Welcome to ATMS 111 Global Warming

http://www.atmos.washington.edu/2010Q1/111

Studying for the Final

Weeks 1-8: Focus on big ideas, connections, how we know what we know about global warming, why is there uncertainty, general impacts

Key facts for weeks 1-8:

- How much global warming has occurred since ~1850
- How much global warming (including uncertainty) is expected in the 21st century
- Present rate of sea level rise
- Plausible range of sea level rise in the 21st century
- Present rate of anthropogenic CO2 emissions
- Fraction of CO2 emissions taken up by the natural carbon cycle

Clicker grades

Check “gradebook” for scores

If you have all zeros after the first week, check the table of IDs we have registered (see class homepage for link)

SEND TYLER YOUR ID! and a short explanation, like
1) “My ID was not in the table. Please add it.”
2) “My correct ID *is* in the table and I’m still getting zeroes!”

Some of you said you registered but your name was not in the database (type 1 error, weird but easy enough to fix)

Some of the IDs had hidden characters, etc, that caused us problems (type 2 error, we think all are cleared up now)

Geothermal Power

Pros

- Reliable supply
- Relatively simple facilities
- Inexpensive
- Small land footprint compared to wind and solar

Cons

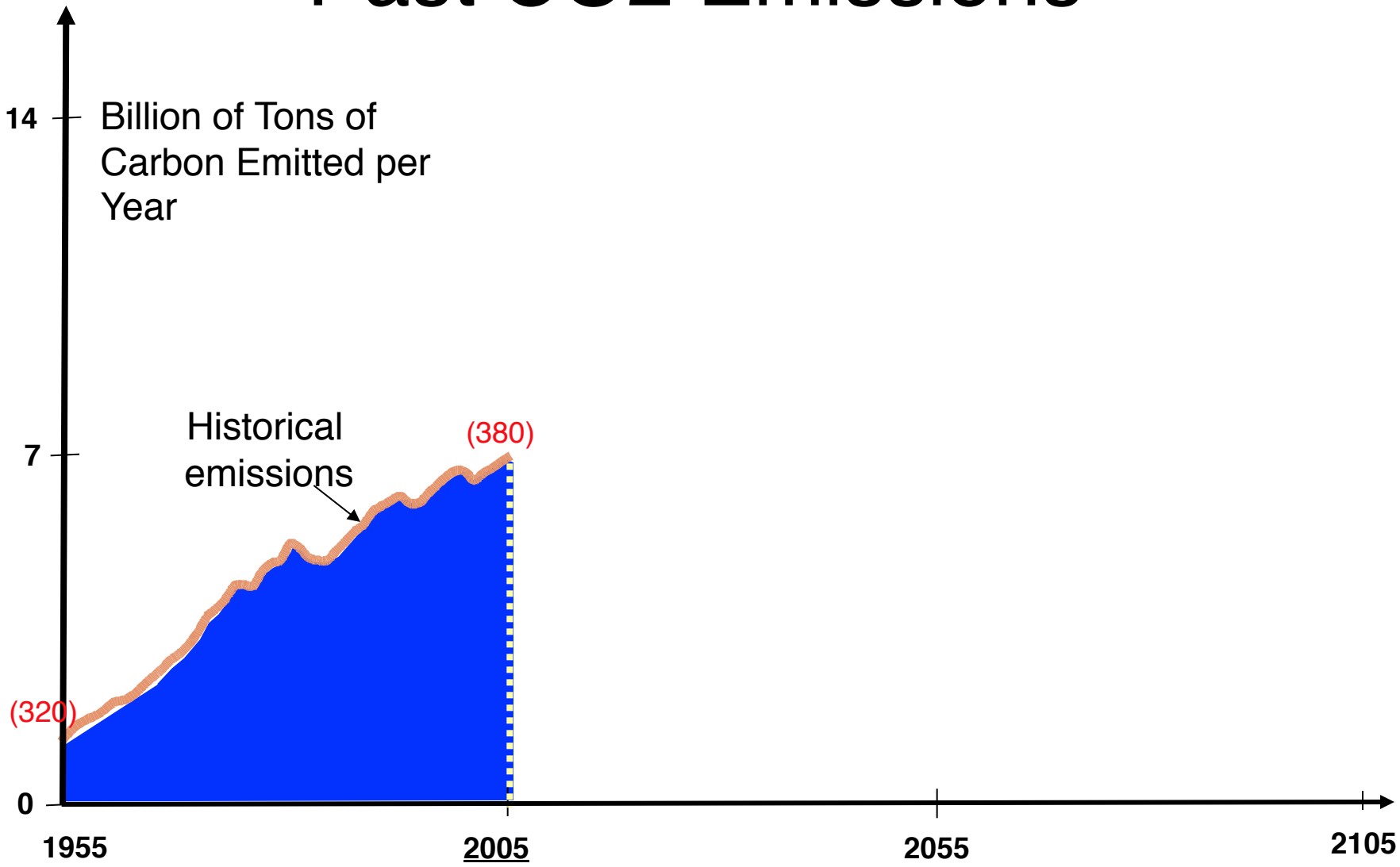
- Regionally limited
- Releases a little CO_2 and other more harmful gases from ground
- Enhanced geothermal systems have caused seismic activity during construction

Stabilizing atmospheric CO_2 at ~ 500ppm

In 2004, Pacala and Socolow proposed a scheme to achieve this goal

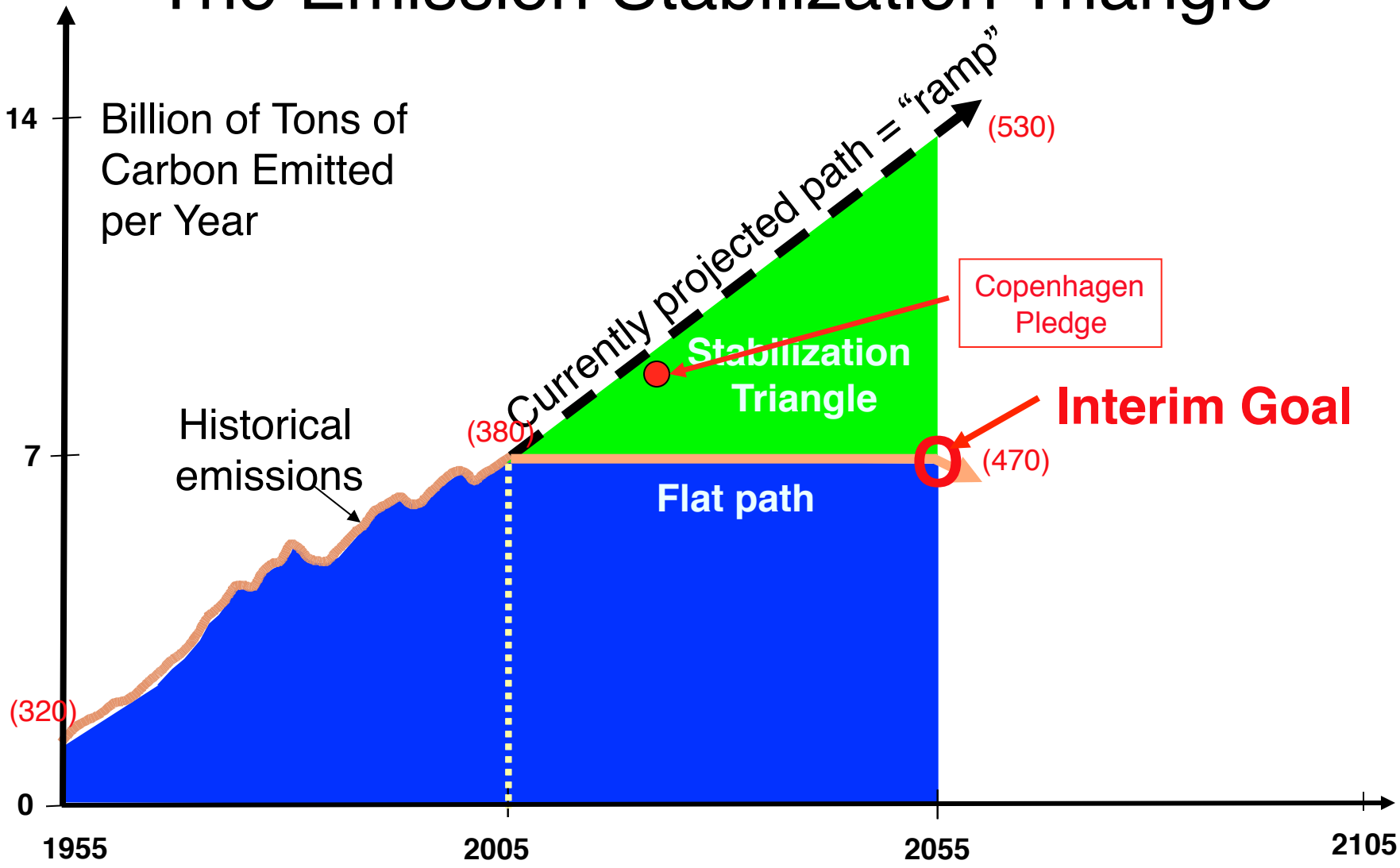
- **Phase 1**: Requires immediate cap on global CO_2 emissions and that economic growth over the next 50 years be achieved by ramping up (scaling up) existing technologies without increasing CO_2 emissions
- **Phase 2**: After 2054, requires rapid and substantial reductions in global emissions. Final emissions of all GHGs must level off by ~2100 to ~ 1.5 Gt/yr, or ~20% of present global emissions
- At that time, the CO_2 ocean uptake will balance the human input (and the ocean will continue to acidify).

Past CO2 Emissions



Values in parentheses are ppm

The Emission Stabilization Triangle

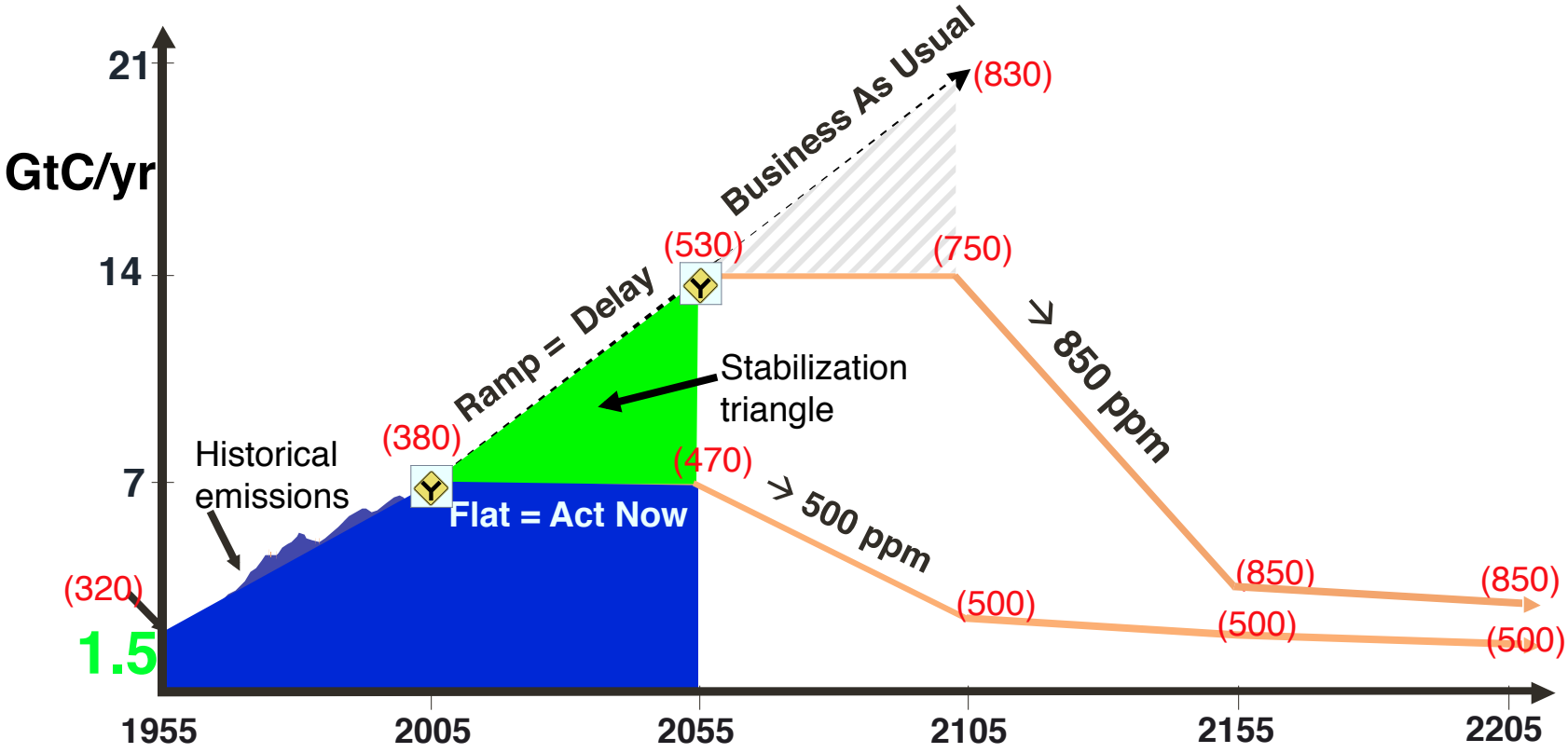


Interim 2054 goal: stabilize emissions immediately (yet increase energy by ~70% in 2054) and invest in technology to have much more energy with reduced emissions after that

Pacala and Socolow (2004)

The Stabilization Triangle:

settle for double or triple pre-industrial CO_2?

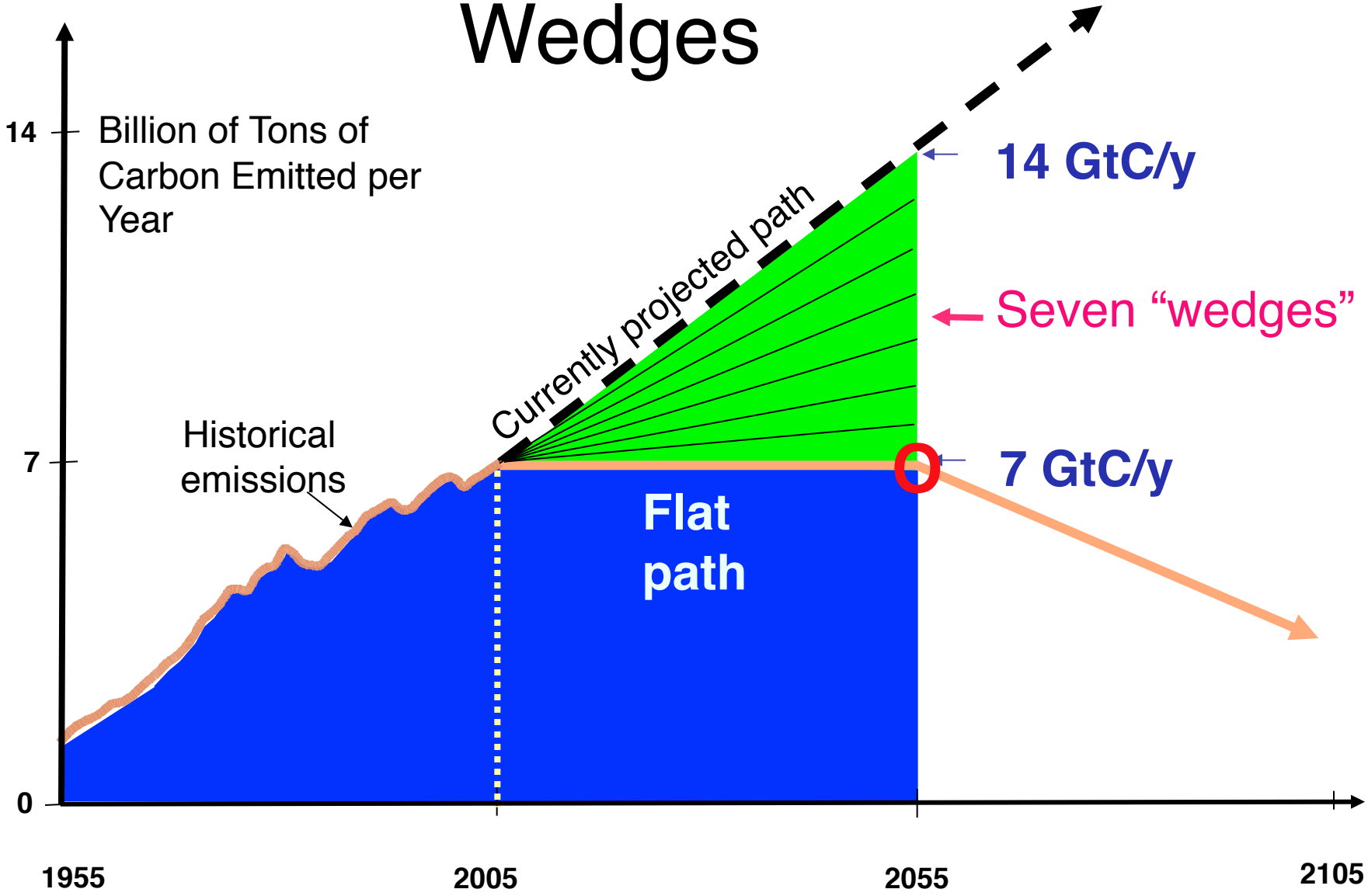


Values in parentheses are ppm (1 ppm = 2.1 GtC).

Stabilizing at 500ppm requires the global emission be 1.5 Gt/yr by 2100

Pacala and Socolow (2004)

Wedges

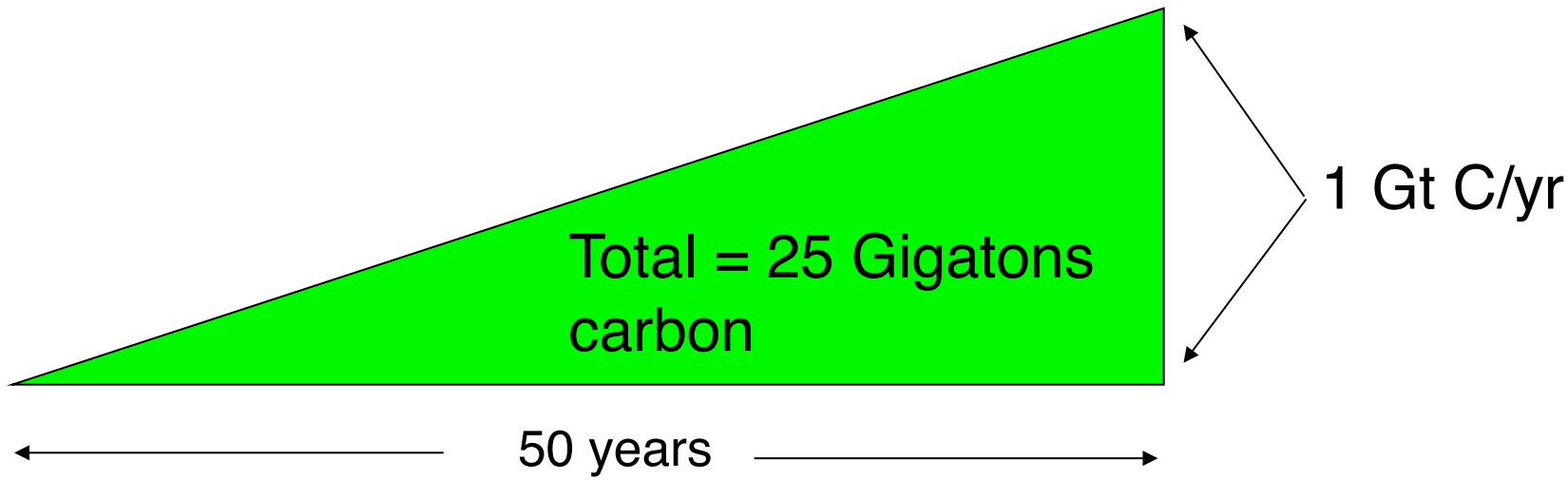


How do we meet the *increase* in energy demand (projected to increase by 70% by 2050 and 200+% by 2100) without increasing emissions of CO_2?

Pacala and Socolow (2004)

What is a “Wedge”?

A “wedge” is a strategy to reduce carbon emissions that grows in 50 years from zero to 1.0 GtC/yr.



Cumulatively, a wedge redirects the flow of 25 Gt C in its first 50 years. Each wedge costs $1.25 trillion at $50/tC. A $50/tC tax or carbon trading value would raise electricity prices by almost 1 cent per kWh (~ 10%).

Pacala and Socolow (2004)

The Interim Goal is Within Reach

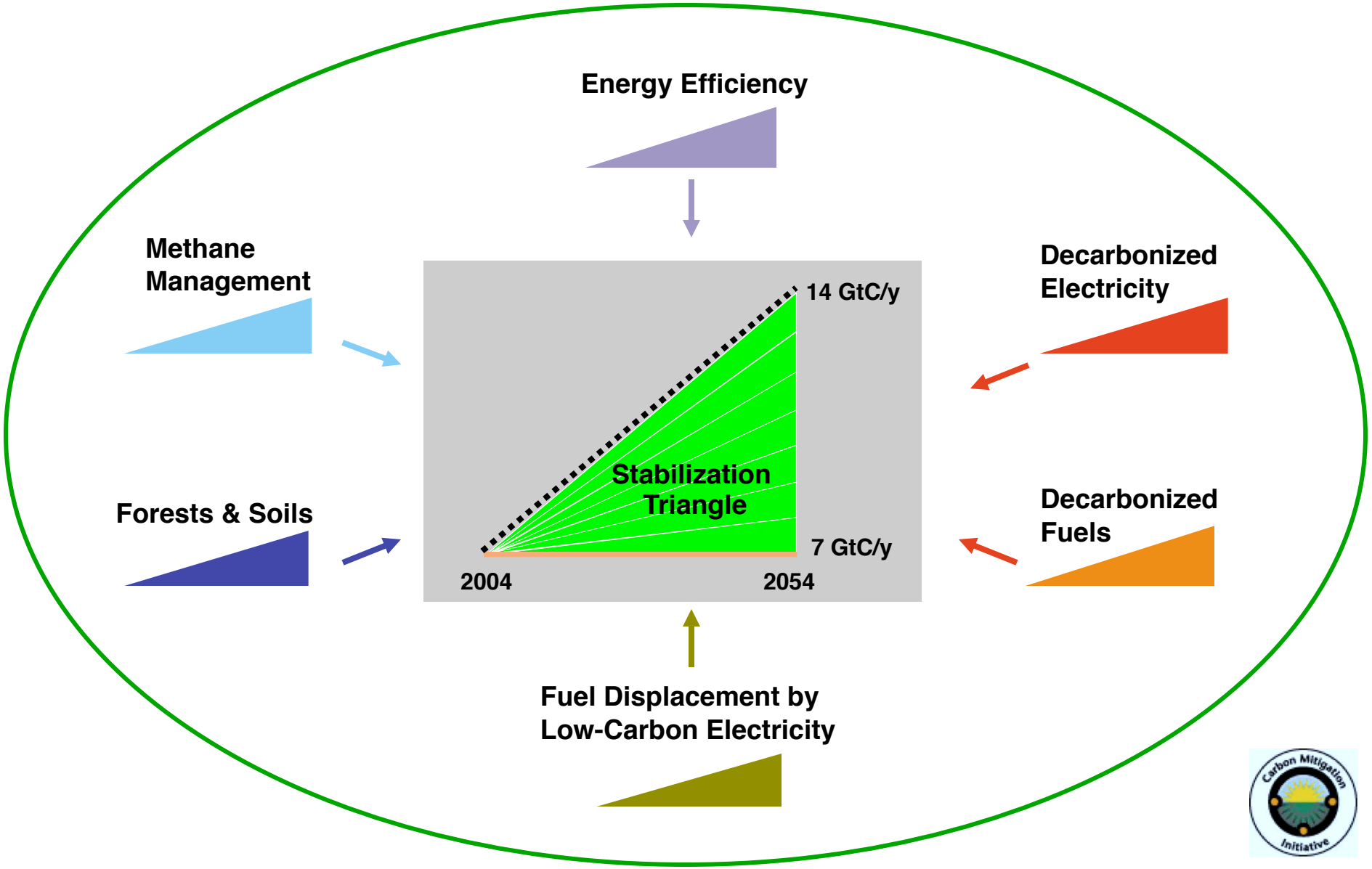
Reasons for optimism that global emissions in 2055 need not exceed today's emissions:

- The world today has a terribly inefficient energy system.
- Carbon emissions have just begun to be priced.
- Most of the 2055 physical plant is not yet built

Pacala and Socolow (2004)

Fill the Stabilization Triangle with Seven Wedges

(~double the energy available in 2054 w/o increasing emissions)



Wind Electricity

Effort needed by 2055 for 1 wedge:

One million 2-MW windmills displacing coal power.

Today: 50,000 MW (1/40)

Prototype of 80 m tall Nordex 2,5 MW wind turbine located in Grevenbroich, Germany

(Danish Wind Industry Association)

R. Socolow (per. comm.)

Pholtovoltaic Power

Effort Needed by 2055 for one wedge:

2000 GW_{peak} (700 times current capacity)

2 million hectares

Solar thermal power via concentrators (troughs and dishes) is produced at high efficiency, like PV.

Graphics courtesy of DOE Photovoltaics Program

Biofuels

Effort needed by 2055 for 1 wedge:

2 billion 60 mpg_e cars running on biofuels instead of gasoline and diesel.

To produce these biofuels: 250 million hectares of high-yield (15 t/ha) crops, one sixth of world cropland.

Challenge: To find ecologically responsible ways to grow biomass for power and fuel on hundreds of millions of hectares.

Usina Santa Elisa mill in Sertaozinho, Brazil (http://www.nrel.gov/data/pix/searchpix.cgi?getrec=5691971&display_type=verbose&search_reverse=1_

Do wedge strategies get used up?

For any strategy, is the second wedge easier or harder to achieve than the first? Are the first million two-megawatt wind turbines more expensive or cheaper than the second million two-megawatt wind turbines?

The first million will be built at the more favorable sites.

But the second million will benefit from the learning acquired building the first million.

The question generalizes to almost all the wedge strategies: Geological storage capacity for CO_2, land for biomass, river valleys for hydropower, uranium ore for nuclear power, semiconductor materials for photovoltaic collectors.

Summary: What's appealing about stabilization wedges?

The stabilization triangle:

- Does not concede doubling is inevitable.
- Shortens the time frame to be within business horizons.

The wedge:

- Decomposes a heroic challenge (the Stabilization Triangle) into a limited set of monumental tasks.
- Permits quantitative discussion of cost, pace, risk.
- Facilitates quantitative comparisons and trade-offs.

Summary: Wedges phase 2

Stabilizing atmospheric CO_2 at 500ppm will require global emissions to be ~ 1.5 Gt C/year (2 in CO_2 equiv) by 2200

- This means a reduction of 80% of the present global emissions (7.6 Gt C/yr, or 9 CO_2 equiv)

If emissions are distributed equally, the US would need to reduce emissions significantly from today's

- We are 1/20 of the world population. Equal per capita emissions allows the US to emit ~ 1.5/20 = 0.08 Gt/yr in 2200
- Current US emissions are 2 Gt/yr
- Hence, we will have to reduce emissions to ~ 4% of today's emissions

$$\frac{0.08}{2} = 0.04 = 4\%$$

Summary: Winners and Losers

Potential for major winners and losers:

Fossil fuel industry phased out and renewable energy industry or nuclear energy industry take over

Will rich countries pay less wealthy countries to bypass the fossil fuel industrialization? Assuming it is cheaper to build new factories rather than retrofit/ replace old ones

The economies of rich countries exploded at a time when fossil fuels were cheap and CO2 was emitted freely

At the scale of households

In 2007, the average yearly residential electrical consumption was 11,000 kilowatthours (kWh)

There are 8,760 hours in a year

So on average our households use 1,250 W

According to the DOE Energy Information Administration
http://tonto.eia.doe.gov/ask/electricity_faqs.asp#electricity_use_home

Residential Windmill (2/3 of household elec use)

amazon.com

Hello, Cecilia M Bitz. We have recommendations for you. (Not Cecilia?)

Cecilia's Amazon.com | Today's Deals | Gifts & Wish Lists | Gift Cards

Shop All Departments | Search | Patio, Lawn & Garden

Patio, Lawn & Garden | Bestsellers | Markdowns | Grills & Smokers | Outdoor Décor | Patio Furniture | Weather Instruments | Hea

Windmax HY600-3 750 Watt Max 24-Volt 3-Blade Residential Wind Generator

Other Windmax products

No customer reviews yet. Be the first.

List Price: ~~$799.00~~

Price: $749.00 & this item ship

Shipping. Details

You Save: $50.00 (6%)

In Stock.

Ships from and sold by **Amazon.com**.

Only 2 left in stock--order soon (more on

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Cecilia M Bitz

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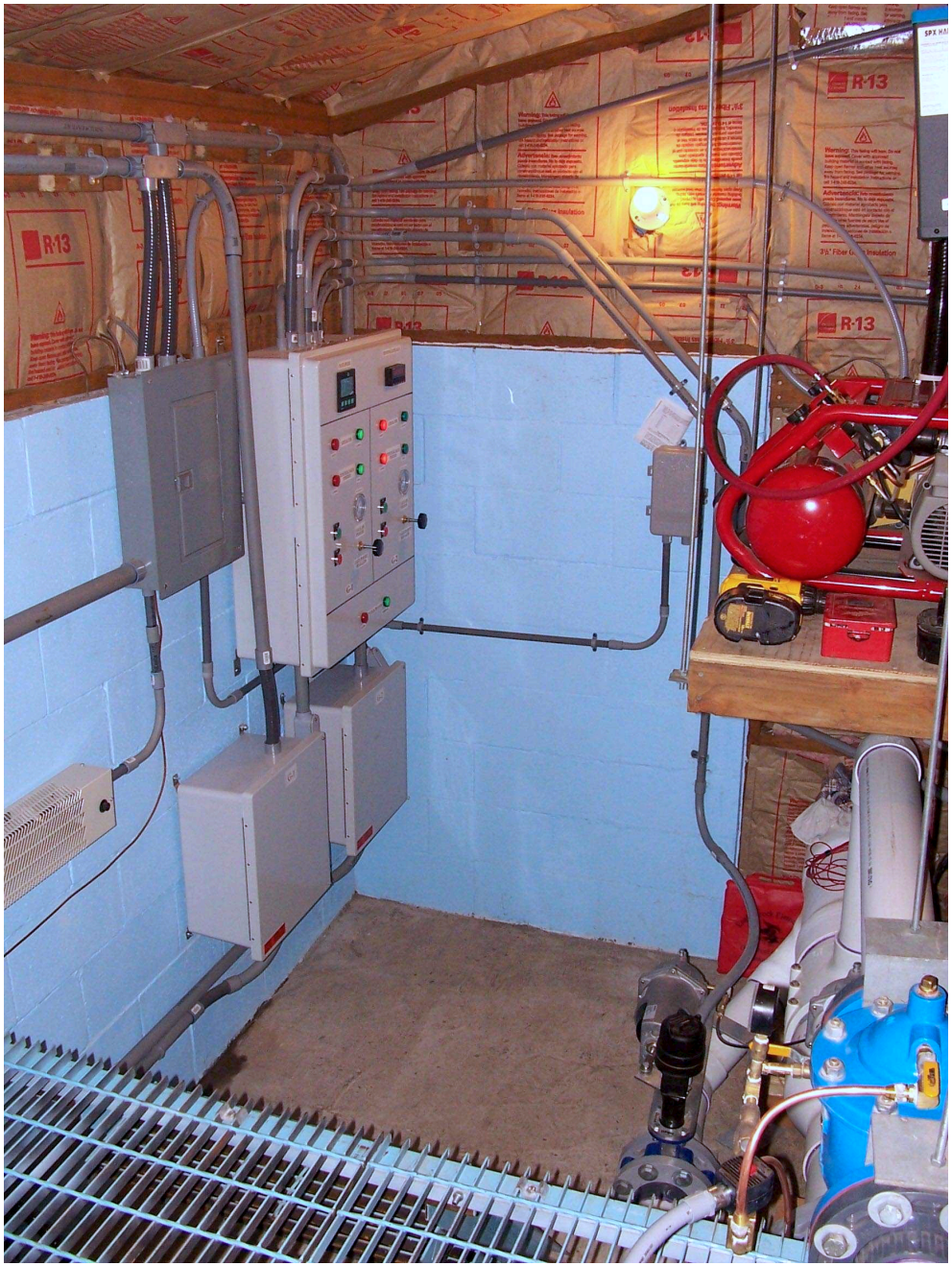
Add to Wish List


The ultimate get-off-the-grid scheme – micro hyrdropower at my sister's house


R-13
R-13
R-13

10” intake pipe - 750 running feet and 40 foot drop to the turbine. Laid by local football team for donation to school.

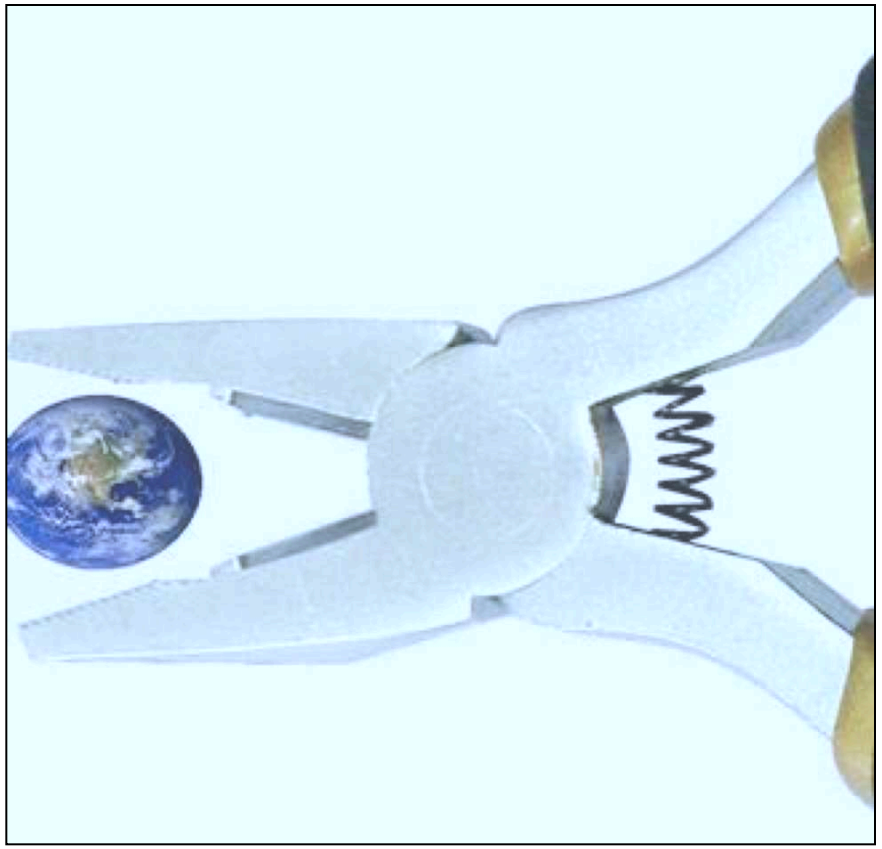
Capacity - 4.4 kW,
Averaging - 25,000 kWh per Year (2+ household).

Total cost - $53,000;
Energy Trust provided $13,000.
Donated labor by the family $25,000
Out of pocket by the family $15,000
(cost recovery in about 12 years).

Reviewed by 20 regulatory bodies (passed all)


Challenge to keep 2.75 cubic feet
per second flowing

Climate engineering



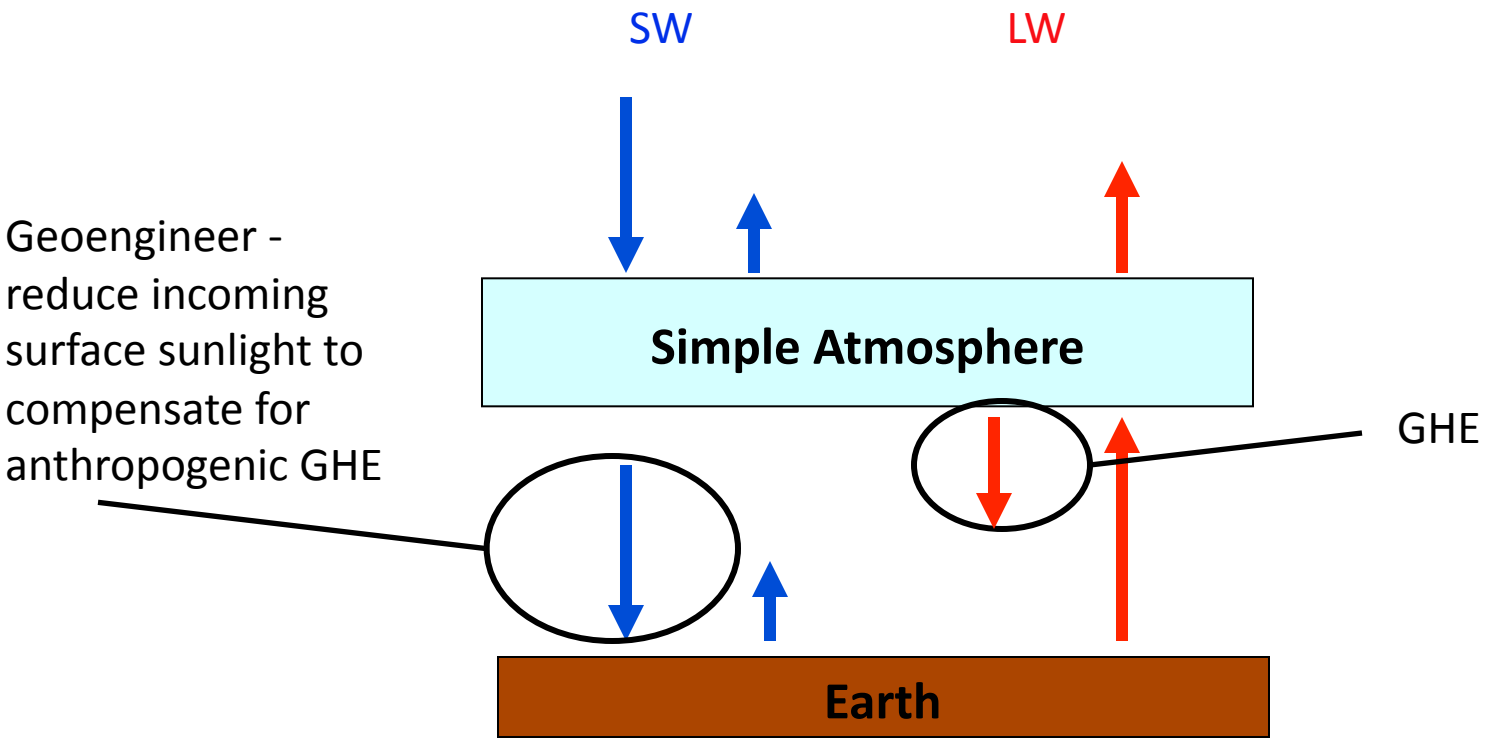
"The intentional, large-scale manipulation of the environment." [David Keith]

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

Climate Engineering

- Brief history
- 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
- Political and Legal Issues
- General pros and cons of climate engineering

Earth with a Simple 1-Layer Atmos.



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 (father of the H-bomb, principal architect of Star Wars Defense Initiative, inspiration for Dr. Strangelove) and collaborators proposed putting designer (nanotech) particles into the stratosphere to deflect sunlight.

- 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.

Climate Engineering: a brief history

- 2009: The Blackstock report - An influential group of US scientists write a prototype plan for Geoengineering research and development, testing and deployment and deliver it to the pentagon. The UK Royal Society writes an influential report outlining the state of the issue.

- 2009: The wildly popular Superfreakonomics book has a chapter about climate cooling that is (according to Joe Romm) “simultaneously skeptical of global warming science, critical of all mitigation measures, but certain that geo-engineering using sulfate aerosols is the answer”.

Why would 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.

- 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

- The Fat Tail of Climate – possibility of very large warming

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

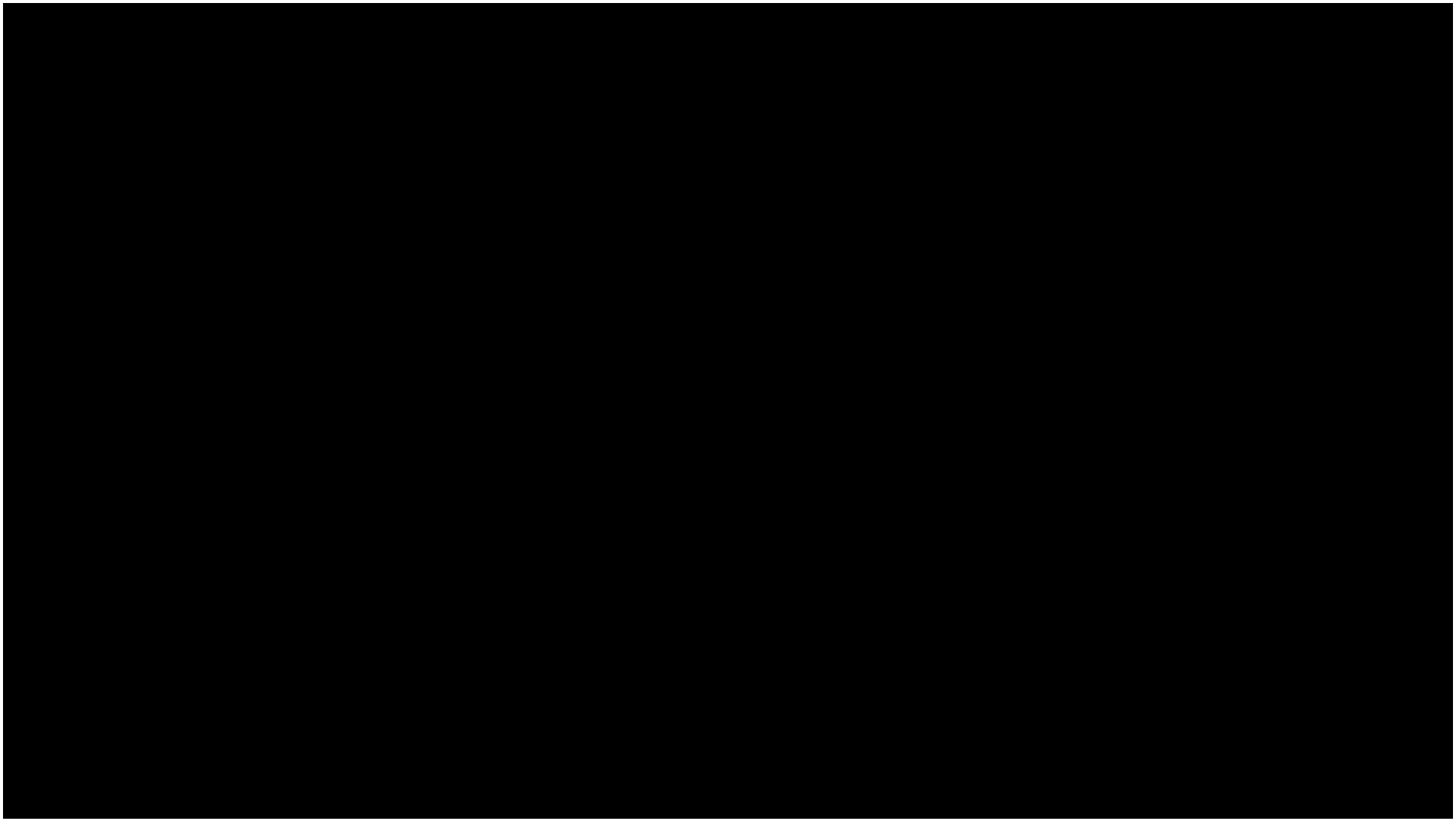
- Solar reflectors placed in outer space at a point where the gravitational field from the earth cancels that from the sun
- Mirrors orbiting the earth to reflect sunlight
- Make clouds brighter (reflect more sunlight to space)
- Place/shoot tiny particles in the stratosphere that reflect visible sunlight but don't absorb infrared radiation

Increasing feasibility

Stratospheric Sulfur Injections

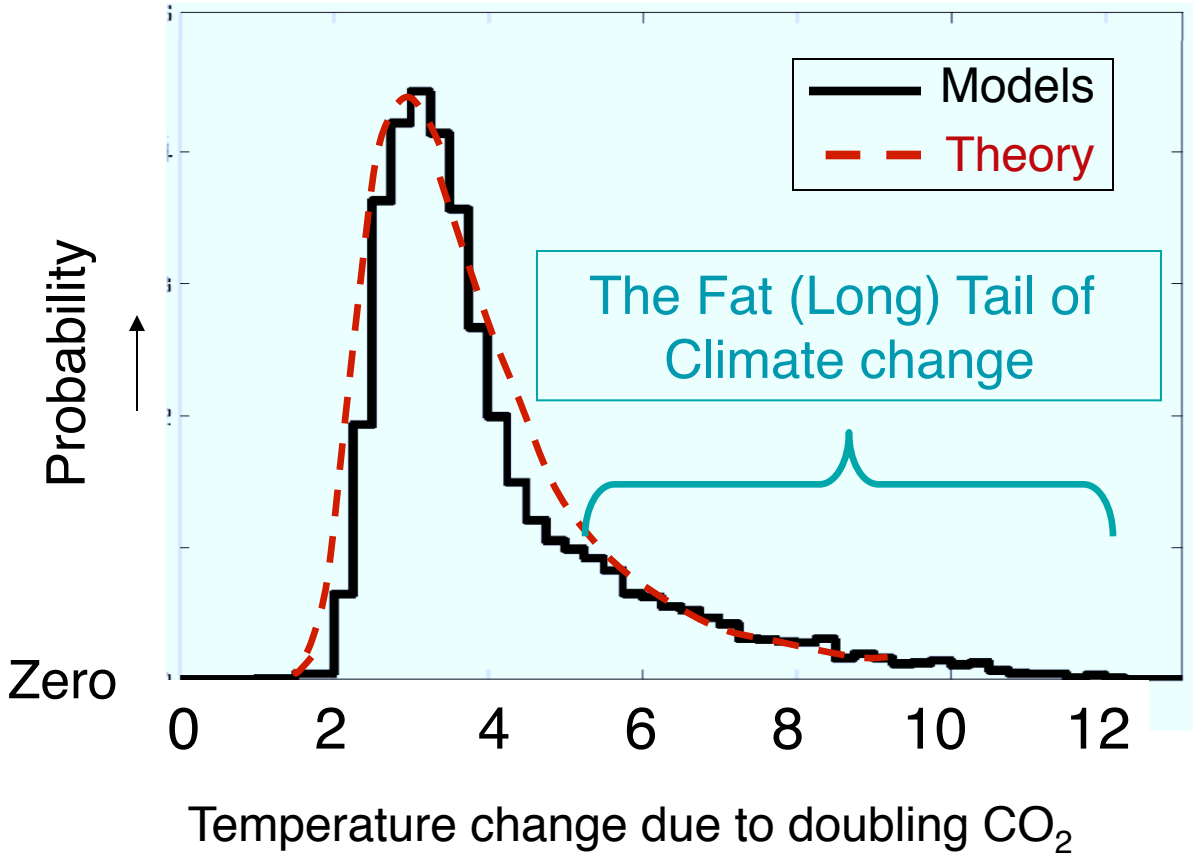
© New York Times
Henning Wagenbreth
Oct. 24, 2007

- Inject a sulfate aerosol precursor (such as SO_2) into the stratosphere that then chemically forms sulfate particles.
- These aerosols increase earth's albedo by backscattering shortwave radiation (sunlight) to space.
- Lifetime in the stratosphere (~1-5 years) is much longer than troposphere (days).
- Cheap compared to mitigation, 10-20 billion $US/year
- Natural analogue: volcanic eruptions.



animation at http://intellectualventureslab.com/?p=296

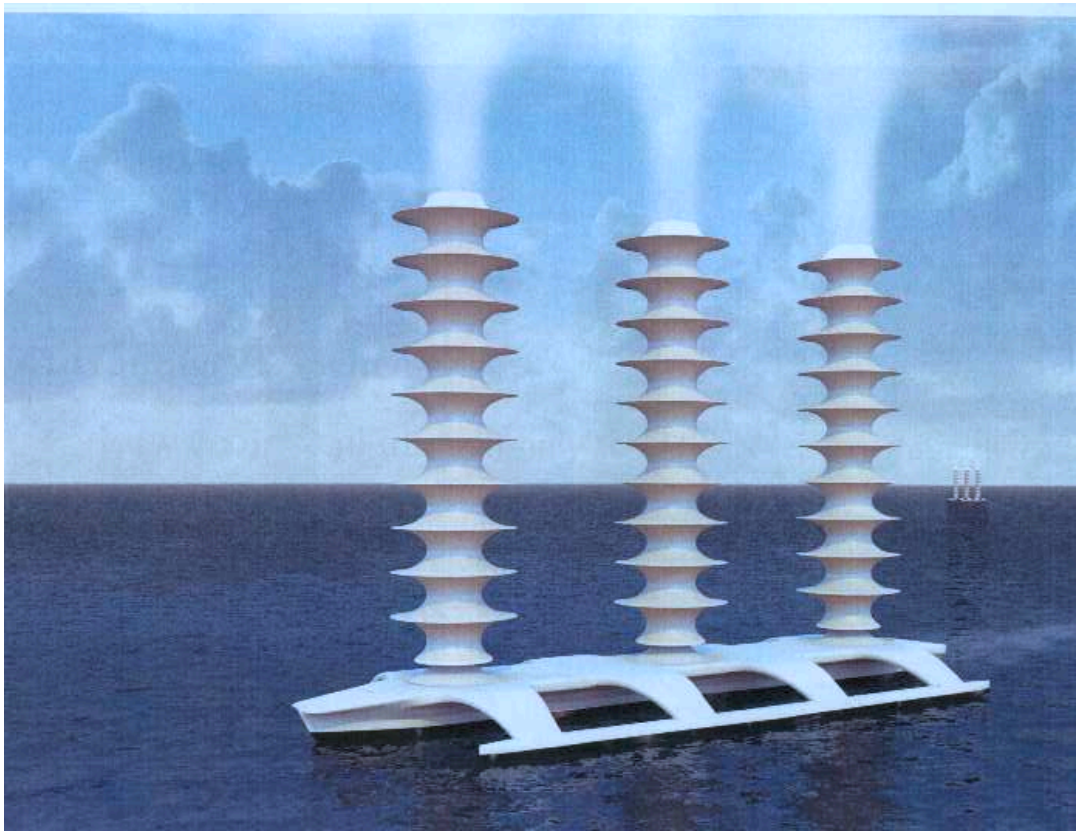
Uncertainty of Equilibrium Climate Sensitivity from ClimatePrediction.net



Probability of warming from doubling CO2 (560ppm compared to 280ppm) at equilibrium

Block enough sunlight to cancel warming due to increasing CO_2

Latham and Salter propose 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 up, making 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
- Natural analogue: ship tracks (sort of)


Note ship tracks are visible in thin cloud areas ONLY
No tracks here where there aren't clouds

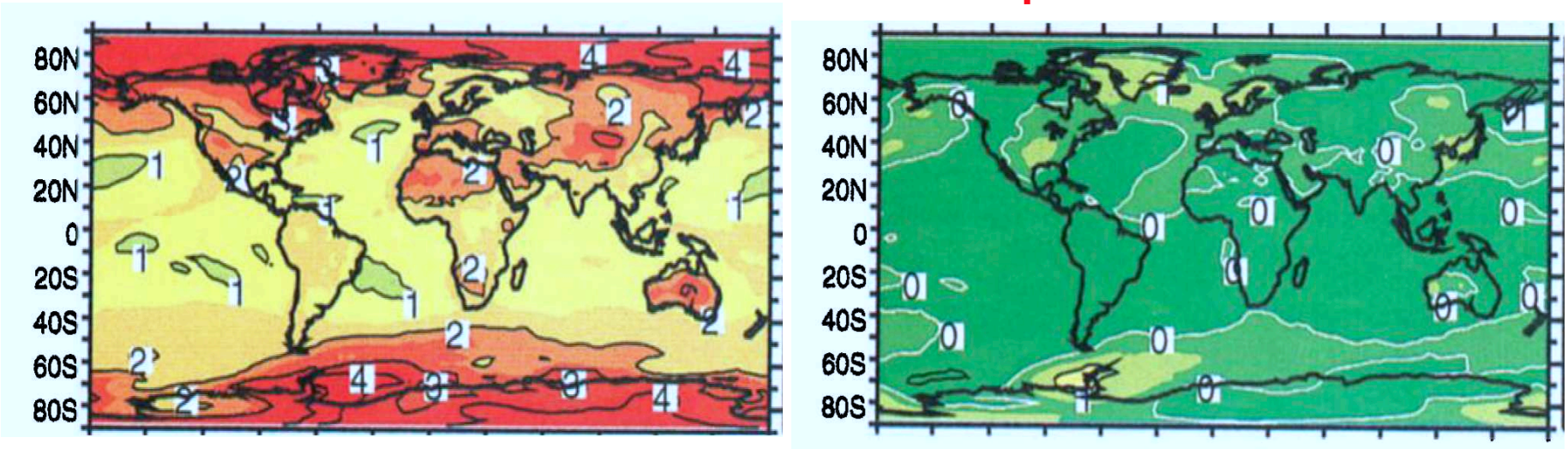
May be able to offset warming but these schemes alter precipitation too:

Stratospheric aerosols tend to dry the tropics

Sea spray-cloud brightening over ocean preferentially cools the ocean, causing land-sea temperature gradients that tend to strengthen summer monsoons

Govindasamy and Caldiera (2000)

Δ Annual Surface Temperature



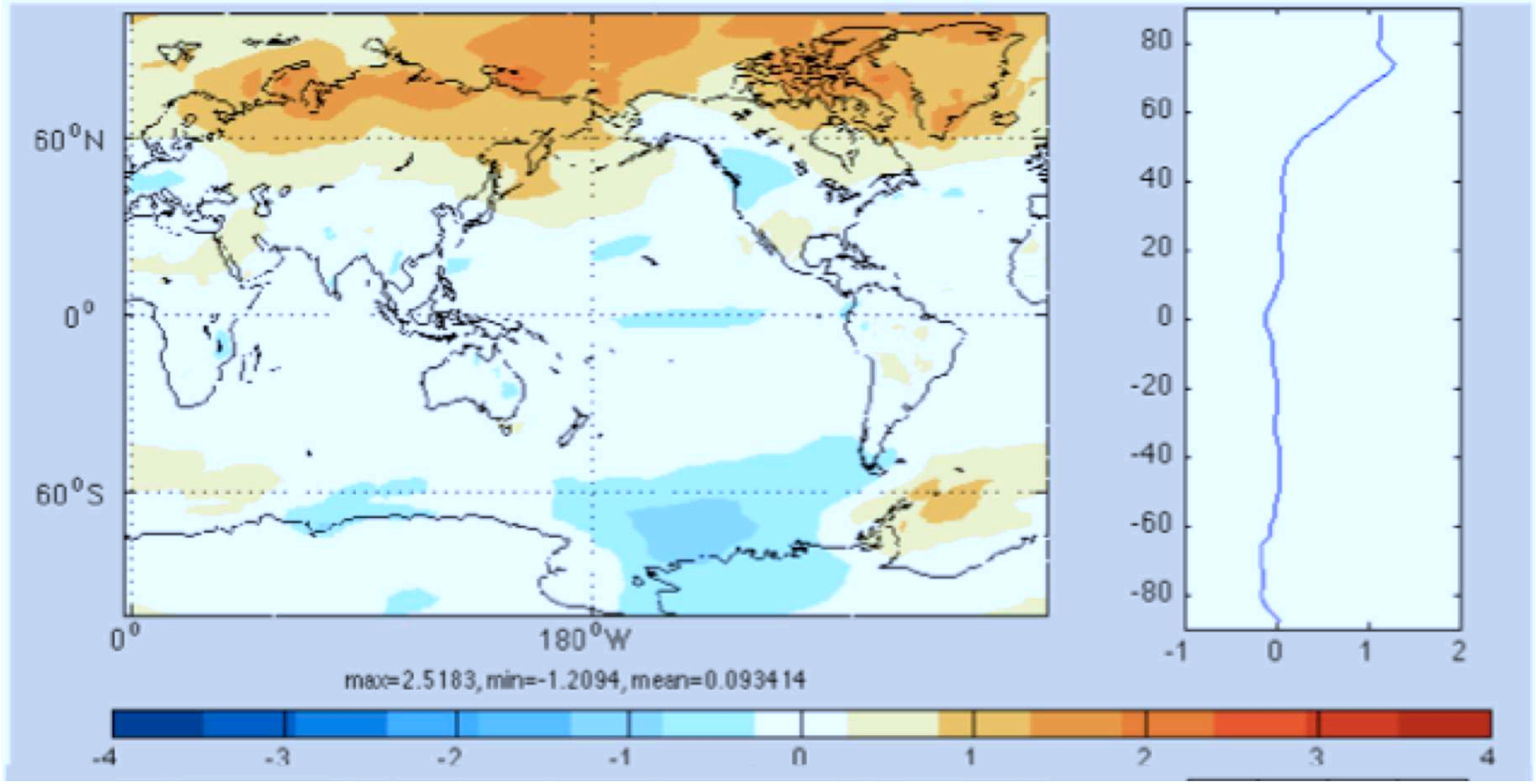
Double CO_2 | Double CO_2 & -1.8% sun

Conclusion - Global *and* regional temperature and precipitation changes are nearly neutralized

Criticism - Aging atmosphere model, shallow (bathtub like) slab ocean (no deep ocean), sea ice is motionless. Turning down the sun is not realistic.

McCusker, Battisti, and Bitz (in preparation)

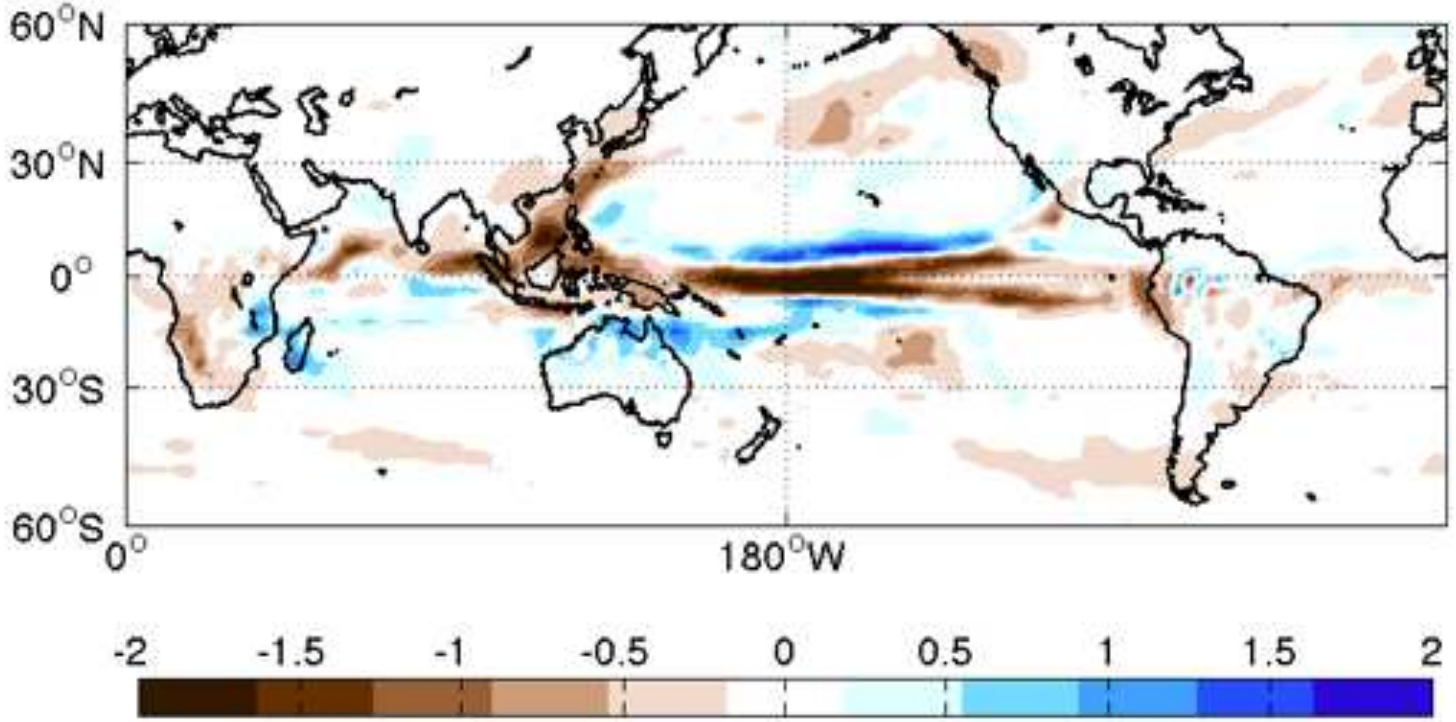
Δ Annual Surface Temperature



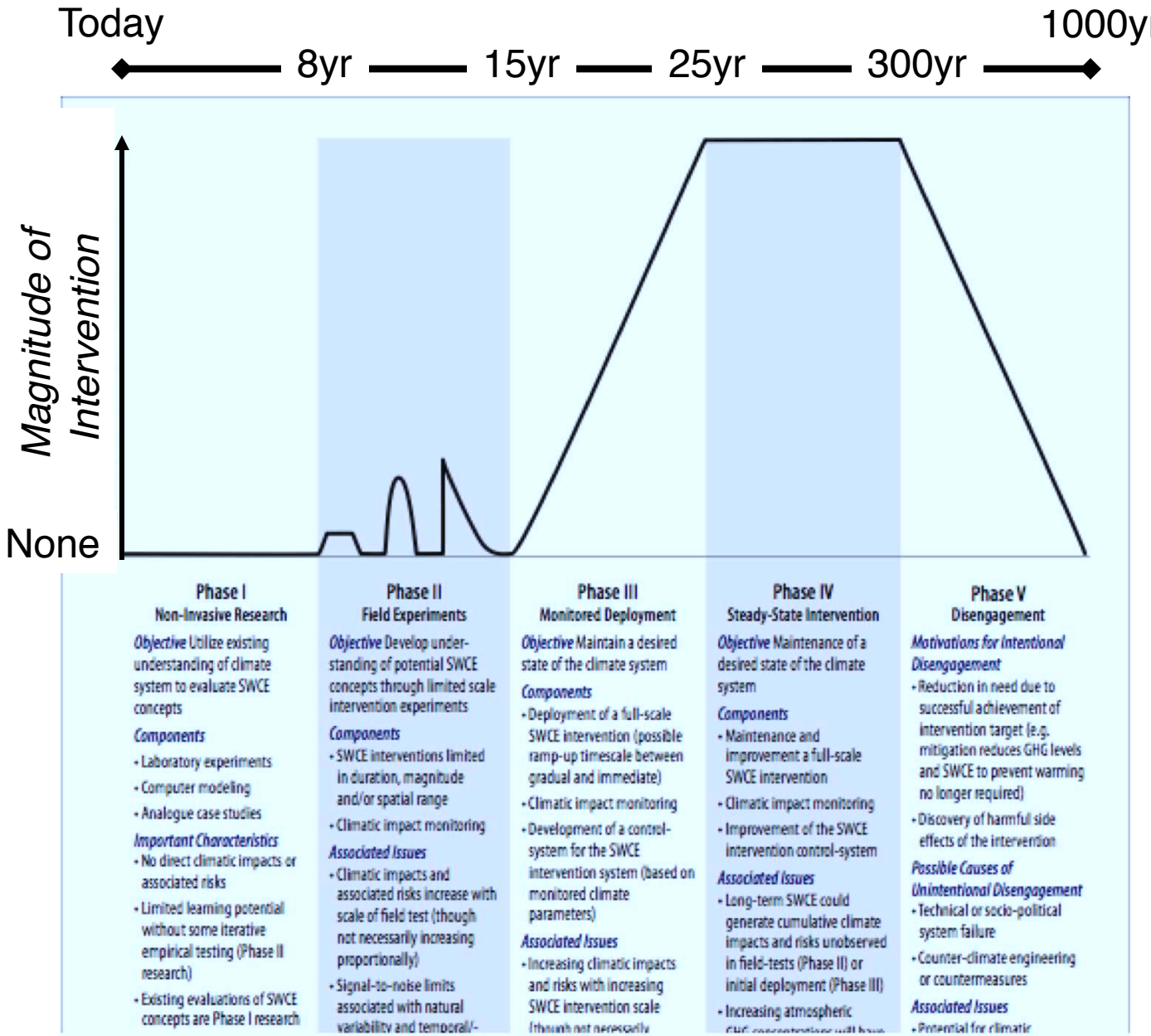
Much better model with deep ocean. Conclusion – climate change not nearly so well neutralized, but arguably better than CO2 alone

McCusker, Battisti, and Bitz (in preparation)

Δ December-February Precipitation



mm/day



Timeline of research, development, testing and deployment (stratospheric aerosols)

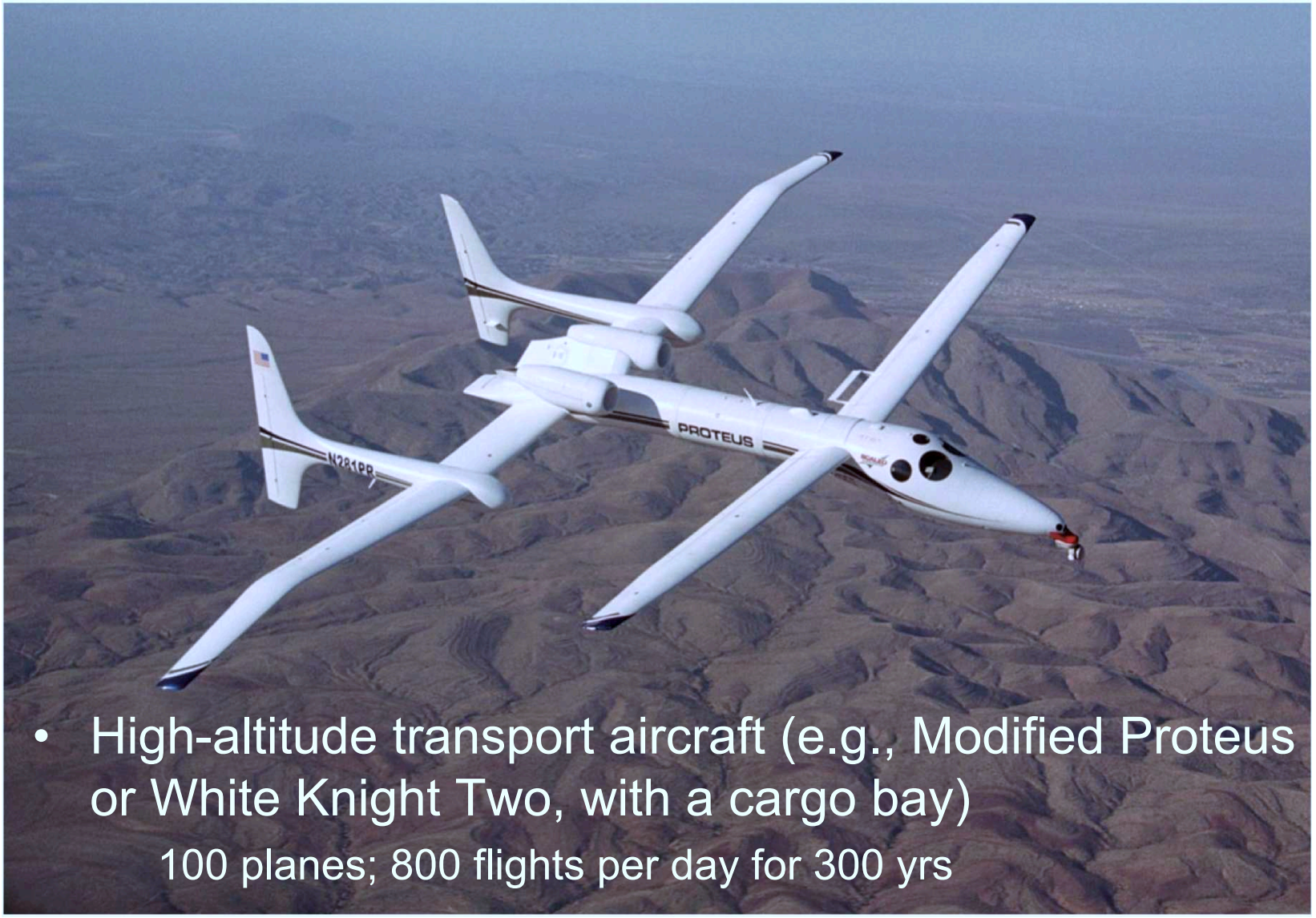
Blackstock et al 2009

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

Some downsides of the stratospheric aerosol sunshade solution

- Large uncertainty to how much/how often you have to inject sulfur into the stratosphere to cancel warming effect of increased CO_2
- Not clear injecting SO_2 works, recent study suggests injecting sulfuric acid instead!
- CO_2 will continue to increase in the atmosphere and continue to acidify the upper ocean
- Sulfur chemicals in the stratosphere may destroy ozone in the protective ozone layer. So try nanoteched particles (may be difficult or impossible to remove).

"Human beings are like cockroaches," Wood says with typical black humor. "It's fairly easy to kill the first ten percent of the population. And if you try really hard, you might even get the next ten percent. But no matter what you do, you'll never get that last ten percent. We will find a way to survive."

Dr. Lowell Wood (aka Dr. Evil)

Both Inadvertent and Advertent Changes are the Subject of International Protocols

- Inadvertent CO2 emissions and resulting climate change could be governed by the *UN Framework Convention on Climate Change* (e.g., Kyoto Protocol).

- Advertent climate change or climate engineering is probably subject to the *UN Convention on the Prohibition of Military or any Other Hostile Use of Environmental Modification Techniques* (US ratification January 17, 1980).

advertent = intentional

The UN Framework Convention on Climate Change

UNFCC was established at the Rio Earth Summit 1992;
subsequent meetings of the UNFCC produced Kyoto Protocol, Bali 2007, Copenhagen 2009…

UNFCC sets objectives for atmospheric stabilization.

Objective 2 calls for:

- Stabilization of the greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.

- Such a level should be achieved within a time frame sufficient
  - to allow ecosystems to adapt naturally to climate change,
  - to ensure that food production is not threatened, and
  - to enable economic development to proceed in a sustainable manner.

Earth Summit, Rio de Janeiro, 1992

(adopted widely by the world community and ratified by the US Senate in 1992)

The 1978 “Convention on the Prohibition of Military or any Other Hostile Use of Environmental Modification Techniques”

Article I.1. Each State Party to this Convention undertakes not to engage in military or any other hostile use of environmental modification techniques having widespread, long-lasting or severe effects as the means of destruction, damage or injury to any other State Party.

The term "environmental modification techniques" refers to any technique for changing -- through the deliberate manipulation of natural processes -- the dynamics, composition or structure of the Earth, including its biota, lithosphere, hydrosphere and atmosphere, or of outer space.

Also, each State Party to this Convention agrees not to assist, encourage or induce any State or international organization to engage in activities contrary to the provisions above.

The 1978 “Convention on the Prohibition of Military or any Other Hostile Use of Environmental Modification Techniques”

Article III.1. The provisions of this Convention shall not hinder the use of environmental modification techniques for peaceful purposes

Article III.2. The States Parties to this Convention undertake to facilitate, and have the right to participate in, the fullest possible exchange of scientific and technological information on the use of environmental modification techniques for peaceful purposes.

Lots of Unresolved *Legal* Questions

The biggest two:

- Does the 1978 Convention *demand* that we deploy climate engineering to avoid harm through global warming?

- What if the overwhelming majority of countries benefit from climate engineering, but a few countries suffer?
  - Does the 1978 Convention *demand* that climate engineering *not* be deployed?
  - If so, doesn't *inaction* on climate engineering violate the UN Framework Convention on Climate Change (which requires we stabilize greenhouse gas concentrations to avoid dangerous climate changes)

In some ways, the two treaties conflict. And given that they affect different countries differently (ie, there will be winners and losers in climate change, as well as in engineering against climate change), these conflicts means the present laws are inadequate to deal with these concomitant issues.

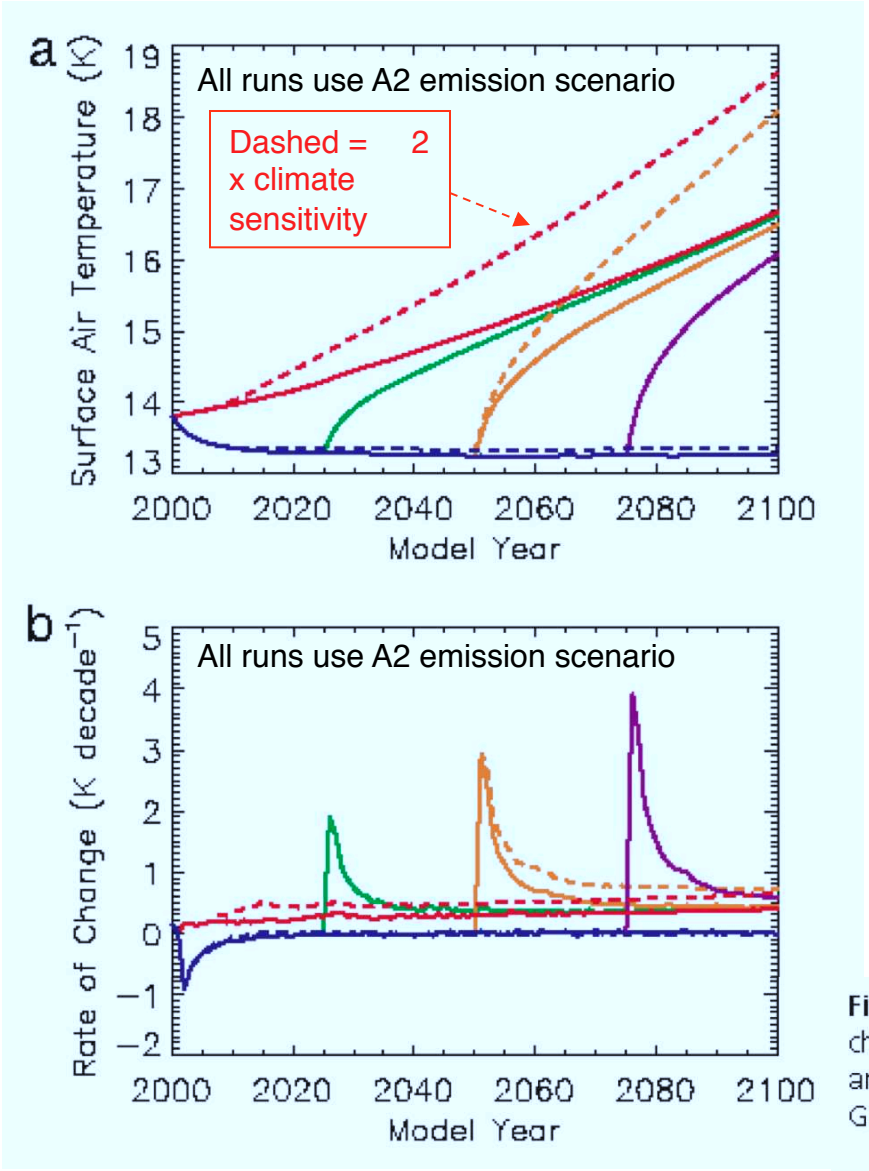
General arguments *against* doing climate engineering

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

General arguments *against* doing climate engineering

(including sun shading by stratospheric aerosols)



- 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., 1-4C in 10 years

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

Fig. 3. 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). Runs with doubled climate sensitivity (A2+CS, GEO+CS, and OFF_2050+CS) are plotted as dashed lines.

Calderia and Wood 2008

Arguments *against* doing climate engineering

- *Overwhelmingly, climate scientists are very skeptical of -- and do not support -- climate engineering. Why?*

  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.

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.

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)

Final Comments on Climate Engineering

- The possibility of “[unanticipated] harmful side effects” is too large for any intentional human intervention to *ever* be considered safe.
- Shortwave climate engineering can be perceived as a substitute for greenhouse gas (GHG) emission reductions, and might therefore “undercut human resolve to deal with the cause of the original problem”.
- If a wide spread political belief developed that climate control is (or will become) possible through climate engineering, significant international tensions might emerge surrounding who gets to define what the “optimum” climate should be.

Final Comments on Climate Engineering

- *"CLIMATE ENGINEERING IS NOT INSURANCE*
  - Maybe after 100 years of intensive research we might begin to know if its insurance
  - But if 50 years of intensive research on global warming have not narrowed the uncertainty in warming forecast, why should we expect it to be any better at sulfate geoengineering?"

    Ray Pierrehumbert, U. Chicago

- *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:
    - a lack of public resolve
    - Lack of leadership and commitment in business and government.

Final Comments on Climate Engineering

- 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., 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?

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

The following slides were not presented in class, but my
be useful for you notes

20 Reasons Why Geoengineering May be a Bad Idea by Alan Robock

1) Effects on Regional Climate, weaker effect in Arctic and drying in the tropics
2) Continued Ocean Acidification
3) Ozone depletion via surface processes on particles
4) Effects on Plants
5) More Acid Deposition

20 Reasons Why Geoengineering May be a Bad Idea

6) Effects on cirrus clouds via seeding

7) Whitening of the sky

8) Less sun for solar power

9) Environmental Impacts of Implementation

10) Rapid Warming if Deployment Stops

20 Reasons Why Geoengineering May be a Bad Idea

11) No Going Back

12) Human Error

13) Undermining Emissions Mitigation

14) Cost - not known (Wood says 1 billion/yr and Crutzen says 25-60 billion/yr)

15) Commercial control of Technology - Who controls it and who is the intended beneficiary (Procedural Justice)

20 Reasons Why Geoengineering May be a Bad Idea

16) Military use of Technology

17) Conflict with Treaties - UN's ENMOD forbids "use of enviro. modification techniques having widespread, long-lasting or severe effects as the means of destruction , damage, or injury to any other State Party"

18) Who controls the thermostat (Procedural Justice)

19) Moral authority - to alter the climate knowingly

20) Unexpected consequences

Argument by Philosopher Martin Bunzl

"… objections to any negative consequences whatsoever isn't a strong enough argument to end discussion.

More trenchant is the worry that the mere possibility of geoengineering would undermine other efforts to decrease our carbon output."

Moral hazard - we behave differently when insulated from risk

Does Dr Evil Console?

Al Gore says global warming “is the only crisis we’ve ever faced that has the capacity to end civilization.”

Lowell Wood “Human beings are like cockroaches. It’s fairly easy to kill the first 10% of the population. And if you try really hard, you might even get the next 10%. But no matter what you do, you’ll never get the last 10%. We find a way to survive”

Rolling Stone Article

"Here is a guy (Crutzen, Noble prize winner in atmospheric chemistry) who knows more about the atmosphere than anyone else alive, and he's telling us the situation is so dire that we need to think about intervening…That's frightening … It's also very interesting", an unnamed scientist

Rolling Stone Article

"Piling one un-understood on top of another un-understood problem is not very smart." Burton Richtor, Noble Prize winner in Physics

Rolling Stone Article

"There is only a small chance to save the patient, but we have to try it," James Lovelock, author of Gaia

Rolling Stone Article

Shading the sun by 25% would maintain the natural level of ice in the Arctic, according to Ken Caldeira.

Crutzen's Essay

"Building trust between scientists and the general public would be needed to make such a large-scale climate modification acceptable."