# 12.340 Global Warming Science

## *Geoengineering*

**Dan Cziczo**

**Thursday, May 10, 2012**

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http://www.technologyreview.com/energy/24157/

# ONLINE SUBJECT EVALUATIONS ARE NOW OPEN

http://web.mit.edu/subjectevaluation

- You have until Monday, May 21 at 9 AM
- Please evaluate all subjects in your list
- Write comments

**Your feedback is read and valued!**

# “Geoengineering” History

Weather modification - The changing of natural weather phenomena by technical means; for example through the microscale of condensation and freezing nuclei.

Terraforming - transform (a planet) so as to resemble the earth, especially so that it can support human life (Oxford Dictionaries, normally attributed to Jack Williamson "Collision Orbit” (1942) although many similarities to H.G. Wells “The War of the Worlds” (1898)).

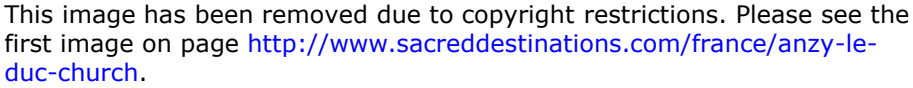

Geoengineering - the deliberate large-scale manipulation of an environmental process that affects the earth’s climate, in an attempt to counteract the effects of global warming (Oxford Dictionaries). Generally attributed to Paul Crutzen (2006) but several earlier works.

http://www.erbzine.com/mag14/marsterr.jpg

Initial attempts at weather modification were of limited success…

# Lest you think this was a long time ago…

## Hail Cannon (1901)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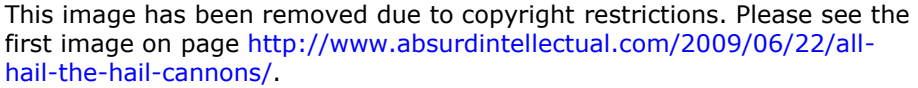
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## Cloud Seeding

# Lest you think this was a long time ago…





In 1902, the regions Castelfranco Veneto and Windisch-Feistritz were each armed with some 200 hail cannons. These were placed in part of these regions, closer together than even suggested by directions of hail gun merchants, and were used intensively. The leader of this Austrian-Italian project, Blaserna, said in his final report that in 1902 often the areas with cannons had more hail damage than those without, and the same negative effect was observed in 1903 and 1904.

JON WIERINGA [1] and IWAN HOLLEMAN [2]

[1] Certified Consulting Meteorologist, De Bilt, Netherlands
[2] Royal Netherlands Meteorological Institute, De Bilt, Netherlands

(Meteorologische Zeitschrift, **15**, issue 3, June 2006)

# The ‘Modern’ Age of Weather Mod

Mid-1940’s. Generally considered to have grown out of the WWII contrail research. The pioneers : Vincent Shaefer, Irving Langmuir and Bernie Vonnegut at GE. Showed that particles with water-ice structure could effectively nucleate ice at temperature near 0° C.

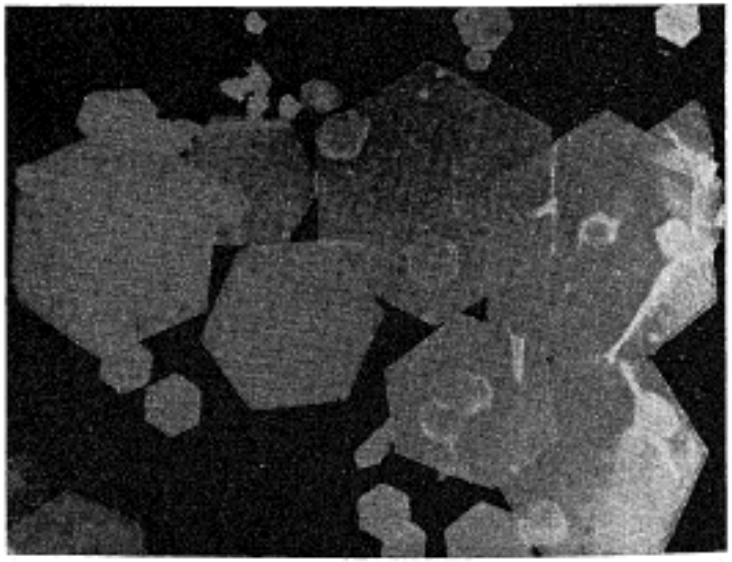
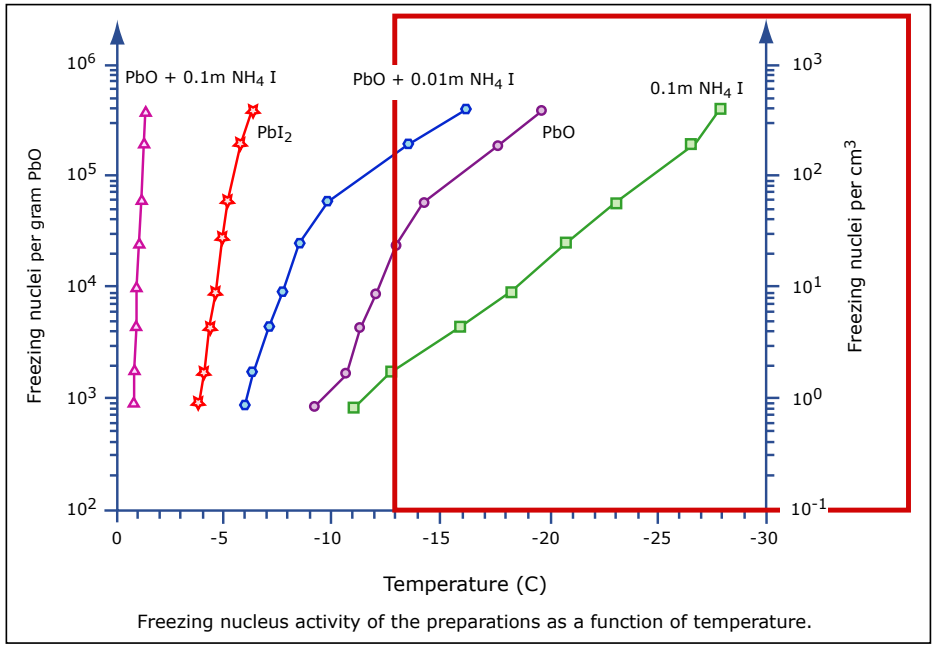


FIG. 3. Lead-iodide crystals formed in cooling water.

This image (published on the Journal of Meteorology by the American Meteorological Society) is copyright © AMS and used with permission.




Freezing nucleus activity of the preparations as a function of temperature.

Image by MIT OpenCourseWare.

OCTOBER 1954 SHORTER CONTRIBUTIONS

SHORTER CONTRIBUTIONS

SILVER AND LEAD IODIDES AS ICE-CRYSTAL NUCLEI

*By Vincent J. Schaefer*

General Electric Research Laboratory[1,2]

(Manuscript received 2 January 1954)

Atmospheric Environment Vol. 9, pp. 955-958. Pergamon Press 1975. Printed in Gt. Britain

PRELIMINARY COMMUNICATIONS

ICE NUCLEI FROM REACTIONS INVOLVING LEAD, AMMONIA AND IODINE

This image has been removed due to copyright restrictions. Please see the image on page http://www.nap.edu/catalog.php?record_id=10829.

National Academy of Science, 2003 : Last comprehensive report on weather modification.

# The ‘Modern’ Age of Weather Mod

Early “demonstrations” with clouds were mixed: increased glaciation was observed but little or no enhanced precipitations (clouds contained too little water).

“Need for impartial assessment” recognized as early as 1957. “Double blind” studies suggested 1957, 1963 (“…it has not been demonstrated that precipitation … can be increased significantly by seeding…”), 1973 (*“ice-nuclei seeding can sometimes lead to more precipitation, can sometimes lead to less precipitation, and at other times … have no effect…”*), 2003 (“…our Committee finds little reason to differ from these findings…”).

Point : Theory itself does not show if a technique works when multiple steps are involved (in this case initiation, not growth and precipitation). Further, the scale of the experiment (lab versus isolated cloud versus system) often leads to different results.

# ALBEDO ENHANCEMENT BY STRATOSPHERIC SULFUR INJECTIONS: A CONTRIBUTION TO RESOLVE A POLICY DILEMMA?

*An Editorial Essay*

PAUL J. CRUTZEN

"By far the preferred way to resolve the policy makers' dilemma is to lower the emissions of the greenhouse gases."

"Therefore, although by far not the best solution, the usefulness of artificially enhancing earth's albedo and thereby cooling climate by adding sunlight reflecting aerosol in the stratosphere (Budyko, 1977; NAS, 1992) might again be explored and debated…"

"Finally, I repeat: the very best would be if emissions of the greenhouse gases could be reduced so much that the stratospheric sulfur release experiment would not need to take place. Currently, this looks like a pious wish."

Climatic Change (2006) 77: 211–219
DOI: 10.1007/s10584-006-9101-y

# Early References…


Budyko, M. I.: 1977, 'Climatic Changes, American Geophysical Society', Washington, D.C., 244 pp.

Bodansky, D.: 1996, 'May we engineer the climate?', *Clim. Change* **33**, 309–321.

Dickinson, R. E.: 1996, 'Climate Engineering. A review of aerosol approaches to changing the global energy balance', *Clim. Change* **33**, 279–290.

Jamieson, D.: 1996, 'Ethics and intentional climate change', *Clim. Change* **33**, 323 336.

Schneider, S. H.: 1996, 'Geoengineering: Could-or-Should-we do it', *Clim. Change* **33**, 291–302.

Keith, D. W.: 2000, 'Geoengineering the climate: History and prospect', *Annu. Rev. Energy Environ.* **25**, 245–284.

National Academy of Sciences (NAS): 1992, Policy Implications of Greenhouse Warming: Mitigation, Adaptation, and the Science Base, Panel on Policy Implications of Greenhouse Warming, Committee on Science, Engineering, and Public Policy, National Academy Press, Washington DC, 918 pp.

# …But Not The Earliest

RESTORING THE QUALITY

OF

OUR ENVIRONMENT


*Report of The*
*Environmental Pollution Panel*
*President's Science Advisory Committee*

THE WHITE HOUSE

NOVEMBER 1965

"The climatic changes that may be produced by the increased $CO_2$ content could be deleterious from the point of view of human beings. The possibilities of **deliberately bringing about countervailing climatic changes** therefore need to be thoroughly explored. A change in the radiation balance in the opposite direction to that which might result from the increase of atmospheric $CO_2$ could be produced by **raising the albedo**, or reflectivity, of the earth. Such a change in albedo could be brought about, for example, by spreading very small reflecting particles over large oceanic areas."

This image has been removed due to copyright restrictions. Please see the image on page http://www.nextnature.net/2010/02/nine-geoengineering-strategies/.

Reduction of Solar Radiation/ Higher Albedo

Carbon Capture



Source: New Scientist

# Albedo Increase / Solar Mitigation

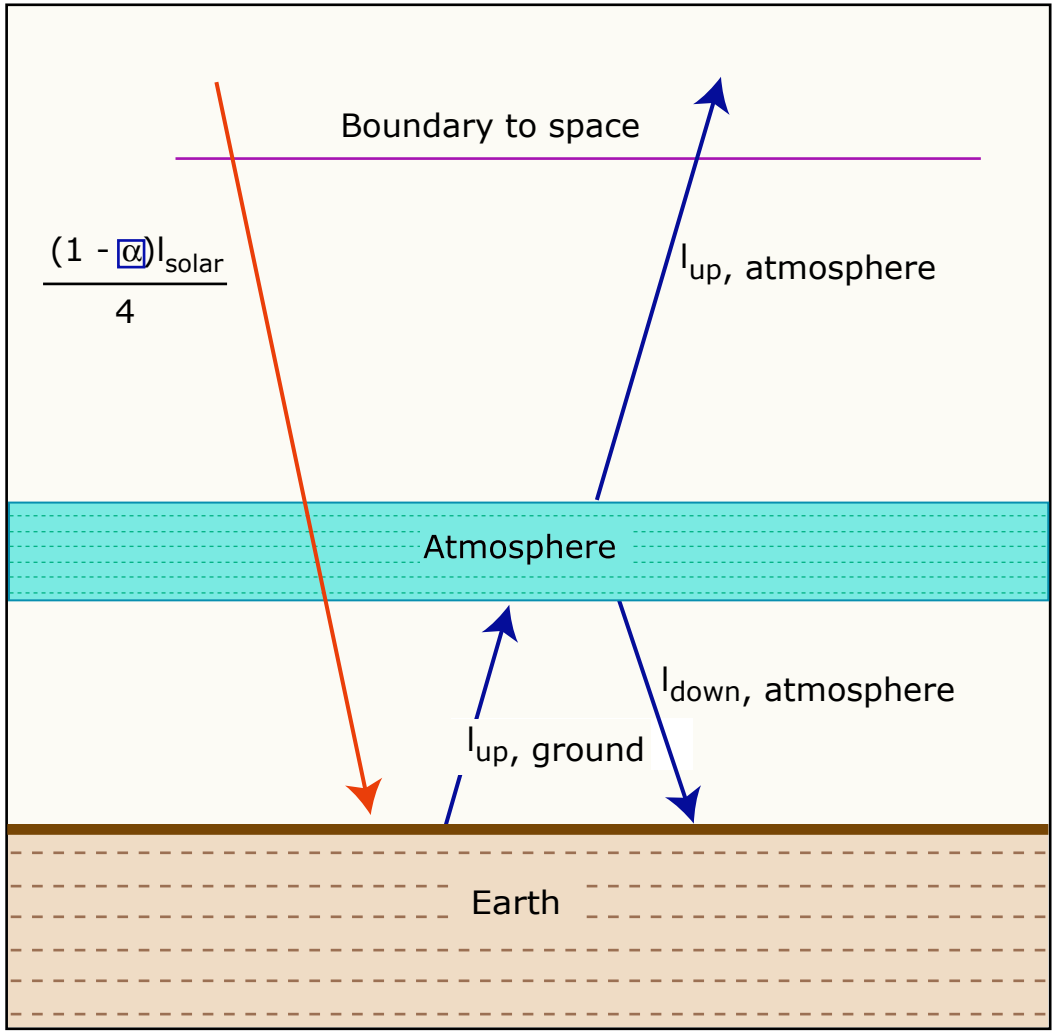



Image by MIT OpenCourseWare.

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# Simple Albedo Increase

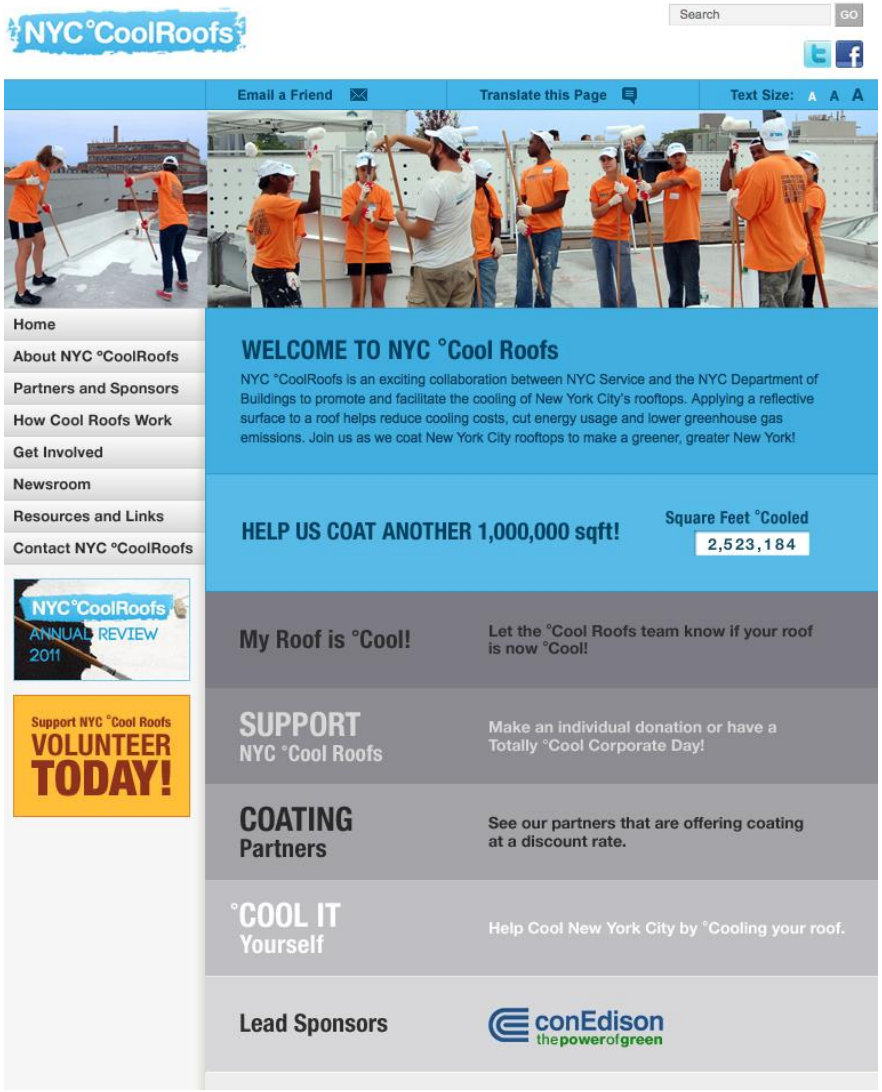



Image courtesy of nyc.gov.

Necessary square footage >> available square footage

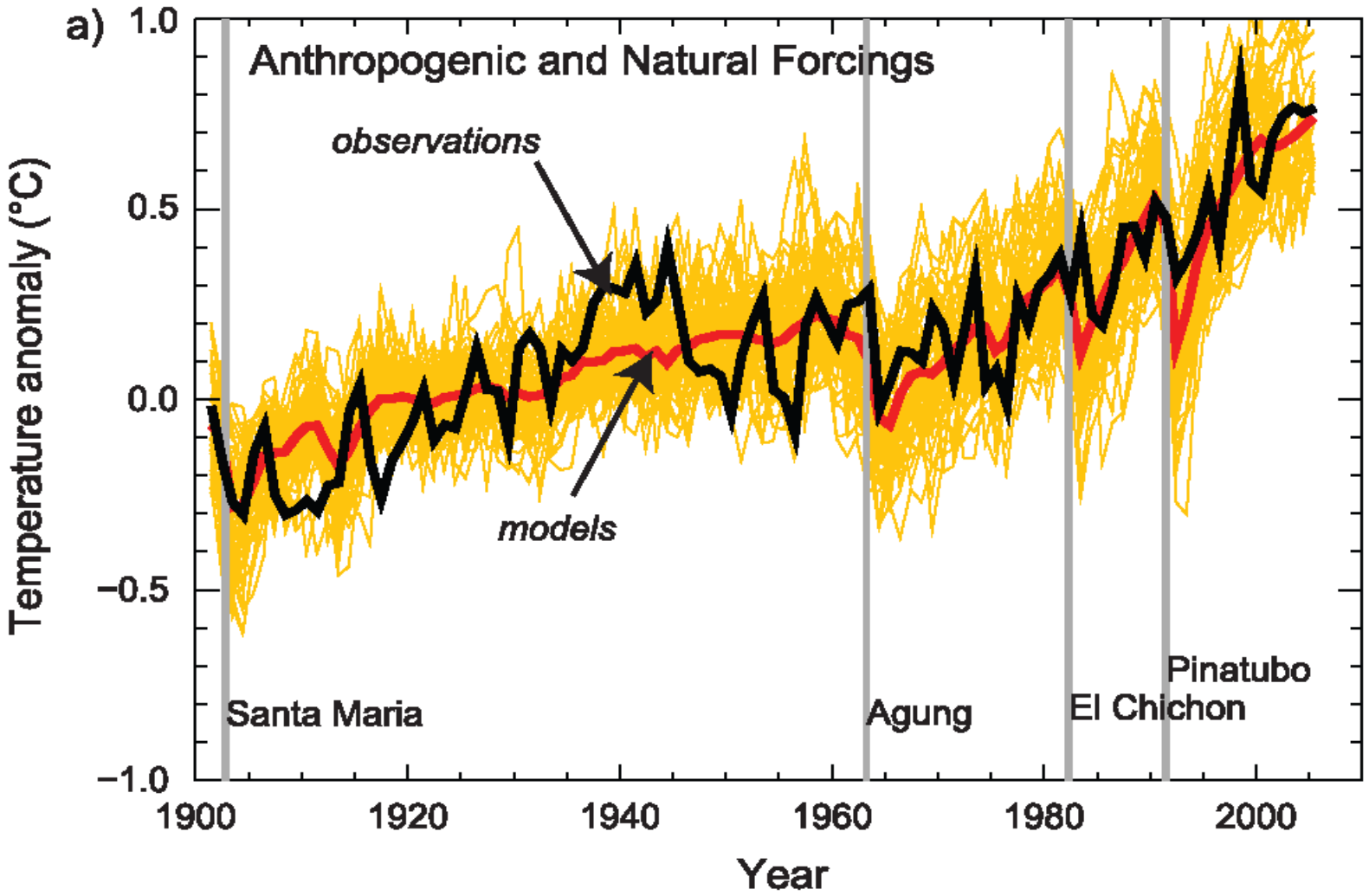
Courtesy Jimmy Gasore, Haider et al., 1997

# Nature's Examples : Direct Effect



Murphy et al. JGR 2009

# Climate Model Response




Climate Change 2007: The Physical Science Basis. Working Group I Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Figure 9.5. Cambridge University Press. Used with permission.

# Natural Version of the Direct Effect Method

Image courtesy of USGS.

Robock, 1998

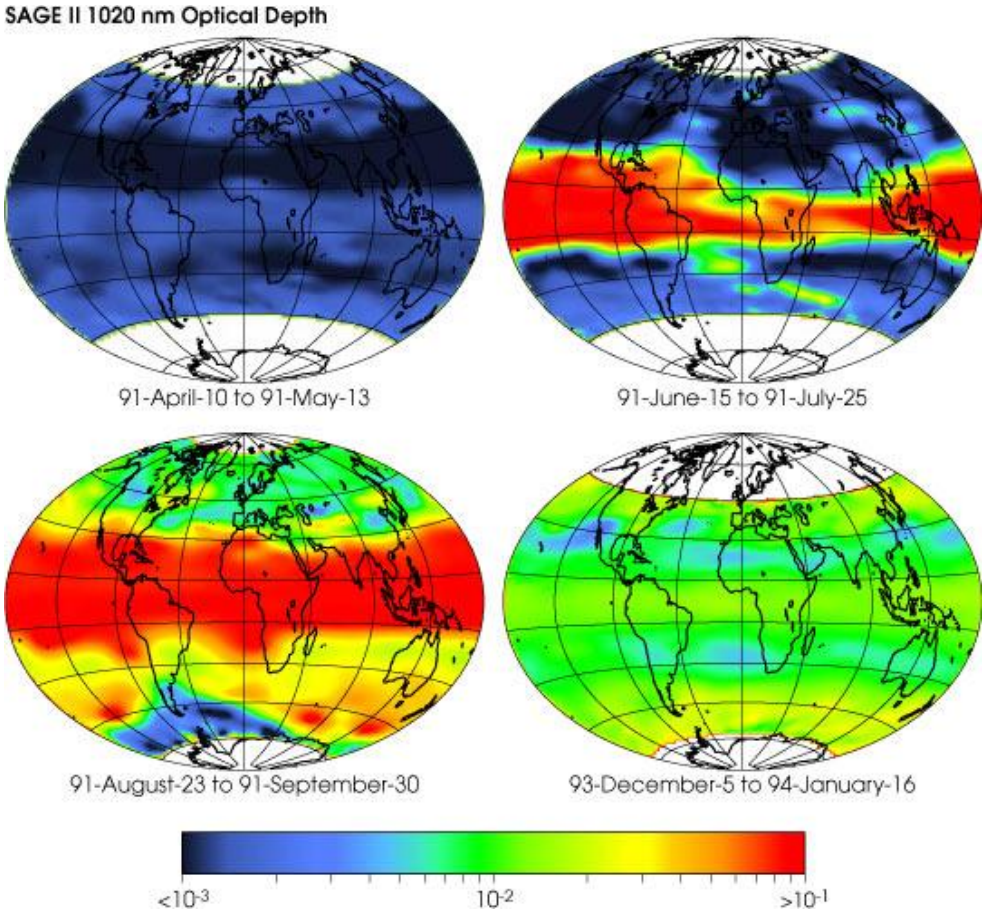



Image courtesy of NASA.

**Pinatubo : ~15 Tg $SO_2$ into the stratosphere.**

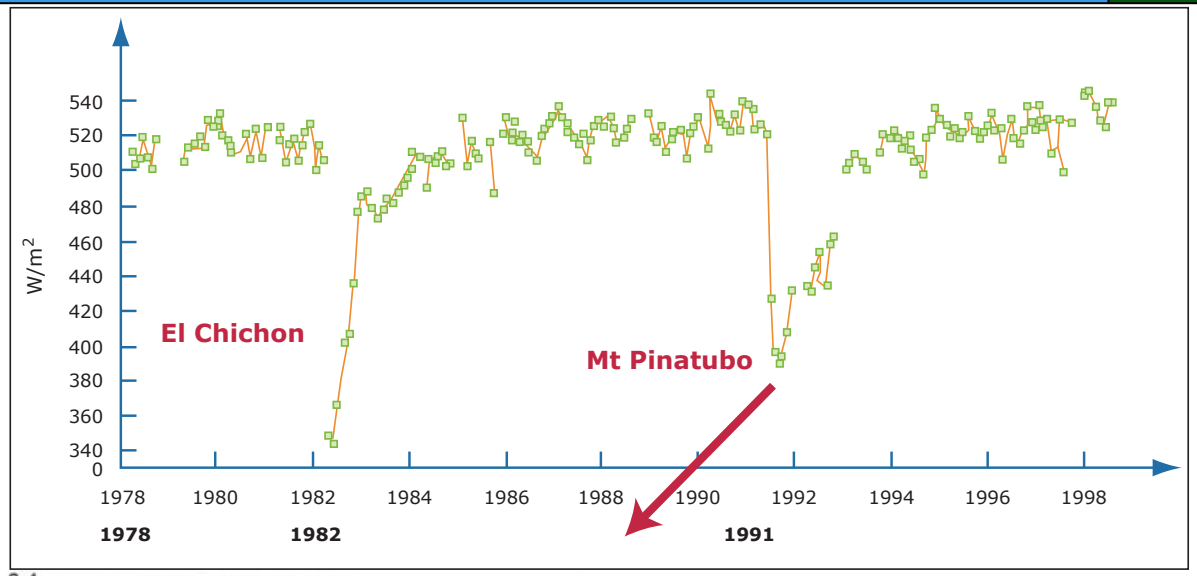
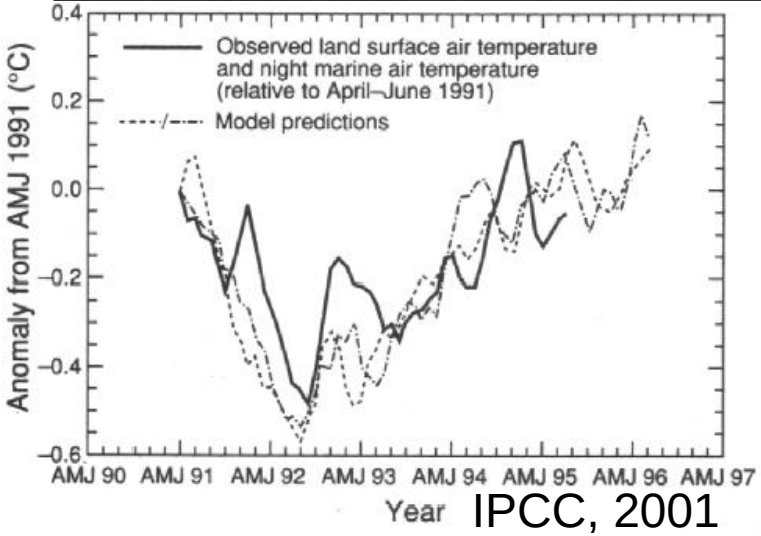



Image by MIT OpenCourseWare.




IPCC, 2001

Houghton, J. T.,Y. Ding, D. J. Griggs, M. Noguer, P. J. van der Linden, X. Dai, K. Maskell, and C. A. Johnson (eds.): Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press. Used with permission.

Global temperatures dropped by 0.4-0.6°C after Pinatubo.
Particle layer persisted for 3 years (e-folding ~1 year).

# The Direct Effect Method



Say we want to “offset” current ~0.75° C warming.

Pinatubo was ~15 Tg $SO_2$ injection.

Some variation of initial injection of ~20 Tg sulfuric acid and then an increasing yearly amount of 10+ Tg

Aircraft, balloon and other ‘designs’ (25km tethered hose) proposed.



http://www.technologyreview.com/energy/24157/

# The Indirect Effect Method

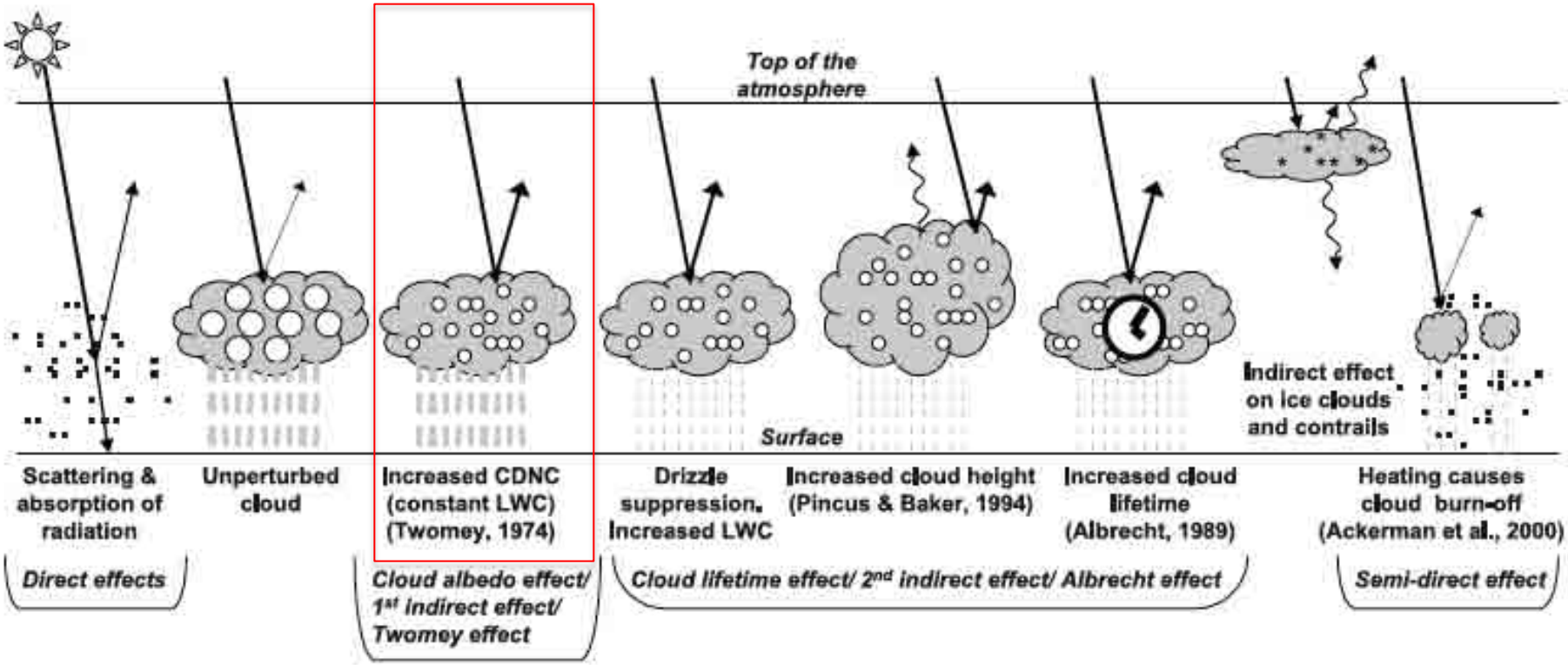


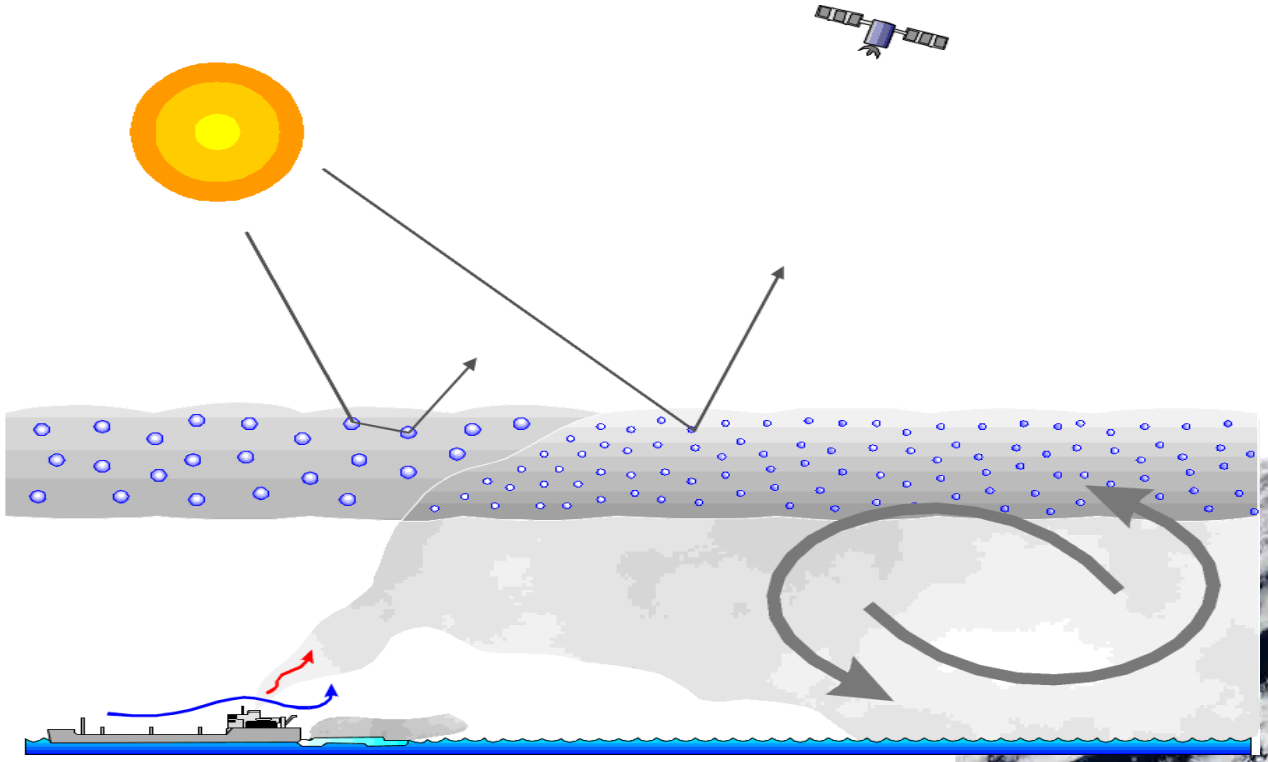

**Figure 2.10.** *Schematic diagram showing the various radiative mechanisms associated with cloud effects that have been identified as significant in relation to aerosols (modified from Haywood and Boucher, 2000). The small black dots represent aerosol particles; the larger open circles cloud droplets. Straight lines represent the incident and reflected solar radiation, and wavy lines represent terrestrial radiation. The filled white circles indicate cloud droplet number concentration (CDNC). The unperturbed cloud contains larger cloud drops as only natural aerosols are available as cloud condensation nuclei, while the perturbed cloud contains a greater number of smaller cloud drops as both natural and anthropogenic aerosols are available as cloud condensation nuclei (CCN). The vertical grey dashes represent rainfall, and LWC refers to the liquid water content.*

Climate Change 2007: The Physical Science Basis. Working Group I Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Figure 2.10. Cambridge University Press. Used with permission.

# Anthropogenic Example



Murphy et al. JGR 2009



from D. Rosenfeld

Image courtesy of Danniel Rosenfeld. Used with permission.

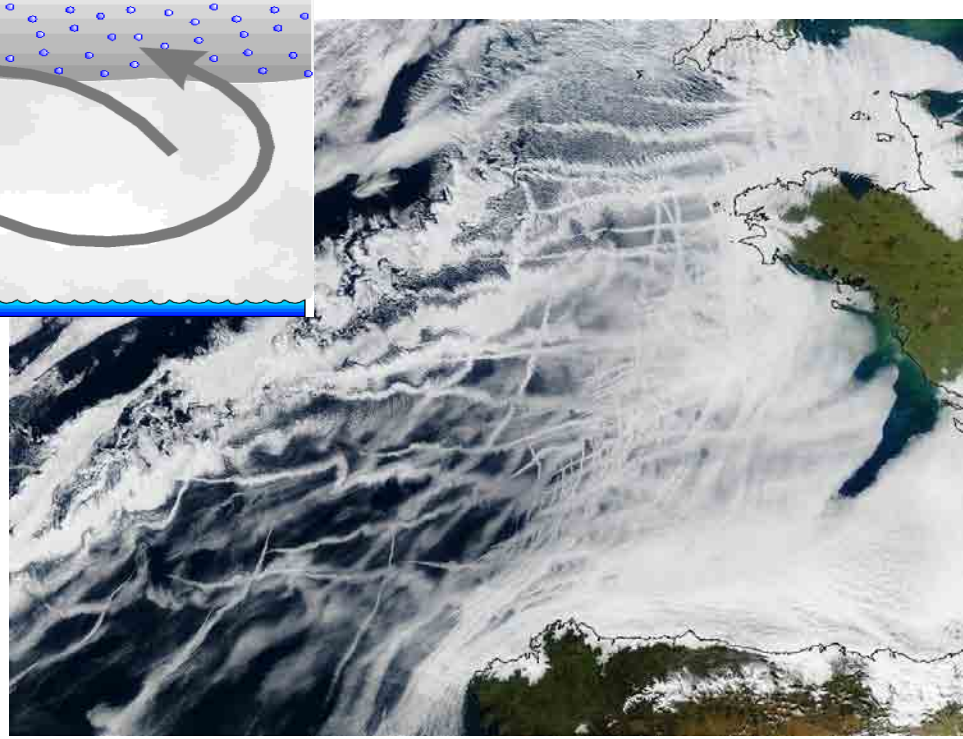
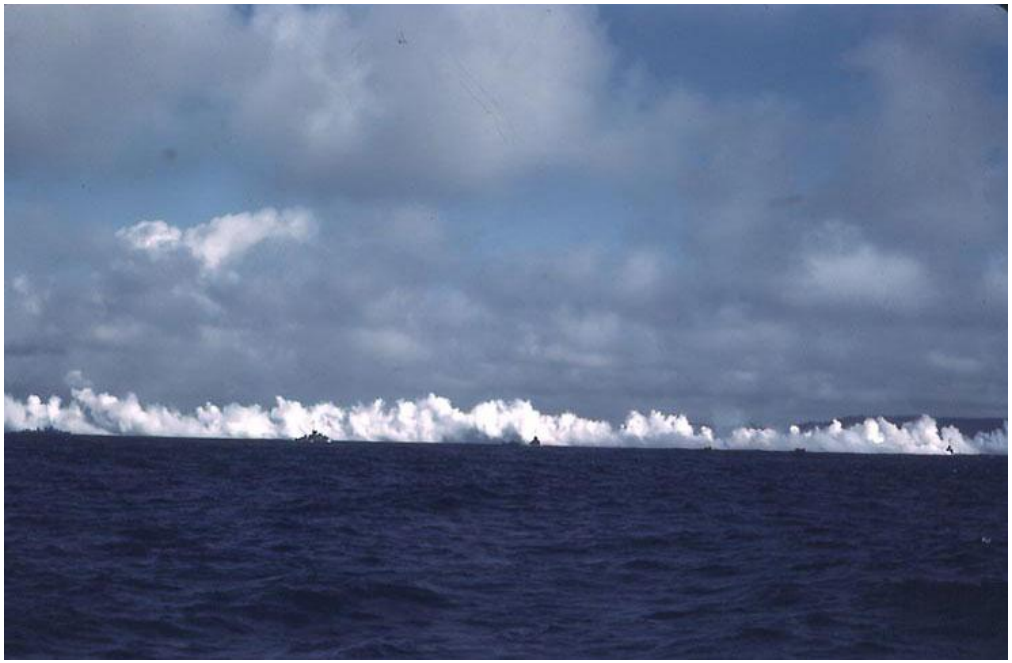


Image courtesy of NASA.



US Navy

Image courtesy of US Navy.

Unpublished results: use of particle production in Marine Boundary Layer (MBL) with cloud formation ~1 in 10 times



Stephen Salter's design

# Risk vs. Reward

EAPS
Earth, Atmospheric and Planetary Sciences

## Reward

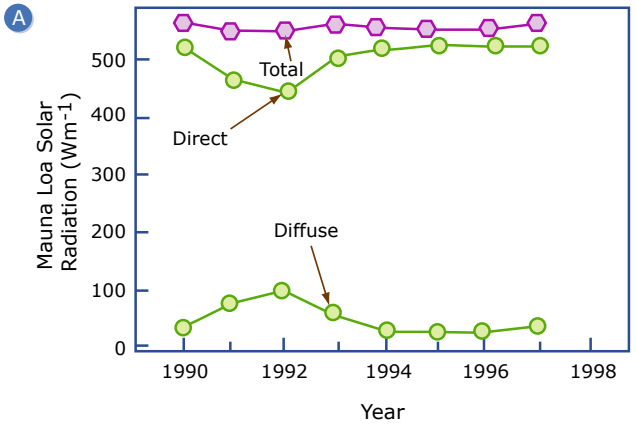
1. Cool planet
2. Reduce or reverse ice loss
3. Reduce or reverse sea level rise
4. Increase plant productivity
5. Nice sunsets
6. Better precipitation control?

## Risk

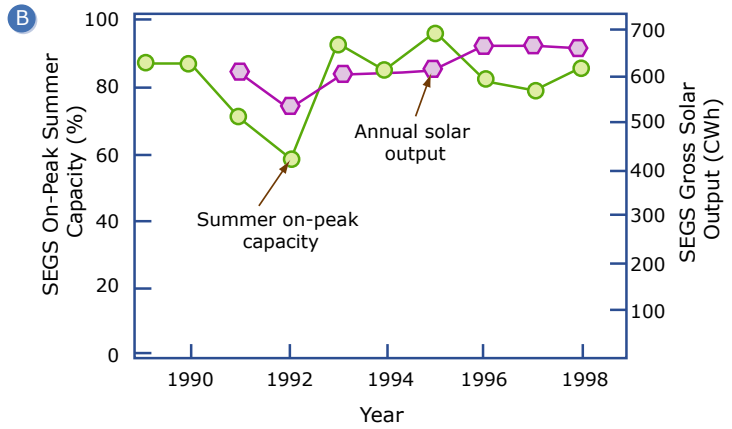
1. Regional droughts
2. Continued ocean acidification
3. Ozone depletion
4. Diffuse radiation effect on plants
5. Acid deposition
6. Cirrus effects
7. White skies
8. Lower solar power margins
9. Environmental side effects
10. Cannot stop effects quickly (1-3 years or more)
11. Rapid warming if stopped (all effects back in 1-3 years)
12. Human error
13. Undermining mitigation efforts
14. Cost
15. Who controls? Commercialization
16. Military use
17. Whose hand on the thermostat?
18. Conflict with treaties
19. "Unknown unknowns"

What would you propose as a method?

1. Model all results first?
2. Small scale tests? For direct effect method how do you do this?
3. Are there effects that can't be accepted?




Sunlight measured at Mauna Loa. The reduction in direct sunlight and increase in diffuse sunlight following the eruption of Mt. Pinatubo in 1991 are readily apparent. The reduction in total sunlight was much smaller.




Output of the solar electric generating systems (SEGS) solar thermal power plants in California (data are from ref 9). The SEGS plants had significant reductions in on-peak capacity and total output following the eruption of Mt. Pinatubo.



As with the example of cheaper natural gas, the “stop gap” makes a possible “long term solution” much less likely

**Effect of Stratospheric Aerosols on Direct Sunlight and Implications for Concentrating Solar Power**

**DANIEL, M. MURPHY***

Earth system research laboratory,
Chemical sciences division,
National oceanic and atmospheric administration,
325 Broadway, Boulder, Colorado 80305

**Summer sea ice goes away with a doubling of $CO_2$**

**Ice returns with geoengineering (but not homogeneously)**

**It is possible to overdo the effect**

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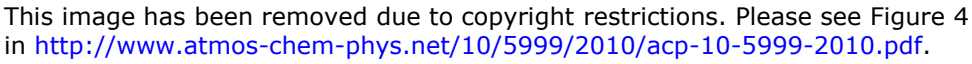
Rasch et al., 2009

# Precipitation change from stratospheric sulfate

EAPS
Earth, Atmospheric and Planetary Sciences

Model #1
(Hadley)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Model #2
(NASA GISS)



Jones et al., 2010

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Precipitation change from marine cloud seeding



Jones et al., 2009

# The Ozone Effect

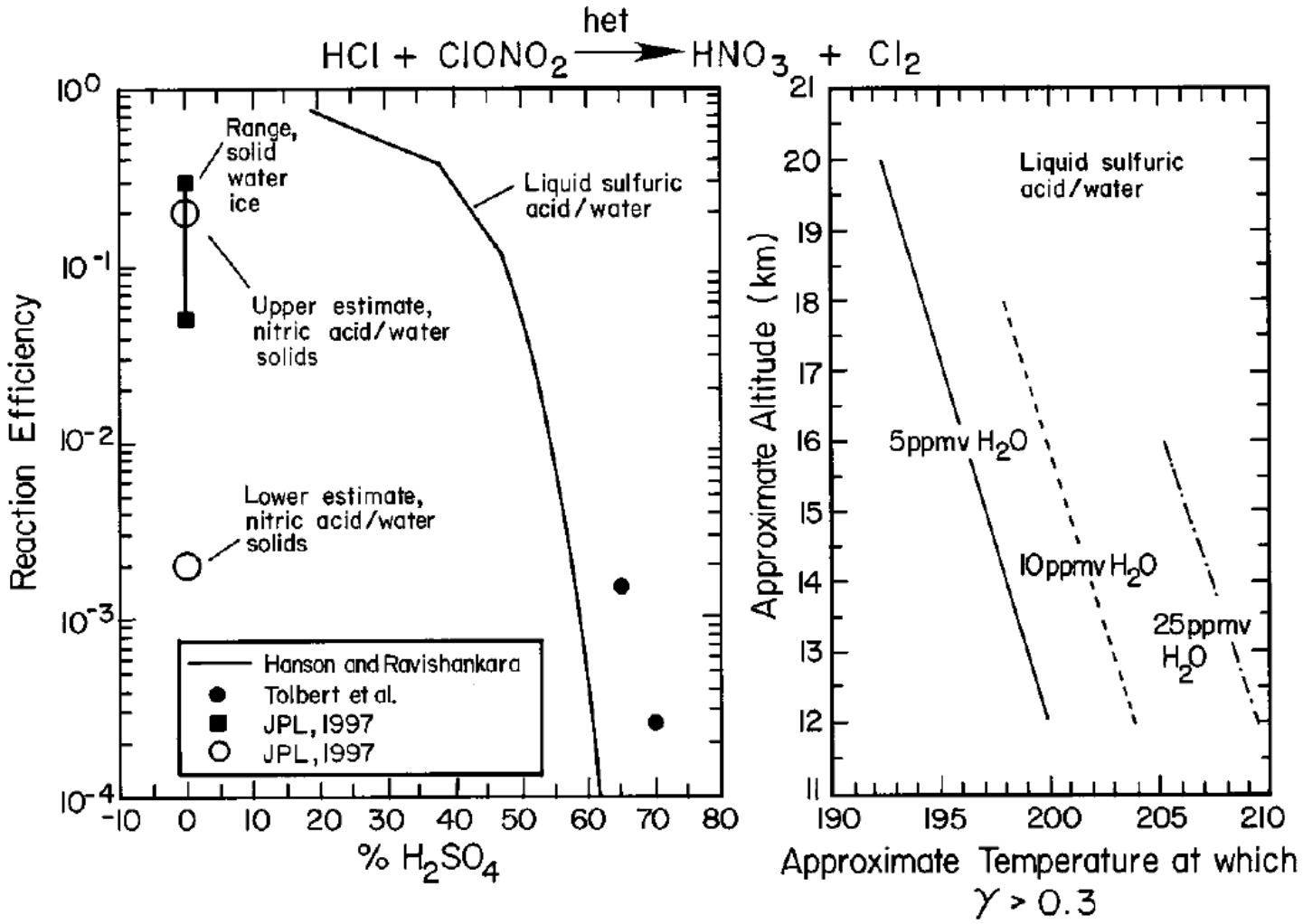



Image courtesy of NOAA.



Susan Solomon
Aeronomy Laboratory
National Oceanic and Atmospheric Administration
Boulder, Colorado

# The Ozone Effect

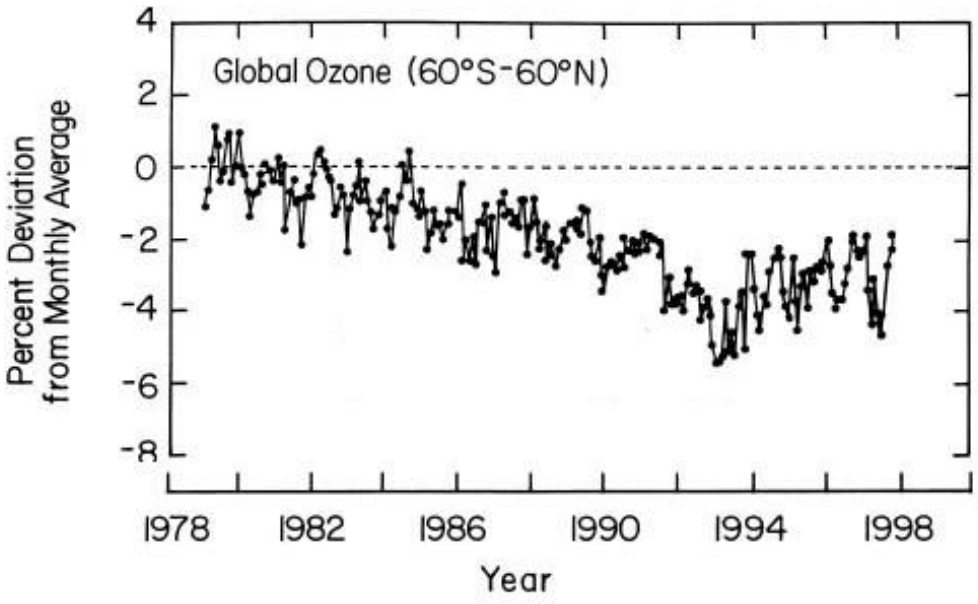
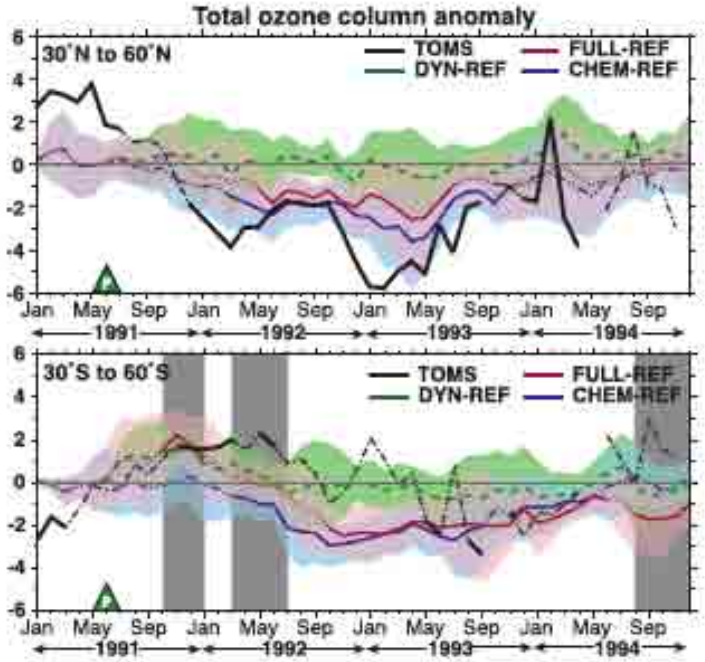



Image courtesy of NOAA.




REVIEW ARTICLE

**Atmospheric effects of the Mt Pinatubo eruption**

**M. Patrick McCormick, Larry W. Thomason & Charles R. Trepte**

FIG. 5. Zonal mean total ozone column anomalies for (top) 30°–60°N and (bottom) 30°–60°S. The black line shows TOMS anomalies (%) after removing the effects of the seasonal cycle, QBO, ENSO, solar cycle, and changing chlorine and bromine (see Fig. 1 for details). The solid black lines are significantly different from zero at $1\sigma$ level. The simulated anomalies for FULL − REF (red), CHEM − REF (blue), and DYN − REF (green) are also shown. The color shaded areas show the standard deviation of each ensemble. Solid red, blue, and green lines are significantly different from zero at the 95% confidence level. The gray shaded times show where the FULL and CHEM simulations are significantly different from one another at the 95% confidence level. The green triangle marks the month of the Pinatubo eruption.

This image (published on the Journal of Atmospheric Sciences by the American Meteorological Society) is copyright © AMS and used with permission.

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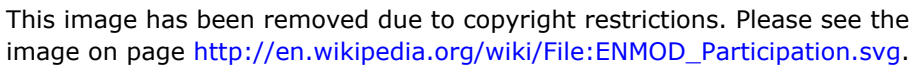
**Baseline** **With Geoengineering**

Ethics in research : when do you decide to stop researching a topic because the result is too negative? When does “we should know more about it in case we try it” conflict with “this is not a good idea”?



Rasch et al., 2008




“Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques” (ENMOD) prohibits the use of the environment as a weapon. A result of opposition to Agent Orange and weather modification during Vietnam

Adopted by the UN General Assembly on 10 December 1976 and opened for signature on 18 May 1977, ENMOD entered into force when Laos, the twentieth State Party, deposited its instrument of ratification on 5 October 1978.



Map : wikipedia

# For you to consider

1. Have we shown that the “cure” is better than the “disease”?
2. Is this really the same as what we’ve already done (“inadvertent” climate modification)?
3. If this is a “last resort” are we certain it is going to work?





http://www.technologyreview.com/energy/24157/

12.340 Global Warming Science

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