Mon Dec 1

Where we're going:

This week: global warming debate

KKC Chap 13 (all) [continued from last week]

Seattle Times Pro/Con debate (web)

Today: Consensus assessment of global warming (IPCC)

Tues: Arguments of the "Skeptics"

Wed: HW #6 DUE... should we make it next Monday?

Evidence for Global Warming (Prof. Richard Gammon)

Thurs: A skeptical view of the current GW paradigm (Tad)

Fri: *tutorial, review for final*

Next week (M-W):

upcoming talks

Upcoming talks/events:

Monday, Dec 1

Smith Hall 115 3:30 (refreshments) 4:00 (talk)
Prof ???, "Climate modeling in the US 1955-2004"

Tues, Dec 2

ATG 310 12:30 Weather Discussion

Public Service Announcements:

ATG 310 3:00 undergraduate program in Atmospheric Sciences, information meeting and social

Suzzallo Espresso, 7pm, free play-reading
"All Powers Necessary and Convenient" by Mark Jenkins

Wed, Dec 3

Health Sciences Bldg, T-239 Studio B, **8:30am**
"Methane in the Precambrian," Prof Jim Kasting, live videoseminar

Thermal Inertial

Question

• How long to heat "Earth" by 1K given climate forcing of 4 W/m^2 ?

- atmosphere
- surface ocean (~100 m)
- entire ocean (~4000 m deep)

Note: 4 W/m^2 is forcing for doubled CO_2

Specific heat capacity, C

How much energy per unit mass does it take to warm a substance by one degree Kelvin?

$$C = \frac{\text{Energy Absorbed}}{\text{Mass} \quad \text{Temperature Change}} = \frac{E}{M\,\Delta T}$$

so,

E = C*M*ΔT = Energy Required to raise temperature by ΔT

Thermal Inertial

$$\text{Time (s)} = \frac{\text{Energy Required (J)}}{\text{Energy Flux Rate (J/s or W)}}$$

normalize everything by unit area of Earth surface, m^2

$$\text{Time (s)} = \frac{E\ (J/m^2)}{4\ (W/m^2)} = \frac{C*M*\Delta T}{4\ (W/m^2)}$$

Reservoir	Specific Heat Capacity, C (J/kg/K)	Mass (kg/m^2)	Time to heat by 1K for flux of 4 W/m^2
Atmosphere	1000	10^4	30 days
Surface Ocean	4000	10^5	3 years
Entire Ocean	4000	$4*10^6$	130 years

Thermal Inertial

Question

• How long to heat "Earth" by 1K given climate forcing of 4 W/m^2 ?

Answer (according to this simple model)

a. 30 days if we just have to heat the atmosphere

b. 3 years if we just have to heat the ocean surface layer

c. 130 years if we just have to heat the entire ocean

(assuming instantaneous mixing - which is unrealistic)

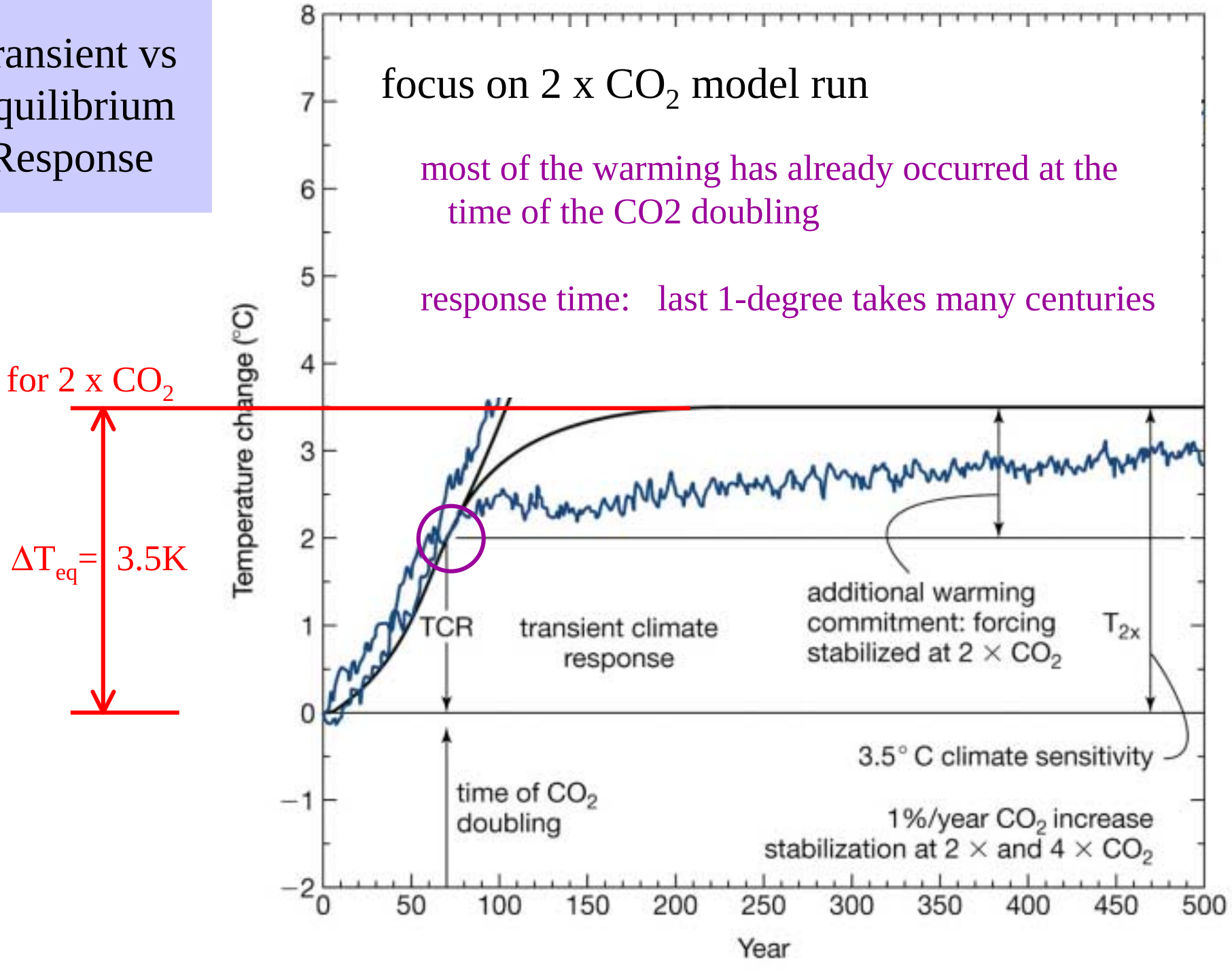
Conclude

• Surface ocean provides thermal inertia on time scale of several years

• Deep ocean provides thermal inertia on time scale of many centuries

• Oceans have a very strong stabilizing effect on climate

Transient vs Equilibrium Response



Lag Factor

Basic Global Warming Forecast Equation

$$\Delta T = \lambda * \Delta F * \text{lag\_factor}$$

Lag Factor

A given amount of forcing corresponds to a certain equilibrium warming.

Most of this warming occurs rather quickly, but the full amount takes several centuries to occur.

The "lag_factor" in this equation predicts how much of the equilibrium warming for a given level of forcing will have occurred by the time that level of forcing is reached.

[Assumes a steadily increasing forcing.]

Climate models indicate: lag_factor is ~0.66 [use in HW6]

IPCC Projection of Climate Forcing

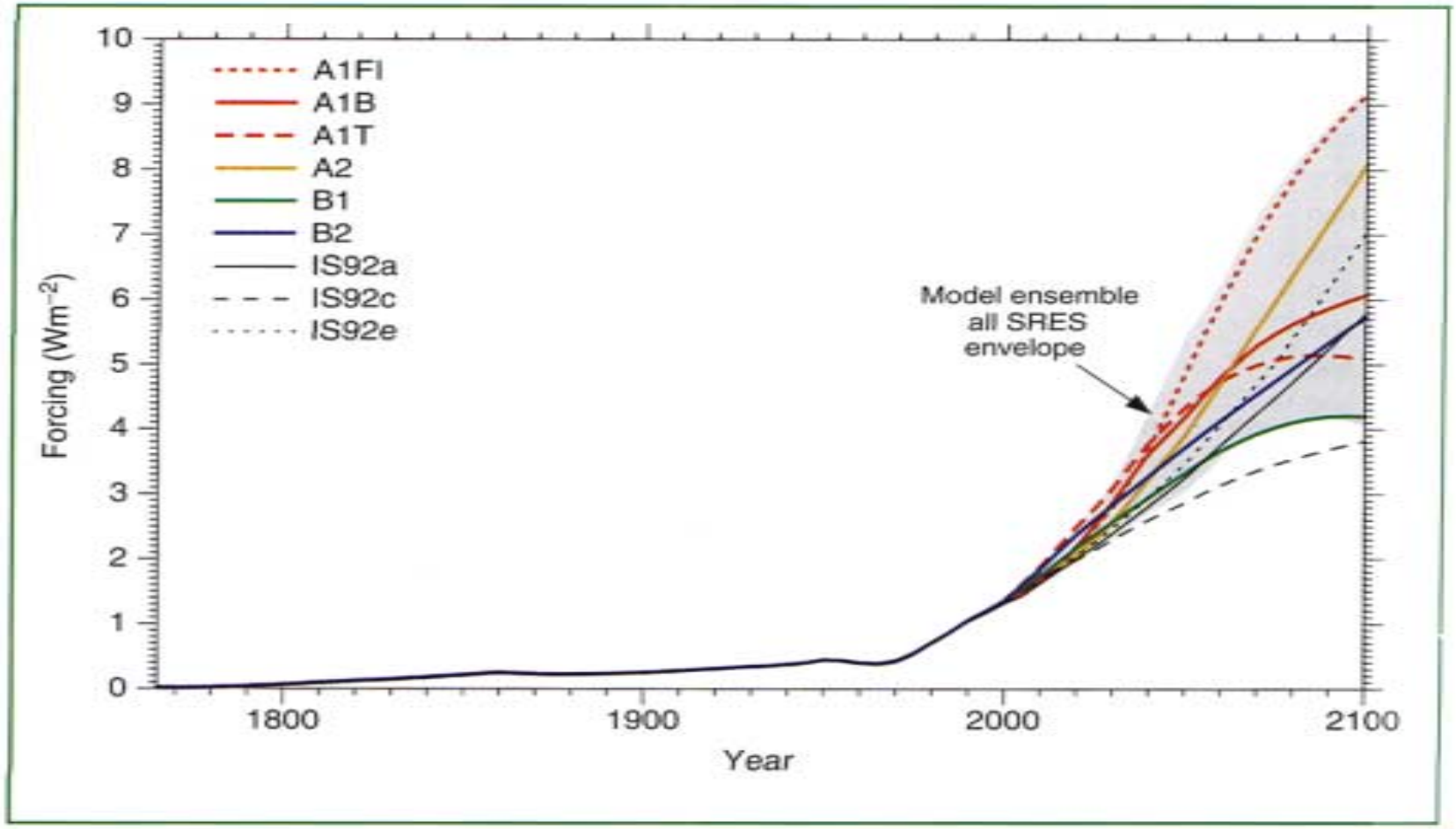


Figure 19: Simple model results: estimated historical anthropogenic radiative forcing up to the year 2000 followed by radiative forcing for the six illustrative SRES scenarios. The shading shows the envelope of forcing that encompasses the full set of thirty five SRES scenarios. The method of calculation closely follows that explained in the chapters. The values are based on the radiative forcing for a doubling of CO_2 from seven AOGCMs. The IS92a, IS92c, and IS92e forcing is also shown following the same method of calculation. [Based on Figure 9.13a]

IPCC (2001) summary

Main points of Summary for Policymakers

- the world is currently warming
- the warming can be attributed to humans
- GHGs (cause of warming) are projected to rise substantially
- aerosols (partial offset of warming) are not projected to rise substantially

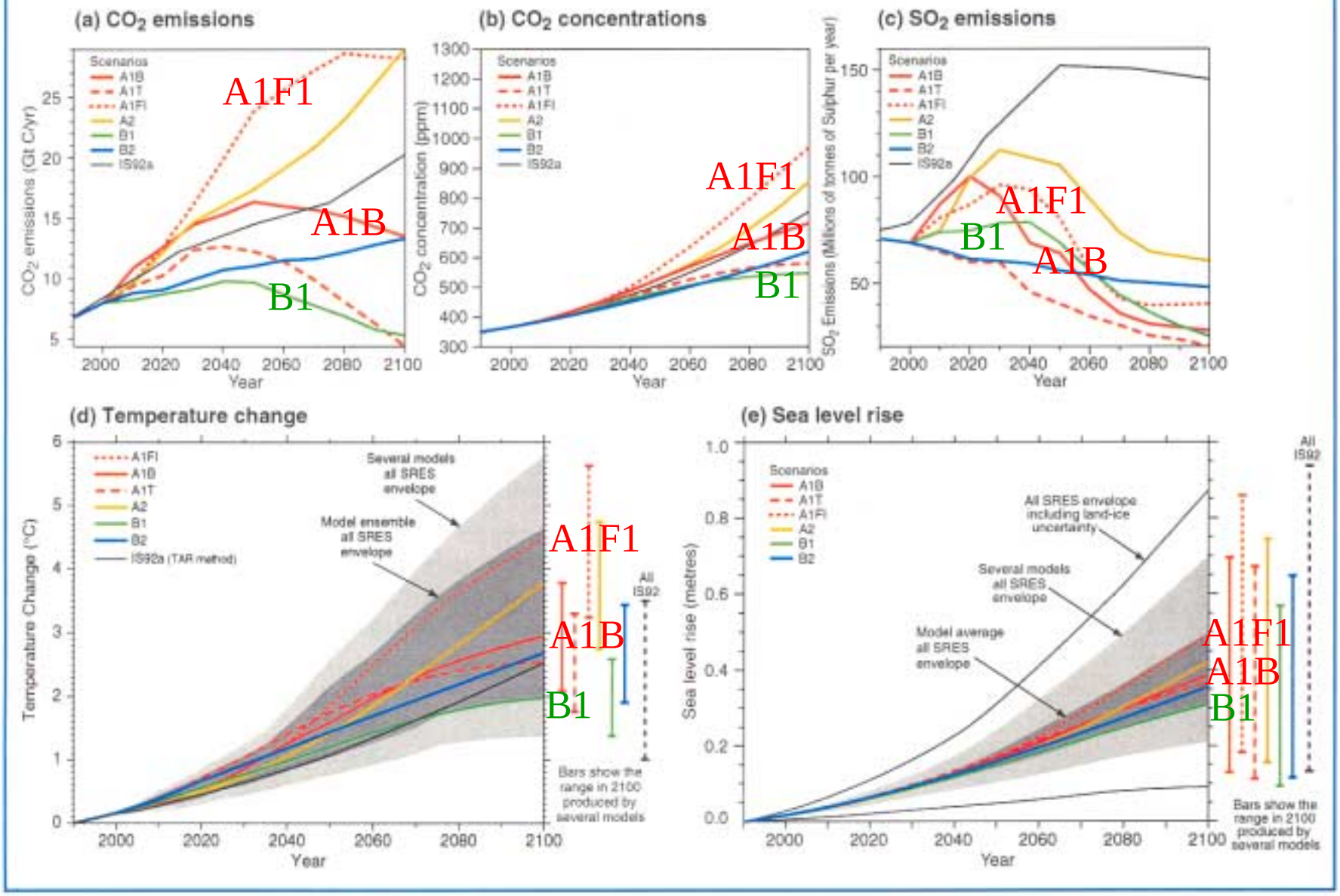
- GAAST projection by year 2100: +1.4 to +5.8 K
- sea-level projection by year 2100: +0.1 to +0.9 m

- GAAST projection in context:

"The projected rate of warming is much larger than the observed changes during the 20th century and is very likely to be without precedent during at least the last 10,000 years based on paleoclimate data."

IPCC SPM Fig 5: scenarios and projections

A1F1, A1B, B1: Scenarios from Homework



IPCC (2001) changes

Change in temperature projections over last 6 six years

1995 projections (SAR): 1.0 to 3.5 K [mean 2.25 K]
2001 projections (TAR): 1.5 to 5.8 K [mean 3.65 K]

>> 1.4 K increase in mean and 2.3 K increase in max in six years! <<

IPCC explanation...

"The higher projected temperatures... are due primarily to the lower projected sulfur dioxide emissions."

translation:

- GHG emissions and concentrations are about the same.
- Sulfate aerosol concentrations are projected to be much lower...
  > human feedback: people won't tolerate deadly pollution
- Aerosol negative forcing in 2001 projections is much lower.

Note: Aerosol forcings are the key to the change in projections in 2001, just as they were key to the increased confidence in human attribution in the 1995 report.

IPCC (2001) sea-level forecast

Sea-level projections

like GAAST, sea-level is a truly global index

but it is more difficult to predict because it is a balance of sources and sinks

despite higher temperature projections, sea-level rise projections are slightly lower in TAR compared to SAR

- thermal expansion causes rise
- Antarctica is expected to grow (more snowfall than melting)
- Greenland is expected to shrink (more melting than snowfall)
- mountain glaciers are expected to shrink dramatically,
  but this is a fairly small reservoir

Tues Dec 2

Announcements:
due date for HW 6 has been extended to Monday, Dec 8

Where we're going:

Today: finish up Consensus assessment of global warming (IPCC)
Arguments of the "Skeptics"

Wed: Evidence for Global Warming (Prof. Richard Gammon)

Thurs: A skeptical view of the current GW paradigm (Tad)

Fri: *tutorial, review for final*

Next week:

Mon: HW#6 DUE
Climate Impacts in the Pacific NW (Dr. Phil Mote)
Tues: Effects of global warming
Wed: Environmental problem-solving
course evaluation

Fri: FINAL, here, 8:30am

upcoming talks

Upcoming talks/events:

Tues, Dec 2

ATG 310 12:30 Weather Discussion

Public Service Announcements:

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IPCC (2001) Detection and Attribution

Testing the global warming theory (detection and attribution):

Warming of the Earth's surface…

- Is predicted by climate models forced with GHG's
- Has in fact been detected
- Match between prediction and observation is sufficiently good that attribution has been claimed

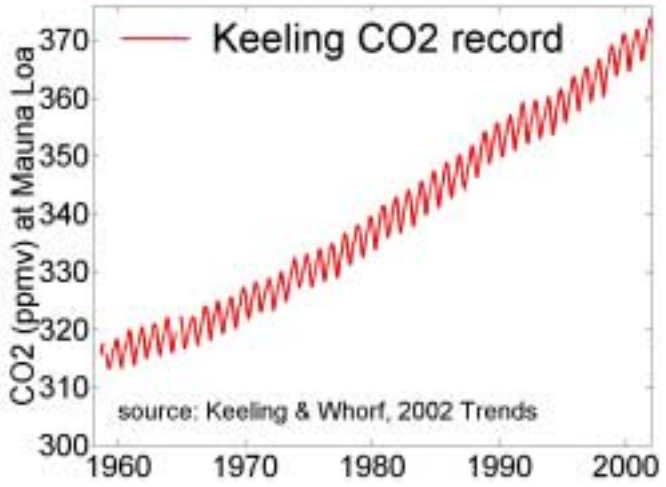
Conceptual framework for this paradigm:

$$\Delta T = \lambda \Delta F \qquad \text{(Eq. 6.1 of IPCC, 2001)}$$

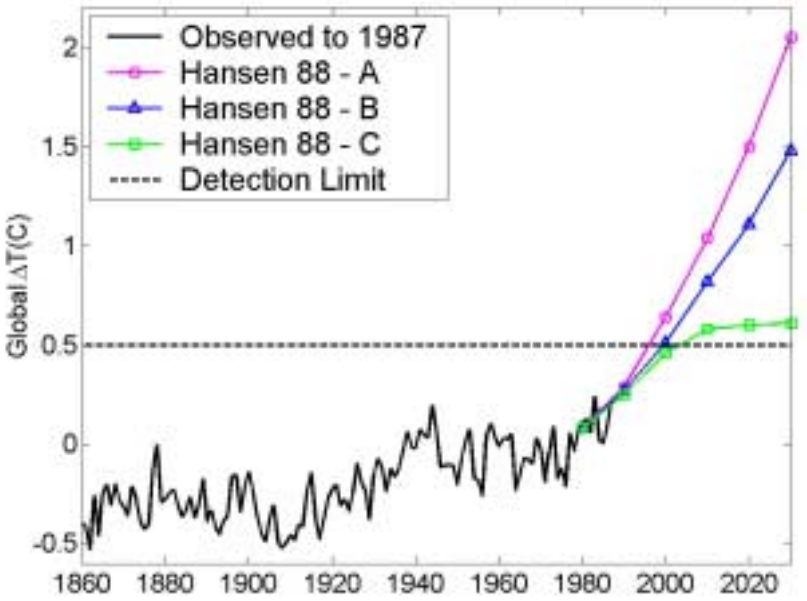
ΔF: externally imposed change in energy balance (W/m^2)
ΔT: resulting change in surface temperature (K)
λ: climate sensitivity

Current paradigm –forcing and models

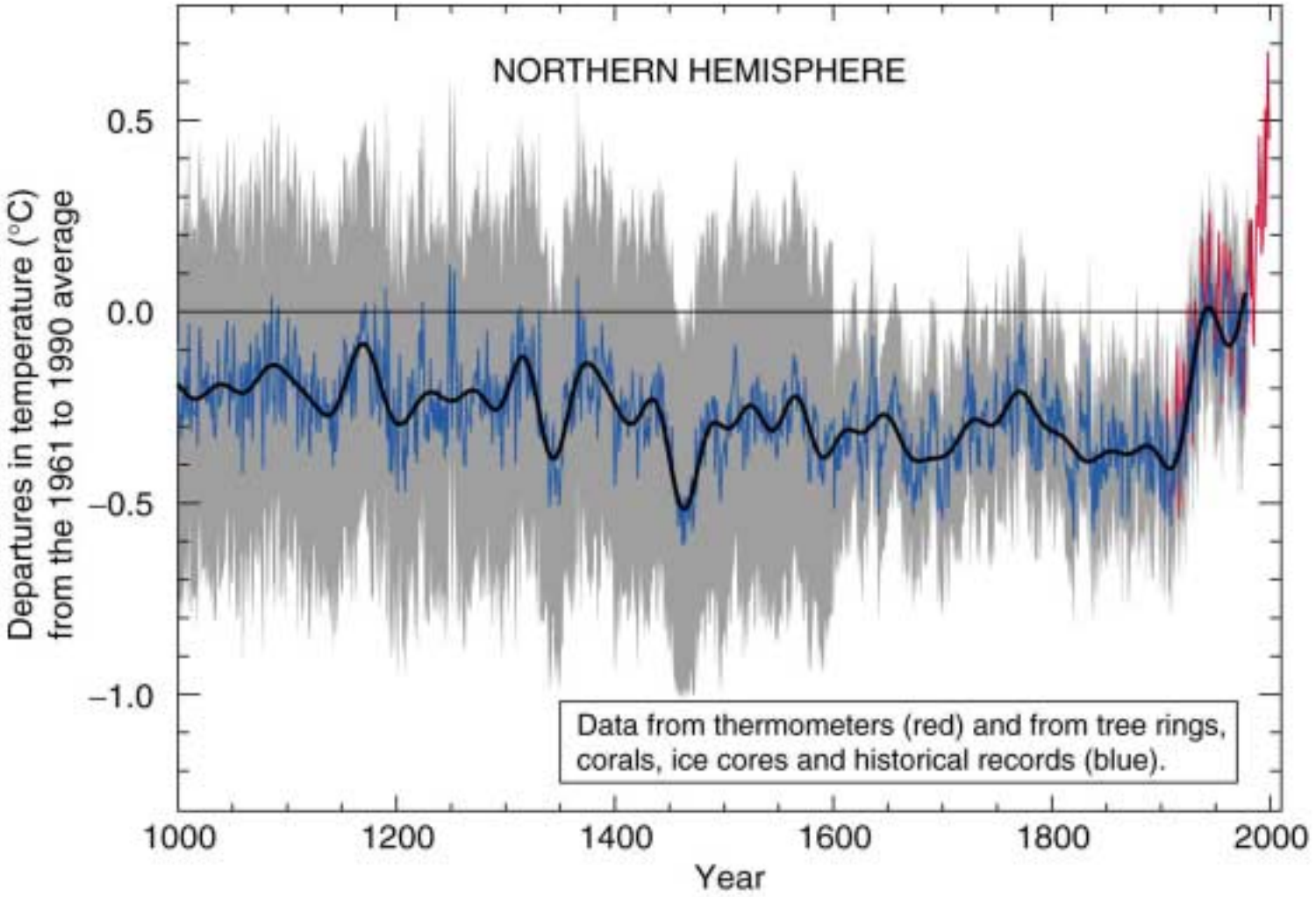
1. Positive forcing from GHG's



2. Climate models predict warming



Current paradigm - Detection of the predicted warming



In-class activity: Identify the largest, 50-year change in the pre-industrial era. What is the magnitude of this change (best-guess and upper bound)?

Current paradigm - Attribution to human causes

4. … the warming has been attributed to humans

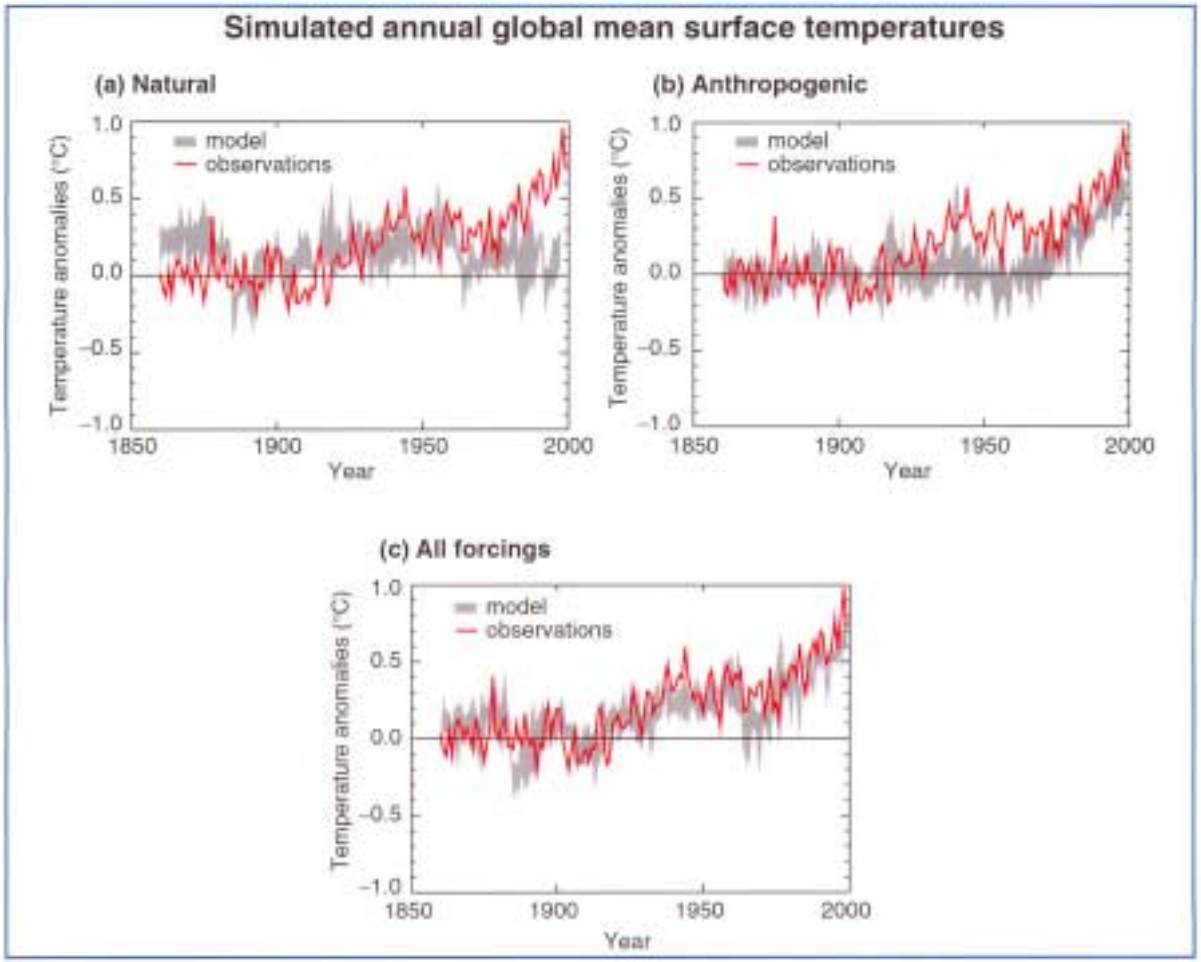
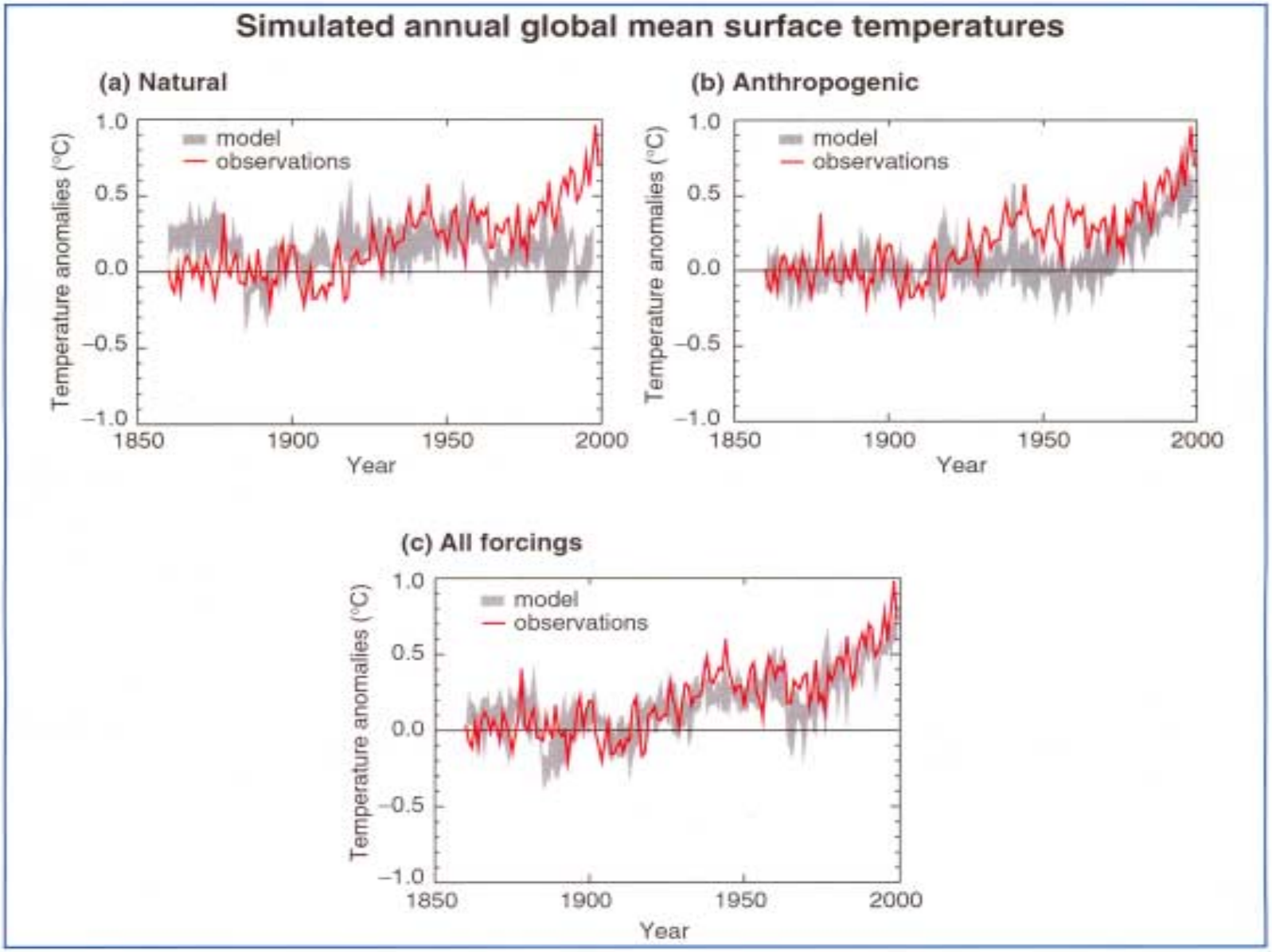


Figure 4: Simulating the Earth's temperature variations, and comparing the results to measured changes, can provide insight into the underlying causes of the major changes.

Source: IPCC 2001, Summary for Policymakers, Fig 4

IPCC (2001) attribution



More on this "attribution" argument on Thursday . . .

(some) Arguments of the "skeptics"

It isn't warming

- satellites do not show warming
- surface thermometers are biased by urban heat-island effect
- this or that region is not warming

It may be warming, but the warming is natural

- the earth is just coming out of the Little Ice Age
- it was warmer during the Medieval Warm Period
- all changes are due to the Sun

Climate models are hopelessly simplistic and unreliable

- [cf Mott Greene's talk yesterday]
- past predictions have been wrong; why believe new ones?

CO2 does not cause warming

- it is a trivial part of the Earth's greenhouse effect, which is almost entirely due to water vapor
- again, all changes are due to the Sun

CO2 and warming are beneficial, not dangerous

- CO2 is a plant fertilizer, not a pollutant
- a warmer Earth will be more productive and more widely inhabitable, especially at high latitudes

The question that "skeptics" fail to confront

Energy balance theory of climate change

- CO_2 is increasing in the atmosphere due to human activity
- CO_2 absorbs infrared radiation and, thus, participates in the Earth's greenhouse effect
- anthropogenic CO_2 is already imposing a climate forcing of 1.5 W/m2 (more than 10-times any measured variations in solar energy)
- doubled CO_2, almost certain by 2100, will impose a forcing of 4 W/m2 (equivalent to increasing solar energy by 1.5%)

None of the above conclusions are disputed by global warming "skeptics". They lead to the following questions:

- How can a sustained, positive forcing be imposed upon the Earth without leading to a change in surface temperature?

- In other words, what strong negative feedback mechanism operates in the Earth's climate system that prevents temperature change in spite of imposed forcings?

Lindzen

Richard Lindzen's (responsible) search for a negative feedback

- a leading greenhouse skeptic, but through peer-reviewed research
- premise: the Earth's climate over the past 10,000 years has been too stable. There MUST be a strong, negative feedback.
- His efforts have focused research on important and neglected aspects of the Earth's climate - in particular, the links between tropical convection and upper tropospheric water vapor.
- To date, he has put forward three or four versions of his negative feedback hypothesis. All were trumpeted by the "skeptics" press. All have failed to pass scientific scrutiny.

Lindzen's latest attempt:

Lindzen et al. (2001): "Does the earth have an adaptive infrared iris?", Bulletin of the American Meteorological Society, 82, 417-432.

Hartmann and Michelsen (2002) "No evidence for iris", BAMS
plus three other articles refuting the evidence and logic.

Case in point: Soon and Baliunas

Soon and Baliunas, "Proxy climatic and environmental changes of the past 1000 years, Climate Research, 23, 89-110, 2003

New finding: the 20th century climate is NOT unusual. In fact, both the "Little Ice Age" and the "Medieval Warm Period" (900-1300) were more anomalous than the 20th century.

Thus, the "detection" argument collapses.

- Heralded in the "skeptics" press as the most thorough analysis of paleoclimate data to date.
- Came out just as the Climate Stewardship Act was being debated in Congress. The article was cited extensively in Senate testimony.
- The White House attempted to re-write the global-warming portion of the EPA "Draft Report on the State of the Environment" to feature the conclusions of this article rather than those of the IPCC.

Case in point: Soon and Baliunas

Scientifically unsound:

1. Paleoclimate data examined for any anomaly, not just temperature.

2. Each location treated separately. No attempt to reconstruct global- or hemispheric-mean temperature. Thus, changing weather patterns can explain the results. (No evidence of changing, global climate.)

3. Fails to consider the late 20th century warming (i.e. the best evidence of anomalous climate).

Note that the editor of the journal that published Soon and Baliunas has since resigned over how the peer review was handled.

Thoroughly discredited at this point. (But it's effect on the political process has already occurred.)

1998 Petition

Petition mailed to thousands of U.S. scientists (nearly all not involved in climate research). Enclosures:

- cover letter by a past president of the National Academy of Sciences
- "review article" formatted to look like a National Academy publication that was, in fact, never published in any refereed journal.

Petition

We urge the United States government to reject the global warming agreement that was written in Kyoto, Japan in December, 1997, and any other similar proposals. The proposed limits on greenhouse gases would harm the environment, hinder the advance of science and technology, and damage the health and welfare of mankind.

There is no convincing scientific evidence that human release of carbon dioxide, methane, or other greenhouse gases is causing or will, in the foreseeable future, cause catastrophic heating of the Earth's atmosphere and disruption of the Earth's climate. Moreover, there is substantial scientific evidence that increases in atmospheric carbon dioxide produce many beneficial effects upon the natural plant and animal environments of the Earth.

_____ ❒ Please send more petition cards for me to distribute.

Please sign here

My academic degree is B.S. ❒ M.S. ❒ Ph.D. ❒ in the field of _____

1998 Petition Cover Letter signed by Frederick Seitz, Past President, National Academy of Sciences, USA

Enclosed is an eight page review of information on the subject of "global warming," a petition in the form of a reply card, and a return envelope. Please consider these materials carefully.

The United States is very close to adopting an international agreement that would ration the use of energy and of technologies that depend upon coal, oil, and natural gas and some other organic compounds.

This treaty is, in our opinion, based upon flawed ideas. Research data on climate change do not show that human use of hydrocarbons is harmful. To the contrary, there is good evidence that increased atmospheric carbon dioxide is environmentally helpful.

The proposed agreement would have very negative effects upon the technology of nations throughout the world, especially those that are currently attempting to lift from poverty and provide opportunities to the over 4 billion people in technologically underdeveloped countries.

It is especially important for America to hear from its citizens who have the training necessary to evaluate the relevant data and offer sound advice.

We urge you to sign and return the enclosed petition card. If you would like more cards for use by your colleagues, these will be sent.

Frederick Seitz

Frederick Seitz
Past President, National Academy of Sciences, U.S.A.
President Emeritus, Rockefeller University

"Fake" article included in petition

Environmental Effects of Increased Atmospheric Carbon Dioxide

ARTHUR B. ROBINSON ‡, SALLIE L. BALIUNAS †, WILLIE SOON †, AND ZACHARY W. ROBINSON ‡

‡Oregon Institute of Science and Medicine, 2251 Dick George Rd., Cave Junction, Oregon 97523 [info@oism.org]
†George C. Marshall Institute, 1730 K St., NW, Ste 905, Washington, DC 20006 [info@marshall.org]

January 1998

ABSTRACT **A review of the research literature concerning the environmental consequences of increased levels of atmospheric carbon dioxide leads to the conclusion that increases during the 20th Century have produced no deleterious effects upon global weather, climate, or temperature. Increased carbon dioxide has, however, markedly increased plant growth rates. Predictions of harmful climatic effects due to future increases in minor greenhouse gases like CO_2 are in error and do not conform to current experimental knowledge.**

SUMMARY

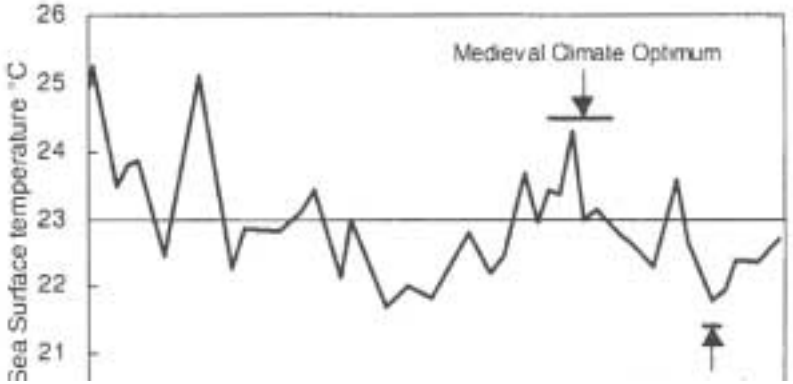
World leaders gathered in Kyoto, Japan, in December 1997 to consider a world treaty restricting emissions of "greenhouse gases," chiefly carbon dioxide (CO_2), that are thought to cause "global warming" – severe increases in Earth's atmospheric and surface temperatures, with disastrous environmental consequences.

Predictions of global warming are based on computer climate modeling, a branch of science still in its infancy. The empirical evidence – actual measurements of Earth's temperature – shows no man-made warming trend. Indeed, over the past two decades, when CO_2 levels have been at their highest, global average temperatures have actually cooled slightly.

To be sure, CO_2 levels have increased substantially since the Industrial Revolution, and are expected to continue doing so. It is reasonable to believe that humans have been responsible for much of

figure 1 are the result of seasonal variations in plant use of carbon dioxide. Solid horizontal lines show the levels that prevailed in 1900 and 1940 (2). The magnitude of this atmospheric increase during the 1980s was about 3 gigatons of carbon (Gt C) per year (3). Total human CO_2 emissions – primarily from use of coal, oil, and natural gas and the production of cement – are currently about 5.5 GT C per year.

To put these figures in perspective, it is estimated that the atmosphere contains 750 Gt C; the surface ocean contains 1,000 Gt C; vegetation, soils, and detritus contain 2,200 Gt C; and the intermediate and deep oceans contain 38,000 Gt C (3). Each year, the surface ocean and atmosphere exchange an estimated 90 Gt C; vegetation and the atmosphere, 60 Gt C; marine biota and the surface ocean, 50 Gt C; and the surface ocean and the intermediate and deep oceans, 100 Gt C (3).



Solar-cycle hypothesis in Wall Street Journal editorial, Dec 4, 1997

THE WALL STREET JOURNAL THURSDAY, DECEMBER 4, 1997

Science Has Spoken: Global Warming Is a Myth

By Arthur B. Robinson
And Zachary W. Robinson

Political leaders are gathered in Kyoto, Japan, working away on an international

ring and is unlikely ever to occur.

The temperature of the atmosphere fluctuates over a wide range, the result of solar activity and other influences. During

rise significantly, indeed catastrophically, if atmospheric carbon dioxide rises. Most of the increase in atmospheric carbon dioxide has occurred during the past 50

beyond current capabilities.

So we needn't worry about human use of hydrocarbons warming the Earth. We also needn't worry about environmental

it released.
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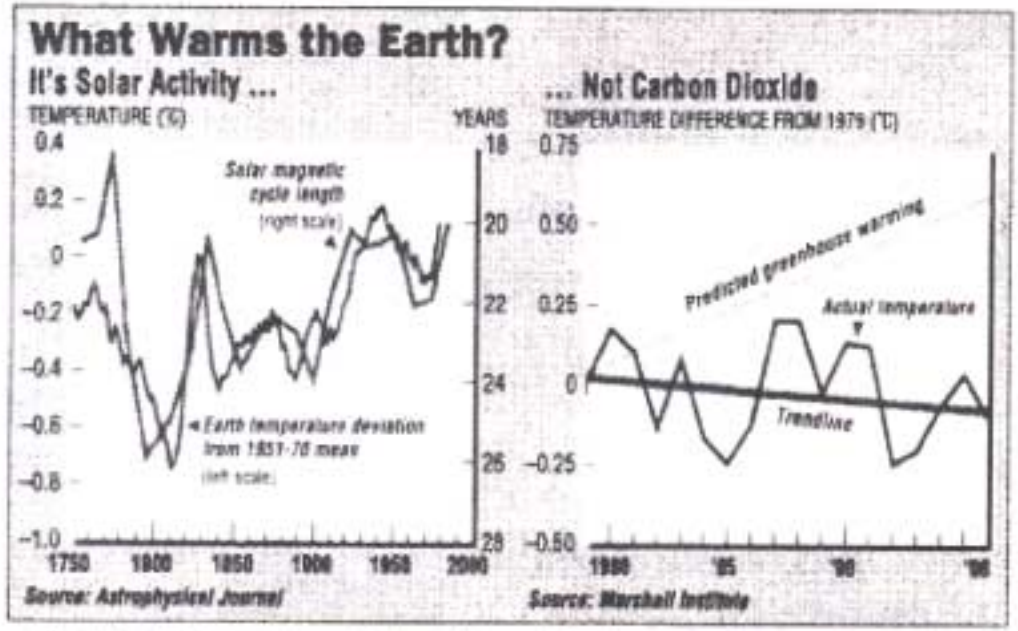

such predictions. Although it is reason-

hypothesis, how-
le. Scientists have

The highest temperatures during this period occurred in about 1940. During the

able to hope that these methods will even-
tually become useful, for now computer

Lush Environmen

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Solar-climate connection: Critical review

PERGAMON

Journal of Atmospheric and Solar-Terrestrial Physics 65 (2003) 801–812

ATMOSPHERIC AND SOLAR-TERRESTRIAL PHYSICS

www.elsevier.com/locate/jastp

Solar activity and terrestrial climate: an analysis of some purported correlations

Peter Laut

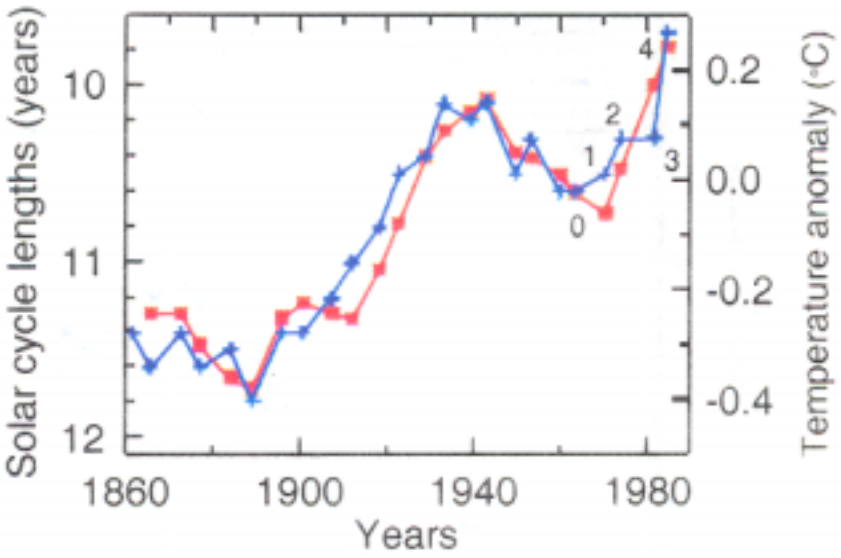
Department of Physics, Technical University of Denmark, DK-2800 Lyngby, Denmark

Received 14 February 2002; received in revised form 23 January 2003; accepted 4 February 2003

Abstract:

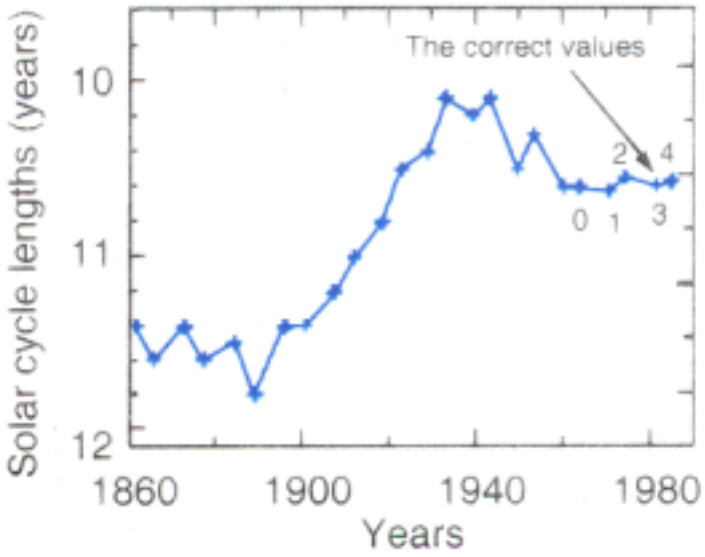
Hypotheses about solar-climate connections have been raised in both public and scientific debates about the possibility of man-made global climate change. "I have analyzed a number of published graphs that have played a major role in these debates and which have been claimed to support solar hypotheses. My analyses show that the apparent strong correlations displayed on these graphs have been obtained by an incorrect handling of the physical data."

Solar-cycle length vs GAAST: instrumental record

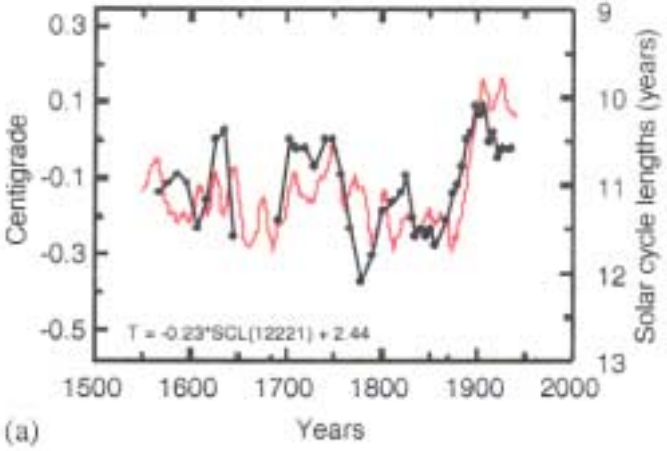


Friis-Christensen and Lassen (1991): last four solar-cycle data points contain arithmetic errors.

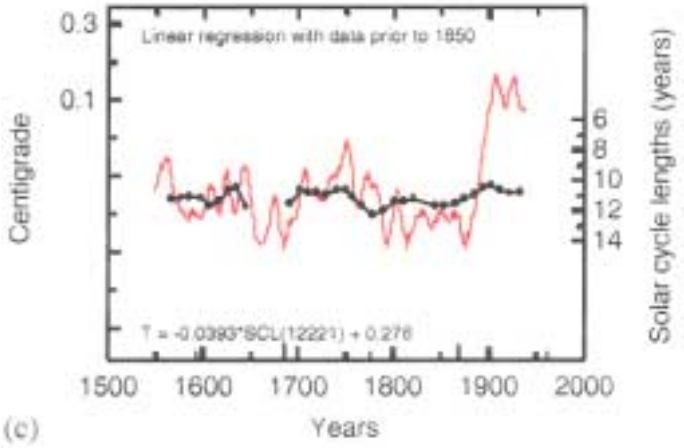
Laut (2003), corrected solar-cycle data. Relation to recent warming vanishes.



Solar-cycle length vs GAAST: last 4 centuries



Friis-Christensen (2000): optimal correlation to industrial-era data (improper method for testing the cause of industrial-era warming)



objective replotting by Laut (2003): optimal correlation to pre-industrial data (known to lack human influence). Test of whether solar variations explain the industrial-era warming now appears to fail.

McIntyre and McKitrick, 2003, Energy and Environ., 14, 751-771

CORRECTIONS TO THE MANN et. al. (1998) PROXY DATA BASE AND NORTHERN HEMISPHERIC AVERAGE TEMPERATURE SERIES

Stephen McIntyre
512-120 Adelaide St. West, Toronto, Ontario Canada M5H 1T1;

Ross McKitrick
Department of Economics, University of Guelph, Guelph Ontario Canada N1G2W1.

ABSTRACT

The data set of proxies of past climate used in Mann, Bradley and Hughes (1998, "MBH98" hereafter) for the estimation of temperatures from 1400 to 1980 contains collation errors, unjustifiable truncation or extrapolation of source data, obsolete data, geographical location errors, incorrect calculation of principal components and other quality control defects. We detail these errors and defects. We then apply MBH98 methodology to the construction of a Northern Hemisphere average temperature index for the 1400-1980 period, using corrected and updated source data. The major finding is that the values in the early 15th century exceed any values in the 20th century. The particular "hockey stick" shape derived in the MBH98 proxy construction – a temperature index that decreases slightly between the early 15th century and early 20th century and then increases dramatically up to 1980 — is primarily an artefact of poor data handling, obsolete data and incorrect calculation of principal components.

revised paleo record: McIntyre 2003

Energy & Environment · Vol. 14, No. 6, 2

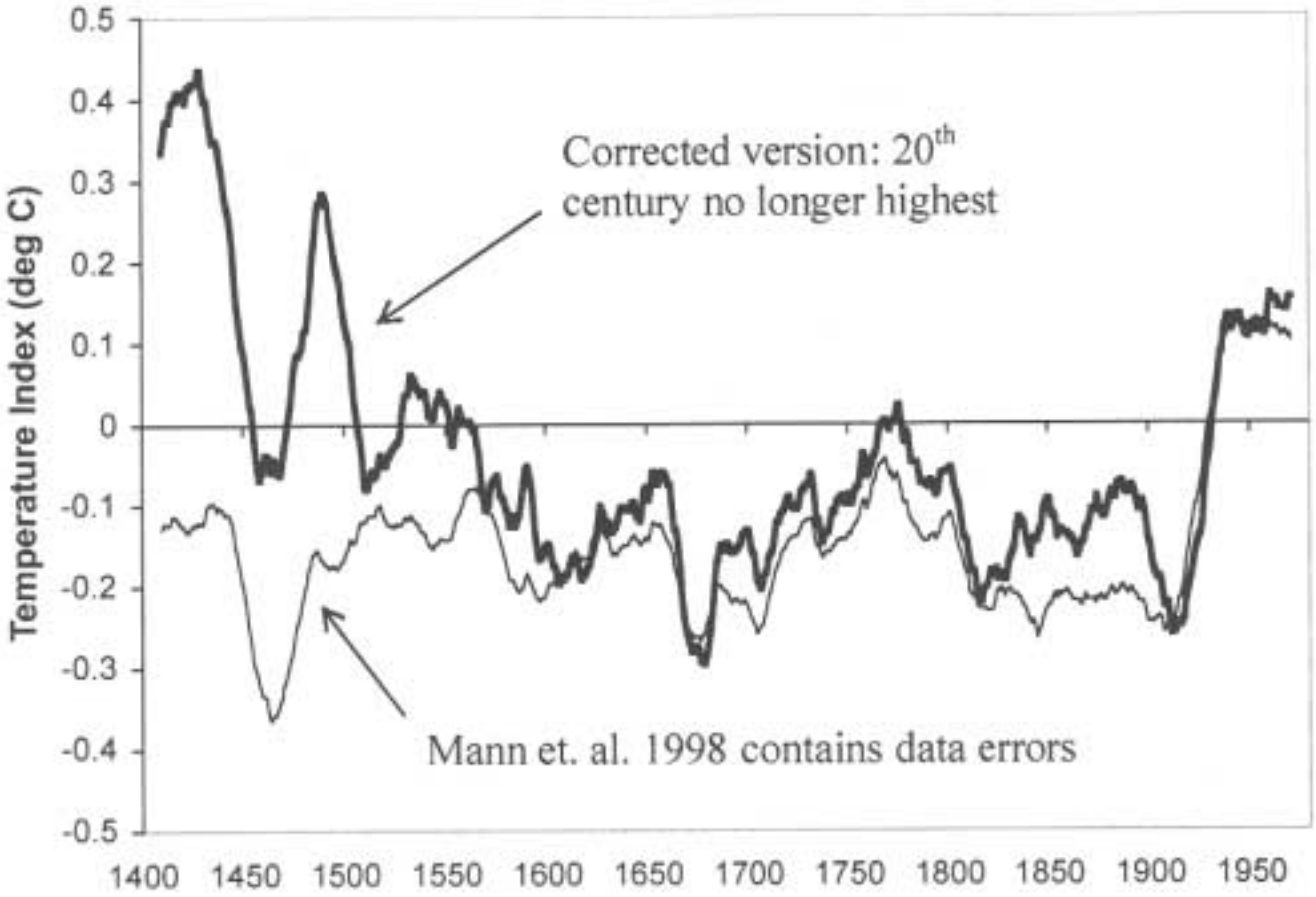
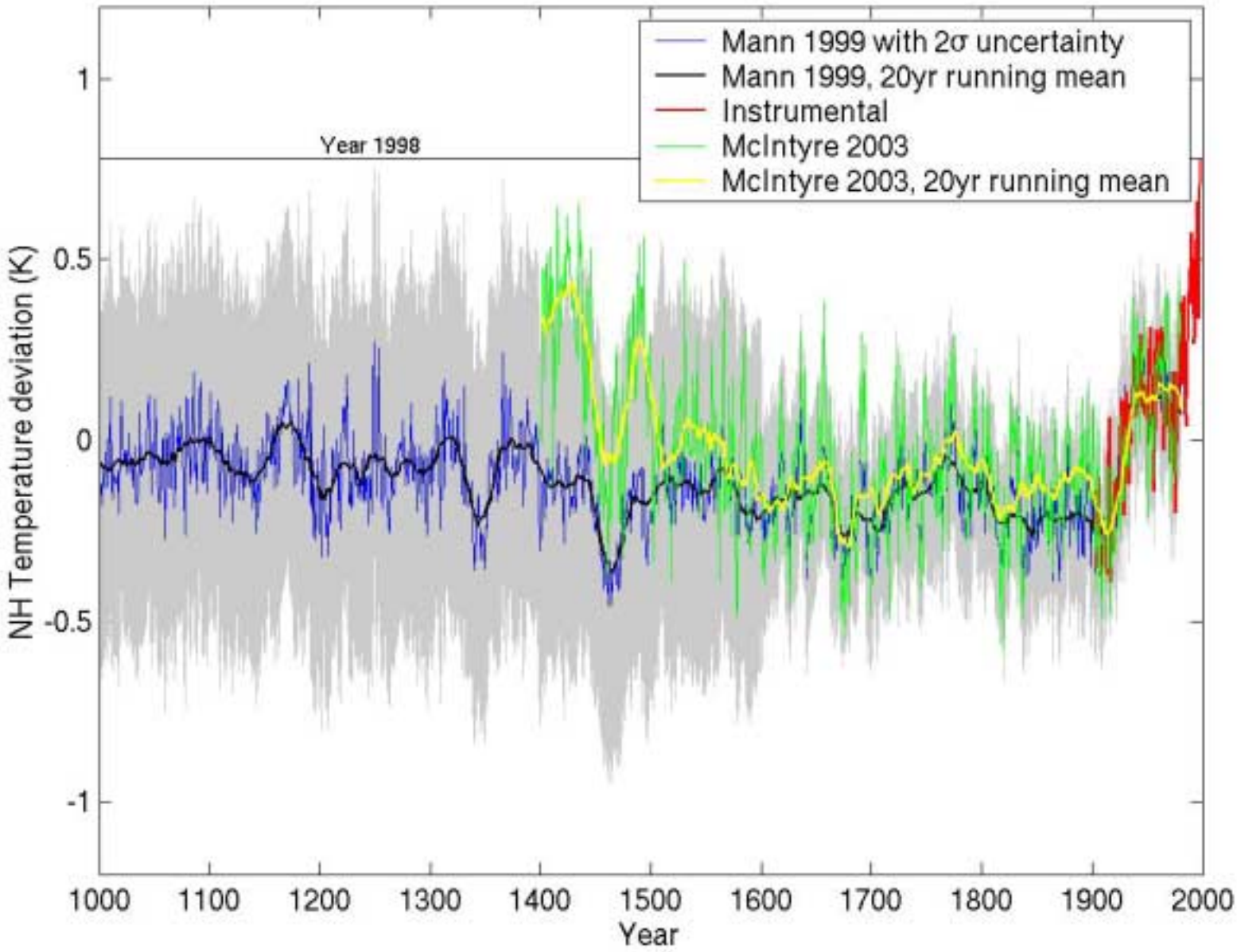


Figure 8. As Figure 7, using 20-year running mean to smooth.

Mann et al vs McIntyre



Wed Dec 3

Announcements:

- grades posted on website
- due date for HW 6 has been extended to Monday, Dec 8

`extra credit talk today`

JHN 64 3:30 Program on Climate Change meeting

Where we're going:

Today: Evidence for Global Warming (Prof. Richard Gammon)

Thurs: A skeptical view of the current GW paradigm (Tad)

Fri: *tutorial, review for final*

Thurs Dec 4

Announcements:

- grades posted on website
- due date for HW 6 has been extended to Monday, Dec 8
- notes on the final...
  - comprehensive (whole course) but emphasizes 2nd half
  - essay questions and problems will be from 2nd half
  - same format as midterm, about 50% longer

Where we're going:

Today: debrief Richard Gammon's talk
discuss Seattle Times editorial?
A skeptical view of the current GW paradigm (Tad)

Fri: *tutorial, review for final*

Richard Gammon's talk on "global warming evidence"

Recent global temperatures are highly anomalous
- 1998, 2002, 1997 are three warmest years on record

The stratosphere has cooled dramatically, as predicted

Extreme weather events are becoming more common:
- no one event can be linked to global warming
- heat-wave (and heat-deaths) in Europe last summer
- massive forest fires in California, Siberia, Australia
- weather-related damages in US have increased dramatically

Arctic is warming: surface thermometers and many other indicators
- spring thaws earlier by 2-3 weeks
- permafrost getting more shallow
- Arctic ice is substantially thinner and covers less area
- snow cover in NH has retreated by about 10%
- Greenland is losing ice-volume (melting at edges)

Mountain glaciers are retreating all over the world

ENSO oscillation is shifting into the warmer, El Nino mode

questions from Gammon's talk

Some of the questions from yesterday's talk:

How does CO2 harm the ocean? How does global warming harm the corral reefs? How important (to humans) is it that corral reefs are dying?

How are heat-related deaths determined? How do we know these are due to global warming? Could they have been prevented?

Cost of weather-related disasters is dramatically increasing... but isn't part of this due to putting buildings in disaster-prone areas?

How are forest fires caused by global warming?

How does the increase in GHGs cause both global warming at the surface and cooling of the stratosphere? Why are effects larger in NH?

The beach in my home town in Japan disappeared overnight. Was this because of the ice melting and sea level rising?

questions from Gammon's talk

Arctic: What is permafrost? If global warming is heating up the Arctic, why are some regions (e.g. central Greenland) getting colder?

Explain how ice melting sometimes does and sometimes does not cause sea level to rise?

Politics: Why are the politicians so unaware of this evidence? What does Putin not like about the Kyoto Protocol?

What is the solution? Can we really stop using fossil fuels? Wouldn't the hard to the economy be even worse than global warming?

Future: How long before we recover from global warming, once we implement a solution?

"Skeptics" wrap-up

Seattle Times Pro/Con editorials:

"Does human activity affect climate?"

"Yes" by J. W. Anderson, Resources for the Future

"1. The world has grown measurably warmer over the past century.
2. The chief cause is probably carbon dioxide... from fossil fuels.
3. Nobody knows what's going to happen as the concentrations of CO2 keep rising."

"No" by Dennis T. Avery, The Hudson Institute

- belittles deliberative, peer-reviewed, scientific consensus
  see Phil Mote comments on this

- considers evidence from the scientific fringes absolutely trustworthy (especially, Soon and Baliunas)

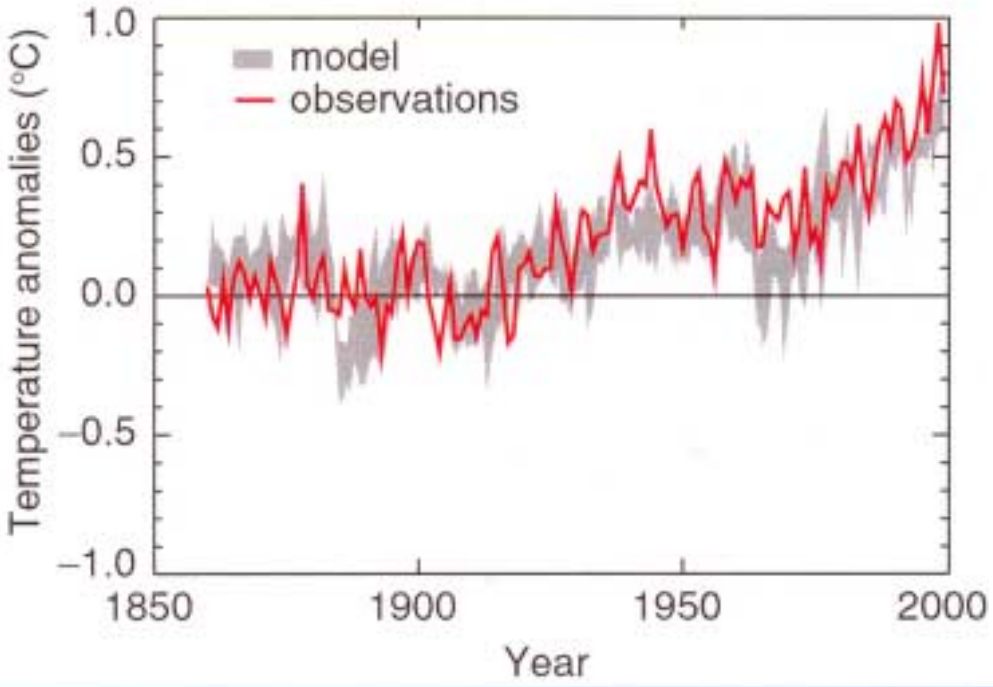
- expresses certainty, even regarding the future (mark of a "true-believer")

  "Meanwhile, the Earth's own historic records, in the fossils, sediments and ice cores, tell us we're in another modest, natural warming cycle that will bring back the finest weather humanity can remember."

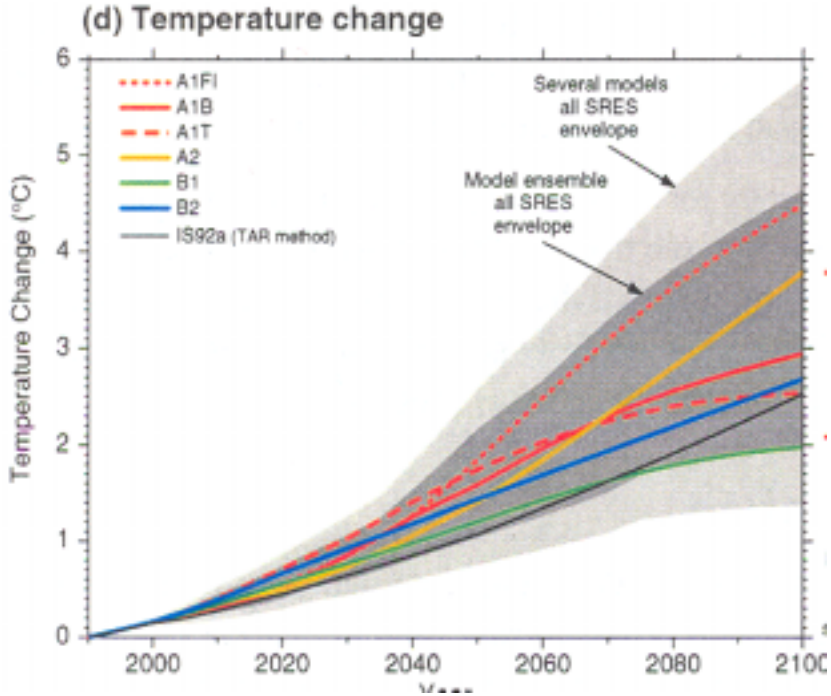
A skeptical view of the current global-warming paradigm*

The current paradigm among climate scientists:
"We understand the causes of the warming to date."

"Therefore, we are in a good position to forecast the future - specifically, the climatic consequences of various emission scenarios."



"Attribution" of past changes



"Projection" of future changes

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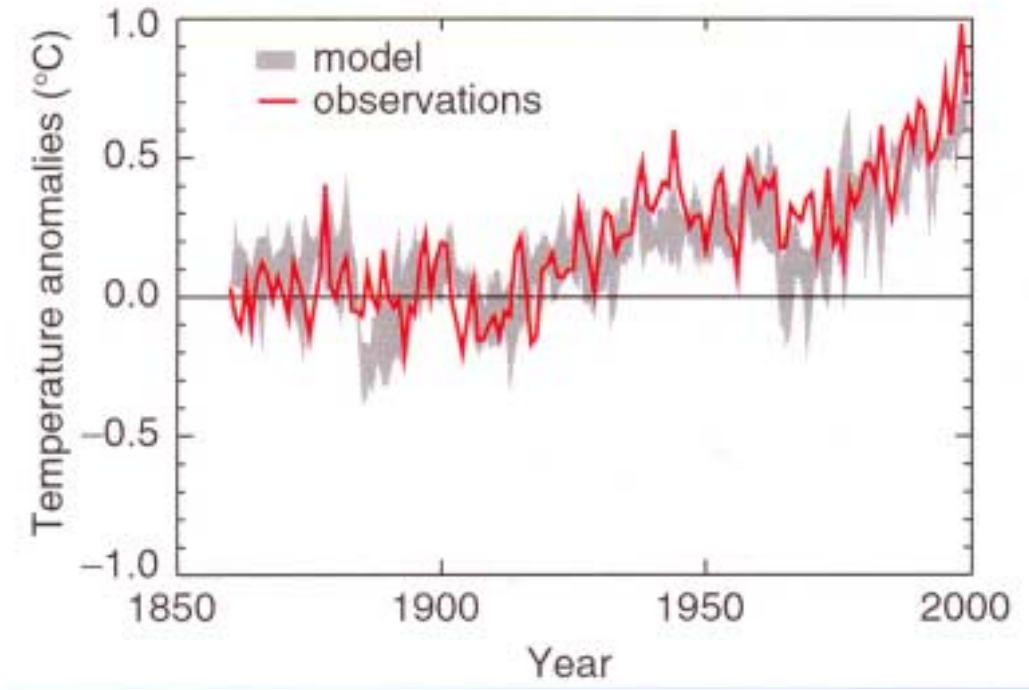
* Reference: Anderson, Charlson, Schwartz, Knutti, Boucher, Rodhe, Heintzenberg (2003), Science, 300, 1103-1104. Reprints available.

Problem with the attribution argument

Attribution:

"When we put known forcings into our climate models, we are able to reproduce the magnitude and pattern of industrial-era temperature changes."



Problem: The forcings (especially aerosol forcings) are not known!

IPCC Forcing bargraph

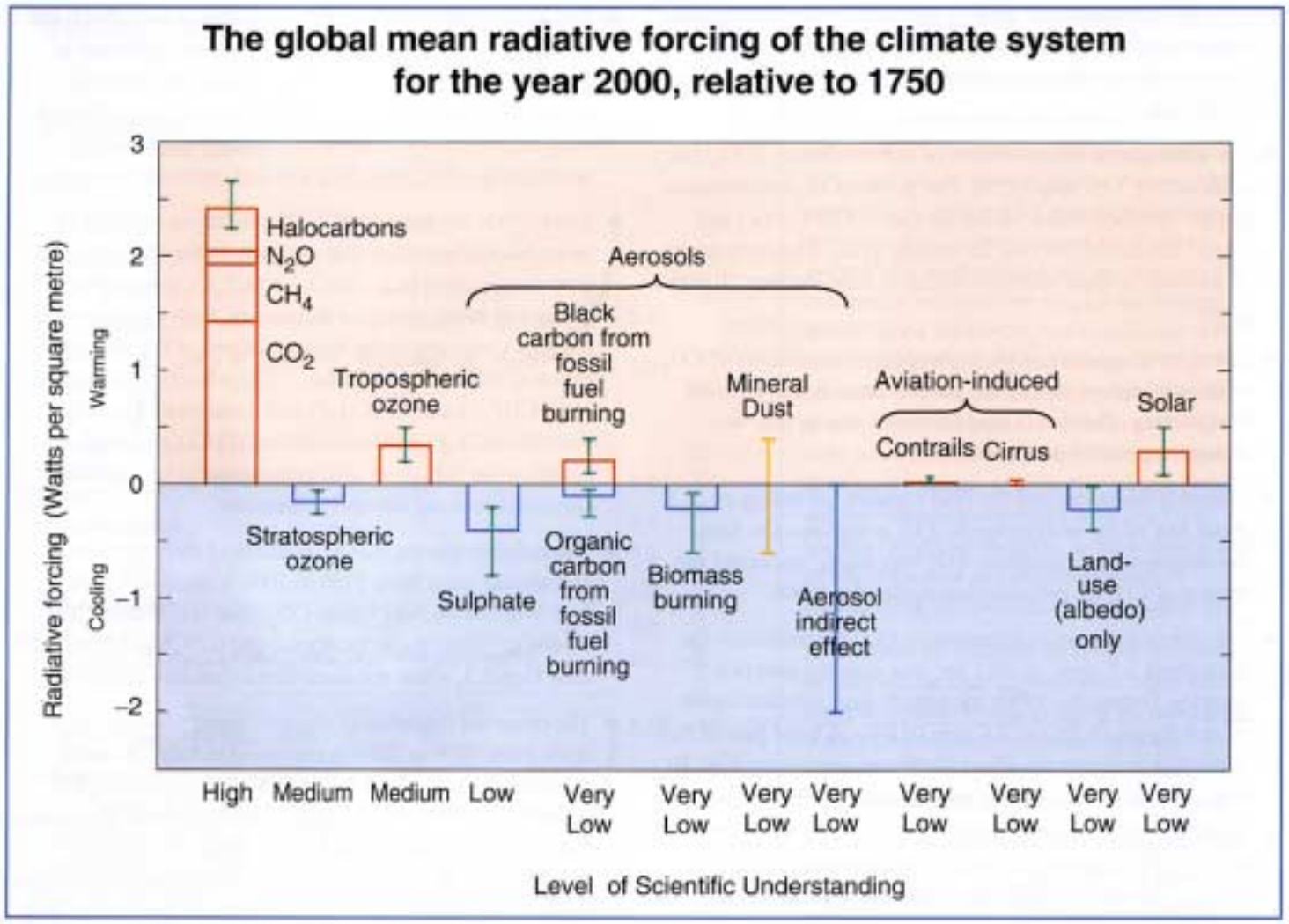
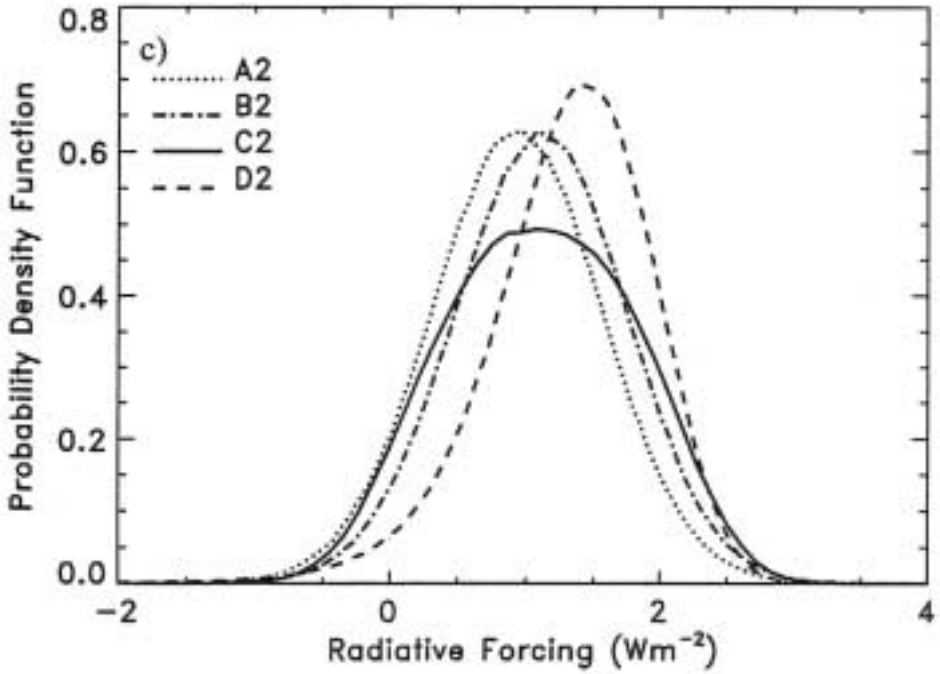


Figure 3: Many external factors force climate change.

Question: What is missing from this plot?

Adding up the industrial-era climate forcings

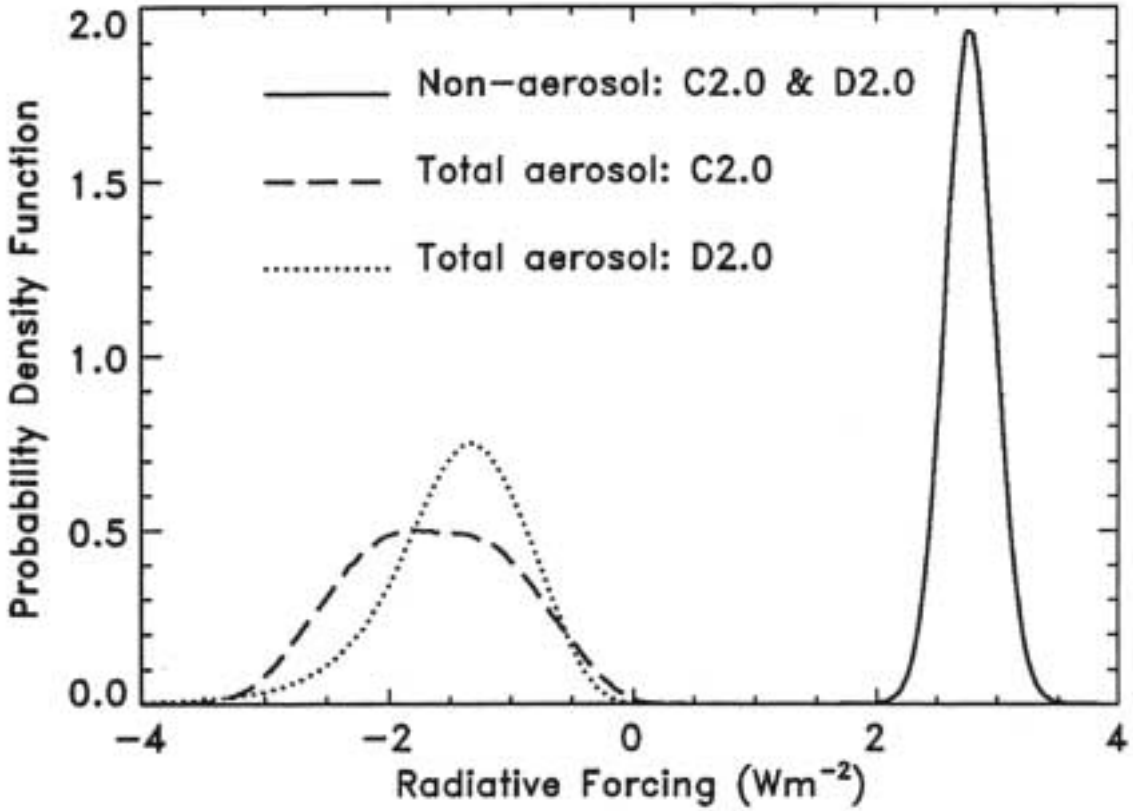
If we add up all the forcings (each of which is uncertain) the result is a probability distribution of the total, industrial-era forcing.
This analysis reveals a substantial possibility that the total forcing is very small or even negative.
What would this imply for the attribution studies? For the current global warming paradigm?



Boucher and Haywood, Clim. Dyn. 18, 297 (2001)

Separate the aerosol from the non-aerosol forcings

Forcing by aerosols is the main cause of this uncertainty.



Boucher and Haywood, Clim. Dyn. 18, 297 (2001)

Climate forcing by anthropogenic aerosols

Direct aerosol forcing: Particles reflect sunlight back to space.

Indirect aerosol forcing: Particles modify the properties of clouds, causing more droplets and, thus, more reflection of sunlight back to space.

Both of these effects:

- tend to cool the earth (thus counteract GHG warming)
- affect the shortwave (or solar) portion of the energy budget

These effects can be visualized using photographs from space (next slide)...

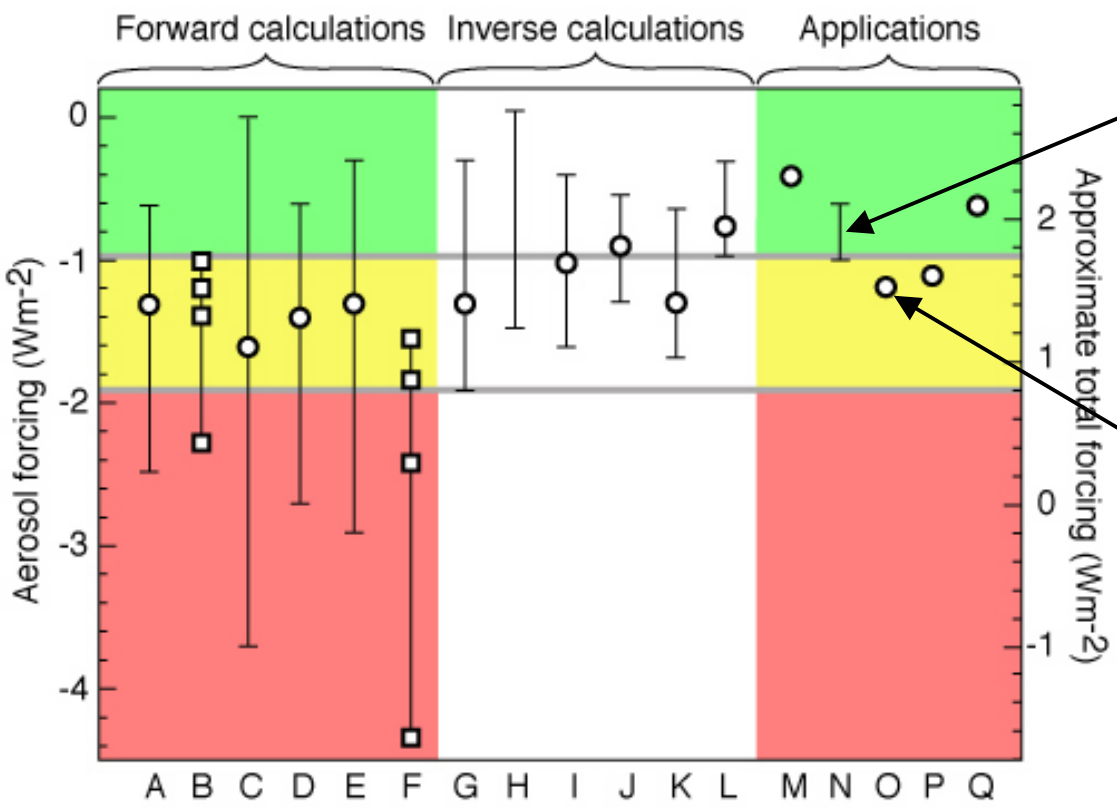
Aerosol Forcing viewed from space

Two methods of calculating aerosol forcing

1. *Forward calculations (study the aerosol)*
   - measure how much aerosol is in the atmosphere and estimate what fraction of this is anthropogenic
   - study optical and cloud-nucleating properties of the aerosol
   - calculate climate forcing due to anthropogenic aerosol

2. *Inverse calculations (fit the T-record)*
   - assume that the observed warming is the response to a substantial, positive forcing
   - make multiple runs of a simple climate model with varying values of aerosol forcing
   - see which values of aerosol forcing give a "fit" to the observed temperature record

Comparison of Aerosol Climate Forcing Methods



IPCC attribution

IPCC climate projection

•Inverse calculations show maximum limit on aerosol forcing magnitude that is consistent with the current paradigm.

•Forward calculations indicate substantial probability that this limit may be exceeded.

•Application studies are ignoring the forward calculations!

Current paradigm: on solid ground?

Danger of circular logic:

i. By fitting the temperature record, we can deduce the aerosol forcing.

ii. When we plug that value of aerosol forcing into our climate models, we can fit the temperature record!

Question: The fact that we can fit the temperature record means that we have a possible explanation for the observed warming. Does it necessarily mean we have the right explanation?

Recall Karl Popper: A good explanation (one that accounts for all the facts) is not necessarily the right explanation. We have no ultimate criteria for recognizing truth. But we do have ways of recognizing error. Therefore, science advances by diligent attempts to disprove current theories. The problem with circular logic is that it rules out the possibility of disproof.

Fitting the temperature record in the 1980's

Source:
Hansen et al.
1981, Science,
213, 957-966

Note: very different set of forcings!

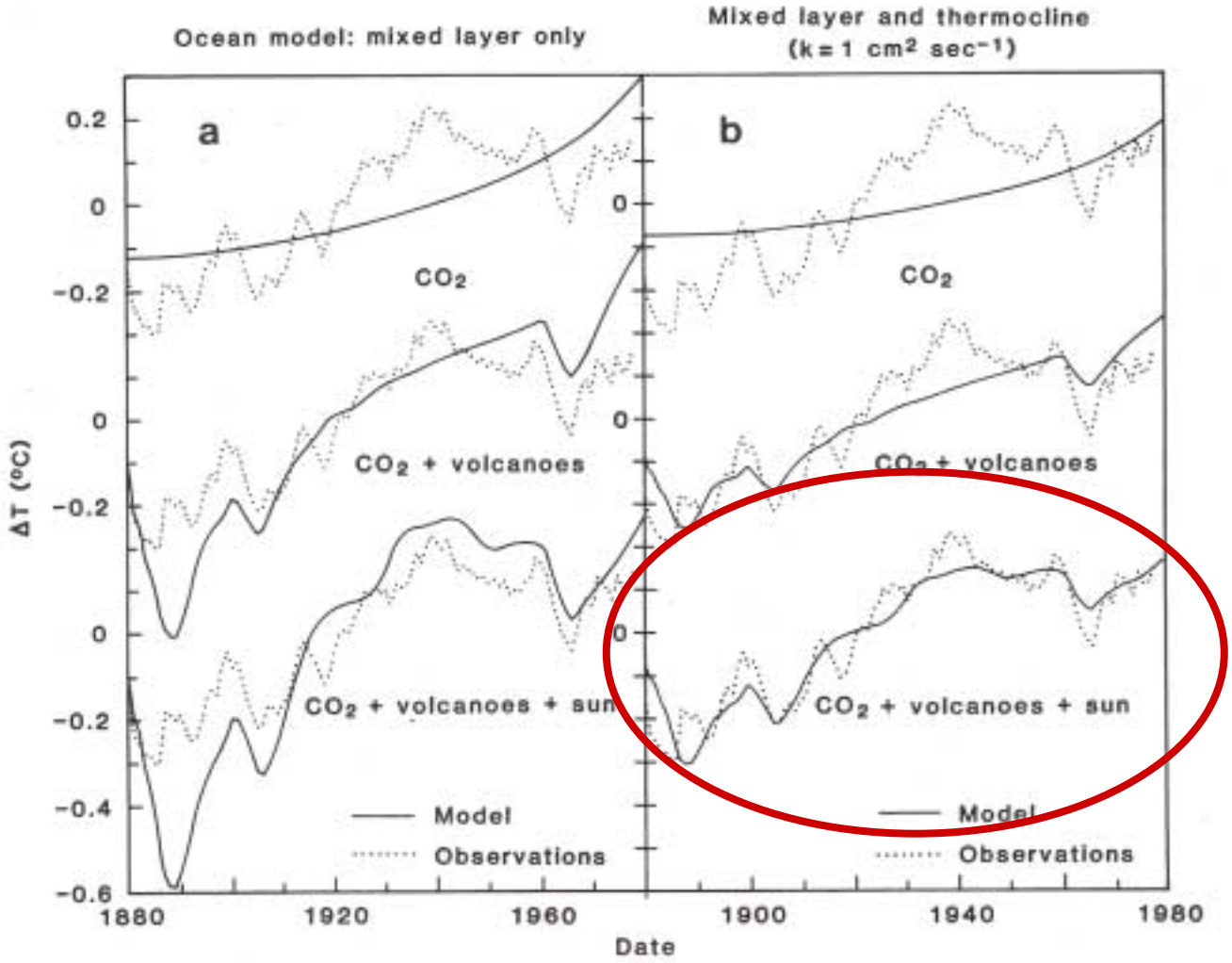


Fig. 5. Global temperature trend obtained from climate model with sensitivity 2.8°C for doubled CO_2. The results in (a) are based on a 100-m mixed-layer ocean for heat capacity; those in (b) include diffusion of heat into the thermocline to 1000 m. The forcings by CO_2, volcanoes, and the sun are based on Broecker (*25*), Lamb (*27*), and Hoyt (*48*). Mean ΔT is zero for observations and model.

Forcing Projection

with uncertainty in current forcing

with uncertainty in 2100 forcing

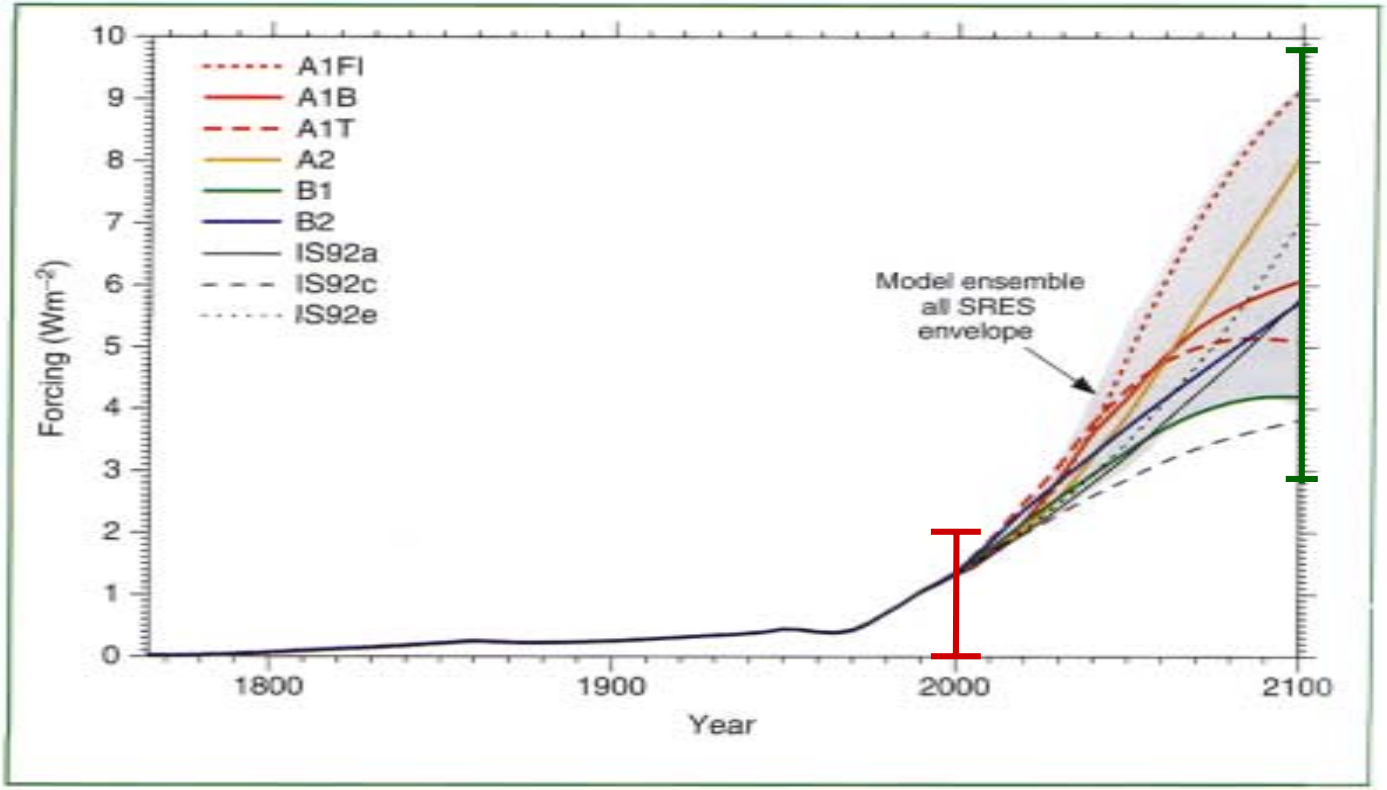


Figure 19: Simple model results: estimated historical anthropogenic radiative forcing up to the year 2000 followed by radiative forcing for the six illustrative SRES scenarios. The shading shows the envelope of forcing that encompasses the full set of thirty five SRES scenarios. The method of calculation closely follows that explained in the chapters. The values are based on the radiative forcing for a doubling of CO_2 from seven AOGCMs. The IS92a, IS92c, and IS92e forcing is also shown following the same method of calculation. [Based on Figure 9.13a]

Summary

Where do we stand?

• a major positive forcing is coming this century
• it is critical that climate scientists figure out how the earth will respond

• the current paradigm is "likely" to be correct, but
• until we have better knowledge of aerosol forcing, we should not rule out the possibilities that total forcing over the industrial-era has been small or even negative

• negative total forcing would imply:
  - the observed warming was not caused by a forcing
  - natural variability may be larger than we currently think

• small total forcing would imply:
  - the observed warming was caused by a smaller forcing than we currently think is possible
  - climate sensitivity may be larger than we currently think