Upcoming lectures

The Biological and Ecological Effects of Climate Change
Dr. Alan Knapp, CSU, Biology
October 9, Thursday, Lory Student Center North Ballroom, 7 pm

The Economics of Climate Change
Dr. Charles Kolstad, University of California, Santa Barbara, Economics
November 6, Thursday, Lory Student Center North Ballroom, 7 pm

Climate Change and the Literary Imagination
Linda Bierds, University of Washington, English, and Marybeth Holleman, University of Alaska, Anchorage, English
November 13, Thursday, University Center for the Arts, 7:30 pm
(Note the different location.)

Solutions to the Climate/Energy Problem
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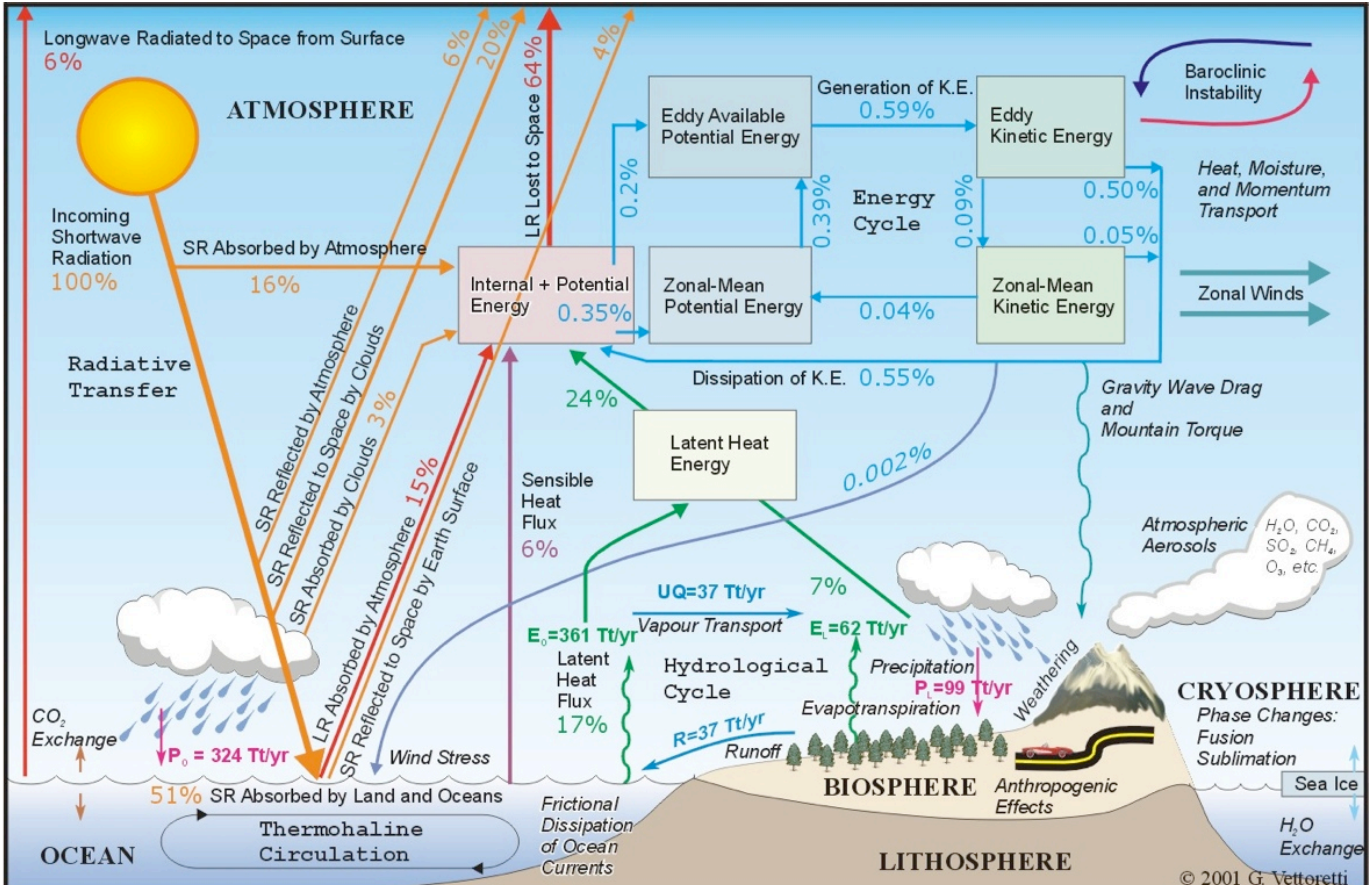
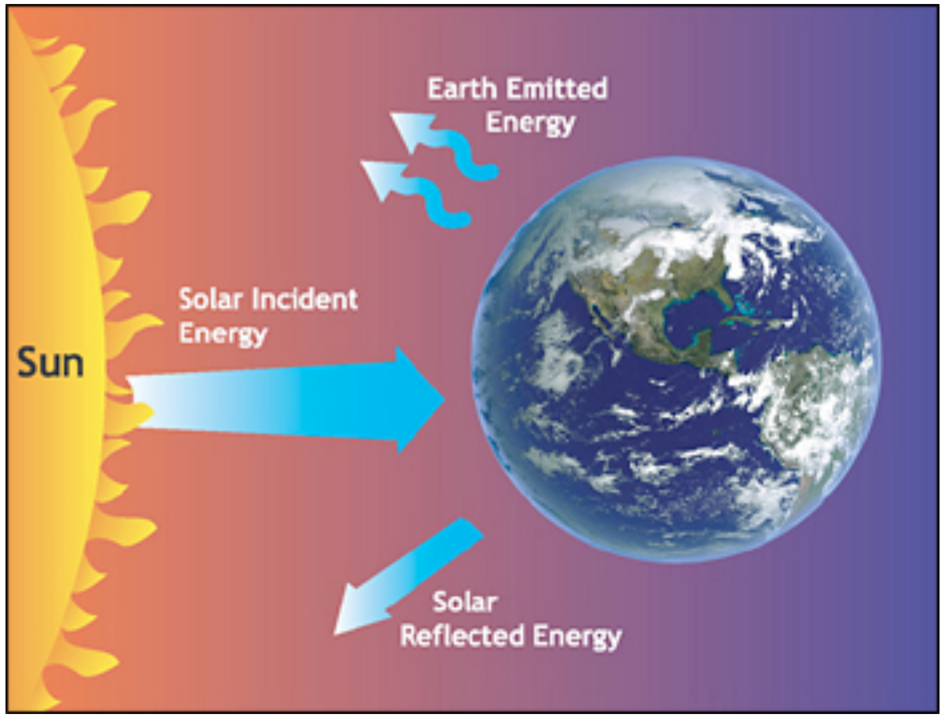
Climate Change: Past, Present, and Future

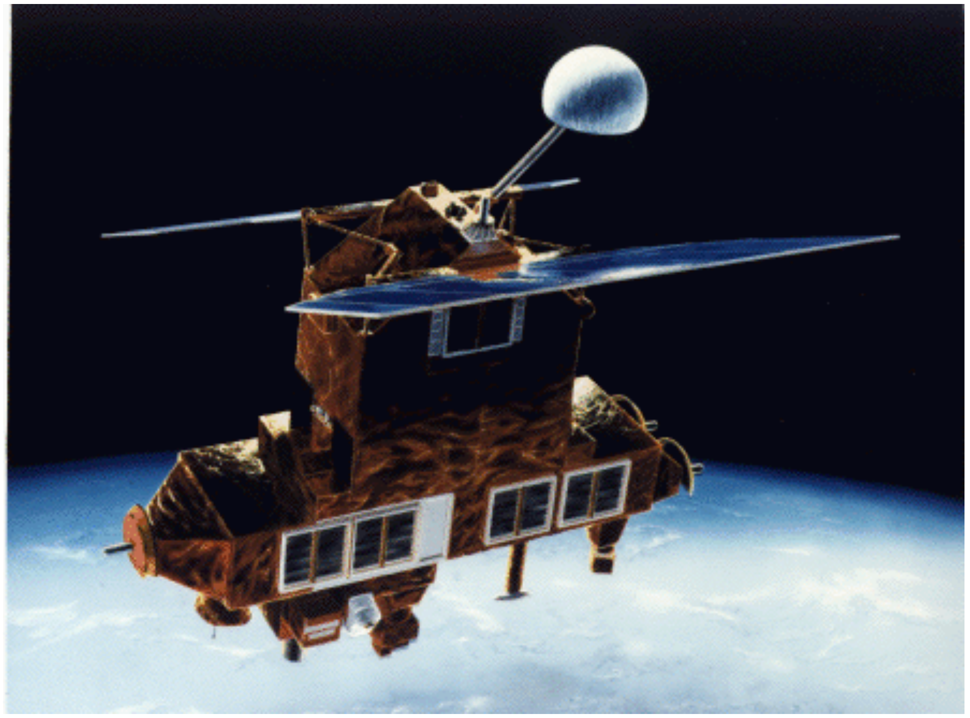
A complicated machine



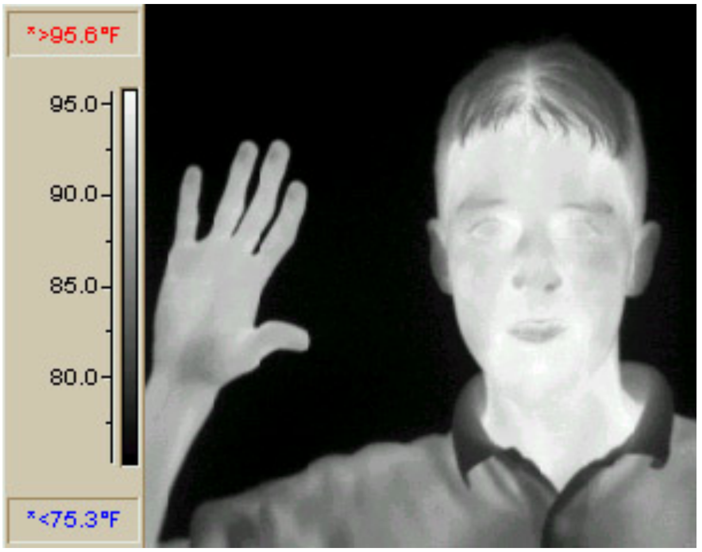
Energy Balance

Sunshine absorbed = Infrared emitted

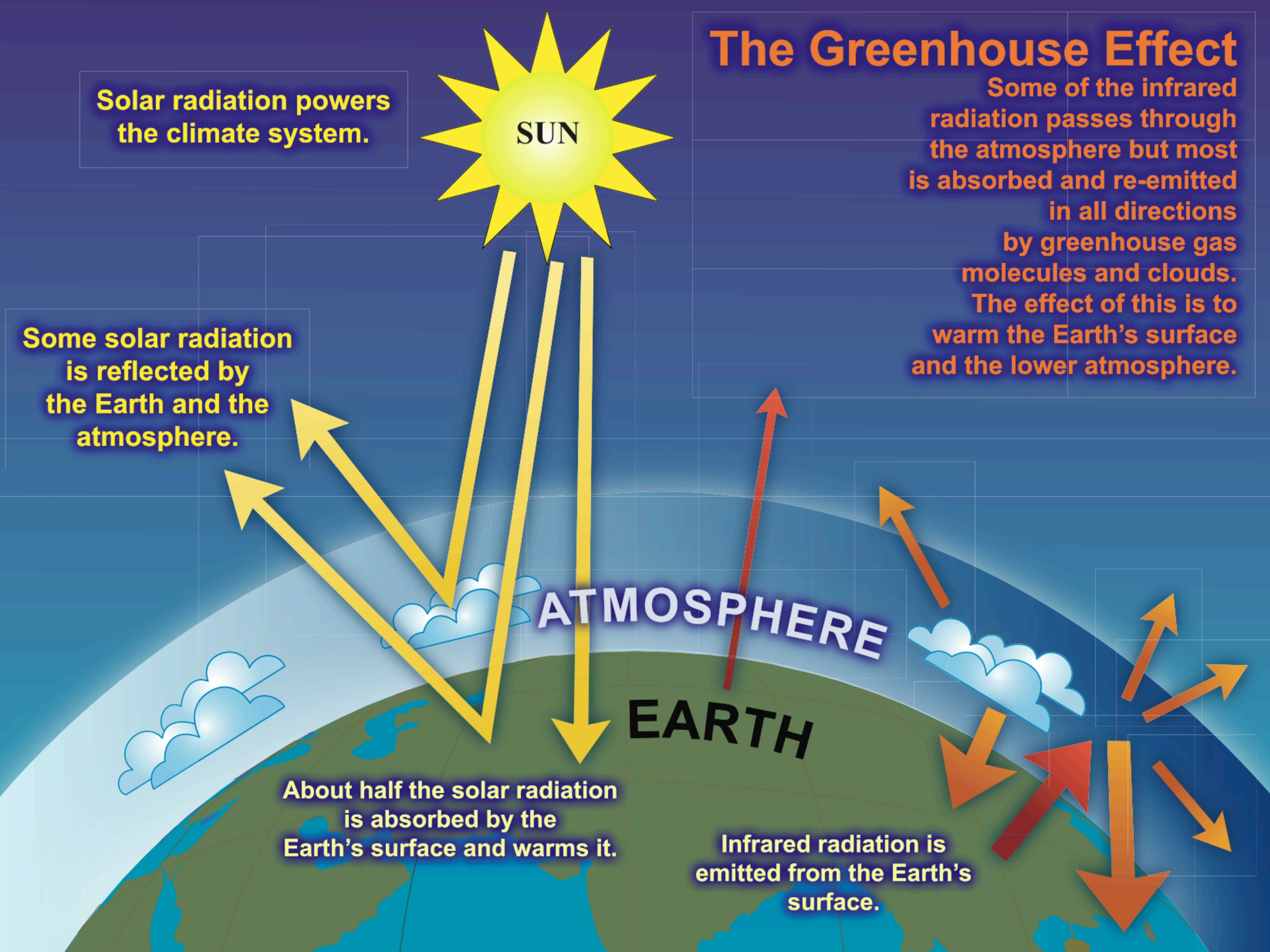




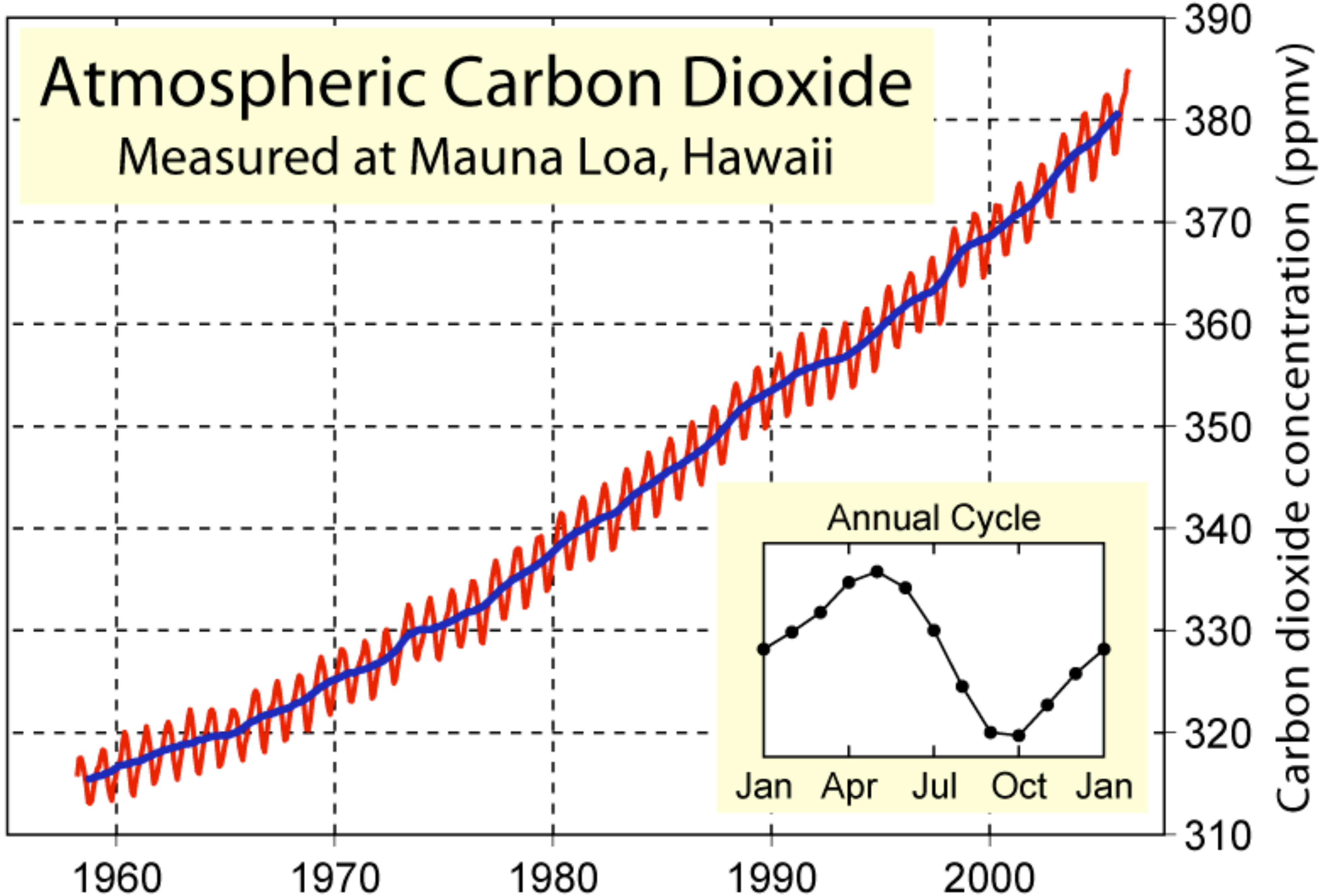
We all shine on.



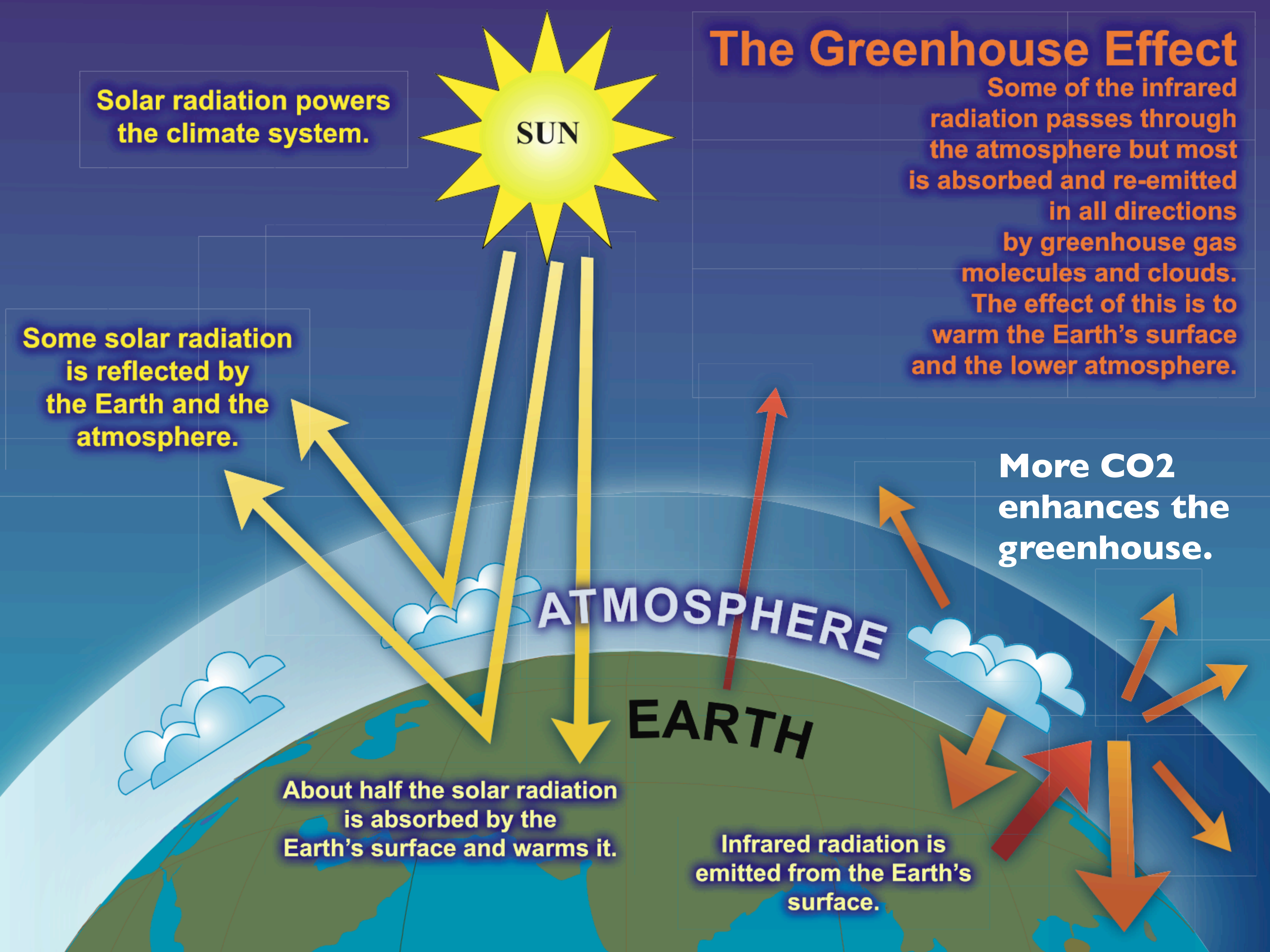
Warm things emit more infrared than cold things.


The Greenhouse Effect
Solar radiation powers the climate system.
SUN
Some solar radiation is reflected by the Earth and the atmosphere.
Some of the infrared radiation passes through the atmosphere but most is absorbed and re-emitted in all directions by greenhouse gas molecules and clouds. The effect of this is to warm the Earth's surface and the lower atmosphere.
ATMOSPHERE
EARTH
About half the solar radiation is absorbed by the Earth's surface and warms it.
Infrared radiation is emitted from the Earth's surface.

50 years of the Keeling Curve



Once CO_2 enters the atmosphere, it stays for ~ 100 years.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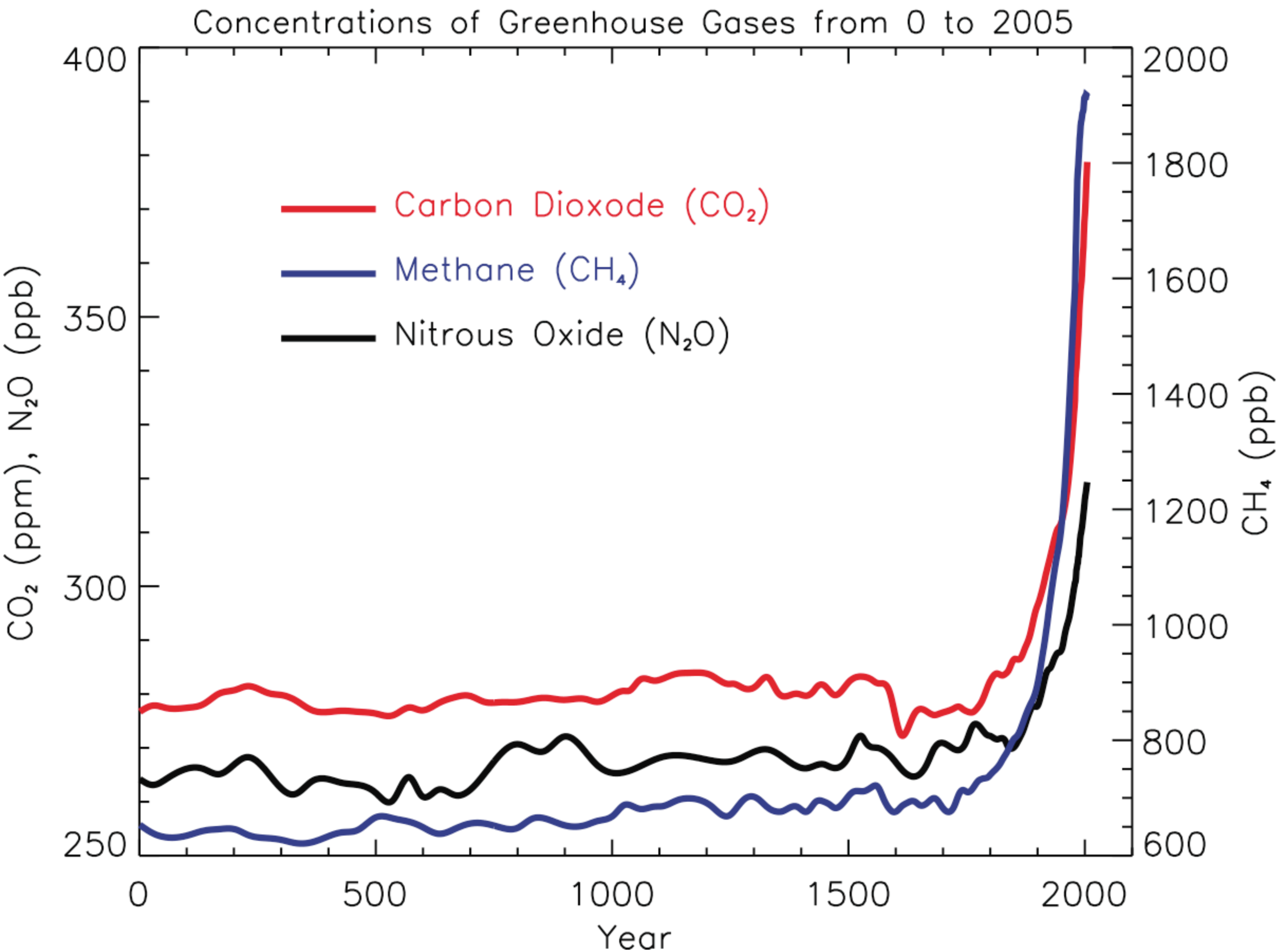
Solar radiation powers the climate system.
SUN
Some solar radiation is reflected by the Earth and the atmosphere.
More CO2 enhances the greenhouse.
ATMOSPHERE
EARTH
About half the solar radiation is absorbed by the Earth's surface and warms it.
Infrared radiation is emitted from the Earth's surface.

Why should increasing CO_2 make the Earth warm up?

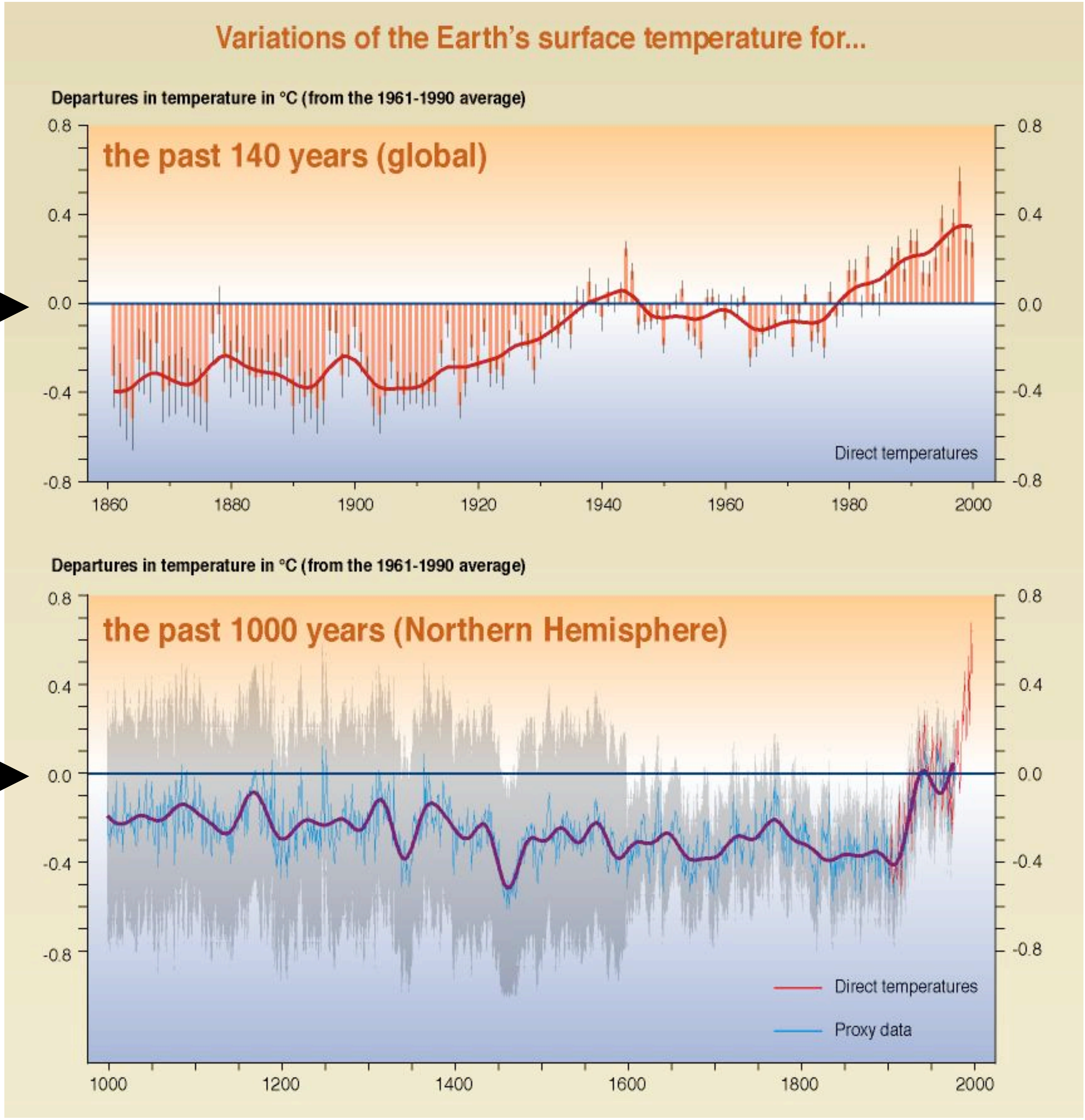
- The flow of energy across the top of the atmosphere has to balance out to zero over time.
- Doubling CO_2 *without changing anything else* would make the Earth's emission to space go down by about 2%.
- To make the emission increase again, and thus re-establish energy balance, the Earth has to warm up.
- Without feedbacks, the Earth would warm up by about 0.5%.
- With feedbacks, the Earth would warm up by about 1%.

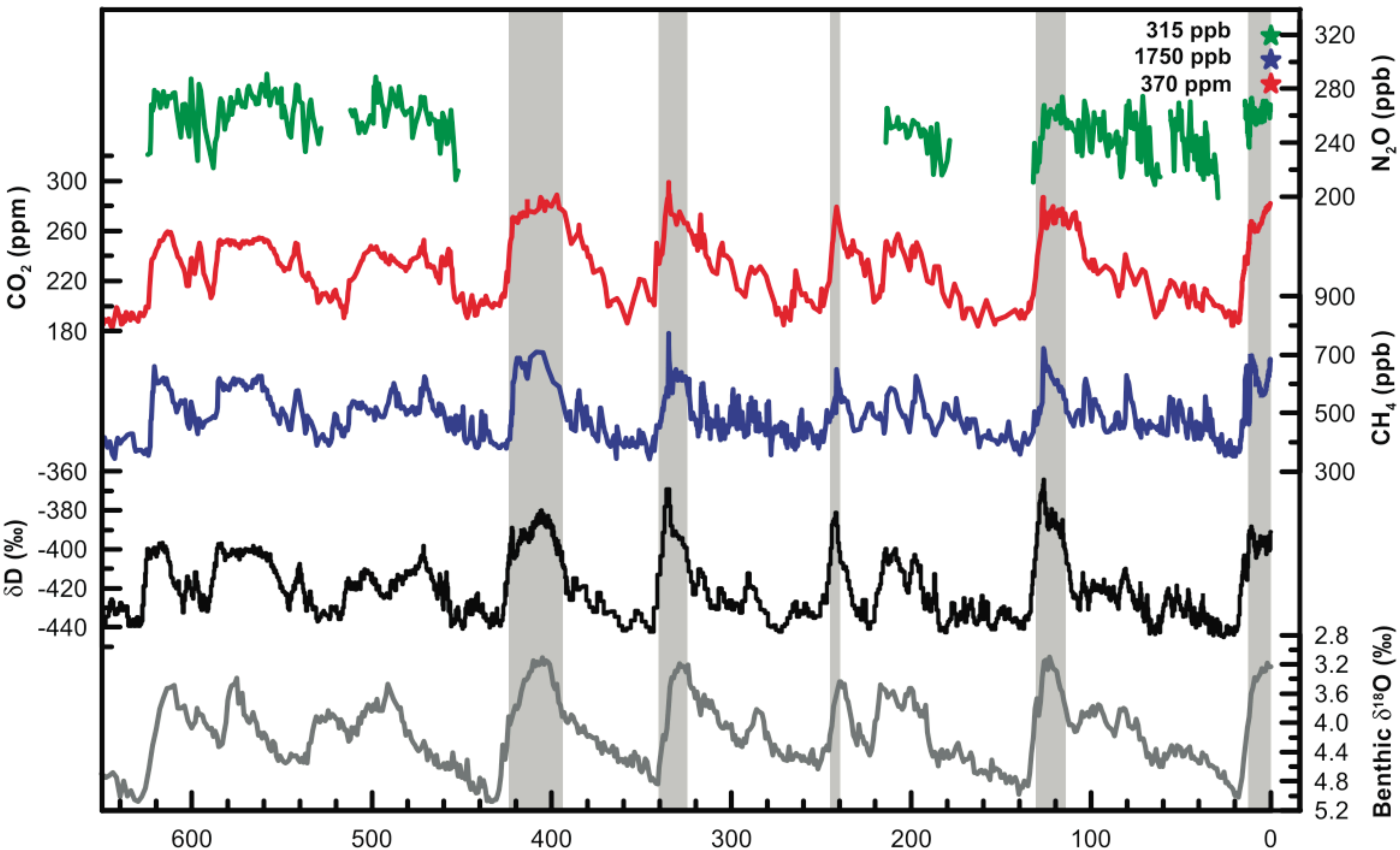
Ice cores

Recent changes are not routine.

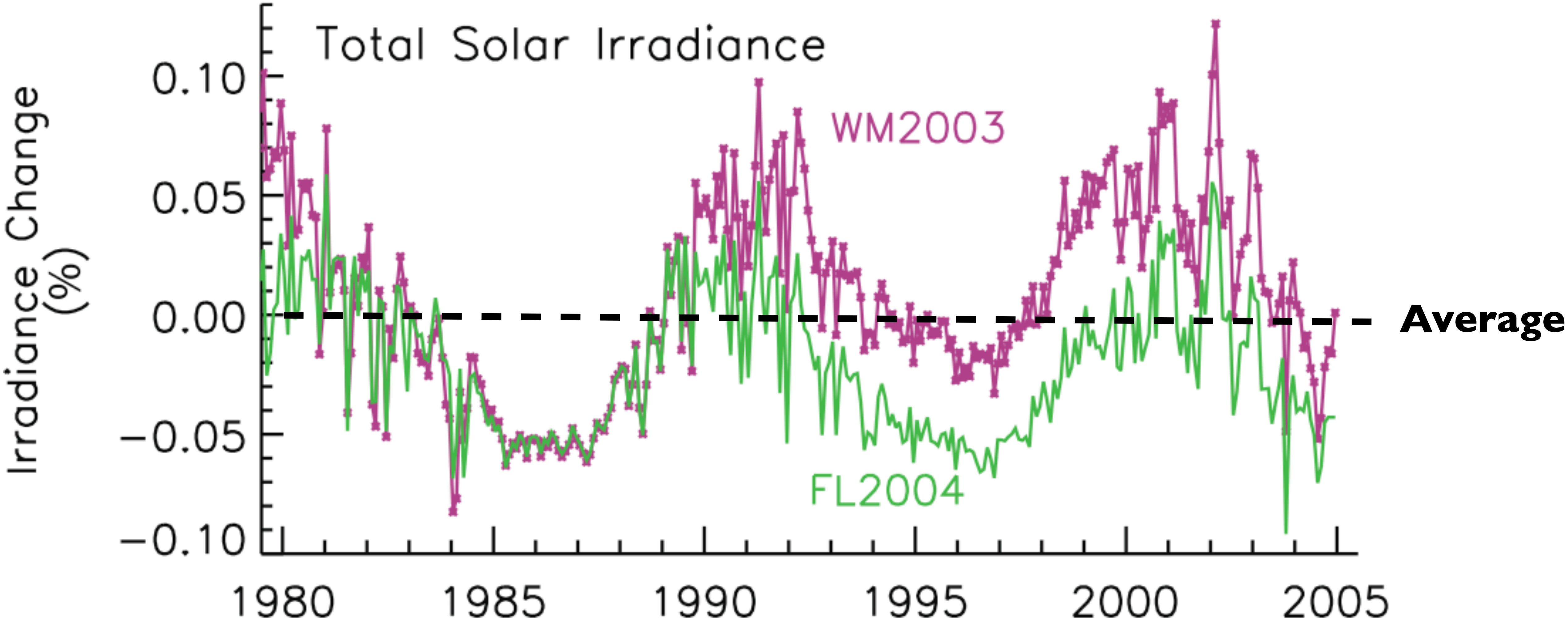


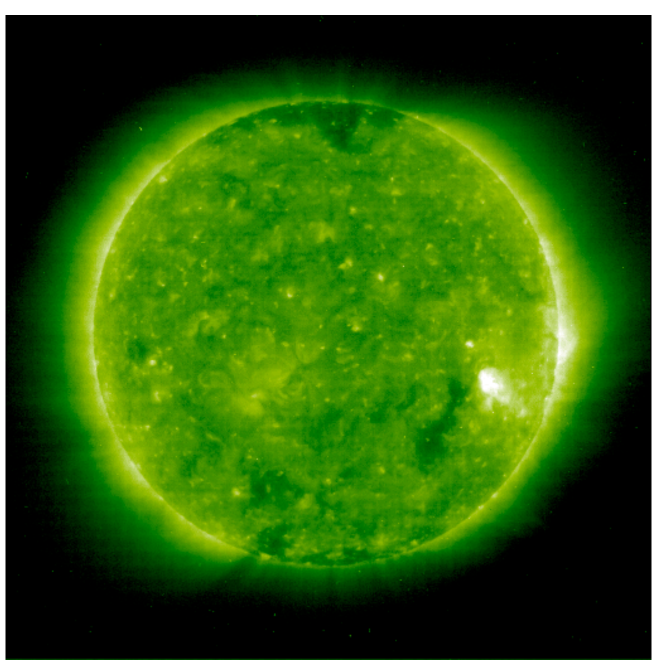
1961-1990 Average





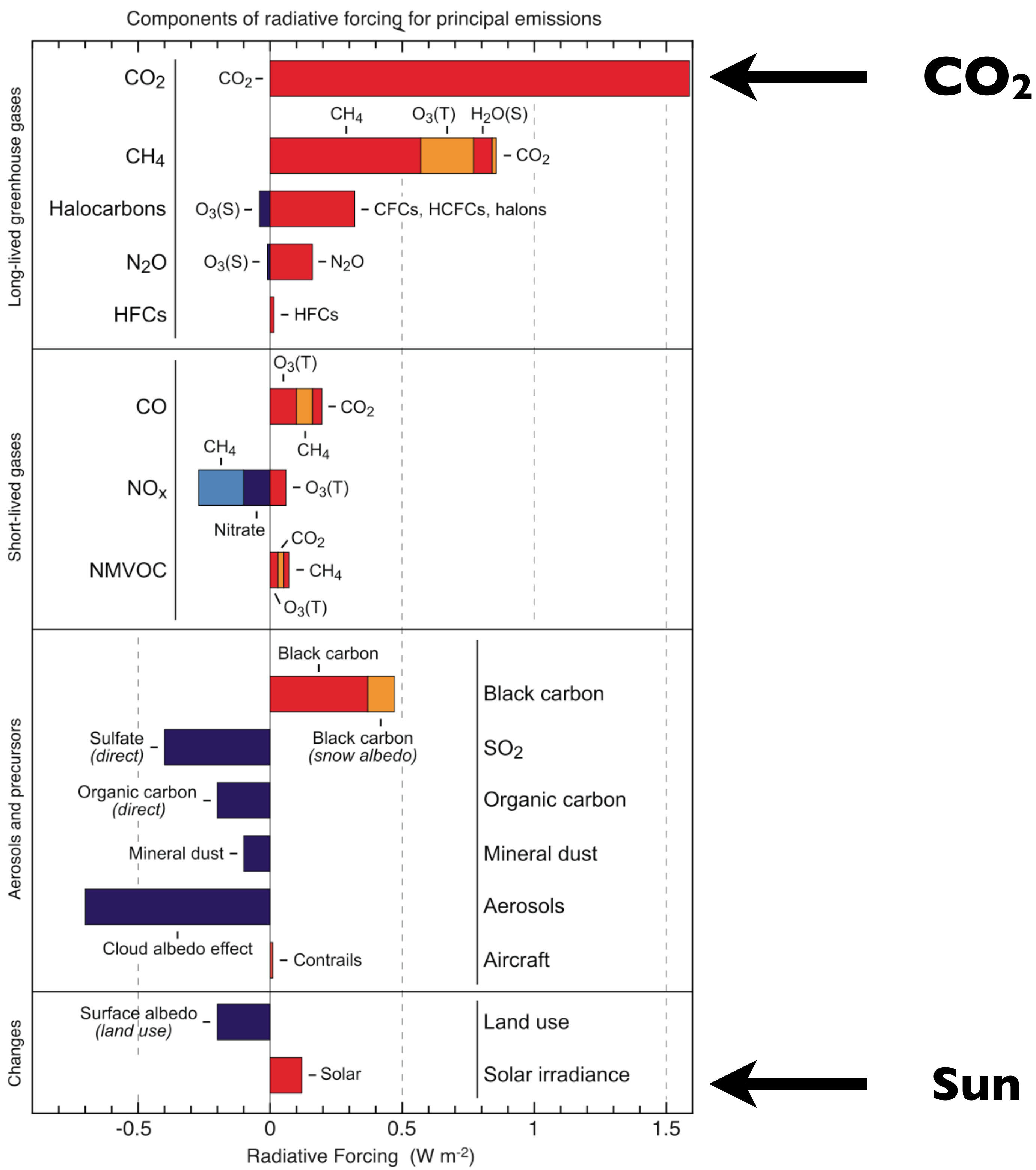
Time before now, in hundreds of thousands of years





Measured changes in the energy output of the sun are very small.

Changes in “forcing” from 1750 - 2005



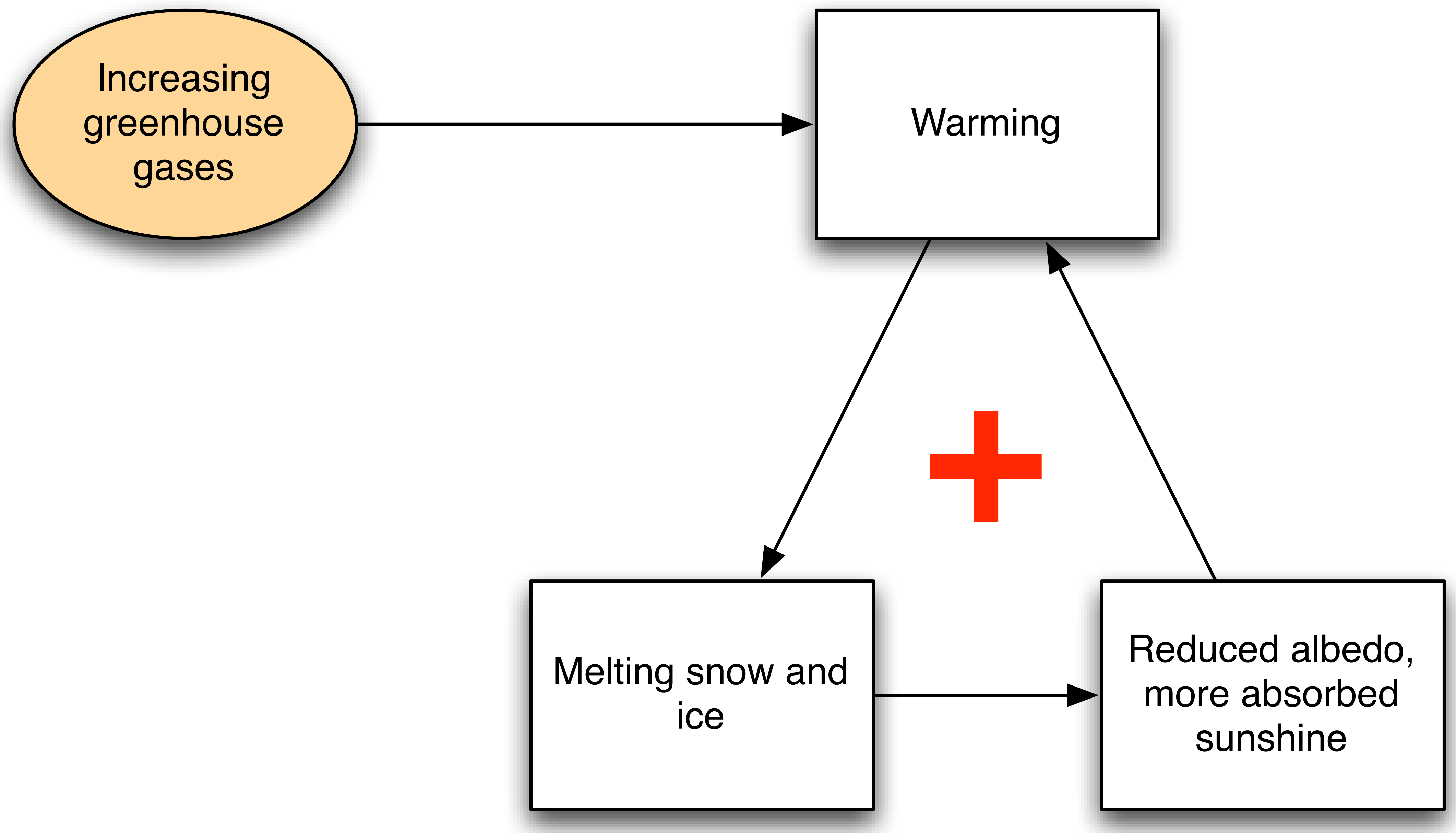
Kinds of Feedbacks

- Albedo Feedback
- Water vapor feedback
- Lapse-rate feedback
- Cloud feedback(s)
- Carbon feedback(s)

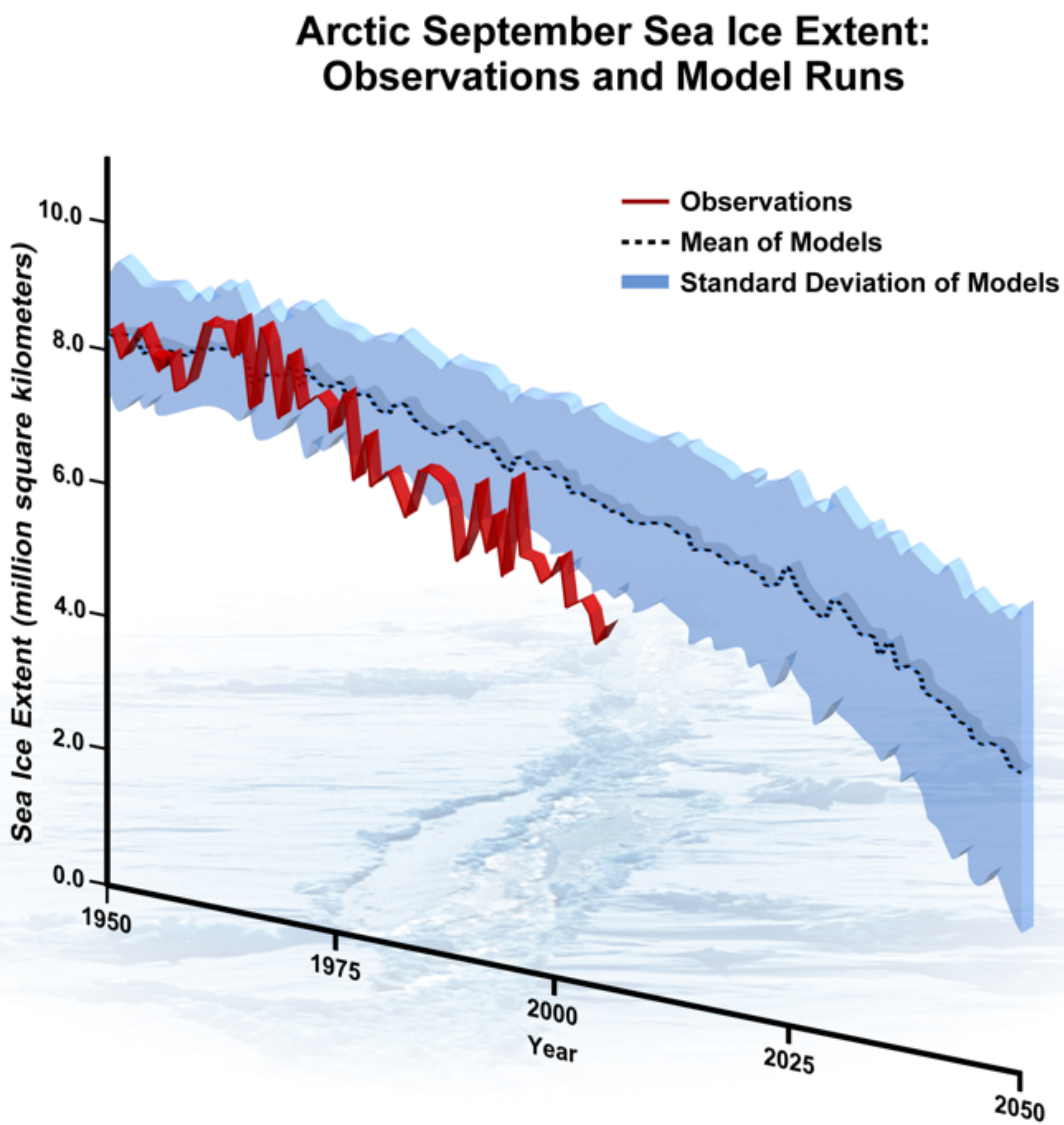
“Positive feedback” means change is amplified.

“Negative feedback” means change is suppressed.

Example: Albedo Feedback



Sea ice is melting



How strong are the feedbacks?

Feeback	Water vapor	Clouds	Albedo	Lapse Rate	Total
Strength	1.7	0.6	0.4	-0.8	1.9
Uncertainty	Small	Large	Small	Small	Moderate

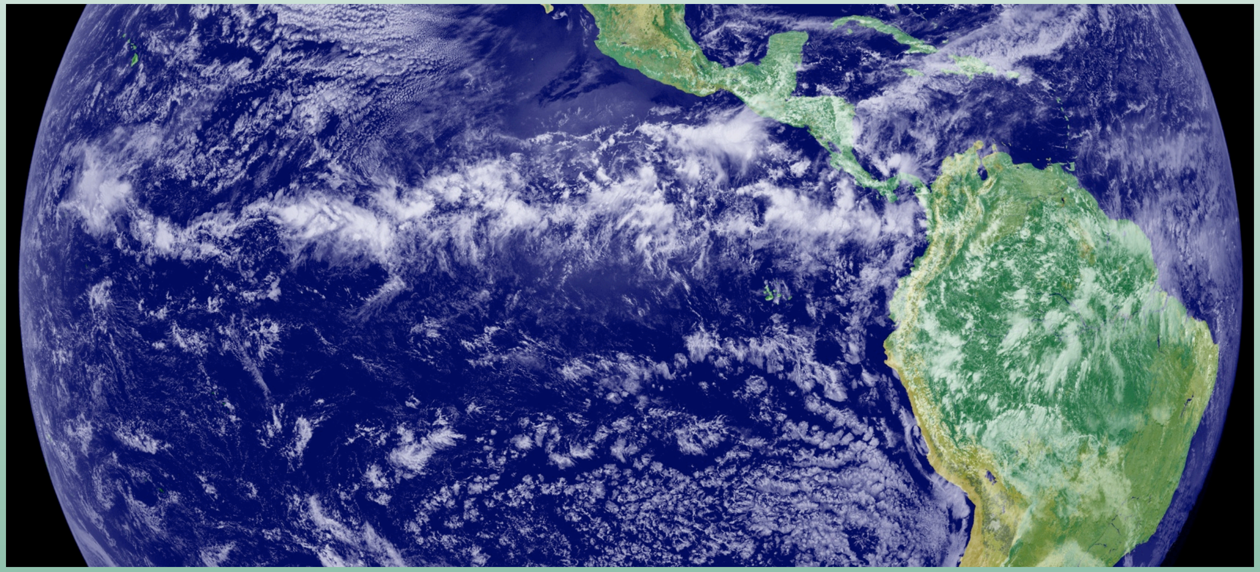
Units: W m^{-2} K^{-1}

The positive feedbacks are stronger than the negative feedbacks.

The combined effect of all feedbacks is to increase the warming by about a factor of two.

What's climate modeling about?

- **Atmosphere model**
- **Ocean model**
- **Land-surface model**



Partial differential equations
Spherical grids
Time steps of a few minutes
Very fast computers

Atmosphere

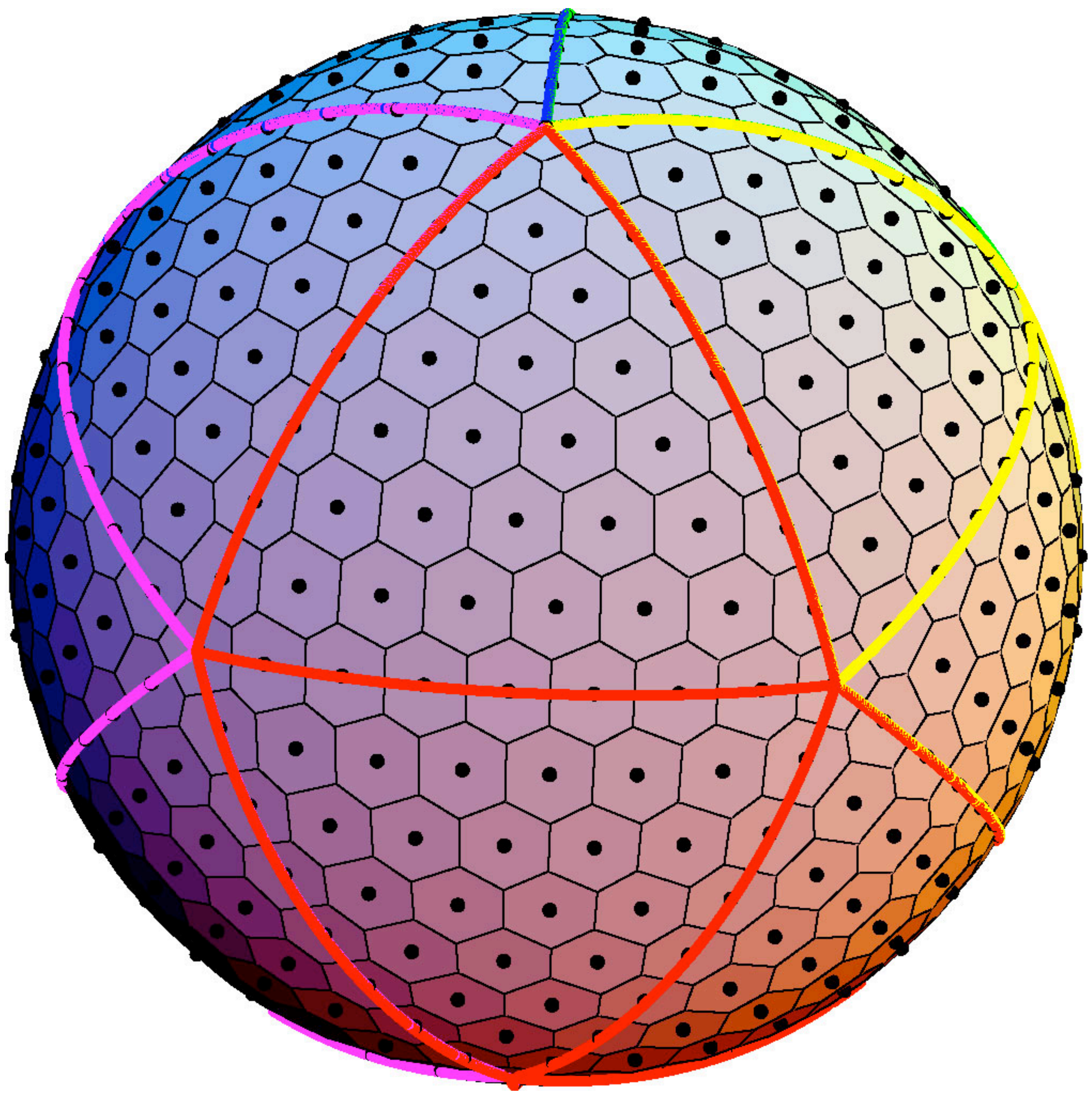
- Winds
- Temperature
- Moisture, including clouds
- Carbon dioxide, ozone, etc.

Ocean

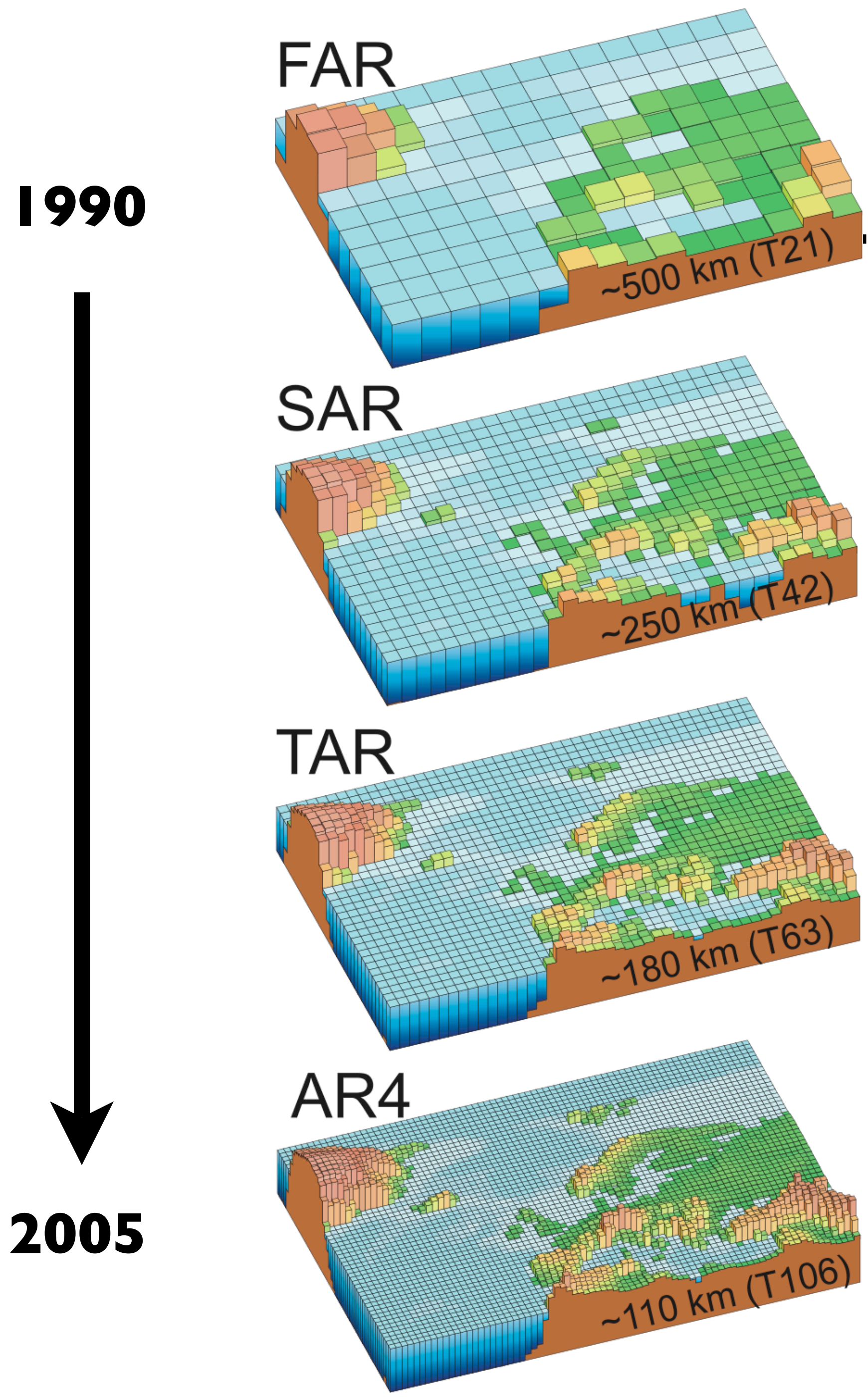
- Currents
- Temperature
- Salt
- Sea ice
- Chemistry
- Biology

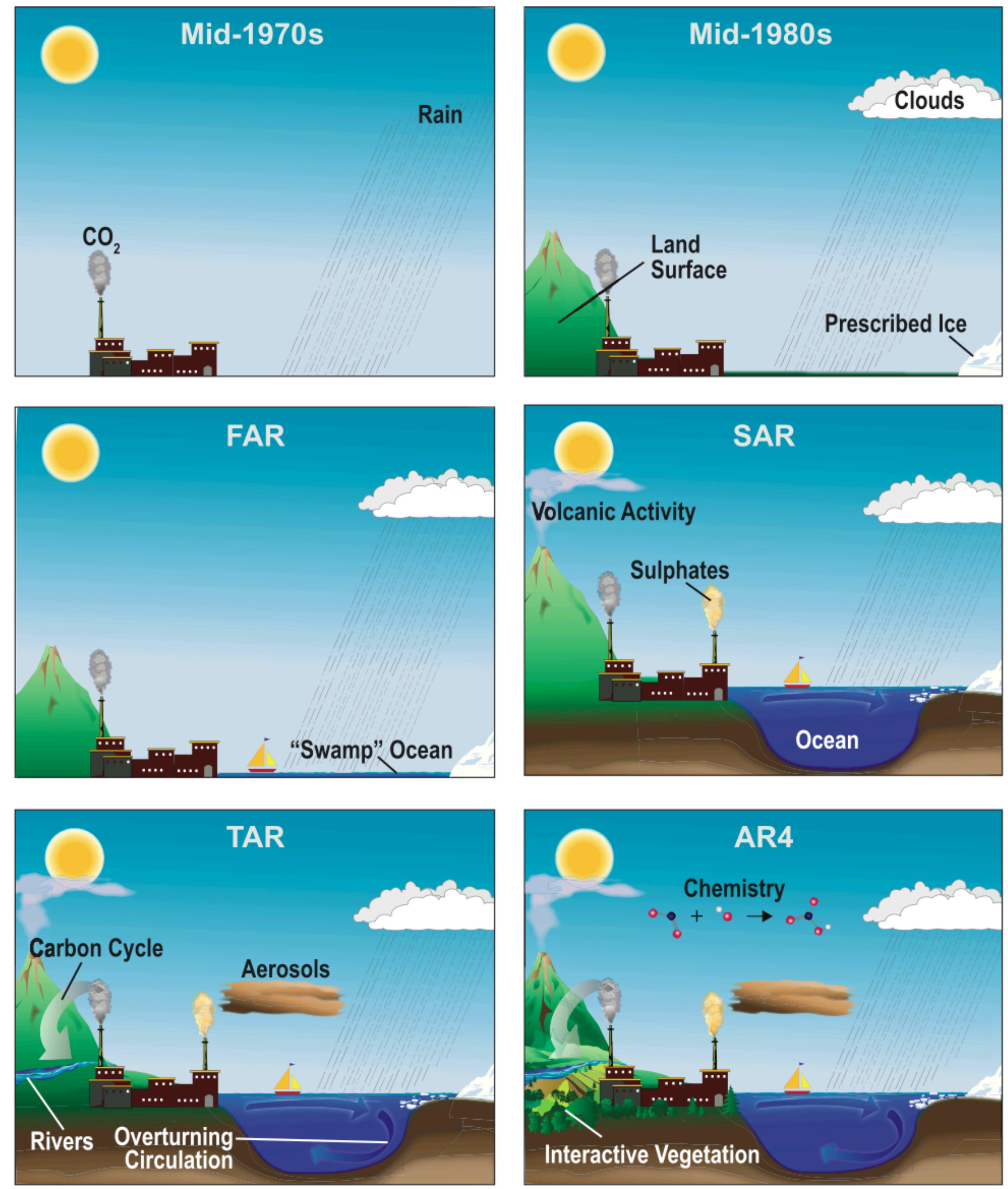

Land Surface
•Soil
•Vegetation
•Water
•Energy
•Snow, etc.
•Carbon

Solve the equations on a grid



Progress


1990
2005
FAR
~500 km (T21)
SAR
~250 km (T42)
TAR
~180 km (T63)
AR4
~110 km (T106)


Mid-1970s
Rain
CO_2
Mid-1980s
Clouds
Land Surface
Prescribed Ice
FAR
"Swamp" Ocean
SAR
Volcanic Activity
Sulphates
Ocean
TAR
Carbon Cycle
Aerosols
Rivers
Overturning Circulation
AR4
Chemistry
Interactive Vegetation

Powerful Computers

It takes about a *trillion* arithmetic operations to simulate one day.

Has a climate model ever made a demonstrably succesful prediction?

VOL. 32, NO. 1 JOURNAL OF THE ATMOSPHERIC SCIENCES JANUARY 1975

The Effects of Doubling the CO_2 Concentration on the Climate of a General Circulation Model[1]

SYUKURO MANABE AND RICHARD T. WETHERALD

Geophysical Fluid Dynamics Laboratory/NOAA, Princeton University, Princeton, N.J. 08540

(Manuscript received 6 June 1974, in revised form 8 August 1974)

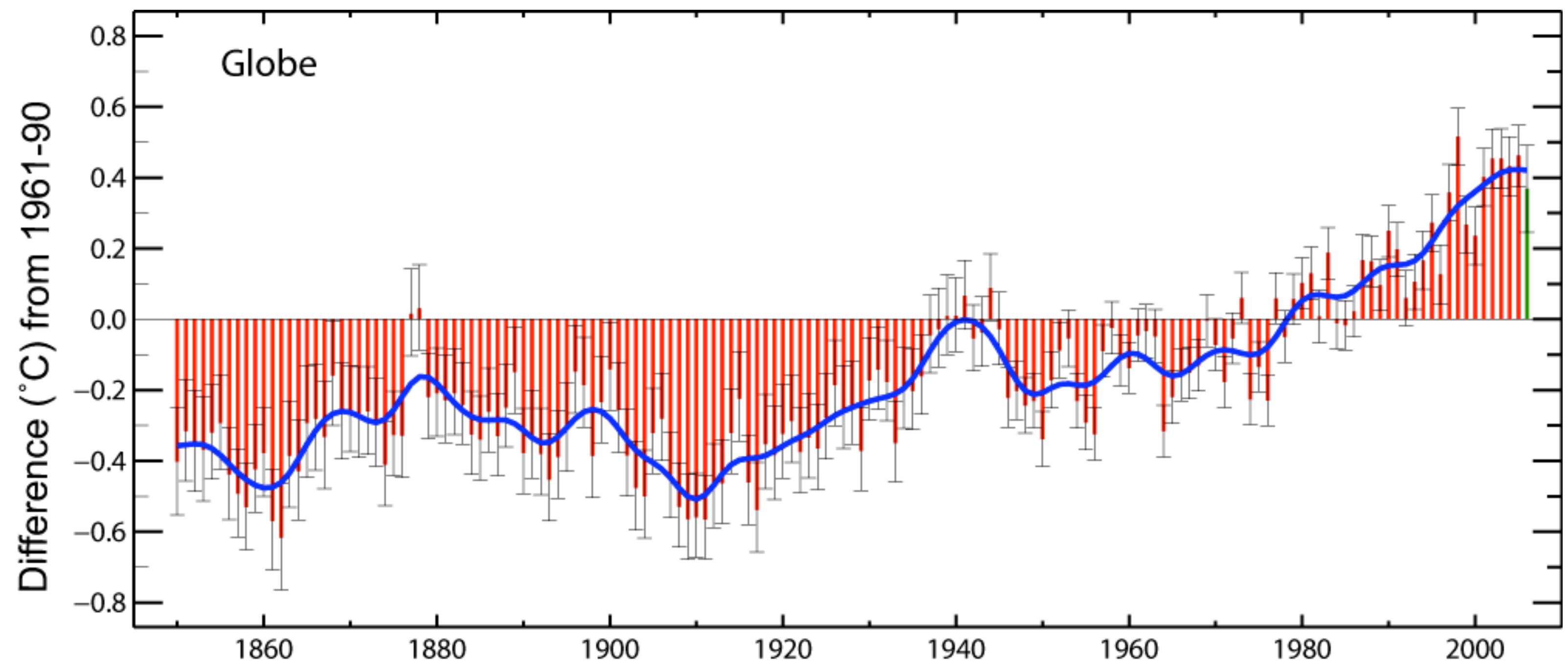
ABSTRACT

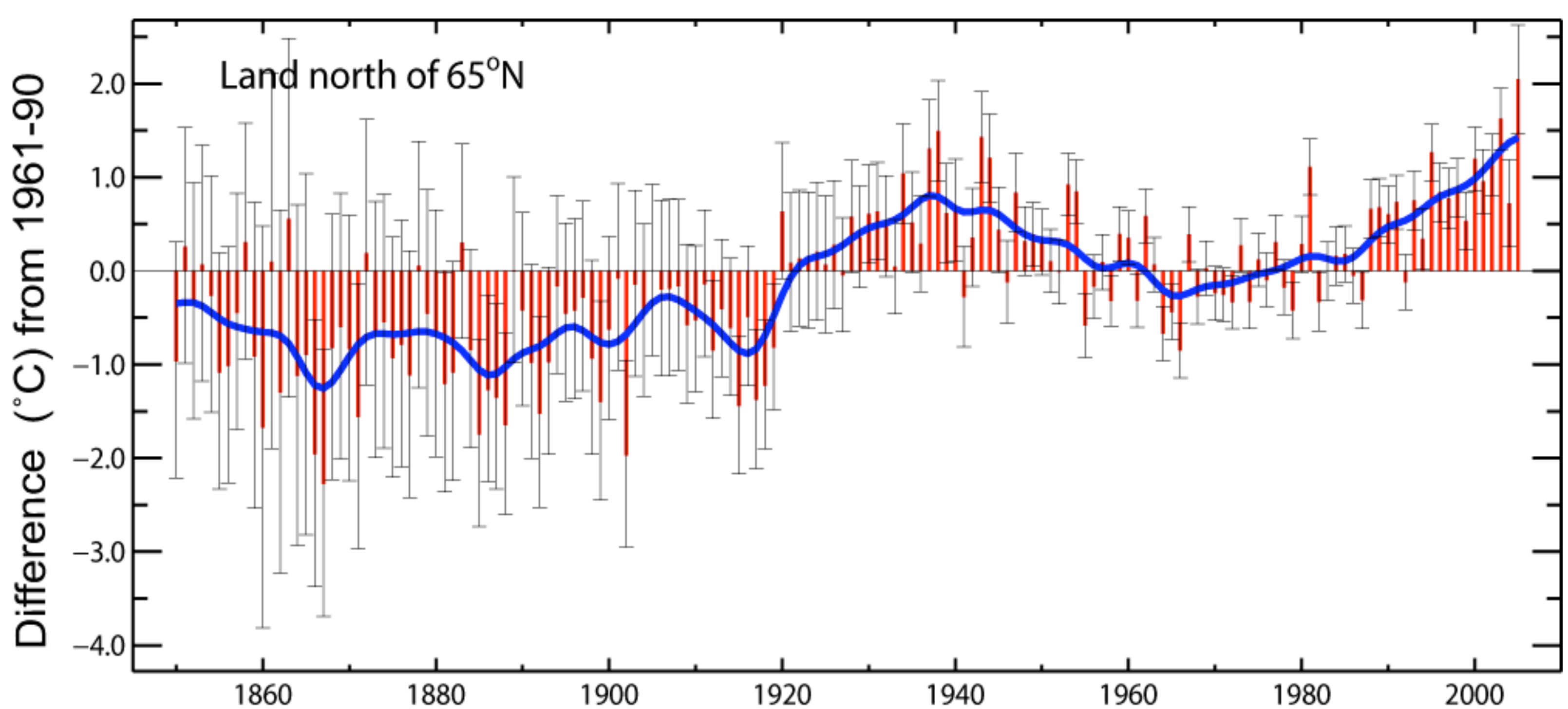
An attempt is made to estimate the temperature changes resulting from doubling the present CO_2 concentration by the use of a simplified three-dimensional general circulation model. This model contains the following simplifications: a limited computational domain, an idealized topography, no heat transport by ocean currents, and fixed cloudiness. Despite these limitations, the results from this computation yield some indication of how the increase of CO_2 concentration may affect the distribution of temperature in the atmosphere. It is shown that the CO_2 increase raises the temperature of the model troposphere, whereas it lowers that of the model stratosphere. The tropospheric warming is somewhat larger than that expected from a radiative-convective equilibrium model. In particular, the increase of surface temperature in higher latitudes is magnified due to the recession of the snow boundary and the thermal stability of the lower troposphere which limits convective heating to the lowest layer. It is also shown that the doubling of carbon dioxide significantly increases the intensity of the hydrologic cycle of the model.

Manabe & Wetherald predicted:

- Warming lower atmosphere
- Greater warming near the poles
- Cooling stratosphere
- More rain and higher humidity

All of these things have now happened.

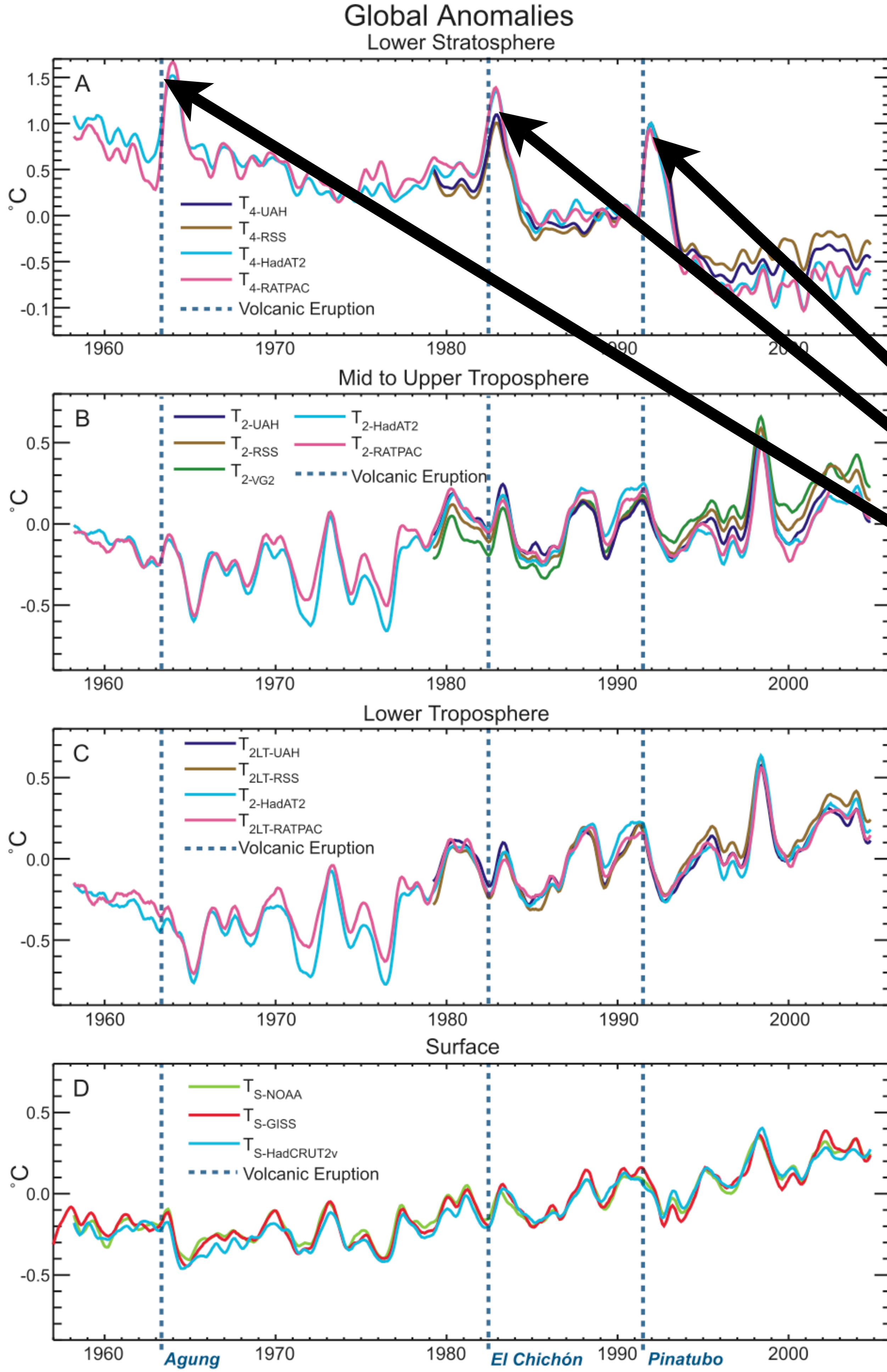




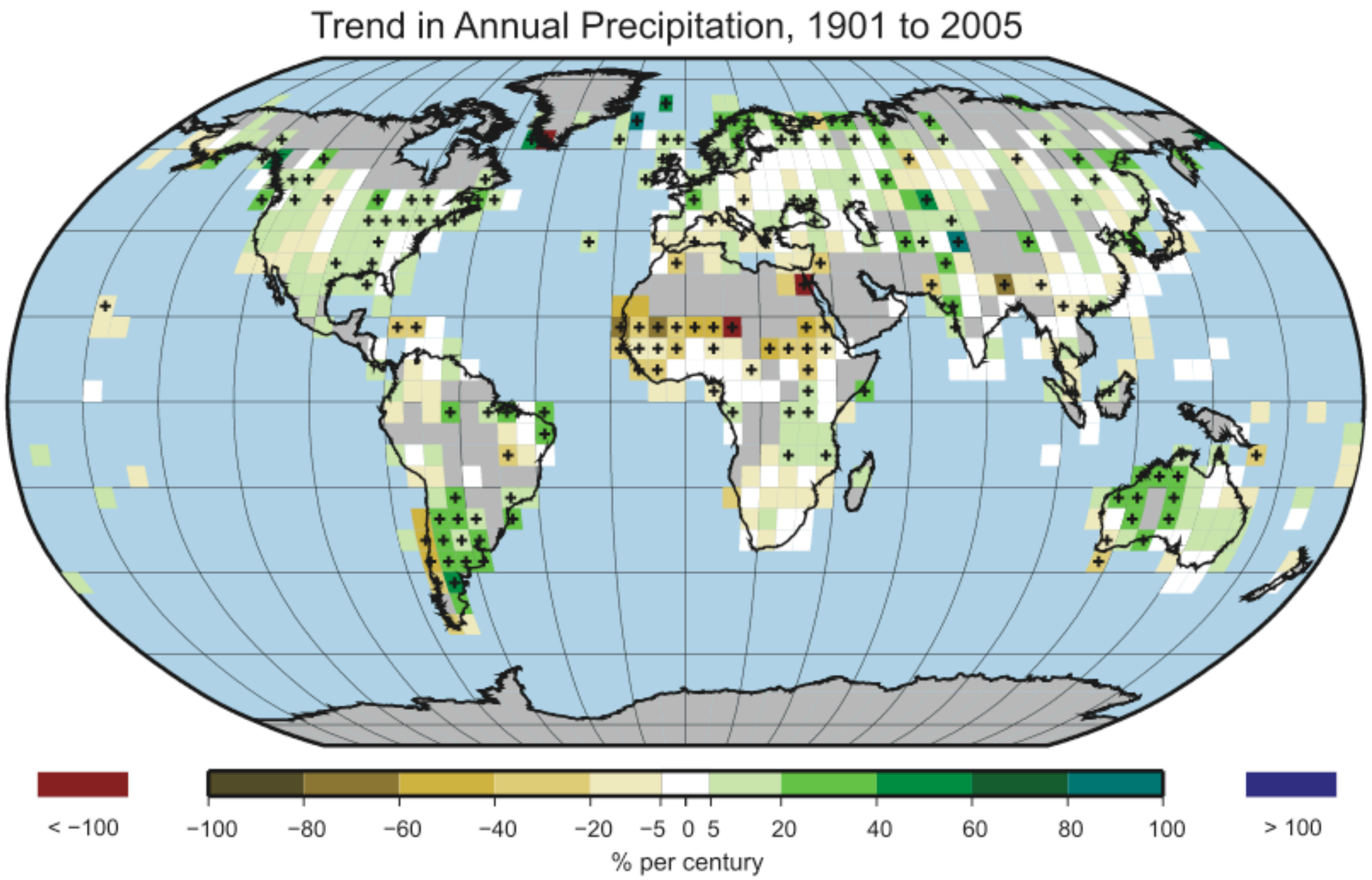
Warming in the Arctic is roughly double that for the whole Earth.

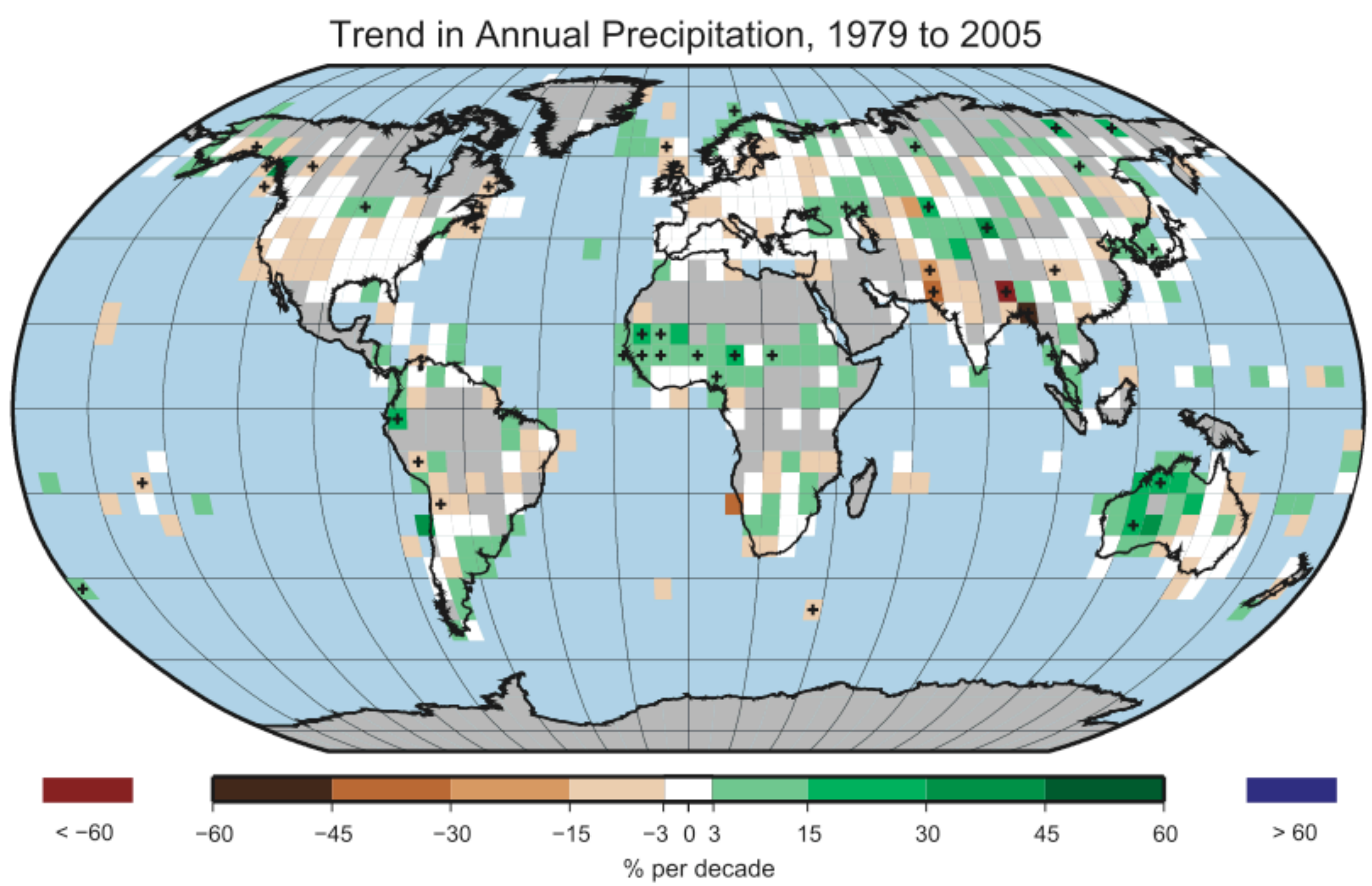
Note different scales

Stratospheric Cooling

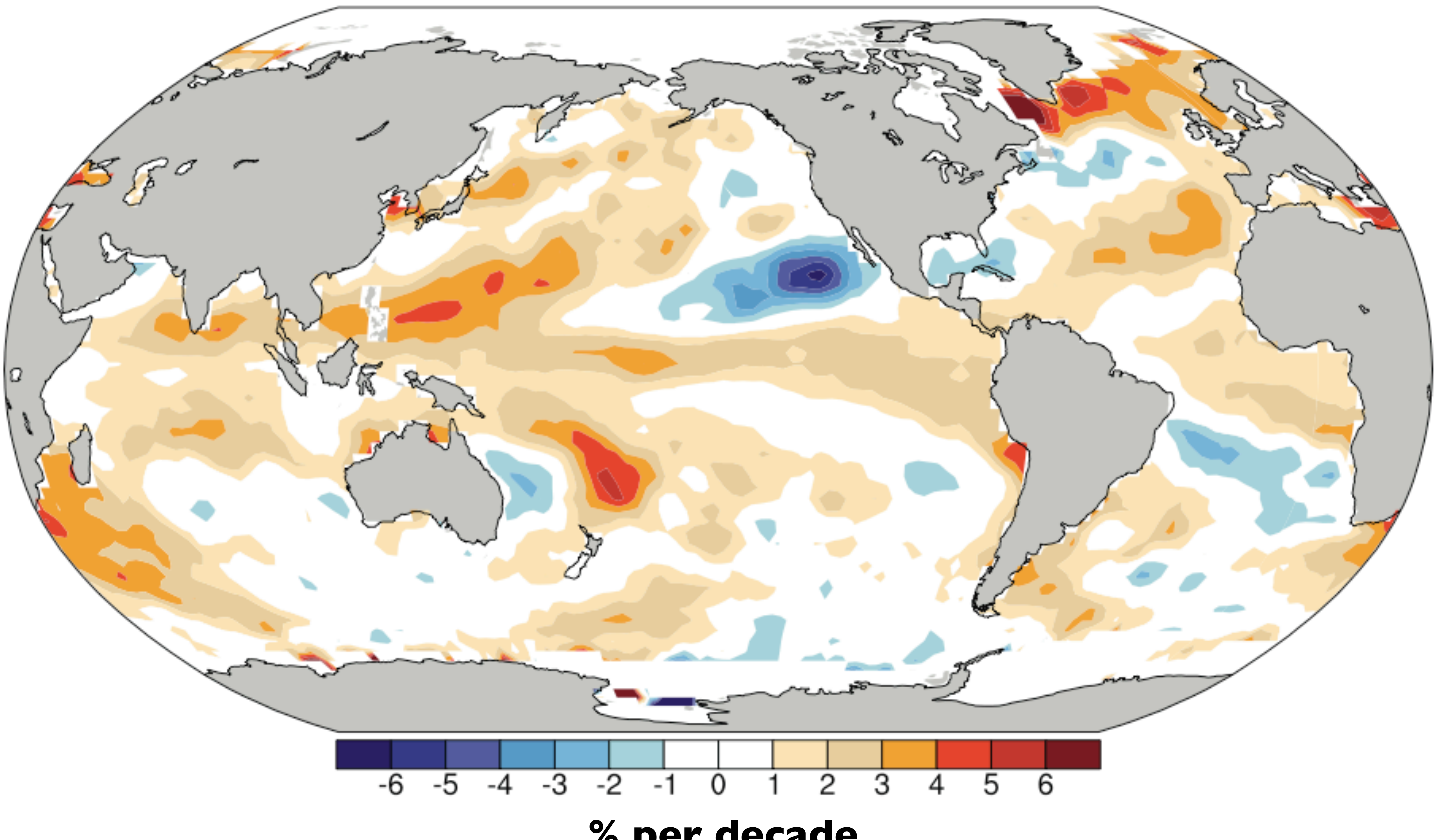


Major volcanoes


Trend in Annual Precipitation, 1901 to 2005
< −100
−100
−80
−60
−40
−20
−5
0
5
20
40
60
80
100
> 100
% per century


Trend in Annual Precipitation, 1979 to 2005
< −60
−60
−45
−30
−15
−3
0
3
15
30
45
60
> 60
% per decade

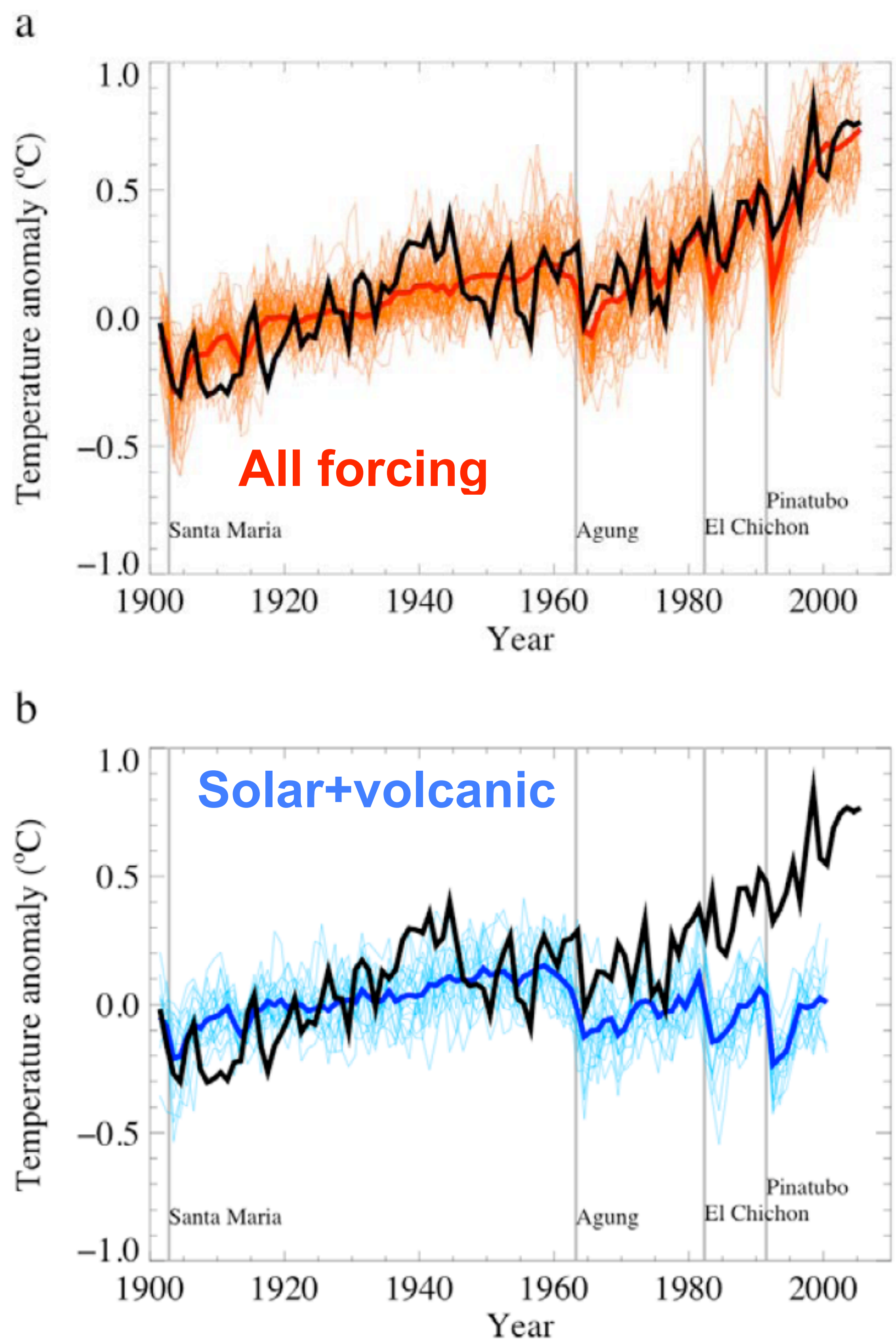
Column water vapor, ocean only, measured trend from 1988 to 2004



The climate of the 20th century

The observed changes are shown by the black curves.

Results from about 20 models are shown in red (upper panel) and blue (lower panel).



The Intergovermental Panel on Climate Change (IPCC)

- The IPCC does not do its own research. It *assesses* published, peer-reviewed research.

- The IPCC does not make recommendations on public policy. It provides scientific input to policy-makers.

The Fourth IPCC Assessment

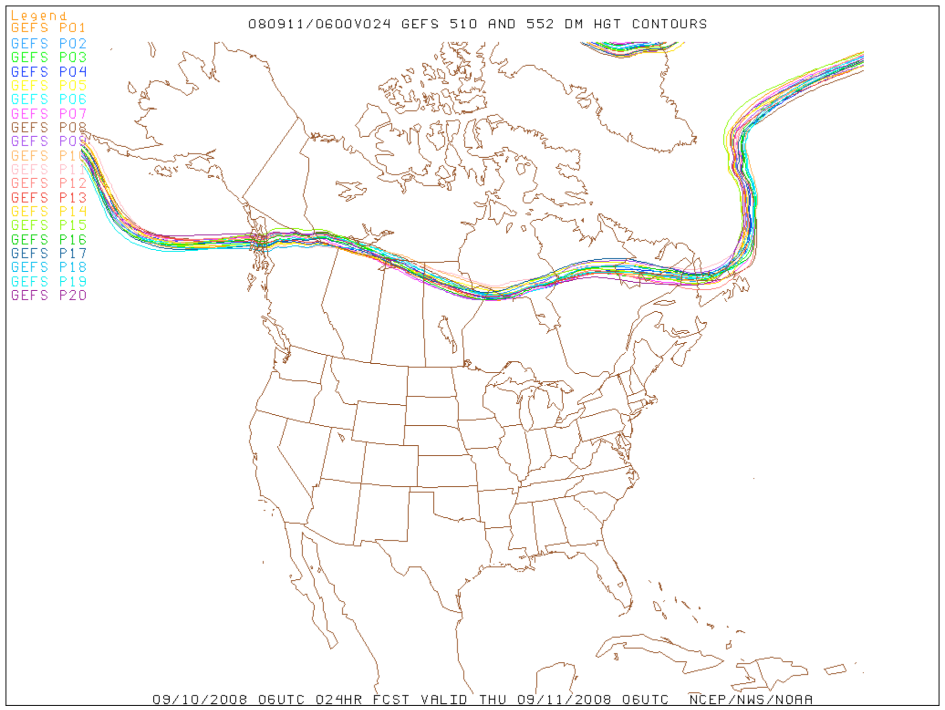
- Three years in the making.
- Authors nominated by national science organizations.
- The US put two draft versions up on a public web site and invited comments,
- 30,000 review comments.
- Every single comment received a response from the Lead Authors.
- The responses are also posted on a public web site.
- The Summary for Policy-Makers was unanimously approved, word for word, by 100+ governments, at a week-long meeting in Paris, early in 2007.

Weather prediction vs climate prediction

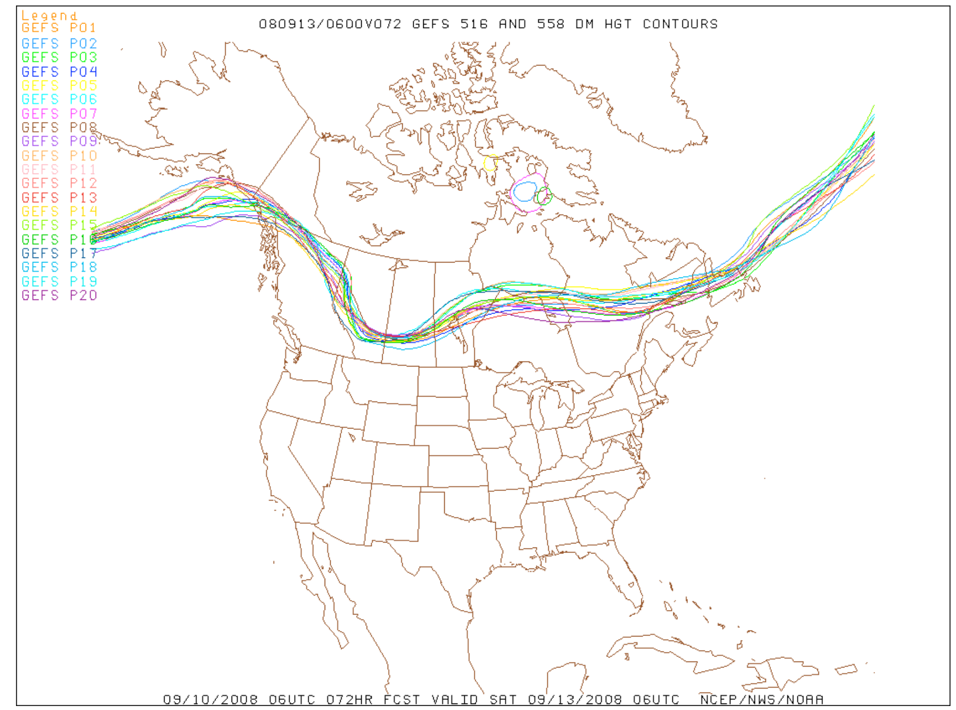
- What will the weather be like over the next few days?
  - Weather patterns form, move, and die.
  - Chaos rules beyond a couple of weeks.

- How will the weather change between now and next summer?
  - The Earth moves around the Sun.
  - The movement itself is highly predictable many years in advance.

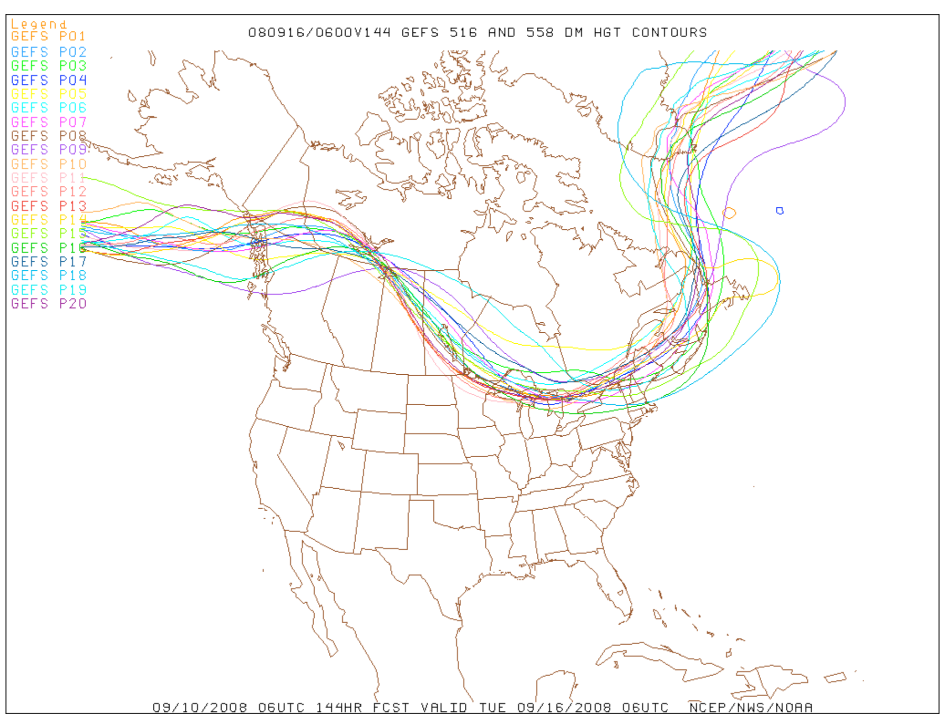
Chaotic weather



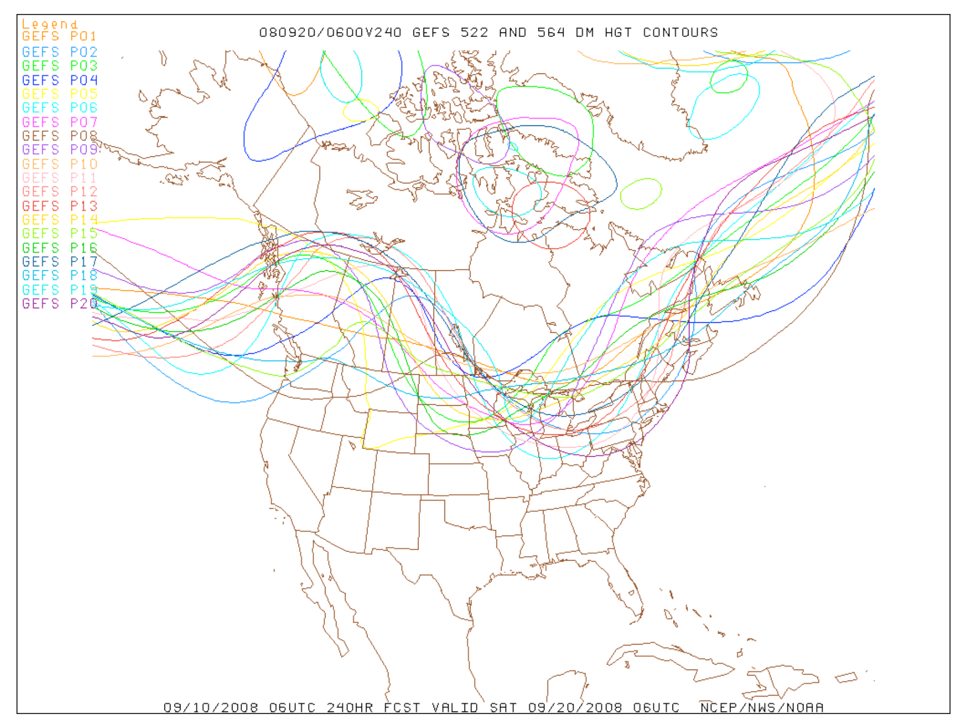
1-day



3-day

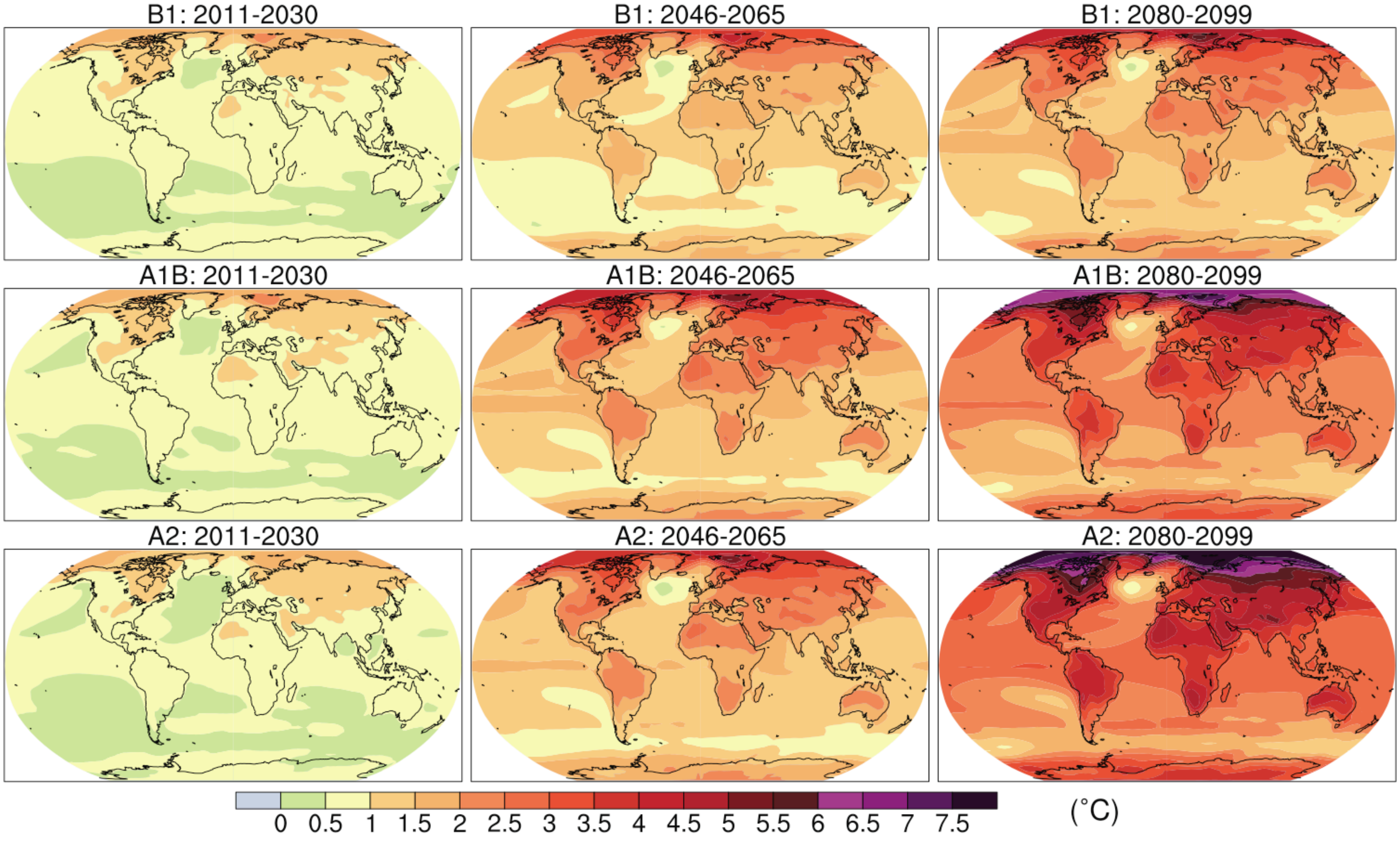


6-day

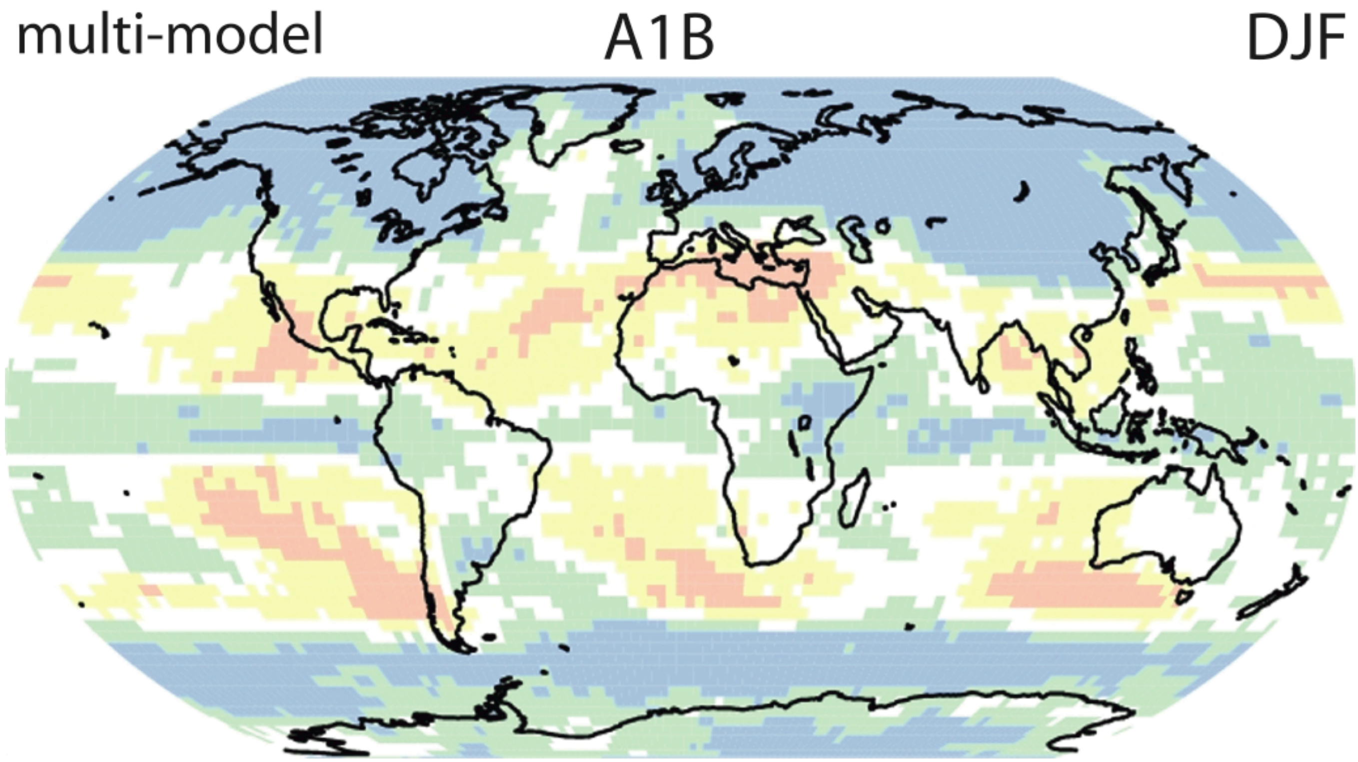


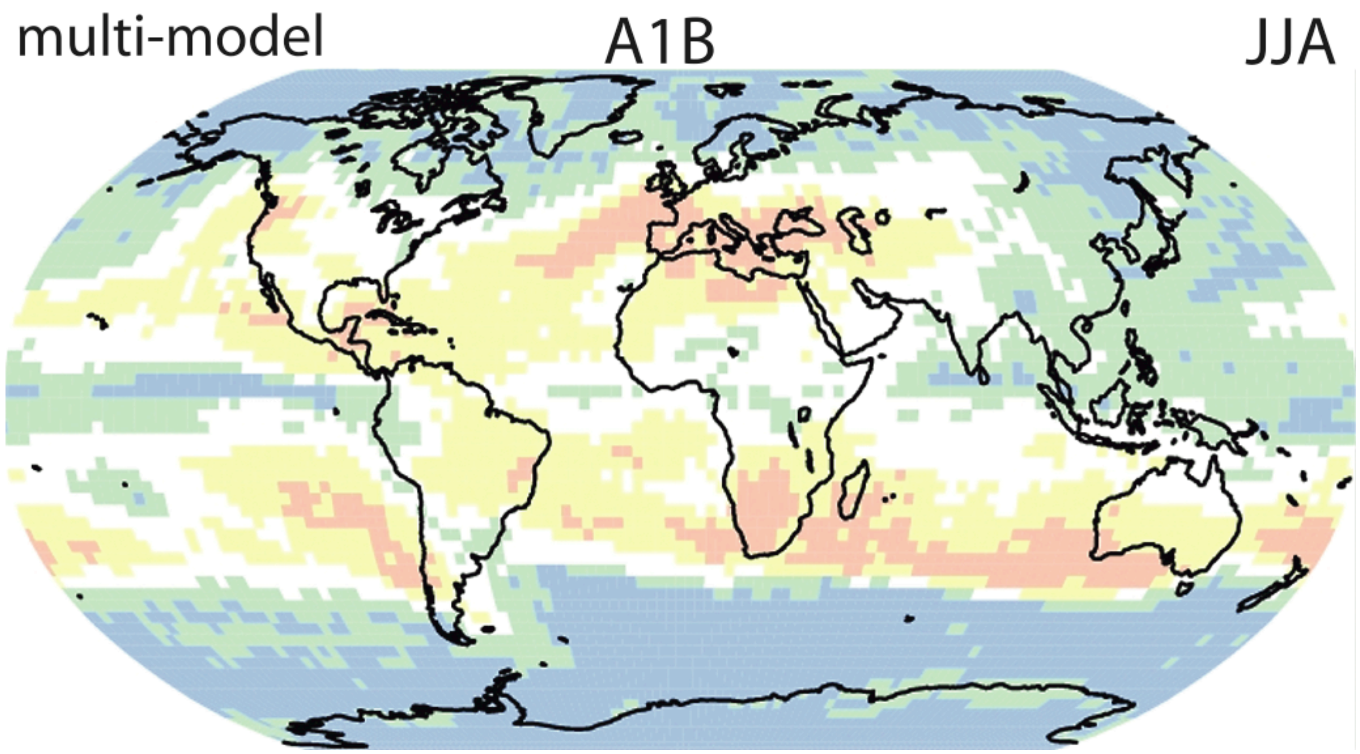
10-day

Forecasts for the 21st Century

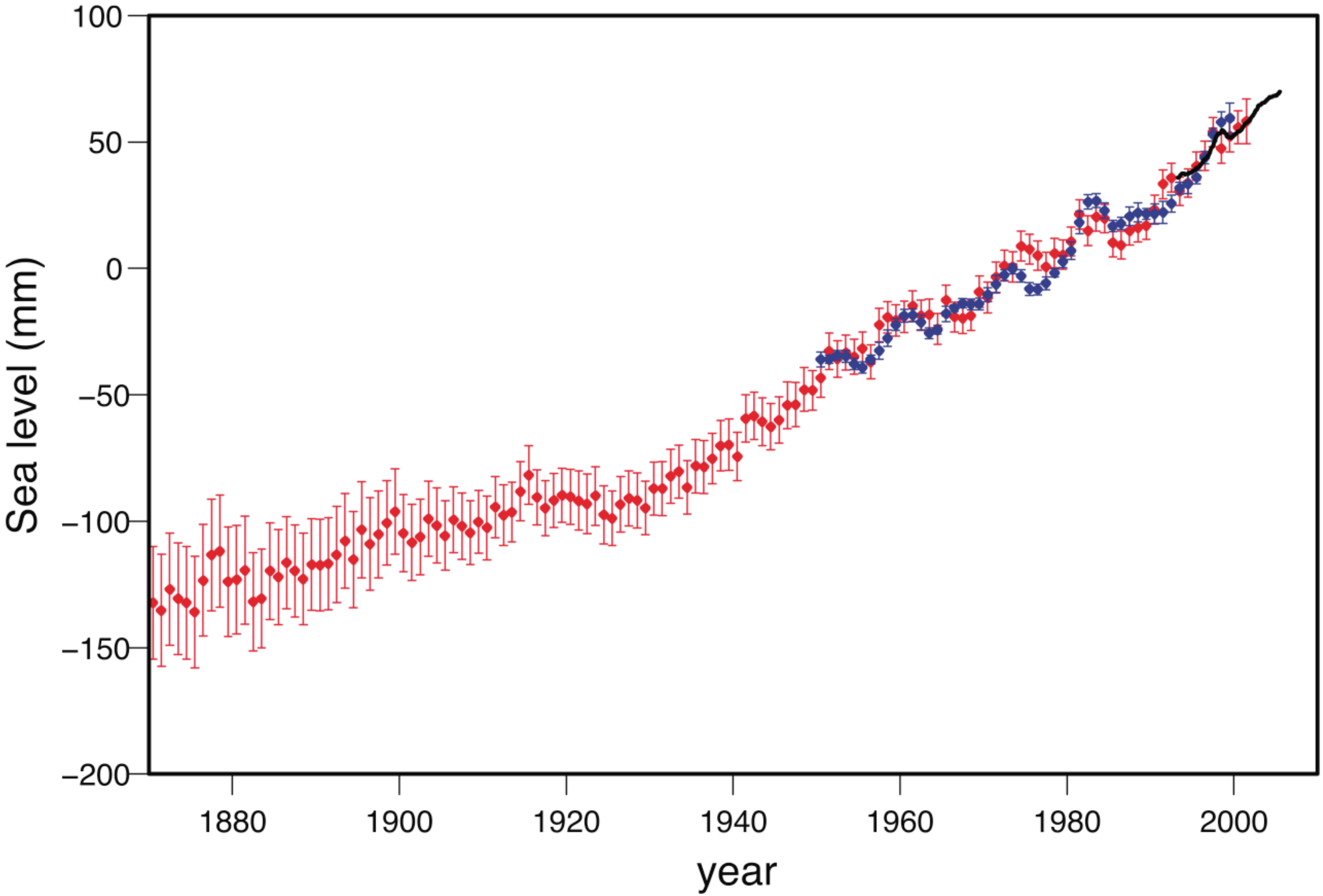


Precipitation:
Late 21st century minus late 20th century

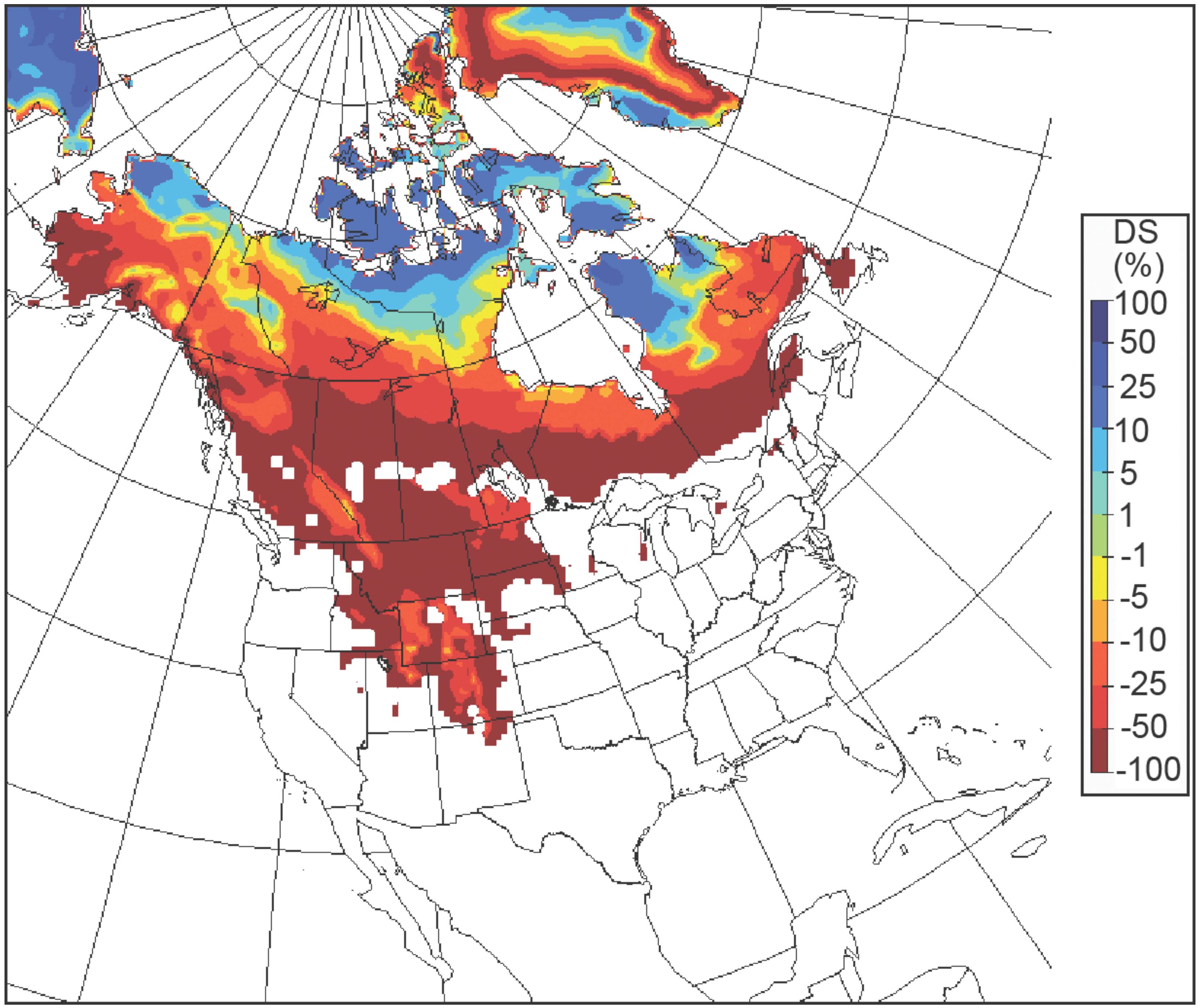




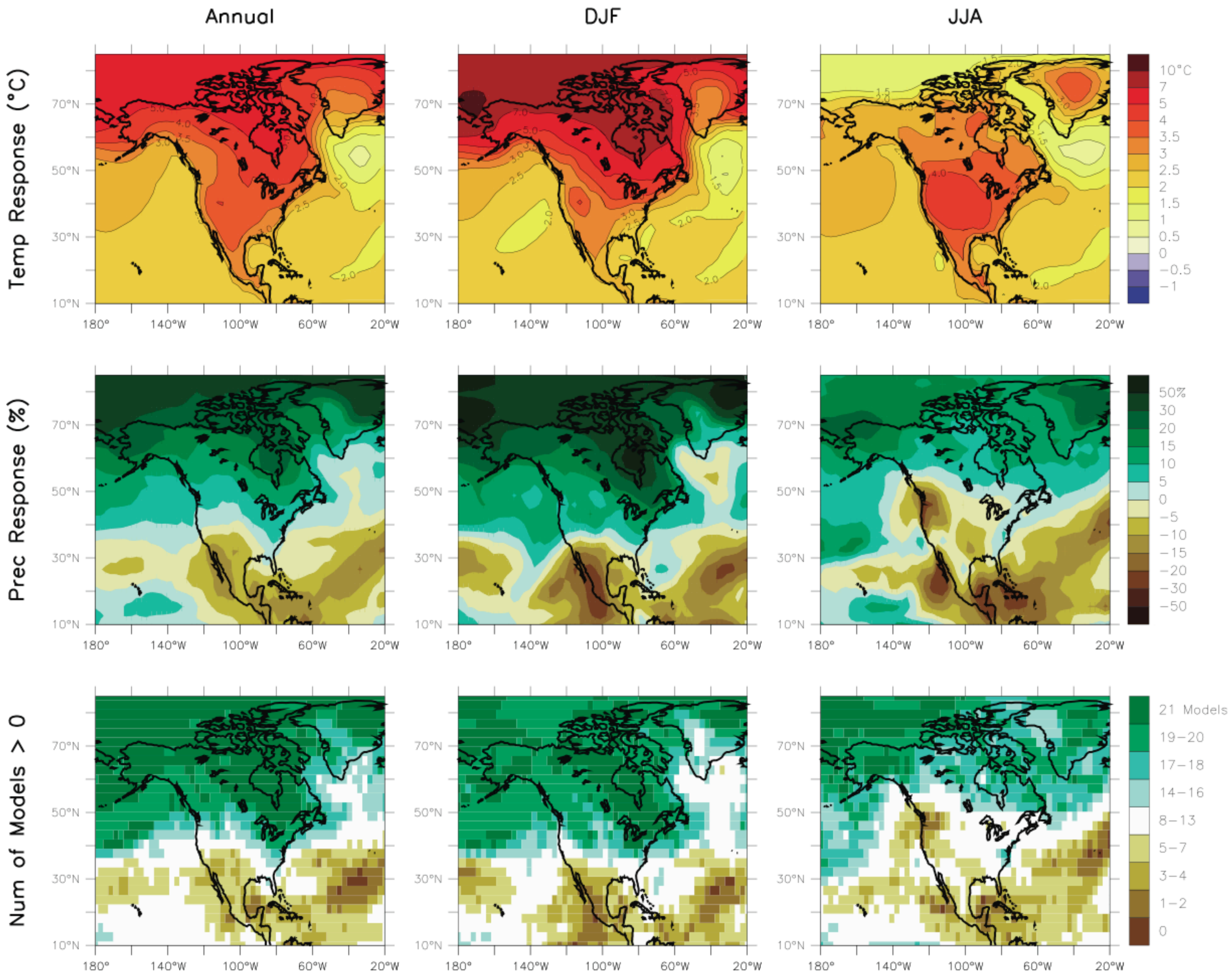
Something to worry about



March Snowcover:
Mid 21st century minus late 20th century



Temperature and Precipitation:
Late 21st century minus late 20th century



LEAD AUTHORS
DENMARK
NIGER
SWAZILAND
the guardian


NORWAY
NIGER
MALAYSIA
MALI
ESTONIE
EGYPT
DOMINICAN REPUBLIC
COSTA RICA


Susan SOLOMON
Co-chair WG 1
Dahe QIN
Co-chair WG 1

The Assessment is free here:

http://www.ipcc.ch/press/index.htm#nobel

You can also buy it from a bookseller.

Summary

- The basic physics of climate change is simple and not controversial.
- Observations show that the climate is changing now at an unprecedented rate.
- Many of the changes that we see now were predicted 35 years ago.
- Predictions for the 21st century include more warming, major changes in precipitation, and rising sea level.

Recommended Reading

- **“What We Know About Climate Change,” by Kerry Emanuel**
- **Climate Change 2007 - The Physical Science Basis: Working Group I Contribution to the Fourth Assessment Report of the IPCC**
- **“Chaos: The Making of a New Science,” by James Gleick**
- **“The Two-Mile Time Machine: Ice Cores, Abrupt Climate Change, and Our Future,” by Richard Alley**

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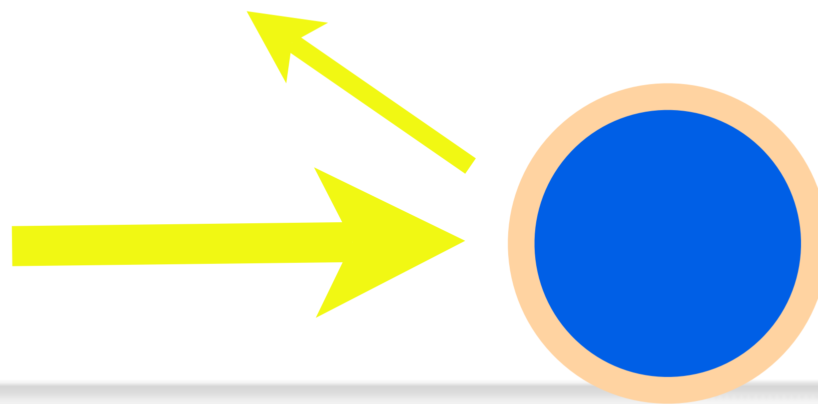
Increasing CO_2 Perturbs the Earth's Radiation Budget



$$(1-\alpha)S\pi a^2 = \varepsilon(\sigma T_S^4)4\pi a^2$$

$$(1-\alpha)S = 4\varepsilon(\sigma T_S^4)$$

$$0 = 4(\Delta\varepsilon)(\sigma T_S^4) + 4\varepsilon(4\sigma T_S^3 \Delta T_S)$$

Assumptions: 1) Only CO_2 is perturbed; 2) No feedbacks.

$$\Delta T_S = -\frac{T_S}{4}\frac{\Delta\varepsilon}{\varepsilon}$$

Let's put in some numbers:

$$\Delta T_S = -\frac{T_S}{4}\frac{\Delta\varepsilon}{\varepsilon}$$

$$\varepsilon(\sigma T_S^4) = 240 \quad W m^{-2}$$

$$(\Delta\varepsilon)(\sigma T_S^4) = -4 \quad W m^{-2}$$

$$\therefore \frac{\Delta\varepsilon}{\varepsilon} = -\frac{4}{240}$$

~2%

$$T_S = 288 \quad K$$

$$\Delta T_S = -\frac{288 \quad K}{4}\left(-\frac{4}{240}\right) = 1.2 \quad K$$

~0.5%