Geoengineering

50th Anniversary of the Global CO_2 Record
Symposium and Celebration,
30 November 2007,
Kona, Hawaii

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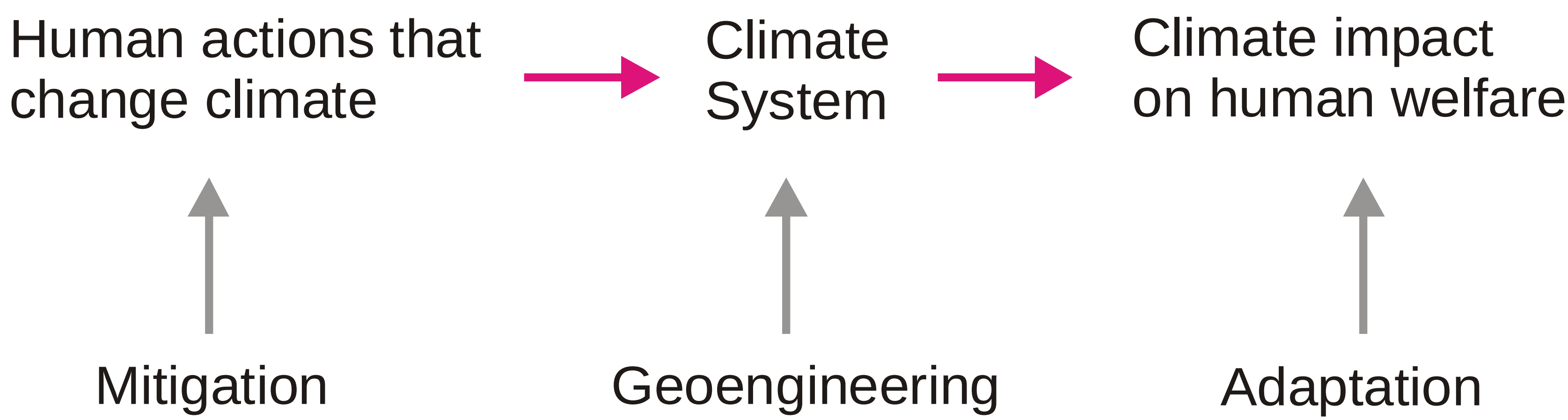
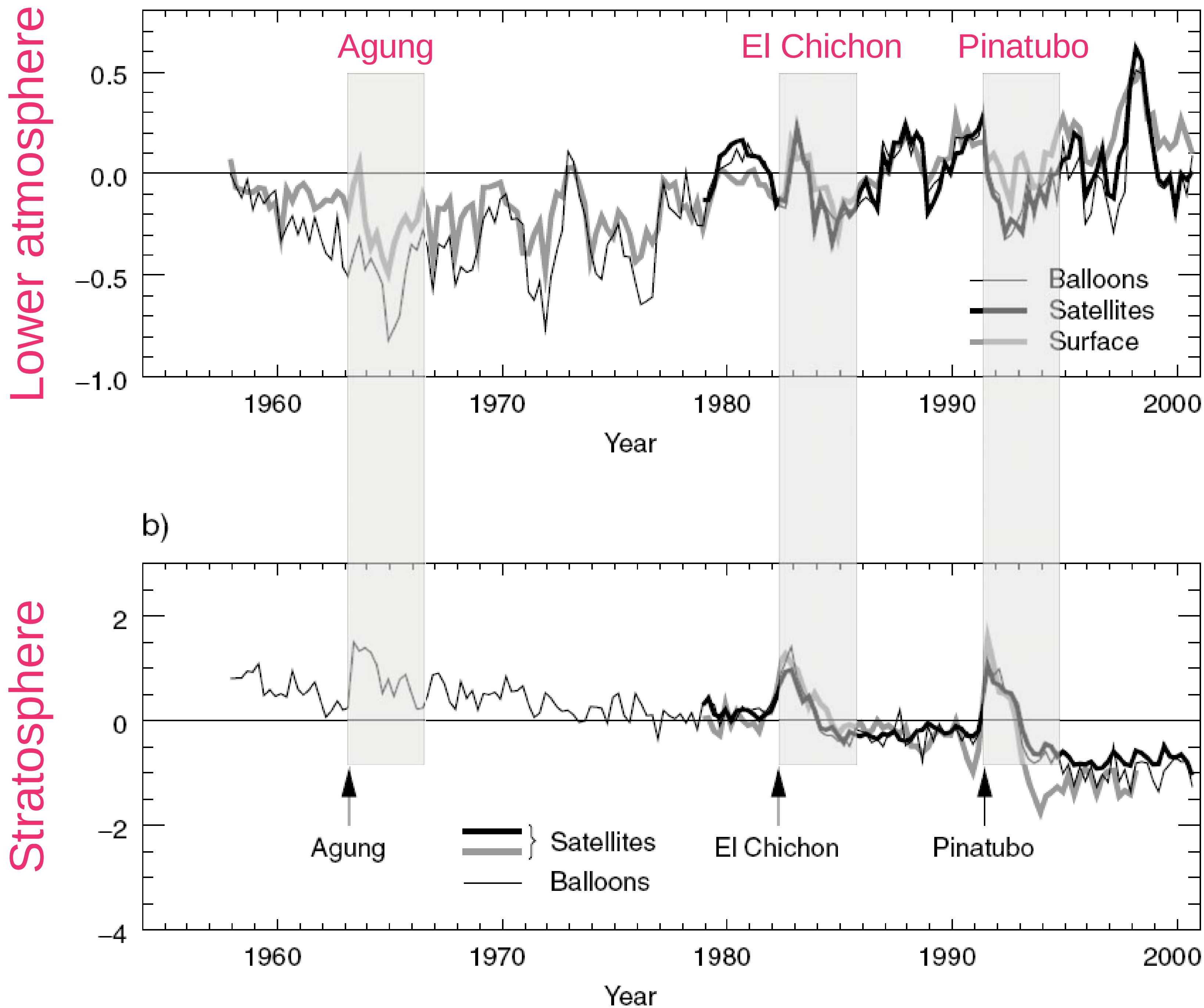
Human actions that change climate → Climate System → Climate impact on human welfare


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

Putting sulfur in the stratosphere

Of order 1-2 Mt-S per year offsets the globaly-averaged radiative forcing from $2 \times CO_2$

(~2-4% of current global S emissions)

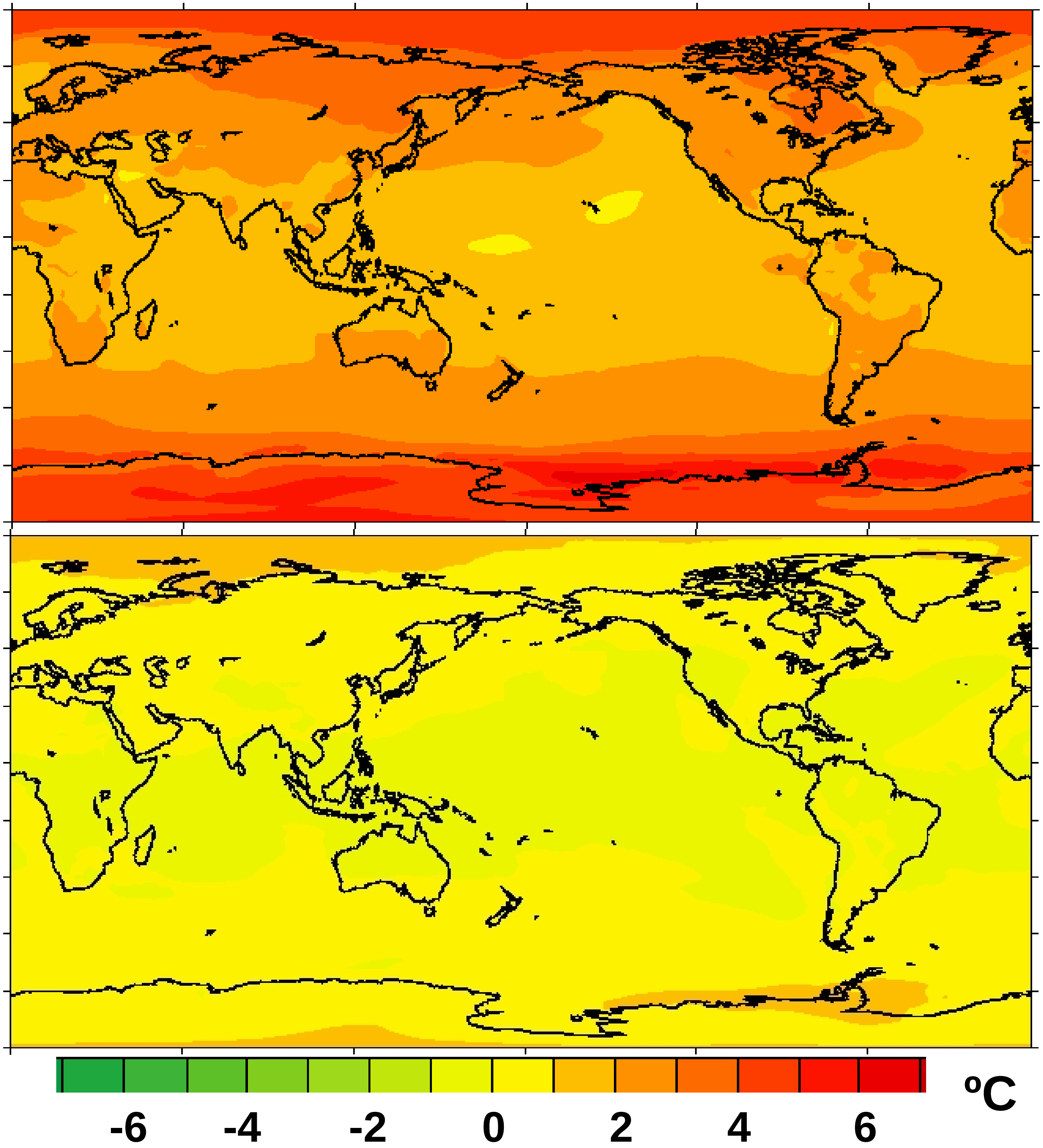
~3 gram sulfur in the stratosphere *roughly* offsets 1 ton carbon in the atmosphere (S:C ~ 1:300,000)

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

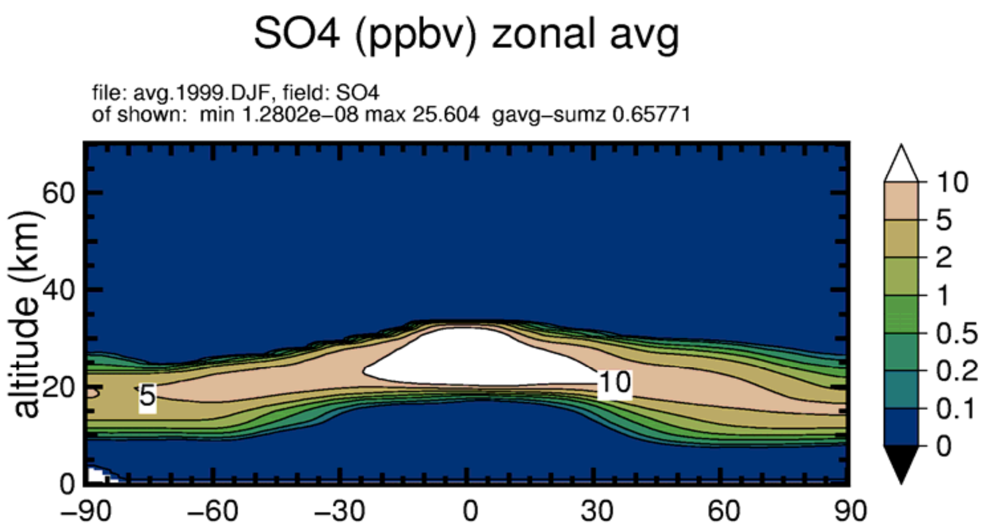
NCAR Community Atmosphere Model

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

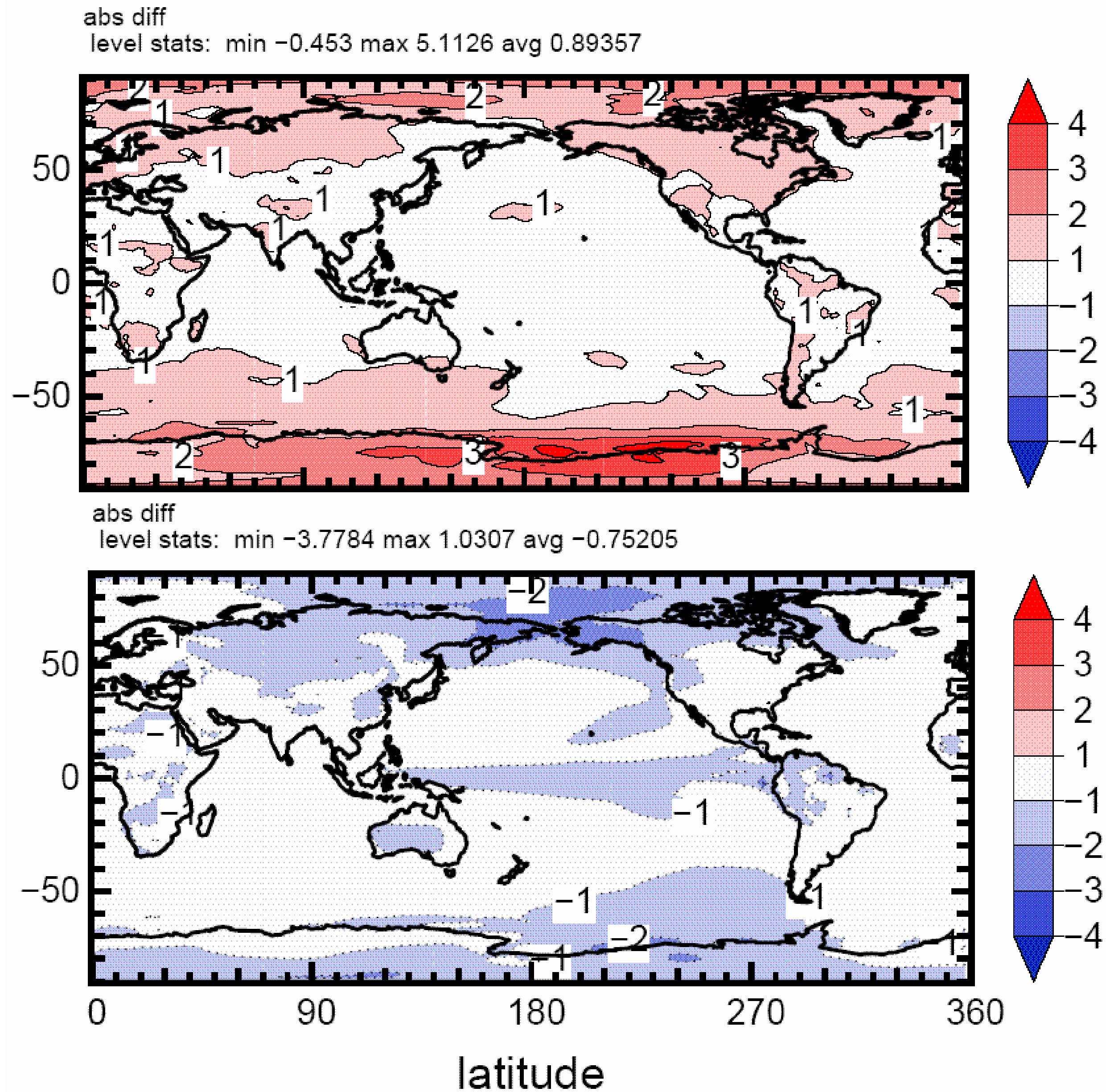
Pinatubo ≈10-30 Tg S

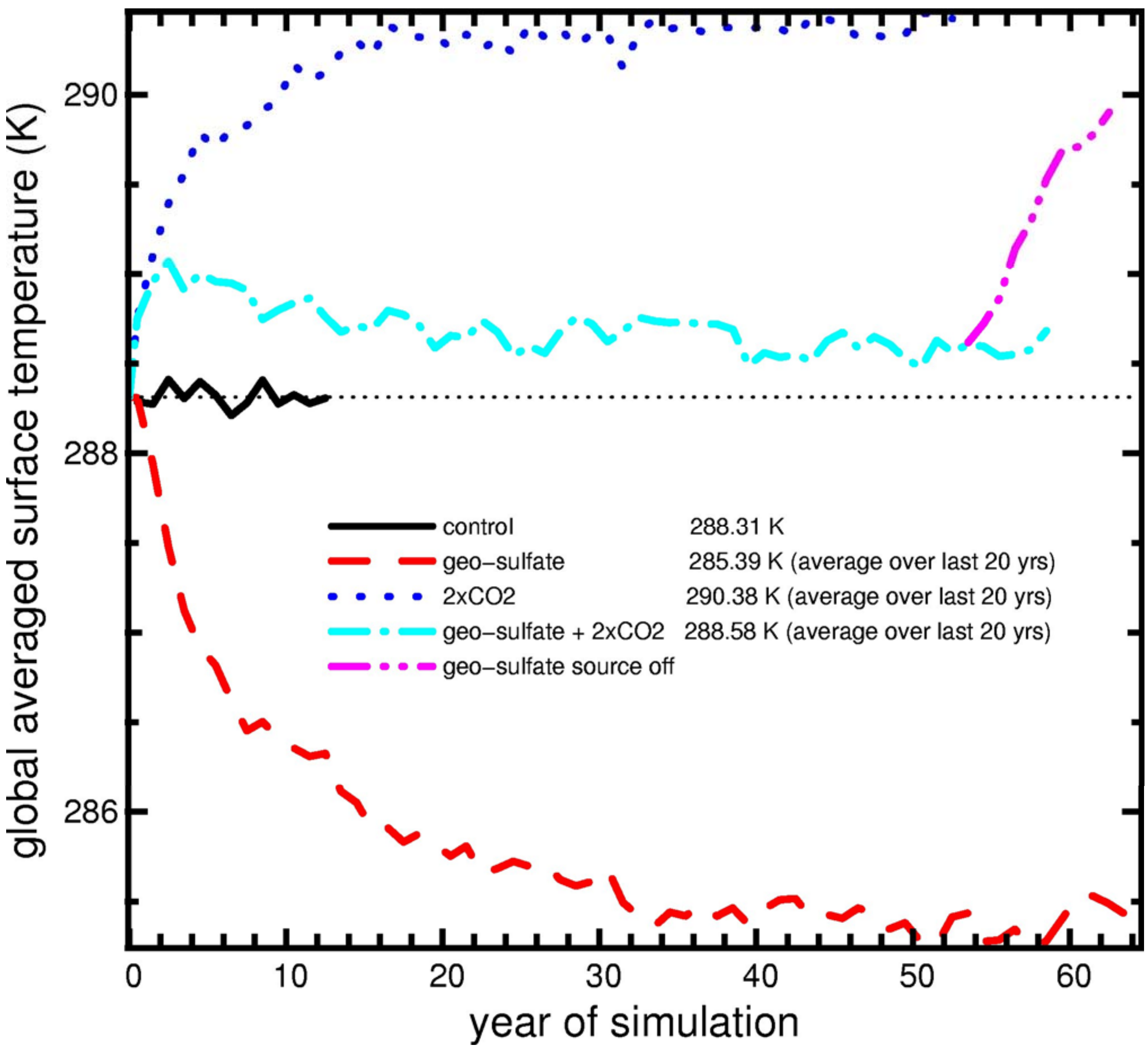


Rasch et al: Annual Average Surface Temperature

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

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 poleward heat flux were increased by 10% through an intensification of the

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.

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

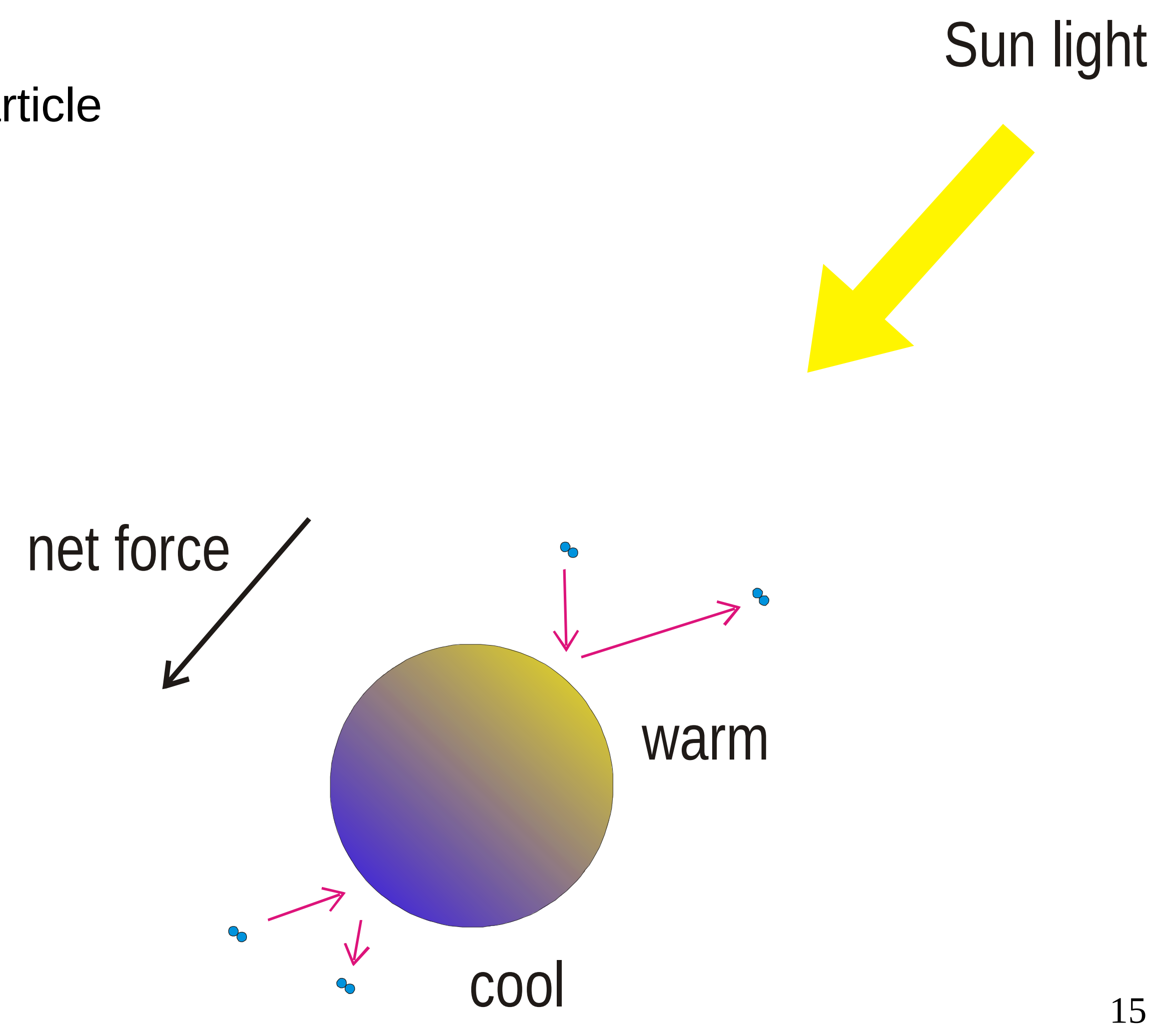
Uneven illumination

↓

Temperature gradient across particle

↓

Net force toward cool side



Gravito-Photophoresis

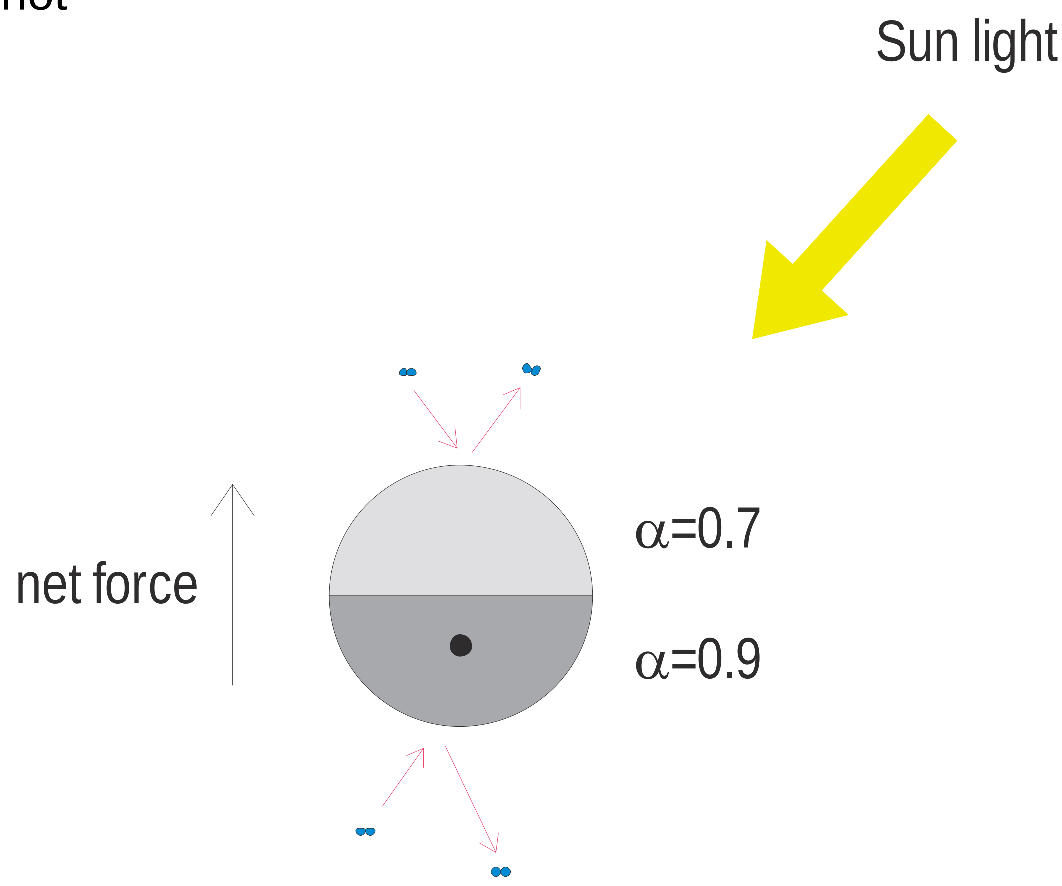
Sunlight warms particle evenly

↓

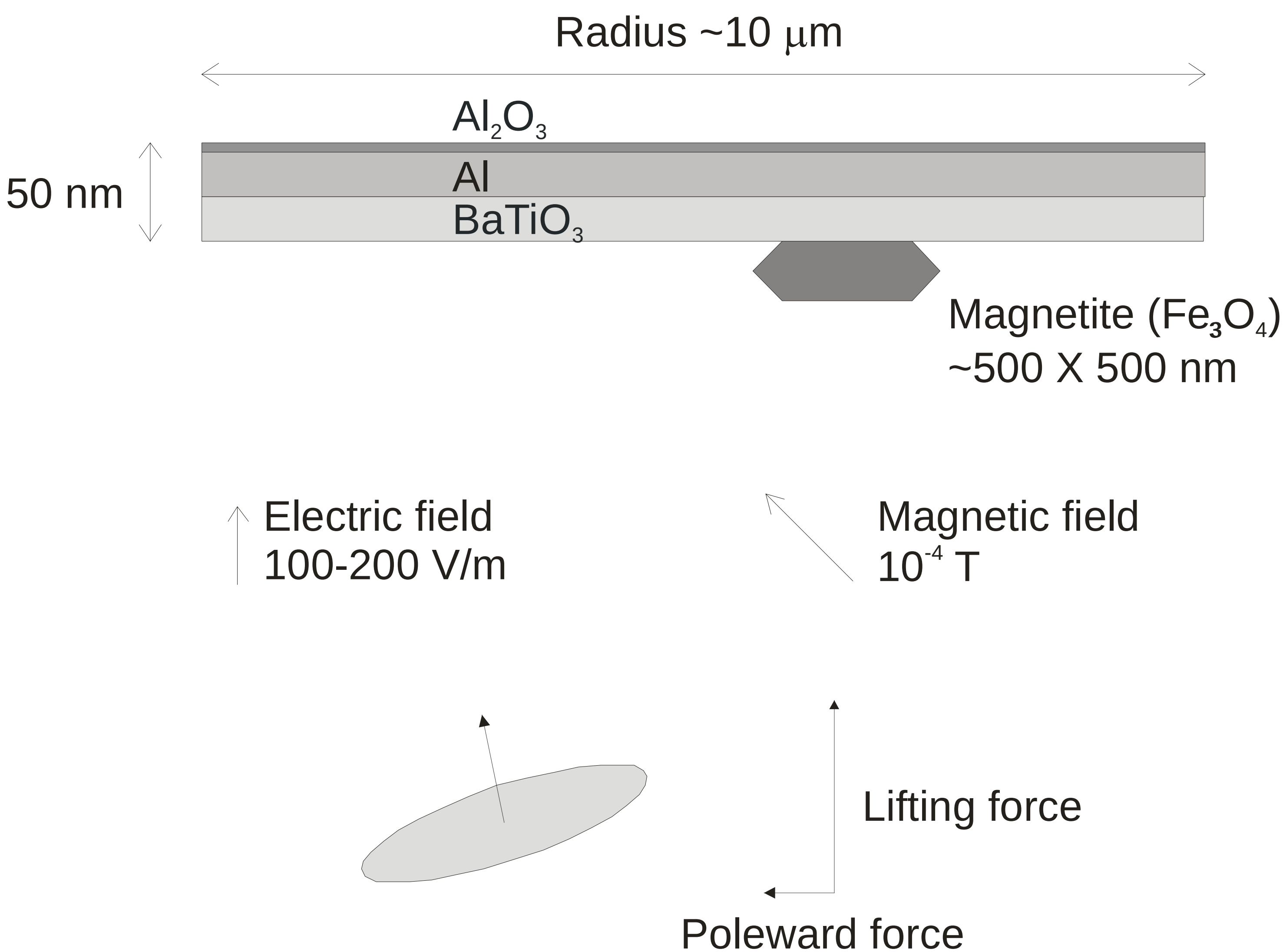
Particles more likely to rebound hot from bottom of particle

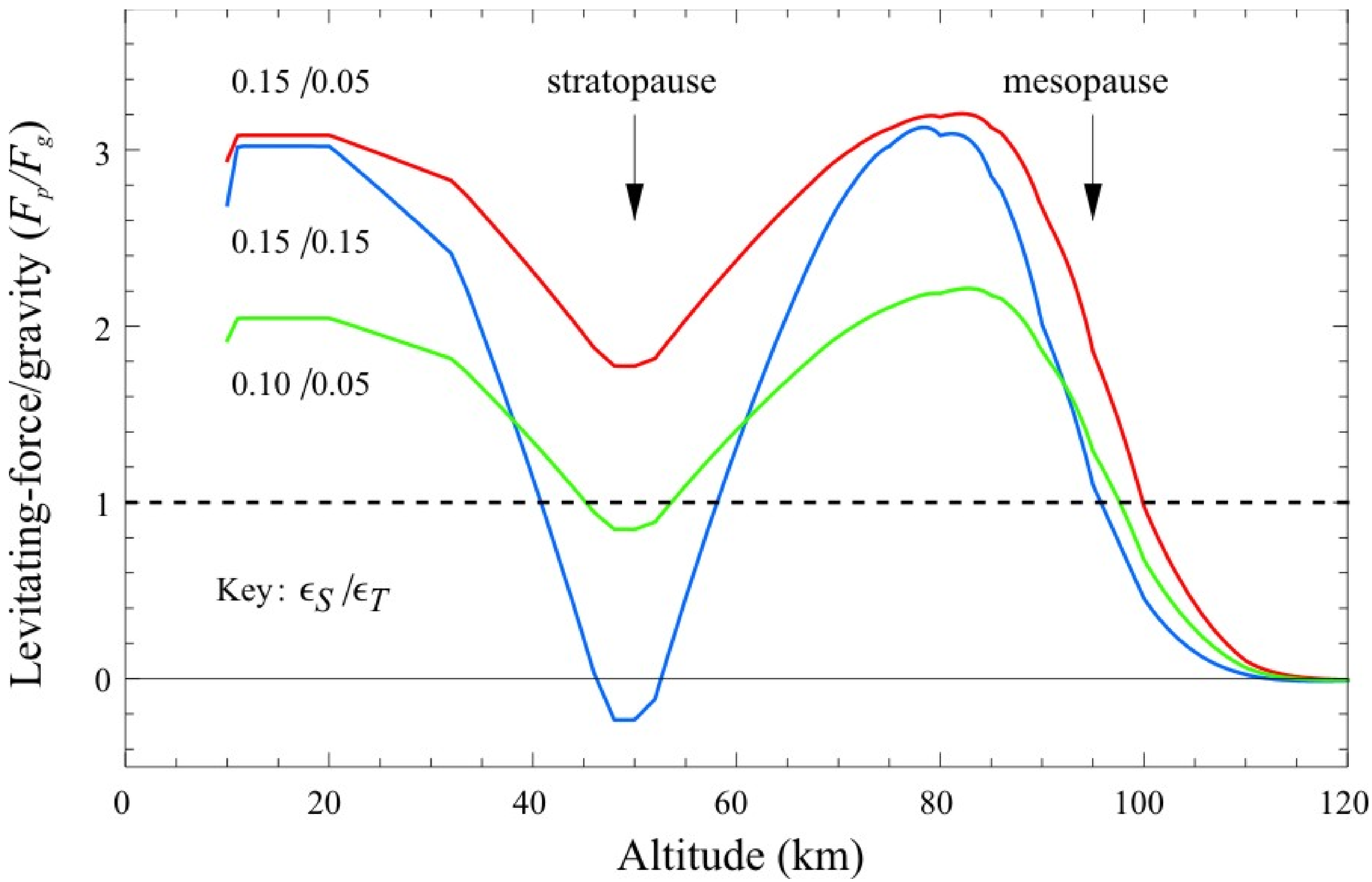
↓

Net upward force



Conceptual design: A levitated disk



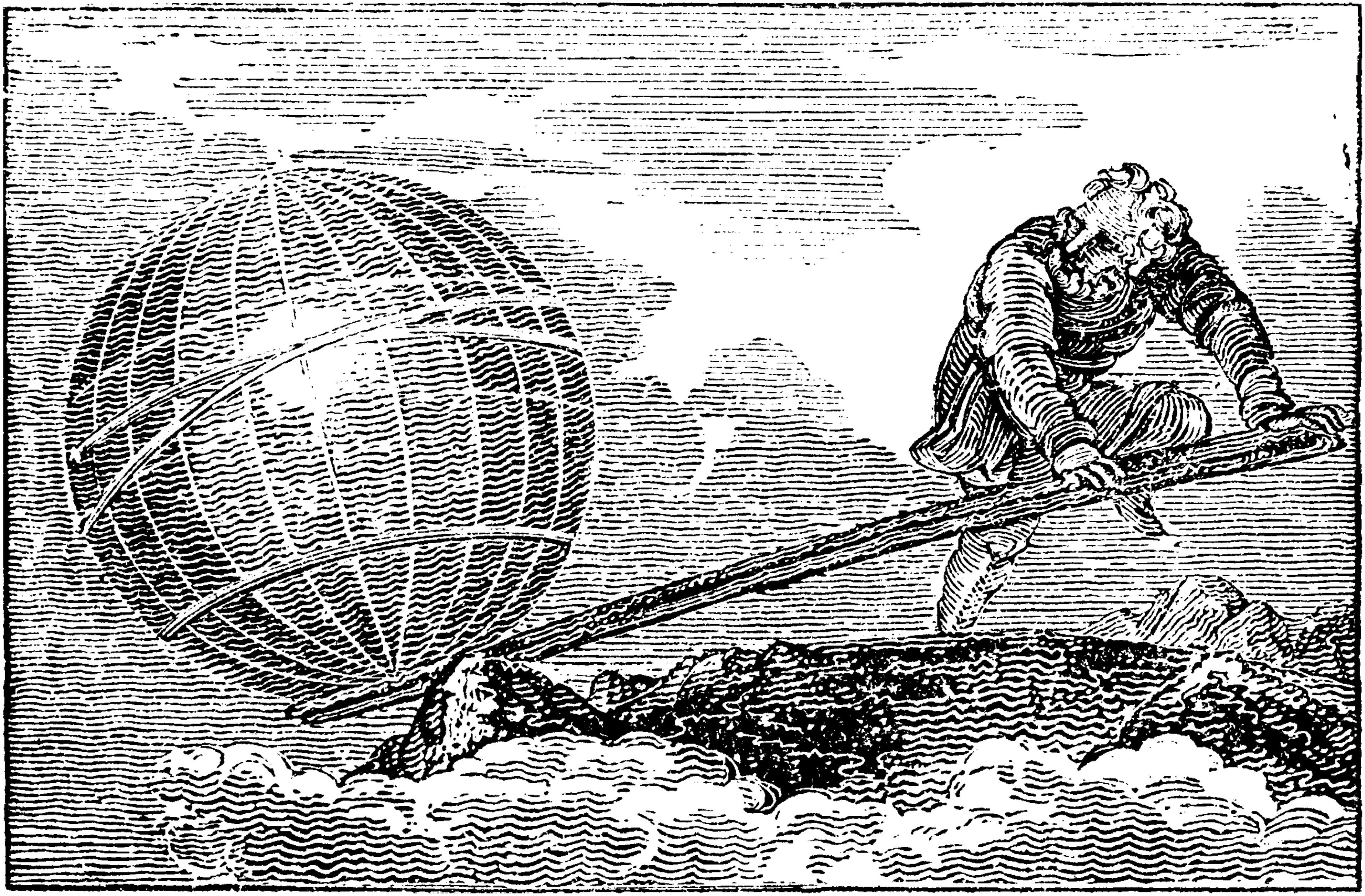

0.15 /0.05
stratopause
mesopause
0.15 /0.15
0.10 /0.05
Key: ϵ_S / ϵ_T
Levitating-force/gravity (F_p/F_g)
Altitude (km)
0
1
2
3
0
20
40
60
80
100
120

Photophoretic levitation of nano-engineered scatterers for climate engineering

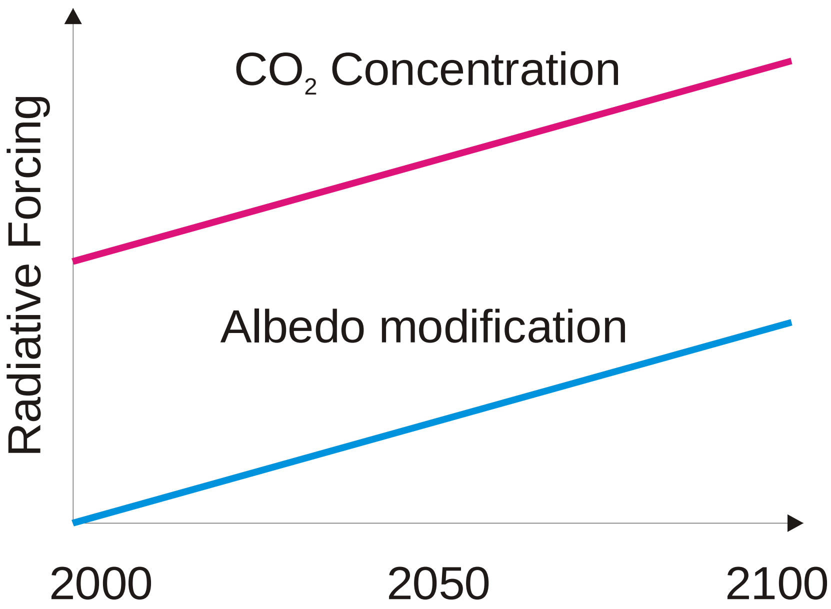
1. Long atmospheric lifetimes
   - ➔ Lower cost and impact of replenishment
   - ➔ Can afford more elaborately engineered scatters

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

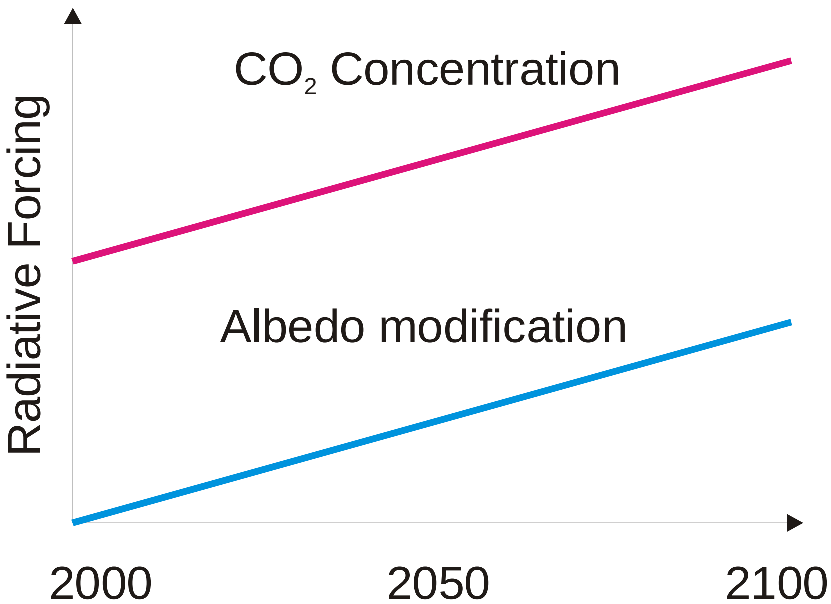
2. The ability to concentrate scattering particles near the poles
   - ➔ Concentrate climate engineering where it's needed most.



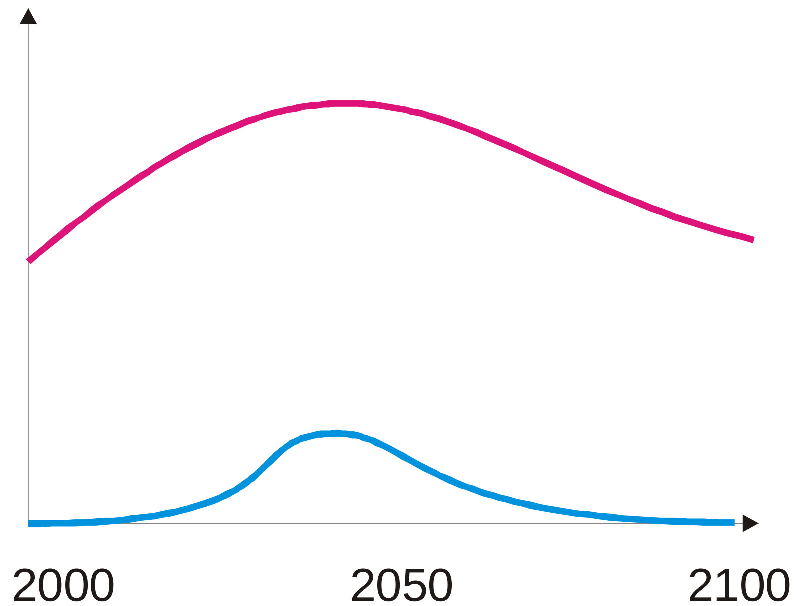
Geoengineering
instead of mitigation



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

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.*

Questions & Opinions

Opinions

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

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

3. 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? An alternate mechanism?

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-