Climate Models and Climate Change

Outline:

- Climate Change 101
- Why do we care?
- Climate models:
  - About, Uncertainties, Performance, and Projections
- Closing thoughts

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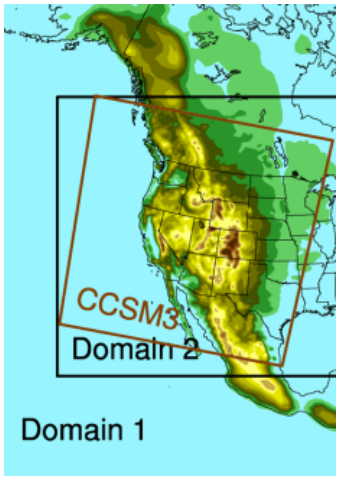
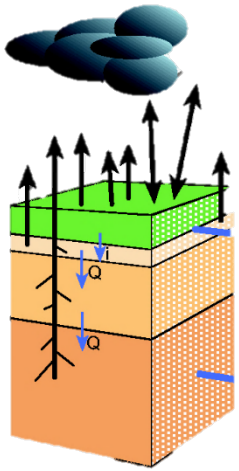
Climate Impacts Group
University of Washington

The Climate Impacts Group

An integrated research and stakeholder engagement team linking climate science and decision making to build climate resilience.

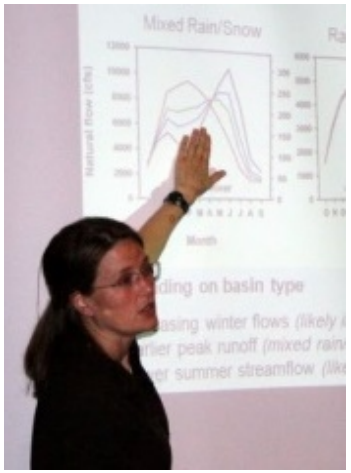


Downscaling global climate models



Macro and fine-scale hydrologic modeling

Impacts assessments



Adaptation planning and outreach

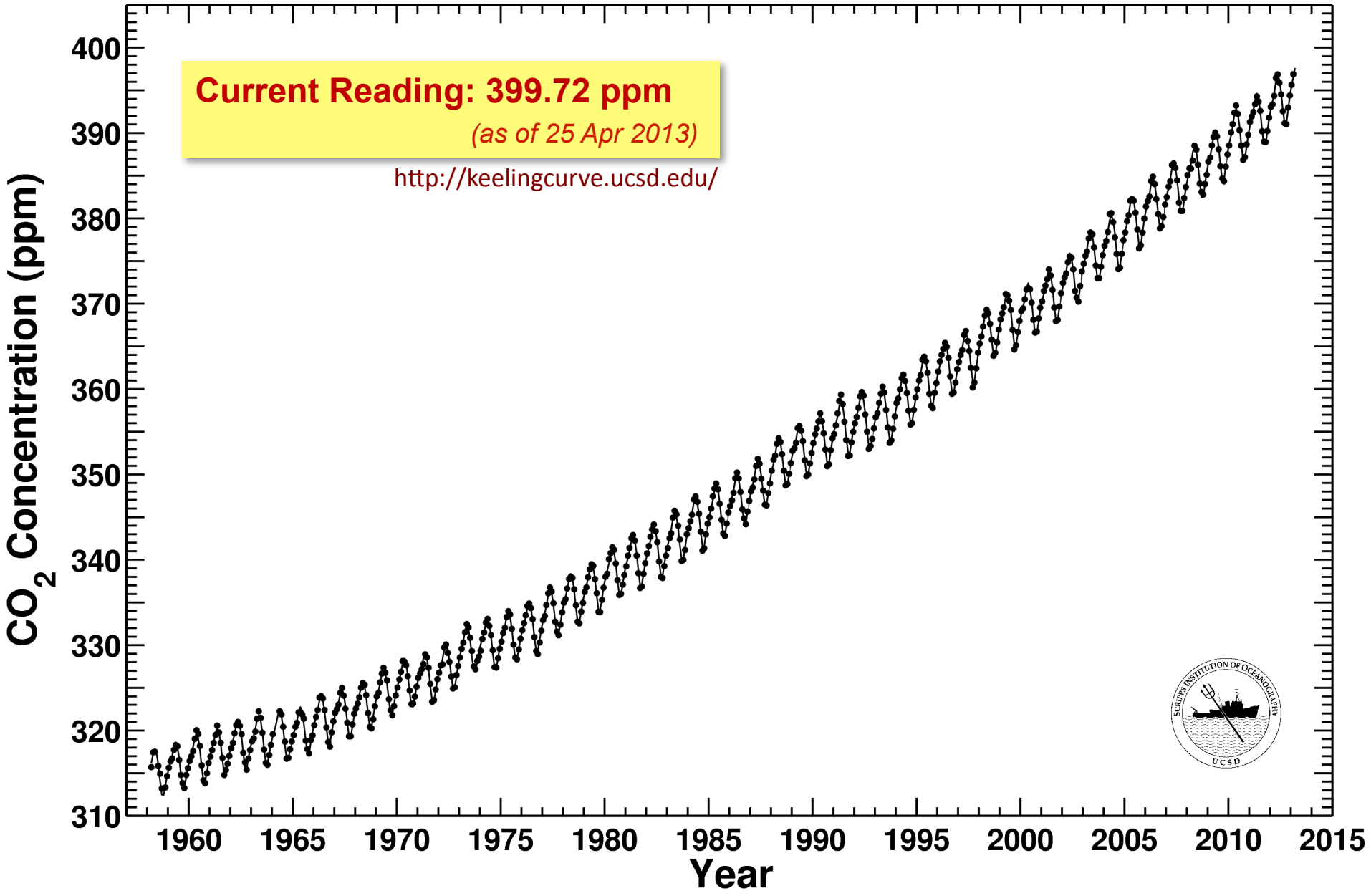
Working since 1995 with a focus on:

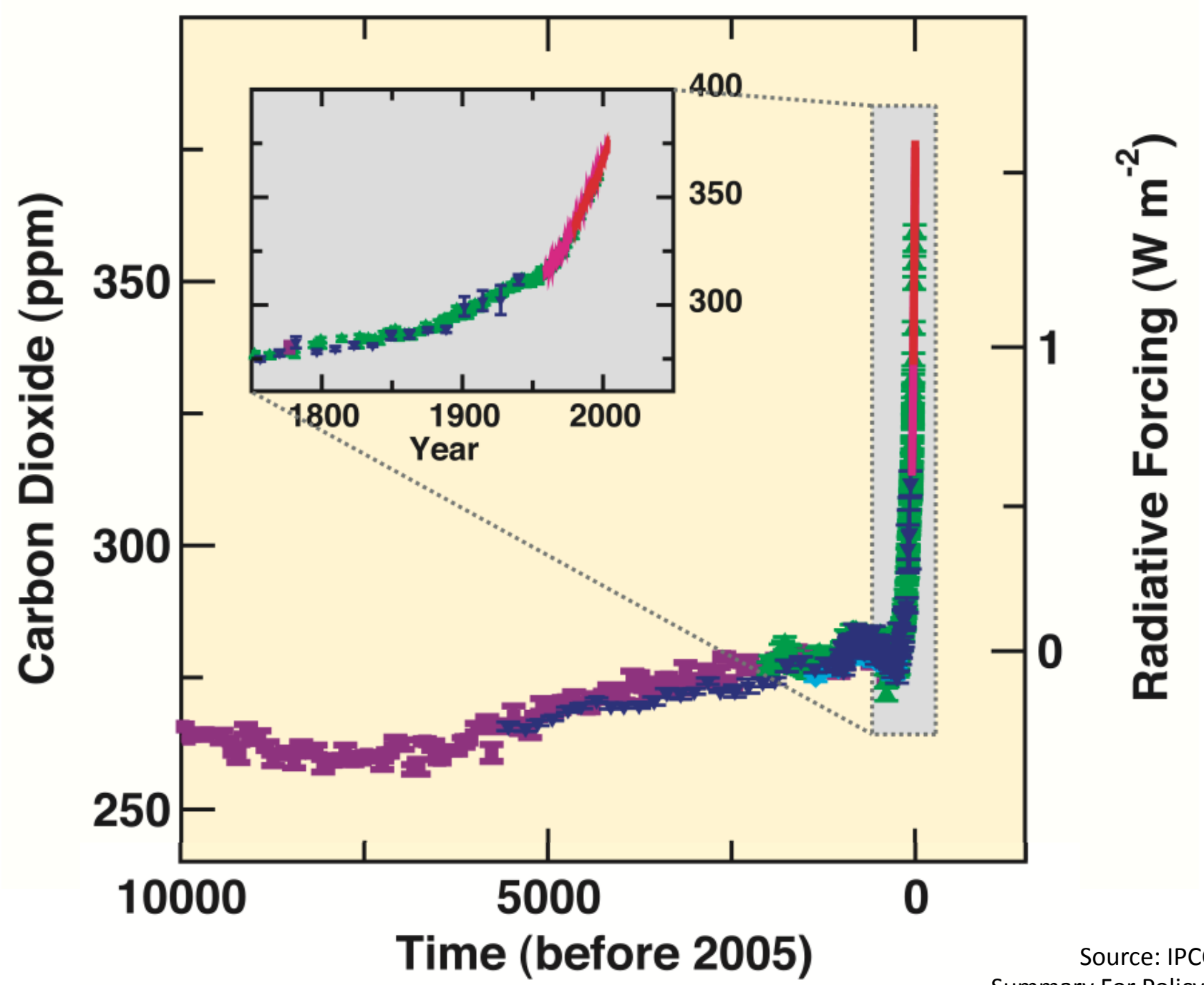
- U.S. Pacific Northwest, Western U.S., Pacific Rim
- Water, forests, fish, coasts, energy, human health, urban areas
- Stakeholders: Private, public & non-governmental actors involved in climate-sensitive policymaking, planning and decision making

Climate Change 101

Mauna Loa Observatory, Hawaii
Monthly Average Carbon Dioxide Concentration

Data from Scripps CO_2 Program Last updated March 2013

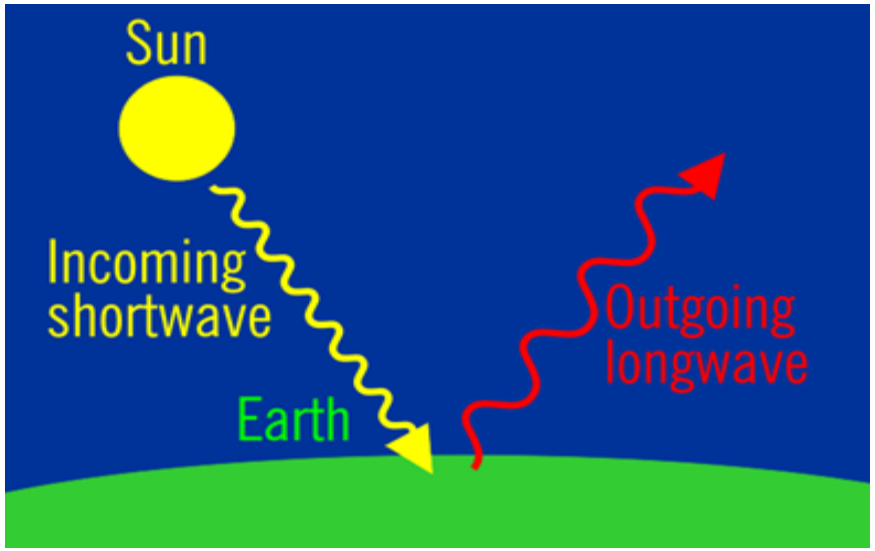


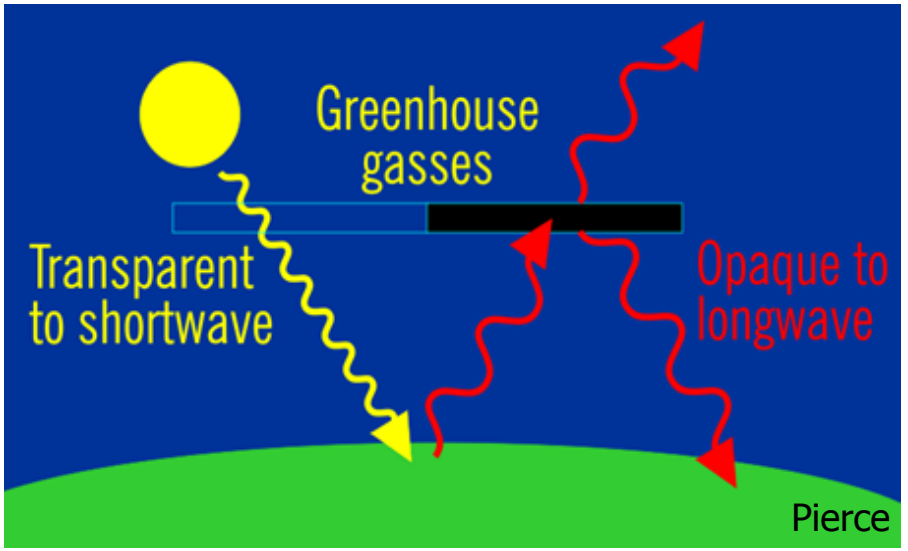


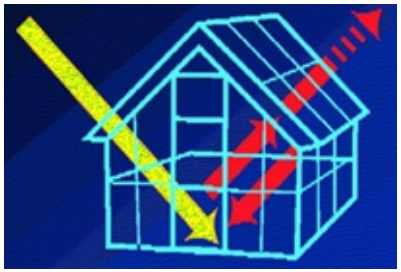
Source: IPCC 2007,
Summary For Policymakers

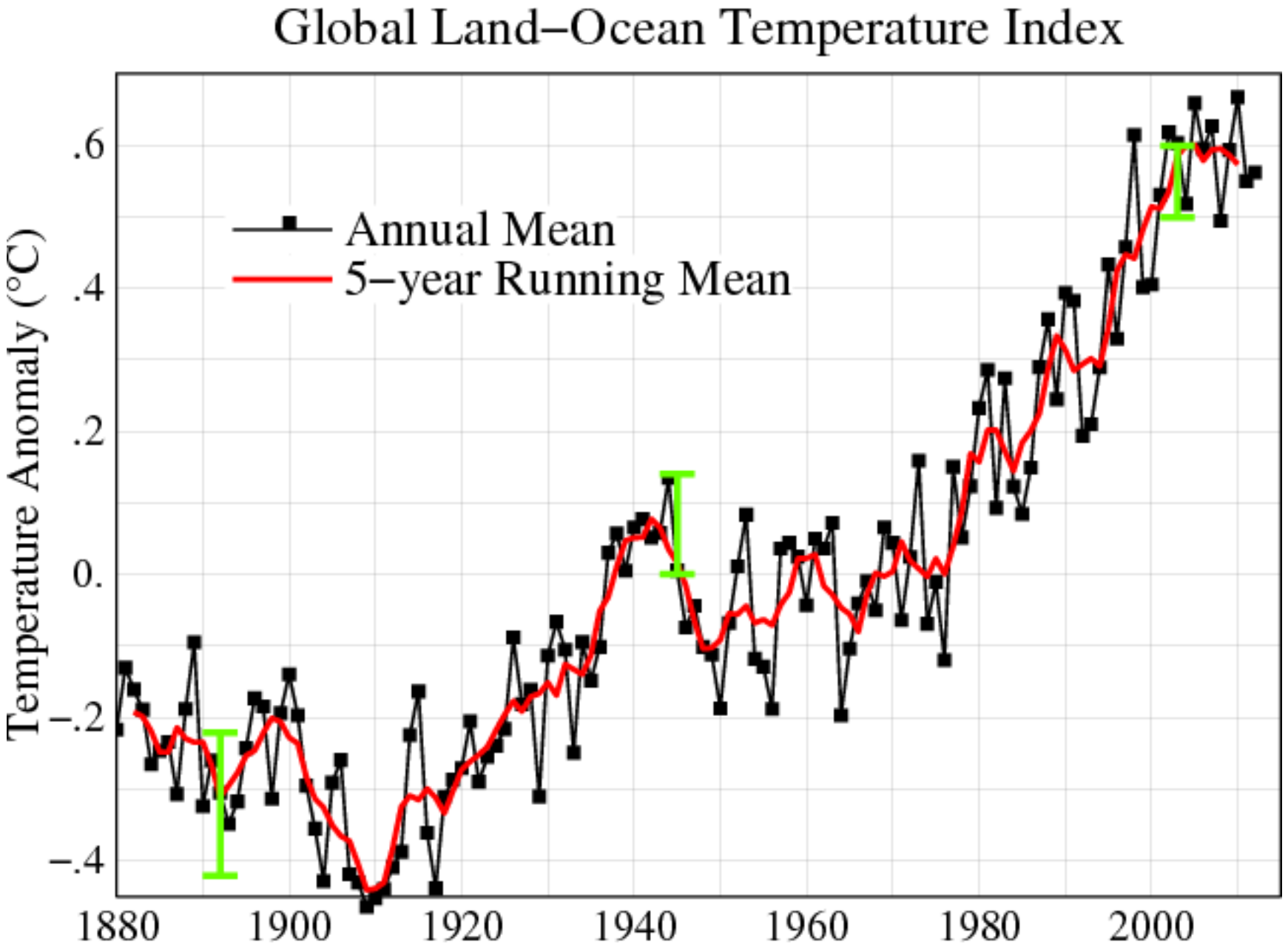
The Greenhouse Effect

Greenhouse gases (water vapor, CO_2, CH_4, N_2O) warm the planet by limiting energy emitted from earth to space









Source: http://data.giss.nasa.gov/gistemp/

Weather vs. Climate

1. "Climate is what you expect,
   weather is what you get."

   – Weather refers to the day-to-day changes in temperature, precipitation, etc. at a specific location

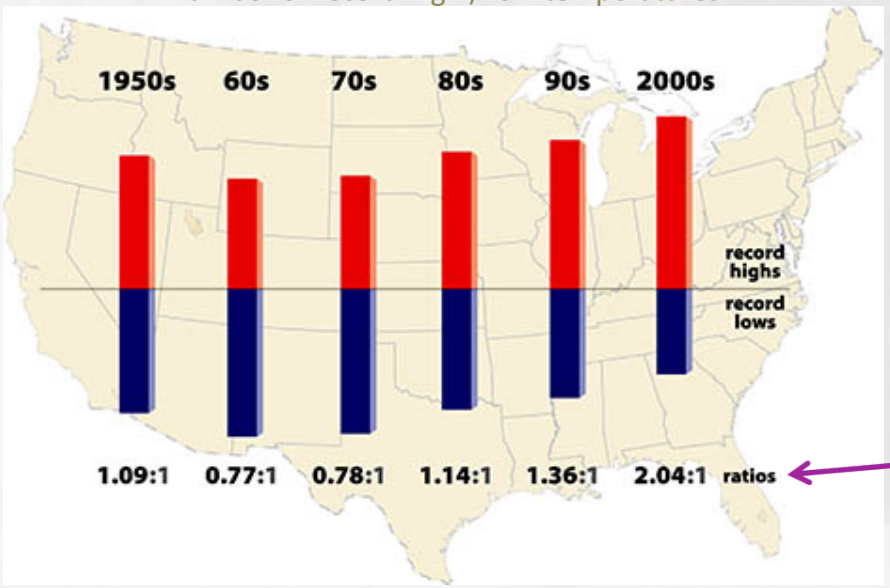
   – Climate refers to the average of these variables over long time periods

   – (e.g., we all know what summer is like, but none of us can say what weather we'll have on July 15th).

Weather vs. Climate

2. Heat waves and ice storms don't prove / disprove climate change. ***Global warming simply changes odds.***

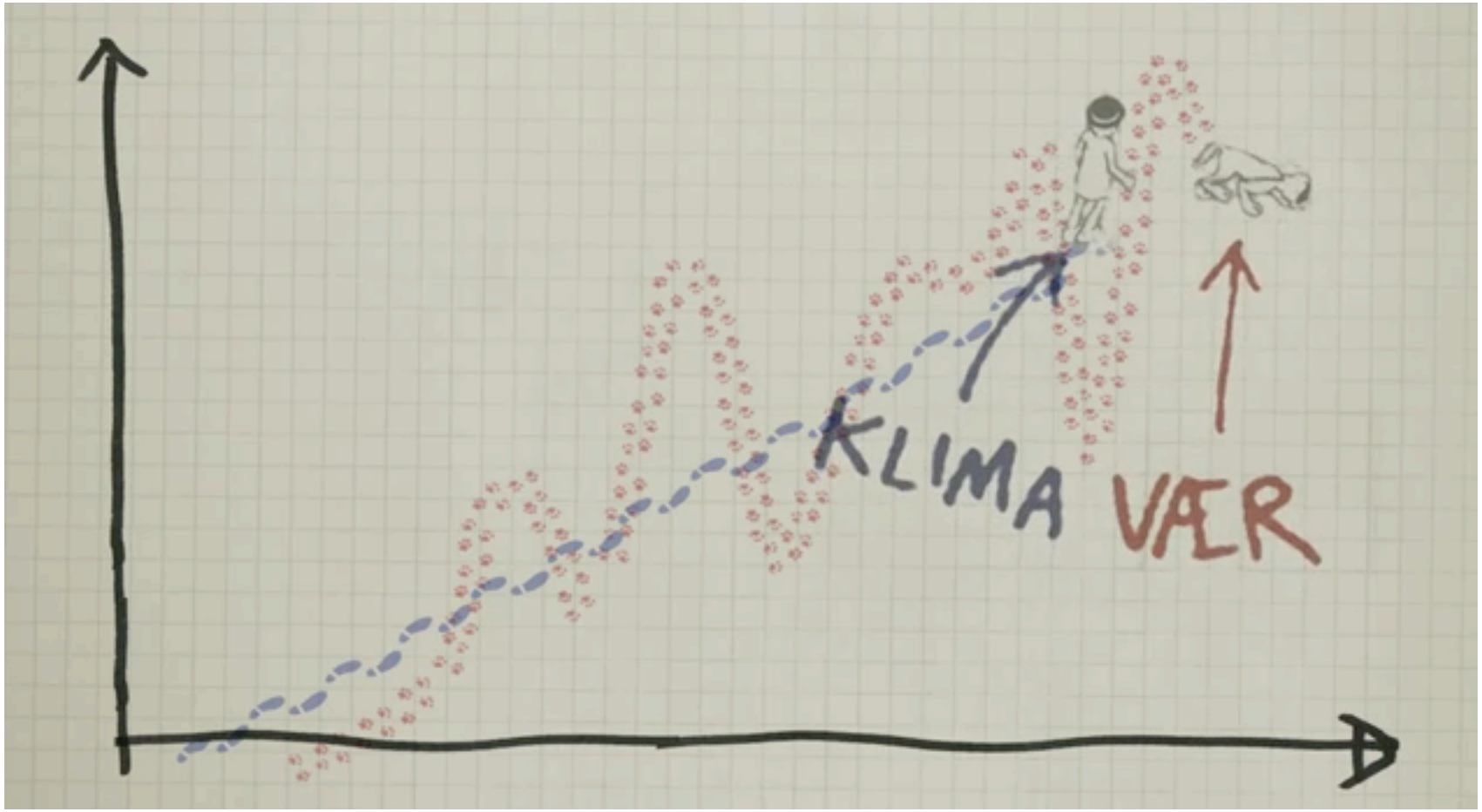
Number of record high / low temperatures



Note: change in ratios

Meehl et al., *Geophys. Res. Letters*, 2009.

Climate Variability vs. Climate Change



http://youtu.be/e0vj-0imOLw ; Search “trend and variation”

Why do we care?

Decreased summer hydropower production

Summer production falls -10% by the 2020s, -15% by the 2040s, -20% by the 2080s, while summer cooling demands increase up to 400% (vs. 1917-2006)

Decreased irrigation supply reliability

Risk of “water short year” (70% level of prorating) in the Yakima increases from 14% (1970-2005) to 32% (2020s), 36% (2040s) and 77% (2080s)

Continued reliability of municipal water supplies

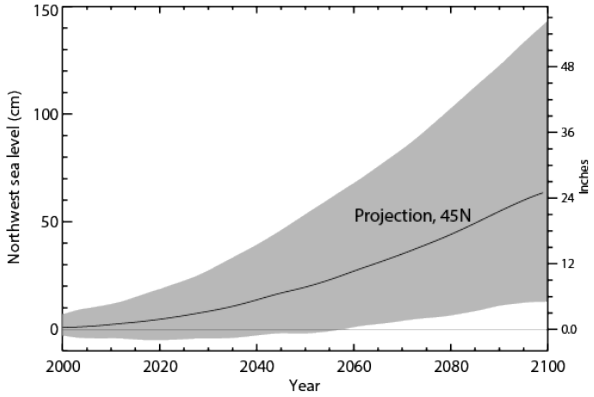
Puget Sound water suppliers project sufficient supply through at least 2050

Future Flood Risks

Nisqually River at Sunshine Point
(Nov, 2006)

Risks to Washington's infrastructure, commerce, and public safety

National Park Service



Sea level rise

Depends on local land movement

for Seattle:

2030	2050	2100
-1.5 to +8.9”	-1.0 to 18.8”	3.9 to 56.3”

NRC 2012

Loss of land to rising seas

More than 140,000 acres of coastal lands lie within 3.3 feet elevation of high tide in WA & OR, exposing public and private property, infrastructure, and habitat to climate impacts.

Multiple Compounding Factors

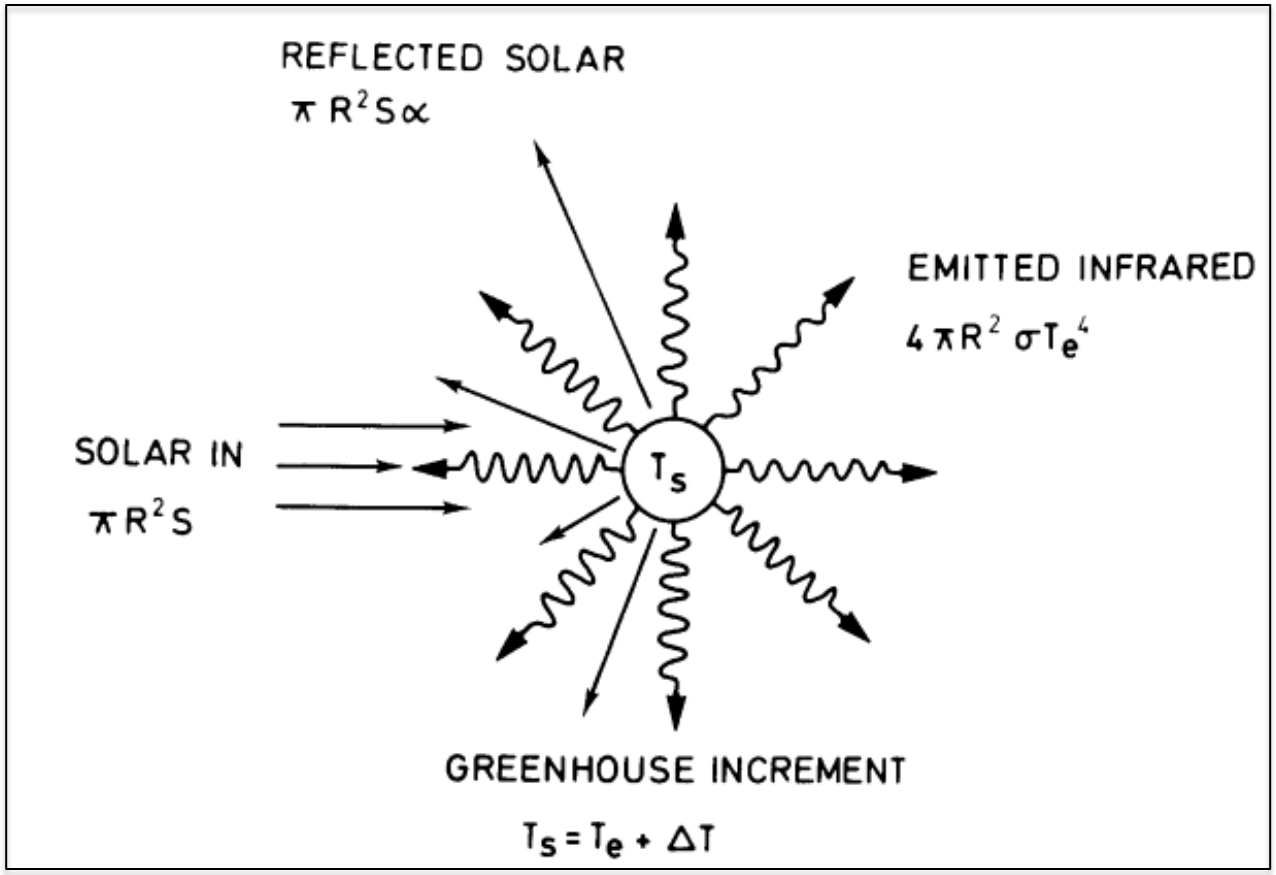
Sea level rise + river flooding + high tide + coastal storms = erosion + landslides + flooding + permanent inundation + …

Climate Models

How are climate models constructed?

Simple climate model:

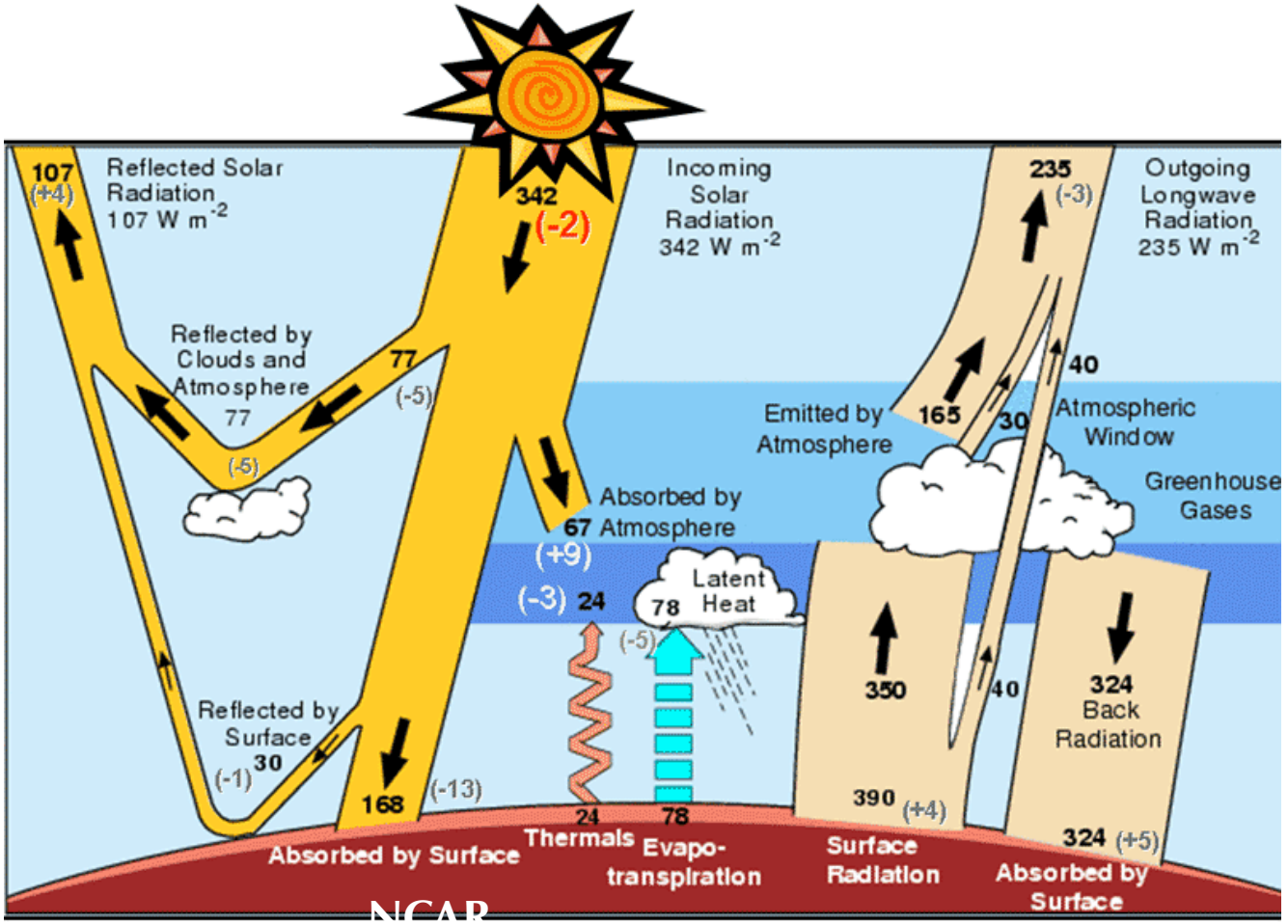
- Treat the entire earth as one point
- *"What goes in must come out"*



http://www.geosc.psu.edu/~dbice/DaveSTELLA/climate/climate_modeling_1.htm

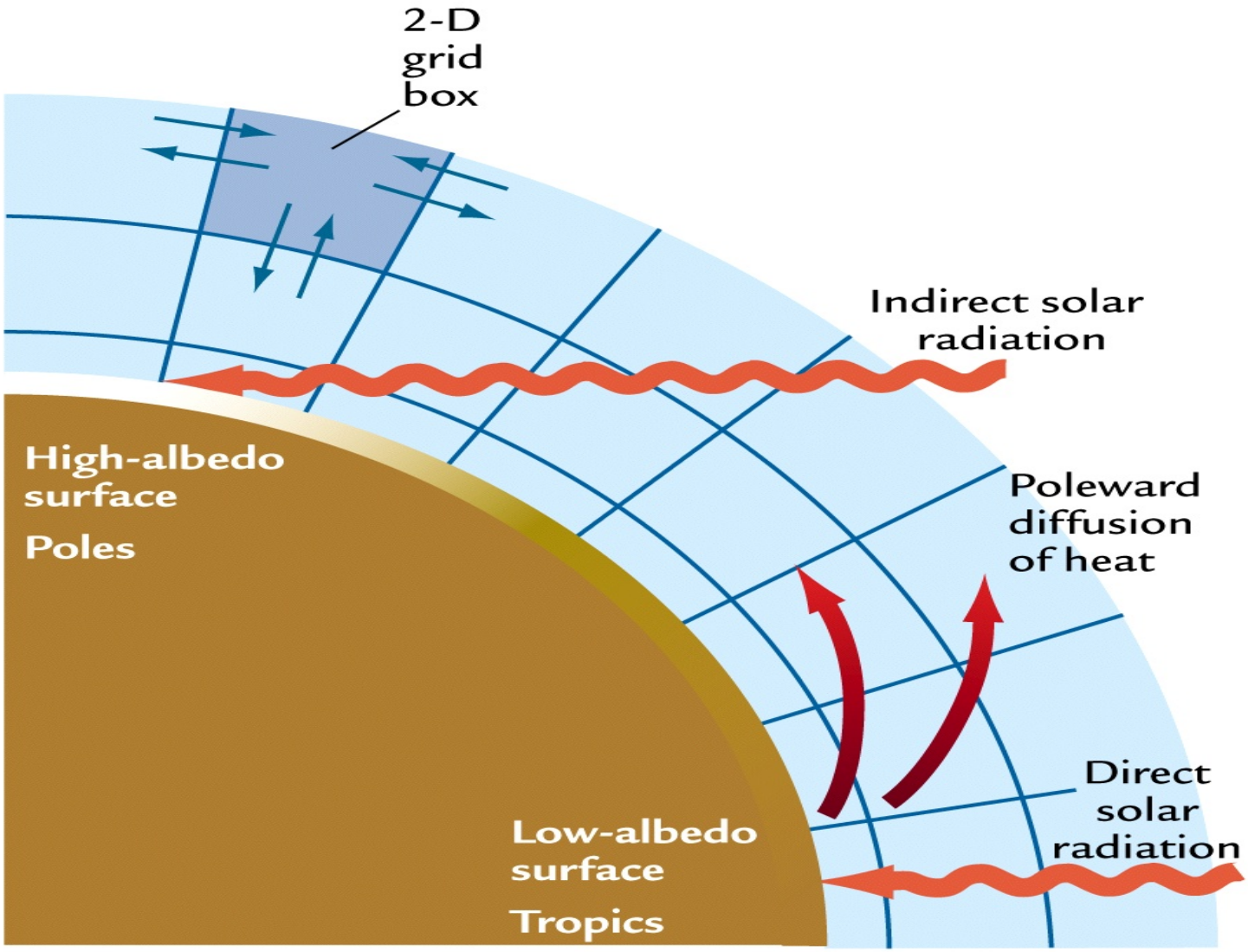
Next step in complexity:

1D Radiative / Convective model



After Kiehl and Trenberth, 1997

2D Climate model:

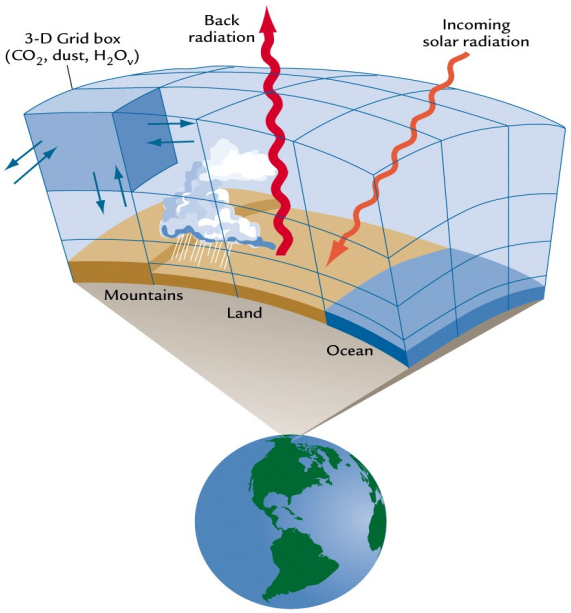


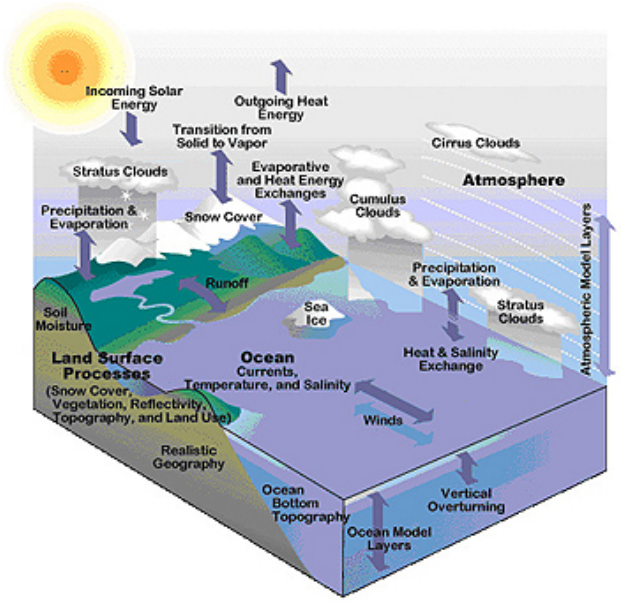
3D Climate models:

aka: "Global Climate Models" (GCMs)

- **GCMS break the world into large grid sizes (~50 to 200 km) and model complex interactions within each grid cell.**

- **Today's GCMs are mostly "coupled", meaning that separate models for the land surface, ocean, sea ice, and atmosphere all interact.**





NOAA

GCMs:

- GCMs respond differently because they approximate the climate in different ways, including:
  - *sensitivity* to greenhouse gas concentrations;
  - how physical processes that affect climate are constructed and described *(e.g., cloud formation and rain)*;
  - how feedbacks between the processes are modeled *(e.g., how increasing temperature melts sea ice which in turn affects temperature through albedo)*
- Some things are common to most or all models; others are treated differently from model to model.

nationality	model	equilibrium sensitivity	TCR
	BCCR	n.a.	n.a.
	CCSM3	2.7	1.5
	CGCM (T47)	3.4	1.9
	CGCM (T63)	3.4	n.a.
	CNRM	n.a.	1.6
	CSIRO	3.1	1.4
	ECHAM5	3.4	2.2
	ECHO-G	3.2	1.7
	FGOALS	2.3	1.2
	GFDL-CM2.0	2.9	1.6
	GFDL-CM2.1	3.4	1.5
	GISS-AOM	n.a.	n.a.
	GISS-ER	2.7	1.5
	HADCM3	3.3	2.0
	HADGEM1	4.4	1.9
	INMCM	2.1	1.6
	IPSL	4.4	2.1
	MIROC	4.0	2.1
	MIROC-hires	4.3	2.6
	PCM	2.1	1.3

Table 1. Equilibrium sensitivity and TCR (°C) as reported by Randall et al. (2007) for models used in **Mote et al. 2008**

What are the main uncertainties?

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- **Distinguishing variability from trends**
  - Uncertainty due to ***Natural Variability***
- Greenhouse gas **emissions scenarios**
  - A form of ***Parameter Uncertainty***
- **Scale**: many processes are unresolved
  - A form of ***Model Uncertainty***
- **Complexity of the Climate system**: fast and slow responses, nonlinearities, thresholds, etc. = surprises
  - Results in ***Prediction Uncertainty***

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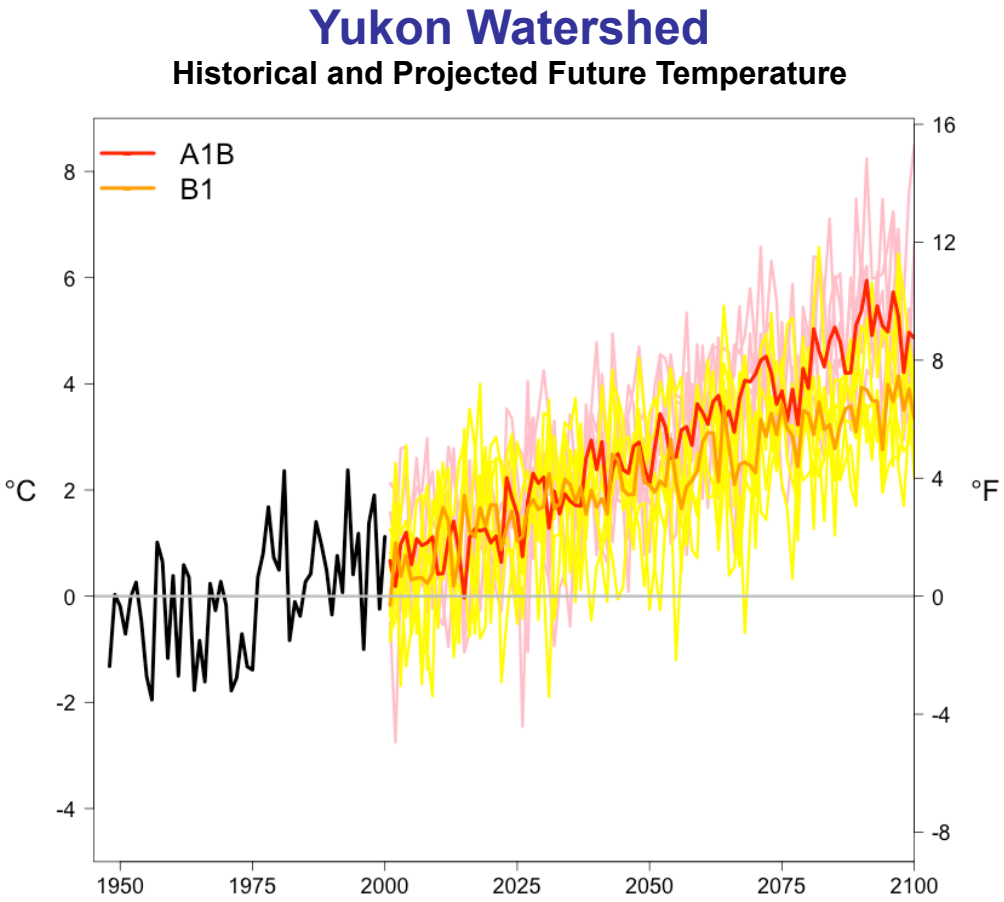
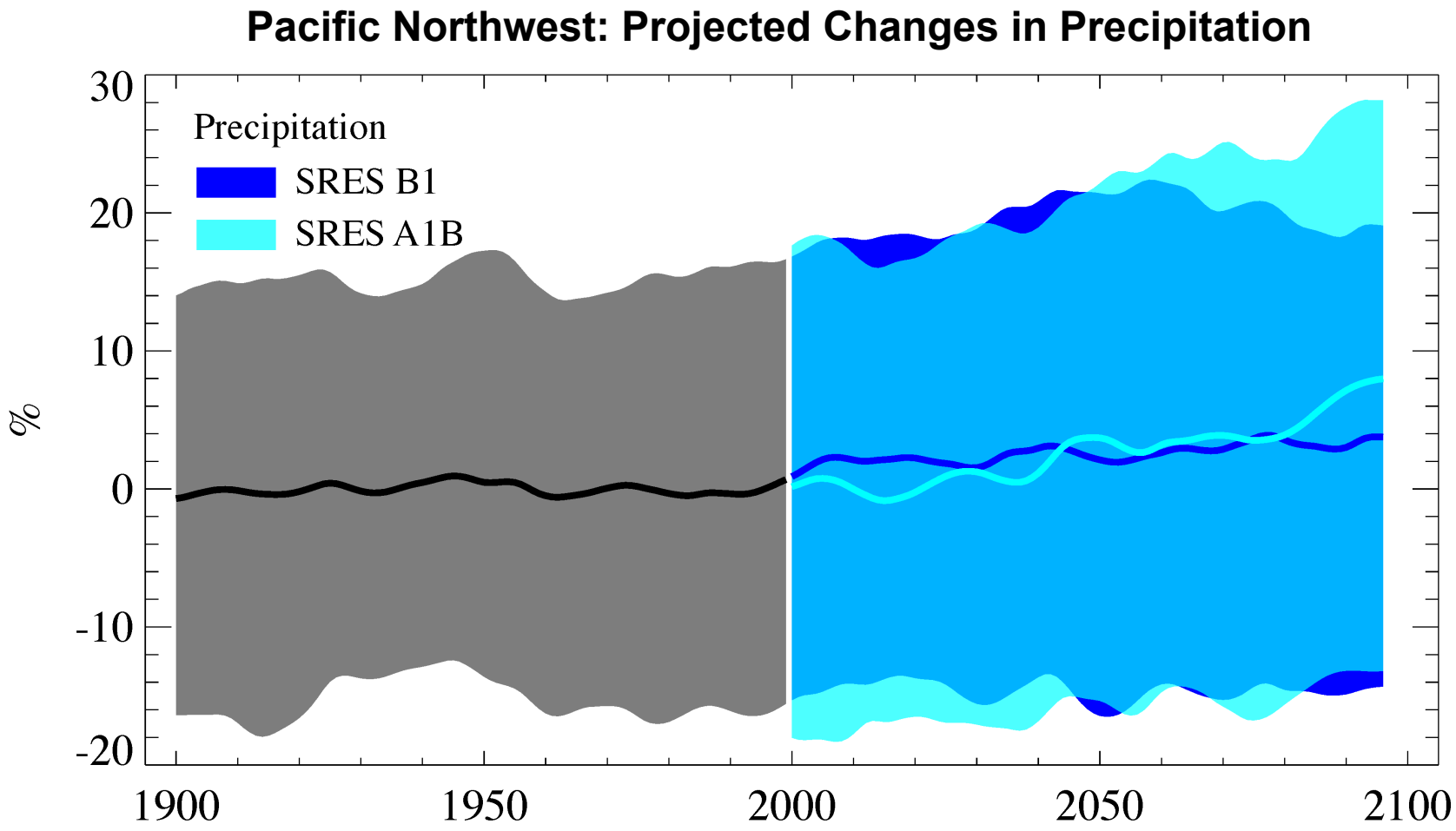
Distinguishing Variability from Trends



Distinguishing Variability from Trends



Compared with 1970-1999 average

Source: Climate Impacts Group 2009, Ch. 1

Next question:

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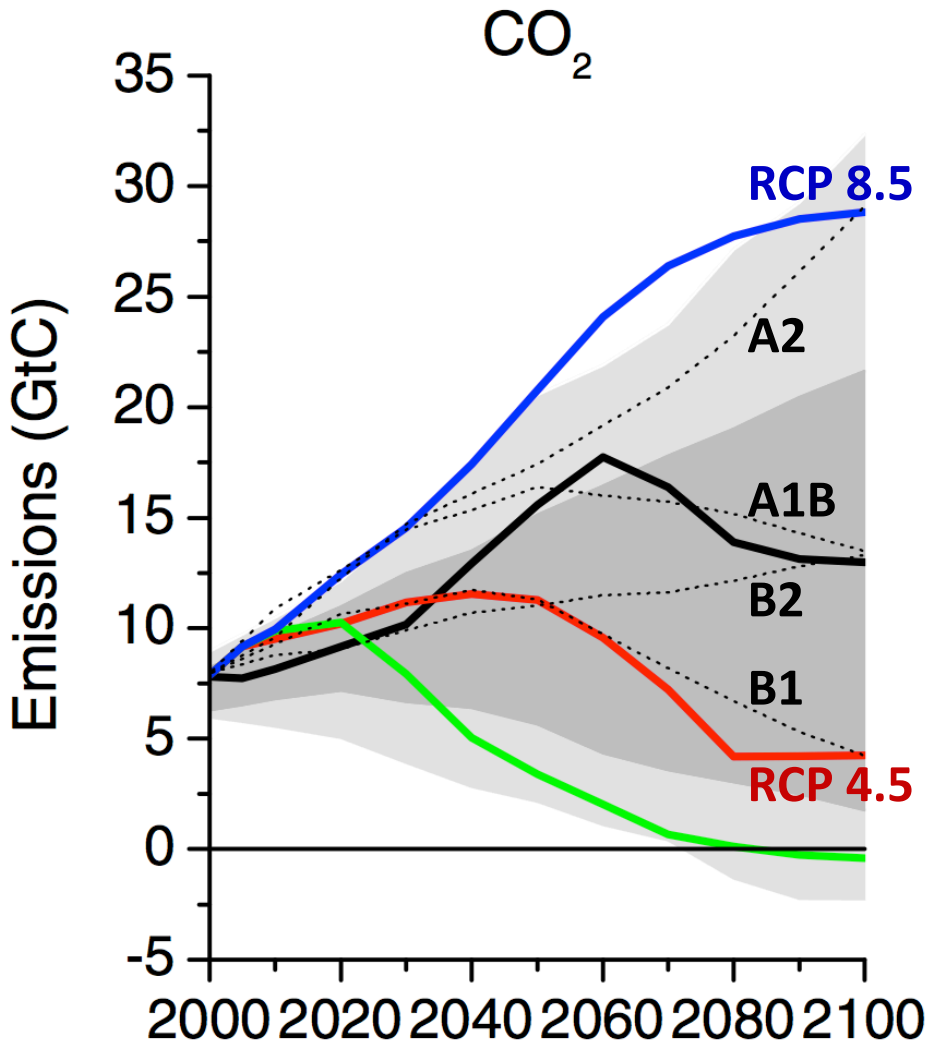
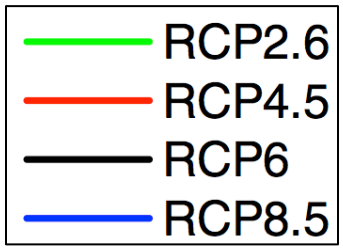
Greenhouse gas Emissions Scenarios



"What if" scenarios of future emissions



vanVuuren et al., Climatic Change, 2011

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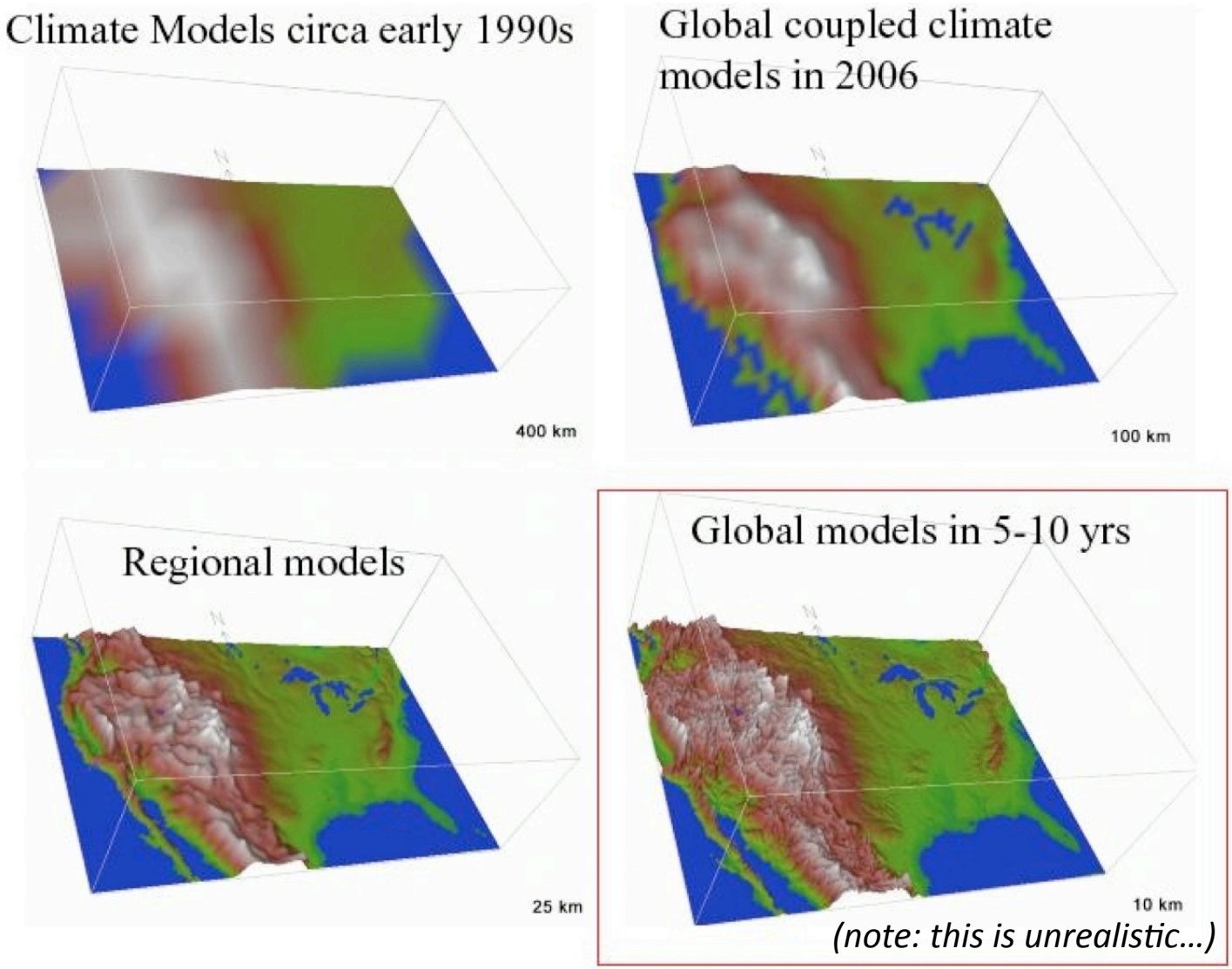
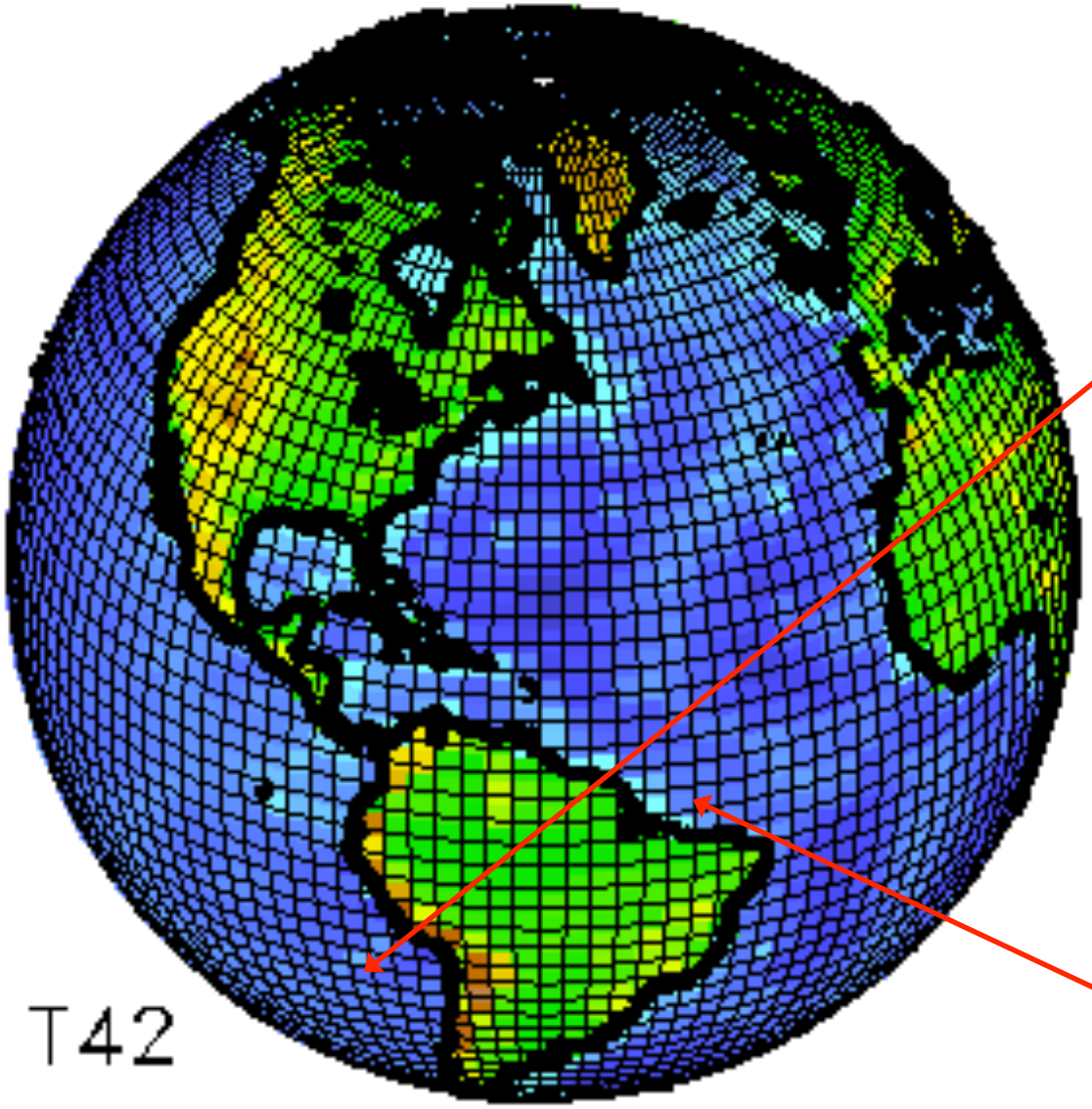
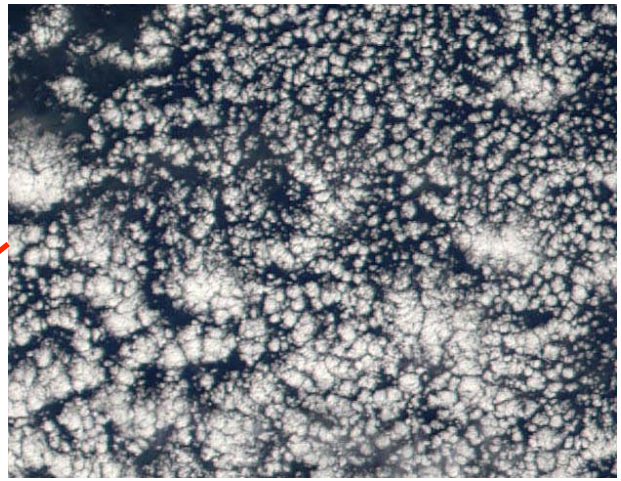
Model Scale:



Source: Strand, UCAR





Prognostic variables: T, q, u, v, w

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Prediction Uncertainty

- *Climate model projections differ because each model is a different approximation of the climate. (quantified uncertainties)*

- *No climate model includes all processes (e.g., none have large ice sheets) – as a result, they could be missing important sensitivities (unquantified uncertainties)*

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Irreducible **uncertainty**

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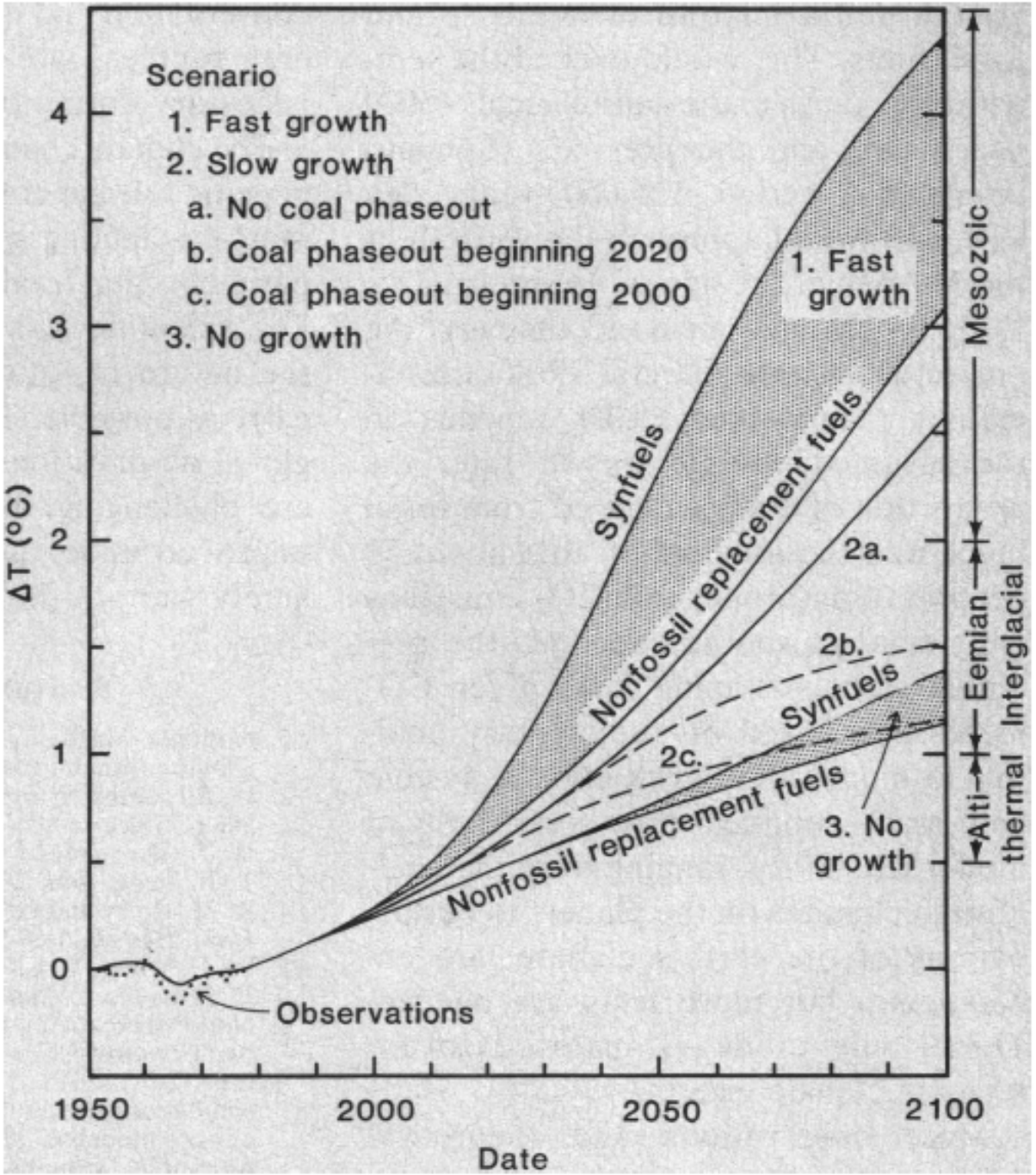
GCM performance

Remember that all models are wrong;
the practical question is how wrong do they have to be to not be useful.

Box and Draper, *Empirical Model-Building*, p. 74

Hansen's 1981 Projections

Fig. 6. Projections of global temperature. The diffusion coefficient beneath the ocean mixed layer is 1.2 cm^2 sec^{-1}, as required for best fit of the model and observations for the period 1880 to 1978. Estimated global mean warming in earlier warm periods is indicated on the right.



Taken From: RealClimate.org ; Source: Hansen et al., Science, 1981

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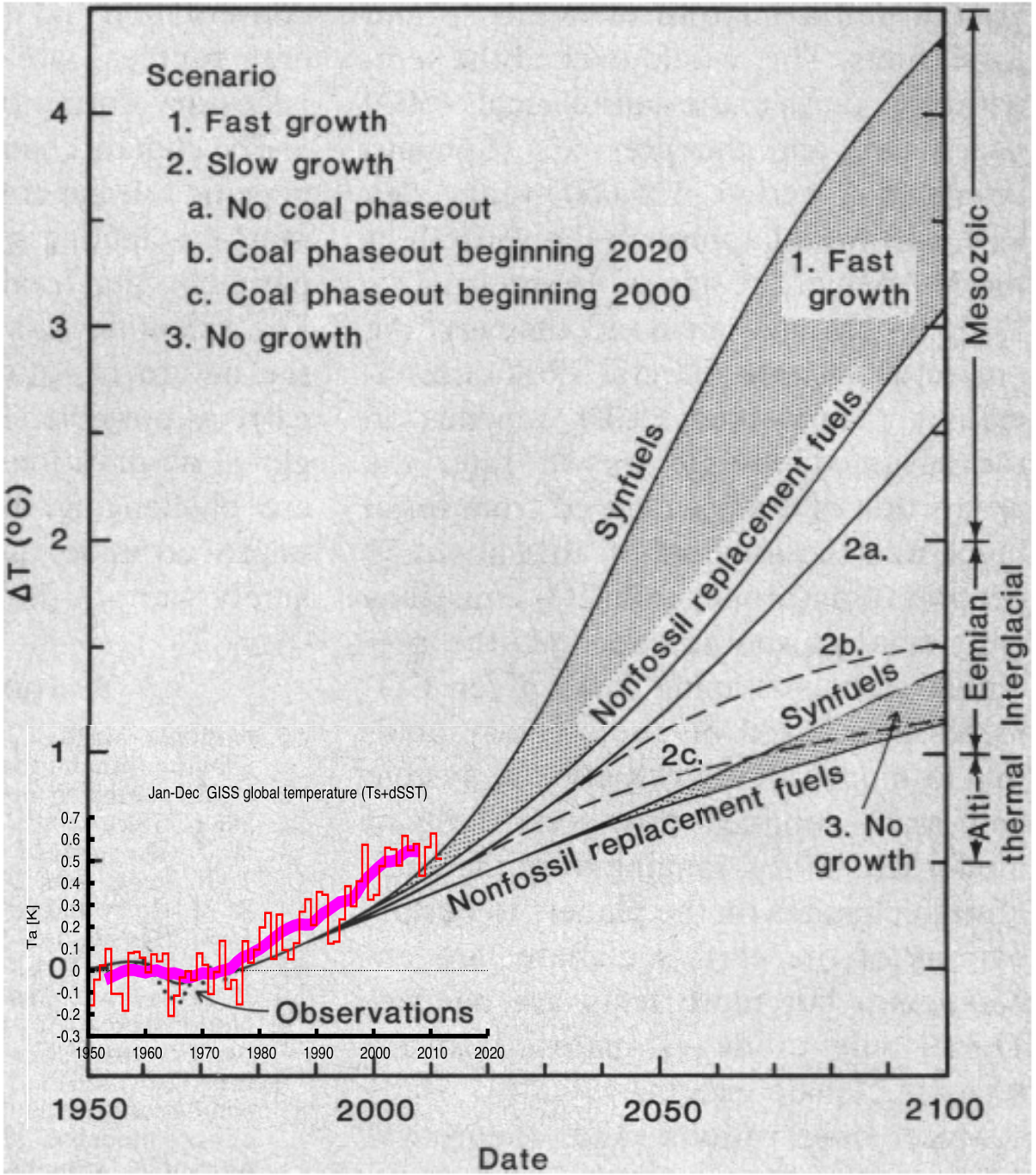

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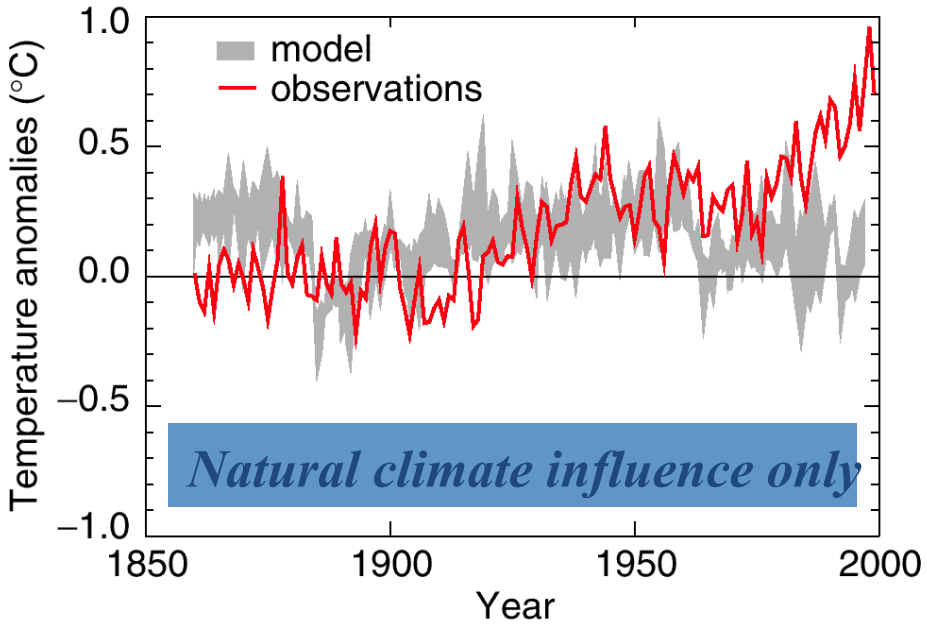
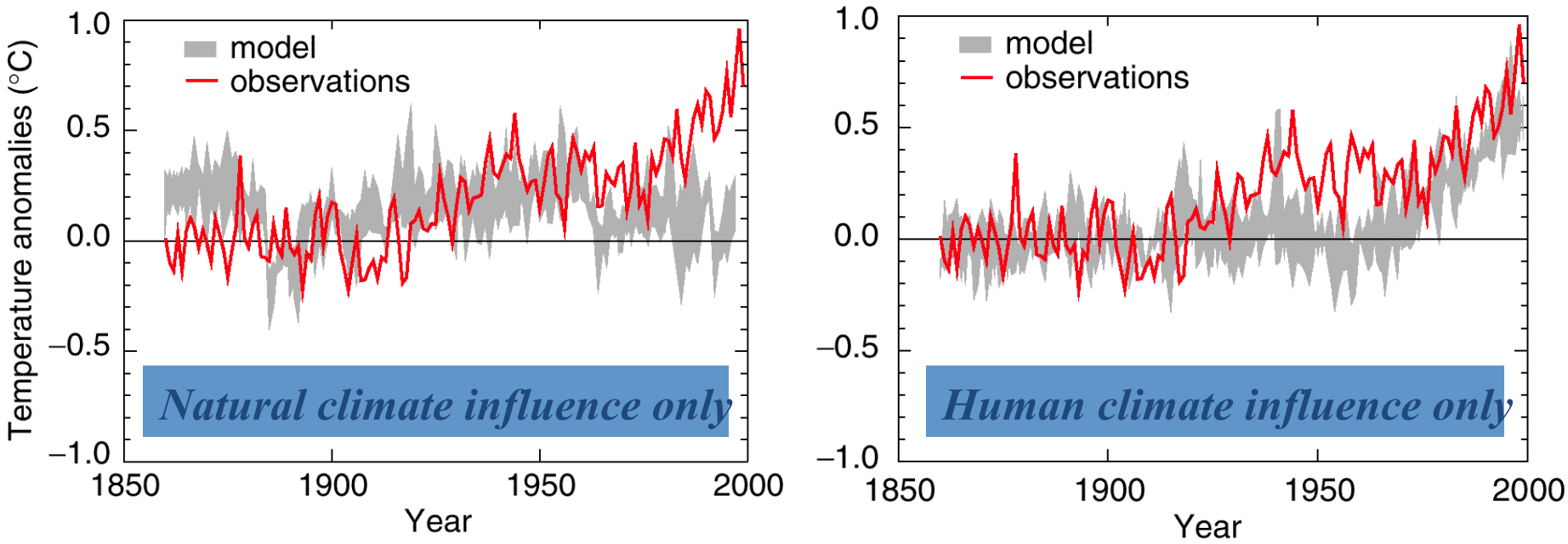

model
observations
Natural climate influence only
Temperature anomalies (°C)
1.0
0.5
0.0
−0.5
−1.0
1850
1900
1950
2000
Year


1.0
0.5
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−1.0
Temperature anomalies (°C)
model
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1850
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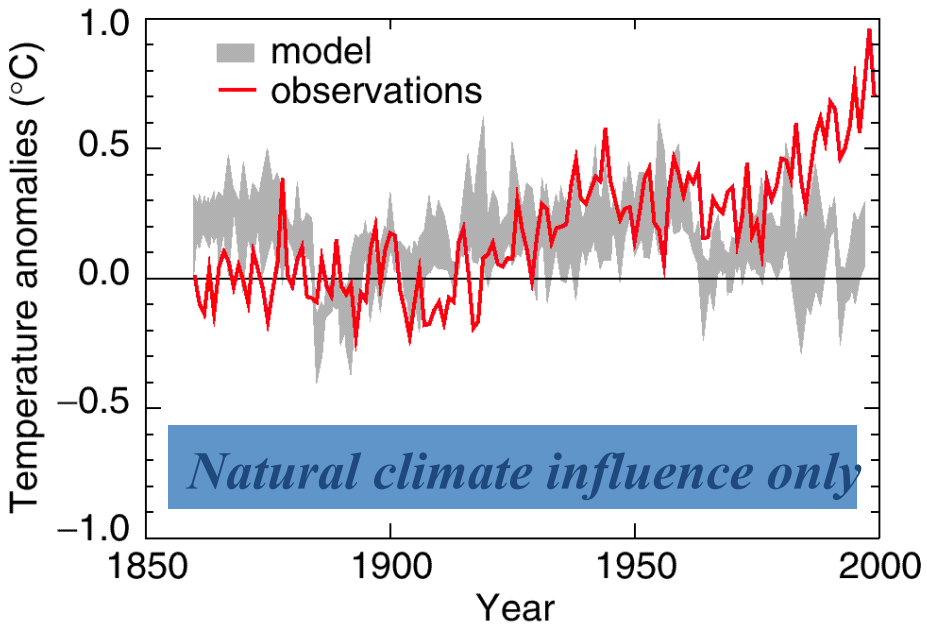
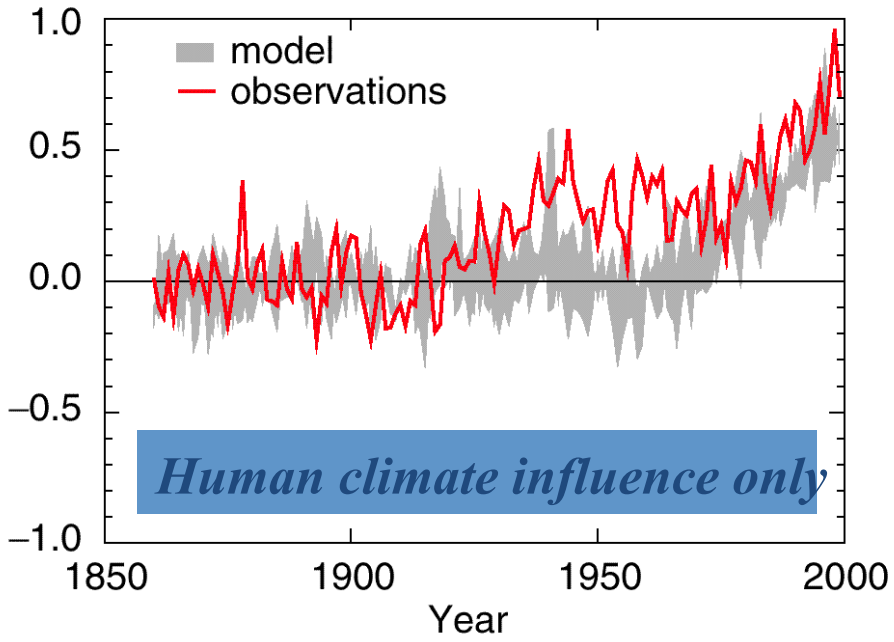
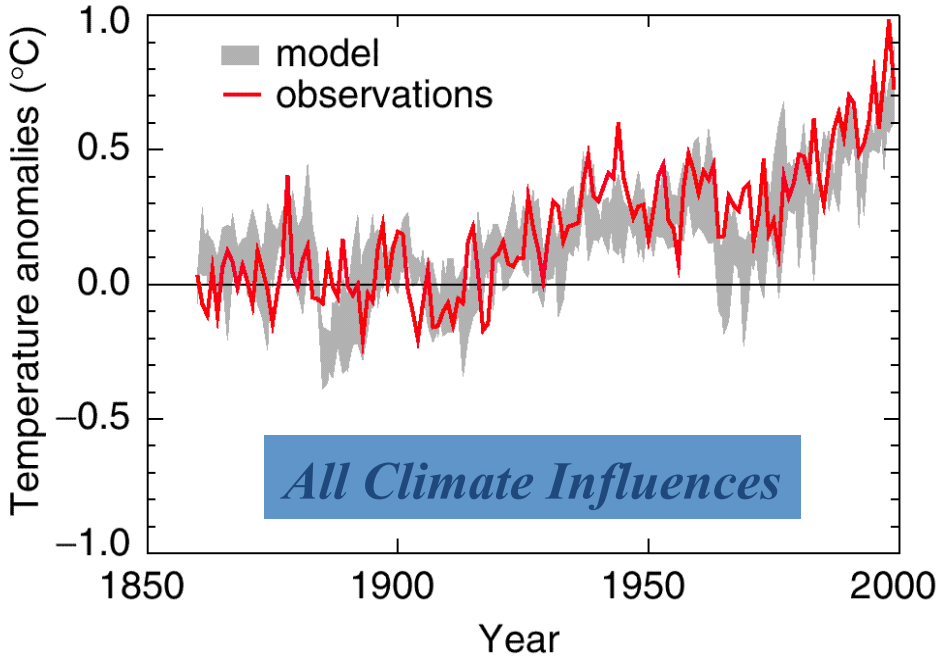
1.0
0.5
0.0
−0.5
−1.0
model
observations
Human climate influence only
1850
1900
1950
2000
Year





Observational record best matched when natural climate influences (solar variation and volcanic activity) and increases in CO2 concentrations are both included.

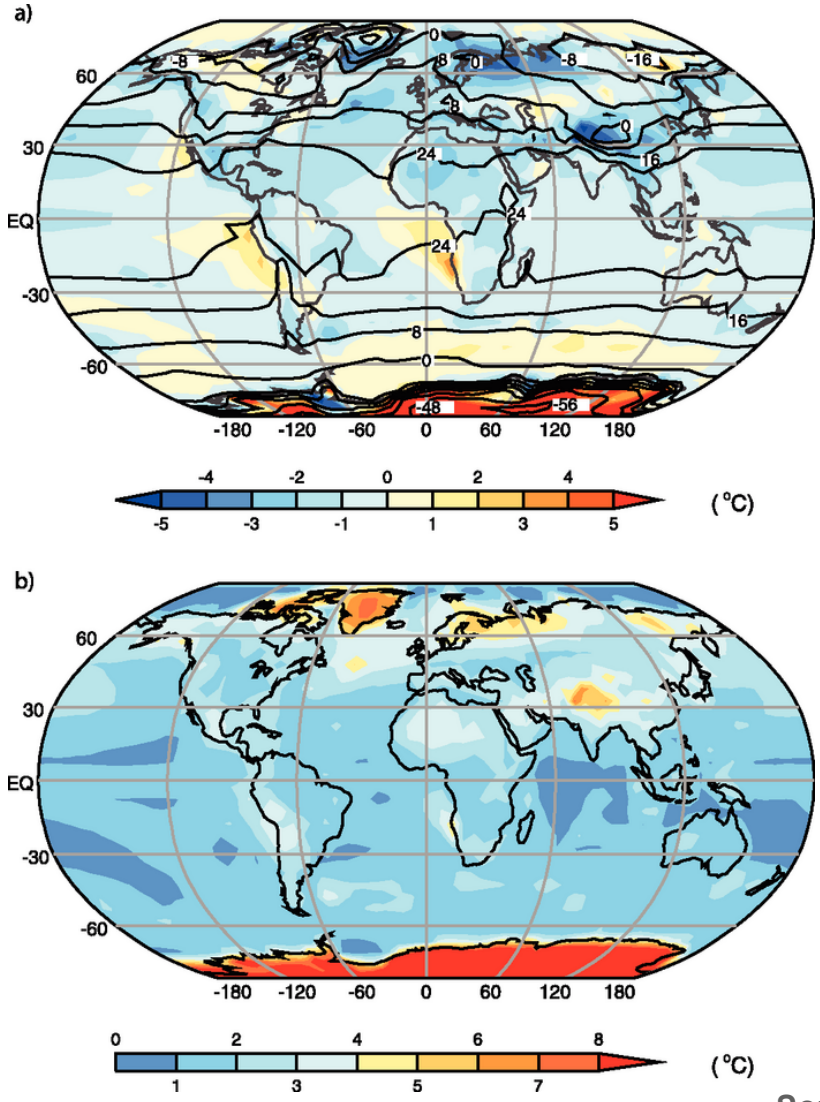


Source: IPCC, 2001

Surface Temperatures

Countors = observations
Shading = model error

model RMS error

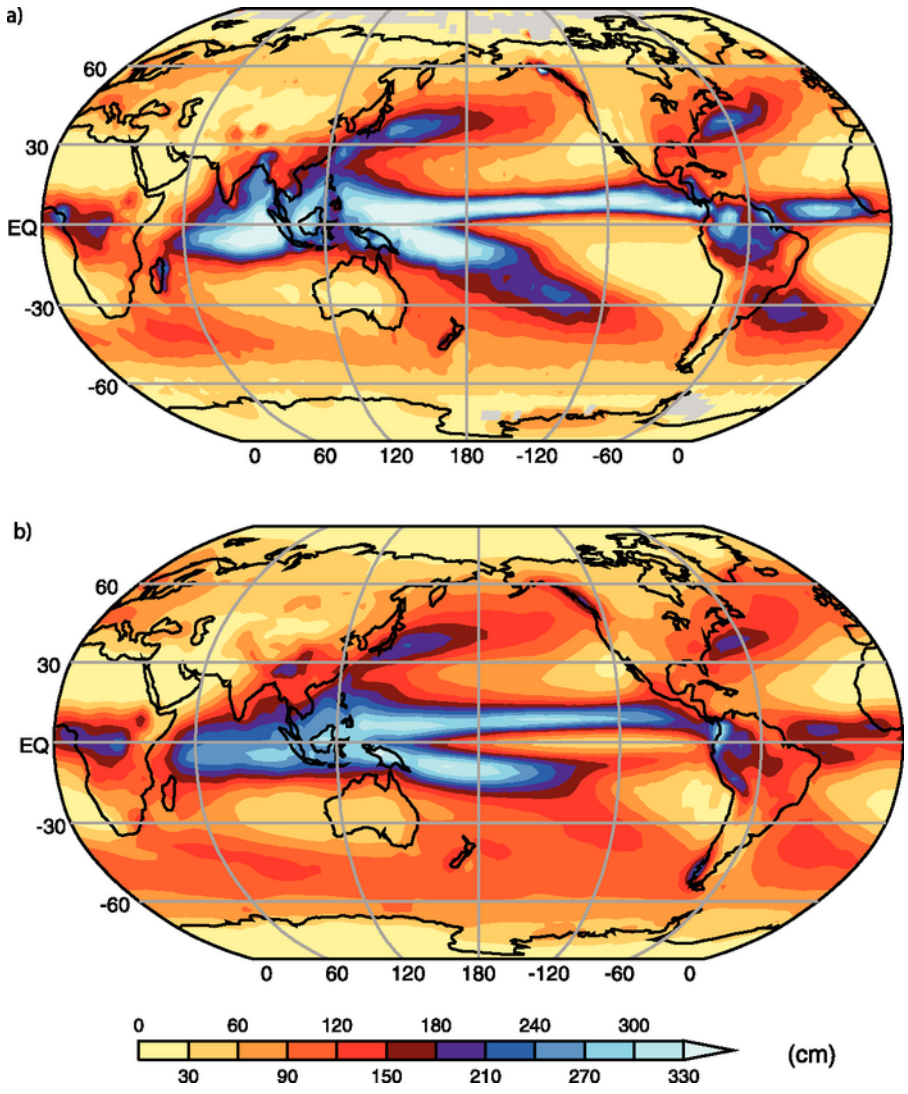


Source: IPCC 2007

Precipitation

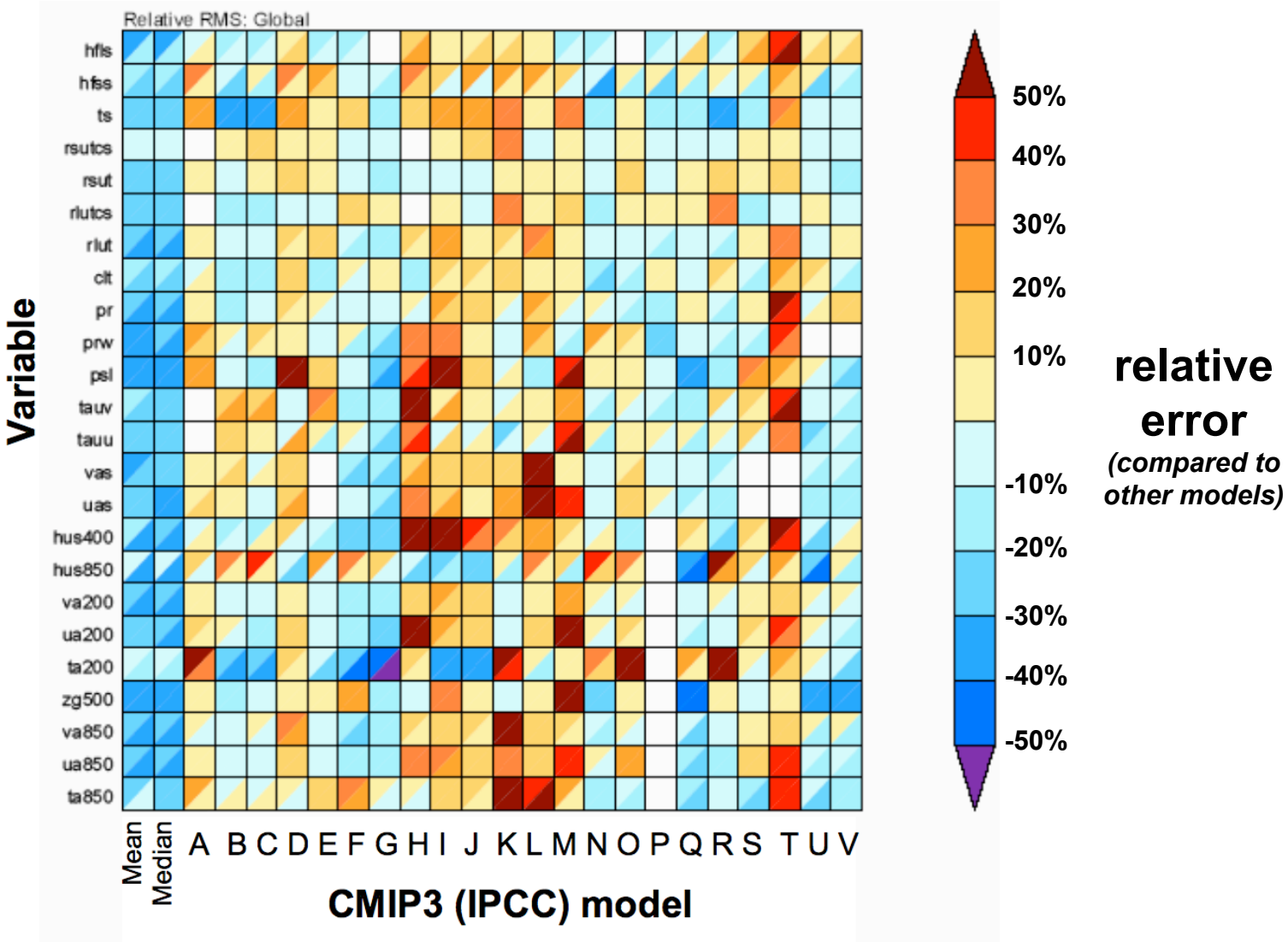
observations

model mean



Source: IPCC 2007

Choosing GCMs:
Ensemble mean vs. individual models

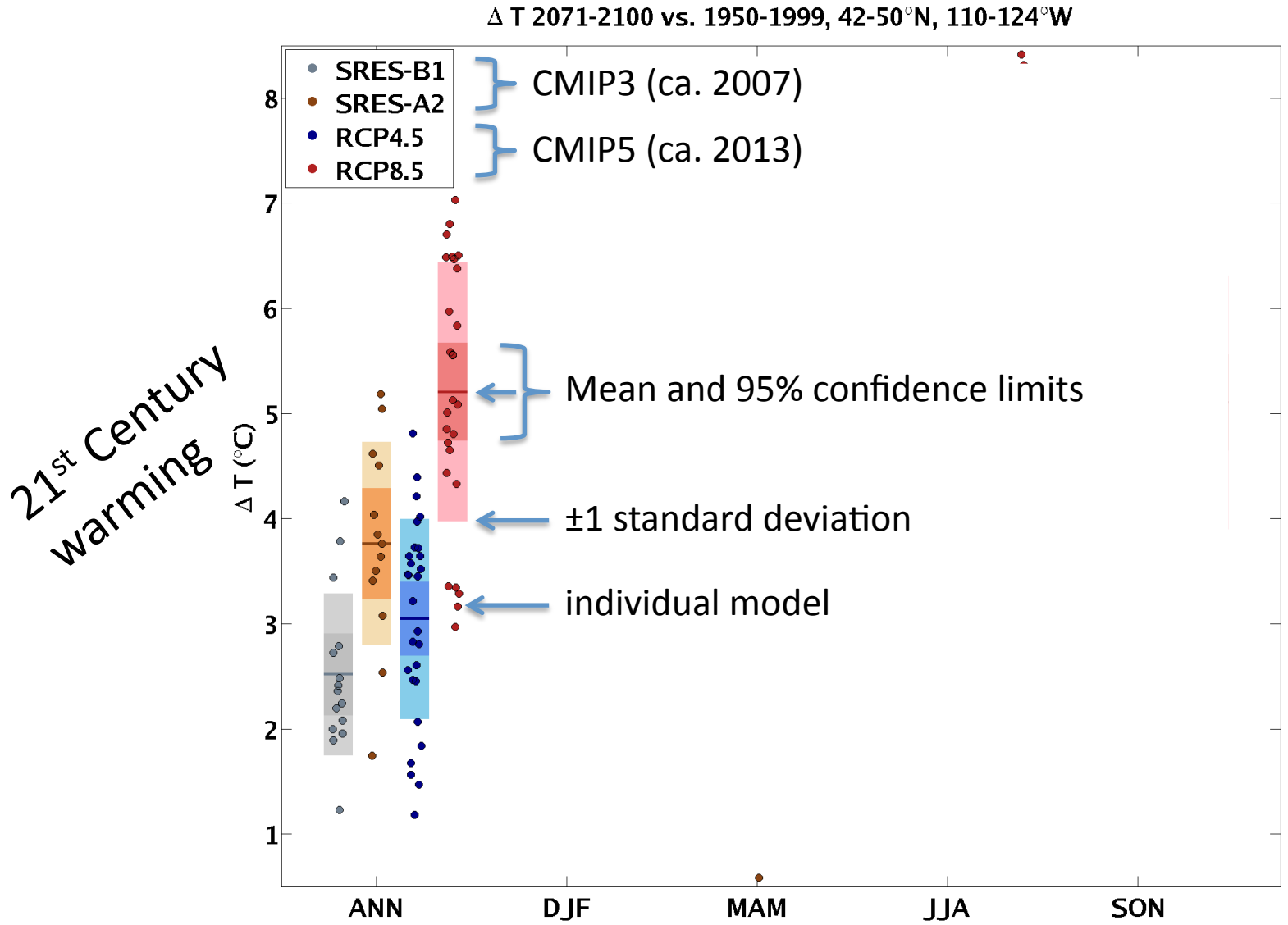


source: Glecker et al., J. Geophys. Research, 2008.

GCM projections for the 21st century

What are the models saying?

Climate Model Projections



Source: John Abatzoglou

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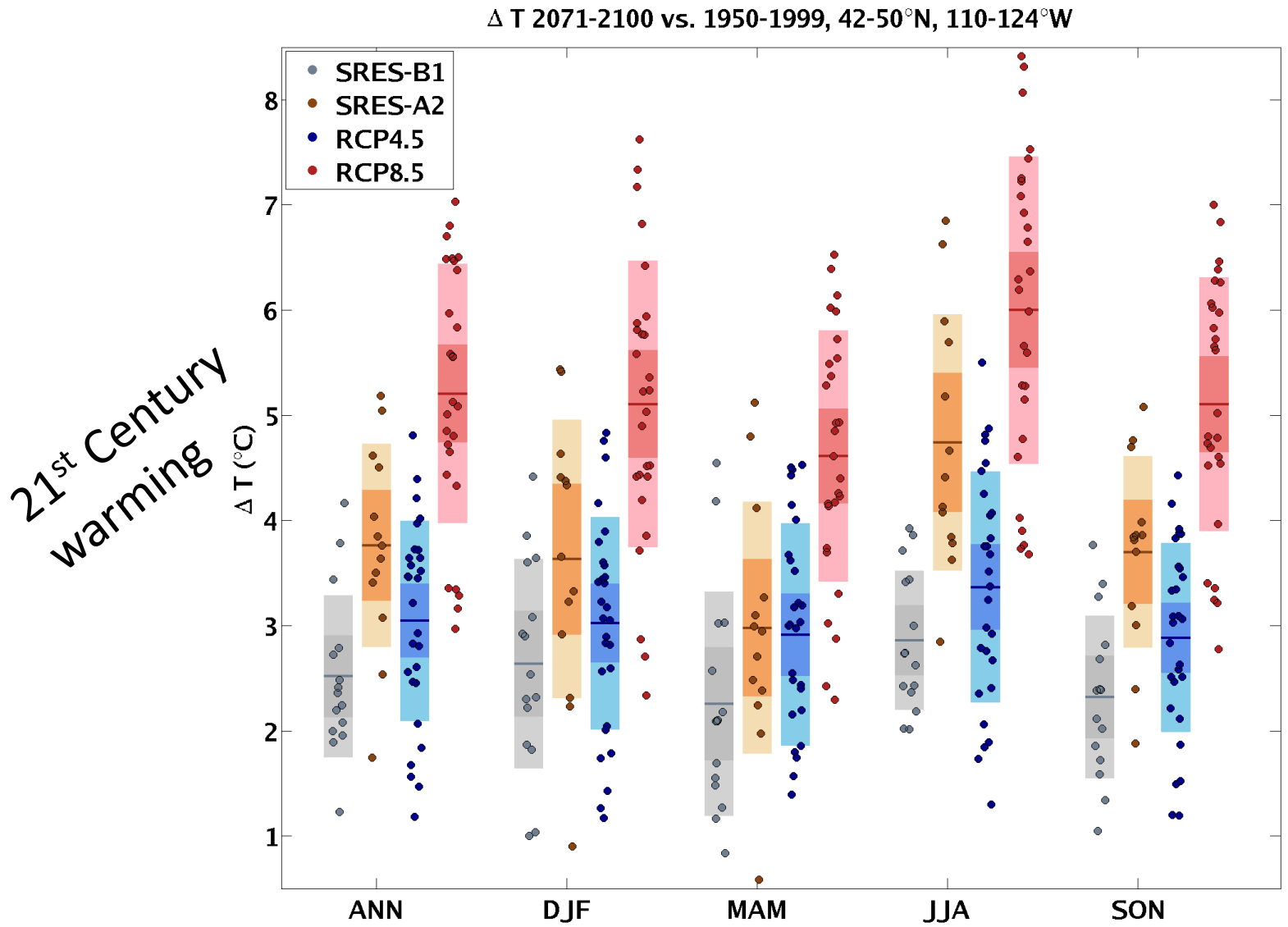
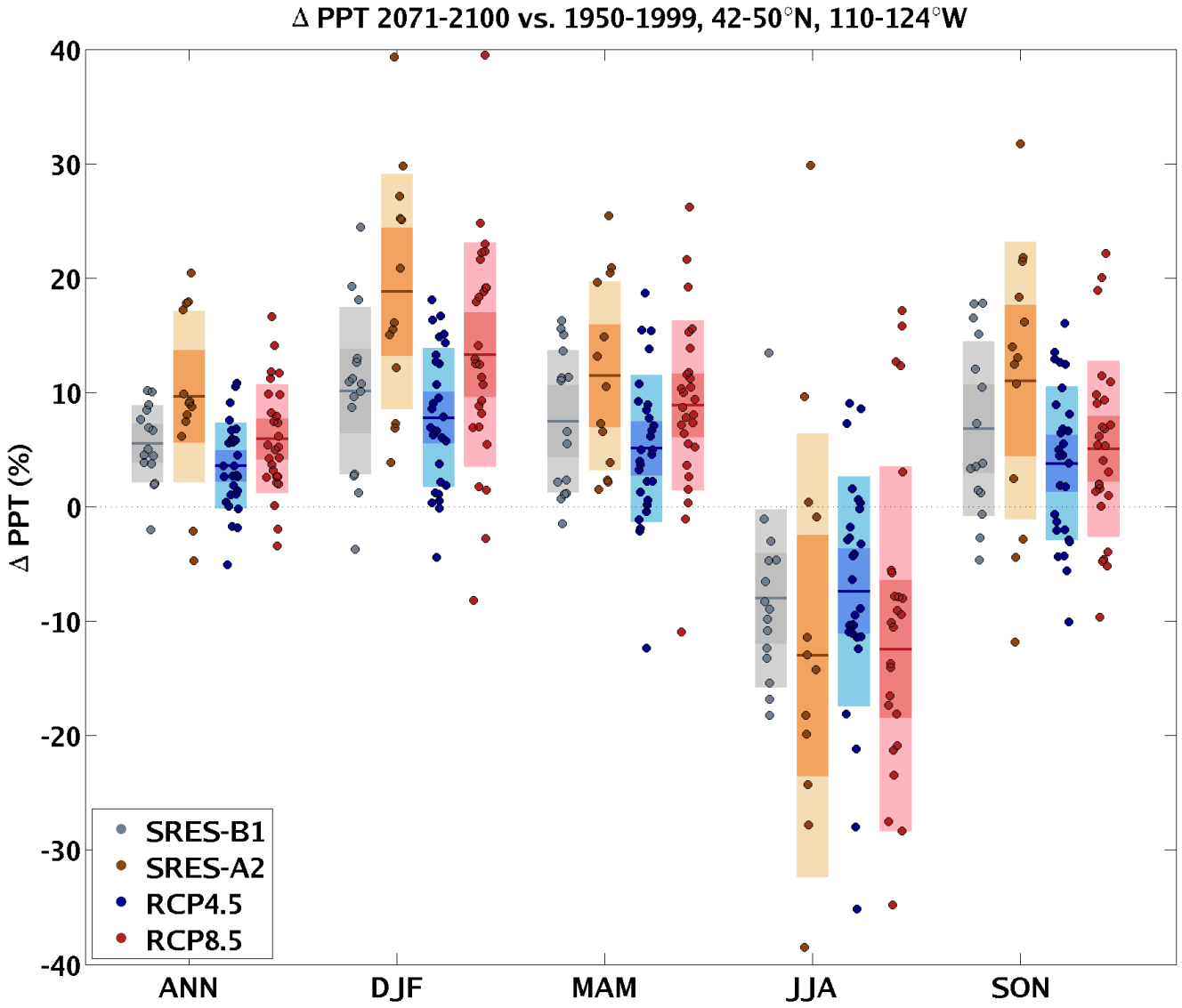


21st Century warming

Source: John Abatzoglou

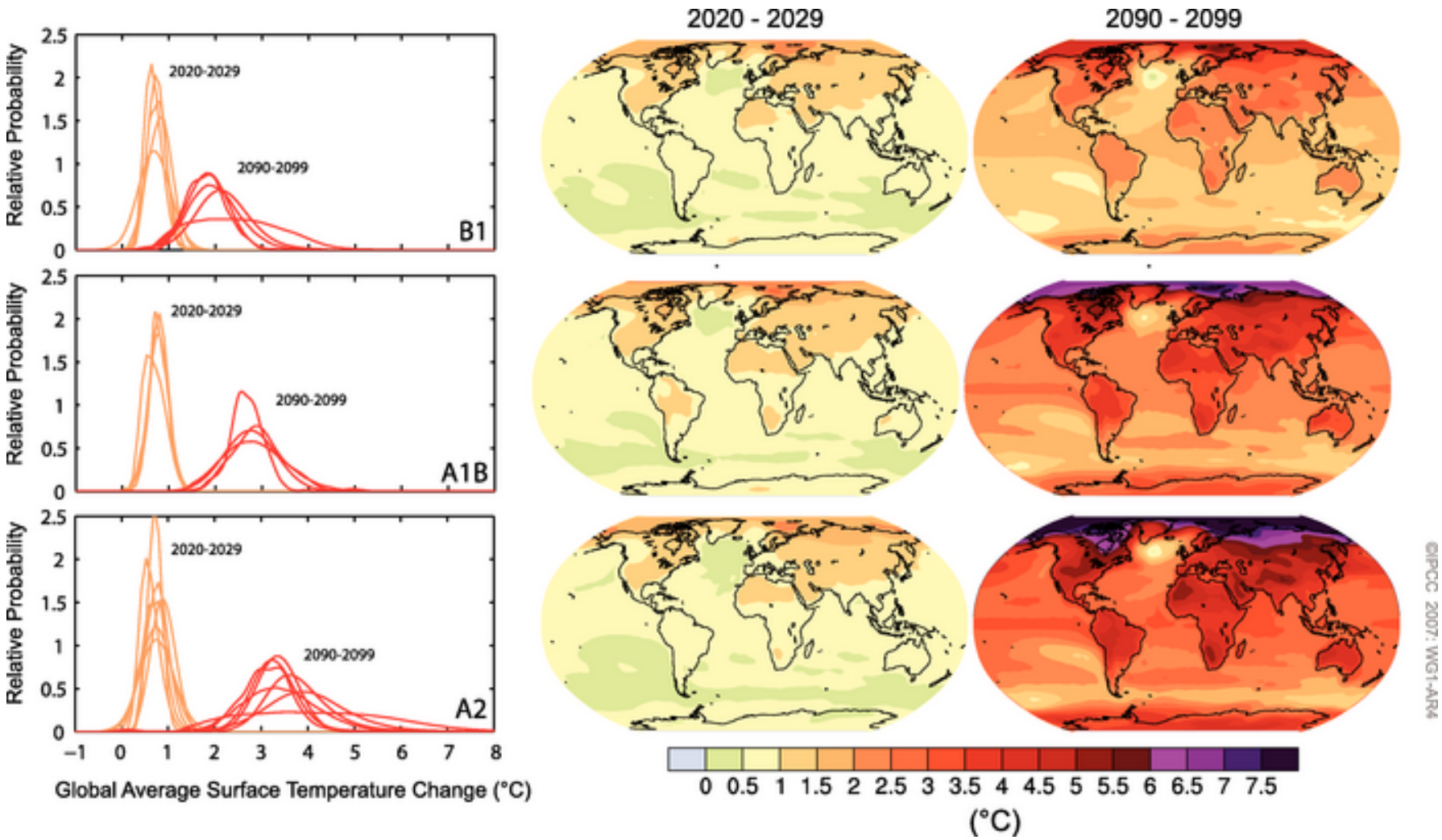
Climate Model Projections

Change in Precip



Source: John Abatzoglou

Climate Model Projections

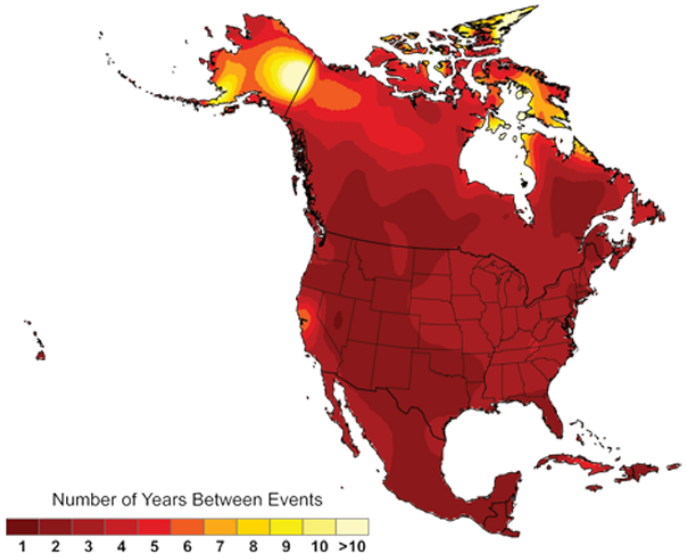


IPCC, 2007

GCM projections for the 21st century

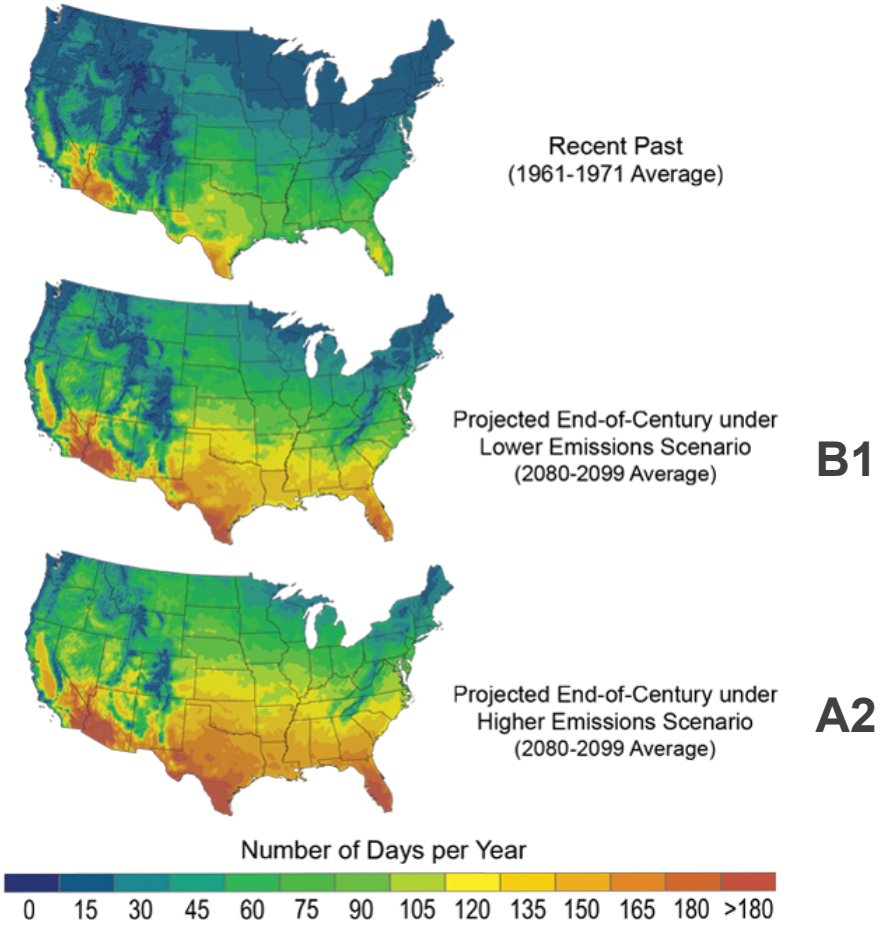
What are the models saying?

Increasing frequency of 20-year heat waves



2080-2099, A2

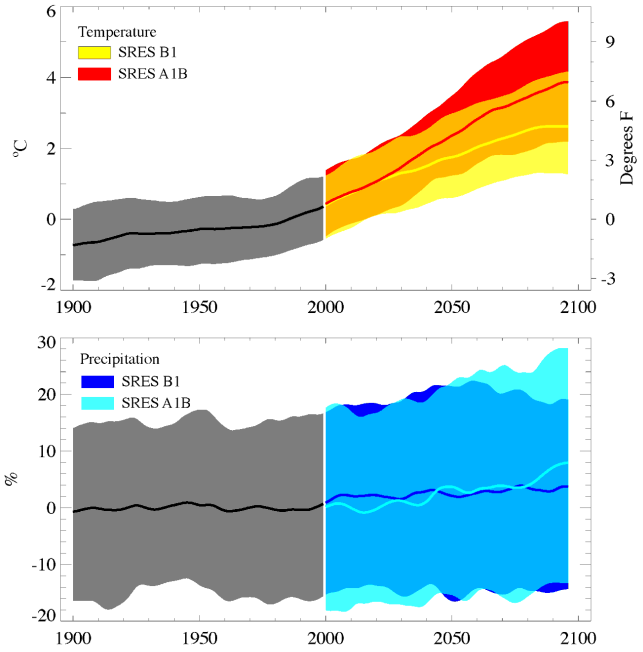
days above 90F

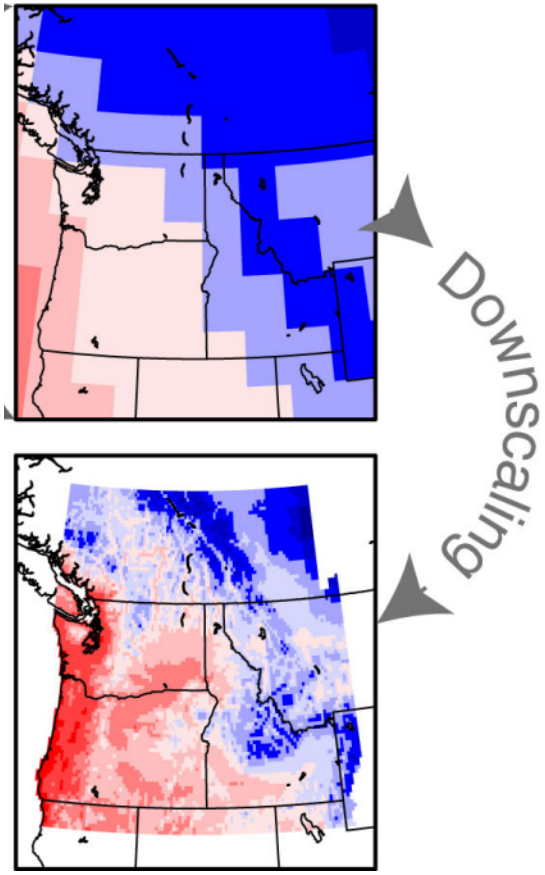


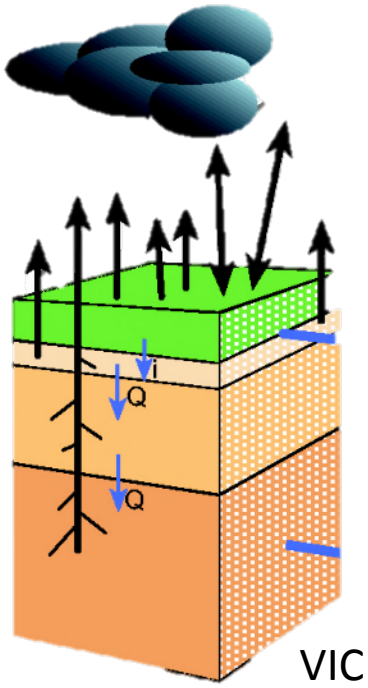
Source: US GCRP, 2009

Translating climate projections, interpreting climate data

Translating from scenarios to impacts







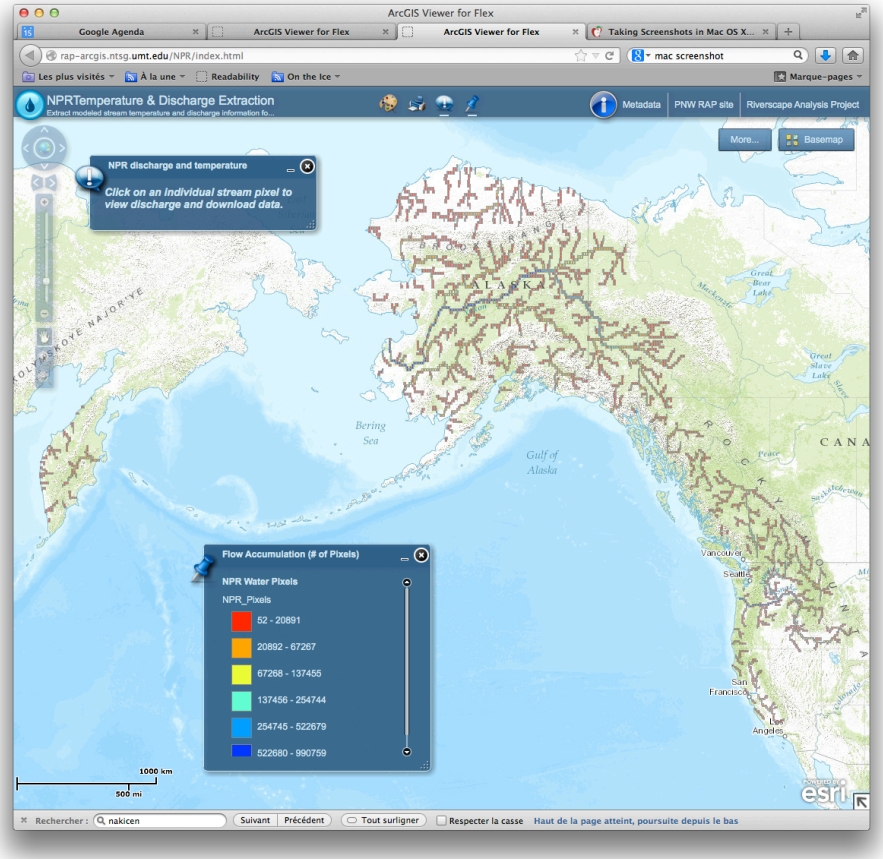
Climate Projections → **Downscaling** → **"Downstream" model**

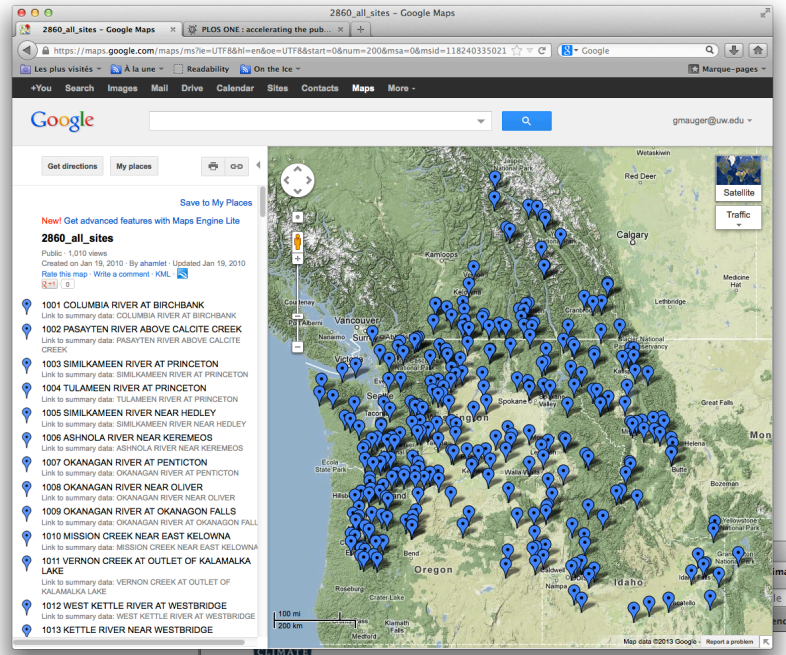
Global Climate Models (GCMs), Emissions scenarios

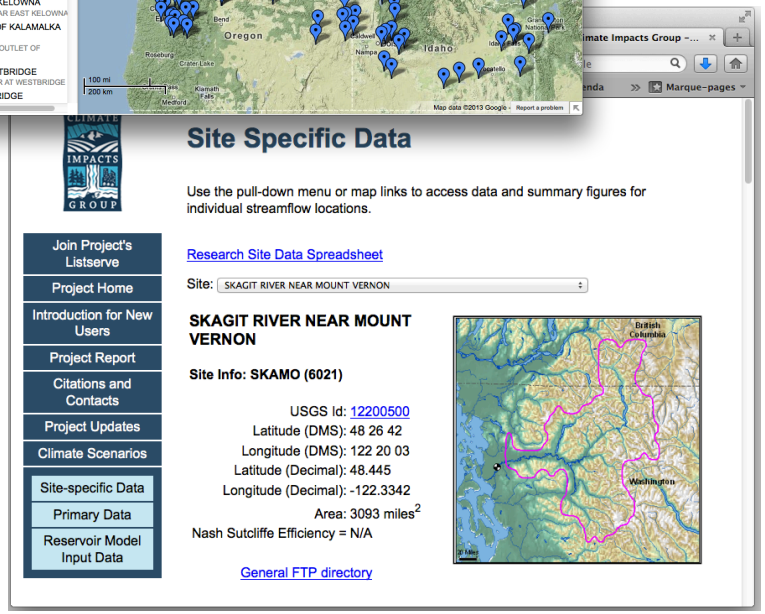
(Relates the "Large" to the "Small")

Translation from climate impacts to, e.g.: water impacts

Visualization, Data access, etc…







Summary

- ***The fundamentals of climate change are well-understood.***
- ***The details still need a lot of work:***
  - Low res.: how to improve & how to contend with
  - Uncertainty: How to estimate, how to plan around
  - Validation: models need to be more fully tested
  - Relevance: How to translate for decision-making
    (Aside: uncertainty in decision-making is not an oxymoron…)
  - Tools for accessing / interpreting / visualizing data

Thanks!

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