Limits to Climate Engineering: Ignorance, Physics and Politics

Santa Barbara, CA

10 May 2008

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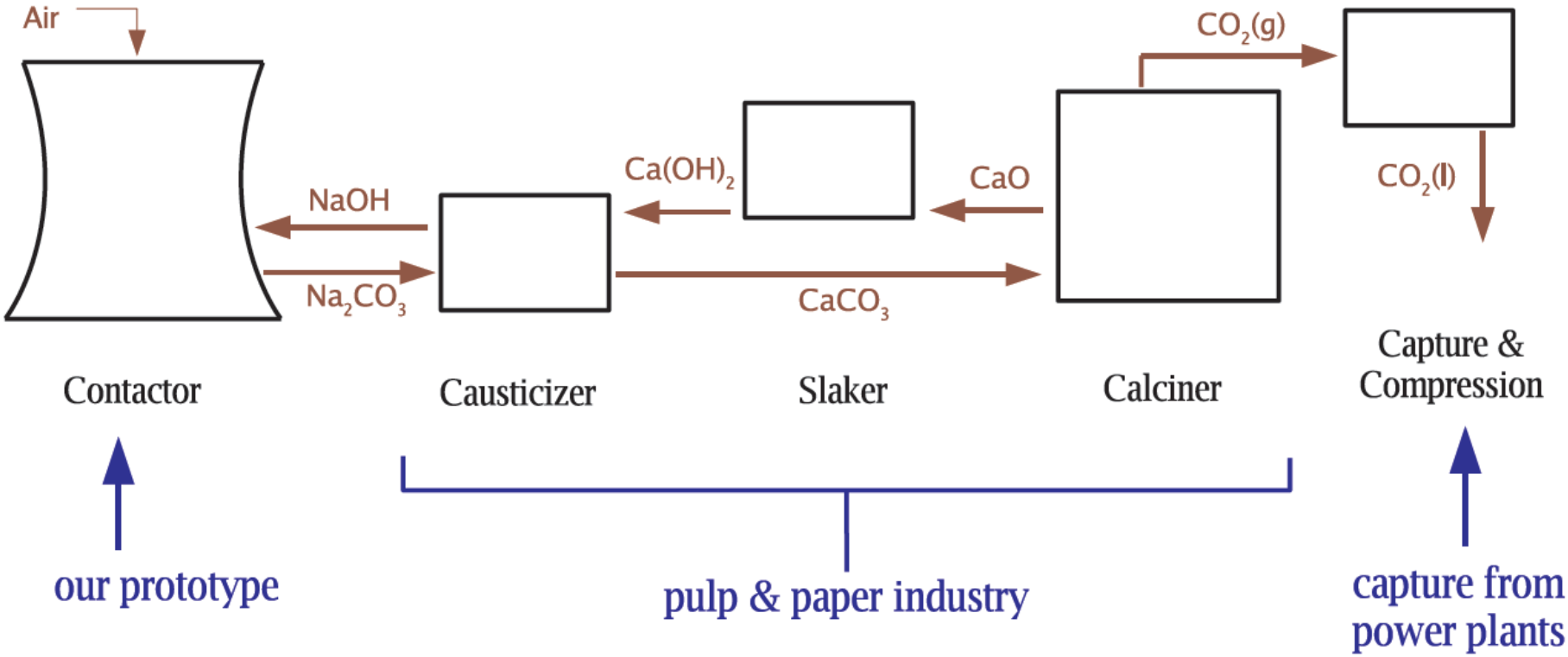
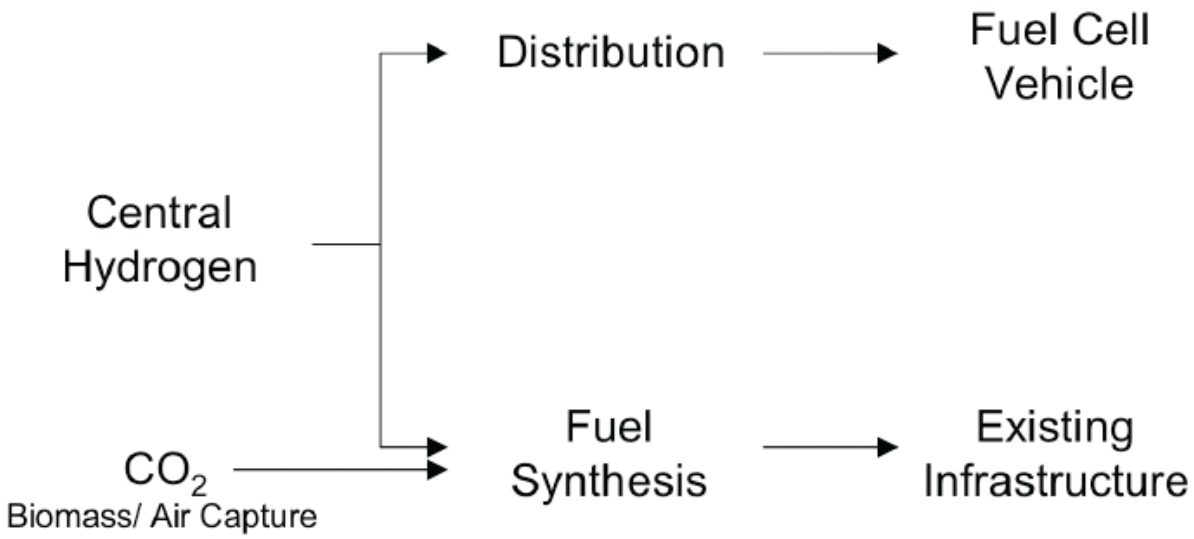
Etymology and Definition

In this review geoengineering is defined as intentional large-scale manipulation of the environment. Scale and intent play central roles in the definition. For an action to be geoengineering, the environmental change must be the primary goal rather than a side effect and the intent and effect of the manipulation must be large in scale, e.g. continental to global. Two examples serve to demonstrate the roles of scale and intent. First, intent without scale: Ornamental gardening is the intentional manipulation of the environment to suit human desires, yet it is not geoengineering because neither the intended nor realized effect is large-scale. Second, scale without intent: The modification of global climate owing to increasing atmospheric CO_2 has global effect, yet it is not geoengineering because it is a side effect resulting from combustion of fossil fuels with the aim of providing energy services.

Direct Air Capture



Hydrogen Economy



Carbon Neutral Hydrocarbons

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

Table 2. Costs Vs. Risks of Geoengineering Schemes

Risk of adverse effect	Cost		
	low	medium	high
low	—	reforestation	solar shields; direct ocean CO_2 injection
medium	SO_2 in troposphere; ocean fertilization-Fe	inert stratospheric aerosols; ocean fertilization-P	balloons in the stratosphere
high	SO_2 in stratosphere	—	—

failed to consider them systematically. We present the beginnings of a more systematic analysis and urge a balanced research program on geoengineering.

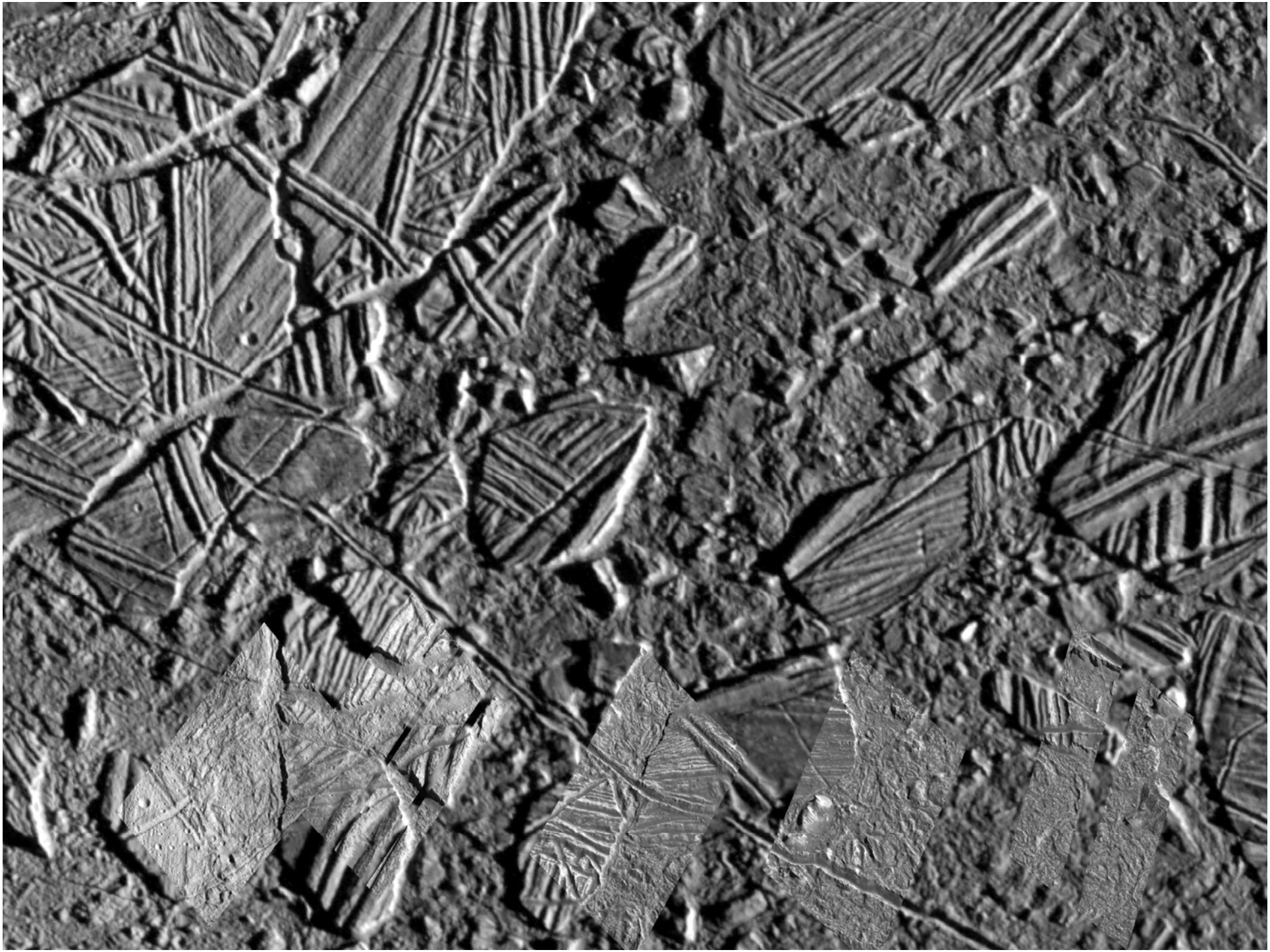
We define geoengineering as actions taken with the primary goal of engineering (controlling by application of science) the climate system. Geoengineering is the deliberate manipulation of climate forcings intended to keep the climate in a desired state, in contrast to abatement, which re-

mate change.

To act as a fallback strategy, geoengineering must be more certain of effect, faster to implement, or provide unlimited mitigation at fixed marginal cost. Our definition of "fallback strategy" is an extension of the term "backstop technology" used in energy systems analysis for a technology providing unlimited energy at fixed (usually high) marginal cost.

The existence of a fallback is critically

which remove CO_2 from the atmosphere, are direct deep-ocean disposal, ocean-surface fertilization, or afforestation. For the second strategy, we discuss albedo modification by placing solar shields in Earth-orbit, or by increasing aerosol concentrations. Our five cases are chosen to survey geoengineering's wide range of risks and costs. With the exception of direct ocean disposal and afforestation, these schemes have the theoretical potential to mitigate the full effect of anthro-



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.

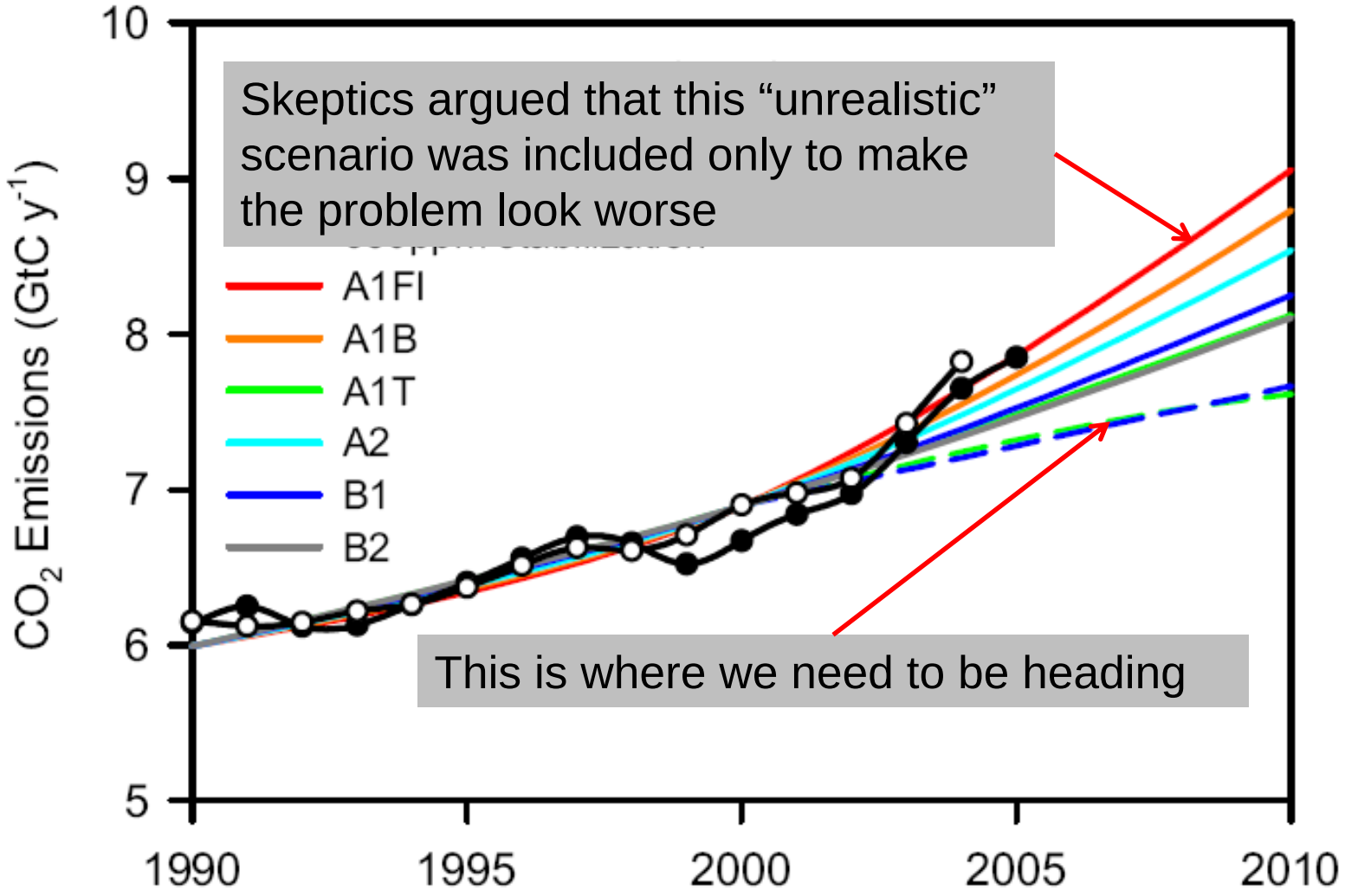
rents necessary for the onset of precipitation. This may mean less rainfall and cloud cover, so that still more sunlight can reach the earth's surface. Thus man tends to make his climate warmer and drier; should there be a decrease in carbon dioxide, a cooler and wetter climate would result.

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

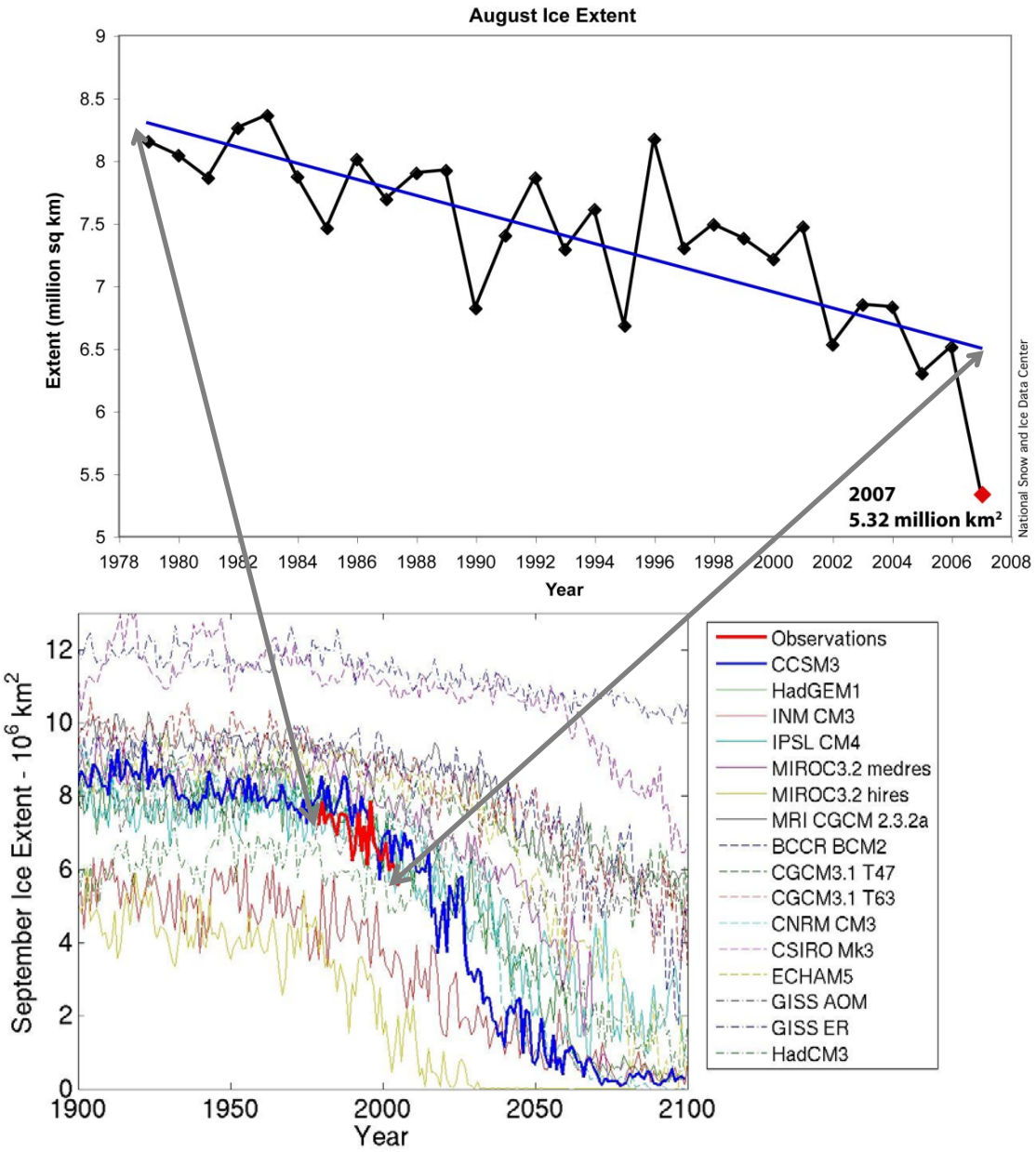
New York Times
May 24th **1953**

Emissions are rising faster than expected

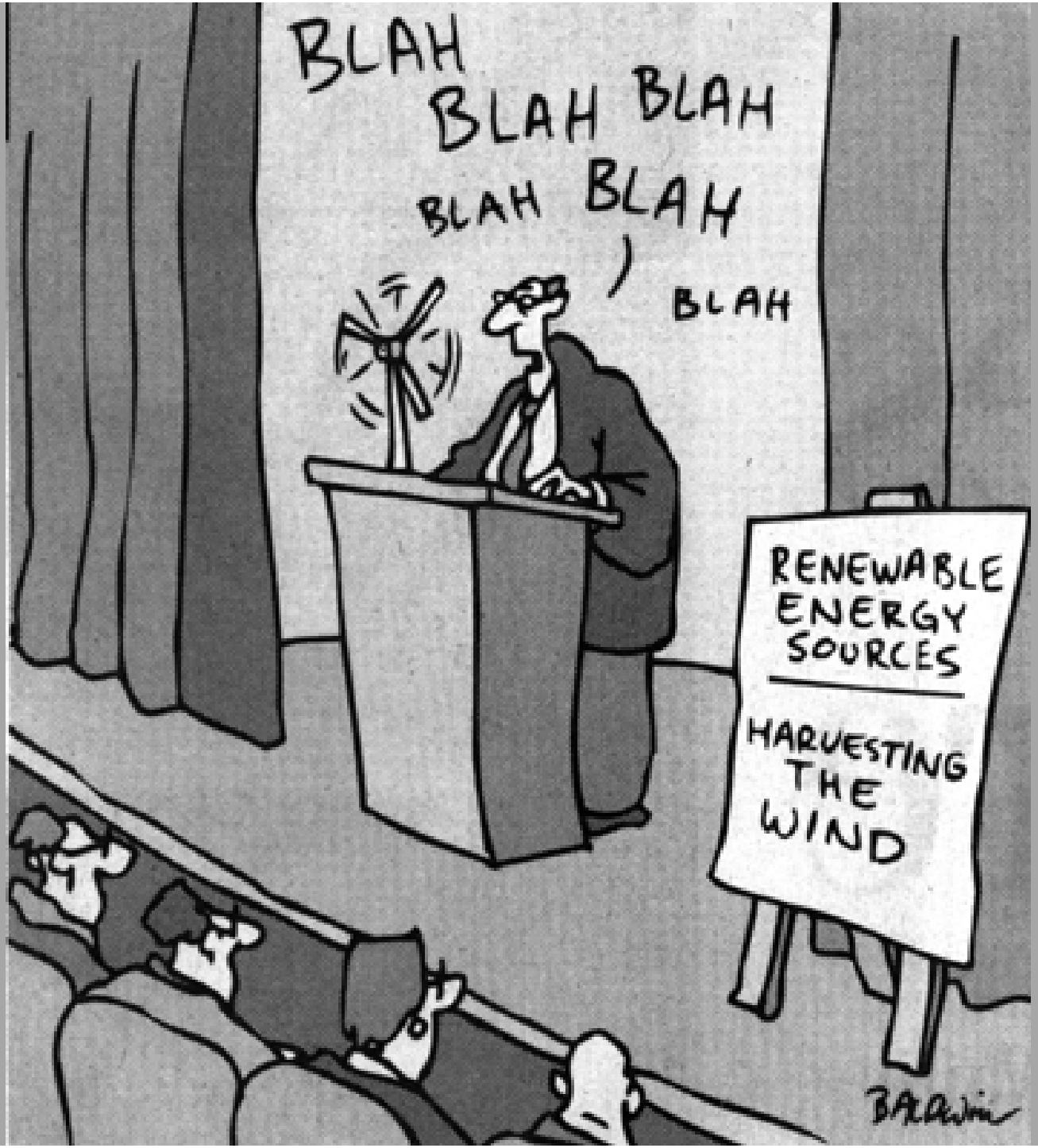


Raupach, et al., PNAS, 2007.

And, it's melting quicker than models predict



National Snow and Ice Data Center


BLAH
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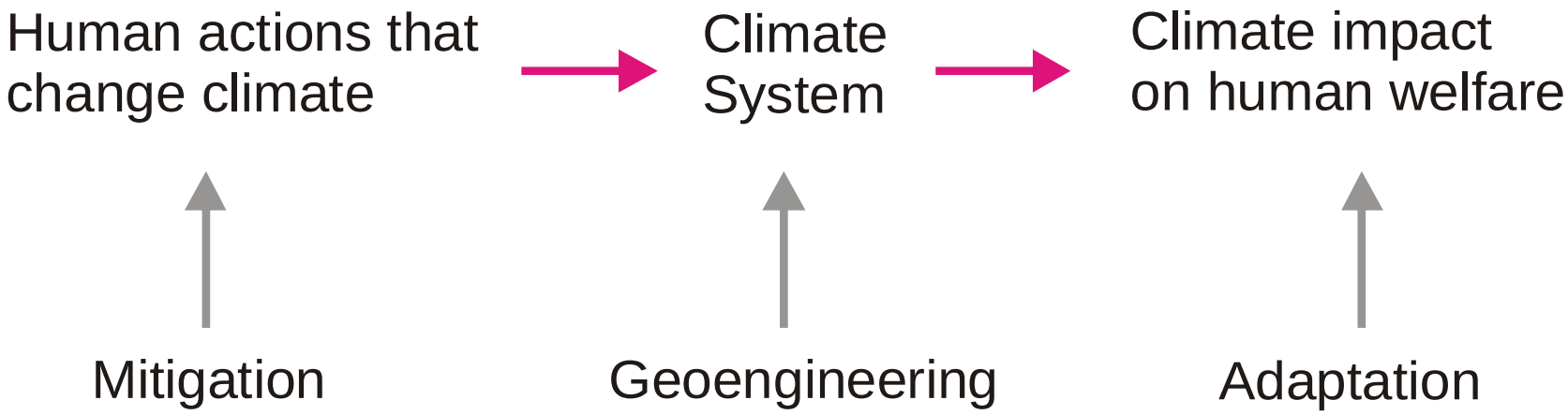
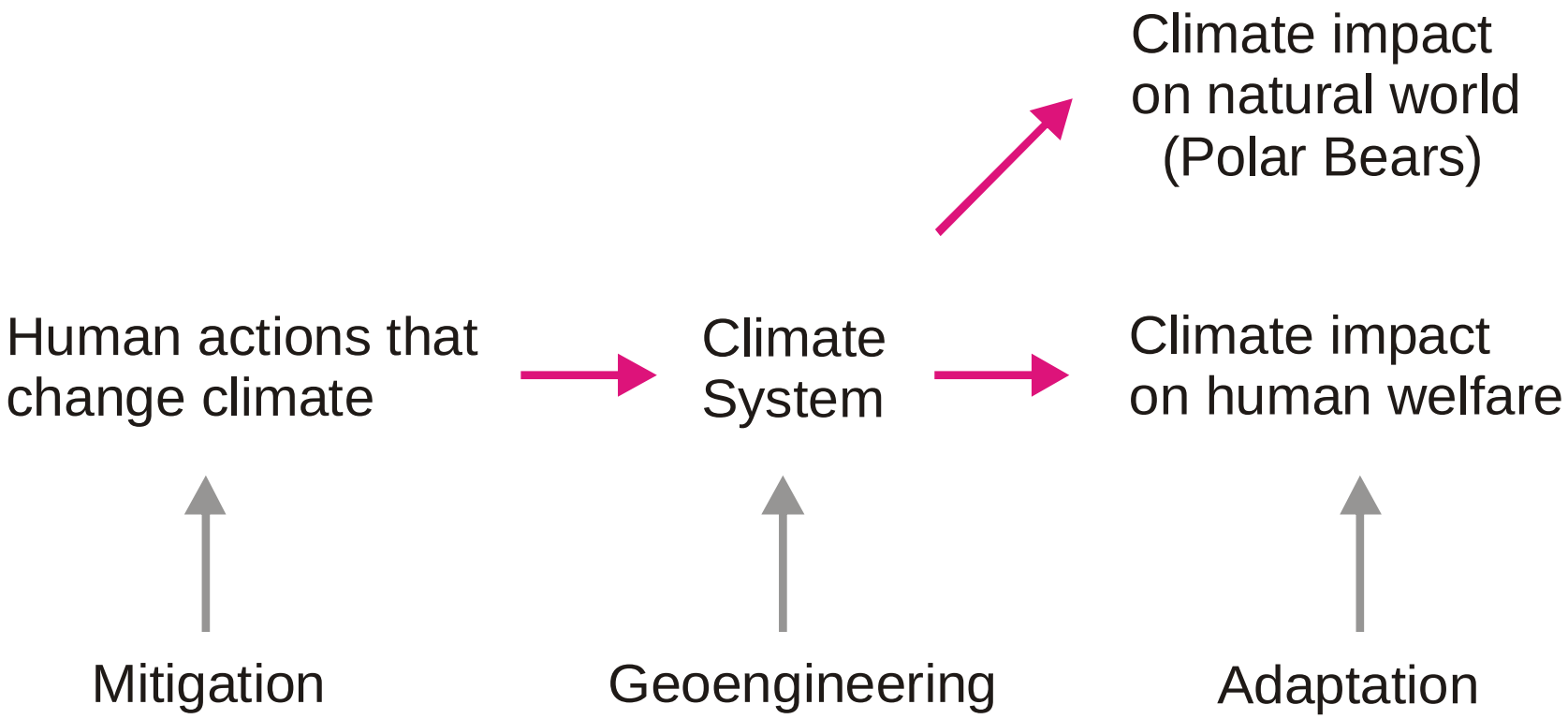
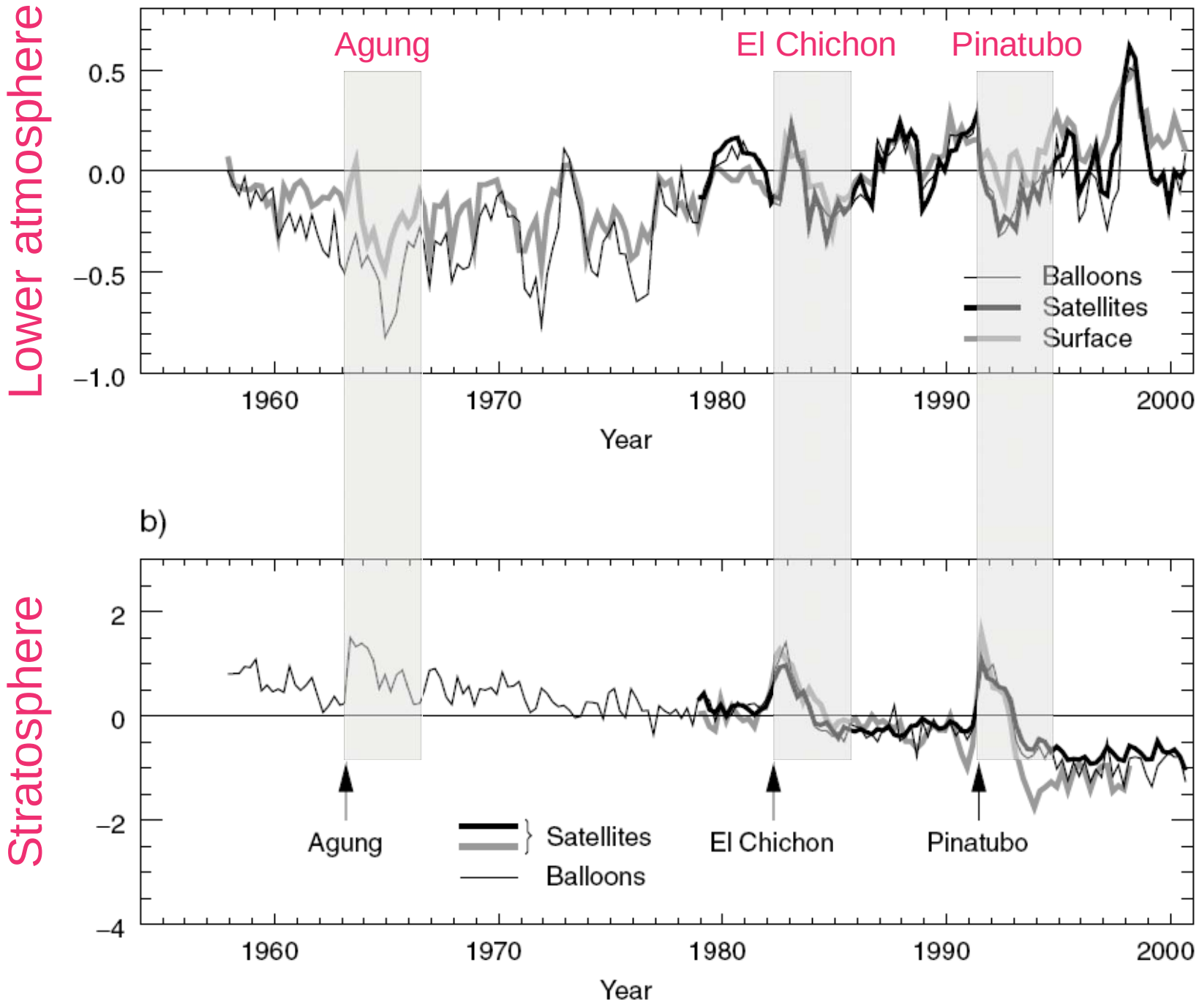
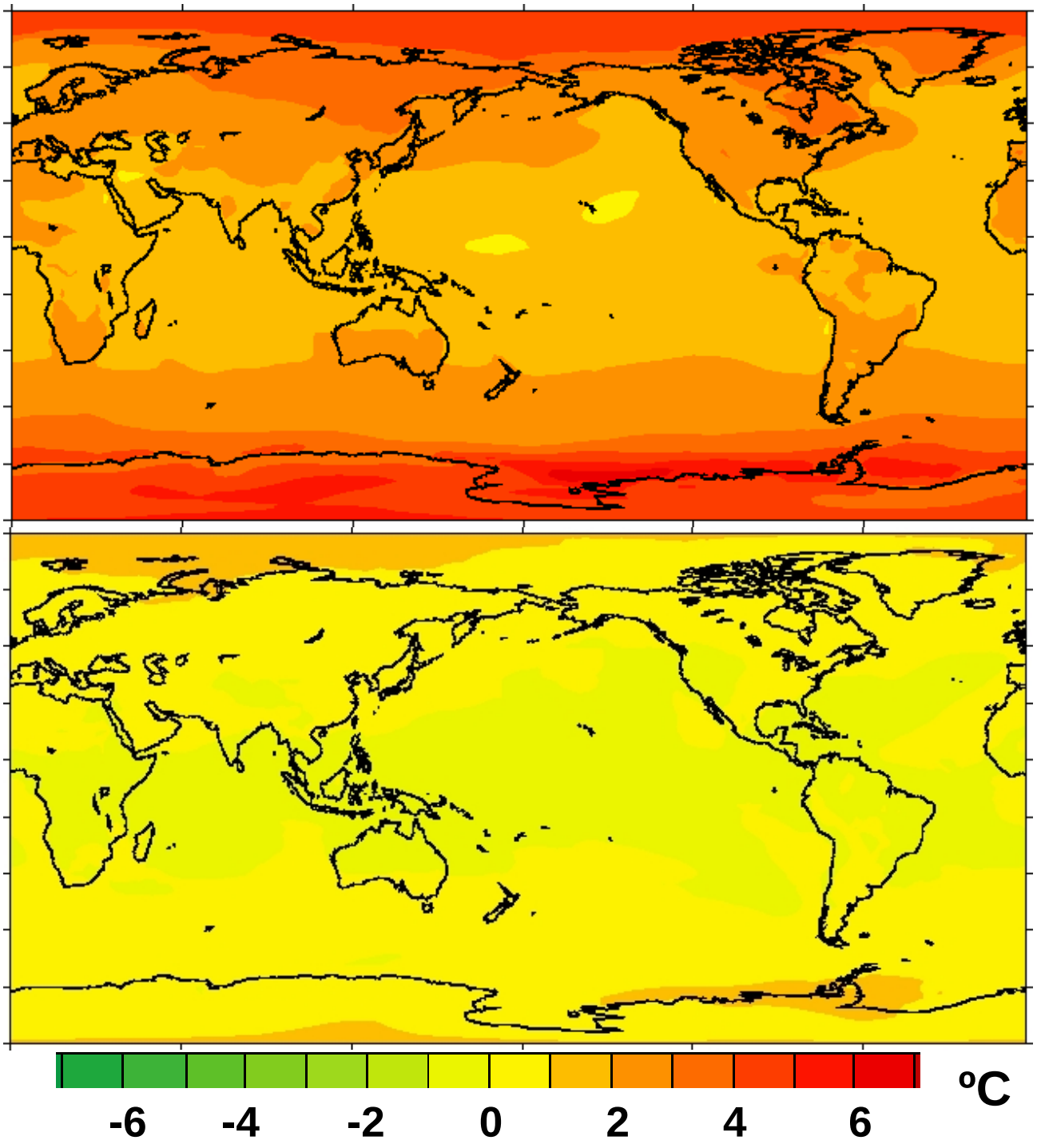
RENEWABLE ENERGY SOURCES
HARVESTING THE WIND


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


Climate impact
on natural world
(Polar Bears)
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



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

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 meridional atmospheric circulation, and that all of this increase in the

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

the sea level would rise about 1 foot every 10 years, 10 feet per century. 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-

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 ag
Environmentalists and mainstream scientists said th
greenhouse gases and preventing global warming in t

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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.

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

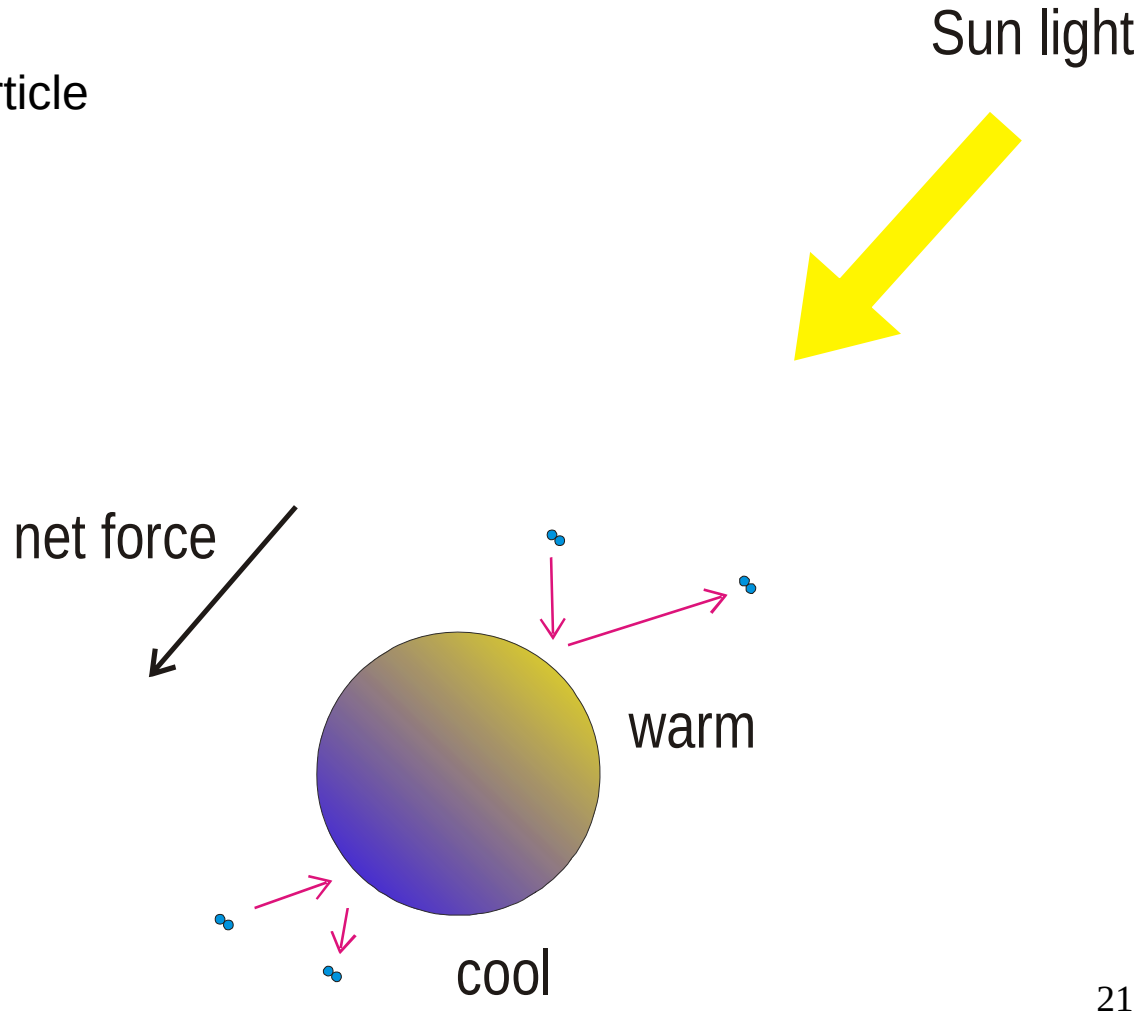
Uneven illumination

↓

Temperature gradient across particle

↓

Net force toward cool side



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.

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.

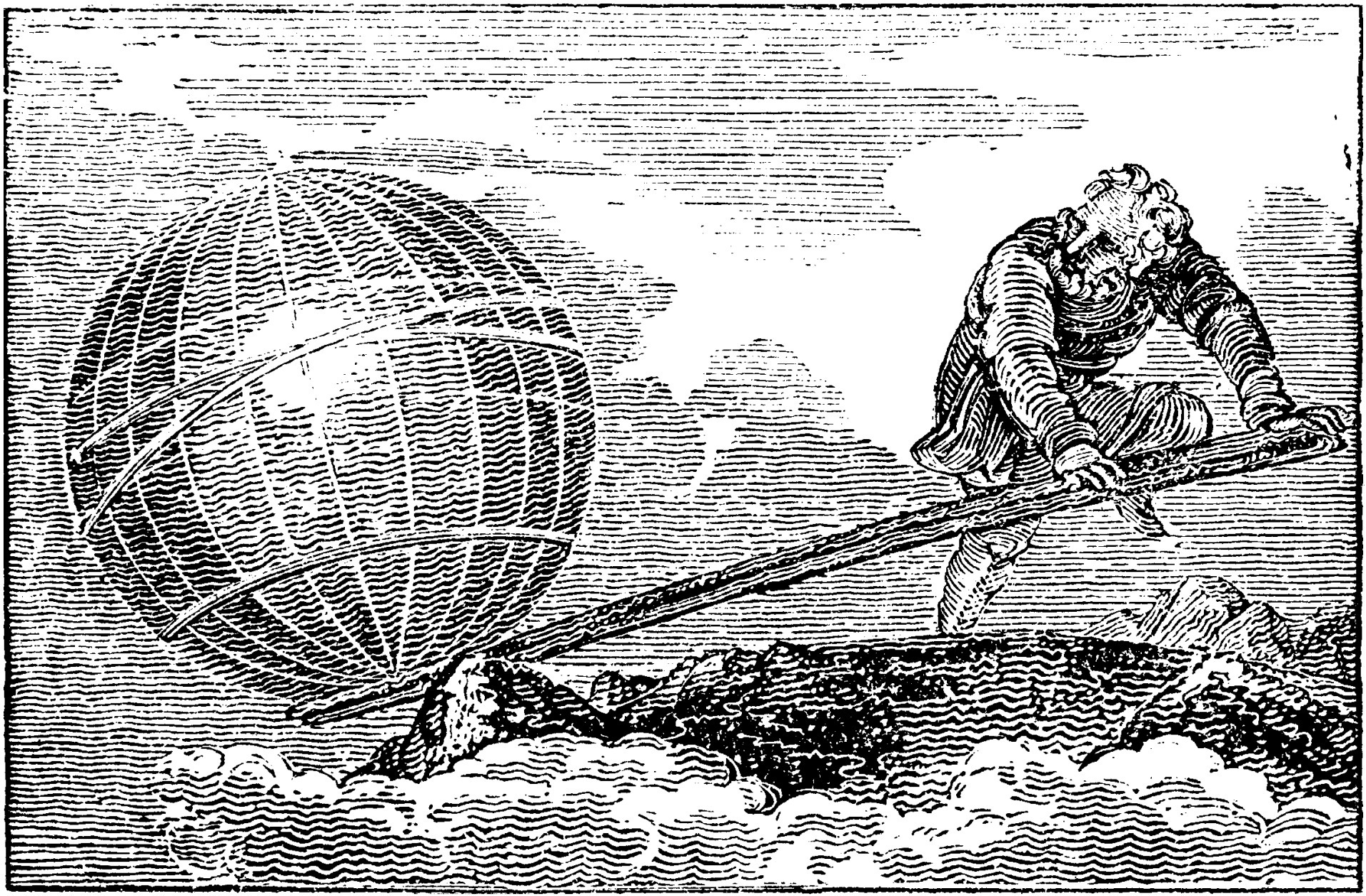
X-29 NASA-DFRC

Improved observations
Improved models
Improved analysis/forecast systems

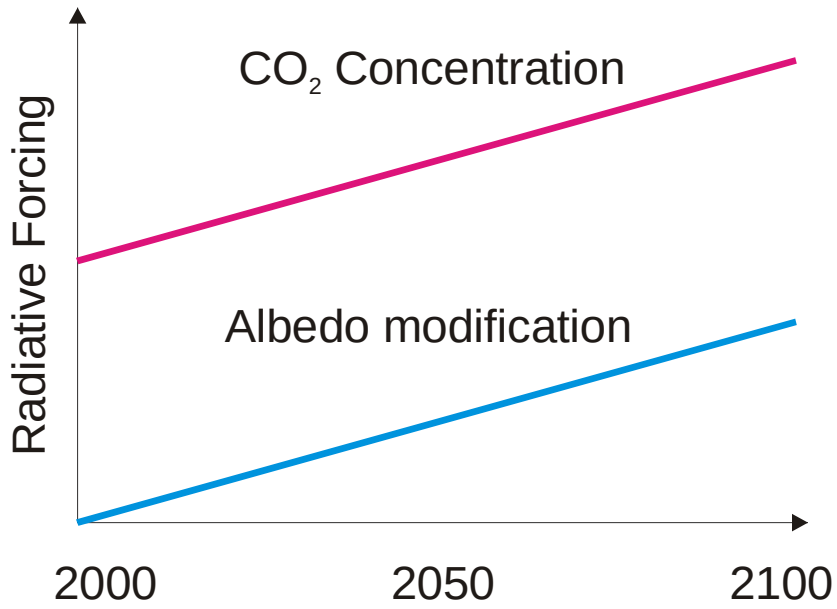
→

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

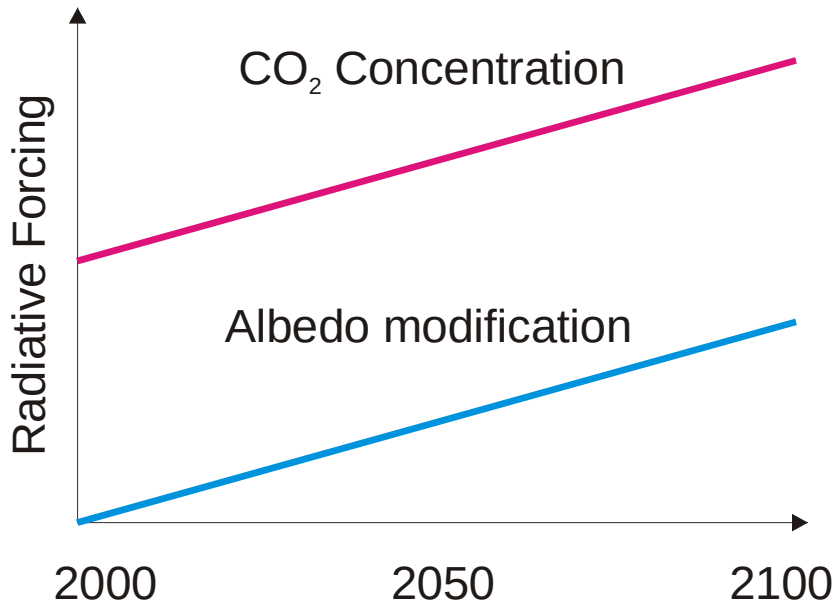
See Ross Hoffman, "Controlling the global weather",
Bulletin of the American Metrological Society February 2002 : 241-248



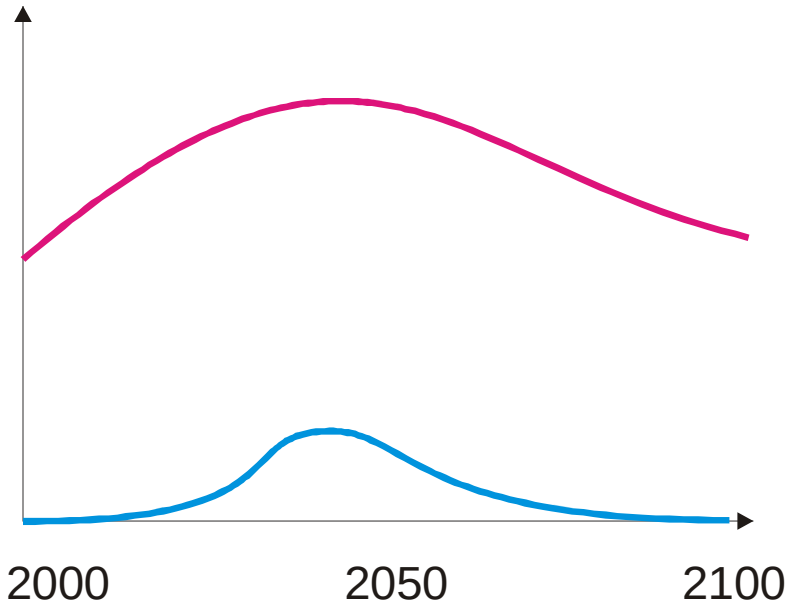
Geoengineering instead of mitigation

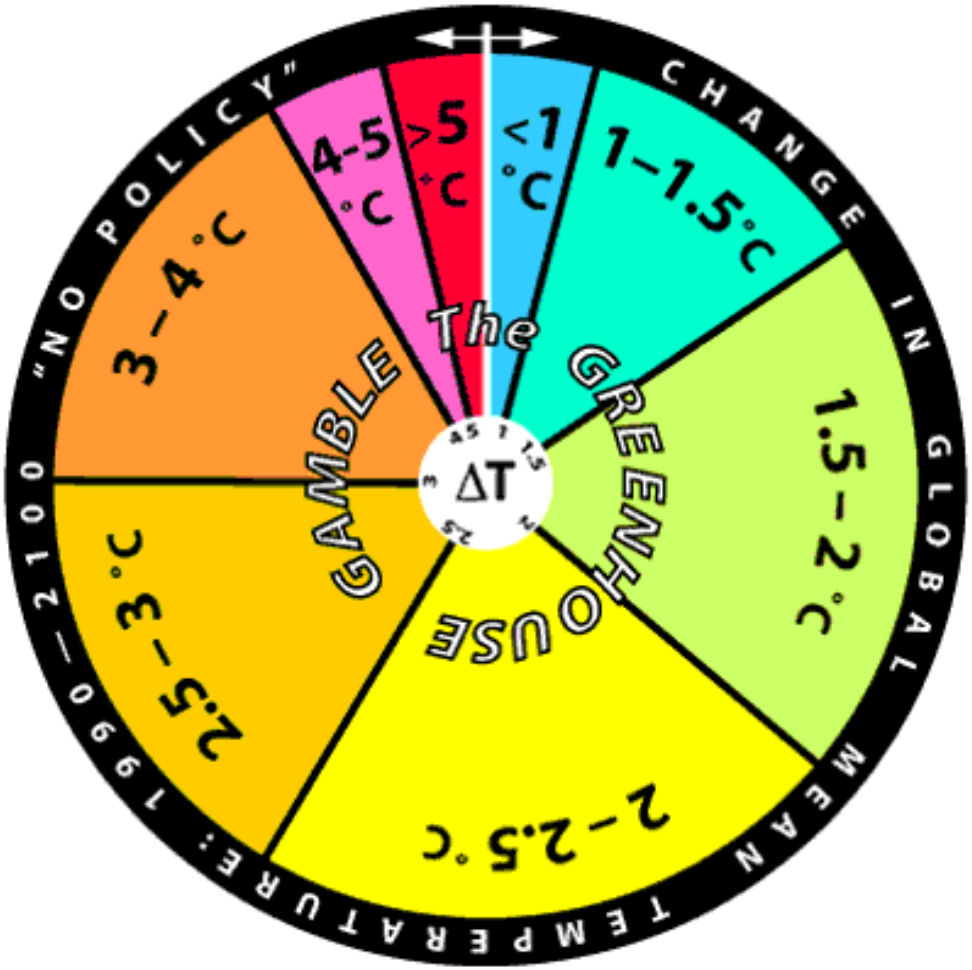


Geoengineering
instead of mitigation

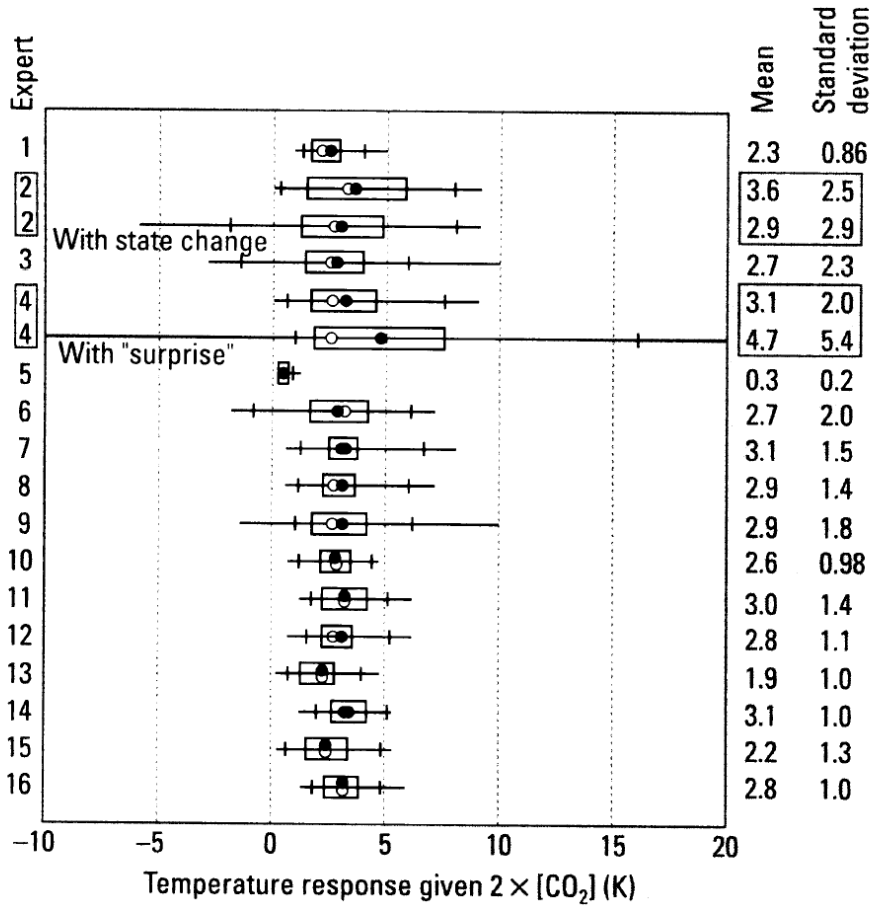


Geoengineering to take
the edge of the heat





Morgan & Keith (1995)



Knowledge that geoengineering is possible

↓

Climate impacts look less fearsome

↓

A weaker commitment to cutting emissions now

Questions

1. Should we do serious research?

2. How can we best we avoid the moral hazard?

3. Do we need a treaty? Norms?

"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*.