Geoengineering the Climate

Joanna D. Haigh

Department of Physics and Grantham Institute for Climate Change
Imperial College London

acknowledgements:
Royal Society Geoengineering Panel
Markus Quante, Helmholtz-Zentrum Geesthacht
Tempting to dismiss/ignore – but no longer possible. On the agenda for governments, industry, IPCC. Needs critical scientific assessment. Ethics? Governance?

Web of Science as of 18 May 2011 papers referring to geoengineering
**Geoengineering in IPCC AR5 2014**

CHAPTER OUTLINE OF THE WORKING GROUP I CONTRIBUTION TO THE IPCC FIFTH ASSESSMENT REPORT (AR5)

Revised version of WG-I: 11th/Doc.2 adopted by the Eleventh Session of Working Group I

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CO₂ and Attribution of causes to climate change

**CO₂ emissions**

Le Quéré et al. (2009)

Growth currently 3.4% /year

**CO₂ concentration**

Mauna Loa Observatory, Hawaii

Quante (2010)

Global temperature record

GCM: all forcings

GCM: only natural forcings
Future?

Temperature change

Ranges:
- 95%
- 90%
- 85%
- 80%
- 68%
- 50%
- Median

SRES A1FI
HALVED-BY-2050

Meinshausen et al. 2009

Global-mean air surface temperature relative to 1860–99 (°C)

Year

1900 1920 1940 1960 1980 2000 2020 2040 2060 2080 2100

max 2°C

Imperial Co London

Grantham Institute for Climate Change
Sea level rise

Satellite measurements

Best estimate by IPCC

Tide gauges

Year

after Rahmstorf 2009

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Options?

Mitigation

GHG emission reduction
energy efficiency, low carbon energy, sufficiency

(but “free-rider” problem: talk globally – postpone nationally)

Adaptation

infrastructure / dikes, reservoirs
change of agricultural habits
resettlement

(inequitable)

Manipulation

geoengineering

(ace up the sleeve? emergency brake?)
Climate problem loop

Socio-economic system

Mitigation

Emissions

Temperature change

Adaptation

Climate system

Geo-engineering

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Mitigation post-Copenhagen and Cancun ??
Some adaptation may be necessary ...
Geoengineering

*Perhaps*

- the solution
- an emergency break
- a time-winning option

*Or*

- the devil’s answer

??
Term coined in a paper by Marchetti (1977) but still has no ‘absolute’ definition.

Geoengineering is intentional large-scale manipulation of the environment.


Keith adds: Scale and intent play a central roles in the definition. Large-scale: continental to global.

Geoengineering is purposeful action intended to manipulate the environment on a very large scale - especially global-scale. Geoengineering is, presumably, undertaken to reverse or reduce impacts of human actions.

Robert A. Frosch, Physics Today (2009)
Weather modification proposals are not new

The Technocrat Collier’s (1954)

• 1945: John von Neumann and other leading scientists meet at Princeton and agreed that modifying weather deliberately might be possible (motivation was “next great war”)

• 1958: US Congress funded expanded rainmaking research (Irving Langmuir, GE)

• Cold War: U.S. military agencies devoted significant funds to research on what came to be called “climatological warfare”
  – one aim was to make the Arctic Ocean navigable
  – extensive cloud-seeding conducted over Ho Chi Minh Trail during Vietnam war

• 1975: Mikhail Budyko calculated that if global warming ever became a serious threat, we could counter with just a few airplane flights a day in the stratosphere, burning sulphur to make aerosols that would reflect sunlight away

• 1977: N.A.S. report looked at a variety of schemes to reduce global warming, should it ever become dangerous, and concluded a turn to renewable energy was a more practical solution than geo-engineering of climate
Early suggestions
Policy Implications of Greenhouse Warming,
NATIONAL ACADEMY PRESS, Washington, D.C. 1992

Chapter 28: Geoengineering (pp 433-464)

Moving forwards:

several reports between 1997 and 2002
New kickstart in 2006


Increasing interest

workshop 2006

workshop 2007

Pontifical Academy of Sciences 2007


policy statement 2009

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Earth’s energy balance

- **Incoming solar irradiance**: 342 W/m²
- **Reflected from atmosphere and surface to space**: 107 W/m²
- **Absorbed by atmosphere**: 67 W/m²
- **Reflected by surface**: 30 W/m²
- **Absorbed at surface**: 168 W/m²
- **Transmitted from the surface to space**: 40 W/m²
- **Absorbed by atmosphere**: 350 W/m²
- **Emitted from atmosphere to space**: 195 W/m²
- **Emitted by surface**: 390 W/m²
- **Emitted by surface and absorbed by surface**: 324 W/m²
- **Emitted to space**: 235 W/m²

**Greenhouse gases**
- **Transferred from surface to atmosphere by convection**: 102 W/m²
Classification of methods

Carbon dioxide removal (CDR):

- Removal of CO$_2$ from the atmosphere and sequestration and land or in ocean

Solar radiation management (SRM):

- Reduction of solar radiation being absorbed at the surface
The "greenhouse effect"

1. 50% of the incident solar radiation is absorbed by the surface.
2. The surface warms and emits heat radiation.
3. The atmosphere absorbs 90% of the heat...
   ...and re-radiates it in all directions.
4. Thus further warming the surface.

N.B. In equilibrium there is a balance between incoming and outgoing radiation at the top of the atmosphere.
Radiative forcing is the instantaneous imbalance in the TOA radiation budget due to a change in atmospheric composition, solar input or surface properties.

E.g. an increase in atmospheric absorption... ...reduces emission to space.....

Warmer atmosphere... ...increases re-radiation...

...causing a positive anomaly in net radiation at TOA*.

...resulting in surface warming and re-establishing balance at TOA.

*TOA=top of the atmosphere
Proposed methods

Climate Change Abatement/Mitigation Technology

**CDR**

- Long Wave Radiation
  - Reduce CO₂ Emissions
    - Switch Energy Sources
    - Improve Efficiency
    - CO₂ capture & storage with fossil carbon

- Remove CO₂ from the air

**SRM**

- Short Wave Radiation
  - Decrease incident solar radiation
  - Increase the Earth’s Albedo
    - Surface albedo
    - Cloud seeding
    - Stratospheric Aerosols
    - Engineered particles

- Biologic Schemes
  - CCS with biomass
  - Iron Fertilization
  - Reforestation

- Chemical Schemes
  - Solvent Regeneration loops
  - Altering the Ocean’s alkalinity

**Kurt Zenz House, Harvard**
CO$_2$ air capture

CO$_2$-scrubber (250000)

May be deployed anywhere

Giant amount of waste to store

2NaOH + CO$_2$ $\rightarrow$ Na$_2$CO$_3$
CO\textsubscript{2} air capture

Need 10 million devices to reduce global CO\textsubscript{2} by 5 ppm/year
Carbon Capture and Storage (CCS)

e.g.
Sleipner gas field
North Sea
(Statoil, Norway)

Utsira-formation
(800-1000m deep)
sand and brine

Official policy in some countries
• research power plants
• energy demanding
• leakage?

Gas

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Afforestation / bio-char
Ocean fertilisation

`Give me half a tanker of iron and I will give you an ice age´,

John Martin, WHOI Oceanographer, 1989

Iron (or nitrogen or phosphorous) to enhance plankton (coccolithophore) blooms

1. Ship off-loads iron.
2. Iron causes growth of phytoplankton, which capture CO₂.
3. Dead plankton sink.
4. Some reach depths where carbon may stay for 100 years or more.

The Fantasy: Plankton populations rebound to historic levels, reviving fisheries and sequestering vast amounts of carbon.

The Fear: Iron leads to the depletion of deep-water oxygen, alters food chain, and promotes toxic species; CO₂ soon resurfaces.
Major conclusion:

Potential of OIF as a means of CO$_2$ sequestration is substantially smaller than previously thought.

_Ulrich Bathmann, Alfred Wegener Institut, 2009_
Other schemes...

Wave-powered nutrient pump

Ice build-up, deep water formation

James ‘Gaia’ Lovelock
an increase in albedo

...so surface temperature returns to ‘normal’

**SRM**

Atmosphere

cools the surface

Surface

*TOA=top of the atmosphere

Climate response

...resulting in reduced emission

and cooler atmosphere

atmospheric emission high due CO₂ content

...so surface temperature returns to ‘normal’
Equal globally-averaged forcing but will the climate response to the combined forcing cancel?

Govindasamy and Caldeira, GRL, 2000
GCM estimates of (generic) SRM

Change in temperature

![Temperature change map](image)

- $2 \times \text{CO}_2$
- $2 \times \text{CO}_2 + \text{TSI} - 1.84\%$

Change in precipitation

![Precipitation change map](image)
Giant mirror in space

Mirror 1.5 M km towards the sun (L1-point)

1% reduction in irradiance for mirror 2000 km diameter

produced on and launched from the moon (Early, 1989)
... or a cloud of small ones

16 trillion sun shades in space

Roger Angel, University of Arizona

Angel, PNAS (2006)

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Artificial volcano?

Drop in temperature following major volcanic eruptions. Could artificially inject sulphur into the stratosphere to counteract global warming?
5 Tg sulphur lifted by balloons to altitudes between 10 and 50 km

S to SO$_2$ to SO$_4$- particles

$25 – 50$ billion p.a.

*Potential (specific) problems:*
Ozone depletion
Acidification
Cirrus production?
A “better solution”

Risky Gamble

Reducing emissions of greenhouse gases may be well intentioned and even helpful. But as the sole strategy for climate change control it is nevertheless inflexible, expensive, risky, and politically unrealistic, according to this government economist. Such a strategy could even make matters worse. Fortunately, there is a better solution.

ALAN CARLIN

Alan Carlin is a Senior Economist at the U.S. Environmental Protection Agency. The views expressed in this article are his own and should not be taken to represent official U.S. policy.

Magazine of the Environmental Law Institute
Climate Engineering – regional SRM deployment

Robock et al. (2008)

Change in Global Temperature and Precipitation

Thick lines T, thin lines precip

Stop of CE

Years from commencement of CE
Aerosols and stratospheric ozone

Enhancement of stratospheric aerosols due to geo-engineering causes a 30 to 70 year delay in the recovery of the Antarctic ozone hole.

Indirect aerosol effect – marine stratus clouds

For same water content:

few large droplets: low albedo

many small droplets: higher albedo
Spray vessels

Slater et al. 2008
Coupled atmosphere ocean model study

assumes technique works and CDNC set to asymptotic maximum

Mean 2030–2059 near-surface temperature change (K) (ALL – A1B) Areas where the change is not statistically significant at the 5% level are in white.

Mean 2030–2059 land precipitation (mm day⁻¹): (a) distribution in A1B; (b) ALL- A1B. Land areas in Figure 4b where the change is not statistically significant at the 5% level are in white.
Other SRM proposals

1. whiten deserts
2. more reflective plants
3. paint roofs and streets in white
4. more reflective glass
5. Float ping pong balls on the oceans

Each Earth inhabitant paints white a surface of 200 m²
Crazier techniques to reduce solar irradiance

It would require the energy of five thousand, million, million hydrogen bombs to move Earth's orbit 1.5 million km out. (Ken Caldeira)
Some objections:

- Treats symptoms not cause: excuse not to reduce GHG?

- Environmental impacts include shifting direct to diffuse radiation (impact on solar PV), sky colour, biospheric impacts, carbon storage rate, ozone depletion;

- SRM techiques would not slow the build-up of CO₂ & would do nothing to slow ocean acidification;

- As a substitute for mitigation would require a permanent, increasing commitment for many future generations

- System failure (or decision to halt ongoing geoengineering operation) would commit the world to a period of even more rapid warming than is ongoing today;

- An international agreement on a governance structure is a huge challenge.
## Benefits and risks

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<th>Risks</th>
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<td>1. Cool planet</td>
<td>1. Drought in Africa and Asia</td>
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<tr>
<td>2. Reduce or reverse sea ice melting</td>
<td>2. Continued ocean acidification from CO₂</td>
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<tr>
<td>3. Reduce or reverse land ice sheet melting</td>
<td>3. Ozone depletion</td>
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<td>4. Reduce or reverse sea level rise</td>
<td>4. No more blue skies</td>
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<td>5. Increase plant productivity</td>
<td>5. Less solar power</td>
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<td>6. Increase terrestrial CO₂ sink</td>
<td>6. Environmental impact of implementation</td>
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<td>7. Rapid warming if stopped</td>
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<td>8. Cannot stop effects quickly</td>
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<td>9. Human error</td>
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<td>10. Unexpected consequences</td>
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<td>11. Commercial control</td>
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<td>12. Military use of technology</td>
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<td>13. Conflicts with current treaties</td>
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<td>14. Whose hand on the thermostat?</td>
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<td>15. Ruin terrestrial optical astronomy</td>
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<td>16. Moral hazard – the prospect of it working would reduce drive for mitigation</td>
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<td>17. Moral authority – do we have the right to do this?</td>
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Ranking geo-engineering schemes

High effectiveness: low affordability

- Space reflector
- CO$_2$ air capture
- Enhanced weathering

High effectiveness: high affordability

- Stratospheric aerosols

Low effectiveness: low affordability

- Surface albedo (desert)
- Surface albedo (urban)

Low effectiveness: high affordability

- CCS at source
- BECS
- Cloud albedo
- Ocean fertilisation
- Afforestation

Colour=risk   Size=speed
Ranking geo-engineering schemes
Remaining issues

Hysteresis effects in climate system?

Are the models good enough?

How to carry out full risk assessment?

Are large scale experiments needed?

Ethical, political and legal aspects...
Ethical, political and legal aspects

“On the issue of ethics, I feel we would be taking on the ultimate state of hubris to believe we can control the Earth.”  

J. Kiehl (2006), Climatic Change

Is it morally tolerable to deliberately make massive changes to the natural environment?

Winners and losers.

“How cold do we want it?” “Who decides?” “Whose hand is on the thermostat?”

Governance structure with sufficient transparency is needed.

UN – IPCC like structure?

How to avoid unilateral implementations?  (reason for war?)

UN Convention on the Prohibition of Military or any Other Hostile Use of Environmental Modification Techniques (ENMOD) 1978

Internationally accepted rules needed...
Forget about a future filled with wind farms and hydrogen cars. The Pentagon's top weaponeer says he has a radical solution that would stop global warming now - no matter how much oil we burn.

Lowell Wood as portrayed in Rolling Stone (Nov. 2006)
Role of scientists

Scientists will be asked for advice, as well as for basic research.

Need to assess limitations of schemes.

How to avoid premature implementation?

*moratorium?*

While a strong scientific basis is necessary for geoengineering, it is far from sufficient. Many ethical and legal issues must be confronted and questions arise as to governance and monitoring, as several authors have noted (e.g. Kellogg and Schneider, 1974; Schneider, 1996; Bodansky, 1996). A useful step might be for scientists to defer participation in geoengineering interventions (while supporting research), which moratorium would continue until acceptable agreements were in hand. Such an agreement would, ideally, include provision for expert, international peer review before actions would be mounted, for significant public involvement, and the establishment of a qualified agency to oversee the design, implementation and monitoring of the experiment.

*R. J. Cicerone (2006), Climatic Change*
Thank You