An Introduction To Geoengineering: The good, the bad and the ugly

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• CO₂ and other greenhouse gases absorb infrared radiation

• Climate warms in response, how much is still uncertain

Carbon-dioxide removal (CDR)

Solar Geoengineering
Atmospheric CO$_2$ Concentrations

We’re in the midst of a massive experiment on a system that is not well understood...

Last time CO$_2$ was this high was 3 million years ago (?) and sea levels were ~50 feet higher (?)
Part of Antarctica Detaches, 2010

B9B – 60 miles long

Marine Ice Sheet Collapse Potentially Under Way for the Thwaites Glacier Basin, West Antarctica

Ian Joughin, Benjamin E. Smith, Brooke Medley

Resting atop a deep marine basin, the West Antarctic Ice Sheet has long been considered prone to instability. Using a numerical model, we investigated the sensitivity of Thwaites Glacier to ocean melt and whether its unstable retreat is already under way. Our model reproduces observed
Climate Change Likely Supercharged Hurricane Harvey

Two separate studies find that climate change boosted the storm’s rainfall by at least 15 percent, according to The New York Times.

2017 Hurricanes: > $200B in damage in US
More Wildfires

“Camp Fire” in California cost ~ $16.5B
Paris Agreement

• “...holding the increase in the global average temperature to well below 2°C above preindustrial levels and to pursue efforts to limit the temperature increase to 1.5°C”

  – Already > 1°C higher
CO2 emissions keep growing...

High emissions leading to dangerous warming

Country pledges (NDCs) for 2030 exceed warming limit of Paris Agreement

Decreasing emissions compatible with a well below 2°C warming limit


Global Fossil CO2 Emissions

2010–17
+1.0%/yr

2010–17
37.1 Gt CO2
△ 2.7% (1.8%–3.7%)

2000–10
+3.1%/yr

1990–2000
+1.1%/yr

© Global Carbon Project • Data: CDIAC/GCP/BP/USGS
CO\textsubscript{2} is not like conventional air pollutants

Conventional pollutants like SO\textsubscript{2} or NO\textsubscript{x} remain in the atmosphere of just a few hours or days. When CO\textsubscript{2} is emitted much of it remains in the atmosphere for \(~100\) years.

For this reason, and because it takes a long time to change the oceans, many aspects of the climate system have great \textit{inertia}. 
What happens if we instantly stop emissions?

- The Earth continues to warm as it is not yet in equilibrium with the forcing from current CO₂ concentrations.
- CO₂ concentrations drop because the ocean is not yet in equilibrium with atmospheric CO₂ concentrations.
- Tropospheric aerosols decline, removing the estimated 0.3°C (??) of cooling they currently provide.
- Short-lived forcers? (Methane, etc.)
Responses to Climate Change

• Clean energy investments / mandates (reducing CO$_2$ and other emissions)
  – Also relevant to energy independence and other environmental (e.g. air quality) concerns
  – Includes research, e.g. CCS (carbon-capture and sequestration), solar...

• Carbon tax or cap and trade?

• Climate change research (improved understanding of what to expect)

• Investments in adaptation (learning to live with climate change)
  – Sea walls and other infrastructure
  – Flood / hurricane insurance, crop insurance?
  – Developing alternate crops

• Geoengineering (removing CO$_2$ from atmosphere or reflecting sunlight)
  – Research (modeling and small-scale atmospheric testing)
  – Deployment (starting with large-scale testing)
Geoengineering is...

“the deliberate large-scale manipulation of the planetary environment to counteract anthropogenic climate change”

-Royal Society, 2009

Two types:
- Carbon dioxide removal (CDR)
- Solar radiation management (SRM)

1.5°C and CO₂ removal

• If we zero out ALL fossil fuel consumption everywhere on the entire planet starting today... there’s still reasonable odds of exceeding 1.5°C*

• We can stay below 1.5°C if we rapidly ramp down CO₂... and then go to net-negative emissions
  – Every molecule of CO₂ we emit from now on, our children need to pay to suck back out...

* Depends on assumptions on non-CO₂ forcers as well.
Carbon Dioxide Removal

• Lots of ideas

• Nothing yet demonstrated at scale
  – Need a worldwide infrastructure comparable in scale to current energy infrastructure
  – Need to develop this in the next few decades

• No silver bullet that is
  – Scalable to *tens of Gigatonnes* per year
  – (Relatively) inexpensive
  – Without local impacts (e.g. food security or water usage)
Solar geoengineering
The Climate System

Generally:

• About 30% of incoming solar (shortwave) is reflected back to space
• About 70% is absorbed and re-emitted by the Earth (longwave)
• The atmosphere is transparent to shortwave, partially opaque to longwave
• “Recycling” of Earth’s energy by the atmosphere warms the surface
How to change the temperature of the Earth

To warm:

- Add greenhouse gases like carbon dioxide
How to change the temperature of the Earth

To warm:

• Add greenhouse gases like carbon dioxide
• Enhance “recycling” power of the atmosphere re-radiating more energy back to the surface and increasing the surface temperature more
How to change the temperature of the Earth

To cool:

• Remove greenhouse gases, or...
How to change the temperature of the Earth

To cool:

• Remove greenhouse gases or...
• Increase reflectivity (“albedo”) of the atmosphere or surface
• Decrease the amount of sunlight that is absorbed and re-emitted by the Earth, and therefore the amount of energy for the atmosphere to recycle
How to reduce global warming with solar geoengineering
Mt. Pinatubo
1991

Resulted in 30Mt of sulfate aerosols in stratosphere
Marine Cloud Brightening
Ship tracks due to aerosols

- A fleet of ships spraying salt-water into low clouds might cool the planet
- Cloud-aerosol interactions are poorly understood!
- Doesn’t work everywhere: spatially heterogeneous radiative forcing
The Good
There is clear evidence from many large past volcanic eruptions that this mechanism cools the planet (Mount Pinatubo produced global scale cooling of about 0.5°C).

Sources NASA; IPCC, 2007.
“We conclude that (a) the basic technological capability to deliver material to the stratosphere at million tonne per year rates exists today, (b) ... a few million tonnes per year would be sufficient to alter radiative forcing ... equivalent to the growth of anticipated greenhouse gas forcing over the next half century, and that (c) several different methods could possibly deliver this quantity for less than $10B per year.”

(J. McClellen et al, 2012)
High CO2 worlds with & without solar geoengineering

Source: Caldeira K, Wood L Phil. Trans. R. Soc. A 2008; 366:4039-4056
High CO2 worlds with & without solar geoengineering

It works surprisingly well at reducing extremes in a high-CO2 world ...

The Good

In summary: solar geoengineering could reduce the effects of climate change quickly, in most places, at low direct cost.
The bad
Effects of CO2 on the global hydrological cycle

1) Temp. Up ➔ Evaporation and Precip. Up
2) Vertical Instability Down ➔ Precip. Down
3) Transpiration Down ➔ Precip. Down

Sources: USGS, Columbia University
Effects of geoengineering on the global hydrological cycle

Source: Cao et al 2012
Influences of temperature and greenhouse gases on precipitation

Source: Ricke et al, 2010
Global Response Overview

SRM SCENARIOS

TEMPERATURE RESPONSE

PRECIPITATION RESPONSE

Source: Ricke et al, 2010
Regional, Seasonal Analysis
A Typical Region:
East Asia, Summer (June, July and August)
A Typical Region: East Asia, Summer (June, July and August)
Regional Comparison Example: China vs. India

(in units of baseline standard deviations; baseline=1990s)

In the 2020s, there are generally a variety of geoengineering scenarios for which a region’s average temperature and precipitation rate is back within one standard deviation of its baseline climate.
Regional Comparison Example: China vs. India
Who controls the thermostat?
Who controls the thermostat?

[Graph showing temperature and precipitation trends with data points for India in the 2020s and 2070s, and China in the 2020s and 2070s, indicating higher temperatures and precipitation variability with less geoengineering.]
“Optimal” activities will vary regionally...

“Optimum” by region in 2020s

Approximate Global Mean SAT (°C)
“Optimal” activities will vary regionally...

“Optimum” by region in 2020s

“Optimum” by region in 2070s

Optical Depth
0.25
0.20
0.15
0.10
0.05
Year
2020 2040 2060 2080

More Geoengineering

Less Geoengineering

Approximate Global-Mean SAT (°C)
14.6 14.8 15.0 15.2 15.4 15.6
Tension between slowing sea-level rise and temperature change

Source: Irvine et al 2012
Reversal of ozone hole recovery?

Source: Tilmes, Müller and Salawitch, 2009
What are the impacts of climate change?

Impacts and risks for selected natural, managed and human systems

- **Purple** indicates very high risks of severe impacts/risks and the presence of significant irreversibility or the persistence of climate-related hazards, combined with limited ability to adapt due to the nature of the hazard or impacts/risks.
- **Red** indicates severe and widespread impacts/risks.
- **Yellow** indicates that impacts/risks are detectable and attributable to climate change with at least medium confidence.
- **White** indicates that no impacts are detectable and attributable to climate change.

Confidence levels for transition: L=Low, M=Medium, H=High and VH=Very high.

IPCC Special Report 1.5 degrees
What are the impacts of geoengineering?

Impacts and risks for selected natural, managed and human systems

- Stratospheric ozone depletion?
- Arctic ecosystem disruption?

IPCC Special Report 1.5 degrees
(+ shout out: Tyler Felgenhauer)
The Bad

In summary: solar geoengineering would have imperfections and side effects that will make global governance difficult ... plus, it’s premature to speculate how its climate effects translate to impacts
The ugly
Risks: social considerations

• Deliberate modification of the climate system is unethical, immoral
• Knowing about geoengineering may make us less likely to reduce emissions
• Thermostat-setting will be an inequitable process, could even lead to conflict
Solar geoengineering termination shock

Simulated surface air temperature (a) and annual rate of temperature change (b) for runs A2 (red), GEO (BLUE), OFF_2025 (green), OFF_2050 (orange), and OFF_2075 (purple).

Source: Matthews H D, Caldeira K PNAS 2007;104:9949-9954
A more acidic ocean...

...may mean the demise of coral reefs and all the ecosystems they support.

375ppm +1°C  450-500ppm +2°C  >500ppm >3°C
‘Cocktail geoengineering’

“The strategy may be somewhat like the treatment of AIDS, with a constantly shifting ‘cocktail’ of drugs.

As the number of interventions rises so will the cost and complexity. More complex systems will be harder to assess because they will involve so many different interactions. To date, none of the technical or economic assessments of geoengineering have examined this kind of complex multi-faceted geoengineering—what I’ll call ‘cocktail geoengineering’.”

(D. Victor, 2008)
Map of potential policy-relevant tipping elements in the climate system

Source: Lenton T M et al. PNAS 2008;105:1786-1793
Map of potential policy-relevant tipping elements in the climate system

Source: Lenton T M et al. PNAS 2008;105:1786-1793
Why do ice sheets melt?
The Ugly

In summary: There’s no evidence we can use it to reverse “climate emergencies” after we’ve detected their arrival... effective use of geoengineering (under the circumstances it’s most needed) could require the same foresight we have not yet employed for emissions abatement
In conclusion
Many Responses to Climate Change

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At best geoengineering is a piece of this...

- Business as usual
- Cut emissions aggressively
- CO₂ removal ("CDR")
- BECCS
- Direct air capture
- Afforestation
- Soil mgmt
- Weathering...

Solar geoengineering?
- Stratospheric aerosols
- Marine cloud brightening
Not a substitute for mitigation

Solar geoengineering...

Cut emissions aggressively

CO₂ removal

Business as usual

(Climate Impacts vs. Time)

(Would require high forcing and a practically indefinite commitment.)
There are many unknowns

IPCC Special Report 1.5 degrees
(+ shout out: Tyler Felgenhauer)
There are many unknowns

... and a huge asymmetry of information we're dealing with when we compare impacts of global warming and geoengineered cooling.

The only way to remedy this asymmetry is to expand the community of researchers and do more research.
Thank you

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