



A quick fix with a silver lining

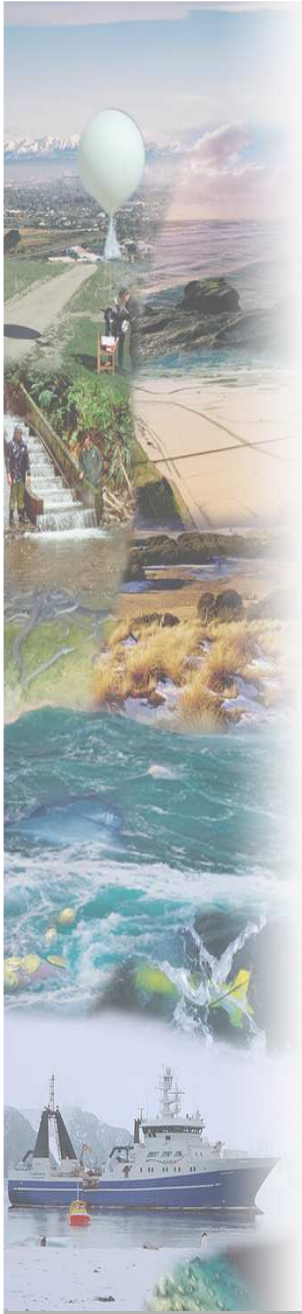
Atmospheric Geoengineering —

Mike Harvey, NIWA - Wellington

GEO-ENGINEERING IMPLICATIONS AN INTERACTIVE WORKSHOP

SCIENTIFIC, TECHNOLOGICAL AND GEOPOLITICAL
ASPECTS OF GEO-ENGINEERING SCHEMES:
IMPLICATIONS FOR NEW ZEALAND

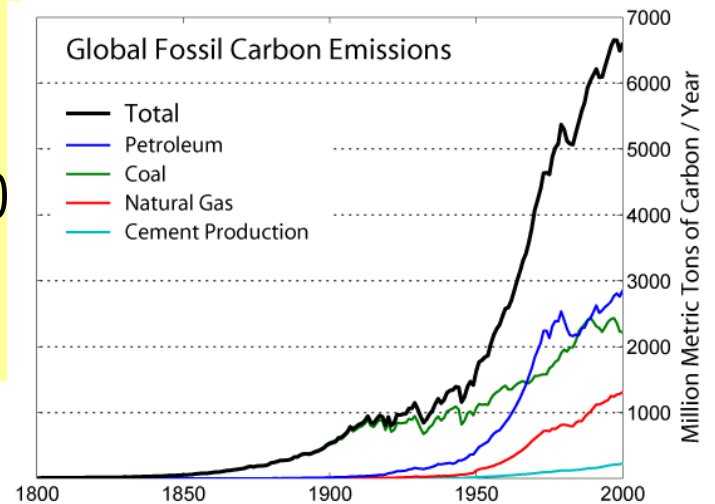
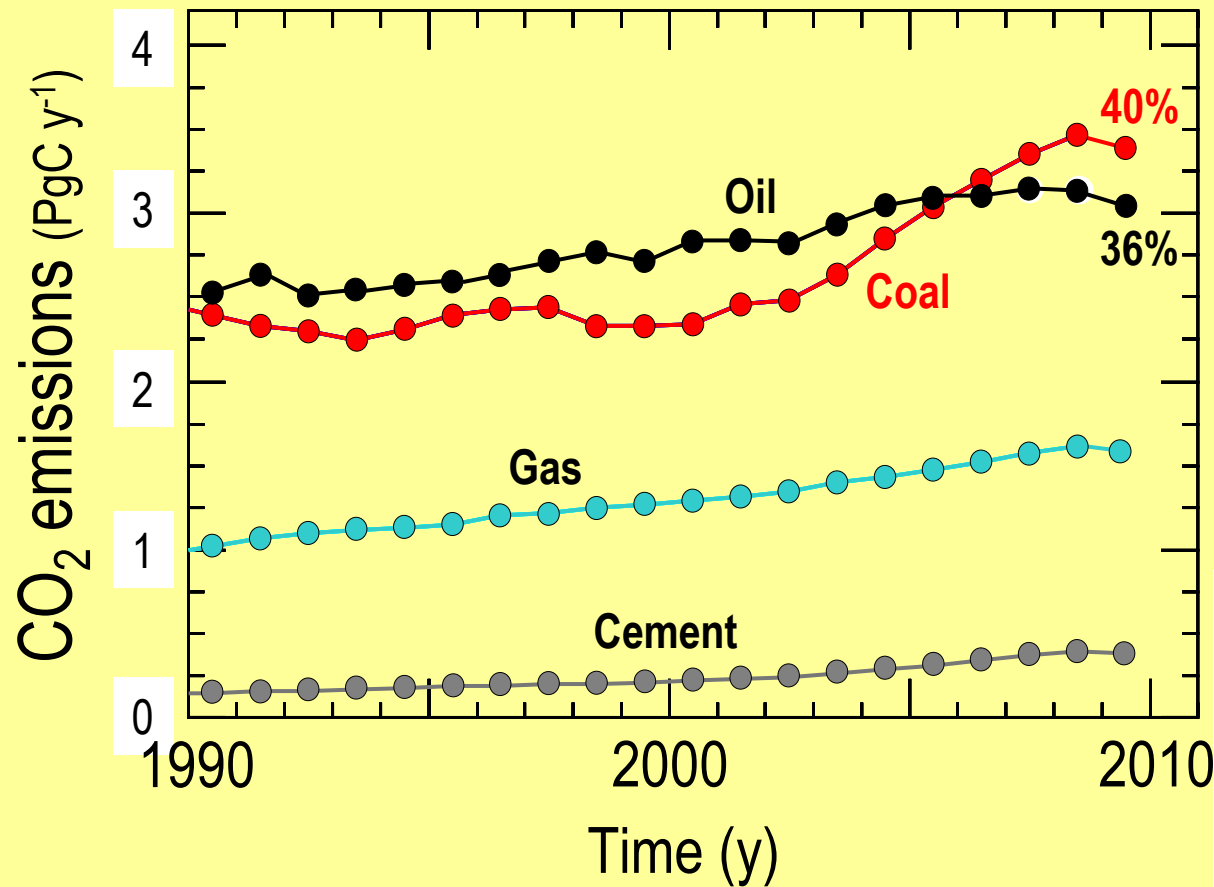
the ROYAL
SOCIETY *of*
NEW ZEALAND
TE APĀRANGI



Outline

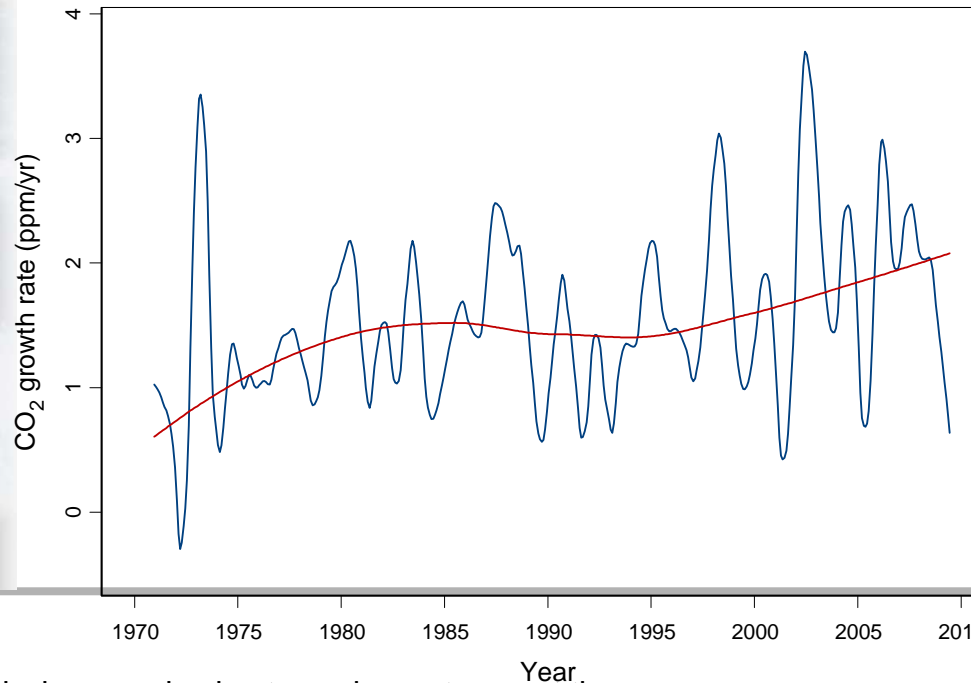
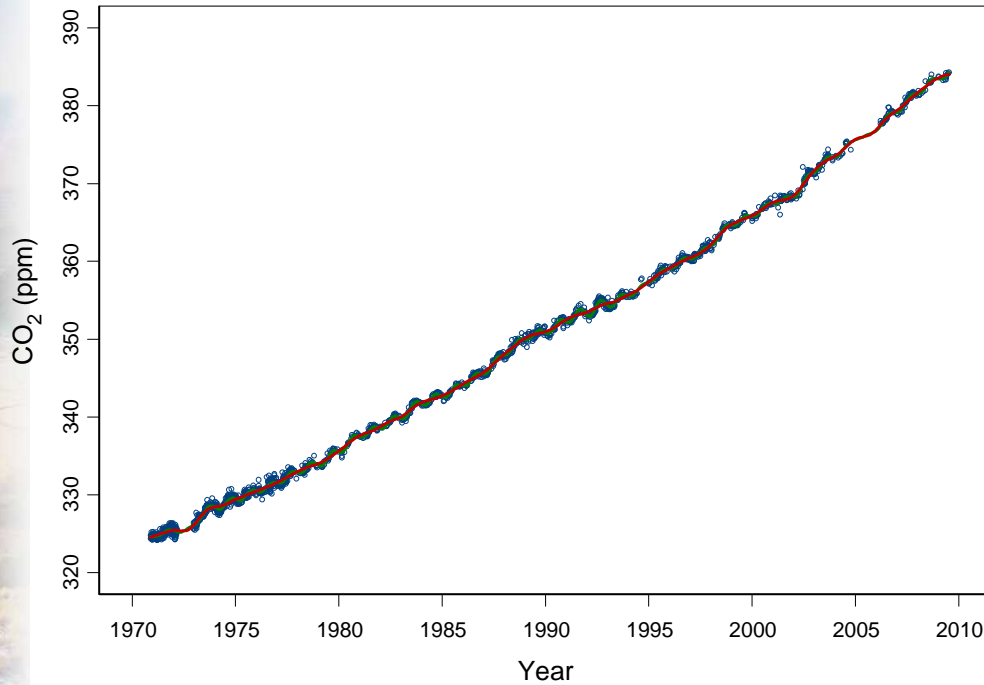
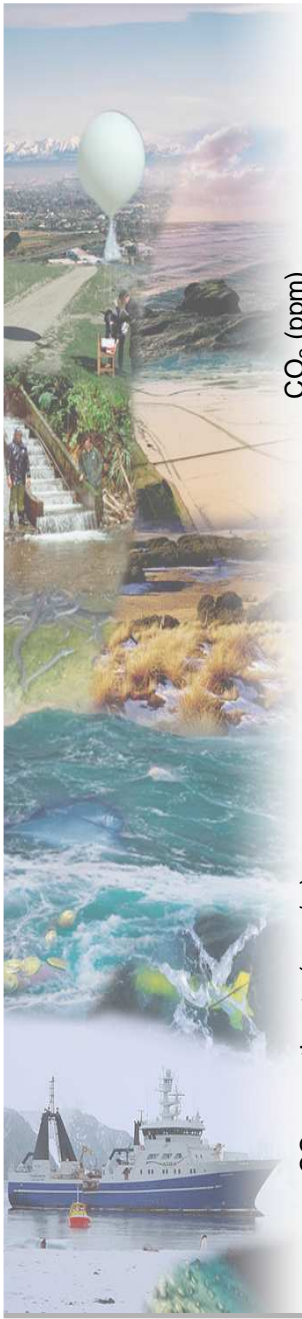
- Motivation for geoengineering
- Outline of atmospheric schemes
- Choice of scheme
- Detail on a couple of schemes
- Debate

Fossil carbon emissions



Total approaching 9PgCy⁻¹

<http://www.globalcarbonproject.org/carbonbudget/>

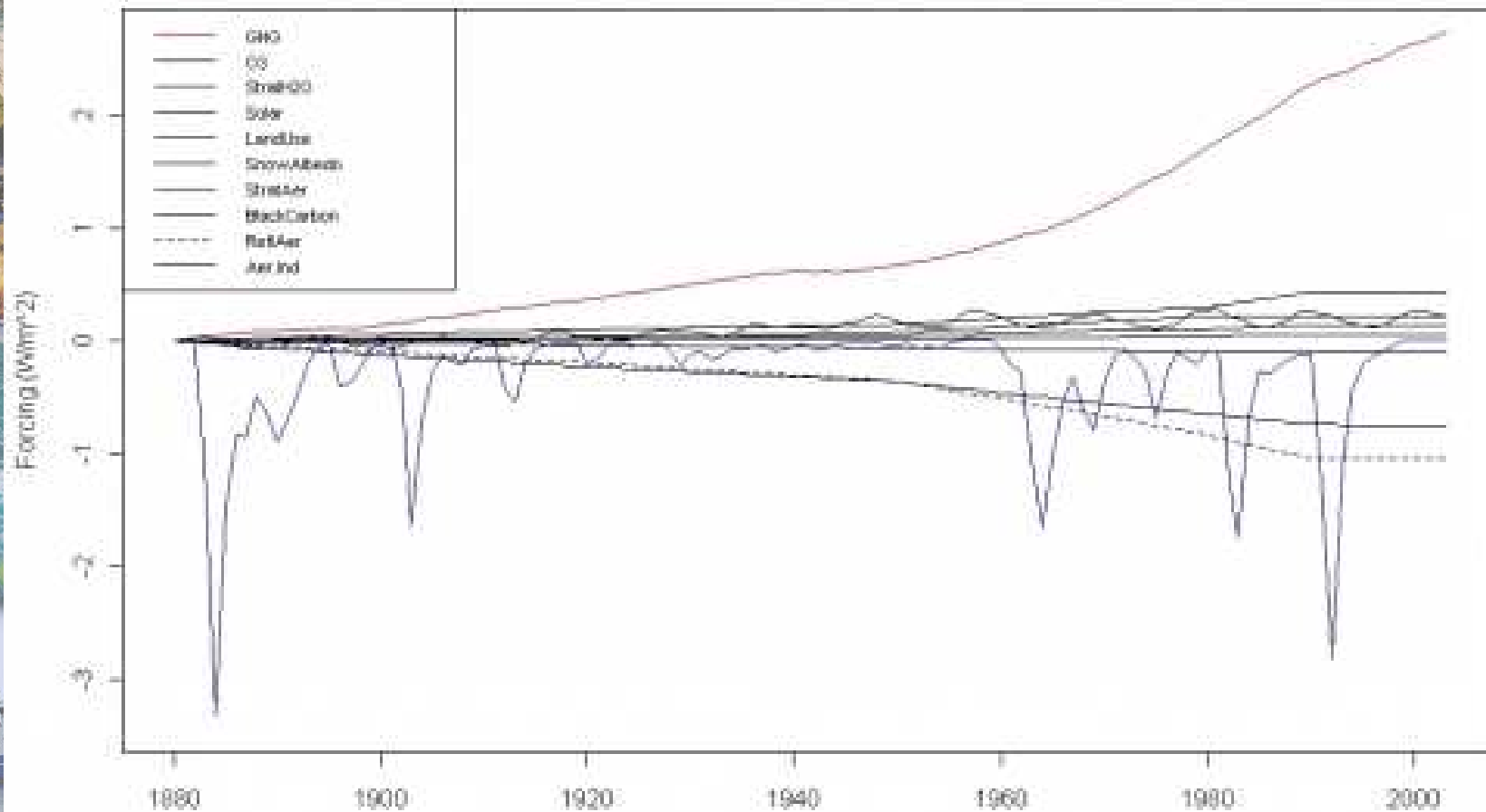


Carbon Dioxide trend and growth at Baring Head



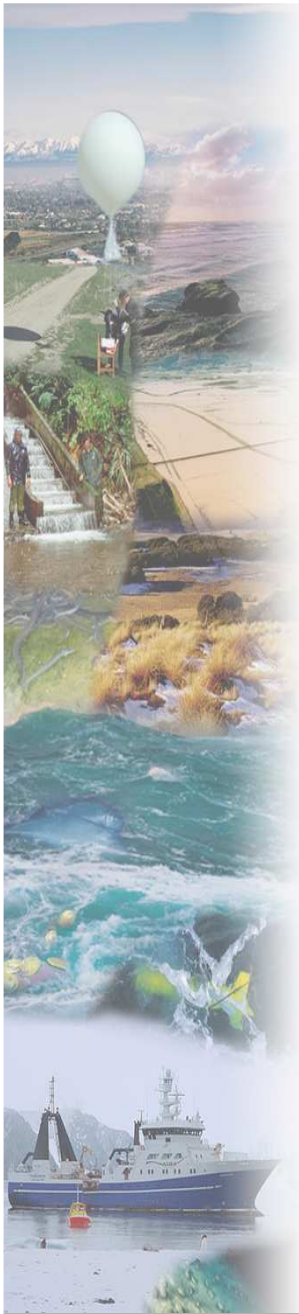
Around 45% of emission remains in atmosphere at current time

Evolution of radiative forcing components

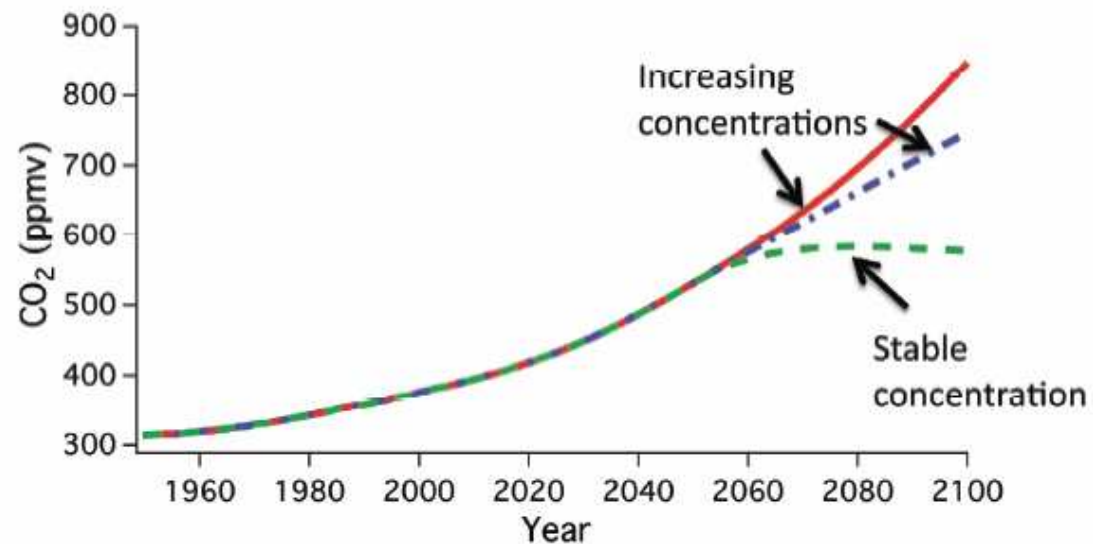
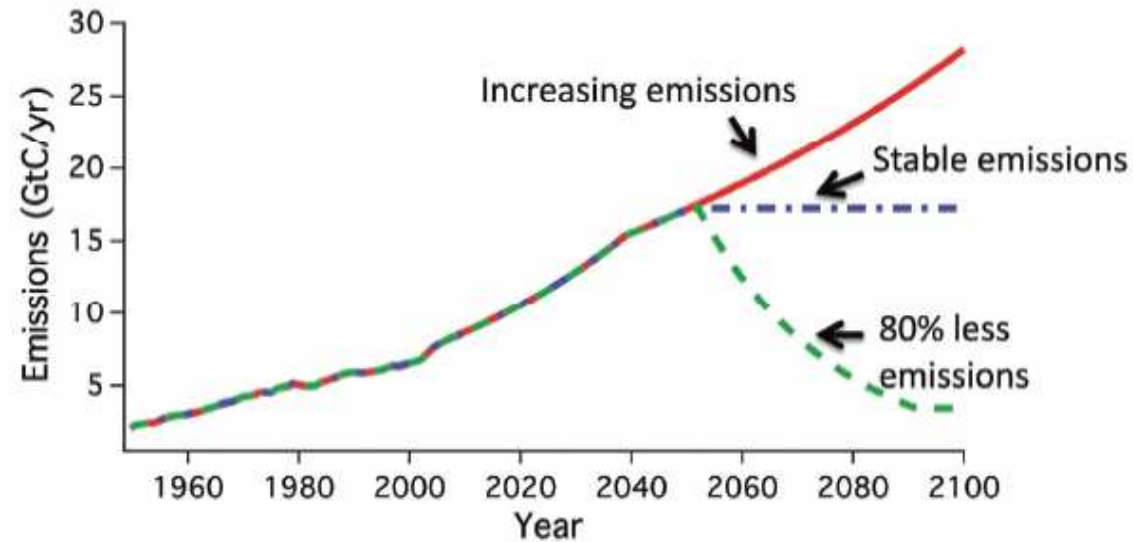


NASA GISS

The only positive (warming) forcing which has reached a level greater than 1 W/m^2
There are episodic large negative forcings from volcanic aerosol injection – leads to proposals for anthropogenic enhancement

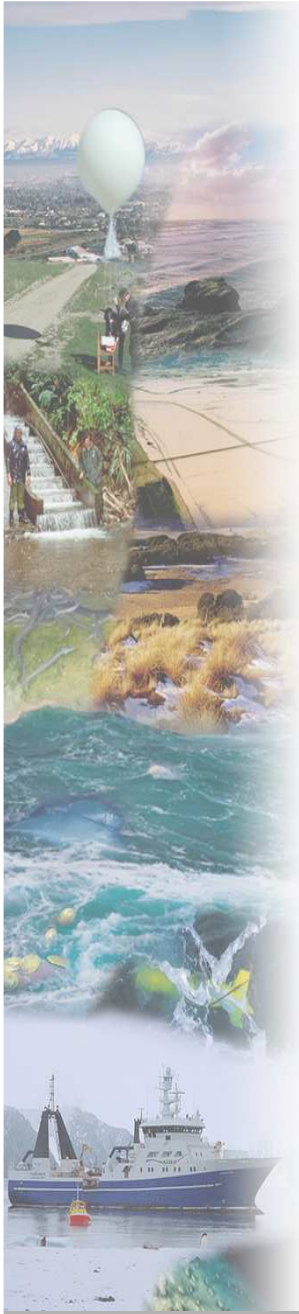


The need for deep cuts in carbon emission to stabilise the atmosphere



Climate Stabilisation targets NRC ISBN: 978-0-309-15176-4
Cmmttee on stabilisation targets / Solomon et al

Geoengineering proposals



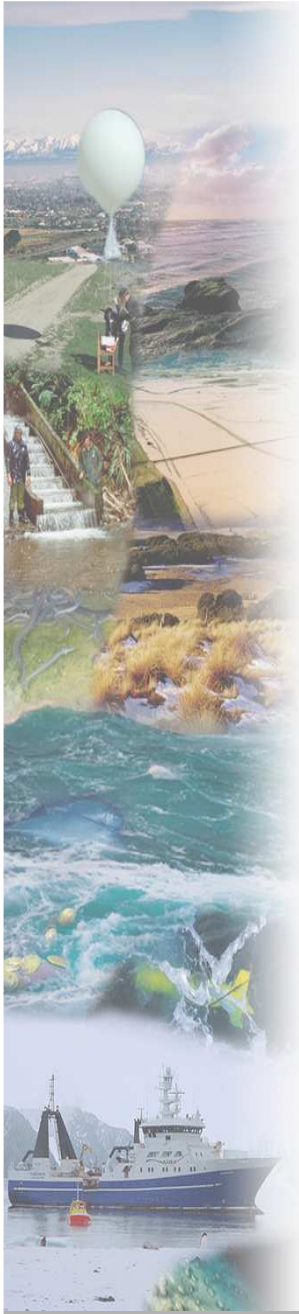
Halt runaway climate change

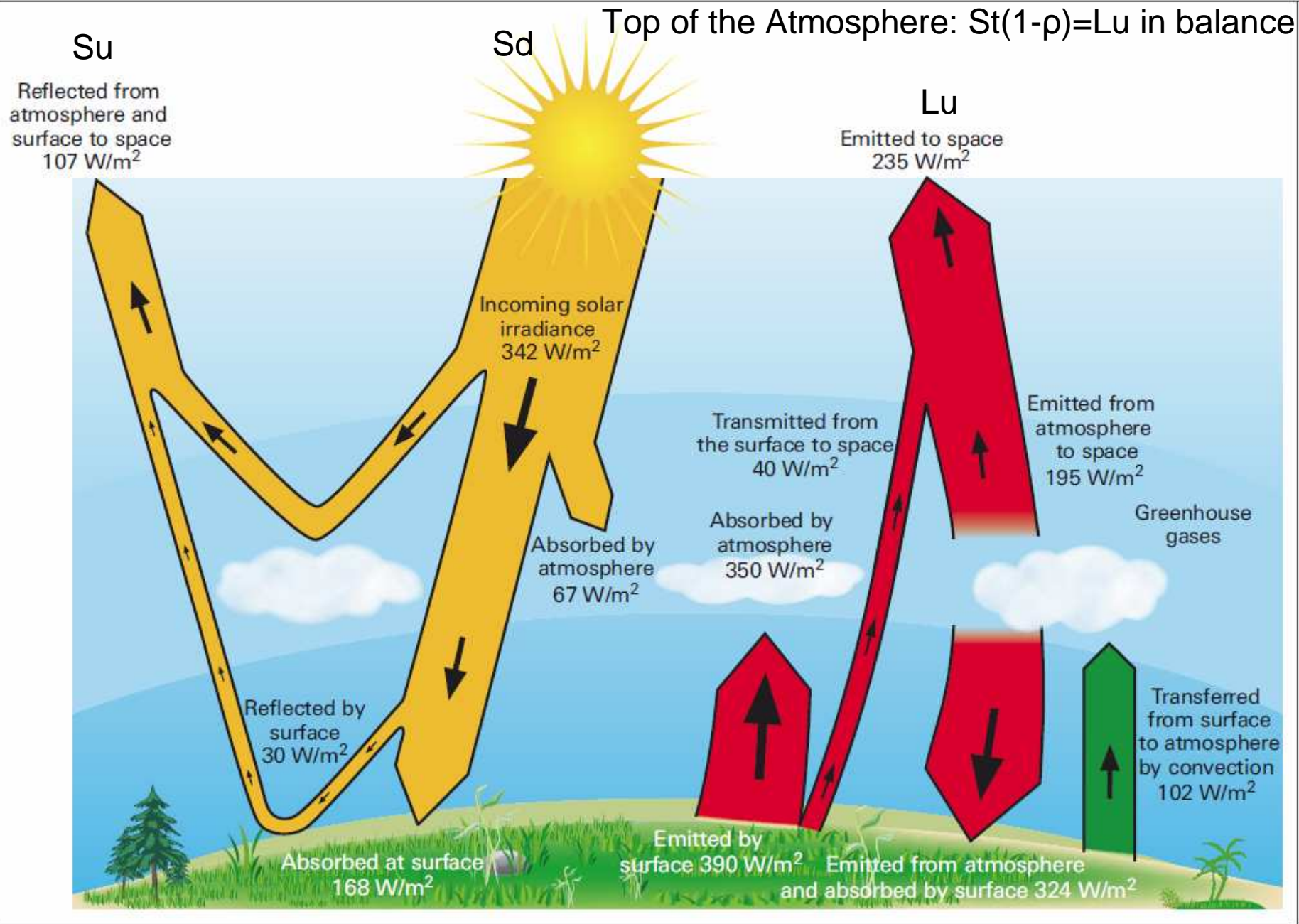


Buy time ahead of long-term solution

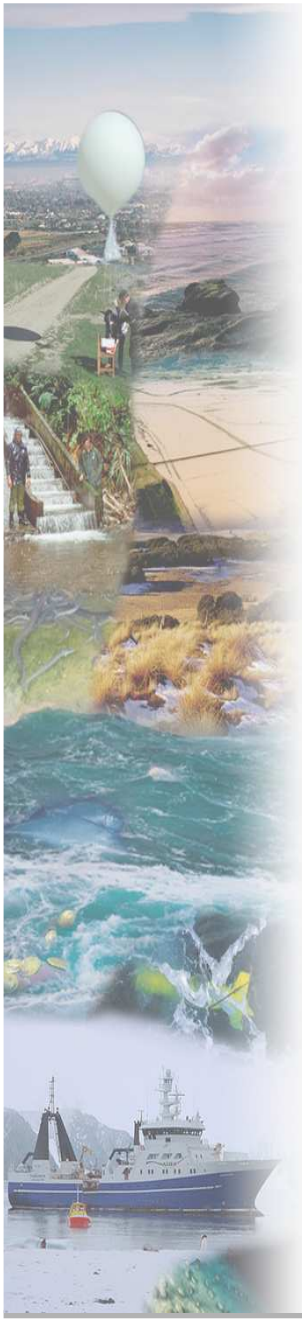
Geoengineering proposals

- Two methods for modifying the earths radiation balance:
- Carbon Dioxide Removal (CDR)
 - Long Wave Infrared
- Solar Radiation Management (SRM)
 - Short Wave Solar
 - techniques to counteract global warming by modifying by ~1% the Earth radiation balance rather than removing the primary causative agents – the greenhouse gases





Some ideas...



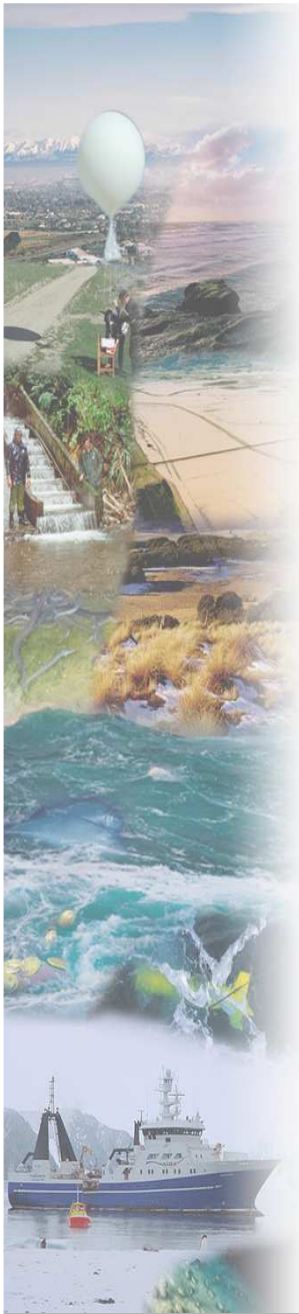
NERC Planet Earth, cover by Oliver Burston

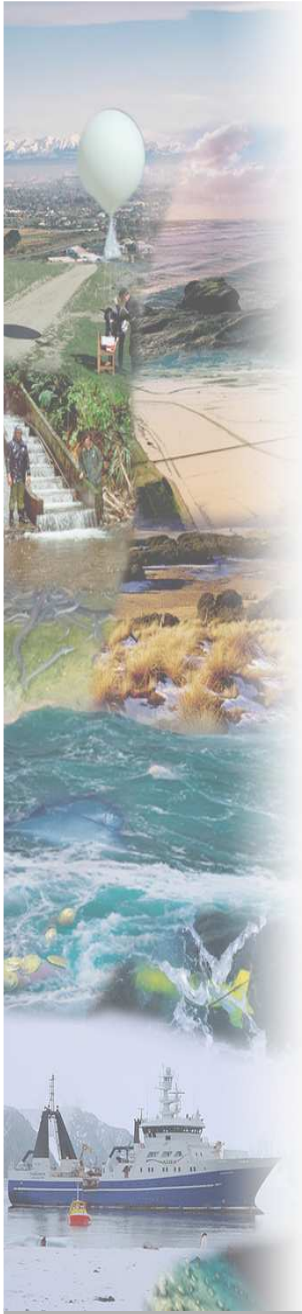
Atmospheric Solar Radiation Management

Atmospheric projects

- Stratospheric sulfur aerosols
- Reflective aerosols or dust
- Cloud methods
 - Cloud whitening / marine cloud brightening / cloud reflectivity enhancement (CCN)
 - Cloud seeding
 - Ocean sulfur cycle enhancement (with OIF)
- Reflective balloons
- Low stratospheric soot

- Air capture (CDR)





Other Solar Radiation Management

Terrestrial albedo modification

- Cool white roof
- Reflective sheeting (in the desert)
- Ocean litter

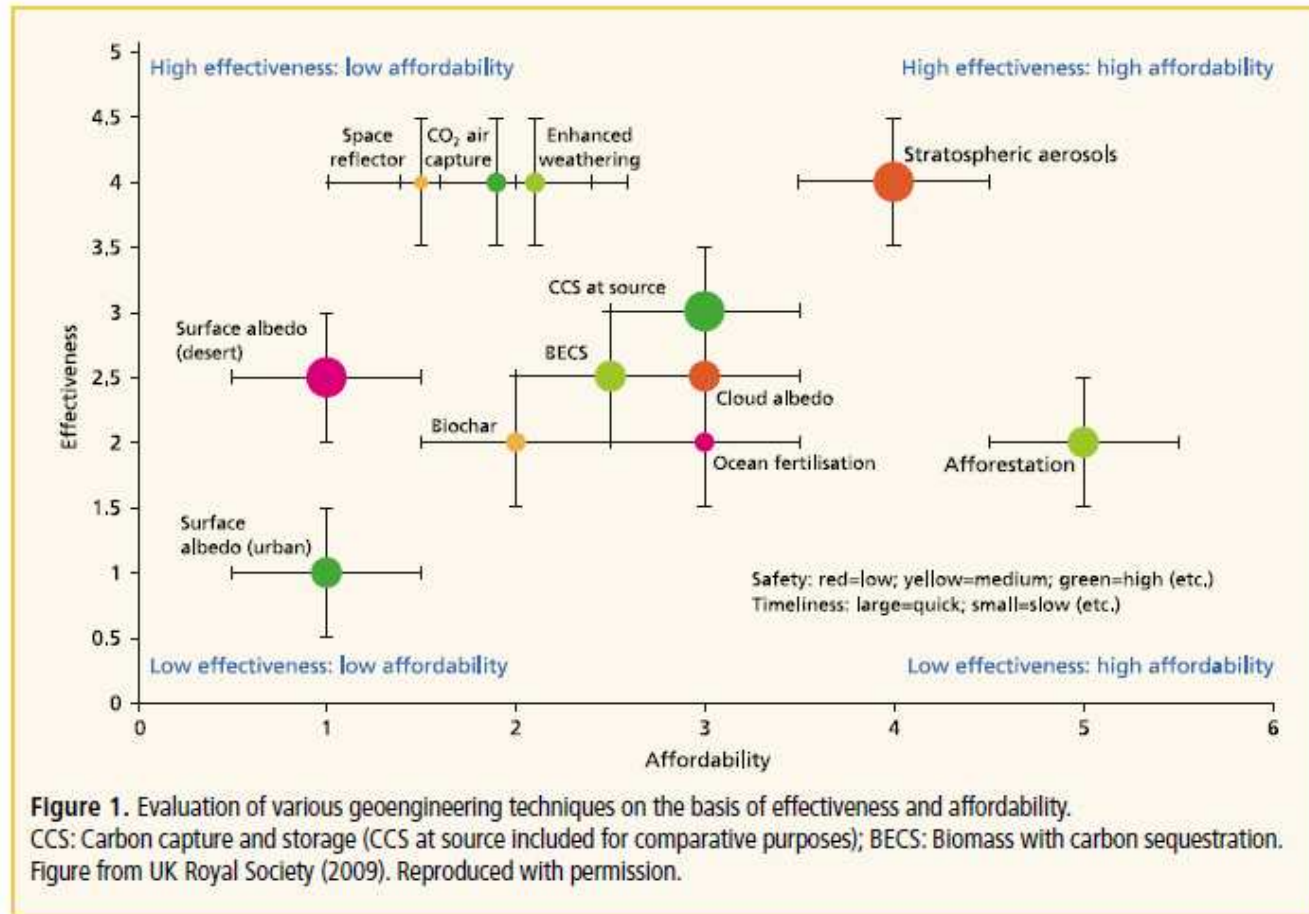
Farming, forestry, and land management

- Forestry
- Grassland management
- High-albedo crop varieties

Space projects

- Space mirrors
- Light dispersive optics in space

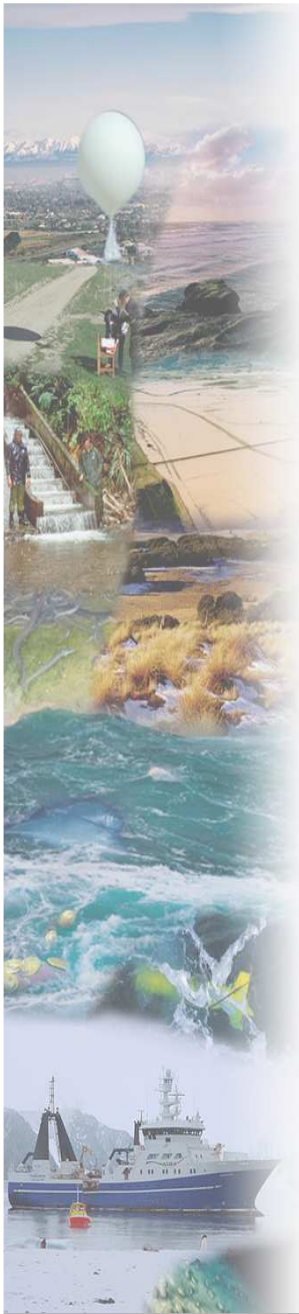
How to rank?



“Given the present incomplete state of knowledge..... This is subjective”

Economists ranking

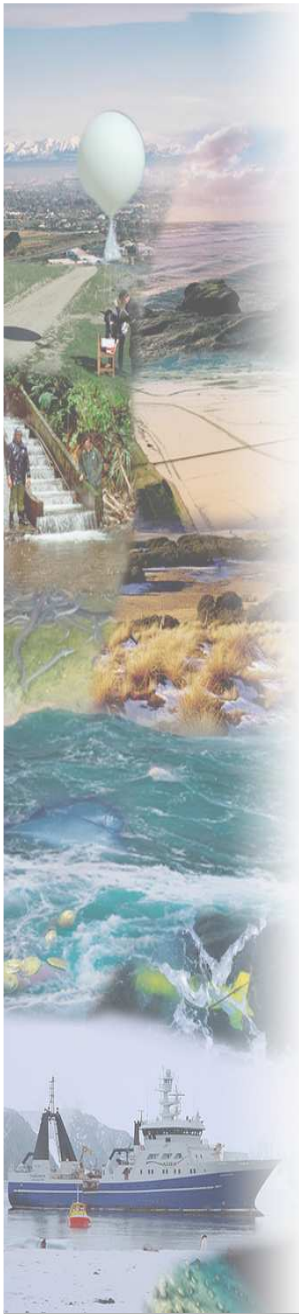
Very Good	<ol style="list-style-type: none"> 1. Marine Cloud whitening 2. Energy R&D 3. Stratospheric Aerosol Injection Research 4. Carbon Storage Research
Good	<ol style="list-style-type: none"> 5. Planning for adaptation 6. Air Capture Research
Fair	<ol style="list-style-type: none"> 7. Technology Transfers 8. Expand and Protect Forests 9. Stoves in developing nations
Poor	<ol style="list-style-type: none"> 10. Methane Reductions portfolio 11. Diesel vehicle emissions 12. \$20 OECD carbon Tax
Very Poor	<ol style="list-style-type: none"> 13...Global CO₂ taxes



Atmospheric Solar Radiation Management

Atmospheric projects

- Stratospheric sulfur aerosols
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Method 1: stratospheric aerosol injection

- Injection of SO_2 , H_2S or other fluidised oxides MgO , Al_2O_3 etc or “designer” particles with optimal reflective properties
- Injection at equator by space elevator, aircraft or balloon, rockets
- -0.75 Wm^{-2} per TgS (Residence 2.5 yrs is long for aerosol)
- 1 Wm^{-2} requires 0.53 Tg S a^{-1} (Mount Pinatubo 10 TgS)
- Annual costs? \$4 to \$40b

“The space Elevator” concept

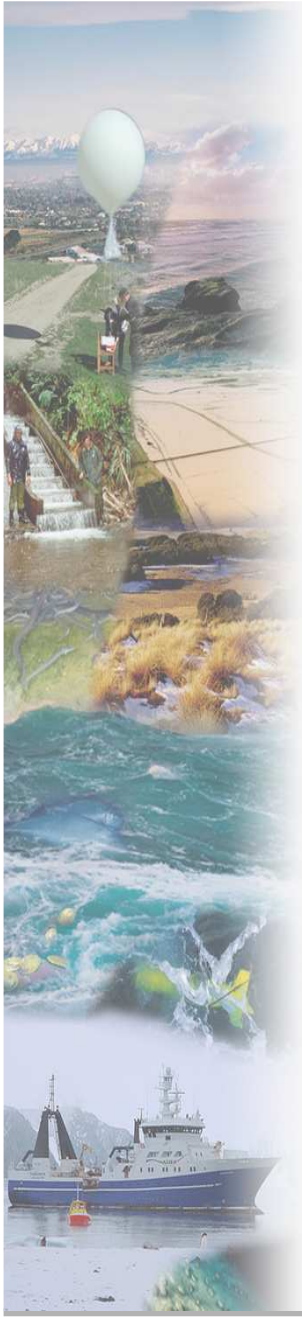
The maximum height of an untapered column that can just support its own weight is illustrated in these three towers for steel, aluminum, and carbon/epoxy composite materials.

• 114-km carbon/epoxy composite tower limit.

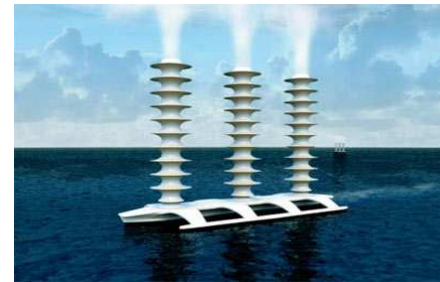
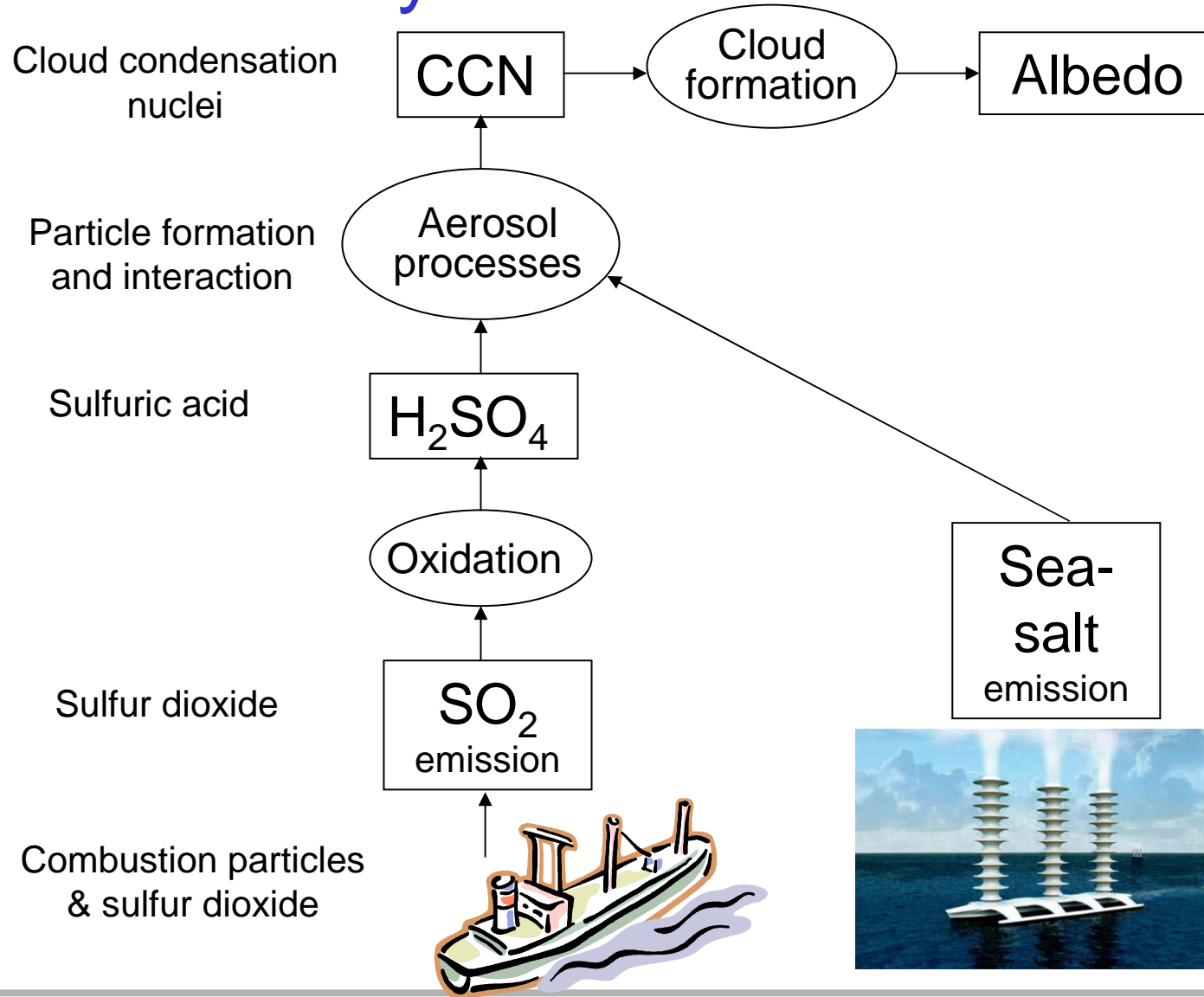
• 15-km aluminum tower limit.

• 5-km steel tower limit.

Method 2: tropospheric aerosol injection / cloud whitening



Chemistry

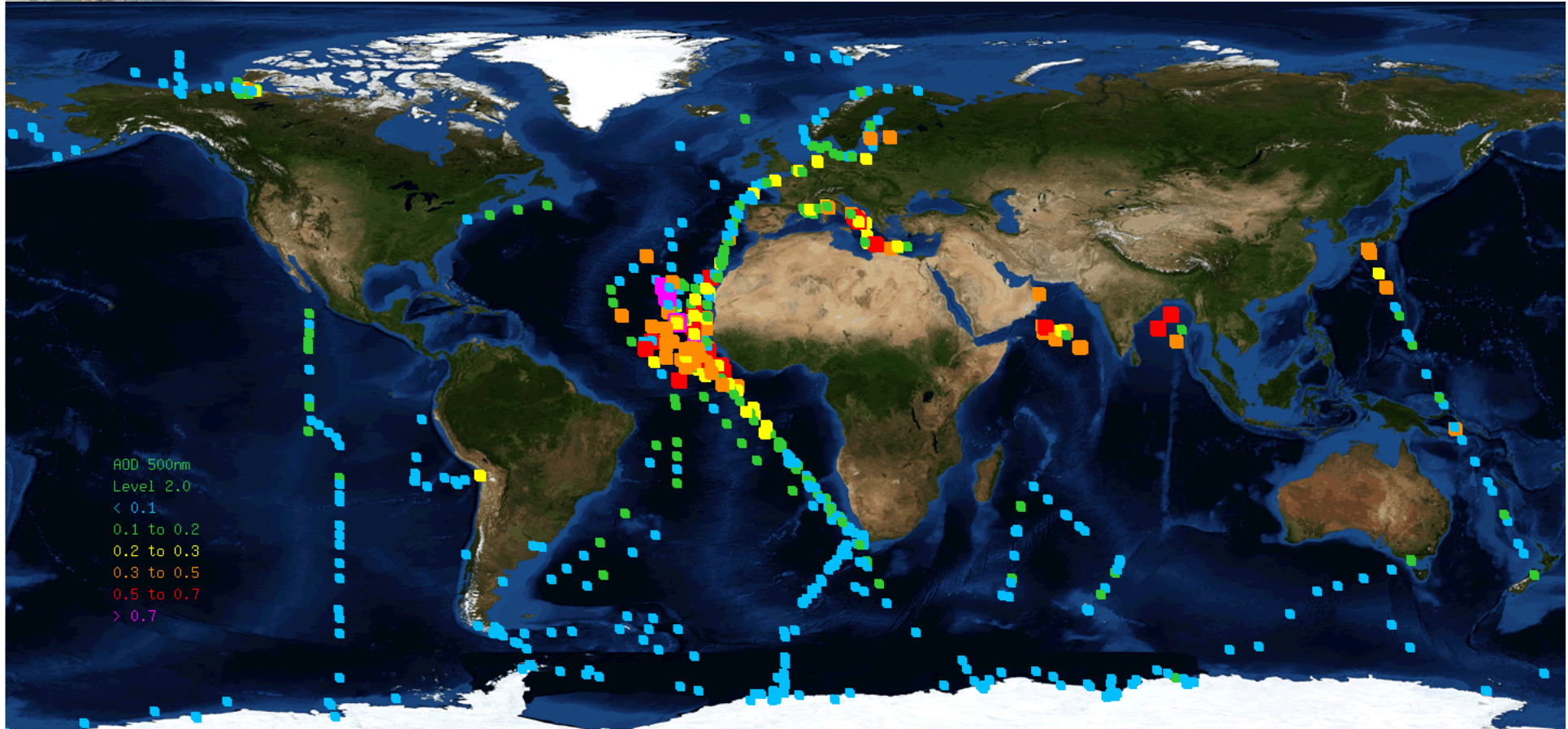




Shiptracks, seen from space, are an example of the indirect effect. Ships sailing beneath these clouds have released particles which have seeded them with more CCN, creating lines of enhanced reflectivity.



Maritime Aerosol Network global coverage (Level 2)

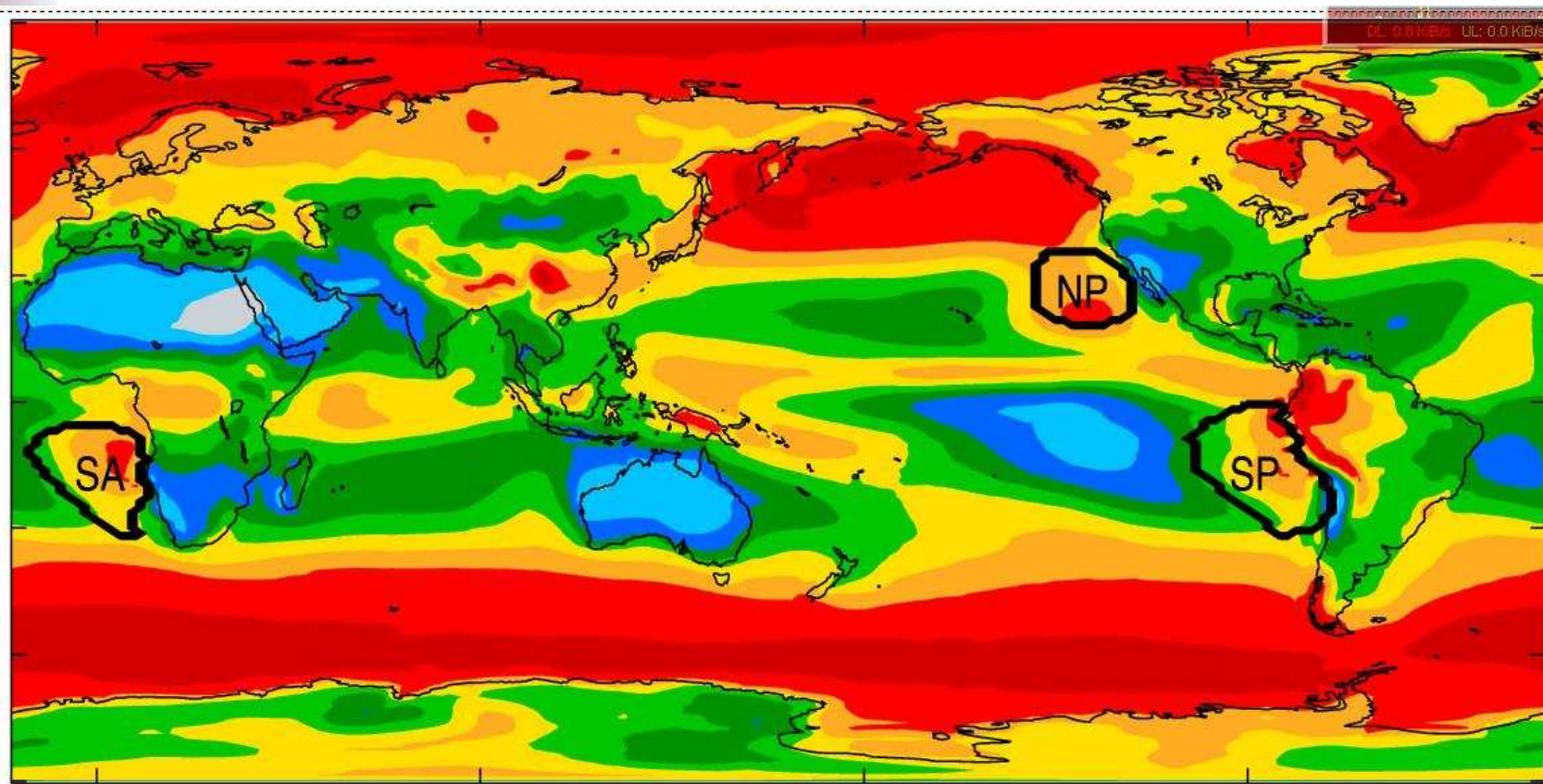


Maritime Aerosol Network - NASA GSFC

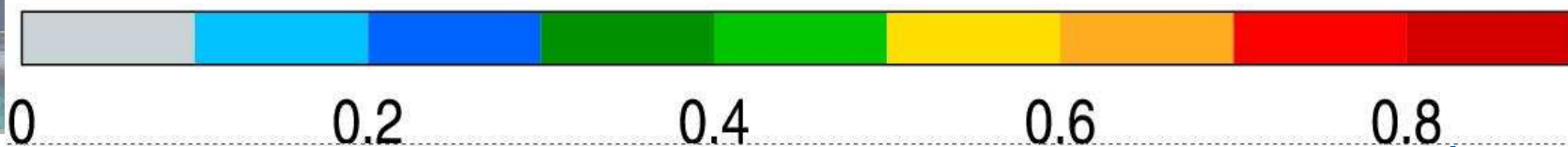
Smirnov et al 2009 – Aerosol optical depth over the ocean basin.
We see lower optical depth in Southern hemisphere
Clouds may be more susceptible to modification

Includes NIWA measurements thru W Pacific

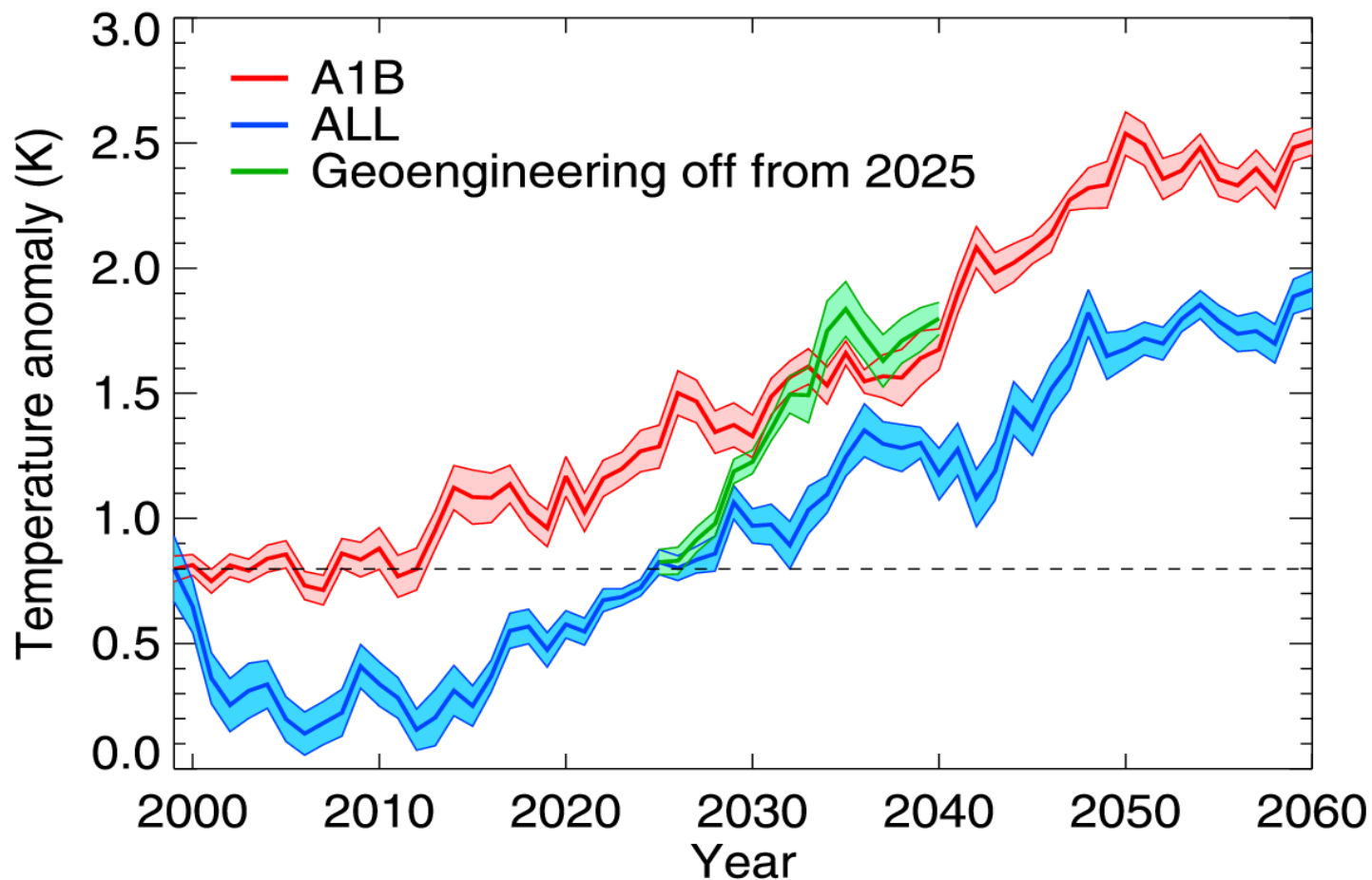
Where to seed? – a model experiment



Control simulation of fractional cloud of model HadGEM2-AML

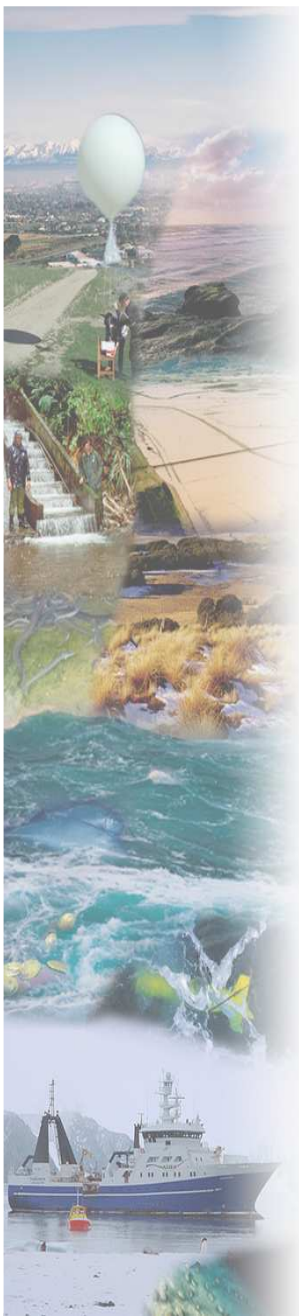


Where to seed? – a model experiment



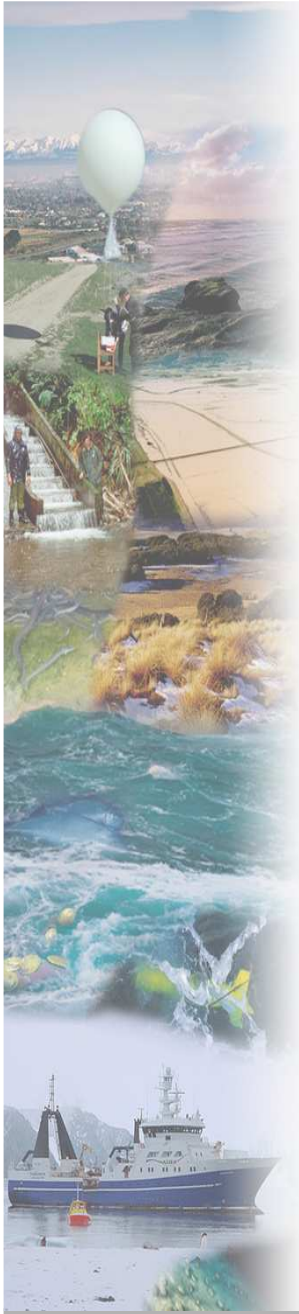
Buy's about 20 yrs of time, recovers if you stop in about 5 years

A1B scenario, Rapid devt, integrated world (1) balanced energy (B)
ALL is 3 expt areas of geoengineering



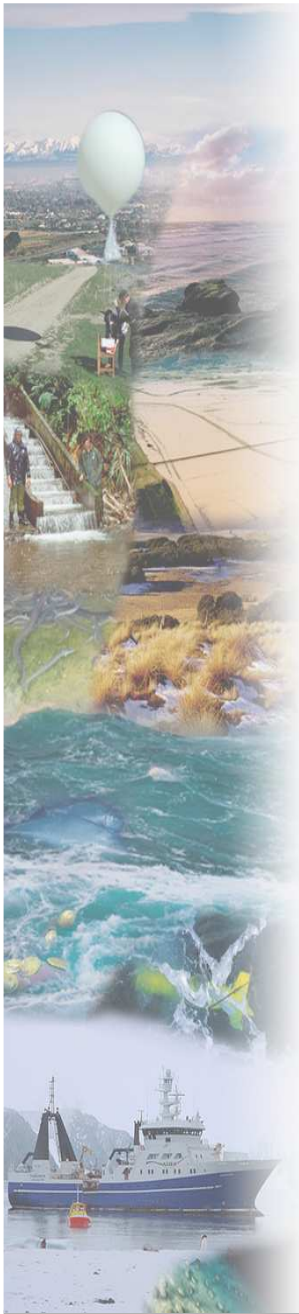
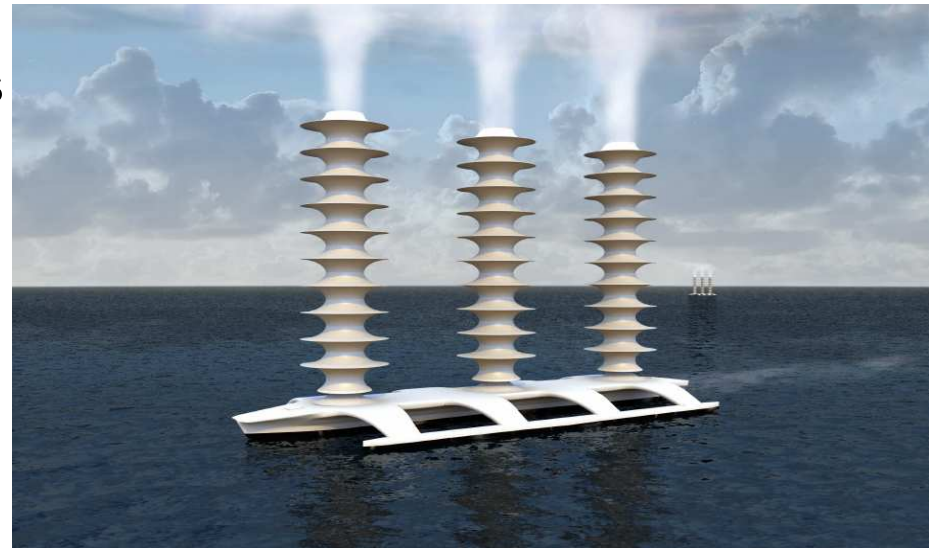
Seeding – practical studies

- Previous attempts at geoengineering or rather weather modification
- One rationale for cloud seeding (this time with ice nuclei rather than other aerosol nuclei) is to enhance rain production processes in cloud
- Seedings done in Tasmania 1964 – 2005
- Possible enhancements – 10% more rain
- The experiments do not provide definitive proof of the enhancement
- With seeding for geoengineering, there is also likely to be heterogeneity and secondary effects e.g. on rainfall and cloud distribution

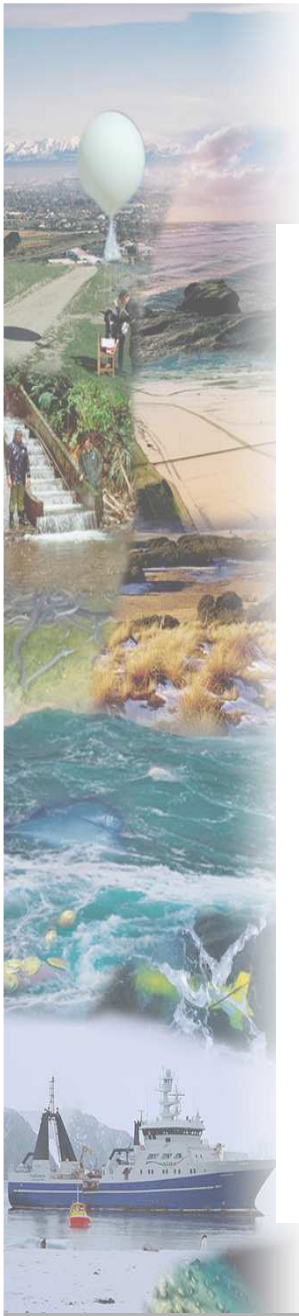


“Albedo” Yachts

- Increase planetary albedo by ~1.5% (0.004)
- <math><1\ \mu\text{m}</math> CCN droplets
- distributing 10^{18} drops a second over oceans with the right cloud conditions would neutralize the thermal effects of a one-year increase of carbon dioxide
- For $2\ \text{Wm}^{-2}$ cooling - say need to seed >30% sc clouds
- Engineering:
 - 300 - 1500 vessels
 - Use Flettner rotor propulsion
 - Costs- ~\$0.1b pa (300 vessels)



Latham, 1990 Nature 347 + Stephen Salter Phil Trans A 2008



Bill Gates Funds Seawater Cloud Seeding, “the Most Benign Form of Geoengineering”



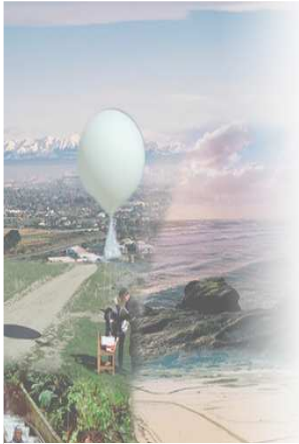
submit to [digg](#)

Bill Gates is getting serious about geoengineering. Back in January, after the failure of governments at the Copenhagen Climate Change summit to do anything serious, the billionaire former head of Microsoft announced he's give nearly \$5 million of his fortune to fund research into geoengineering projects. Recently he announced his first concrete foray into the field: giving \$300,000 to project that would spray seawater into the sky, seeding clouds that would hopefully block some of the sun's UV rays.

The machines, developed by a San Francisco-based research group called Silver Lining, turn seawater into tiny particles that can be shot up over 3,000 feet in the air. The particles increase the density of clouds by increasing the amount of nuclei contained within. Silver Lining's floating machines can suck up ten tons of water per second. If all goes well, Silver Lining plans to test the process with 10 ships spread throughout 3800 square miles of ocean [Inhabitat].



Method 3: Air capture



Two methods

- Photosynthesis (biomass)
- Chemical Scrubbers
- Relatively high cost – but some developments – Klaus Lackner, Columbia + (Global Research Technologies) “Synthetic trees” - based on ion exchange resins
- 1 unit will sink ~1tonne CO₂ per day – scale to millions of units for CO₂ reduction
- Likely costs for stabilisation will be ~5% of global GDP
- Storage?



THE CO₂ SITUATION
Roughly a third of carbon dioxide emissions come from cars, planes, and other vehicles. Scientists are developing scrubbers to capture colorless CO₂ from the outside air.

THE SOLUTION
In physicist Klaus Lackner's plan, a single scrubber, small enough to fit in a shipping container, could capture a ton of CO₂ a day—the output of 75 average U.S. cars. CO₂ spreads quickly, so scrubbing it out anywhere benefits everyone.

HOW IT WORKS

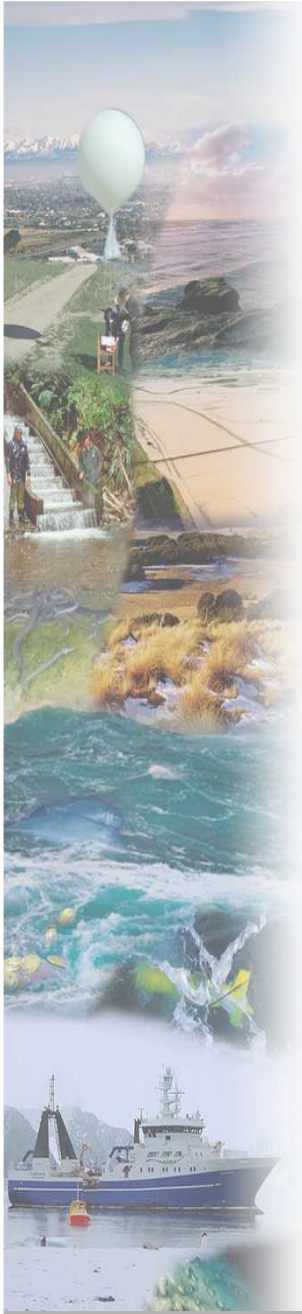
1 Wind blows air through a carousel's plastic filters, which are laced with an absorbing agent that extracts CO₂. When the air reemerges, it contains less CO₂.

2 As filters become saturated, they are lowered into vacuum chambers and rinsed with water vapor, which removes the lightly bound CO₂ from the filters.

3 The filters return to the carousel. The CO₂ is separated from the water, compressed to a liquid, and pumped underground (see following page).

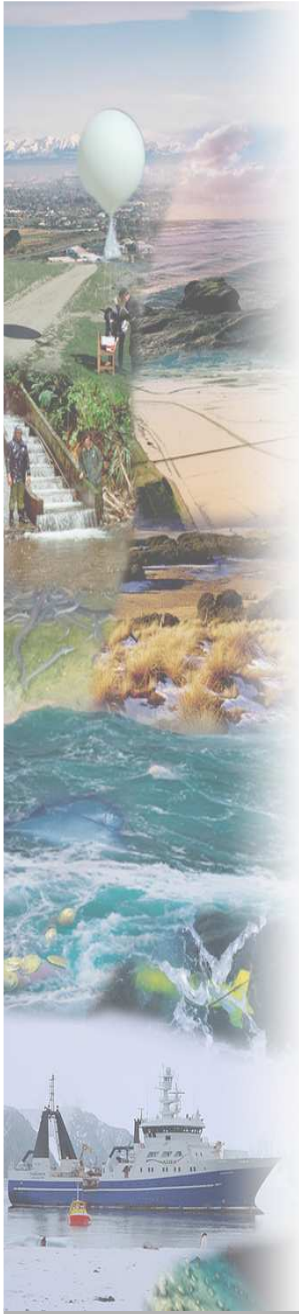
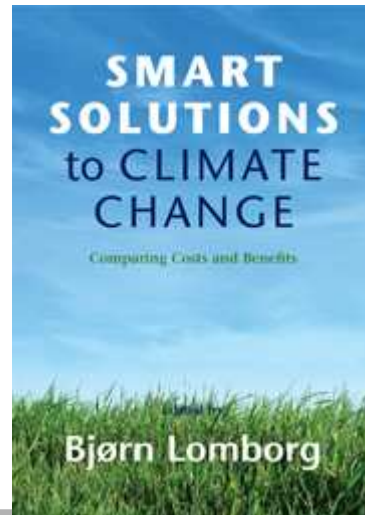
Debate

- Efficacy
- Poor understanding of complex system
- Unintended consequences
- Ethics



Debate

- **Bjørn Lomborg: \$100bn a year needed to fight climate change**
- **Exclusive** 'Sceptical environmentalist' and critic of climate scientists to declare global warming a chief concern facing world
- Lomborg also admitted climate engineering could cause "**really bad stuff**" to happen, but argued if it could be a cheap and **quick** way to reduce the worst impacts of climate change and thus there was an "obligation to at least look at it".



Debate



Schemes to reflect sunlight away from Earth by injecting sulphur into the atmosphere have been called a threat to global biodiversity.

CLIMATE CHANGE

Geoengineering faces ban

Moratorium on schemes to reduce global warming clashes with reports urging more research.

Geoengineering – “unintended consequences”

* Not in all places

Table 1. Benefits and Risks of Stratospheric Geoengineering^a

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?

← Perhaps elsewhere
Could be very detrimental to Amazon

*

*

Not in all places

^aThe right column is an update of *Robock* [2008a].

Acid deposition

Effects on cirrus

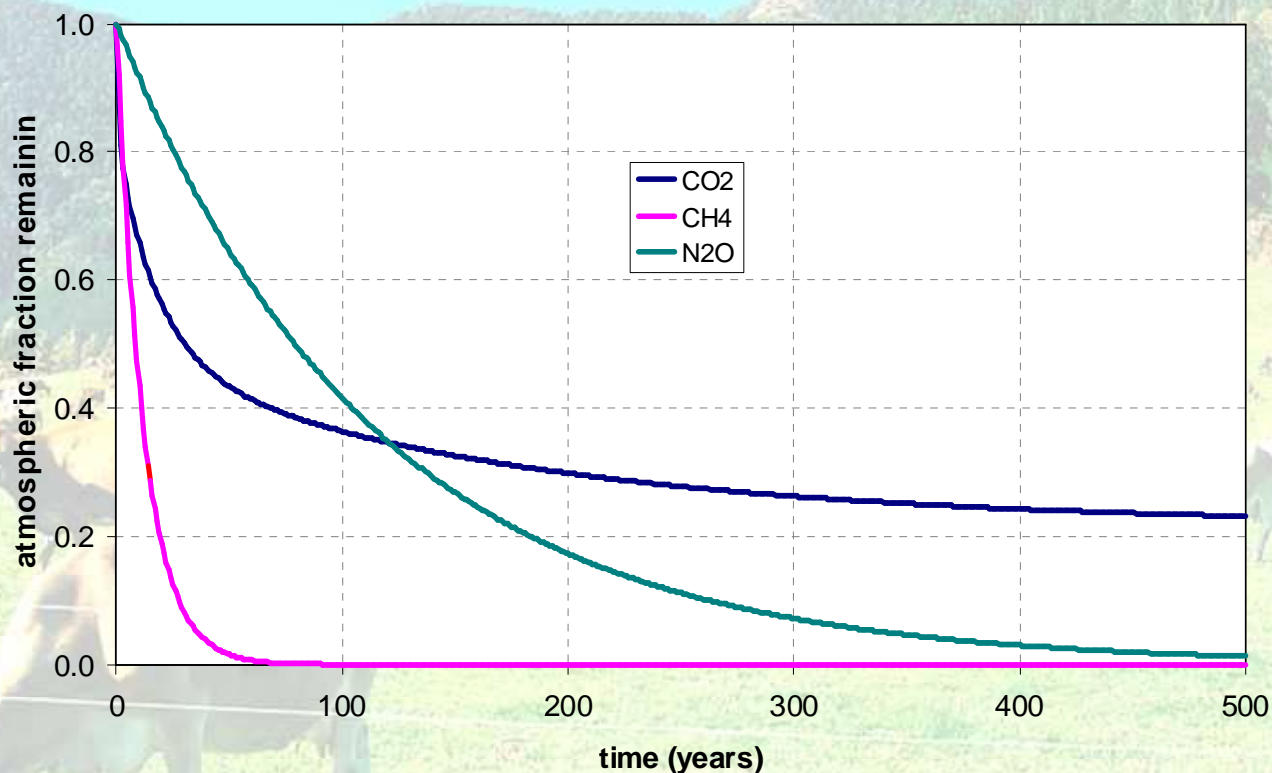
Rainfall and food production / plant growth

Issue of timescales

Aerosols are very short lived (a few years) by comparison With long-lived GHG



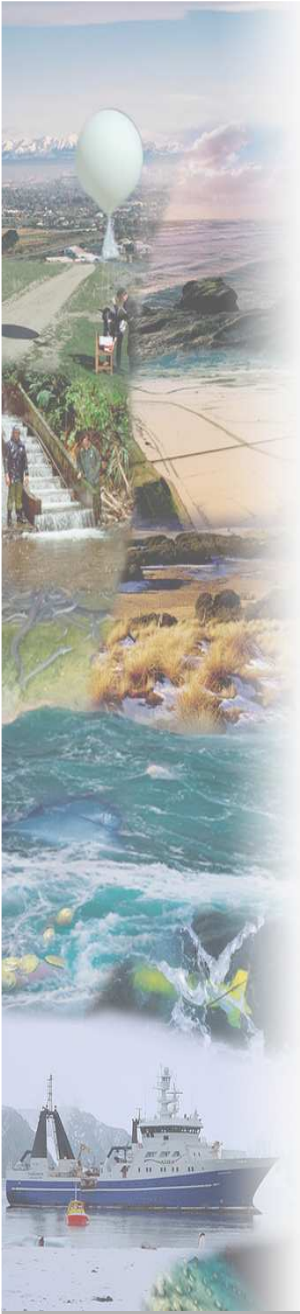
Atmospheric persistences



The persistence of a pulse of CO₂, CH₄ and N₂O injected into the atmosphere, based on the responses reported in AR4 WG1 report. (Note: this is not residence time of individual CO₂ molecules)

Current situation / recommendations

- The IPCC will assess the risks, feasibility, mitigation potential, costs and governance requirements of geoengineering for the first time in its Fifth Assessment Report, due to be released in 2013–14.
- Work towards understanding the processes, efficacy, side effects and mode of action is really just beginning; it requires a strong interdisciplinary approach
- Evolution of models will help us look at the issue - GCM / Chem-Climate Model/ESM but we must remember that not all climate processes are well modelled currently
- Extreme caution is needed before field experimentation especially if reversibility is in doubt



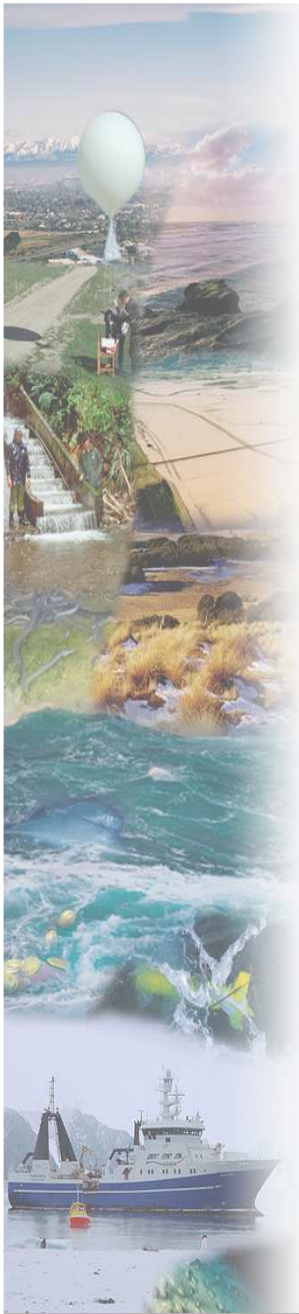
American Meteorological Society recommendations

- ...research to date has not determined whether there are large-scale geoengineering approaches that would produce significant benefits, or whether those benefits would substantially outweigh the detriments.

The American Meteorological Society recommends:

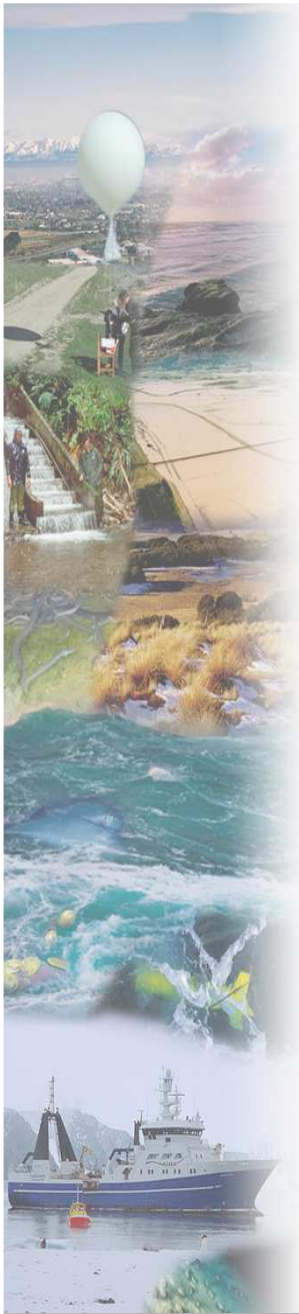
1. Enhanced research on the scientific and technological potential for geoengineering
2. Coordinated study of historical, ethical, legal, and social implications of geoengineering...
3. Development and analysis of policy options to promote transparency and international cooperation in exploring geoengineering options along with restrictions on reckless efforts to manipulate the climate system.

http://www.ametsoc.org/policy/2009geoengineeringclimate_amsstatement.html



References:

- Committee on Stabilization Targets for Atmospheric Greenhouse Gas Concentrations. (2010) Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia National Research Council
- Crutzen, P. (2006). Albedo Enhancement by Stratospheric Sulfur Injections: A Contribution to Resolve a Policy Dilemma? *Climatic Change* 77(3): 211-220.
- Latham, J. (1990). Control of global warming? *Nature* 347(6291): 339-340.
- Lomborg, B. (2010) Smart Solutions to Climate Change. Cambridge University Press
- The Royal Society (2009) Geoengineering the climate: Science, governance and uncertainty. RS Policy Document 10/09 ISBN: 978-0-85403-773-5



Some New Zealand specifics

- New Zealand known for its clear sky and good air quality and visibility (a high aerosol environment would significantly degrade this)
- Water budget and rainfall is critical to the economy: adverse impacts on rainfall need to be considered and avoided
- The science is at an early stage. Other potential impacts will come to light as research develops.

