What did we do in the Fall of 2012?

Week 1 Introduction; Origin of the Earth's Atmosphere; Atmosphere composition today

Week 2 Heat and Temperature; Heat Forms and Transport; Radiation; Concepts in EM Radiation; Solar Radiation and the Earth; Albedo

Week 3 Energy Balance; Greenhouse gases and the Greenhouse Effect; Seasonal Temperature Cycles

Week 4 Seasonal and diurnal temperature cycles; Pressure; Hydrostatic balance

Week 5 Coriolis effect and geostrophic wind

Week 6 Jet streams; Midterm; General Circulation of the Atmosphere

1/3

Week 7 General Circulation of the Atmosphere (cont); The Role of Mountains in Climate; Ice Ages and how we know they happened; Milankovitch theory

Week 8 Human Induced Changes in Greenhouse Gases and their Impact on Climate (the 20th Century); Climate models; Climate variability and forced climate change defined.

Week 9 Climate variability and forced climate change (cont); ENSO, volcanic forcing, Solar forcing, human forcing

Week 10 Projected Climate Change (today to 2100 and beyond)

Week 11 Climate Change in the Pacific Northwest; Geoengineering

2/3

Climate Engineering (aka Geoengineering)

- What is it?
- Why do it?
  - Large changes ahead (including some unforeseen)
- How do we stop the climate from changing without reducing CO_2 emissions by climate engineering?
  - Take CO_2 out of the atmosphere (unlikely)
  - Reduce sunlight to counter increased CO_2 due to human activity
- General pros and cons of climate engineering

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Climate engineering

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

"The deliberate modification of Earth's environment on a large scale 'to suit human needs and promote habitability.'" [wikipedia.org]

Climate Engineering: a brief history

- 1974: Mikhail Budyko proposed injecting sulfur dioxide in the stratosphere to create sulfate droplets that would scatter sunlight and cool the earth
- Early 1990's: Edward Teller* and collaborators proposed putting designer particles into the stratosphere to deflect sunlight.

  *Father of the H-bomb, principal architect of Star Wars Defense Initiative, inspiration for Dr. Strangelove
- 1992: The National Academy of Sciences issues a detailed study on geoengineering options for avoiding climate change, which includes evaluation of the science and a cost-benefit analysis for each option.
- 2006: Paul Crutzen (Nobel Prize winner for his work on the Ozone Hole) re-discovers Budyko's plan. He argues persuasively that the scope and speed of climate changes due to increasing CO_2 -- coupled with the lack of any progress on mitigation -- requires this geoengineering solution be seriously considered.

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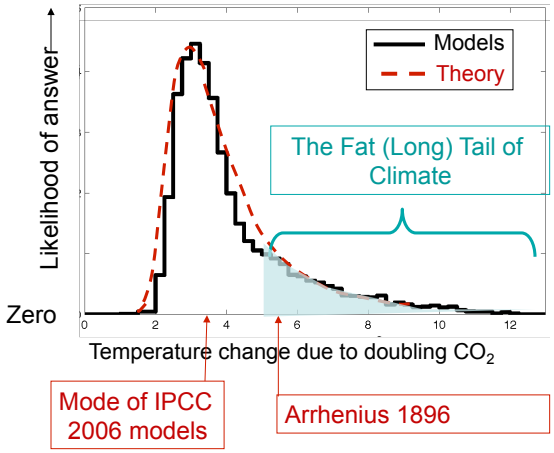
Why must we consider Climate Engineering?

- The projected climate changes are large and fast enough to cause large disruptions and distress in the global economy, society and in the environment.
  - World food production: 20% reduction in global grain production by 2050 due to increased temperature alone
  - Ecosystem changes are underway: biodiversity is being lost at an unprecedented rate

Why must we consider Climate Engineering?

- To avoid large increases in atmospheric CO_2 requires huge changes in current technological systems (power, transport, buildings), creates winners and losers, and presents deep challenges to equity. A very tall order.
- The potential for unanticipated climate catastrophes
  - Sea level: the Antarctic ice shelves may become unstable; could raise global sea level abruptly by meters.
  - Temperature increase: methane released to atmosphere by melting permafrost could double atmospheric CO_2.
- The Fat Tail of Climate

The Fat Tail of Climate Sensitivity



200,000 climate models (Sanderson et al 2007)

The fat tail means there is a 20% chance the response to increasing CO_2 will be *at least twice as great* as that projected by the consensus IPCC

The Fat Tail of Climate Sensitivity

Many influential, *mainstream* economists have concluded that we cannot exceed an increase of 2-3ºC in global temperature without catastrophic damages to the global economy

Prof. Lawrence Summers (Harvard)
US Secretary of the Treasury (Clinton)
Former Director, White House National Economic Council (Obama)

Prof. Marty Weitzman (H
"among the most influential econ
the world" and often stated as an
upcoming recipient of the Nobel Prize in
Economics

"Climate change, at the fat tail, threatens to drive all of planetary welfare to disastrously low levels in the most extreme scenarios."

Sir Nicholas Stern (LSE)
Fmr Chief Economist, World Bank. Chair of the Stern Review of Economics of Climate Change

The Executive Summary of the Stern Review on the Economics of Climate Change is here: www.hm-treasury.gov.uk/sternreview_summary.htm

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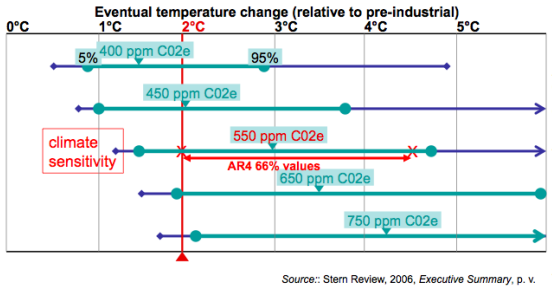

Source:: Stern Review, 2006, *Executive Summary*, p. v.

Unfortunately, the Fat Tail of climate sensitivity means even 500ppm is terribly risky.

Climate Engineering (aka Geoengineering)

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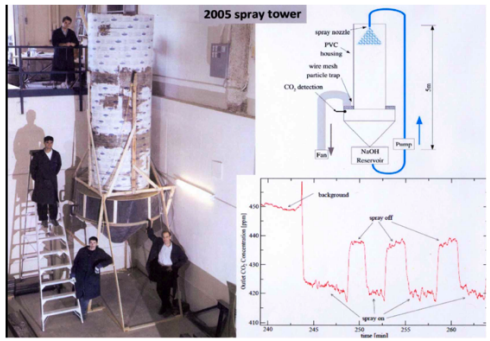
Take CO_2 out of the air



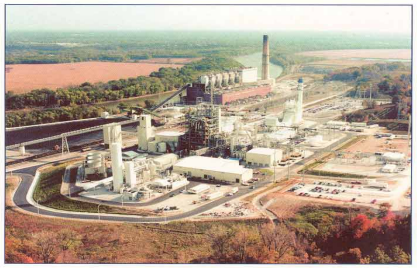
Source: David Keith, MIT talk, Sept. 16, 2008

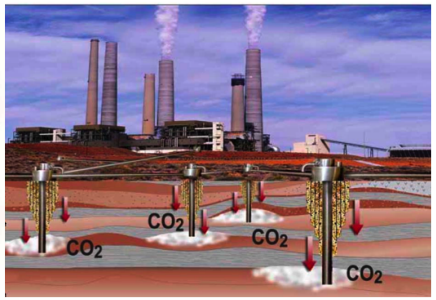
Currently four ways to do this. None have left the prototype stage. All are projected to be astoundingly expensive.

Take CO_2 out of the air (cont)

- Stuff it into trees and make sure they don't rot
  - Requires management of organic material so it doesn't rot
  - Requires massive amount of land currently used for growing food to capture only a fraction of the required carbon

Carbon Capture and Storage





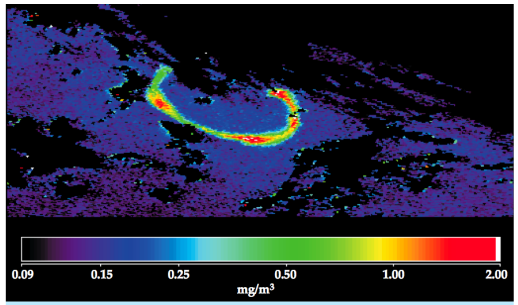
The Wabash River
Coal Gasification Repowering Project

Graphics courtesy of DOE Office of Fossil Energy

- Works for CO_2 emitted from coal, but not applicable to non-point sources (e.g., CO_2 emitted from oil)
- Makes energy from coal expensive compared to many other sources, including renewables

Take CO_2 out of the air (cont)

- Fertilize the ocean with iron (a limiting nutrient) to promote photosynthesis and thus remove CO_2 from the atmosphere
- Downsides:
  - All peer-reviewed published experiments to date show this doesn't work: after the phytoplankton grow they die, and most carbon goes right back into the atmosphere)
  - Major disruption to the base of the food chain (leading to changed ecology and often red tides)



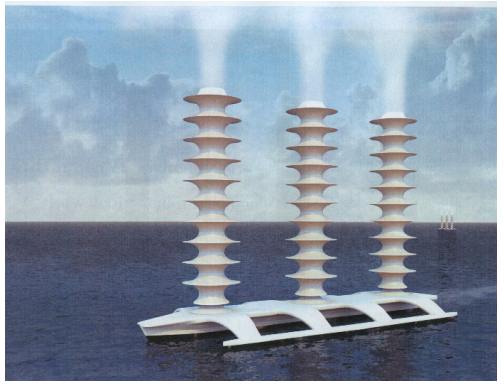
Phytoplankton bloom following an iron-fertilization experiment in the Southern Ocean. The area covered spans about 1 degree of latitude and 2 degrees of longitude. Color scale indicates the mass of chlorophyll per cubic meter of seawater, mostly contained in phytoplankton. (Image provided by the NASA Goddard Earth Sciences Data and Information Services Center.)

Block enough sunlight to cancel warming 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
  - Downside:
    - Launch alone cost ~10 trillion dollars
    - Once in place, impossible to remove. If they fail, it will take many years to replace them (and without the shading, the climate would warm dramatically)
- Mirrors orbiting the earth to reflect sunlight
  - Downside: Very expensive, a nightmare for space navigation, impossible to retrieve

Block enough sunlight to cancel warming due to increasing CO_2

The controlled enhancement of the the albedo and longevity of low-level maritime clouds



Cheap: 2-4 B$US/year

- 3000 wind-powered ships
- Shoot a spray of very fine sea water into the clouds, making the cloud droplets smaller and thus more reflective of sunlight
- Basic idea: reduce uptake of solar energy by the oceans
- Approach works best in pristine (ocean) areas
- Downside:
  - clouds are the weak link in understanding climate change
  - Ocean continues to acidify
  - Once you start, you can never stop

Block enough sunlight to cancel warming due to increasing CO_2

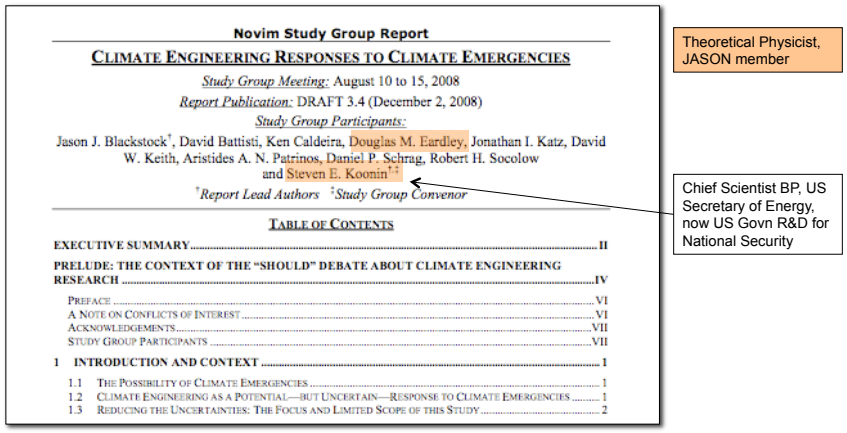
- Place tiny particles in the stratosphere that reflect visible sunlight but don't absorb infrared radiation
- Nature does this ever so often: launching sulfur dioxide into the stratosphere that turns into sulfate particles
  - Particles reflects sunlight and cool the planet
  - Particles fall out after a year or two
- Upsides:
  - We know it works to cool (volcanoes do it)
  - Its cheap (~10 B$ per year)

Possible (unproven) option 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 10,000 yrs
  - Barrels replaced every 100 mins
  - "…surprisingly practical" (NAS 1992) (cost about 10B, or 0.1% of US GDP)

Blackstock et al 2008

The prototype plan for R&D, testing and deployment



Novim Study Group Report

CLIMATE ENGINEERING RESPONSES TO CLIMATE EMERGENCIES

Study Group Meeting: August 10 to 15, 2008

Report Publication: DRAFT 3.4 (December 2, 2008)

Study Group Participants:

Jason J. Blackstock[†], David Battisti, Ken Caldeira, Douglas M. Eardley, Jonathan I. Katz, David W. Keith, Aristides A. N. Patrinos, Daniel P. Schrag, Robert H. Socolow and Steven E. Koonin[†‡]

[†]*Report Lead Authors* [‡]*Study Group Convenor*

TABLE OF CONTENTS

EXECUTIVE SUMMARY II

PRELUDE: THE CONTEXT OF THE "SHOULD" DEBATE ABOUT CLIMATE ENGINEERING RESEARCH IV

PREFACE VI
A NOTE ON CONFLICTS OF INTEREST VI
ACKNOWLEDGEMENTS VII
STUDY GROUP PARTICIPANTS VII

1 INTRODUCTION AND CONTEXT 1

1.1 THE POSSIBILITY OF CLIMATE EMERGENCIES 1
1.2 CLIMATE ENGINEERING AS A POTENTIAL—BUT UNCERTAIN—RESPONSE TO CLIMATE EMERGENCIES 1
1.3 REDUCING THE UNCERTAINTIES: THE FOCUS AND LIMITED SCOPE OF THIS STUDY 2

Theoretical Physicist, JASON member

Chief Scientist BP, US Secretary of Energy, now US Govn R&D for National Security

… has been delivered to the Pentagon

Block enough sunlight to cancel warming due to increasing CO_2

- Downsides:
  - It is cheap: many individual countries could do it
  - Milky sky (impact on biology and agriculture unknown)
  - Climate response doesn't exactly cancel the CO_2 response. For example:
    - it will probably enhance the likelihood that the Antarctic ice sheet becomes unstable)
    - Global precipitation decreases
    - Ocean continues to acidify (disrupting the base of the food marine chain)
  - **Once you start, you can never stop**

Climate Engineering (aka Geoengineering)

- What is it?
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General arguments *for* doing climate engineering

- Reducing CO_2 emissions is a Herculean political, social, economic and technological feat. Our present efforts have fallen far short of what is required to stabilize and reduce CO_2 to avoid large, unprecedented changes in climate that are very likely to have serious deleterious impacts on the global economy, society and the environment.
- Increasing greenhouse gases may cause climate changes that create climate emergencies: impacts that are not presently deemed likely or were not anticipated, but that have dire consequences.

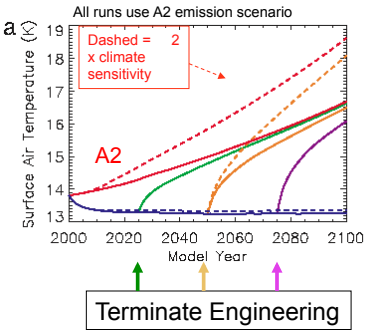
General arguments *against* doing climate engineering
(including sun shading by stratospheric aerosols)

- The ocean will continue to acidify
- Technology is still in its infancy
  - We have a large community of scientist and ~50 years of experience on the global warming problem (with modest progress on reducing uncertainty)
  - A handful (10-20) of scientist have spent ~5-10 years thinking about what might happen if we deploy a particular climate engineering solution. The science is in its infancy, and all of the work being done in the US is funded by private sources.
- The climate system is inherently complex and the possibility of "[unanticipated] harmful side effects" is too large for any intentional human intervention to *ever* be considered safe.
- Even when emissions of CO_2 go to zero, we will have to continue to deploy the aerosols until the CO_2 returns to a safe level (> 1000 years)

- Once you start, you can never stop.

General arguments *against* doing climate engineering
(including sun shading by stratospheric aerosols)

Stopping either deliberately (an adverse side-effect is discovered, or a terrorist act) or unintentionally (loss of capability, political will) will result in disaster.



- If sun shade technology is deployed to cancel warming due to large increases in CO_2, then a temporary failure in deployment (unintentional or not) would cause the planet to warm greatly and catastrophically

  e.g., 1 - 4 °C in 10 years

  (cf. 20th century at 0.09 °C/10 yrs, or nature at 4 °C/10,000 yrs)

Calderia and Wood 2008

Profound and unaddressed issues associated with climate engineering

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

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

- Moral hazard:
  - If we have an alternative solution to carbon management, we will be less inclined to pursue efforts to reduce carbon emissions

- We can't rule out unanticipated harmful and perhaps irreversible consequences (e.g., CFCs and the Ozone Hole)

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 ~10B/yr compared to ~200B/yr to reduce carbon emissions
  - 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 limited/reduced (oil and gas companies, libertarians) don't loose from climate engineering

- Whoever holds the contract for CE solution has huge influence and unlimited profits for a millennium
  - E.g., Projects are already being develop by the major defense contractors and venture capitalists, including some of the richest people in the world

WILL CLIMATE ENGINEERING HAPPEN?

Bill Gates
Also owns Carbon Enginnering

Sir Richard Branson
Virgin Atlantic Airways

Murry Edwards
Canadian Tar Sands Magnate

… and other oligarchs are funding groups of people to develop the technology

Video resources on climate engineering

- David Kieth's TED talk:
  http://www.ted.com/talks/david_keith_s_surprising_ideas_on_climate_change.html
- The recent MIT conference on climate engineering
  http://web.mit.edu/esi/symposia/symposium-2009/symposium2009-presentations.html
  I particularly enjoyed the talk by Prof Layzer, "What's the "Rational" Choice?: Risk, Values and the Politics of Geoengineering"