PCC 587, Fundamentals of Climate Change

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LAST DAY OF LECTURES!: 12/4/2013

Climate engineering
AKA geoengineering

"The intentional, large-scale manipulation of the environment." [David Keith]

"Deliberate, large-scale intervention in the Earth's climate system, in order to moderate global warming.'" [Royal Society]

Geoengineering History

- 1974: Mikhail Budyko proposed injecting sulfur dioxide in the stratosphere to cool the earth (like volcanoes)
- Early 1990s: Edward Teller and collaborators proposed putting designer (nanotech) particles into the stratosphere to deflect sunlight

Geoengineering History

- 1992: The National Academy of Sciences issues a detailed study on geoengineering options, including a cost-benefit analysis for each option
- 2006: Paul Crutzen (Nobel Prize winner for ozone hole) says we should consider it
  - The scope and speed of climate changes due to increasing CO_2 -- coupled with the lack of any progress on mitigation – requires sulfate aerosol geoengineering solution be seriously considered

Two Main Strategies of Geoengineering

- Taking CO_2 out of the atmosphere
- "Solar radiation management": blocking out the Sun to cool the Earth back down
  - This is what **most people are talking about** when they refer to geoengineering
  - Various ideas to do this kind of thing (some sound like sci-fi!)

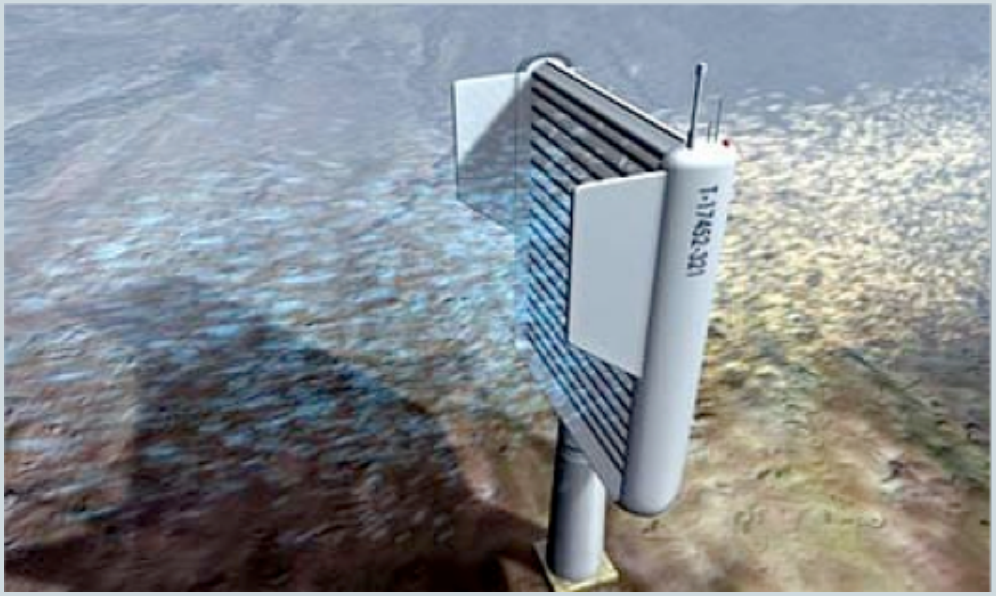
Air Scrubbers

Chemically remove CO2 by passing air through a scrubber

Not operational yet

Estimated cost of prototype ~ $160,000

Require millions of these scrubbers

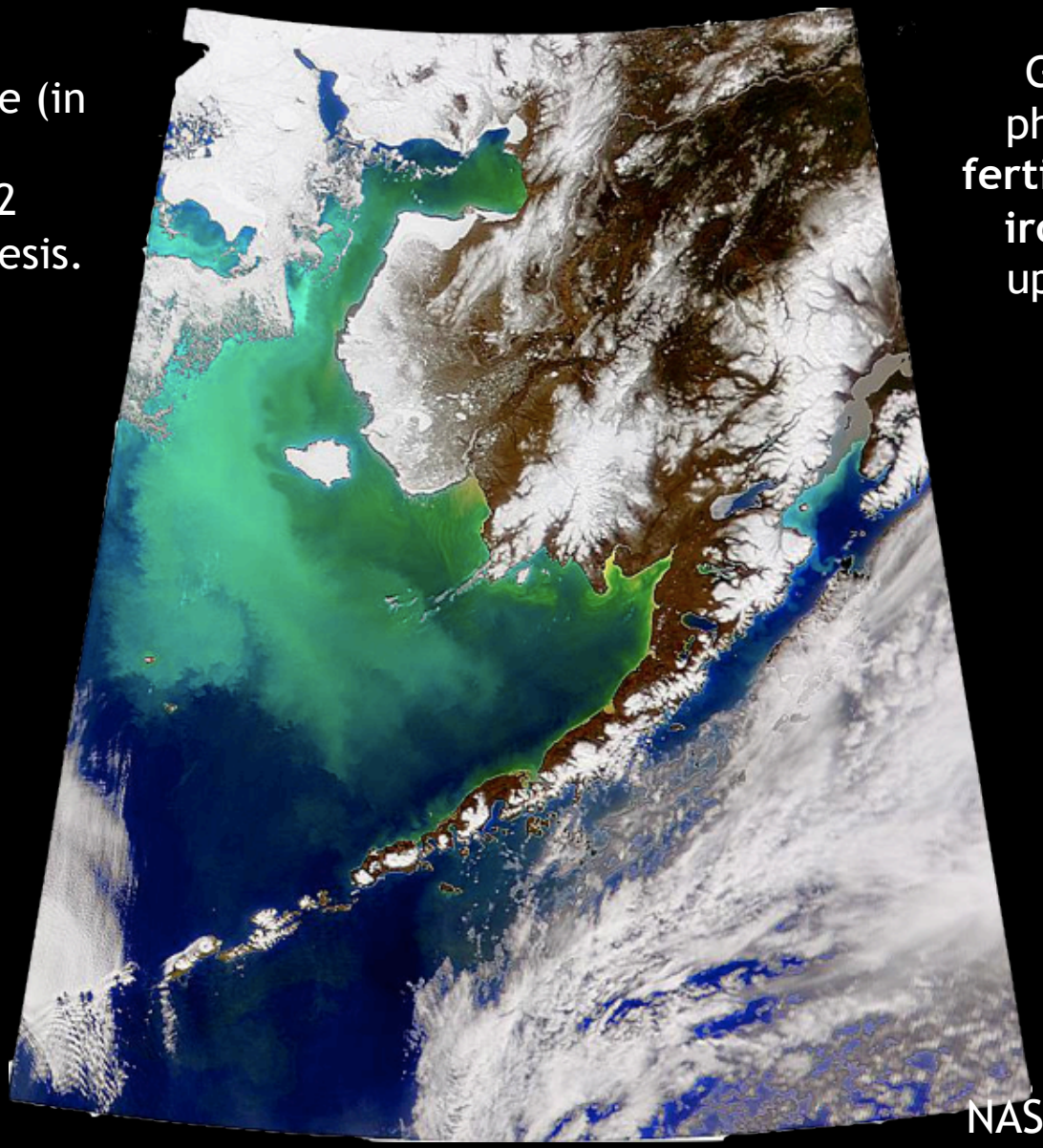


Lackner scrubber

Phytoplankton/algae (in green!) uptake atmospheric CO2 through photosynthesis.

Organisms die and sink to deep ocean, having fixed the carbon.

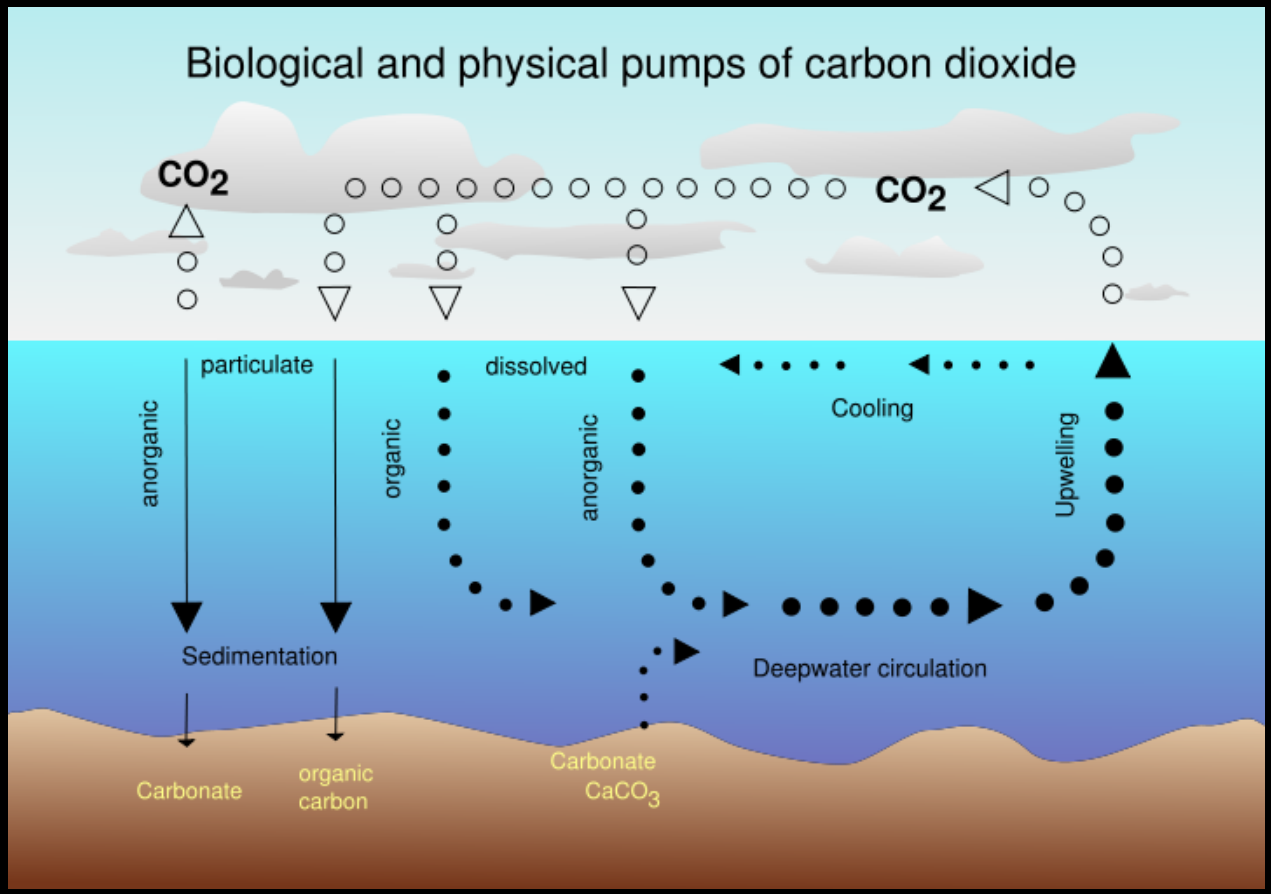
Thus, carbon is removed from contact with atmosphere.



Generate **more** phytoplankton by **fertilizing** ocean with **iron**--> more CO2 uptake by ocean.

NASA/GSFC SeaWiFS project

Kelly McCusker



the question is, even if greening uptakes more CO2, does it remove the carbon from the atmosphere for long enough?

Kelly McCusker

Burying carbon in soils

- "Terra preta" ("black earth" in Portugese) in the **Amazon basin** has tons of old carbon in it

Created by **humans** between 450 BC and AD 950

Adding charcoal to soil can keep carbon there for thousands of years!

Extremely **high quality soil** too

Biochar

- Burning biomass without oxygen (*pyrolysis*) creates biochar
  - Can be made in biomass synfuel plants (half the carbon goes into **fuel**, half into **char**)
  - Burying that carbon makes the fuel carbon **negative**!
- Can be buried in the ground to sequester carbon
  - Also improves soil quality: nutrients, water holding quality, buffering
  - Increases surface albedo though

Solar Radiation Management

- Goal of solar radiation management: reduce **shortwave radiation** that gets to the surface
  - If the **radiative forcing** *decrease* from this equals the radiative forcing *increase* from CO_2, the global temperature change should be close to zero
- A balanced energy budget would be the goal:

Energy out is **decreased** by more **greenhouse** effect (from CO_2)

$$E_{in} = E_{out}$$

Goal of geoengineering: decrease energy in from the Sun to make energy balance happen (& stop warming)

The basic strategy: Block enough sunlight to cancel radiative forcing due to increasing CO_2

- **Solar reflectors** placed in outer space at a point where the gravitational field from the earth cancels that from the sun
- **Mirrors** orbiting the earth to reflect sunlight
- Make **more clouds** or more reflective clouds
- Place/shoot tiny **particles in the stratosphere** that reflect sunlight

Increasing feasibility

Stratospheric Sulfur Injections

© New York Times
Henning Wagenbreth
Oct. 24, 2007

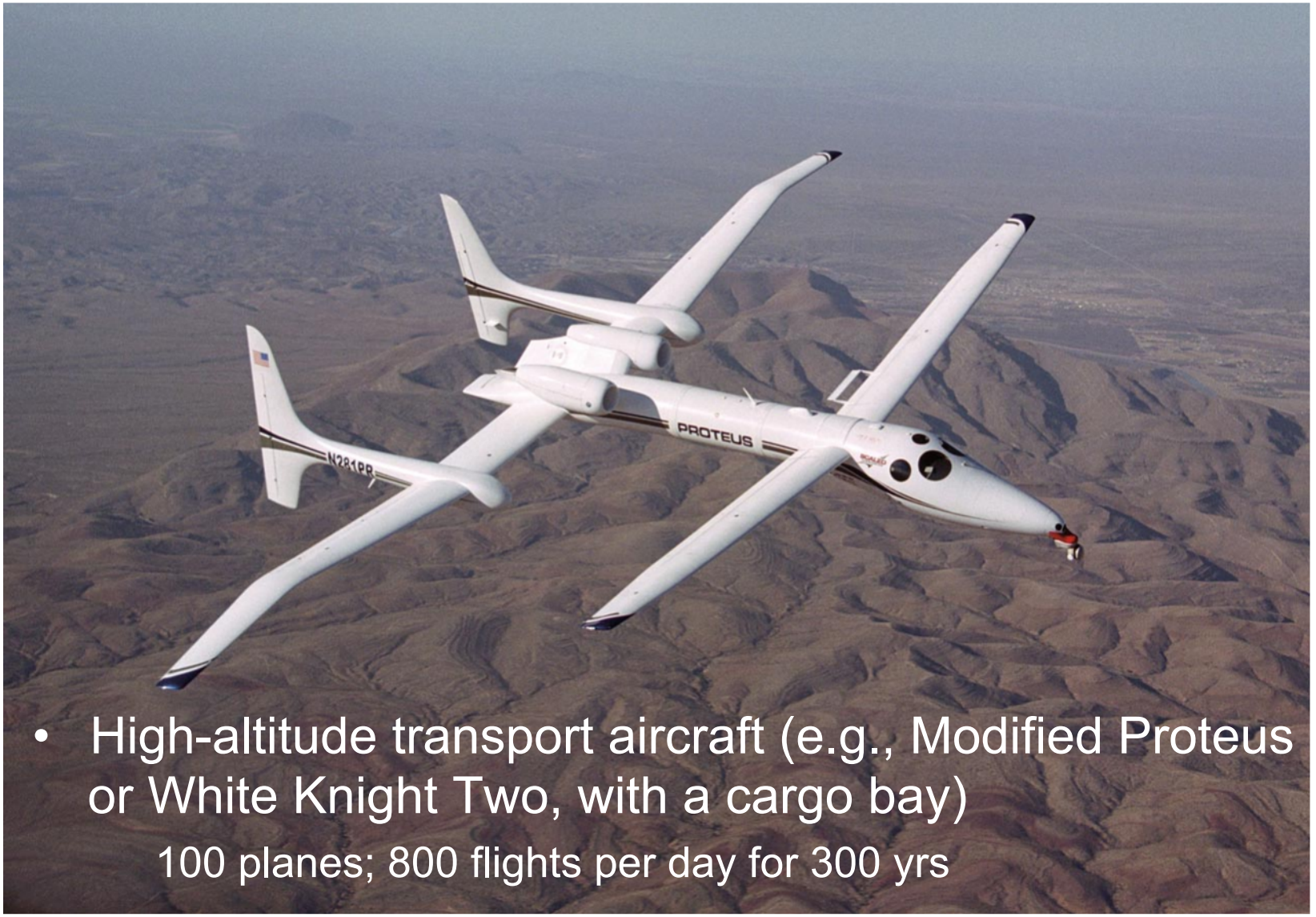
- Designed to imitate **volcano eruptions**
- Inject a **sulfate** aerosol precursor (such as sulfur dioxide SO_2) into the stratosphere that then forms sulfuric acid solutions & eventually small particles.
- These aerosols increase earth's **albedo** by reflecting solar radiation back to space.
- When injected really high up & if the particles remain small, they take a long time to fall out (months).
- Cheap compared to some estimates of mitigation costs, 10-20 billion $US/year

Possible (unproven) options for getting 10Mt of sulfur aerosols in stratosphere each year

- Artillery: shooting barrels of particles into stratosphere with 16” Iowa Class naval guns
  - Three guns firing twice per minute for 300 yrs
  - “…surprisingly practical” (NAS 1992)

Blackstock et al 2009

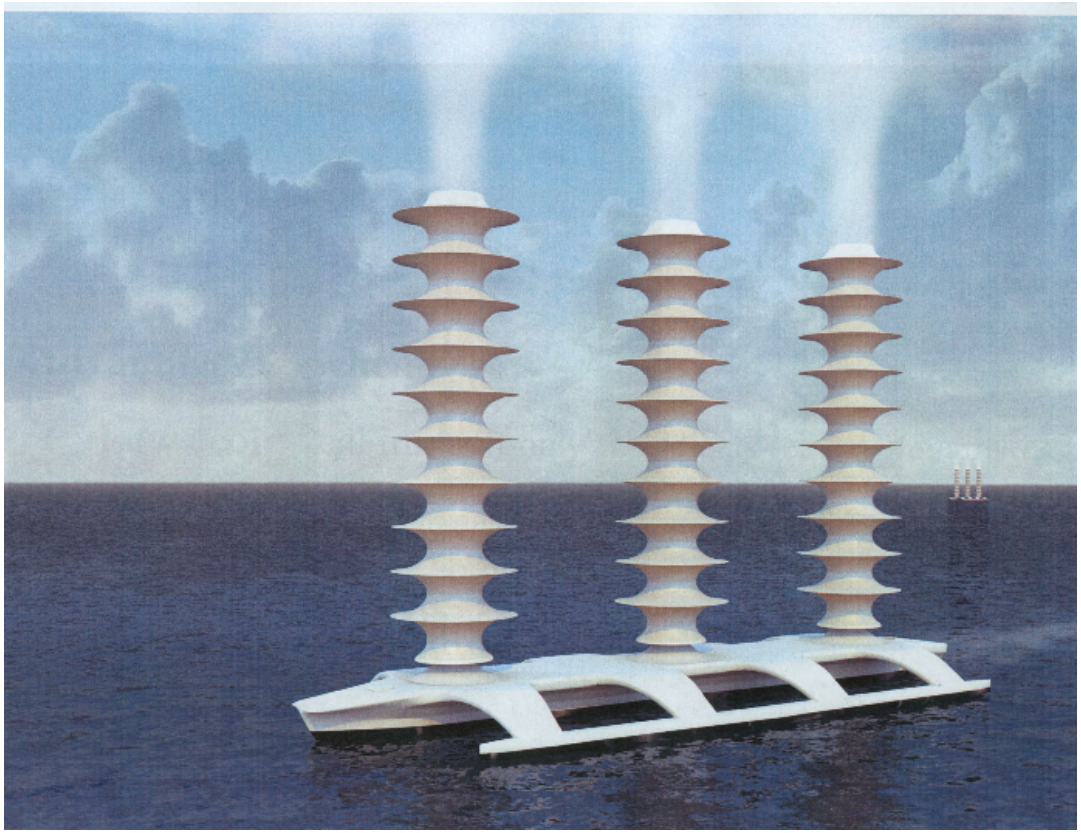
Possible (unproven) options for getting 10Mt of sulfur aerosols in stratosphere each year



- High-altitude transport aircraft (e.g., Modified Proteus or White Knight Two, with a cargo bay)
  - 100 planes; 800 flights per day for 300 yrs

Cloud modification

Controlled enhancement of the albedo and longevity of low-level maritime clouds



Cheap: 2-4 billion $US/year

- Shoot a very fine spray of sea water into the air: makes cloud droplets smaller and thus more reflective of sunlight
- Works best in pristine (ocean) areas. Need thousands of ships
- Downside: clouds are the weakest link in understanding climate change

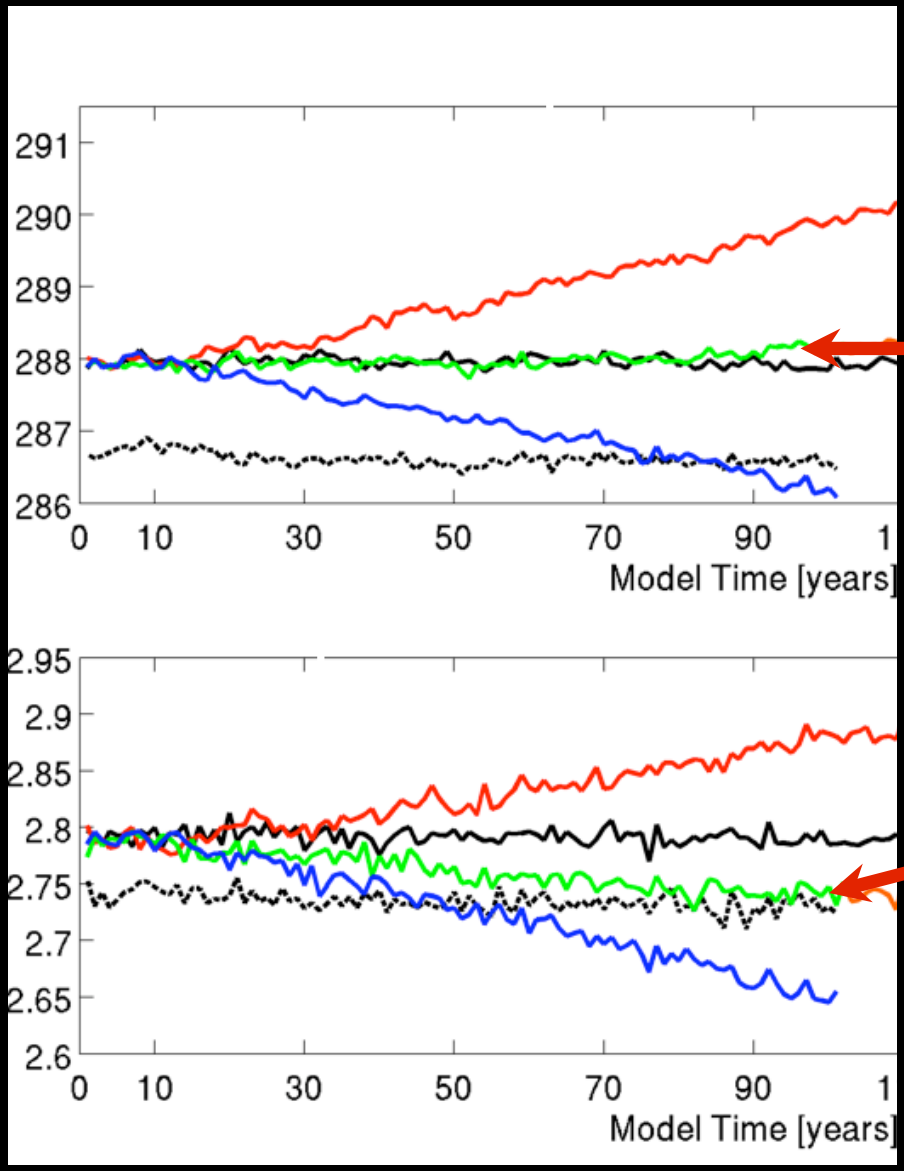
Can Dimming the Skies Perfectly Cancel CO_2?

- **No!** Solar radiation and greenhouse gases have different effects
- Remember **attribution** of global warming?
  - Greenhouse gases have a different signature than solar forcing
- E.g., greenhouse gases warm **nights** more
  - Geoengineering would cool **days** more

Other Problems with Dimming the Skies

- **Precipitation** has a different sensitivity to solar vs greenhouse gases
  - Geoengineering should **dry out** the climate more (solar radiation helps evaporate more water vapor from the surface)

Precip decreases when temps are stablized



Temp is stabilized

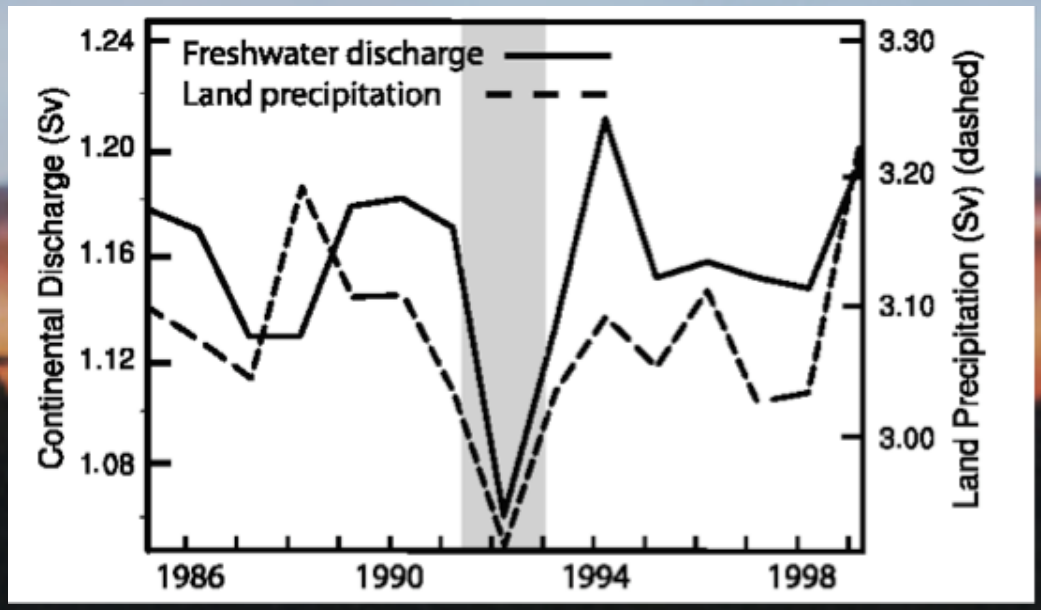
Precip continues to decline

this is just one example....

Kelly McCusker

Effect of volcanoes on land precip

- Volcanoes have been shown to reduce the amount land precipitation and disrupt monsoons



Mount Pinatubo (erupted in 1991) caused about 5% less land precipitation

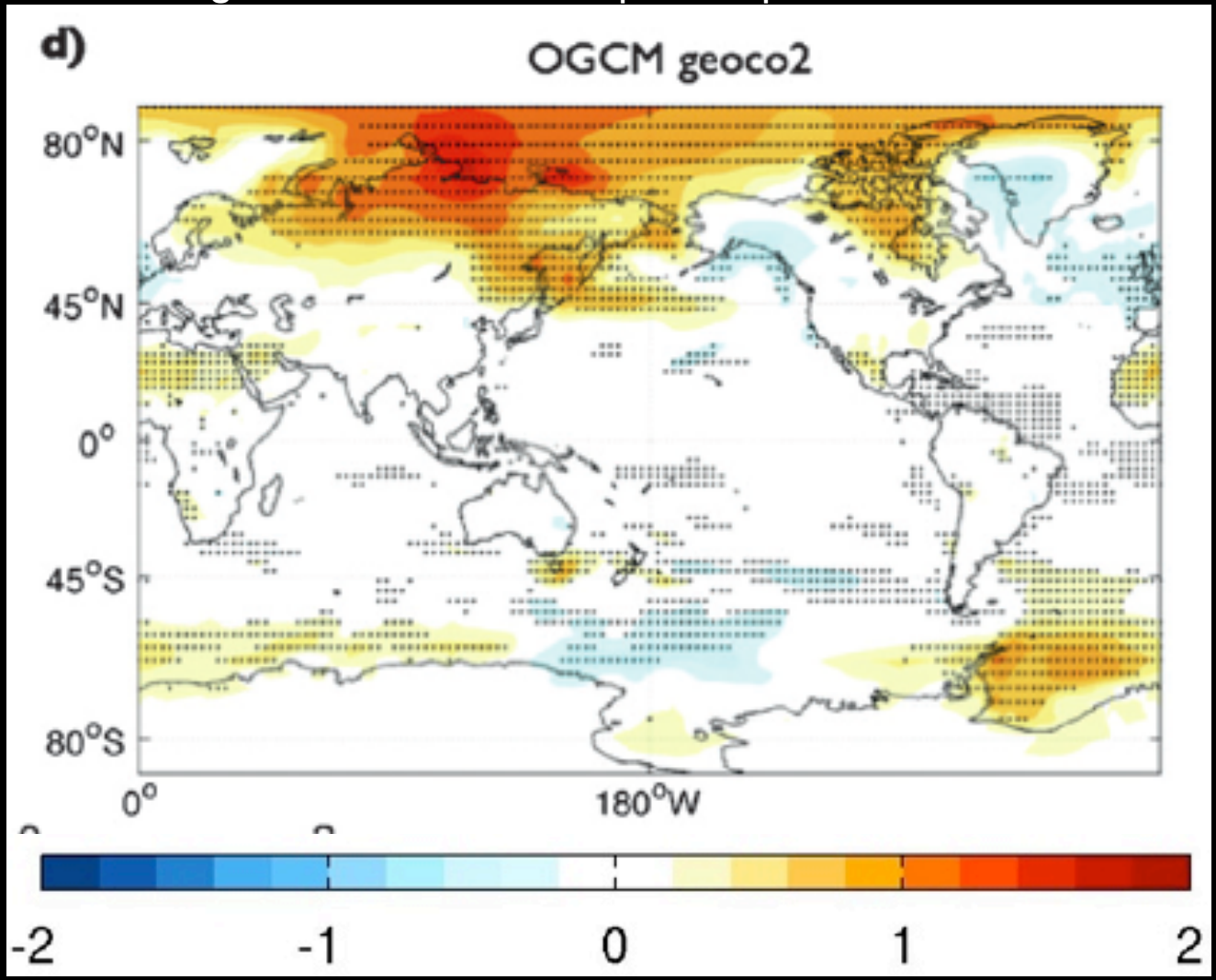
Trenberth & Dai 2007

Other Problems with Dimming the Skies

- **Temperature** has a different sensitivity to geoengineering vs greenhouse gases
  - Seems hard to cancel everywhere – especially in the Southern Ocean

Muted effect on polar regions?

change in annual mean SAT: quickramp - 20thC

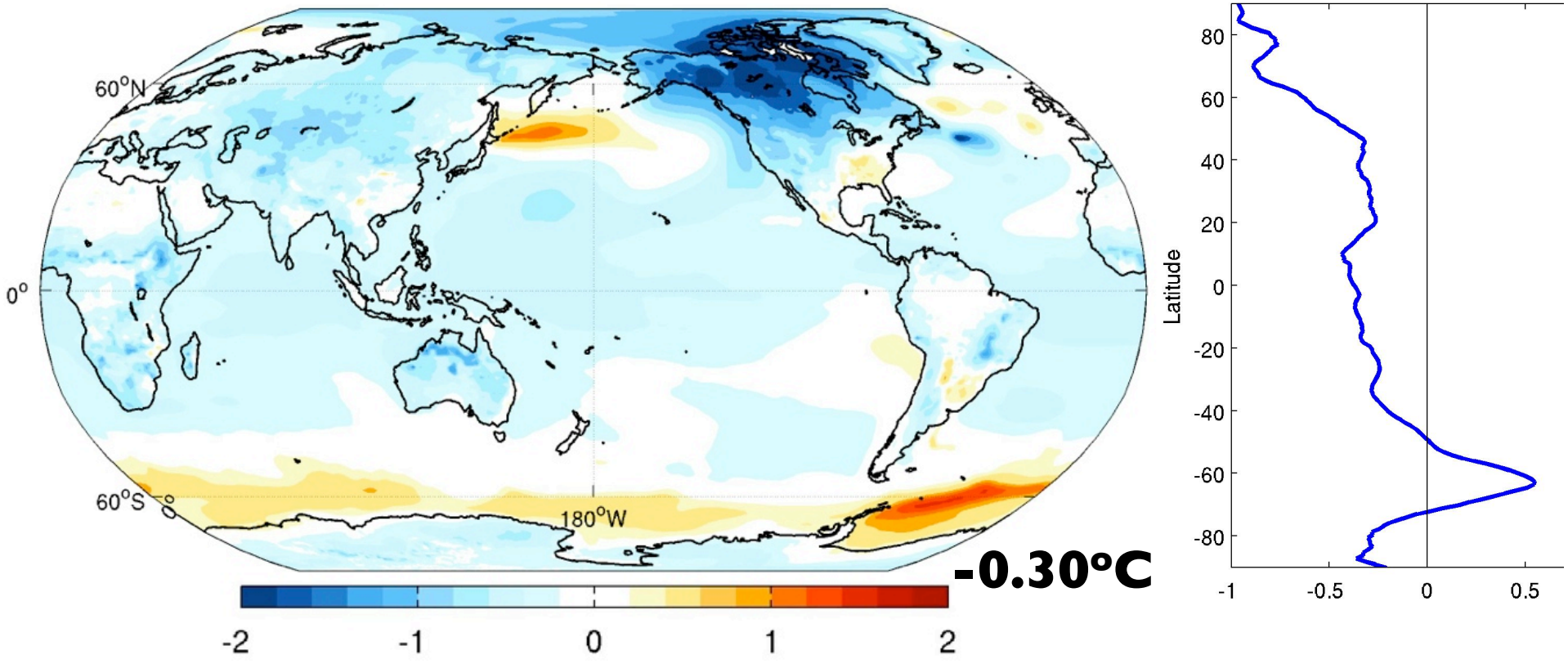


McCusker et al 2012

quickramp = 2045-2054

20thC = 1970-1999

Another case of fast geoengineering…



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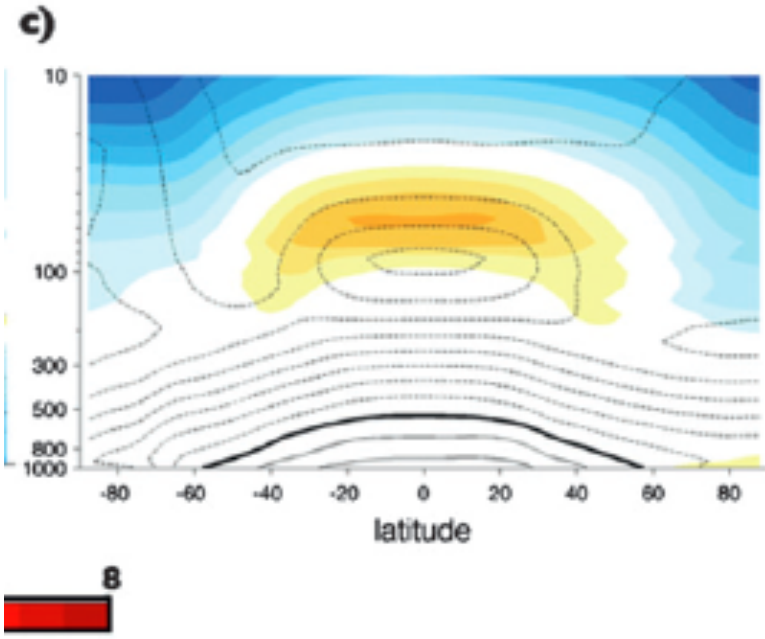
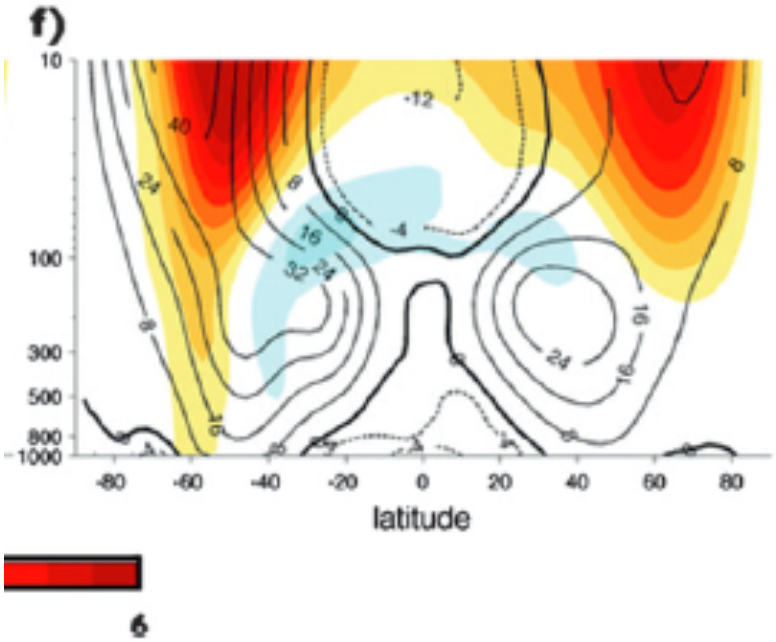




Temperature change…
(from stratospheric cooling + some solar absorption by aerosols)

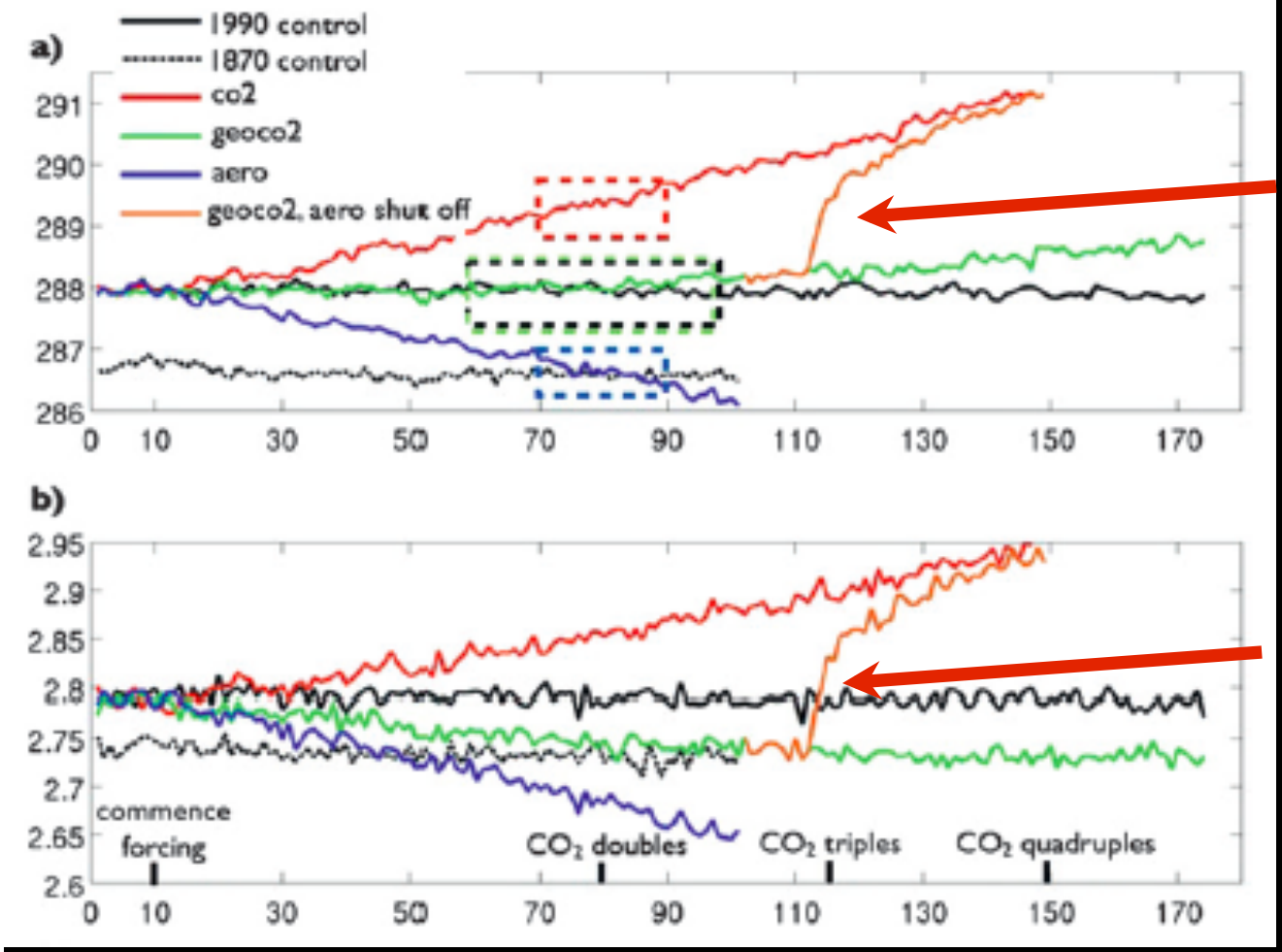
… leads to **wind** changes (poleward shift!).

This then affects ocean currents in the Southern Ocean

McCusker et al 2012

Other Problems with Dimming the Skies

- We would have to do it **forever** (almost)
  - If somehow we weren't able to continue the scheme, Earth would experience **very rapid** warming
    - Estimates suggest **2-4° C** warming within **10 years**
  - Even after emissions go to zero (i.e., once we run out of fossil fuels), we'll have to continue to do this until CO2 returned to a safe level (1000 years?)



Huge **temperature** jump if you stop!

Also immediate **precip** change

McCusker et al 2012

Other Problems with Dimming the Skies

- Effects on **plant** growth?
  - **Direct** vs **diffuse** light can have differing impacts though
- **Ocean acidification** would continue
  - Remember this just depends on atmospheric CO_2 levels
  - Large effects on marine life would not be prevented
- With these problems in mind, let's take a look at some proposed schemes

Profound and unaddressed issues associated with geoengineering

- Who decides **if** it should be deployed, and at **what level**? Who decides if it should be **stopped**?
  - What if one country decides to do it **on its own**, even though it harms another country?

- There are important cultural, legal, political, and economic implications of geoengineering. How will they be balanced?

- Moral hazard:
  - If we have a possible solution to global warming, will we be less inclined to reduce carbon emissions?

- We can't rule out unanticipated harmful and perhaps irreversible consequences (e.g., ozone hole)

Final Comments on Geoengineering

- *CLIMATE ENGINEERING IS NOT NECESSARY*
  - We have the technology and innovation (but not the commitment of government incentives) to halt the increase emissions of CO_2, reasonably fast and even reduce emissions greatly.
  - Progress has been (still is) too slow to stem the tide however:
    - Lack of public resolve
    - Lack of leadership and commitment in business and government.

Final Comments on Geoengineering

- WILL CLIMATE ENGINEERING HAPPEN?
  - It is incredibly easy and (in the short term) inexpensive compared with reducing emissions and transitioning to a non-carbon emission economy
    - Cost is maybe only ~$10B/yr compared to ~$200B/yr to reduce carbon emissions (lots of uncertainty in these estimates though)
    - Cost is less than 0.1% GDP for US, less than 2% for about 30 countries
  - Players who are currently influential and have a lot to lose if greenhouse gas emissions are reduced (oil companies, libertarians) **don't lose** from climate engineering
  - Whoever holds the contract for the solution has huge profits guaranteed for a millennium
    - E.g., initial work is largely funded by defense contractors and venture capitalists, including some of the richest people in the world
  - Will we develop and deploy this technology?