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Geoengineering the Climate

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Imperial College London

acknowledgements: Royal Society Geoengineering Panel
Markus Quante, Helmholtz-Zentrum Geesthacht

Geoengineering

Tempting to dismiss/ignore – but no longer possible.

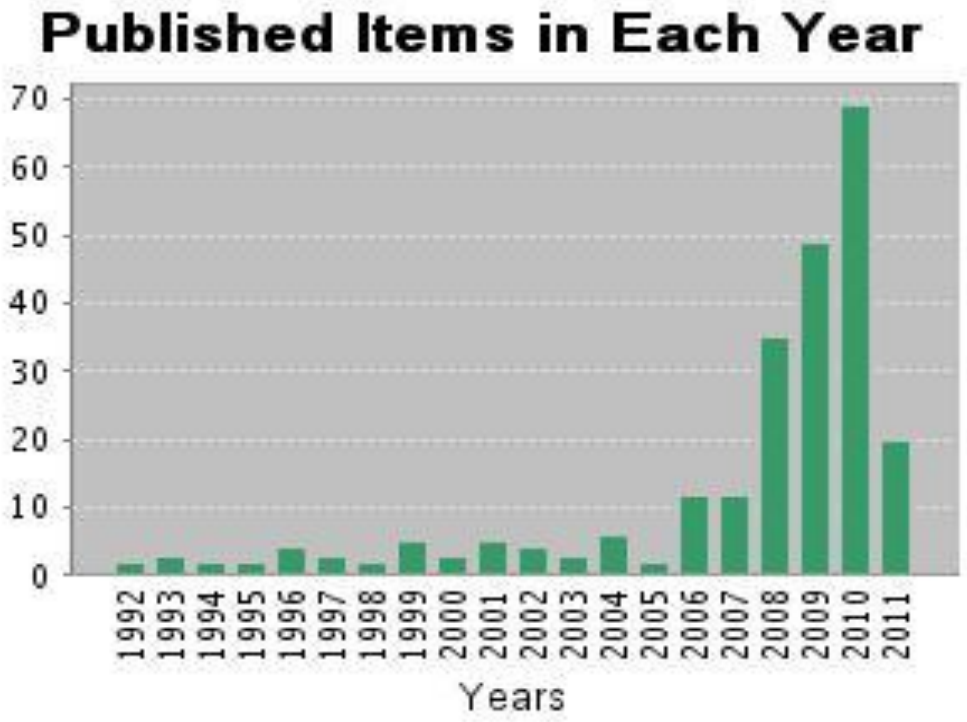
On the agenda for governments, industry, IPCC.

Needs critical scientific assessment.

Ethics ? Governance ?

Web of Science as of 18 May 2011

papers referring to geoengineering



Geoengineering in IPCC AR5 2014

CHAPTER OUTLINE OF THE WORKING GROUP I CONTRIBUTION TO THE IPCC FIFTH ASSESSMENT REPORT (AR5)

Revised version of WG-I: 11th /Doc.2 adopted by the Eleventh Session of Working Group I

Chapter 6: Carbon and Other Biogeochemical Cycles

Executive Summary

- Past changes in CO_2, CH_4, N_2O and biogeochemical cycles
- Recent trends in global and regional sources, sinks and inventories, including land use change
- Processes and understanding of changes, including ocean acidification
- Interactions between the carbon and other biogeochemical cycles, including the nitrogen cycle
- Projections of changes in carbon and other biogeochemical cycles
- Greenhouse gas stabilisation
- Carbon cycle – climate feedbacks and irreversibility
- → Geoengineering involving the carbon cycle

Frequently Asked Questions

Chapter 7: Clouds and Aerosols

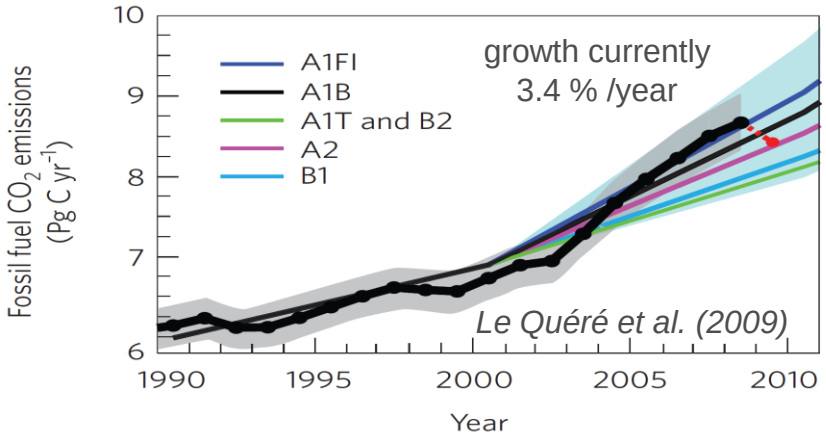
Executive Summary

- Observations of clouds and their representation in models
- Coupling of clouds, water vapour, precipitation and the large-scale circulation
- Cloud and water vapour feedbacks and their effects on climate sensitivity
- Observations of aerosols and their representation in models
- Aerosol types including black carbon: chemistry, sources, sinks and distribution
- Direct and indirect aerosol forcing and effects, including contrails and cosmic rays
- Aerosol-cloud-precipitation interactions
- → Geoengineering involving clouds and aerosols

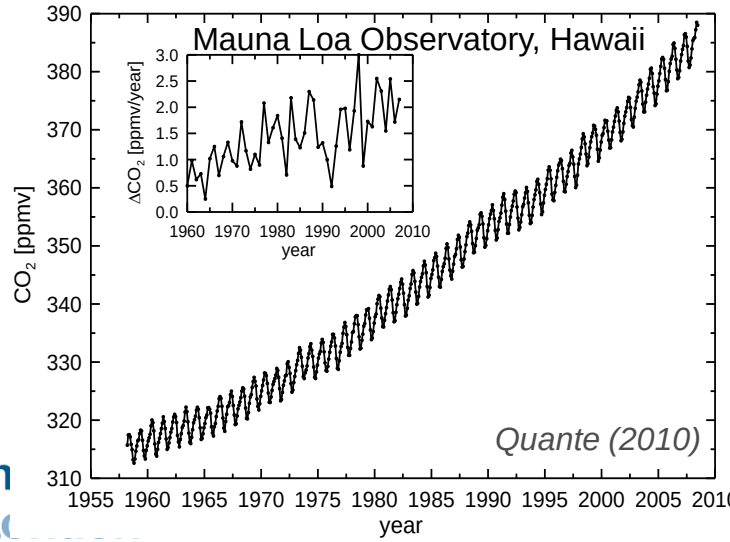
Frequently Asked Questions

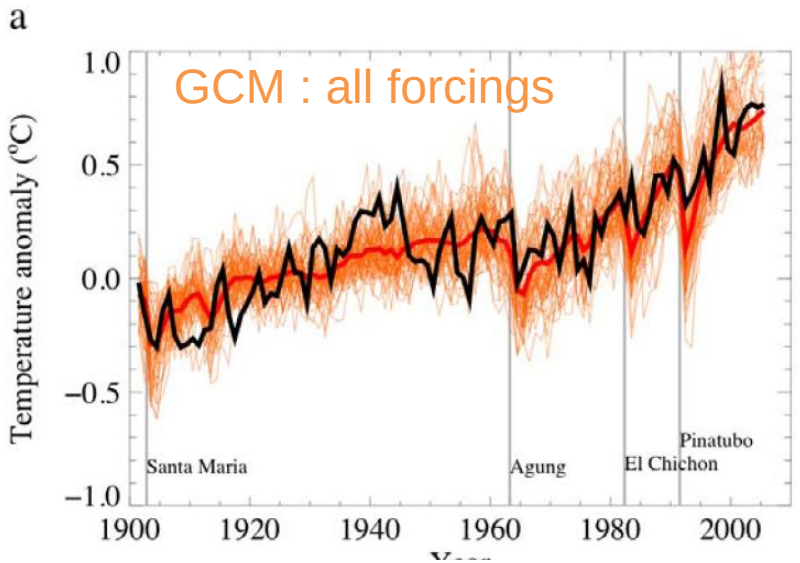
CO_2 and Attribution of causes to climate change

CO_2 emissions

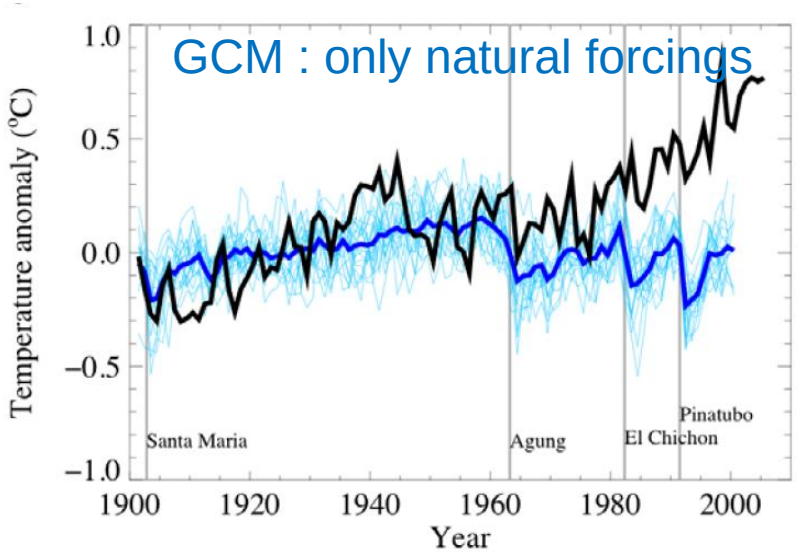


CO_2 concentration

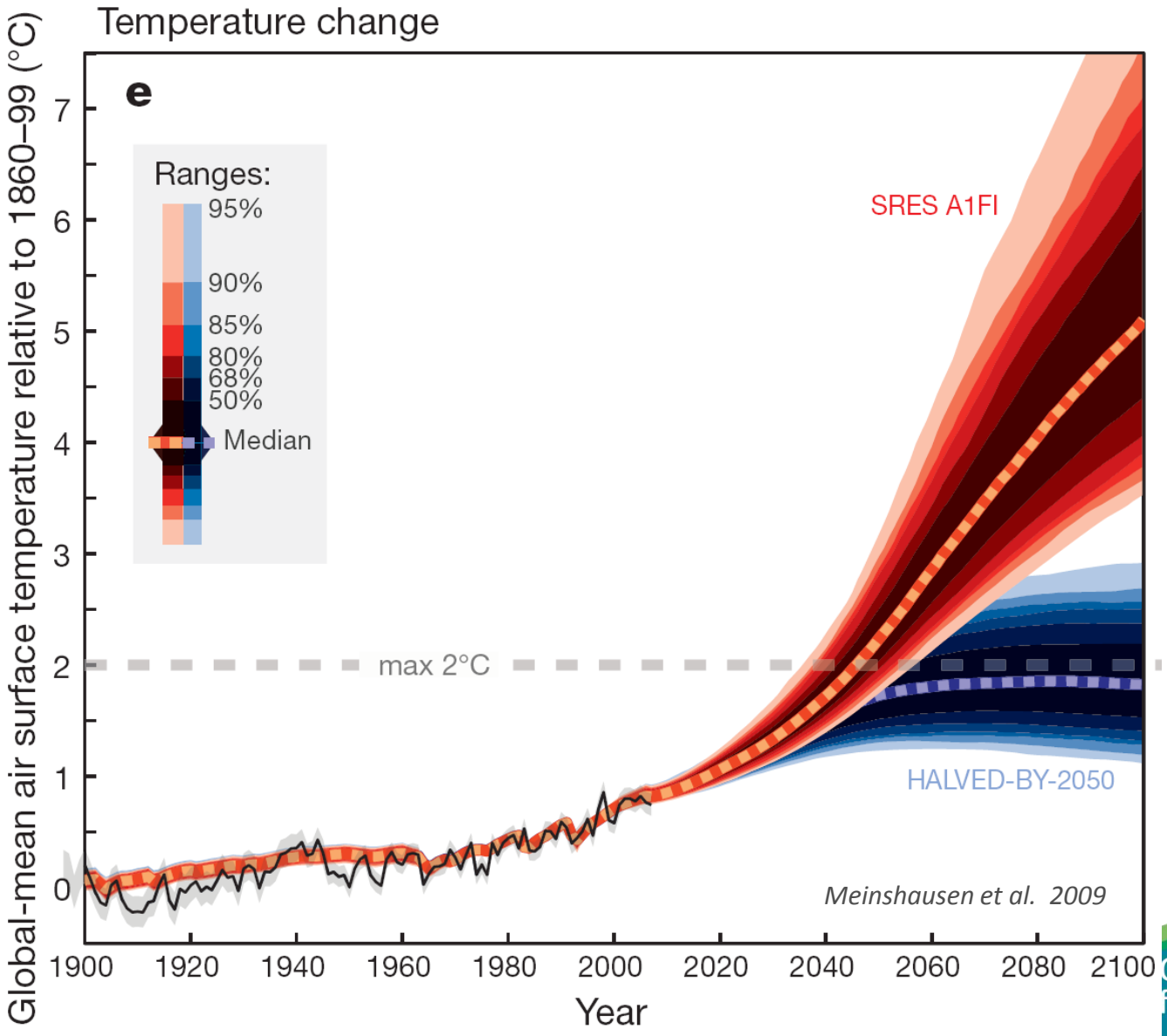




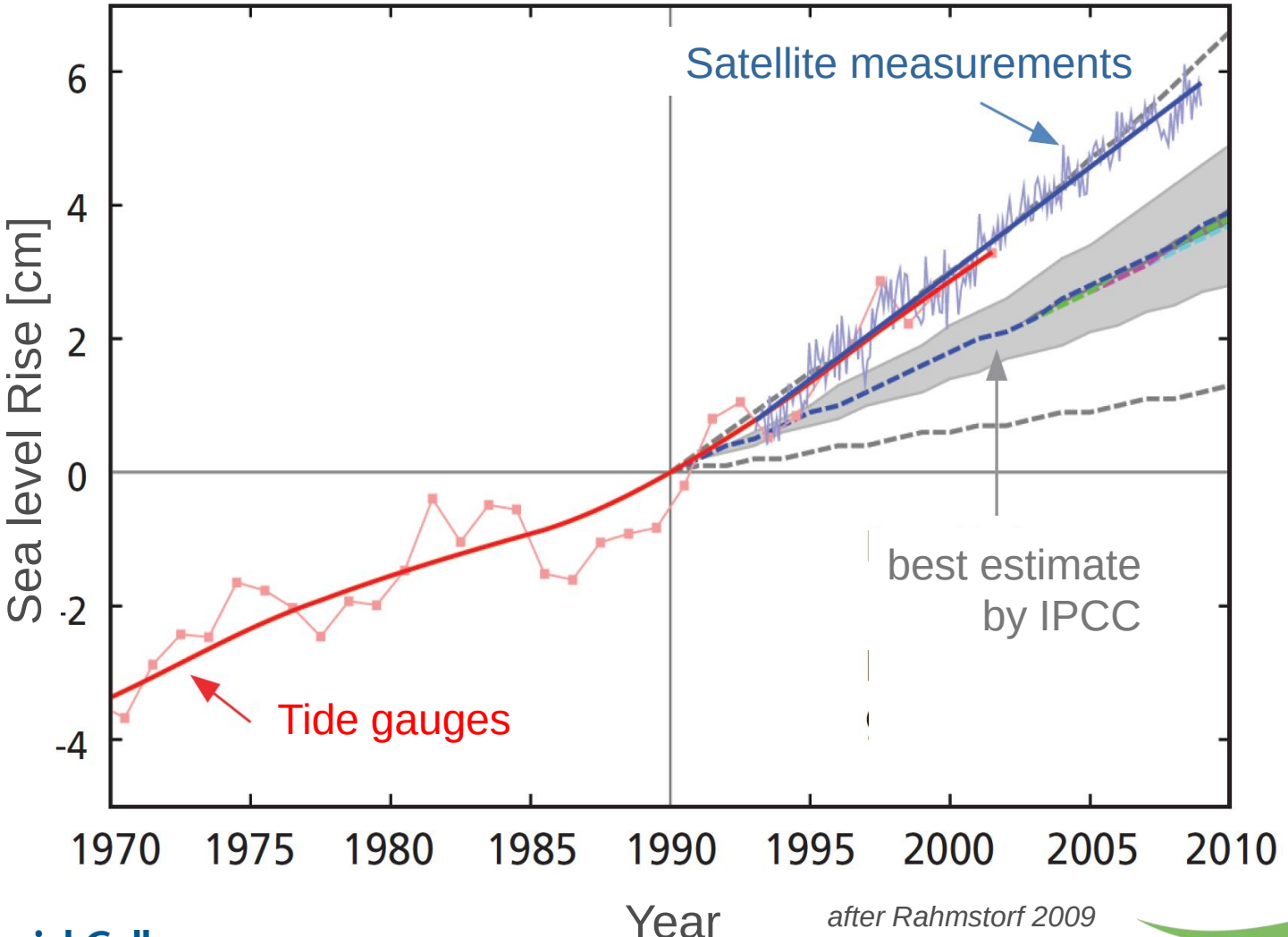
Global temperature record



Future?

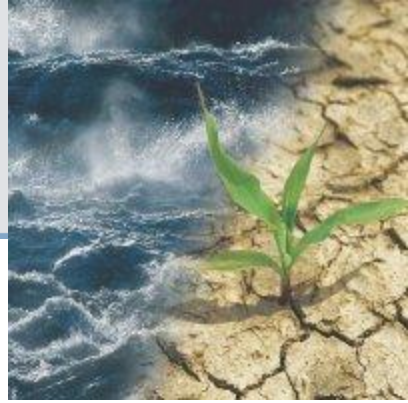

Temperature change
e
Ranges:
95%
90%
85%
80%
68%
50%
Median
SRES A1FI
max 2°C
HALVED-BY-2050
Meinshausen et al. 2009
Global-mean air surface temperature relative to 1860–99 (°C)
0
1
2
3
4
5
6
7
1900
1920
1940
1960
1980
2000
2020
2040
2060
2080
2100
Year

Sea level rise



after Rahmstorf 2009

Options?



Mitigation

GHG emission reduction

energy efficiency, low carbon energy, sufficiency

(but “free-rider” problem : talk globally – postpone nationally)

Adaptation

infrastructure / dikes, reservoirs

change of agricultural habits

resettlement

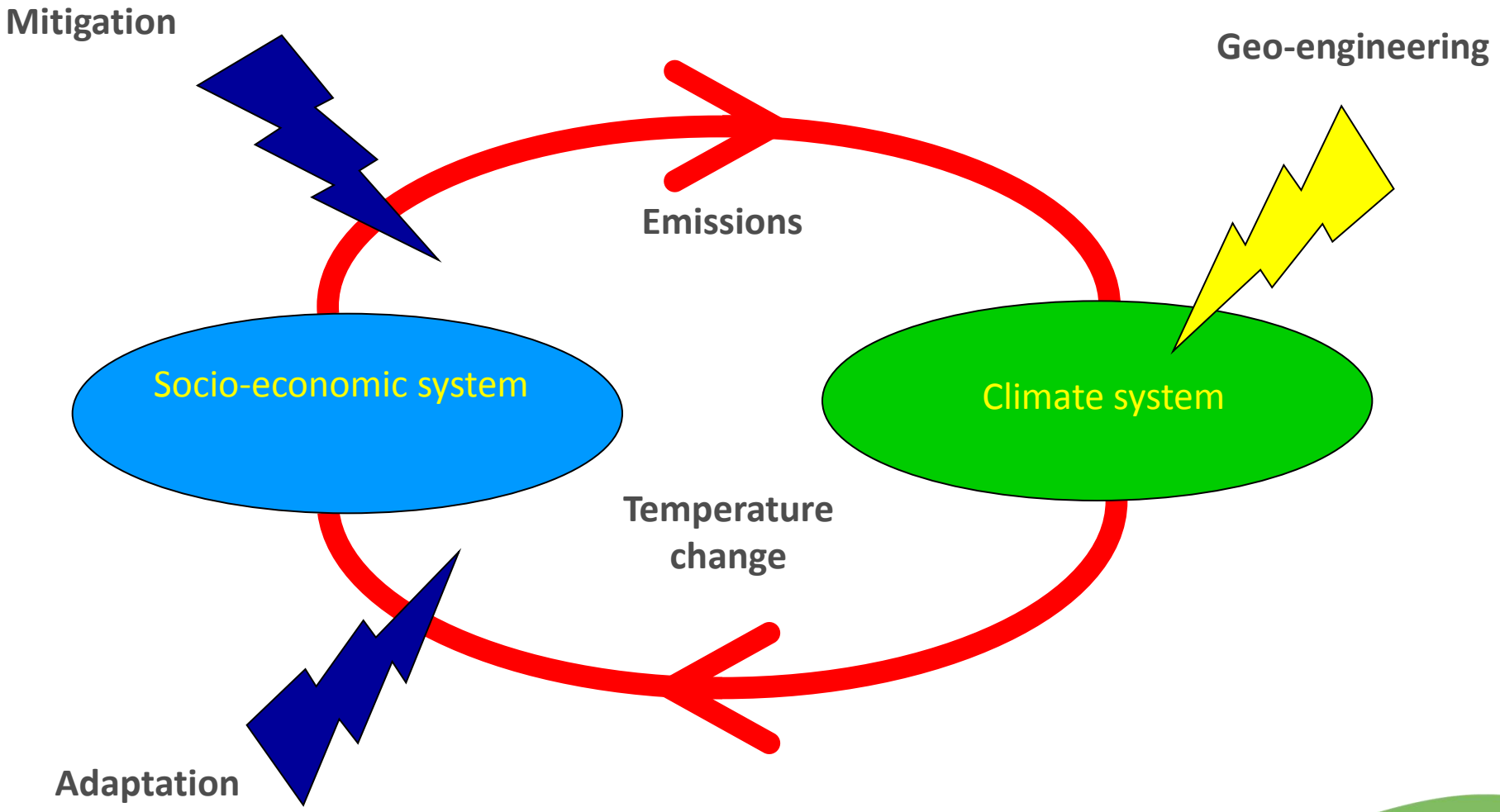
(inequitable)

Manipulation

geoengineering

(ace up the sleeve? emergency brake ?)

Climate problem loop



Mitigation post-Copenhagen and Cancun ??

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SGR 21 May 2011

Grantham Institute for Climate Change

Some adaptation may be necessary …

© Bill Hare

Geoengineering

Perhaps

- **the** solution
- an emergency break
- a time-winning option

Or

- the devil's answer

?

Definition

Term coined in a paper by Marchetti (1977) but still has no 'absolute' definition.

Geoengineering is intentional large-scale manipulation of the environment.

Keith, D. W. , Annu. Rev. Energy Environ. (2000).

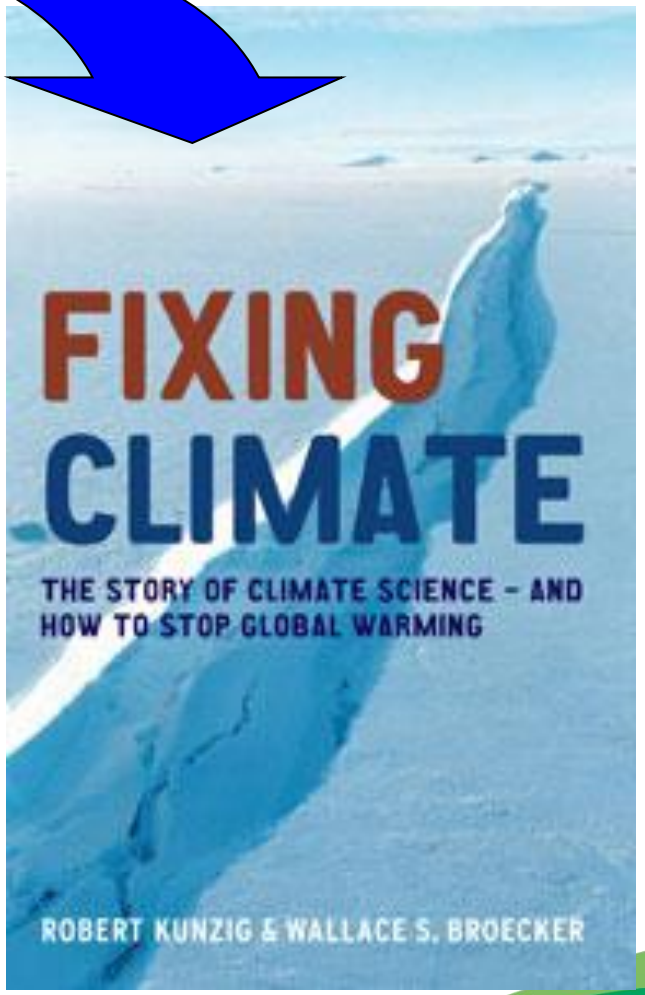
Keith adds: Scale and intent play a central roles in the definition. Large-scale: continental to global.

Geoengineering is purposeful action intended to manipulate the environment on a very large scale - especially global-scale. Geoengineering is, presumably, undertaken to reverse or reduce impacts of human actions.

Robert A. Frosch, Physics Today (2009)

Weather modification proposals are not new

The Technocrat *Collier's (1954)*



Simon & Schuster (2008)

Precursors to current ideas of geoengineering

• 1945: John von Neumann and other leading scientists meet at Princeton and agreed that **modifying weather** deliberately might be possible (motivation was "next great war")

• 1958: US Congress funded expanded **rainmaking** research (Irving Langmuir, GE)

• Cold War: U.S. military agencies devoted significant funds to research on what came to be called **"climatological warfare"**
- one aim was to make the Arctic Ocean navigable
- extensive cloud-seeding conducted over Ho Chi Minh Trail during Vietnam war

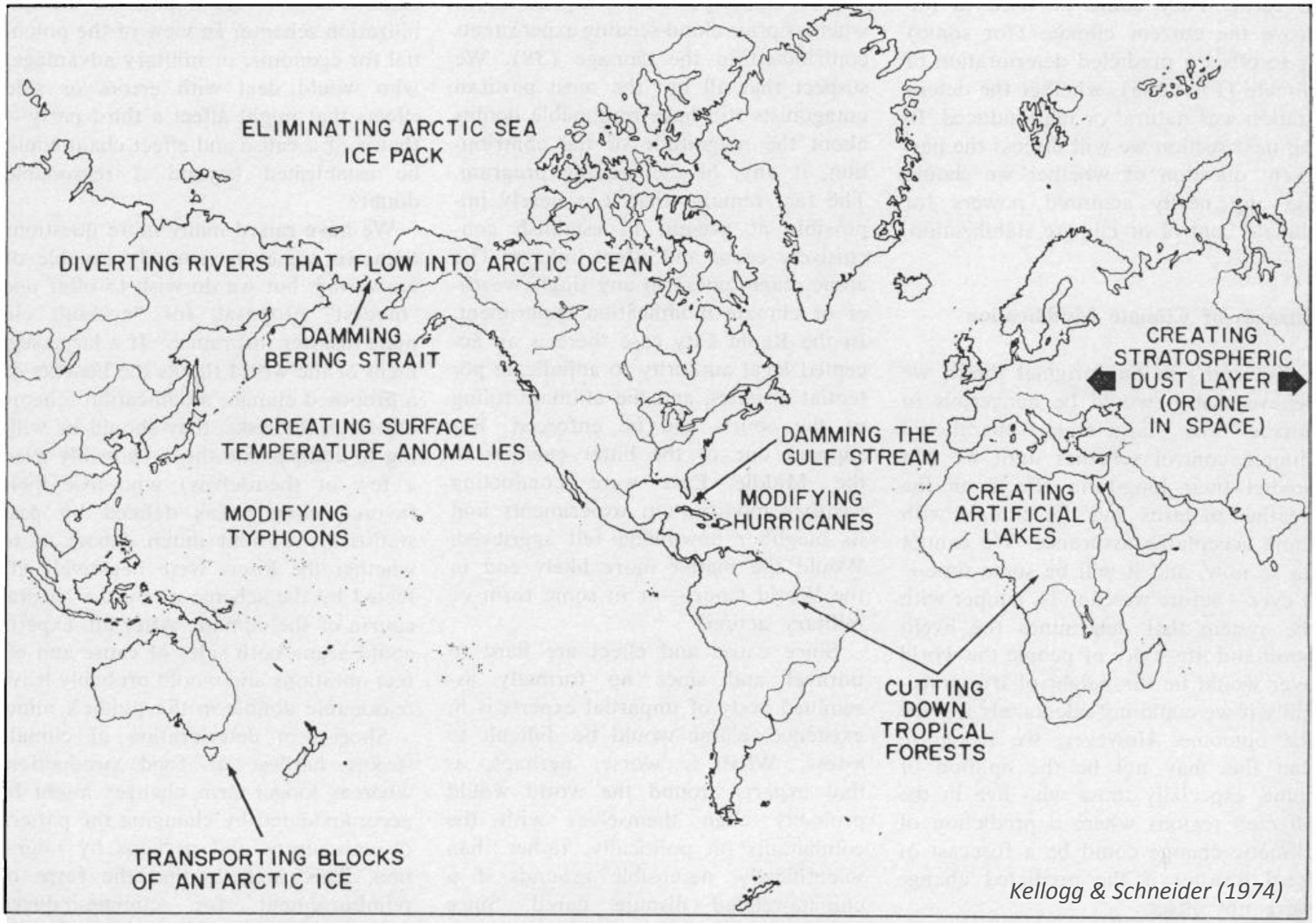
• 1975: Mikhail Budyko calculated that if global warming ever became a serious threat, we could counter with just a few airplane flights a day in the stratosphere, burning sulphur to make aerosols that would **reflect sunlight away**

• 1977: N.A.S. report looked at a variety of **schemes to reduce global warming**, should it ever become dangerous, and concluded a turn to renewable energy was a more practical solution than geo-engineering of climate

Vincent Schaefer (1946)

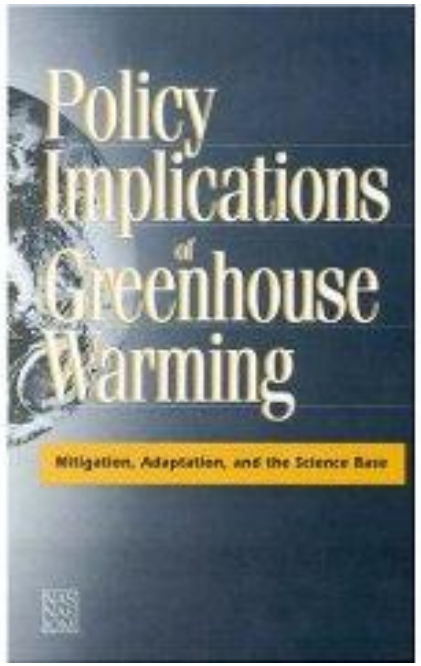
Michail Budyko

Early suggestions



Kellogg & Schneider (1974)

Moving forwards:

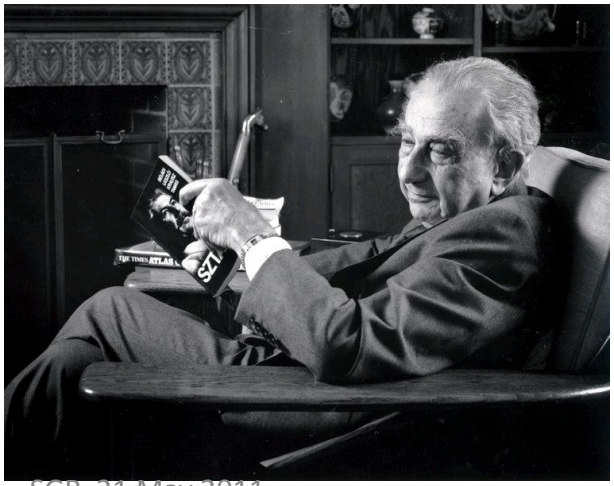


Policy Implications of Greenhouse Warming,
NATIONAL ACADEMY PRESS, Washington, D.C. 1992

Chapter 28: Geoengineering (pp 433-464)

several reports between
1997 and 2002

University of California
Lawrence Livermore
National Laboratory



Edward Teller

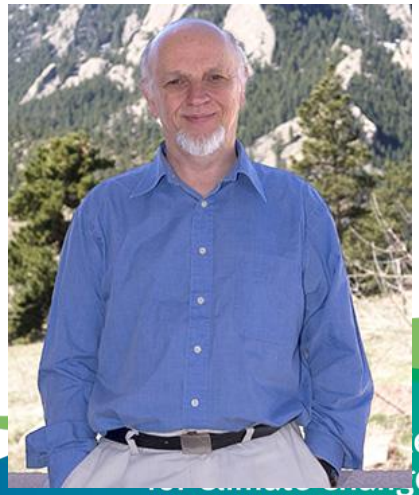
Lowell Wood

New kickstart in 2006

Crutzen, P. J. (2006) Albedo enhancement by stratospheric sulfur injections: a contribution to resolve a policy dilemma? *Climatic Change*, 77, 211-219.

Paul Crutzen

Wigley, T. M. L. (2006) A combined mitigation/geoengineering approach to climate stabilization. *Science*, 314, 452-454.



Tom Wigley

Increasing interest

Ames Research Center

workshop 2006

workshop 2007

Pontifical Academy of Sciences 2007

sessions (2008, 2009, 2010)

policy statement 2009

NKGCF
www.nkgcf.org
Nationales Komitee für Global Change Forschung

Rundgespräch

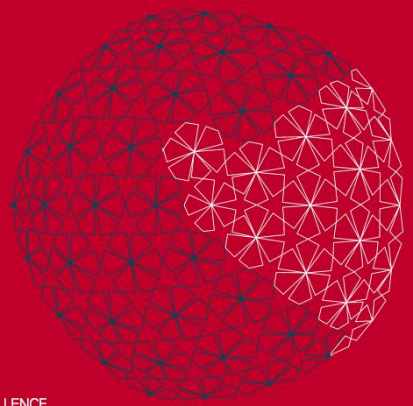
„Geoengineering – Rolle der Wissenschaften“

Kiel, 4. Juni 2009

Geoengineering the climate

Science, governance and uncertainty

September 2009



EXCELLENCE IN SCIENCE

THE ROYAL SOCIETY

Novim

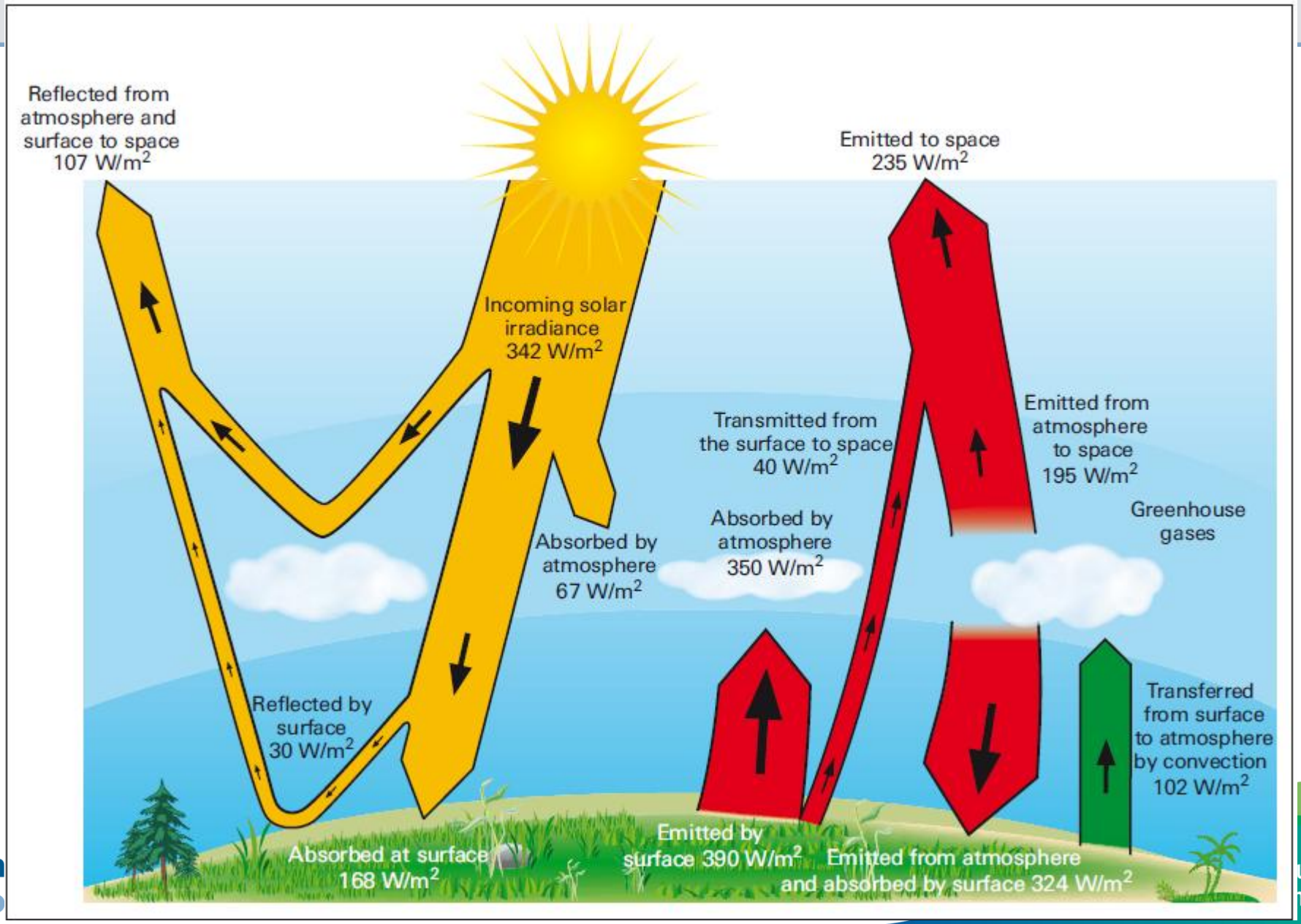
Climate Engineering Responses to Climate Emergencies

Jason J. Blackstock[†]
David S. 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 Convener*

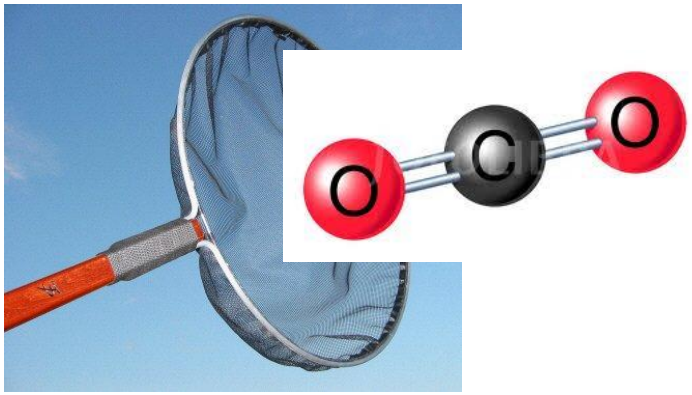
July 29, 2009

Santa Barbara, California

Earth's energy balance



Classification of methods

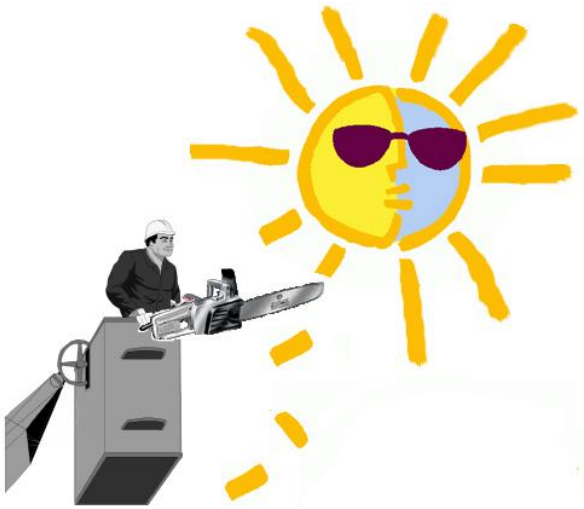


Carbon dioxide removal (CDR):

- Removal of CO_2 from the atmosphere and sequestration and land or in ocean

Solar radiation management (SRM):

- Reduction of solar radiation being absorbed at the surface



Geoengineering schemes

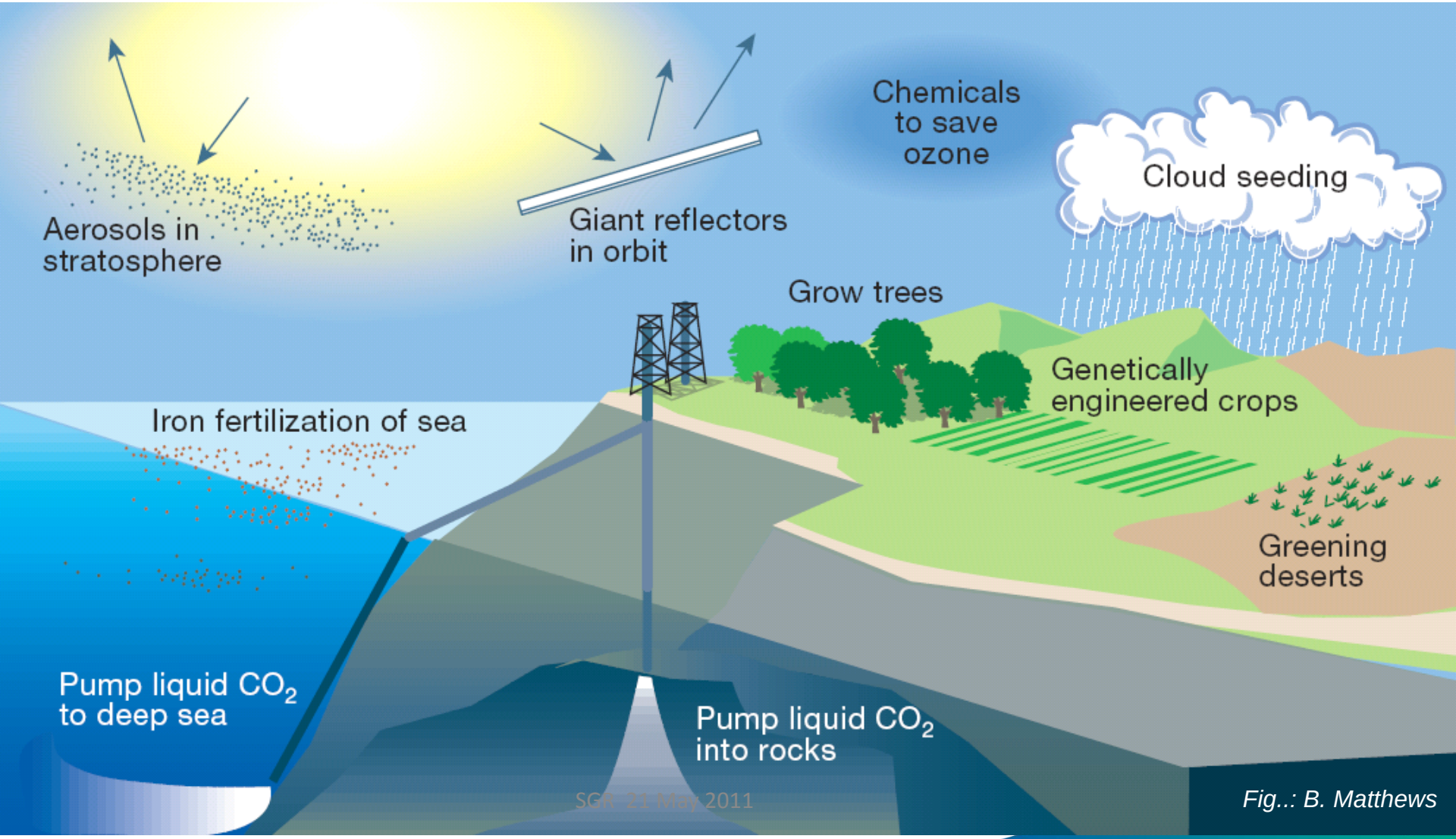
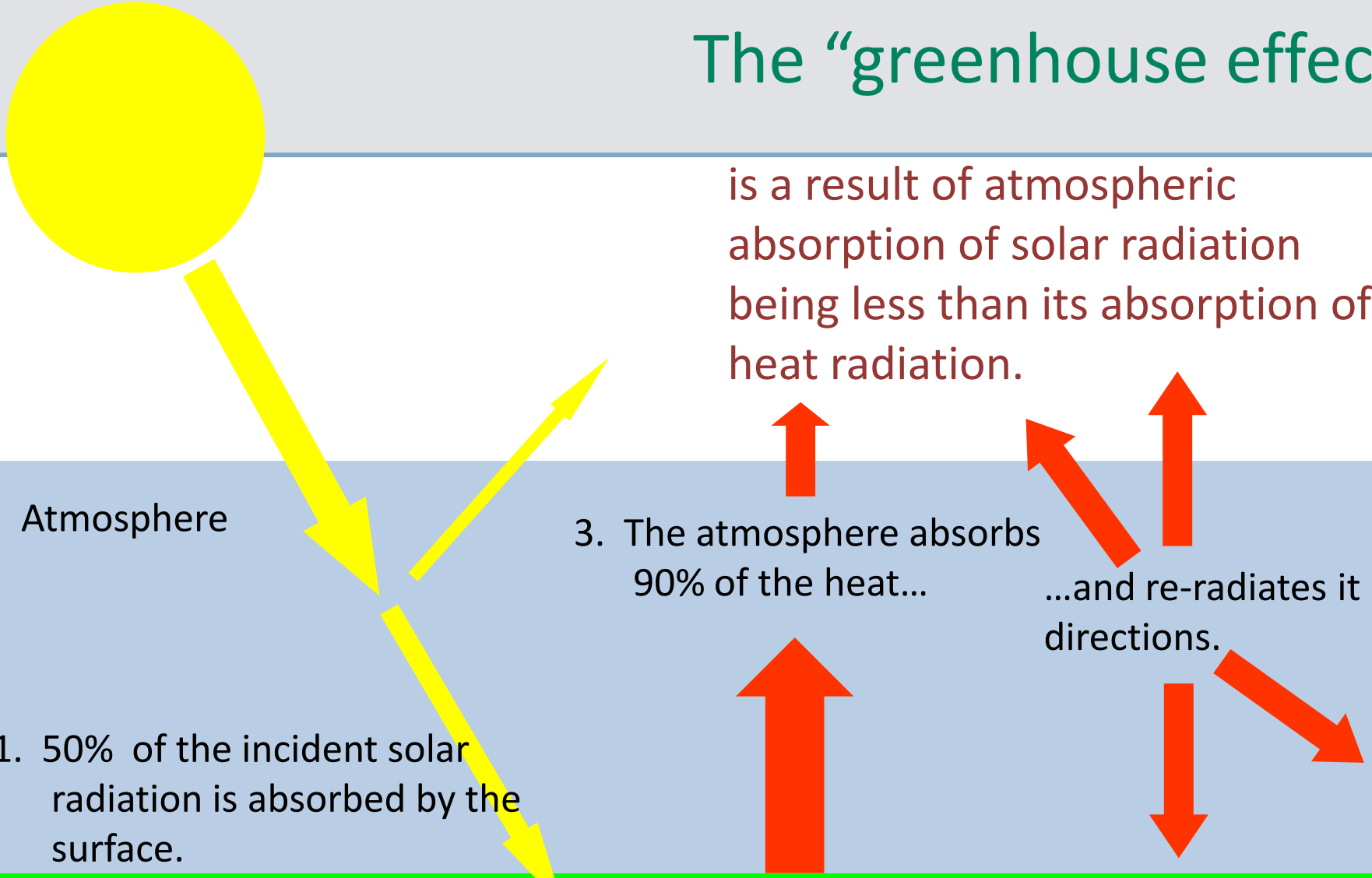


Fig..: B. Matthews

The “greenhouse effect”

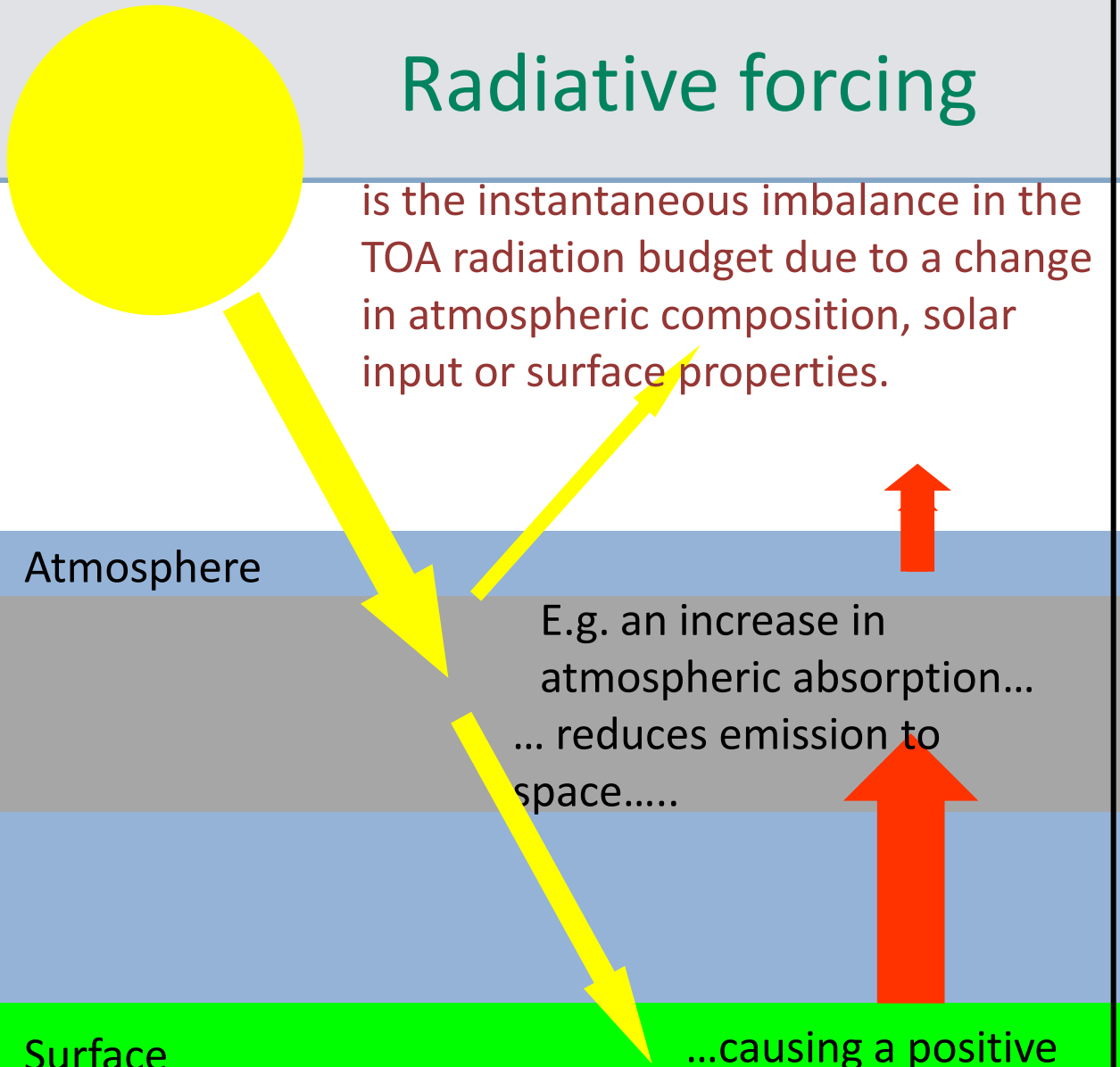
is a result of atmospheric absorption of solar radiation being less than its absorption of heat radiation.



N.B. In equilibrium there is a balance between incoming and outgoing radiation at the top of the atmosphere.

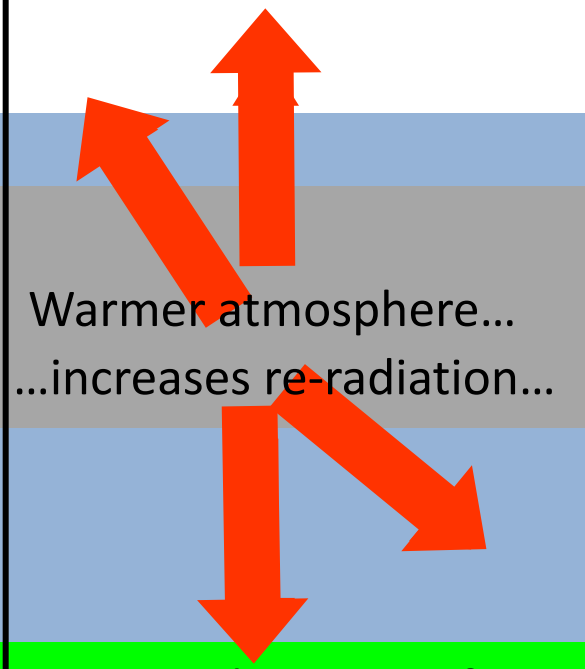
Radiative forcing

is the instantaneous imbalance in the TOA radiation budget due to a change in atmospheric composition, solar input or surface properties.



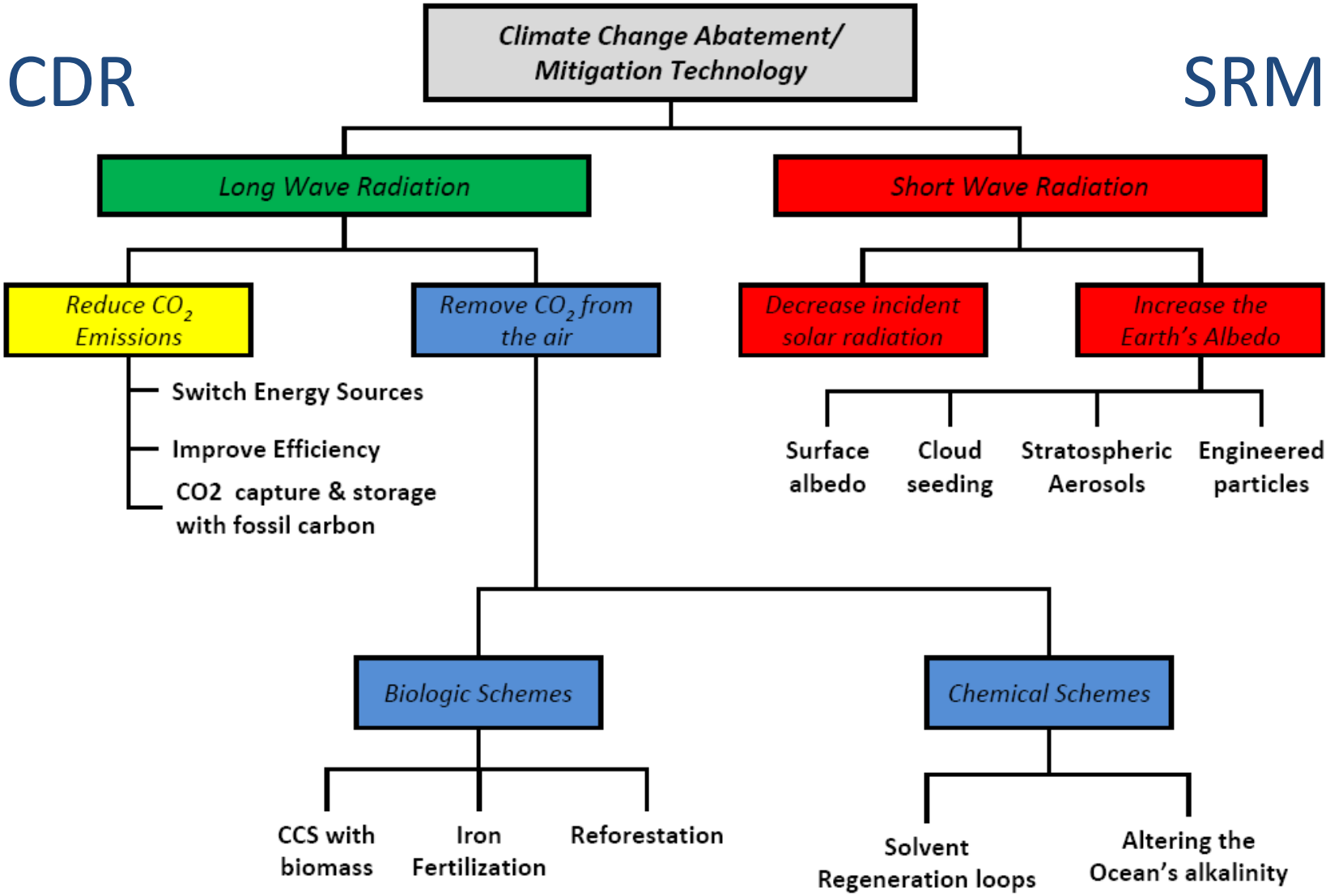
*TOA=top of the atmosphere

Climate response



…resulting in surface warming and re-establishing balance at TOA.

Proposed methods



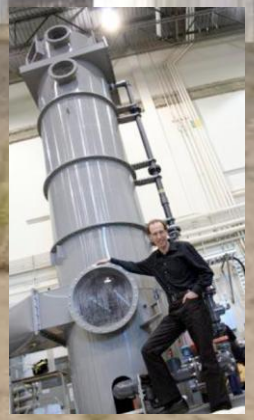
CO_2 air capture

CO_2-scrubber (250000)

May be deployed anywhere

Giant amount of waste to store

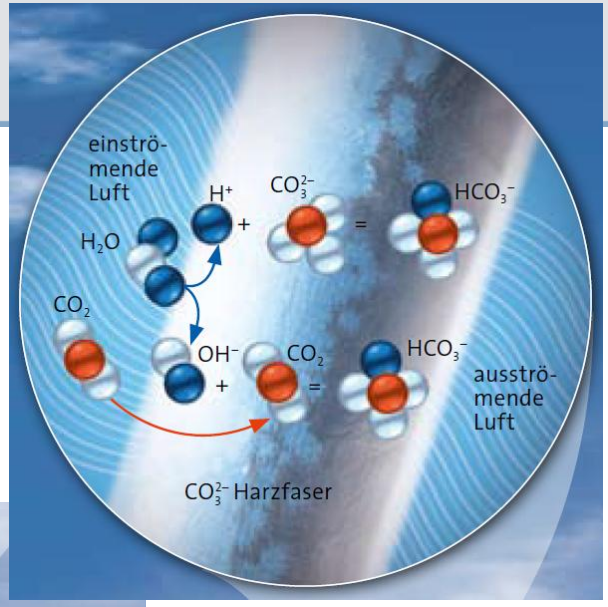
$2NaOH + CO_2 \rightarrow Na_2CO_3$



Art Courtesy Stonehaven CCS, Montreal

CO_2 air capture

Need 10 million devices to reduce global CO_2 by 5 ppm/year



Klaus Lackner, Columbia

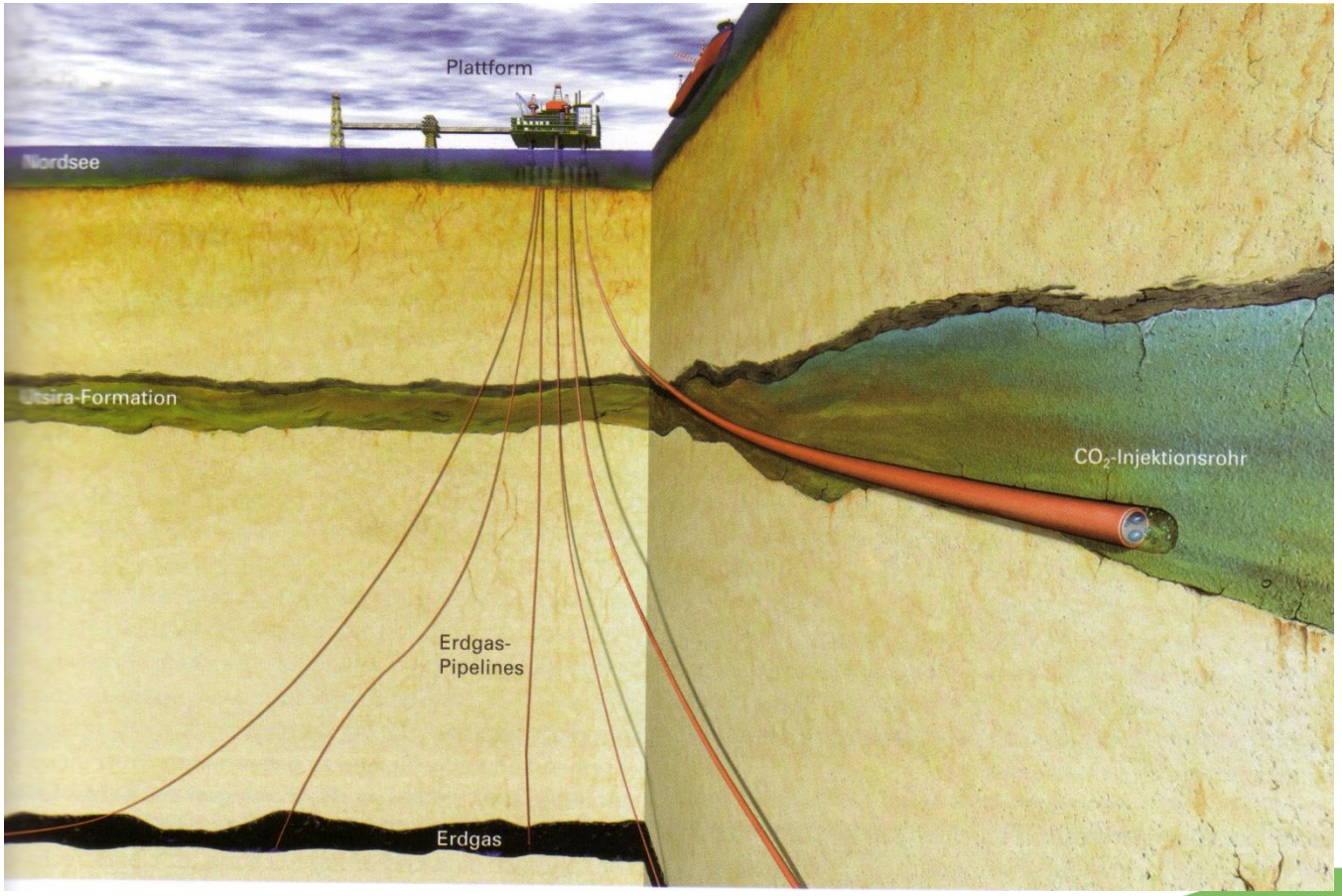
Carbon Capture and Storage (CCS)

e.g.
Sleipner gas field
North Sea
(Statoil, Norway)

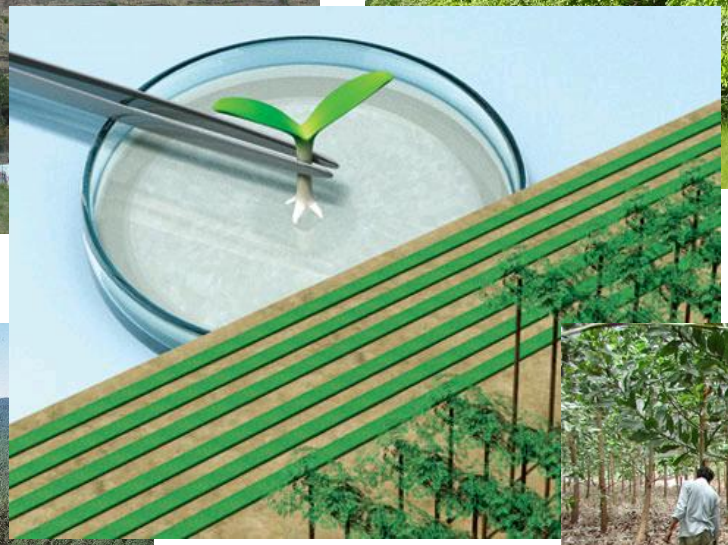
Utsira-formation
(800-1000m deep)
sand and brine

Official policy in some countries
- research power plants
- energy demanding
- leakage?

Gas



Afforestation / bio-char

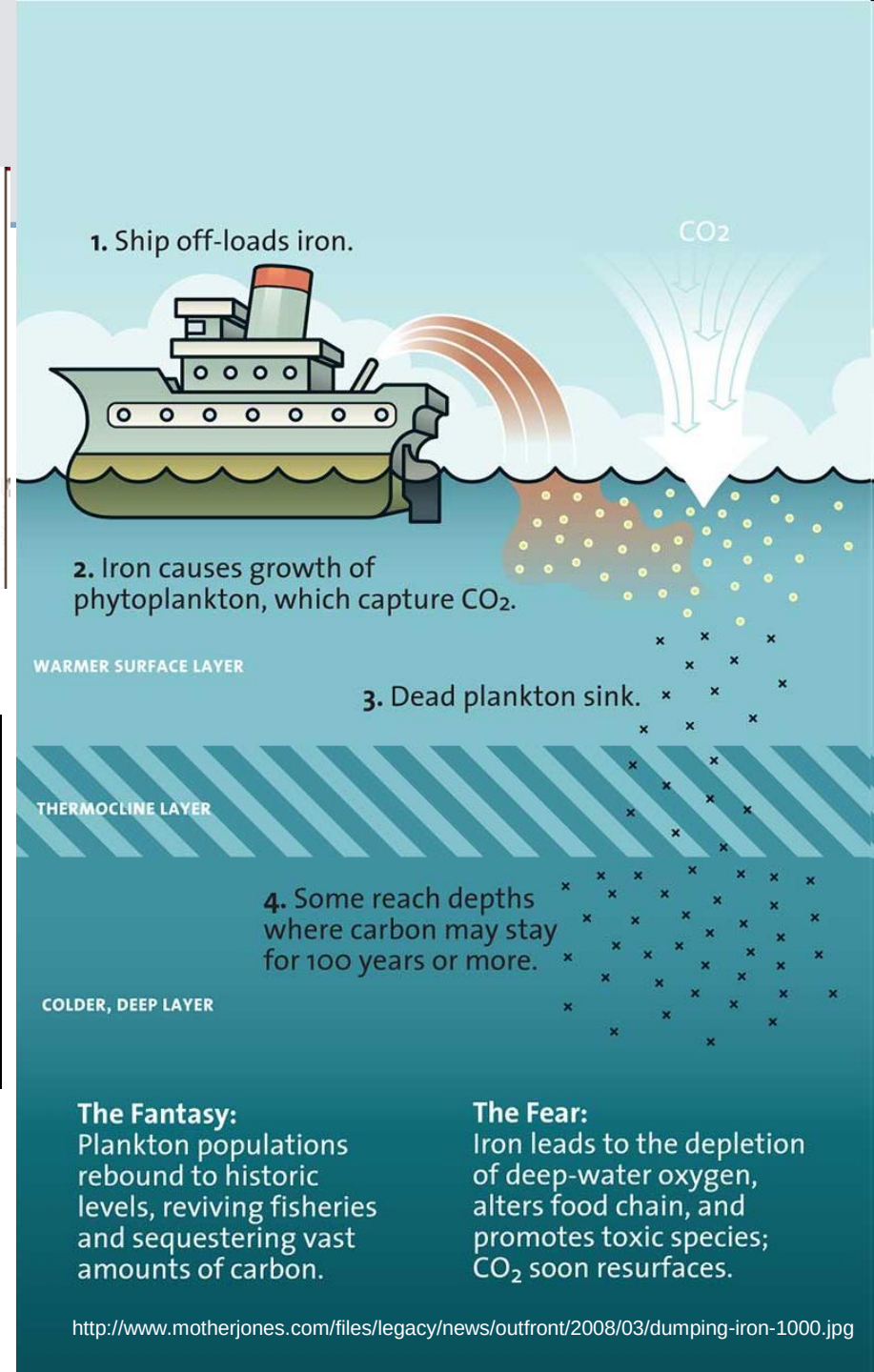


Ocean fertilisation

`Give me half a tanker of iron and I will give you an ice age´,

John Martin, WHOI Oceanographer, 1989

Iron (or nitrogen or phosphorous) to enhance plankton (coccolithophore) blooms



http://www.motherjones.com/files/legacy/news/outfront/2008/03/dumping-iron-1000.jpg

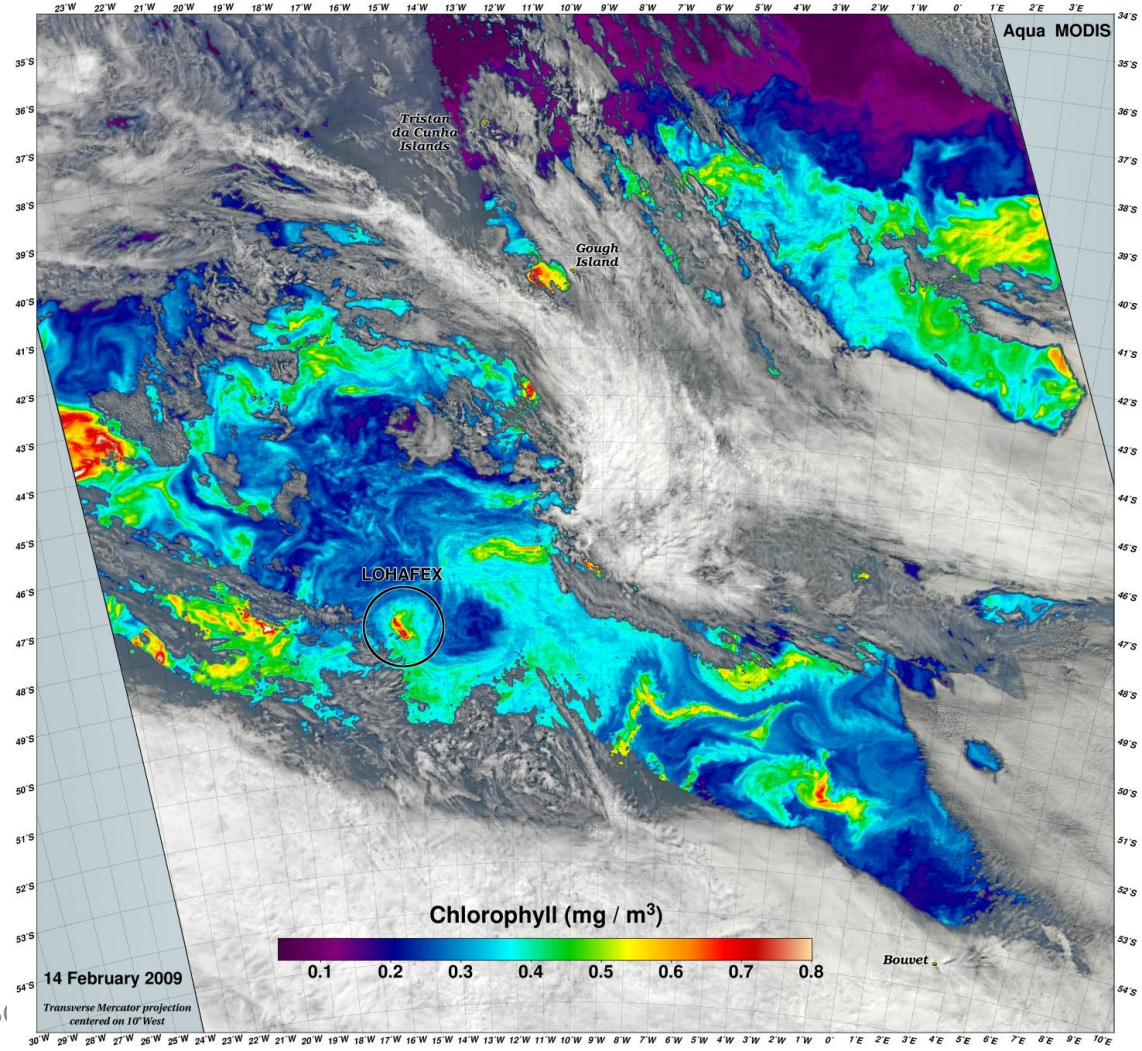
LOHAFEX experiment in South Pacific

Major conclusion:

Potential of OIF as a means of CO_2 sequestration
is substantially smaller than previously thought.

Ulrich Bathmann,
Alfred Wegener Institut ,2009

Resulting Bloom as seen by MODIS satellite



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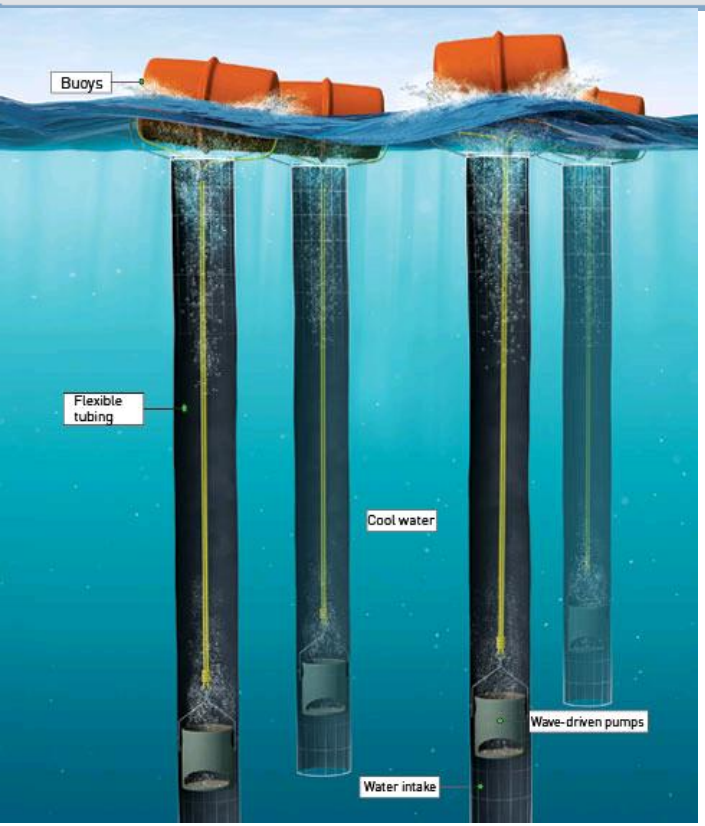
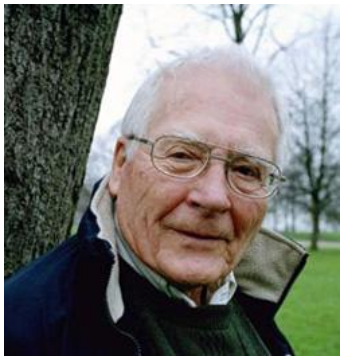
Other schemes…

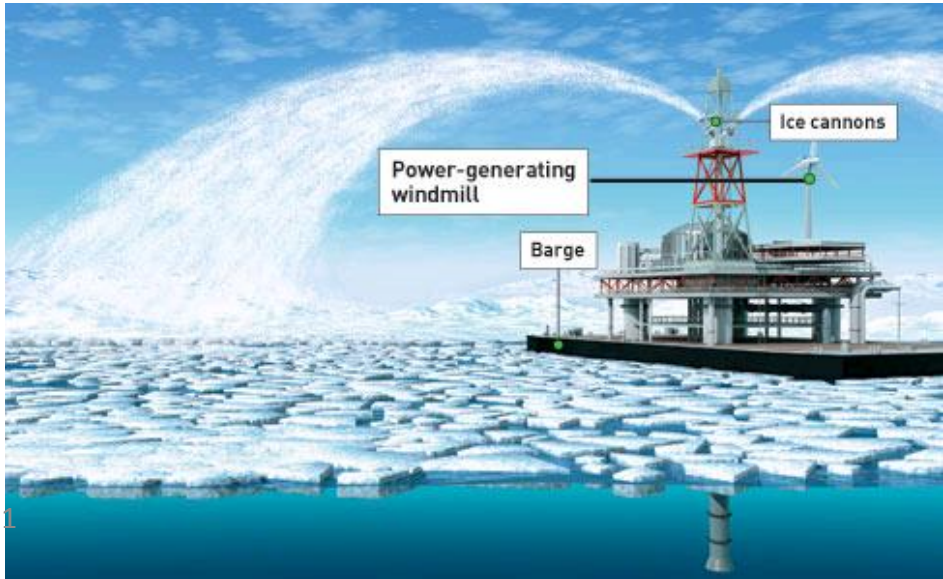


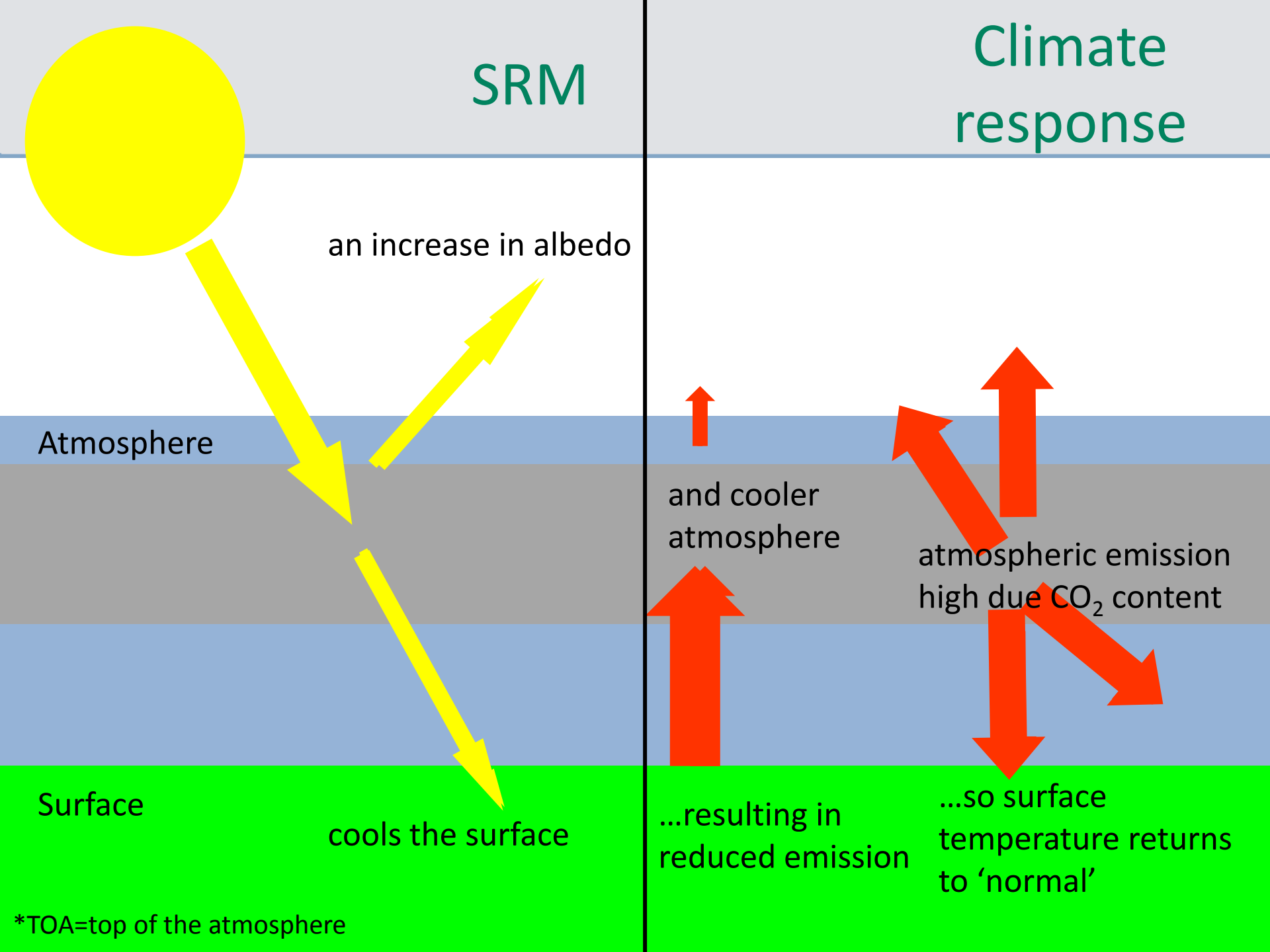
Wave-powered nutrient pump



James 'Gaia' Lovelock

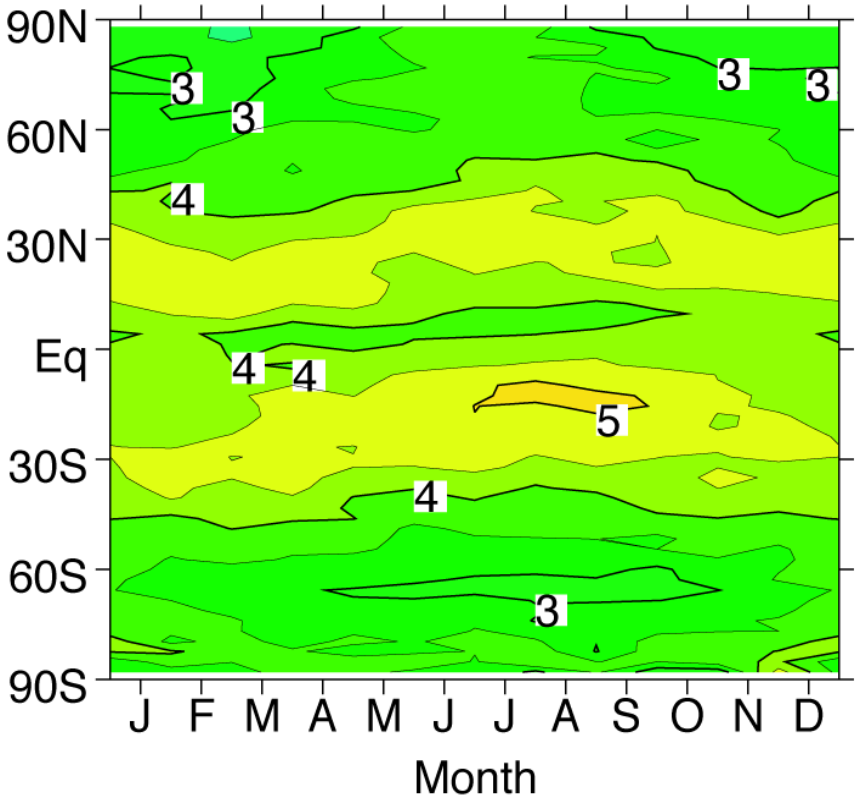
Ice build-up, deep water formation



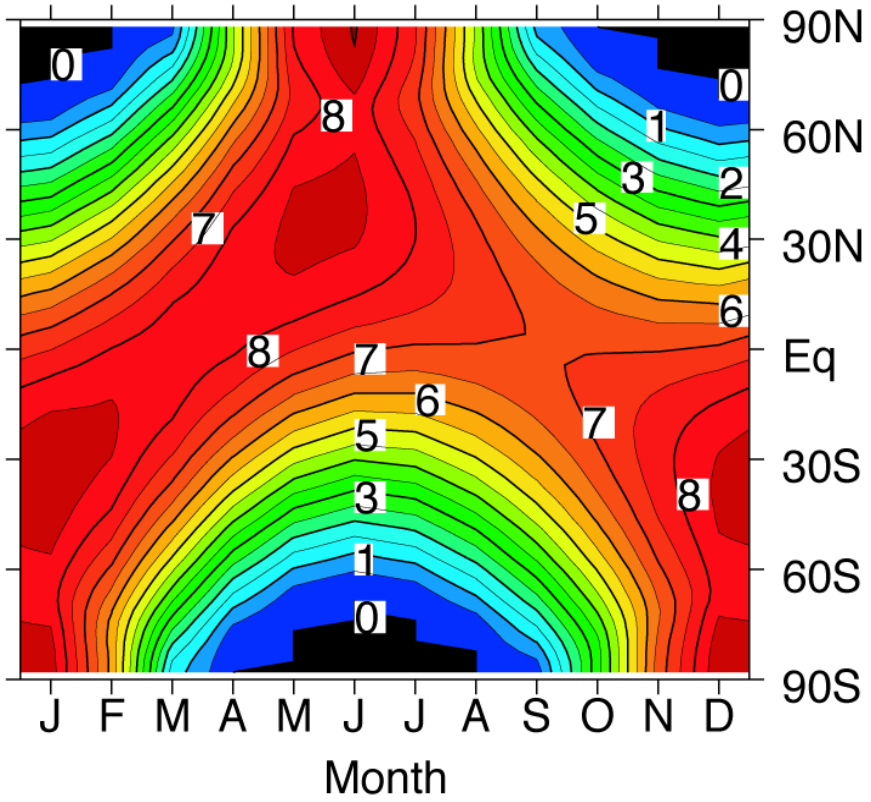

SRM
Climate response
an increase in albedo
Atmosphere
Surface
cools the surface
*TOA=top of the atmosphere
and cooler atmosphere
atmospheric emission high due CO_2 content
…resulting in reduced emission
…so surface temperature returns to 'normal'

Geographic distribution of forcings

CO_2 radiative forcing
from a CO_2 doubling (W / m^2)



Radiative forcing from 1.8% reduction
in solar intensity (W / m^2)



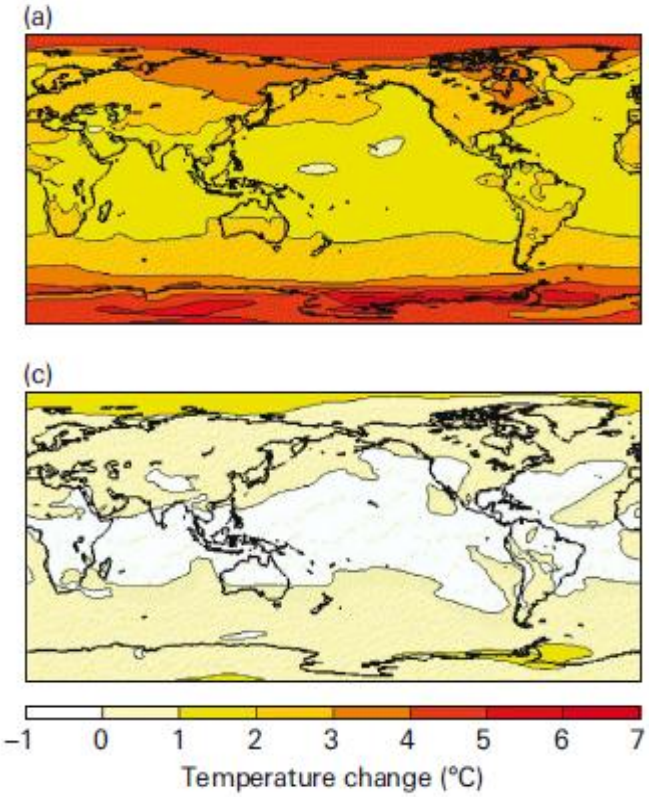
Equal globally-averaged forcing but
will the climate response to the combined forcing cancel ?

Govindasamy and Caldeira, GRL, 2000

GCM estimates of (generic) SRM

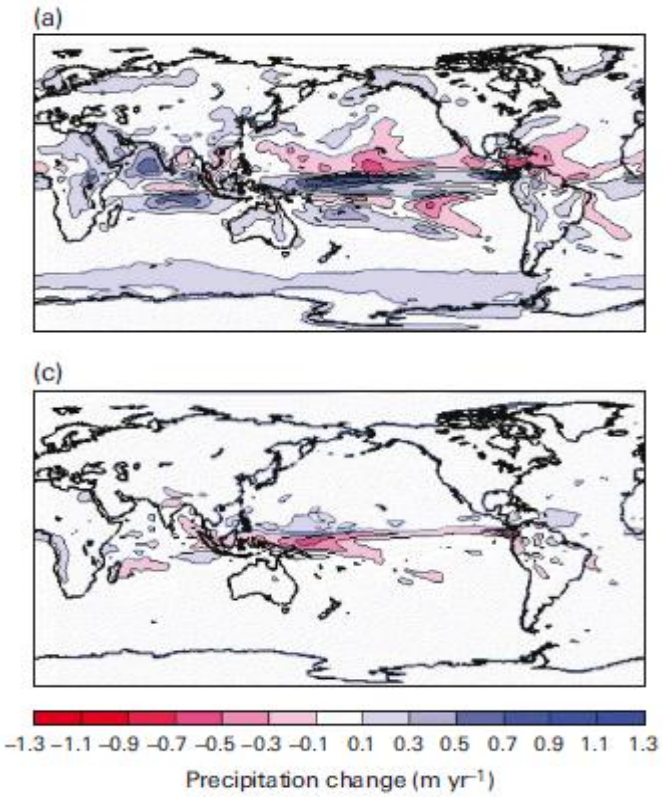
Change in temperature

Change in precipitation



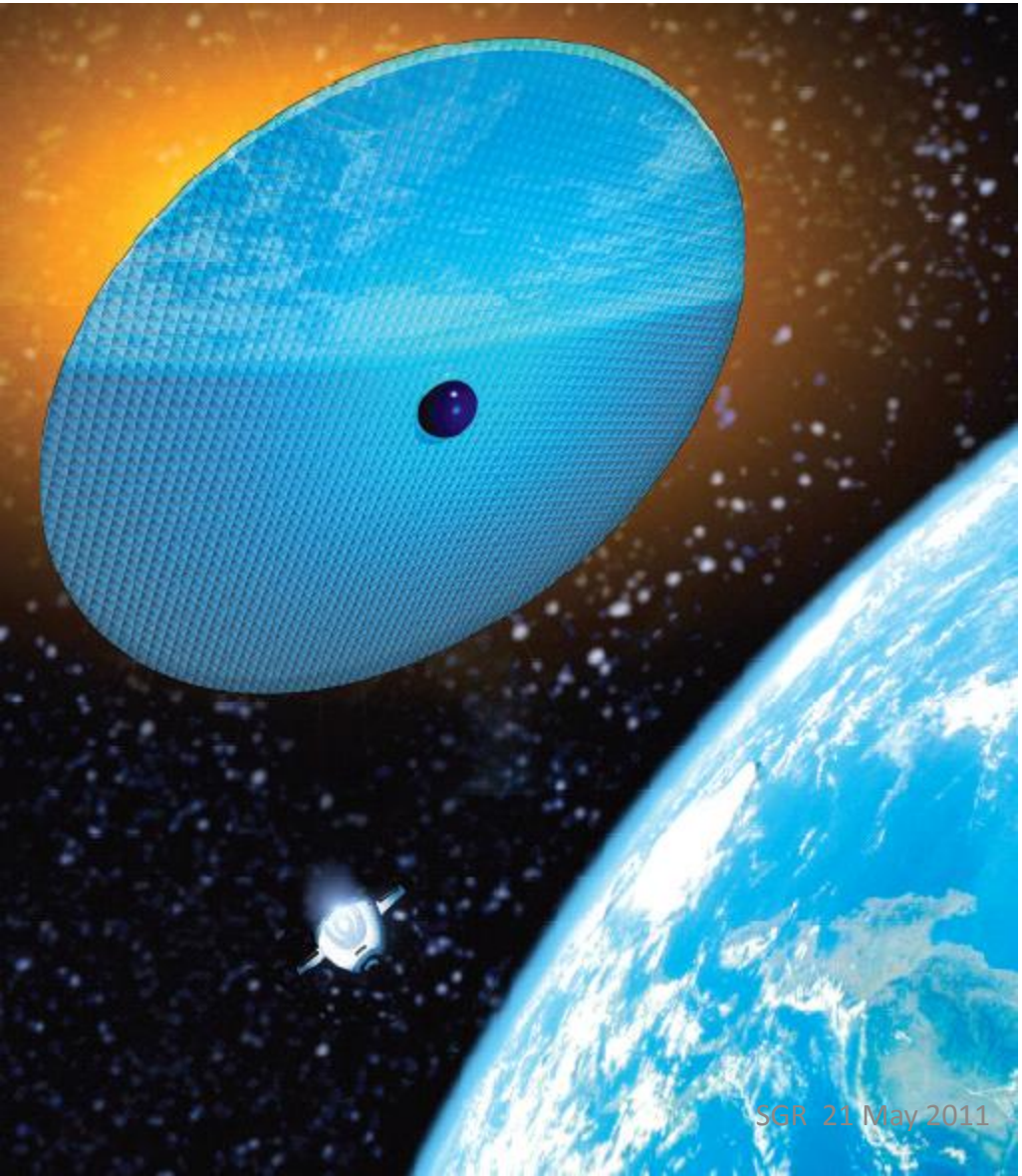
2 x CO_2

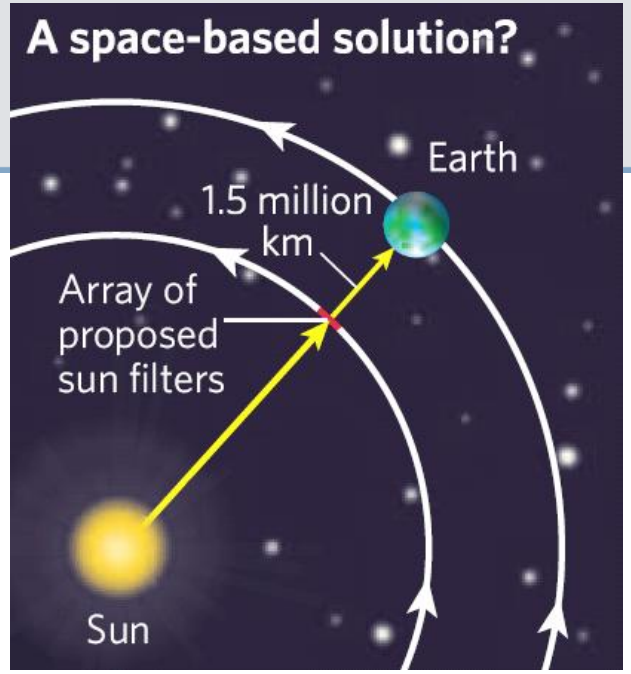
2 x CO_2
+
TSI - 1.84%



Caldeira and Wood (2008)

Giant mirror in space



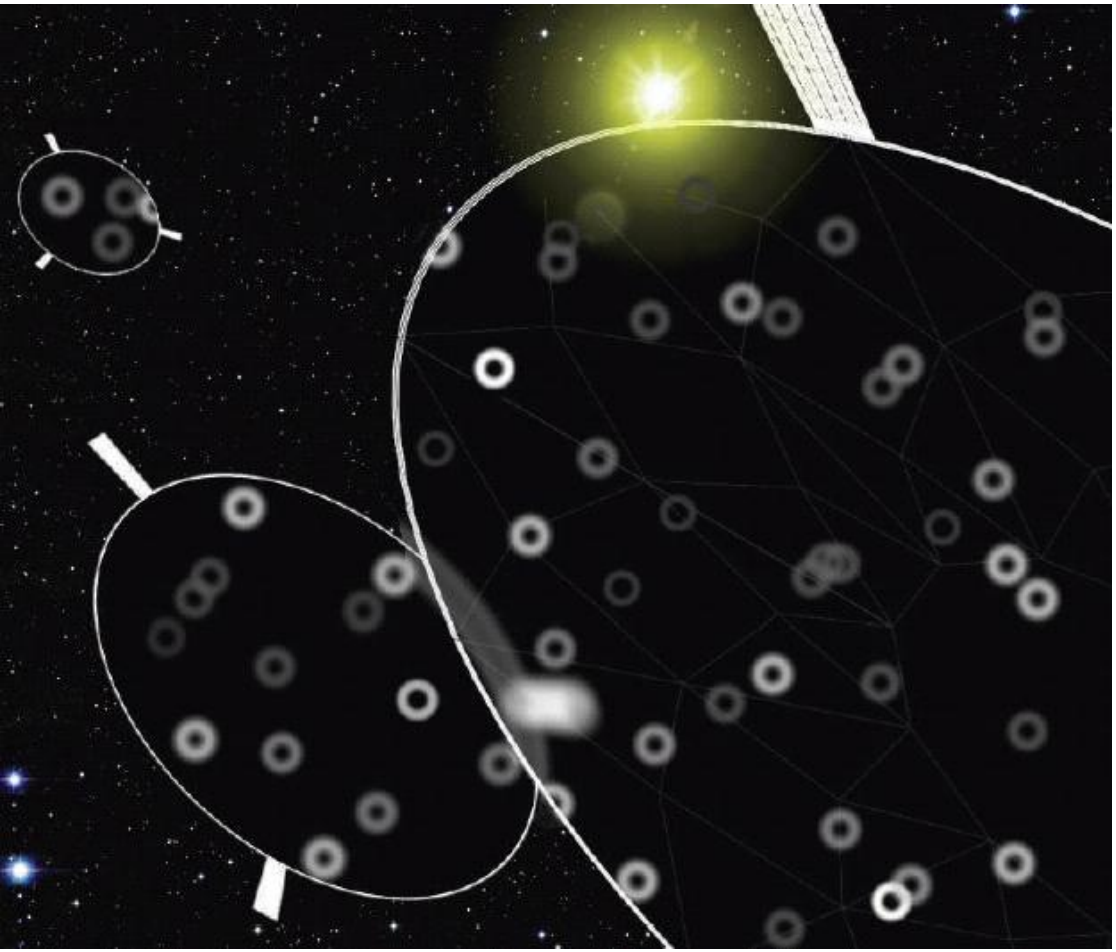


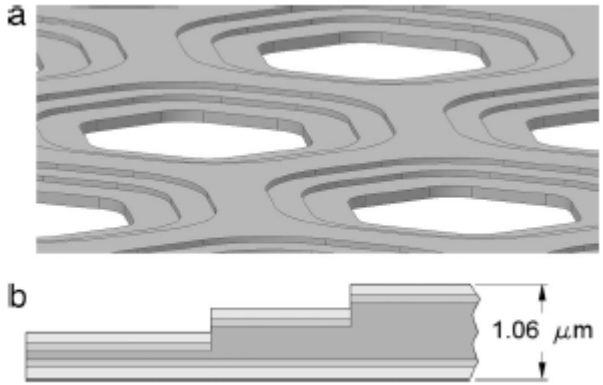
Mirror 1.5 M km towards the sun (L1-point)

1% reduction in irradiance for mirror 2000 km diameter

produced on and launched from the moon *(Early, 1989)*

… or a cloud of small ones

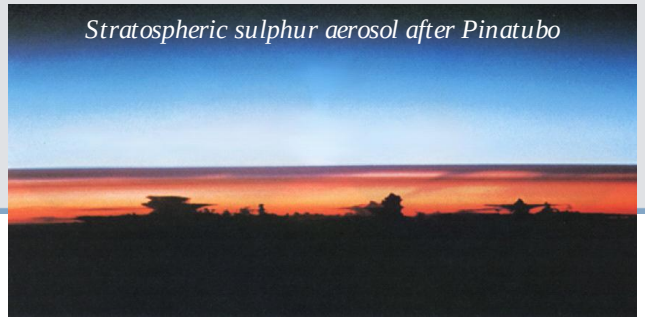




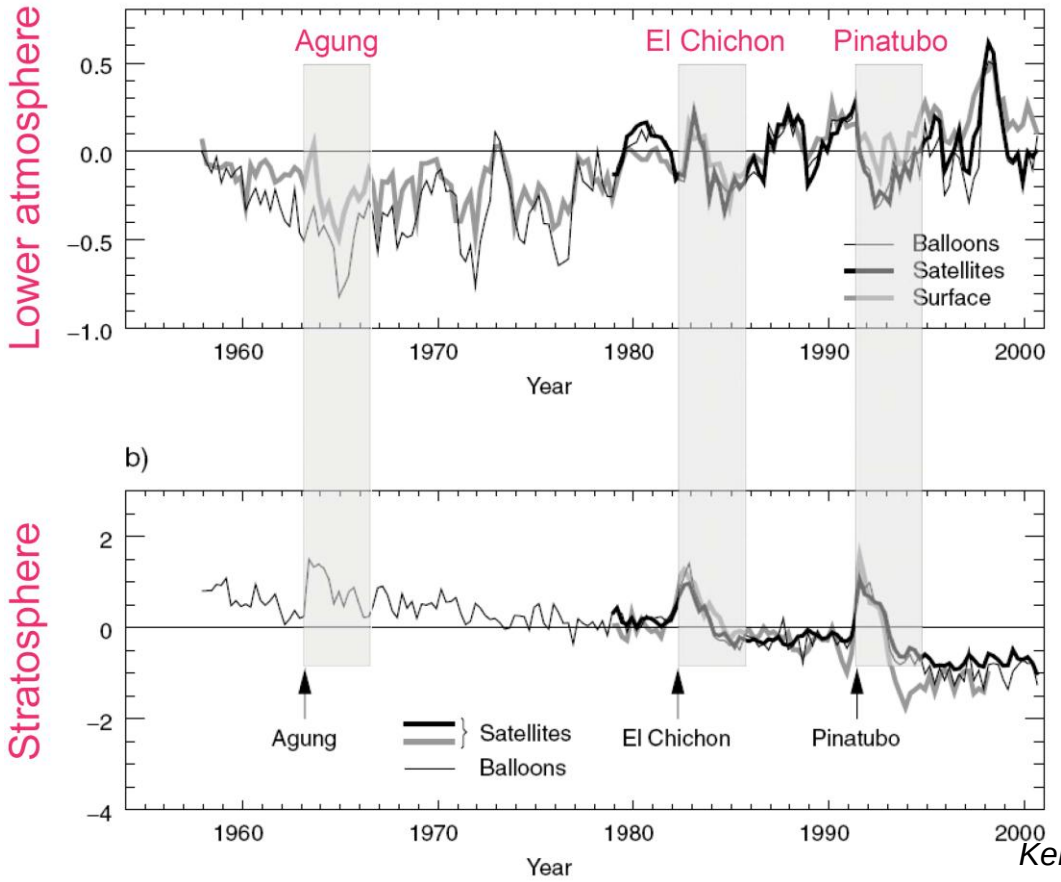
16 trillion sun shades in space

Angel, PNAS (2006)

Roger Angel, University of Arizona



Artificial volcano?



Keith 2008

Drop in temperature following major volcanic eruptions.

Could artificially inject sulphur into the stratosphere to counteract global warming?

Crutzen “emergency program” 2006

5 Tg sulphur lifted by balloons to altitudes between 10 and 50 km

S to SO_2 to SO_4- particles

$25 – 50 billion p.a.

Potential (specific) problems:
Ozone depletion
Acidification
Cirrus production?

A “better solution”

Watching Gary Bass Watch OMB

THE Environmental Forum®

ADVANCING ENVIRONMENTAL PROTECTION THROUGH • ANALYSIS • OPINION • DEBATE

Volume 24, Number 5 September/October 2007

Risky Gamble

Reducing emissions of greenhouse gases may be well intentioned and even helpful. But as the sole strategy for climate change control it is nevertheless inflexible, expensive, risky, and politically unrealistic, according to this government economist. Such a strategy could even make matters worse. Fortunately, there is a better solution.

ALAN CARLIN

Alan Carlin *is a Senior Economist at the U.S. Environmental Protection Agency. The views expressed in this article are his own and should not be taken to represent official U.S. policy.*

The Inadequacy of Global Climate Change Policy

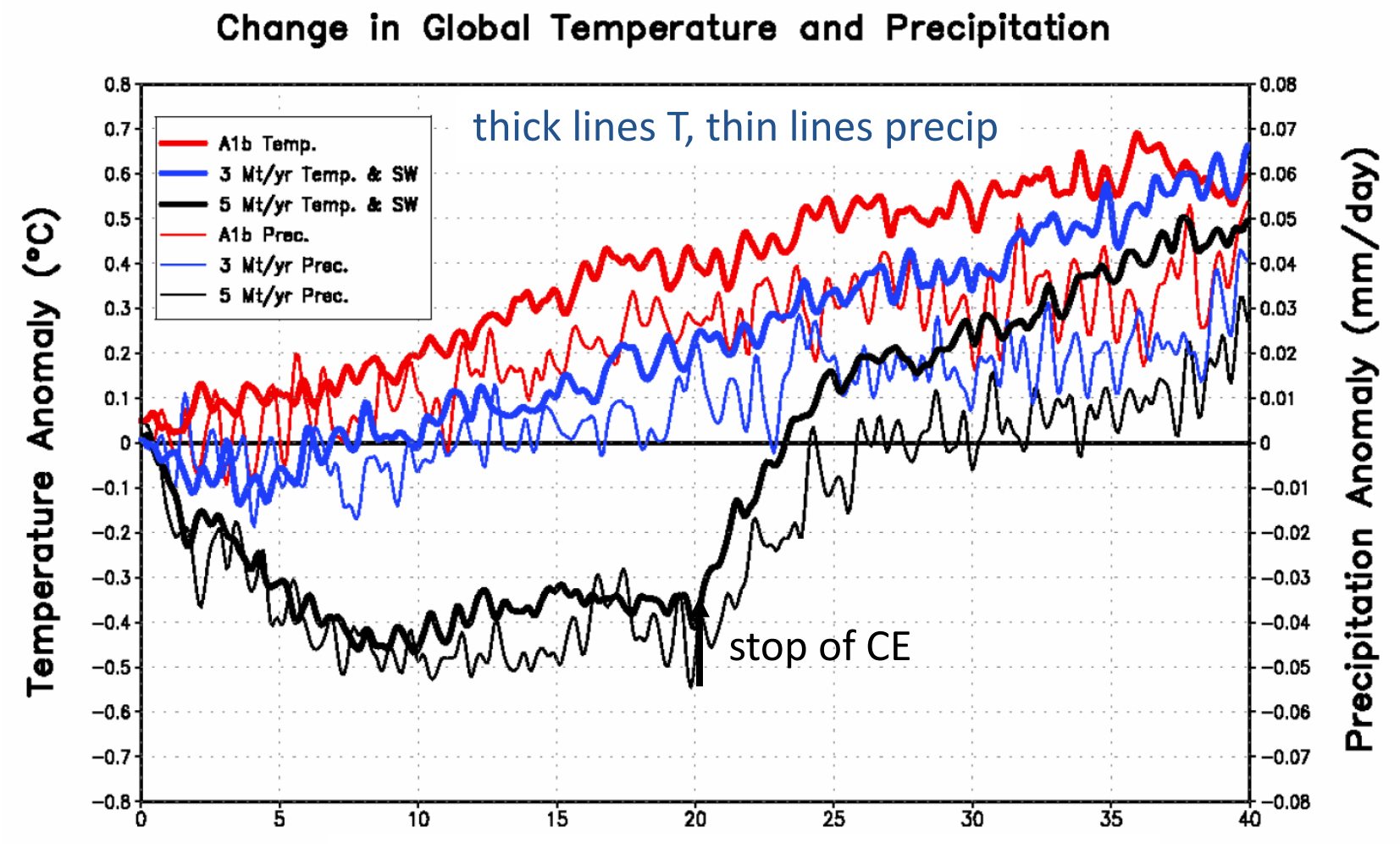
“Death” Watch | *Environmentalism in Limbo*
Sufficient Nexus | *Which Waters Are Protected?*
Book Excerpt | *Global Environmental Governance*

THE POLICY JOURNAL OF THE ENVIRONMENTAL LAW INSTITUTE®

Magazine of the Environmental Law Institute

Climate Engineering – regional SRM deployment

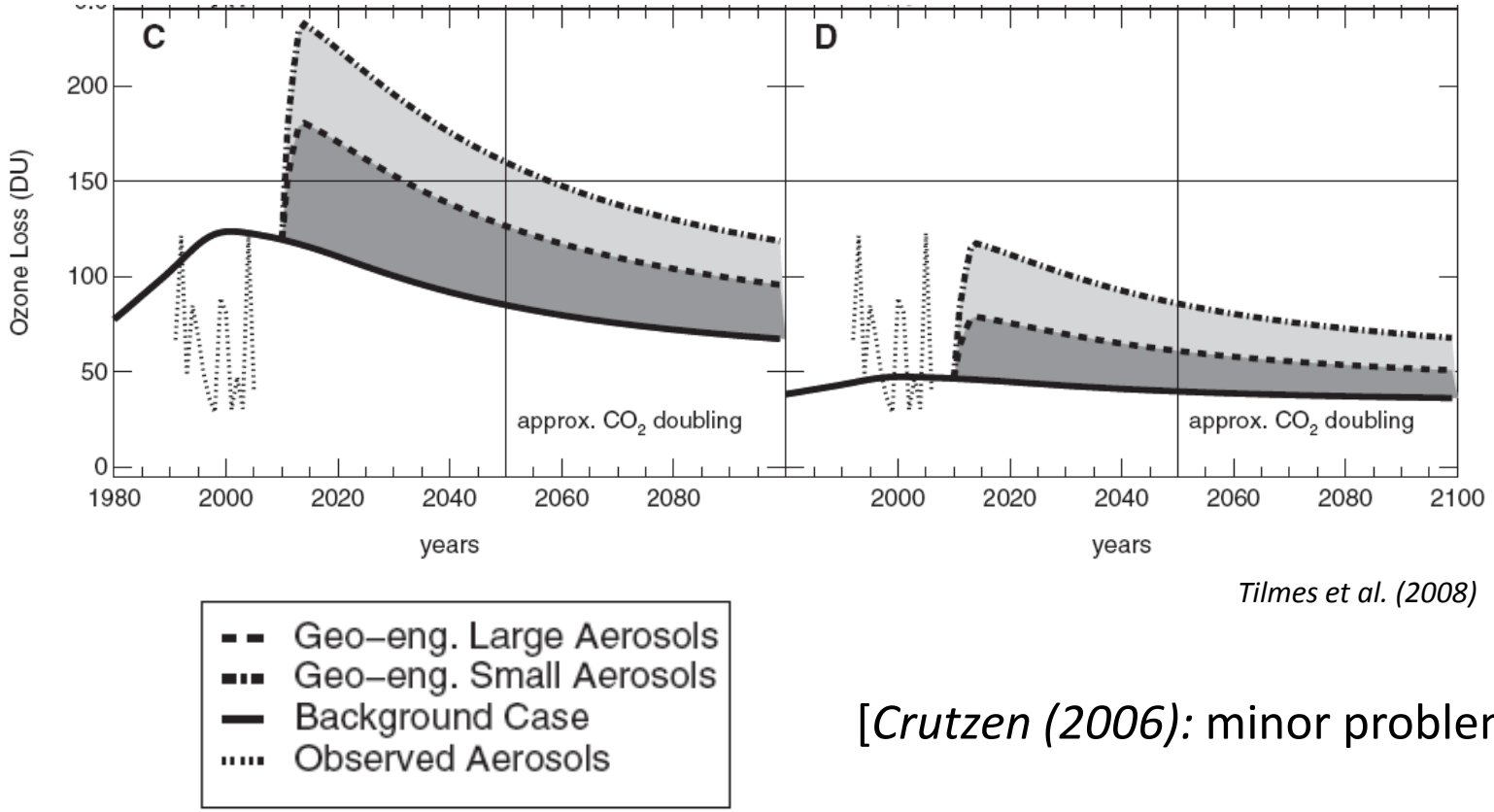
Robock et al. (2008)



Aerosols and stratospheric ozone

Cold Arctic winters

Mild Arctic winters

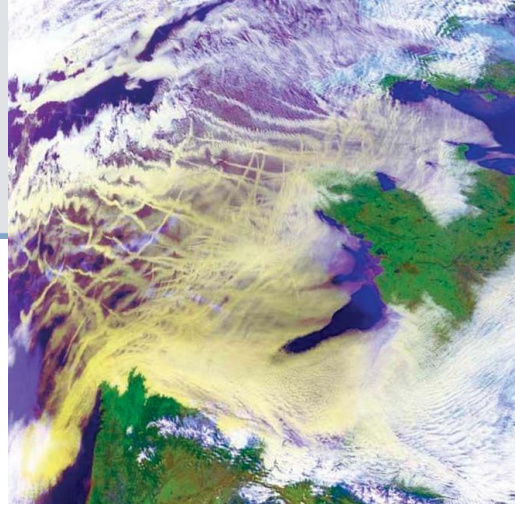


Tilmes et al. (2008)

[*Crutzen (2006):* minor problem]

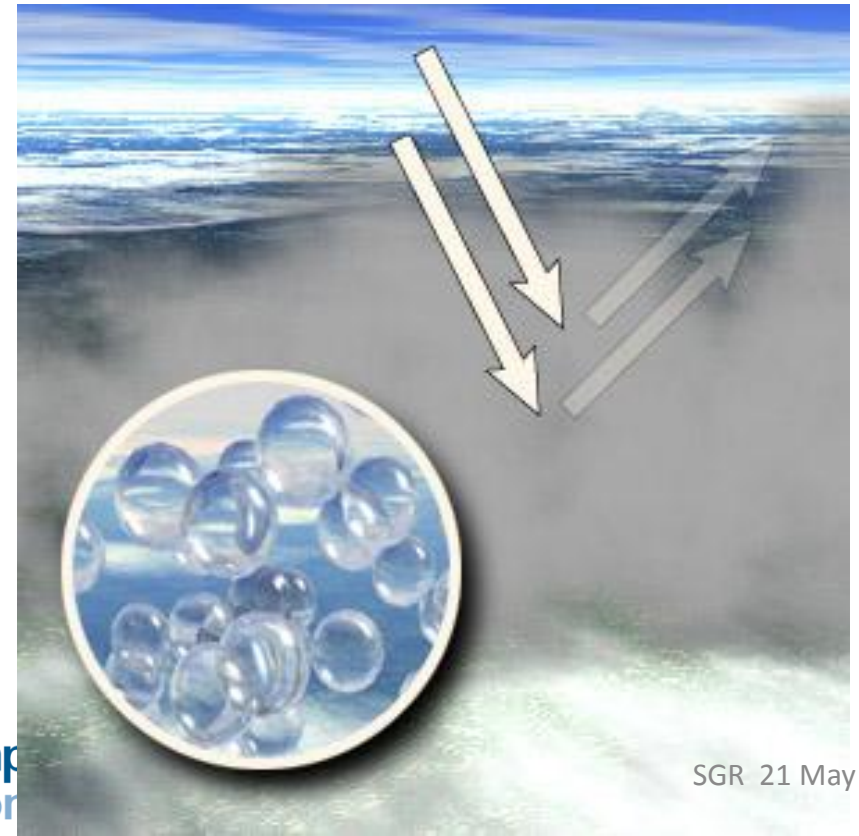
Enhancement of stratospheric aerosols due to geo-engineering causes a 30 to 70 year delay in the recovery of the Antarctic ozone hole.

Indirect aerosol effect – marine stratus clouds

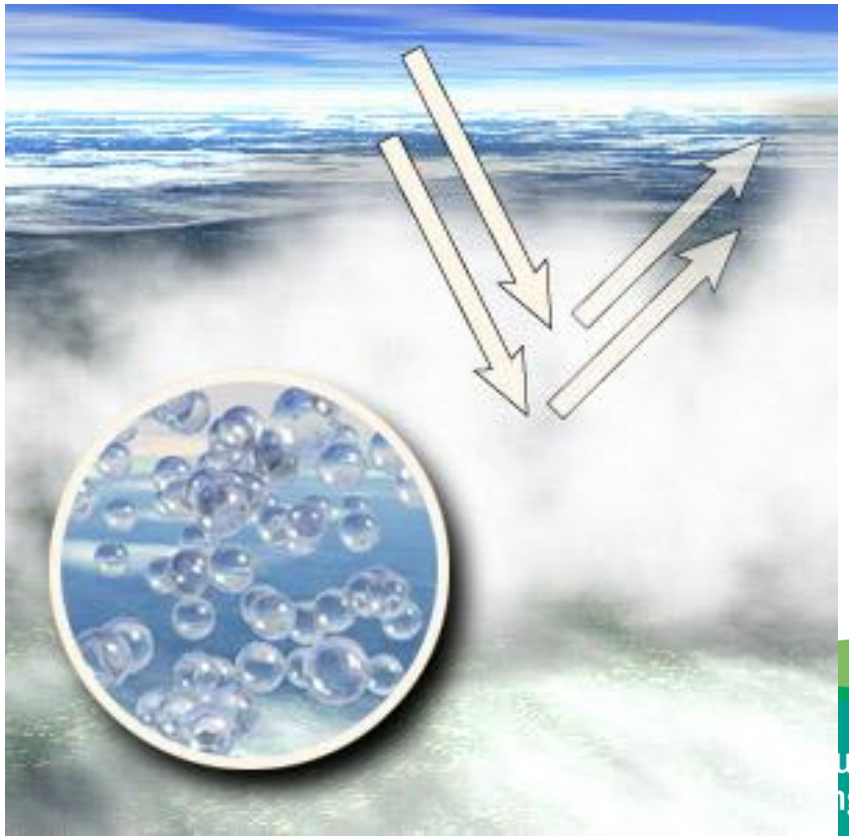


For same water content:

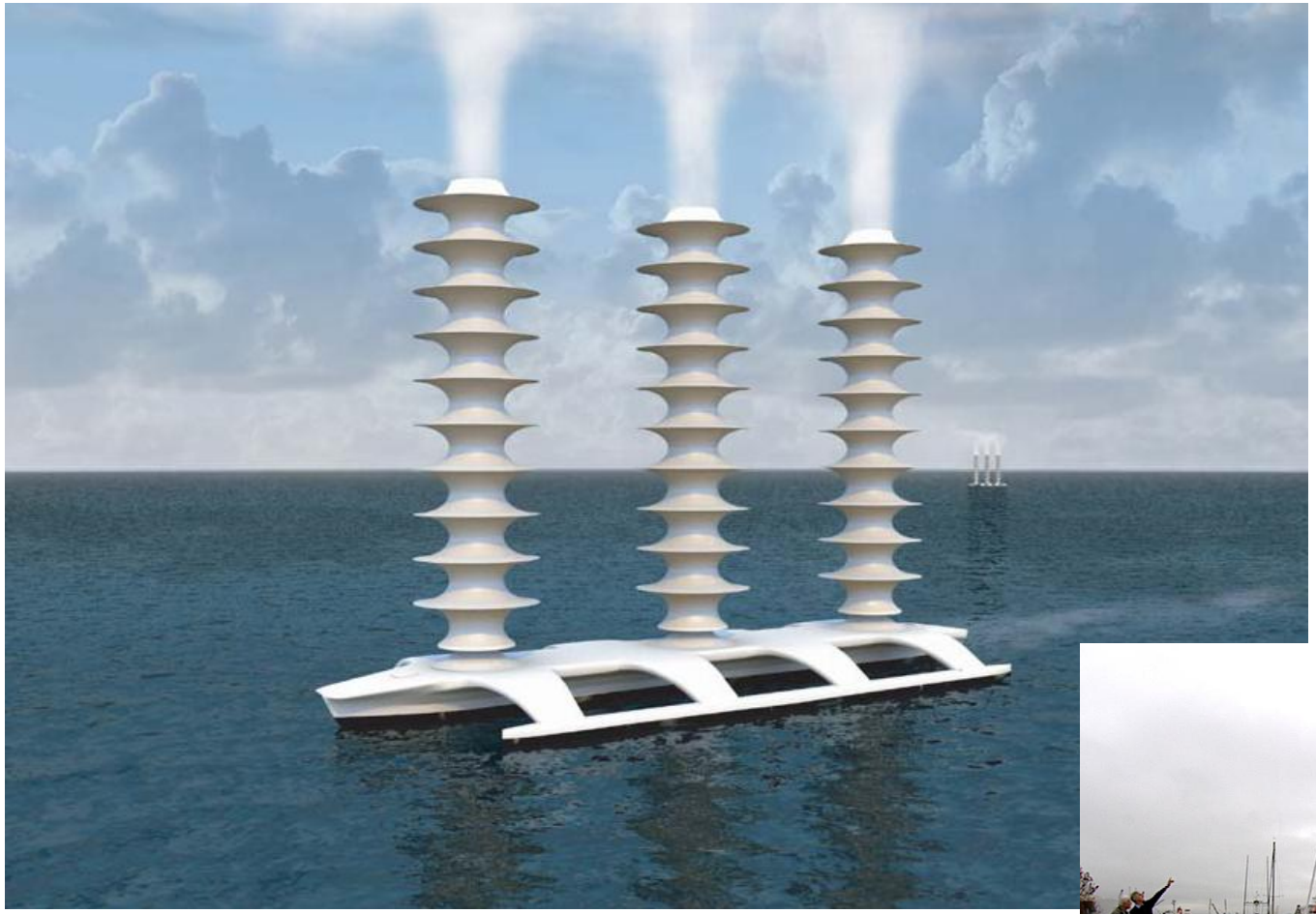
few large droplets: low albedo



many small droplets: higher albedo



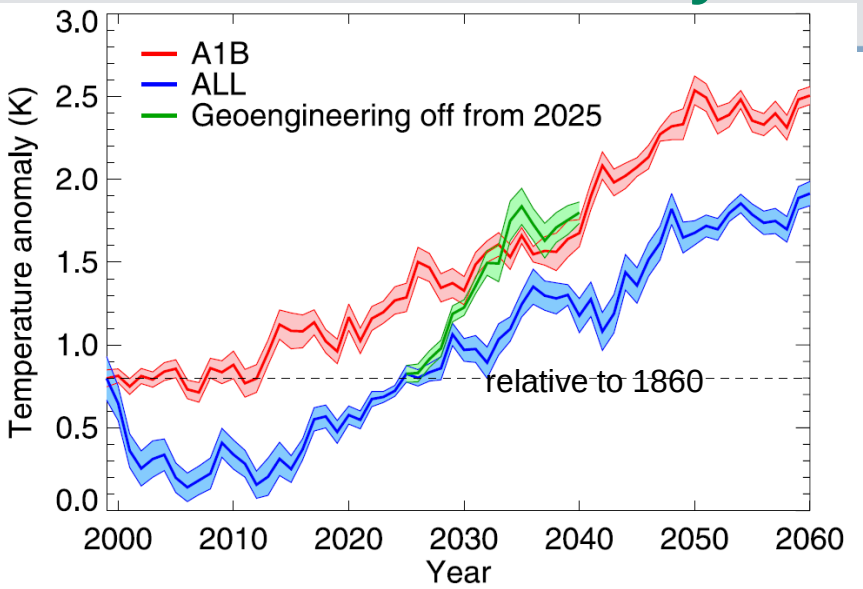
Spray vessels

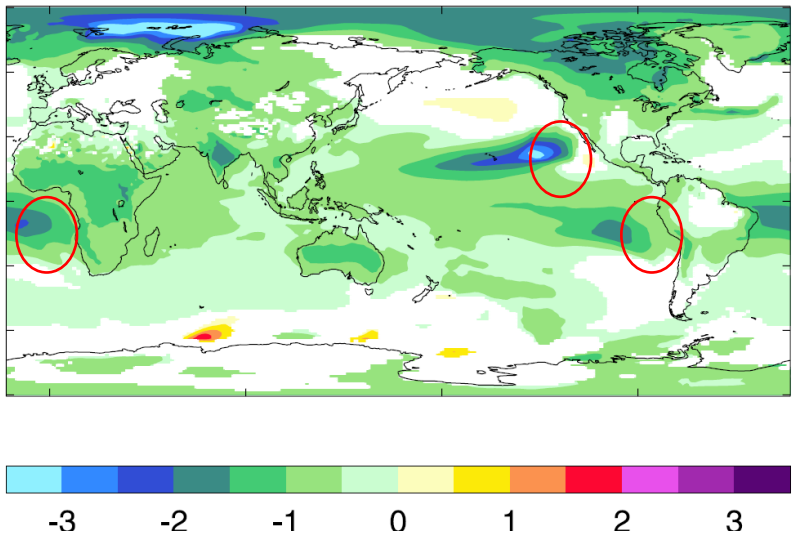


Slater et al. 2008

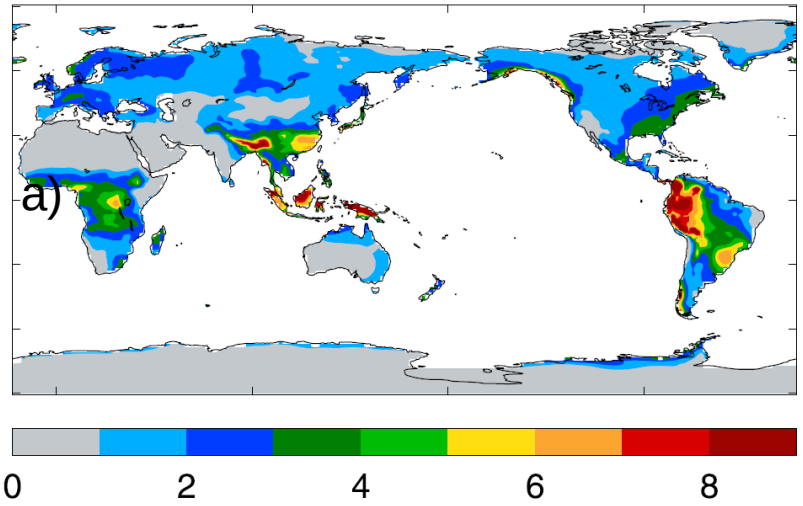
Coupled atmosphere ocean model study

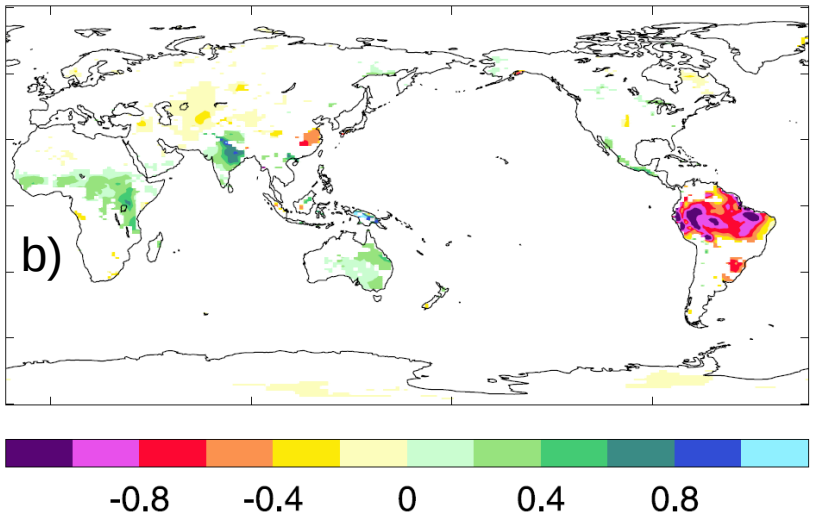
assumes technique works and CDNC set to asymptotic maximum





Mean 2030–2059 near-surface temperature change (K) (ALL – A1B) Areas where the change is not statistically significant at the 5% level are in white.



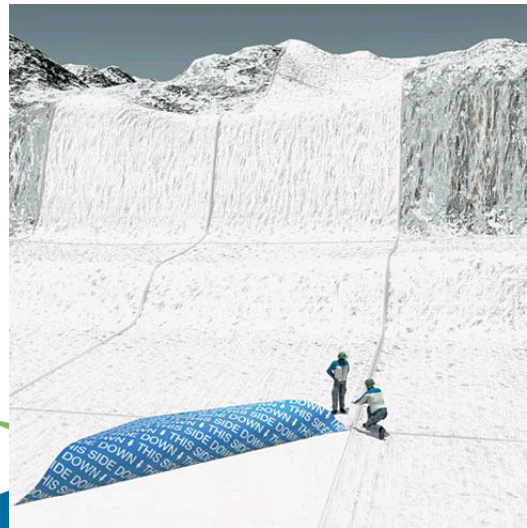


Mean 2030–2059 land precipitation (mm day-1): (a) distribution in A1B; (b) ALL- A1B. Land areas in Figure 4b where the change is not statistically significant at the 5% level are in white.

Jones et al. JGR (2009)

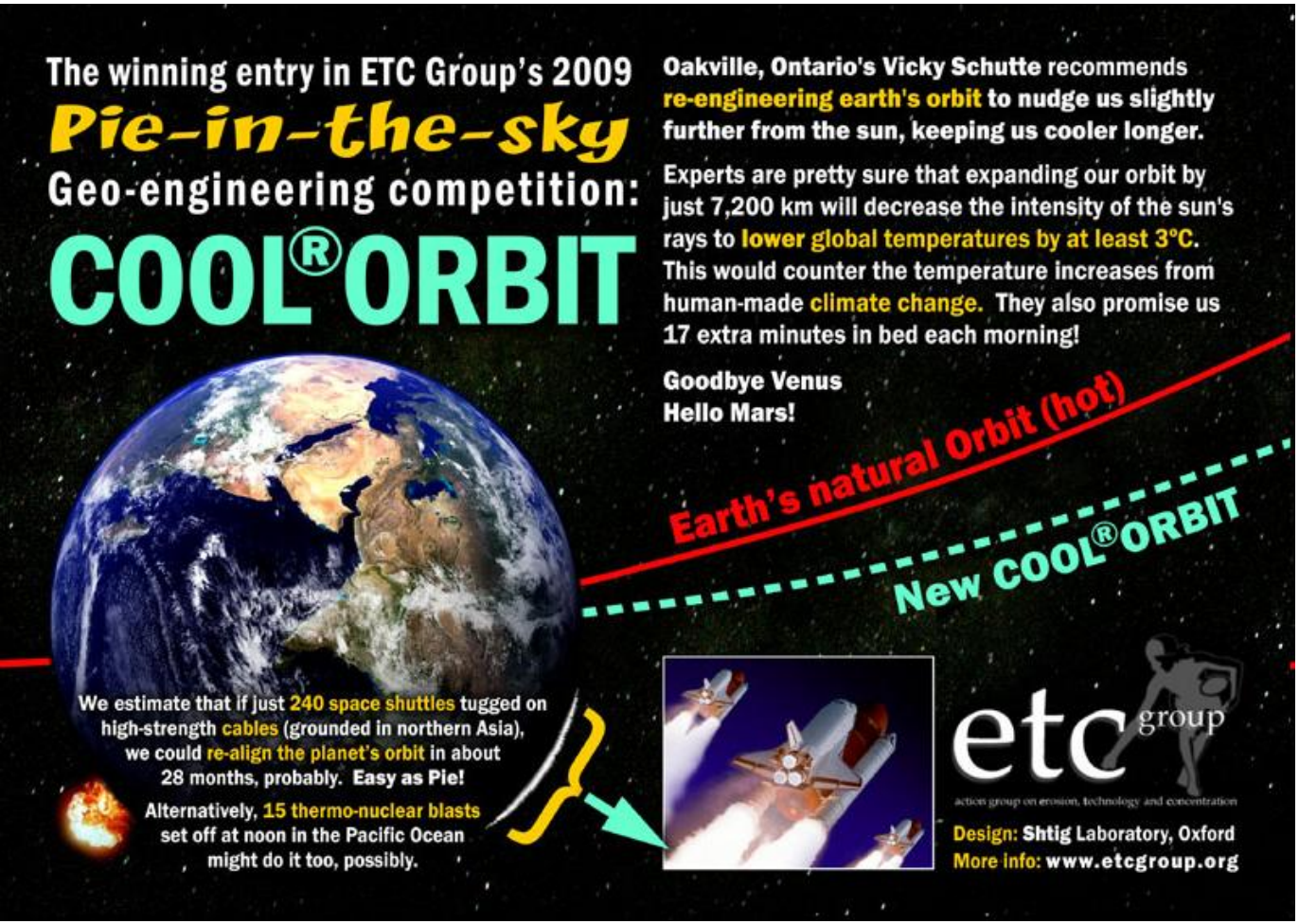
Other SRM proposals

1. whiten deserts
2. more reflective plants
3. paint roofs and streets in white
4. more reflective glass
5. Float ping pong balls on the oceans



Each Earth inhabitant paints white a surface of 200 m^2

Crazier techniques to reduce solar irradiance



It would require the energy of five thousand, million, million hydrogen bombs to move Earth's orbit 1.5 million km out.
(Ken Caldeira)

Some objections:

- Treats symptoms not cause: excuse not to reduce GHG?
- Environmental impacts include shifting direct to diffuse radiation (impact on solar PV), sky colour, biospheric impacts, carbon storage rate, ozone depletion;
- SRM techiques would not slow the build-up of CO_2 & would do nothing to slow ocean acidification;
- As a substitute for mitigation would require a permanent, increasing commitment for many future generations
- System failure (or decision to halt ongoing geoengineering operation) would commit the world to a period of even more rapid warming than is ongoing today;
- An international agreement on a governance structure is a huge challenge.

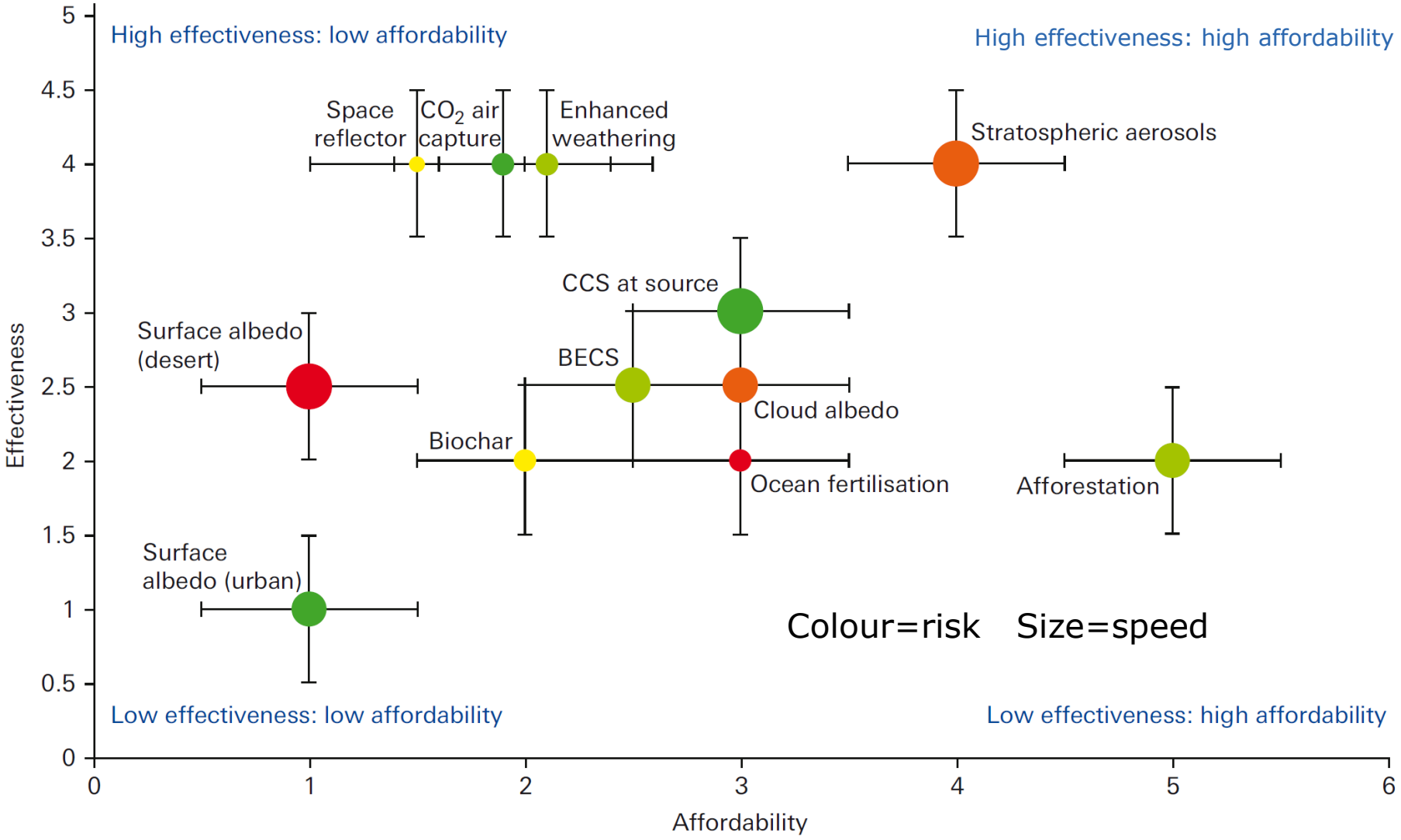
Benefits and risks

Benefits	Risks
1. Cool planet	1. Drought in Africa and Asia
2. Reduce or reverse sea ice melting	2. Continued ocean acidification from CO_2
3. Reduce or reverse land ice sheet melting	3. Ozone depletion
4. Reduce or reverse sea level rise	4. No more blue skies
5. Increase plant productivity	5. Less solar power
6. Increase terrestrial CO_2 sink	6. Environmental impact of implementation
	7. Rapid warming if stopped
	8. Cannot stop effects quickly
	9. Human error
	10. Unexpected consequences
	11. Commercial control
	12. Military use of technology
	13. Conflicts with current treaties
	14. Whose hand on the thermostat?
	15. Ruin terrestrial optical astronomy
	16. Moral hazard – the prospect of it working would reduce drive for mitigation
	17. Moral authority – do we have the right to do this?

Robock et al., GRL (2009)

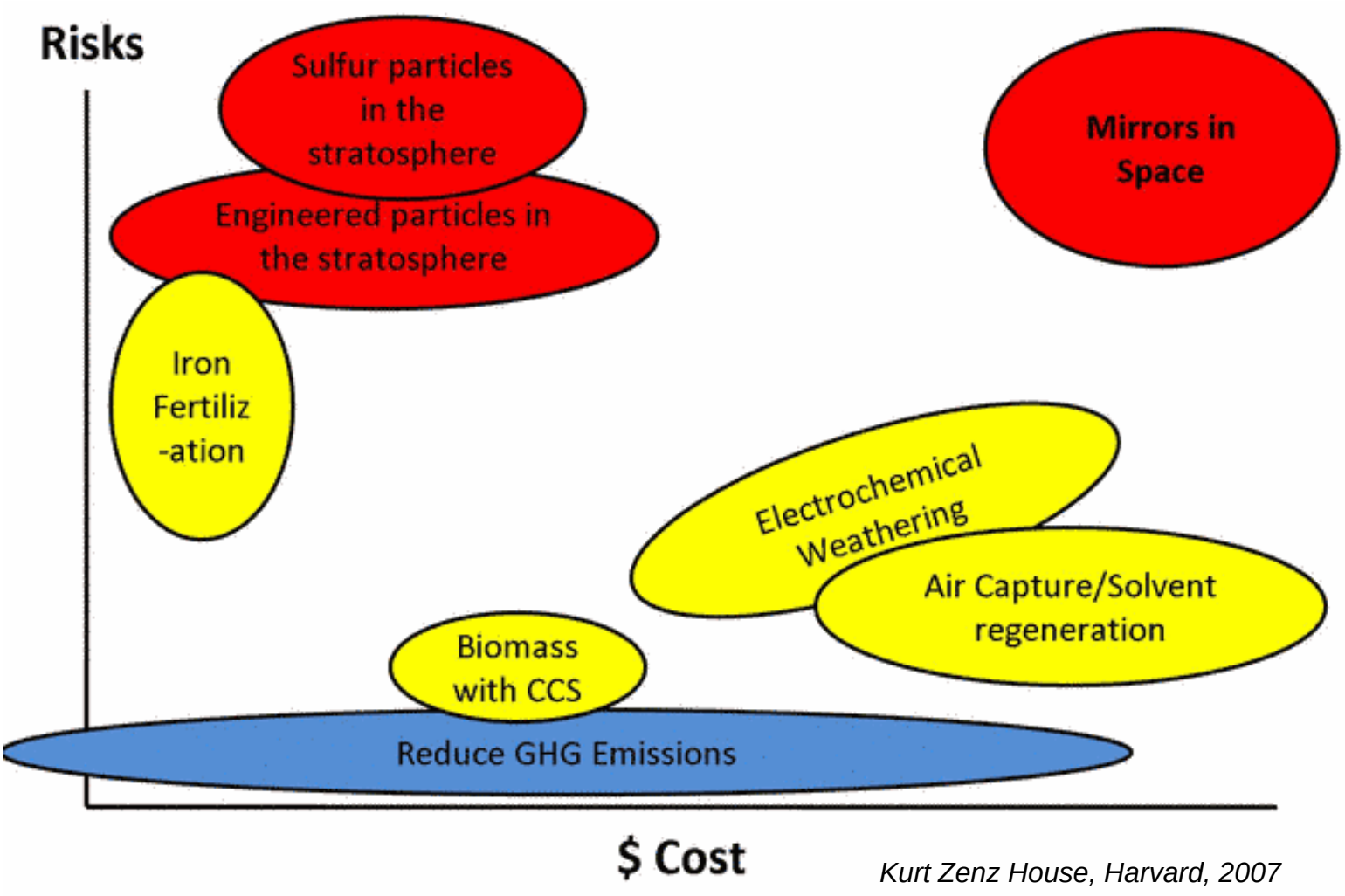
Abridged from:
*Robock, A., 2008: 20 reasons why geoengineering may be a bad idea. Bull. Atomic Scientists, **64**, No. 2, 14-18.*

Ranking geo-engineering schemes



Royal Society 2009

Ranking geo-engineering schemes



Kurt Zenz House, Harvard, 2007

Remaining issues

Hysteresis effects in climate system ?

Are the models good enough ?

How to carry out full risk assessment?

Are large scale experiments needed ?

Ethical, political and legal aspects...

Ethical, political and legal aspects

" On the issue of ethics, I feel we would be taking on the ultimate state of hubris to believe we can control the Earth." *J. Kiehl (2006), Climatic Change*

Is it morally tolerable to deliberately make massive changes to the natural environment?

Winners and losers.

"How cold do we want it ?" "Who decides?" "Whose hand is on the thermostat?"

Governance structure with sufficient transparency is needed.

UN – IPCC like structure ?

How to avoid unilateral implementations ? (reason for war ?)

UN Convention on the Prohibition of Military or any Other Hostile Use of Environmental Modification Techniques (ENMOD) 1978

Internationally accepted rules needed…

“We will take care of it..... ” ???

Forget about a future filled with wind farms and hydrogen cars. The Pentagon's top weaponeer says he has a radical solution that would stop global warming now - no matter how much oil we burn.

Lowell Wood as portrayed in *Rolling Stone* (Nov. 2006)

Role of scientists

Scientists will be asked for advice, as well as for basic research.

Need to assess limitations of schemes.

How to avoid premature implementation?

moratorium?

> While a strong scientific basis is necessary for geoengineering, it is far from sufficient. Many ethical and legal issues must be confronted and questions arise as to governance and monitoring, as several authors have noted (e.g. Kellogg and Schneider, 1974; Schneider, 1996; Bodansky, 1996). A useful step might be for scientists to defer participation in geoengineering interventions (while supporting research), which moratorium would continue until acceptable agreements were in hand. Such an agreement would, ideally, include provision for expert, international peer review before actions would be mounted, for significant public involvement, and the establishment of a qualified agency to oversee the design, implementation and monitoring of the experiment.

R. J. Cicerone (2006), Climatic Change

Thank You