Presenting:

Climate Change and Climate Engineering

J. Eric Bickel

DAAG Conference 2013

DAAG is the annual conference of the SDP.
To find out more about SDP or to become a member, visit
www.decisionprofessionals.com

Operations Research
The University of Texas
1 University Station, C2200
ETC 5.128D
512.232.8316
ebickel@mail.utexas.edu

Climate Change and Climate Engineering

Presented by:
J. Eric Bickel
Graduate Program in Operations Research
The Center for International Energy and Environmental Policy
The University of Texas at Austin
ebickel@mail.utexas.edu

Presented at:
DAAG 2013

11 April 2013

This talk is based upon the following work:

challenge paper

CLIMATE CHANGE,
CLIMATE ENGINEERING R&D

JAMES ERIC BICKEL

Climatic Change
DOI 10.1007/s10584-012-0619-x

...nomics of aerosol geoengineering

...rawal

... October 2012
... Dordrecht 2012

...extend the work of Goes, Tuana, and Keller (Climatic ...xamining the economic benefit, of aerosol geoengineer- ...plete substitution of geoengineering for CO_2 abatement ... a wide range of scenarios regarding (i) the probability ... be aborted and (ii) the economic damages caused by ...s paper, we reframe the conditions under which GTK ...uld/could be used. In so doing, we demonstrate that ...ost-benefit test over a wide range of scenarios originally

Environ Syst Decis (2013) 33:152–167
DOI 10.1007/s10669-013-9435-8

Climate engineering and climate tipping-point scenarios

J. Eric Bickel

Published online: 6 February 2013

Abstract Many scientists fear that anthropogenic emissions of greenhouse gases have set the Earth on a path of significant, possibly catastrophic, changes. This includes the possibility of exceeding particular thresholds or tipping points in the climate system. In response, governments have proposed emissions reduction targets, but no agreement has been reached. These facts have led some scientists and economists to suggest research into climate engineering. In this paper, we analyze the potential value of one climate engineering technology family, known as solar radiation management (SRM) to manage the risk of differing tipping-point scenarios. We find that adding SRM to a policy of emissions controls may be able to help manage the risk of climate tipping points and that its potential benefits are ...

This CO2 production alters the Earth's carbon cycle, leading to an increase in atmospheric CO2 concentrations (IPCC 2007a). All else being equal, this increase will raise the average surface temperature of the Earth (Stocker 2003; Trenberth et al. 2009). Thus far, the Earth has warmed about 0.7 °C (1.3 °F), relative to 1900, while CO2 concentrations have increased about 100 parts per million (ppm)—from a baseline of about 280 ppm (0.028 %).

This warming and associated climate changes such as ocean acidification are likely to bring economic damages (Parry et al. 2007). In addition, some scientists warn that the climate contains "tipping points" beyond which significant changes in the Earth system will occur. These may include loss of Arctic sea ice, melting of the Greenland and ...

I have participated in two Copenhagen Consensus projects:

2009

"If the global community wants to spend up to, say $250 billion per year over the next 10 years to diminish the adverse effects of climate changes, and to do most good for the world, which solutions would yield the greatest net benefits? – i.e. what are the costs and benefits of different viable climate interventions…given some reasonable assumptions about sensible policies for the rest of 21st century?"

- Finn E Kydland, Nobel Laureate
- Thomas C Schelling, Nobel Laureate
- Vernon L Smith, Nobel Laureate
- Nancy L Stokey, Frederick Henry Prince Distinguished Service Professor of Economics at the University of Chicago
- Jagdish Bhagwati, University Professor at Columbia University

2012

"If the global community wants to spend up to, say, $75 billion over the next four years to do most good for the world, which solutions would yield the greatest net benefits?"

- Finn E. Kydland, University of California, Santa Barbara (Nobel Laureate)
- Robert Mundell, Columbia University in New York (Nobel Laureate)
- Thomas Schelling, University of Maryland (Nobel Laureate)
- Vernon Smith, Chapman University (Nobel Laureate)
- Nancy Stokey, University of Chicago

All the authors presented their work to an expert panel.

Expert Panel (from left to right, running clockwise): Finn Kydland (Nobel Laureate), Thomas Schelling (Nobel Laureate), Vernon Smith (Nobel Laureate), Bjørn Lomborg, Jadgish Bhagwati, and Nancy Stokey.

The 2009 results:

Climate Engineering - Research into Marine Cloud Whitening	01
Technology - Technology-led Policy Response	02
Climate Engineering - Research into Stratospheric Aerosol Insertion	03
Technology - Research into Carbon Storage	04
Adaptation - Planning for Adaptation	05
Climate Engineering - Research into Air Capture	06
Technology Transfers - Technology Transfers	07
Forestry - Expand and Protect Forests	08
Cut Black Carbon - Stoves in Developing Nations	09
Cut Methane - Methane Reduction Portfolio	10
Cut Black Carbon - Diesel Vehicle emissions	11
Cut Carbon - OECD Carbon Tax	12
Cut Carbon - $0.5 Global CO2 Tax	13
Cut Carbon - $3 Global CO2 Tax	14
Cut Carbon - $68 Global CO2 Tax	15

Source: http://fixtheclimate.com/component-1/the-result-prioritization/

My co-author (Lee Lane, American Enterprise Institute) and I worked on the climate engineering responses (ranked #1, #3, and #6).

The 2012 results:

PRIORITIZED LIST

	Challenge	Solution
1	Hunger & Education	Bundled Interventions to Reduce Undernutrition in Pre-Schoolers
2	Infectious Disease	Subsidy for Malaria Combination Treatment
3	Infectious Disease	Expanded Childhood Immunization Coverage
4	Infectious Disease	Deworming of Schoolchildren
5	Infectious Disease	Expanding Tuberculosis Treatment
6	Hunger & Biodiversity & Climate Change	R&D to Increase Yield Enhancements
7	Natural Disasters	Investing in Effective Early Warning Systems
8	Infectious Disease	Strengthening Surgical Capacity
9	Chronic Disease	Hepatitis B Immunization
10	Chronic Disease	Acute Heart Attack Low-Cost Drugs
11	Chronic Disease	Salt Reduction Campaign
12	Climate Change	Geo-Engineering R&D
13	Education	Conditional Cash Transfers for School Attendance
14	Infectious Disease	Accelerated HIV Vaccine R&D
15	Education	Information Campaign on Benefits From Schooling
16	Water and Sanitation	Borehole and Public Hand Pump Intervention
17	Climate Change	Increased Funding for Green Energy R&D
18	Population Growth	Increase Availability of Family Planning
19	Chronic Disease	Heart Attack Risk Reduction Generic Pill
20	Water and Sanitation	Community Led Total Sanitation
21	Water and Sanitation	Sanitation as a Business
22	Chronic Disease	Increasing Tobacco Taxation
23	Natural Disasters	Community Walls Against Floods
24	Water and Sanitation	The Reinvented Toilet
25	Biodiversity	Protecting All Forests
26	Natural Disasters	Retrofitting Schools to Withstand Earthquake Damage
27	Hunger	Crop Advisory Text Messages
28	Biodiversity	Extension of Protected Areas
29	Natural Disasters	Strengthening Structures Against Hurricanes and Storms
30	Natural Disasters	Elevating Residential Structures to Avoid Flooding

My argument proceeds as follows:

1. All else being equal, anthropogenic emissions of CO_2 will warm the Earth. How much they will warm Earth is uncertain. This warming will, on balance, result in economic damage.

2. It is unlikely that negotiations will have a significant impact on temperatures for many decades.

3. Emissions reductions, even steep ones, cannot eliminate the possibility of significant warming. In addition, emissions reductions give us almost no ability to respond in a climate emergency.

4. Thus, we should consider additional approaches to climate change, including climate engineering (CE).

5. One particular CE technology, known as solar radiation management (SRM), might be able to effectively lower the risk of climate tipping points. However, this technology does not exist and its risks are not completely understood.

6. Thus, we should invest in research. If successful, we should develop this technology and be prepared to deploy it.

Agenda

- Background
- Climate Engineering
- Climate Change Risk Drivers
- The Weakness of Emissions Reductions
- The Option Value of Climate Engineering

Two types of radiation are important in discussions of global warming: shortwave (sunlight) and longwave (heat).

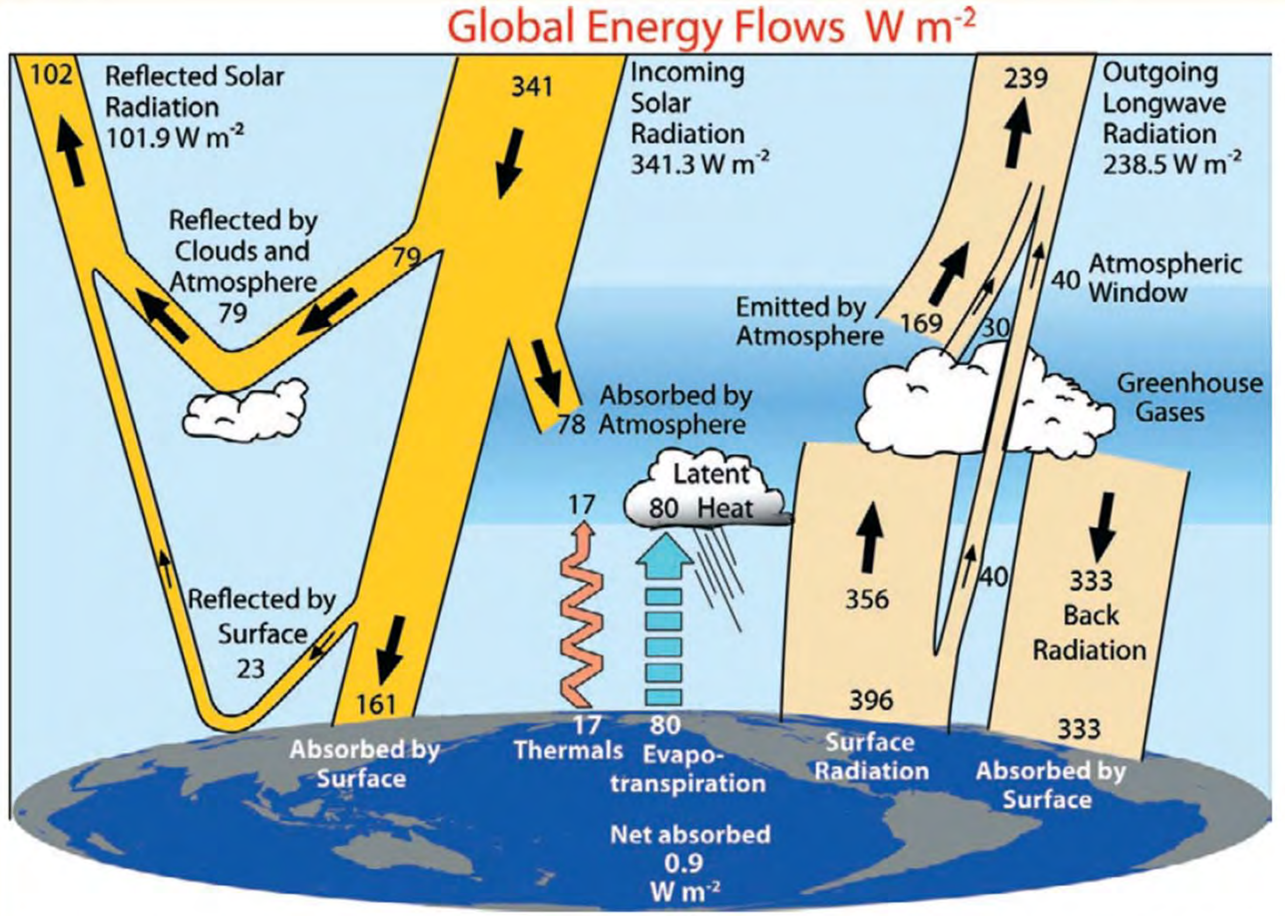


FIG. 1. The global annual mean Earth's energy budget for the Mar 2000 to May 2004 period (W m⁻²). The broad arrows indicate the schematic flow of energy in proportion to their importance.

Planetary Albedo

$$= \frac{102}{341} \approx 0.30$$

Source: Trenberth, Kevin E., John T. Fasullo, and Jeffrey Kiehl. 2009. Earth's Global Energy Budget. *Bulletin of the American Meteorological Society* 90(3) 311-323.

Human activity contributes to climate change and global warming.

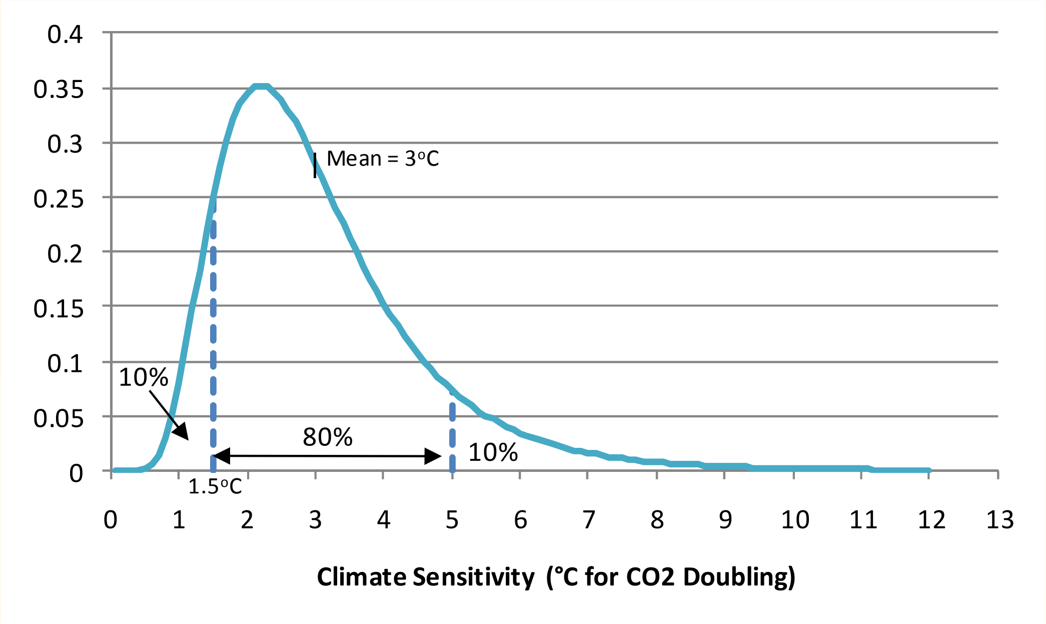
Global Warming

- Greenhouse gases (GHGs) in the Earth's atmosphere cause the planet's surface temperature to be about 30^oC (59^oF) warmer than would otherwise be the case.
- These gases allow the passage of shortwave radiation (sunlight), but absorb longwave radiation (heat) and reflect a fraction back to the Earth's surface.
- The burning of fossil fuels and land use changes alter the Earth's carbon cycle, leading to an accumulation of carbon-dioxide (CO2) in the atmosphere.
- All else being equal, although all else may not be equal, higher GHG concentrations will raise the global mean temperature.
- Thus far, the Earth has warmed about 0.7^oC (1.3^oF), while CO2 concentrations have increased from 280 ppm (0.028%) to about 380 ppm (0.038%).

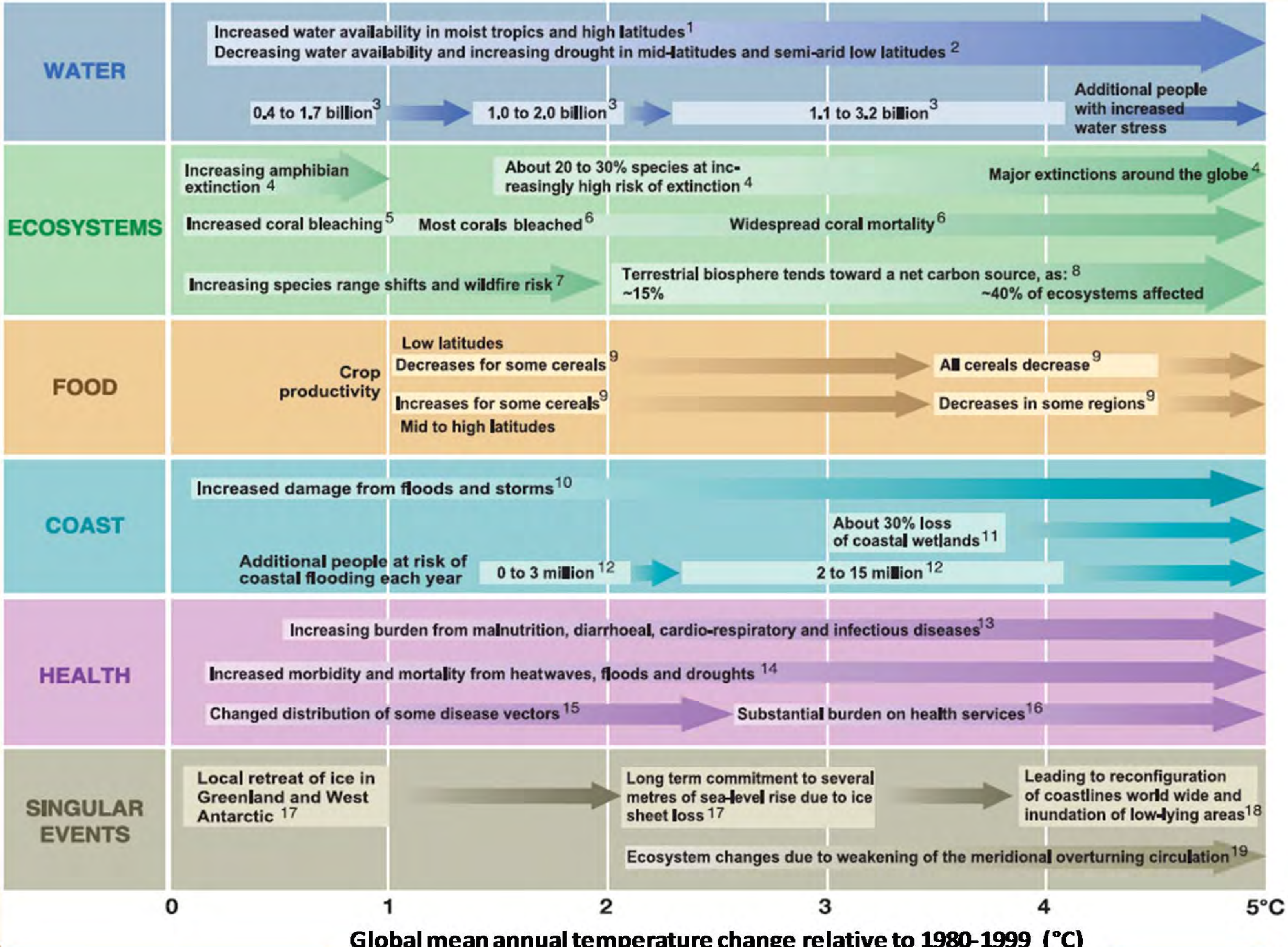
The most critical uncertainty is known as the "climate sensitivity" – warming for 2X CO_2.

- "The equilibrium climate sensitivity…is *likely* to be between 2°C and 4.5°C, with a best estimate of 3°C and it is *very unlikely* to be less than 1.5°C. Values substantially higher than 4.5°C cannot be excluded, but agreement of models with observations is not as good for those values [emphasis in original]" (IPCC 2007).

- The IPCC defines likely as greater than a 66% probability and very unlikely as less than a 10% probability (IPCC 2005).



The IPCC forecasts significant damages as temperatures increase.



Source: IPCC (Parry et al. 2007).

In addition to these costs of gradual climate change, scientists believe that the Earth's climate system includes several tipping points.

- These include loss of Arctic sea ice, melting of the Greenland and Antarctic ice sheets, irreversible loss of the Amazon rain forest, and abrupt changes in the Indian and West African monsoons.

- Lenton et al. (2008) are particularly concerned about the loss of Arctic sea ice and melting of the Greenland Ice Sheet (GIS).

    - As Arctic sea ice melts, the darker ocean waters are exposed, which leads to additional warming, known as a positive feedback mechanism.

    - They conclude that "a summer ice-loss threshold, if not already passed may be very close and a transition could occur well within this century."

Against this backdrop of uncertainty, one thing is clear: 20 years of negotiations have failed to reduce emissions.

- "The year 2008 marks the 20th anniversary of the first meeting of the IPCC, the international body established by the UN to solve the problem of warming. The 'progress' to date has been almost purely rhetorical. Currently, according to the US Energy Information Agency, global emissions of CO_2, the most important greenhouse gas, were over a third higher than they had been in 1988. The IPCC reports that the rise in atmospheric concentrations has accelerated through the last several decades." (Lane and Montgomery 2008).
- In fact, CO_2 emissions grew four times more quickly between 2000 and 2007 than they did between 1990 and 1999 (Global Carbon Project 2008).
- This is hardly surprising. Many large emitters may benefit from some degree of warming and have large populations in poverty.

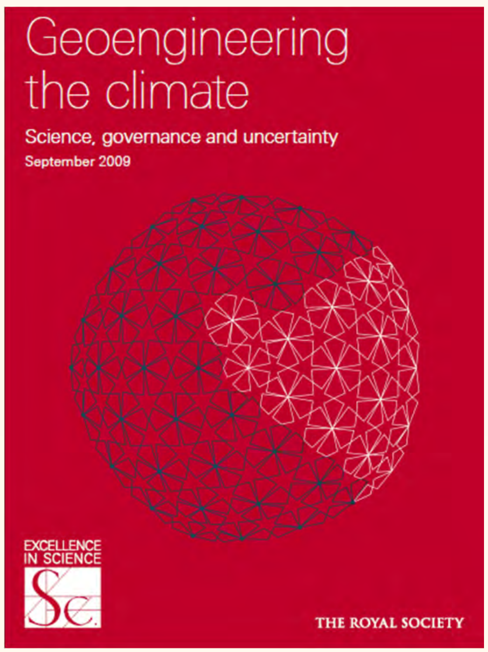
Agenda

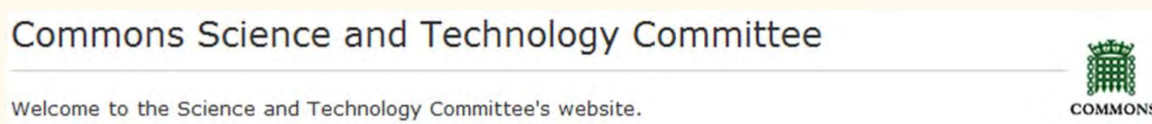
- Background
- Climate Engineering
- Climate Change Risk Drivers
- The Weakness of Emissions Reductions
- The Option Value of Climate Engineering

Governments and scientific societies are discussing climate engineering.

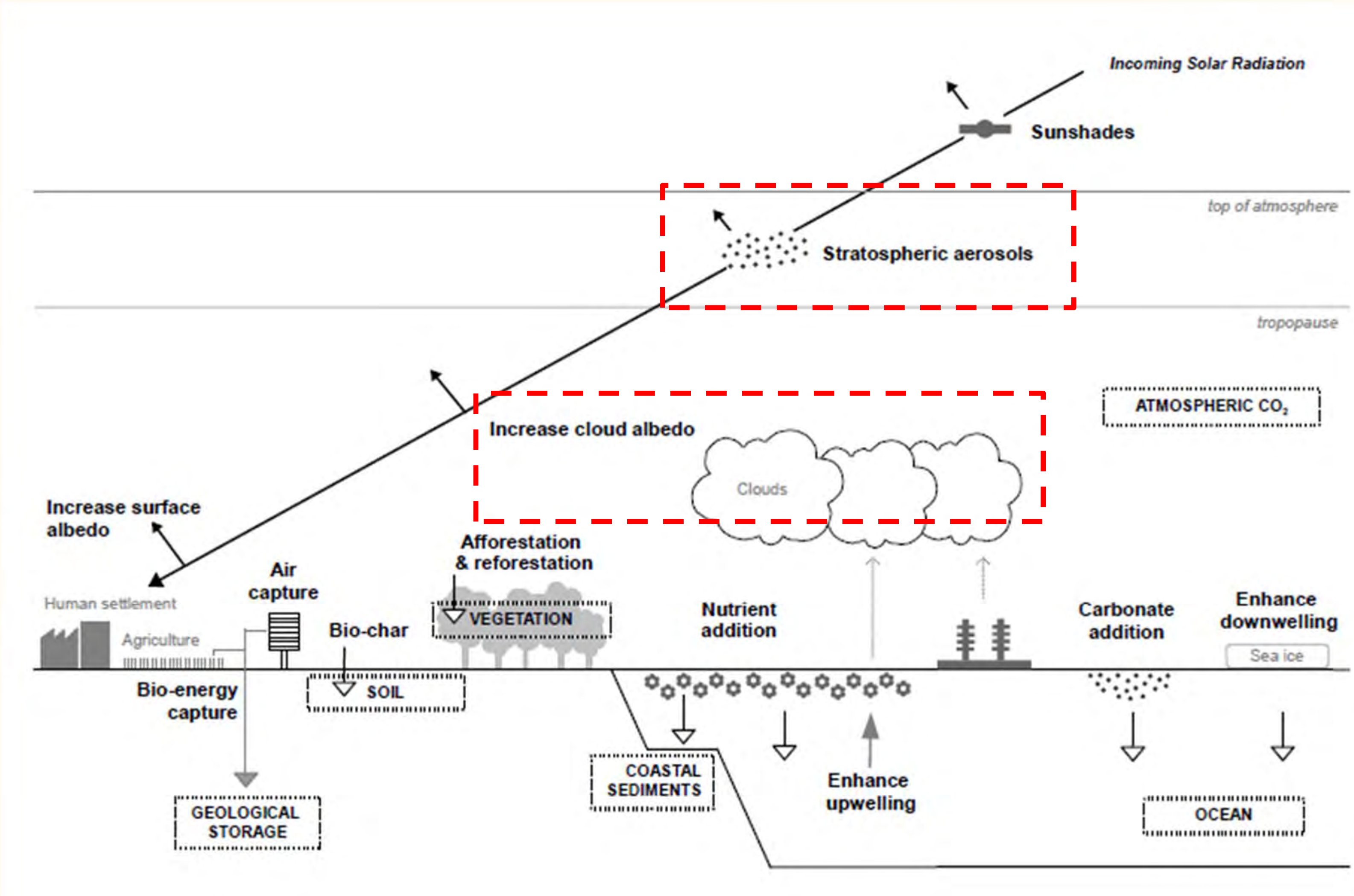
Climate Engineering Definition

The Royal Society defines climate engineering (or geoengineering) as "the deliberate large-scale intervention in the Earth's climate system, in order to moderate global warming." (The Royal Society 2009).



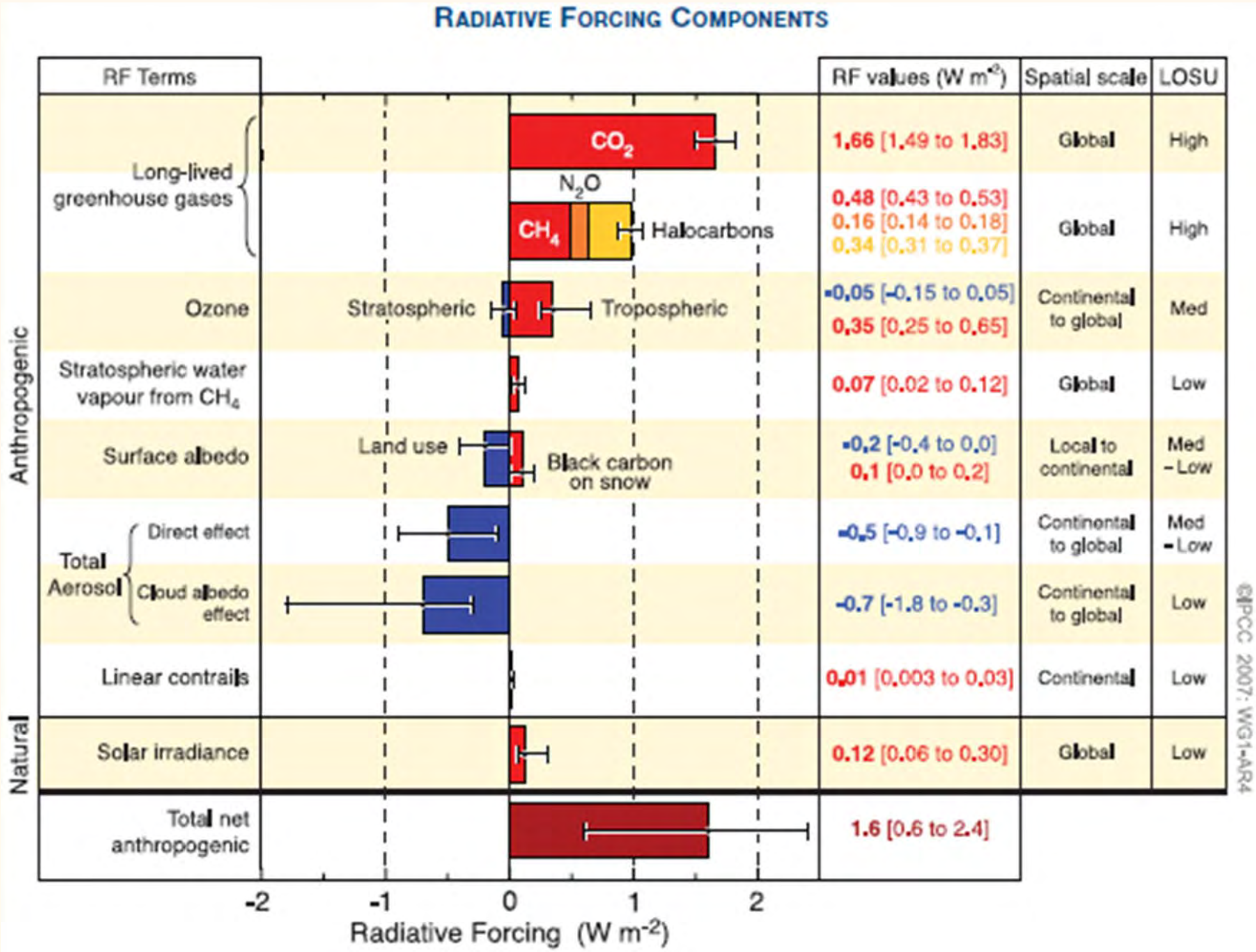


There are two climate engineering families: air capture (AC) and solar radiation management (SRM).



Source: Lenton, T. M. and N. E. Vaughan. 2009. The radiative forcing potential of different climate geoengineering options. *Atmos. Chem. Phys. Discuss.*, 9 2559-2608.

The IPCC estimates that aerosols already offset 40% of anthropogenic radiative forcing.



Source: IPCC 2007.

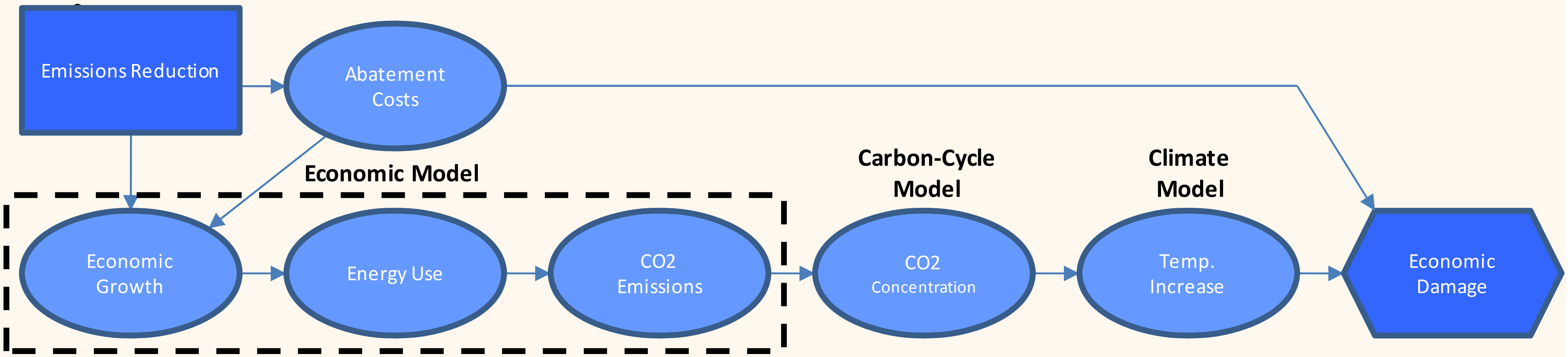
Agenda

- Background
- Climate Engineering
- Climate Change Risk Drivers
- The Weakness of Emissions Reductions
- The Option Value of Climate Engineering

We use the Dynamic Integrated model of Climate and the Economy (DICE; Nordhaus 2008) to understand risk of climate change.

DICE

- DICE is a deterministic optimal-economic-growth model.

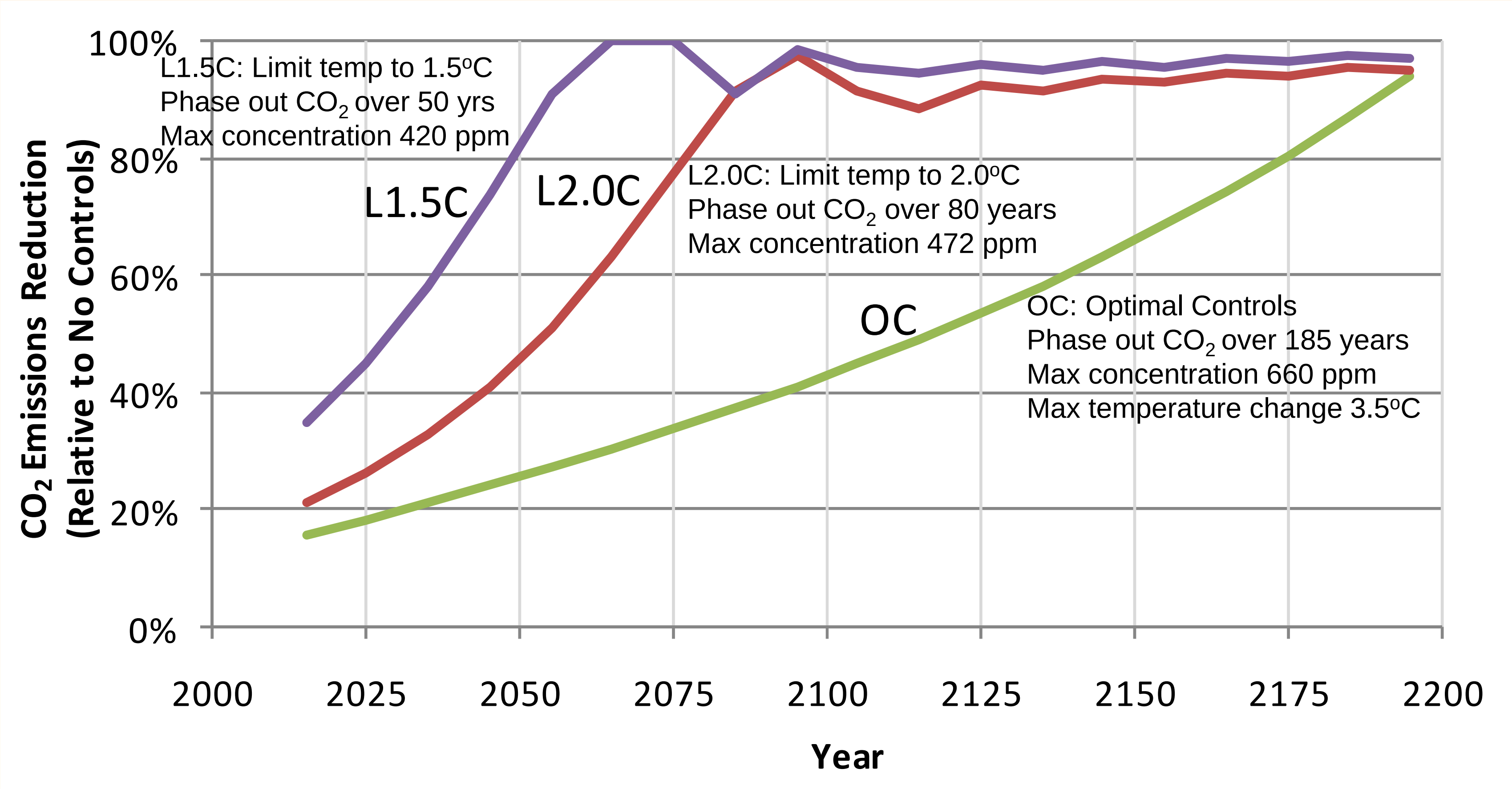


- Emissions reductions lessen warming, but are costly and lower economic growth. DICE balances these competing factors to arrive at the "optimal" level of emissions through time—called Optimal Controls (OC).

DICE can also manage emissions to a particular temperature target.

Limiting temperatures to 2.0ºC requires completely phasing out CO_2 emissions by the end of the century.

Example DICE Emissions Control Regimes



DICE determines the economic value of these emissions control regimes.

Optimal Controls is $3 trillion better than No Controls.

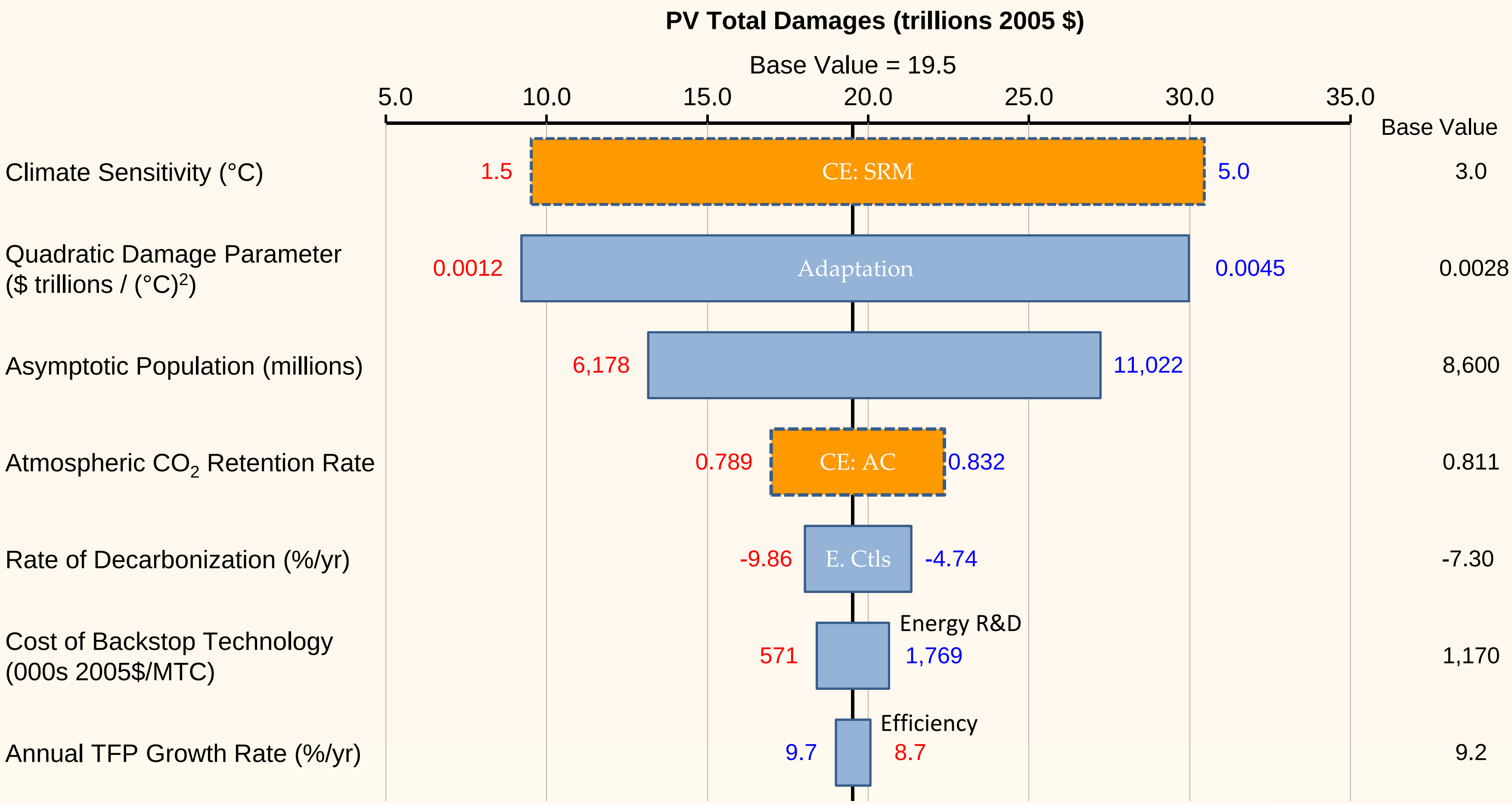
DICE Base Case Present Values (trillions 2005 $)

Emissions Control Regime	Climate Damages	Abatement Costs	Total Damages	Max Temp Increase (ºC) & Year
No Controls	$22.5	$0	$22.5	5.2 (2205)
Optimal Controls	$17.4	$2.1	$19.5	3.5 (2185)
L2.0C	$13.4	$11.8	$25.2	2.0 (2095)
L1.5C	$10.5	$28.8	$39.3	1.5 (2065)

Limiting temperatures to 2.0ºC or 1.5ºC is worse than No Controls.

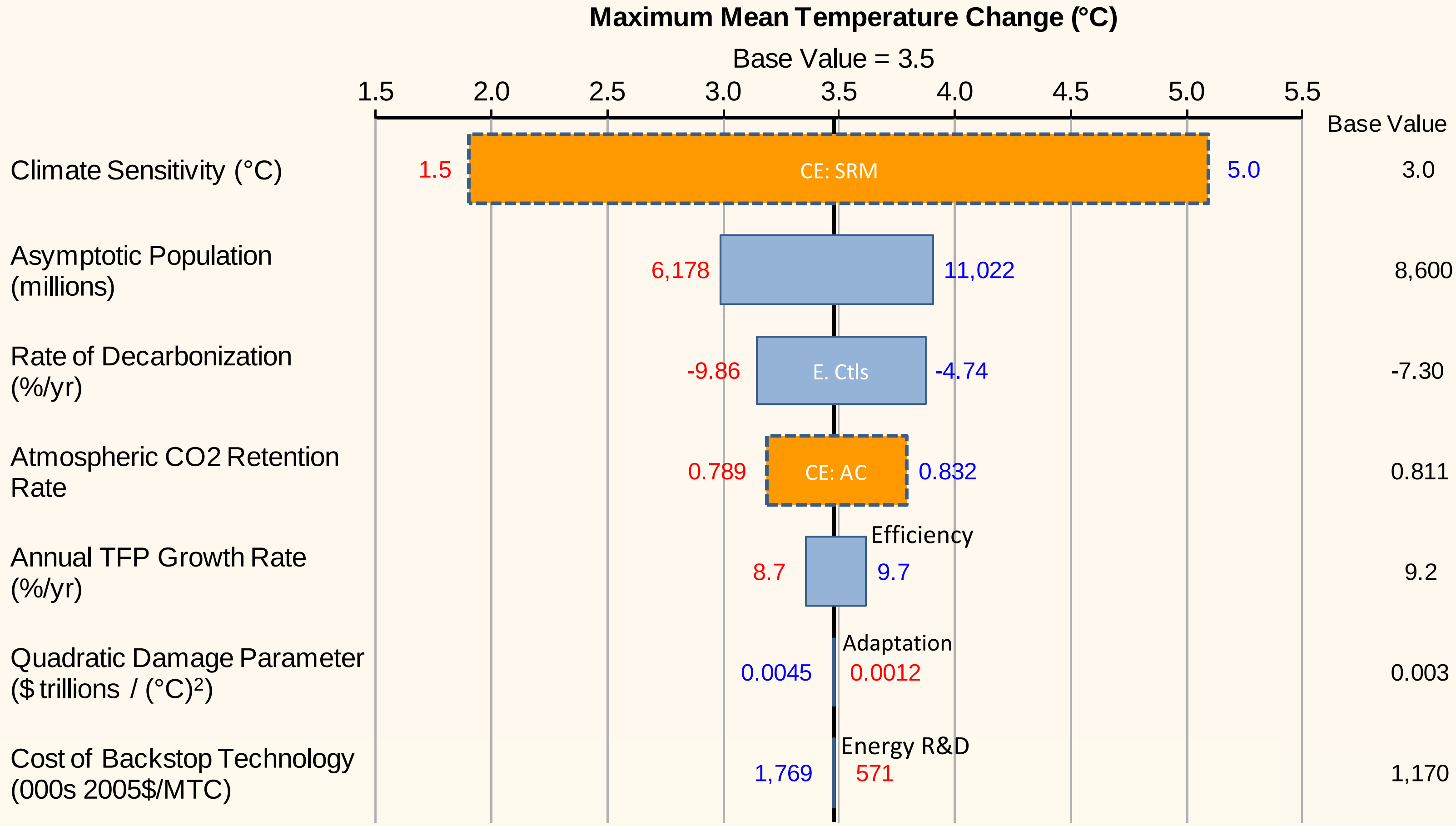
What are the largest drivers of risk and uncertainty in these estimates?

The climate sensitivity is the primary risk factor.



We can perform a similar analysis for temperature increase.

The climate sensitivity is an even more dominant factor when we focus only on temperature increase.



Thus far, our policy discussions and research efforts are not focused on the topic risk driver.

Agenda

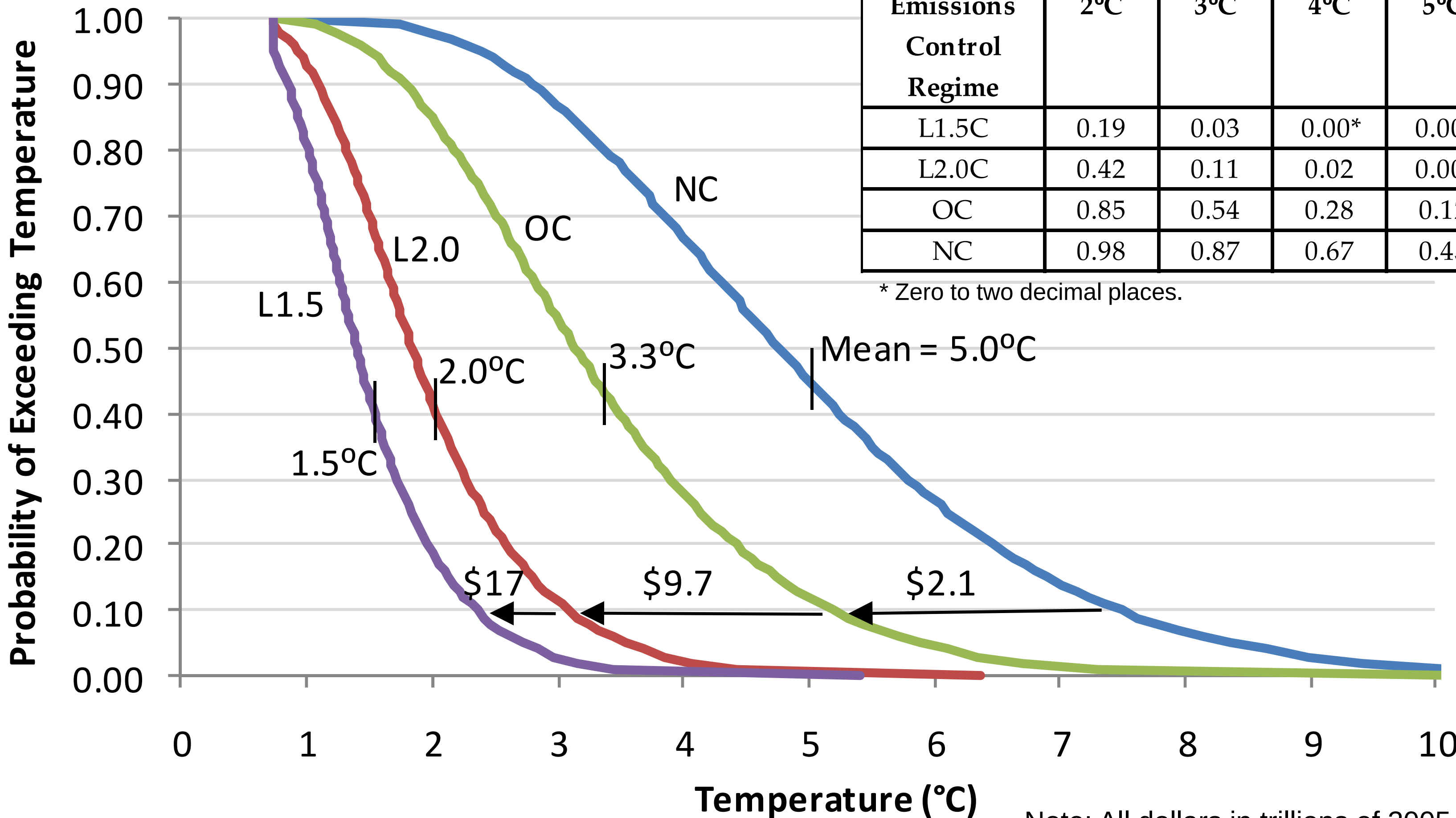
- Background
- Climate Engineering
- Climate Change Risk Drivers
- The Weakness of Emissions Reductions
- The Option Value of Climate Engineering

Managing tipping points with emissions reductions is very costly, because we are paying to reduce the probability at all temperatures.

Probability of Exceeding Given Temperature

Emissions Control Regime	2ºC	3ºC	4ºC	5ºC
L1.5C	0.19	0.03	0.00*	0.00*
L2.0C	0.42	0.11	0.02	0.00*
OC	0.85	0.54	0.28	0.12
NC	0.98	0.87	0.67	0.45

* Zero to two decimal places.



Note: All dollars in trillions of 2005 $

We are paying trillions for single digit decreases in the *probability* of crossing a tipping point.

SRM may be the *only* human action that could cool the planet in an emergency.

"It would appear that only rapid, repeated, large-scale deployment of potent shortwave geoengineering options (e.g., stratospheric aerosols) could conceivably cool the climate to near its preindustrial state on the 2050 timescale."

-- Lenton and Vaughan (2009)

Keller et al. (2005) estimate that it would cost 110% of GWP (about $60 trillion) to reduce the chance of exceeding 2.5ºC to 5% and that reducing the probability of crossing a temperature threshold to *de minimis* levels involves costs that are "politically infeasible."

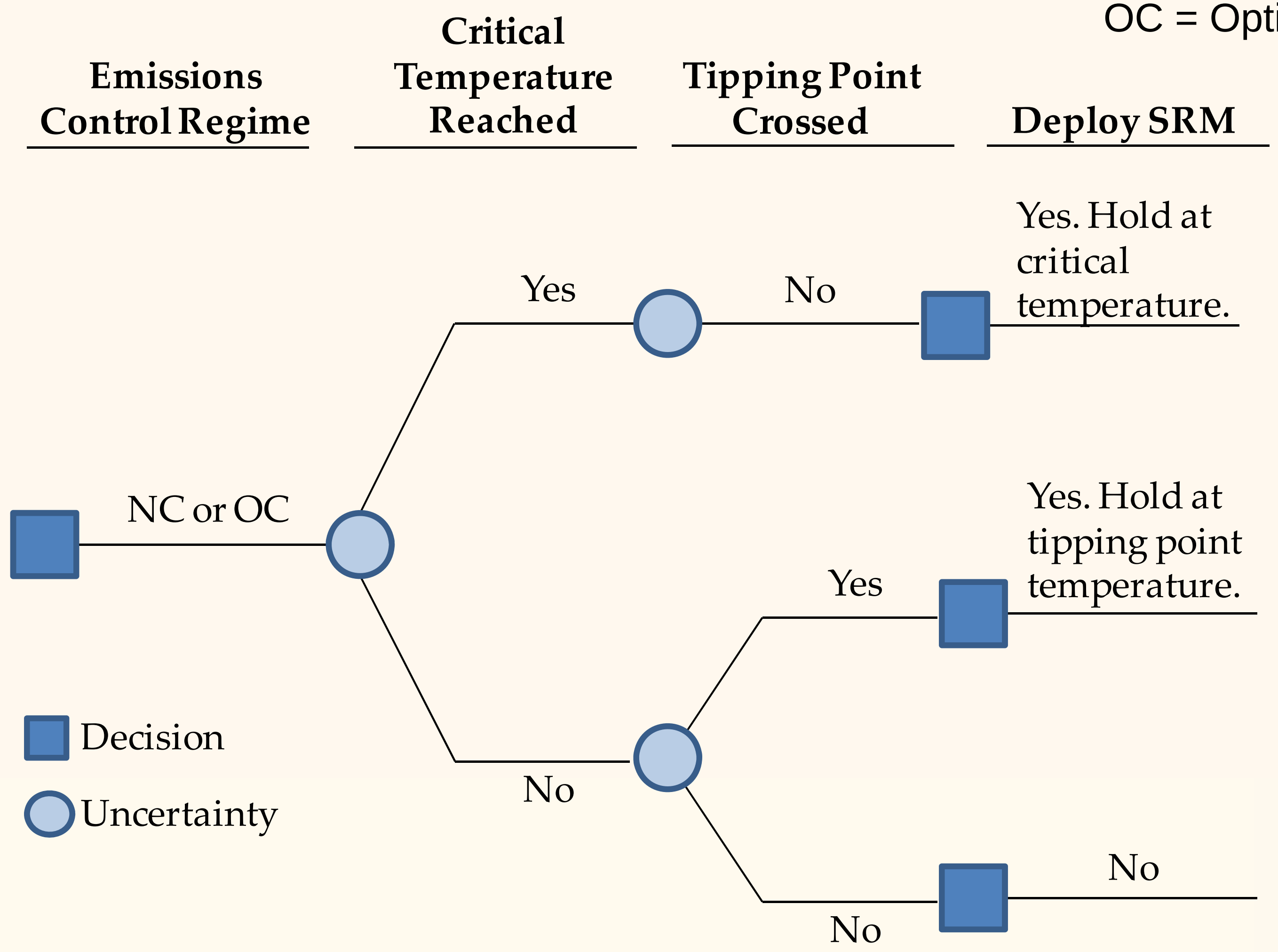
If we are truly concerned about tipping points in the climate system then we need to develop a control over temperature.

Agenda

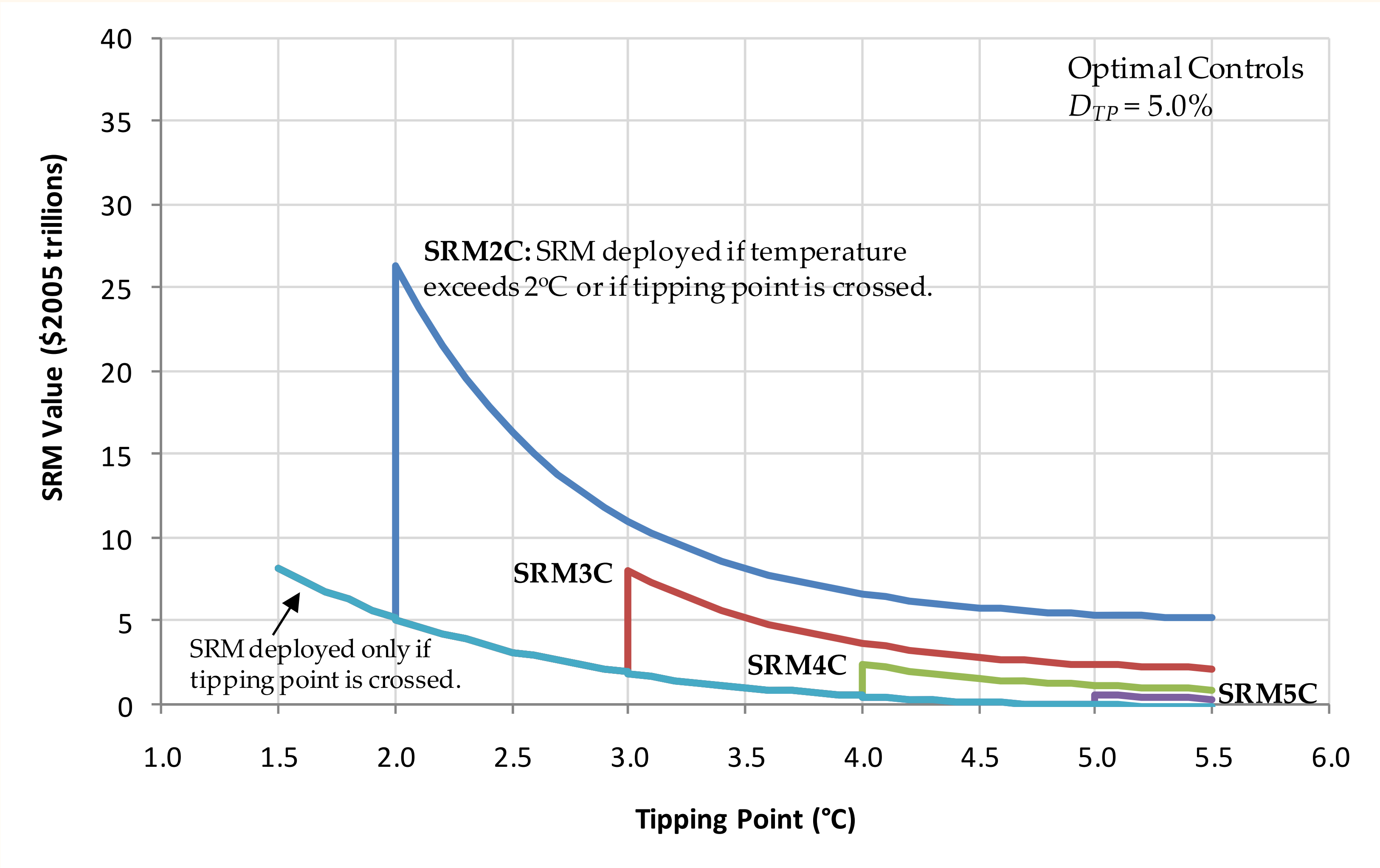
- Background
- Climate Engineering
- Climate Change Risk Drivers
- The Weakness of Emissions Reductions
- The Option Value of Climate Engineering

We assume society has decided to deploy SRM in two emergency scenarios.

NC = No Controls
OC = Optimal Controls



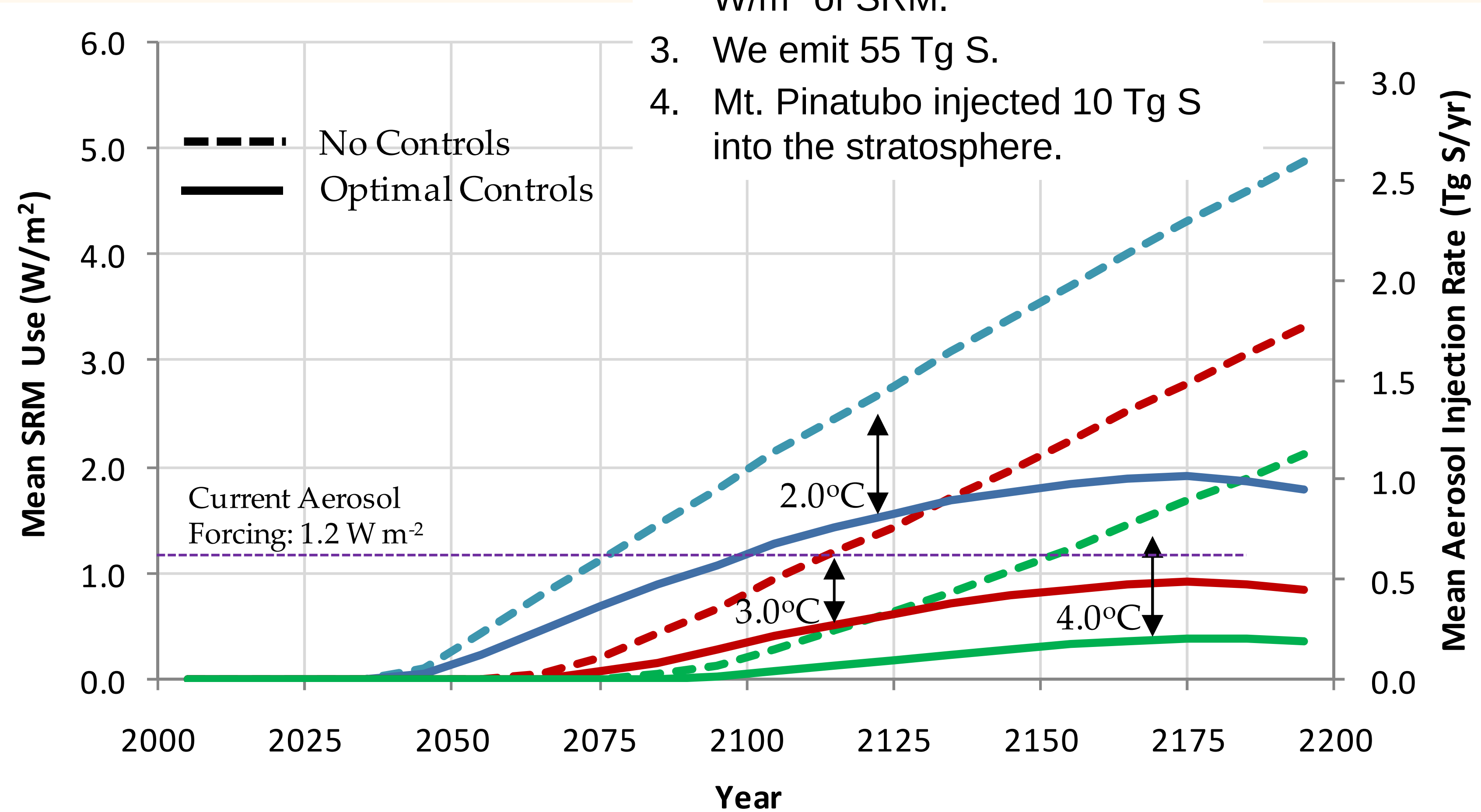
The option to deploy SRM is worth trillions, possibly tens of trillions, of dollars.



The cost to deploy SRM in these scenarios is on the order of $50 billion.

The required SRM to hold temperatures to 2°C through the end of this century are on the order of current interventions in the climate system.

1. We receive 341 W/m² of power from the sun.
2. We currently deploy about 1.2 W/m² of SRM.
3. We emit 55 Tg S.
4. Mt. Pinatubo injected 10 Tg S into the stratosphere.



The direct net benefits of SRM appear to be (very) large and appear to far exceed the cost of an R&D program.

Yet, many important uncertainties remain…

- The technologies need to be developed.
- SRM may alter precipitation patterns, as may climate change itself.
- Aerosol injection may delay recovery of the ozone layer.
- Other unknown side effects may be discovered.

These uncertainties will only be resolved through a substantial research and development program.

We conclude:

- Emissions controls (and air capture) do not directly address the largest risk factor: the climate sensitivity.
- Emissions controls cannot guarantee that we will not pass a tipping point.
- Emissions controls are likely to be a very expensive way of managing tipping points.
- Thus, we should pursue research into solar radiation management.

Thank You!

An SRM R&D program is estimated to cost in the low billions of dollars.

- Based on discussions with SRM researchers, Bickel and Lane (2009) estimated that a 10-year R&D program would start out in the low millions of dollars and ramp up to the low billions once field tests began.

- Keith et al. (2010) estimate that an international research budget starting out near $10 million per year and increasing to $1 billion per year over the next decade would be sufficient to test SRM and build the capability to deploy it.

Thus, the direct benefits exceed the R&D costs by 1000 times.

References

Bickel, J. Eric and Lee L. Lane. 2009. An analysis of climate engineering as a response to climate change, Copenhagen Consensus Center, Copenhagen. To appear in Copenhagen Consensus Recommendations for COP-15, Bjørn Lomborg (ed). Cambridge University Press: Cambridge, UK. http://fixtheclimate.com/

Global Carbon Project. 2008. Carbon budget and trends 2007, www.globalcarbonproject.org.

IPCC. 2005. Guidance notes for lead authors of the IPCC Fourth Assessment report on addressing uncertainties.

IPCC. 2007. Summary for policymakers. In: S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis et al. (eds.), Climate change 2007: The physical science basis. Contribution of Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press: Cambridge, UK and New York, NY, USA.

Keith, David W., Edward Parson and M. Granger Morgan. 2010. Research on global sun block needed now. Nature 463(28) 426-427.

Lane, Lee and David Montgomery. 2008. Political institutions and greenhouse gas controls. AEI Center for Regulatory and Market Studies: Washington, DC.

Lenton, T. M. and N. E. Vaughan. 2009. The radiative forcing potential of different climate engineering options. Atmos. Chem. Phys. Discuss. 9 2559-2608.

Lenton, Timothy M. Hermann Held, Elmar Kriegler, Jim W. Hall, Wolfgang Lucht, Stefan Rahmstorf and Hans Joachim Schellnhuber. 2008. Tipping elements in the earth's climate system. PNAS 105(6) 1786-1793.

Nordhaus, William D. 2008. A question of balance. Yale University Press: New Haven, CT.

The Royal Society. 2009. Geoengineering the climate: Science, governance and uncertainty. London. http://royalsociety.org/geoengineeringclimate/

Trenberth, Kevin E., John T. Fasullo and Jeffrey T. Kiehl. 2009. earth's global energy budget. Bulletin of the American Meteorological Society 90(3) 311-323.

In addition, two individuals wrote critiques of our work.

Seating at the round table is the same. Seated at the table in the foreground, from left to right, are Roger Pielke, Jr., Anne Smith, and Lee Lane (my co-author).

Here are some of DICE's more important equations:

.

$$F(t) = \eta \log_2 \frac{M_{AT}(t)}{M_{AT}(1750)} + F_{EX}(t) \qquad \eta = \frac{3.8\,\mathrm{Wm}^{-2}}{2xCO_2}$$

$$M_{AT}(t) = E(t-1) + \phi_{11} M_{AT}(t-1) + \phi_{21} M_{UP}(t-1)$$

↗

Fraction of carbon that stays in the atmosphere

$$T_{AT}(t) = T_{AT}(t-1) + \xi_1 \Big[F(t) - \xi_2 T_{AT}(t-1) - \xi_3 \big[T_{AT}(t-1) - T_{LO}(t-1) \big] \Big]$$

$$\xi_2 = \frac{\eta}{\Delta T_{2x}} = \frac{3.8\,\mathrm{Wm}^{-2} / 2xCO_2}{3^{\circ}\mathrm{C} / 2xCO_2} \approx 1.27 \frac{\mathrm{Wm}^{-2}}{^{\circ}\mathrm{C}}$$

$$\xi_2^{-1} \approx 0.80 \frac{^{\circ}\mathrm{C}}{\mathrm{Wm}^{-2}}$$

$$D(t) = \psi_1 T_{AT}(t) + \psi_2 T_{AT}(t)^2$$