Issues in Geoengineering

EPRI Climate Research Seminar

Washington, DC

21 May 2008

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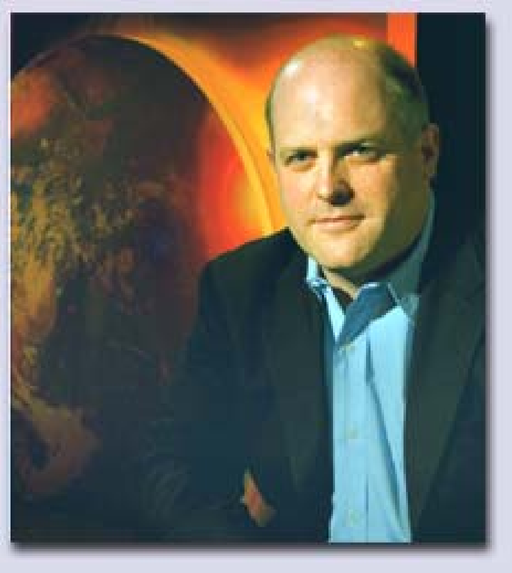
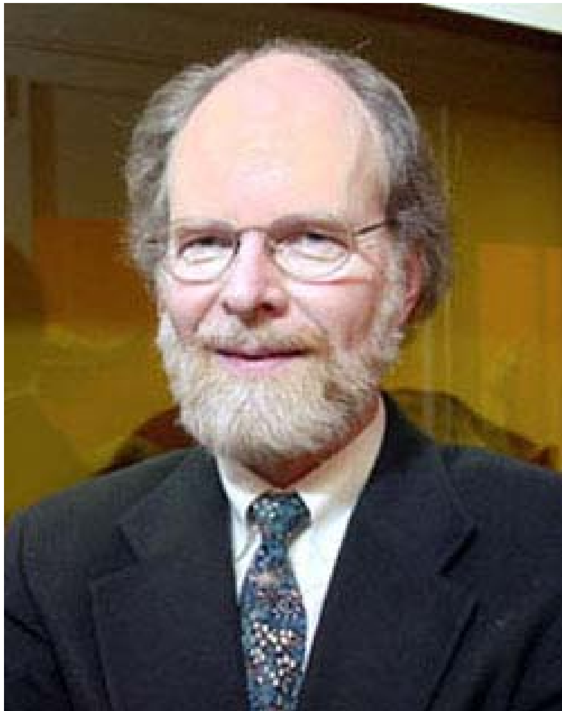
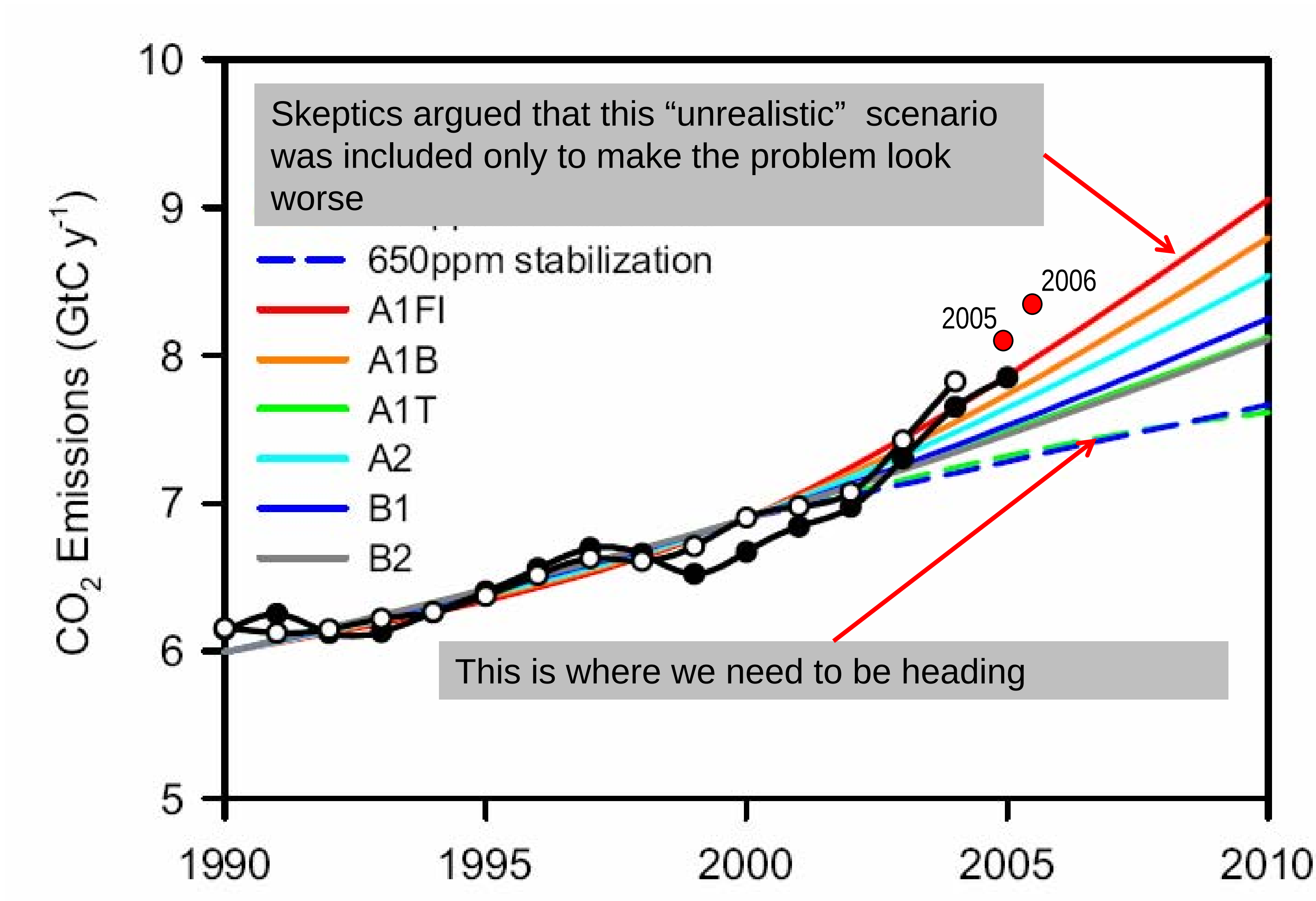


Emissions are rising faster than expected



Raupach, et al., PNAS, 2007.

How Industry May Change Climate

The amount of carbon dioxide in the air will double by the year 2080 and raise the temperature an average of at least 4 per cent. The burning of about two billion tons of coal and oil a year keeps the average ground temperature somewhat higher than it would otherwise be. If industrial growth extended over several thousand years instead of over a century only, the oceans would have absorbed most of the excess carbon dioxide. Seas circulate so slowly that they have had little effect in reducing the amount of the gas as man's smoke-making abilities multiplied during a hundred years.

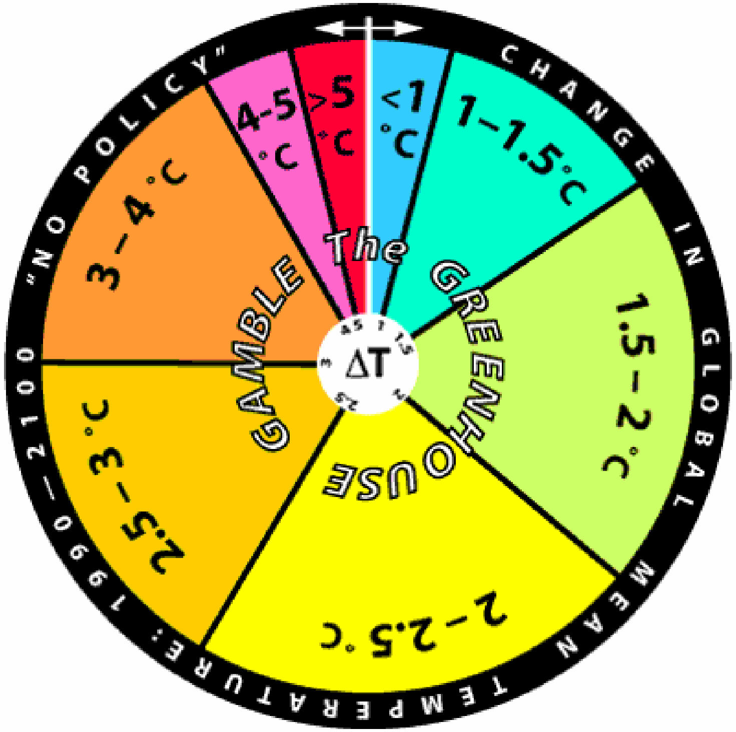
All this and more came out in the course of a paper that Dr. Gilbert N. Plass of Johns Hopkins presented before the American Geophysical Union. He found that man's industries add six billion tons of carbon dioxide to the atmosphere.

rents necessary for the onset of precipitation. This may mean less rainfall and cloud cover, so that still more sunlight can reach the earth's surface. Thus man tends to make his climate warmer and drier; should there be a decrease in carbon dioxide, a cooler and wetter climate would result.

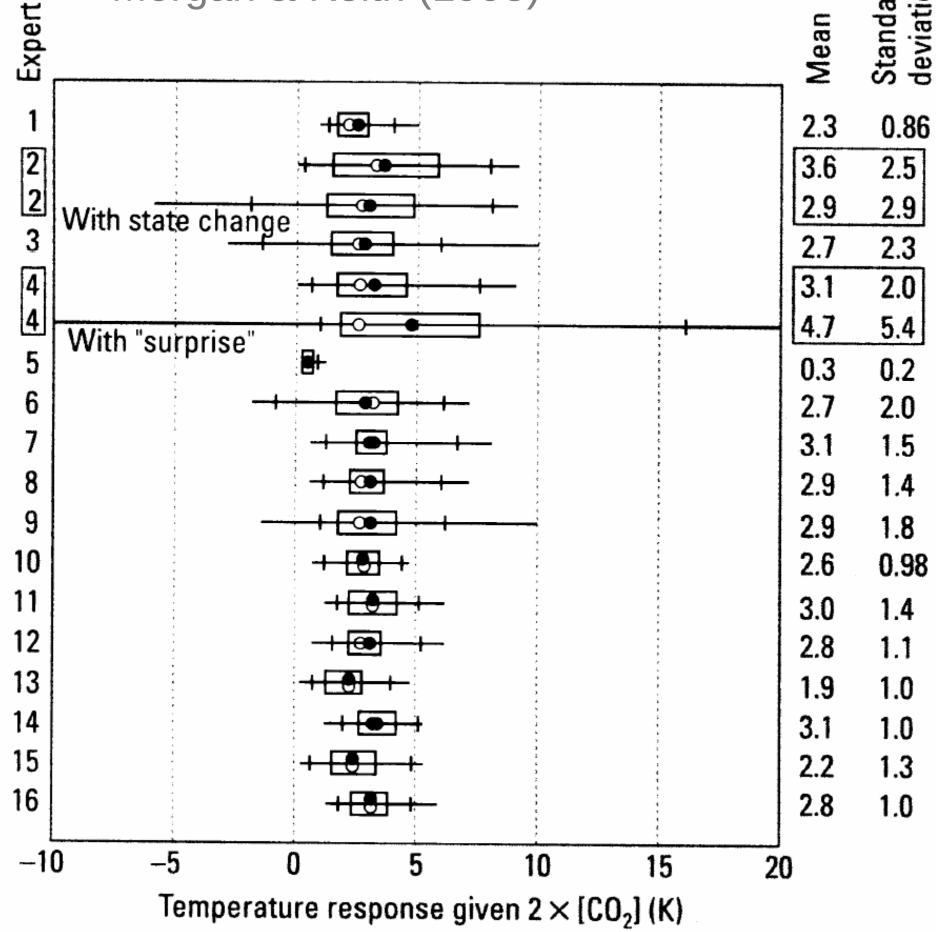
Theory Applied to Glaciers

All this reinforces a theory advanced in 1861 that decreases in carbon dioxide explain the growth and advance of glaciers at various intervals in the

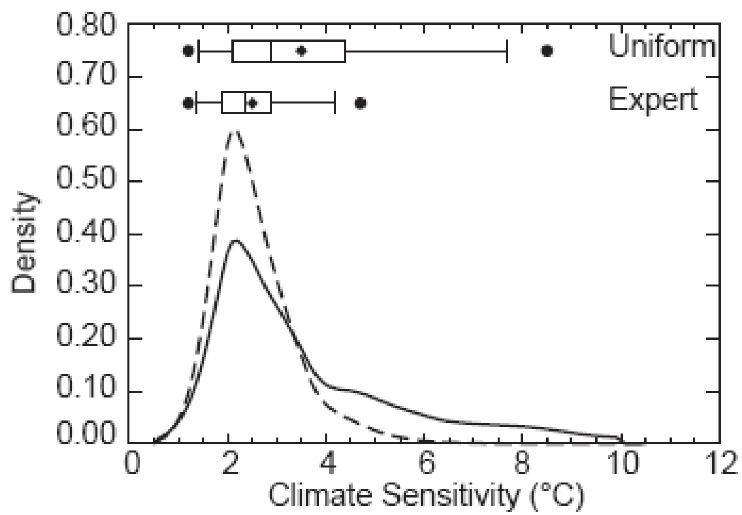
New York Times
May 24th **1953**



Morgan & Keith (1995)



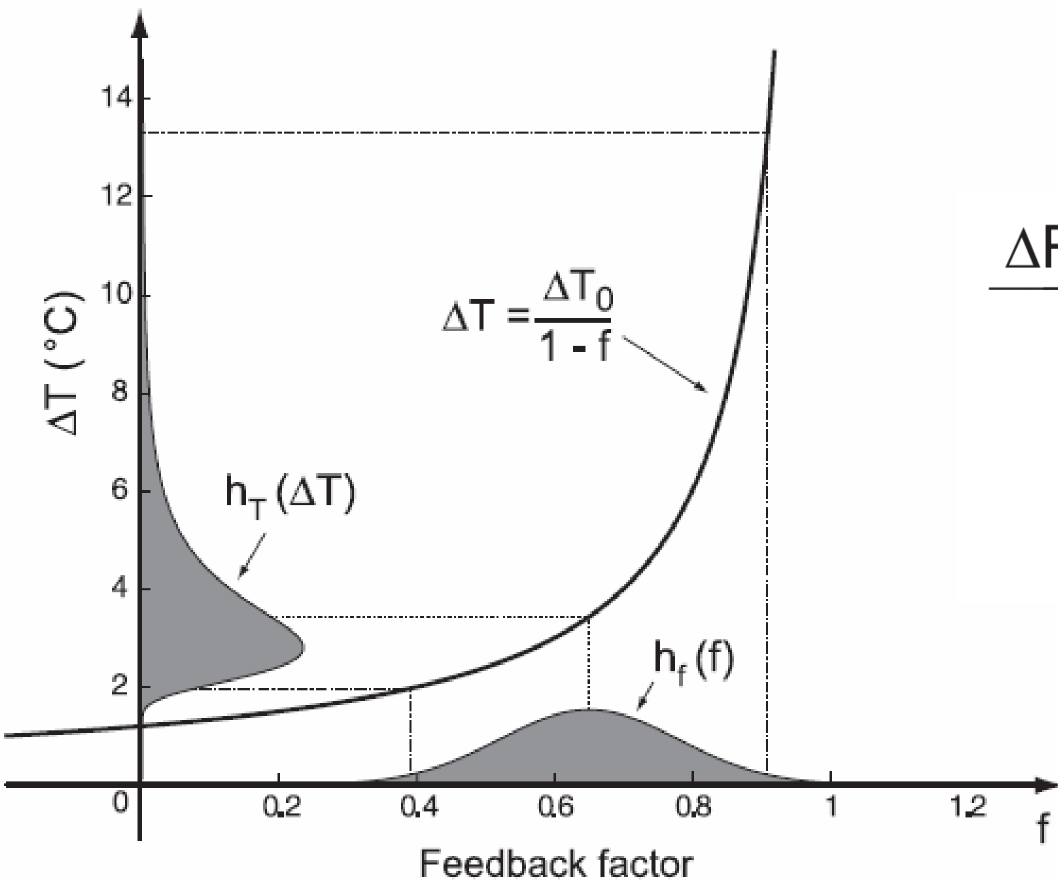
Forest et al (2002)

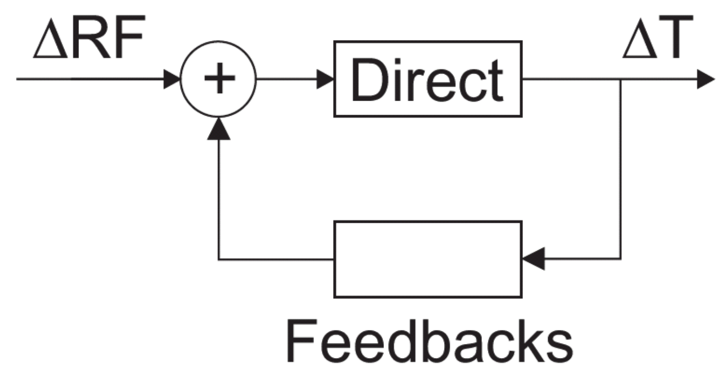


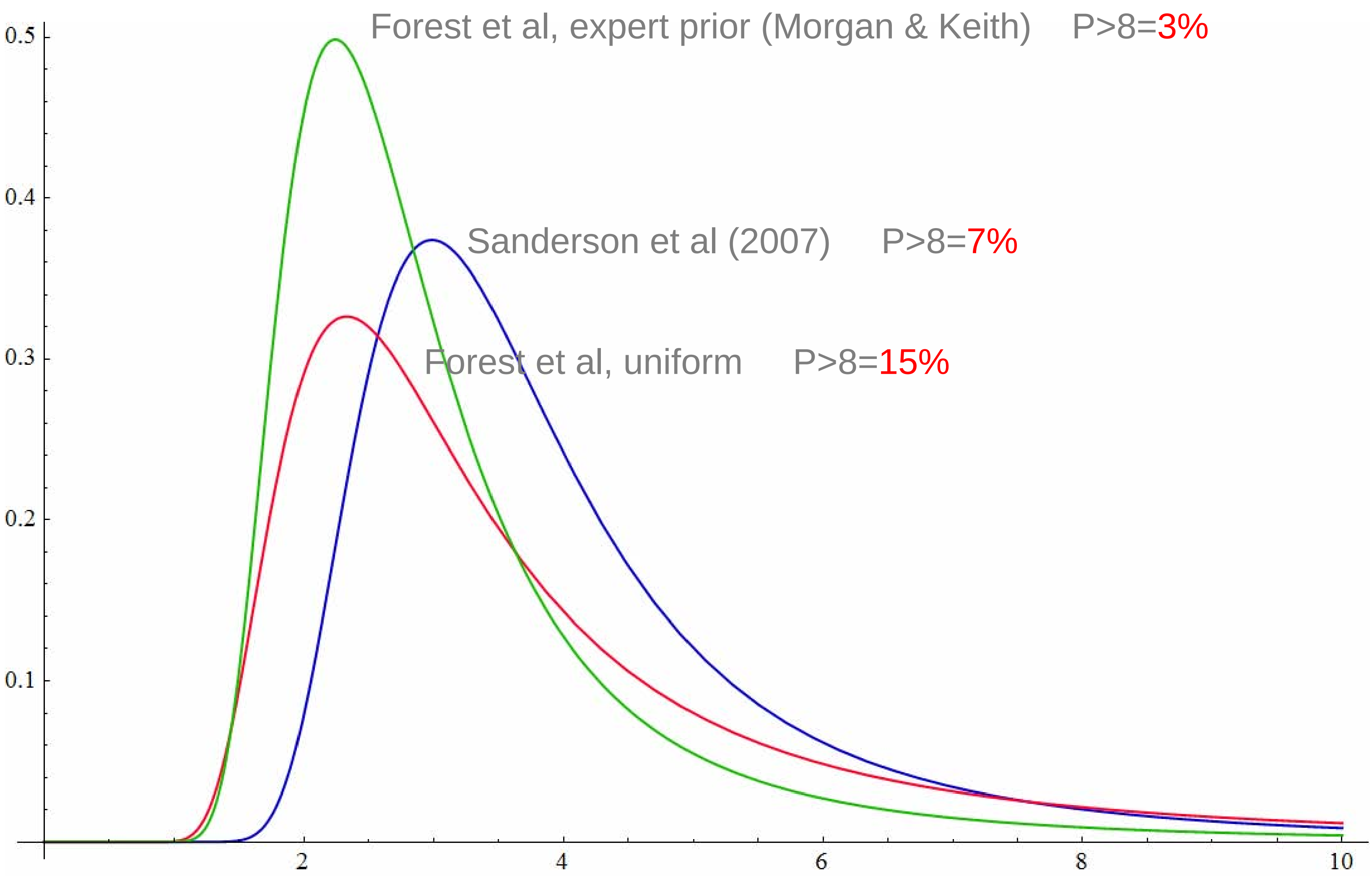
Why Is Climate Sensitivity So Unpredictable?

SCIENCE
26 OCTOBER 2007

Gerard H. Roe* and Marcia B. Baker

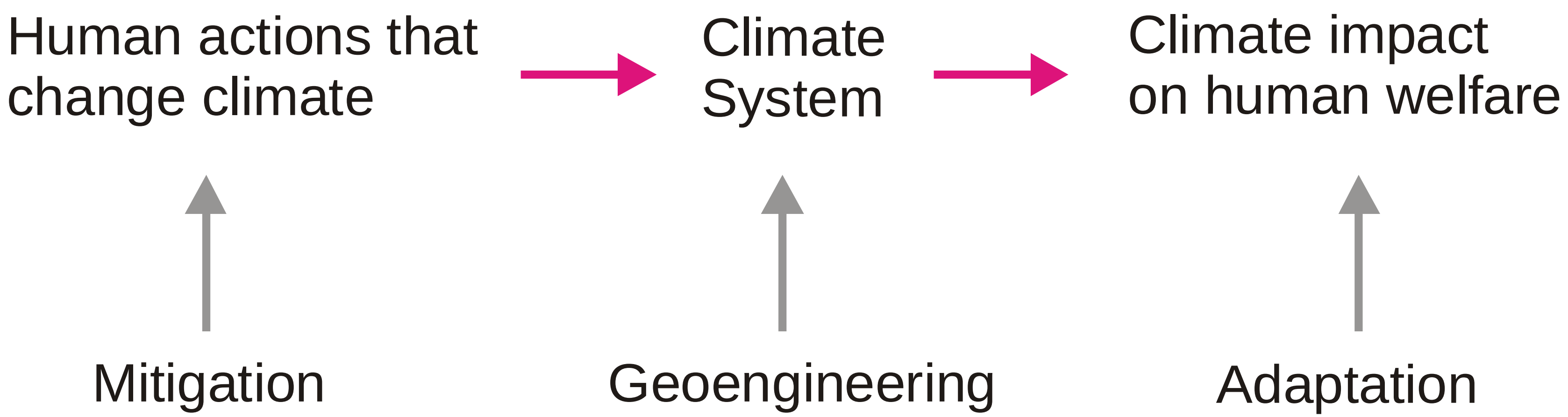


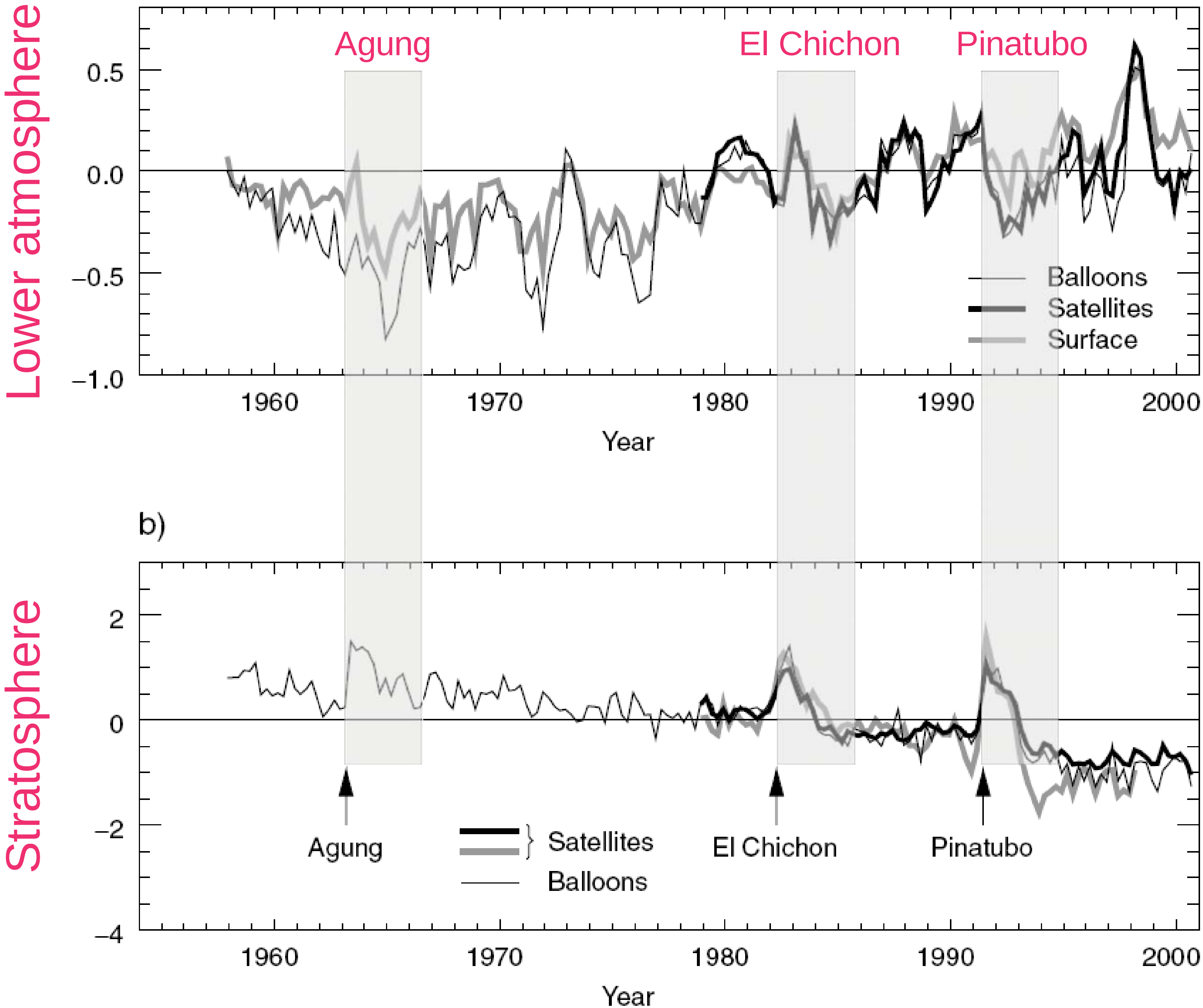




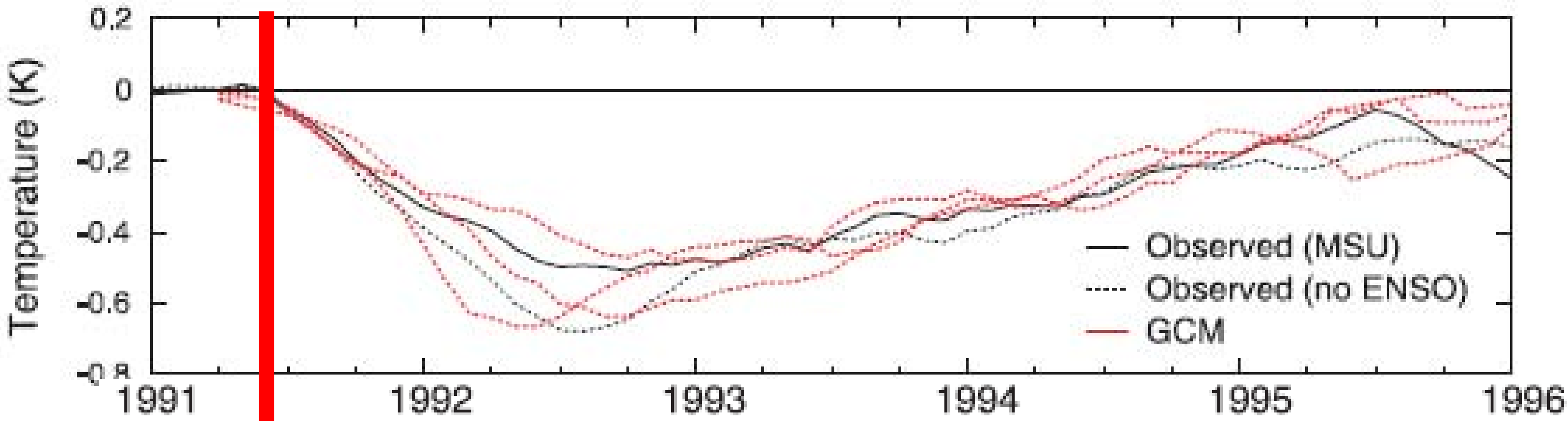
Forest et al, expert prior (Morgan & Keith) P>8=3%
Sanderson et al (2007) P>8=7%
Forest et al, uniform P>8=15%
0.5
0.4
0.3
0.2
0.1
2
4
6
8
10

Human actions that change climate → Climate System → Climate impact on human welfare


Human actions that change climate
Climate System
Climate impact on human welfare
Mitigation
Geoengineering
Adaptation


Lower atmosphere
Agung
El Chichon
Pinatubo
0.5
0.0
−0.5
−1.0
Balloons
Satellites
Surface
1960
1970
1980
1990
2000
Year
b)
Stratosphere
2
0
−2
−4
Agung
Satellites
Balloons
El Chichon
Pinatubo
1960
1970
1980
1990
2000
Year

Temperatures after Mt. Pinatubo



Soden et al., 2002

USGS

If the radiative forcing from Mt Pinatubo were sustained, temperature changes may have been 10 times greater

(thermal inertia of ocean)

Putting sulfur in the stratosphere

Of order 1-2 Mt-S per year offsets the radiative forcing of 2×CO_2
(~2-4% of current global S emissions)

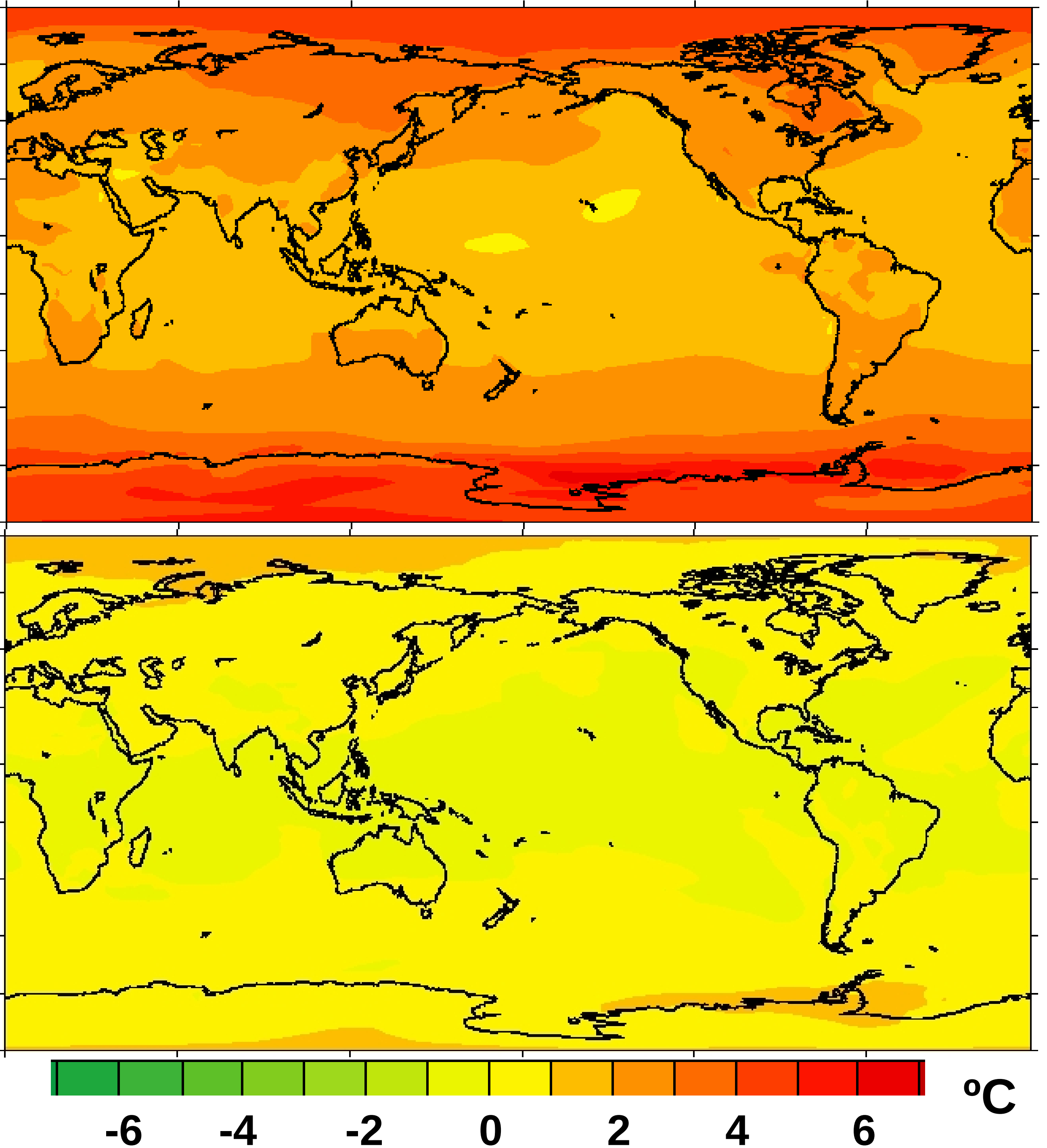
~3 gram sulfur in the stratosphere *roughly* offsets 1 ton carbon in the atmosphere (S:C ~ 1:300,000)

Assuming the NAS 1992 number of 20 $/kg → 30 billion per year.

Methods:

1. Naval guns
2. Aircraft
3. Tethered balloon with a hose

Models suggest the compensation is quite good



2 x CO_2

2 x CO_2
and
1.8% reduction in solar intensity

Caldeira et al., in prep, 2007

Experiments by Phil Rasch, Paul Crutzen, Danielle Coleman

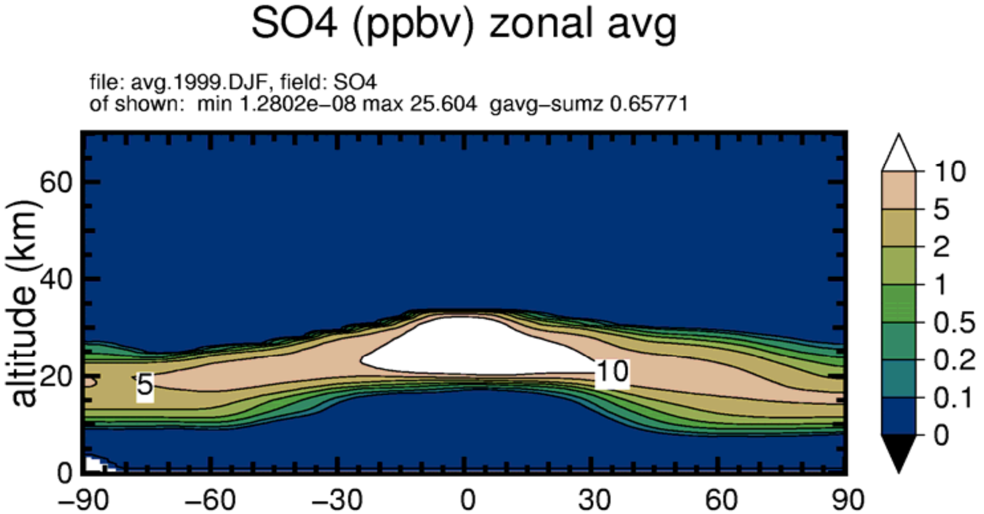
NCAR Community Atmosphere Model

Middle atmosphere configuration
- Model top at about 80km
- 52 layers
- 2x2.5 Degree Horizontal resolution
- Finite Volume solution for dynamics with desirable properties for transport

Photochemistry includes only that relevant to oxidation of DMS and SO_2 –> SO_4

Injection of SO_2
- at 25km
- from 10N - 10S
- 1 Tg S/yr assuming a small (or background) aerosol size distribution

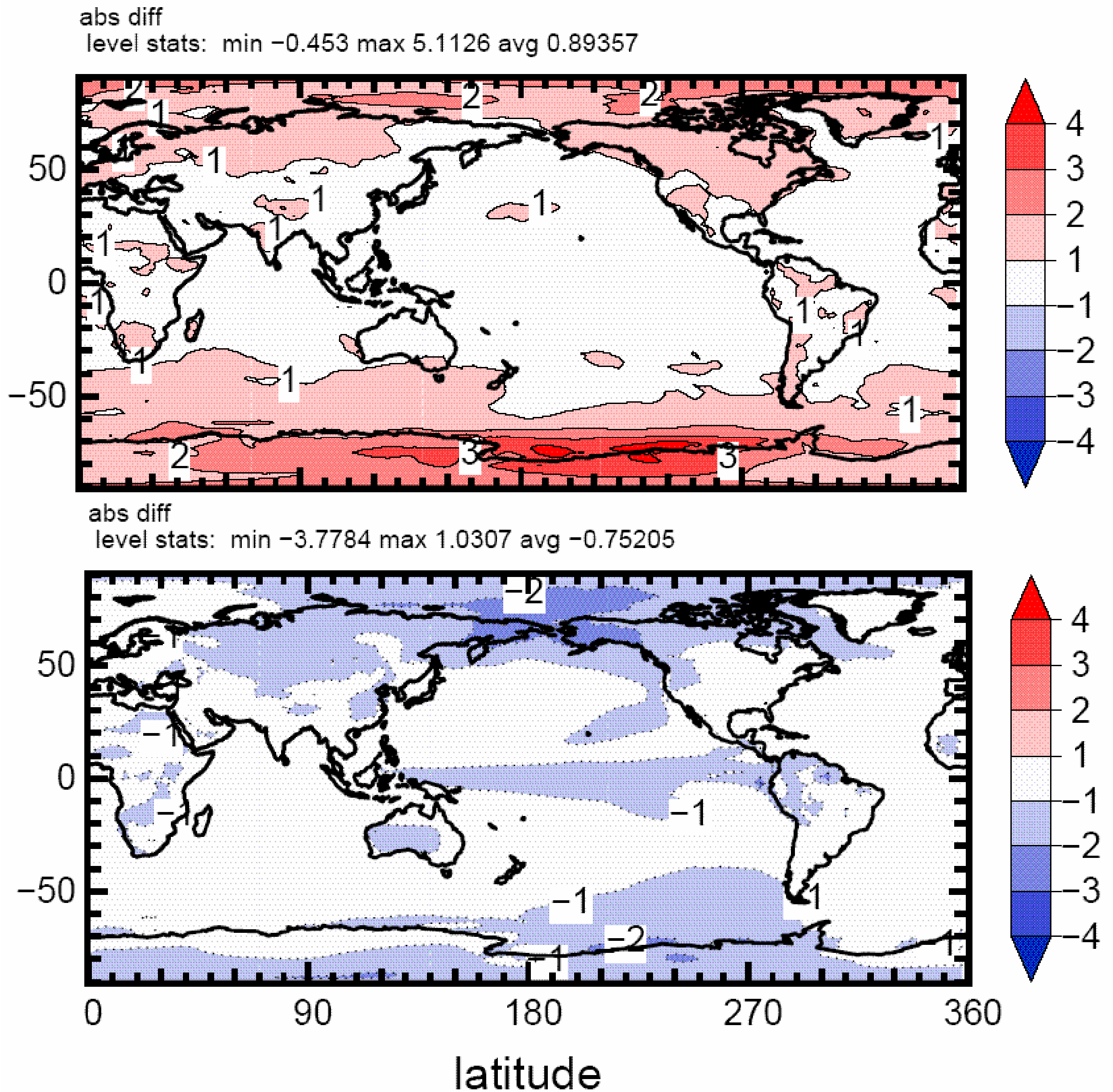
Pinatubo ≈10-30 Tg S

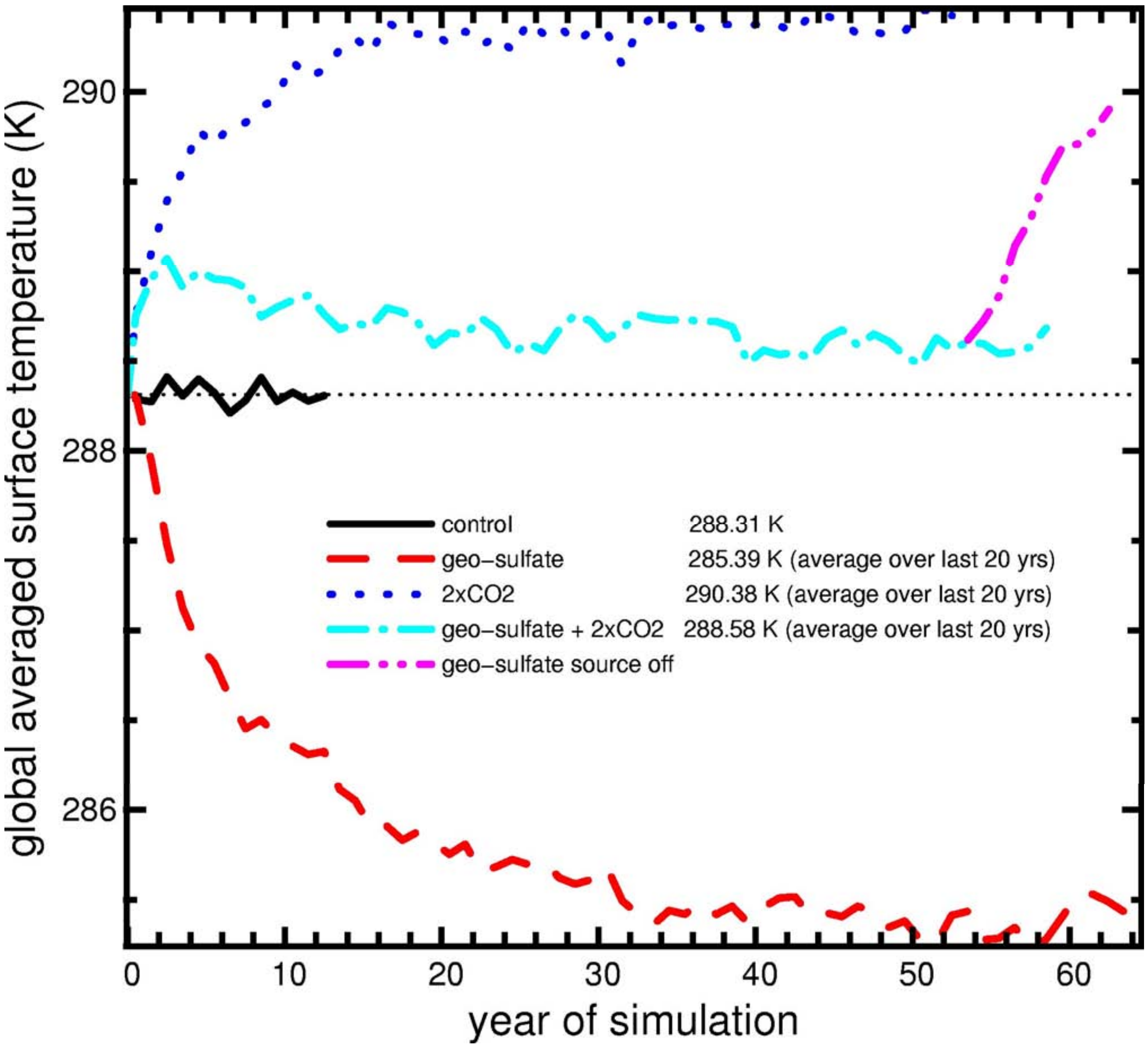


Rasch et al: Annual Average Surface Temperature

Geo-SO4/2xCO2 (1Tg Bkg)- Control

Geo-SO4/2xCO2 (2Tg Bkg)- Control





global averaged surface temperature (K)
290
288
286
0
10
20
30
40
50
60
year of simulation
control 288.31 K
geo−sulfate 285.39 K (average over last 20 yrs)
2xCO2 290.38 K (average over last 20 yrs)
geo−sulfate + 2xCO2 288.58 K (average over last 20 yrs)
geo−sulfate source off

Engineered scattering systems

Alternative scattering systems

- Oxides
  - H_2SO_4 or Al_2O_3
- Metallic particles ($10\text{-}10^3 \times$ lower mass)
  - Disks, micro-balloons or gratings
- Resonant ($10^4\text{-}10^6 \times$ lower mass ??)
  - Encapsulated organic dyes

What you might get:

- Much lower mass
- Spectral selectivity

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 105, NO. D3, PAGES 3727–3736, FEBRUARY 16, 2000

Vertical transport of anthropogenic soot aerosol into the middle atmosphere

R. F. Pueschel,[1] S.Verma,[2] H. Rohatschek,[3] G. V. Ferry,[1] N. Boiadjieva,[4] S. D. Howard,[5] and A. W. Strawa[1]

Abstract. Gravito-photophoresis, a sunlight-induced force acting on particles which are geometrically asymmetric and which have uneven surface distribution of thermal accommodation coefficients, explains vertical transport of fractal soot aerosol emitted by aircraft in conventional flight corridors (10-12 km altitude) into the mesosphere (>80 km altitude). While direct optical effects of this aerosol appear nonsignificant, it is conceivable that they play a role in mesospheric physics by providing nuclei for polar mesospheric cloud formation and by affecting the ionization of the mesosphere to contribute to polar mesospheric summer echoes.

Photophoresis

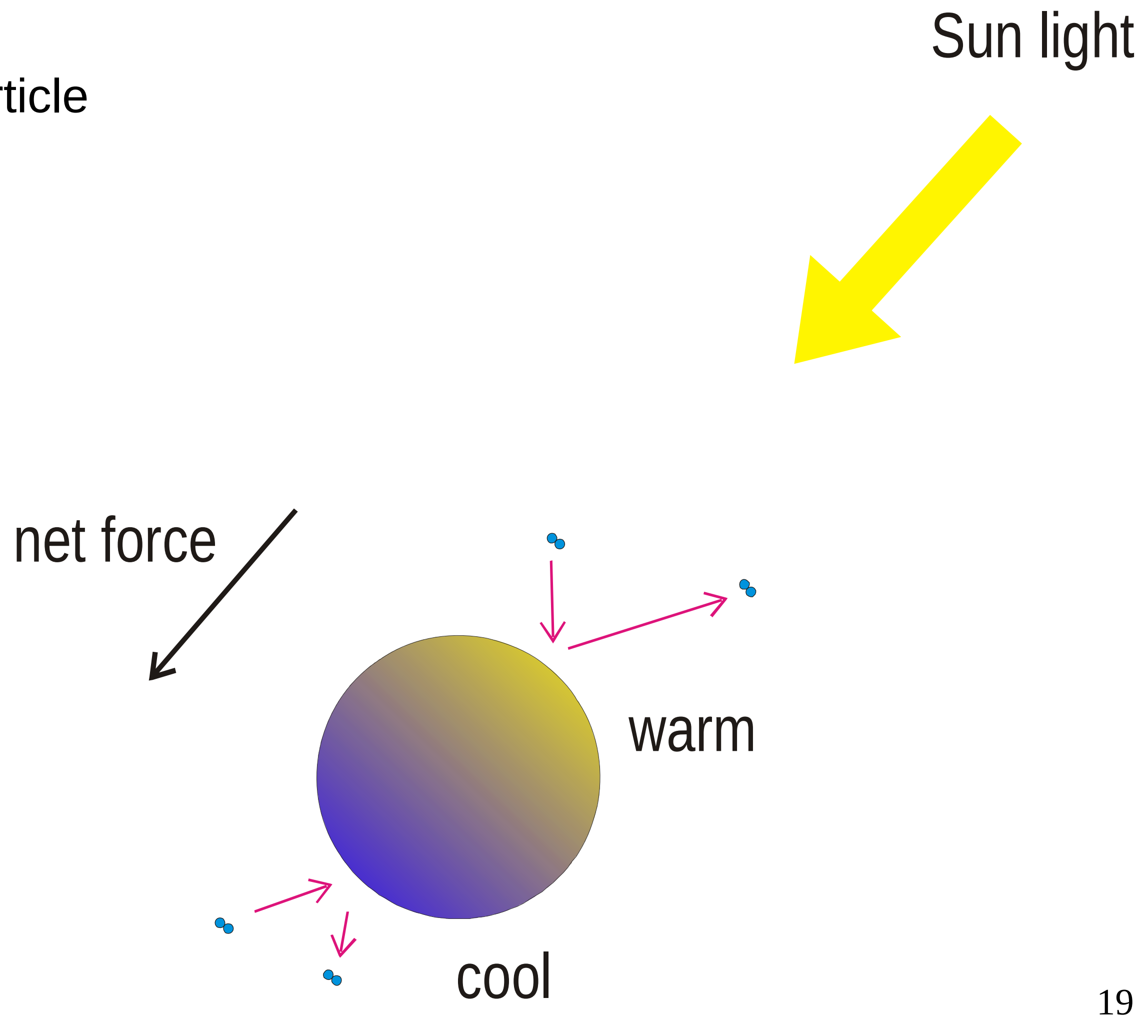
Uneven illumination

↓

Temperature gradient across particle

↓

Net force toward cool side



Gravito-Photophoresis

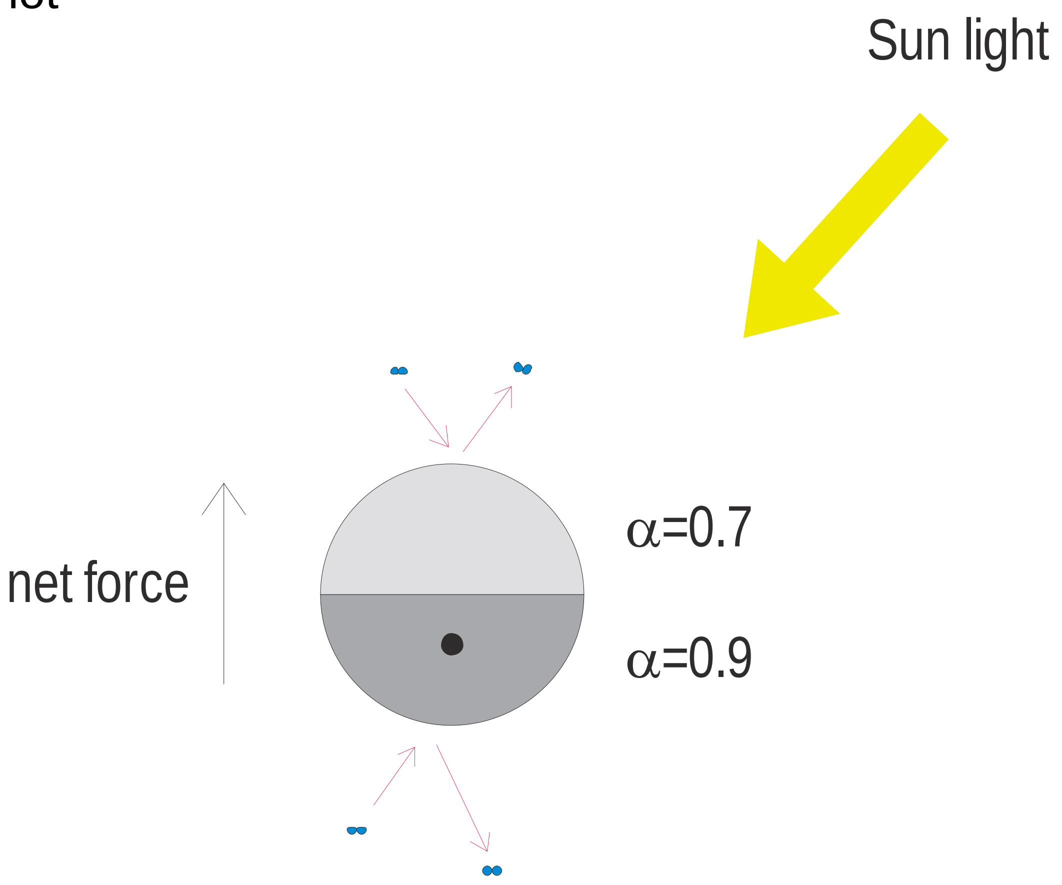
Sunlight warms particle evenly

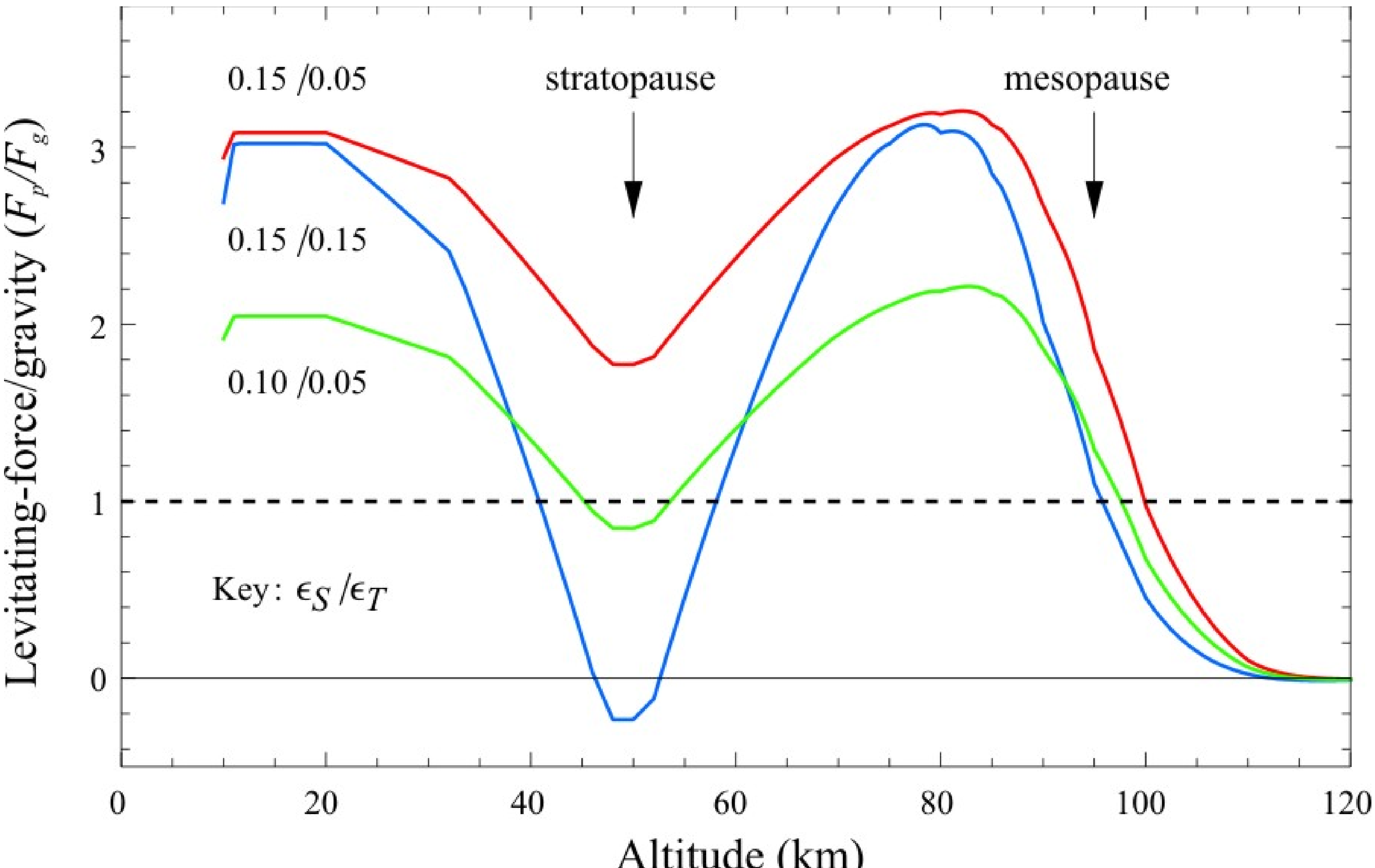
↓

Particles more likely to rebound hot from bottom of particle

↓

Net upward force




0.15 /0.05
stratopause
mesopause
0.15 /0.15
0.10 /0.05
Key: ϵ_S / ϵ_T
Levitating-force/gravity (F_p/F_g)
Altitude (km)
0
1
2
3
0
20
40
60
80
100
120

Photophoretic levitation of nano-engineered scatterers for climate engineering

1. Long atmospheric lifetimes
   - ➔ Lower cost and impact of replenishment
   - ➔ Can afford more elaborately engineered scatters

2. Particles above the stratosphere
   - ➔ less ozone impact.

3. The ability to concentrate scattering particles near the poles
   - ➔ Concentrate climate engineering where it’s needed most.

4. Non-spherical scattering particle designs
   - ➔ Minimal forward scattering.
   - ➔ Advanced designs that are spectrally selective.

RESTORING THE QUALITY

OF

OUR ENVIRONMENT

THE WHITE HOUSE

NOVEMBER 1965

OTHER POSSIBLE EFFECTS OF AN INCREASE IN ATMOSPHERIC CARBON DIOXIDE

Melting of the Antarctic ice cap.—It has sometimes been suggested that atmospheric warming due to an increase in the CO_2 content of the atmosphere may result in a catastrophically rapid melting of the Antarctic ice cap, with an accompanying rise in sea level. From our knowledge of events at the end of the Wisconsin period, 10 to 11 thousand years ago, we know that melting of continental ice caps can occur very rapidly on a geologic time scale. But such melting must occur relatively slowly on a human scale.

The Antarctic ice cap covers 14 million square kilometers and is about 3 kilometers thick. It contains roughly 4×10^{16} tons of ice, hence 4×10^{24} gram calories of heat energy would be required to melt it. At the present time, the poleward heat flow across 70° latitude is 10^{22} gram calories per year, and this heat is being radiated to space over Antarctica without much measurable effect on the ice cap. Suppose that the pole-

This is a hundred times greater than present worldwide rates of sea level change.

Warming of sea water.—If the average air temperature rises, the temperature of the surface ocean waters in temperate and tropical regions could be expected to rise by an equal amount. (Water temperatures in the polar regions are roughly stabilized by the melting and freezing of ice.) An oceanic warming of 1° to 2°C (about 2°F) oc-

The climatic changes that may be produced by the increased CO_2 content could be deleterious from the point of view of human beings. The possibilities of deliberately bringing about countervailing climatic changes therefore need to be thoroughly explored. A change in the radiation balance in the opposite direction to that which might result from the increase of atmospheric CO_2 could be produced by raising the albedo, or reflectivity, of the earth. Such a change in albedo could be

ALBEDO ENHANCEMENT BY STRATOSPHERIC SULFUR INJECTIONS: A CONTRIBUTION TO RESOLVE A POLICY DILEMMA?

Economist.com

WORLD

INTERNATIONAL

Green.view

Dr Strangelove saves the earth

Jan 15th 2007

From Economist.com

How big science might fix climate change

"massive and drastic" operations, as the chief U.N

describes them.

The Nobel Prize-winning scientist who first made th

himself "not enthusiastic about it."

heat-trapping greenhouse gases.

Their proposals were relegated to the fringes of clima

Few journals would publish them. Few government a

Environmentalists and mainstream scientists said th

greenhouse gases and preventing global warming in t

Tuesday, September 25, 2007

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Cool Geo-Whiz Warming Ideas

More scientists are thinking outside the box on global warming-way outside

By Bret Schulte

Posted 10/15/06

Page 2 of 2

A number of scientists are practically knocking down the door with geoengineering solutions. Advancing an idea once worked on by the father of the hydrogen bomb, Edward Teller, atmospheric scientist and Nobel Prize-winner Paul Crutzen believes Earth's temperature could be quickly brought down by spraying pollution into the atmosphere on a global scale. He issued a paper earlier this year pointing out that heavy artillery could fire rockets into the stratosphere. Once there, emissions from a special fuel would convert into sunlight-reflecting sulfate particles.

Is climate control impossible?

Chaos = extreme sensitivity to initial conditions

One might assume: Weather is chaotic ~~→~~ control is impossible

Not so!

Control of chaotic systems requires four things

1. A model (initial conditions → future state).
2. Observations.
3. An appropriate lever.
4. Feedback.

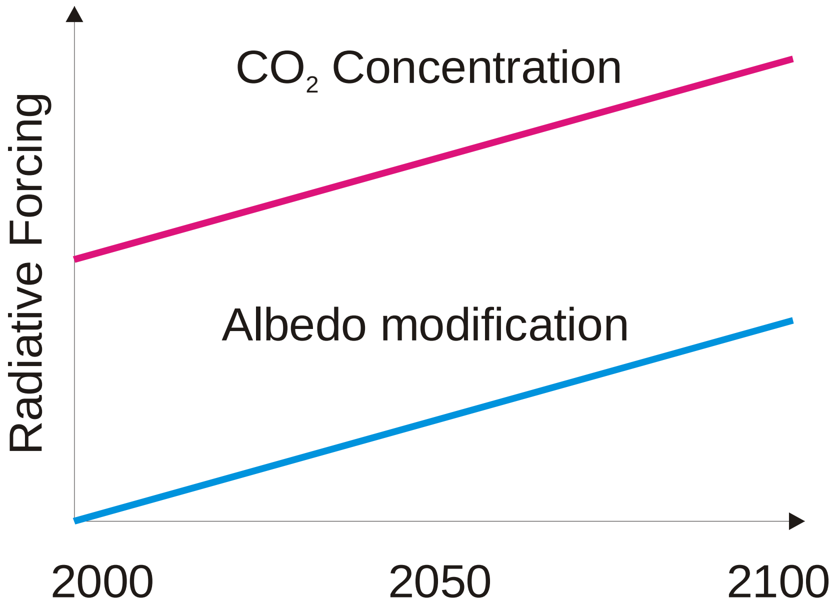
X-29 NASA-DFRC

Improved observations
Improved models
Improved analysis/forecast systems

→ A bigger lever → Smaller perturbations needed to achieve a given degree of weather control

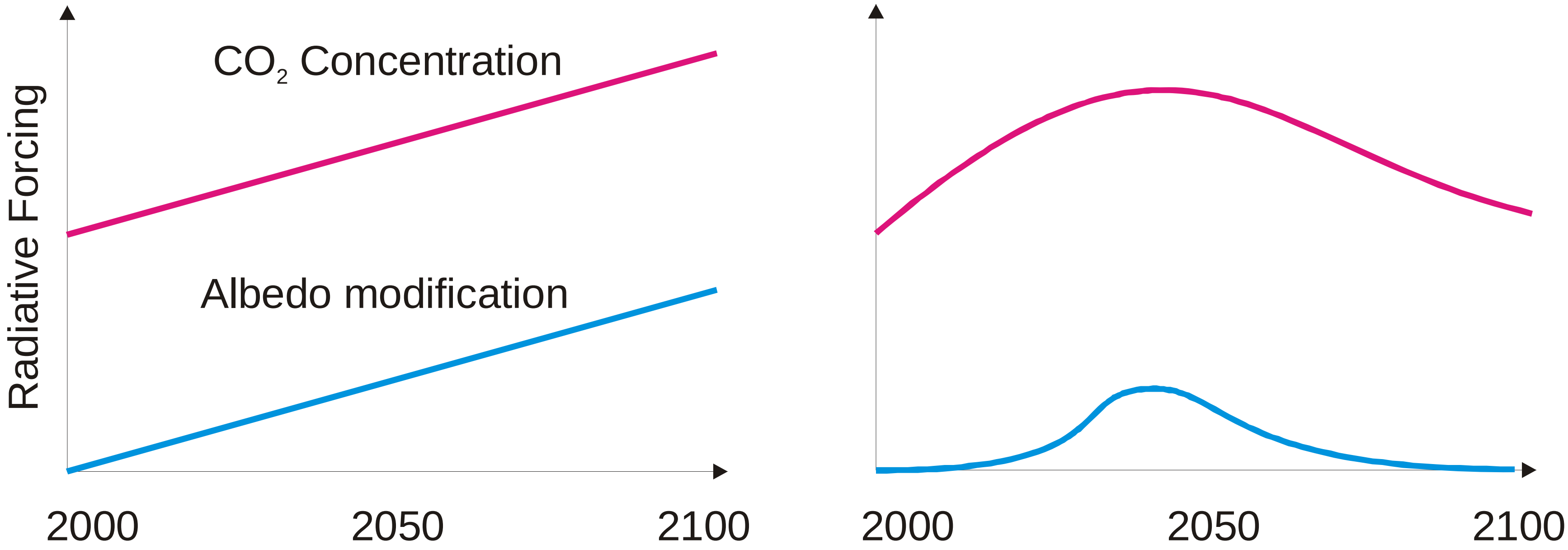
See Ross Hoffman, "Controlling the global weather",
Bulletin of the American Metrological Society February 2002 : 241-248

Geoengineering instead of mitigation



Geoengineering instead of mitigation

Geoengineering to take the edge of the heat



Warning: Moral Hazard

Knowledge that geoengineering is possible

↓

Climate impacts look less fearsome

↓

A weaker commitment to cutting emissions now

Value of knowing more about climate engineering

Assumptions:

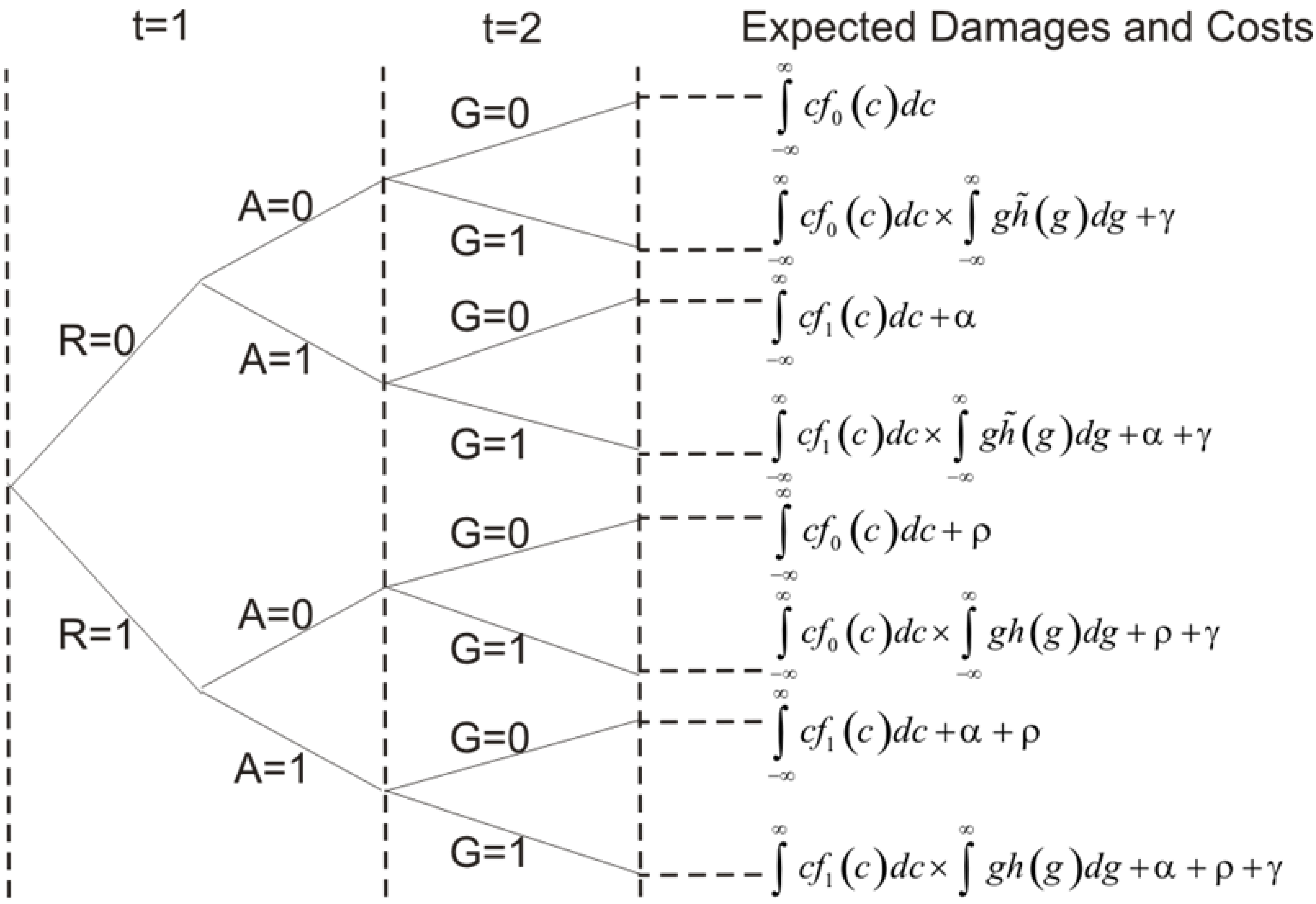
1. The prior probability that climate engineering will reduce climate risk.

2. The cost of research to narrow the uncertainty about the effectiveness of climate engineering.

3. The probability of big climate impacts for CO_2 above ~500 ppm.

Summary: you need to be **very sure** that climate engineering will never work, or think that the climate risk is **very small** to conclude that research is not justified.

Value of knowing more about climate engineering



Eos, Transactions, American Geophysical Union, Vol. 73, No. 27, July 7, 1992, Pages 289, and 292–293.

Current discussions of geoengineering are unsystematic and take insufficient account of prior results. The possibility of unpleasant suprises in the climate system justifies a more coherent (though not large) research program in order to define fallback options needed to make reasonable policy choices. A rational allocation of research priorities dictates that some resources be spent to study geoengineering unless nasty surprises are assigned a zero probability.

erate manipulation of climate forcings intended to keep the climate in a desired state, in contrast to abatement, which re-

unlimited energy at fixed (usually high) marginal cost.

The existence of a fallback is critically

ception of direct ocean disposal and afforestation, these schemes have the theoretical potential to mitigate the full effect of anthro-

Questions & Opinions

Opinions

1. We need a serious research program
   - Impacts, methods and implications
   - International
   - Need not be large $$ to make enormous progress.

2. Current understanding of climate systems suggests that intelligently executed climate engineering would reduce climate risks.

3. Geoengineering should be treated as a means of managing the worst impacts of climate change, not as a substitute for emissions controls.

4. The science community should expect to loose control.

Questions

1. How can we best avoid the geoengineering ←→ mitigation trade off?

2. Should we work toward a treaty? Norms? An alternate mechanism?

www.ucalgary.ca/~keith/Bibliography.html

Username: carbon

Password: graphite

Warning: Slippery Slope

“Interest in CO_2 may generate or reinforce a lasting interest in national or international means of climate and weather modification; once generated, that interest may flourish independent of whatever is done about CO_2.”

1982 US National Academy study, *Changing Climate.*