RUTGERS
THE STATE UNIVERSITY
OF NEW JERSEY

Twenty Reasons Why Geoengineering May Be a Bad Idea

Alan Robock

Department of Environmental Sciences
Rutgers University, New Brunswick, New Jersey USA

robock@envsci.rutgers.edu

http://climate.envsci.rutgers.edu/robock/robock_geopapers.html

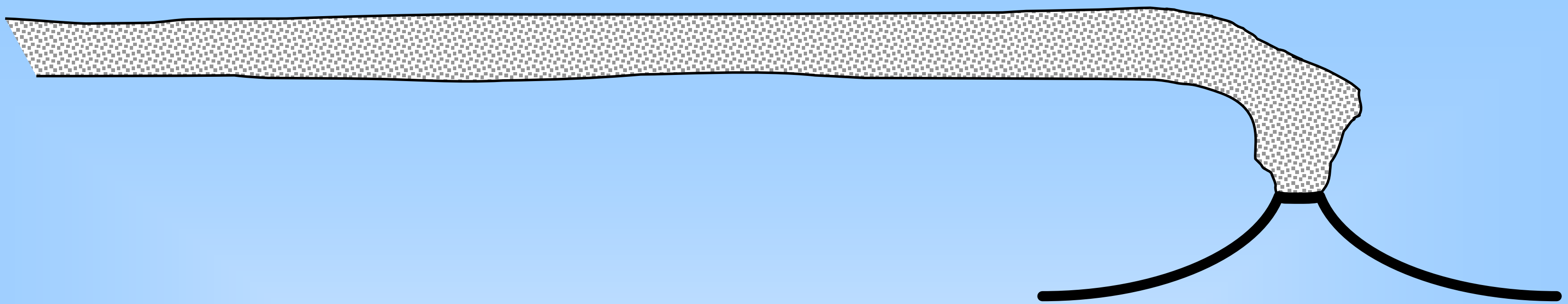
This work is done in collaboration with

Luke Oman and Georgiy Stenchikov

Johns Hopkins Rutgers University

Ben Kravitz and Allison Marquardt

Rutgers University



This talk focuses on injecting sulfate aerosol precursors into the stratosphere to reduce insolation to counter global warming, which brings up the question:

Are volcanic eruptions an innocuous example that can be used to demonstrate the safety of geoengineering? **No.**

Reasons geoengineering may be a bad idea

Climate system response

1. Regional climate change, including temperature and precipitation
2. Continued ocean acidification
3. Ozone depletion
4. Effects on plants of changing the amount of solar radiation and partitioning between direct and diffuse
5. Enhanced acid precipitation
6. Effects on cirrus clouds as aerosols fall into the troposphere
7. Whitening of the sky (but nice sunsets)
8. Less solar radiation for solar power, especially for those requiring direct radiation
9. Rapid warming when it stops
10. How rapidly could effects be stopped?
11. Environmental impacts of aerosol injection, including producing and delivering aerosols

Robock, Alan, 2008: 20 reasons why geoengineering may be a bad idea. *Bull. Atomic Scientists*, **64**, No. 2, 14-18, 59, doi:10.2968/064002006.

Reasons geoengineering may be a bad idea

Climate system response

1. **Regional climate change, including temperature and precipitation**
2. Continued ocean acidification
3. Ozone depletion
4. Effects on plants of changing the amount of solar radiation and partitioning between direct and diffuse
5. Enhanced acid precipitation
6. Effects on cirrus clouds as aerosols fall into the troposphere
7. Whitening of the sky (but nice sunsets)
8. Less solar radiation for solar power, especially for those requiring direct radiation
9. Rapid warming when it stops
10. How rapidly could effects be stopped?
11. Environmental impacts of aerosol injection, including producing and delivering aerosols

Proposals for "solar radiation management" using injection of stratospheric aerosols

1. Inject them into the tropical stratosphere, where winds will spread them around the world and produce global cooling, like tropical volcanic eruptions have.
2. Inject them at high latitudes in the Arctic, where they will keep sea ice from melting, while any negative effects would not affect many people.

We conducted the following geoengineering simulations with the NASA GISS ModelE atmosphere-ocean general circulation model run at 4°x 5° horizontal resolution with 23 vertical levels up to 80 km, coupled to a 4°x 5° dynamic ocean with 13 vertical levels and an online chemistry and transport module:

- 80-yr control run
- 40-yr anthropogenic forcing, IPCC A1B scenario: greenhouse gases (CO_2, CH_4, N_2O, O_3) and tropospheric aerosols (sulfate, biogenic, and soot), 3-member ensemble
- 40-yr IPCC A1B + Arctic lower stratospheric injection of 3 Mt SO_2/yr, 3-member ensemble
- 40-yr IPCC A1B + Tropical lower stratospheric injection of 5 Mt SO_2/yr, 3-member ensemble
- 40-yr IPCC A1B + Tropical lower stratospheric injection of 10 Mt SO_2/yr

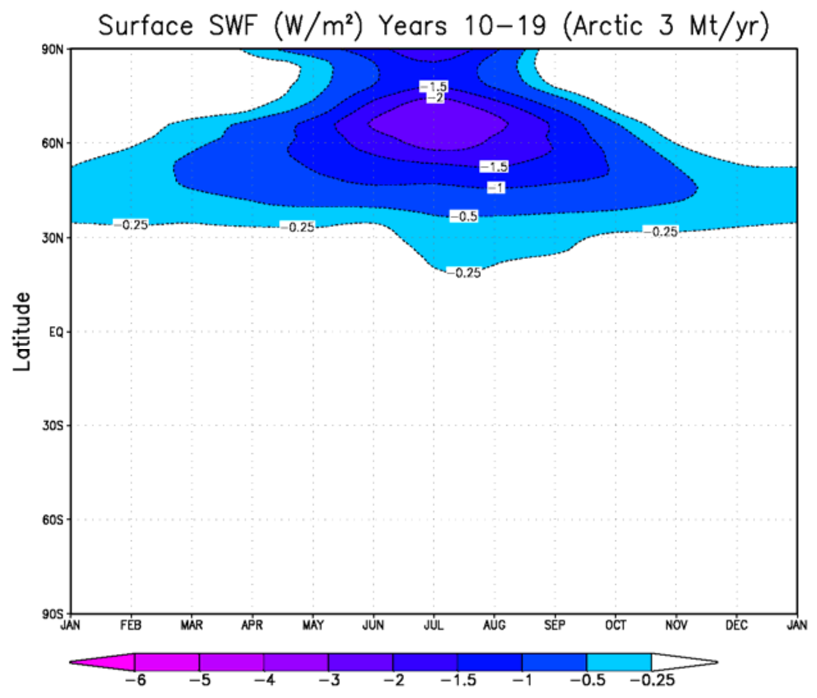
Robock, Alan, Luke Oman, and Georgiy Stenchikov, 2008: Regional climate responses to geoengineering with tropical and Arctic SO_2 injections. *J. Geophys. Res.*, **113**, D16101, doi:10.1029/2008JD010050

Latitudes and Altitudes

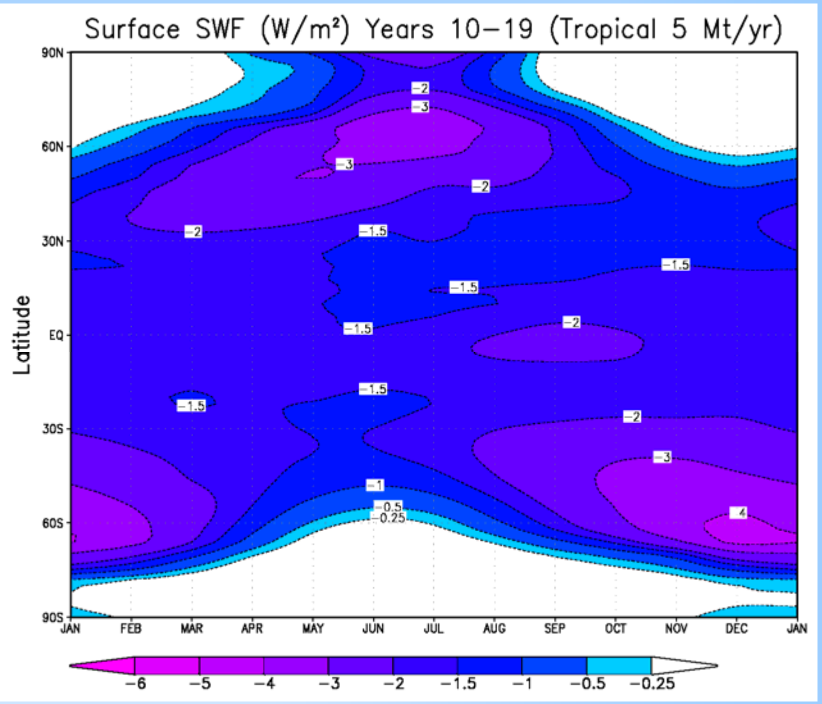
Tropical: We put SO_2 into the lower stratosphere (16-22 km) over the Equator at a daily rate equal to
5 Mt/yr (1 Pinatubo every 4 years) or
10 Mt/yr (1 Pinatubo every 2 years) for 20 years,
and then continue to run for another 20 years to see how fast the system warms afterwards.

Arctic: We put SO_2 into the lower stratosphere (10-15 km) at 68°N at a daily rate equal to 3 Mt/yr for 20 years,
and then continue to run for another 20 years to see how fast the system warms afterwards.

Change in downward solar radiation at Earth's surface

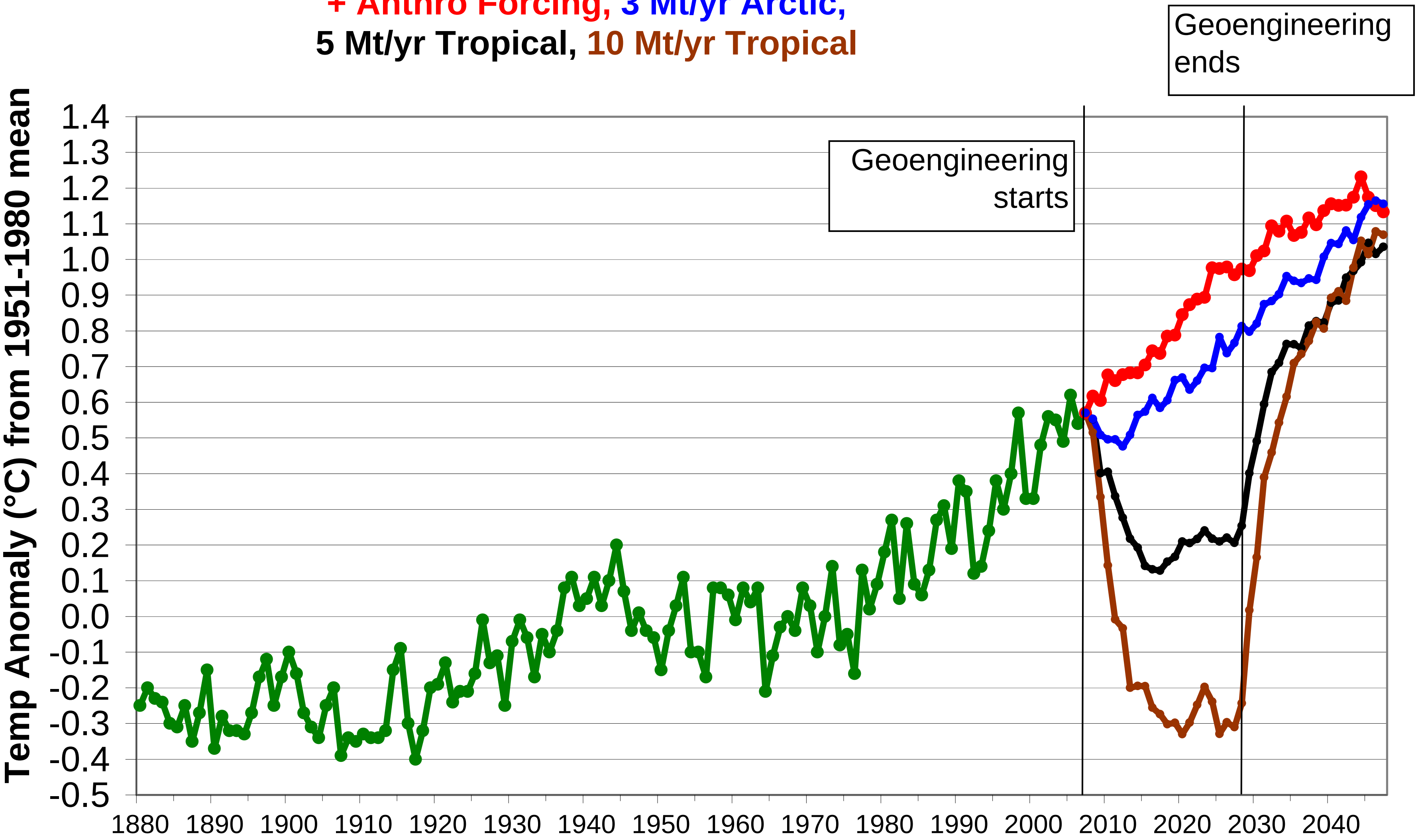


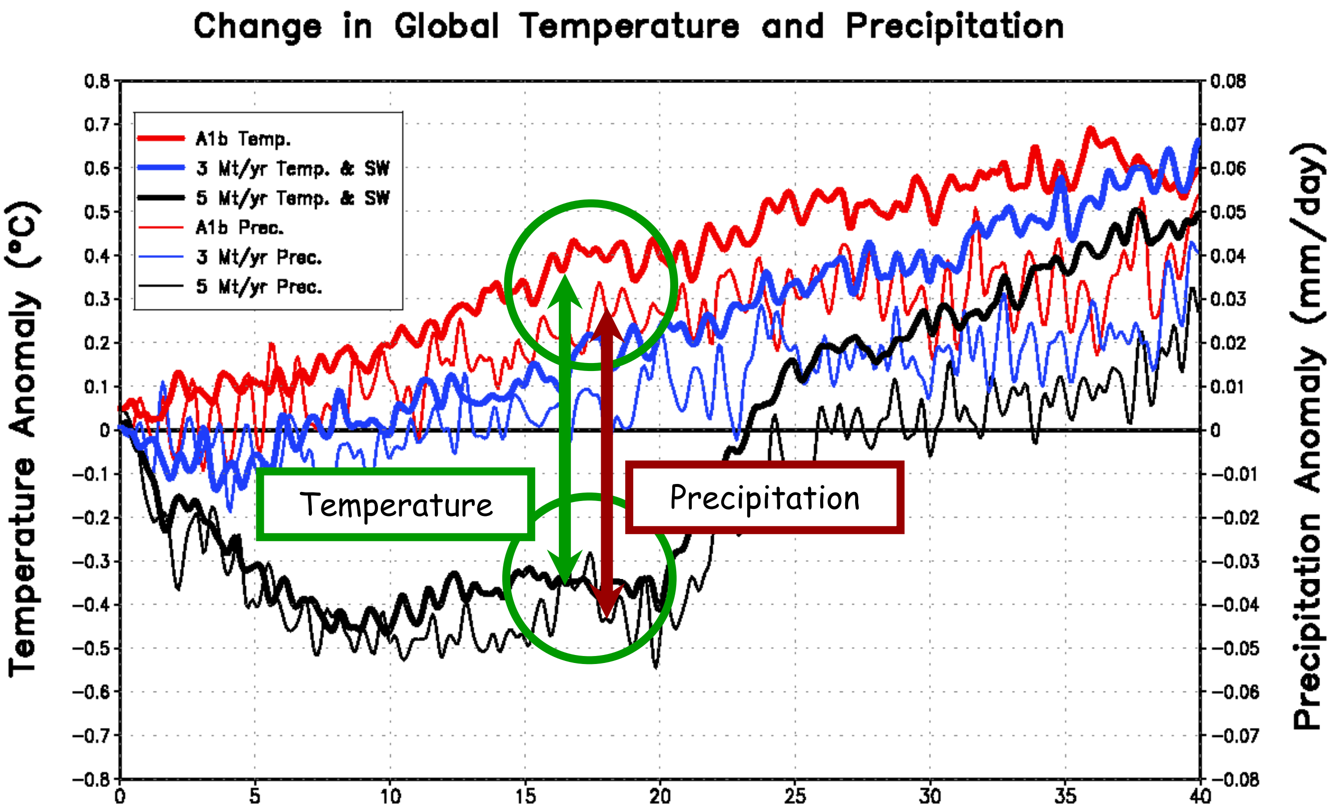
Arctic emission at 68°N leaks into the subtropics



Tropical emission spreads to cover the planet

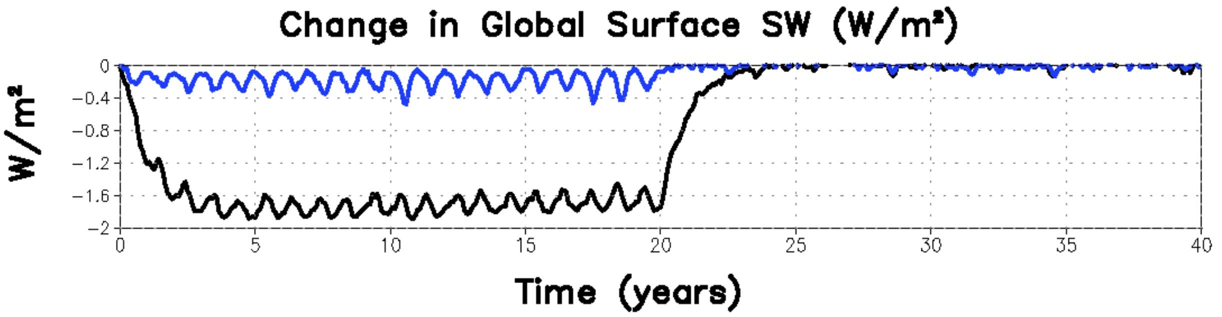
GISS Global Average Temperature Anomaly
+ Anthro Forcing, 3 Mt/yr Arctic,
5 Mt/yr Tropical, 10 Mt/yr Tropical



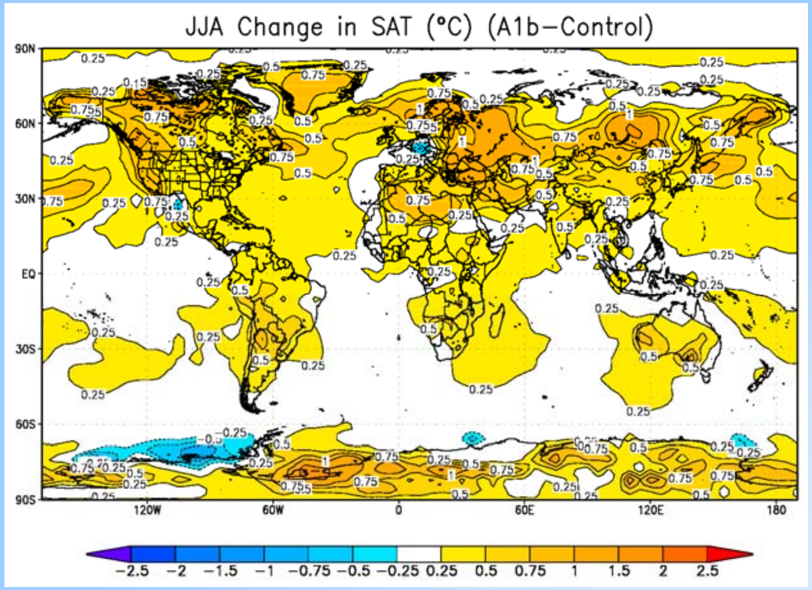


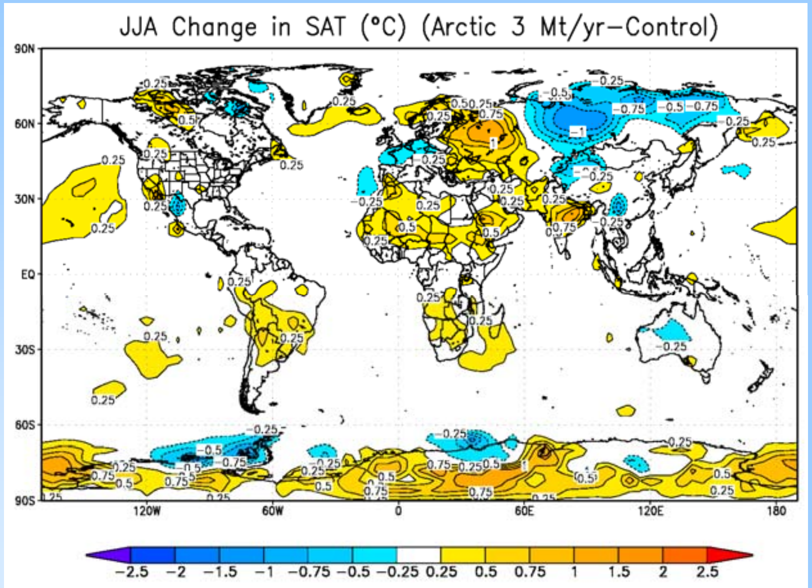
Temperature

Precipitation

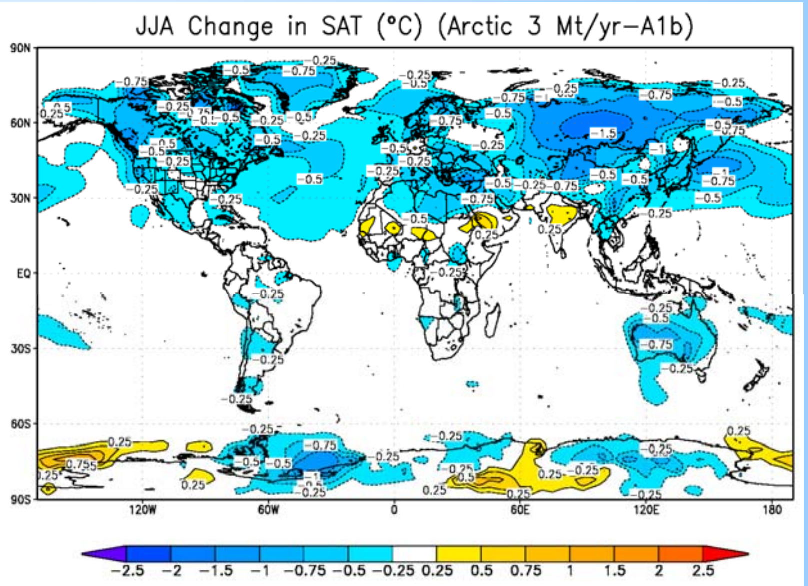


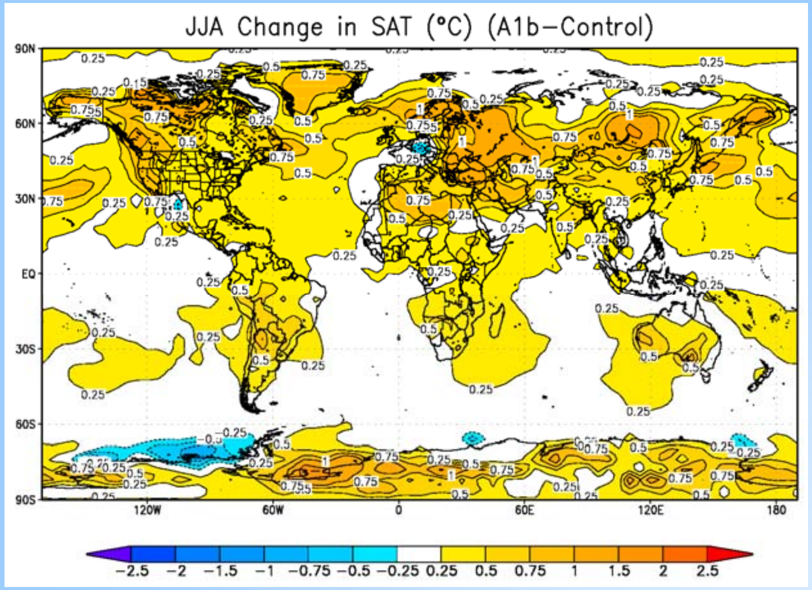
Global average changes in temperature, precipitation, and downward shortwave radiation for A1B, Arctic 3 Mt/yr and Tropical 5 Mt/yr geoengineering runs.

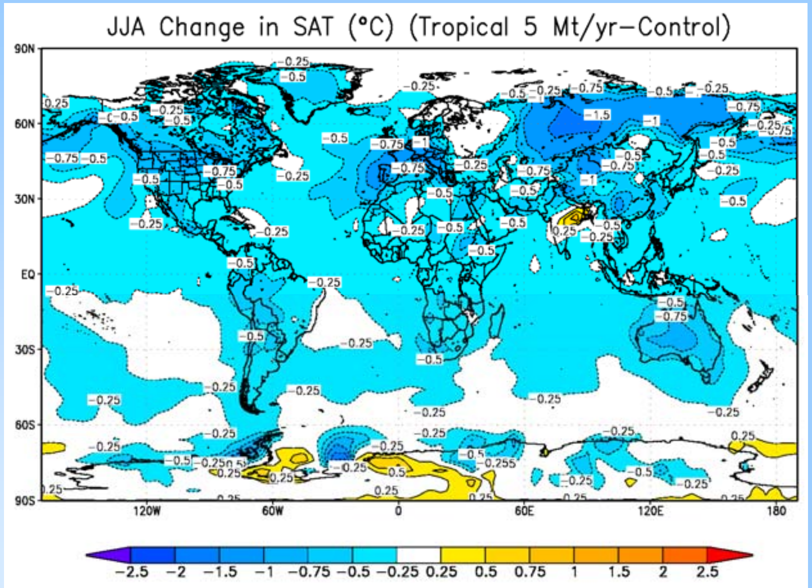

JJA Change in SAT (°C) (A1b–Control)


JJA Change in SAT (°C) (Arctic 3 Mt/yr–Control)

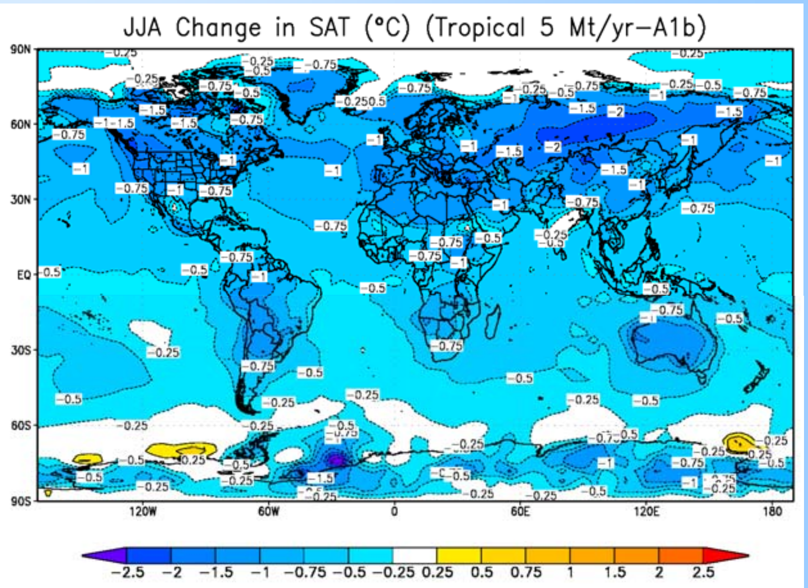
Mean response for second decade of aerosol injection for IPCC A1B + Arctic 3 Mt/yr case for NH summer surface air temperature

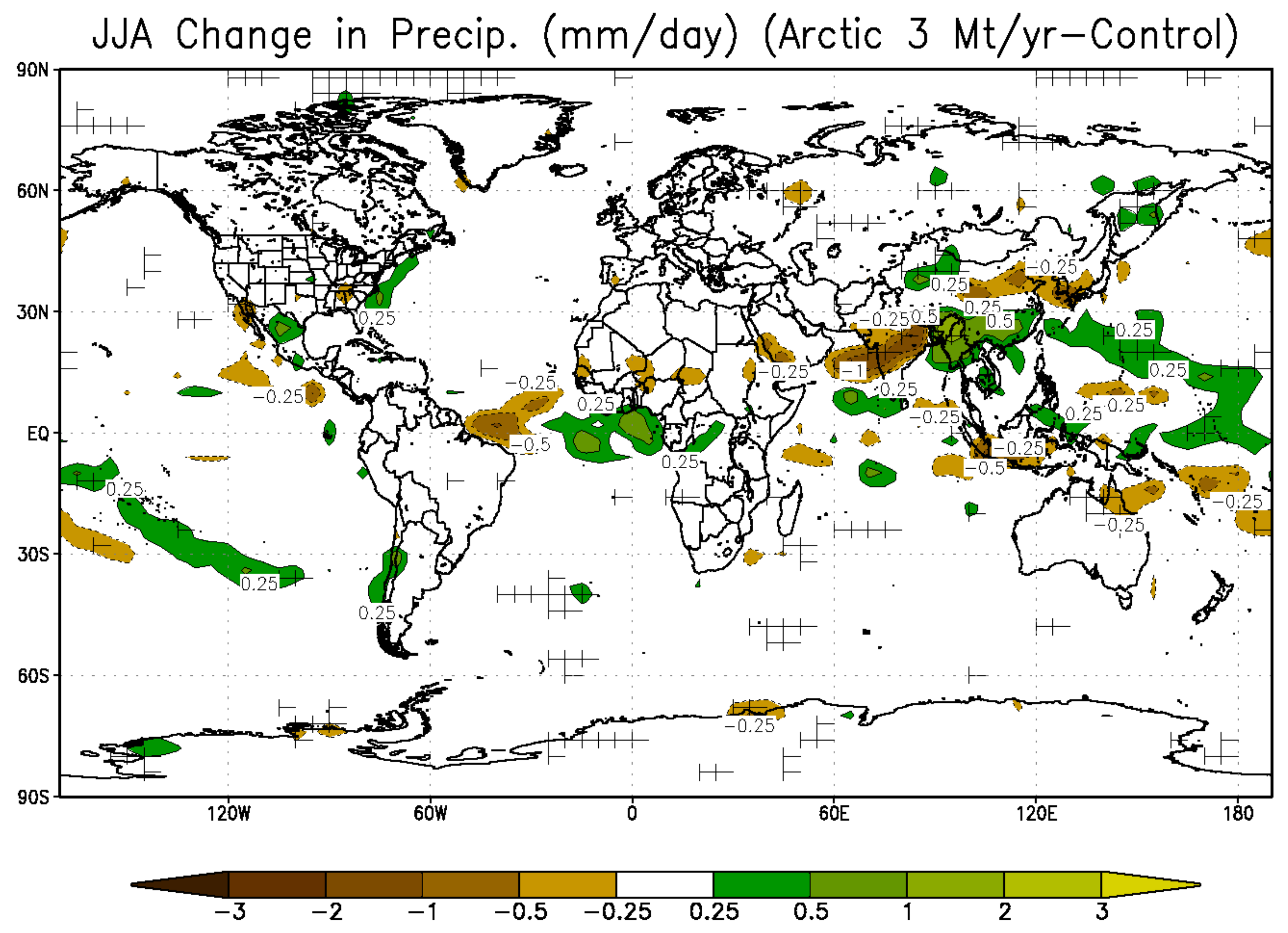

JJA Change in SAT (°C) (Arctic 3 Mt/yr–A1b)



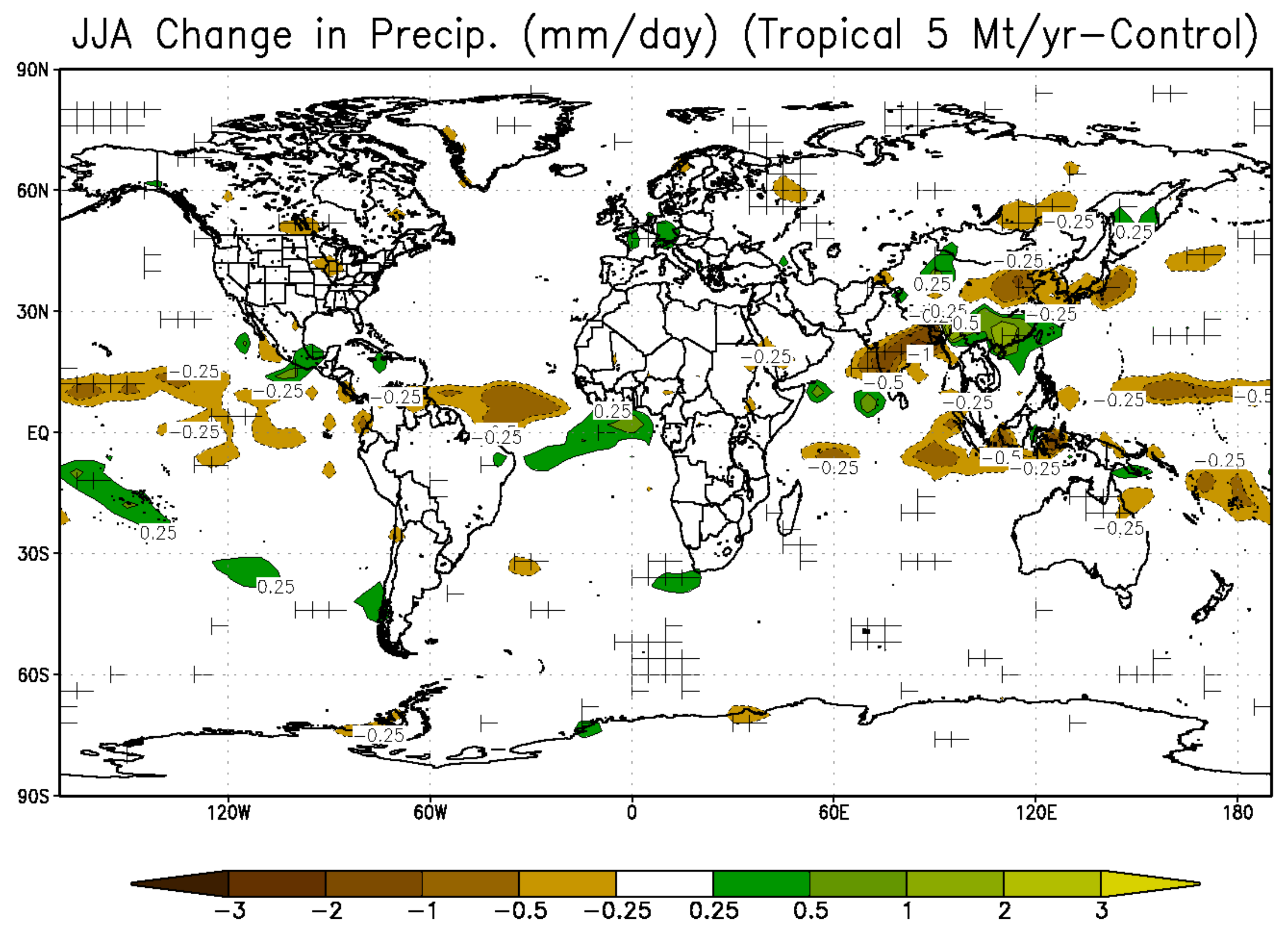


Mean response for second decade of aerosol injection for IPCC A1B + Tropical 5 Mt/yr case for NH summer surface air temperature

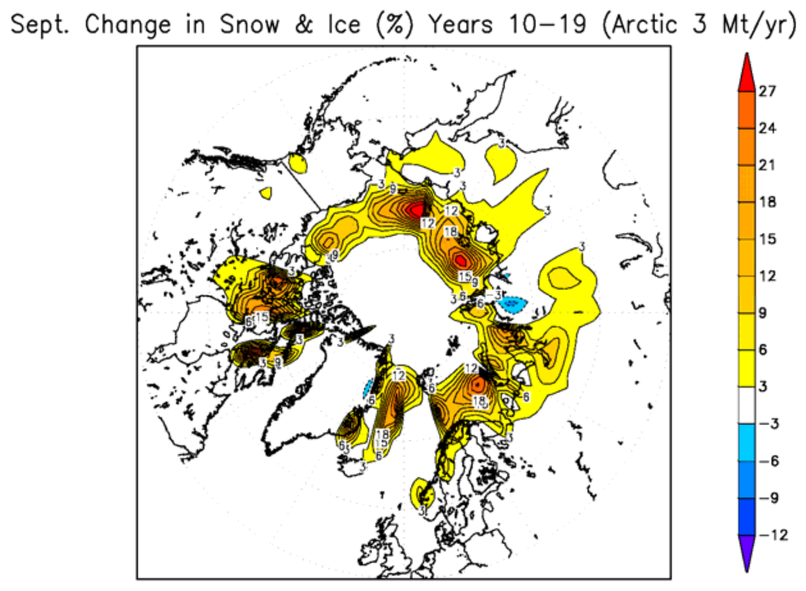




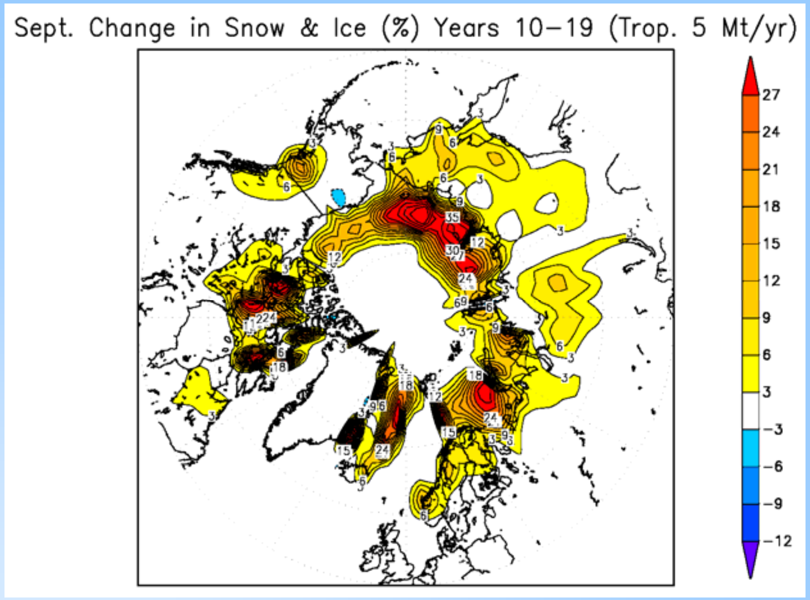
⌗ = significant at the 95% level



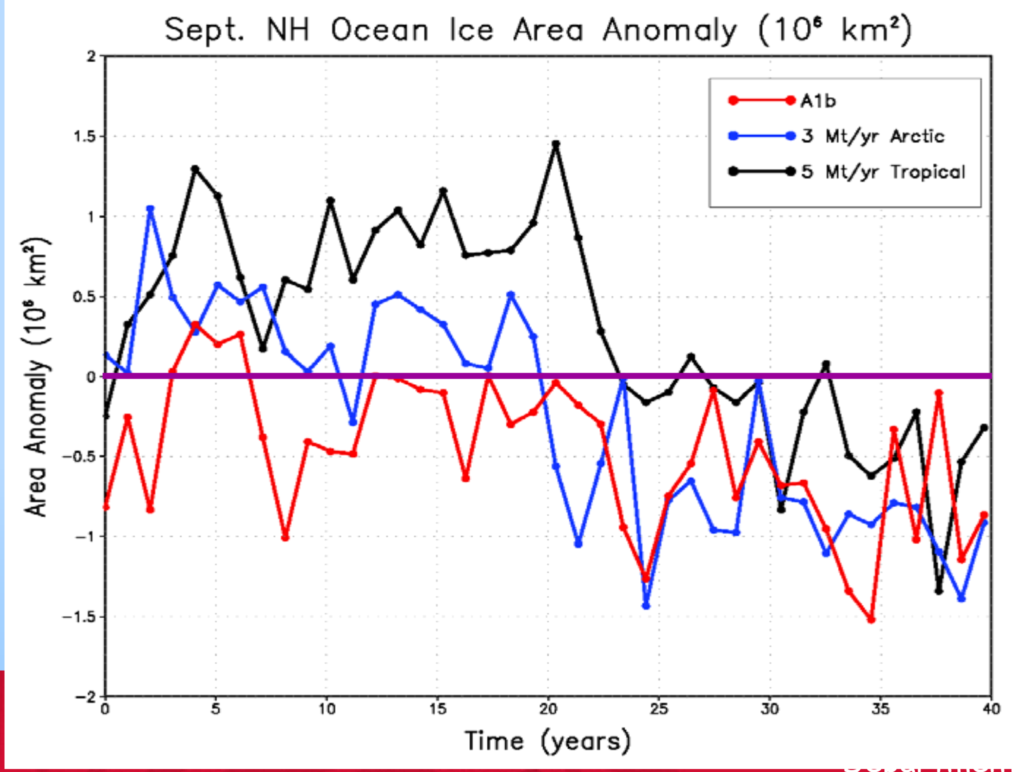
= significant at the 95% level



Sept. Change in Snow & Ice (%) Years 10–19 (Arctic 3 Mt/yr)



Sept. Change in Snow & Ice (%) Years 10–19 (Trop. 5 Mt/yr)

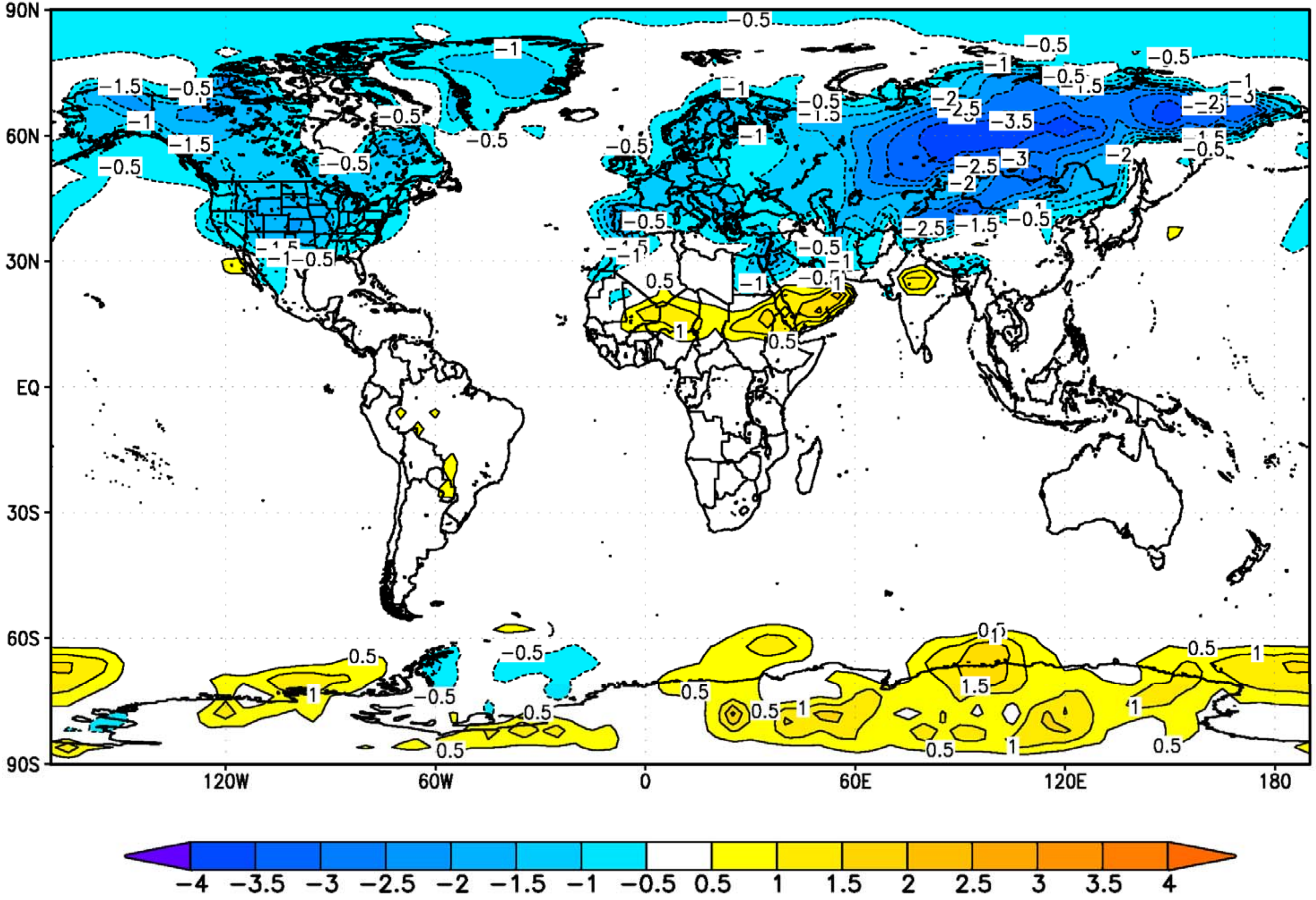


Sept. NH Ocean Ice Area Anomaly (10^6 km²)

Conclusions

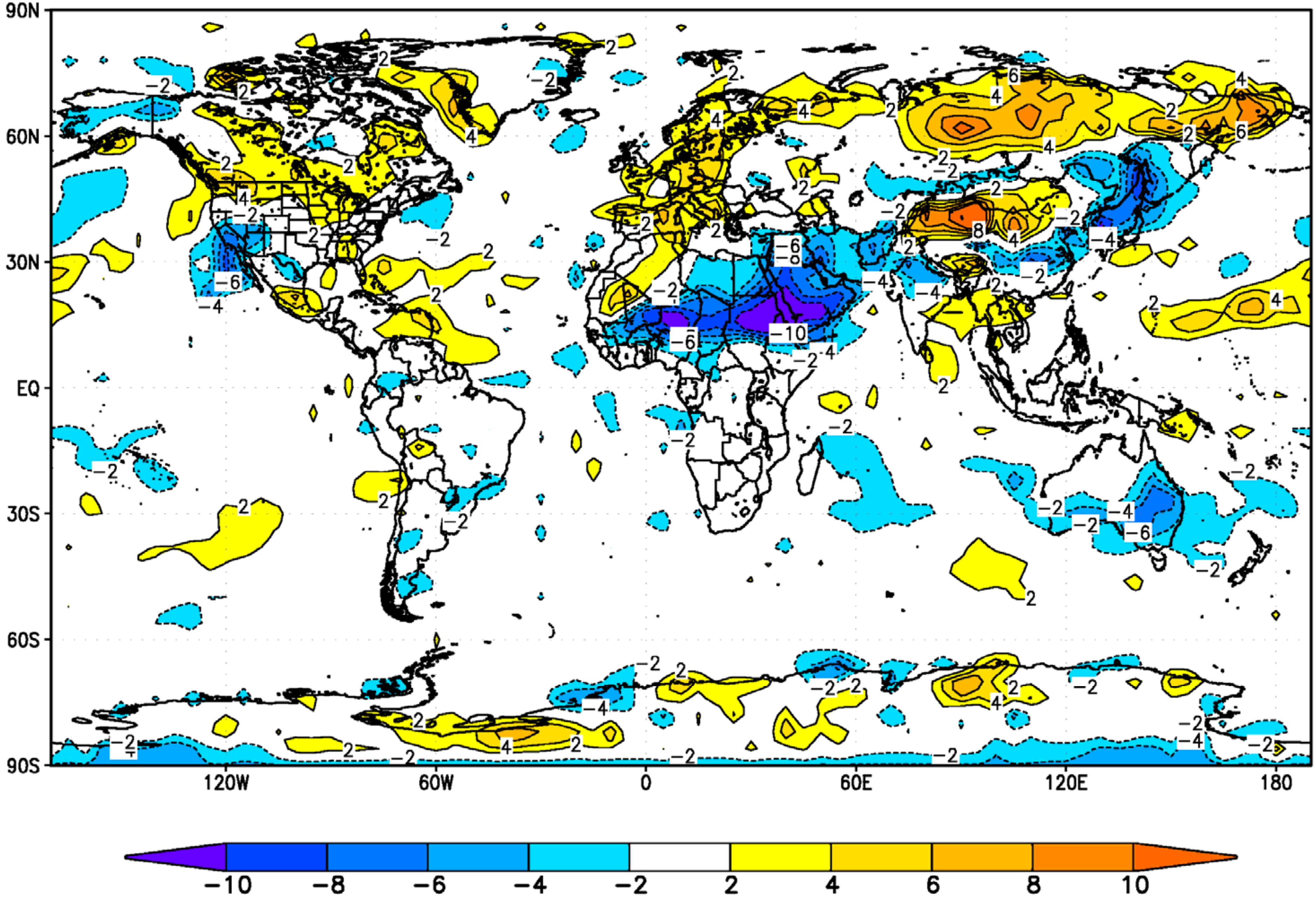
1. If there were a way to continuously inject SO_2 into the lower stratosphere, it would produce global cooling.
2. Tropical SO_2 injection would produce sustained cooling over most of the world, with more cooling over continents.
3. Arctic SO_2 injection would not just cool the Arctic.
4. Solar radiation reduction produces larger precipitation response than temperature, as compared to greenhouse gases.
5. Both tropical and Arctic SO_2 injection would disrupt the Asian and African summer monsoons, reducing precipitation to the food supply for billions of people.

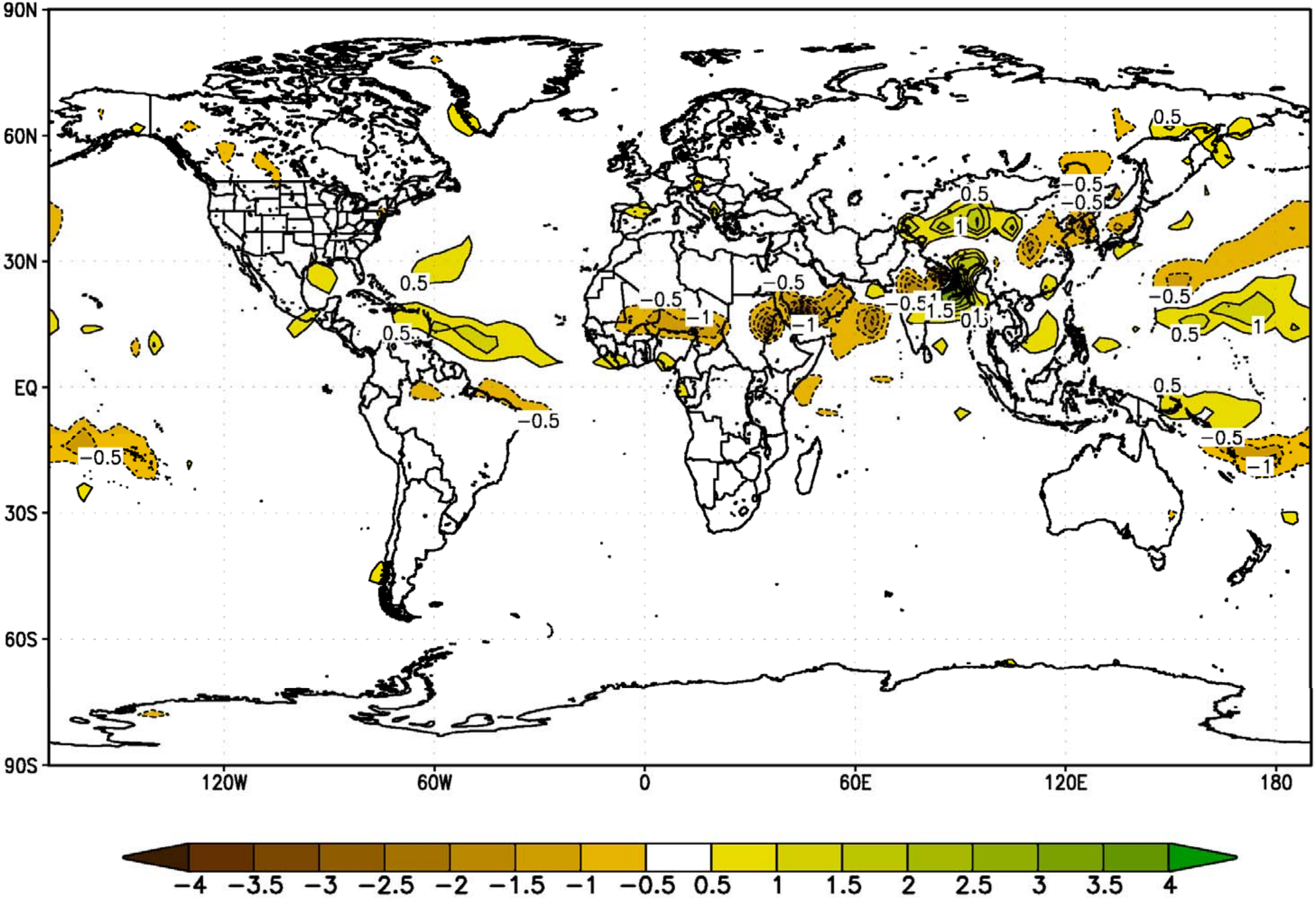
1783-84, Lakagígar (Laki), Iceland



Laki SAT Anomaly (°C) JJA 1783 q-flux

Laki Cloud Cover Anomaly (%) JJA 1783 q−flux





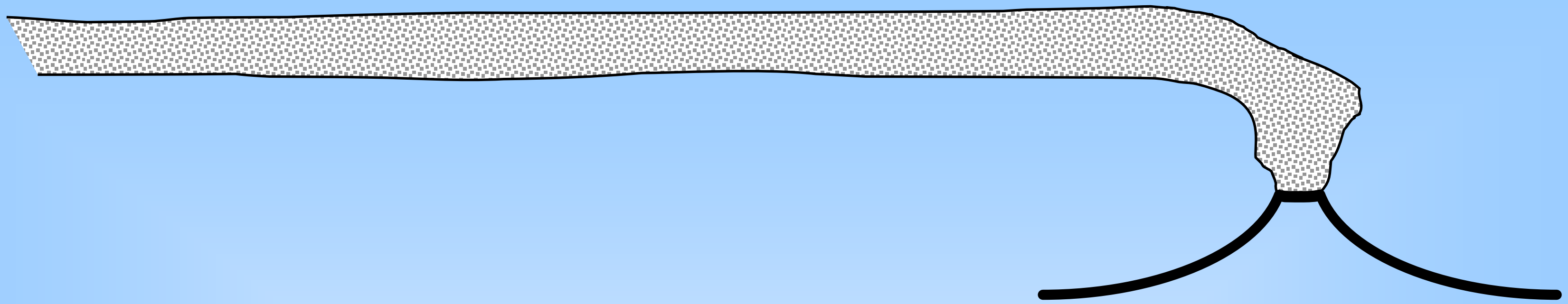
Laki Precip. Anomaly (mm/day) JJA 1783 q-flux

M. C-F. Volney, *Travels through Syria and Egypt, in the years 1783, 1784, and 1785, Vol. I*, Dublin, 258 pp. (1788)

"The inundation of 1783 was not sufficient, great part of the lands therefore could not be sown for want of being watered, and another part was in the same predicament for want of seed. In 1784, the Nile again did not rise to the favorable height, and the dearth immediately became excessive. Soon after the end of November, the famine carried off, at Cairo, nearly as many as the plague; the streets, which before were full of beggars, now afforded not a single one: all had perished or deserted the city."

By January 1785, 1/6 of the population of Egypt had either died or left the country in the previous two years.

http://www.academie-francaise.fr/images/immortels/portraits/volney.jpg

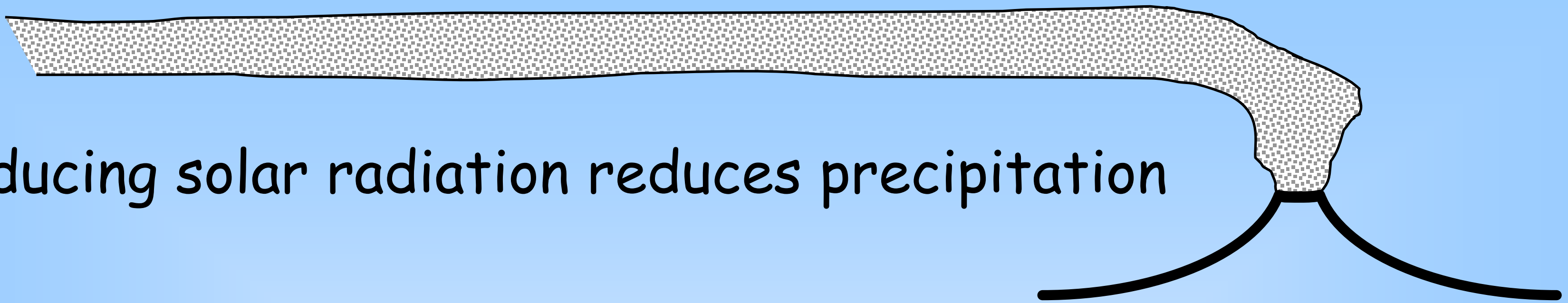


FAMINE IN INDIA AND CHINA IN 1783

The Chalisa Famine devastated India as the monsoon failed in the summer of 1783.

There was also the Great Tenmei Famine in Japan in 1783-1787, which was locally exacerbated by the Mount Asama eruption of 1783.

Reducing solar radiation reduces precipitation

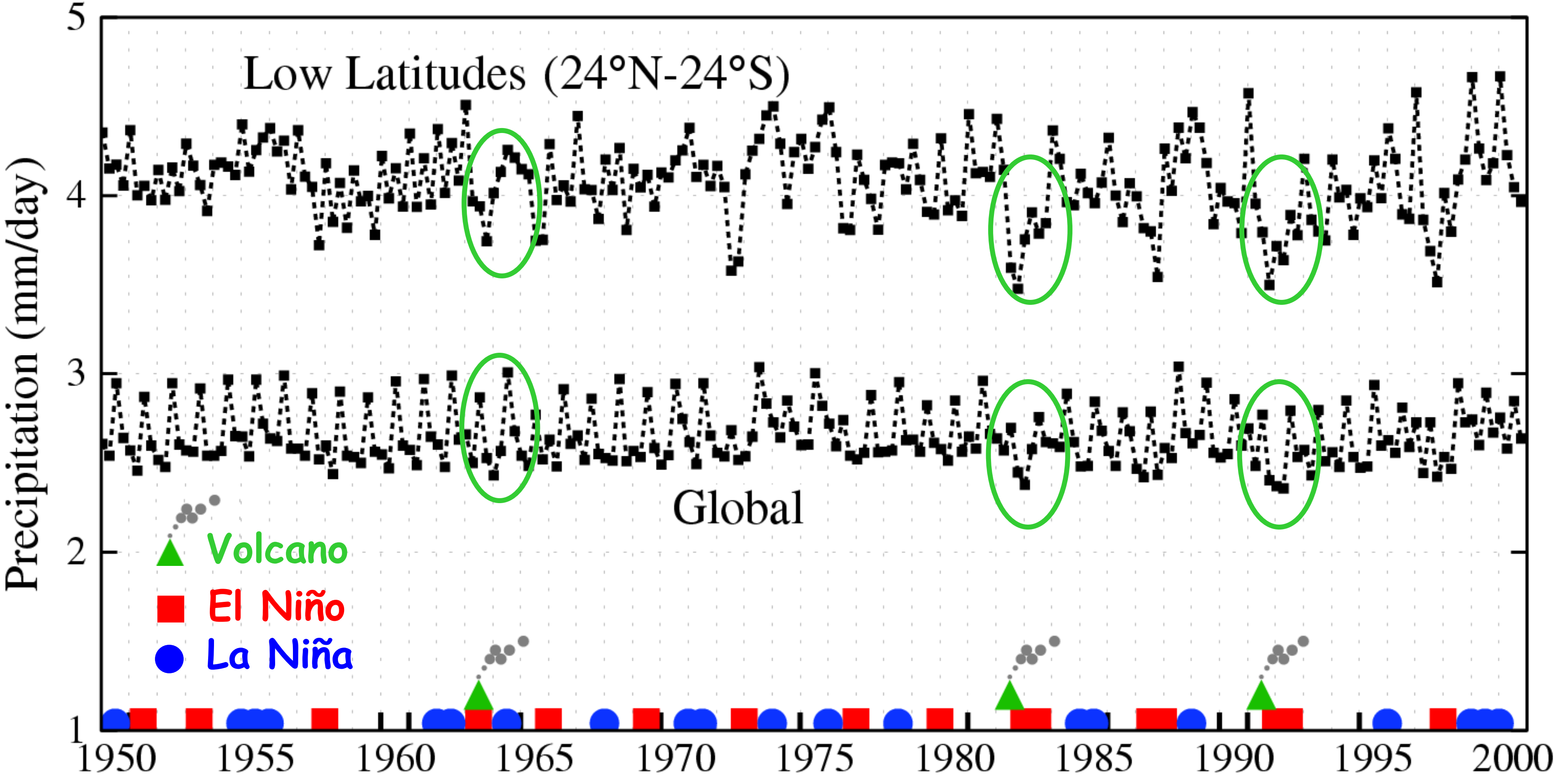


If we compensate for the increased downward longwave (heat) radiation from greenhouse gases by reducing solar radiation by the same amount, we can produce a net radiation balance at the surface so temperature will not change.

However, this will result in a reduction of precipitation, since changing solar radiation has a larger impact on precipitation than changing longwave radiation.

This will produce warming from drier surfaces requiring even more solar reduction and more drying.

Precipitation Change at Seasonal Resolution



Drawn by Makiko Sato (NASA GISS)
using CRU TS 2.0 data

Trenberth and Dai (2007)

Effects of Mount Pinatubo volcanic eruption on the hydrological cycle as an analog of geoengineering

Geophys. Res. Lett.

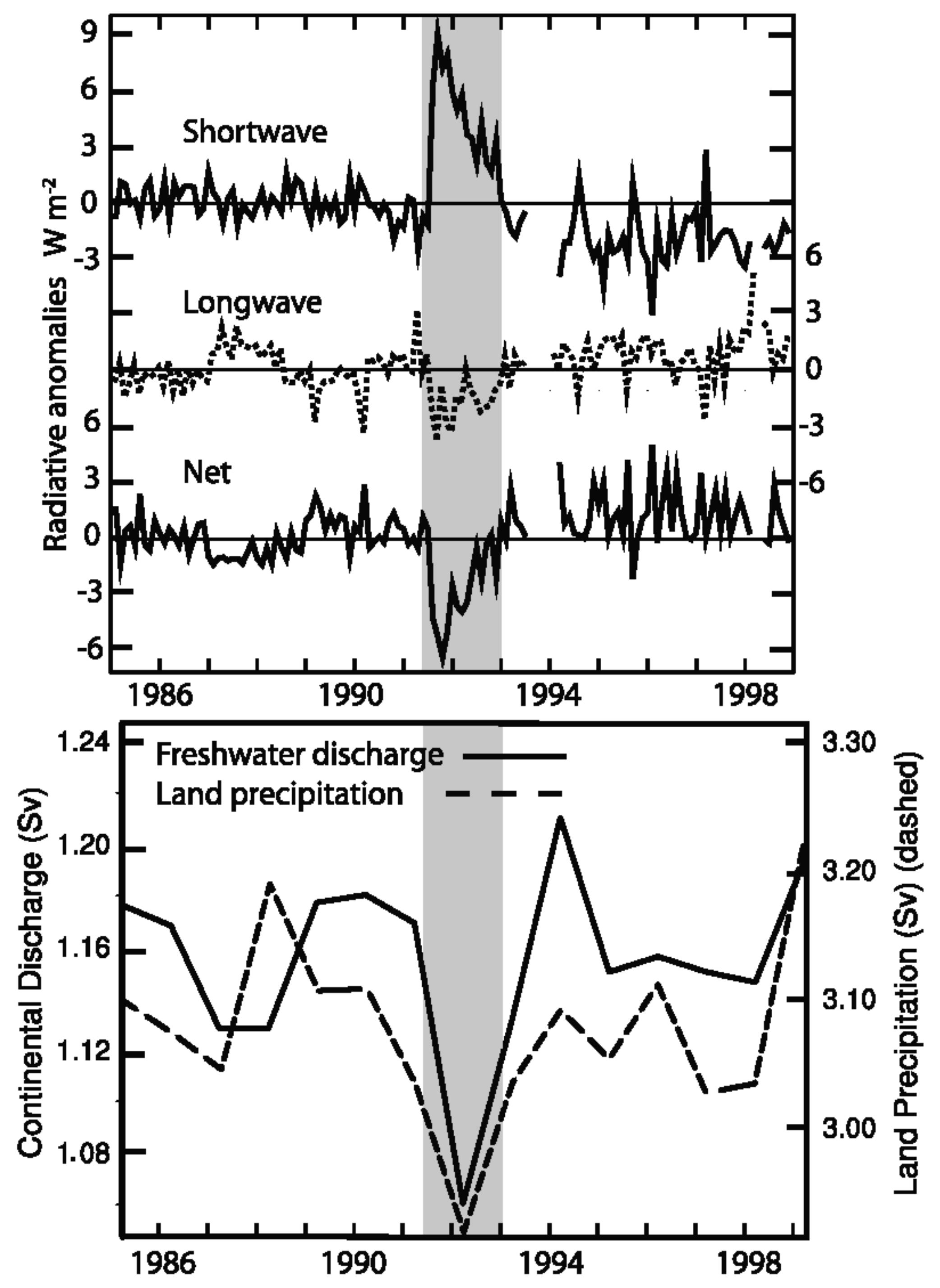
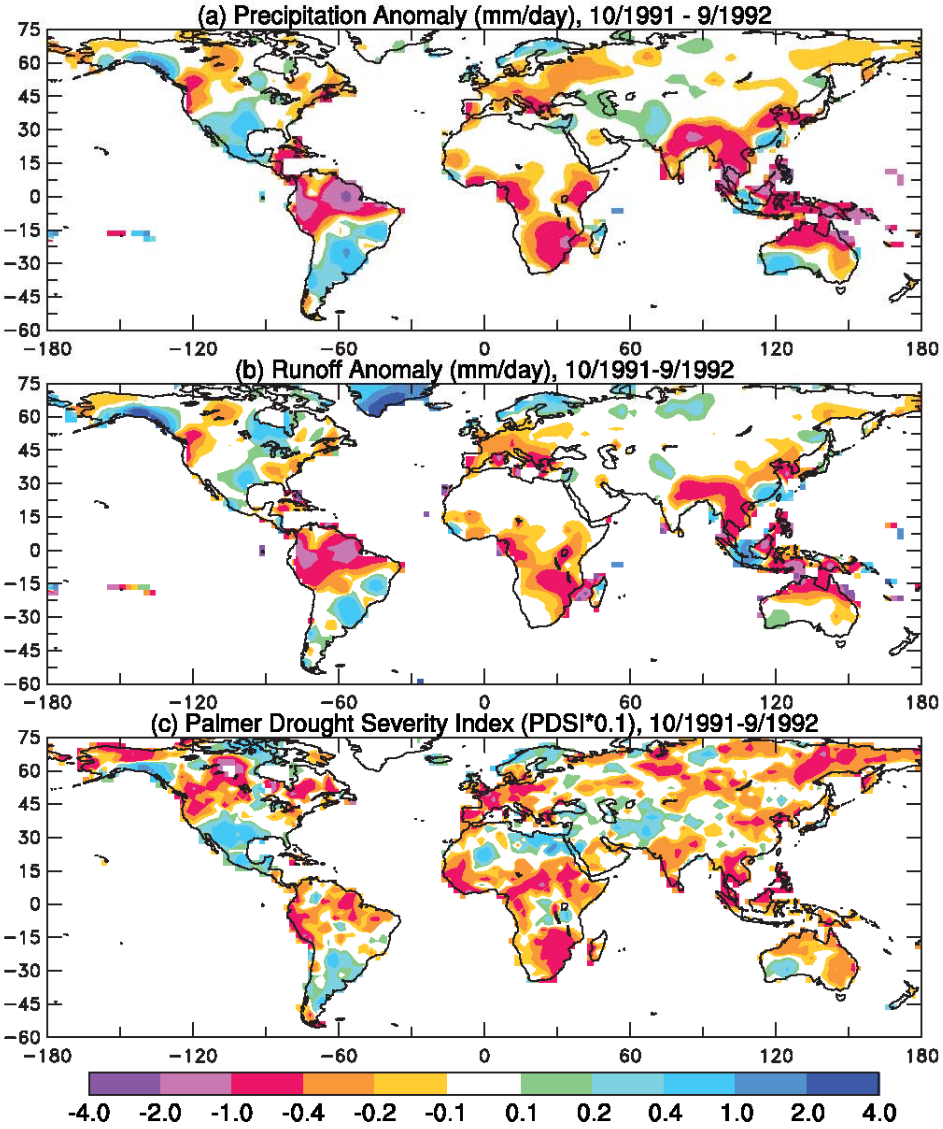


Figure 2. (top) Adapted time series of 20°N to 20°S ERBS non-scanner wide-field-of-view broadband shortwave, longwave, and net radiation anomalies from 1985 to 1999 [*Wielicki et al.*, 2002a, 2002b] where the anomalies are defined with respect to the 1985 to 1989 period with Edition 3_Rev 1 data [*Wong et al.*, 2006]. (bottom) Time series of the annual water year (Oct. to Sep.); note slight offset of points plotted vs. tick marks indicating January continental freshwater discharge and land precipitation (from Figure 1) for the 1985 to 1999 period. The period clearly influenced by the Mount Pinatubo eruption is indicated by grey shading.



(a) Precipitation Anomaly (mm/day), 10/1991 - 9/1992

(b) Runoff Anomaly (mm/day), 10/1991-9/1992

(c) Palmer Drought Severity Index (PDSI*0.1), 10/1991-9/1992

Figure 3. (a) Observed precipitation anomalies (relative to 1950–2004 mean) in mm/day during October 1991–September 1992 over land. Warm colors indicate below normal precipitation. (b) As for Figure 3a but for the simulated runoff [*Qian et al.*, 2006] using a comprehensive land surface model forced with observed precipitation and other atmospheric forcing in mm/day. (c) Palmer Drought Severity Index (PDSI, multiplied by 0.1) for October 1991–September 1992 [*Dai et al.*, 2004]. Warm colors indicate drying. Values less than −2 (0.2 on scale) indicate moderate drought, and those less than −3 indicate severe drought.

Reasons geoengineering may be a bad idea

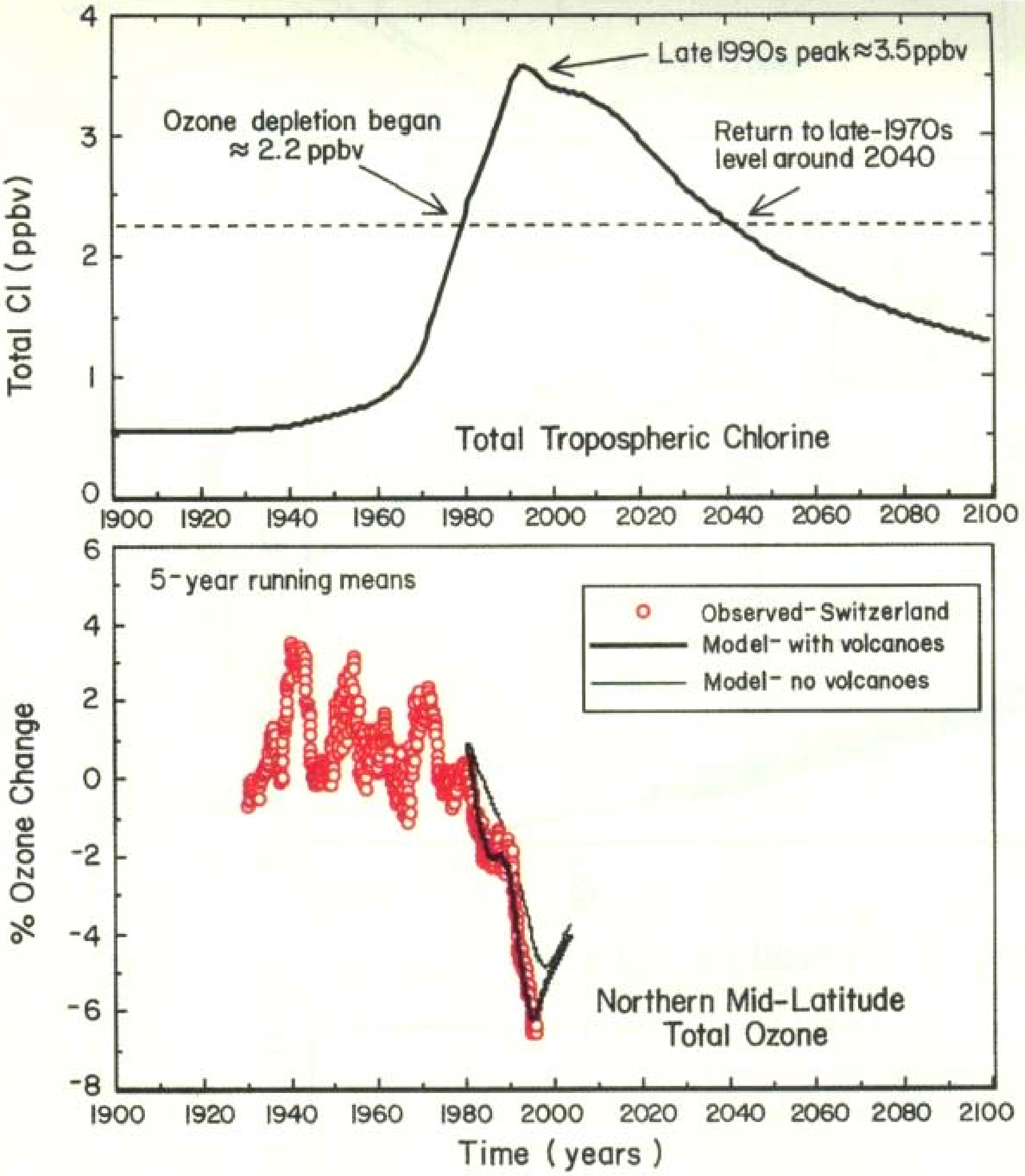
Climate system response

✓1. Regional climate change, including temperature and precipitation
✓2. Continued ocean acidification
3. **Ozone depletion**
4. Effects on plants of changing the amount of solar radiation and partitioning between direct and diffuse
5. Enhanced acid precipitation
6. Effects on cirrus clouds as aerosols fall into the troposphere
7. Whitening of the sky (but nice sunsets)
8. Less solar radiation for solar power, especially for those requiring direct radiation
9. Rapid warming when it stops
10. How rapidly could effects be stopped?
11. Environmental impacts of aerosol injection, including producing and delivering aerosols

Tropospheric chlorine diffuses to stratosphere.

Volcanic aerosols make chlorine available to destroy ozone.

Solomon (1999)

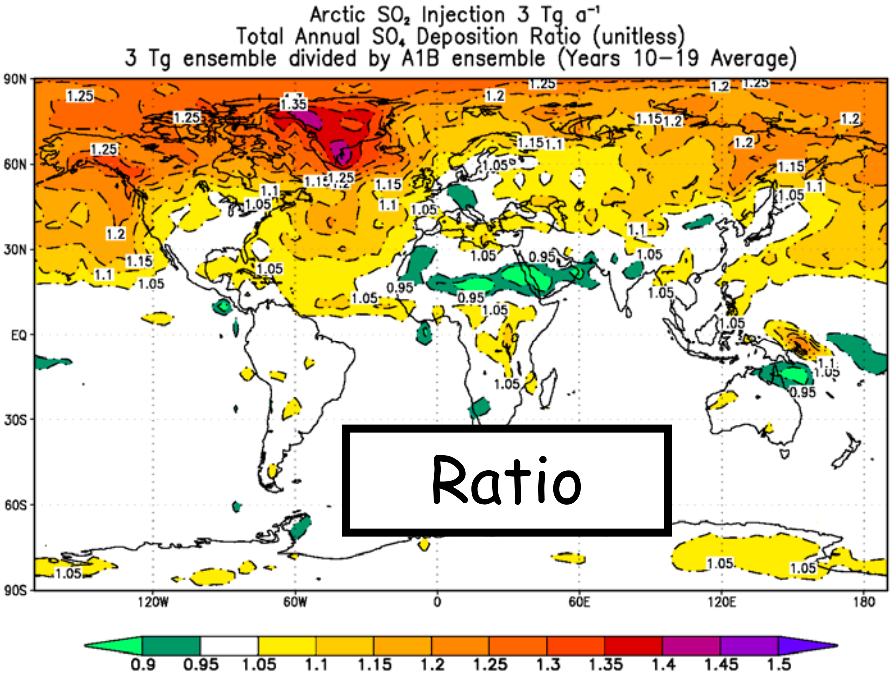


Reasons geoengineering may be a bad idea

Climate system response

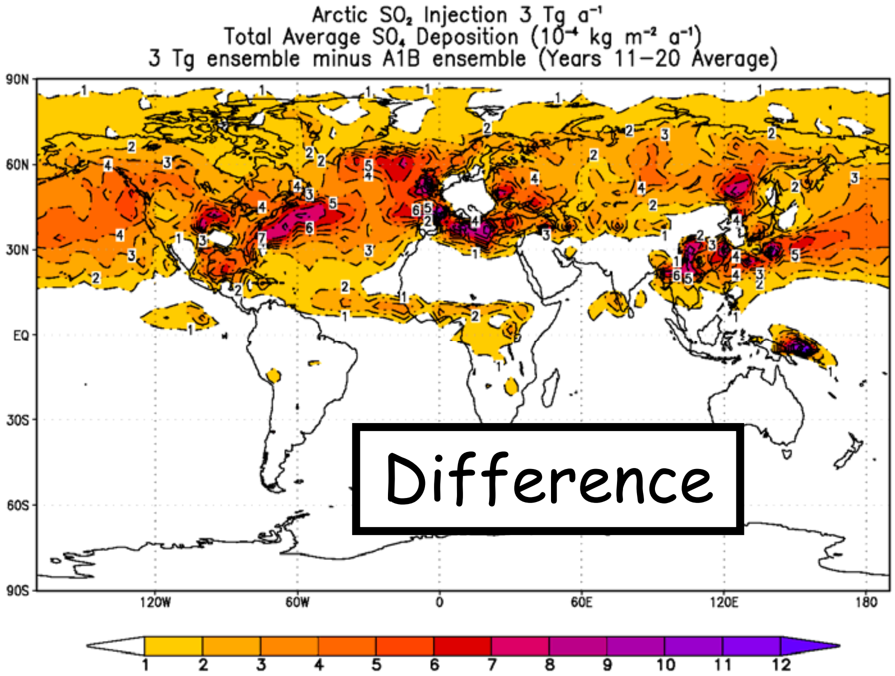
✓1. Regional climate change, including temperature and precipitation
✓2. Continued ocean acidification
✓3. Ozone depletion
? 4. Effects on plants of changing the amount of solar radiation and partitioning between direct and diffuse
5. Enhanced acid precipitation
6. Effects on cirrus clouds as aerosols fall into the troposphere
7. Whitening of the sky (but nice sunsets)
8. Less solar radiation for solar power, especially for those requiring direct radiation
9. Rapid warming when it stops
10. How rapidly could effects be stopped?
11. Environmental impacts of aerosol injection, including producing and delivering aerosols

Robock, Alan, 2008: Whither geoengineering? *Science*, **320**, 1166-1167.



Arctic SO_2 Injection 3 Tg a^{-1}
Total Annual SO_4 Deposition Ratio (unitless)
3 Tg ensemble divided by A1B ensemble (Years 10–19 Average)

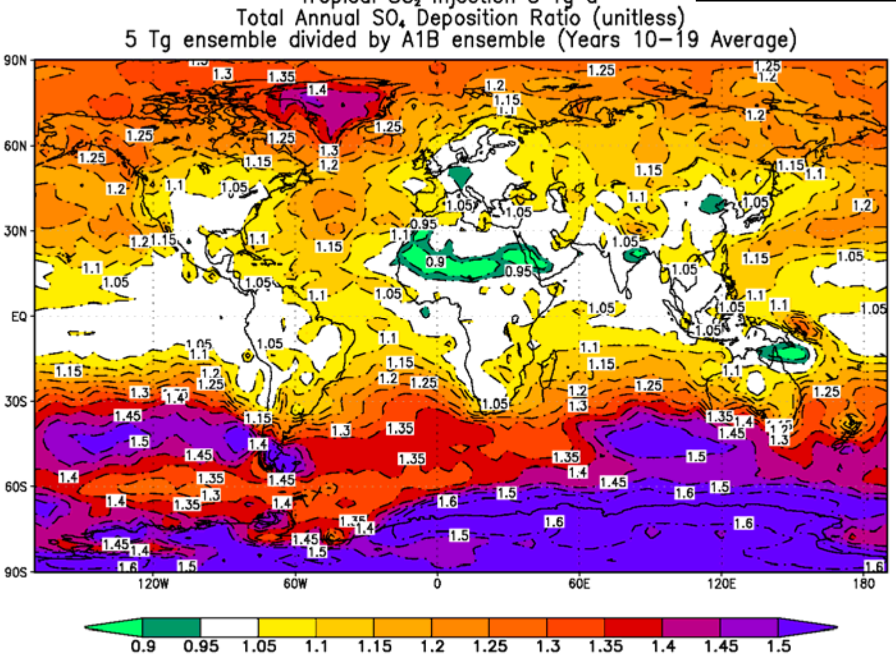
Ratio



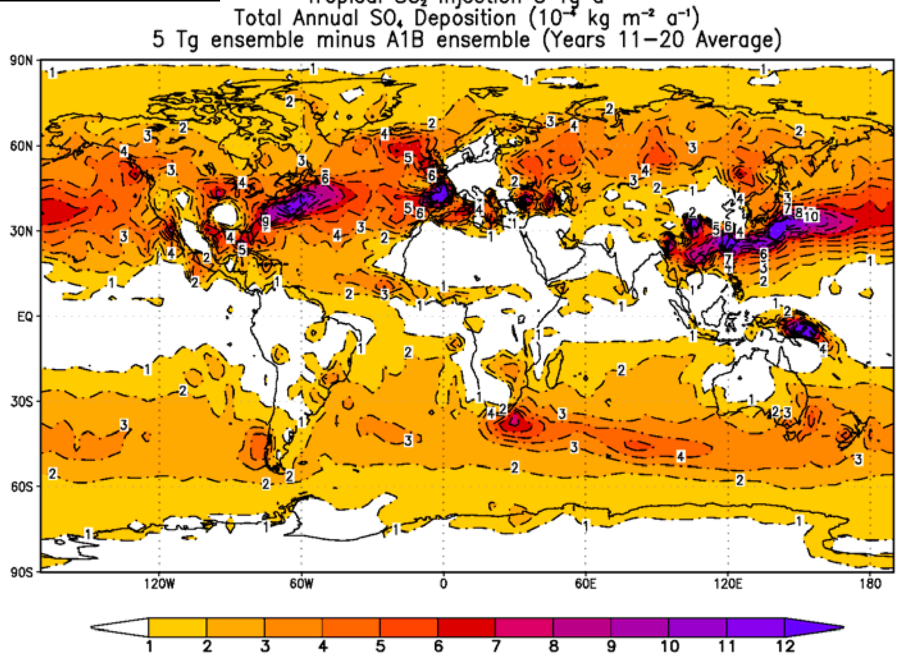
Arctic SO_2 Injection 3 Tg a^{-1}
Total Average SO_4 Deposition (10^{-4} kg m^{-2} a^{-1})
3 Tg ensemble minus A1B ensemble (Years 11–20 Average)

Difference

Kravitz et al. (2008), submitted to *GRL*



Tropical SO_2 Injection 5 Tg a^{-1}
Total Annual SO_4 Deposition Ratio (unitless)
5 Tg ensemble divided by A1B ensemble (Years 10–19 Average)

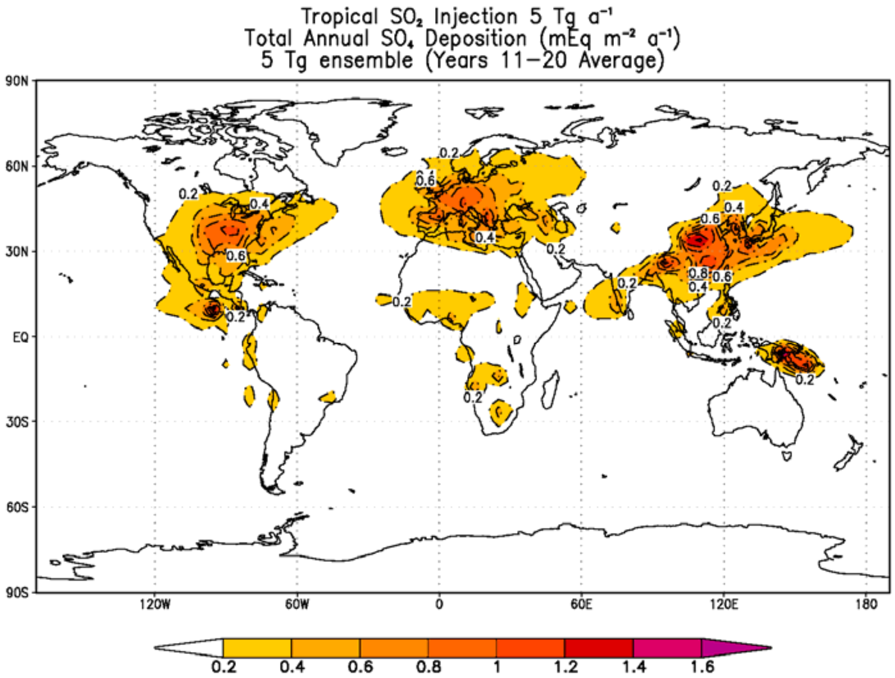


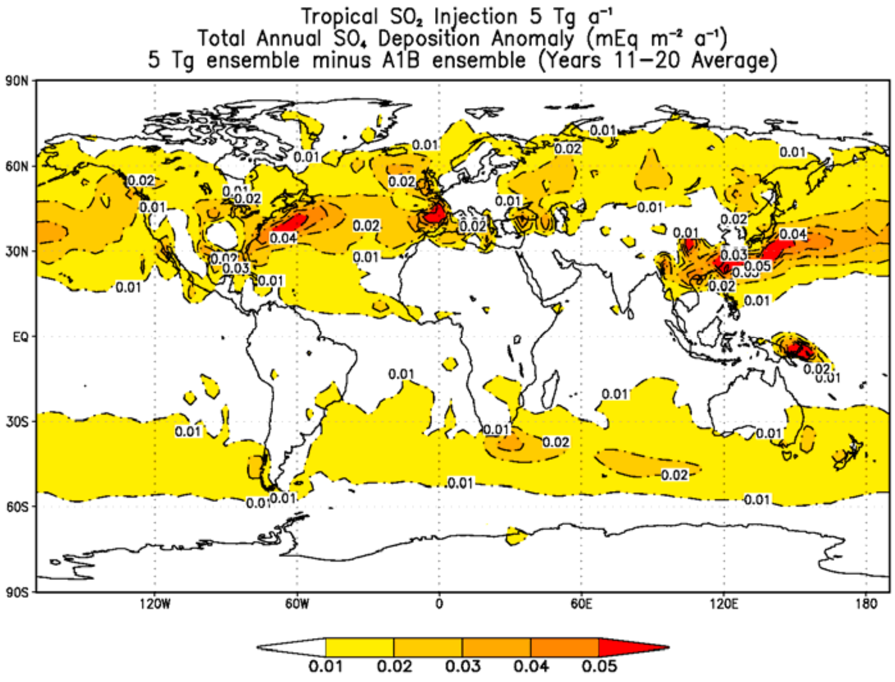
Tropical SO_2 Injection 5 Tg a^{-1}
Total Annual SO_4 Deposition (10^{-4} kg m^{-2} a^{-1})
5 Tg ensemble minus A1B ensemble (Years 11–20 Average)

Ranges of critical loading of pollutant deposition (including sulfur) for various sites in Europe [*Skeffington*, 2006]

Region	**Critical Load ($mEq\ m^{-2}\ a^{-1}$)**
Coniferous forests in Southern Sweden	13-61
Deciduous forests in Southern Sweden	15-72
Varied sites in the UK	24-182
Aber in North Wales	32-134
Uhlirska in the Czech Republic	260-358
Fårahall in Sweden	29-134
Several varied sites in China (sulfur only)	63-880
Waterways in Sweden	1-44

Excess deposition is orders of magnitude too small to be harmful.





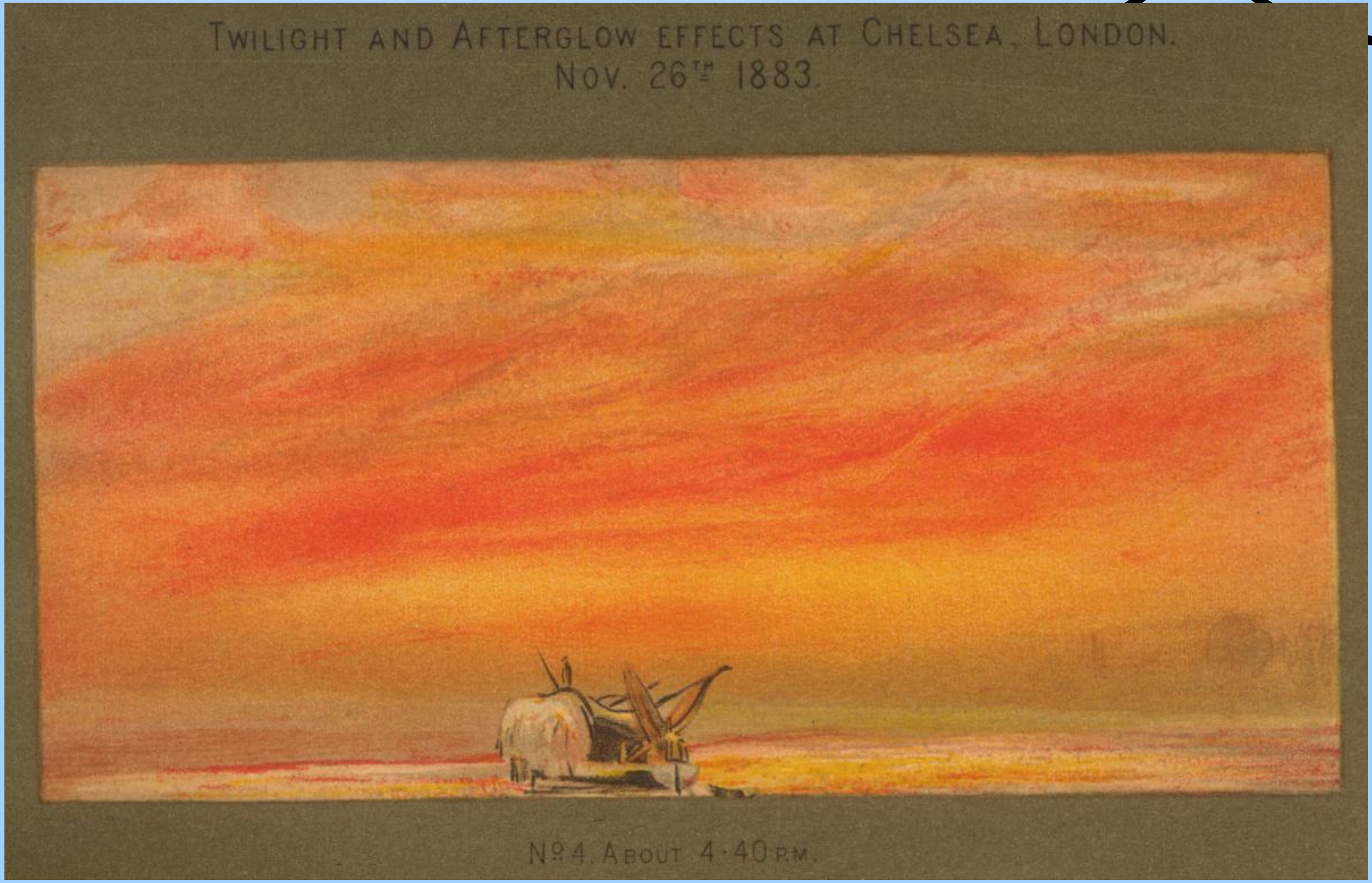
Kravitz et al. (2008), submitted to *GRL*

Reasons geoengineering may be a bad idea

Climate system response

✓1. Regional climate change, including temperature and precipitation
✓2. Continued ocean acidification
✓3. Ozone depletion
? 4. Effects on plants of changing the amount of solar radiation and partitioning between direct and diffuse
X5. Enhanced acid precipitation
? 6. Effects on cirrus clouds as aerosols fall into the troposphere
7. Whitening of the sky (but nice sunsets)
8. Less solar radiation for solar power, especially for those requiring direct radiation
9. Rapid warming when it stops
10. How rapidly could effects be stopped?
11. Environmental impacts of aerosol injection, including producing and delivering aerosols

Krakatau, 1883
Watercolor by William Ascroft



TWILIGHT AND AFTERGLOW EFFECTS AT CHELSEA, LONDON.
NOV. 26TH 1883.

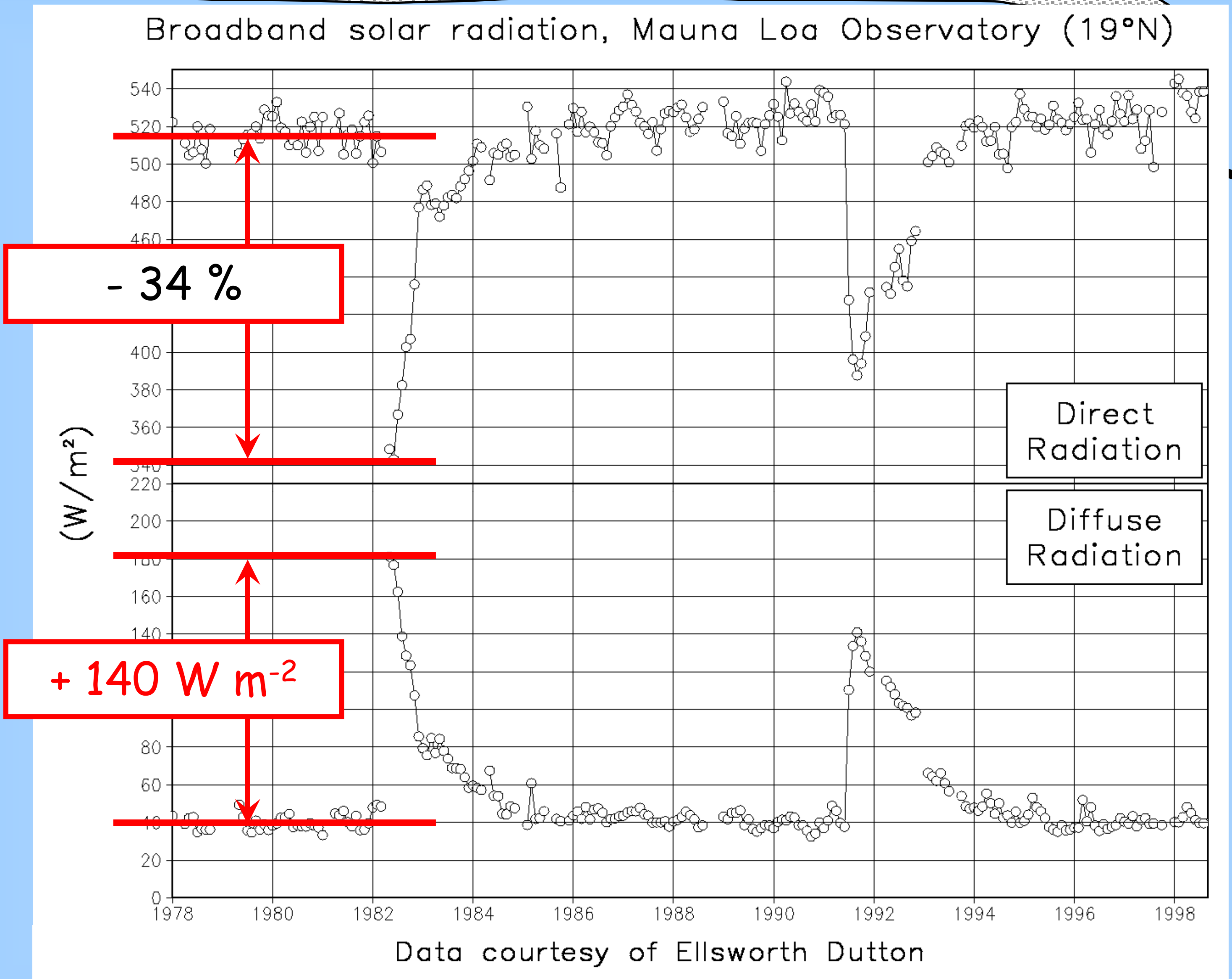
No. 4. ABOUT 4·40 P.M.

Figure from Symons (1888)

“The Scream”

Edvard Munch

Painted in 1893 based on Munch’s memory of the brilliant sunsets following the 1883 Krakatau eruption.



Broadband solar radiation, Mauna Loa Observatory (19°N)

- 34 %

+ 140 W m^{-2}

Data courtesy of Ellsworth Dutton

Robock (2000), Dutton and Bodhaine (2001)

Nevada Solar One
64 MW

Solar steam generators
requiring direct solar

Seville, Spain
Solar Tower
11 MW

http://www.electronichealing.co.uk/articles/solar_power_tower_spain.htm

http://judykitsune.wordpress.com/2007/09/12/solar-seville/

Reasons geoengineering may be a bad idea

Climate system response

✓1. Regional climate change, including temperature and precipitation
✓2. Continued ocean acidification
✓3. Ozone depletion
? 4. Effects on plants of changing the amount of solar radiation and partitioning between direct and diffuse
X5. Enhanced acid precipitation
? 6. Effects on cirrus clouds as aerosols fall into the troposphere
✓7. Whitening of the sky (but nice sunsets)
✓8. Less solar radiation for solar power, especially for those requiring direct radiation
✓9. Rapid warming when it stops
✓10. How rapidly could effects be stopped?
?11. Environmental impacts of aerosol injection, including producing and delivering aerosols

Reasons geoengineering may be a bad idea

Unknowns

✓12. Human error

✓13. Unexpected consequences (How well can we predict the expected effects of geoengineering? What about unforeseen effects?)

Political, ethical and moral issues

✓14. Schemes perceived to work will lessen the incentive to mitigate greenhouse gas emissions

? 15. Use of the technology for military purposes. Are we developing weapons?

? 16. Commercial control of technology

✓17. Violates UN Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques

18. Could be tremendously expensive

19. Even if it works, whose hand will be on the thermostat? How could the world agree on the optimal climate?

20. Who has the moral right to advertently modify the global climate?

How could we actually get the sulfate aerosols into the stratosphere?

Artillery?

Aircraft?

Balloons? (fill with a mixture of H_2 and H_2S to self-loft and burst in the stratosphere)

Space elevator?

Drawing by Brian West

Crude estimates show it would cost a few billion dollars to build a system, cost a few billion dollars per year to operate, and take less than a decade to implement.

Is this inexpensive?

Some say "yes" compared to other government expenditures or oil company profits.

Reasons geoengineering may be a bad idea

Unknowns

✓12. Human error
✓13. Unexpected consequences (How well can we predict the expected effects of geoengineering? What about unforeseen effects?)

Political, ethical and moral issues

✓14. Schemes perceived to work will lessen the incentive to mitigate greenhouse gas emissions
? 15. Use of the technology for military purposes. Are we developing weapons?
? 16. Commercial control of technology
✓17. Violates UN Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques
X18. Could be tremendously expensive
✓19. Even if it works, whose hand will be on the thermostat? How could the world agree on the optimal climate?
✓20. Who has the moral right to advertently modify the global climate?

Conclusions

Of the 20 reasons why geoengineering may be a bad idea:

13 ✓

2 X

5 ?

As of now, there are at least 13 reasons why geoengineering is a bad idea.

Reasons mitigation is a good idea

Proponents of geoengineering say that mitigation is not possible, as they see no evidence of it yet. But it is clearly a political and not a technical problem.

Mitigation will not only reduce global warming but it will also

- reduce ocean acidification,
- reduce our dependence on foreign sources of energy,
- stop subsidizing terrorism with our gas dollars,
- reduce our military budget, freeing resources for other uses,
- clean up the air, and
- provide economic opportunities for a green economy, to provide solar, wind, cellulosic ethanol, energy efficiency, and other technologies we can sell around the world.

The United Nations Framework Convention On Climate Change
1992

Signed by 194 countries and ratified by 188 (as of February 26, 2004)

Signed and ratified in 1992 by the United States

The ultimate objective of this Convention ... is to achieve ... stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.

The UN Framework Convention on Climate Change thought of “dangerous anthropogenic interference” as due to inadvertent effects on climate.

We now must include geoengineering in our pledge to “prevent dangerous anthropogenic interference with the climate system.”