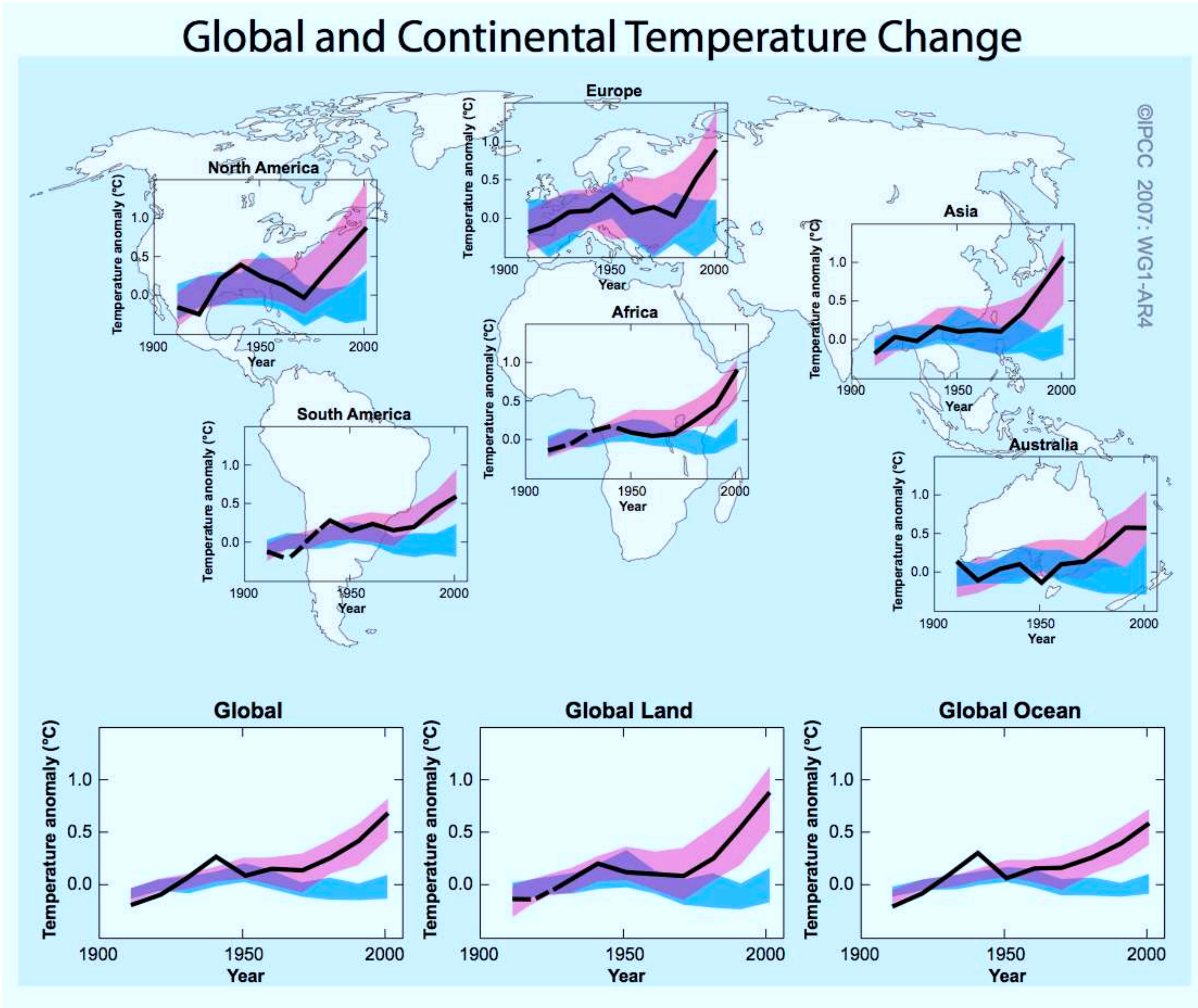
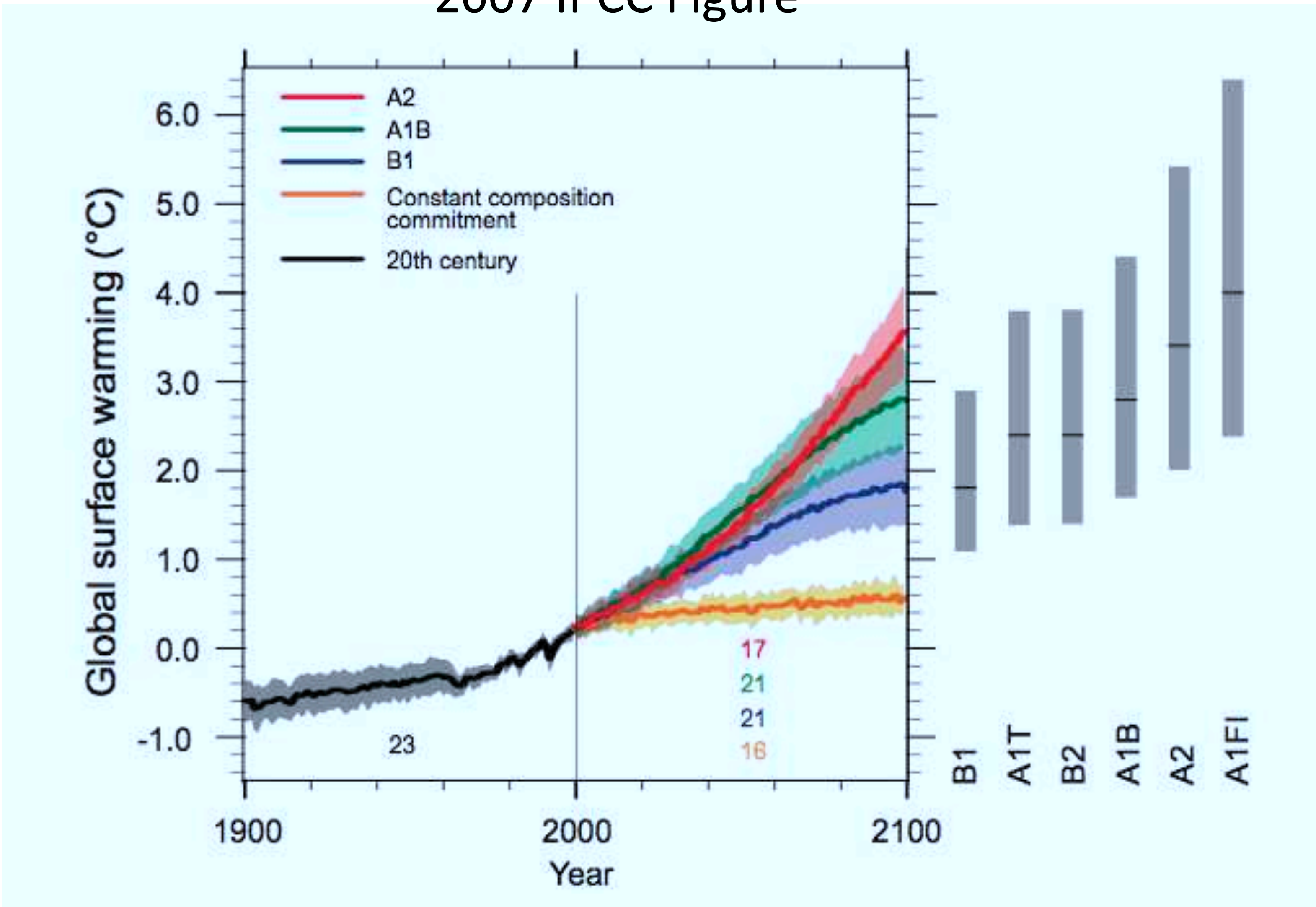
2007 IPCC Figure



2007 IPCC - for the first time claimed to detect anthropogenic signal over regions of the globe (not just the whole globe)

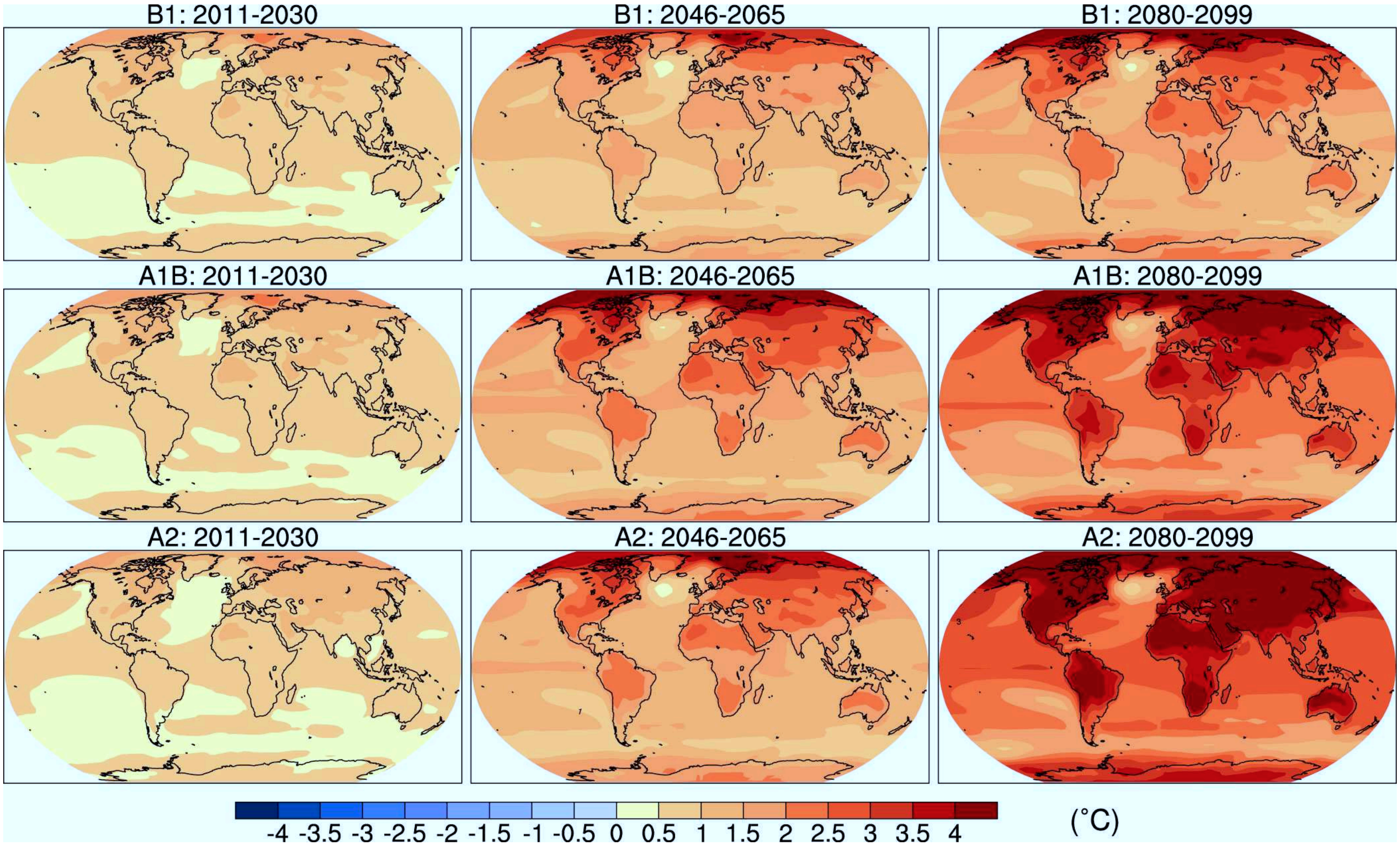
2007 IPCC Figure



Half the uncertainty is model spread and half is scenario spread

Scenarios were constructed by economists based on elaborate projections of future politics, technological growth and population

2007 IPCC Figure



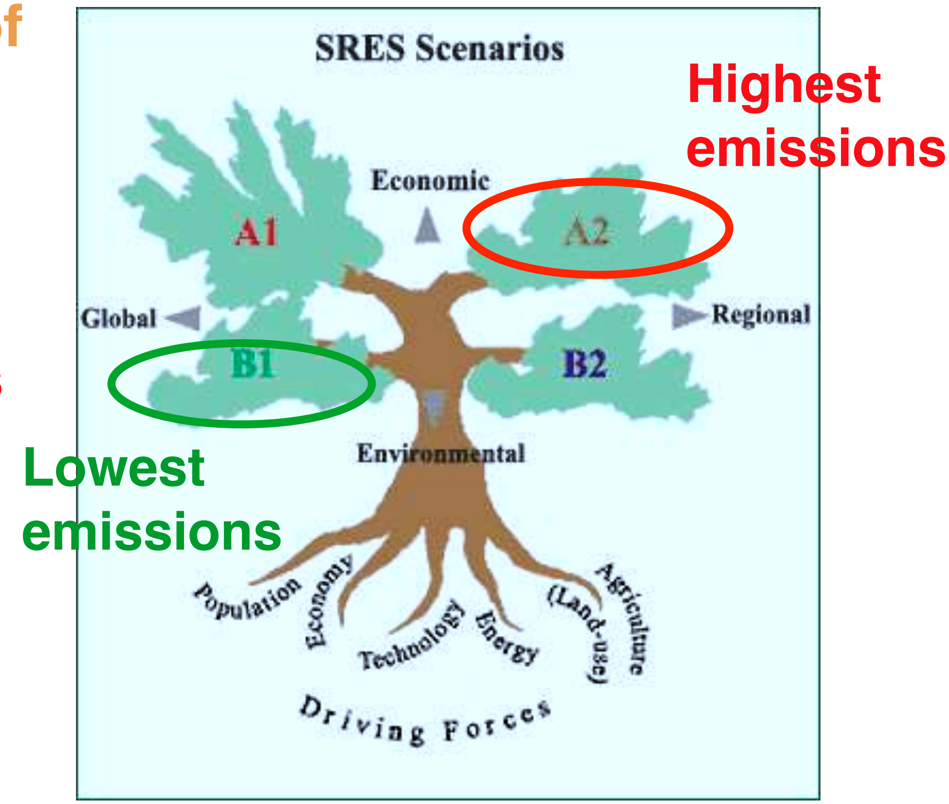
2007 IPCC Scenarios summarized

A1: Rapid economic growth followed by rapid introductions of new and more efficient technologies

A2: A very heterogenous world with an emphasis on local values and traditions

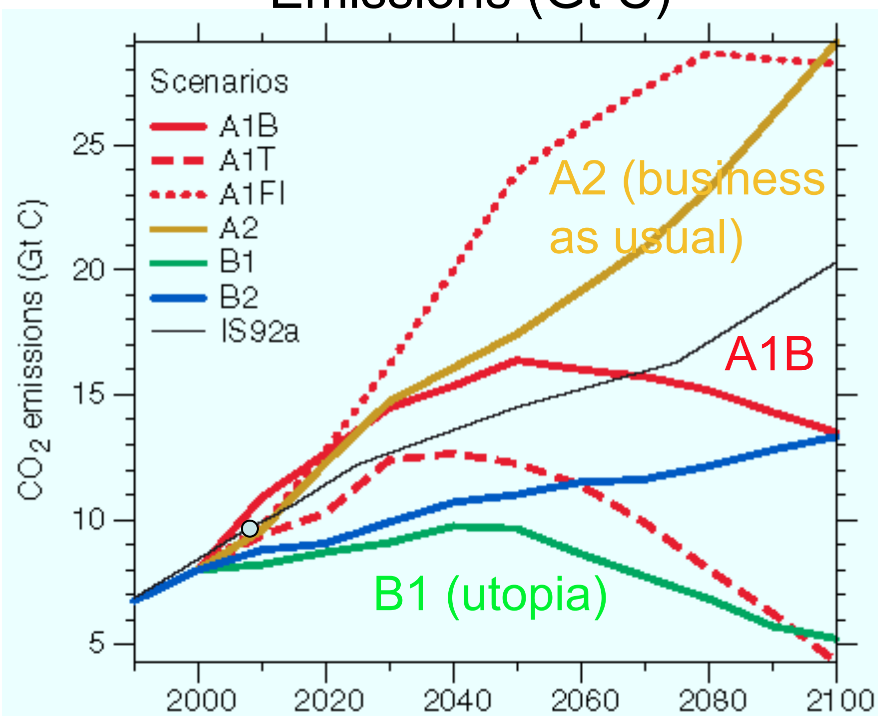
B1: Introduction of clean technologies

B2: Emphasis on local solutions to economic and environmental sustainability

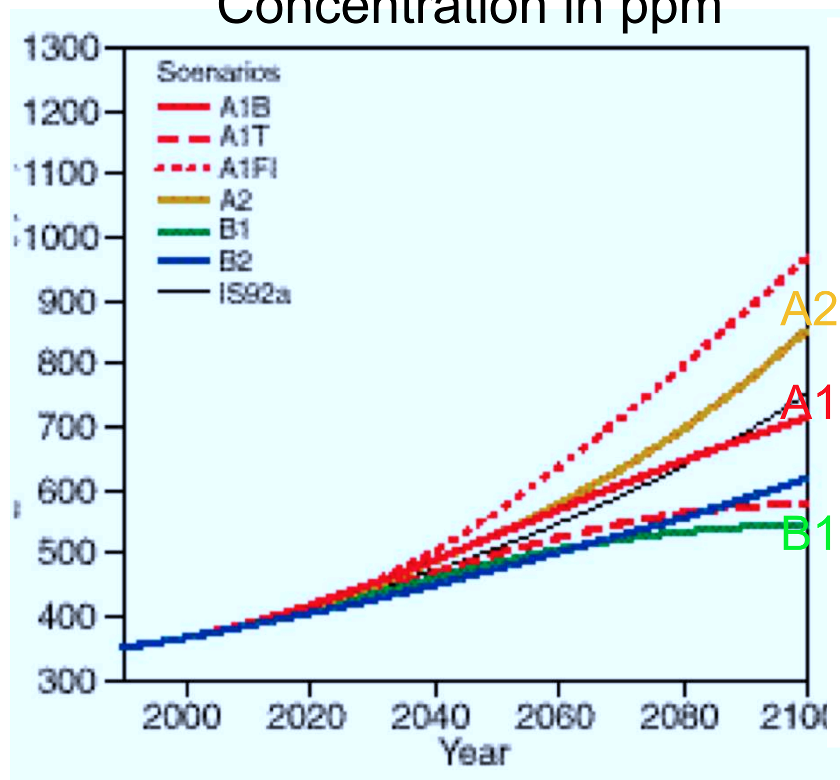


How much Carbon Dioxide will be released into the atmosphere?

Emissions (Gt C)



Concentration in ppm



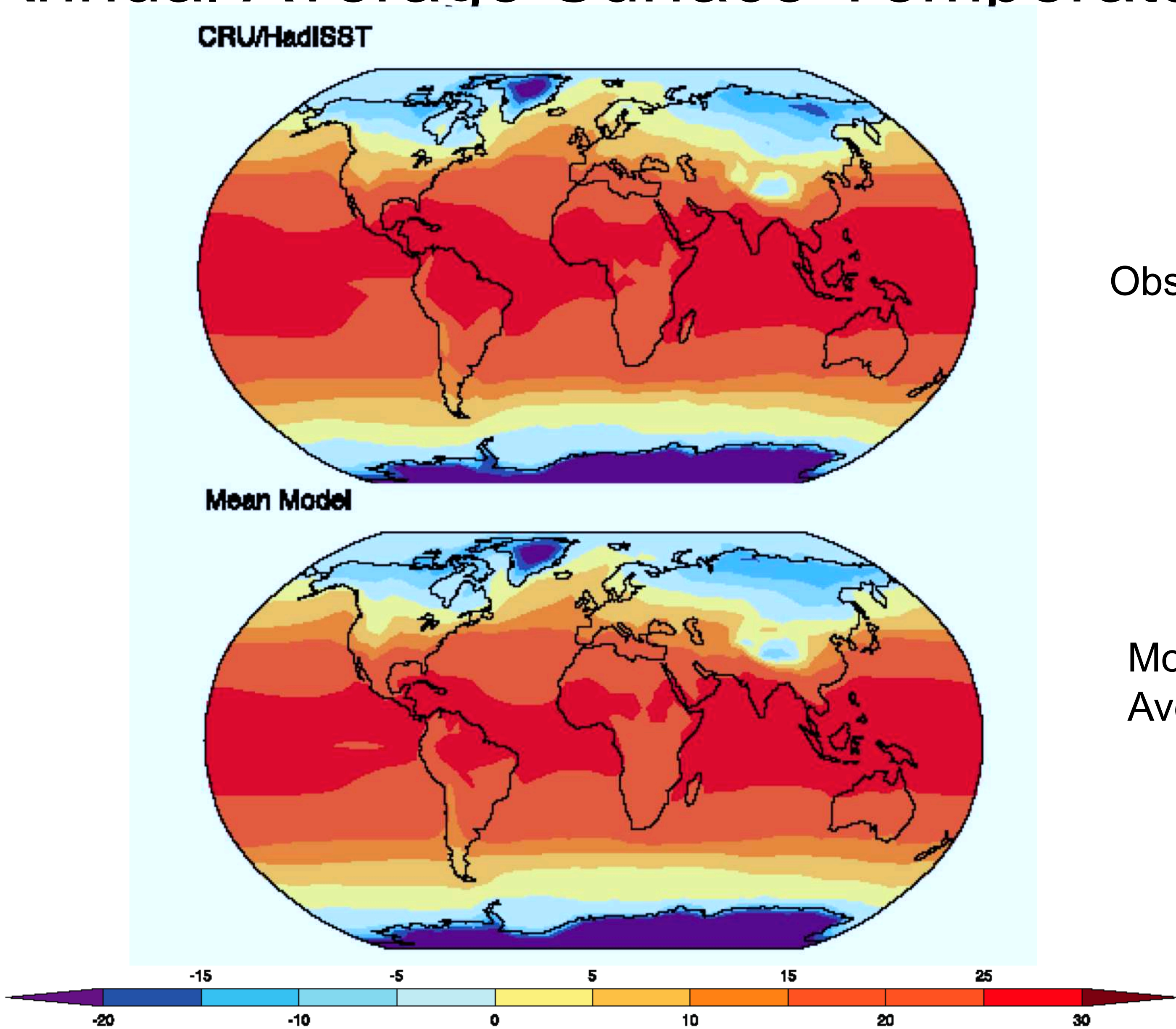
The 3 on the previous slide weren't enough…

Many of us show A1B (wishful thinking)

How can we trust models?

Why can't models adjust physics to match the 1850-2010 observational record and then also agree into the future for a given greenhouse gas scenario?

Annual Average Surface Temperature



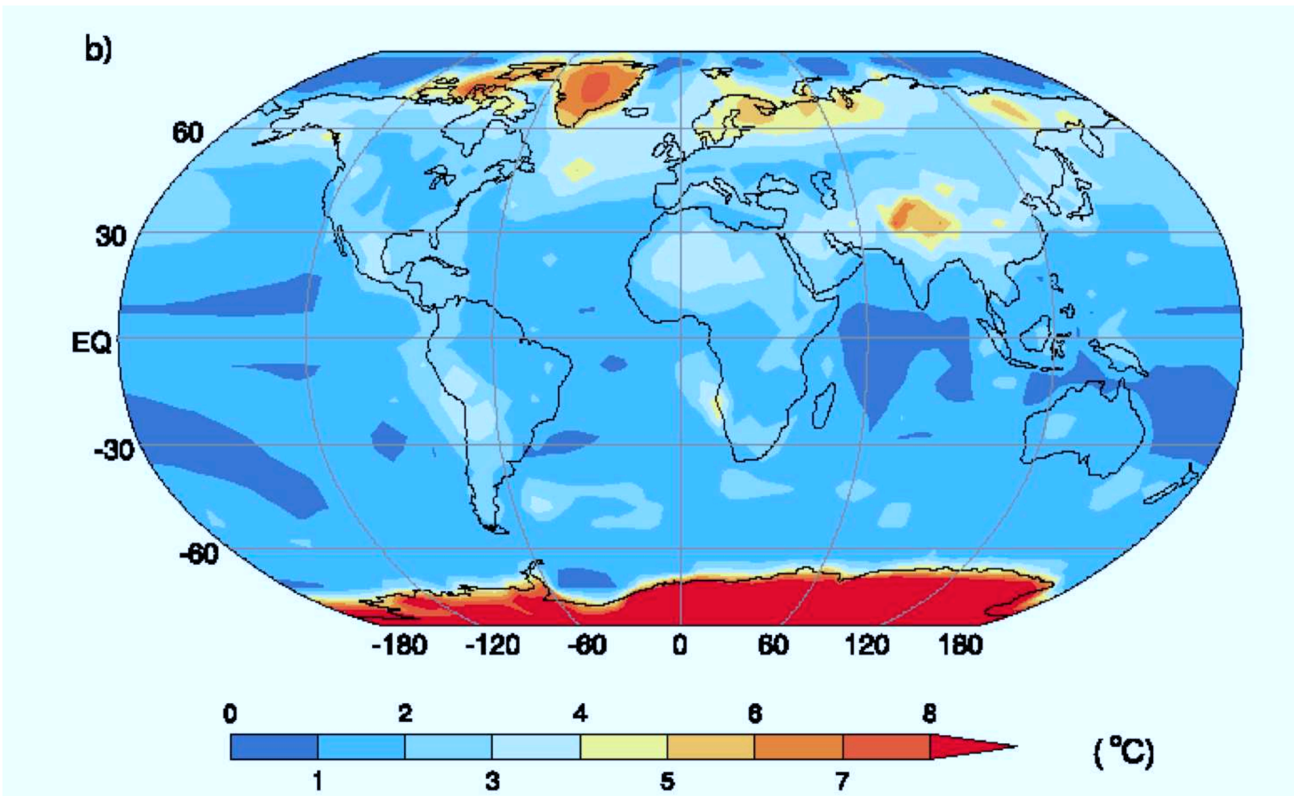
Observed

Model Average

ºC

IPCC 2007

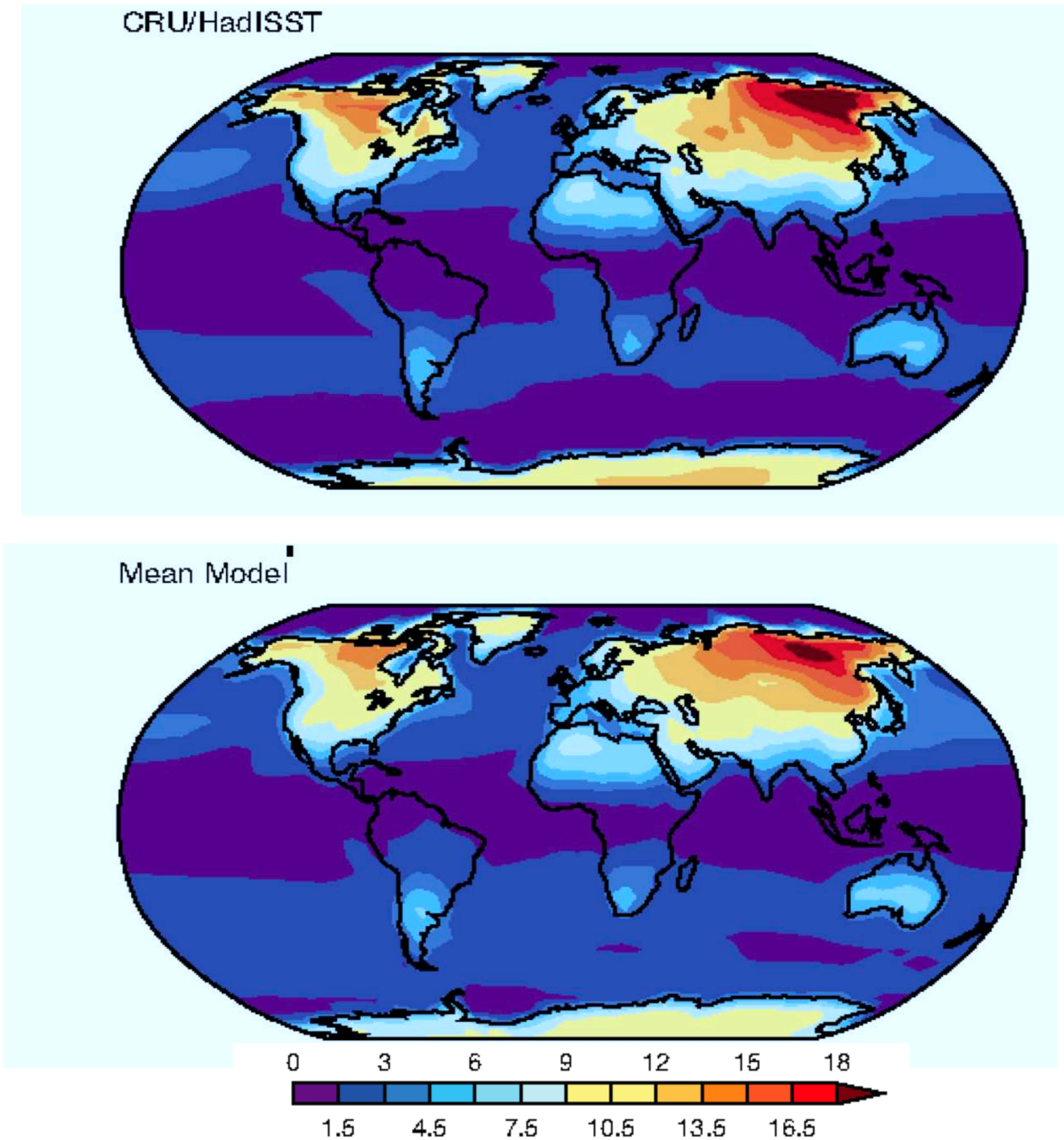
Annual Average Surface Temperature,
Absolute value of model minus observations,
Then average across models



IPCC 2007

Range of Annual Cycle* in Surface Temperature

* Multiply by ~3 to get approximately the difference in July and January temperature

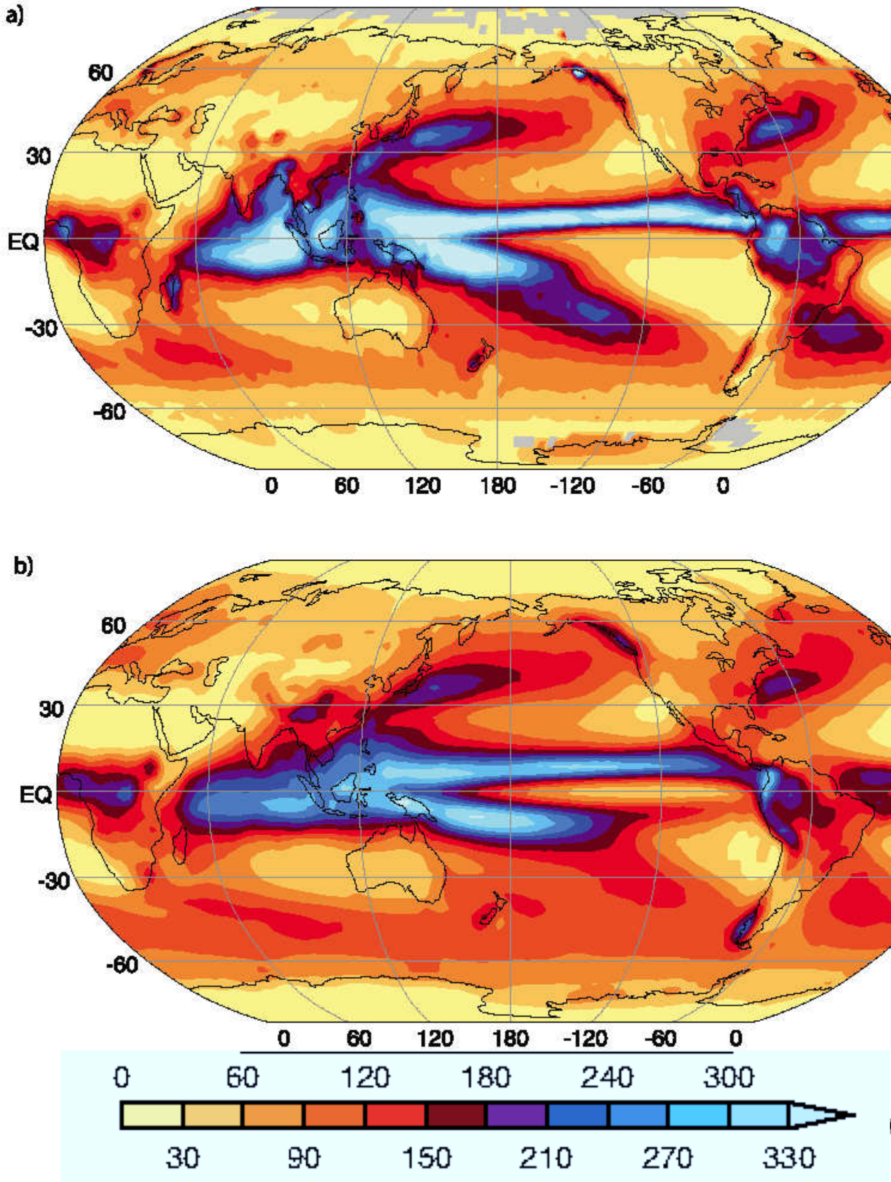


Observed

Model Average

IPCC 2007

Annual Average Precipitation



Observed (cm/year)

Average of the models

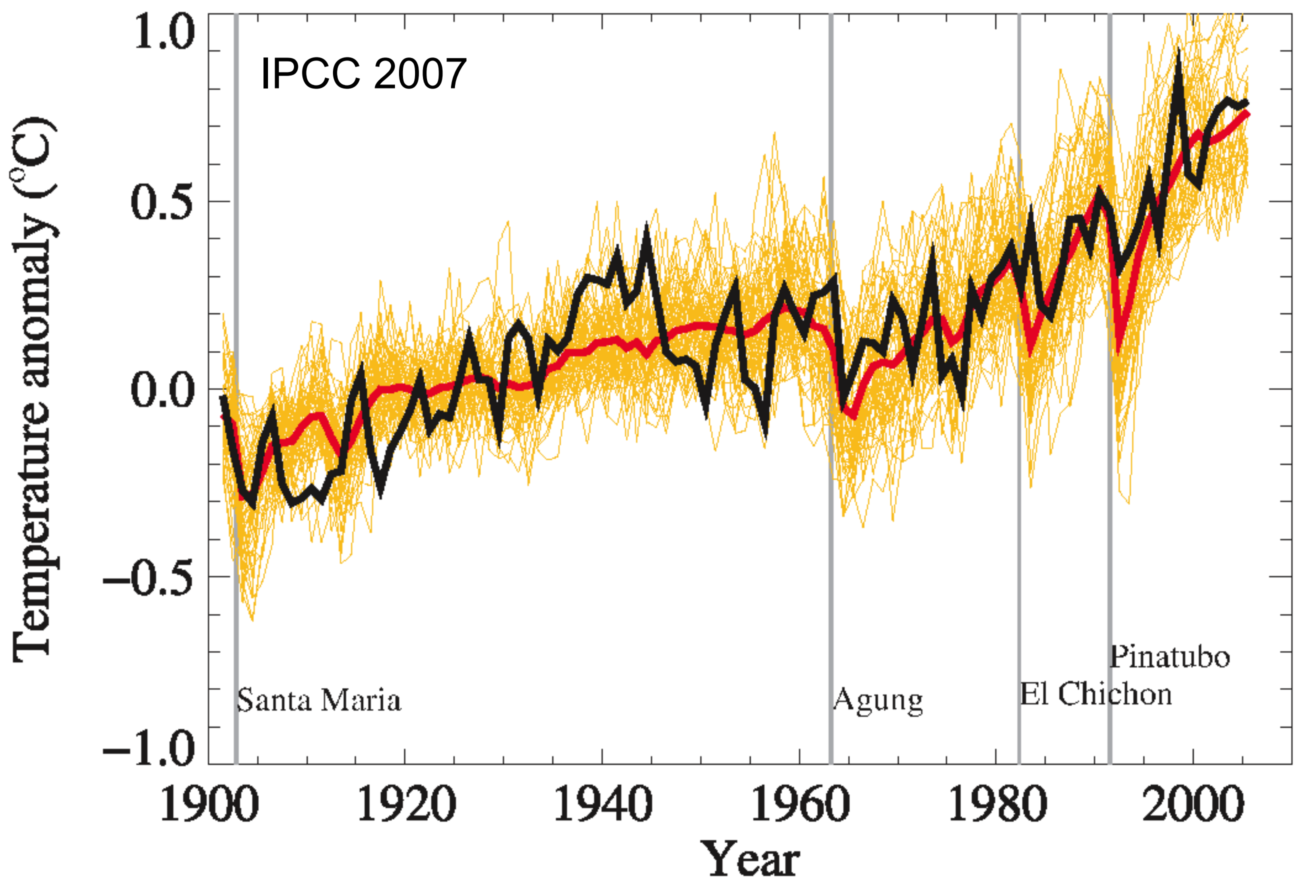
IPCC 2007

More test of the Models

- They have been used to simulate climates of the past and evaluated against the paleoclimate (proxy) data

- Climate variability

Simulating the Global Average Temperature over the 20th Century



Each yellow line is one simulation.

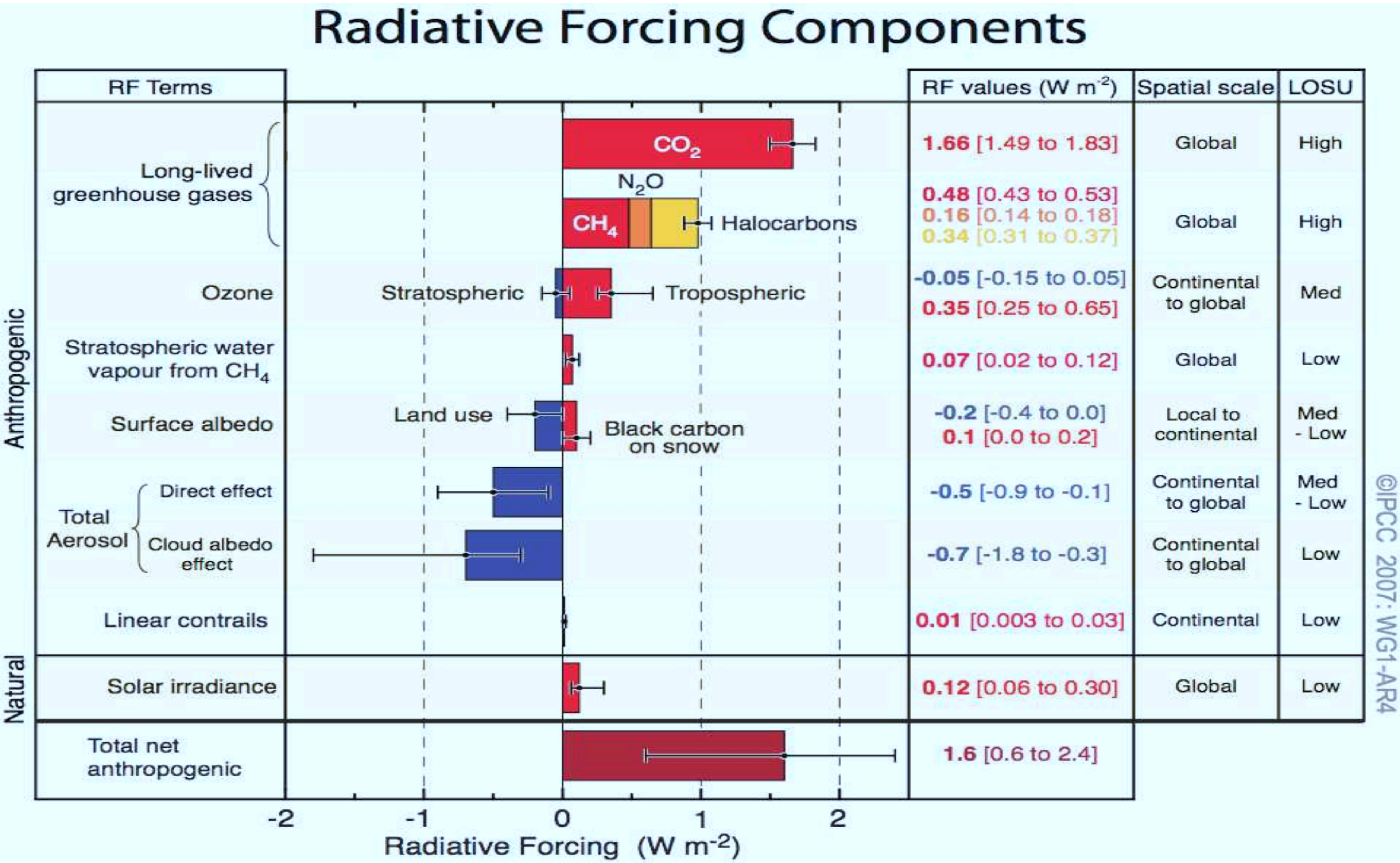
Red line = average of all 58 simulations

Black line = observed

Simulations include natural (solar and volcanic) and human (carbon dioxide, etc) forcing

14 models were used in this figure with a total of 58 simulations

Twentieth Century



This is equivalent to what we have called ΔQ
for example, we let ΔQ = 3.7 W/m2 for doubling CO2

A serious problem with climate model validation of sensitivity to forcing is we don’t know what the forcing was with sufficient accuracy.

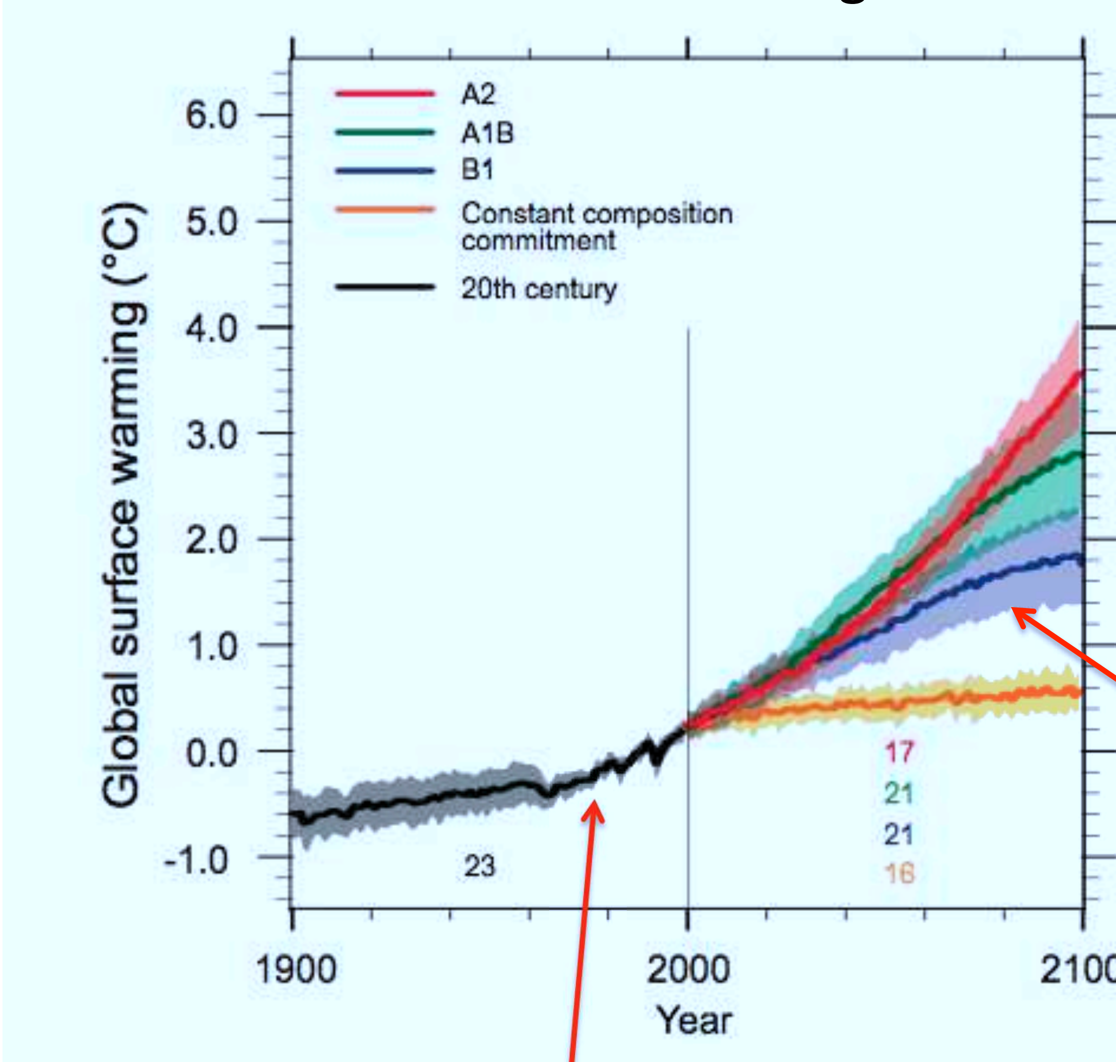
In other words, forcing for the 20^{th} century in IPCC 2007 was a free for all!

Therefore, two models can equally match the observed record but one is forced with twice the radiative forcing as another!

This happened mostly because of the enormous uncertainty of the radiative forcing of the aerosol indirect effect

However, in the future the radiative forcing from CO2 will swamp that of aerosols (assuming humans can’t tolerate much increased chemical damage to our lungs). At this point the models diverge much more.

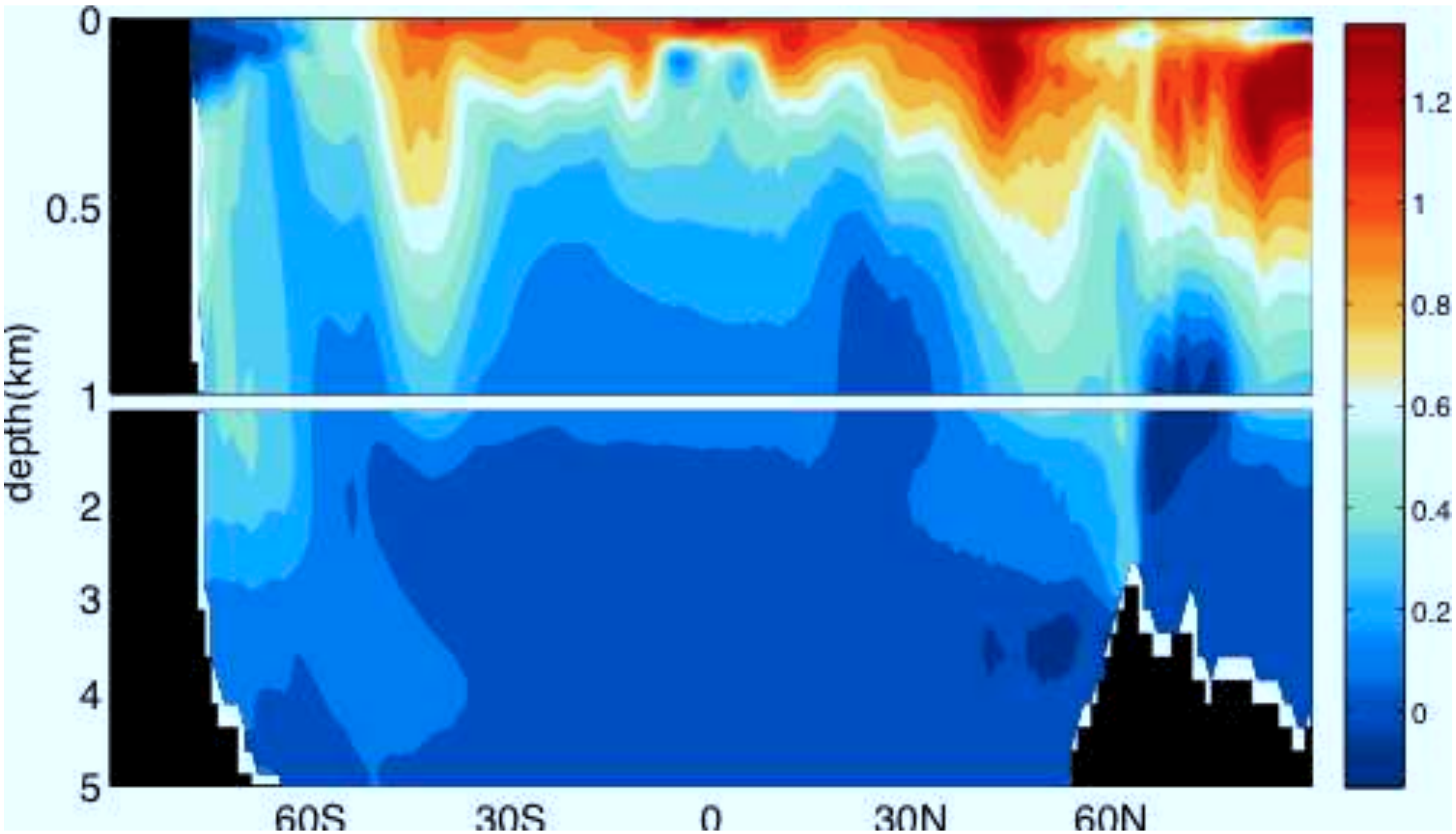
2007 IPCC Figure



Spread is larger (even for just one scenario) because aerosols can't mask anymore

Spread is smaller, because aerosols mask spread

Ocean heat uptake - warming in the ocean mid 21st century (deg C) (not perfectly mixed)



Antarctic
Deep
Heats up!

Arctic
Near Surface
Heats up

About ocean heat uptake

- **Surface ocean provides thermal inertia on time scale of several years**

- **Deep ocean provides thermal inertia on time scale of many centuries (our estimate is even shorter than reality due to perfect mixing assumption)**

- **Oceans have a very strong stabilizing effect on climate**

Motivation for simpler warming “scenario”

Ocean heat uptake is complex and leads to major differences among models

At equilibrium the deep heat content is constant so no further heat “uptake”

Uncertainty about future emissions scenario is source of future uncertainty in the climate

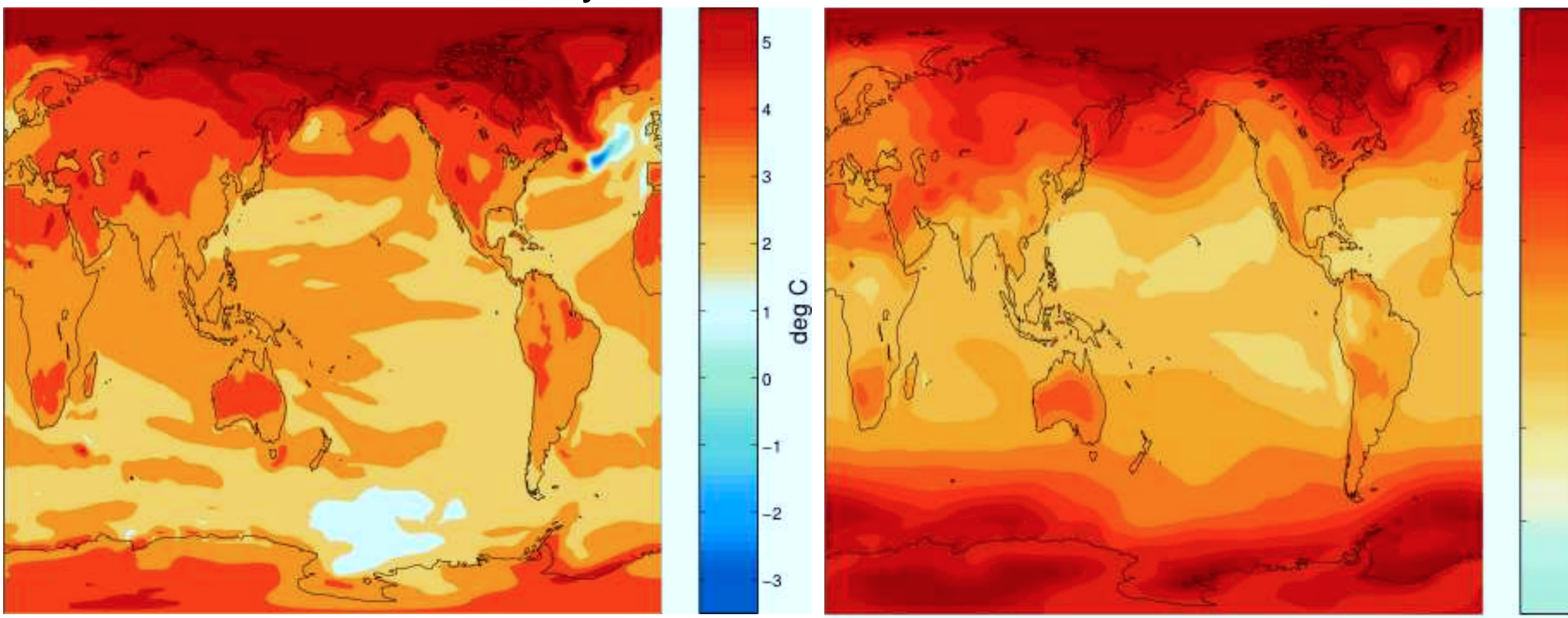
Solution:

1. Run models without deep ocean - replace ocean component with shallow mixed layer only
2. Instantly double CO2
3. Wait about 10 yrs to get equilibrium response

Transient versus Equilibrium warming

Warming at 2100
relative to end of last century

Warming from 2XCO2



- Transient warming is smaller, yet forcing is much larger
- Transient warming is asymmetric across hemispheres
- Transient warming is modest in the northern North Atlantic

Equilibrium warming from 2XCO2

Used to compare models without worrying about deep ocean heat uptake or various scenarios. But still ΔT_{EQ} ranges from 1.5-4.5 C

- The range is awfully large (factor of three!)
- Hasn't narrowed in 30 years - makes scientists look bad, but models have a lot more features now
- Are predictions even useful for policy-making purposes?

Late in 2006 (while waiting for IPCC 2007 to be published) the following issues came up:

1. Heightened interest in short term (next several decades) climate change information on regional scales, and regional weather and climate extremes
2. Scenario frustration: take too long to make, outdated when done
3. Magnitude of carbon cycle feedback was least quantified uncertainty; need to coordinate how models start to model it.

This and the following 7 slides are adapted from Jerry Meehl

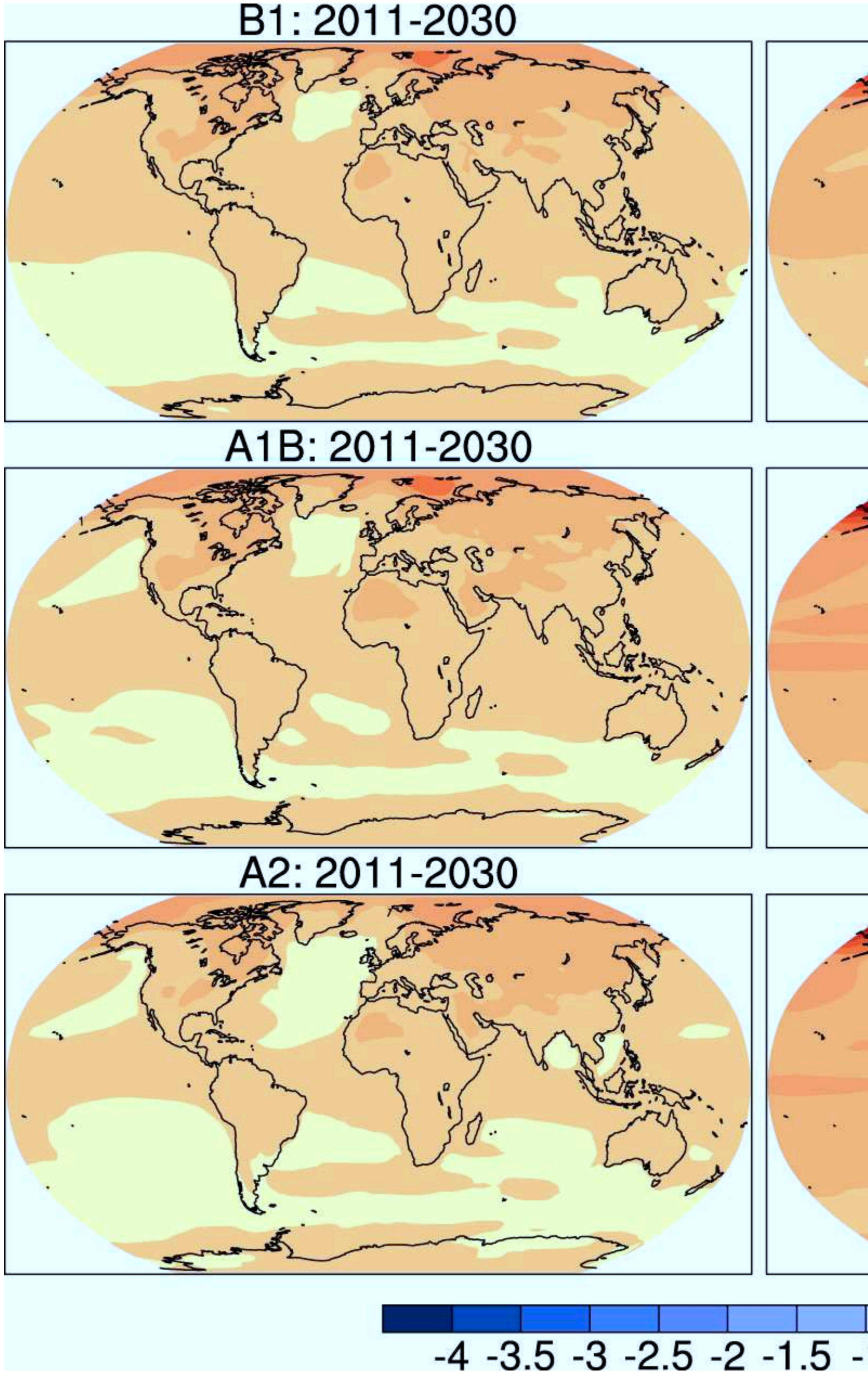
Aspen Global Change Institute in August 2006 formulated a new strategy for climate change modeling and emerging Earth System Models (ESMs)

Make the process community-based and not IPCC-driven (though results from a new set of coordinated experiments would be eligible for assessment for IPCC 2013, also called AR5)

Decadal prediction

By averaging over a multi-model ensemble, the decadal signal is, at minimum, 1) the forced response to increasing GHGs (doesn't depend much on which scenario is used) and 2) climate change commitment

But if there are modes of decadal variability that could be predicted, the regional skill of decadal predictions could be increased



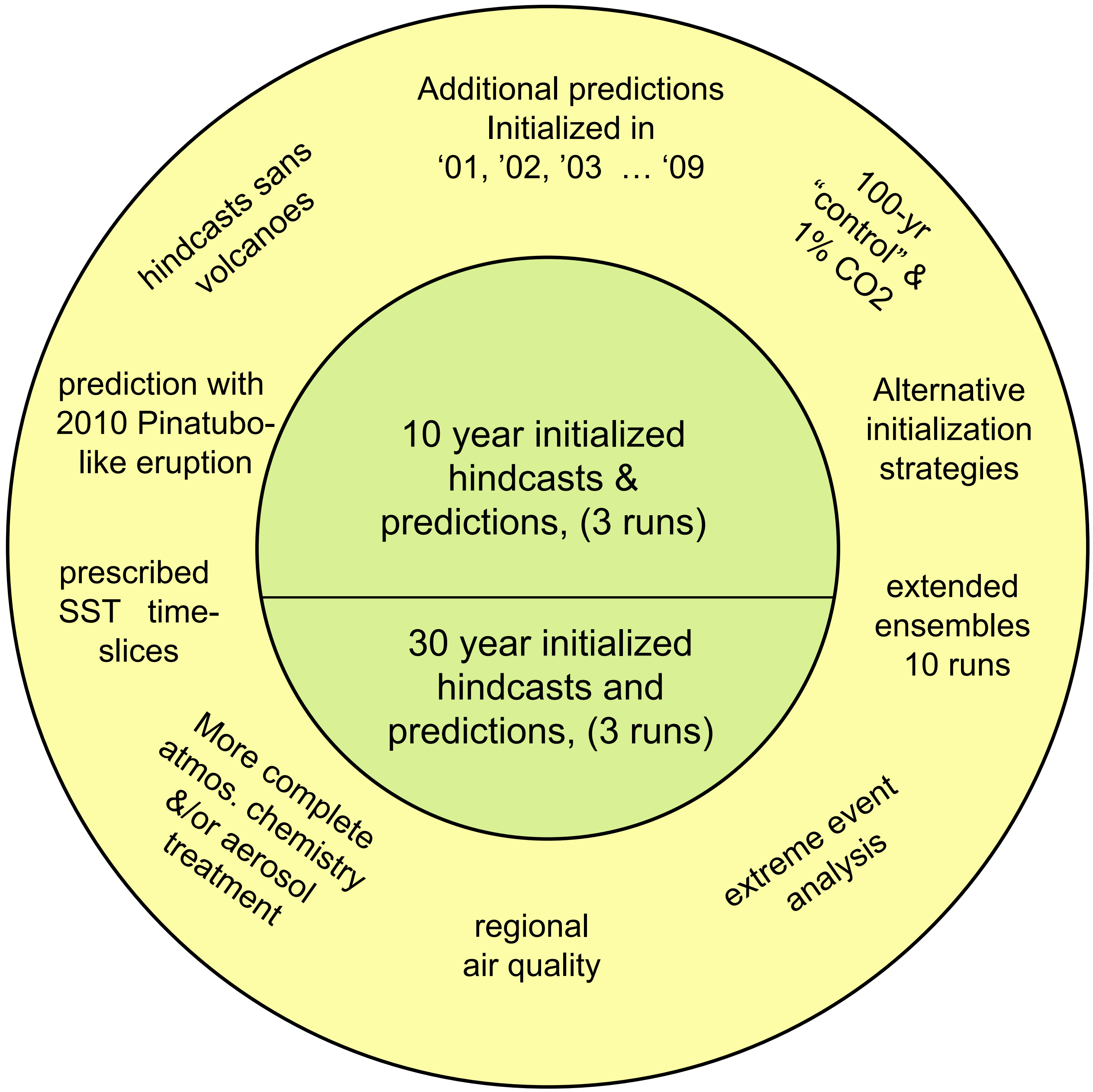
Two classes of models to address two time frames and two sets of science questions:

Decadal predictability/prediction (to 2035)
higher resolution (~50 km), no carbon cycle, some chemistry and aerosols, single scenario
science questions: regional climate and extremes

Long term (to 2100 and beyond)
intermediate resolution (~200 km), carbon cycle, specified/ simple chemistry and aerosols, new mitigation scenarios: *"representative concentration pathways" (RCPs)*
science questions: feedbacks, slower processes

(Meehl and Hibbard, 2007; Hibbard et al., 2007)

CMIP5 Decadal Predictability/Prediction Experiments



Decadal predictability/prediction core model runs:

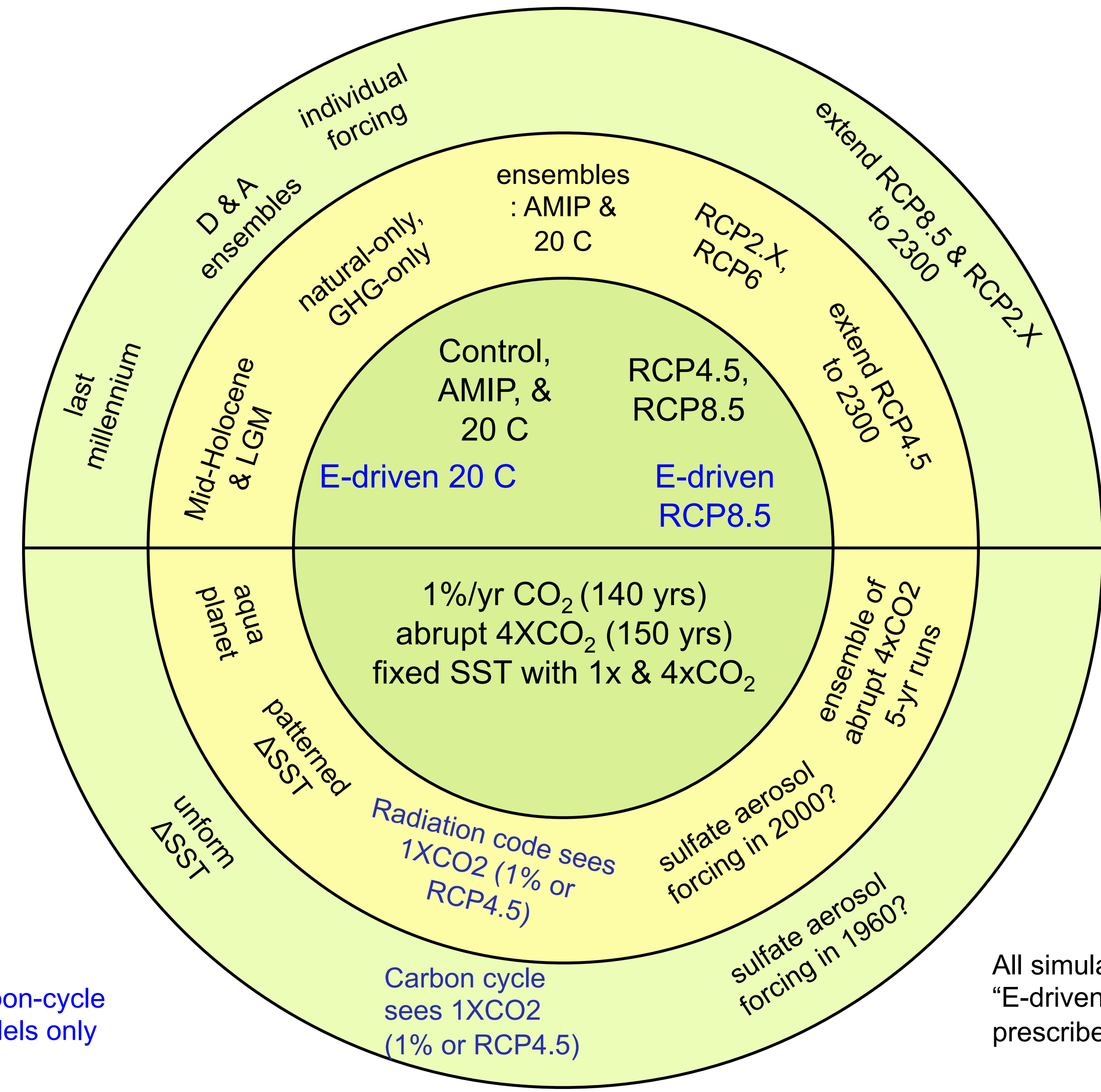
1.1 10 year integrations with initial dates towards the end of 1960, 1965, 1970, 1975, 1980, 1985, 1990, 1995 and 2000 and 2005

- Ensemble size of 3, optionally to be increased to O(10)
- Ocean initial conditions should be in some way representative of the observed anomalies or full fields for the start date
- Land, sea-ice and atmosphere initial conditions left to the discretion of each group
- Model run time: 300 years (optionally, an additional 700 years)

1.2 Extend integrations with initial dates near the end of 1960, 1980 and 2005 to 30 yrs.

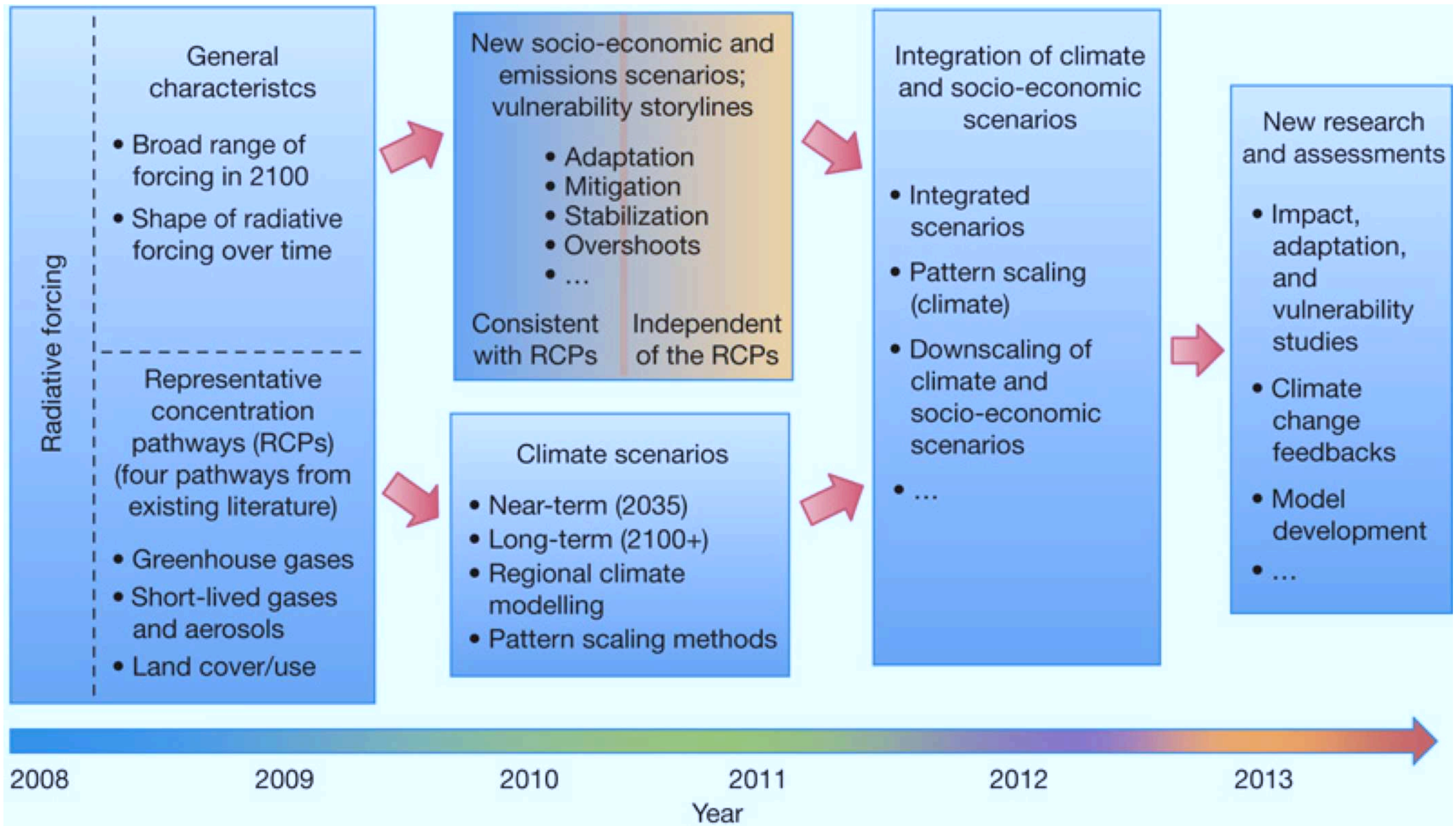
- Each start date to use a 3 member ensemble, optionally to be increased to O(10)
- Ocean initial conditions represent the observed anomalies or full fields.
- Model run time: 180 years (optionally, an additional 420 years)

CMIP5 Long-term Experiments



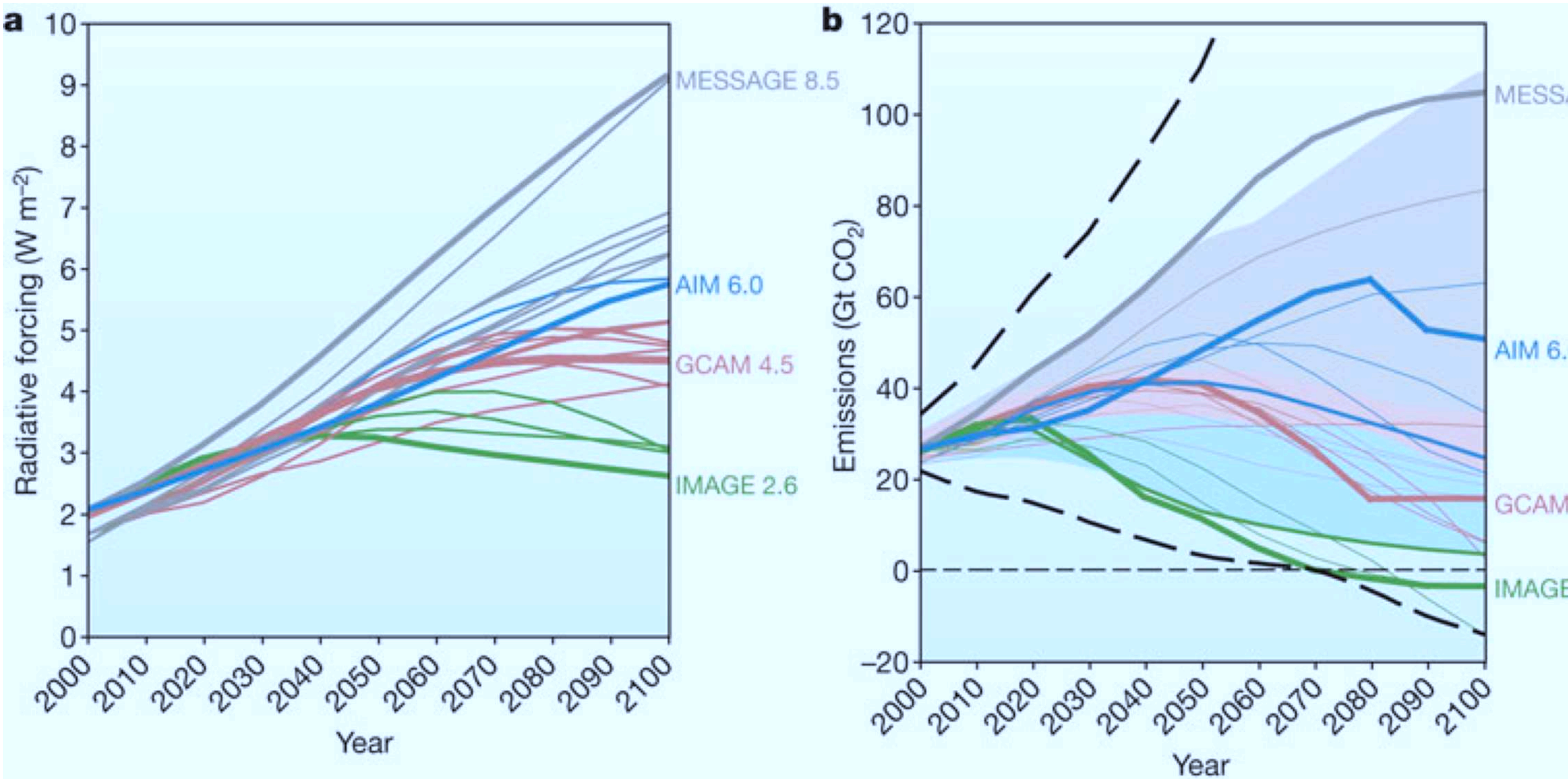
Coupled carbon-cycle climate models only

All simulations except those “E-driven” are forced by prescribed concentrations



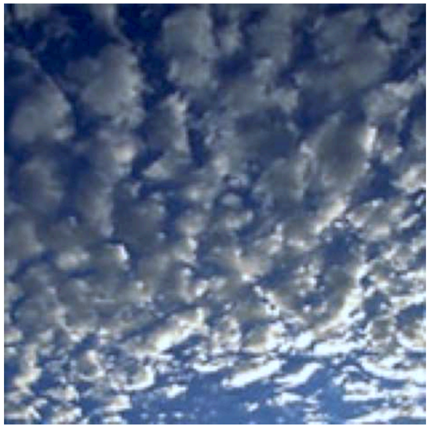
Radiative forcing
General characteristcs
• Broad range of forcing in 2100
• Shape of radiative forcing over time
Representative concentration pathways (RCPs) (four pathways from existing literature)
• Greenhouse gases
• Short-lived gases and aerosols
• Land cover/use
New socio-economic and emissions scenarios; vulnerability storylines
• Adaptation
• Mitigation
• Stabilization
• Overshoots
• …
Consistent with RCPs
Independent of the RCPs
Climate scenarios
• Near-term (2035)
• Long-term (2100+)
• Regional climate modelling
• Pattern scaling methods
Integration of climate and socio-economic scenarios
• Integrated scenarios
• Pattern scaling (climate)
• Downscaling of climate and socio-economic scenarios
• …
New research and assessments
• Impact, adaptation, and vulnerability studies
• Climate change feedbacks
• Model development
• …
2008
2009
2010
2011
2012
2013
Year

Name	Radiative forcing	Concentration(p.p.m.)	Pathway	pro
RCP8.5	$>8.5 Wm^{-2}$ in 2100	$>1,370$ CO_2-equiv. in 2100	Rising	N
RCP6.0	$\sim 6 Wm^{-2}$ at stabilization after 2100	~850 CO_2-equiv. (at stabilization after 2100)	Stabilization without overshoot	
RCP4.5	$\sim 4.5 Wm^{-2}$ at stabilization after 2100	~650 CO_2-equiv. (at stabilization after 2100)	Stabilization without overshoot	
RCP2.6	Peak at $\sim 3 Wm^{-2}$ before 2100 and then declines	Peak at ~490 CO_2-equiv. before 2100 and then declines	Peak and decline	



RH Moss *et al.* *Nature* **463**, 747-756 (2010) doi:10.1038/nature08823

Community
Climate
System
Model (CCSM)



One of three US climate models, the others are NOAA GFDL and NASA GISS

Changed its name to CESM when the following were released with the model

- Aerosol indirect effect (aerosols are created by atmospheric chemistry and they affect cloud formation)
- Carbon cycle (atmospheric CO_2 is computed dynamically)
- Ice sheet model

In this class we have been using the CESM “code base” though we turned all this stuff off. No one knows what to call the model now.

Who is involved?

- National Center for Atmospheric Research

  also the project's home base
- Other National Labs
- Universities, Now you!

~350 people attend the annual meeting

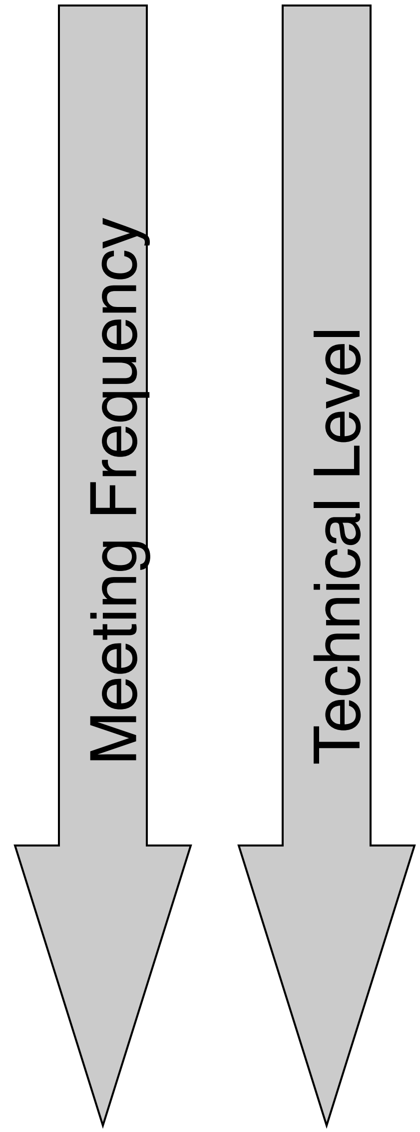
All are part of the "community"

Organization

Advisory Board
Guidance and Evaluation
Communicates with Funding Agencies

Scientific Steering Committee
Strategic Direction, Priorities,
Approve Changes, Keep Deadlines

Working Groups
Design and Development,
Distribution, Support,
Users



The Working Groups

Atmosphere Model
Land Model
Ocean Model
Land Ice
Polar Climate (manage the sea ice model)
Biogeochemistry
Chemistry-climate
Whole atmosphere (aka above the troposphere)
Software Engineering

Climate Variability
Climate Change
Paleoclimate

For your presentations on Friday

Recommended Outline

1) Motivation
2) Brief Model Description (e.g., Slab ocean version of CCSM3, resolution, length of run)
3) Brief Description of the experiment
4) Results
5) Conclusions about what you learned

Plan on speaking for 8 min

Please email me your presentation in advance

I’ll come early and we can install them with a memory stick too

Today – Applications of climate modeling

GLOBAL ATMOSPHERIC CONSEQUENCES OF NUCLEAR WAR

R. P. Turco
R & D Associates, Marina del Rey, CA 92091

O. B. Toon, T. P. Ackerman and J. B. Pollack
NASA Ames Research Center, Moffett Field, CA 94035

Carl Sagan
Cornell University, Ithaca, NY 14853

[redacted] Science in Press

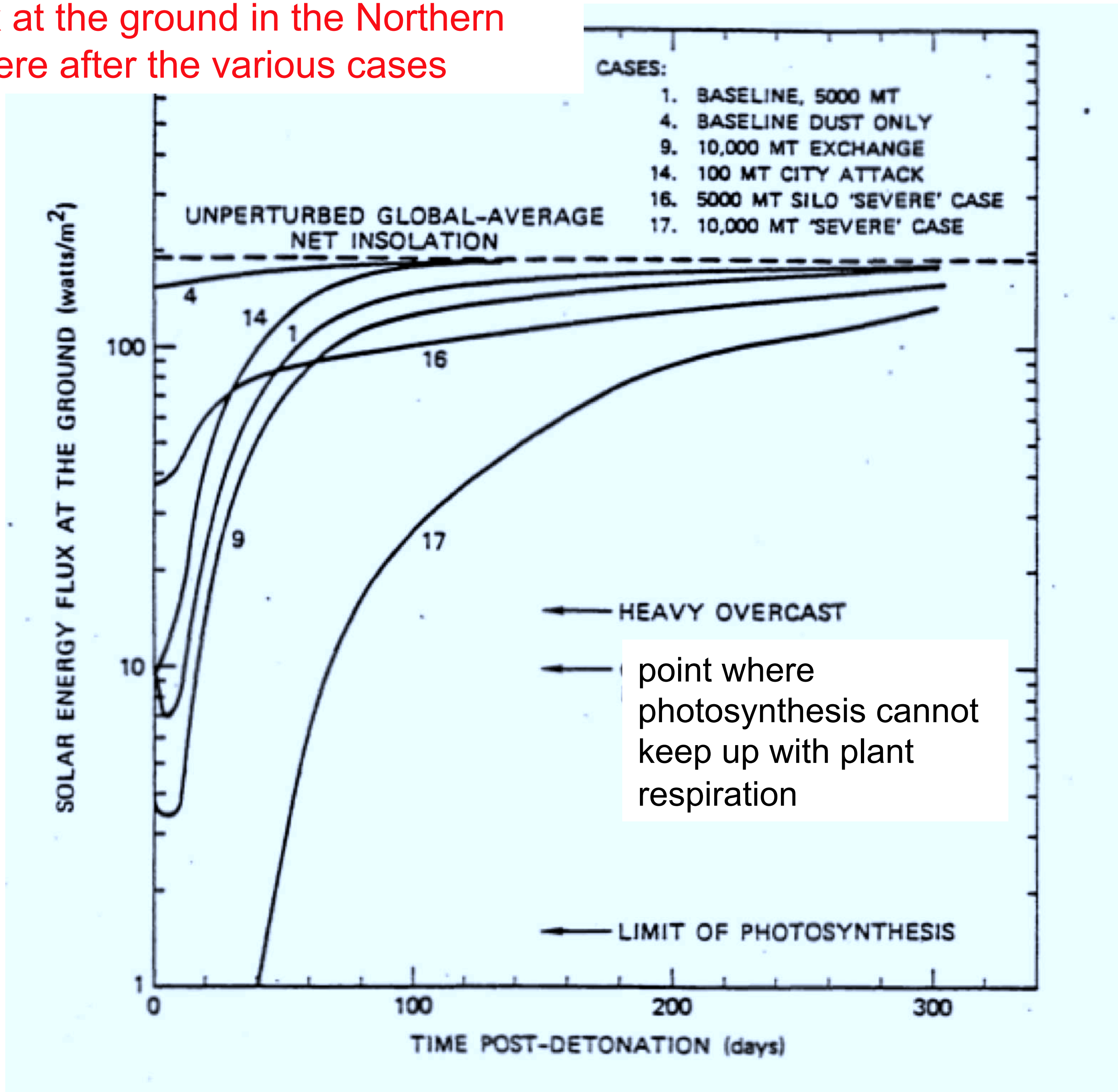
1983

To study these phenomena, we employ a series of physical models: a nuclear scenario model, a particle microphysics model, and a radiative-convective model. The nuclear scenario model calculates the altitude-dependent dust, radioactivity, smoke and NO_x

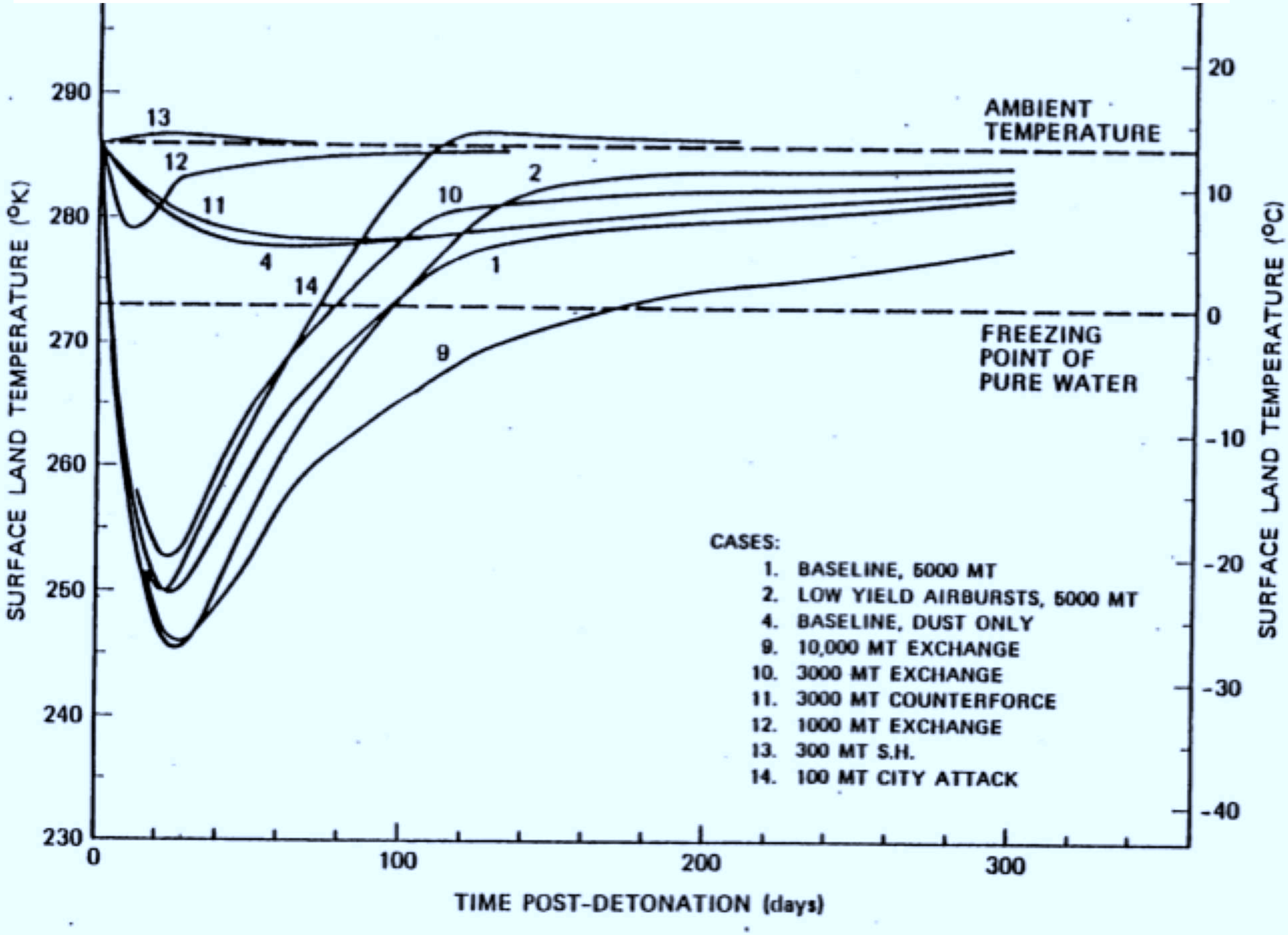
The authors of this paper coined the term “Nuclear winter”

A radiative-convective model is like a climate model, but without dynamics (just the physics).

Solar flux at the ground in the Northern Hemisphere after the various cases



Surface temperature in the interior of continents in the Northern Hemisphere after the various cases, many give cooling of 30deg C for several months



Soviet scientists in the same year published about nuclear winter:

Alexandrov, V. V. and G. I. Stenchikov (1983): "On the modeling of the climatic consequences of the nuclear war" The Proceeding of Appl. Mathematics

Some disputed the nuclear winter idea too

"Models made by Russian and American scientists showed that a nuclear war would result in a nuclear winter that would be extremely destructive to all life on Earth; the knowledge of that was a great stimulus to us, to people of honor and morality, to act in that situation."

Mikhail Gorbachev, 2000

“The response to the 150 Tg scenario [of smoke and soot] can still be characterized as ‘‘nuclear winter,’’ but both produce global catastrophic consequences. The changes are more long-lasting than previously thought”

Nuclear winter revisited with a modern climate model and current nuclear arsenals: Still catastrophic consequences 2008 Alan Robock, Luke Oman, and Georgiy, Stenchikov in the Journal of Geophysical Research

Alan Robock is a guest of Fidel Castro and speaks about nuclear winter

http://climate.envsci.rutgers.edu/Cuba/

Vladimir Alexandrov

From Wikipedia, the free encyclopedia

Vladimir Valentinovich Alexandrov (Russian: Владимир Валентинович Александров) was a Russian physicist who created a mathematical model for the nuclear winter theory. He disappeared in 1985 while at a nuclear winter conference in Madrid and his ultimate fate remains unknown.

Conspiracy theories abound

Had been a guest of UW and the National Center for Atmospheric Research that year.

Paleoclimate Modeling

To address questions like…

Has climate changed in the past?
How much?
How fast?

The answers provide a context for assessing human-induced climate change (e.g. global warming).

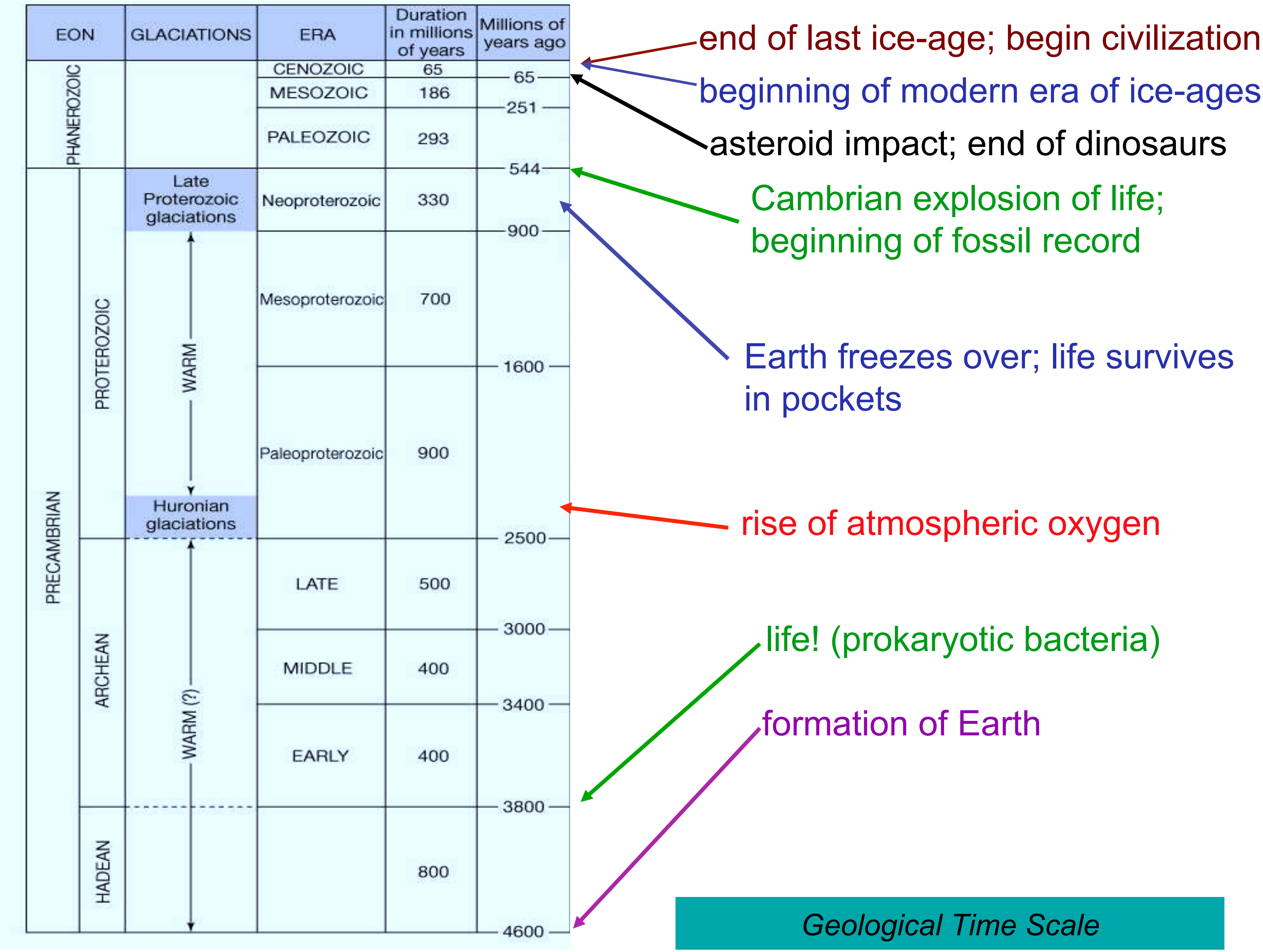
Paleoclimate studies may give us insights into

- mechanisms of climate change
- functioning of the Earth system
- stabilizing or amplifying feedbacks

Eight Memorable Events in Earth History

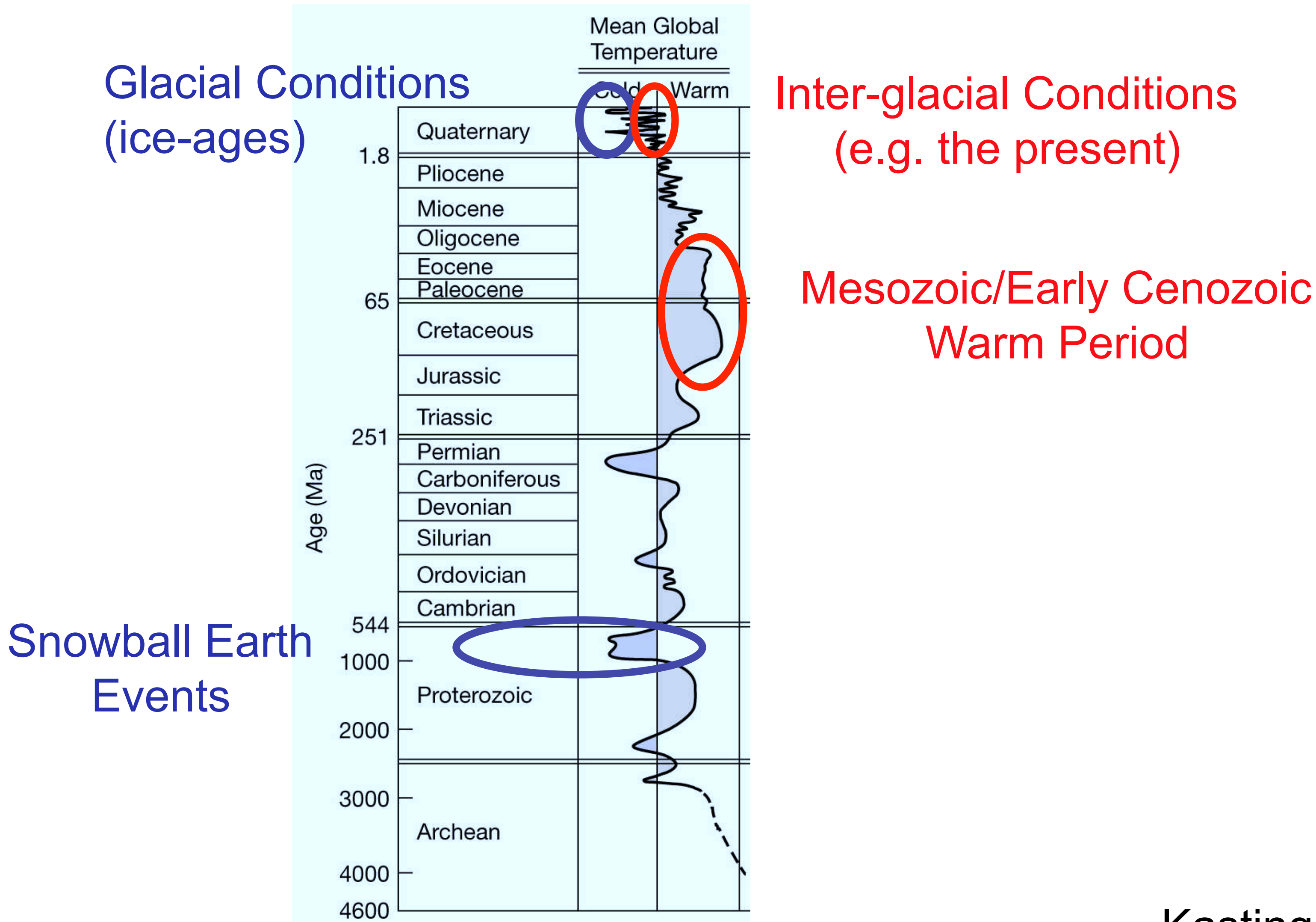
Birth of Planet (4.6 Byr BP)
Formation of Oceans (~4.2 Byr BP)
Life (3.5 Byr BP)
Rise of Oxygen (2.3 Byr BP)
photosynthesis began
Earth Freezes over (750 Myr BP)
Multicellular Life Possible (500 Myr BP)
explosion of life
Asteroid Hit (65 Myr BP)
Beginning of Ice ages (3 Myr BP)

End of Ice Ages (10 kyr BP)
beginning of Agriculture & Civilization



Geological Time Scale

Descent into the Ice-Ages



Kasting et al

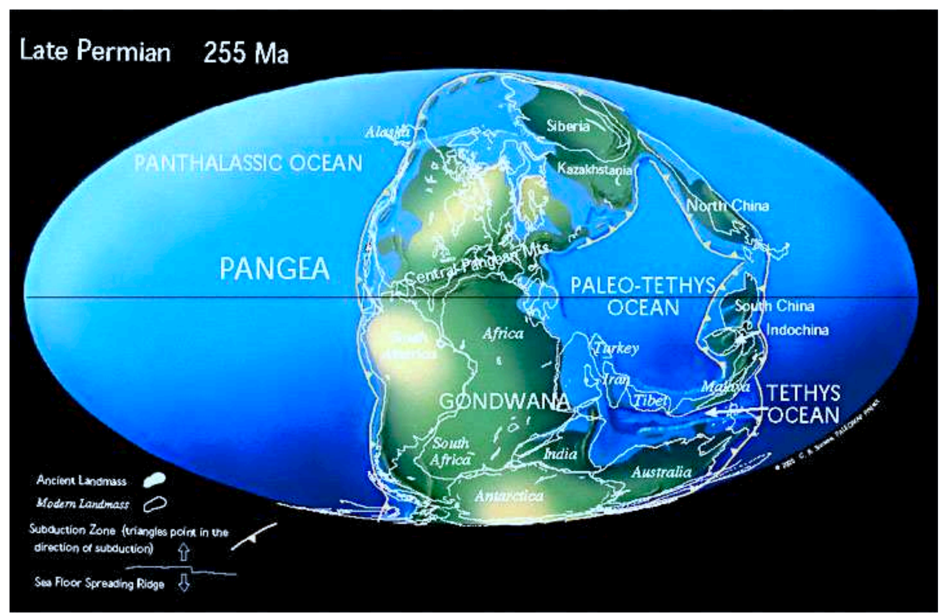
The largest extinction of life in Earth’s history occurred in the late Permian (251 million years ago). Why?

Simulation with CCSM3 by Kiehl and Shields, 2005

TABLE 1. BOUNDARY CONDITIONS FOR THE LATEST PERMIAN SIMULATION

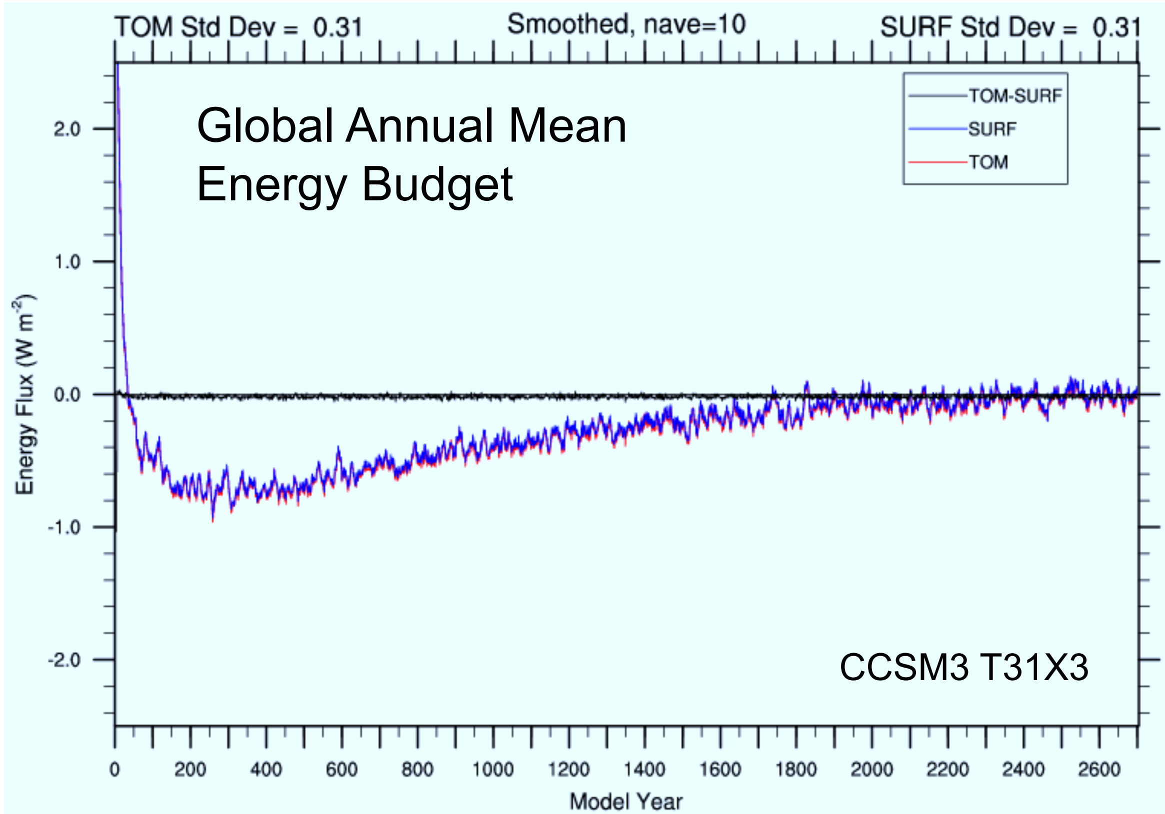
	CO_2 (ppmv)	CH_4 (ppmv)	N_2O (ppmv)	S_0 (Wm^{-2})	Eccentricity	Obliquity (Degrees)
Value	3550	0.7	0.275	1338	0	23.5

Note: ppmv is parts per million by volume.



The solar “constant” was lower, but CO2 was higher by a factor of 10 or so

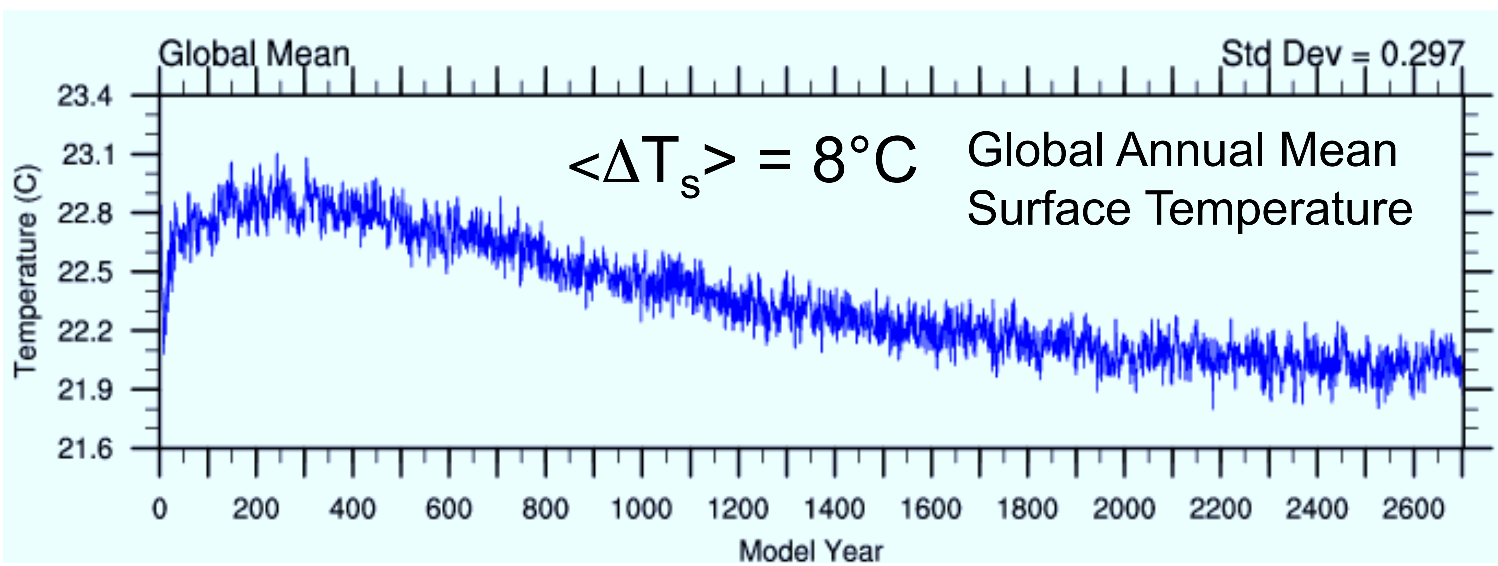
Forcing of 10X increase in CO_2 and Permian paleogeography



Permian coupled model run for 2700 years to new equilibrium state

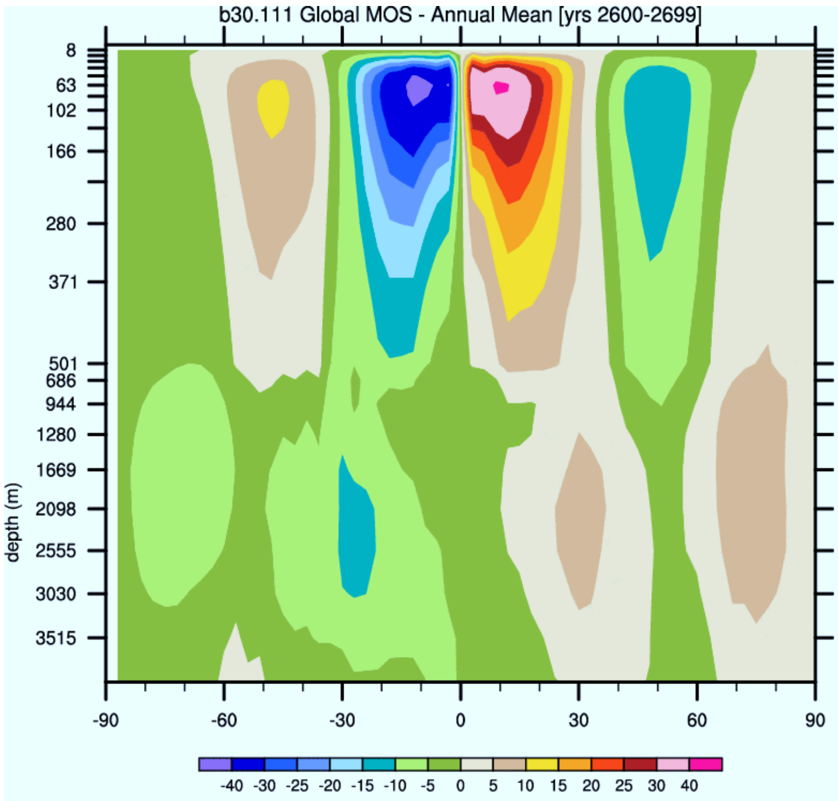
Kiehl and Shields

(2005)



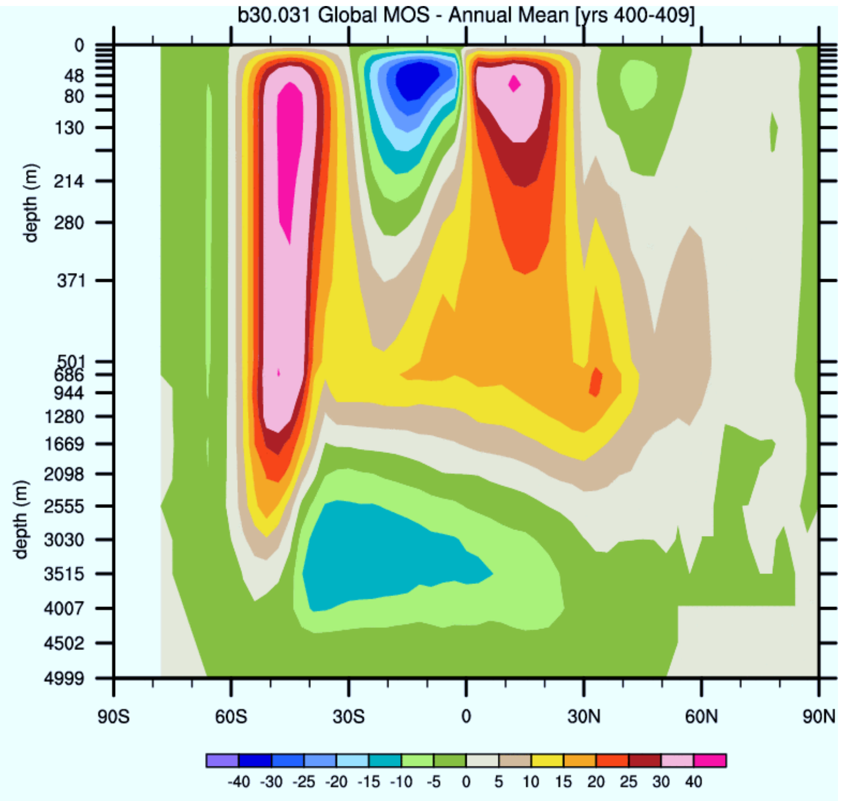
Meridional Overturning Circulation (MOC), a measure of ocean circulation

Permian MOC



Sv

Present MOC

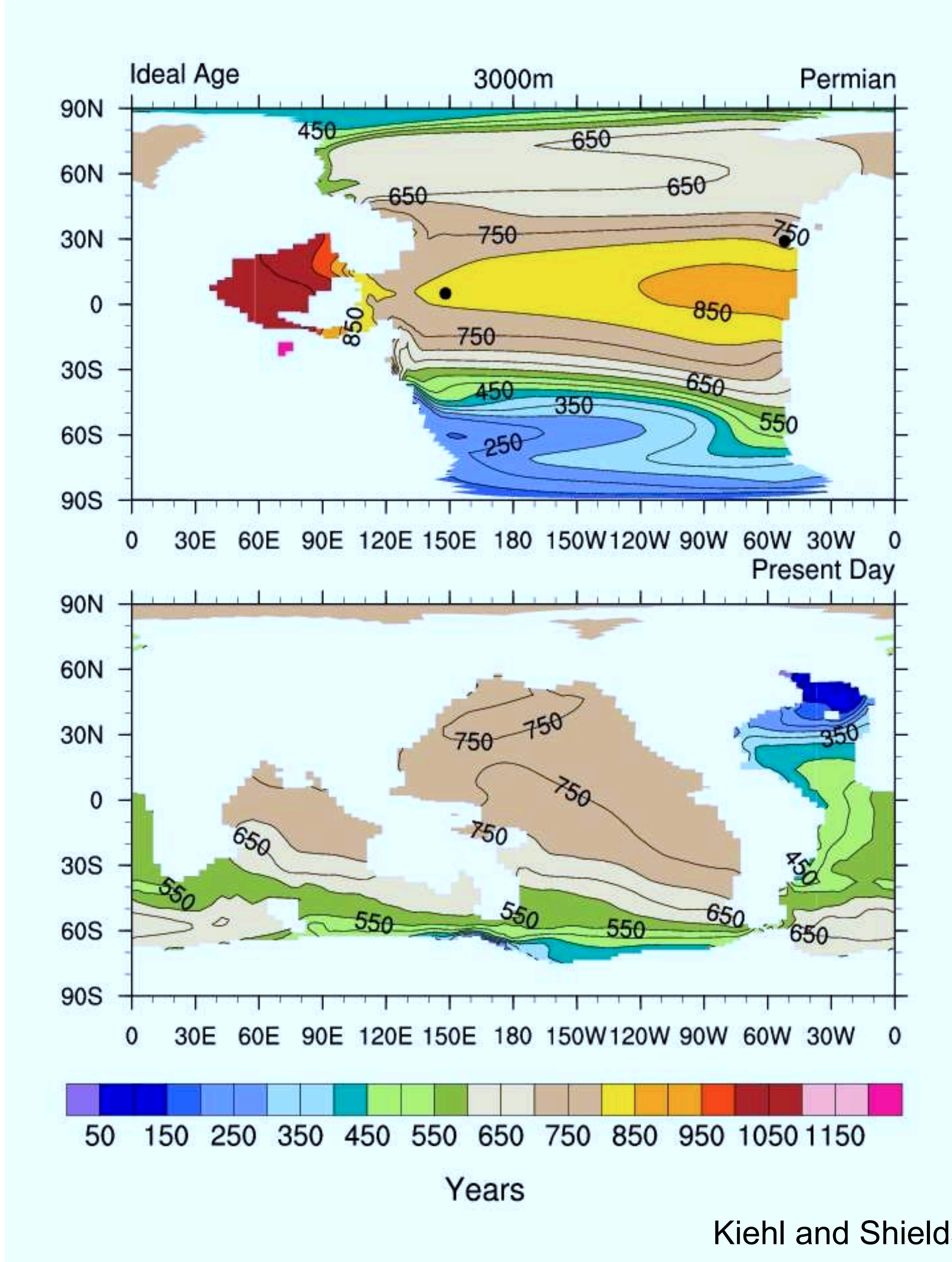


Sv

Shallow circulation in Permian because surface was so warm, made ocean stagnant, and low in oxygen. Bad for marine organisms.

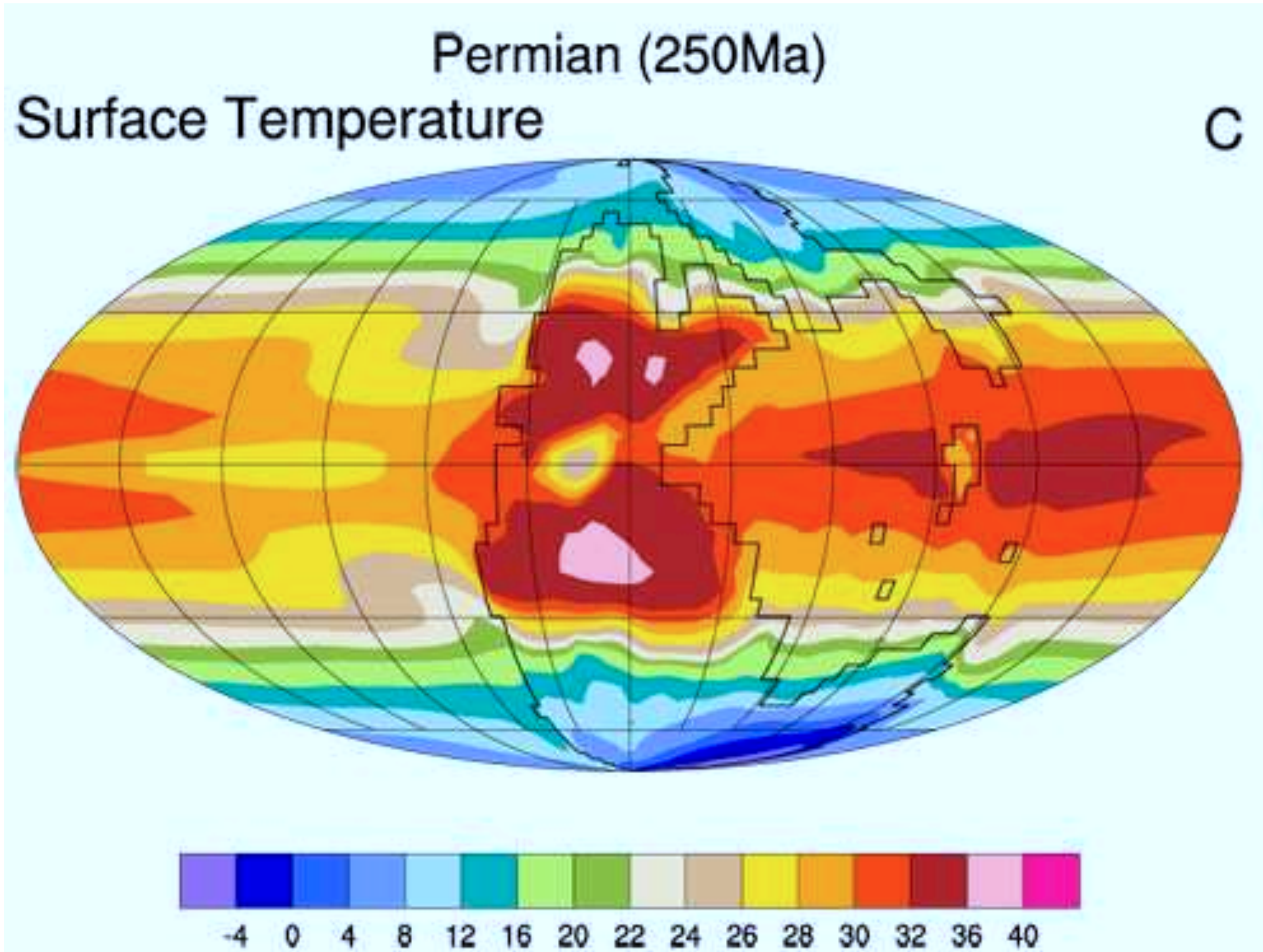
Ideal age at 3km depth in ocean.

Inefficient mixing in Permian ocean indicative of anoxia



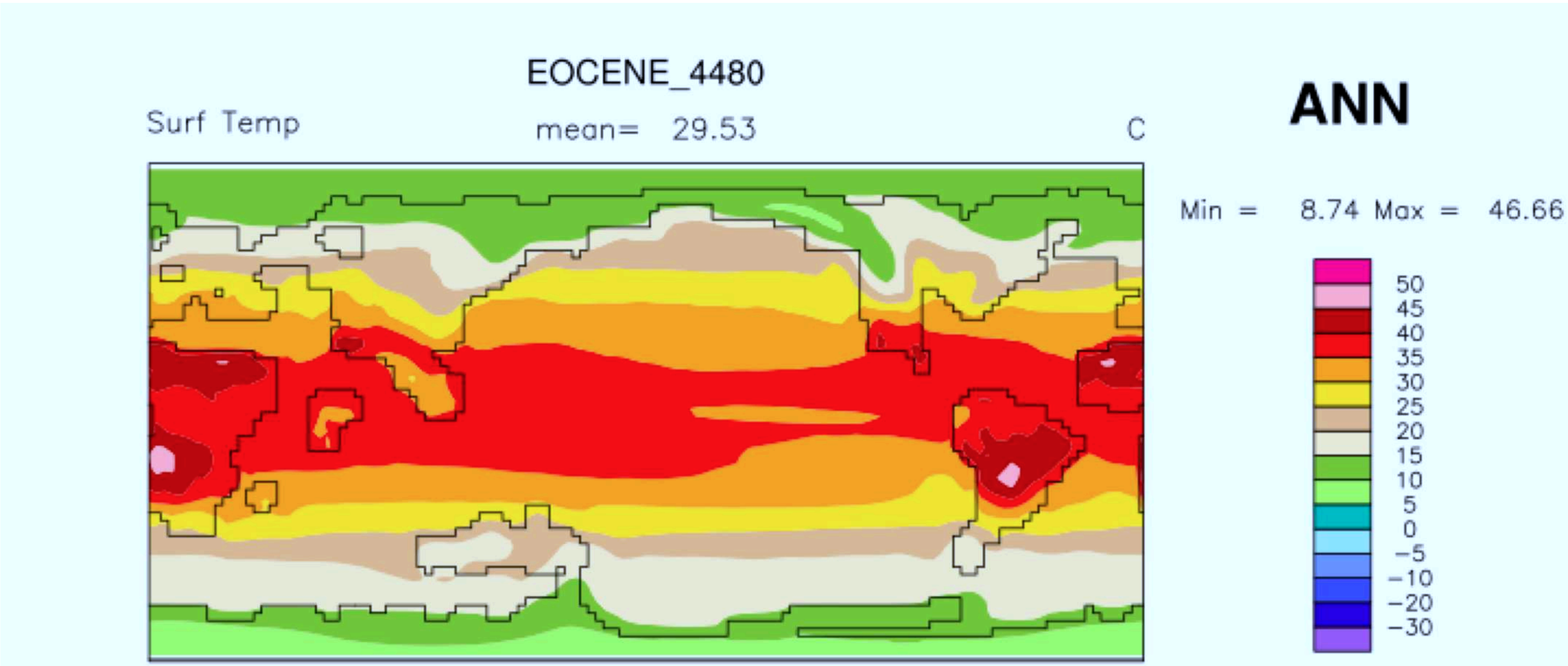
Kiehl and Shields (2005)

Winter Surface Temperature on Land (note strange geometry) is very warm

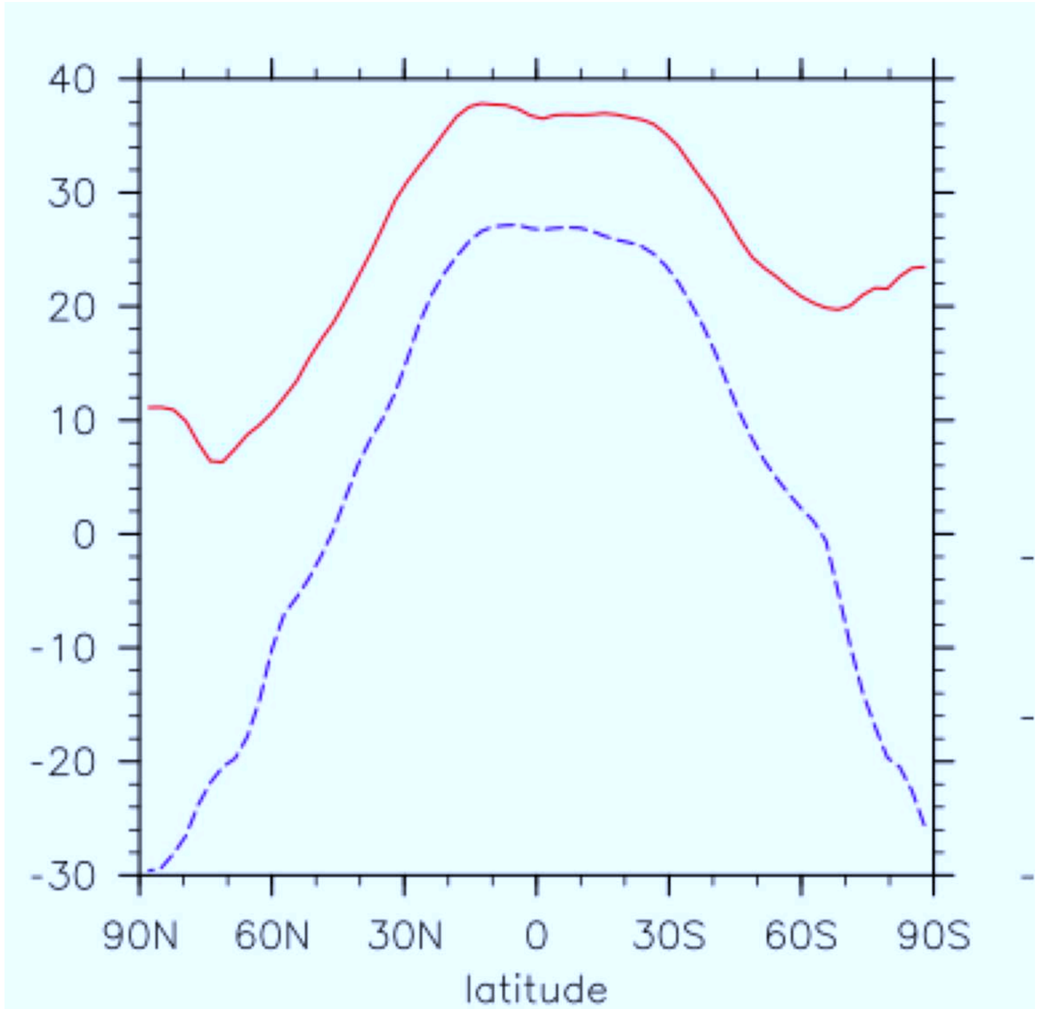


Eocene, 65million years ago, and “equable” climates

Huber and Caballero 2011



CO2 of 4480ppmv. The solar constant is set at 1365 W m2, aerosol radiative effects are set to zero,and other trace gas concentrations and orbital parameters were set to pre-industrial conditions.


40
30
20
10
0
-10
-20
-30
90N
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latitude