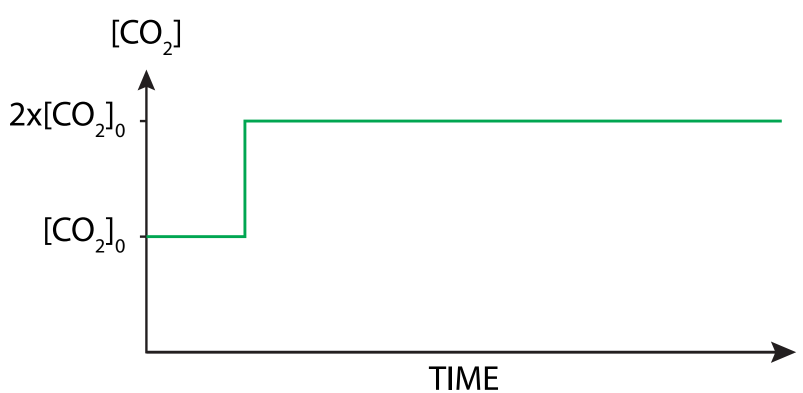

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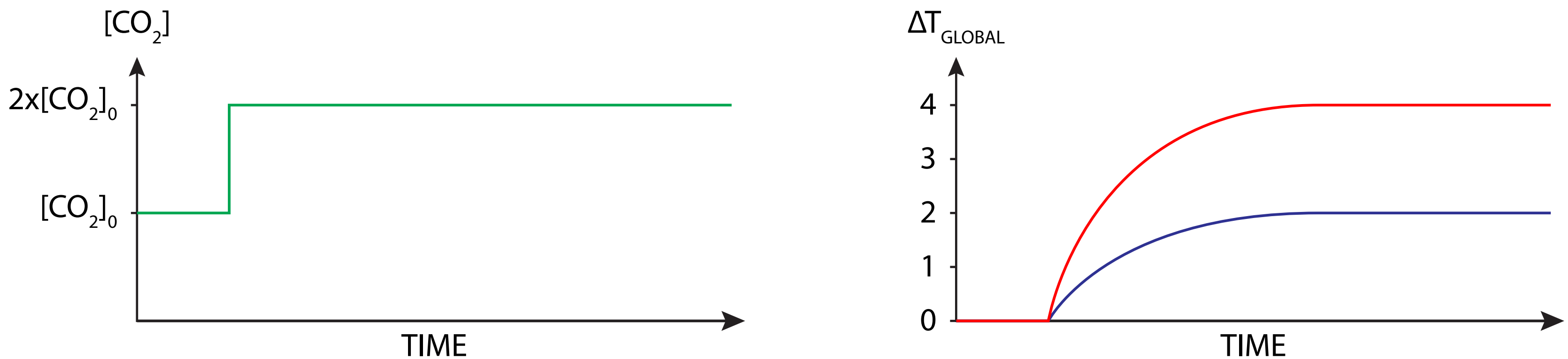

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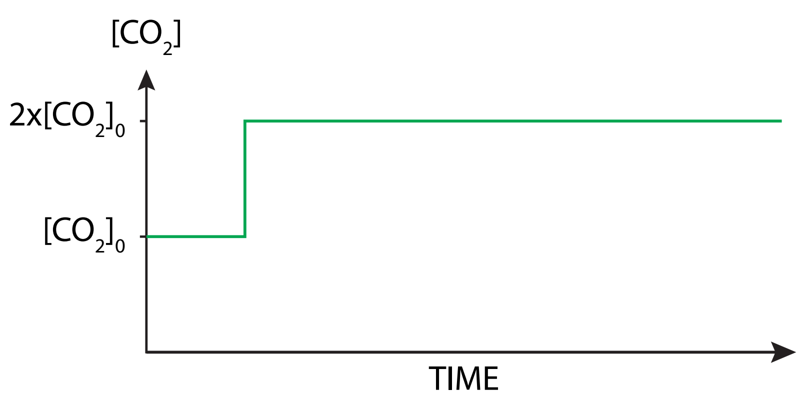
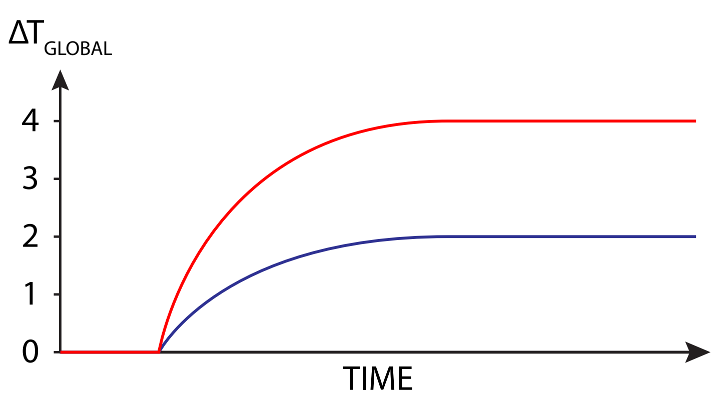
Rate at which the heat stored by the global ocean increases in time





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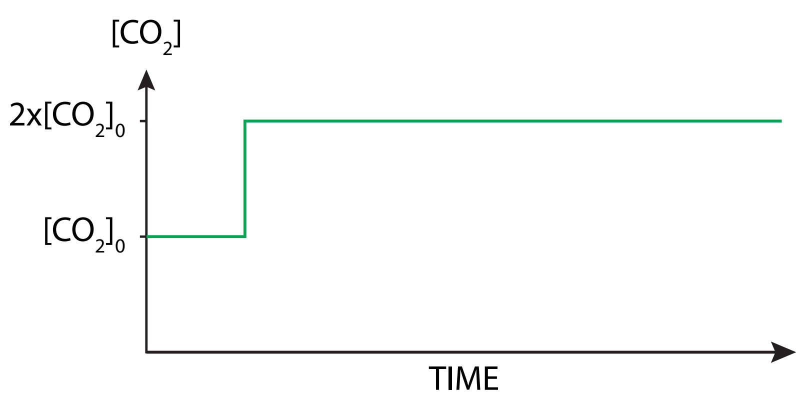

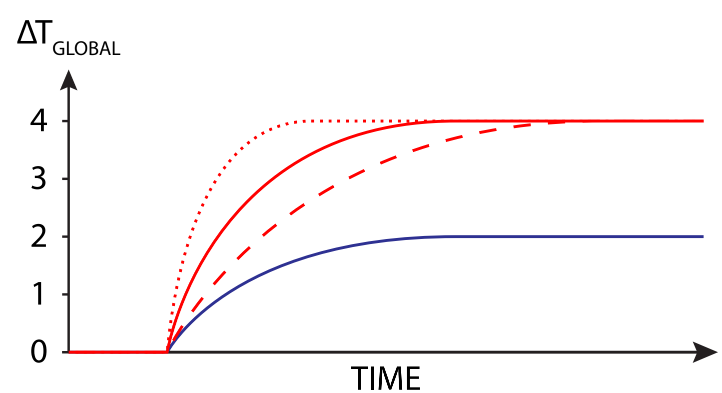

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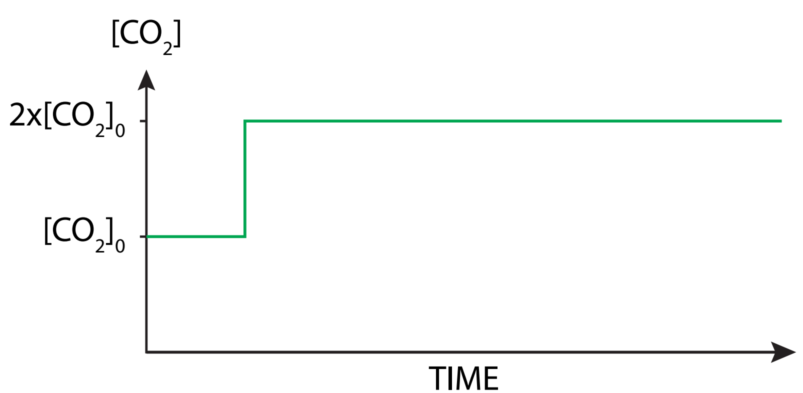
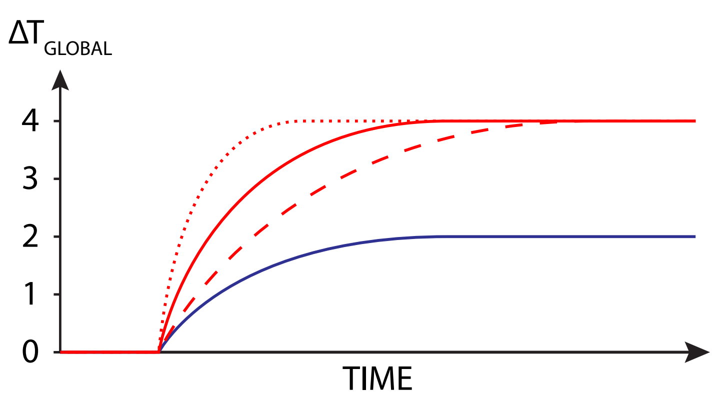
  - Aerosol forcing

Radiative forcing of aerosol particles, both direct and indirect (clouds)





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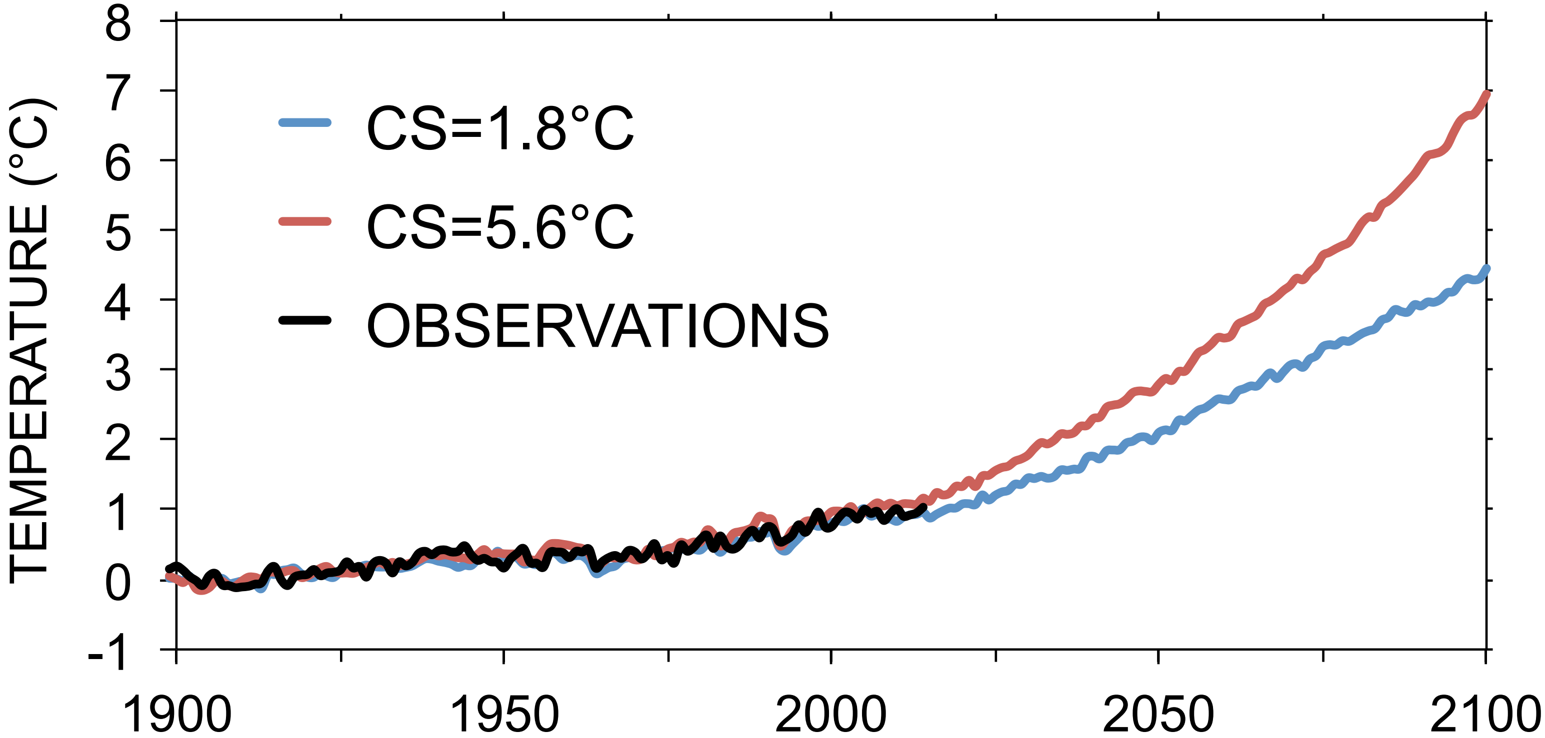

BRIEF HISTORY OF CLIMATE SENSITIVITY

Svante Arrhenius

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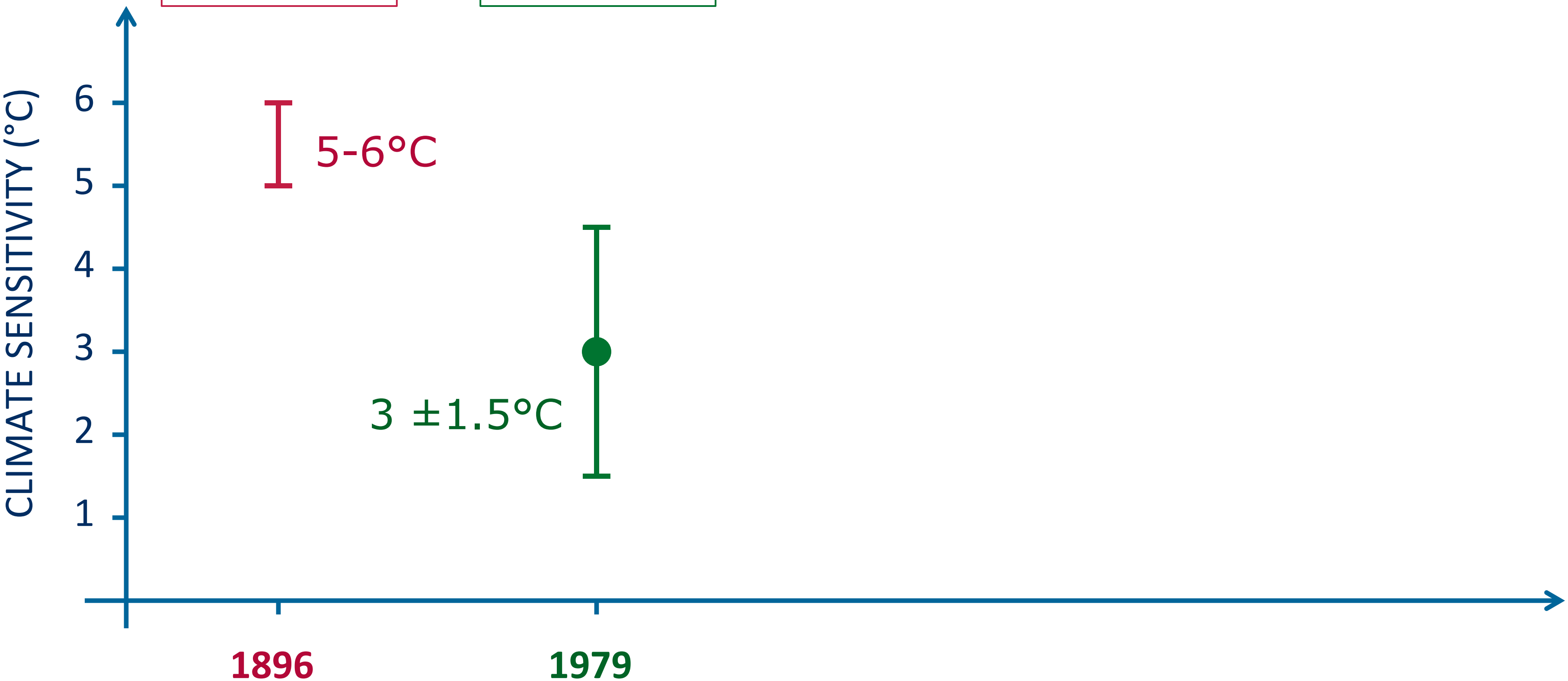

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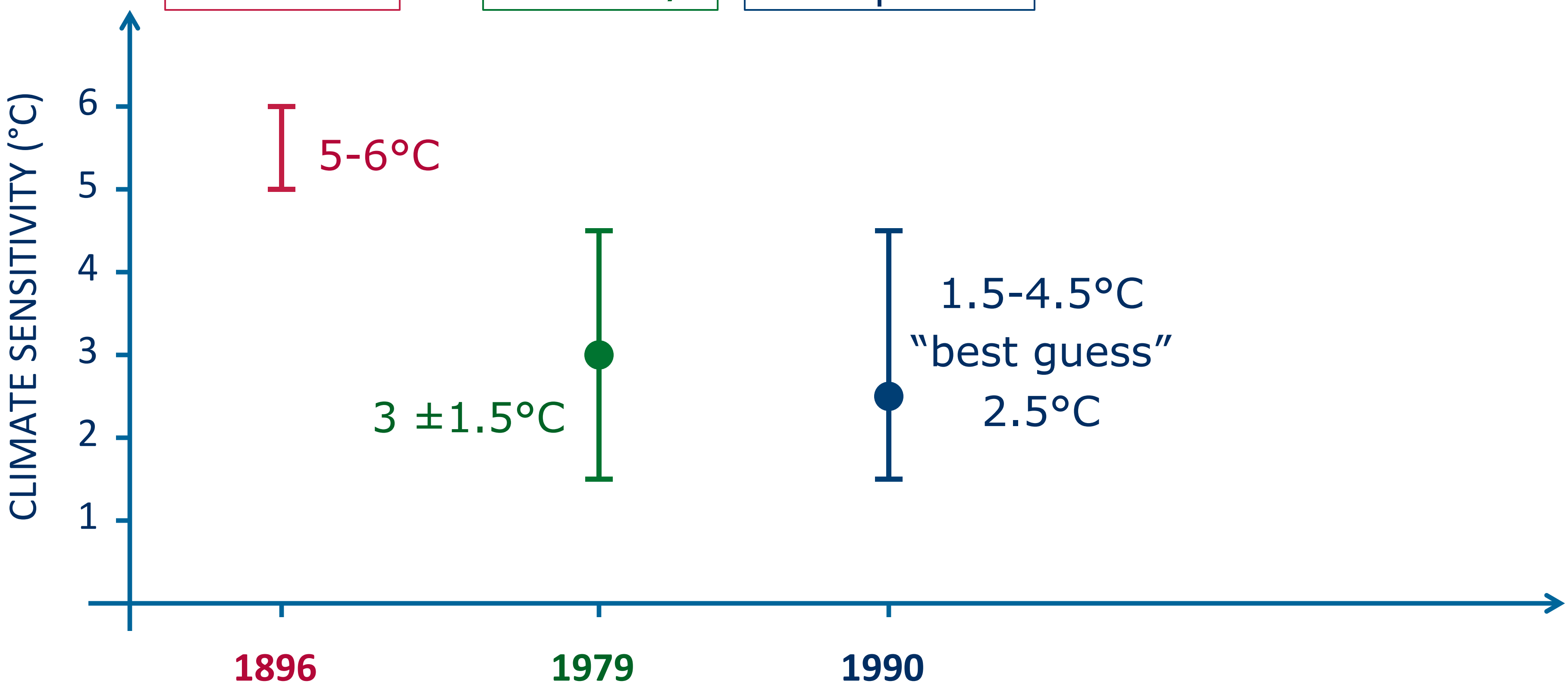

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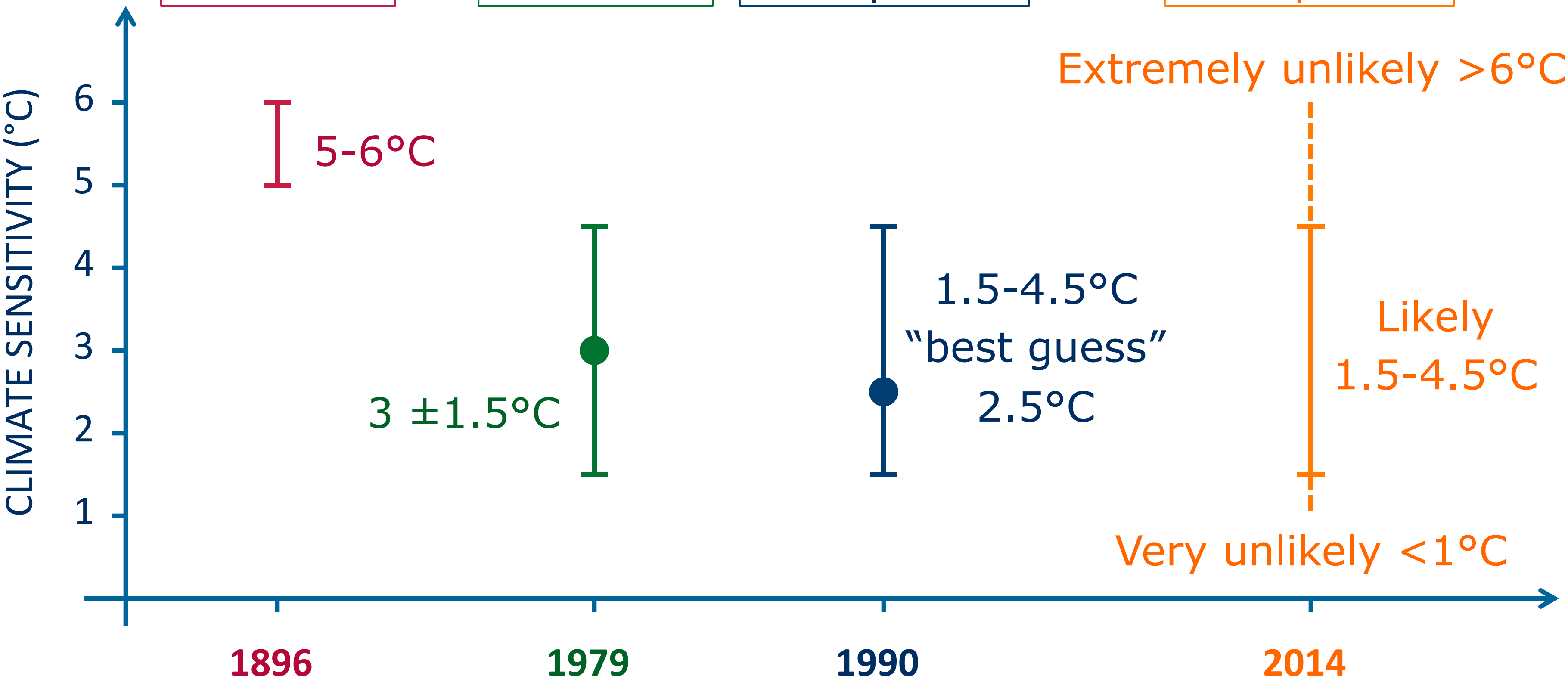
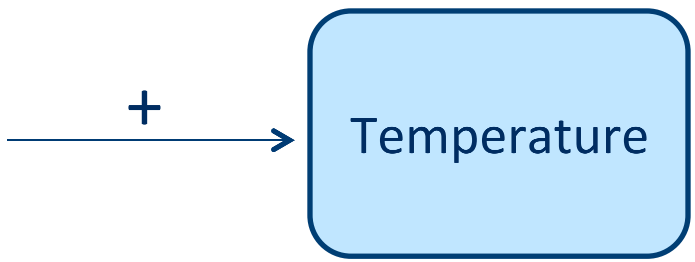
Fifth IPCC Assessment Report



CRYOSPHERIC FEEDBACK



WHAT CONTROLS THE CLIMATE SENSITIVITY?

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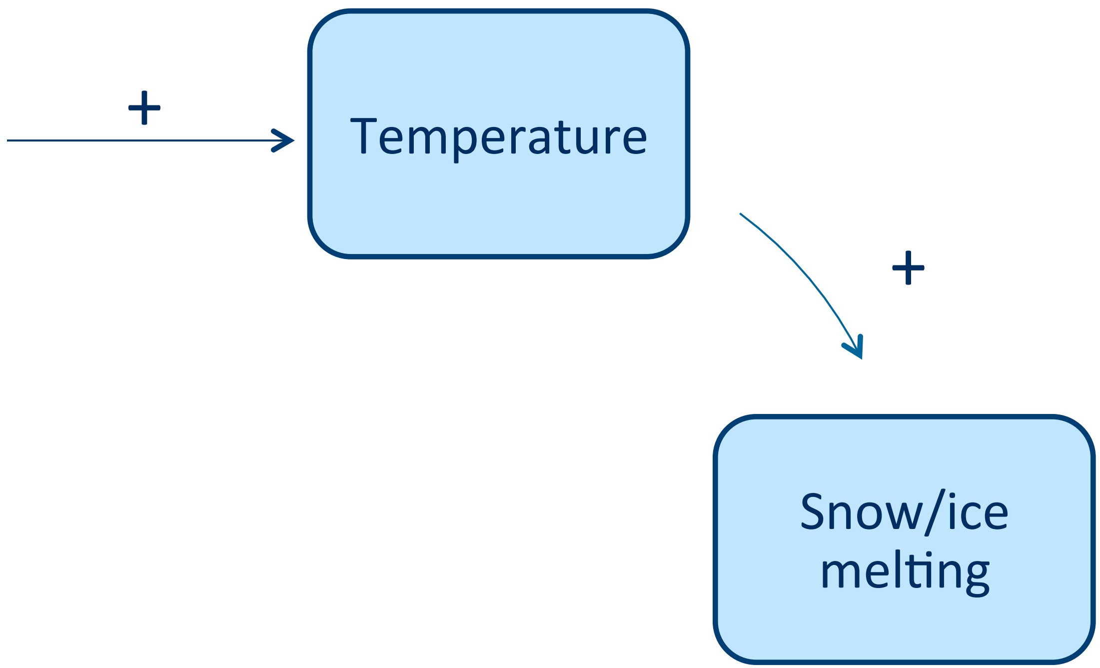

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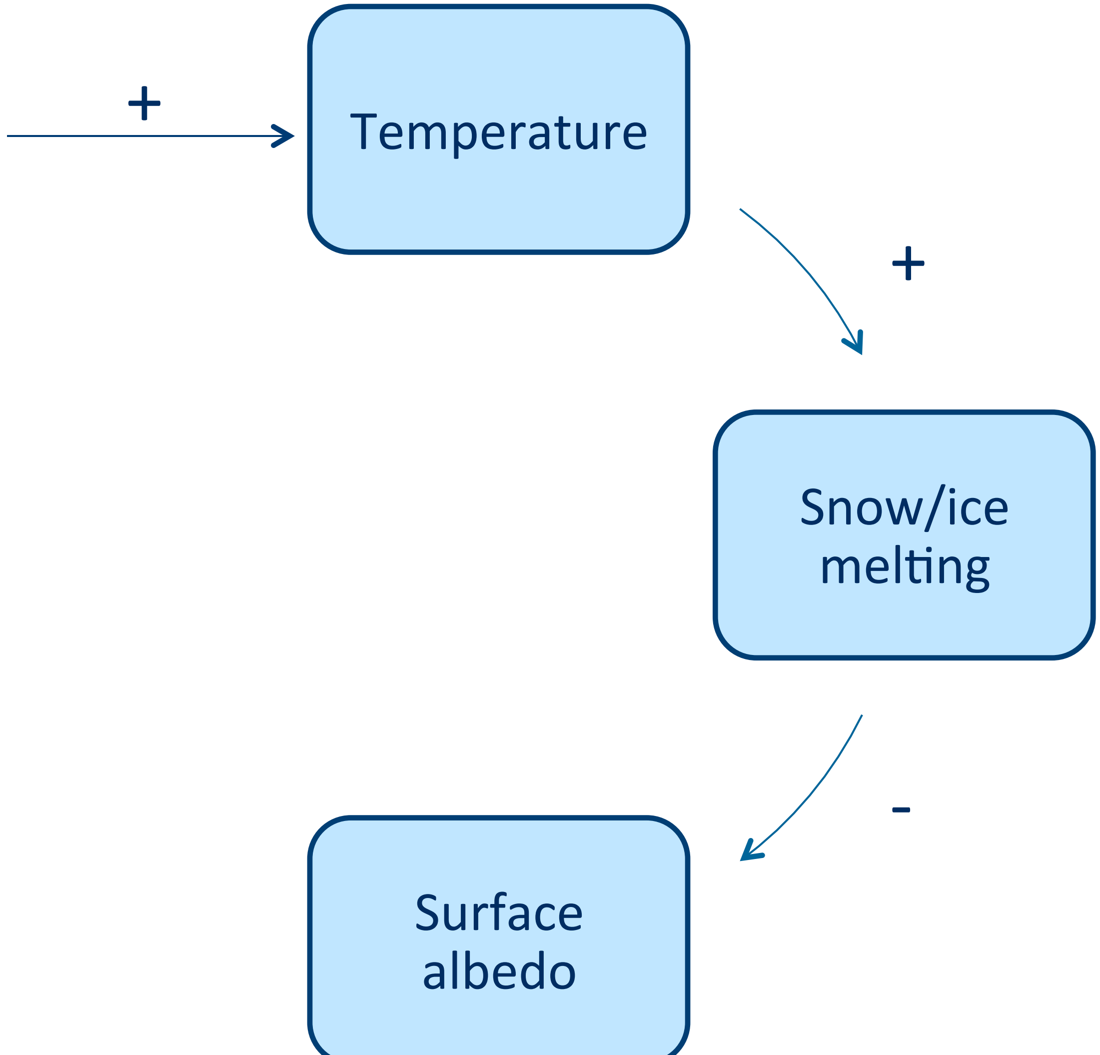

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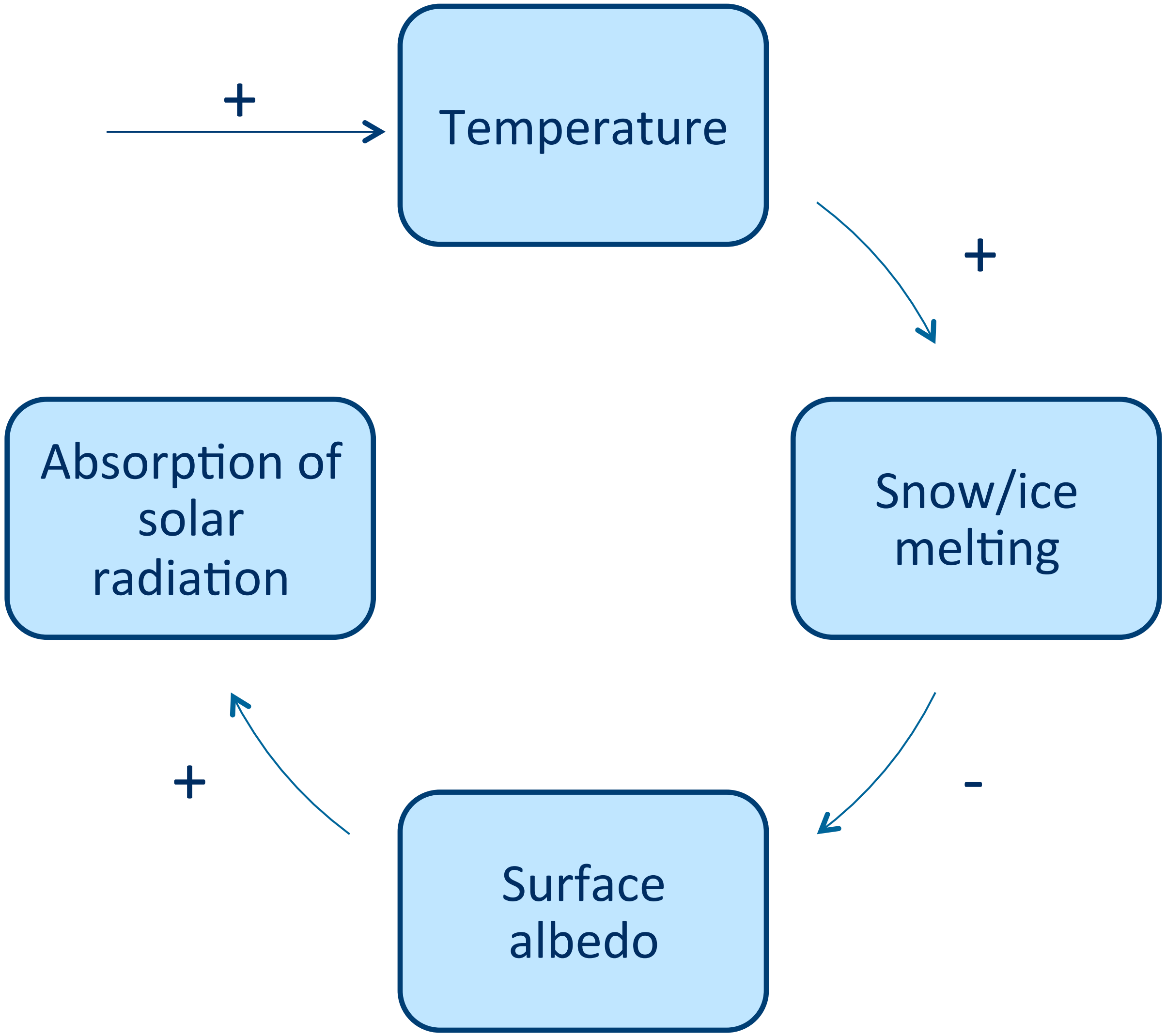

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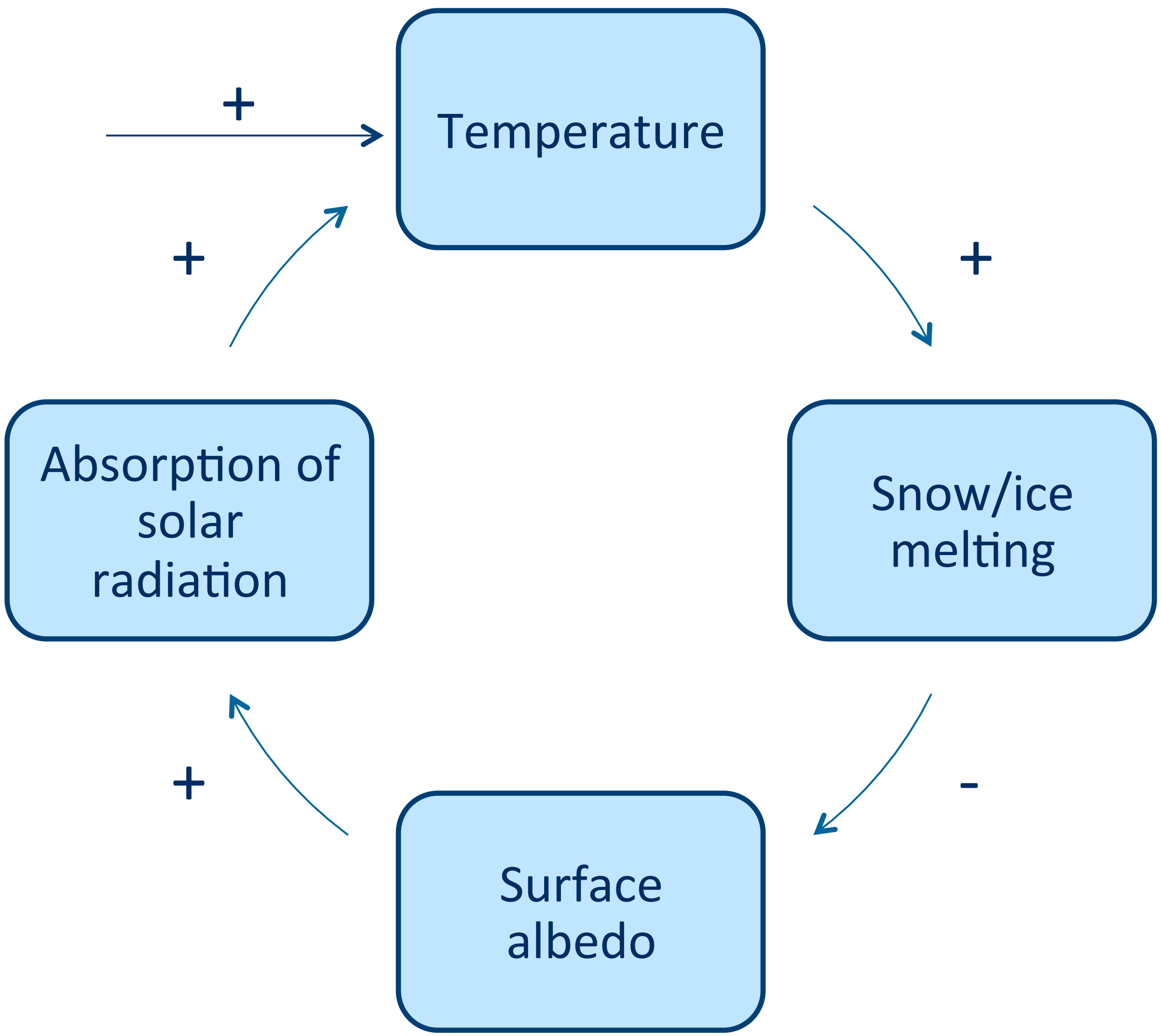

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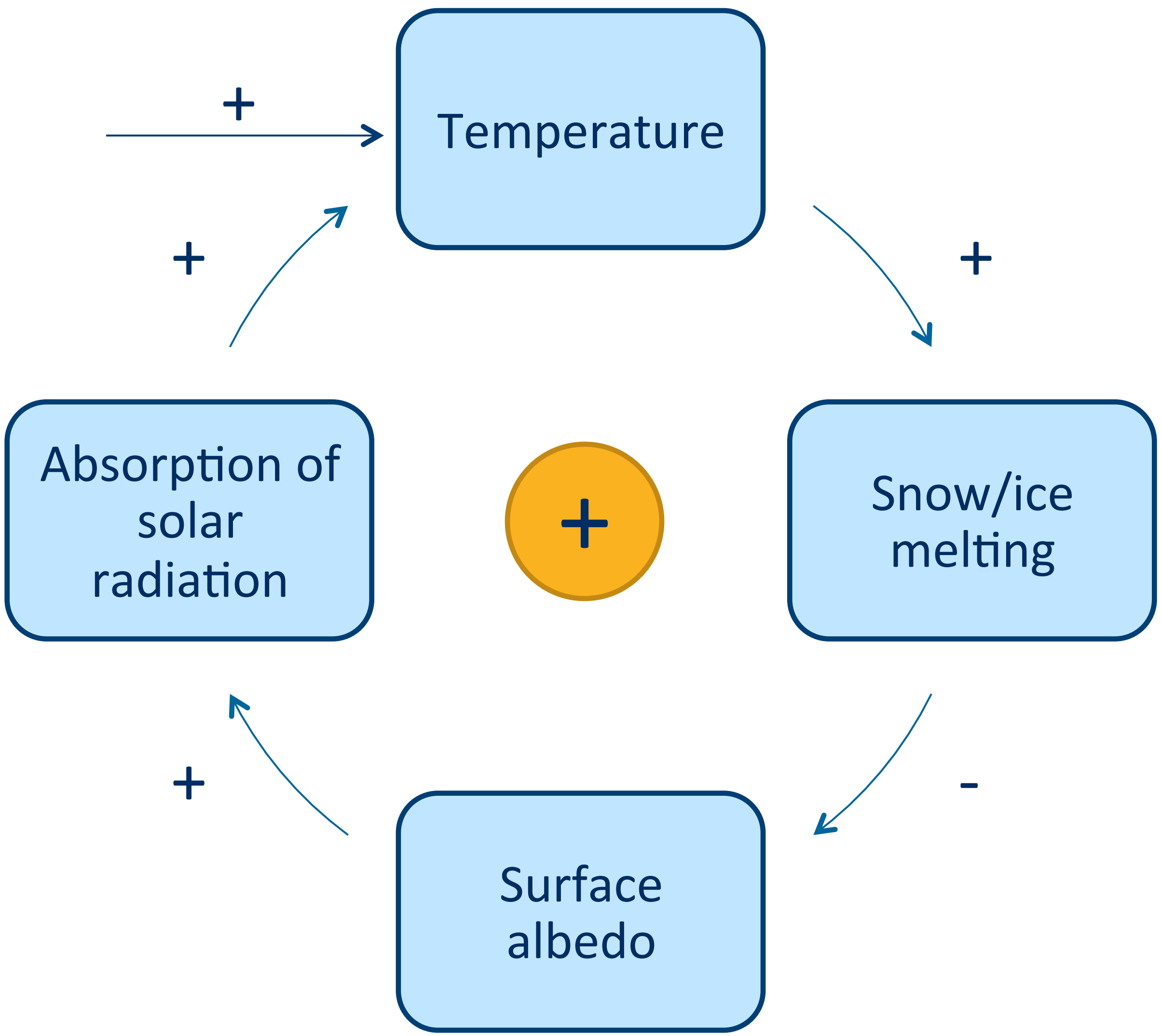
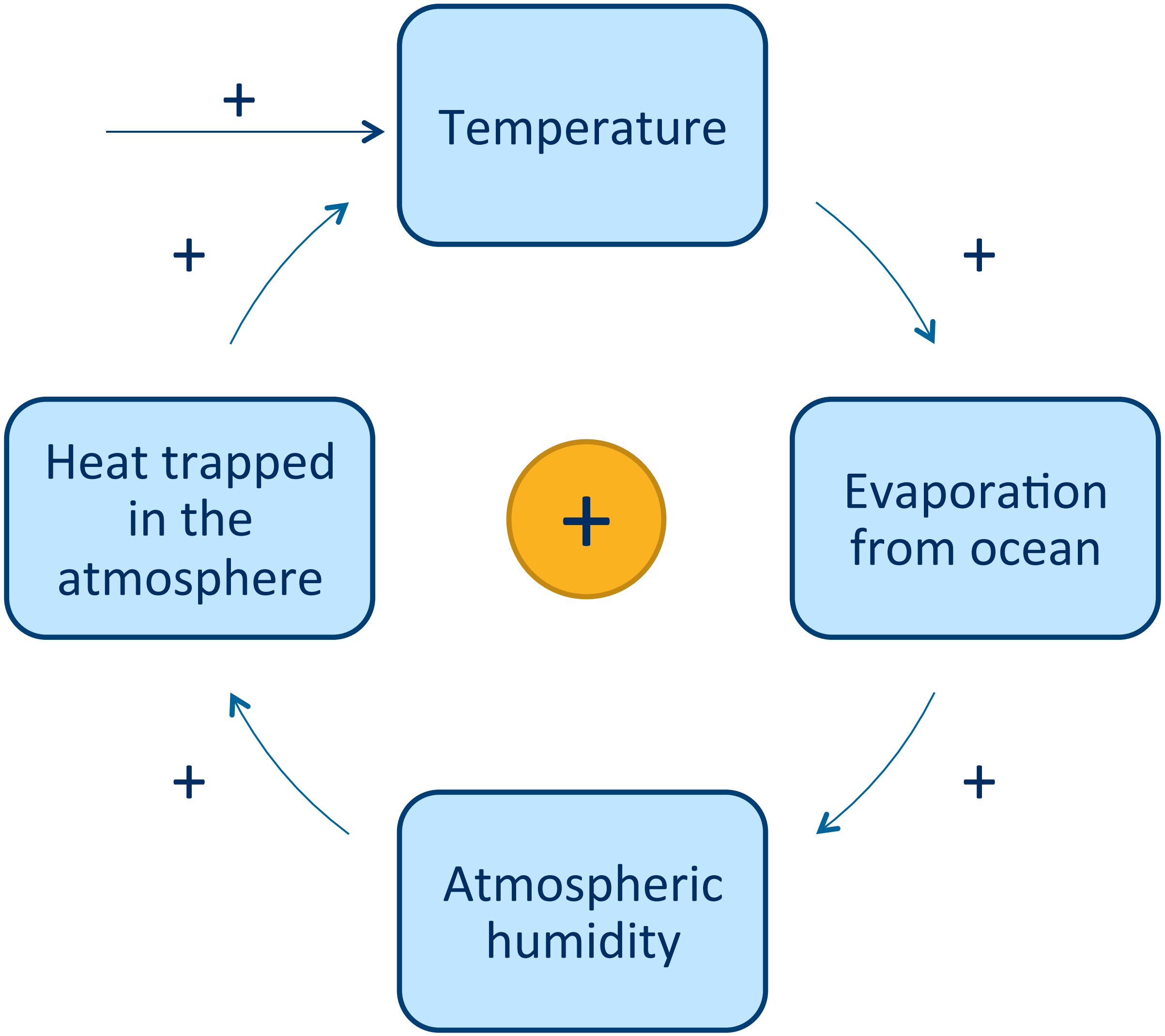


WHAT CONTROLS THE CLIMATE SENSITIVITY?

WATER VAPOR FEEDBACK



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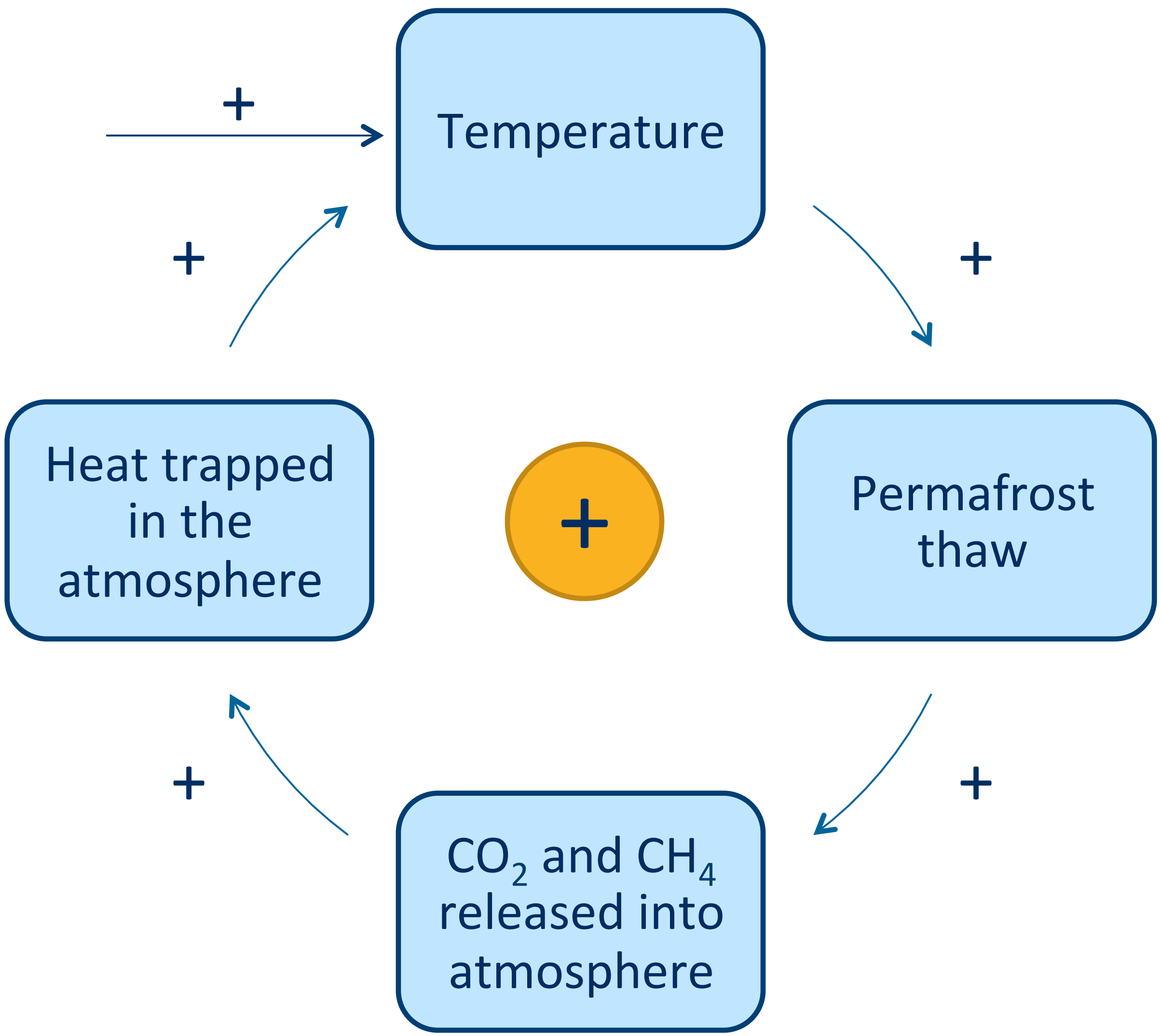
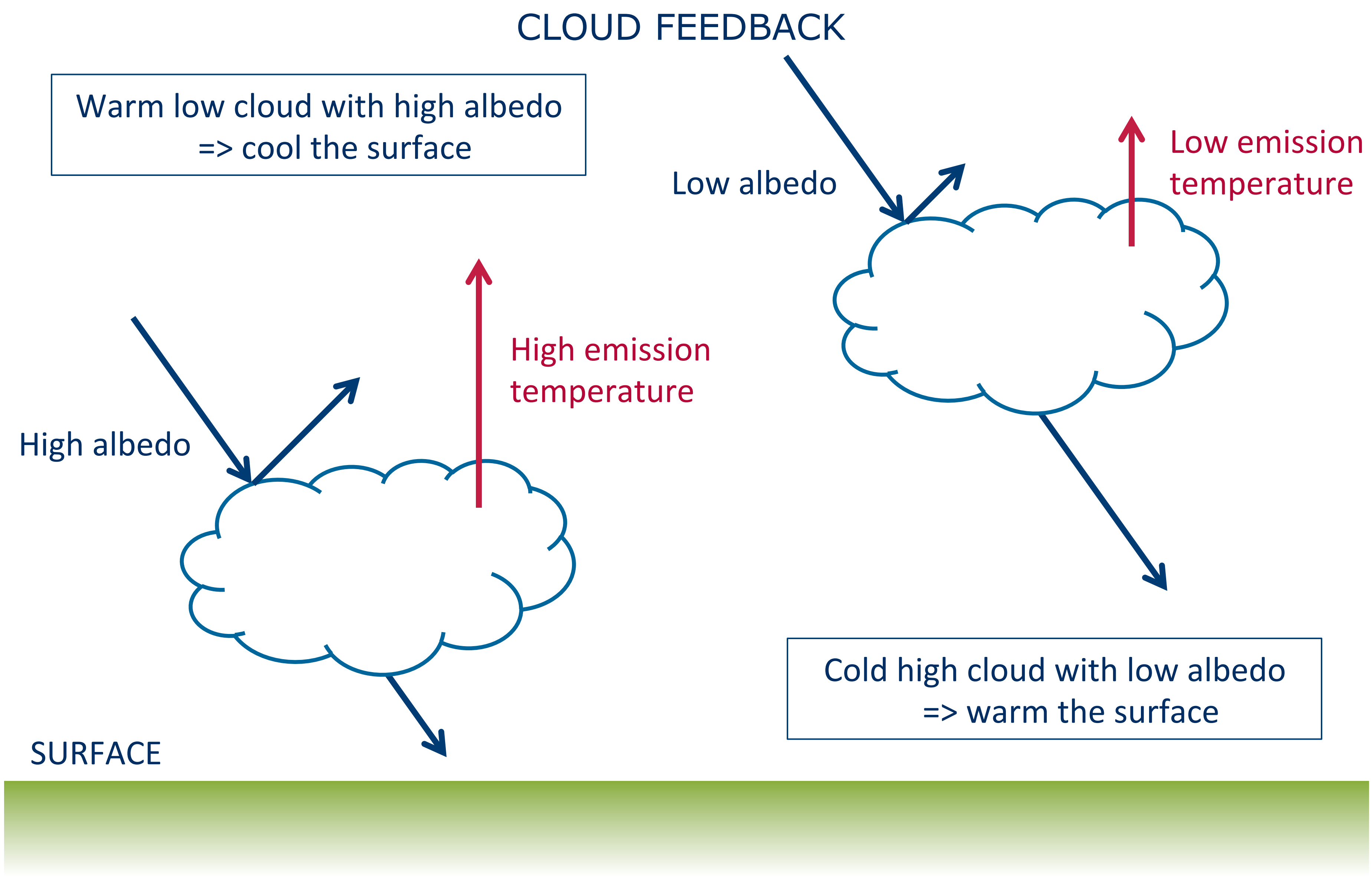
PERMAFROST FEEDBACK

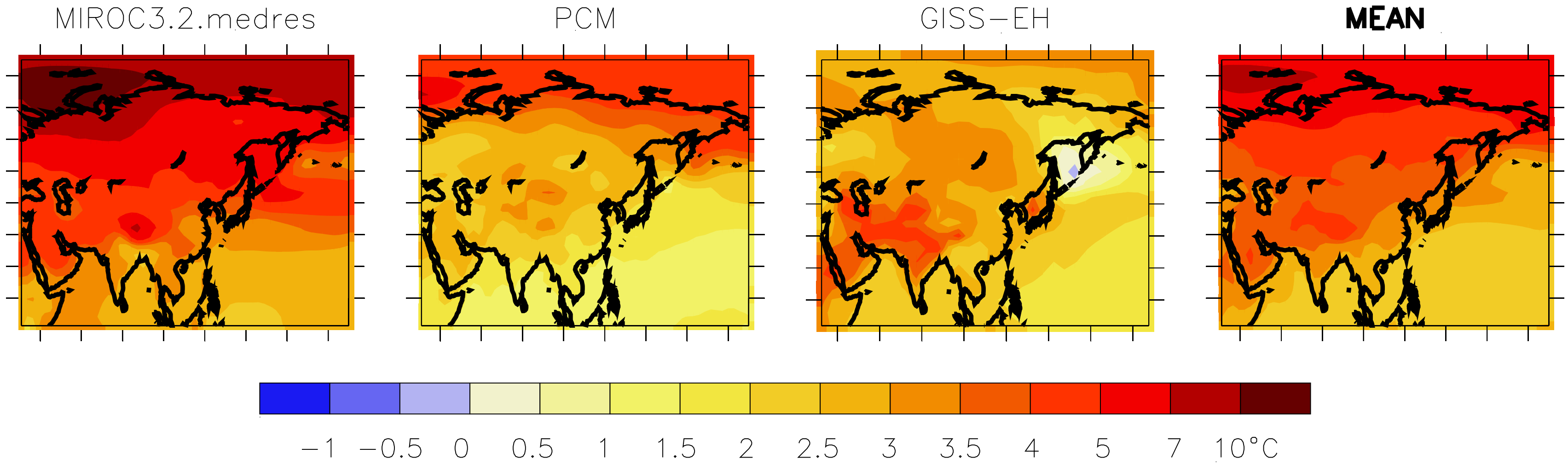


CLIMATE FEEDBACKS



REGIONAL PATTERNS OF CHANGE

Annual Mean Surface Air Temperature Response



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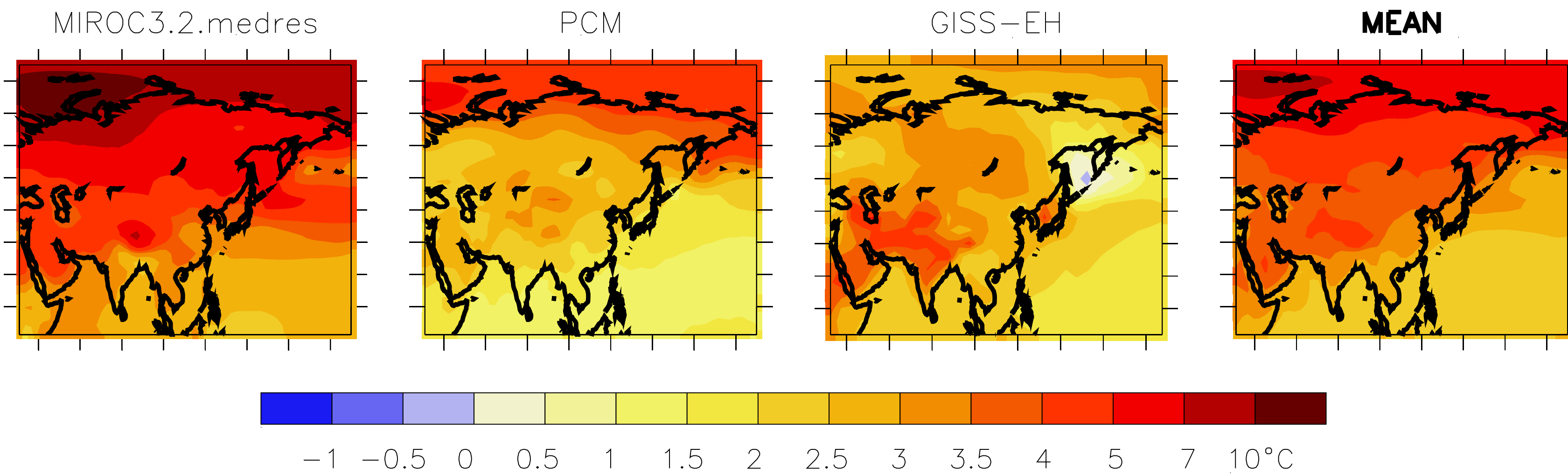
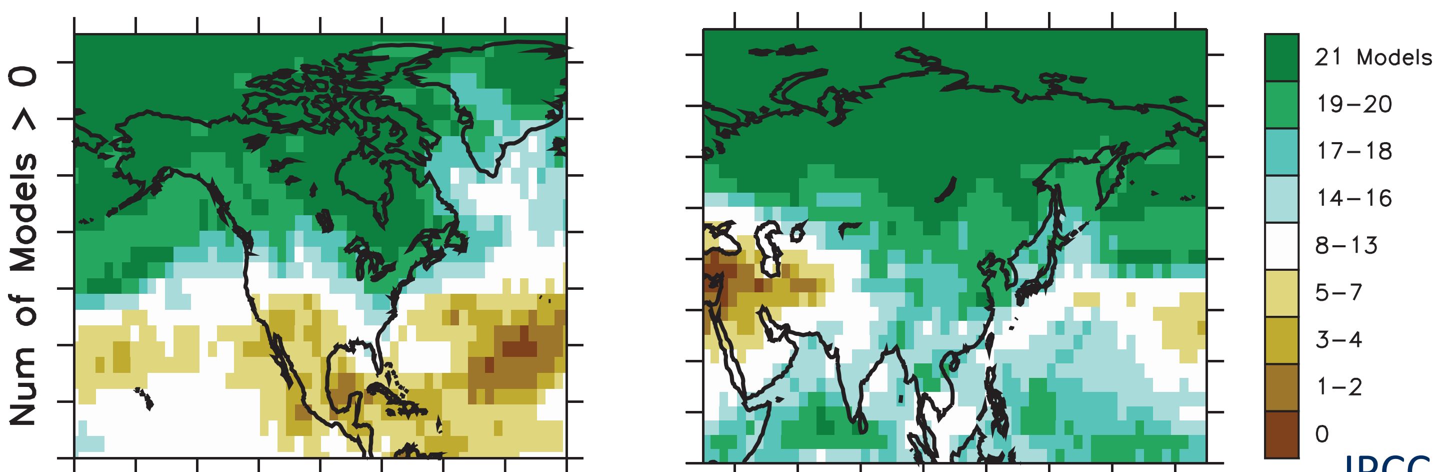


Annual Mean Precipitation Response



IPCC AR4 (2007)

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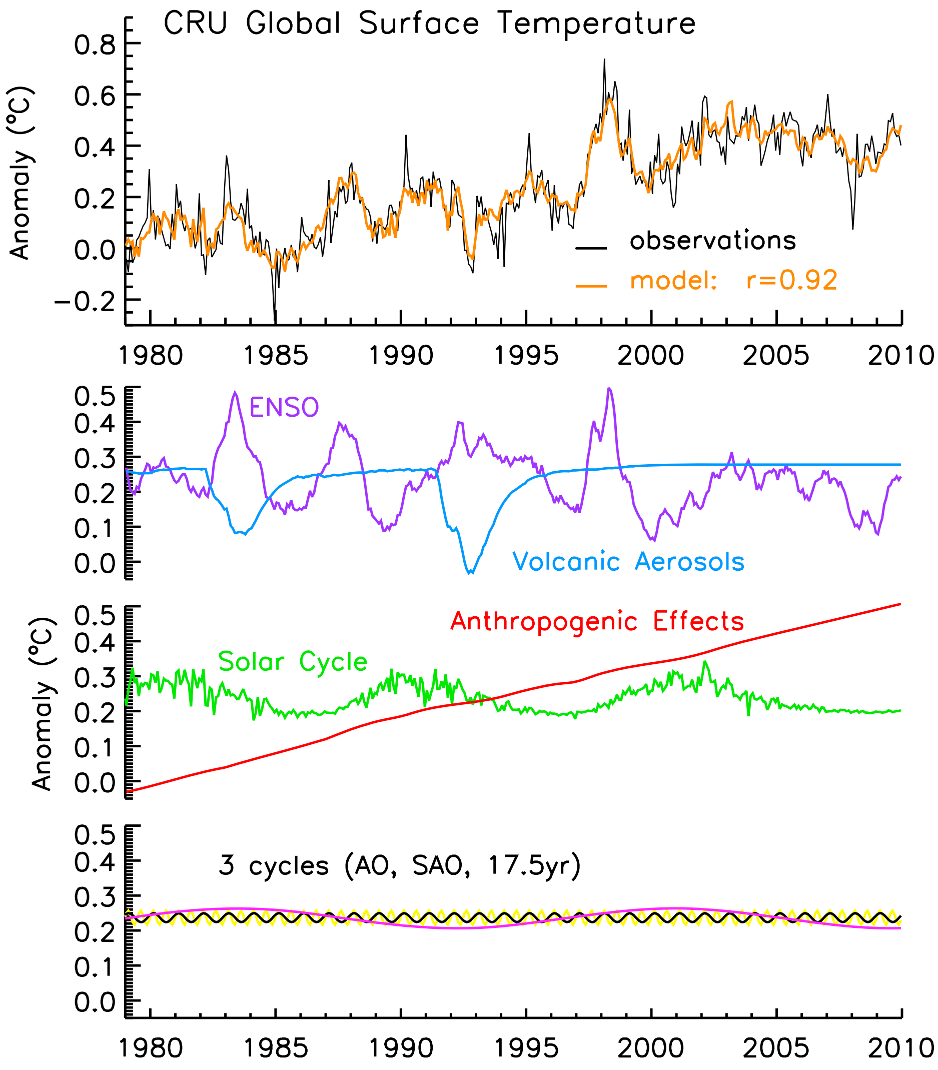
NATURAL VARIABILITY



Kopp and Lean (2011)

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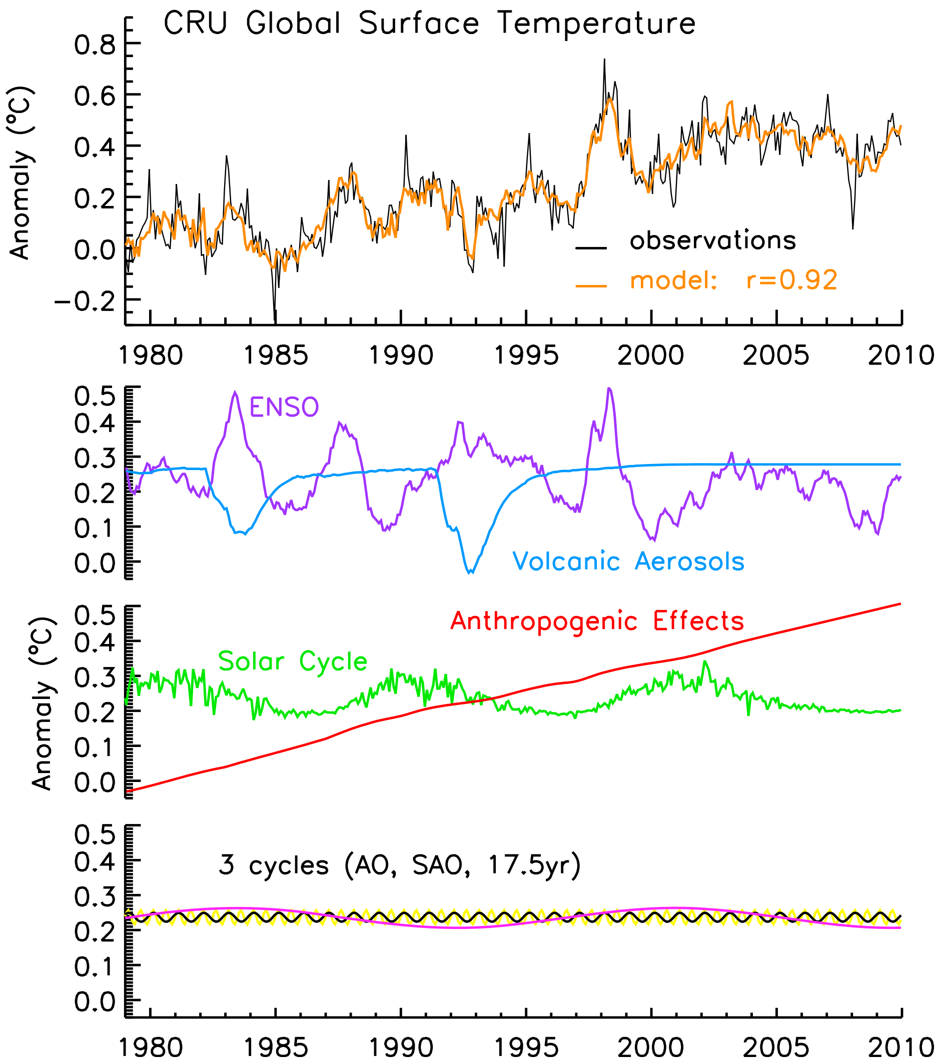

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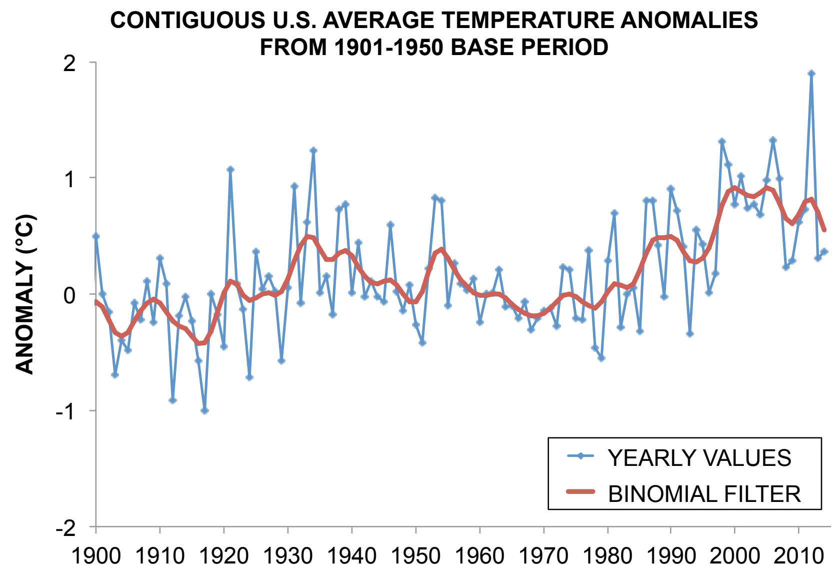
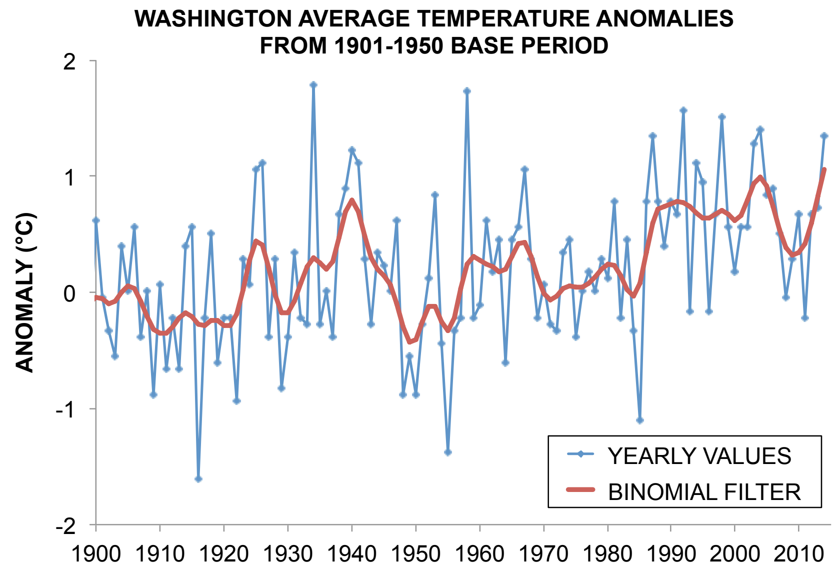
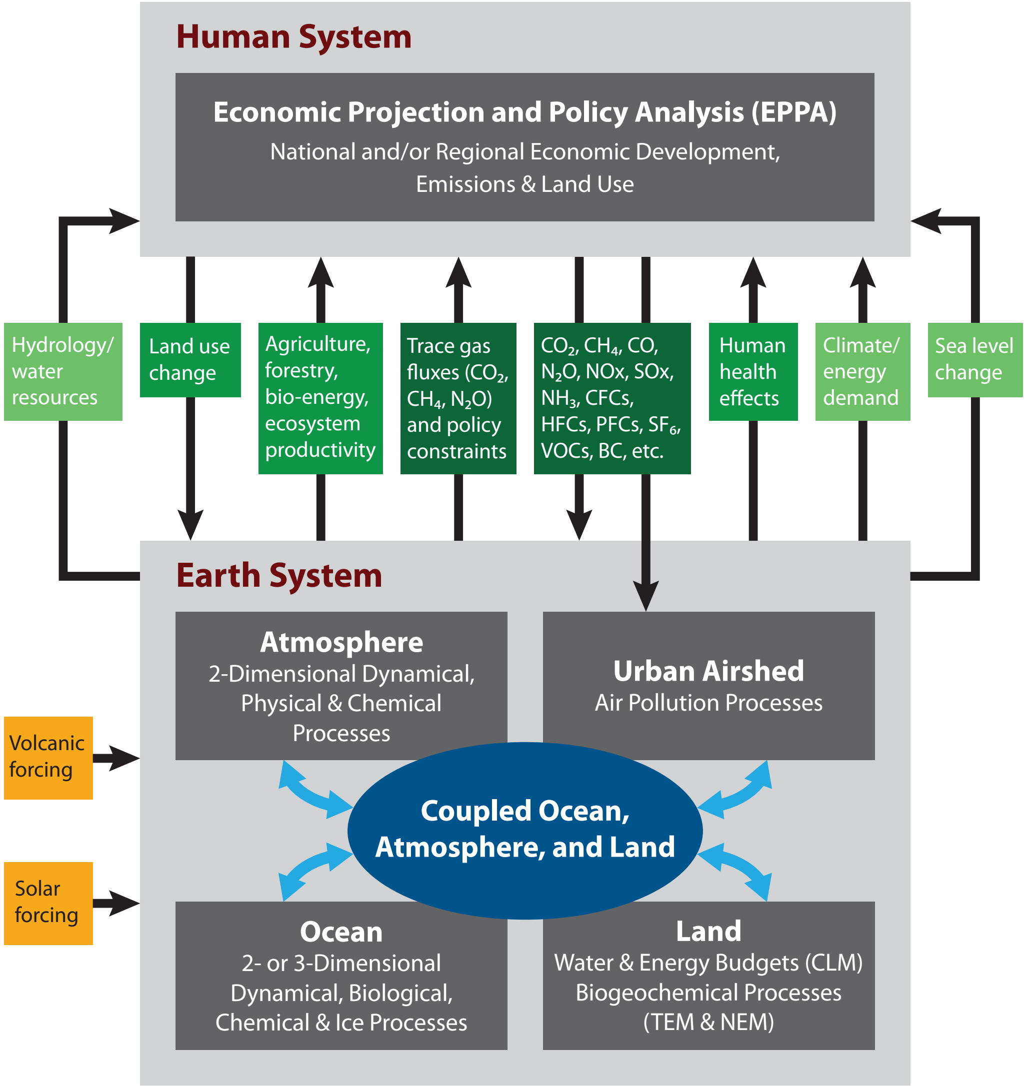




INTRODUCTION TO THE MIT IGSM

THE MIT INTEGRATED GLOBAL SYSTEM MODEL



The IGSM couples:

- a human activity model (EPPA)
- an Earth system model of intermediate complexity (MESM)

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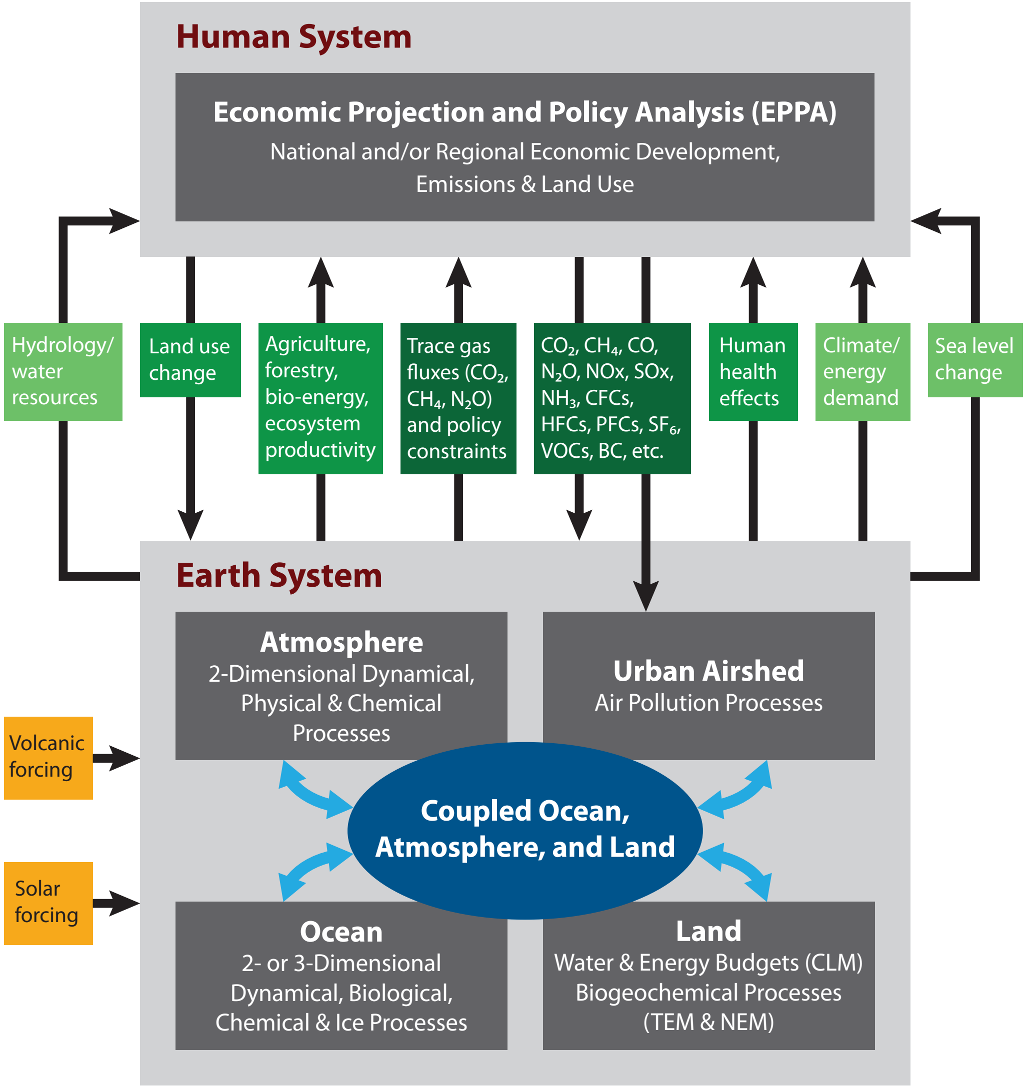

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Flexibility of IGSM include:

- Varying climate parameters
- Varying model parameters controlling emissions
- Implementing climate policies
- Computationally efficient (can run 1000s of simulations)

THE MIT INTEGRATED GLOBAL SYSTEM MODEL

Human System

Economic Projection and Policy Analysis (EPPA)

National and/or Regional Economic Development,
Emissions & Land Use

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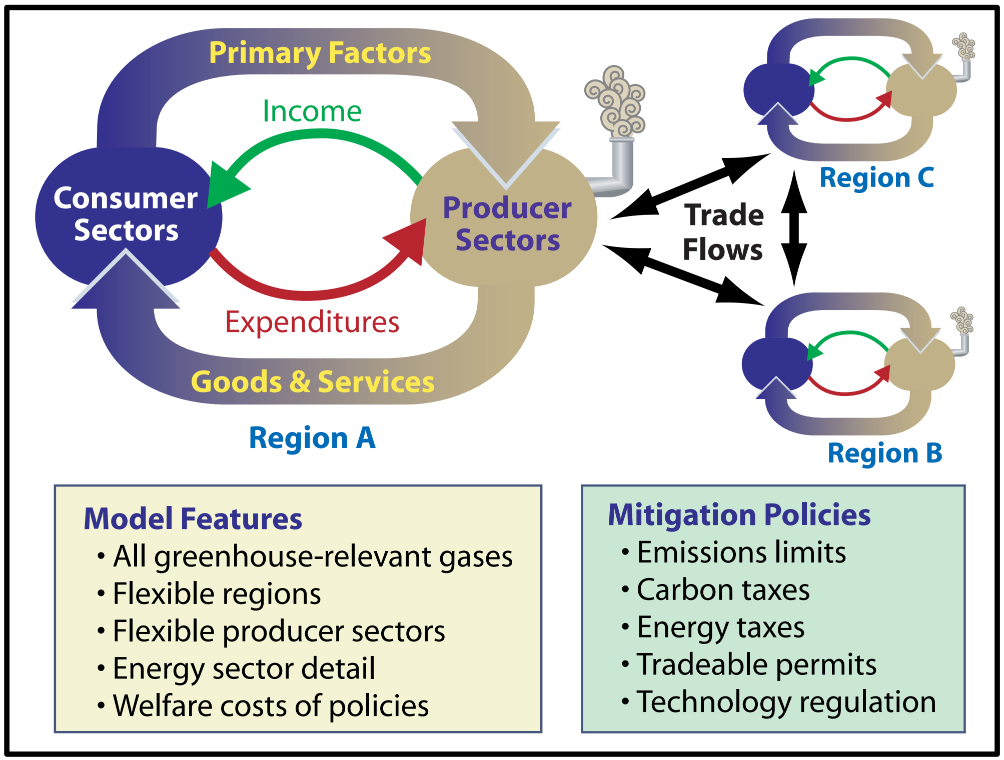

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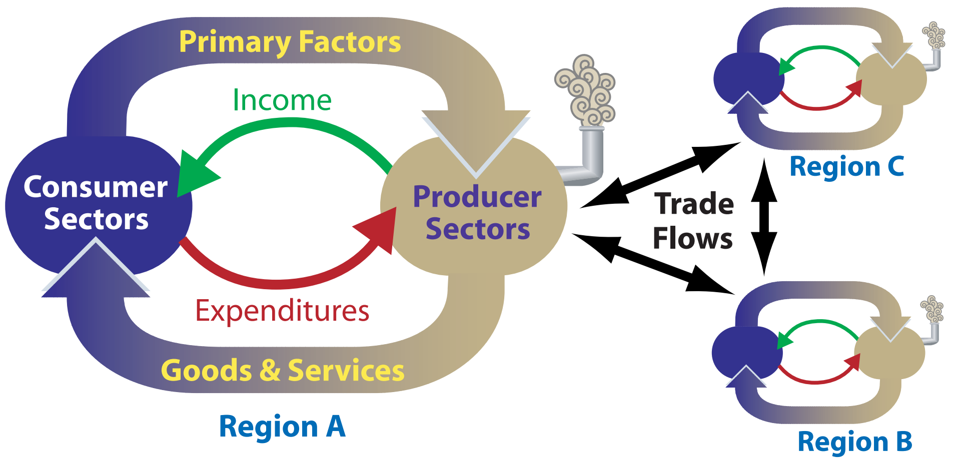
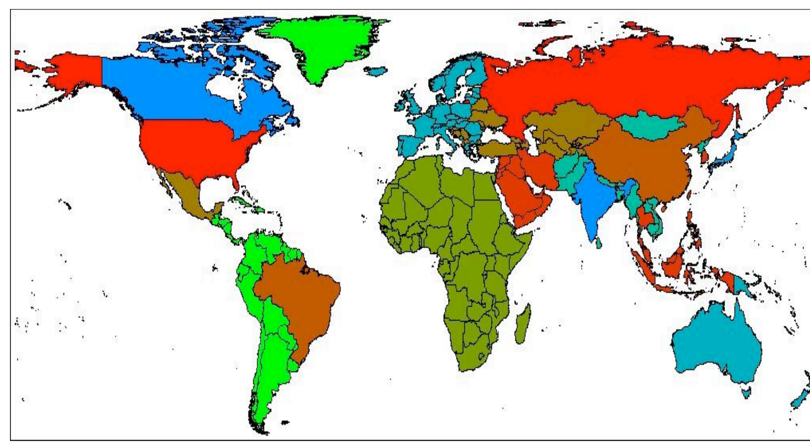


Model Features
- All greenhouse-relevant gases
- Flexible regions
- Flexible producer sectors
- Energy sector detail
- Welfare costs of policies

Mitigation Policies
- Emissions limits
- Carbon taxes
- Energy taxes
- Tradeable permits
- Technology regulation

16 REGIONS:

United States
European Union
Russia
Rest of Eurasia
Middle East
Mexico
Brazil
Rest of Latin Am.
Dynamic Asia
Rest of Asia
Aus. & N.Z.
Canada
Japan
China
India
Africa



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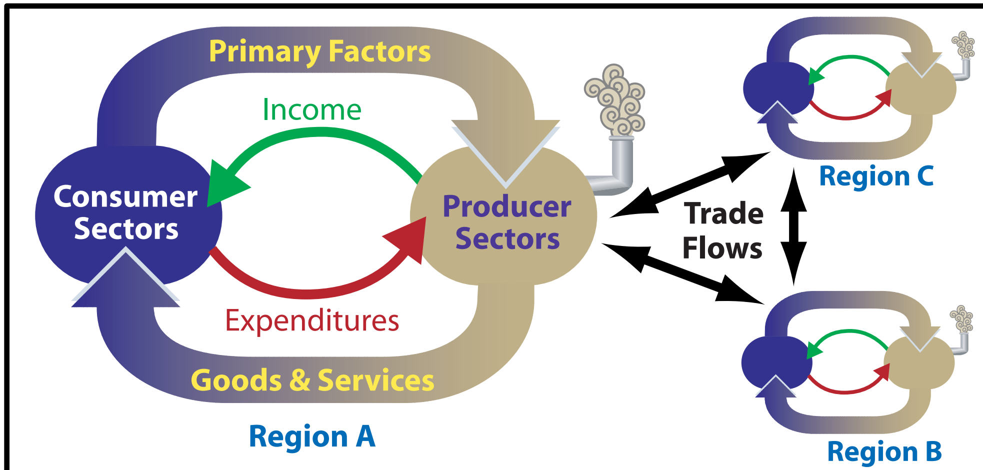

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SECTORS:

<u>Non-Energy</u>
- Agriculture
- Energy Intensive Ind.
- Other Industry
- Services
- Industrial Transport
- Household Transport
- Other Household Cons.

<u>Fuels Supply</u>
- Crude oil
- Refined oil
- Biofuel
- Shale oil
- Coal
- Natural gas

<u>Electric Generation</u>

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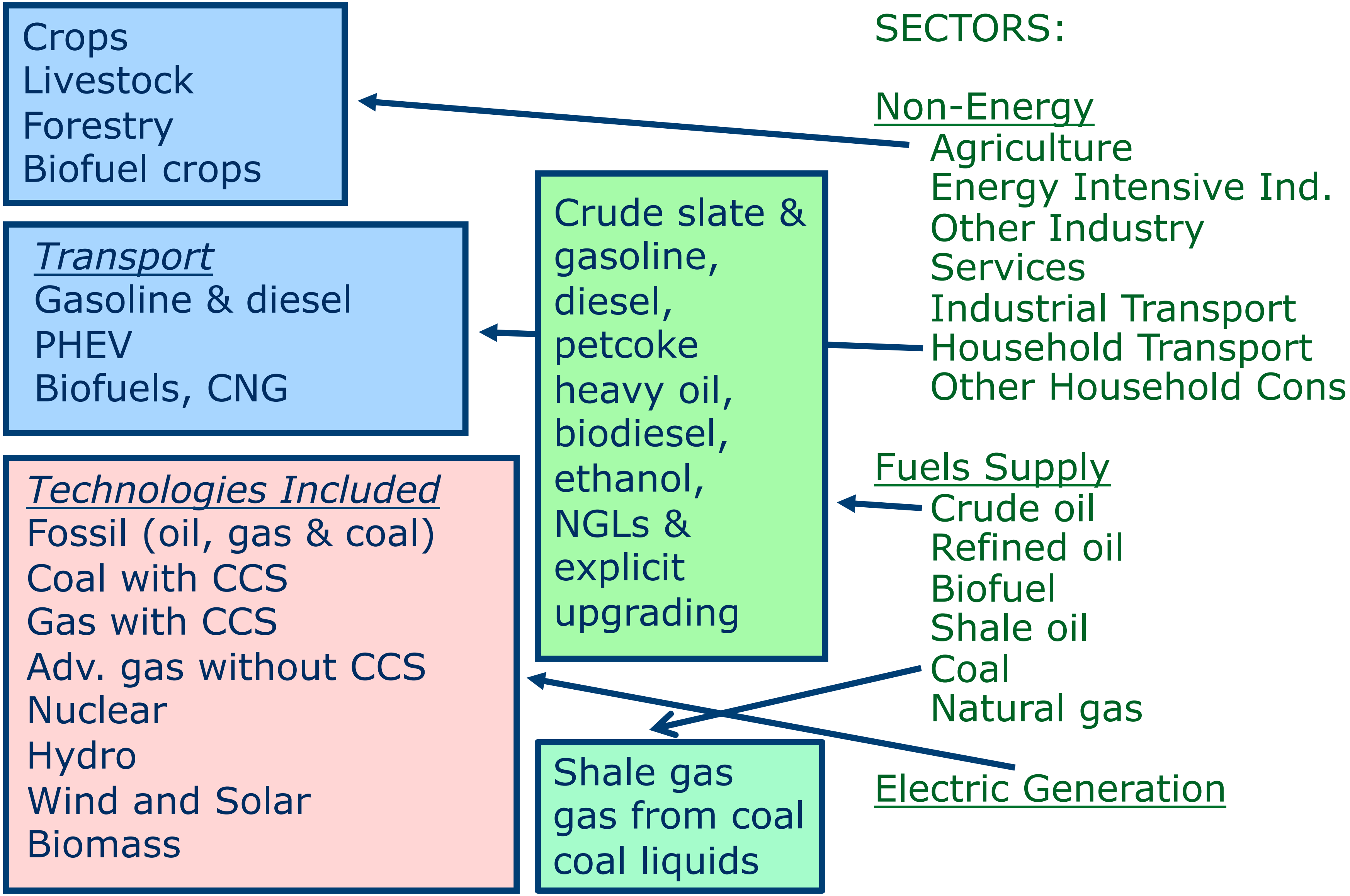

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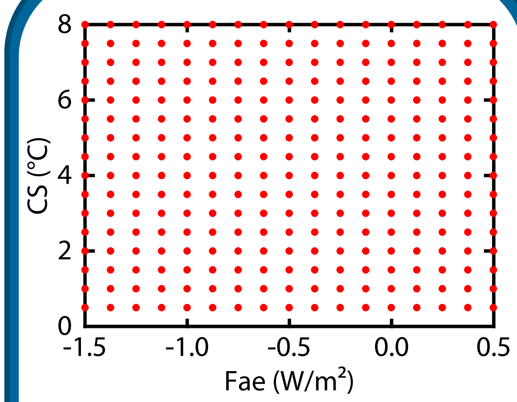
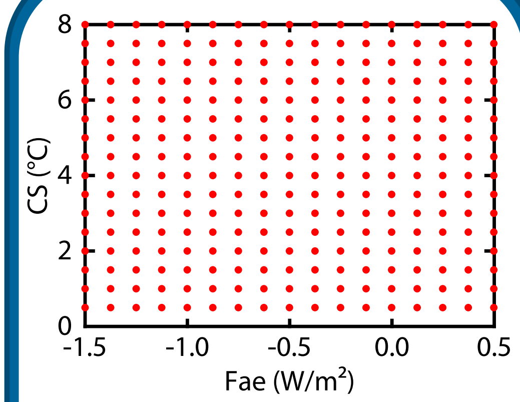


1000s IGSM runs sampling the 3 climate parameters

THE MIT INTEGRATED GLOBAL SYSTEM MODEL

OPTIMAL FINGERPRINT DIAGNOSTICS BASED ON 20th CENTURY CLIMATE RECORD



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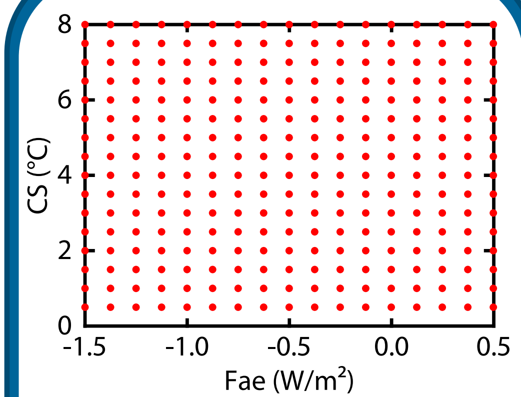

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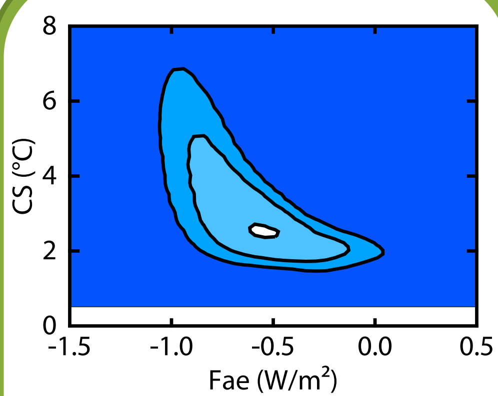


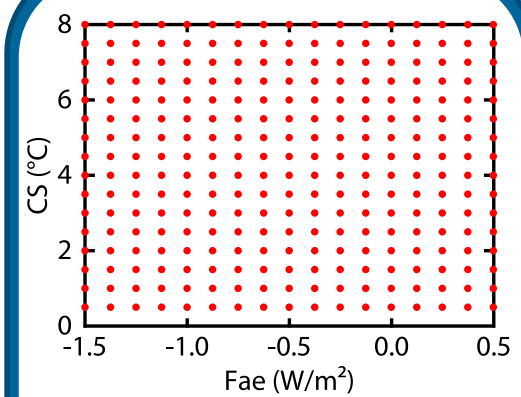
Monier et al. (2013a)

Probability density functions (PDFs) of climate parameters

THE MIT INTEGRATED GLOBAL SYSTEM MODEL

OPTIMAL FINGERPRINT DIAGNOSTICS BASED ON 20th CENTURY CLIMATE RECORD

LATIN HYPERCUBE SAMPLING OF PDFs OF CLIMATE PARAMETERS



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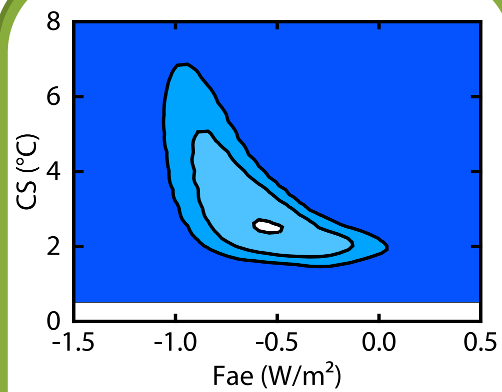

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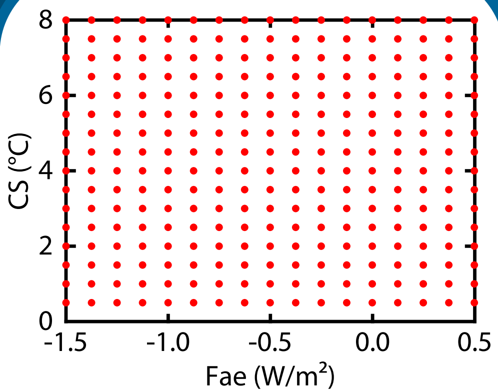

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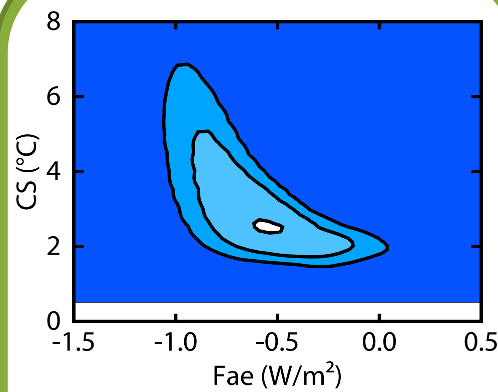

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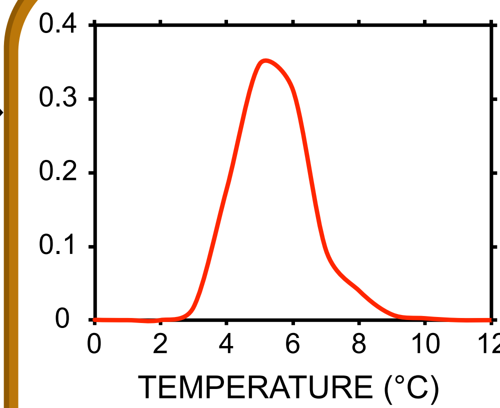
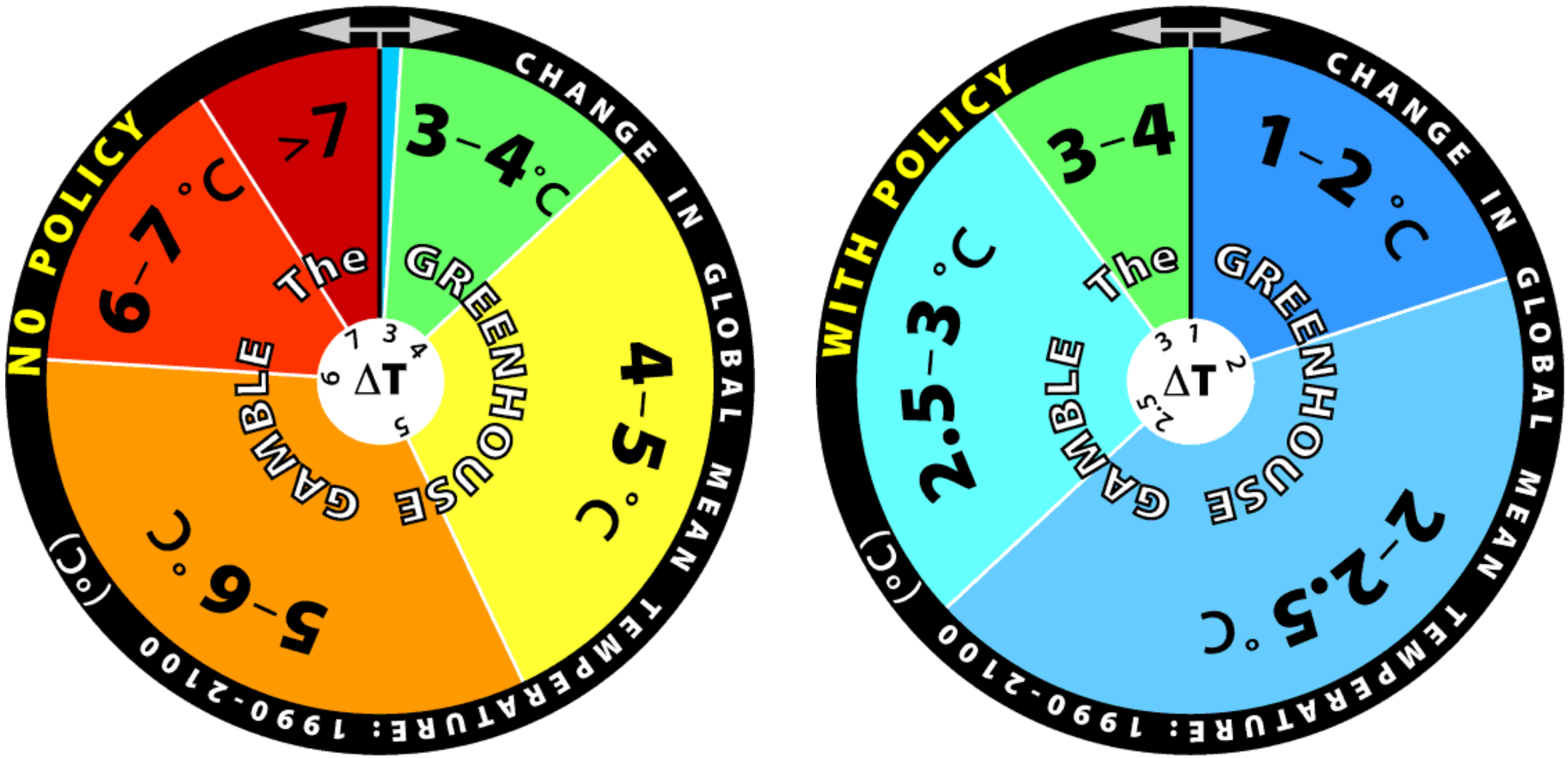
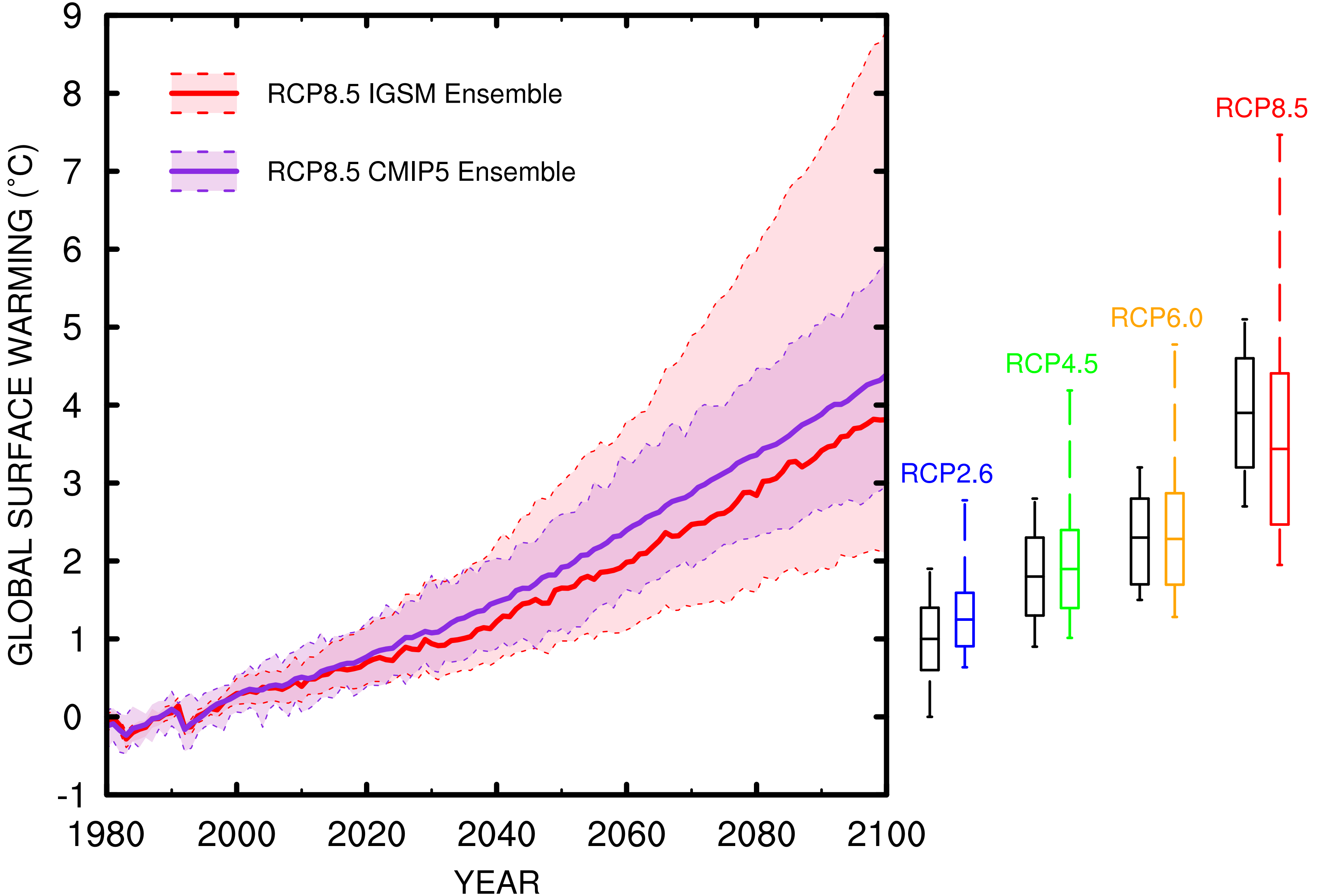


Distribution of future changes in global mean temperature

GREENHOUSE GAMBLE™ WHEELS

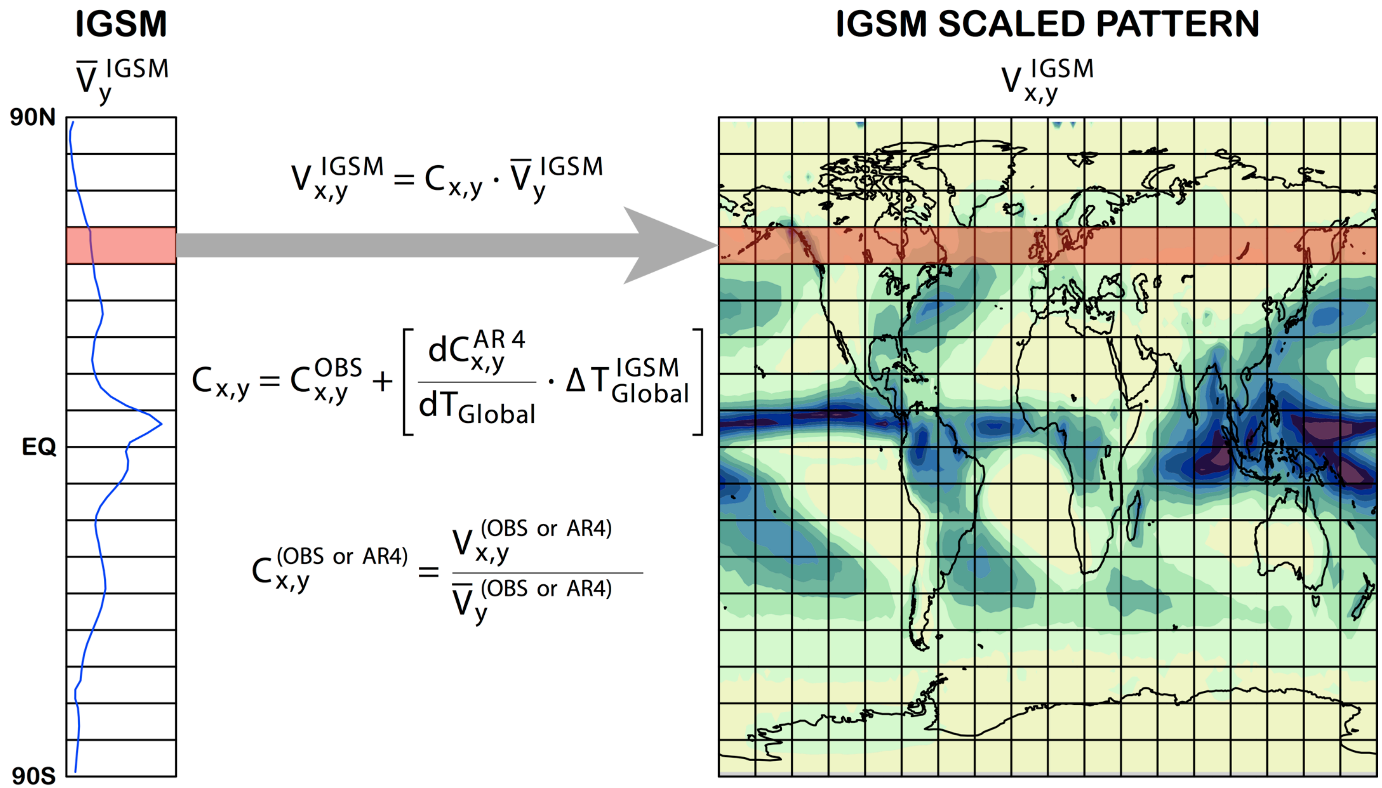


IGSM VERSUS IPCC MODELS



STATISTICAL DOWNSCALING

Pattern scaling method:

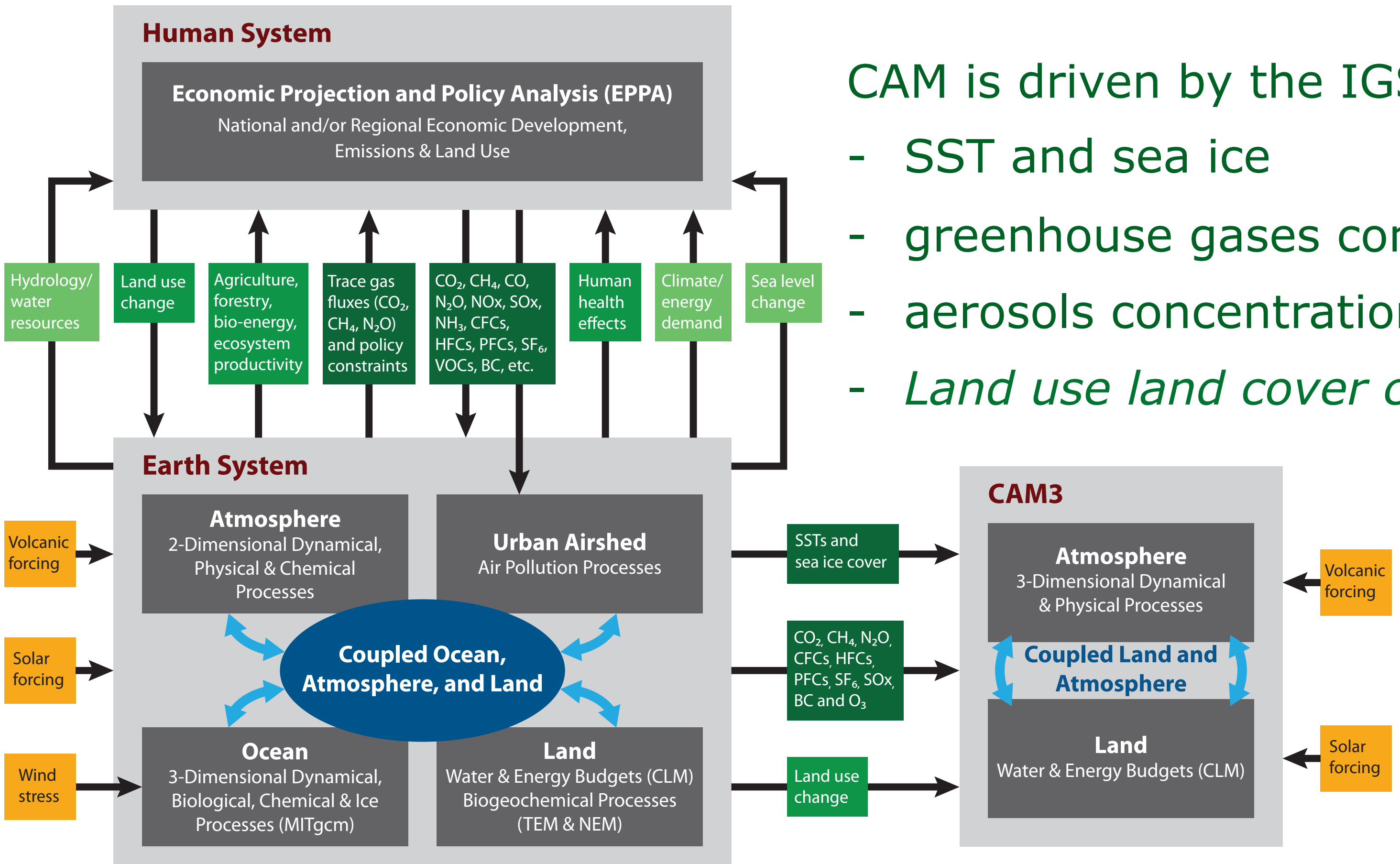


- Efficient method
- Can emulate multiple climate models
- Can be combined with the IGSM distributions of climate change

DYNAMICAL DOWNSCALING

MIT IGSM-CAM framework:

The MIT IGSM is linked to the NCAR 3-dimensional Community Atmospheric Model (CAM) version 3 (*Monier et al., 2013*).



CAM is driven by the IGSM:

- SST and sea ice
- greenhouse gases concentrations
- aerosols concentrations
- *Land use land cover change*

Monier et al. (2013a)

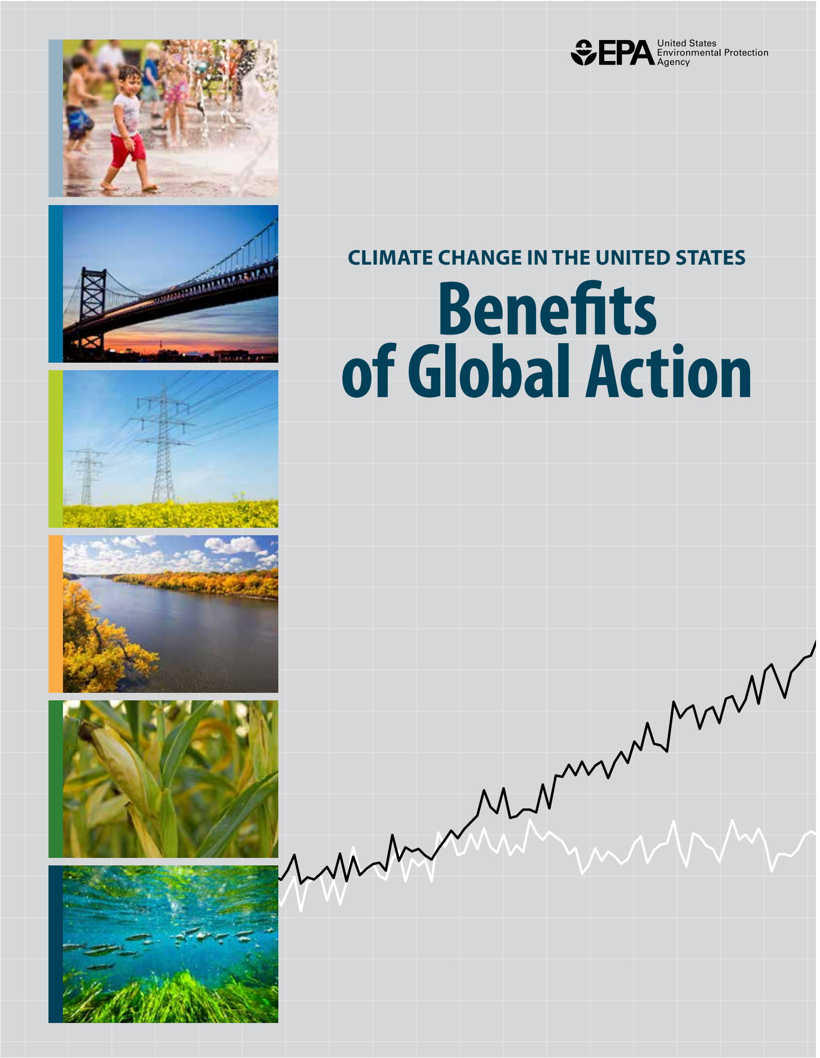
SUMMARY OF MODELING FRAMEWORK

Strengths and limitations of the 2 downscaling methods

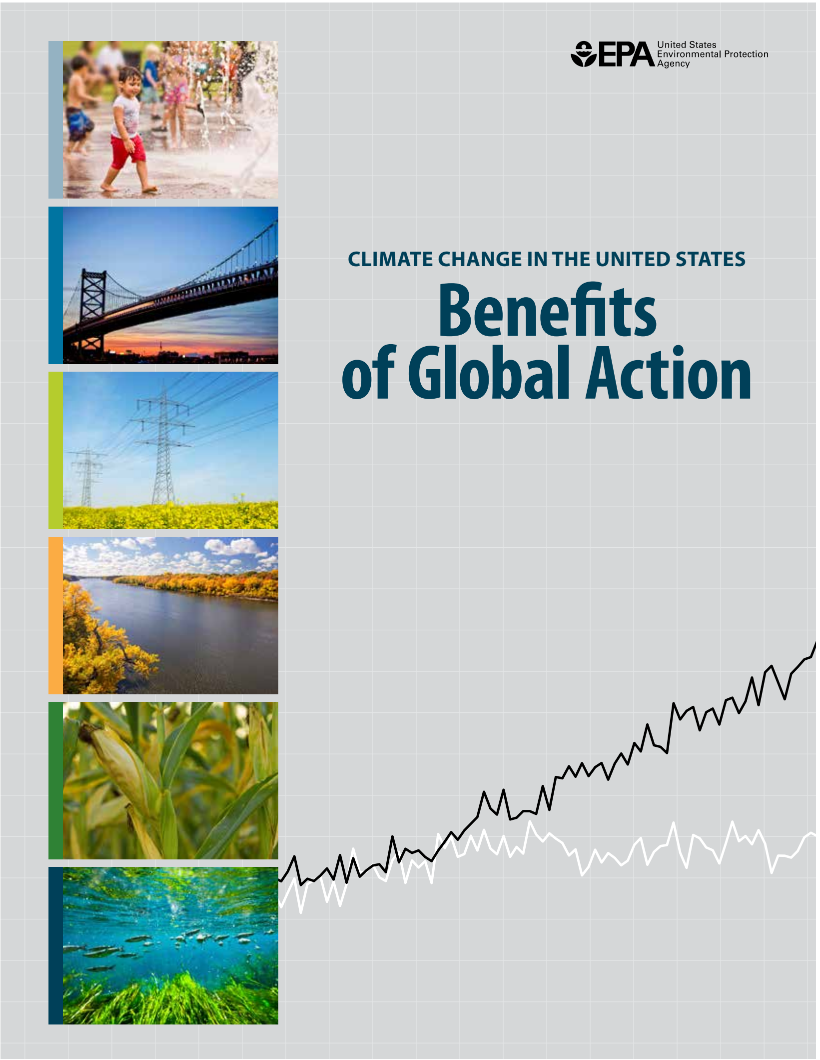
APPROACH	STRENGTHS	LIMITATIONS
IGSM-Pattern scaling (statistical approach)	• Can emulate multiple models • Computationally efficient • Can derive full distributions	• Limited to T and P • Limited to monthly time scale • Cannot simulate changes in variability and extremes
IGSM-CAM (dynamical approach)	• Can simulate changes in variability and extremes • Not limited to T,P (can drive models requiring various input variables or 3D fields) • High temporal resolution	• Limited to a single model • Computationally intensive • Can only approximate the bounds of the distributions

U.S. EPA
CLIMATE IMPACTS & RISK ANALYSIS (CIRA) PROJECT

THE CIRA PROJECT



THE CIRA PROJECT



STEP 1 | DESIGN GHG EMISSIONS SCENARIOS

Three scenarios:

- Business as usual or "Reference" scenario
- 2 global emissions reduction or "Mitigation" scenarios

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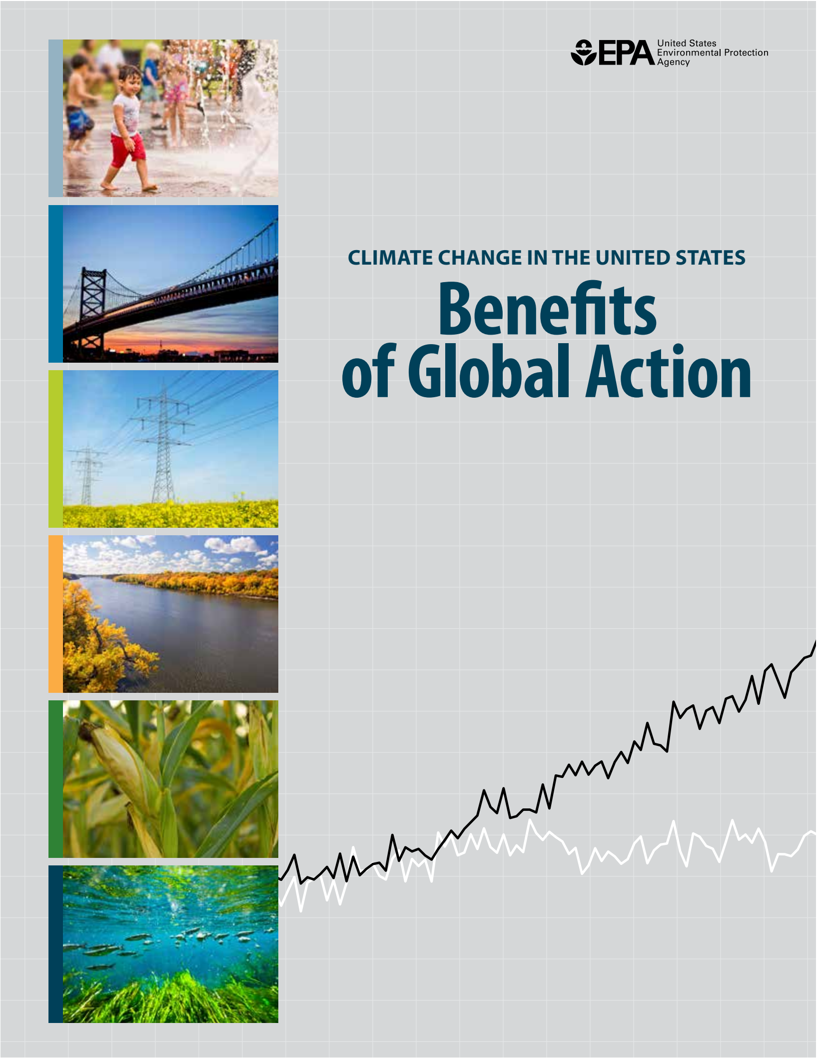

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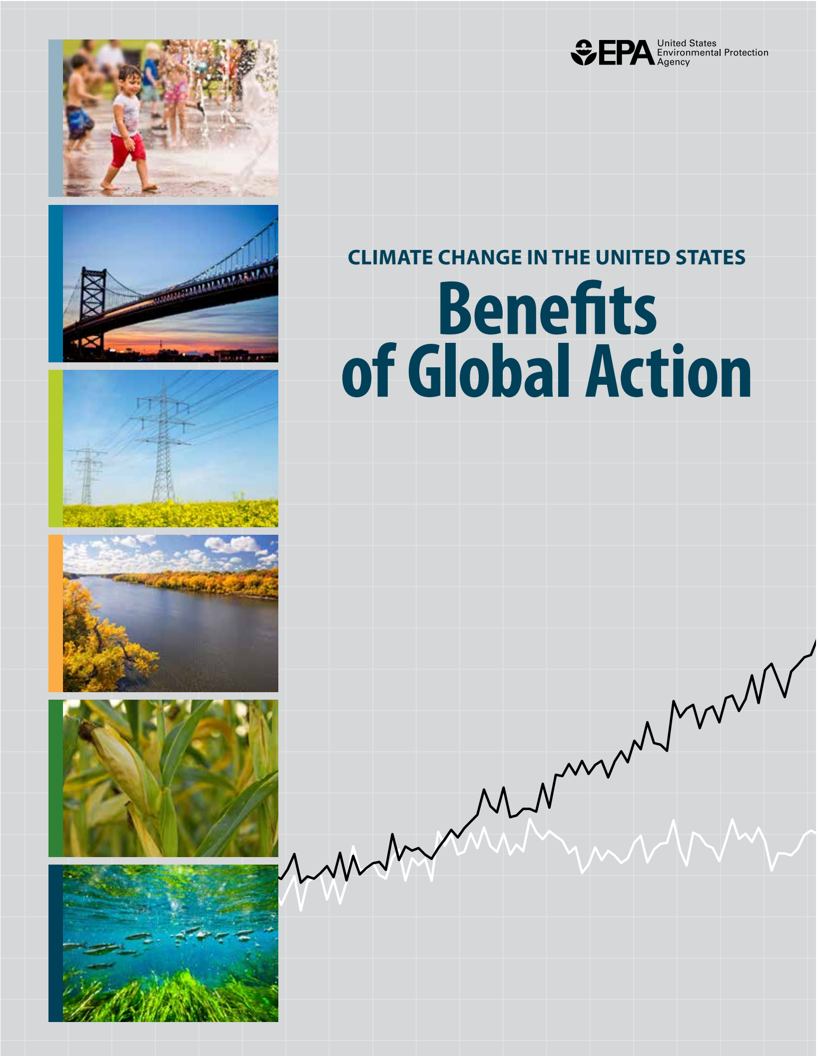

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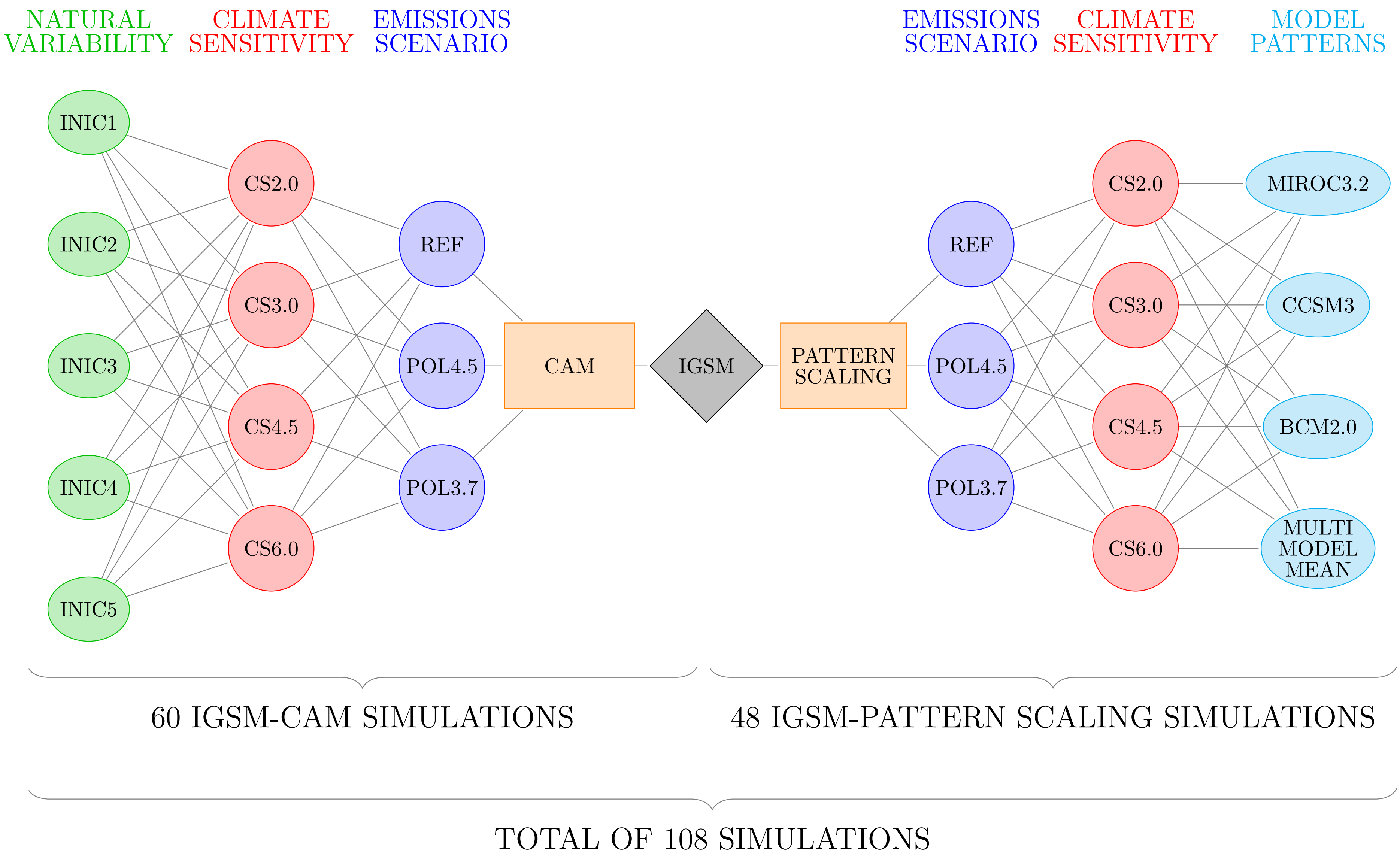
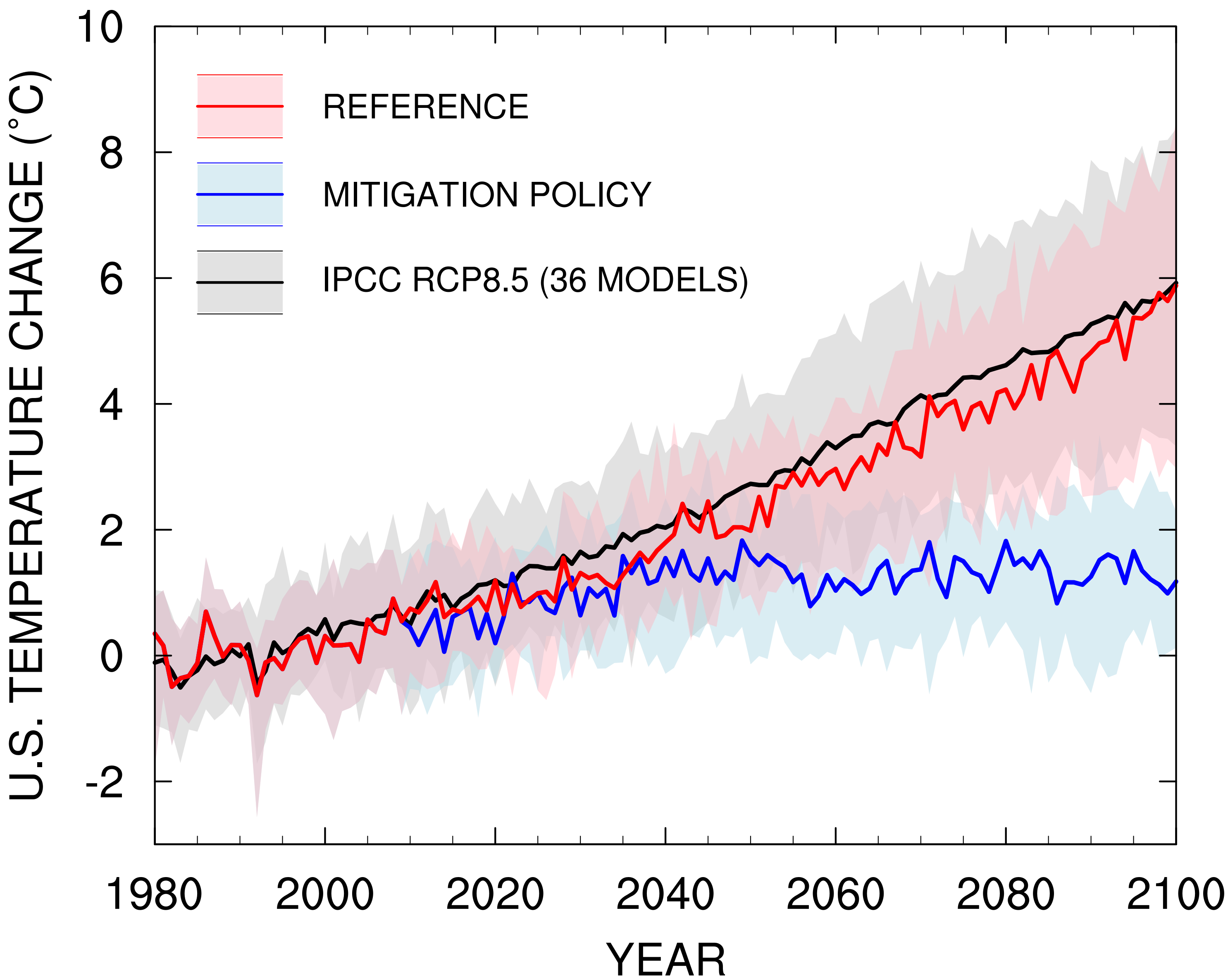
STEP 3 | ANALYZE SECTORAL IMPACTS

- HEALTH
- INFRASTRUCTURE
- ELECTRICITY
- WATER RESOURCES
- AGRICULTURE & FORESTRY
- ECOSYSTEMS

MATRIX OF SIMULATIONS



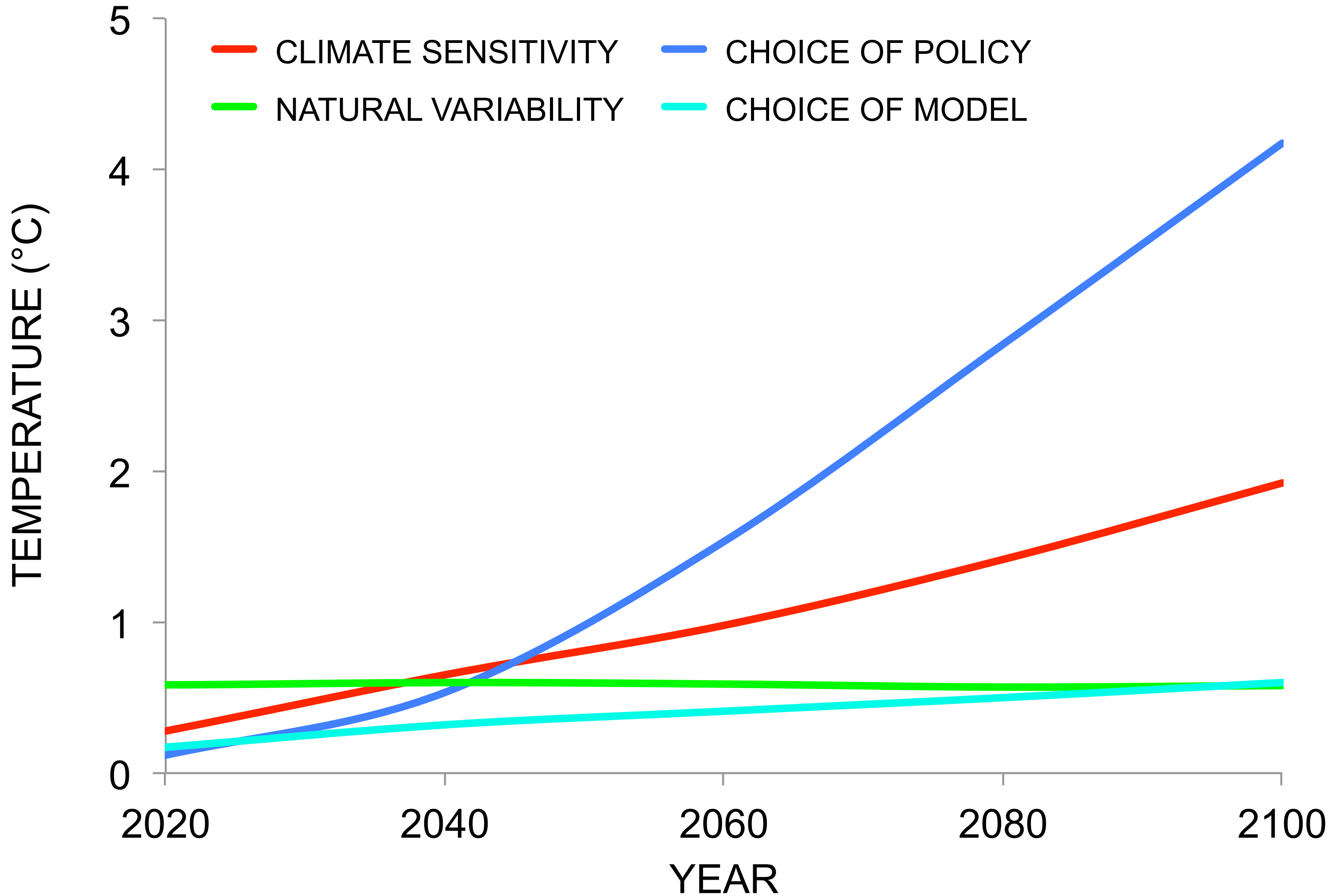
RANGE OF TEMPERATURE PROJECTIONS



http://globalchange.mit.edu/

IMPACT OF SOURCES OF UNCERTAINTY

RANGE OF US TEMPERATURE CHANGE FROM 1981-2000 PERIOD
FOR THE 4 SOURCES OF UNCERTAINTY CONSIDERED



Adapted from Monier et al. (2014)

IMPACT OF SOURCES OF UNCERTAINTY

RANGE OF US PRECIPITATION CHANGE FROM 1981-2000 PERIOD
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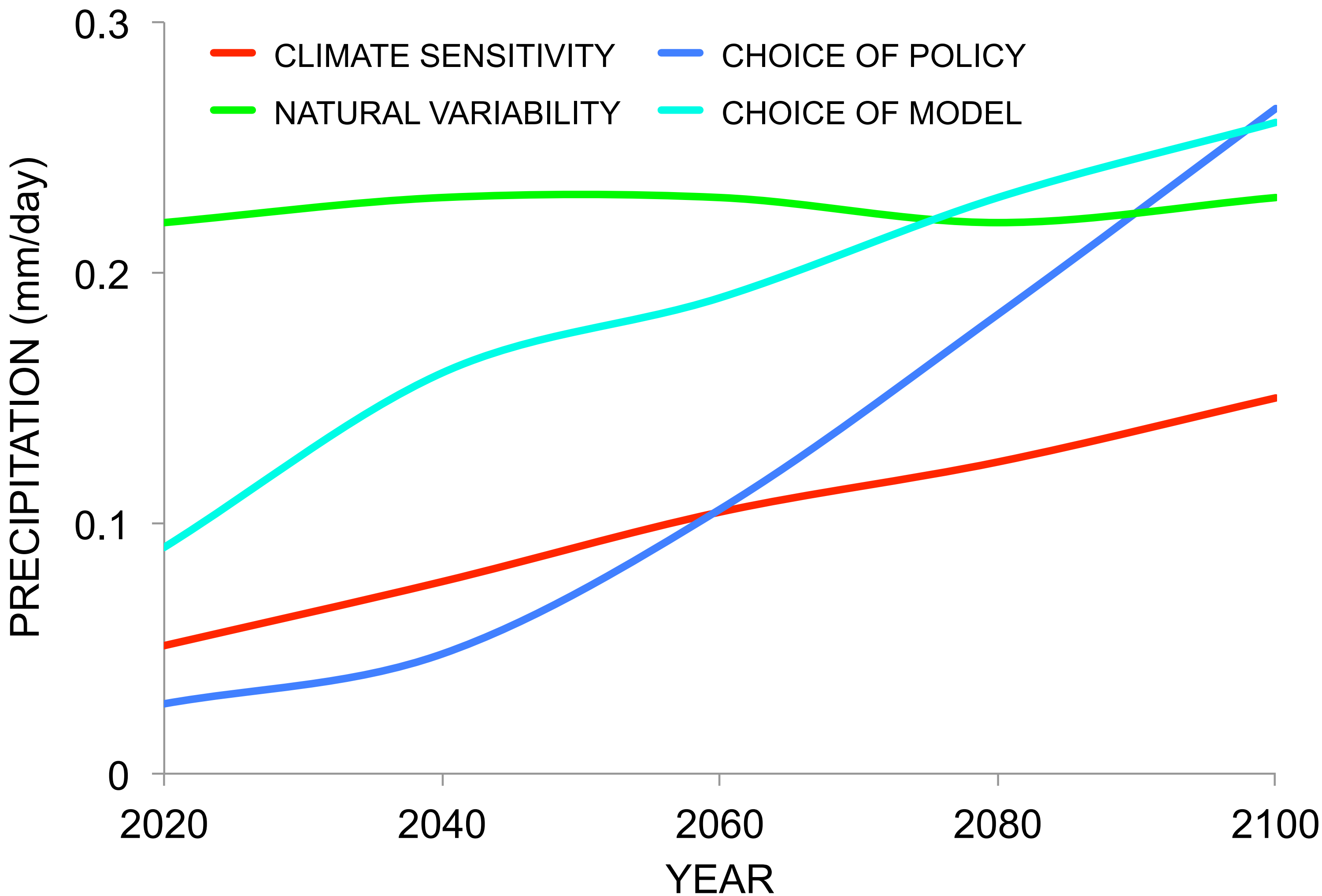
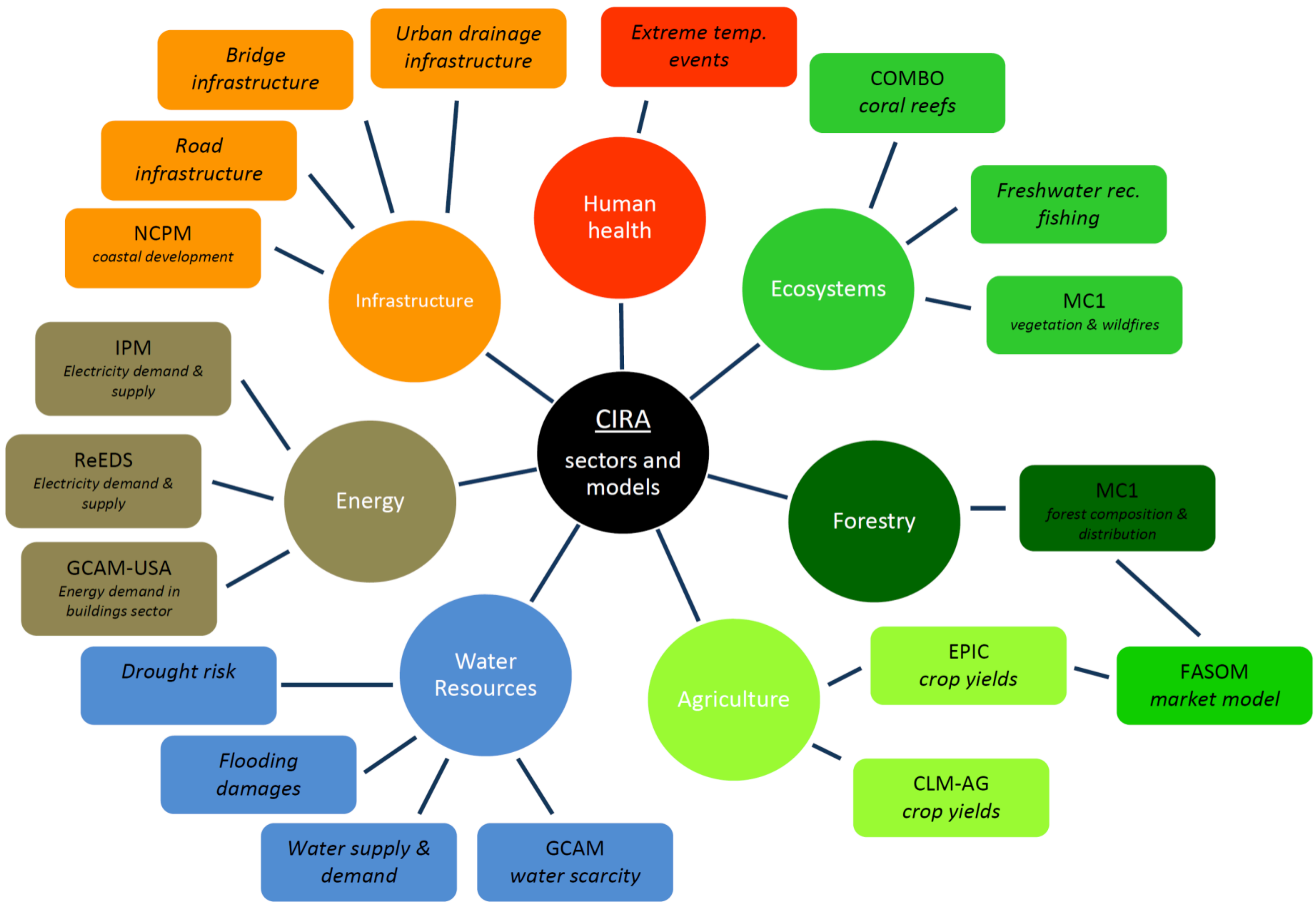


CLIMATE IMPACT ANALYSIS



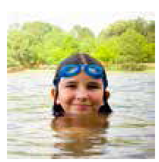
BENEFITS OF CLIMATE ACTION

HEALTH

AIR QUALITY
An estimated 57,000 fewer deaths from poor air quality in 2100

EXTREME TEMPERATURE
In 49 major U.S. cities, an estimated 12,000 fewer deaths from extreme temperature in 2100

LABOR
Approximately $110 billion in avoided damages from lost labor due to extreme temperatures in 2100



WATER QUALITY
An estimated $2.6-$3.0 billion in avoided damages from poor water quality in 2100

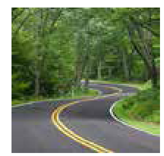
ELECTRICITY

ELECTRICITY DEMAND
An avoided increase in electricity demand of 1.1%-4.0% in 2050

ELECTRICITY SUPPLY
An estimated $10-$34 billion in savings on power system costs in 2050

INFRASTRUCTURE

BRIDGES
An estimated 720-2,200 fewer bridges made structurally vulnerable in 2100



ROADS
An estimated $4.2 to $7.4 billion in avoided adaptation costs in 2100

URBAN DRAINAGE
In 50 U.S. cities, an estimated $50 million to $6.4 billion in avoided adaptation costs in 2100

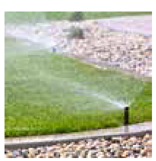
COASTAL PROPERTY
Approximately $3.1 billion in avoided damages and adaptation costs from sea level rise and storm surge in 2100

BENEFITS OF CLIMATE ACTION

WATER RESOURCES

INLAND FLOODING
Estimates range from approximately $2.8 billion in avoided damages to $38 million in increases damages in 2100

DROUGHT
An estimated 40%-59% fewer severe and extreme droughts in 2100



SUPPLY & DEMAND
An estimated $11 to $180 billion in avoided damages from water shortages in key economic sectors in 2100

AGRICULTURE AND FORESTRY

AGRICULTURE
An estimated $6.6-$11 billion in avoided damages to agriculture in 2100

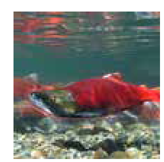
FORESTRY
An estimated $520 million to $1.5 billion in avoided damages to forestry in 2100

ECOSYSTEMS

CORAL REEFS
An avoided loss of approximately 35% of current Hawaiian coral in 2100, with a recreational value of $1.1 billion

SHELLFISH
An avoided loss of approximately 34% of the U.S. oyster supply, 37% of scallops, and 29% of clams in 2100

WILDFIRE
An estimated 6.0-7.9 million fewer acres burned by wildfires in 2100



FRESHWATER FISH
An estimated 230,000-360,000 acres of cold-water fish habitat preserved in 2100

CARBON STORAGE
An estimated 1.0 to 26 million fewer tons of carbon stored in vegetation in 2100

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The modeling framework can be used to analyze the impact of climate mitigation and the benefits of climate action under uncertainty

THANK YOU,
ANY QUESTIONS?