The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

1986-2

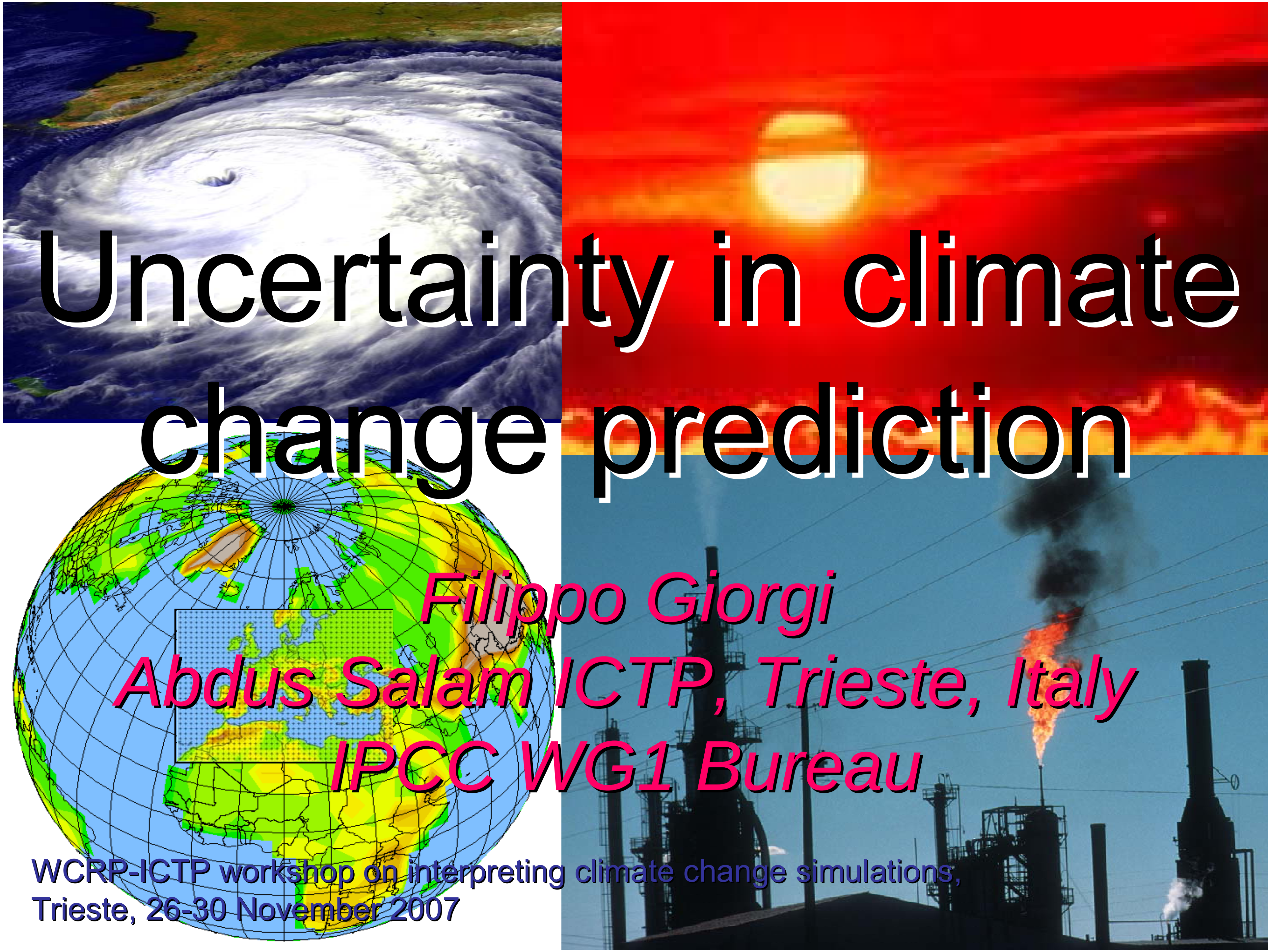
WCRP and ICTP Interpreting Climate Change Simulations: Capacity Building for Developing Nations Seminar

26 - 30 November 2007

Uncertainty in climate change prediction.

Filippo Giorgi

ICTP
Physics of Weather and Climate Group
Strada Costiera 11, P.O. Box 586
34014 Trieste
ITALY



Uncertainty in climate change prediction

Filippo Giorgi
Abdus Salam ICTP, Trieste, Italy
IPCC WG1 Bureau

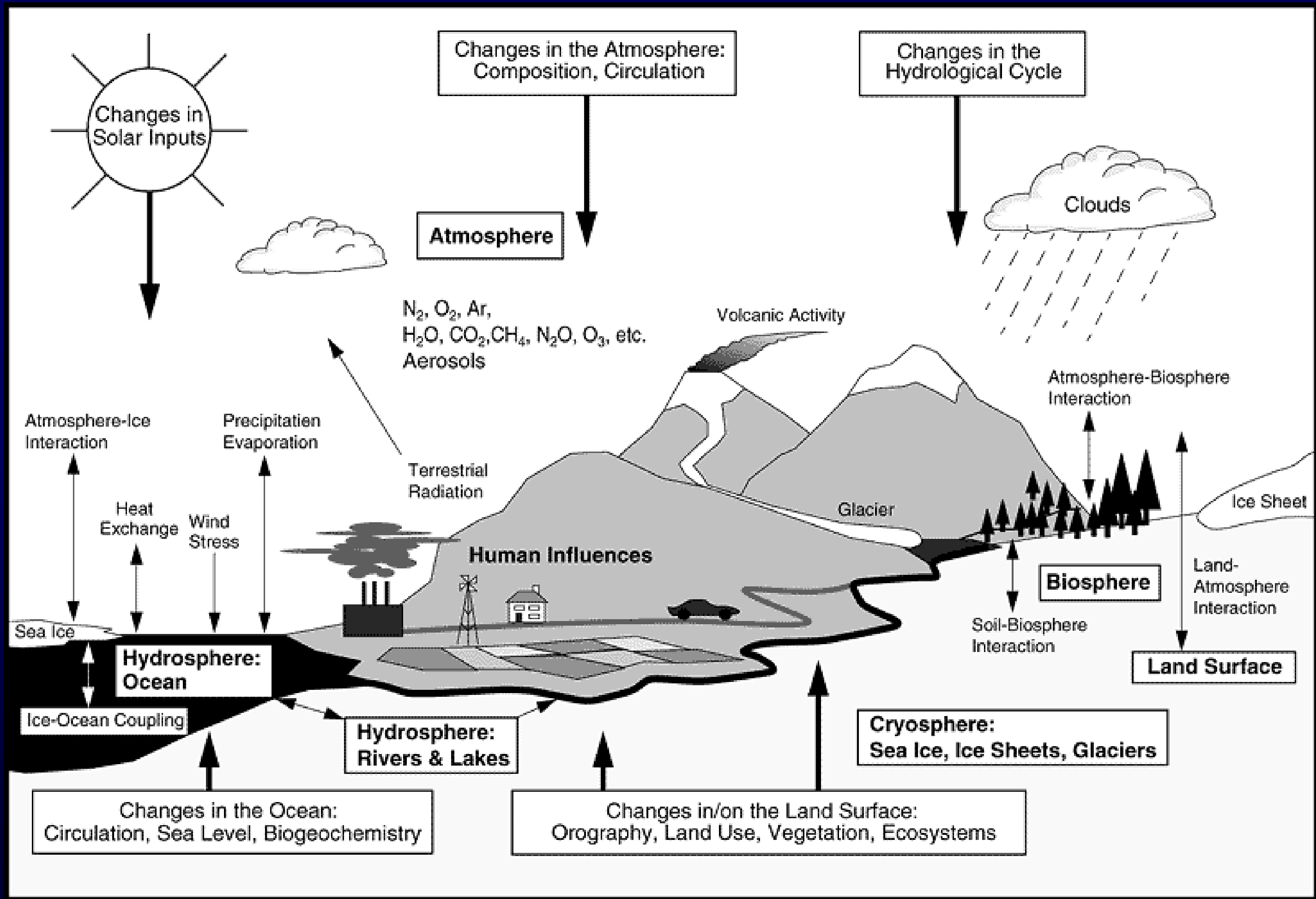
WCRP-ICTP workshop on interpreting climate change simulations,
Trieste, 26-30 November 2007

Lecture outline

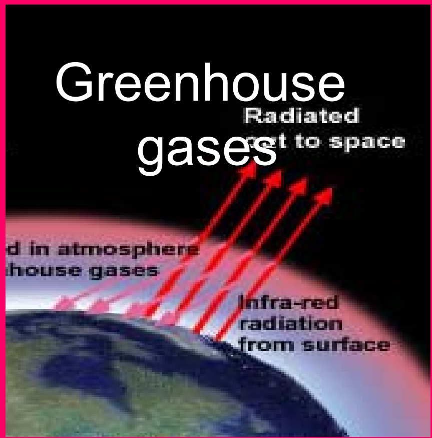
- Some basic concepts
- Sources of uncertainty in climate change prediction
- The concept of climate change prediction
- Assessing uncertainty and reliability in climate change prediction
- Most material from: Giorgi, Climatic Change, 2005

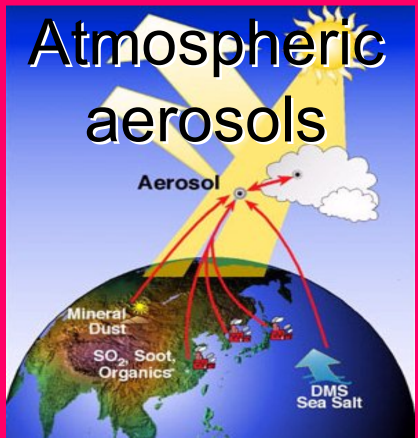
Coupled system processes

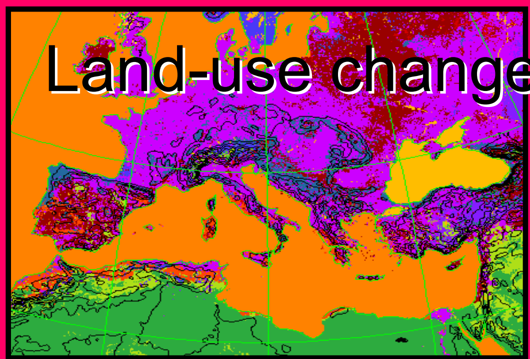
We live in a non-linearly coupled Climate System characterized by a wide range of spatial and temporal scales



Human factors

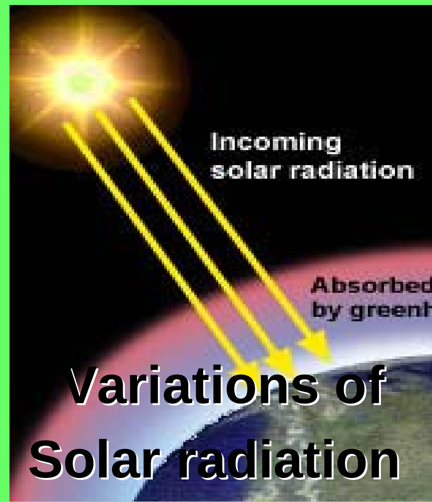


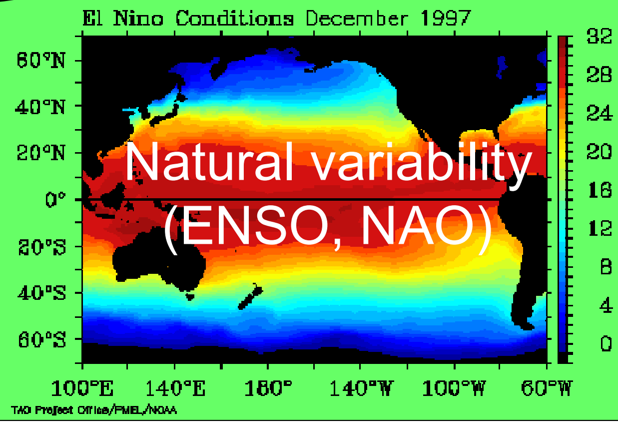




The earth's climate can change because of many human and natural factors

Natural factors



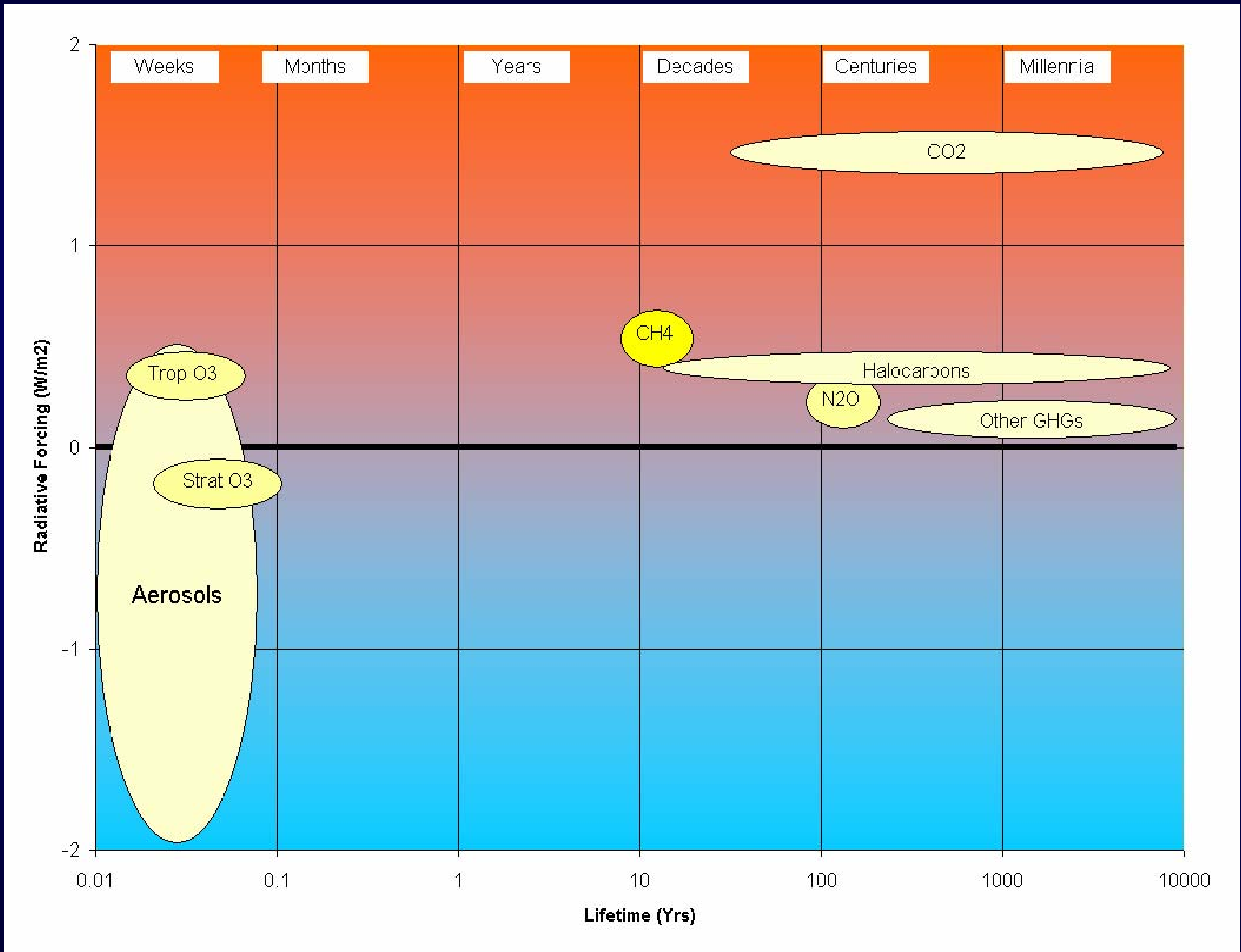


Temporal scales of forcings

Many key warming agents live for decades or more

All known cooling agents are relatively short-lived

-> implications for short and long-term effects and options



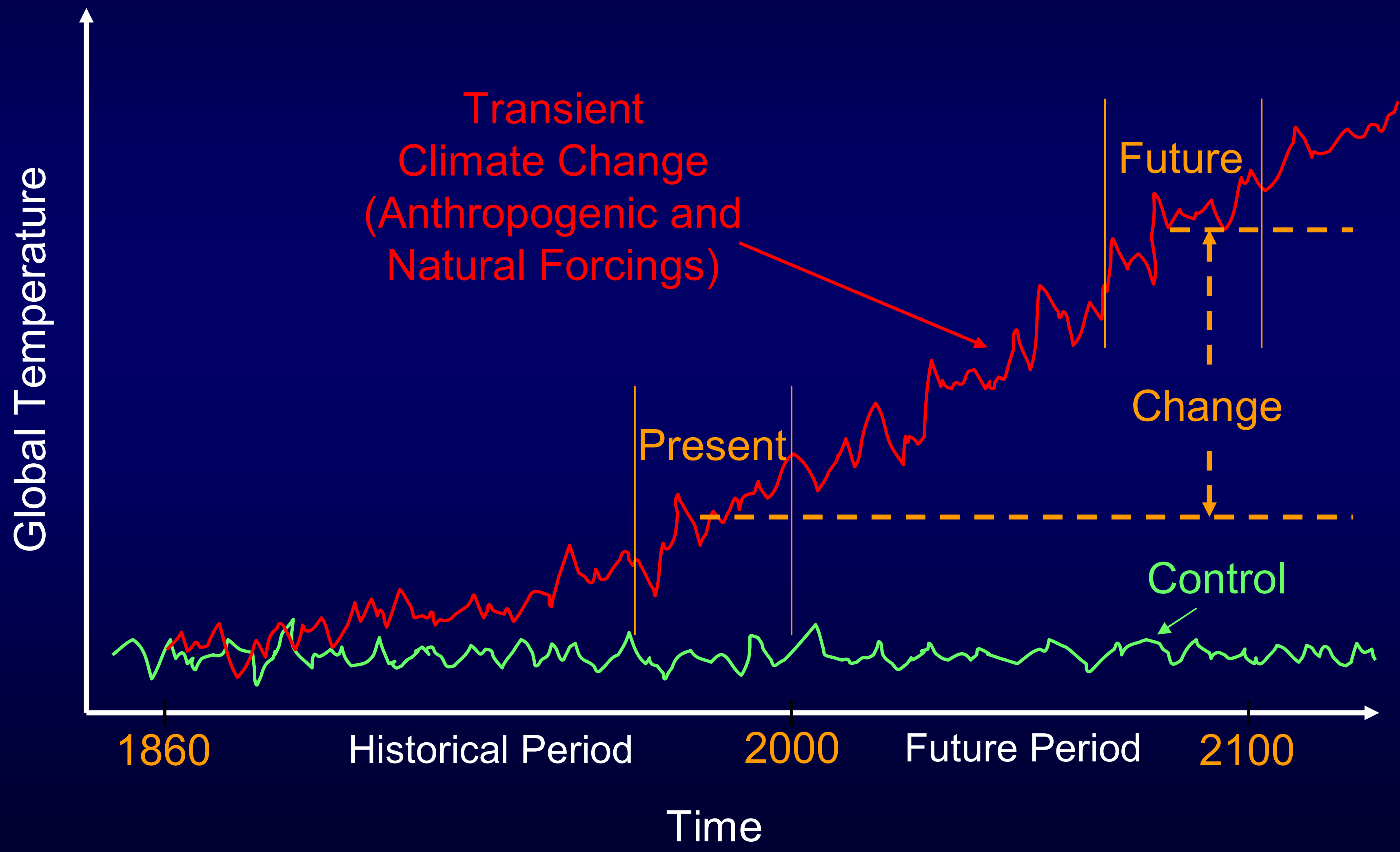
The concept of climate prediction (Lorenz 1975)

- Predictability of the first kind
  - Initial value problem: Prediction of the evolution of the climate system given some knowledge of the initial state
- Predictability of the second kind
  - Boundary value problem: Prediction of the response of the climate system to external forcings
- The predictability range depends on the time scale of the phenomenon of interest

Anthropogenic Climate Change Prediction

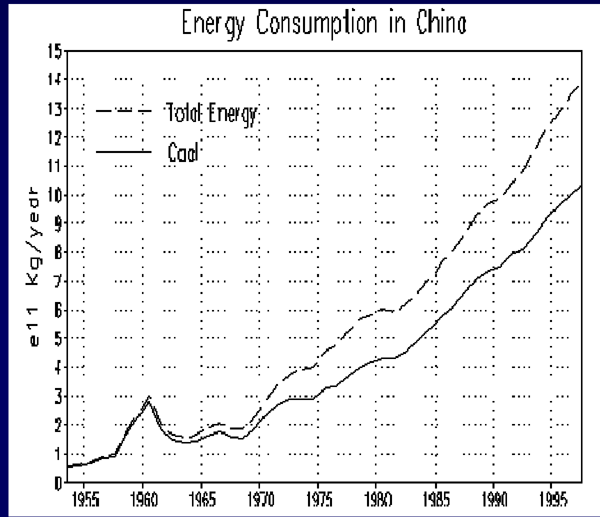
- Time scale of interest is decades to centuries
- Fundamentally, climate change prediction is a predictability problem of the second kind
  - Response of climate statistics (mean, variability, extremes) to changing anthropogenic forcings
- However, a first kind predictability component arises because of the long time scales involved in ocean, cryosphere and biosphere processes
  - The transient evolution of climate statistics may depend on the initial state of the ocean and biosphere

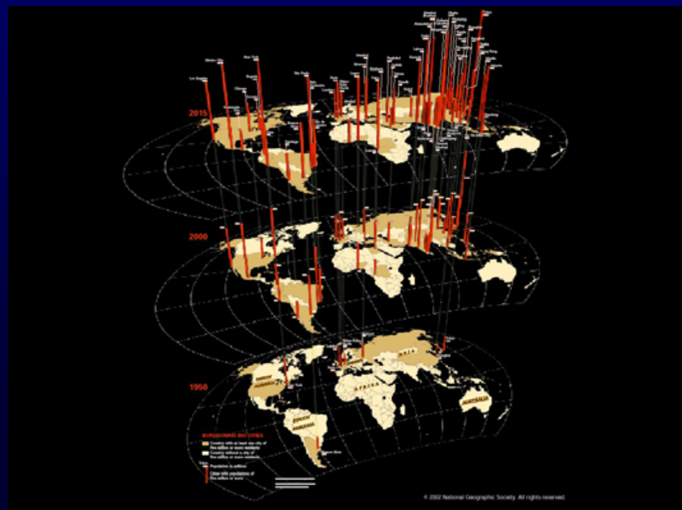
What is a transient Climate Change Simulation?



INTRINSIC SOURCES OF UNCERTAINTY IN CLIMATE CHANGE PREDICTION

Intrinsic sources of uncertainty in climate change prediction: Unpredictability of natural and anthropogenic forcings





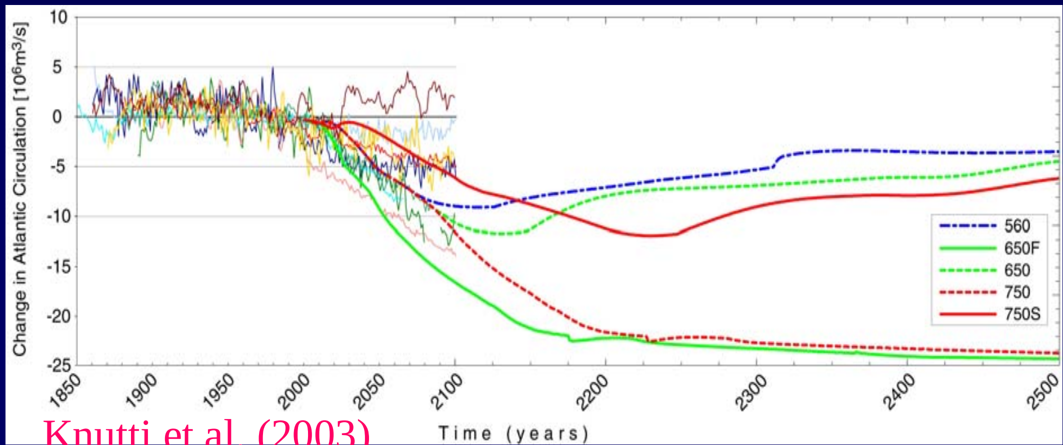
It is impossible to predict major volcanic eruptions or social/technological developments

(scenarios instead of predictions)

Intrinsic sources of uncertainty in Climate Change Prediction: Thresholds and feedbacks

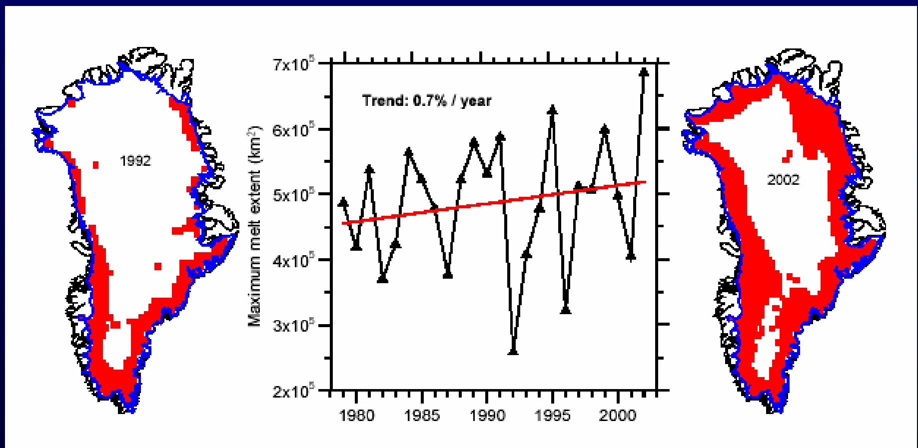
- Feedbacks within the climate system can enhance its non-linearity and thus decrease predictability
  - Snow and sea-ice albedo feedback
  - Biogeochemical / hydrologic feedbacks
  - Adaptation / mitigation feedbacks
- Threshold behaviors also enhance nonlinearity and decrease predictability
  - Shut down of the Thermohaline Circulation
  - Melting of Greenland and Antarctic Ice Sheets

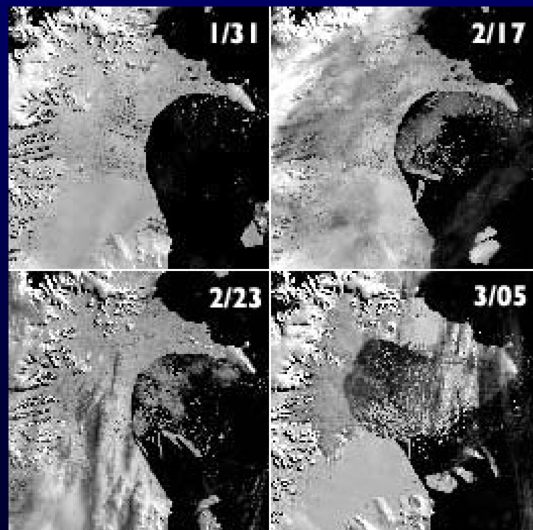
Examples of threshold or feedback behavior



Knutti et al. (2003)

Shut down of the deep oceanic circulation





Melting of Greenland and the West Antarctic ice sheet

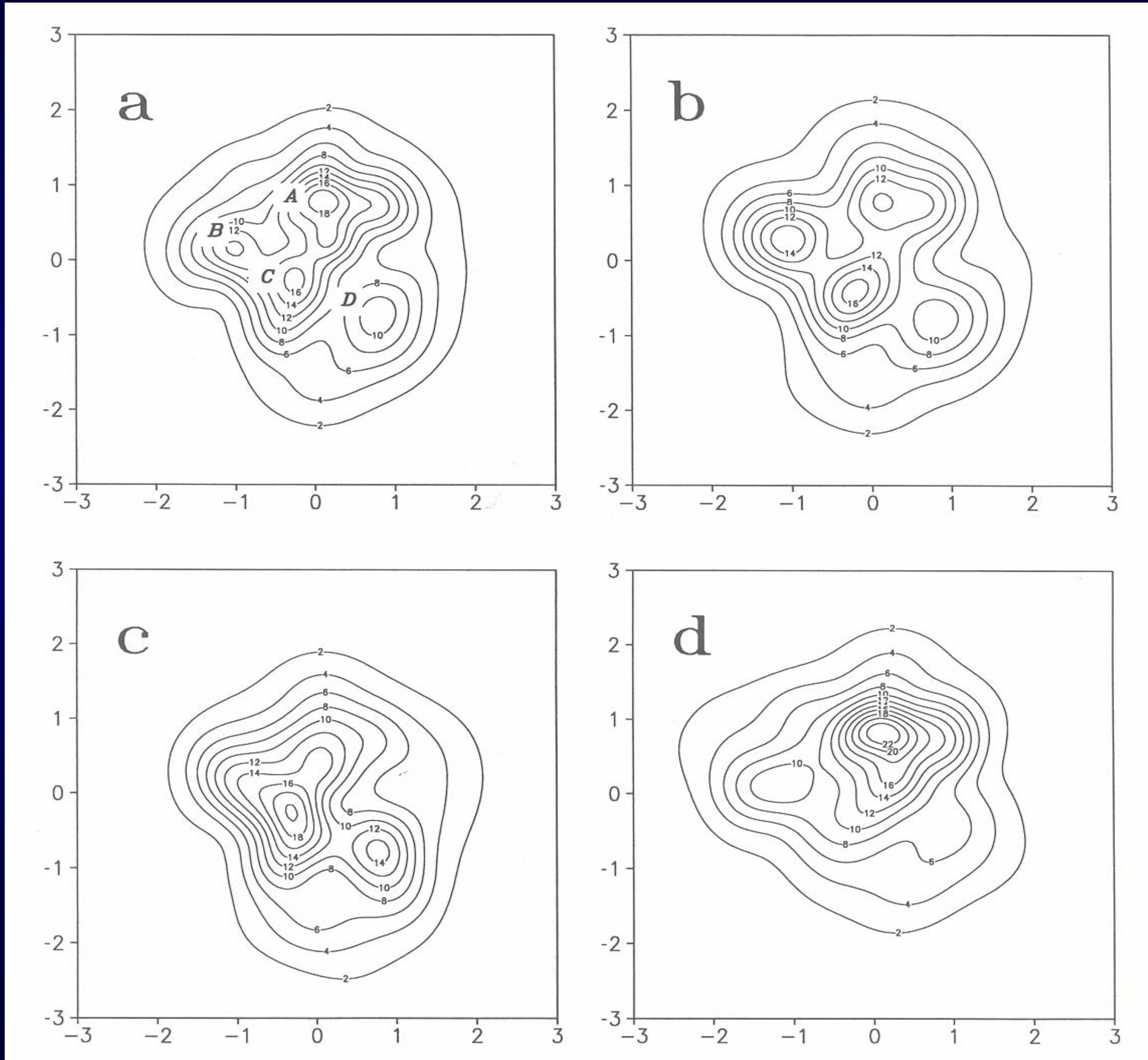
Intrinsic sources of uncertainty in Climate Change Prediction: Regimes

- There is evidence of quasi-stationary regimes within the climate system
- External forcings can modify the frequency of occurrence (PDF) or the structure of different regimes
  - Corti et al. (1999)
  - Laird et al. (1996)

PDF of 500 Hpa Height (Corti et al. 1999)

1949 / 94

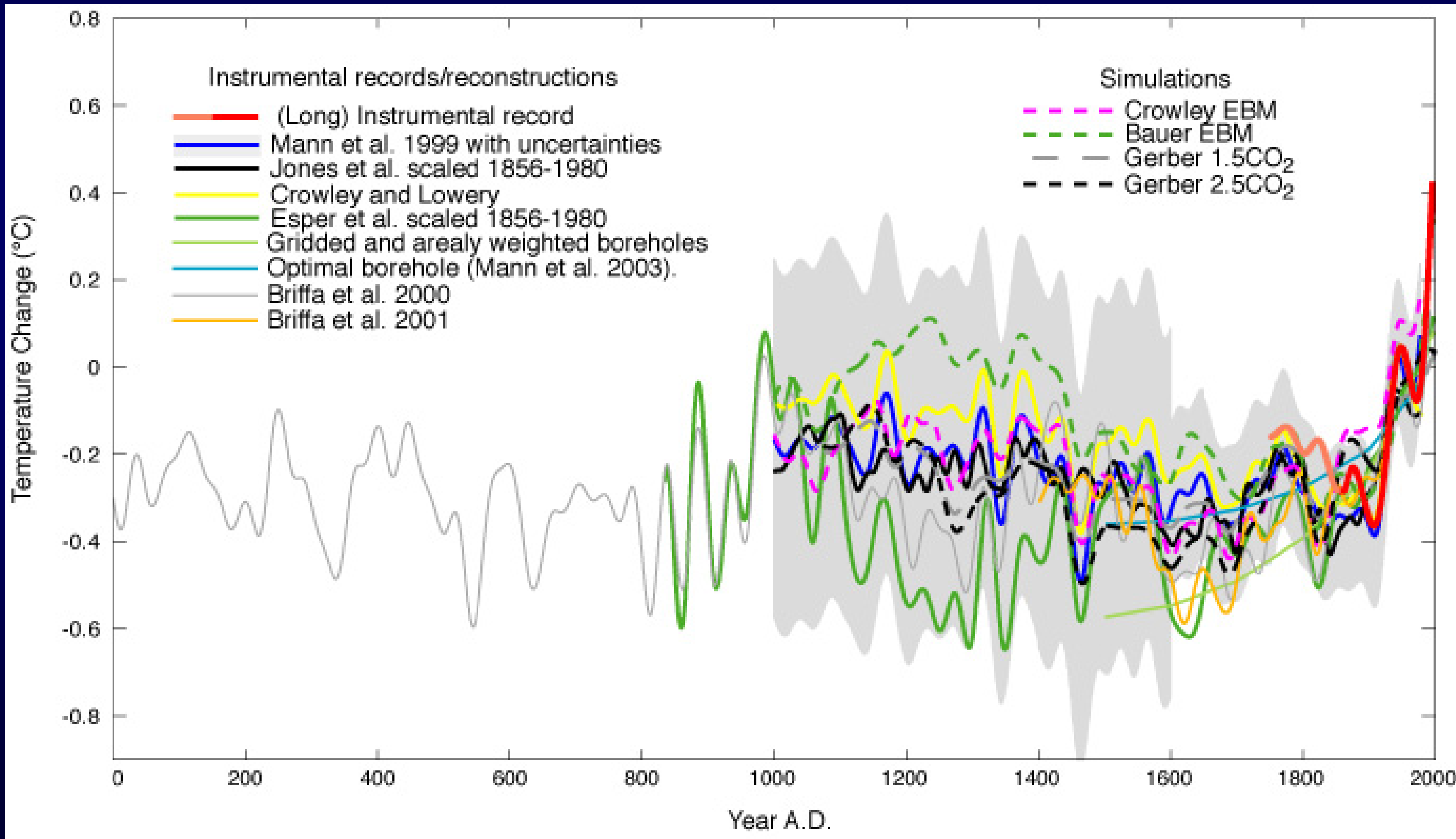
1949 / 94
No EN-LN



1949 / 71

1971 / 94

Intrinsic sources of uncertainty in Climate Change Prediction: Natural variability

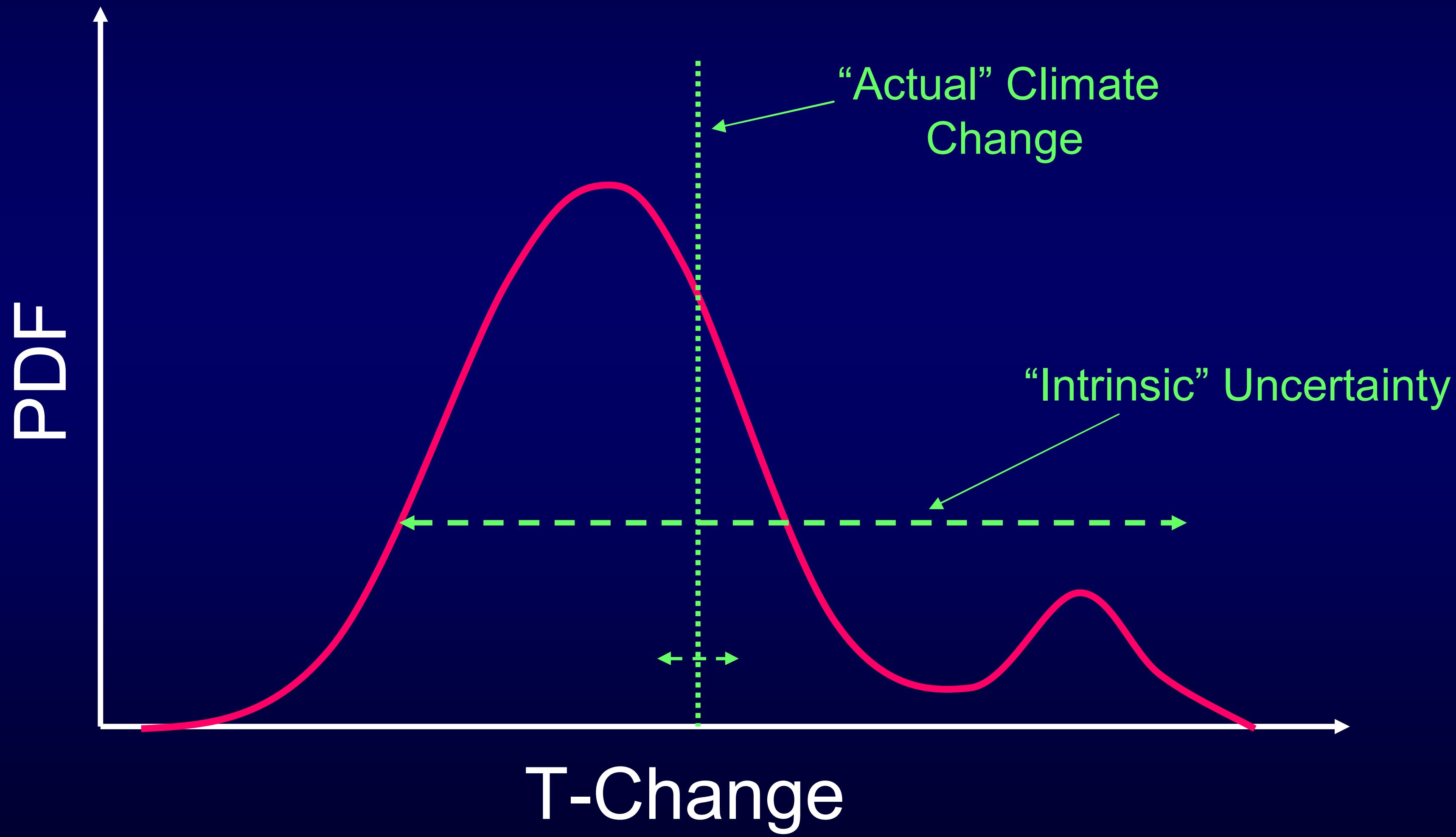


The uncertainty of Climate Change

Because of the internal variability and non-linearity of the climate system and the random component of the external natural and anthropogenic forcings, the climate change of interest is only one realization within a range of possible realizations, each characterized by a certain likelihood to occur.

Climate change is characterized by an intrinsic (unavoidable) uncertainty which needs to be fully explored

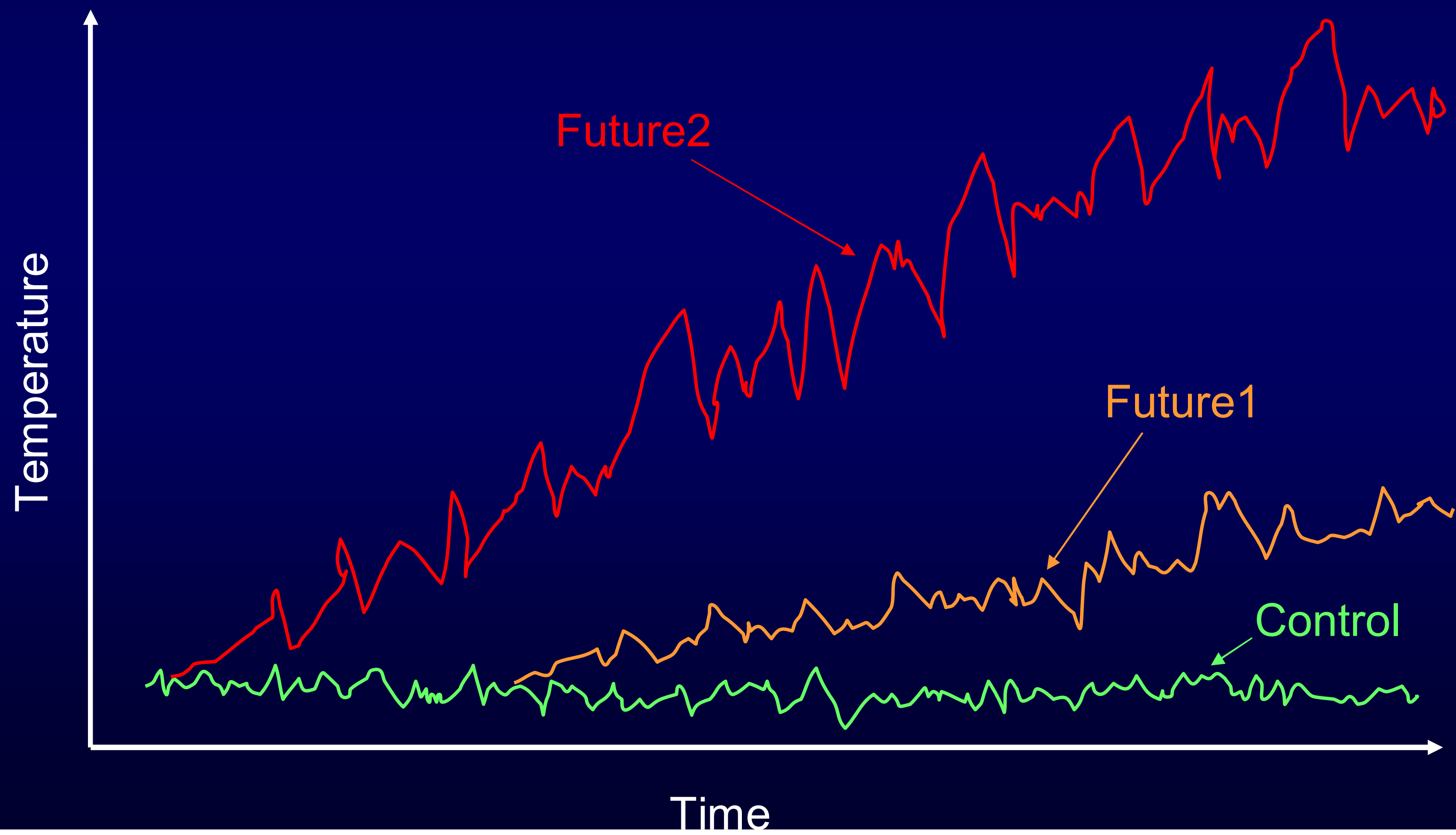
“Actual” Climate Change PDF



ADDED SOURCES OF UNCERTAINTY IN CLIMATE CHANGE PREDICTION

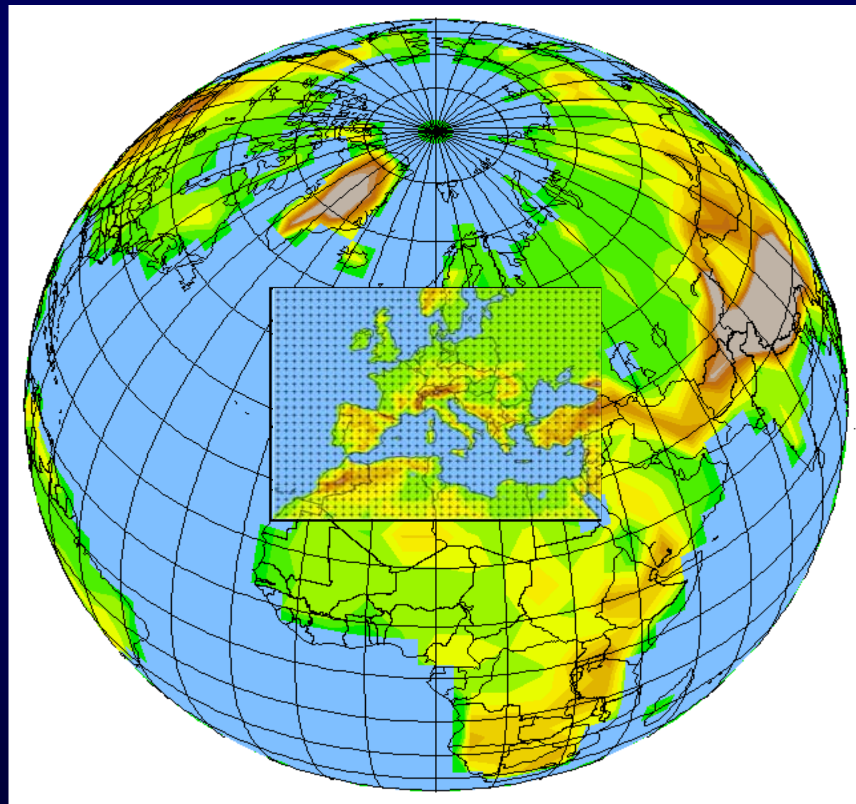
Added sources of uncertainty in Climate Change Prediction: Initial Conditions

Climate can evolve differently depending on the initial conditions of its slow components (which we do not know with good accuracy)



Added sources of uncertainty in Climate Change Prediction: Climate Models

Climate models are imperfect representations of the climate system and different models respond differently to the same climate forcing agents.

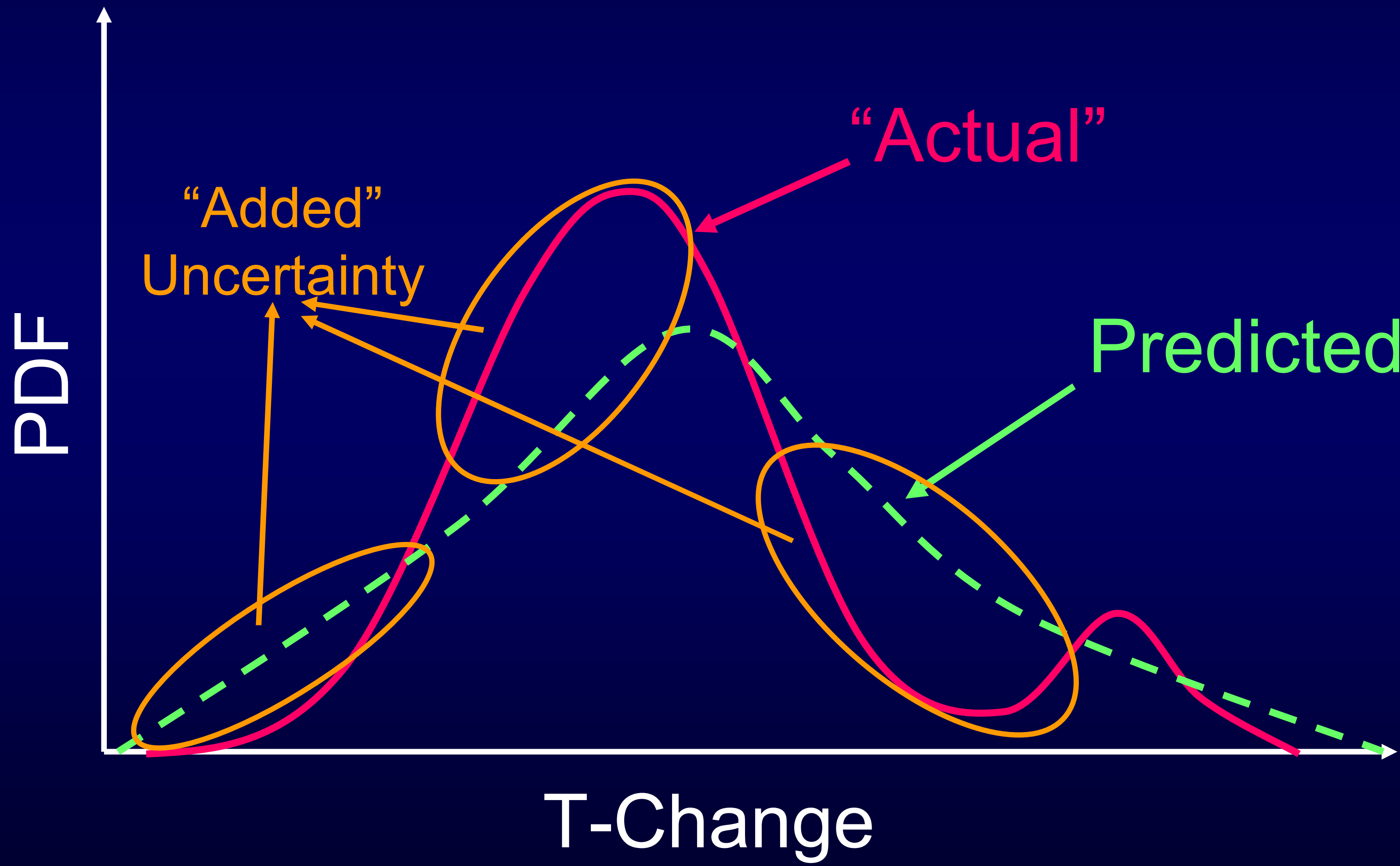


The Climate Change Prediction Problem

The purpose of climate prediction is not to predict what will be the exact climate of the future, but to reconstruct as closely as possible the PDF of possible future climates, i.e. climate change prediction needs to be approached in a probabilistic way.

The use of imperfect models and observations adds an element of uncertainty that needs to be reduced to the extent possible.

Predicted vs. “Actual” Climate Change PDF

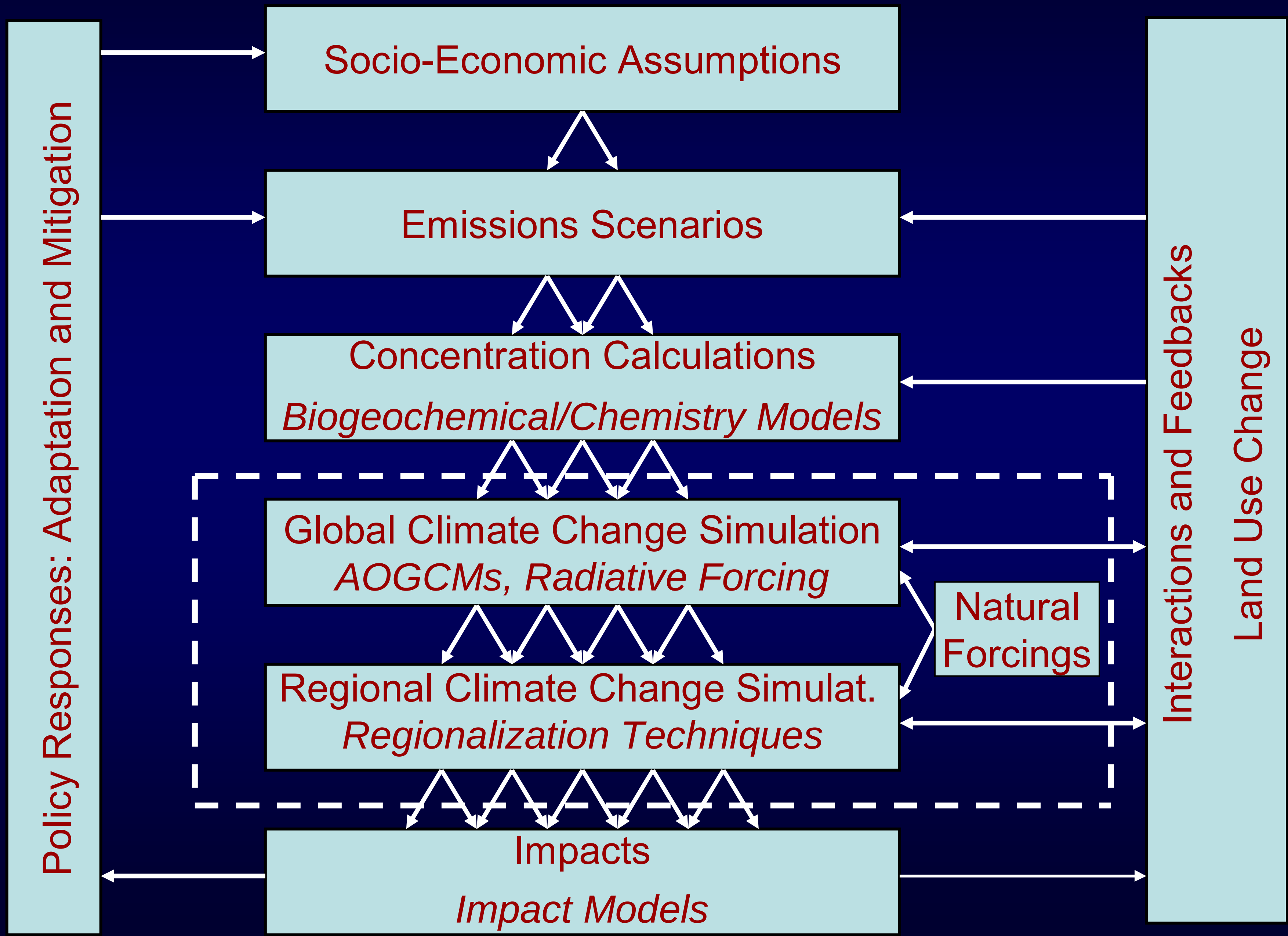


Assessing uncertainty and reliability in climate change prediction

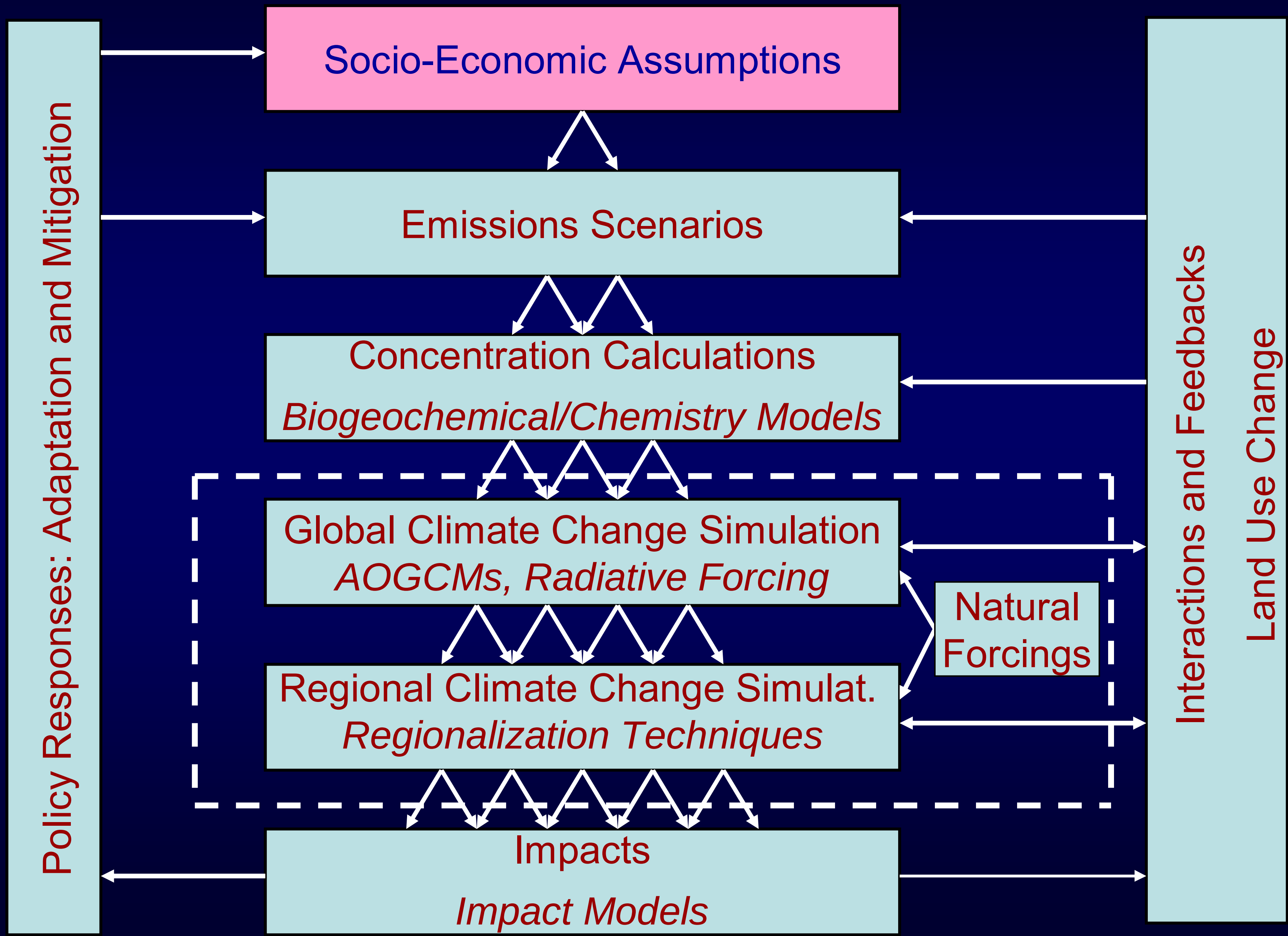
Assessing Uncertainty and Reliability

- We do not have specific case studies to test our anthropogenic climate change predictions, e.g. as in weather and seasonal prediction, and as a result it is critical to:
  - Understand and possibly quantify the uncertainties underlying our predictions
  - Evaluate and possibly quantify the reliability of our predictions

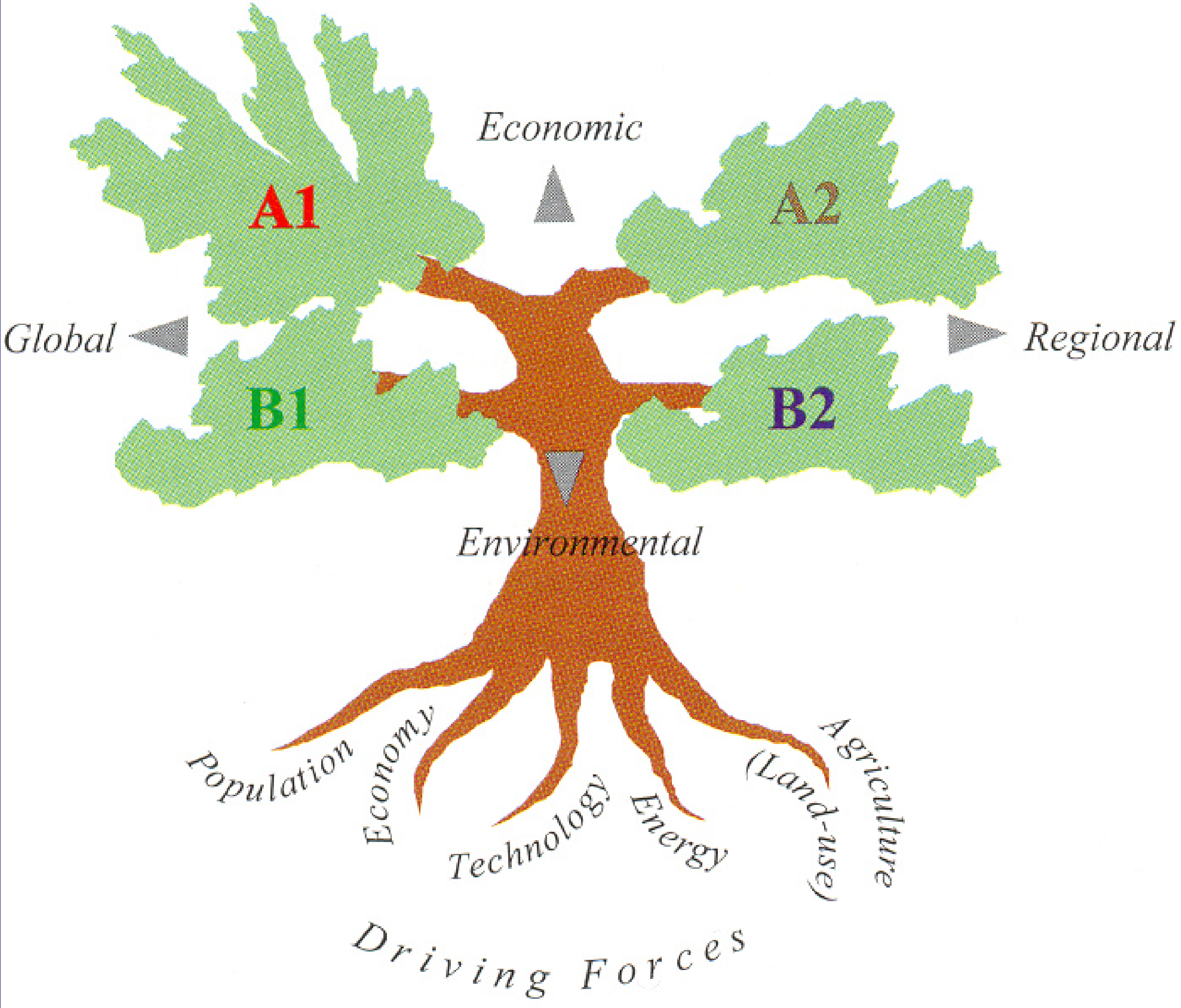
Cascade of uncertainty in climate change prediction



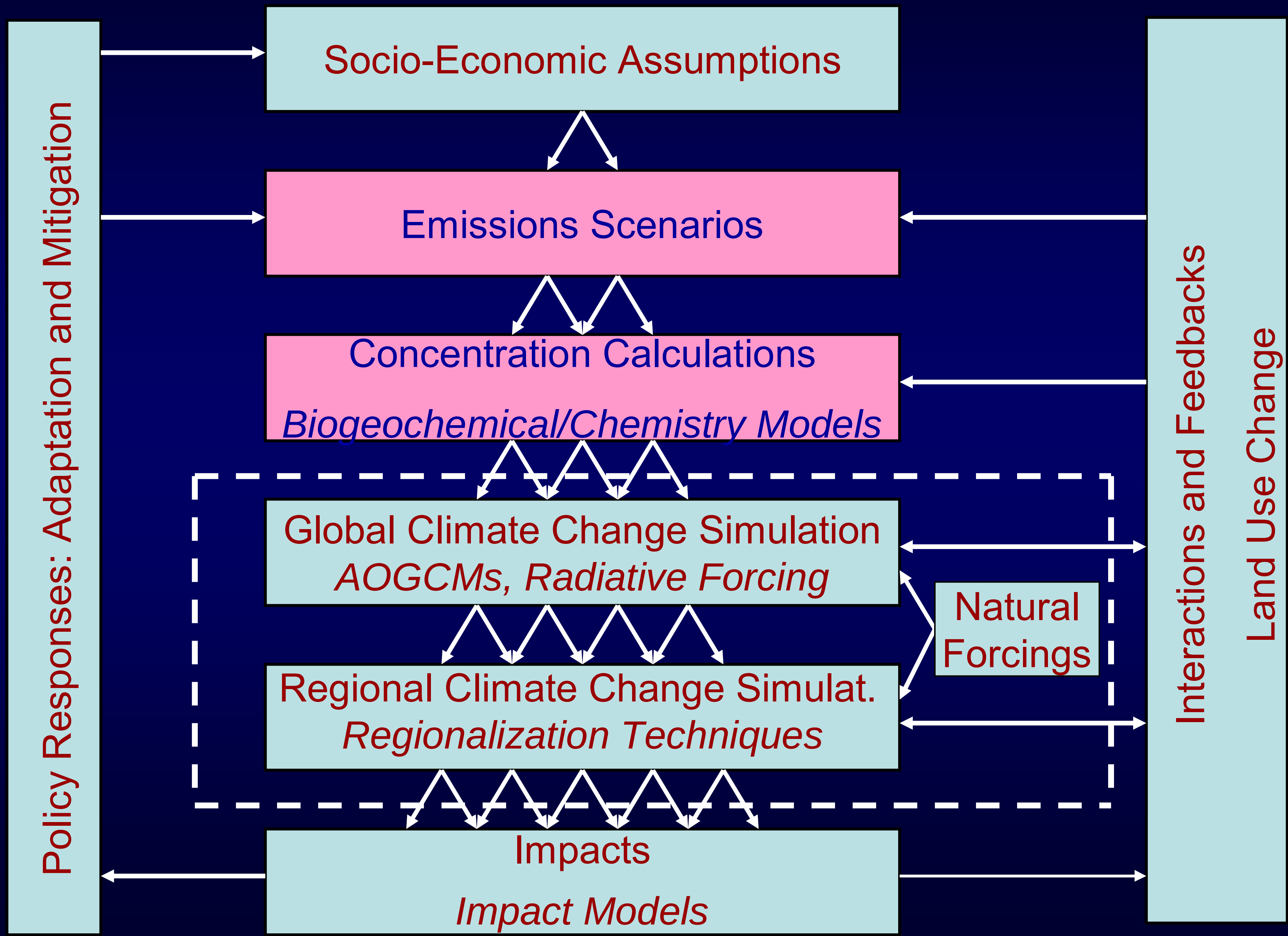
Cascade of uncertainty in climate change prediction



SRES Emission Scenarios

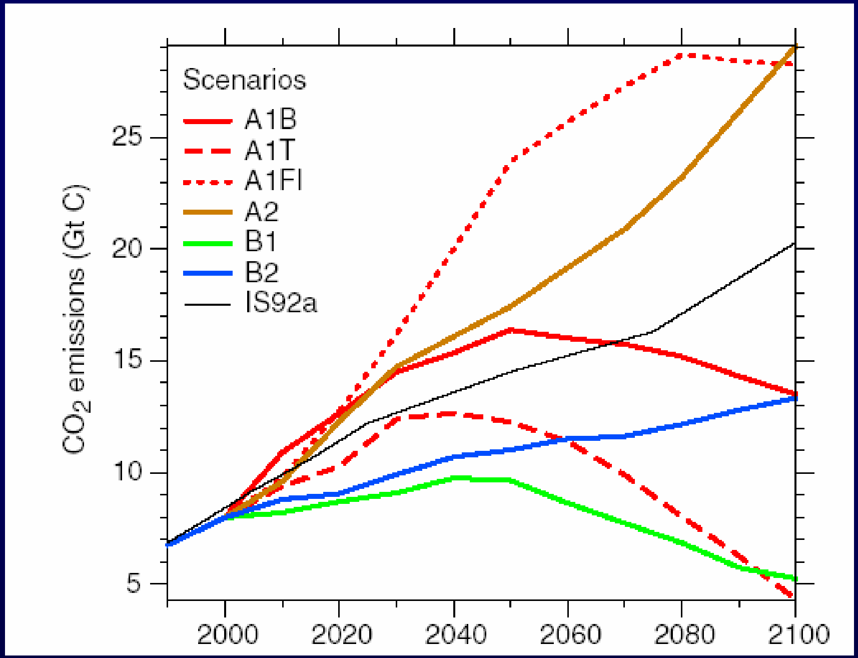


Cascade of uncertainty in climate change prediction

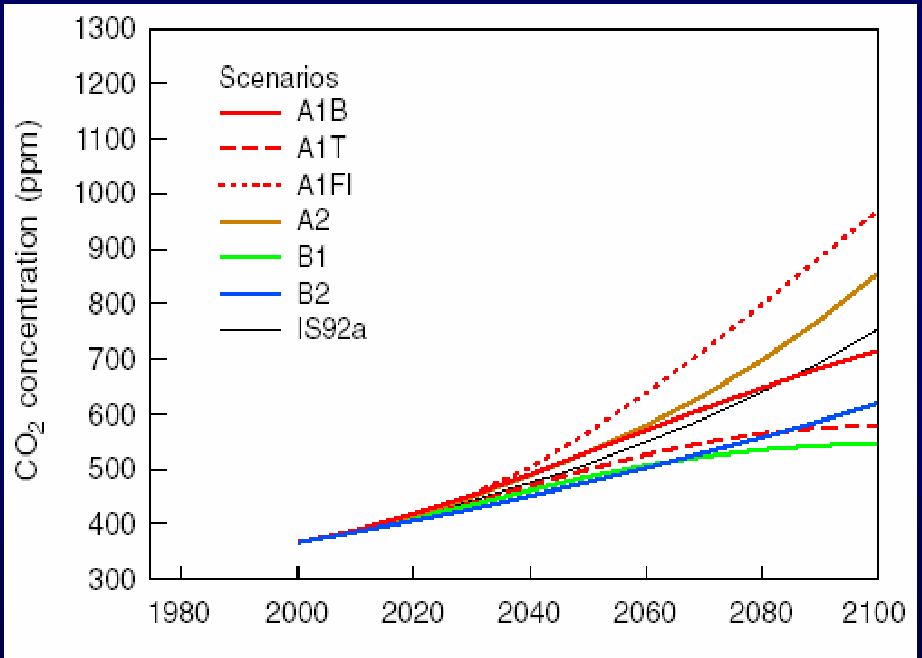


IPCC Emission and Concentration Scenarios

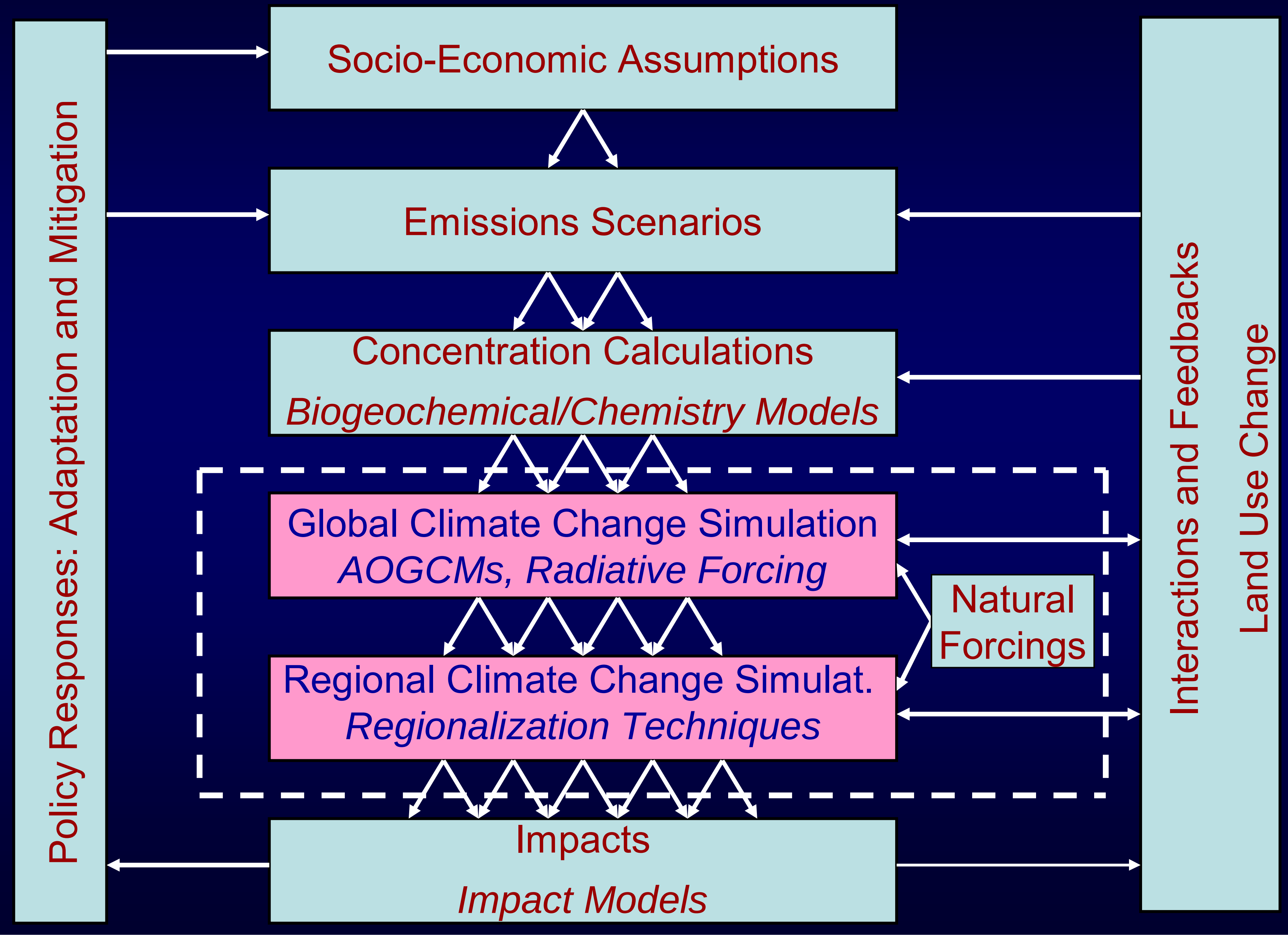
CO2 Emissions



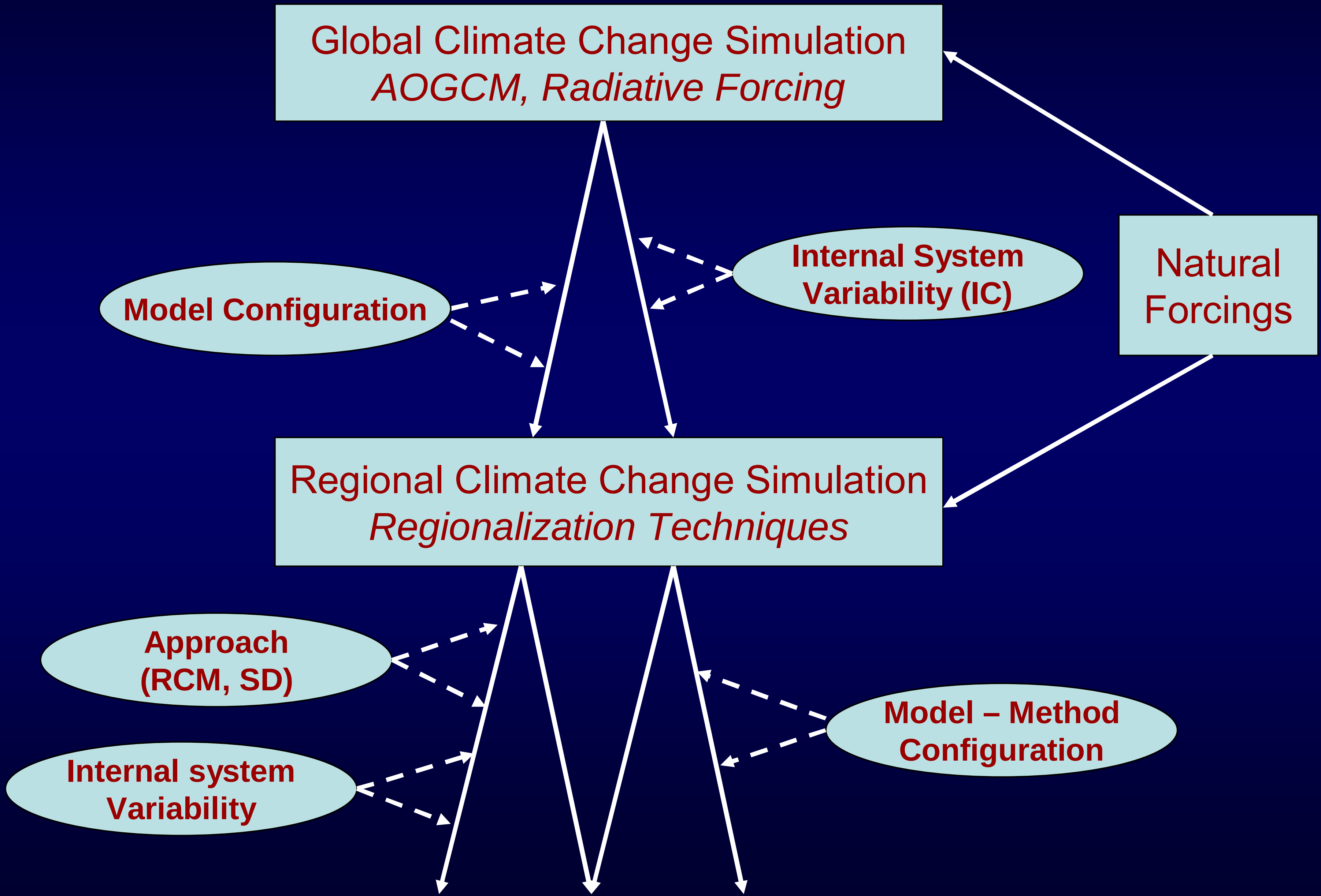
CO2 Concentrations



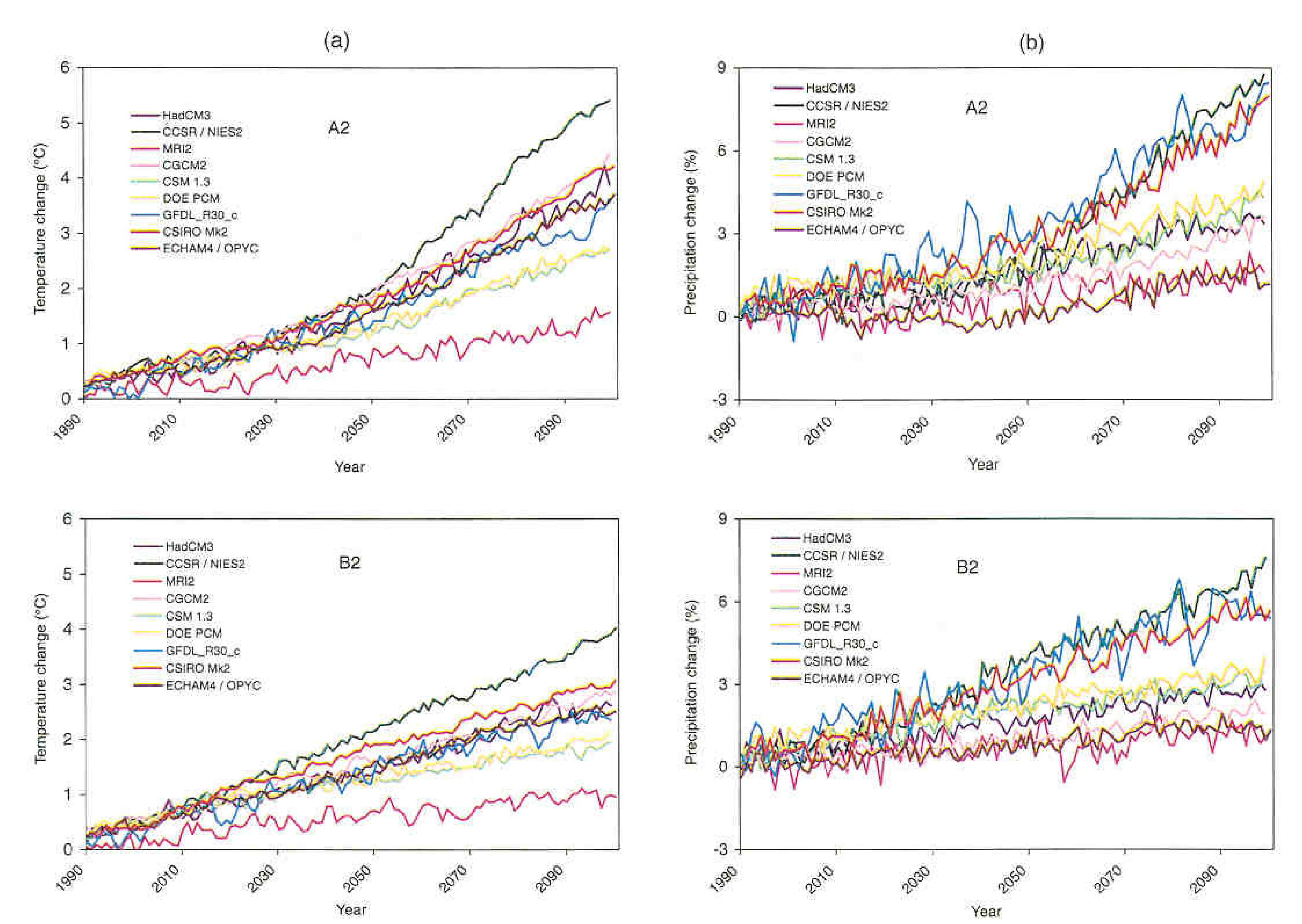
Cascade of uncertainty in climate change prediction



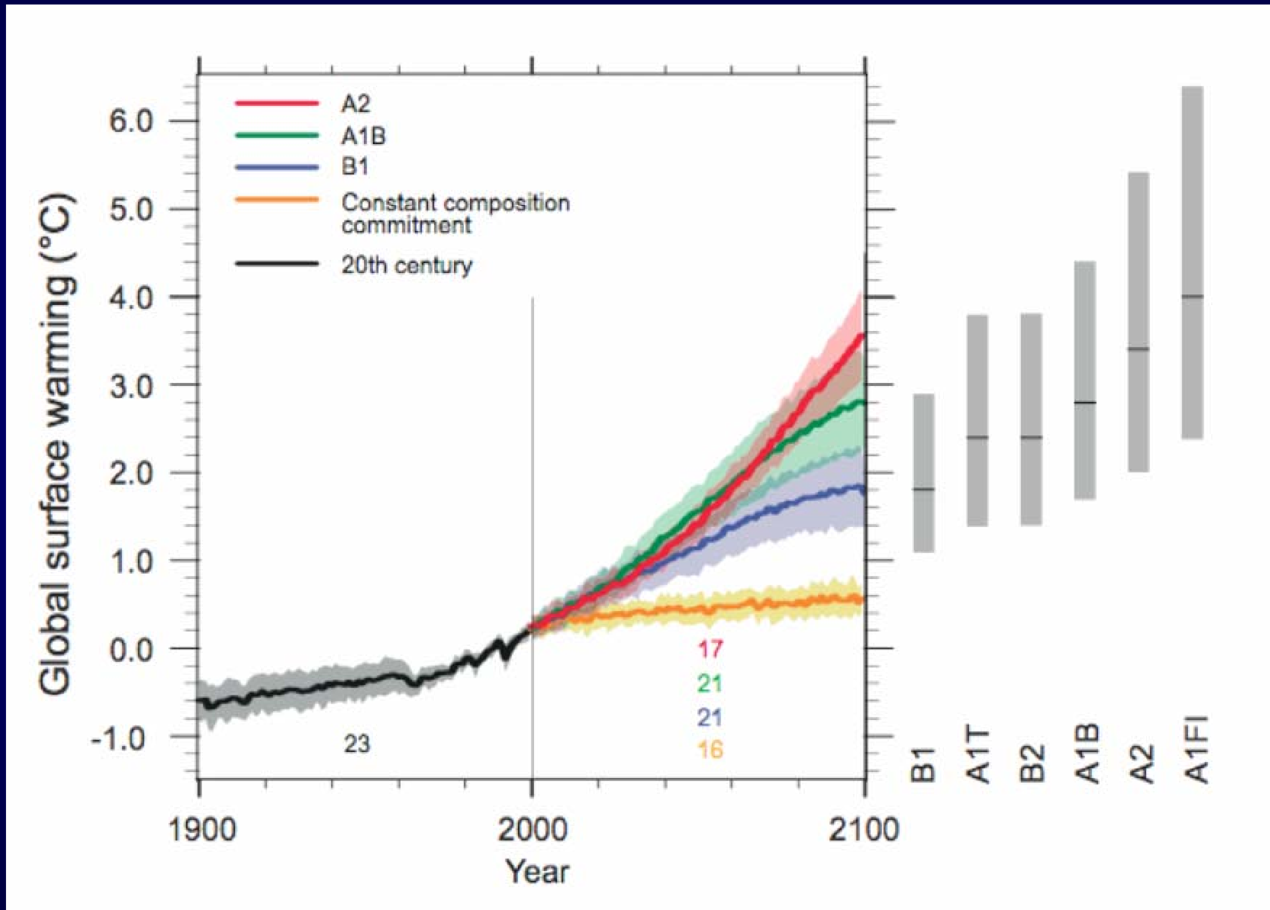
Climate Simulation Segment of the Uncertainty Cascade



Model configuration uncertainty
Global scale

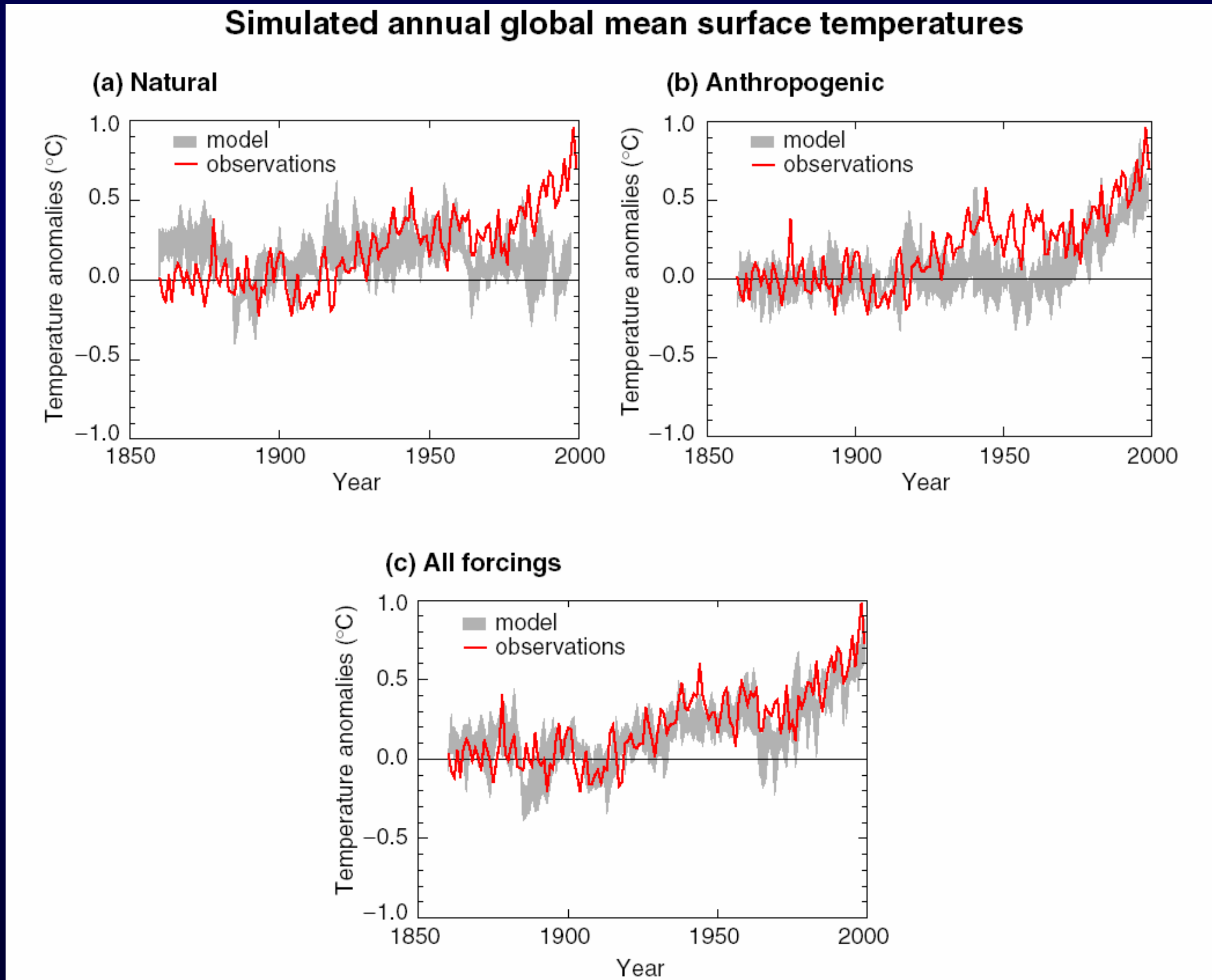


IPCC – 2007: Global temperature change projections for the 21st century

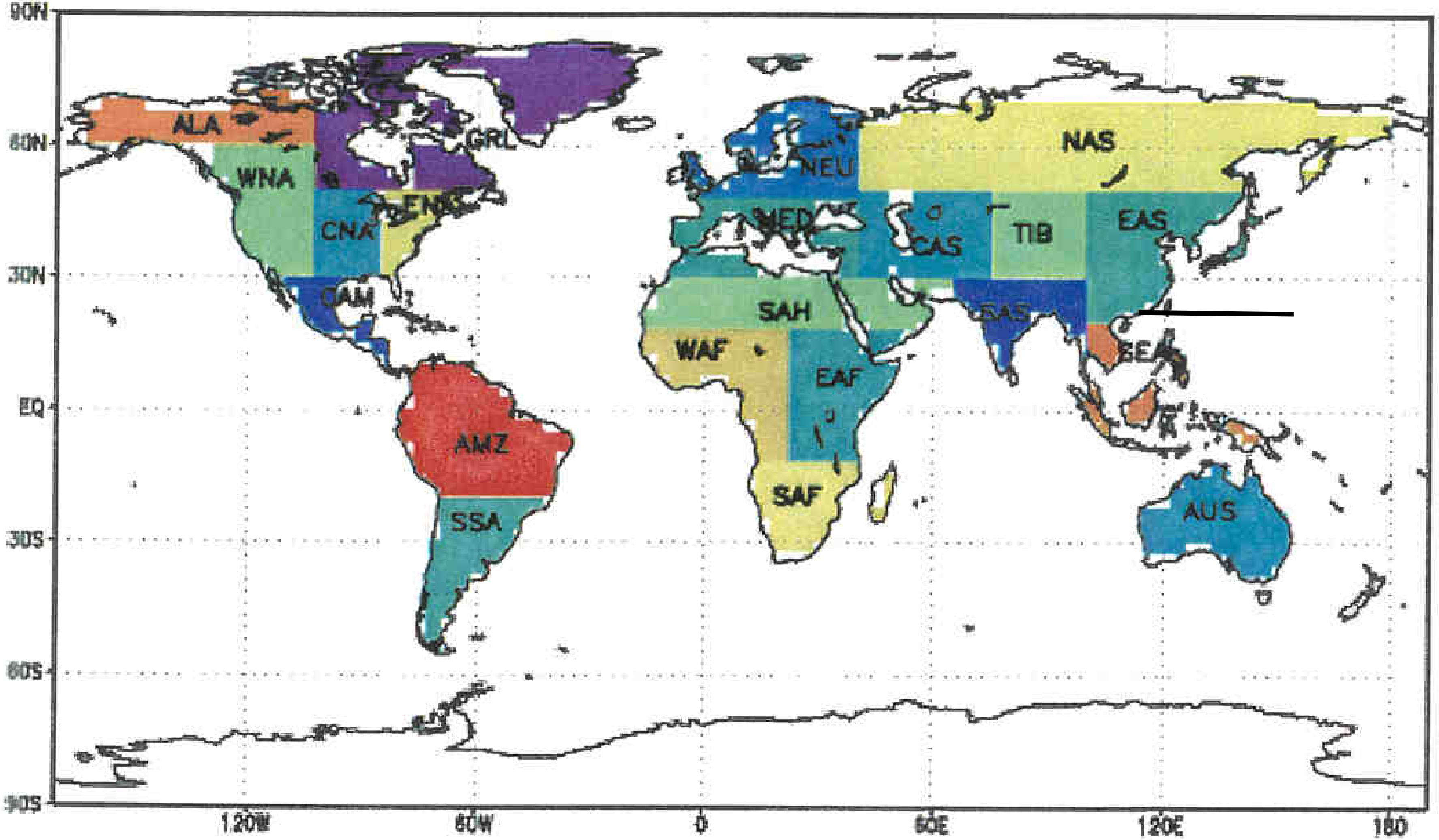


Model configuration and scenario uncertainty contribute approximately equally to the global warming projection uncertainty

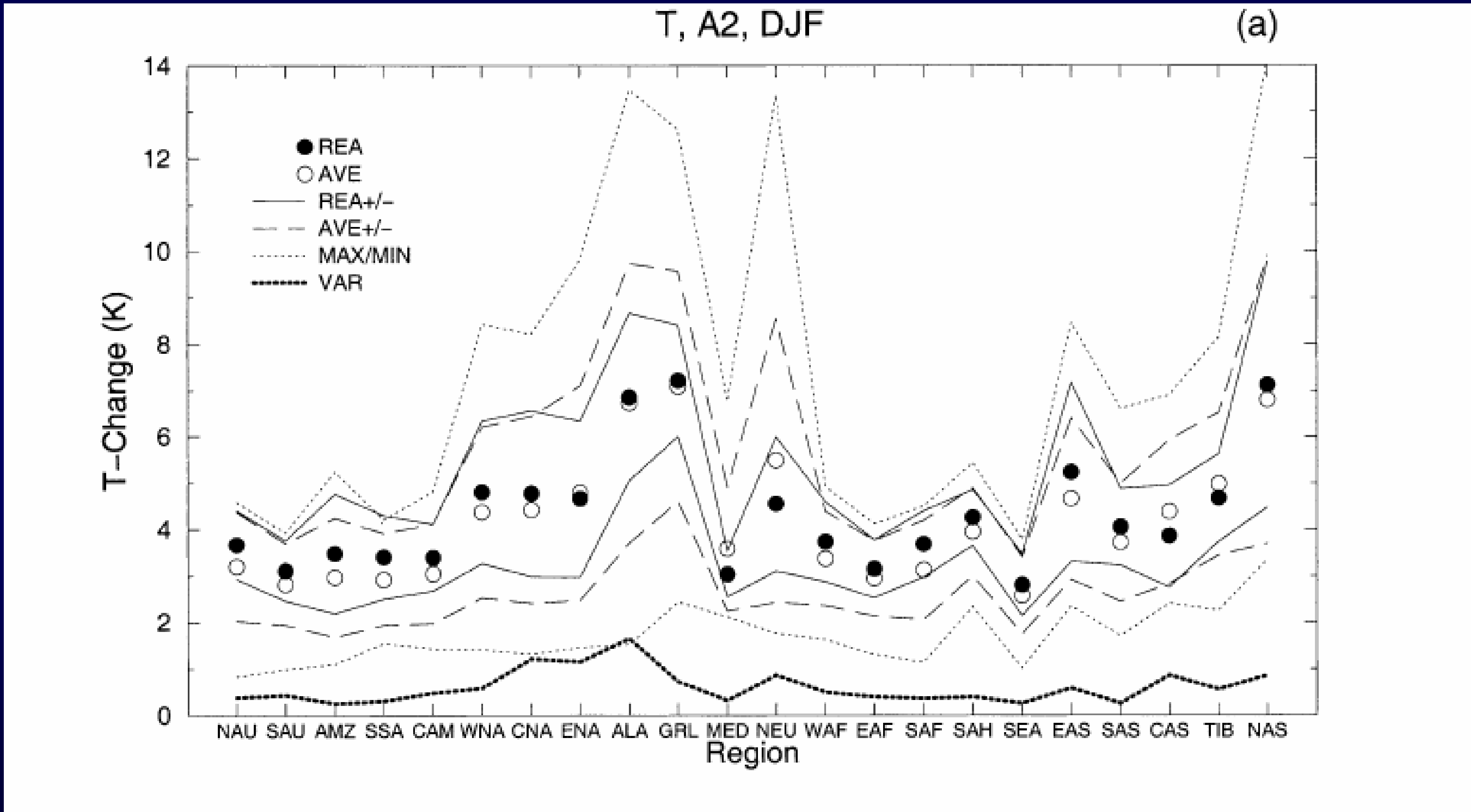
Internal system variability: Global scale



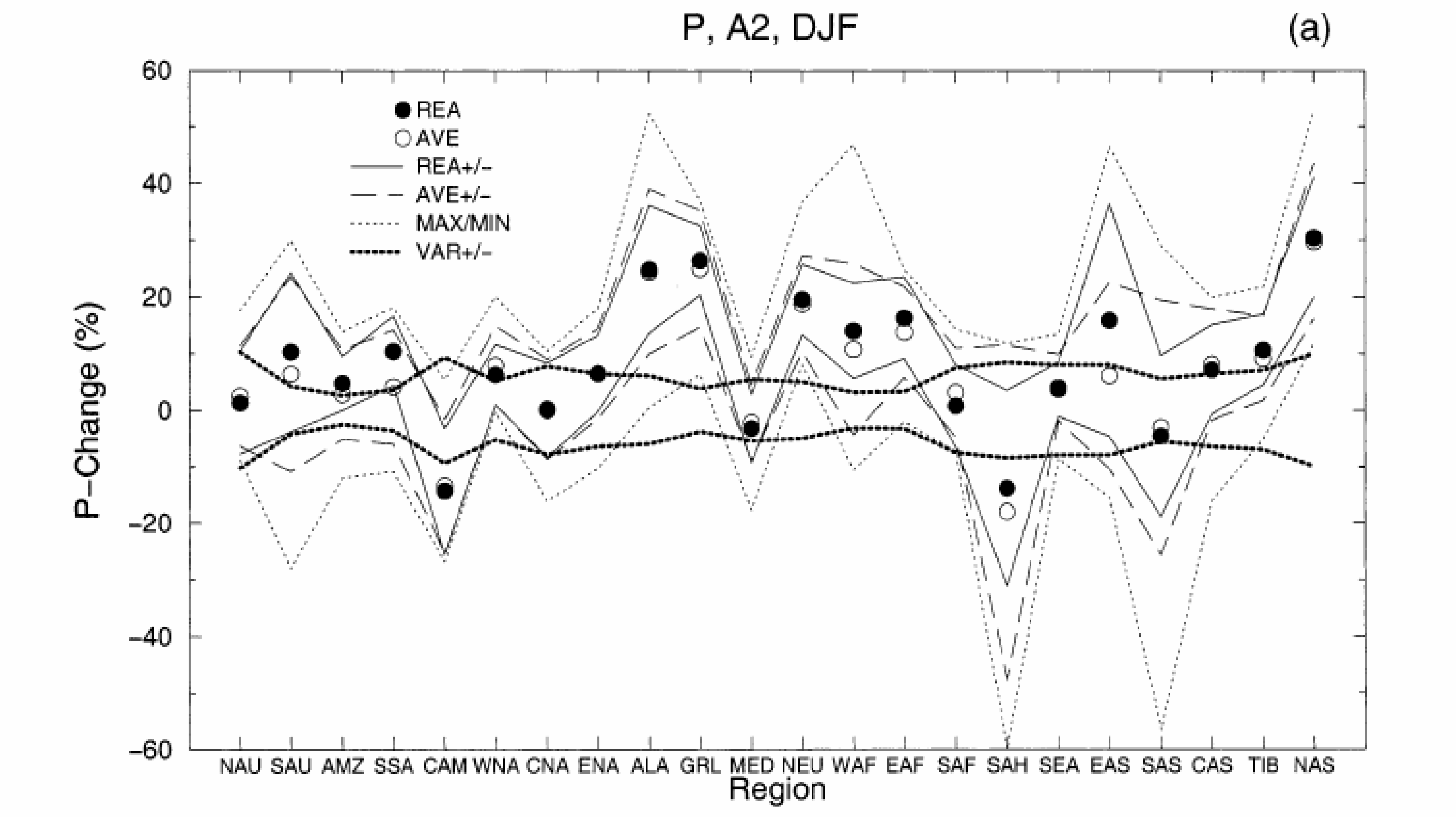
Model configuration uncertainty
Regional scale



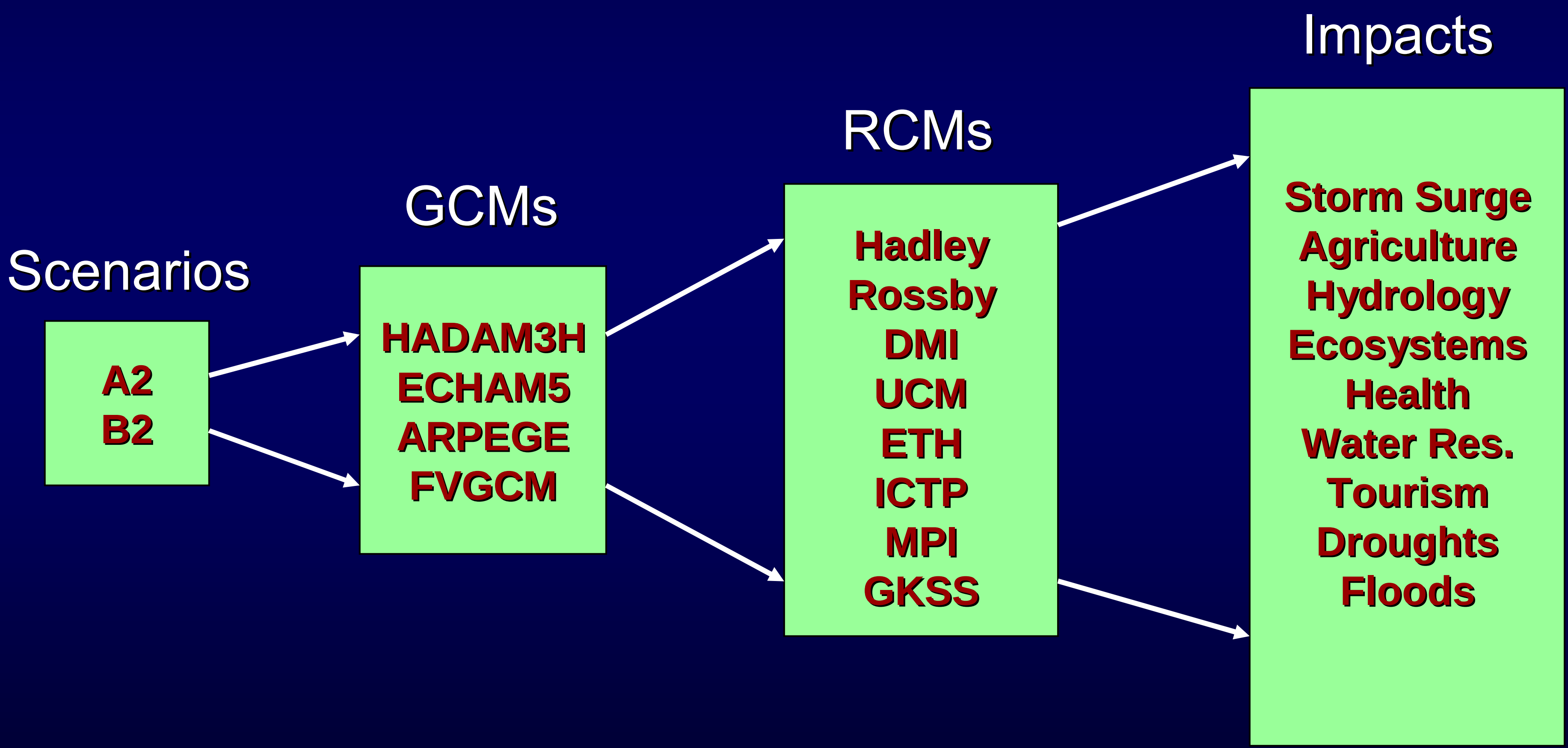
Regional Temperature Change A2, DJF, 9 AOGCMs



Regional Precipitation Change
A2, DJF, 9 AOGCMs

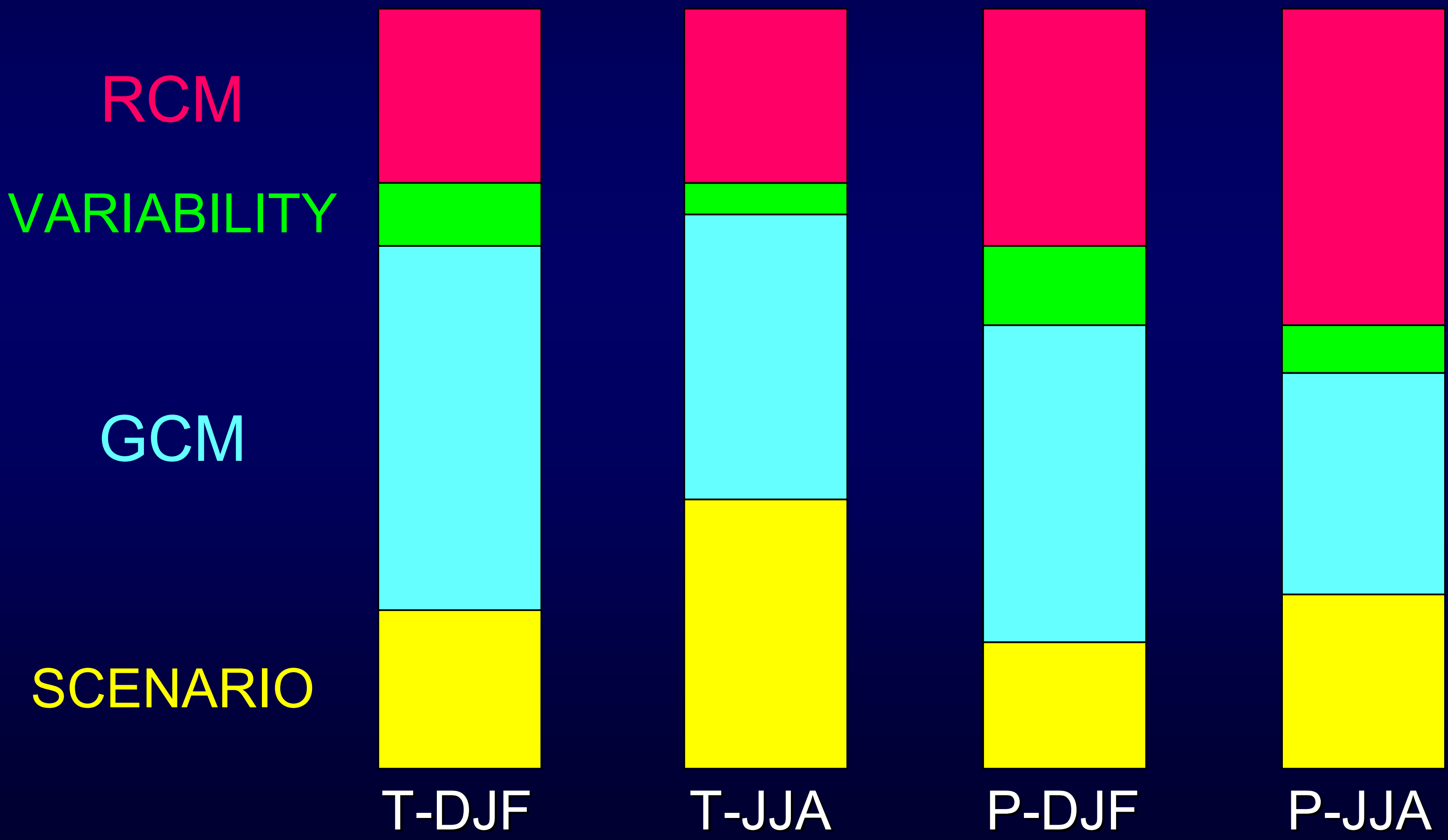


Uncertainties in regional climate change projections: The PRUDENCE strategy



Sources of uncertainty in the simulation of temperature and precipitation change (2071-2100 minus 1961-1990) by the ensemble of PRUDENCE simulations (whole Europe)

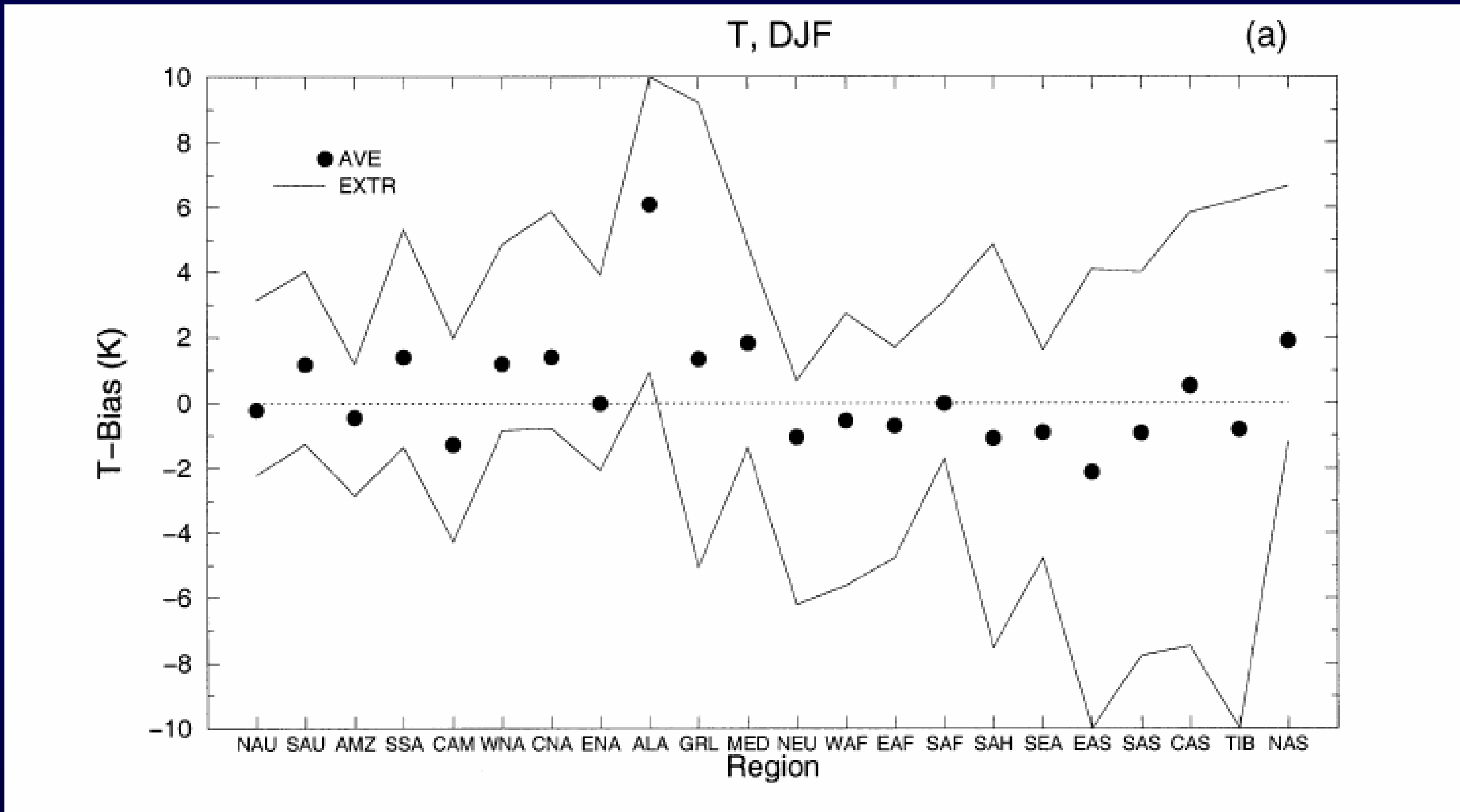
(Note: the scenario range is about half of the full IPCC range, the GCM range does not cover the full IPCC range) (Adapted from Deque et al. 2006)



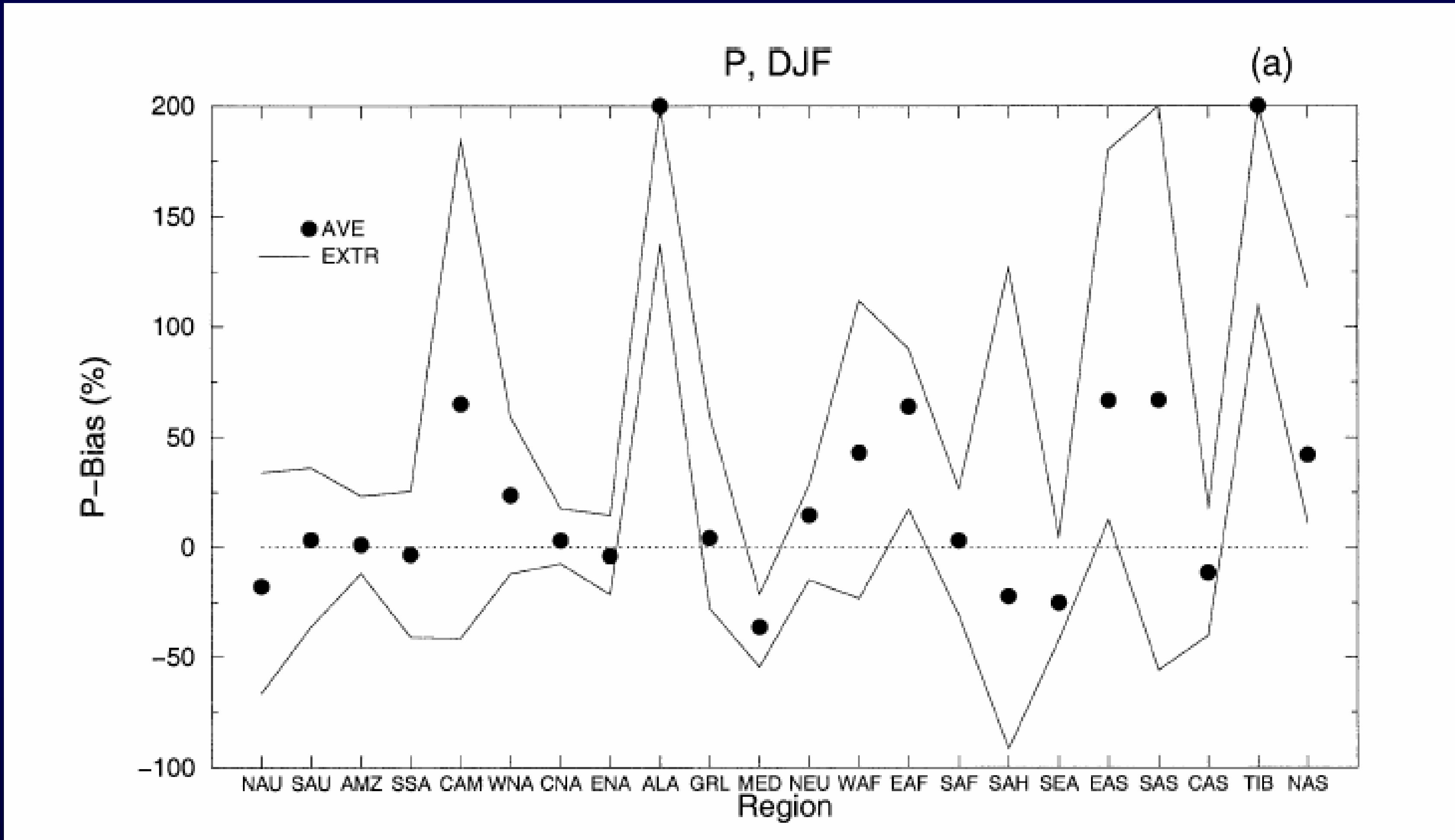
Assessing reliability in climate change prediction

- Model performance in reproducing observed features of the historical climate
- Inter-model agreement in the simulation of climate change features
- Model performance in reproducing reconstructed features of past climates
- Physical soundness of the processes that lead to the simulated changes

Temperature Bias, 9 AOGCMs



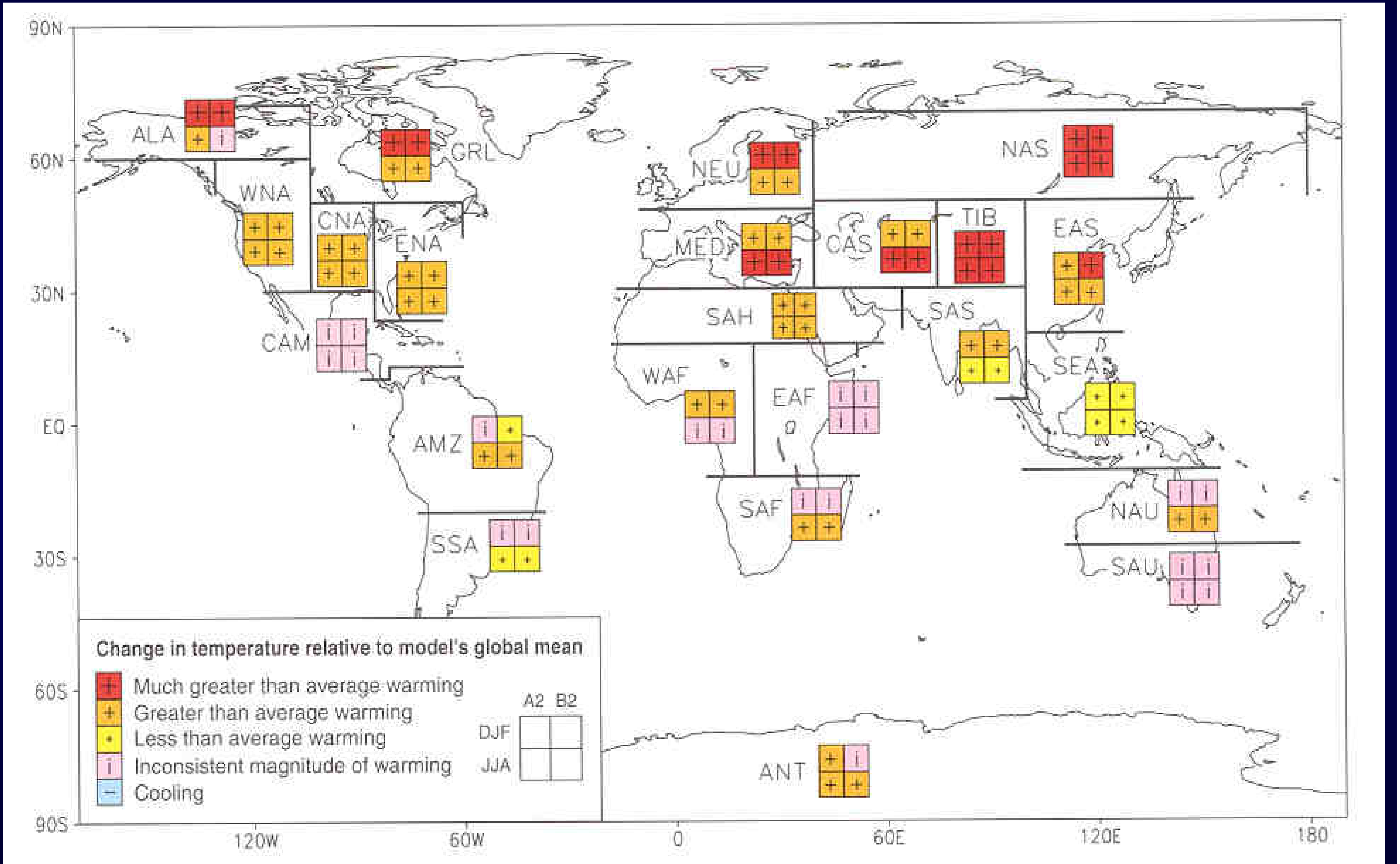
Precipitation Bias, 9 AOGCMs



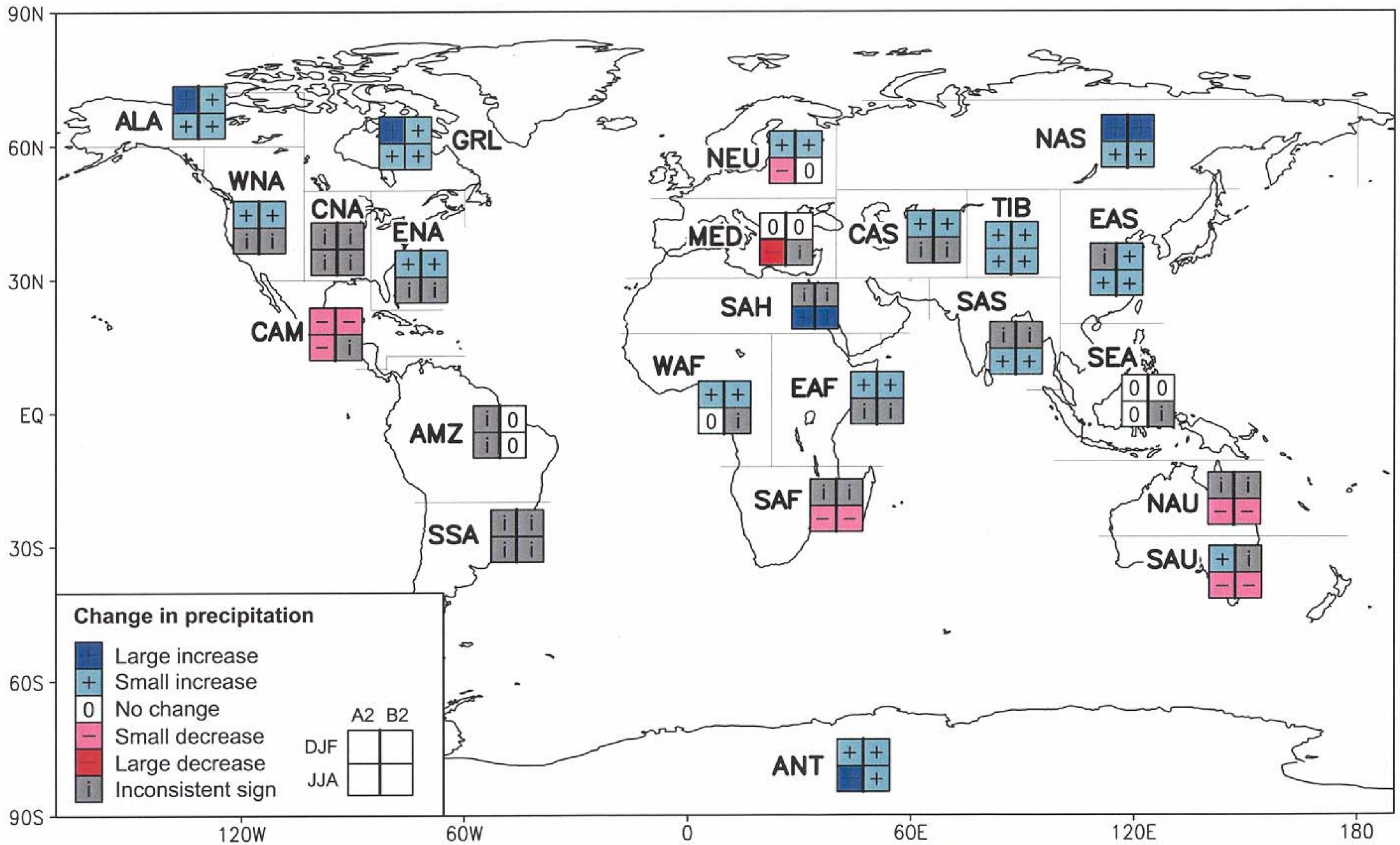
Reliability Criteria

- Model performance in reproducing observed features of the historical climate
- Inter-model agreement in the simulation of climate change features
- Model performance in reproducing reconstructed features of past climates
- Physical soundness of the processes that lead to the simulated changes

Inter-model agreement in the simulation of temperature change



Inter-model agreement in the simulation of precipitation change



Accounting for model performance and convergence criteria : The REA Method (Giorgi and Mearns 2002,2003)

$$\widetilde{\Delta T} = \tilde{A}(\Delta T) = \frac{\sum_i R_i \Delta T_i}{\sum_i R_i},$$

$$\tilde{\delta}_{\Delta T} = [\tilde{A}(\Delta T_i - \widetilde{\Delta T})^2]^{1/2} = \left[\frac{\sum_i R_i (\Delta T_i - \widetilde{\Delta T})^2}{\sum_i R_i}\right]^{1/2}$$

$$R_i = [(R_{B,i})^m \times (R_{D,i})^n]^{[1/(m\times n)]}$$
$$= \left\{\left[\frac{\epsilon_T}{\mathrm{abs}(B_{T,i})}\right]^m \left[\frac{\epsilon_T}{\mathrm{abs}(D_{T,i})}\right]^n\right\}^{[1/(m\times n)]}$$

- ΔT_i = temperature change for model i
- R_i = reliability for model i
- R_B = bias reliability
- R_D = convergence reliability
- Є = measure of natural variability

Ensemble model reliability

$$\tilde{\rho} = \tilde{A}(R) = \frac{\sum_i R_i^2}{\sum_i R_i}$$

Reliability Criteria

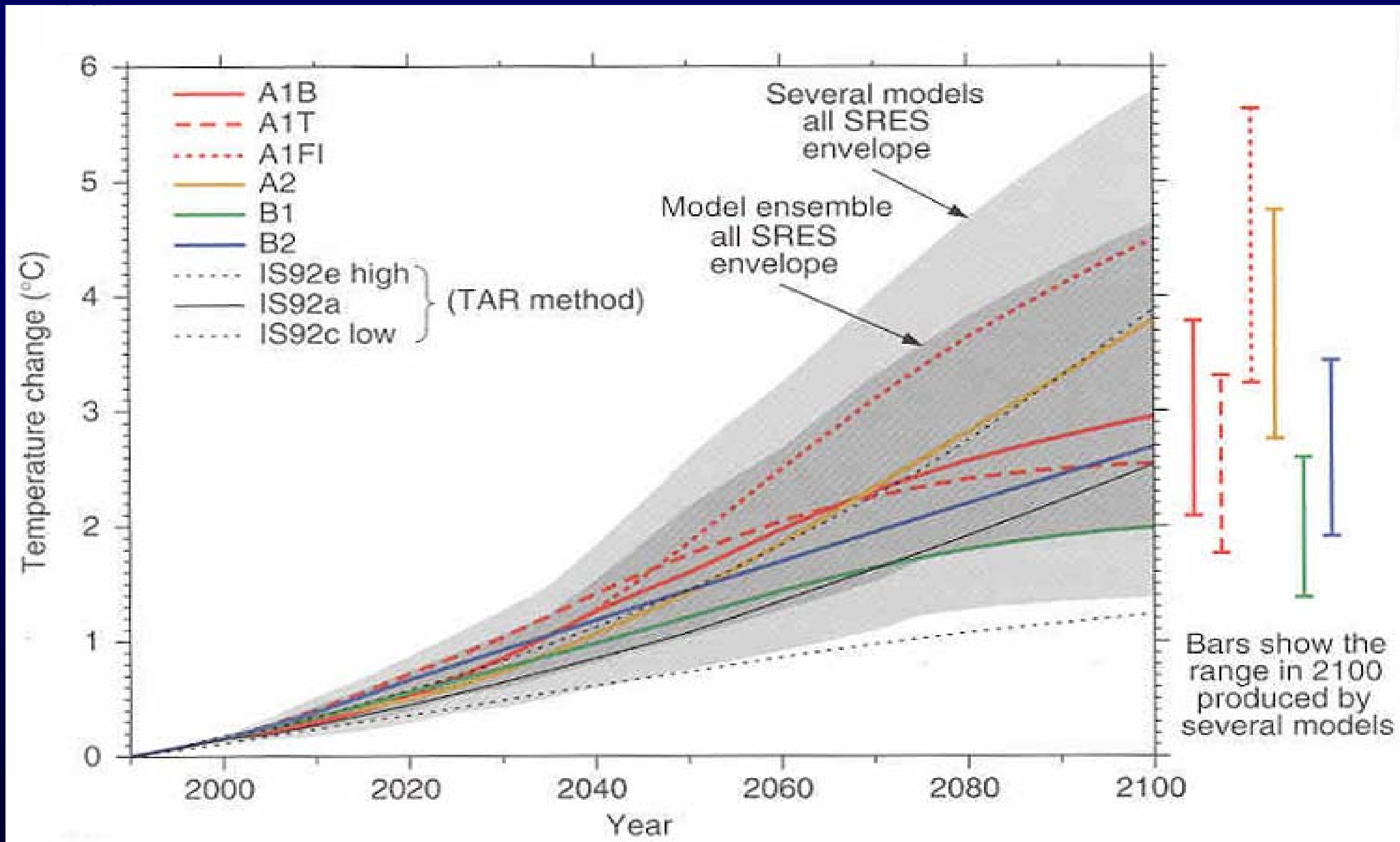
- Model performance in reproducing observed features of the historical climate
- Inter-model agreement in the simulation of climate change features
- Model performance in reproducing reconstructed features of past climates
- Physical soundness of the processes that lead to the simulated changes
  - Process understanding

Predicting climate change

- There is substantial uncertainty across models in the simulation of climate change, therefore a climate change prediction needs to be based on the compounded information from different models and, where available, different methods
- Different approaches are being developed to produce probabilistic climate change information from ensembles of model simulations

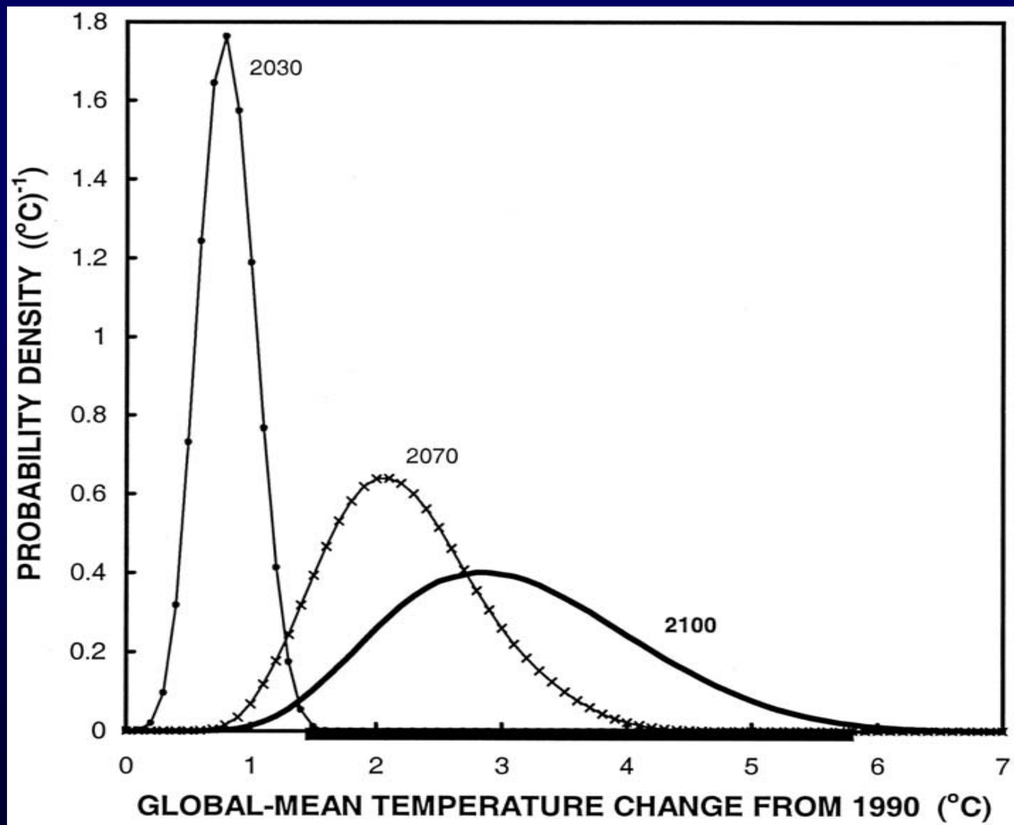
Methods to Produce PDFs of Future Climate Conditions

Model range with flat distribution (IPCC 2001)



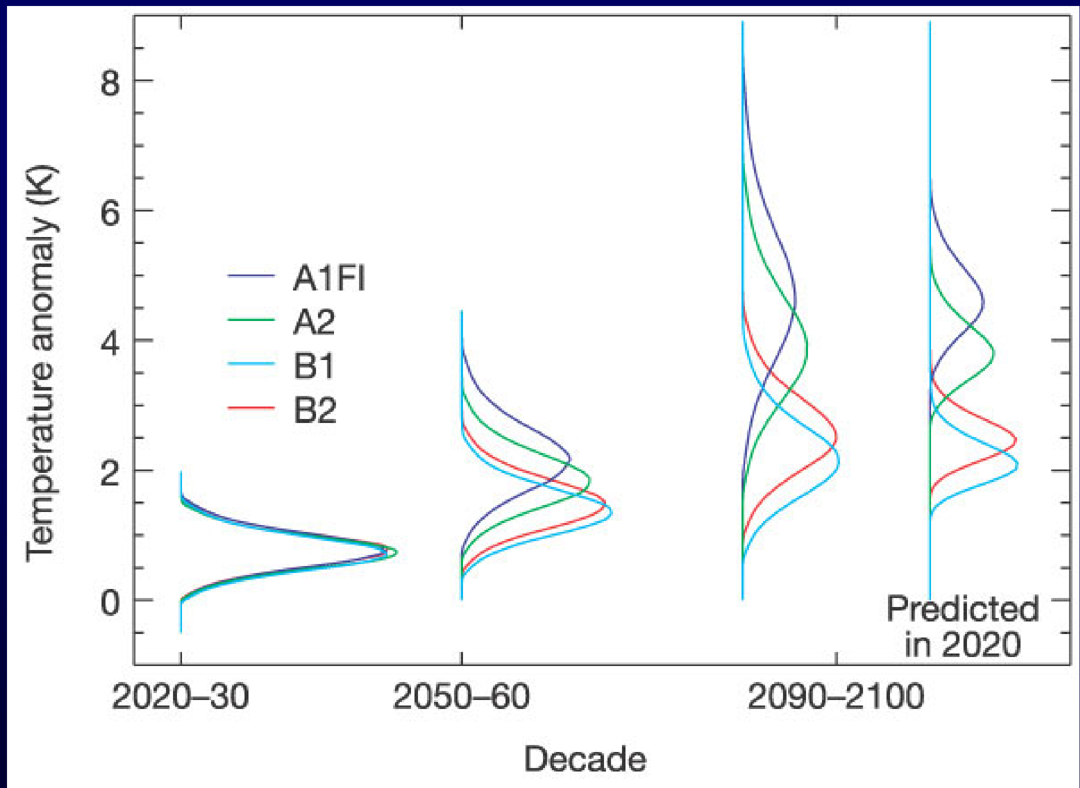
Methods to Produce PDFs of Future Climate Conditions

Large ensembles using simplified climate models
(Wigley and Raper 2001; Webster et al 2004)



Methods to Produce PDFs of Future Climate Conditions

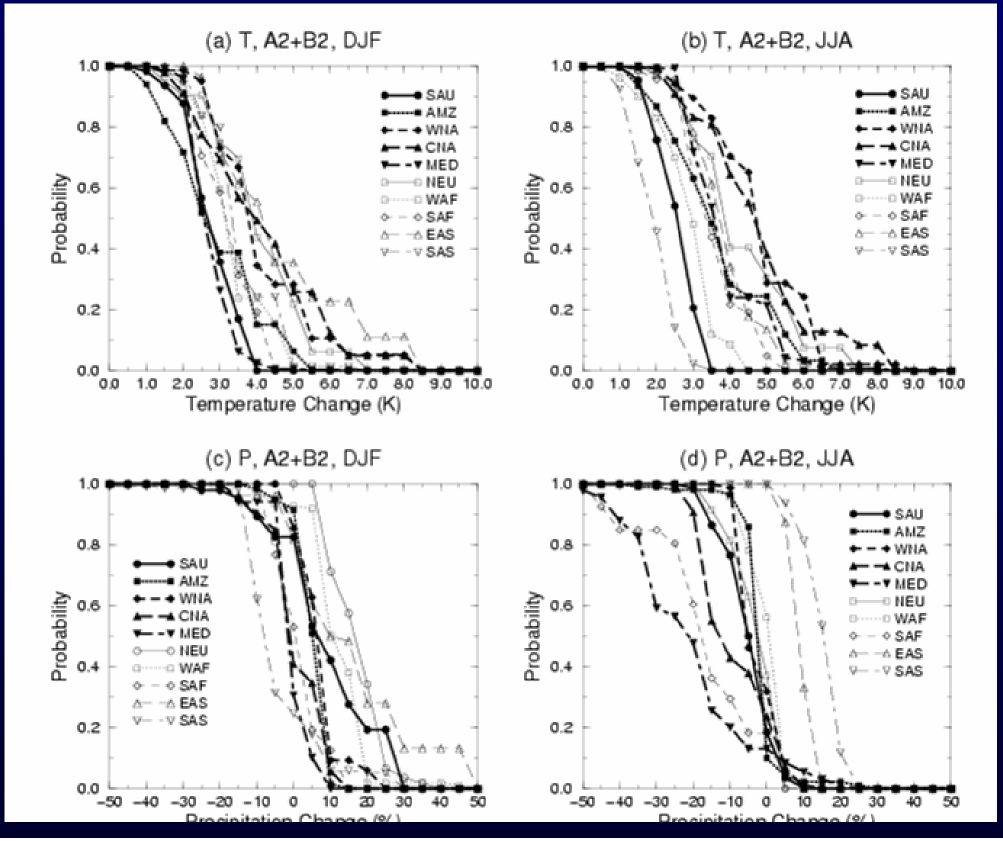
Use of scaling factors to increase the ensemble size
(Stott and Kettleborough 2002; Murphy et al. 2004)



Methods to Produce PDFs of Future Climate Conditions

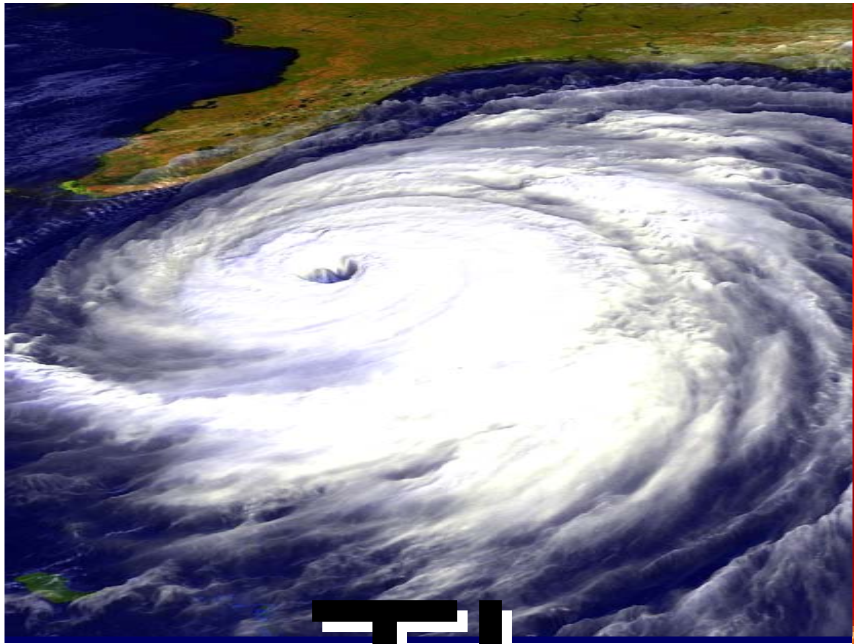
Information from ensembles of AOGCM runs

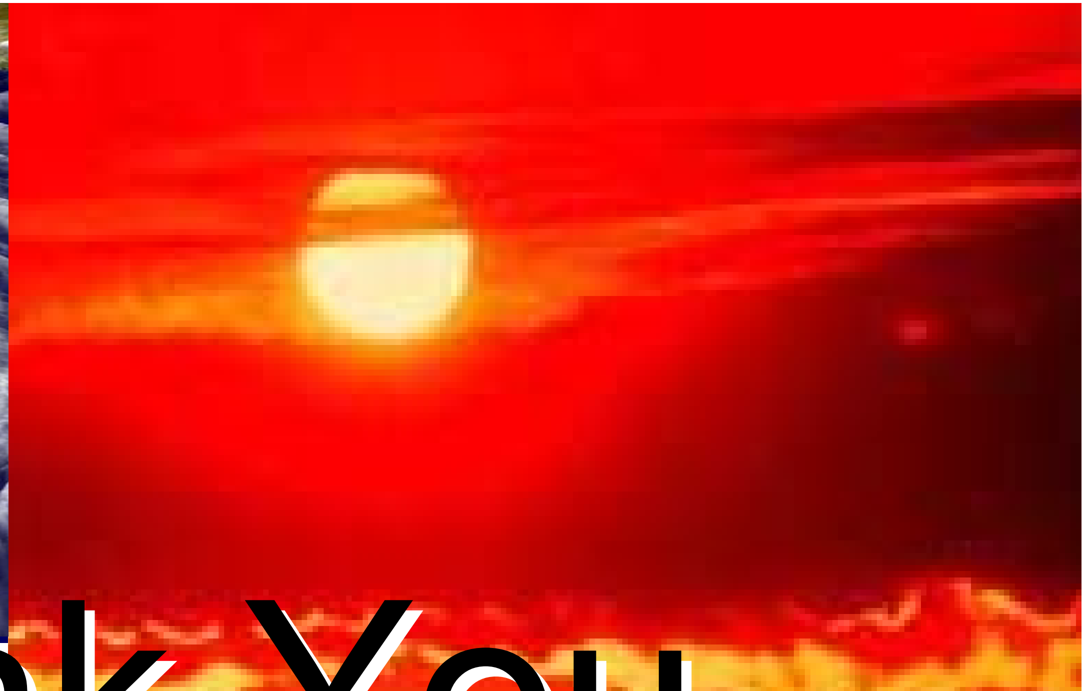
(Raisanen and Palmer 2001; REA method, Giorgi and Mearns 2002,03; Bayesian approach, Tebaldi et al. 2004)



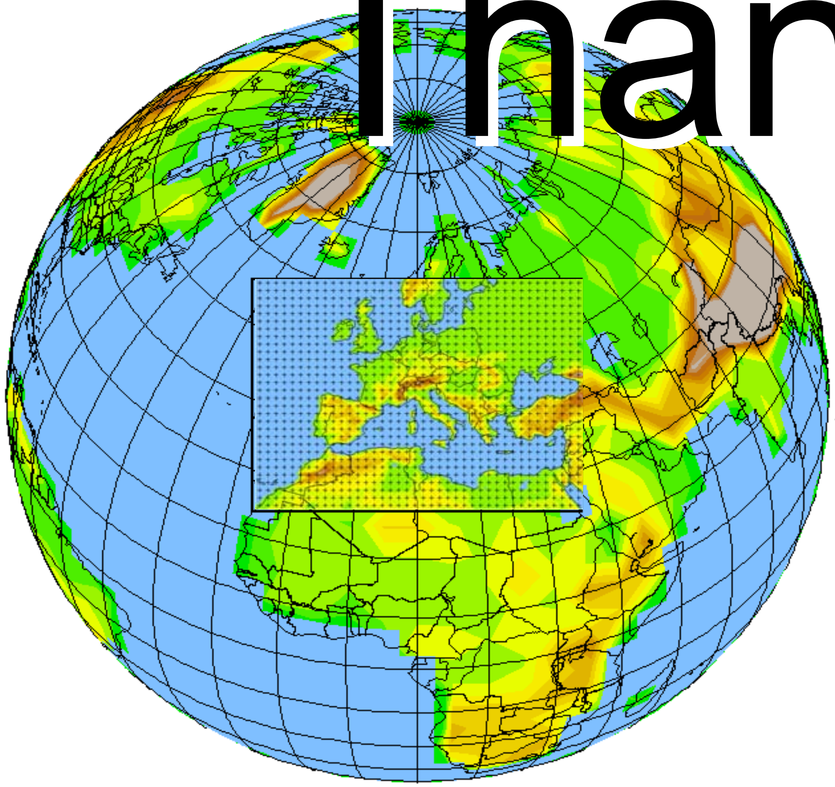
Conclusions

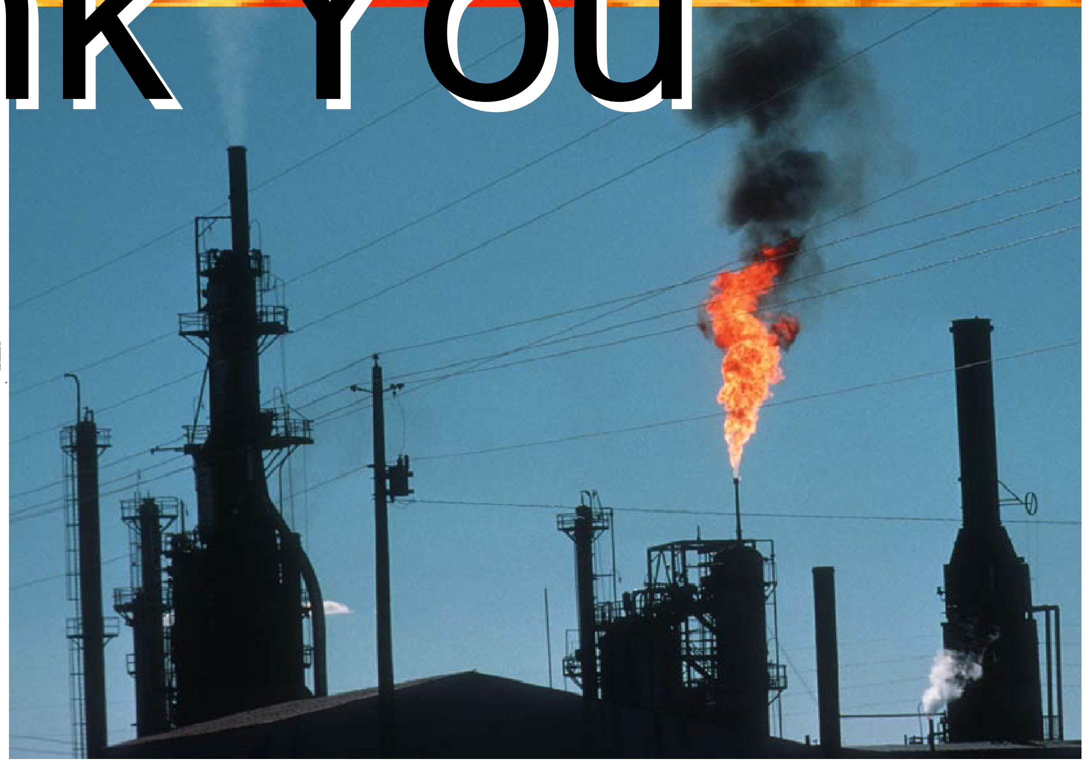
- Climate change prediction is characterized by an intrinsic uncertainty and by an added uncertainty due to the prediction process
- Because of its nature, climate prediction needs to be approached in a probabilistic way
- Large ensembles of simulations are needed in order to fill the phase space of possible future climates (and climate change paths) and to produce meaningful PDFs
  - Different initial conditions, model configurations, scenarios, feedback processes, regionalization techniques
  - Especially important at the regional scale and for changes of hydrologic variables
- A clear understanding of uncertainties and processes is critical
  - Understanding and reducing the climate sensitivity range





Thank You





A climate change prediction strategy