Issues in Geoengineering

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Emissions are rising faster than expected

Skeptics argued that this “unrealistic” scenario was included only to make the problem look worse.

This is where we need to be heading.

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.

Theory Applied to Glaciers

All this reinforces a theory advanced in 1851 that decreases in carbon dioxide explain the growth and advance of glaciers at various intervals in the earth’s history. Dr. Plass finds the
Forest et al (2002)

Morgan & Keith (1995)
Why Is Climate Sensitivity So Unpredictable?

Gerard H. Roe* and Marcia B. Baker
Forest et al, uniform  P>8=15%

Forest et al, expert prior (Morgan & Keith)  P>8=3%

Sanderson et al (2007)  P>8=7%

Forest et al, uniform  P>8=15%
Human actions that change climate → Climate System → Climate impact on human welfare
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Mitigation → Geoengineering → Adaptation
Temperatures after Mt. Pinatubo

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 $2\times\text{CO}_2$

(~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 \rightarrow 30\text{ billion per year.}

Methods:
1. Naval guns
2. Aircraft
3. Tethered balloon with a hose
Models suggest the compensation is quite good.

$2 \times \text{CO}_2$

and

$2 \times \text{CO}_2$

and

1.8% reduction in solar intensity.

Caldeira et al., in prep, 2007
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 \( \text{SO}_2 \rightarrow \text{SO}_4 \)

Injection of \( \text{SO}_2 \)
- at 25km
- from 10N - 10S
- 1 Tg S/yr assuming a small (or background) aerosol size distribution

Pinatubo \( \approx 10-30 \) Tg S
Rasch et al: Annual Average Surface Temperature

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

Geo-SO4/2xCO2 (2Tg Bkg) - Control
The graph shows the global averaged surface temperature (K) over the years of simulation. The temperature is represented in Kelvin (K) on the y-axis, and the year of simulation is on the x-axis.

- **control**: 200.31 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**
  - $\text{H}_2\text{SO}_4$ or $\text{Al}_2\text{O}_3$

- **Metallic particles** ($10^{-3} \times$ lower mass)
  - Disks, micro-balloons or gratings

- **Resonant** ($10^4-10^6 \times$ lower mass ??)
  - Encapsulated organic dyes

**What you might get:**

- Much lower mass
- Spectral selectivity
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. Strawa1

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

Sun light

net force

warm

cool
Gravito-Photophoresis

Sunlight warms particle evenly

Particles more likely to rebound hot from bottom of particle

Net upward force

$\alpha = 0.7$

$\alpha = 0.9$

Sun light
Levitating-force/gravity ($F_p/F_g$)

- 0.15 / 0.05
- 0.15 / 0.15
- 0.10 / 0.05

Key: $\varepsilon_S / \varepsilon_T$

Altitude (km)

stratopause
mesopause
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 climatic changes that may be produced by the increased CO₂ 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 CO₂ could be produced by raising the albedo, or reflectivity, of the earth. Such a change in albedo could be achieved only if we were able to mask about 10% of the earth's surface. 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-
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 of T describes them.

The Nobel Prize-winning scientist who first made the idea of "downwind trapping greenhouse gases" popular is in his 80s and no longer around to see the fruits of his labor. Their proposals were relegated to the fringes of climate change discussions.

Few journals would publish them. Few governments have the money to fund such projects. Environmentalists and mainstream scientists said they were too risky.

Cool Geo-Whiz Warming Ideas

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

By Bret Schulte
Posted 10/15/06

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 \(\Rightarrow\) control is impossible

**Not so!**
Control of chaotic systems requires four things
1. A model (initial conditions \(\rightarrow\) future state).
2. Observations.
3. An appropriate lever.

Improved observations
Improved models
Improved analysis/forecast systems

A bigger lever \(\Rightarrow\) Smaller perturbations needed to achieve a given degree of weather control

Geoengineering instead of mitigation

- CO$_2$ Concentration
- Albedo modification

Radiative Forcing

2000 2050 2100
Geoengineering instead of mitigation

Geoengineering to take the edge of the heat

CO₂ Concentration

Albedo modification
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 $\sim$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

\[ \int_{-\infty}^{\infty} cf_0(c)dc \]
\[ \int_{-\infty}^{\infty} cf_0(c)dc \times \int_{-\infty}^{\infty} gh(g)dg + \gamma \]
\[ \int_{-\infty}^{\infty} cf_1(c)dc + \alpha \]
\[ \int_{-\infty}^{\infty} cf_1(c)dc \times \int_{-\infty}^{\infty} gh(g)dg + \alpha + \gamma \]
\[ \int_{-\infty}^{\infty} cf_0(c)dc + \rho \]
\[ \int_{-\infty}^{\infty} cf_0(c)dc \times \int_{-\infty}^{\infty} gh(g)dg + \rho + \gamma \]
\[ \int_{-\infty}^{\infty} cf_1(c)dc + \alpha + \rho \]
\[ \int_{-\infty}^{\infty} cf_1(c)dc \times \int_{-\infty}^{\infty} gh(g)dg + \alpha + \rho + \gamma \]
Current discussions of geoengineering are unsystematic and take insufficient account of prior results. The possibility of unpleasant surprises 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.

The existence of a fallback is critically important. Unlimited energy at fixed (usually high) marginal cost.

The exception 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 lose 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.