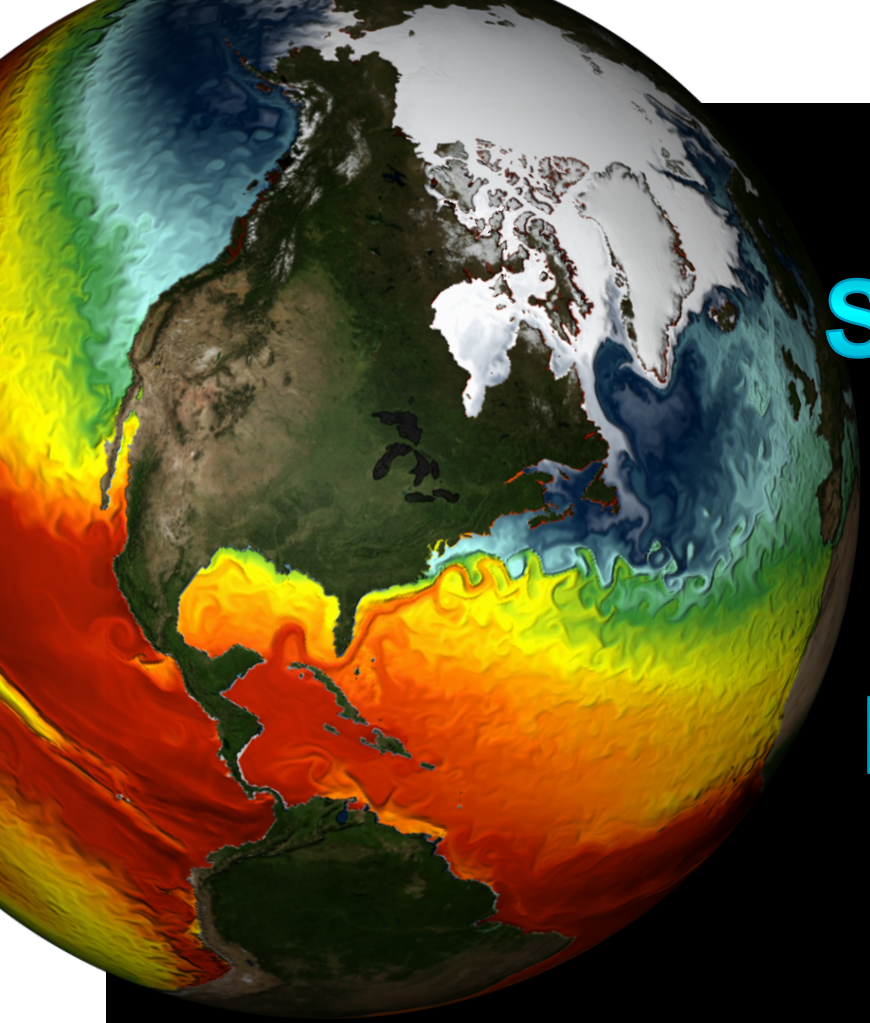
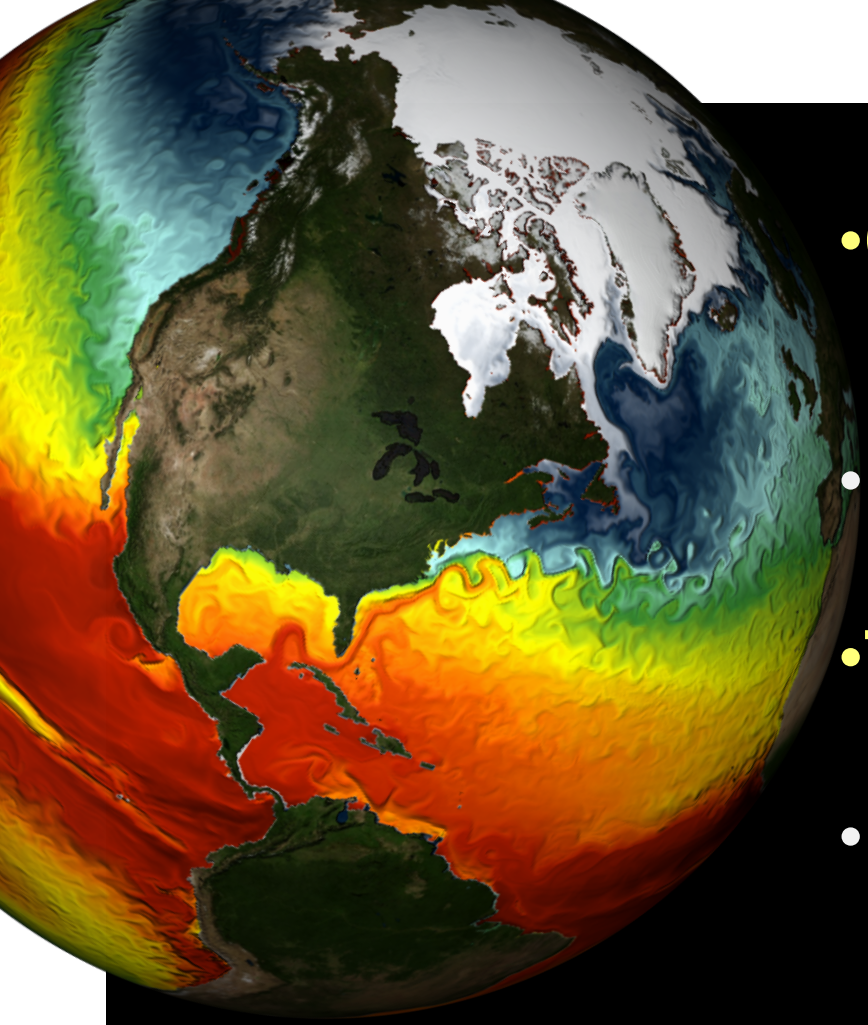


SPANNING TIME AND SPATIAL SCALES:

MODELING OUR PLANET'S CLIMATE

Keith W. Dixon
research meteorologist / climate modeler
NOAA Geophysical Fluid Dynamics Laboratory
Princeton, NJ
www.gfdl.noaa.gov

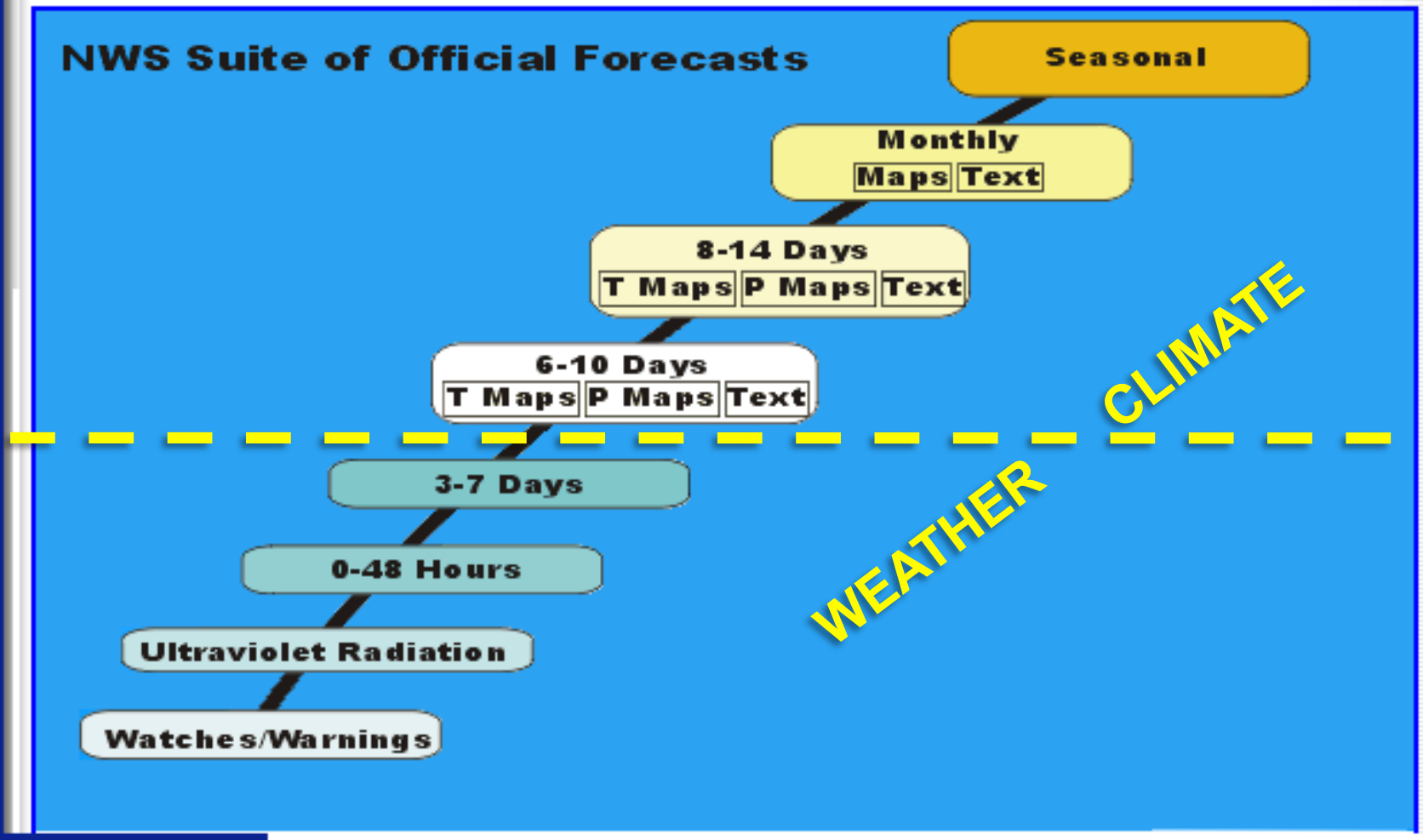


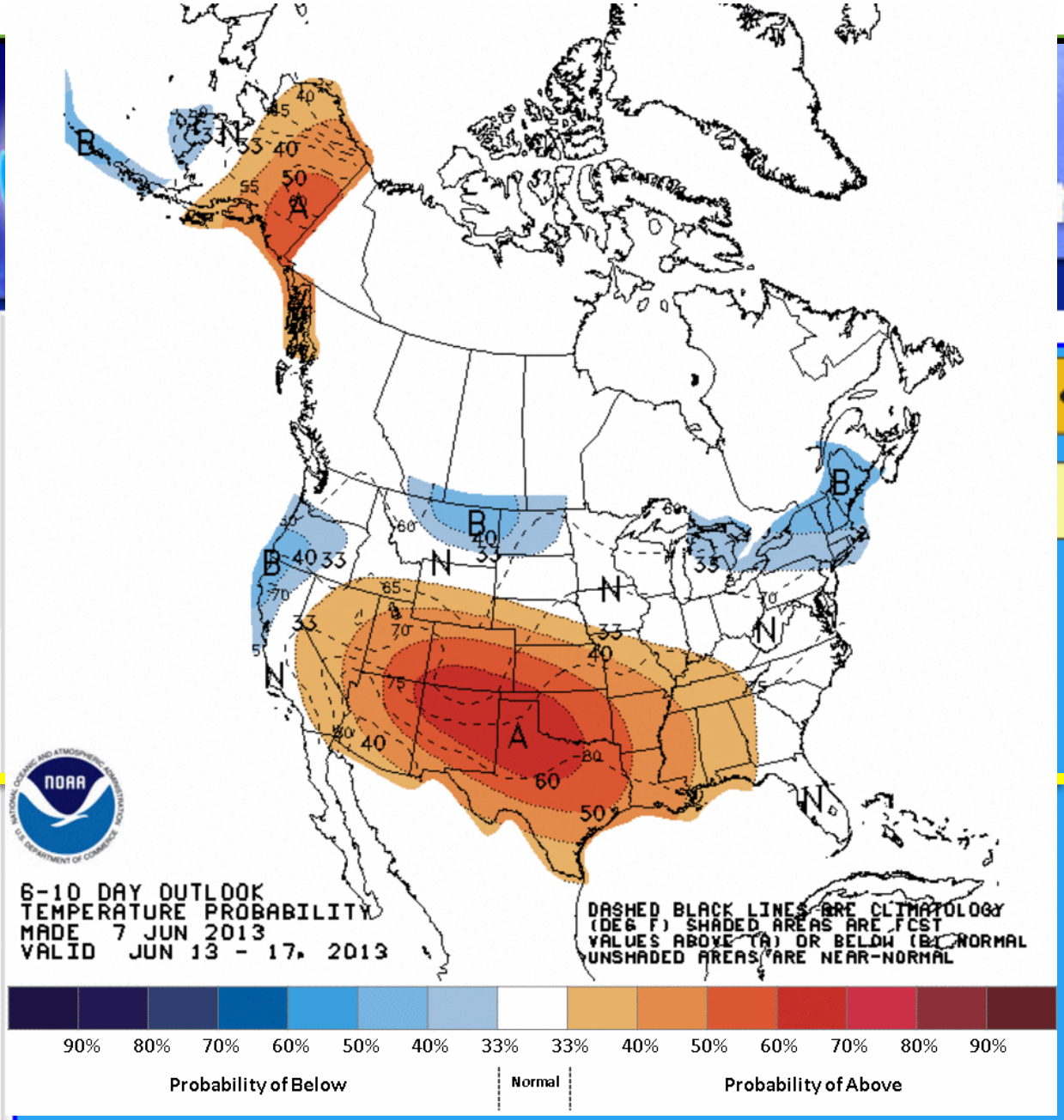
- **CLIMATE**
  - One Word, Many Meanings,
  - Initial Value vs. Boundary Value Problems
- **DYNAMICAL CLIMATE MODELS**
  - One Tool in our Toolbox
- **TODAY'S CLIMATE MODELS**
  - Evolution in Complexity & Resolution
- **USE & MISUSE OF MODELS**
  - Projections vs. Predictions, Ensembles,
  - Consideration of Spatial & Temporal Scales
- **WHAT MAKES A BETTER CLIMATE MODEL?**

www.gfdl.noaa.gov

National Weather Service

Climate Prediction Center

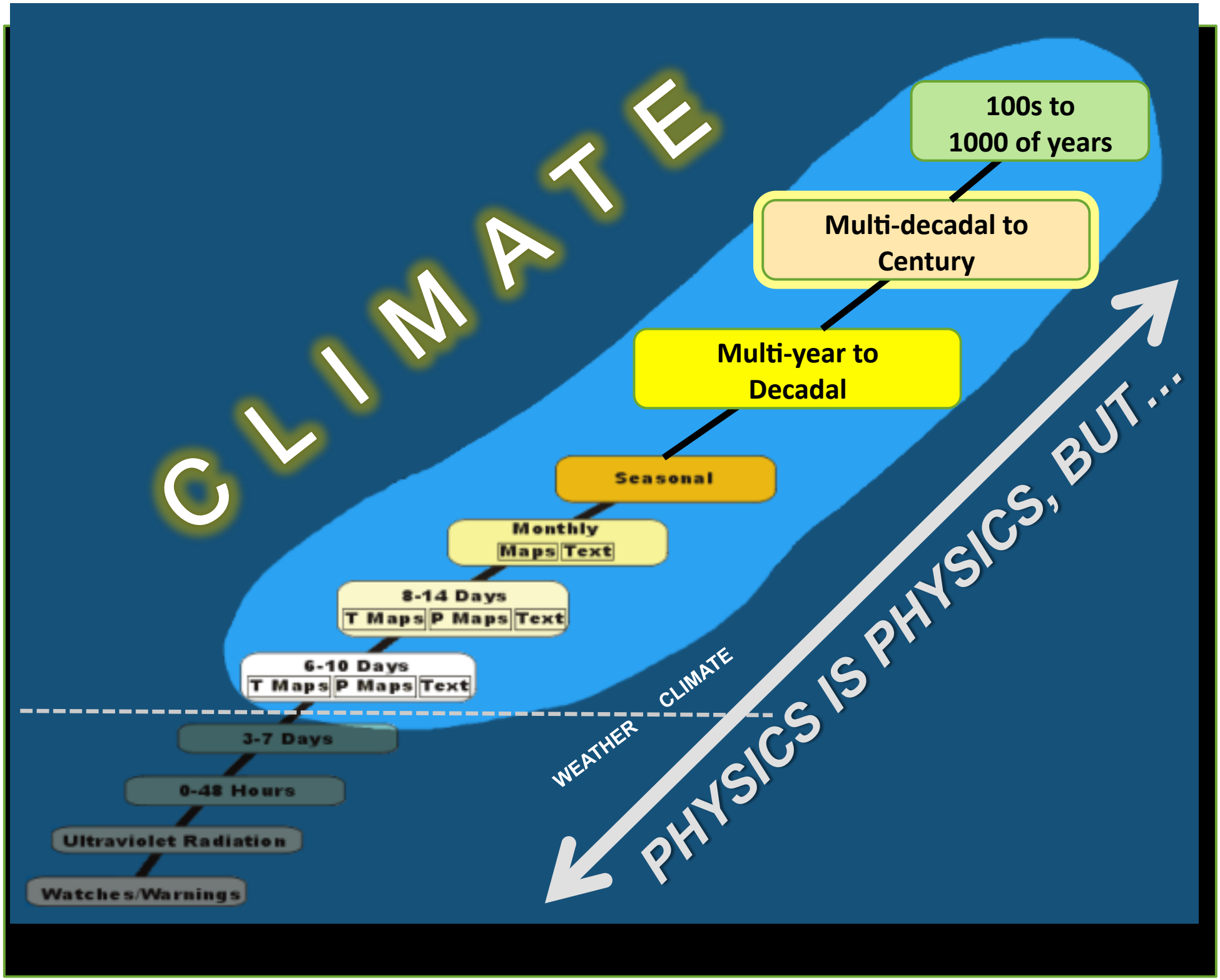




nter

easonal

CLIMATE

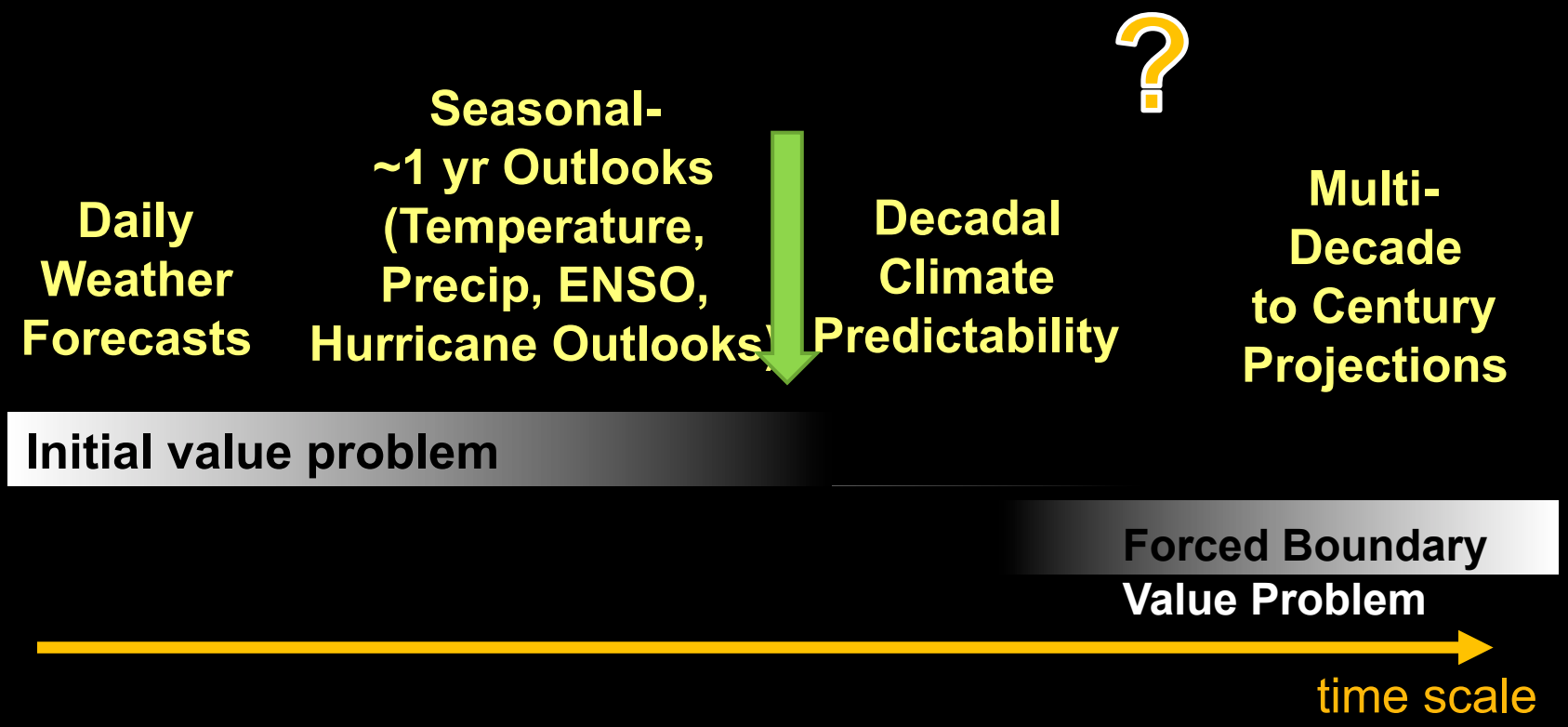

CLIMATE
100s to
1000 of years
Multi-decadal to
Century
Multi-year to
Decadal
Seasonal
Monthly
Maps Text
8-14 Days
T Maps P Maps Text
6-10 Days
T Maps P Maps Text
3-7 Days
0-48 Hours
Ultraviolet Radiation
Watches/Warnings
WEATHER
CLIMATE
PHYSICS IS PHYSICS, BUT ...

Daily Weather Forecasts

Seasonal-
~1 yr Outlooks
(Temperature, Precip, ENSO, Hurricane Outlooks)

Initial value problem

time scale



For more info, see *"**Weather Prediction, Climate Prediction. What's the Diff?**"* by Bill Chameides on the PopSci web site… http://goo.gl.xUVSB

Though weather and climate models are similar in many ways (physics is physics….) they are used to address different questions.

WEATHER "An Initial Value Problem"

vs.

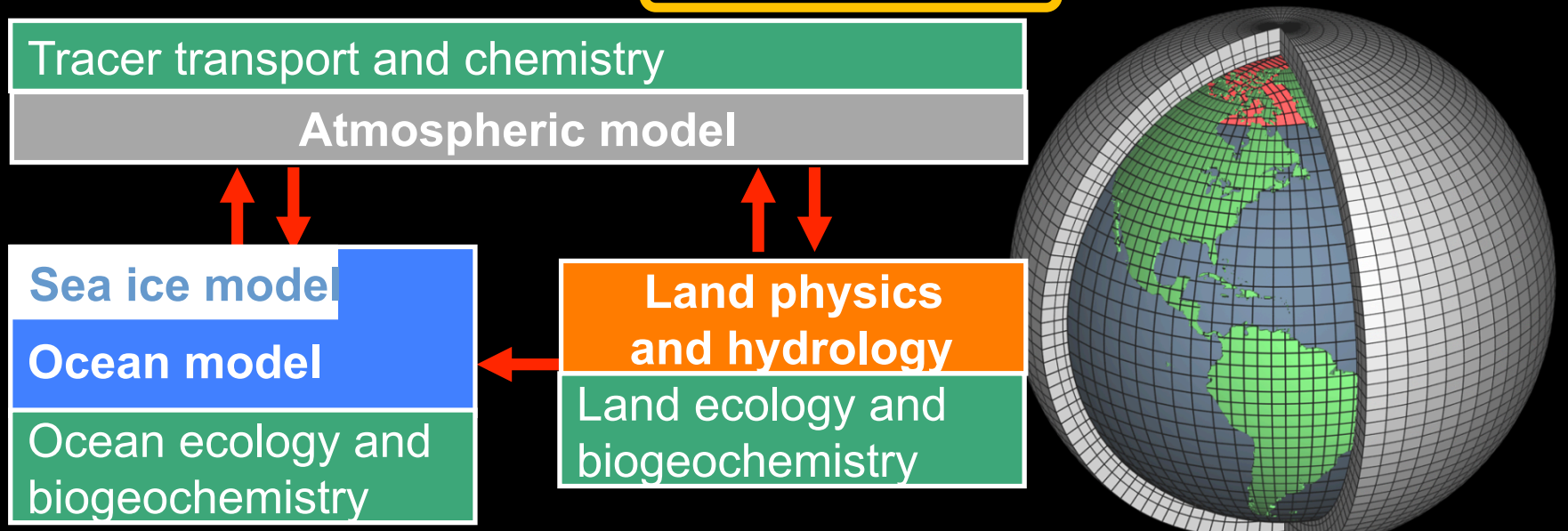
CLIMATE "A Boundary Condition Problem"

Progress in Climate Science occurs as a combination of ***Observations***, ***Theory***, & ***Numerical Modeling***

Since the 1970s, many of the major advancements in climate science have come about as improved observations, refinements to theory, and the results of computer modeling have revealed a consistent story.

Large spatial scales…
Multi-decade time scales

Climate models - *our "virtual Earths"* - provide a method to estimate how the planet's climate varies internally *-and-* how it will respond to changes in greenhouse gases and other climate "forcing agents"

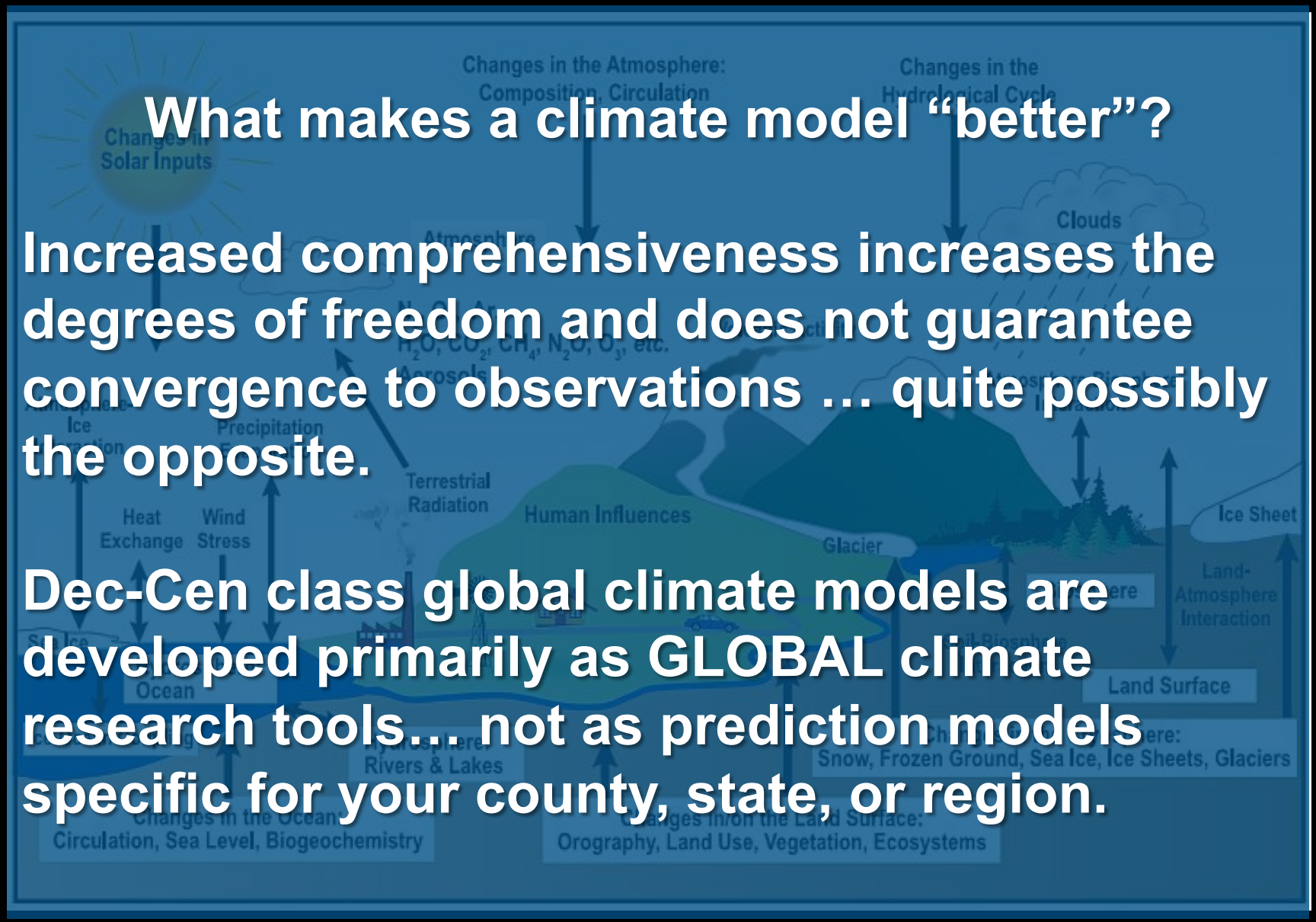


Physics of Climate Models

* Basics: conservation of energy, equations of motion for a fluid on a rotating sphere, equations of state, latent heat, C-C, etc.
* Parameterizations: empirical formulae representing the effects of processes not resolved by the model grid.

see also: "The Physics of Climate Modeling" by G. Schmidt, (2007), Physics Today.

Model "Comprehensiveness"

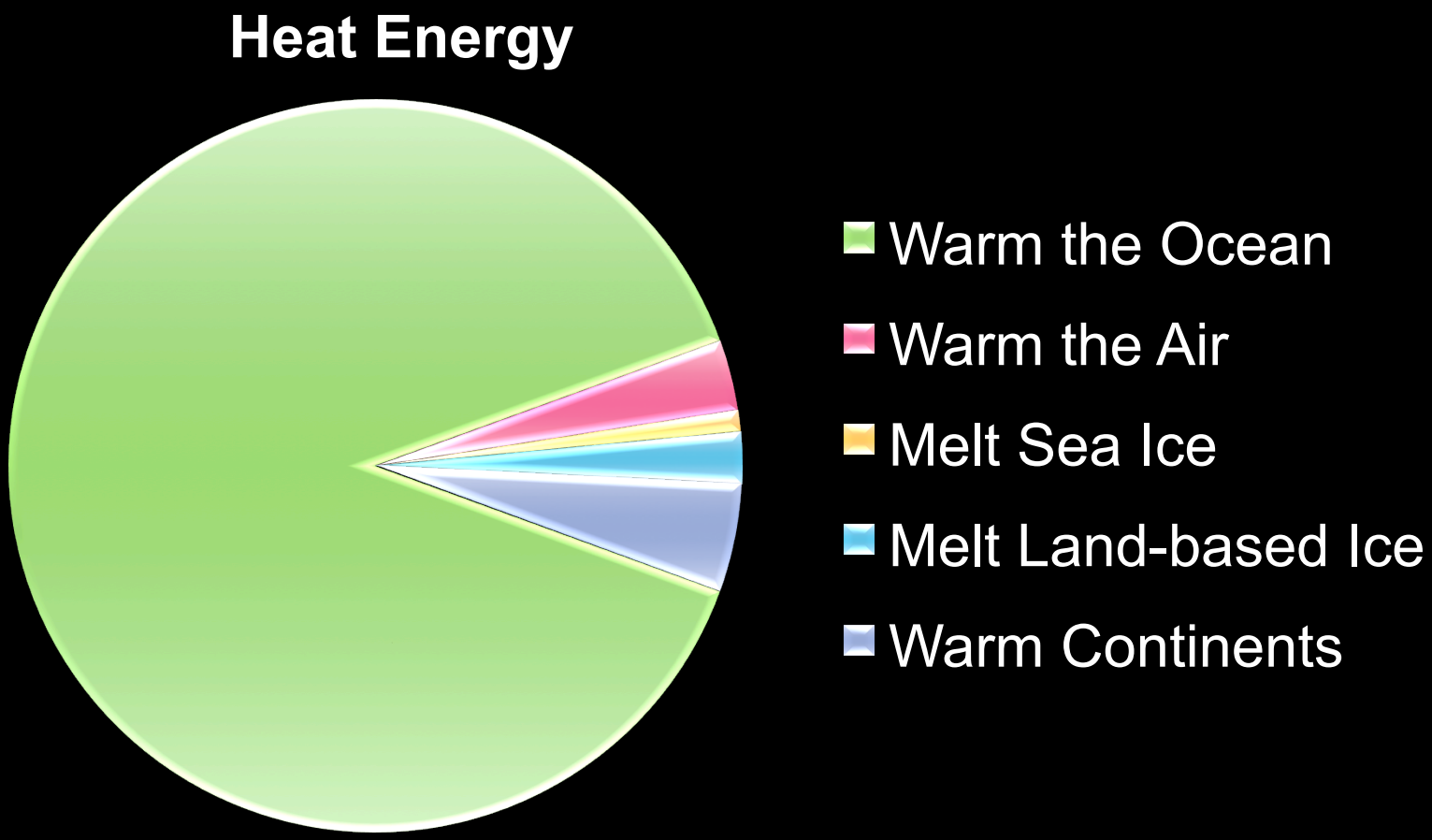


What makes a climate model "better"?

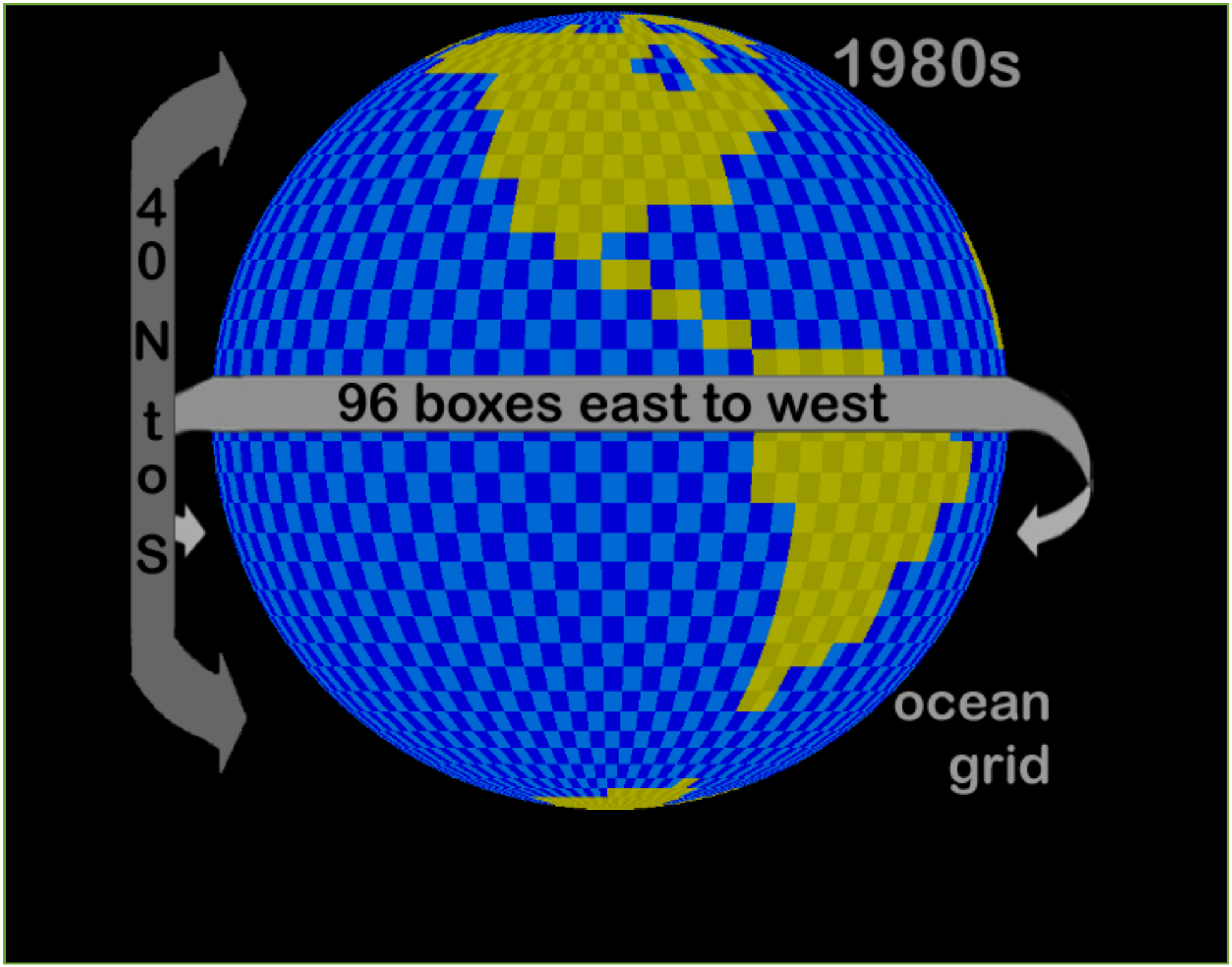
Increased comprehensiveness increases the degrees of freedom and does not guarantee convergence to observations … quite possibly the opposite.

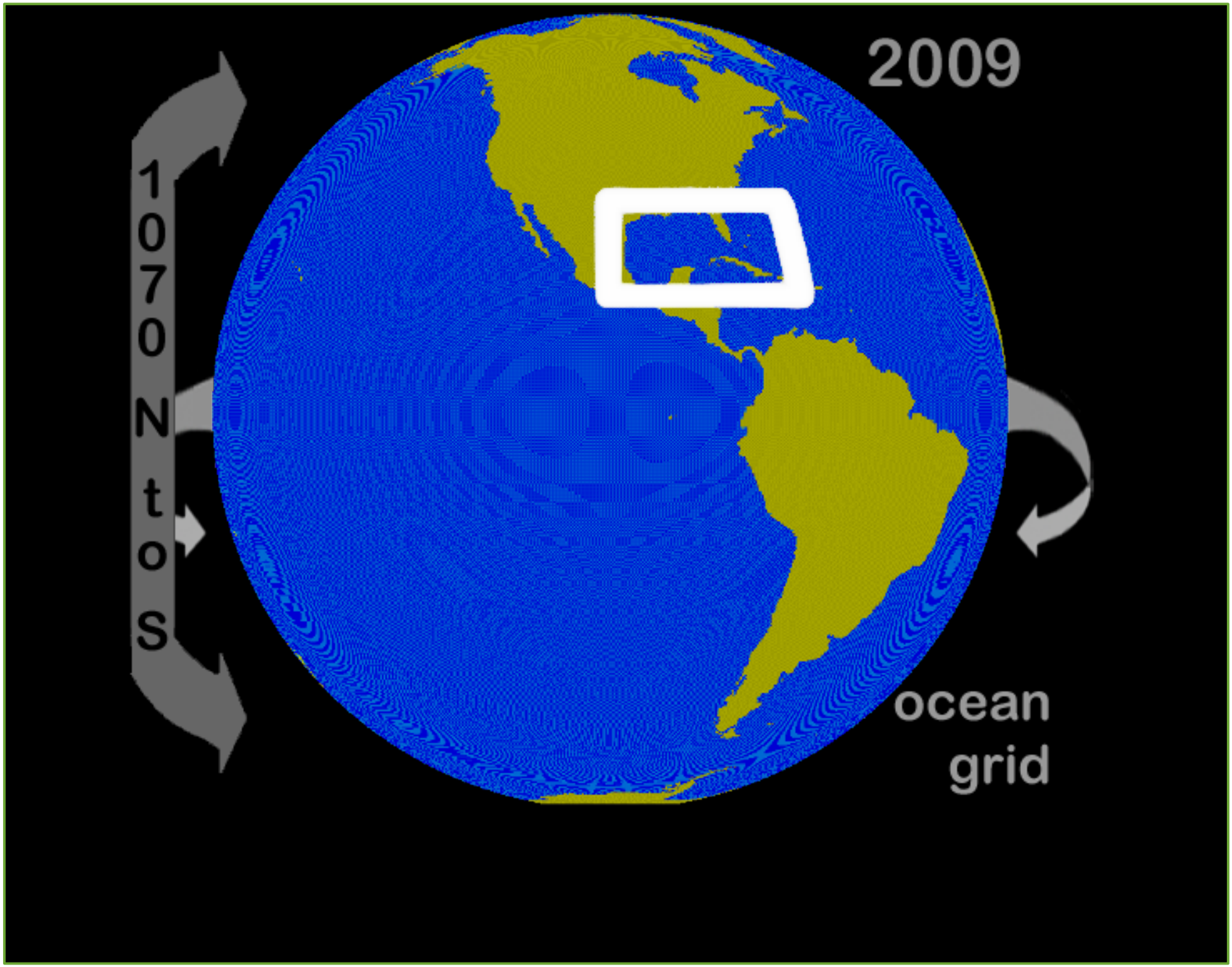
Dec-Cen class global climate models are developed primarily as GLOBAL climate research tools… not as prediction models specific for your county, state, or region.

Where has the additional heat energy gone? (1961-2003)

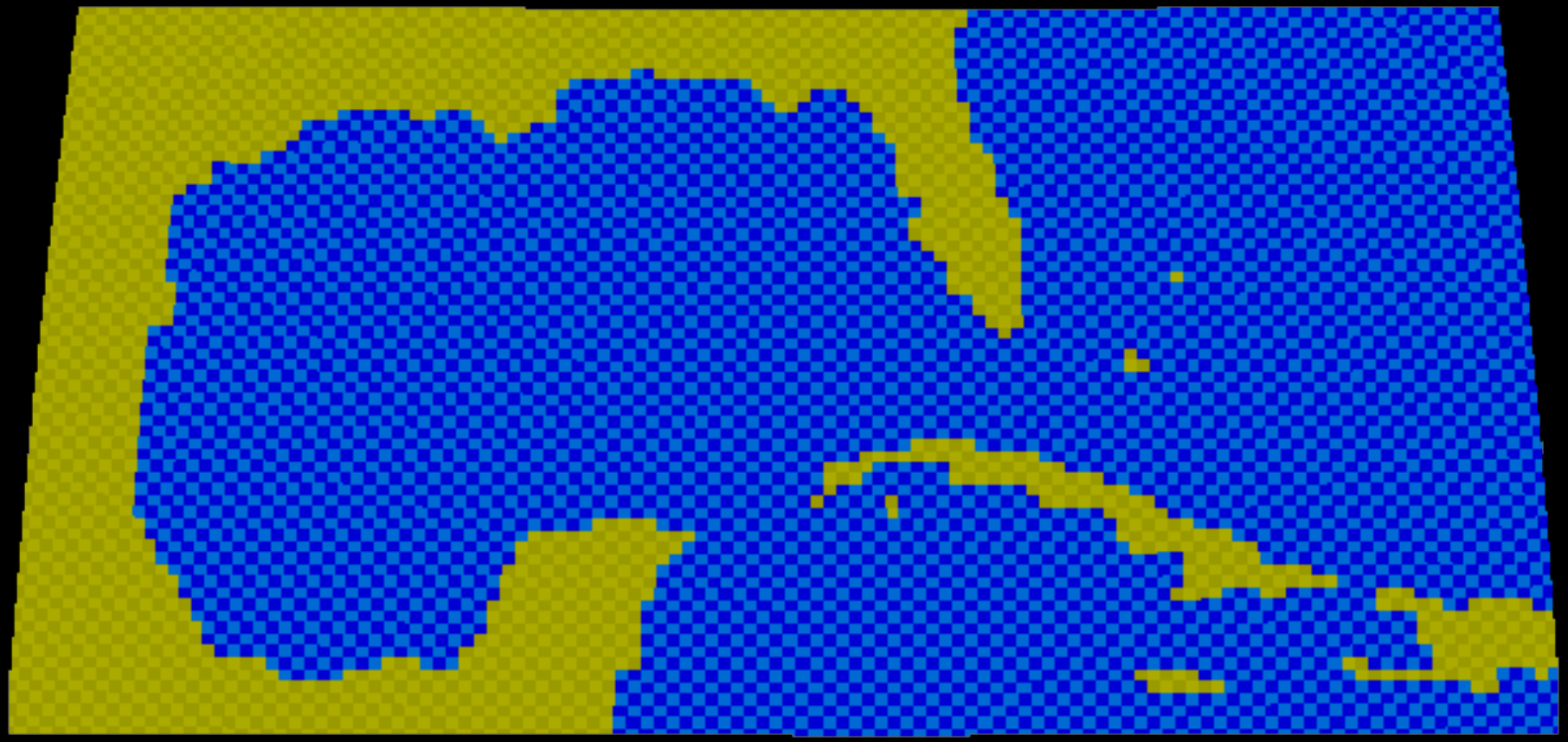


Data source:
IPCC 2007 WG1-AR4 , Fig. 5-4

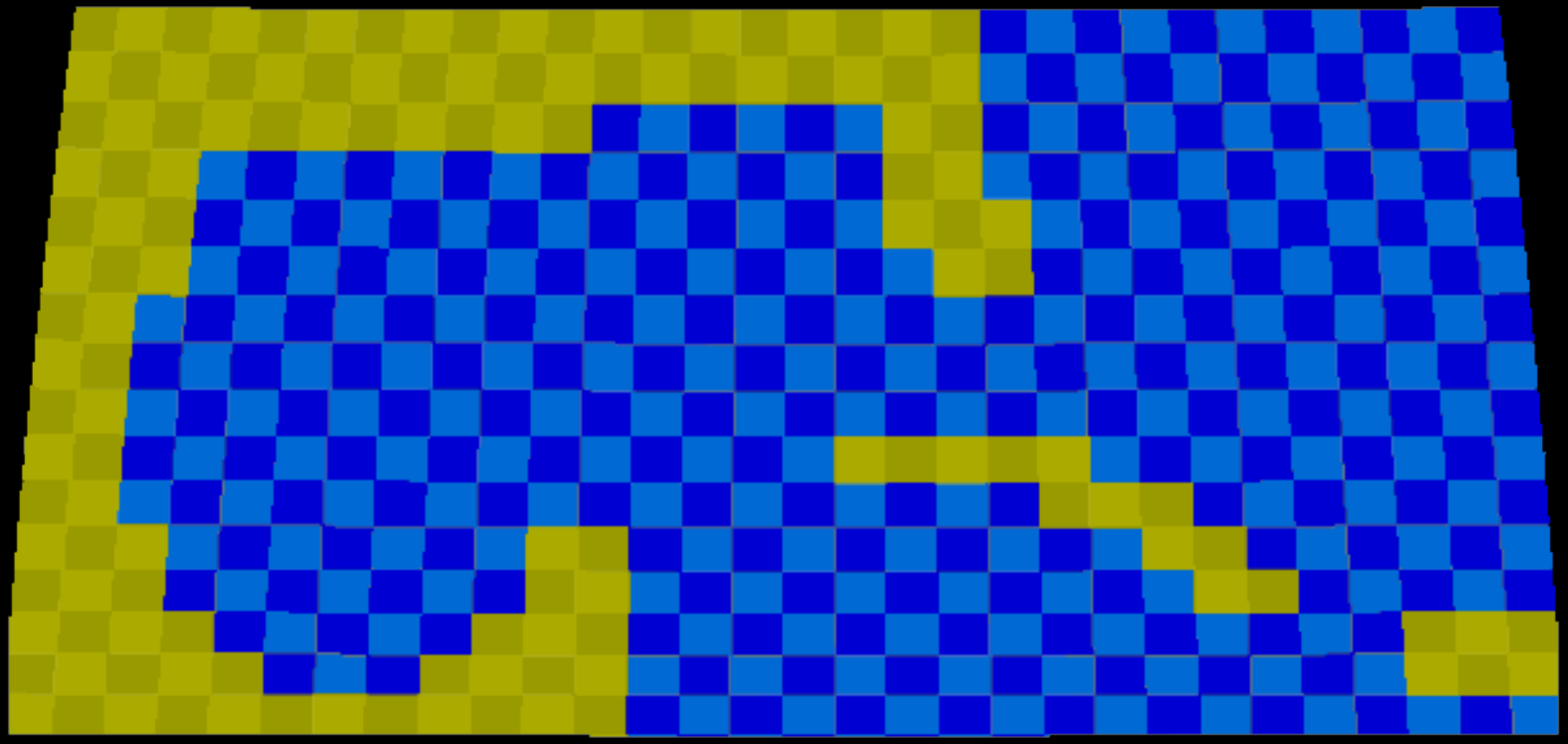

1980s
40 N to S
96 boxes east to west
ocean
grid


2009
1070 N to S
ocean
grid

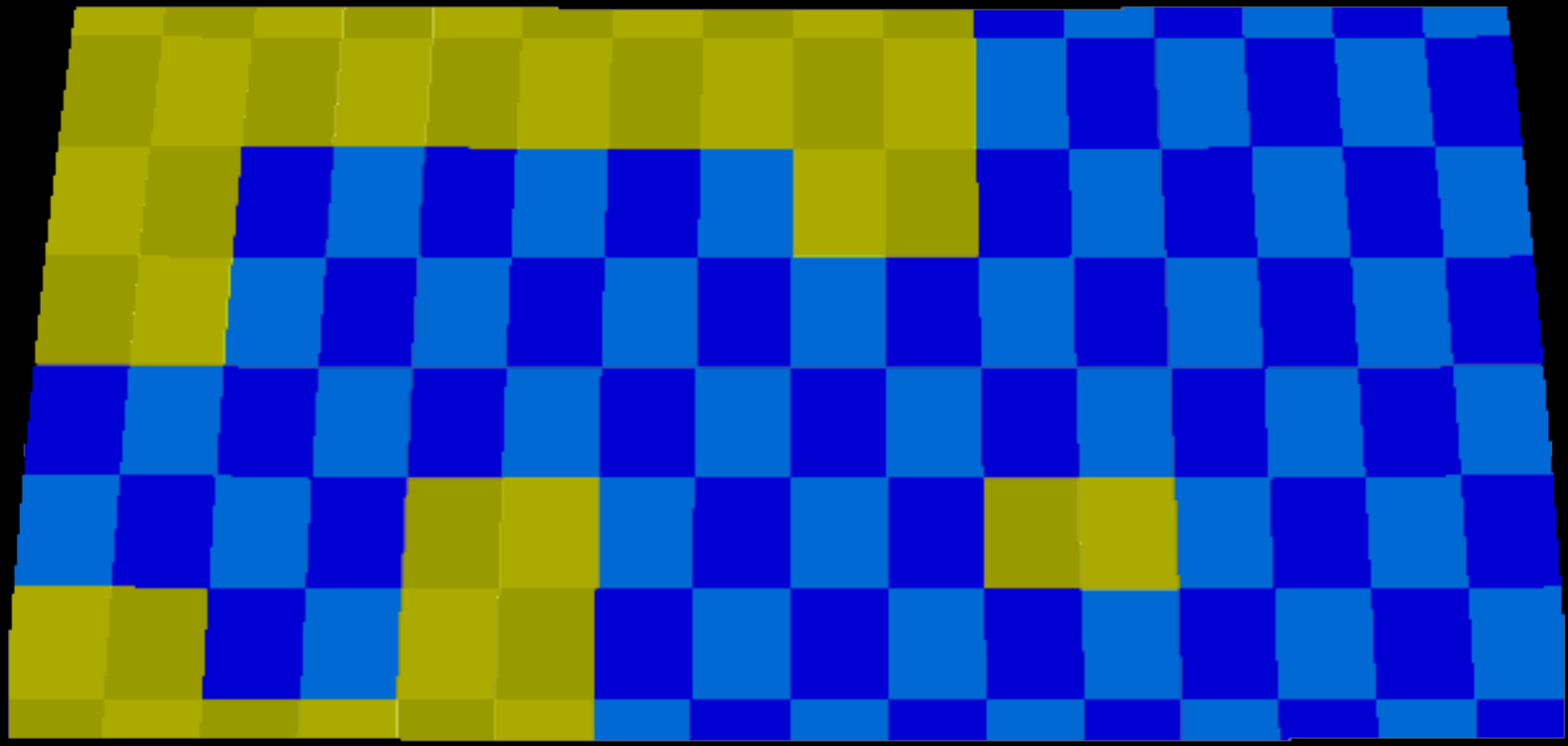
2009



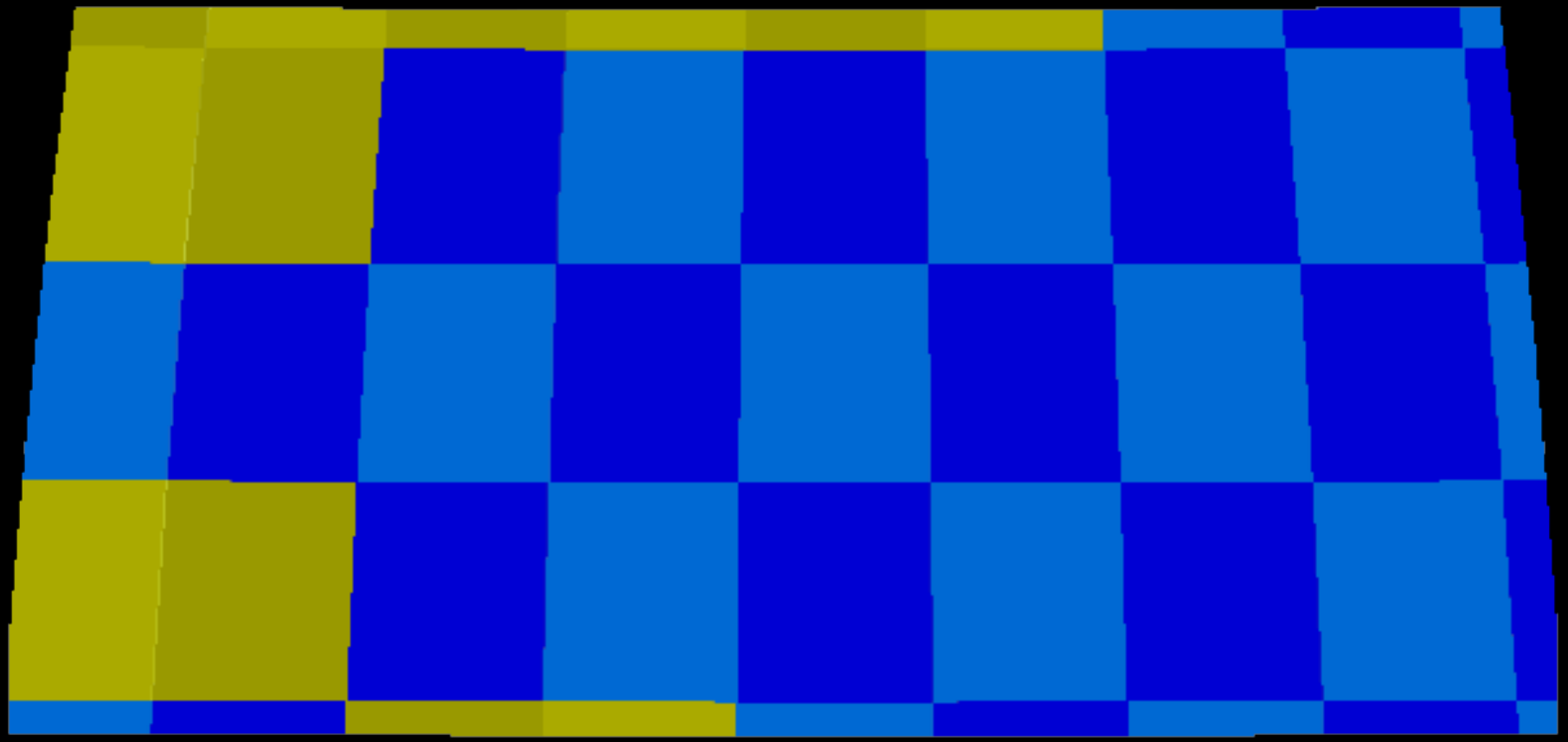
2004

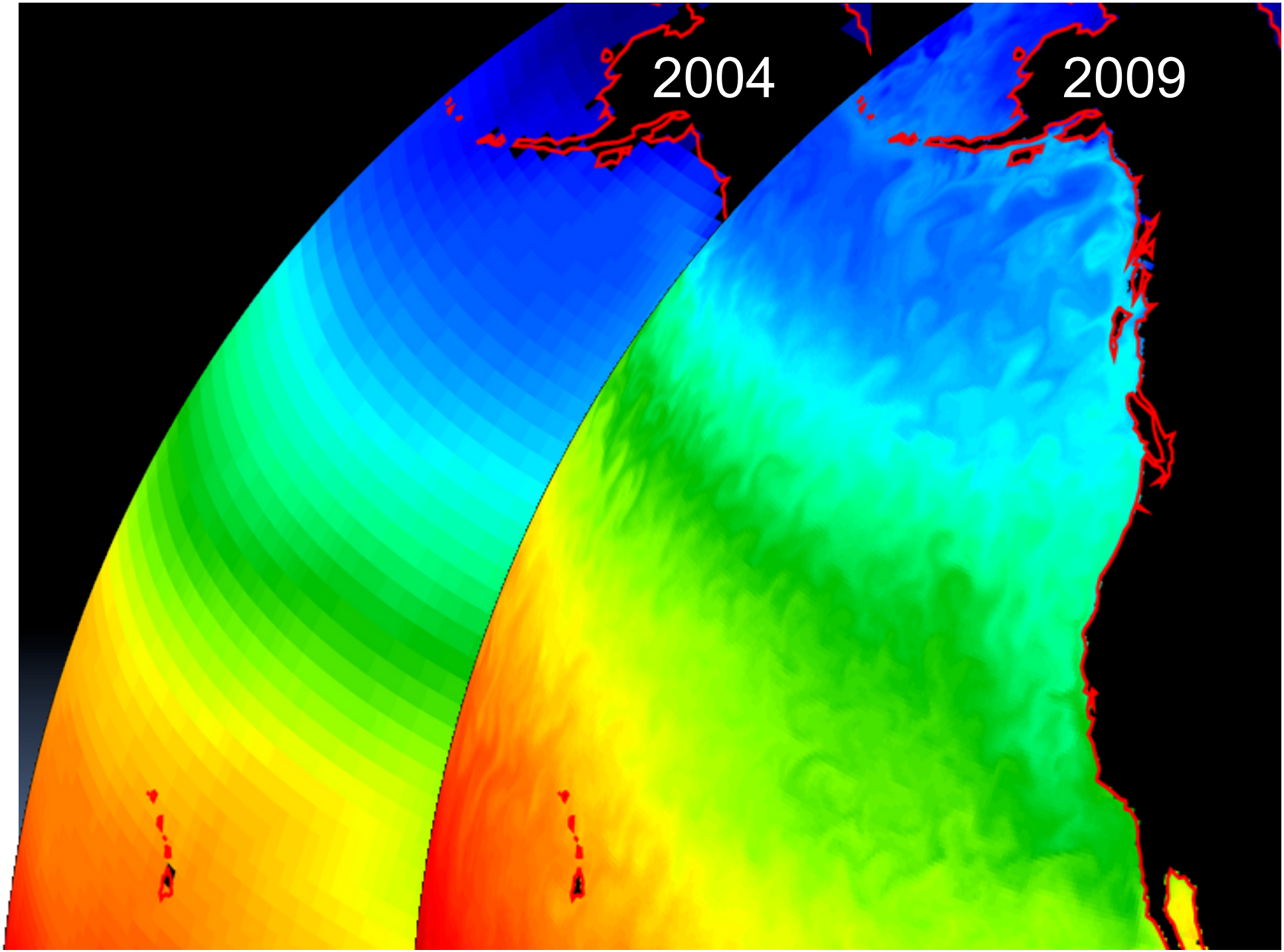


1990s



1980s




2004
2009

Atmospheric Model Resolution: Weather vs. Dec-Cen Climate Models

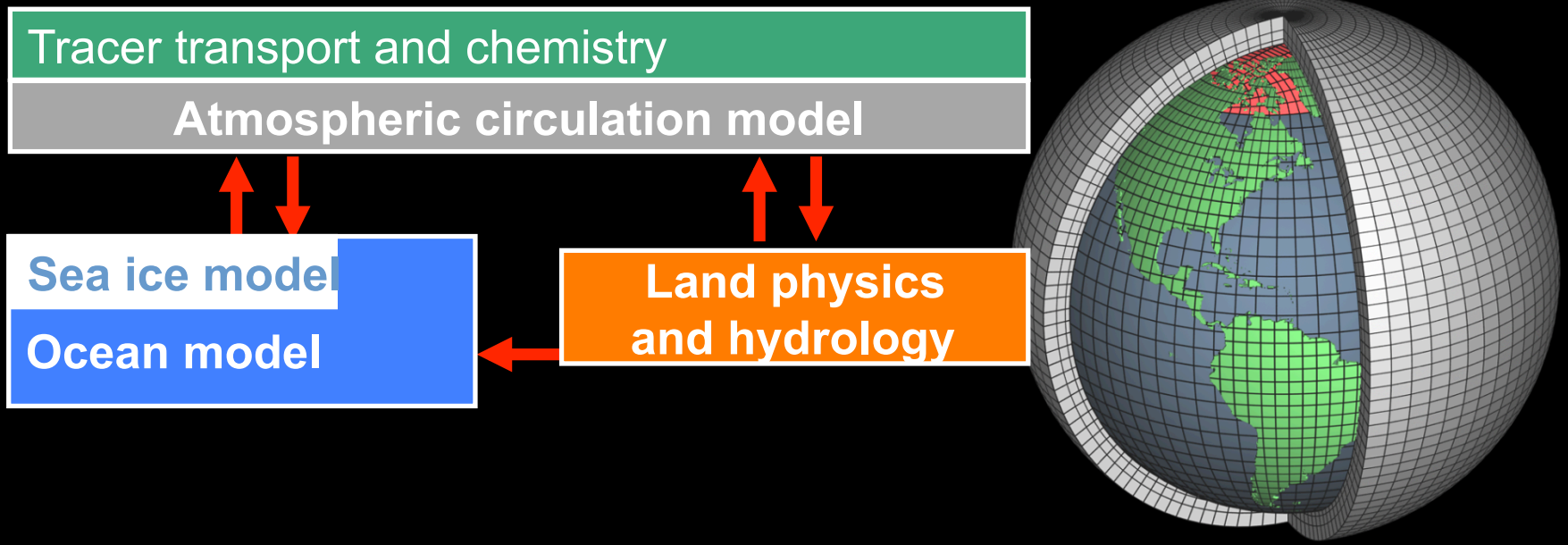
NWP 1980s

- The Limited Fine Mesh Model II (**LFMII**) grid points were ~116 km apart at 45° latitude (7 layers).
- The Nested Grid Model (**NGM**) had 3 grids. Its coarsest grid covered N. Hemisphere. The finest-mesh grid covered the east Pacific and N America with a resolution of 84 km at 45° (16 vertical layers).

Recent GFDL climate models

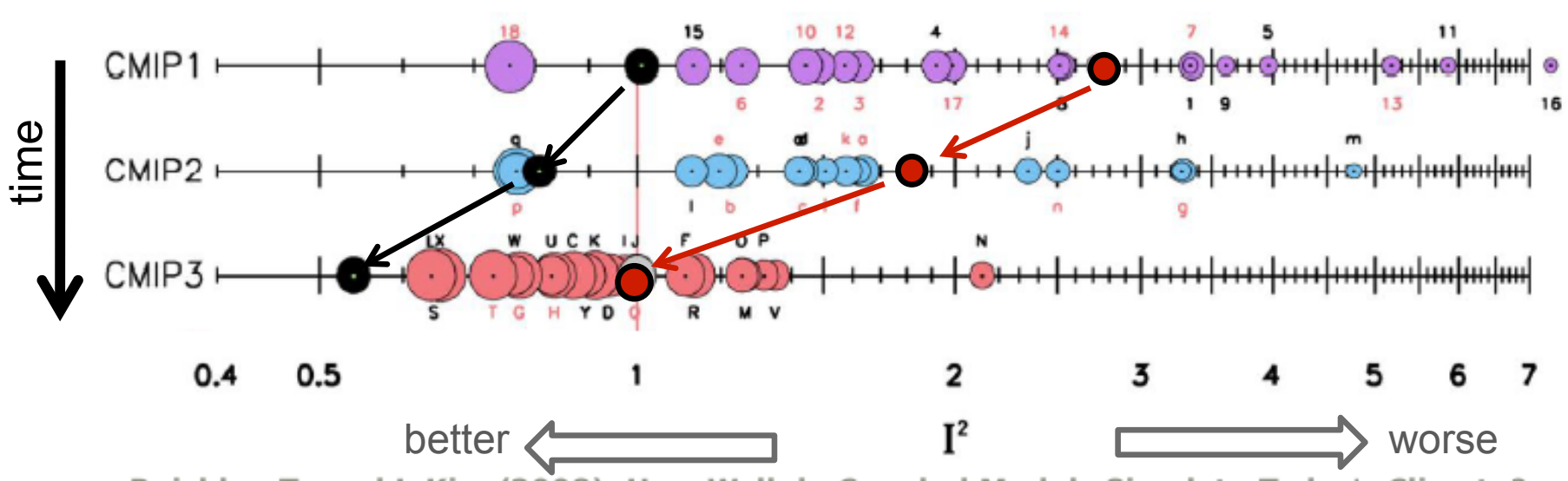
- **GFDL CM2.1** (~2004) atmospheric grid resolution of ~194 km at 45° (24 vertical layers).
- **GFDL CM2.5** (2011) atmospheric grid resolution of 50 km (32 vertical layers).

Climate models - *our "virtual Earths"* - provide a method to estimate how the planet's climate varies internally *-and-* how it will respond to changes in greenhouse gases and other climate "forcing agents".



How well have global climate models simulated the climate of recent decades?

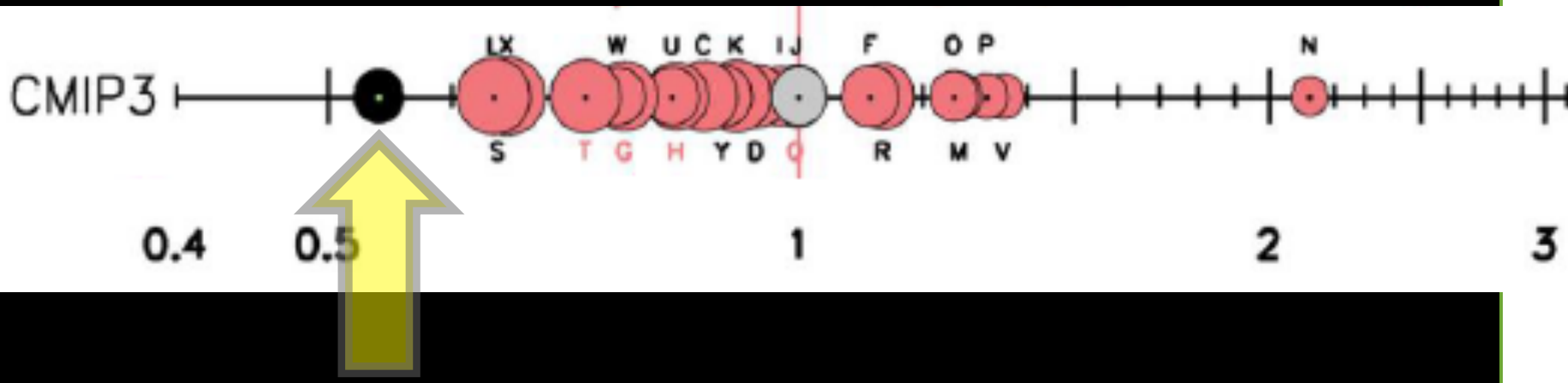
The Value of Multi-Model Ensembles



Reichler, T., and J. Kim (2008): How Well do Coupled Models Simulate Today's Climate? Bull. Amer. Meteor. Soc., 89, 303-311.

Performance error index of 14 metrics *for individual models (circles) and model generations (rows).* Black circles indicate the *index value of the multimodel mean taken over one model group.*
***Best performing* models have low index *values and are located toward the left. Circle sizes indicate the length of the 95% confidence* intervals.**

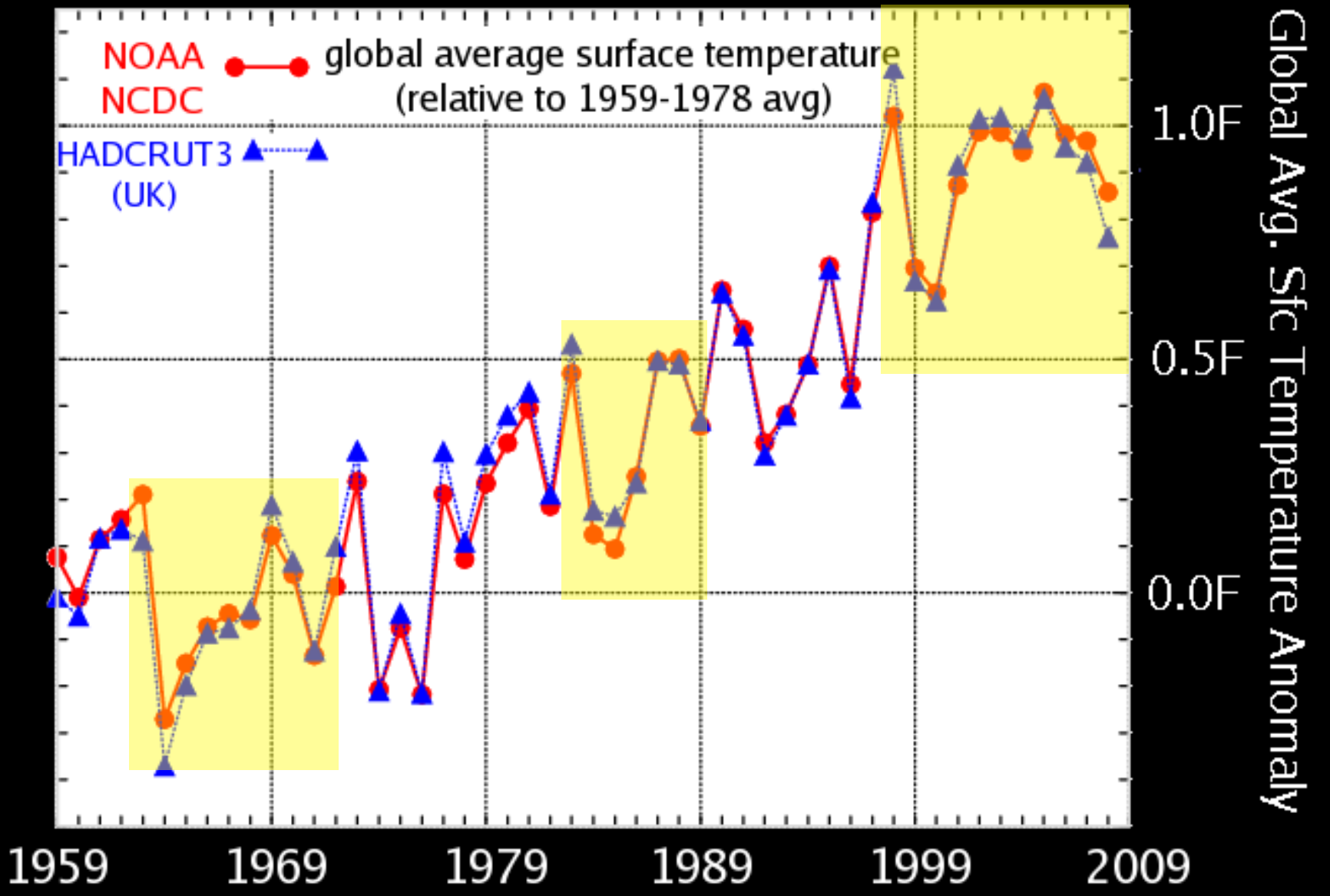
The Value of Multi-Model Ensembles



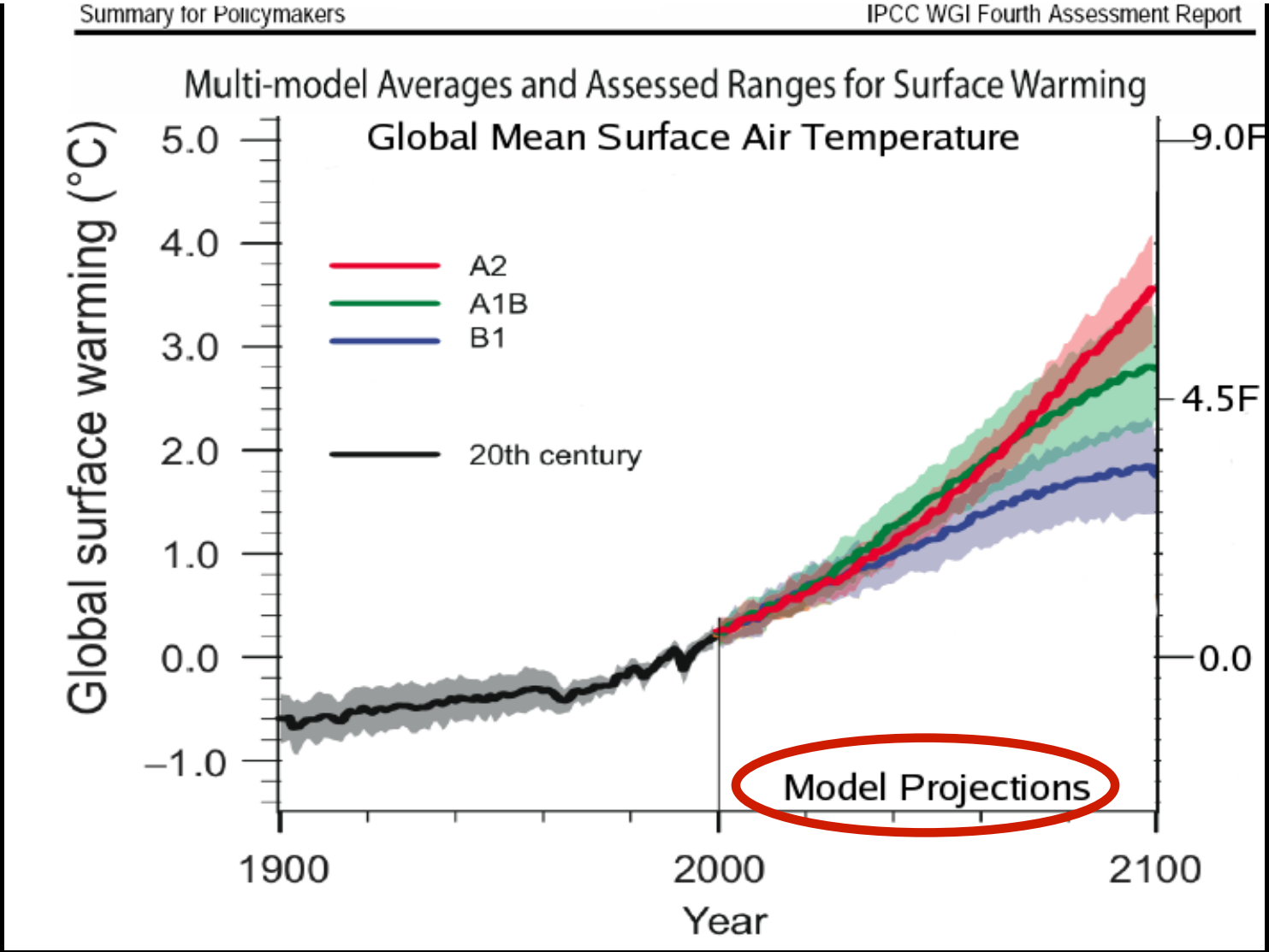
The multi-model ensemble mean (black circle) outperforms each of the individual models.

Analogous to how in a weather forecast contest it is difficult over the long term to beat the “consensus forecast” (the average of all the participating forecasters).

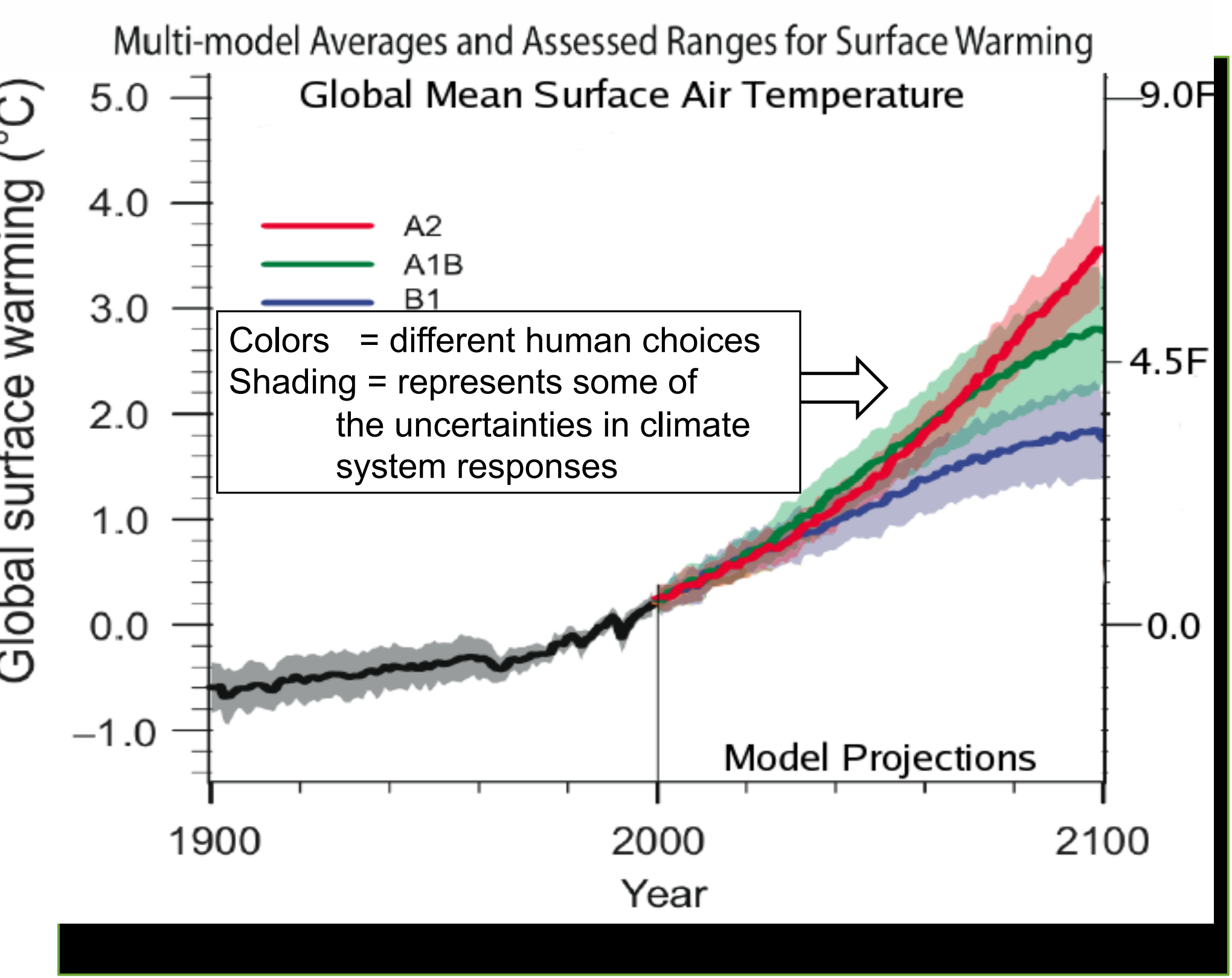
What we see in observations is a trend superimposed onto the natural variability.



Multi-model means of surface warming (relative to 1980–1999) for the scenarios A2, A1B and B1, shown as continuations of the 20th-century simulation. Lines show the multi-model means, shading denotes the ±1 standard deviation range of individual model annual means.



Source: IPCC 2007 WG1-AR4, Fig 10-4


Multi-model Averages and Assessed Ranges for Surface Warming
Global Mean Surface Air Temperature
Global surface warming (°C)
5.0
4.0
3.0
2.0
1.0
0.0
–1.0
9.0F
4.5F
0.0
A2
A1B
B1
Colors = different human choices
Shading = represents some of the uncertainties in climate system responses
Model Projections
1900
2000
2100
Year

Uncertainties In Climate Change Projections

Three broad types of uncertainties:

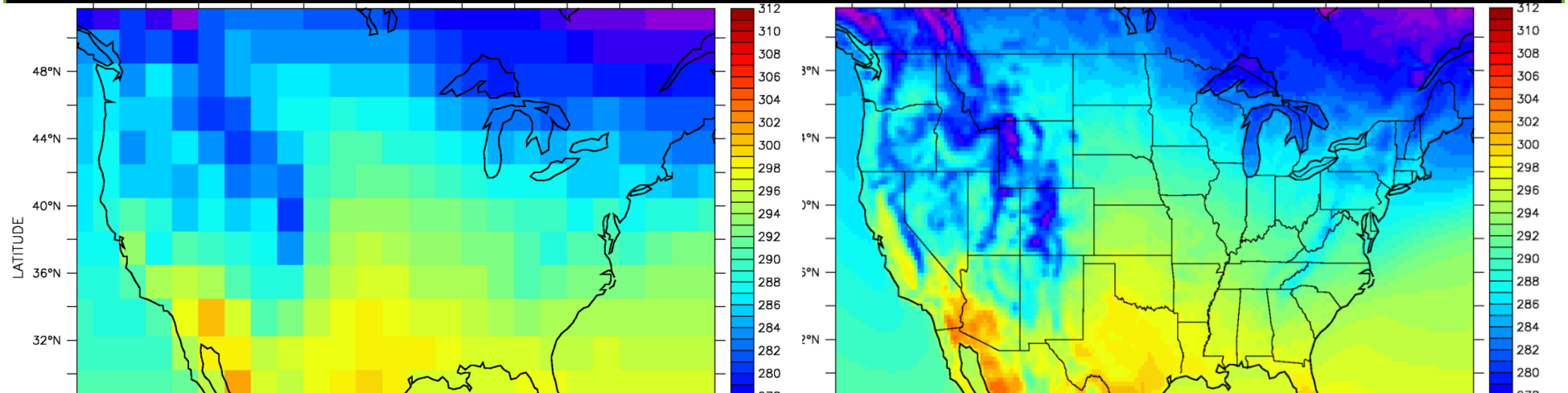
1) **What will be the future emissions of greenhouse gases, etc. in the atmosphere?**
   *(**these are climate model inputs** – they depend on population size, economic growth, energy use efficiency, alternative energy sources, treaties…)*
2) **How will the climate system respond to the changes in greenhouse gases, etc.?**
   *(**these are climate model outputs** – they're valuable, but computer models are incomplete & are not perfect)*
3) **How will changes in the climate affect crops, viruses, polar bears, coastal erosion, etc., etc., etc.?**
   *(**climate change impacts** – some researchers use climate model output as input to their own analyses)*

Adding Value to Dynamical Model Output

The MOS (Model Output Statistics) for daily weather forecasts *-are analogous to-* Statistical Downscaling of DecCen climate model output.

Both aim to add value to raw model output by addressing model shortcomings (e.g., biases) and adding addition localized detail not captured by the dynamical model.

Both involve comparing archived model output to observational data to “train” statistical methods on how to account for model shortcomings.

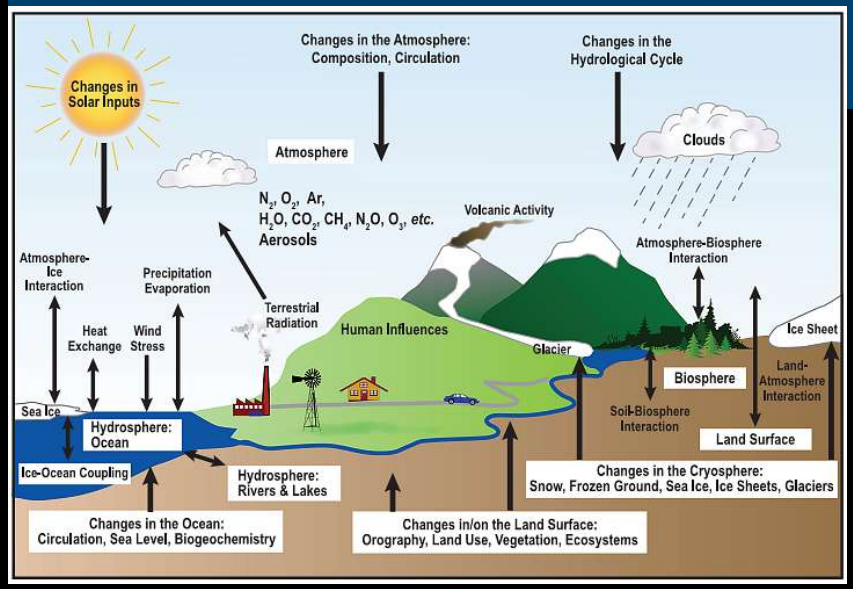


▶ What makes a climate model "better"?

A. Ability to reproduce climate observations of the past… determine via 'objective' skill scores, etc.

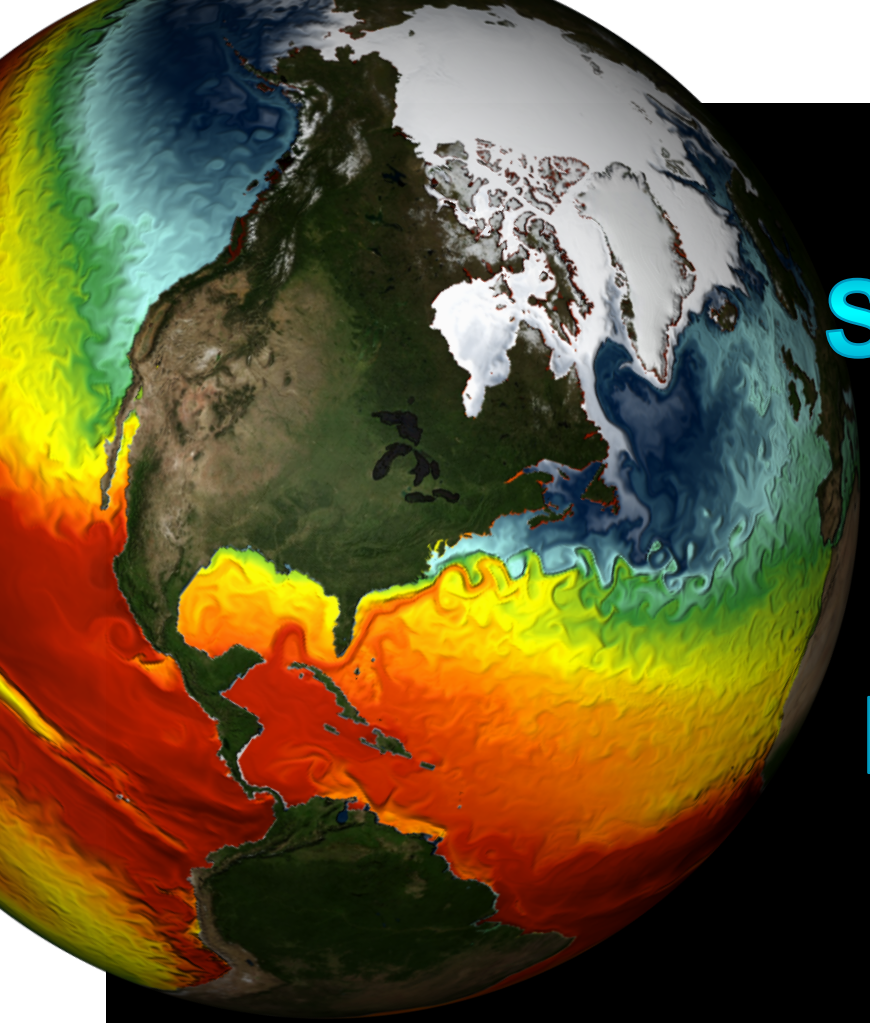
…

Z. "Comprehensiveness" of the model. Representating physics, biogeochemical processes etc. in a way that reduces reliance on more simplistic, or non-physical parameterizations.



A diversity of options exist in the community.

Somewhat dependent on the research question of interest.



SPANNING TIME AND SPATIAL SCALES:

MODELING OUR PLANET'S CLIMATE

Keith W. Dixon
research meteorologist / climate modeler
NOAA Geophysical Fluid Dynamics Laboratory
Princeton, NJ
www.gfdl.noaa.gov