

# Plan for the day

- 08:30 – 09:15 Overview of >25 years of HDGC, CDMC and CEDM – Granger Morgan
- 09:15 – 10:00 Uncertainty in energy efficiency, Part 1: technologies, strategies, behavior and policy – Inês Azevedo
- 10:00 – 10:30 Uncertainty in energy efficiency, Part 2: technologies, strategies, behavior and policy – Alex Davis
- 10:45 – 11:15 **Coffee break**
- 11:15 – 11:45 Decision support for implementing the EPA Clean Power Plan Proposed Rule – Jeff Anderson
- 11:45 – 12:30 Marginal emissions factors, health and climate change co-benefits and trade-offs - Inês Azevedo
- 12:30 – 13:30 **Lunch break**
- 13:30 – 13:55 Insights from twenty years of work on expert elicitation and projections – Granger Morgan
- 13:55 – 14:05 Transitioning to a low carbon economy, Part 1: Insights from the RenewElec Project – Granger Morgan
- 14:05 – 14:30 Transitioning to a low carbon economy, Part 2: Insights from ITC and BC's Climate Policy – Hadi Dowlatabadi
- 14:30 – 15:10 Strategies for supporting investment decisions about large energy infrastructure in the face of regulatory and other uncertainty – Dalia Patiño
- 15:10 – 15:40 **Coffee break**
- 15:40 – 16:00 Reflections on Research and Governance wrt Albedo Modification – Granger Morgan
- 16:00 – 16:45 Insights From Our Experience in Building and Using ICAMs – Hadi Dowlatabadi
- 17:45 – 17:00 Muddling through on climate policy: good, but not good enough to avoid the risk of dead ends – Granger Morgan
- 17:00 – 17:30 Discussion and round table on what investigators in CEDM might best work on in the next several years to be most useful to the IA and energy modeling communities.



**engineering and public policy**

Preparing Technical Leaders to Address Policy Issues  
that Involve Science and Technology.



# Reflections on Research and Governance wrt Albedo Modification

Prof. M. Granger Morgan  
Department of Engineering  
and Public Policy  
Carnegie Mellon University  
412-268-2672  
[granger.morgan@andrew.cmu.edu](mailto:granger.morgan@andrew.cmu.edu)

# Under HIGG we...

## ...we took a look at albedo modification.

Eos, Transactions, American Geophysical Union, Vol. 73, No. 27, July 7, 1992, Pages 289, and 292-293.

### A Serious Look at Geoengineering

David W. Keith and Hadi Dowlatabadi

Possible responses to the problem of anthropogenic climate change fall into three broad categories: abatement of human impacts by reducing the climate forcings, adaptation to reduce the impact of altered climate on human systems, and deliberate intervention in the climate system to change the effects of anthropogenic forcing—geoengineering. Recent reports from the National Academy of Sciences [1991] and the Office of Technology Assessment [1991] aimed to provide a comprehensive look at possible responses to climate change. While they included geoengineering options, they failed to consider them systematically. We present the beginnings of a more systematic analysis and urge a balanced research program on geoengineering.

We define geoengineering as actions taken with the primary goal of engineering (controlling by application of science) the climate system. Geoengineering is the deliberate manipulation of climate forcings intended to keep the climate in a desired state, in contrast to abatement, which reduces anthropogenic forcing.

Speculation about geoengineering dates to the beginning of the century when Arrhenius [1908] suggested that burning fossil fuels might help prevent the coming ice age. Some technical possibilities for geoengineering were summarized by Dyson and Marland [1979]. Since then, increased concern about climate change has generated more literature, but no systematic research program has emerged. For example, the OTA report has a cursory description of two geoengineering options with no contextual discussion. The NAS report contains a more substantial review, although it has significant technical omissions. Neither provides a basis other than cost for comparing the options nor includes a discussion of the relationship between geoengineering and abatement.

We do not advocate geoengineering, but we offer these justifications for a more systematic evaluation of geoengineering options.

• Geoengineering may be needed if climate change is worse than we expect. That is, geoengineering could serve as fallback technology—one that puts an upper bound

on the worst case, thereby allowing more confidence in pursuing other policy options. • It seems very unlikely that world greenhouse gas (GHG) emissions can be kept below ~40% of 1990 levels—a prerequisite for averting climate change in the long term [Houghton et al., 1990].

Doubt about the prospects for cooperative abatement of global GHG emissions is a pragmatic reason to consider geoengineering, whose implementation requires fewer cooperating actors than abatement. Thus, geoengineering fills a unique niche because of its potential to mitigate catastrophic climate change.

To act as a fallback strategy, geoengineering must be more certain of effect, faster to implement, or provide unlimited mitigation at fixed marginal cost. Our definition of "fallback strategy" is an extension of the term "backstop technology" used in energy systems analysis for a technology providing unlimited energy at fixed (usually high) marginal cost.

The existence of a fallback is critically

important, as it allows more confidence in choosing a moderate response strategy. Moderate responses are difficult to implement when catastrophic consequences are possible from weak anthropogenic climate forcing. Fallback strategies permit moderate responses to be adopted with the knowledge that should these prove inadequate, an alternative mitigation option is available. We examine a range of geoengineering techniques to gauge their suitability as fallback strategies.

#### Examples of Geoengineering Techniques

Geoengineering affects climate by altering global energy fluxes through one of two strategies, either by increasing the amount of outgoing infrared radiation through reduction of GHGs, or by decreasing the amount of absorbed solar radiation through an increase in albedo.

Three examples of the first strategy, which remove CO<sub>2</sub> from the atmosphere, are direct deep-ocean disposal, ocean-surface fertilization, or afforestation. For the second strategy, we discuss albedo modification by placing solar shields in Earth-orbit, or by increasing aerosol concentrations. Our five cases are chosen to survey geoengineering's wide range of risks and costs. With the exception of direct ocean disposal and afforestation, these schemes have the theoretical potential to mitigate the full effect of anthropo-

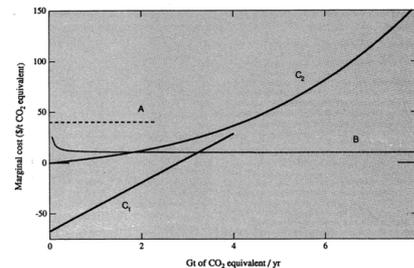


Fig. 1. Marginal cost of mitigation versus total mitigation for the United States. The lower axis is the total mitigation in Gt of CO<sub>2</sub> equivalent. The costs of geoengineering are given by two curves: A, CO<sub>2</sub> injection; and B, solar shields. Curves C<sub>1</sub> and C<sub>2</sub> represent a range of mitigation costs. CO<sub>2</sub> accounts for about half of the global-warming potential of U.S. emissions. Stabilizing GHG concentrations requires about a 60% emissions cut, for example, ~6 Gt CO<sub>2</sub> equivalent per year for the United States. The marginal cost of deep-ocean disposal of CO<sub>2</sub> (A) is taken from Golomb et al. [1989]. Its application is limited to the total amount of CO<sub>2</sub> currently released by centralized facilities. The solar shield costs (B) are assumed to be \$10/t with an initial capital cost of 10% of the full cost. The costs of abatement (C) are taken from the NAS report. The lower branch (C<sub>1</sub>) is from the "technical costing method" and was generated using a linear fit to the midpoint data in Figure 1.1.1 of the NAS report. The upper branch (C<sub>2</sub>) is from the "economic modeling method" (Figure Q.2) using a quadratic polynomial fit.

David W. Keith and Hadi Dowlatabadi, Department of Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, PA 15213-3890

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### GEOENGINEERING THE CLIMATE: History and Prospect<sup>1</sup>

David W. Keith

Department of Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, Pennsylvania 15213; e-mail: keith@cru.edu

**Key Words** climate change, weather modification, mitigation, earth systems engineering, integrated assessment, environmental history

■ **Abstract** Geoengineering is the intentional large-scale manipulation of the environment, particularly manipulation that is intended to reduce undesired anthropogenic climate change. The post-war rise of climate and weather modification and the history of U.S. assessments of the CO<sub>2</sub>-climate problem is reviewed. Proposals to engineer the climate are shown to be an integral element of this history. Climate engineering is reviewed with an emphasis on recent developments, including low-mass space-based scattering systems for altering the planetary albedo, simulation of the climate's response to albedo modification, and new findings on iron fertilization in oceanic ecosystems. There is a continuum of human responses to the climate problem that vary in resemblance to hard geoengineering schemes such as space-based mirrors. The distinction between geoengineering and mitigation is therefore fuzzy. A definition is advanced that clarifies the distinction between geoengineering and industrial carbon management. Assessment of geoengineering is reviewed under various framings including economics, risk, politics, and environmental ethics. Finally, arguments are presented for the importance of explicit debate about the implications of countervailing measures such as geoengineering.

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<sup>1</sup> Acronyms used in text: COM, Cost of Mitigation; FAR/SAR/TAR, First/Second/Third Assessment Report of the IPCC; FCCC, Framework Convention on Climate Change; ICM, Industrial Carbon Management; IPCC, Inter-Governmental Panel on Climate Change; MIT, Massachusetts Institute of Technology; NAS, National Academy of Science; NASA, National Aeronautics and Space Administration; NSF, National Science Foundation; WG, Working Group.

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245

And then, because it appeared to be so cheap, imperfect, and tempting, we decided to focus our work on abatement & adaptation

# But as time went on..

...and nobody was getting serious about abatement, we grew concerned that the diplomatic community was almost completely unaware of SRM. In 2008 we organized a workshop at the Council on Foreign Relations in Washington, DC.



The workshop led to a paper that appeared in the 2009 March/April issue of *Foreign Affairs*.



## FOREIGN AFFAIRS

### The Geoengineering Option

A Last Resort Against Global Warming?

*David G. Victor, M. Granger Morgan, Jay Apt,  
John Steinbruner, and Katharine Ricke*

EACH YEAR, the effects of climate change are coming into sharper focus. Barely a month goes by without some fresh bad news: ice sheets and glaciers are melting faster than expected, sea levels are rising more rapidly than ever in recorded history, plants are blooming earlier in the spring, water supplies and habitats are in danger, birds are being forced to find new migratory patterns.

The odds that the global climate will reach a dangerous tipping point are increasing. Over the course of the twenty-first century, key ocean currents, such as the Gulf Stream, could shift radically, and thawing permafrost could release huge amounts of additional green-

Participants in the 2008 workshop were all from North America.

To extend the conversation to a more international group, we ran a second workshop in April 2009 in Lisbon, Portugal.

# The Lisbon Workshop...

...was hosted by the Ministry of Science, Technology and Higher Education of the Government of Portugal. The two-day workshop was held at the facilities of the Gulbenkian Foundation.

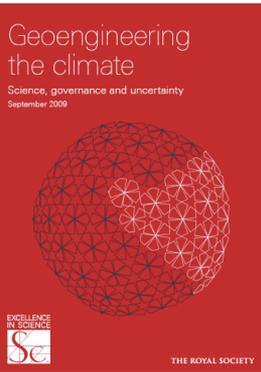


Co-sponsors included: IRGC, CMU-CDMC, U Calgary. Participants came from N. America, EU, China, Russia, and India.



Sources:  
Gulbenkian & Qian Yi

# Some subsequent events...



Sept. 2009: The governance section of the Royal Society's report on Geoengineering

March 2010: The discussion of risk governance at the Asilomar conference on geoengineering



Rickey et al 2010

Nov 2010: IRGC opinion piece on governance

Jan 2010

Jan 2011

June 2009: U.S. NRC workshop on geoengineering



March 2010: Testimony to a joint session of the U.S. House Science Committee and the Science Committee of the UK Parliament

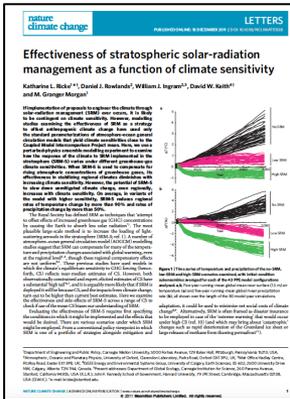
August 2010: First multi-university summer study program for graduate students on geoengineering held at Heidelberg.



Geoengineering Options to Respond to Climate Change: Steps to Establish a Research Agenda

March 2010: Evening briefing to CFR





# SRM...(Cont.)



Ricky et al. 2011

October 2011: BPC report on U.S. research

April 2012: CMU workshop on managing knowledge



May 2012: DC CIT event

March 2011: SRMGI Kavli Center



June 2011: Lima IPCC expert meeting on geoengineering



Jan 2011

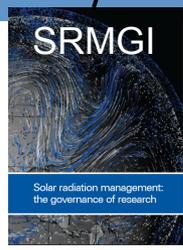
Jan 2012

January 2011: La Jolla IGBP workshop on ecosystem impacts of geoengineering



Paper now in press at *AMBIO*

August 2011: Second multi-university summer study program for graduate students and other young investigators held at Banff





**While there is...**  
 ...a great deal of uncertainty about stratospheric SRM, in 2010 David Keith, Ted Parson and I argued in *Nature* that three things are pretty certain:

**"Solar-radiation management has three essential characteristics: it is cheap, fast and imperfect."**

## OPINION

### Research on global sun block needed now

Geoengineering studies of solar-radiation management should begin urgently, argue **David W. Keith, Edward Parson and M. Granger Morgan** — before a rogue state takes action.

The idea of deliberately manipulating Earth's energy balance to offset human-driven climate change strikes many as dangerous hubris. Solar-radiation management (SRM), a proposed form of geoengineering, aims to reduce Earth's absorption of solar energy by, for example, adding light-scattering aerosols to the upper atmosphere or increasing the lifetime and reflectivity of low-altitude clouds. Many scientists have argued against research on SRM, saying that developing the capability to perform such tasks will reduce the political will to lower greenhouse-gas emissions. We believe that the risks of not doing research outweigh the risks of doing it. Solar-radiation management may be the only human response that can fend off rapid and high-consequence climate impacts. Furthermore, the potential of unilateral deployment of SRM poses environmental and geopolitical risks which can best be managed by developing widely shared knowledge, risk assessment and norms of governance.

SRM has three essential characteristics: it is cheap, fast and imperfect. Long-established estimates show that SRM could offset this century's global-average temperature rise more than 100 times more cheaply than achieving the same cooling by emission cuts. A few grams of sulphate particles in the stratosphere could offset the radiative forcing of a tonne of atmospheric carbon dioxide. At about US\$1,000 a tonne for aerosol delivery, that adds up to just billions of dollars per year. This low price tag is attractive, but it raises the risks of single groups acting alone and of facile cheerleading that promotes excessive reliance on SRM.

#### High leverage

SRM could alter the global climate within months — as suggested by the 1991 eruption of Mount Pinatubo, which cooled the globe about 0.5 °C in less than a year by injecting sulphate into the stratosphere. In contrast, because of the carbon cycle's inertia, even a massive programme of emission cuts or CO<sub>2</sub> removal will take many decades to slow global warming discernibly. SRM's speed provides strong grounds to pursue it as a hedge against the real

but unlikely possibility that climate is much more sensitive than expected to rising greenhouse gases, or against extreme impacts such as major ice-sheet collapse. Because of the high level of uncertainty, even cutting emissions by an order of magnitude cannot ensure climate effects are held at acceptable levels.

These qualities make SRM a promising tool against climate change. But it is vital to remember that a world cooled by managing sunlight will not be the same as one cooled by lowering emissions. An SRM-cooled world would have less precipitation and less evaporation. Some areas would be more protected from temperature changes, creating local 'winners' and 'losers'. SRM could conceivably weaken monsoon rains and winds. It would not combat ocean acidification or other CO<sub>2</sub>-driven ecosystem changes, and would introduce other environmental risks such as delaying the recovery of the ozone hole. Initial studies<sup>1</sup> suggest that known risks are small, but unanticipated risks remain a serious underlying concern. If the world relies solely on SRM to limit warming, these problems will eventually pose risks as large as those from uncontrolled emissions.

To posit a binary choice between SRM and cutting emissions creates a false and dangerous dichotomy — like previous suggestions of a binary choice between mitigation and adaptation. A prudent climate strategy requires adaptation and deep cuts in global emissions. We must develop the capability to do SRM in a manner that complements such cuts, while managing the associated environmental and political risks.

The path through this thicket involves two activities that must both begin immediately: a carefully designed, incremental, transparent and international programme of SRM research; and linked activities to create norms and understanding for international governance of SRM.

Research so far has largely consisted of a handful of climate-model studies, using very simple parameterization of aerosol microphysics. More complex models should be developed, and linked to global climate models. Field tests will be needed, such as generating and tracking stratospheric aerosols to block sunlight, and dispersing sea-salt aerosols to

#### SUMMARY

- Field testing is required to understand the risks of solar radiation management (SRM)
- Linked activities must create norms and understanding for international governance of SRM
- If SRM is unworkable, the sooner we know, the less moral hazard it poses

brighten marine clouds. Such tests can be small: releasing tonnes, not megatonnes, of material.

#### Dearth of data

Decades of upper atmosphere research — such as that done to investigate the effect of supersonic passenger aircraft — has produced a mass of relevant science. But, except for a recent, small Russian test, there have been no field tests of SRM. Until now, there has been essentially no government research funding available for SRM anywhere in the world; although a few programmes for geoengineering have begun in the past few months. The environmental hazards of SRM cannot be assessed without knowing the specific techniques that might be used, and it is impossible to identify and develop techniques without field testing.

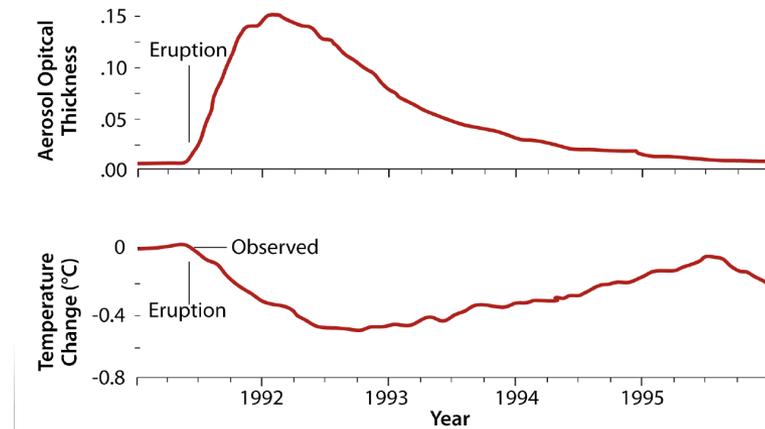
It is often assumed, for example, that a suitable distribution of stratospheric sulphate aerosols can be produced by releasing sulphur dioxide in the stratosphere. In fact, new simulations<sup>2</sup> of aerosol physics suggest that the resultant aerosol size distribution would be skewed to large particles that are relatively ineffective. Several aerosol compositions and delivery methods may offer a way around this problem, but choosing between them and quantifying their environmental effects will require in-situ testing. NASA's ER-2 high-altitude research plane might be used to release aerosols into the stratosphere, and fly through the plume to assess the effects. Such tests take years to plan and cost millions of dollars.

It would be reckless to conduct the first large-scale SRM tests in an emergency. Experiments should expand gradually to scales big enough to produce barely detectable climate effects and reveal unexpected problems, yet small enough (of the order of hundreds of kilotonnes) to limit risks. The ability to detect the climatic response

# Cheap, fast and imperfect

**Cheap:** 0.0002% to 0.2% of world GDP/year  
*versus* 0.4% to 5.5% of world GDP/year

**Fast:** A few months.



**Imperfect:** A long list (spelled out in back-up slides).

# Some bottom lines:

- Given the slow pace at which the world is making progress on reducing emissions we need to start serious research *now* on strategies for stratospheric albedo modification, this because.
  - Someone might engage unilaterally and we need to know the risks
  - In an emergency the world might need to do a bit.
- Research will have to include some small scale atmospheric studies that have negligible impact.
- U.S. federal agencies should take the lead on developing a model “code of research governance best practice.” The U.S. should then press other nations to adopt similar rules.

# We spelled out these arguments...

...in a paper in *Issues in Science and Technology*.

M. GRANGER MORGAN  
ROBERT R. NORDHAUS  
PAUL GOTTLIEB

## Needed: Research Guidelines for Solar Radiation Management

*As this approach to geoengineering gains attention, a coordinated plan for research will make it possible to understand how it might work and what dangers it could present.*

**E**missions of carbon dioxide (CO<sub>2</sub>) and other greenhouse gases (GHGs) continue to rise. The effects of climate change are becoming ever more apparent. Yet prospects for reducing global emissions of CO<sub>2</sub> by an order of magnitude, as would be needed to reduce threats of climate change, seem more remote than ever.

When emissions of air pollutants, such as sulfur dioxide and oxides of nitrogen, are reduced, improvements occur in a matter of days or weeks, because the gases quickly disappear from the atmosphere. This is not true for GHGs. Once emitted, they remain in the atmosphere for many decades or centuries. As a result, to stabilize atmospheric concentrations, emissions must be dramatically reduced. Further, there is inertia in the earth-ocean system, so the full effects of the emissions that have already occurred have yet to be felt. If the planet is to avoid serious climate change and its largely adverse consequences, global emissions of

GHGs will have to fall by 80 to 90% over the next few decades.

Because the world has already lost so much time, and because it does not appear that serious efforts will be made to reduce emissions in the major economies any time soon, interest has been growing in the possibility that warming might be offset by engineering the planet: a concept called geoengineering. The term solar radiation management (SRM) is used to refer to a number of strategies that might be used to increase the fraction of sunlight reflected back into space by just a couple of percentage points in order to offset the temperature increase caused by rising atmospheric concentrations of CO<sub>2</sub> and other GHGs. Of these strategies, the one that appears to be most affordable and most capable of being quickly implemented involves injecting small reflective particles into the stratosphere.

There is nothing theoretical about whether SRM could cool the planet. Every time a large volcano explodes and injects tons of material into the stratosphere, Earth's average temperature drops. When Mount Pinatubo exploded in

# Code of research governance best practice

In parallel with, or even before, developing a full research agenda, there is a pressing need to develop a code of best SRM research practices.

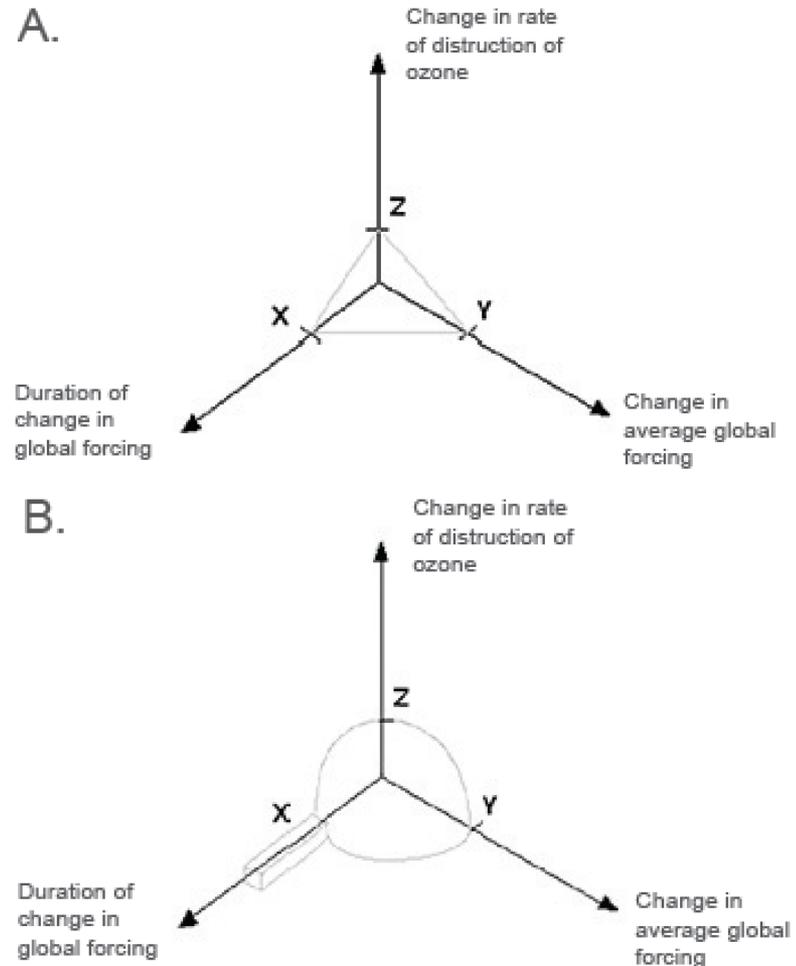
This code will need three components.

1. Guidelines to provide open access to SRM knowledge by making research results available to decision makers and the public.
2. Delineation of categories of field experiments that are unlikely to have adverse impacts on health safety, or the environment (that is, experiments conducted within an agreed-upon “allowed zone” of experimental parameters and expected effects on the stratosphere.)
3. agreement that no field research will be conducted outside the allowed zone before a clear national and international governance framework has been developed.

# Code of research governance best practice

Code needs to:

- define what counts as SRM and what constitutes SRM research;
- Define activities that should be subject to a requirement of prior notification;
- Spell out what is covered by open access;
- Define an “allowed zone.”



We need to be *very* careful...

We need to be *very* careful...  
...we've only got one planet.



End

Backup slides on  
cheap, fast and imperfect

# 1. Cheap

# The cost of GHG abatement

Today, the world is emitting about  $50 \times 10^9$  tonnes per year  $\text{CO}_2\text{-eq}$   
(of which about  $30 \times 10^9$  is  $\text{CO}_2$ )

The IPCC 4<sup>th</sup> assessment says:

"Modelling studies show that global carbon prices rising to US\$20-80/  
 $\text{tCO}_2\text{-eq}$  by 2030 are consistent with stabilisation at around 550ppm  $\text{CO}_2\text{-eq}$   
by 2100. For the same stabilisation level, induced technological change  
may lower these price ranges to US\$5-65/ $\text{tCO}_2\text{-eq}$  in 2030."

$$(50 \times 10^9 \text{ tCO}_2\text{-eq})(5 \text{ to } 65 \$/\text{tCO}_2\text{-eq}) = 250 \text{ to } 3300 \times 10^9 \text{ \$/year}$$

The size of the global economy is of the order of  $\$60 \times 10^{12}$

$$\frac{0.25 \text{ to } 3.3 \times 10^{12} \text{ \$/year}}{60 \times 10^{12} \text{ \$/year}} \longrightarrow 0.4\% \text{ to } 5.5\% \text{ of world GDP/year}$$

...a few million tonnes per year would be sufficient [to offset warming]... anticipated...over the next half century...[this could be done] for less than \$8B per year.

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IOP Publishing

Environ. Res. Lett. 7 (2012) 034019 (8pp)

ENVIRONMENTAL RESEARCH LETTERS

doi:10.1088/1748-9326/7/3/034019

# Cost analysis of stratospheric albedo modification delivery systems

Justin McClellan<sup>1</sup>, David W Keith<sup>2</sup> and Jay Apt<sup>3</sup>

<sup>1</sup> Aurora Flight Science Corporation, 4 Cambridge Center, Suite 11, Cambridge, MA 02142, USA

<sup>2</sup> School of Engineering and Applied Sciences and Kennedy School, Harvard University, Pierce Hall, 29 Oxford Street, Cambridge, MA 02138, USA

<sup>3</sup> Tepper School of Business and Department of Engineering and Public Policy, Carnegie Mellon University, Posner Hall 254, Pittsburgh, PA 15213, USA

E-mail: apt@cmu.edu

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## Abstract

We perform engineering cost analyses of systems capable of delivering 1–5 million metric tonnes (Mt) of albedo modification material to altitudes of 18–30 km. The goal is to compare a range of delivery systems evaluated on a consistent cost basis. Cost estimates are developed with statistical cost estimating relationships based on historical costs of aerospace development programs and operations concepts using labor rates appropriate to the operations. We evaluate existing aircraft cost of acquisition and operations, perform in-depth new aircraft and airship design studies and cost analyses, and survey rockets, guns, and suspended gas and slurry pipes, comparing their costs to those of aircraft and airships. Annual costs for delivery systems based on new aircraft designs are estimated to be \$1–3B to deliver 1 Mt to 20–30 km or \$2–8B to deliver 5 Mt to the same altitude range. Costs for hybrid airships may be competitive, but their large surface area complicates operations in high altitude wind shear, and development costs are more uncertain than those for airplanes. Pipes suspended by floating platforms provide low recurring costs to pump a liquid or gas to altitudes as high as ~20 km, but the research, development, testing and evaluation costs of these systems are high and carry a large uncertainty; the pipe system's high operating pressures and tensile strength requirements bring the feasibility of this system into question. The costs for rockets and guns are significantly higher than those for other systems. We conclude that (a) the basic technological capability to deliver material to the stratosphere at million tonne per year rates exists today, (b) based on prior literature, a few million tonnes per year would be sufficient to alter radiative forcing by an amount roughly 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 \$8B per year. We do not address here the science of aerosols in the stratosphere, nor issues of risk, effectiveness or governance that will add to the costs of solar geoengineering.

**Keywords:** geoengineering, albedo modification, solar radiation management, high-altitude aircraft

Online supplementary data available from [stacks.iop.org/ERL/7/034019/mmedia](http://stacks.iop.org/ERL/7/034019/mmedia)

# The cost of geoengineering

A National Research Council 1992 report estimated the undiscounted annual costs for a 40-year project to be \$100-billion.

Teller, Wood and Hyde have suggested that well designed systems might reduce this cost to as little as a few hundred million dollars per year.

If we take cost to be between \$100-million and \$100-billion per year

$$\frac{0.1-100 \times 10^9 \text{ \$/year}}{50 \times 10^{12} \text{ \$/year}} \longrightarrow 0.0002\% \text{ to } 0.2\% \text{ of world GDP/year}$$

# Bottom line on cost

It is probably safe to assume that the direct monetary cost of geoengineering would be *at least* 100 times less than the cost of a full program of GHG abatement...

*...and perhaps even cheaper than that.*

# 2. Fast

# Experience with...

...large volcanic explosions make it clear that cooling can be very rapid.

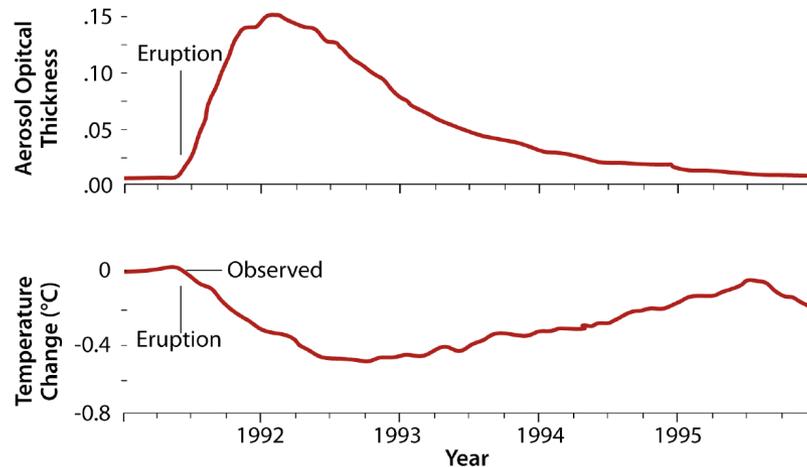
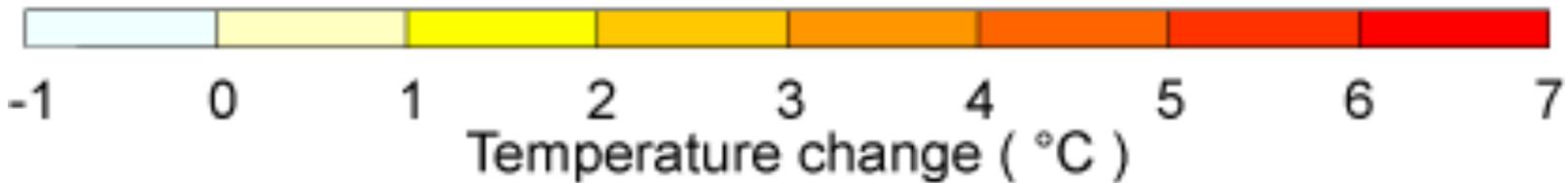
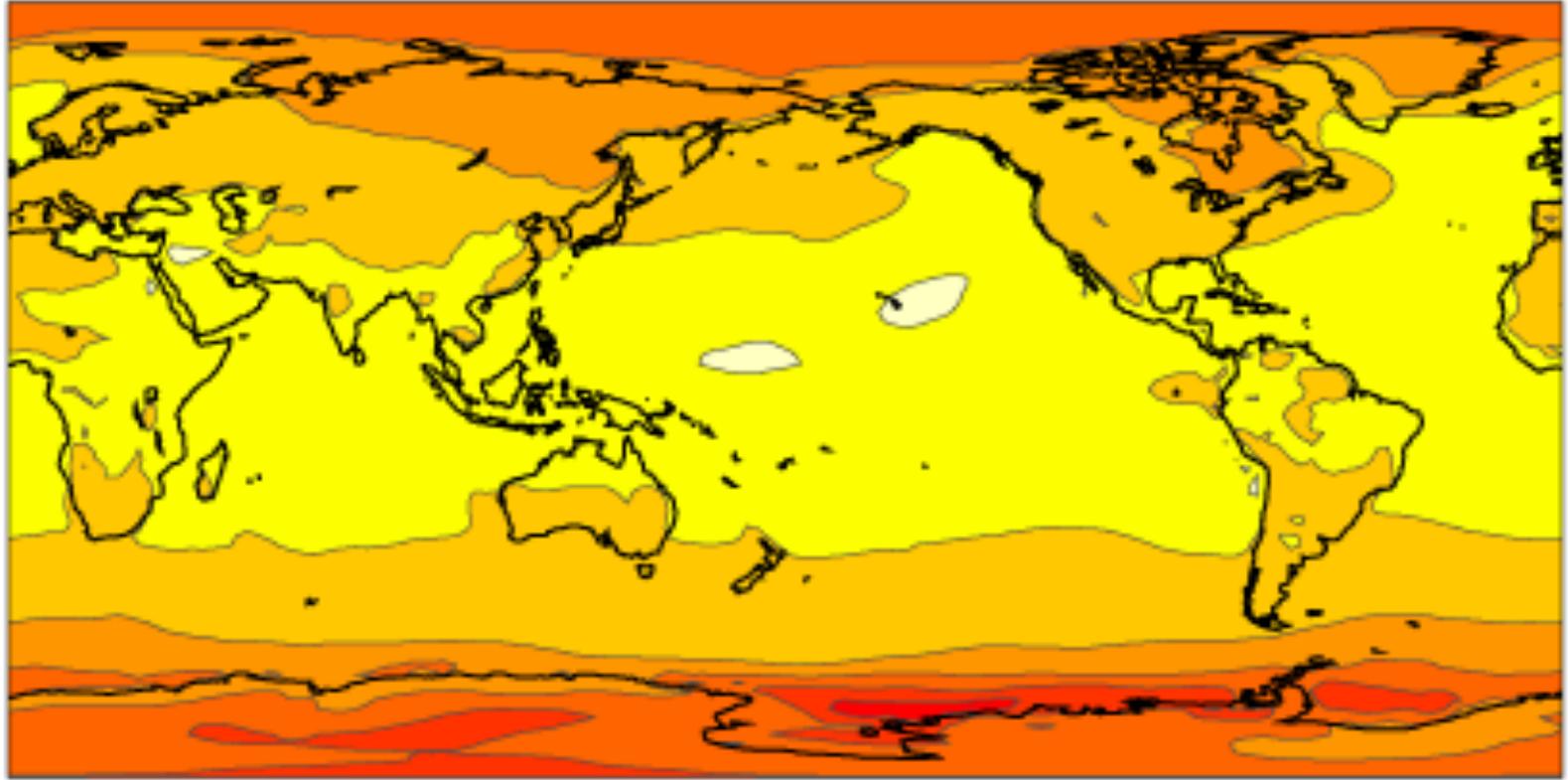


Figure source: NASA and IPCC.  
Source: Novim report, 2009, p. 14

# Temperature effects of doubled CO<sub>2</sub>

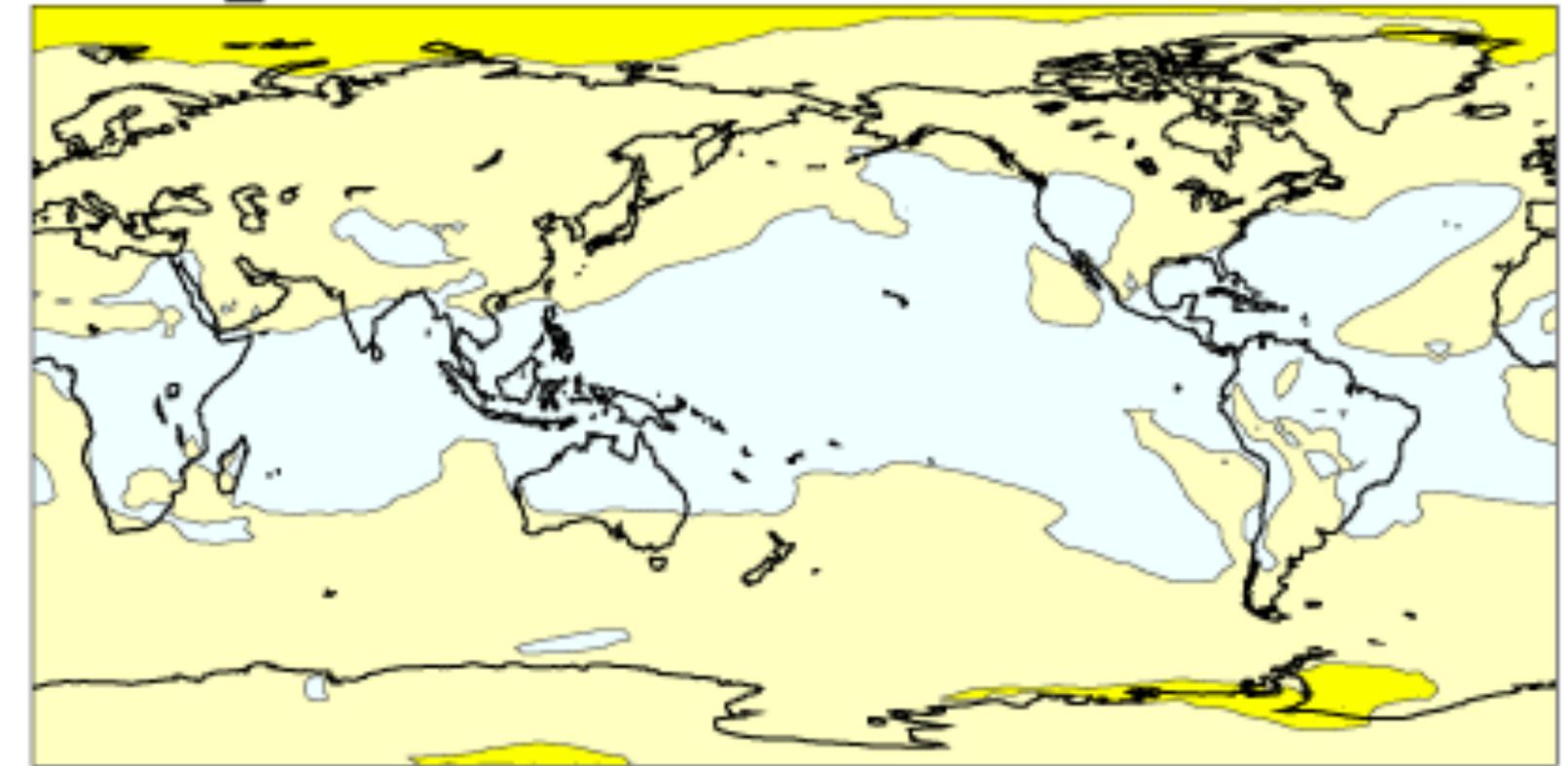
2xCO<sub>2</sub>



# Temperature effects of doubled CO<sub>2</sub>

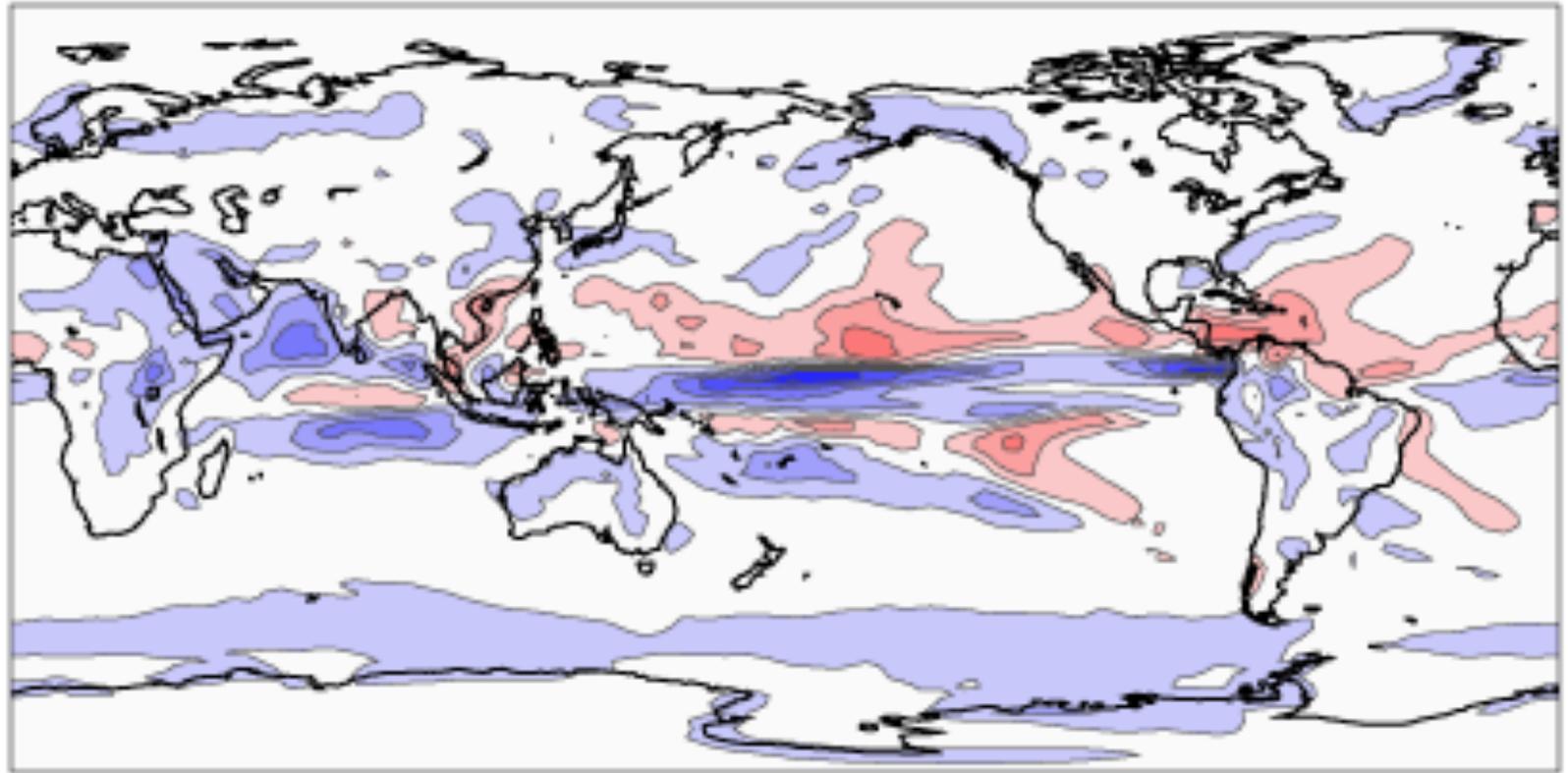
with a uniform deflection of 1.84% of sunlight

Global\_1.84



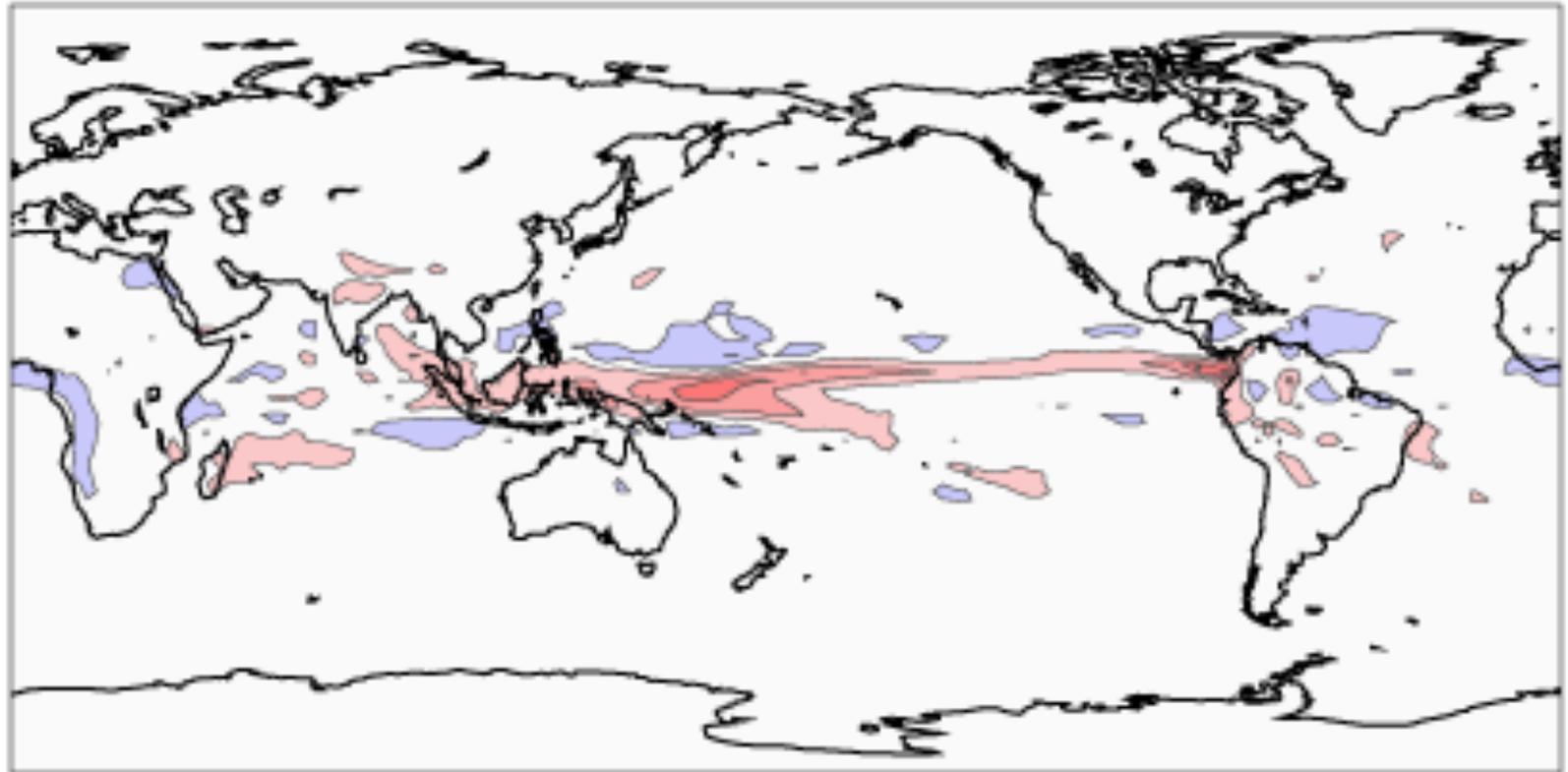
# Precipitation effects of doubled CO<sub>2</sub>

2xCO<sub>2</sub>



# Temperature effects of doubled CO<sub>2</sub> with a uniform deflection of 1.84% of sunlight

Global\_1.84



That handles  
cheap and fast

Now let's consider imperfect

# If we change albedo a little...

...to cool the planet, what else might happen?

Possibilities include:

- Impacts will not be uniform. Some places will change more than others (but all probably closer to present climate than a very high CO<sub>2</sub> world).
- Precipitation patterns will shift (of course, that is also happening under climate change).
- Changes in terrestrial ecosystems due to higher CO<sub>2</sub>, change in precipitation.
- Continued and growing impacts on the oceans as they take up more and more CO<sub>2</sub>.
- Particles in the stratosphere can provide reactive surfaces that might contribute to the destruction of the ozone layer.

# For more...

...on the policy and risk governance issues in SRM go to "publications" at:

[www.IRGC.org](http://www.IRGC.org)



An Opinion Piece for IRGC

**Cooling the Earth Through  
Solar Radiation Management:**

**The need for research and an  
approach to its governance**

M. Granger Morgan  
Katharine Ricke  
Department of Engineering and Public Policy  
Carnegie Mellon University

