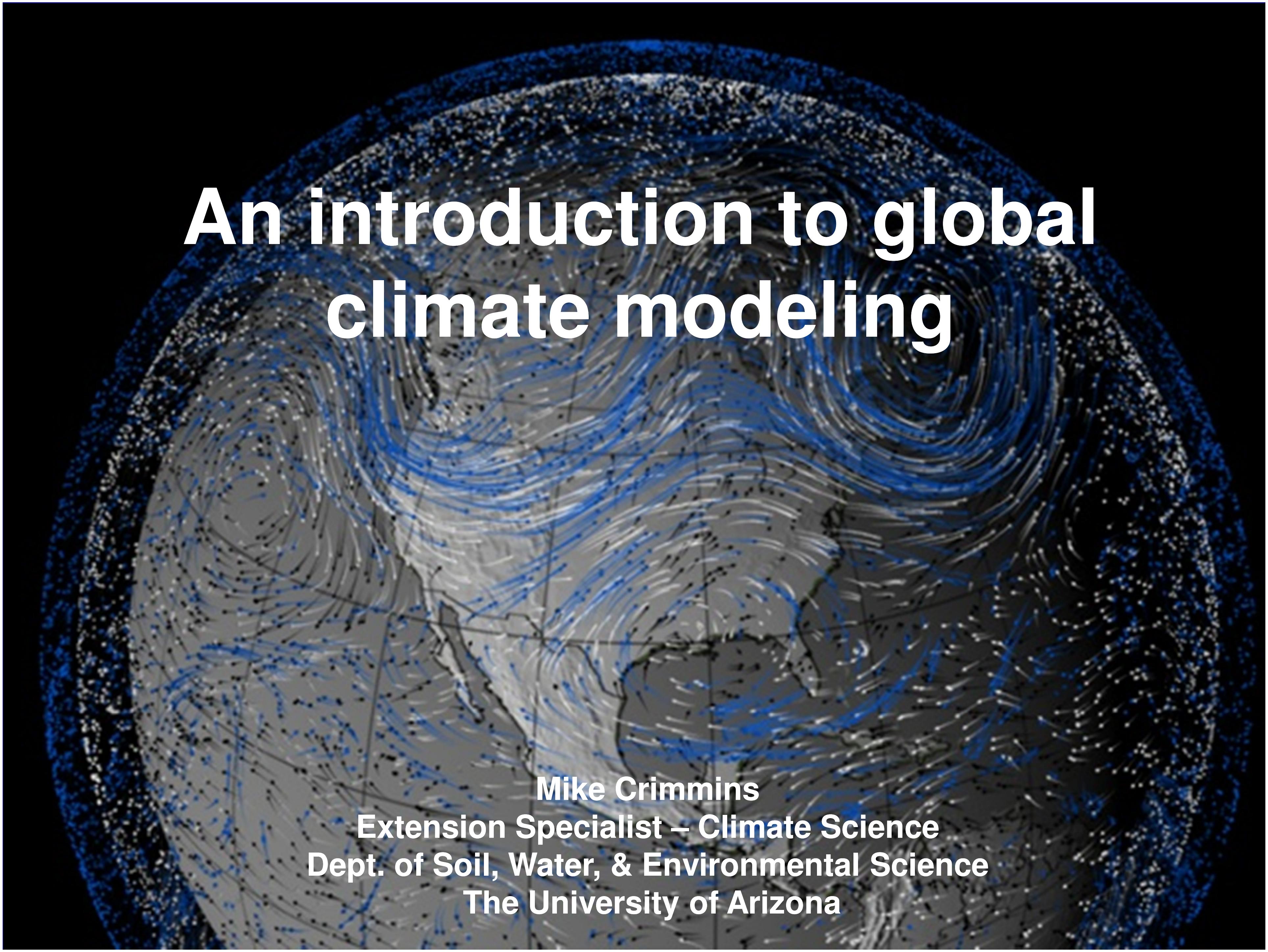

An introduction to global climate modeling

Mike Crimmins
Extension Specialist – Climate Science
Dept. of Soil, Water, & Environmental Science
The University of Arizona

Scientific Method

“The scientific method is the process by which scientists, collectively and over time, endeavor to construct an accurate (that is, reliable, consistent and non-arbitrary) representation of the world.”

From http://teacher.nsrl.rochester.edu

Scientific Method

1. Observation and description of a phenomenon or group of phenomena.
2. Formulation of an hypothesis to explain the phenomena. In physics, the hypothesis often takes the form of a causal mechanism or a mathematical relation.
3. Use of the hypothesis to predict the existence of other phenomena, or to predict quantitatively the results of new observations.
4. Performance of experimental tests of the predictions by several independent experimenters and properly performed experiments.

From http://teacher.nsrl.rochester.edu

Climate Science?

mod·el

- a usually miniature representation of something; *also* **:** a pattern of something to be made
- an example for imitation or emulation
- a system of postulates, data, and inferences presented as a mathematical description of an entity or state of affairs; *also***:** a computer simulation based on such a system

From Merriam-Webster.com

Building Climate Models

- Create a conceptual model of the Earth's climate system
- Translate the conceptual model into mathematical formulas → develop computer code that connects the formulas together through systems, space and time
- Run the model through time
- Refine the model based on observed data

Adapted from http://nas-sites.org/climatemodeling

Conceptual model of Earth system processes…

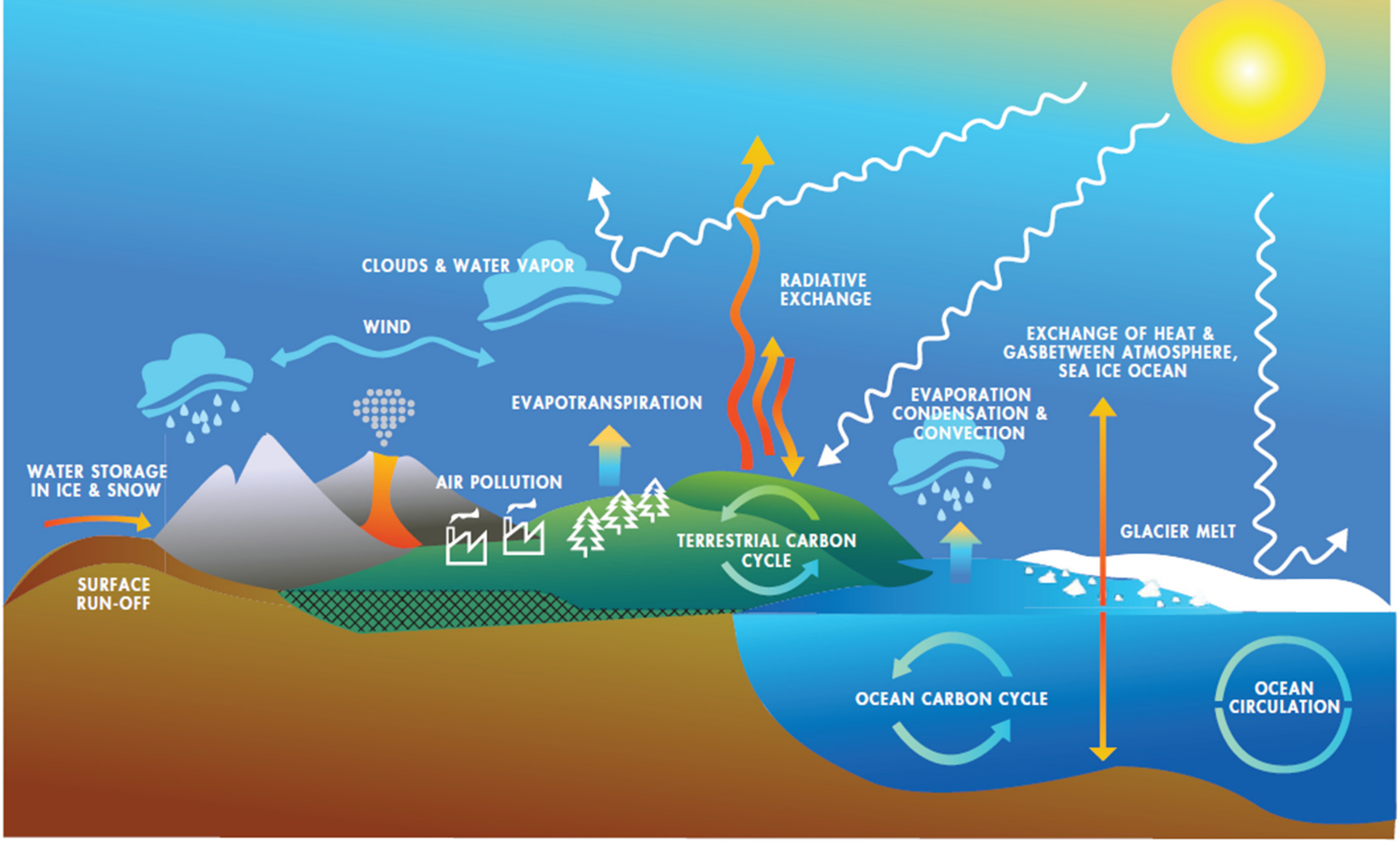

FIGURE 1.3 Climate models are mathematical representations of the physical, chemical, and biological processes in the Earth system. SOURCE: Marian Koshland Science Museum.

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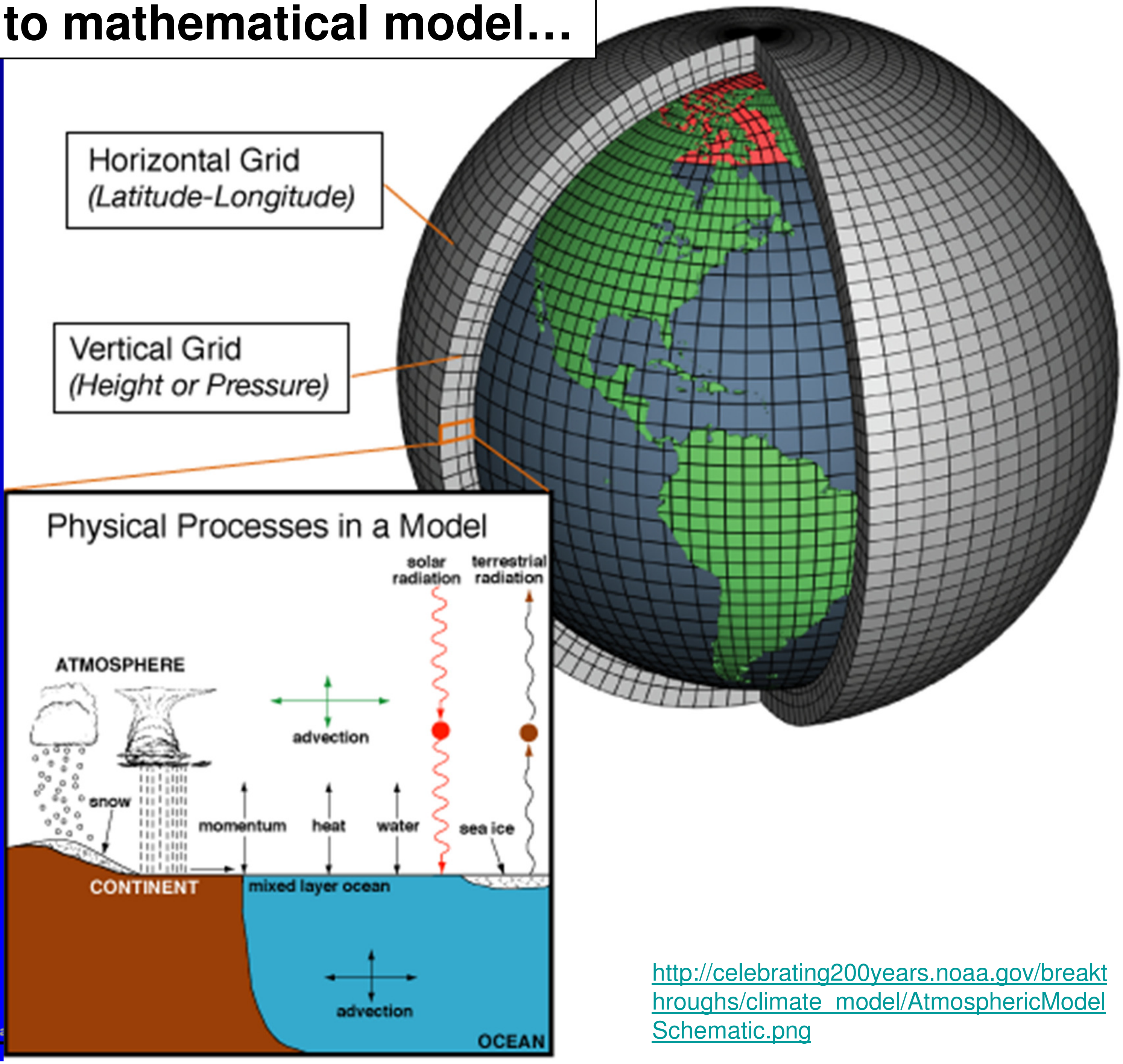
Conceptual to mathematical model…



http://celebrating200years.noaa.gov/breakthroughs/climate_model/AtmosphericModelSchematic.png

Fundamental Equations

- Temperature (T)
- Pressure (P)
- Winds (U,V)
- Humidity (Q)

- Conservation of momentum

$$\frac{\partial \vec{V}}{\partial t} = -(\vec{V}\cdot\nabla)\vec{V} - \frac{1}{\rho}\nabla p - \vec{g} - 2\vec{\Omega}\times\vec{V} + \nabla\cdot(k_m\nabla\vec{V}) - \vec{F}_d$$

- Conservation of energy

$$\rho c_{\vec{v}}\frac{\partial T}{\partial t} = -\rho c_{\vec{v}}(\vec{V}\cdot\nabla)T - \nabla\cdot\vec{R} + \nabla\cdot(k_T\nabla T) + C + S$$

- Conservation of mass

$$\frac{\partial \rho}{\partial t} = -(\vec{V}\cdot\nabla)\rho - \rho(\nabla\cdot\vec{V})$$

- Conservation of H_2O (vapor, liquid, solid)

$$\frac{\partial q}{\partial t} = -(\vec{V}\cdot\nabla)q + \nabla\cdot(k_q\nabla q) + S_q + E$$

- Equation of state

$$p = \rho R_d T$$

Calculated for each grid cell at each time step

From http://serc.carleton.edu/eet/envisioningclimatechange/part_2.html

But, What Is a GCM *really*?: A Computer Program

From http://serc.carleton.edu/eet/envisioningclimatechange/part_2.html

```
Global_Warming_Sim2.R  Model II 8/24/2000

Owner: Dr. Mark Chandler, chandler@giss.nasa.gov
Group: Paleoclimate Group
This experiment simulates climate change based on a
1 percent/year increase in CO2

Object modules:
MainC9 DiagC9 RadC9
FFTC9
UTILC9

Data input files:
7=G8X10_600Ma
9=NOV1910.rsf_snowball
15=O8X10_600Ma
19=CD8X10_600Ma
23=V8X10_600Ma
26=Z8X101_600Ma
21=RTAU.G25L15
22=RPLK25
29=Snowball_Earth_Regions

Label and Namelist:
Global_Warming_Sim2 (Transient increase in CO2)

 &INPUTZ
  TAUI=10176.,IYEAR=1900,
```

```
C** INITIALIZE SOME ARRAYS AT THE BEGINNING OF SPECIFIED DAYS

       fName = './prt/'//JMNTH0(1:3)//CYEAR//'.prt'//LABEL1(

       IF(JDAY.NE.32) GO TO 294
       JEQ=1+JM/2
       DO 292 J=JEQ,JM
       DO 292 I=1,IM
 292   TSFREZ(I,J,1)=JDAY
       JEQM1=JEQ-1
       DO 293 J=1,JEQM1
       DO 293 I=1,IM
 293   TSFREZ(I,J,2)=JDAY
       GO TO 296
 294   IF(JDAY.NE.213) GO TO 296
       JEQM1=JM/2
       DO 295 J=1,JEQM1
       DO 295 I=1,IM
 295   TSFREZ(I,J,1)=JDAY
C**** INITIALIZE SOME ARRAYS AT THE BEGINNING OF EACH DAY
 296   DO 297 J=1,JM
       DO 297 I=1,IM

       TDIURN(I,J,1)=1000.
       TDIURN(I,J,2)=-1000.

       TDIURN(I,J,6)=-1000.

       PEARTH=FDATA(I,J,2)*(1.-FDATA(I,J,3))
```

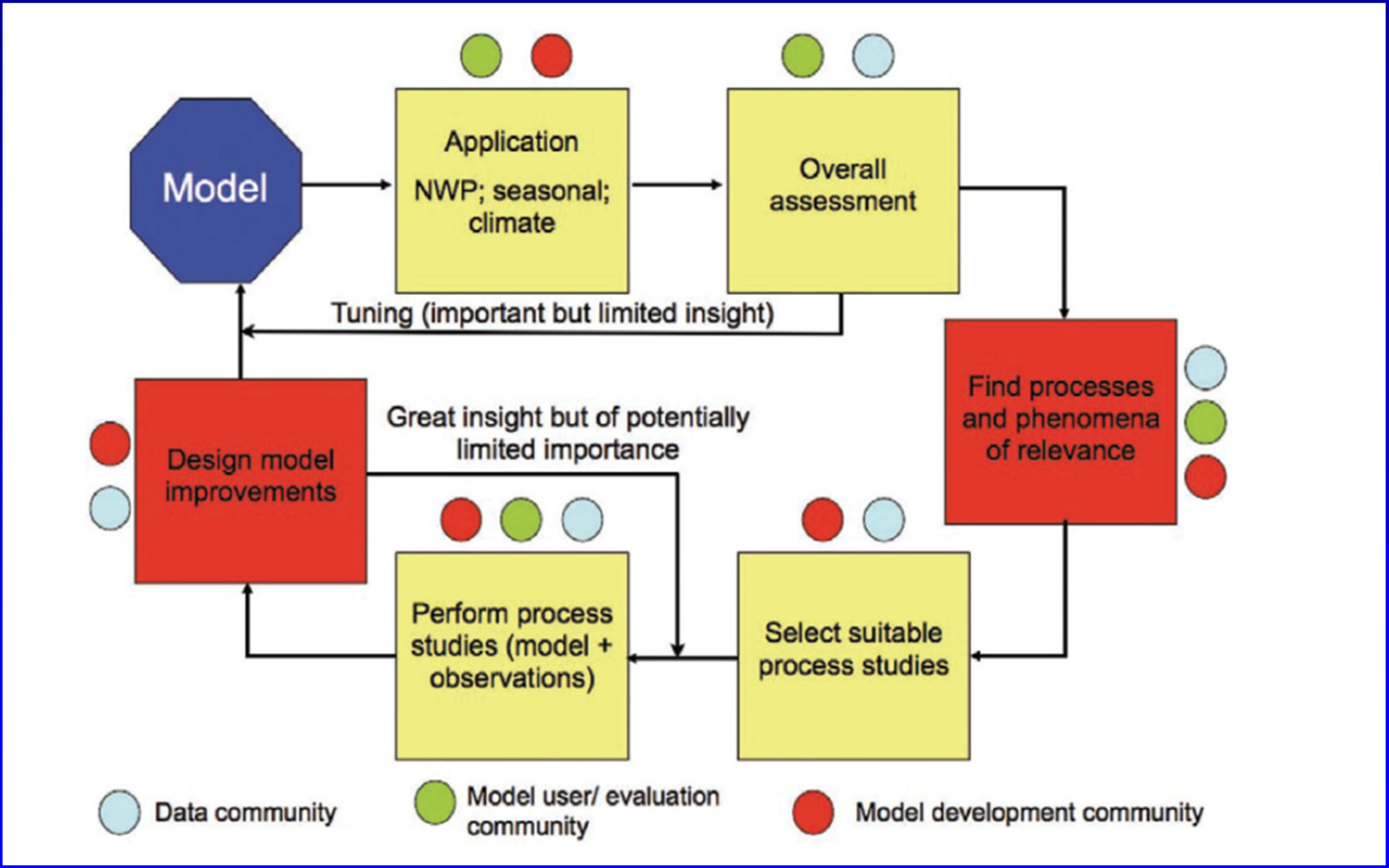
Unix scripts and Fortran Code

Requiring significant programming skills to operate

GCMs require enormous computing power!

FIGURE 1.5 Global climate models are run on supercomputers, like the NOAA climate research supercomputer Gaea at Oak Ridge National Laboratory in Tennessee (pictured). It has a peak speed of 1.1 petaflops (more than 1,000 trillion calculations per second). SOURCE: ORNL photos/Jay Nave (http://blogs.knoxnews.com/munger/2011/12/noaas-petascale-computer-for-c.html).

Run…compare…test…refine…run…



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Who does climate modeling?

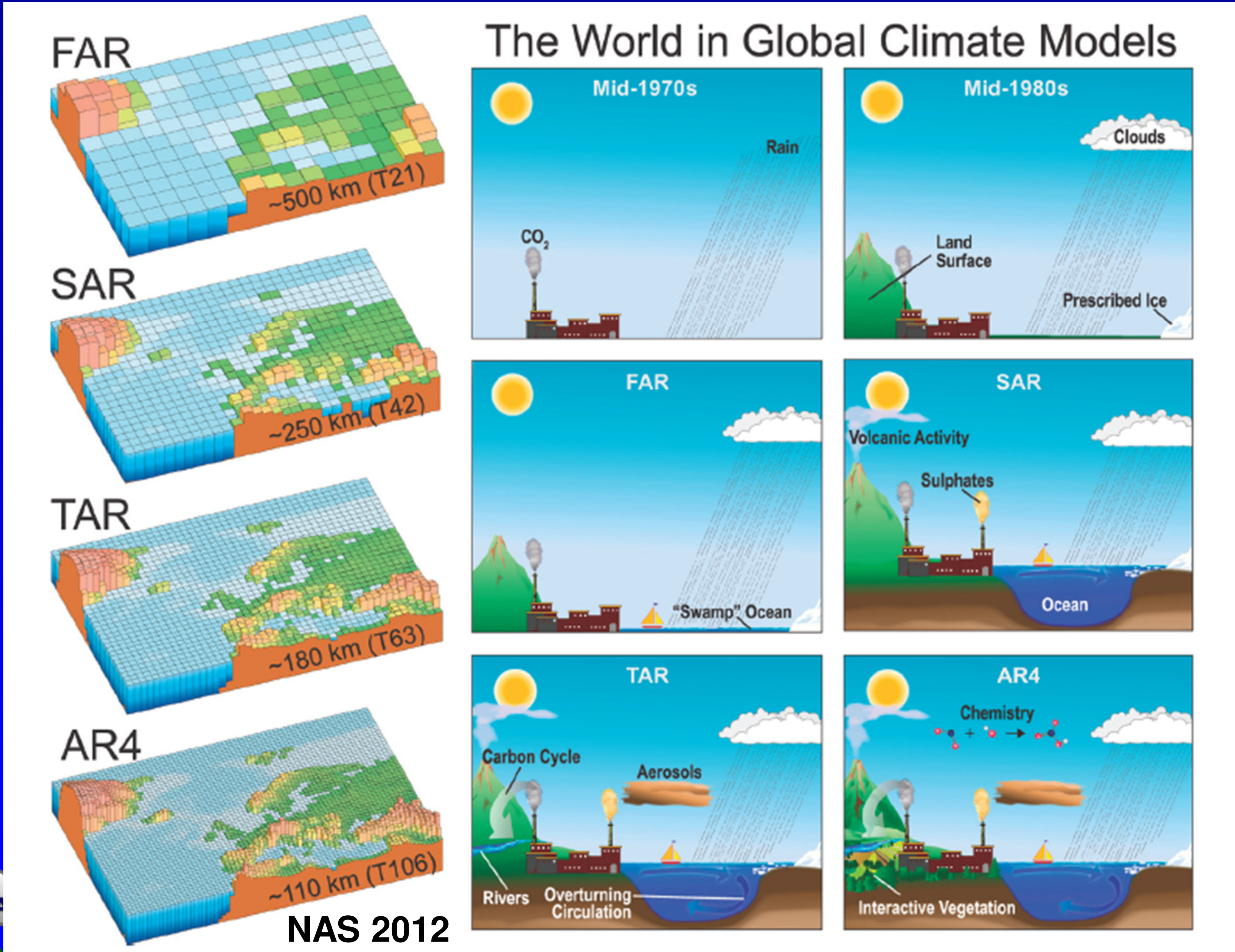
About WCRP CMIP3 Model Output

CMIP3 Climate Model Documentation, References, and Links

Last updated 17 July 2007

Originating Group(s)	Country	CMIP3 I.D.
Beijing Climate Center	China	BCC-CM1
Bjerknes Centre for Climate Research	Norway	BCCR-BCM2.0
National Center for Atmospheric Research	USA	CCSM3
Canadian Centre for Climate Modelling & Analysis	Canada	CGCM3.1(T47)
Canadian Centre for Climate Modelling & Analysis	Canada	CGCM3.1(T63)
Météo-France / Centre National de Recherches Météorologiques	France	CNRM-CM3
CSIRO Atmospheric Research	Australia	CSIRO-Mk3.0
CSIRO Atmospheric Research	Australia	CSIRO-Mk3.5
Max Planck Institute for Meteorology	Germany	ECHAM5/MPI-OM
Meteorological Institute of the University of Bonn, Meteorological Research Institute of KMA, and Model and Data group.	Germany / Korea	ECHO-G
LASG / Institute of Atmospheric Physics	China	FGOALS-g1.0
US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory	USA	GFDL-CM2.0
US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory	USA	GFDL-CM2.1
NASA / Goddard Institute for Space Studies	USA	GISS-AOM
NASA / Goddard Institute for Space Studies	USA	GISS-EH
NASA / Goddard Institute for Space Studies	USA	GISS-ER
Instituto Nazionale di Geofisica e Vulcanologia	Italy	INGV-SXG
Institute for Numerical Mathematics	Russia	INM-CM3.0
Institut Pierre Simon Laplace	France	IPSL-CM4
Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC)	Japan	MIROC3.2(hires)
Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC)	Japan	MIROC3.2(medres)
Meteorological Research Institute	Japan	MRI-CGCM2.3.2
National Center for Atmospheric Research	USA	PCM
Hadley Centre for Climate Prediction and Research / Met Office	UK	UKMO-HadCM3
Hadley Centre for Climate Prediction and Research / Met Office	UK	UKMO-HadGEM1

Evolution of climate models



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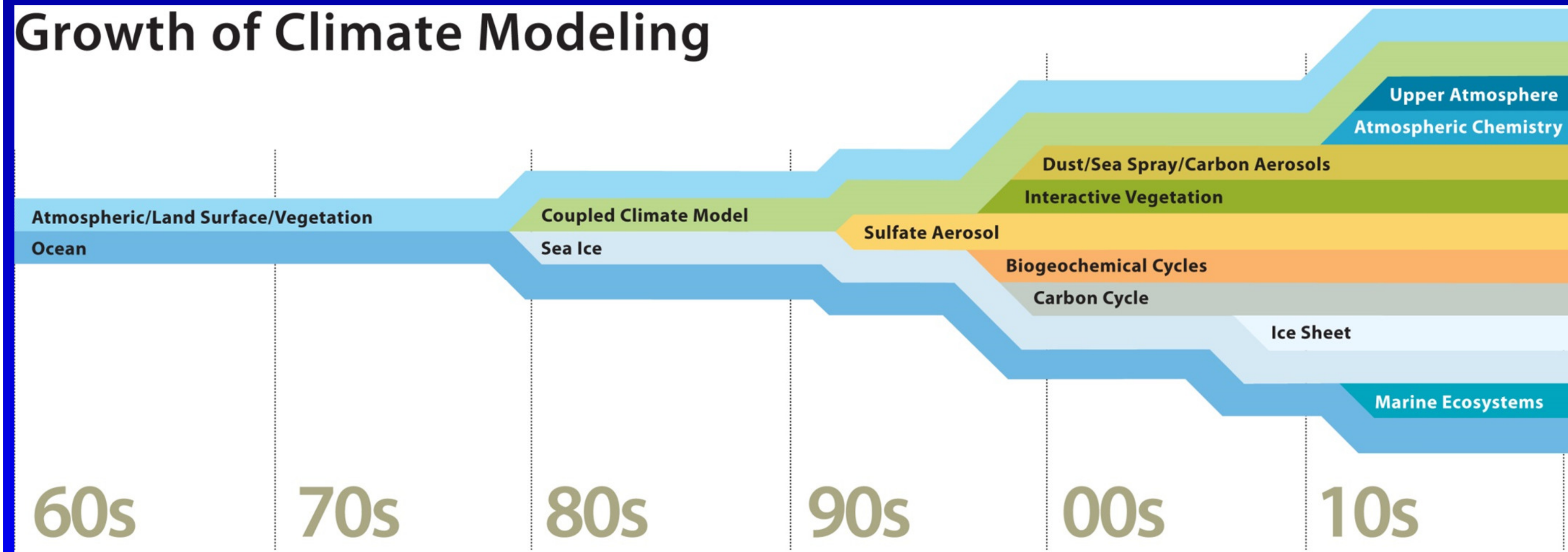
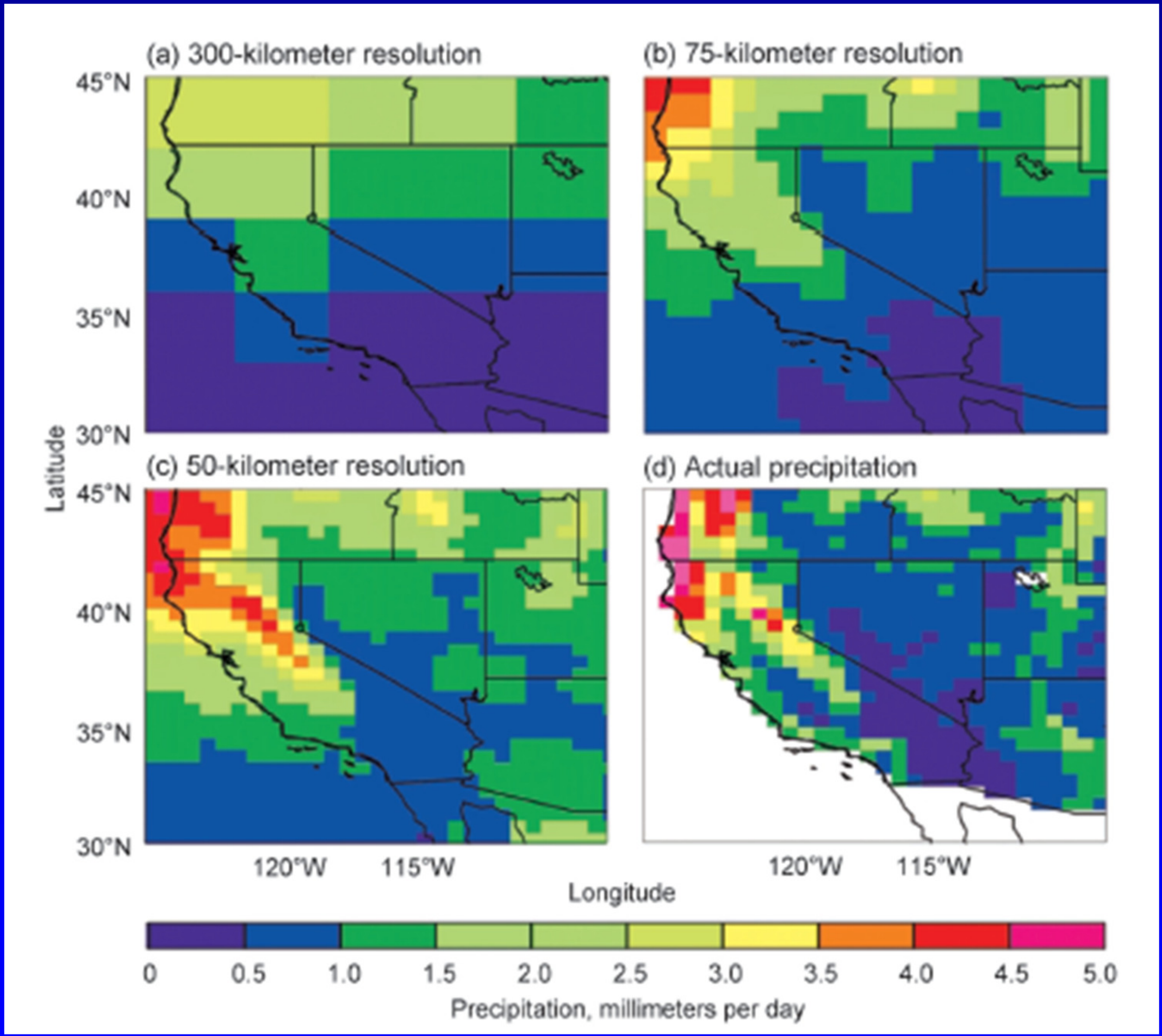
Evolution of climate models



https://www2.ucar.edu/sites/default/files/news/2011/predictFlow2.jpg

Modeled Annual Precipitation across SW



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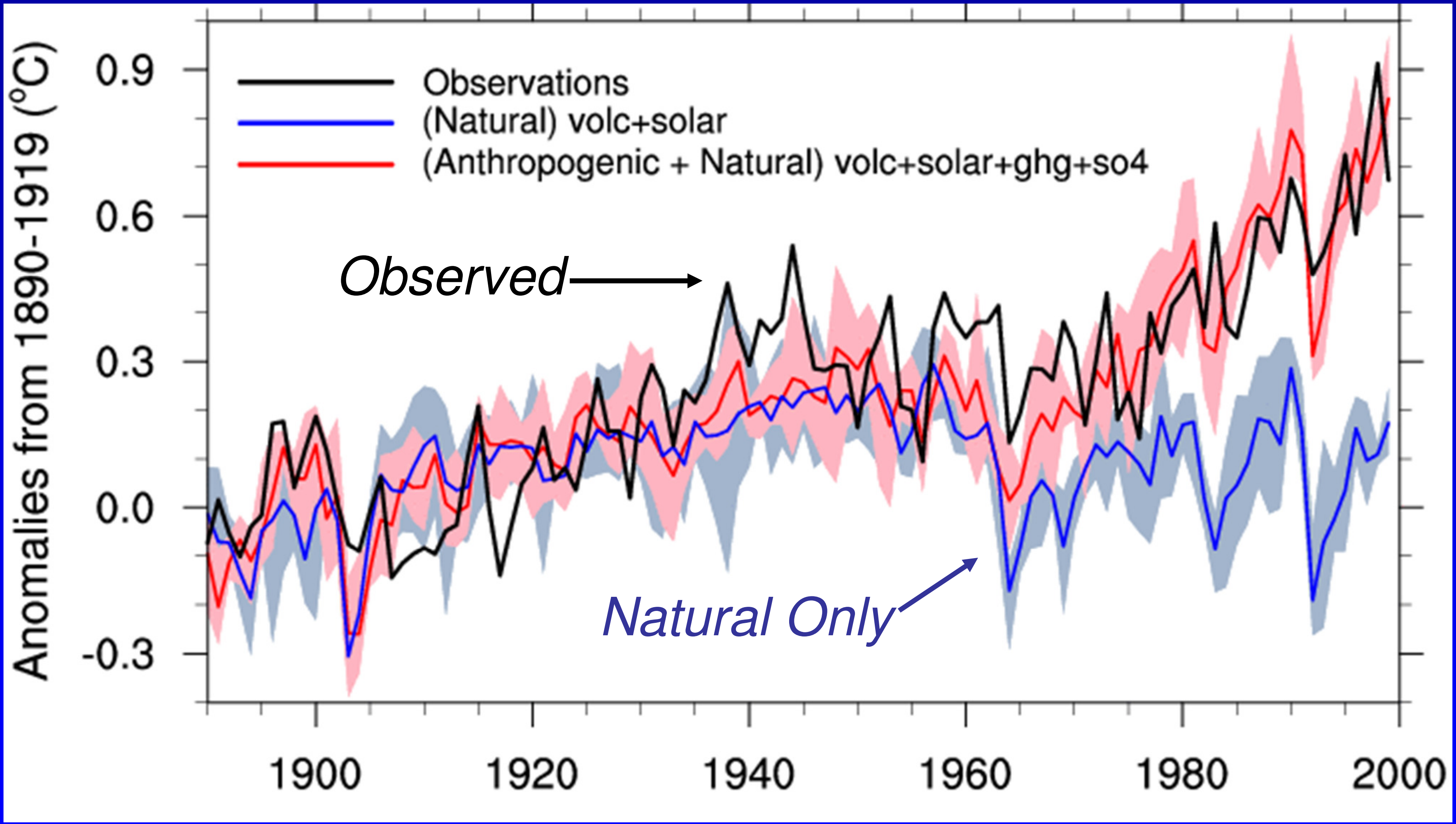
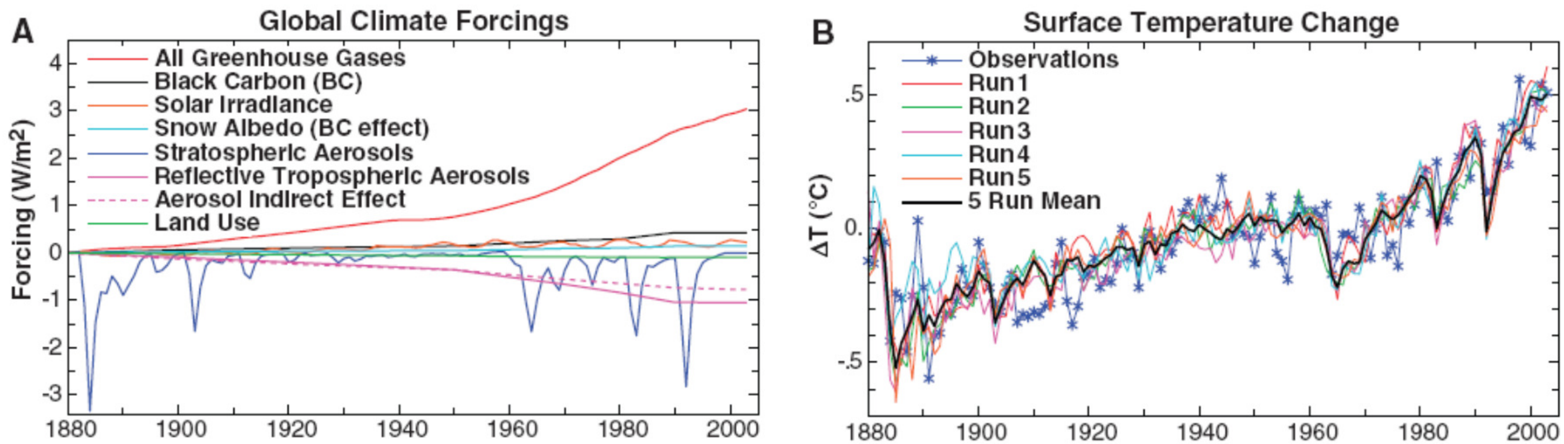
Climate Experiments: Detection and Attribution

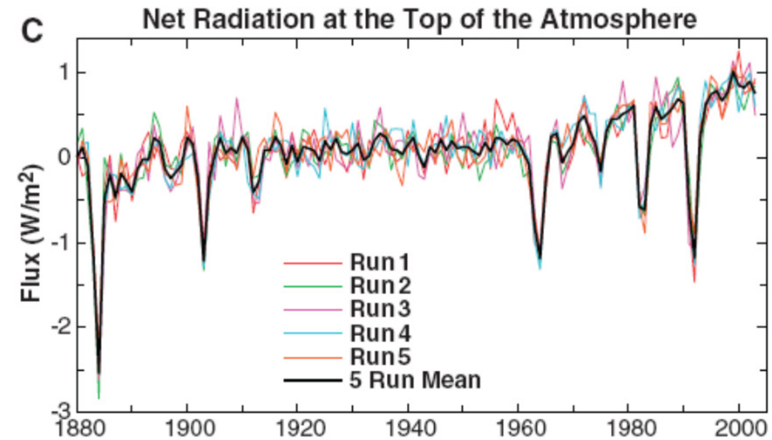


Stott et al. (2000)

Case Example: Sensitivity of the Earth’s Climate



- Earth is now radiating 0.85 W/m² less energy than it is receiving
- Imbalance and associated warming are consistent with GHG forcings
- Components of natural variability (e.g. solar irradiance and volcanic aerosols) are small
- More warming “in the pipeline”



Hansen et al. 2005

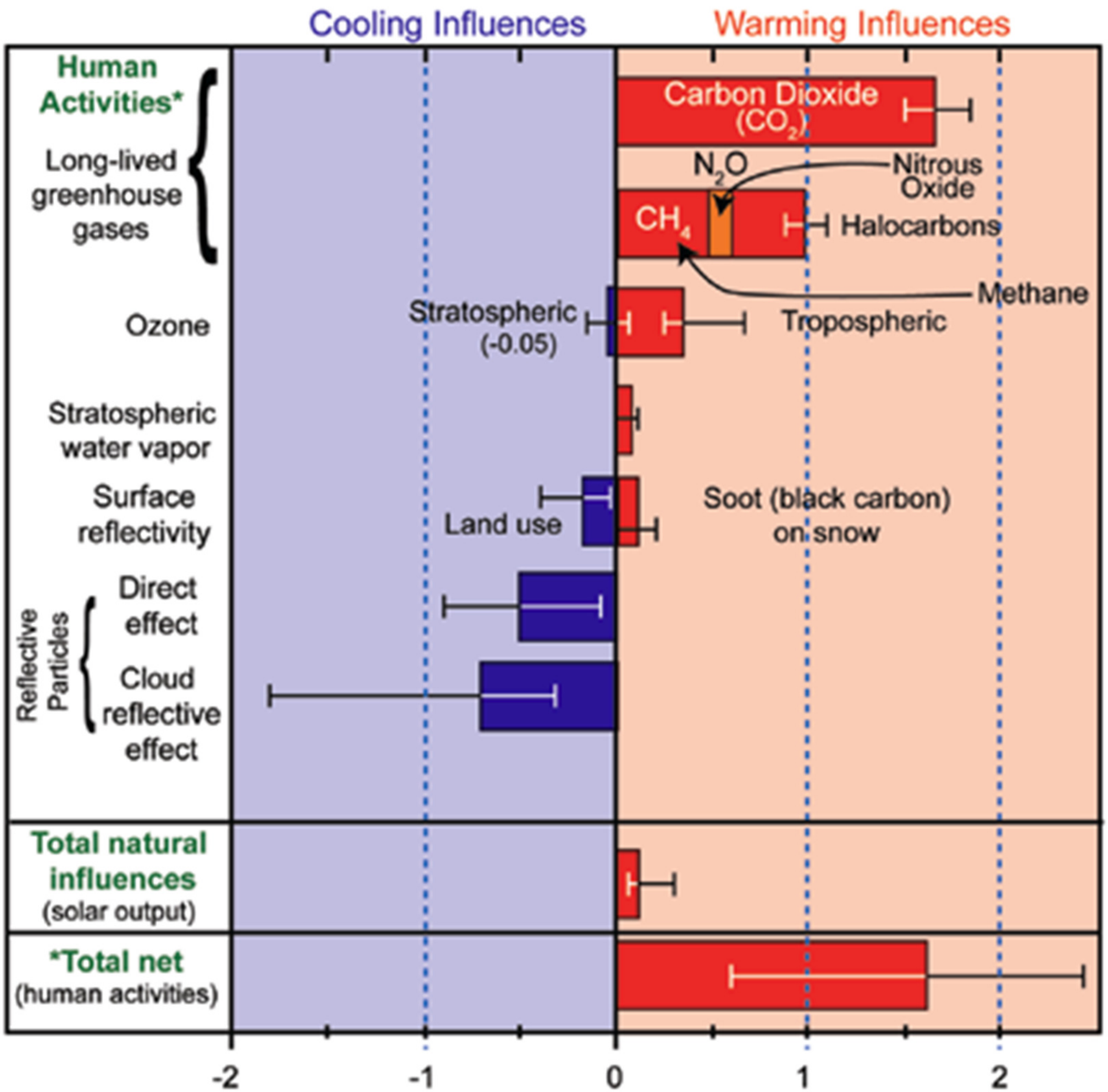
How 'good' are these models?

"…all models are wrong, but some are useful."
--G.E. Box

What do models have to get right to work well?

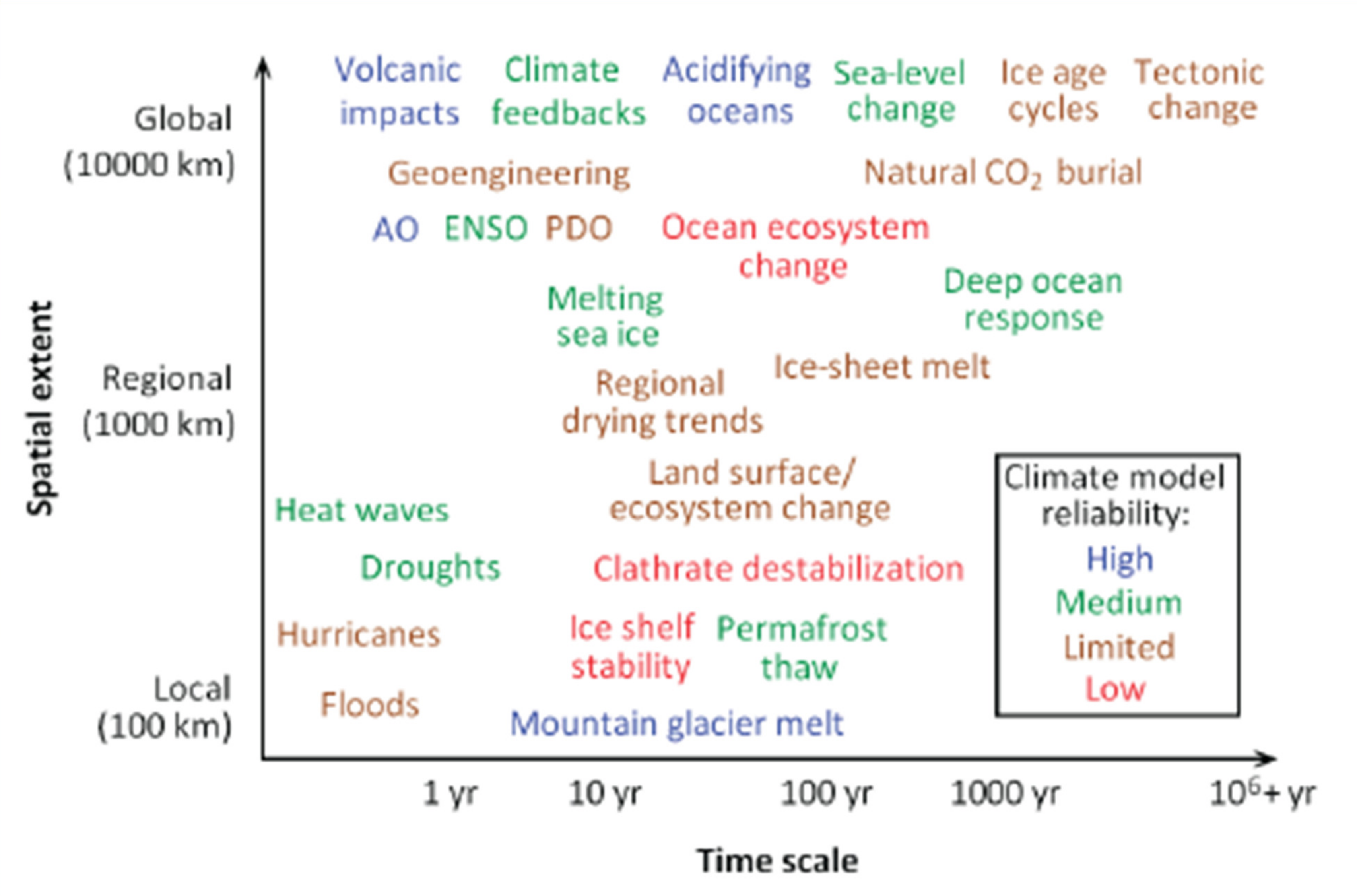
Major warming and cooling influences on climate: 1750-2005

USGCRP 2009



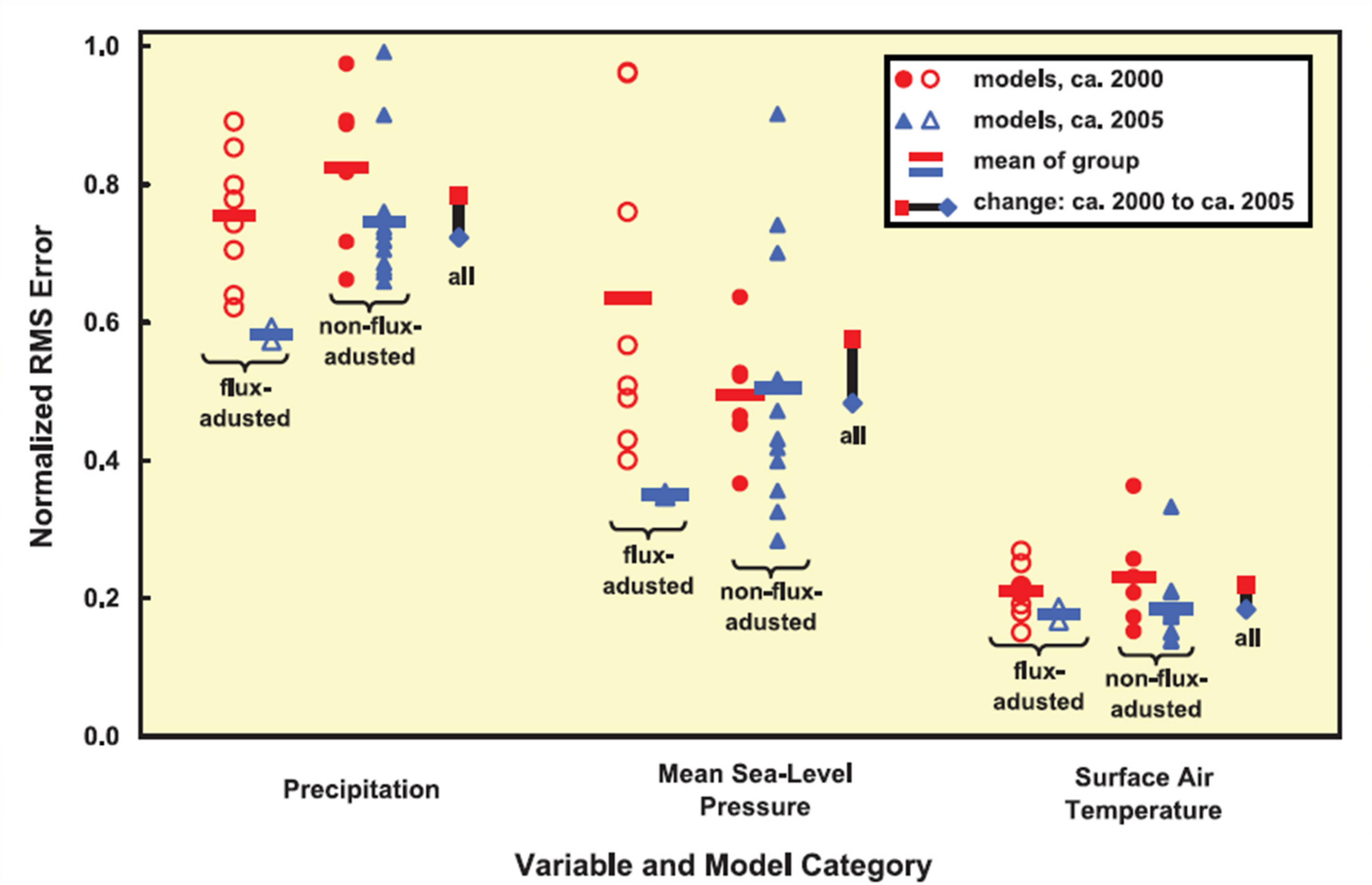
CSAP Climate Science Applications

Climate model reliability vs. scale and phenomena



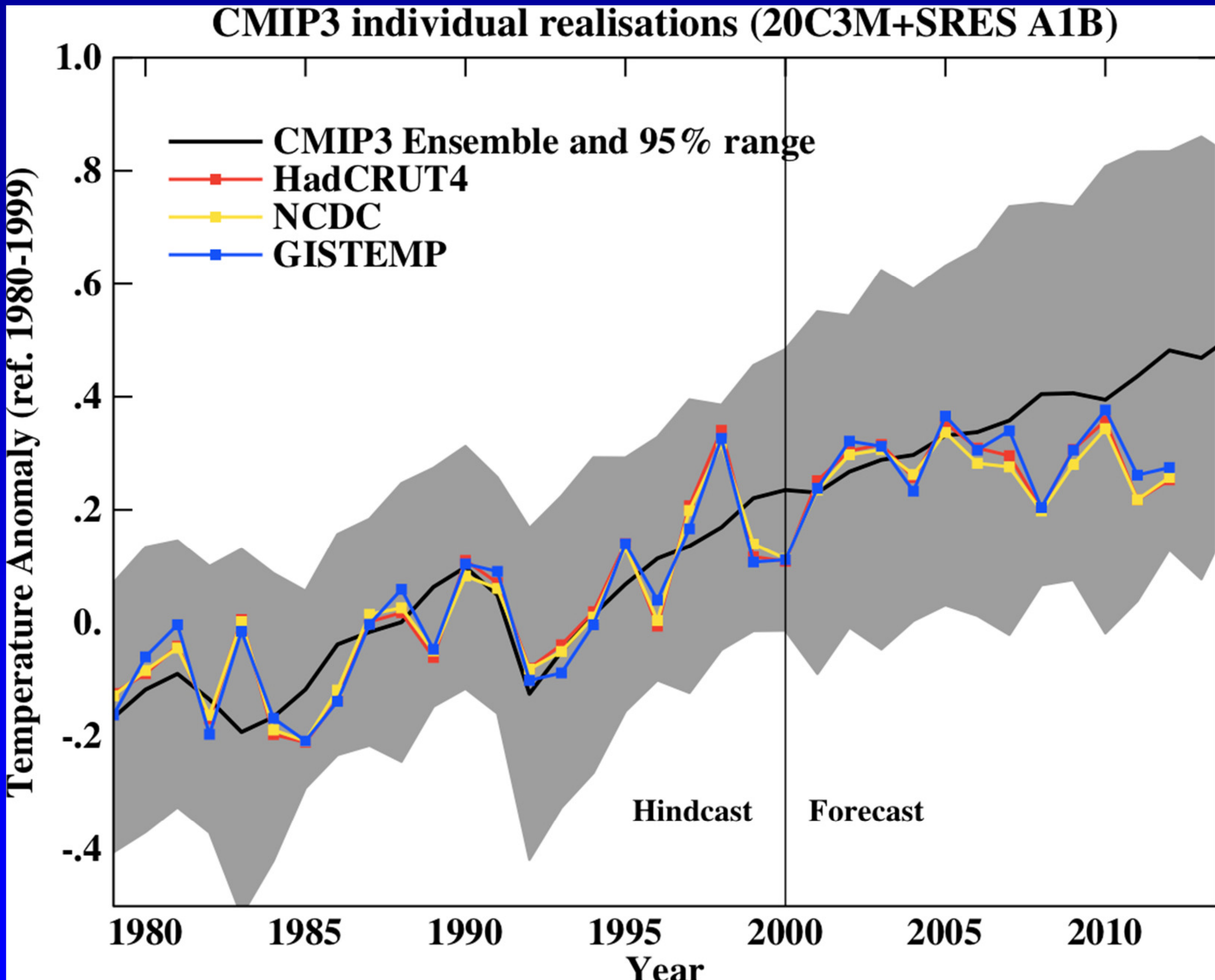
NAS 2012

Climate model error



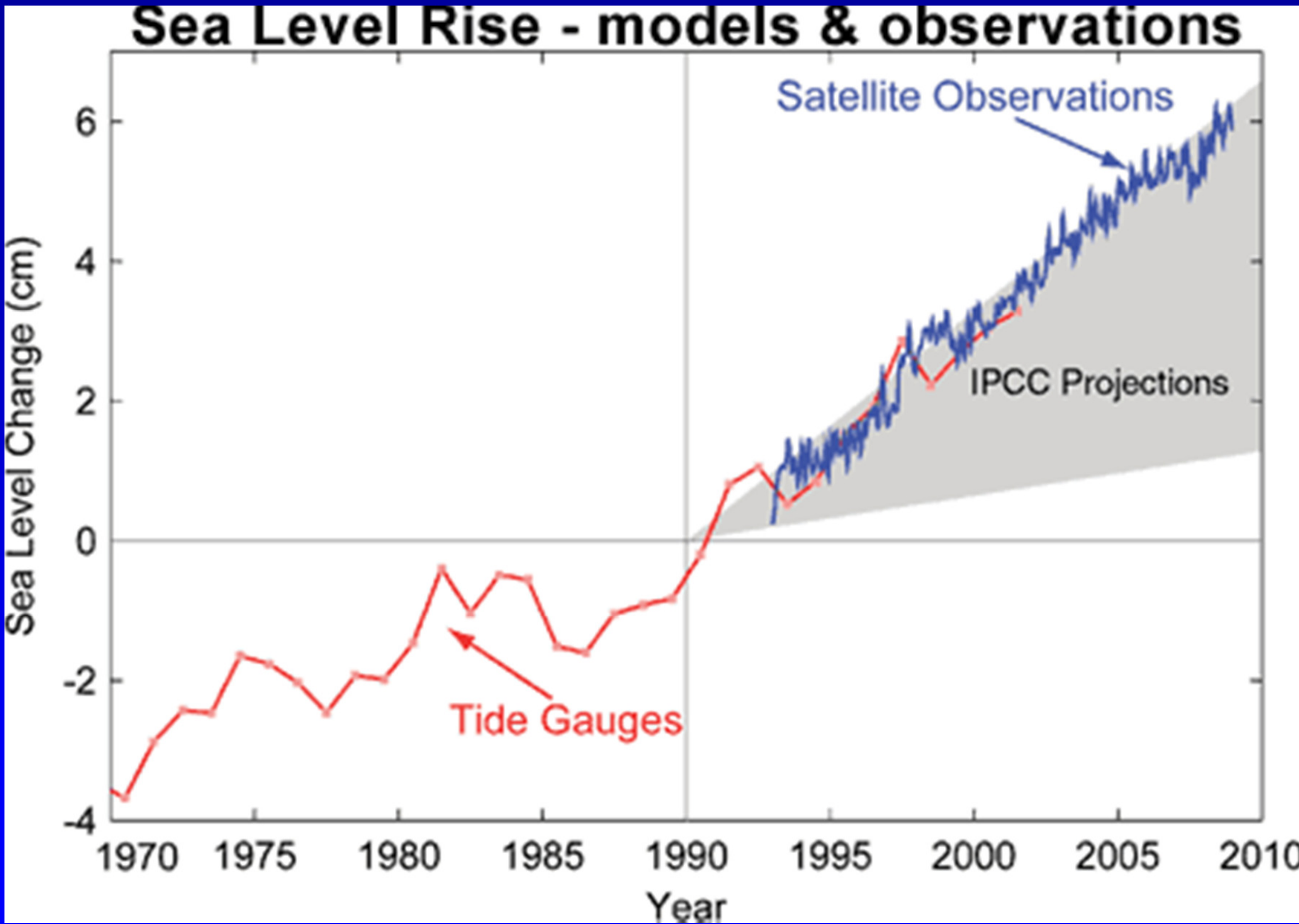
IPCC 2007

How are the climate models doing?



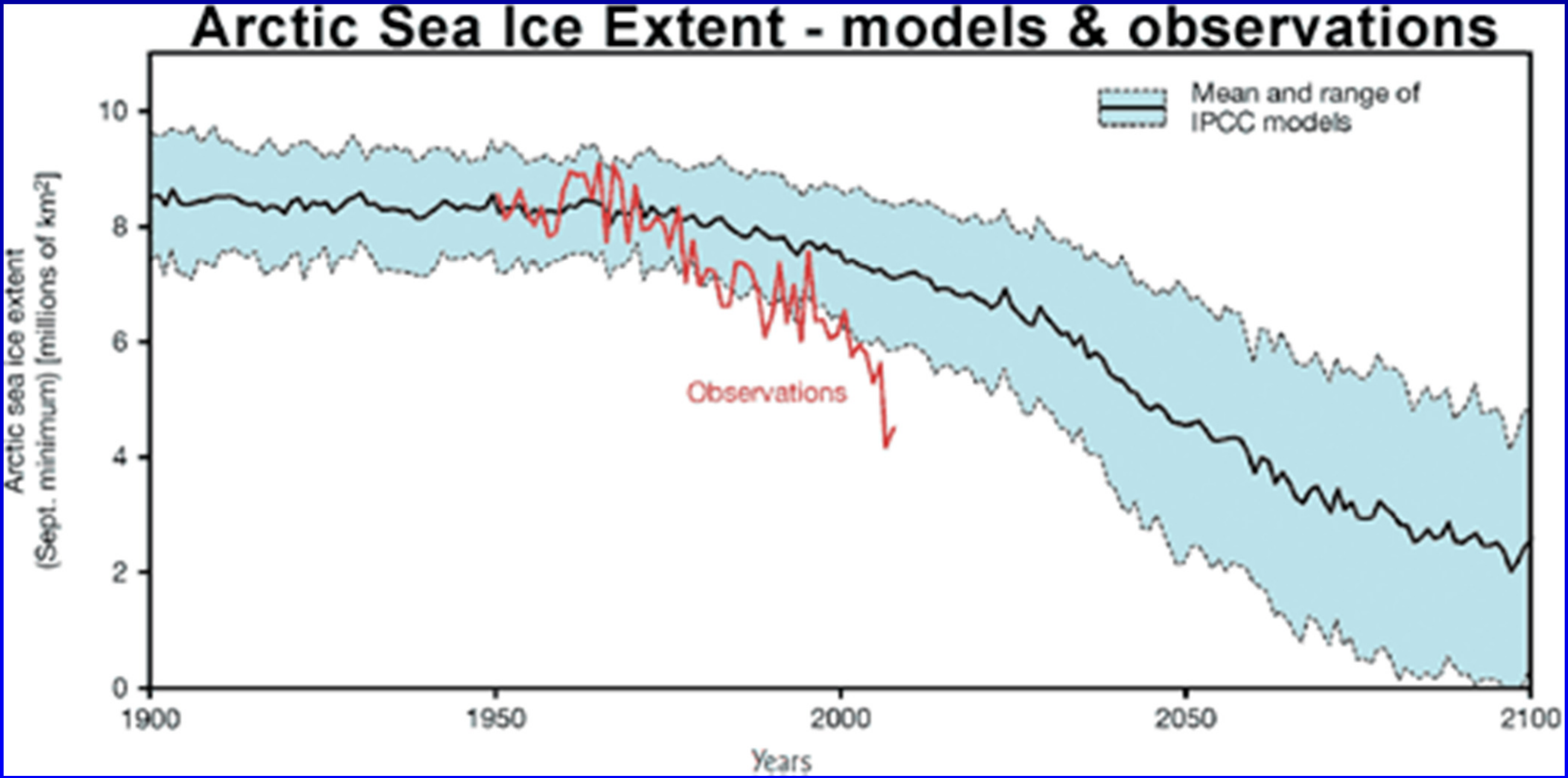
http://www.realclimate.org/index.php/archives/2013/02/2012-updates-to-model-observation-comparions/

How are the climate models doing?



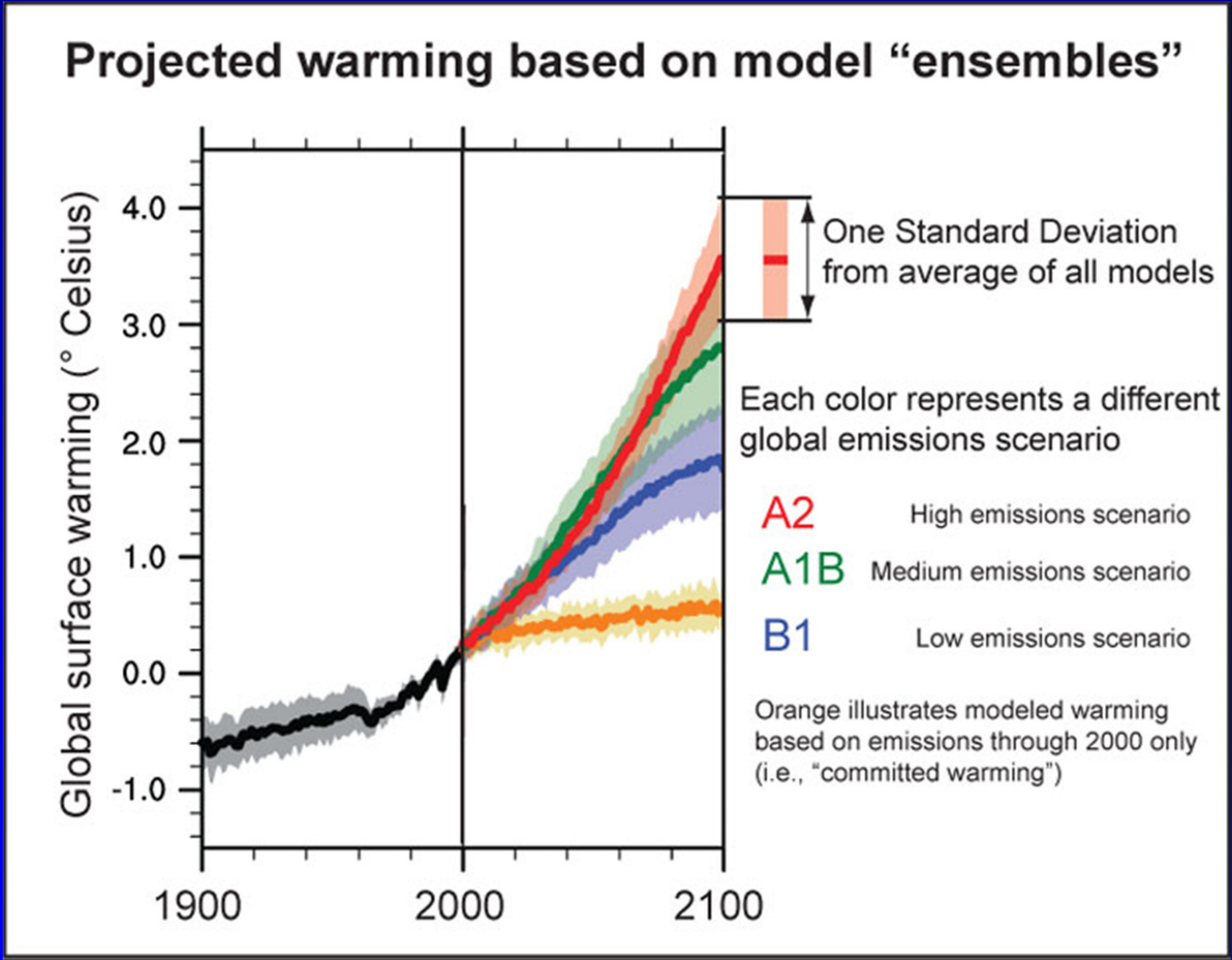
http://www.skepticalscience.com/images/SLR_models_obs.gif

How are the climate models doing?



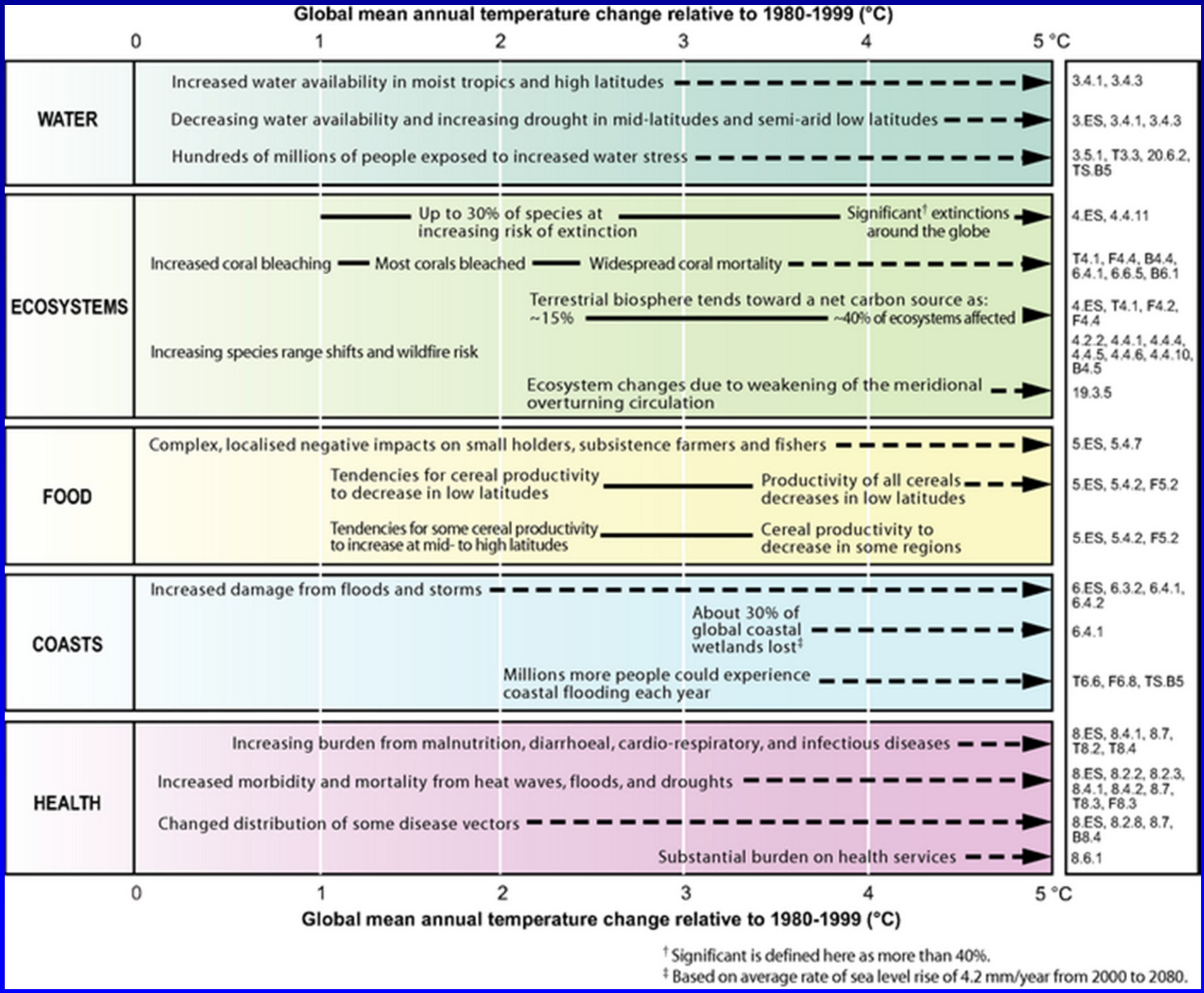
http://www.skepticalscience.com/images/Arctic_models_obs.gif

Using climate models

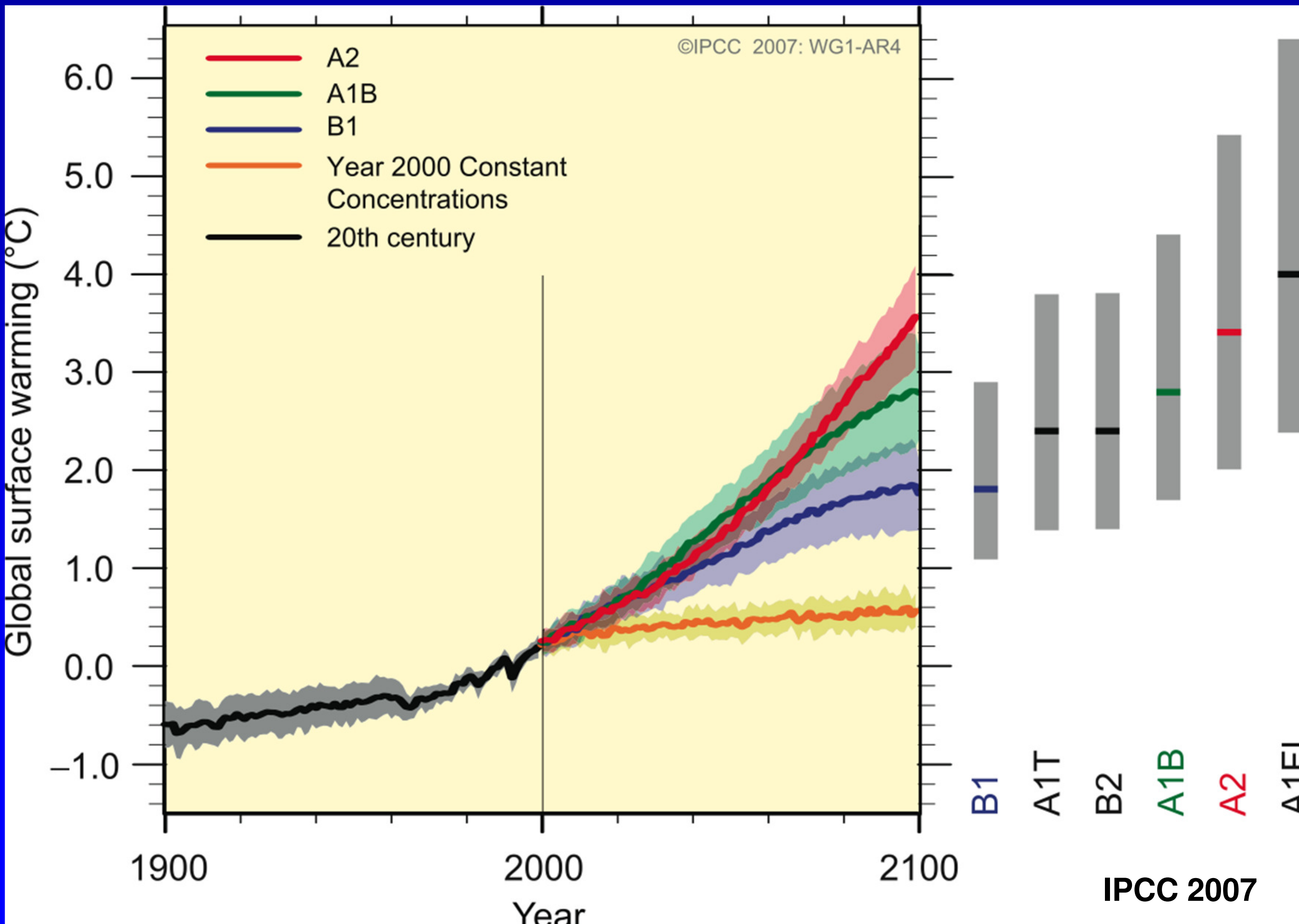


http://www.southwestclimatechange.org/files/cc/figures/projected-warming.jpg

Climate models: guiding decisions and anticipating impacts

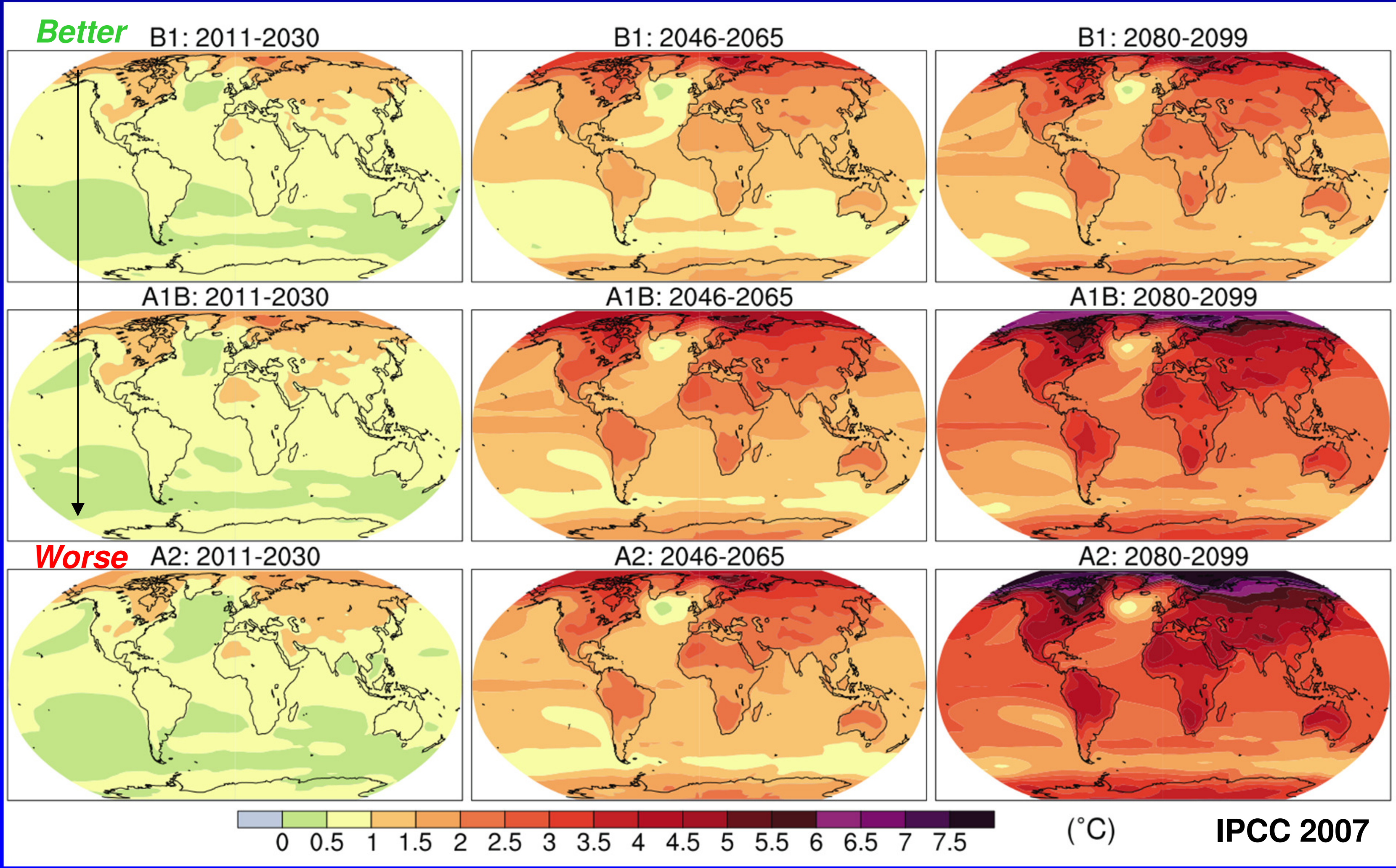


Emission Scenarios and Temperature Projections



IPCC 2007

Range of projections



Closing Points

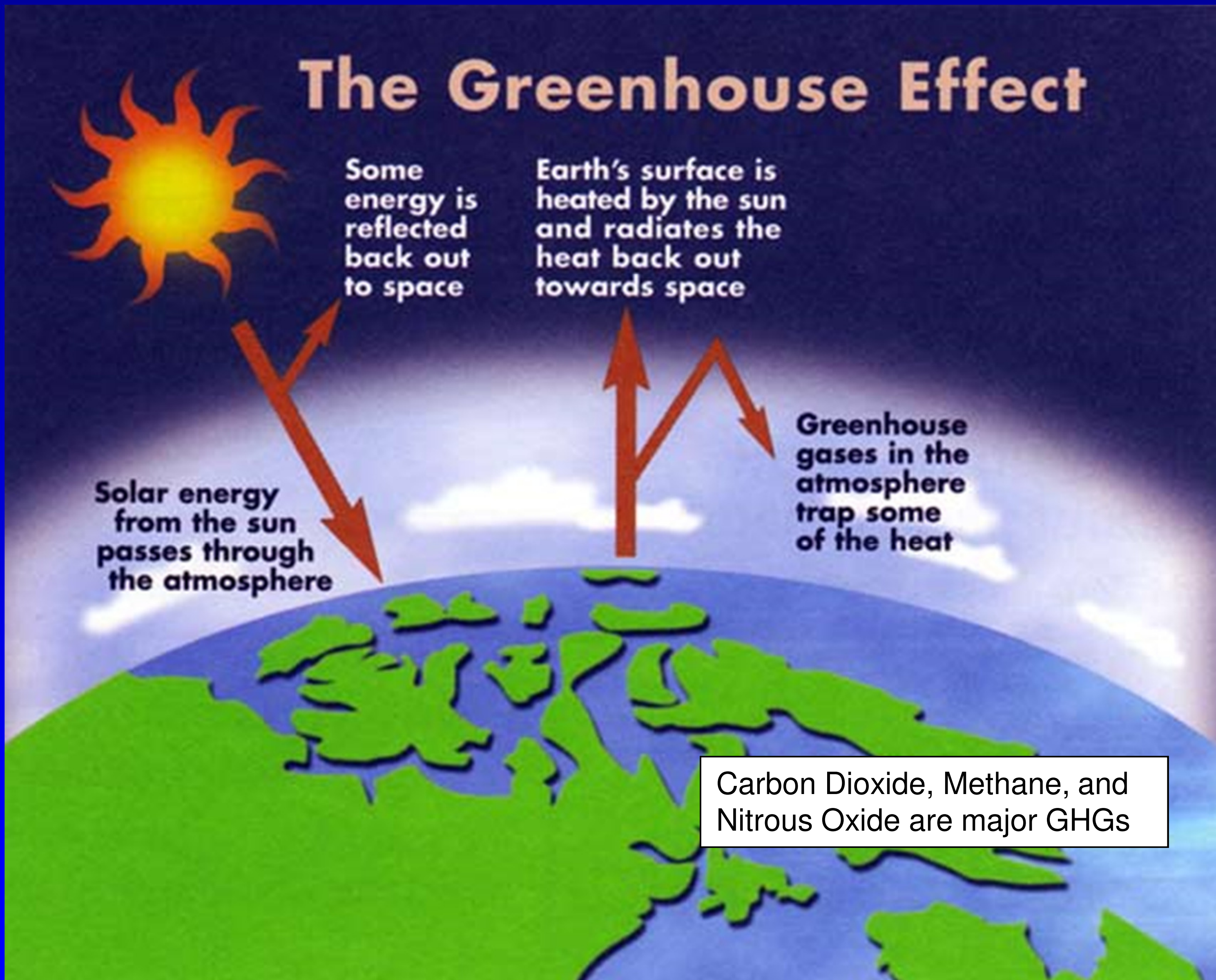
- Climate models are a necessary part of climate science → tool to capture complex interactions between different Earth systems
- Models and computational power have improved dramatically over the past decade, improving model performance
- Models will never be perfect; only a tool to inform decision making and risk management

Thanks!

crimmins@email.arizona.edu
http://cals.arizona.edu/climate

Climate Change

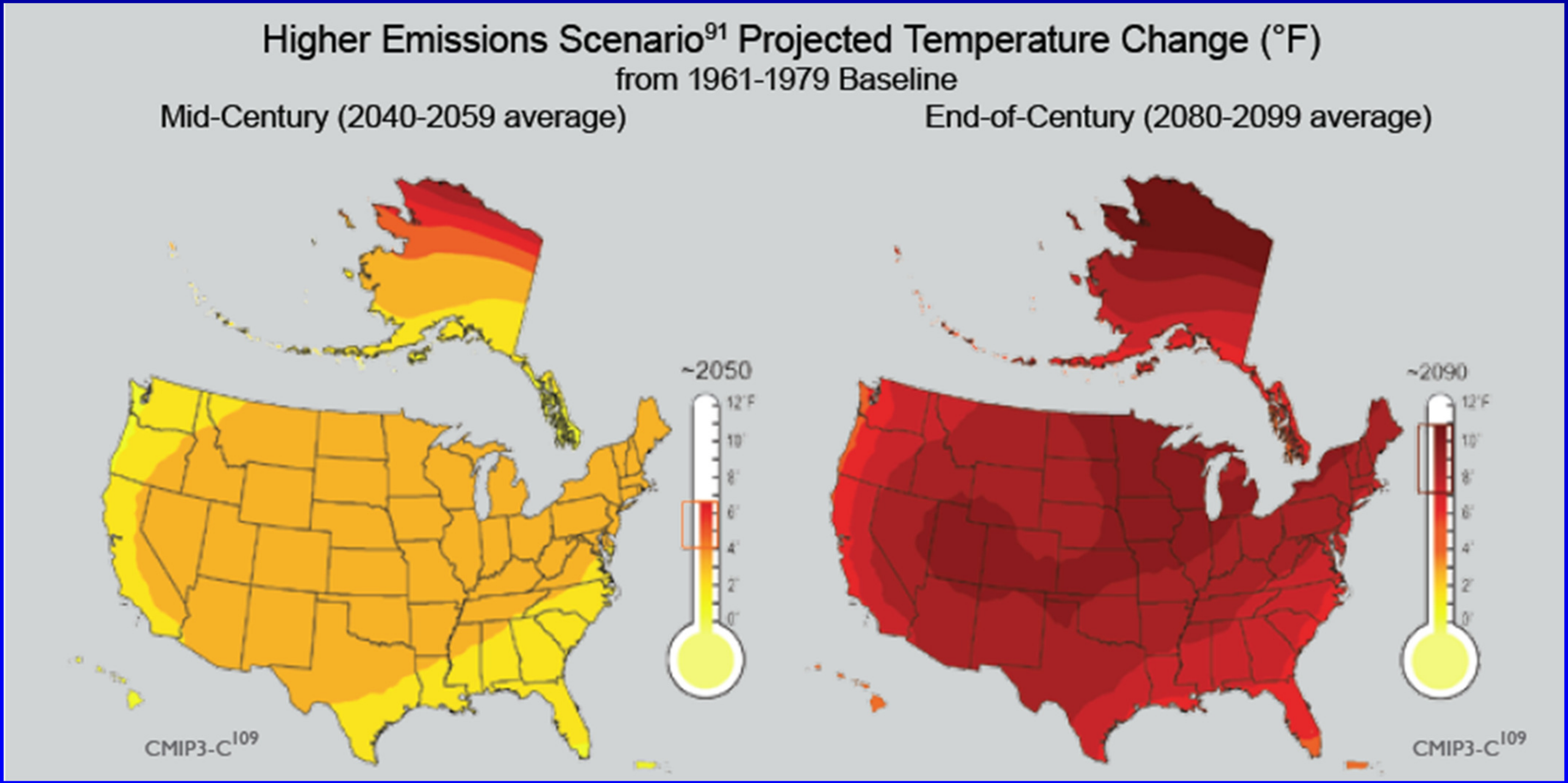
What is causing climate change?



Carbon Dioxide, Methane, and Nitrous Oxide are major GHGs

From http://www.climatechange.gc.ca

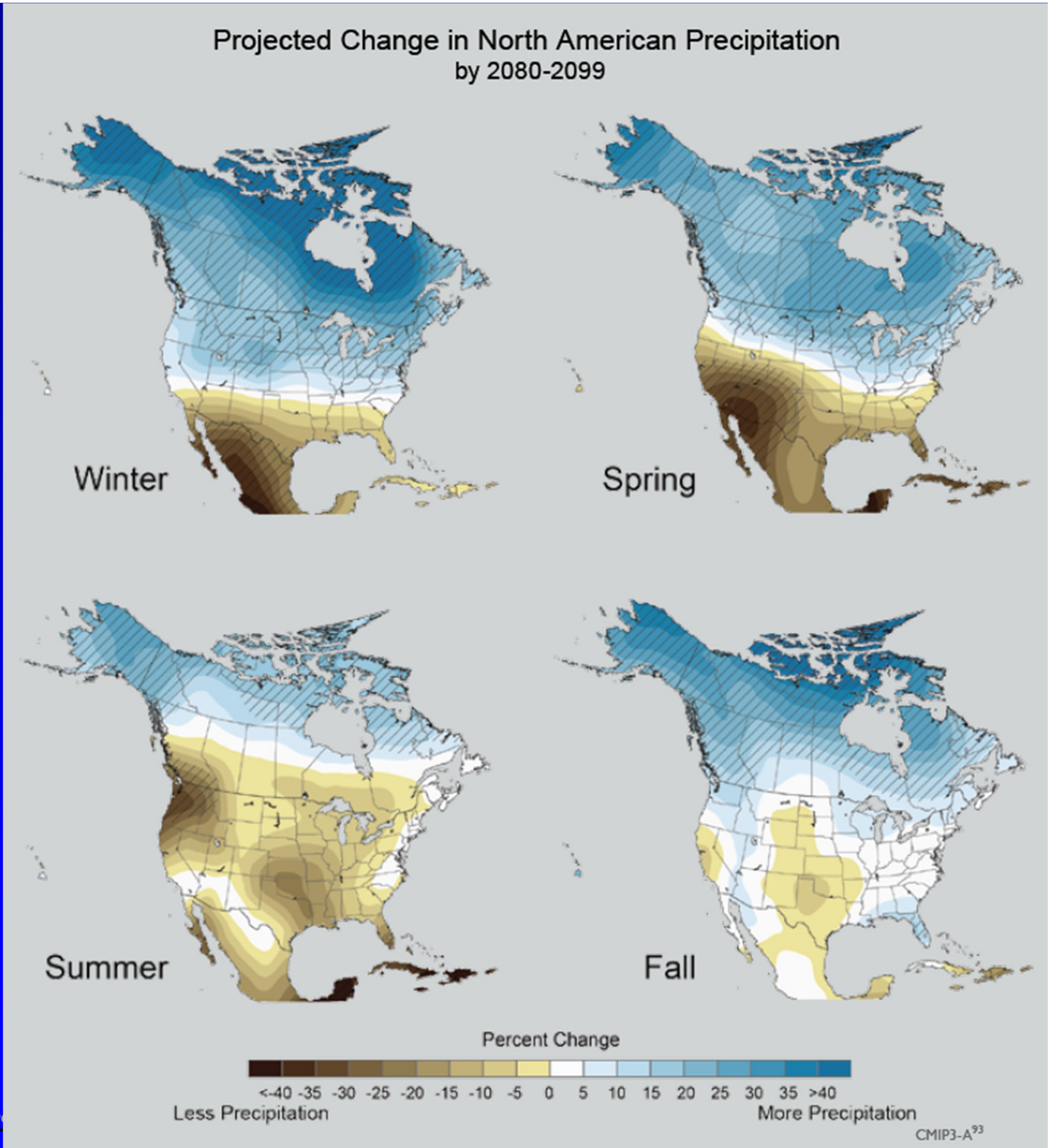
Temperature Projections



USGCRP 2009

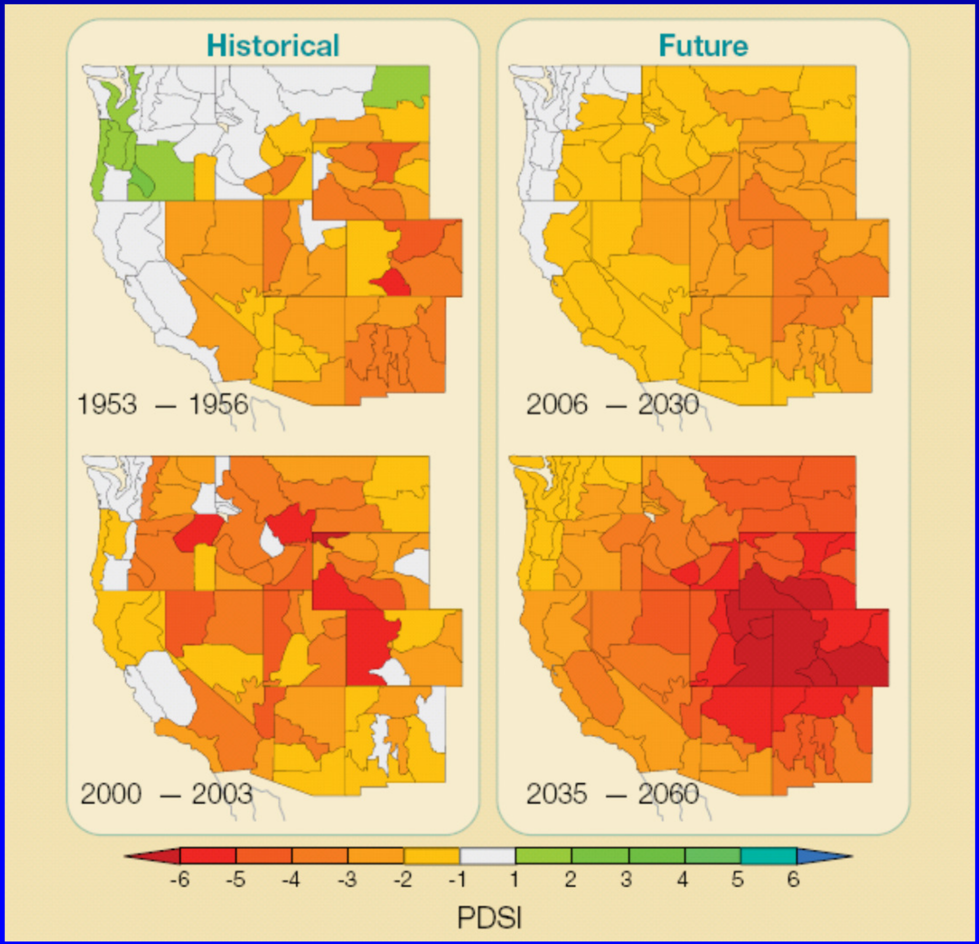
Precipitation Projections

USGCRP 2009



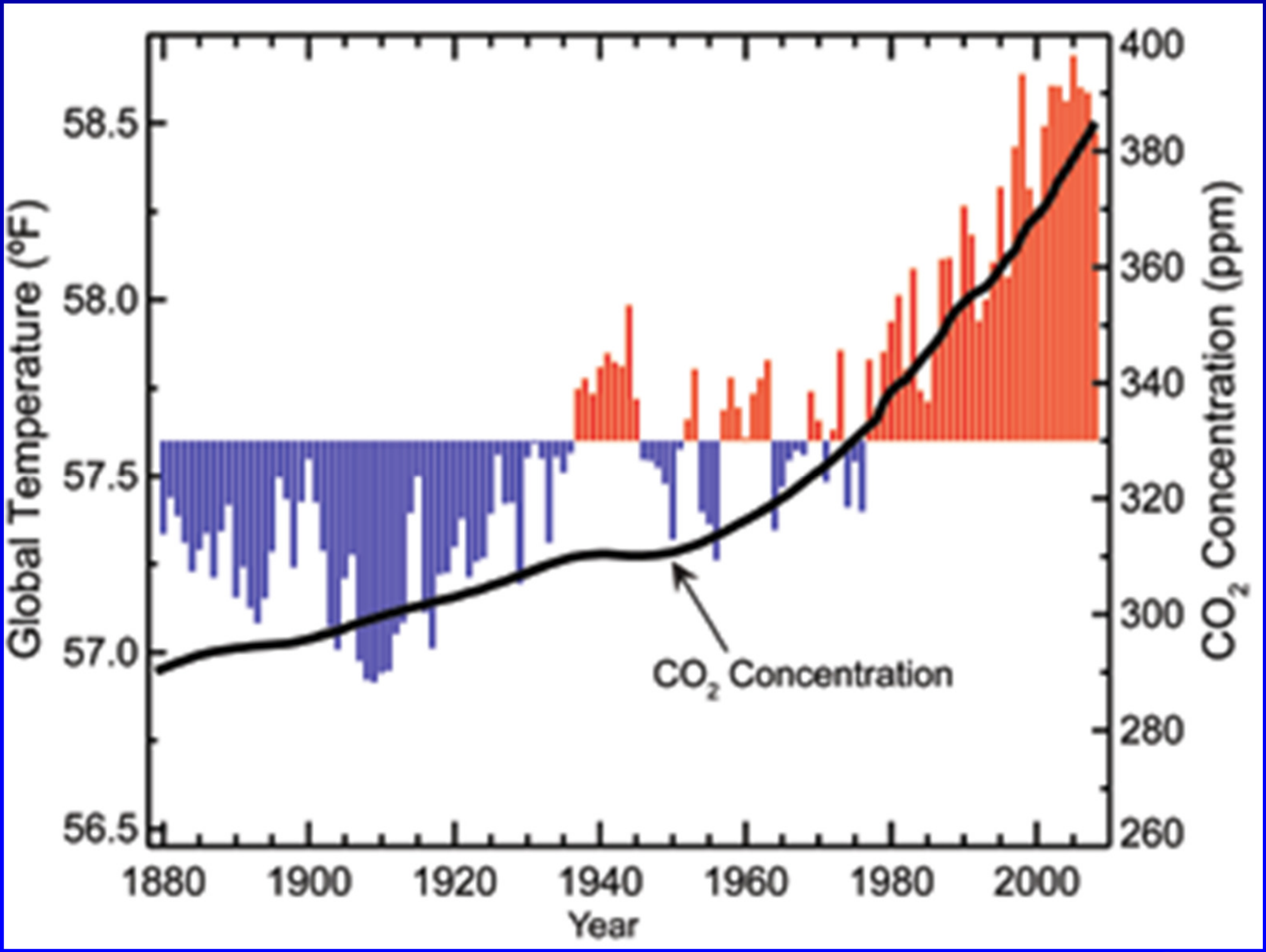
Interactions between temperature and precipitation

- Confidence in continuation of increasing temperatures
- Projections on precipitation variability are less clear
- Increasing temperatures alone will increase aridity

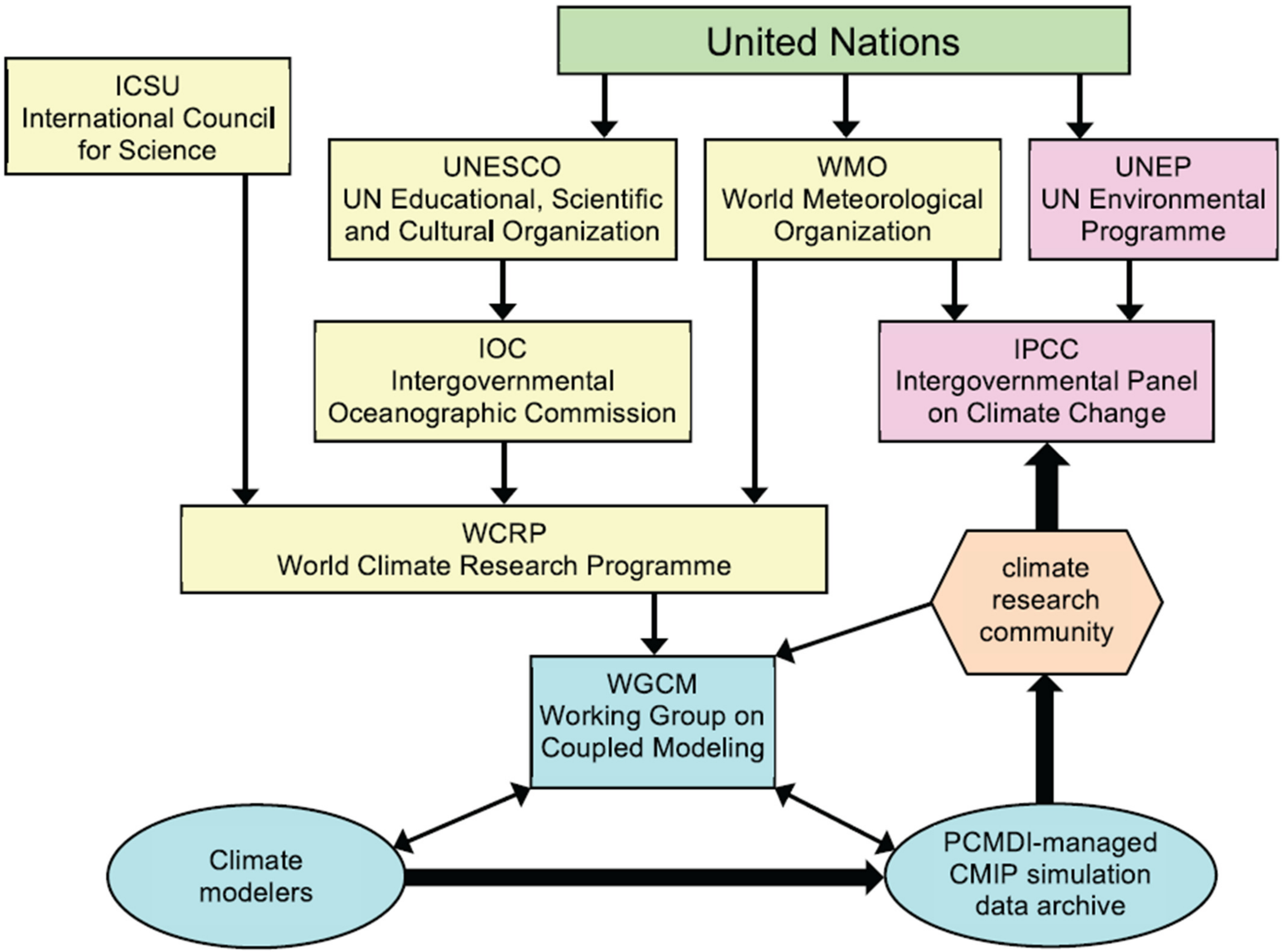


Hoerling & Eischeid 2007

Global Temperature and Carbon Dioxide



USGCRP 2009


United Nations
ICSU
International Council
for Science
UNESCO
UN Educational, Scientific
and Cultural Organization
WMO
World Meteorological
Organization
UNEP
UN Environmental
Programme
IOC
Intergovernmental
Oceanographic Commission
IPCC
Intergovernmental Panel
on Climate Change
WCRP
World Climate Research Programme
climate
research
community
WGCM
Working Group on
Coupled Modeling
Climate
modelers
PCMDI-managed
CMIP simulation
data archive