Solar Shield Program

A Proposal to Mitigate Global Warming

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- Confidential -

Executive Summary

This presentation is intended mostly for informal discussion about the viability of a solar shield program to mitigate the some of the worst side-effects of global warming.

This document proposes a program to mitigate global warming by building and managing a cost-effective solar shield around the Earth. The solar shield allows mankind to adaptively manage Earth's average temperature. The solar shield reduces the Earth's total insolation by scattering (reflecting) a small percentage of the sun's light away from Earth. The solar shield would consist of sub-microscopic "nanoparticles" dispersed around the earth somewhere between the troposphere and low Earth orbit. The nanoparticles are engineered to be half-wave reflectors ("optical chaff" or "window") around the peak of the solar irradiance spectrum.

There is immediate need to develop a tool to help counter global warming. For example, recent results show that Greenland's icecap appears unstable and may have significantly melted in 30-50 years. If that were to happen the mean level of world's oceans could rise up to seven metres (twenty-three feet). A fraction of such a rise would devastate the world's major coastal communities. Amsterdam, London, New York, Shanghai, Surabaya, Hamburg and St. Petersburg are just a few of the susceptible cities. Even a one meter rise would swamp much of low-lying countries like Bangladesh and the Maldives.

To be ready to deploy a solar shield it is necessary to begin a multi-year multi-phase program of research and development. Four existing technologies must be developed and then proven: (1) nanoparticle design, (2) mass production of the nanoparticles, (3) delivery of the particles to altitude, and (4) efficient deployment at altitude.

Full-scale production (phase seven) should be able to begin fourteen years after the first phase (R&D). Measurable change in the environment (cooling: 0.5 percent reduction of insolation) should be observed after eight years of production. Stabilization occurs after twenty years of production. The cost of the program is about $4 million US dollars annually in the first year, ramping up to (estimated) $10 billion US dollars annually in full-scale production.

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Version History

Date	Description
2006_09_02	versions a, b
	(b) Add inputs from Berol Robinson. Notes on algae and the 'ocean desert'.
	(a) Add notes on marine acidification chemistry; agricultural boom comes from excess atmospheric $C0_2$ and not from the solar shield;
2006_08_02	versions a, b, c, d – review using ideas courtesy of Bruno Comby
	Continue tinkering
2006_07_12	versions a, b, c, d
	Make ppt presentation based on initial analysis
2006_07_04	More detailed spreadsheet calculations
2006_06_15	Extended initial calculations for project plan

Solar Shield Program
A Proposal to Mitigate Global Warming
Introduction

The document proposes a solar shield program to reduce and then eliminate the thermal runaway caused by the excess greenhouse gases associated with global warming. The required time to implement a functioning solar shield would be a little more than three decades.

The solar shield is based on tiny particles known as “nanoparticles”. The nanoparticles are engineered to be half-wave optical scatterers. The particles are deployed in the stratosphere or low Earth orbit. They act together to reduce Earth’s insolation by a small percentage, nominally one or two percent. The lost insolation is scattered back into space.

The desired small reduction in the effective solar constant will tend to cool the Earth to pre-1990 levels. The amount of cooling would be carefully managed by the program. The solar shield reduces the temperature of the Earth at the same time as the greenhouse effect of excessive CO_2 emissions increases temperatures. The immediate goal is to cancel global warming with the solar shield: the mean average temperature of the Earth should stay constant at the desired “thermostat” point.

The solar shield is not persistent: it is designed to disappear after a few decades of not adding new nanoparticles.

The solar shield is based on existing technologies and extensions of existing technologies. The technical risk is reduced in a multi-phase multi-year research and development effort in the beginning of the program.

Driving Earth's Ecology and the Solar Shield

The Sun's power is the primary driver of Earth's tropospheric temperature by more than a factor of 1000.

- solar power is about 1366 Watts per square meter outside the atmosphere
- total solar power incident on the Earth:
  - 1.7458×10^{17} Watts = 174.58 petaWatts
- the variability in the solar "constant" is about 0.1% over an 11-year solar cycle

The solar shield consists of microscopic free-floating "nanoparticles". They reduce the solar power entering the Earth's ecosystem by scattering solar power energy back into space

Models indicate that reducing the total solar power reaching the Earth's troposphere by 1.8% is adequate to cancel the temperature increase (global warming) caused a net doubling of the greenhouse gases from the levels in the year 1750 CE.

How Does it Work, Technically?

Solar Shield: Composition

The solar shield's nanoparticles or "nanotech" are optical dipoles, operating around the peak of the solar irradiance spectrum.

The dipoles scatter / reflect solar energy back into space

Dipoles are simple yet efficient scatterers / reflectors of electromagnetic energy

Dipole Structure:

- an electrical conductor (a gold nanowire) one-half optical wavelength long
- much thinner in thickness and width

The nanotech / dipole particles are deployed in the stratosphere or low Earth orbit.

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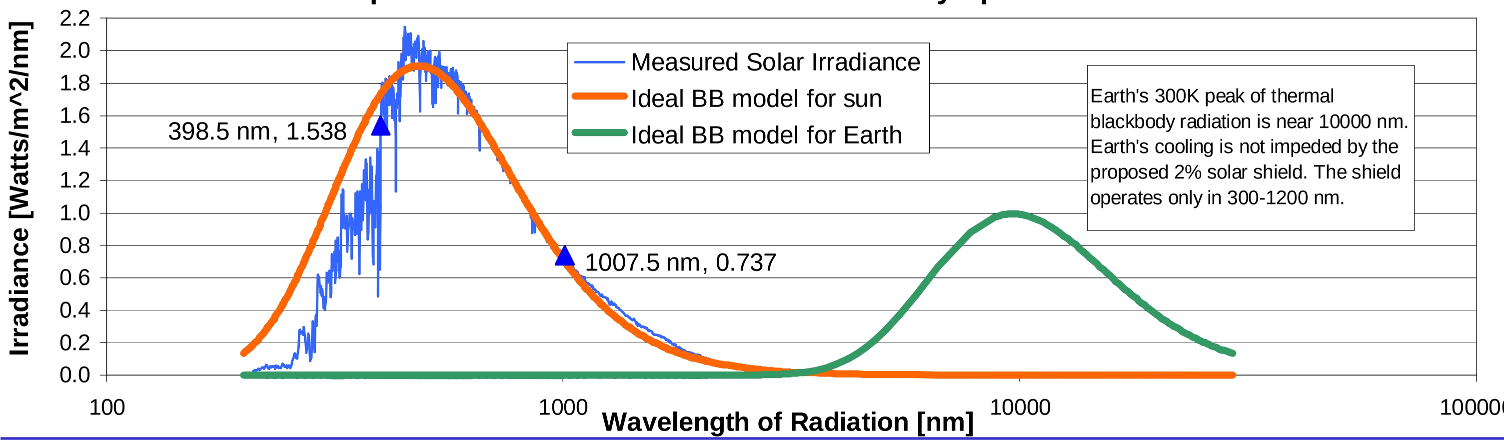
How Does it Work, Technically?

Solar Shield: Spectral Performance and Black-Body Spectral Radiance

The nanotech dipoles act together to reduce Earth’s insolation by a small percentage, nominally one or two percent. The lost insolation is scattered back into space.

The scatterers do not hold the Earth’s heat in because they are designed to work well in the visible and near infra-red light (300 to 1200 nm). The dipoles scatter Earth’s radiant heat very ineffectively because Earth radiates mostly in the far infra-red (3000 to 25000 nm) (the peak of the black-body spectrum at 300°K is near wavelength 10000 nm per Wien’s displacement law).

Solar Spectral Irradiance and Earth's Black Body Spectral Irradiance



Solar Shield: Intended Results and the Marine Ecosystem

The solar shield tends to reduce the Earth's mean temperature, counteracting the temperature increase caused by the increased CO_2 content of the atmosphere.

A small one to two percent reduction in the effective solar constant will tend to cool the Earth's mean temperature by a few degrees.

N.B.: Marine Ecosystem
The proposed solar shield would help two of the problems in the marine ecosystem related to global warming: falling biomass of algae and acidification. The solar shield helps cool the seas and thereby helps to increase the now-falling biomass of CO_2-fixing algae and plankton. In doing so the solar shield mitigates the related ecological problem of the acidification of the surface marine ecosystems. **Reference:** Appendix XII.

Solar Shield: Adaptive Climate Management

The solar shield's performance will be carefully managed by the program

Main inputs for adaptive climate management:

- measured change of insolation
- measurements of mean temperatures around the world
- measurements of atmospheric CO_2 content + other greenhouse gases
- measurements of Greenland and Antarctic ice
- computer-generated climate models

The target is zero global warming over the whole Earth: retain traditional climates over the entire planet. This is achieved after 20 years of production. The solar shield balances the temperature-increases caused by greenhouse gases within one degree of some TBD mean global temperature.

Adaptive climate management cancels the global warming with the solar shield: traditional climates are preserved and the mean average temperature of the Earth will stay constant at the desired "thermostat" point.

Economics of Solar Shield Production

Solar Shield: Production & Operation Economics

In production, the solar shield program requires revenues of about $10 billion US dollars each year. After 20 years of production the global mean temperatures are stabilized.

The funds support:

- manufacturing 200-500 metric tonnes per year of nanotech particles (half-wave dipoles)
- packaging the particles for efficient deployment in the stratosphere
- 50-125 rocket launches (payload: 4000 kg nanotech + 1000 kg packaging) per year (assuming we use rockets to deliver the nanotech to altitude)
- maintenance and upkeep of nanotech factories and equipment
- climate monitoring, climate research and climate modelling
- continuing R&D work improving solar shield activities

Solar Shield: Compared with Other Large Economies

Compare the annual cost of the proposed solar shield other economic activities:

Solar shield program	$10	billion US dollars each year estimated for full production
Global warming studies	>$3	billion US dollars / year globally (2003)
NSF (USA) budget	$6	billion US dollars / year (2003)
Intel Corp. revenue	$39	billion US dollars (2005)
Microsoft revenue	$40	billion US dollars (2005)
USA Iraq / Afghanistan project	$55	billion US dollars / year averaged 2001-2005
IBM revenue	$91	billion US dollars (2005)
General Electric revenue	$150	billion US dollars (2005)
USA Dept of Defense budget	$437	billion US dollars (2004)
GDP – Netherlands	$503	billion international dollars (2005)
National income – USA	$9,680	billion US dollars (2003)
GDP – USA	$12,278	billion international dollars (2005)
GDP – EU	$12,427	billion international dollars (2005)
GDP – world	$61,078	billion international dollars (2005)

Economics of Solar Shield Production

Solar Shield: as a Percentage of other Large Economies

The solar shield stabilizes global mean temperatures after 20 years of production.

Compare the annual cost of the proposed solar shield program (<$10 billion US dollars) in full production with other economic activities:

Solar shield program:	<0.016%	of GDP – world	(2005)
	<0.080%	of GDP – EU	(2005)
	<0.081%	of GDP – USA	(2005)
	<0.10%	of USA national income	(2003)
	<2.0%	of GDP-Netherlands	(2005)
	<2.3%	of USA Dept of Defense budget	(2004)
	<6.7%	of General Electric Revenue	(2005)
	<11%	of IBM revenue	(2005)
	<20%	annual cost of USA's Iraq / Afghan project	(2001-2005)
	<25%	of Microsoft revenue	(2005)
	<25%	of Intel revenue	(2005)
	<170%	of USA NSF budget	(2003)

Economics of Solar Shield Production

Solar Shield: Discussion of Economy

The solar shield program requires a small annual fraction of the USA or EU GDP, and it partially pays for itself in improved economies and spin-off activities within two decades after production begins.

The solar shield program in full production annually costs less than 0.1% of the GDP of the USA or the EU, and less than 0.02% of the GDP of the world in 2005.

The cost is approximately:
- one quarter of the annual revenue of a company like Microsoft or Intel
- one tenth of the annual revenue of a company like IBM
- one fifteenth of the annual revenue of a company like General Electric.

Solar Shield: Benefits

The main benefit of the solar shield program is long term climate stability. Climate stability means:

- no global warming (fewer severe hurricanes / tropical cyclones) **Reference:** Fred Pearce, The Last Generation, © 2006, ISBN 1903919878 pp 267-269 quoting Kerry Emanuel (MIT), Peter Webster & Judy Curry (Georgia Tech) and Greg Holland (NCAR).

- stable sea-levels (stable icecaps in Greenland and Antarctica)

- increased biomass of marine algae & plankton, reduced marine acidification, and accelerated fixing of atmospheric CO_2 in the oceans.

- no economic disruption due to global flooding of the ocean coastlines

- reduced commercial risk

- better long-term profits

Continuing Production Costs of Solar Shield Program			
Annual Gold requirement:	9,720,214	[Troy ounces/year]	Amount of gold per year required to achieve the design percent reduction of solar flux (thin metallization)
Unit cost of refined Gold:	$715.50	[$USD/Troy ounce]	London Gold Fixing of 2006_05_11 (a local high)
Extended Cost of Refined Gold:	$6,954,813,109	[USD]	Estimated cost per YEAR to purchase gold through regular channels
		Gold cost:	
Cost of Fabrication:	$69,548,131	[USD]	Estimated cost per YEAR to fabricate the nanotech
Cost of Packaging:	$69,548,131	[USD]	Estimated cost per YEAR to package the nanotech for deployment
Number of rocket flights:	73		Assuming five metric tonne payloads (4 tonnes gold + 1 tonne packaging)
Cost of each rocket flight:	$20,000,000	[USD]	Estimated to deliver the one metric tonne of nanotech to altitude
Extended Cost of Rocket Flights:	$1,460,000,000	[USD]	Estimated cost per YEAR to deliver the nanotech to altitude
Cost of Deployment Mechanisms:	$292,000,000	[USD]	Estimated cost per YEAR of deployment mechanisms @$4M per rocket
Grand Total:	$8,845,909,371	[USD]	Estimated production cost per YEAR of solar shield program

Economics of Commercial Rocket Launches

How Much Would Commercial Rockets Cost to Launch the Solar Shield?

The cost of rocket launch of a five metric tonne payload to LEO is estimated to be $20 million US dollars… costing $4000 per kilogram (gold + packaging + deployment mechanism).

- a typical solar shield payload in production consists of four metric tonnes of gold dipoles plus one tonne of packaging & deployment mechanisms.

- estimated launch costs approximately $5000 per kilogram of gold

- equivalent to either lofting four metric tonnes of payload for $20 million US dollars (using Russia's "Tsyklon" rocket) or else lofting thirteen tonnes of payload for $65M (using Russia/Ukraine's "Zenit-2" rocket).

I expect launch cost is under-estimated because:

(a) the examples of commercial rockets listed on the next page, and

(b) expected per-launch savings due to the rather large number of rockets required (>70 per year).

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Economics of Commercial Rocket Launches

Examples of Commercial Rockets

(1) Russia's "Tsyklon": $12 million US dollars in 1994, four metric tonne payload to low Earth orbit, operational since 1977: $3000 per kilogram

(2) Russia/Ukraine's "Zenit-2": $82 million US dollars in 1994, $42.5 million in 2000, >thirteen metric tonne payload to low Earth orbit, operational since 1970: $3093 per kilogram in 2000.

Estimated payload launch cost per kilogram: about $3000 US dollars.

References:

1994 data: NASA / SAIC http://www1.jsc.nasa.gov/bu2/ELV_INTL.html

2000 data: Futron Corp., Bethesda, Maryland USA

www.futron.com and www.futron.com/spaceandtelecom/src/srclist.htm, document:

"Space Transportation Costs: Trends in Price Per Pound to Orbit, 1990-2000", September 6, 2002

Economics of Solar Shield Production

Comparison: USA program in Iraq & Afghan (2005) vs Production Funding for Solar Shield

	$25,000,000,000	[USD]	FY2005 DOD Appropriations Act
	$4,600,000,000	[USD]	Transfers of Regular DOD Appropriations to fund war-related needs
	$75,900,000,000	[USD]	FY2005 Emergency Supplemental
Total for 2005:	$105,500,000,000	[USD]	http://www.house.gov/appropriations_democrats/Reports.shtml
Cost per calendar day:	$289,041,096	[USD]	Cost per DAY of the effort in Iraq and Afganistan
	$8,845,909,371	[USD]	Cost per YEAR of solar shield production
	0.066	[unitless]	Ratio of the cost per YEAR of the Solar Shield Program to USA's Iraq / Afganistan project (2005)
	6.6%		ditto

Expected near-term results of the solar shield program:

- stabilized global mean temperatures (after 20 years' production)
  - no net increases in temperature

- stabilized global sea-level
  - no rising sea-levels

- stabilized icecaps on Greenland and Antarctica

- increased biomass of marine algae & plankton, reduced marine acidification and accelerated fixing of atmospheric CO_2 into the oceans.

- invigorated nanotech industry
  - spin-off activities

- invigorated space industry
  - spin-off activities

Solar Shield: Milestones

The milestones and budget for the solar shield program are designed to design, test and fabricate a viable solar shield. The shield's main purpose is to eliminate the thermal runaway associated with global warming after twenty years of production.

Phase 1:	R&D	48 months	$40 million US dollars (total)
Phase 2:	Small Scale Testing	36 months	$130 million US dollars (total)
Phase 3:	Medium Scale Testing	36 months	$480 million US dollars (total)
Phase 4:	Large Scale Testing	24 months	$1.5 billion US dollars (total)
Phase 5:	Production-Scale Testing	24 months	$7.5 billion US dollars (total)
Phase 6:	Initial Production	60 months	$5 billion US dollars annually
Phase 7:	Continuing Production	120-240 months	$10 billion US dollars annually

Each one of the seven program phases is described briefly on the next pages.

Milestones: Phase 1: R&D

Phase 1: R&D: 48 months

- start international negotiations and funding plans

- prototype nanotech design and lab-test (on a glass microscope slide) - DARPA / UK ?

- studies: select altitude(s) for nanotech deployment:
  LLNL? NOAA? NASA? ESA?
- studies: bulk transport mechanism study (rockets? airplanes? balloons?)
  ESA / DARPA / Orbital etc
- studies: atmospheric / space dispersal: initial safe release mechanism
  ESA / DARPA / Raytheon?
- studies: atmospheric / space dispersal: atmospheric transport mechanisms
  - ESA / NOAA /MET?
- studies: new high volume production techniques and factories
  - DARPA? Intel? Alcatel?
- annual budgets: $4, $6, $10 and $20 million US dollars

Phase 2: Small Scale Testing: 36 months

- begin international review of results + negotiations and funding plans

- 1-1000 grams of nanotech released in small-scale lab and field tests

- small-scale test deployment at various altitudes including deployment from LEO

- field test the prototype bulk transport mechanism (rockets?):
  : multi-vendor submissions version 1

- field test the release / deployment mechanisms: expect multiple revisions

- test the atmospheric transport mechanisms: are they adequate for the program?

- continue drive to new high volume production techniques and factories

- annual budgets: $30, $40, and $60 million US dollars

Milestones: Phase 3: Medium Scale Testing

Phase 3: Medium Scale Testing: 36 months

- continue international review of results + negotiations and funding plans

- 1-100 kg packages of nanotech released in medium-scale field tests

- medium-scale test deployments at various altitudes including deployment from LEO

- field test the prototype bulk transport mechanism (rockets?):
  : multi-vendor submissions on version 2

- field test the release / deployment mechanisms: expect multiple revisions

- test the atmospheric transport mechanisms: are they adequate for the program?

- continue drive to new high volume production techniques and factories

- annual budgets: $90, $140, and $250 million US dollars

Phase 4: Large Scale Testing: 24 months

- continue international review of results + negotiations and funding plans

- 100-1000 kg packages of nanotech released in large-scale field tests

- large-scale test deployments at various altitudes including deployment from LEO

- field test the prototype bulk transport mechanism (rockets?):
  : finalize vendor(s)

- field test the release / deployment mechanisms: finalize vendor(s)

- continue testing the atmospheric transport mechanisms: are they adequate for proper dispersal of the nanotech particles?

- continue drive to new high volume production techniques and factories

- annual budgets: $500 and $1000 million US dollars

Milestones: Phase 5: Production Scale Testing

Phase 5: Production Scale Testing: 24 months

- continue international review of results + negotiations and funding plans

- 1000-4000 kg packages of nanotech released in production-scale field tests

- production-scale test deployments at various altitudes including deployment from LEO

- field test the production bulk transport mechanism (rockets?)

- field test the production release / deployment mechanisms

- continue testing the atmospheric transport mechanisms: are they adequate for proper dispersal of the nanotech particles?

- continue drive to new high volume production techniques and factories

- complete factories to support initial production

- annual budgets: $2500 and $5000 million US dollars

Milestones: Phase 6: Initial Production

Phase 6: Initial Production: 60 months (five years)

- continue an annual international review of results + negotiations and funding plans

- after five years of initial production one should observe one percent reduction in the solar constant and initial reduction in global warming.

- one 4000 kg package of nanotech is deployed per launch

- 73 launches and deployments of 4000 kg nanotech payloads per year (plus 1000 kg packaging & deployment mechanisms)

- annual budget: $5 billion US dollars

Milestones: Phase 7: Continued Production

Phase 7: Continued Production and Operations: 120-240 months (10-20 years)

- continue an annual international review of results + negotiations and funding plans

- after ten years one needs to use feedback from the world's climate to modify the rate of nanotech deployment

- one 4000 kg payload of nanotech is deployed per launch

- nominally 73 launches and deployments per year

- annual budget: $10 billion US dollars

Summary

The document proposes a solar shield to allow mankind to eliminate the world's increased temperatures that may be caused by greenhouse gases in the atmosphere. The program stabilizes Earth's sea level and the global mean temperature. The program mitigates global warming and stabilizes the now-melting icecaps in Greenland. The solar shield does these things by decreasing the effective "solar constant" by a small and carefully managed percentage.

In the event of unexpected side-effects or undesired global cooling in the lifetime of the solar shield, the shield has a half-life (of TBD years). The shield is designed to fall apart after some time and let the maximum possible solar flux reach the earth.

The solar shield is a layer of tiny nanoparticles somewhere (tbd) above the troposphere. The shield reflects / scatters a small percentage of the solar flux (from more energetic parts of the solar spectrum) back into space. Nanoparticles are optical chaff (or "window"). Nanoparticle length is nominally one-half an optical wavelength. The metal in each nanoparticle has a larger electro-magnetic cross-sectional surface area than they do physically near the design wavelength. This means that the solar shield needs only a tiny fraction of the metal otherwise needed to construct a viable solar shield.

The full-scale operational cost of the solar shield program is about $10 billion US dollars annually. Before operations can begin there is a multi-year multi-phase development for impact studies and to refine the existing technical base to meet the requirement.

Discussion of Planning

Global warming has been discussed academically, in conferences, peer-to-peer reviews and study groups both nationally and internationally for decades. Most proposed governmental and institutional responses to global warming and the associated rise in sea level are “crisis management” responses. They generally address the management of the global response (to global flooding, tens of millions of refugees, mass famine, and wars) and reduce greenhouse emissions.

The solar shield is a completely different kind of response. Instead of crisis management, the solar shield program uses modern technology to cost-effectively contain and mitigate the most negative side-effects of global warming.

The solar shield would permit the decade-by-decade adaptive control (management) of Earth’s temperature.

Discussion of Planning

The immediate need for the solar shield is long term (decades) but not forever: we have to consider avoiding a new ice-age after (perhaps quite a long time after) the year 2100.

Assuming mankind adopts sustainable practices such as reduced greenhouse gas emissions and alternative power sources, the solar shield might become obsolete in 100 years.

The increased atmospheric CO_2 levels put a severe strain on Earth's ecosystem. Yet in the decades while the levels last there are some benefits, in particular improved agriculture yields.

- double [CO_2] is modelled to give 75% greater yield (Govindasamy et al.)
- a two percent reduction of insolation reduces the agricultural boom by about two percent to 73.5% improved yield.
- world-wide increases in the total area that is suitable for farming
- significantly faster forest growth

Solar Shield Program
A Proposal to Mitigate Global Warming
Conclusions 1

The solar shield program is a proposed as a cost-effective technique to reduce and largely eliminate some of the worst climate changes (higher temperatures and sea-level rise) brought about by global warming.

The goal is accomplished by building and managing a shield of nanoparticles around the Earth in conjunction with in-depth long-term climate monitoring and continued basic and applied research into the Earth's ecological systems.

Conclusions 2

The advantages of a solar shield are many, some are listed here.

First, global warming is eliminated. Earth's coastal communities and the global economy will be safe from rising sea levels because the oceans will not rise.

Second, the solar shield program keeps the global mean temperatures remain constant or decrease slightly. Meanwhile the still troubling high CO_2 concentration in the atmosphere delivers a proportional increase in agricultural production.

Third, the solar shield program helps the marine ecosystem by increased biomass of marine algae & plankton, reduced marine acidification, and accelerated fixing of atmospheric CO_2 in the oceans.

Fourth, the solar shield program develops technologies that could be used to stop global cooling and an ice-age from starting – a possibility after 2100 CE.

Conclusions 3

The known disadvantages of the solar shield program are:

First, we are not ready to implement it yet because we don’t yet have enough planetary science to be sure that we do no harm. At the same time we *are* ready to begin R&D on the solar shield. Even if we wanted it we have to wait for years to start building it because we lack proof-of-design, new techniques and new factories.

Second, we have not performed lab-scale, small-scale or medium-scale testing – neither for engineering effectiveness, nor testing for ecological safety, nor testing for human health impacts.

Conclusions 4

The solar shield program requires an organization or organizations to evaluate and champion it. In order to start phase 1 (R&D) the program requires a number of things:

(1) Organizational support
(2) Public supporters
(3) Media awareness
(4) Political supporters
(5) Academic supporters
(6) Multi-year multi-phase funding
(7) Research into solar shield hardware
(8) Research into the planetary ecosystem

Where does the solar shield go from here?

Notes

(1) Cost of global warming studies in 2003: $4 billion US dollars per year
(2) Cost of solar shield program in production: $10 billion US dollars per year
(3) Benefits claimed for the solar shield program:
  (i) Reduced global warming, possibly eliminated
  (ii) No rise in sea level or at worst a limited controlled rise
  (iii) Less disruption to Earth's sea-port communities
  (iv) Fewer severe tropical cyclones
  (v) Increased biomass of marine algae & plankton, reduced marine acidification, and accelerated fixing of atmospheric CO_2 in the oceans.
  (vi) Stronger nanotech and space industries
  (vii) Develops technologies that could be used centuries later to avert global cooling / ice age

(4) Disadvantages of solar shield program:
  (i) Potentially fewer studies on the effects of greenhouse emissions
  (ii) Potentially a less urgent focus on renewable energies and alternative fuels

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Appendices

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Appendices: Preface

Appendices: Preface

The appendices contain ecology, industry, and engineering details that are pertinent to mitigating global warming: for example, "what do we know about the stability of Greenland's icecap?" in Appendix I. I assembled the appendices partly because when I started considering the possibility of a solar shield program, I thought it was an interesting intellectual exercise but not really a tool that we might want to use. That was in spring, 2006. I had difficulty believing what my parents told me, that Greenland's icecap appeared to be more and more unstable. I was under the impression that global warming could still be a topic for debate and not a serious economic reality.

By summer 2006 I had collected information about Greenland, northern hemisphere temperature data for the years 1000-2000ce, atmospheric CO_2 data for the years 1000-2000ce, recent emissions data, and global economic impact estimates for small rises in sea-level. The data convinced me that global warming and dangerous increases in sea level is real for our generation and a significant economic challenge for Earth's nations and peoples.

I am convinced that we need to continue studying the Earth's climate - especially ice and ocean processes - to better understand the science of how the Earth is adapting to the collected excess greenhouse gases. I am convinced that we need to reduce greenhouse gas emissions and increase our use of alternative fuels like nuclear power. Finally, I am convinced that we need to prepare to deploy one or more technical tools – like the solar shield program – in case the more conservative options prove to be inadequate.

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A Proposal to Mitigate Global Warming

Appendix I:

Greenland's Disappearing Icecap

Appendix I:
Greenland’s Disappearing Icecap
Is there really “global warming”?

In short, yes there is “global warming”. Quoting an IPCC report from 2001:

“Global surface temperatures have increased between 0.4 and 0.8℃ since the late 19th century, but most of this increase has occurred in two distinct periods, 1910 to 1945 and since 1976.

“The rate of temperature increase since 1976 has been over 0.15℃/decade.

“Our confidence in the rate of warming has increased since the SAR due to new analyses including:

- model simulations using observed SSTs with and without corrections for time-dependent biases,
- new studies of the effect of urbanisation on global land temperature trends,
- new evidence for mass ablation of glaciers,
- continued reductions in snow-cover extent, and
- a significant reduction in Arctic sea-ice extent in spring and summer, and in thickness.”

Credit: © IPCC 2001: IPCC WG1 TAR, “Climate Change 2001: Working Group I: The Scientific Basis”

Reference: http://www.grida.no/climate/ipcc_tar/wg1/066.htm Section 2.2.7 “Summary”

Is there really "global warming"?

In short, yes there is "global warming". Continuing the quote from an IPCC report from 2001:

"… there is some disagreement between warming rates in the various land and ocean-based data sets in the 1990s, though all agree on appreciable warming.

"New analyses of mean daily maximum and minimum temperatures continue to support a reduction in the diurnal temperature range with **minimum temperatures increasing at about twice the rate of maximum temperatures over the second half of the 20th century**."

Credit: © IPCC 2001: IPCC WG1 TAR, "Climate Change 2001: Working Group I: The Scientific Basis"

Reference: http://www.grida.no/climate/ipcc_tar/wg1/066.htm Section 2.2.7 "Summary"

Appendix I:
Greenland's Disappearing Icecap
IGS-NASA Survey 1992-2002

2006-03-08

"In Greenland, the survey [IGS-NASA survey of 1992-2002] saw large ice losses along the southeastern coast and a large increase in ice thickness at higher elevations in the interior due to relatively high rates of snowfall. This study suggests there was a slight gain in the total mass of frozen water in the ice sheet over the decade studied, contrary to previous assessments.

"This **situation may have changed in just the past few years**, according to Zwally. Last month NASA scientists at the Jet Propulsion Laboratory, Pasadena, Calif., reported a speed up of ice flow into the sea from several Greenland glaciers. That study included observations through 2005; Zwally's survey concluded with 2002 data. 'The melting of ice at the edges of the ice sheet is also increasing, which causes the ice to flow faster,' Zwally said. 'A race is going on in Greenland between these competing forces of snow build-up in the interior and ice loss on the edges. But **we don't know how long they will be approximately in balance with each other or if that balance has already tipped in favor of the recently accelerating outflow from glaciers.'"**

Credit: Joint press release, NASA and International Glaciological Society:
"nasa survey confirms climate warming impact on polar ice sheets"

Reference: **www.igsoc.org/news/pressreleases/200603a.html**

Dr H Jay Zwally <**zwally@icesat2.gsfc.nasa.gov** >

Appendix I:
Greenland's Disappearing Icecap
Greenland's Ice Meltwater Flows into a Large Moulin

2002-06-06

"In an article published in Science magazine's online Sciencexpress June 7 [2002], Jay Zwally, an ICESat Project scientist at the NASA Goddard Space Flight Center, Greenbelt, Md., Waleed Abdalati, Polar Program scientist at NASA Headquarters, Washington, and colleagues report that **increases in ice velocity during the summer are correlated with the timing and the intensity of ice sheet surface melting.** "

Image from Summer 2002:
Meltwater stream flowing into a large moulin in the ablation zone (area below the equilibrium line) of the Greenland ice sheet.

Credit: Roger J. Braithwaite, The University of Manchester, UK

Reference:
www.gsfc.nasa.gov/topstory/20020606greenland.html

http://icesat.gsfc.nasa.gov/

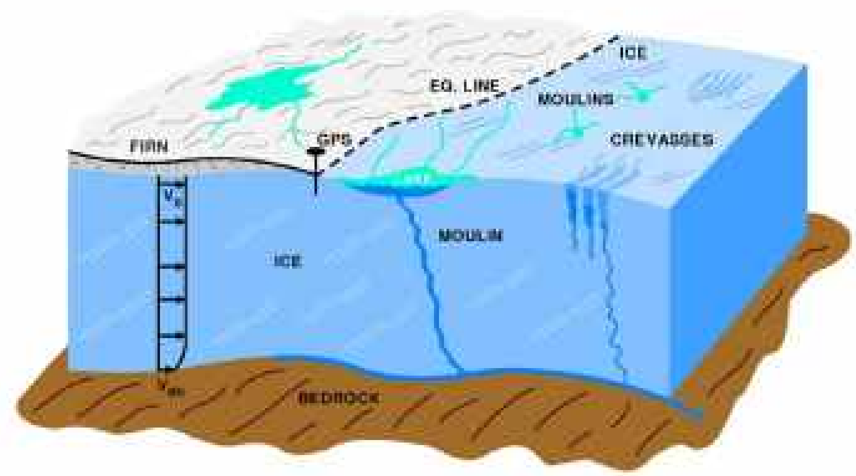
Appendix I:
Greenland's Disappearing Icecap
Greenland's Ice Meltwater Speeds the Iceflow

2002-06-06

Image:
"This schematic highlights glaciological features of the ice sheet including surface lakes, crevasses, and large openings called moulins, that stretch up to 10 meters in diameter and drain to the bedrock. **Meltwater descends through the moulins, down to the bedrock**, contributing to the movement of the ice sheet."

Credit: Jay Zwally, NASA/GSFC

Reference:
www.gsfc.nasa.gov/topstory/20020606greenland.html
http://icesat.gsfc.nasa.gov/



Appendix I: Greenland's Disappearing Icecap Greenland's Largest Glacier in May 2006

2006-06-25
JAKOBSHAVN GLACIER, GREENLAND –

"Mile upon mile of the steep fjord was choked with icy rubble from the glacier's disintegrated leading edge. **More than six miles of the Jakobshavn had simply crumbled into open water**."

…

"Across the ice cap, however, the area of seasonal melting was broader last year than in 27 years of record keeping, University of Colorado climate scientists reported. In early May, temperatures on the ice cap some days were almost 20 degrees above normal, hovering just below freezing."

…

"From cores of ancient Greenland ice extracted by the National Science Foundation, researchers have identified at least **20 sudden climate changes** in the past 110,000 years, in which **average temperatures fluctuated as much as 15 degrees in a single decade**."

Credit: Robert Lee Hotz, Los Angeles Times
"Pace of Greenland melting jolts scientists, shakes the ice"

Reference: Jay Zwally, NASA/GSFC
www.newsobserver.com/689/story/454464.html

Appendix I: Greenland's Disappearing Icecap The "Status Quo" Hypothesis

2006-06-25
JAKOBSHAVN GLACIER, GREENLAND –

"The ice sheet seemed such a stolid reservoir of cold that **many experts had been confident of its taking centuries for higher temperatures to work their way thousands of feet down to the base of the ice cap and undermine its stability**."

"By and large, **computer models supported that view**, predicting that as winter temperatures rose, more snow would fall across the dome of the ice cap. Thus, by the seasonal bookkeeping of the ice sheet, Greenland would neatly balance its losses through new snow."

"Indeed, Zwally and his colleagues in March released an analysis of data from two European remote-sensing satellites showing the amount of water locked up in the ice sheet had risen slightly between 1992 and 2002."

"Then the ice sheet began to **confound** predictions."

Credit: Robert Lee Hotz, Los Angeles Times
"Pace of Greenland melting jolts scientists, shakes the ice"
Reference: Jay Zwally, NASA/GSFC
www.newsobserver.com/689/story/454464.html

Appendix I: Greenland's Disappearing Icecap Measurements 2003-2005: Increasing Glacial Instability

2006-06-25
JAKOBSHAVN GLACIER, GREENLAND –

"Then the ice sheet began to **confound** predictions."

"By 2005, Greenland was beginning to lose more ice volume than anyone had anticipated -- an annual loss of up to 52 cubic miles -- according to more recent satellite gravity measurements released by JPL. The volume of freshwater ice dumped into the Atlantic Ocean has almost tripled in a decade."

…

"In a way no one had detected, the warm water made its way through thousands of feet of ice to the bedrock -- in weeks, not decades or centuries. So much water streamed beneath the ice that in high summer the entire ice sheet near Swiss Camp briefly bulged 2 feet higher."

Credit: Robert Lee Hotz, Los Angeles Times
"Pace of Greenland melting jolts scientists, shakes the ice"

Reference: Jay Zwally, NASA/GSFC
www.newsobserver.com/689/story/454464.html

Appendix I: Greenland's Disappearing Icecap Measurements 2003-2005: Unexpected Tunnels, Pipes and Cracks

2006-06-25
JAKOBSHAVN GLACIER, GREENLAND –

…"University of Texas physicist Ginny Catania pulled an **ice-penetrating radar** in a search pattern around the camp, seeking evidence of any melt holes or drainage crevices that could so quickly channel the water of global warming deep into the ice. "

"To her surprise, **she detected a maze of tunnels, natural pipes and cracks** beneath the unblemished surface. "I have never seen anything like it, except in an area where people have been drilling bore holes," Catania said."

Credit: Robert Lee Hotz, Los Angeles Times
"Pace of Greenland melting jolts scientists, shakes the ice"
Reference: Jay Zwally, NASA/GSFC
www.newsobserver.com/689/story/454464.html

Appendix I: Greenland's Disappearing Icecap Unexpected Glacial Dynamics. A Sudden Total Release is Possible

2006-06-25
JAKOBSHAVN GLACIER, GREENLAND –

"Since 2002, Greenland's **three largest outlet glaciers have started moving faster**, satellite data show."

…

"In all, 12 major outlet glaciers drain the ice sheet the way rivers drain a watershed, setting the pace of its release to the ocean. If they all slide too quickly, **there is a possibility that**, perhaps **decades from now**, **they could collapse suddenly and release the entire ice sheet into the ocean**."

Credit: Robert Lee Hotz, Los Angeles Times
"Pace of Greenland melting jolts scientists, shakes the ice"
Reference: Jay Zwally, NASA/GSFC
www.newsobserver.com/689/story/454464.html

Appendix I: Greenland's Disappearing Icecap
2005: 400% Increase in Ice-Induced Seismic Activity from 1993-1996

2006-06-25
JAKOBSHAVN GLACIER, GREENLAND –

"The accelerating ice flow has been accompanied by a **dramatic increase in seismic activity**, as the three immense streams of ice shake the Earth in their wake.

"The **lurching ice has generated earthquakes up to magnitude 5.0**, researchers at Harvard University and the Lamont-Doherty Earth Observatory at Columbia University reported in March.

"**Last year alone**, the Harvard and Columbia researchers detected **as many ice quakes as the total recorded from 1993 through 1996**, with five times as many in the summer as in the winter months."

Credit: Robert Lee Hotz, Los Angeles Times
"Pace of Greenland melting jolts scientists, shakes the ice"

Reference: Jay Zwally, NASA/GSFC
www.newsobserver.com/689/story/454464.html

Appendix I: Greenland's Disappearing Icecap Jonathan Gregory, University of Reading

Jonathan M. Gregory <jonathan.gregory@metoffice.gov.uk> <j.m.gregory@reading.ac.uk > is a climate modeller working on mechanisms of global and large-scale change in climate and sea level on multidecadal and longer timescales. He is currently a senior scientist in the core team at the NCAS Centre for Global Atmospheric Modelling (CGAM), located in the Department of Meteorology of the University of Reading; and a Met Office Fellow in the climate-change group at the Hadley Centre.

He was a co-ordinating Lead Author of the IPCC TAR chapter 11 Changes in Sea Level [1], and a contributing author to the SAR chapter.

Personal website: **www.met.rdg.ac.uk/~jonathan/**

Reference: **http://en.wikipedia.org/wiki/Jonathan_M._Gregory**

Publications:

Ridley, J. K., P. Huybrechts, J. M. Gregory, J. A. Lowe, 2005.
Elimination of the Greenland Ice Sheet in a High CO2 Climate
Journal of Climate, 18, 17, pg(s). 3409-3427

Appendix I:

Greenland's Disappearing Icecap

"Greenland Melt May Swamp LA, Other Cities, Study Says": by Stefan Lovgren for National Geographic News, April 8, 2004

Greenland's massive ice sheet could begin to melt this century and may disappear completely within the next thousand years if global warming continues at its present rate.

According to a new climate change study, the melting of Greenland's ice sheet would raise the oceans by seven meters (23 feet), threatening to submerge cities located at sea level, from London to Los Angeles.

Even a partial melting of the ice sheet could have catastrophic consequences for low-lying countries like Bangladesh and the Maldives.

continued…

Reference: **http://news.nationalgeographic.com/news/2004/04/0408_040408_greenlandicemelt.html**

Appendix I:

Greenland's Disappearing Icecap

"Greenland Melt May Swamp LA, Other Cities, Study Says": by Stefan Lovgren for National Geographic News, April 8, 2004

…continued

"A one-meter [three-foot] sea level rise would submerge a substantial amount of Bangladesh," Jonathan Gregory, the study's lead author and a climate scientist at the University of Reading in England, said in a telephone interview.

Scientists have previously calculated that if the annual average temperature in Greenland increases by almost 3°Celsius (5.4°Fahrenheit), its ice sheet will begin to melt.

Many experts believe the concentration of carbon dioxide in the atmosphere will have reached levels around the year 2100 that would cause the temperature to rise that much.

"We're not saying how long it will take to get to the three degrees or how long it will take to lose the ice sheet," Gregory said. "We're saying there's a high likelihood of passing this threshold of viability with the carbon dioxide levels that are currently being considered."

The research is described in this week's issue of the science journal Nature.
Reference: **http://news.nationalgeographic.com/news/2004/04/0408_040408_greenlandicemelt.html**

Appendix I: Greenland's Disappearing Icecap
Icecap Facts

Greenland Ice Cap area:	1.8 million square kilometres (approximately)	
		…almost 14 times the size of England
Ice cap thickness:	>3	km to the bedrock (maximum)
	1.5	km (average) (a guess by NCP)
Volume of ice:	2.7	million cubic kilometres of ice
	2.7×10^{15}	cubic metres
Surface area of earth's oceans:	3.6×10^{8}	square kilometres
Age of bottom-ice:	up to 2 million years old	
Terraforming:	the weight of the Ice Cap has pressed the original bedrock down about 800 meters.	

Credit:
Reference: http://www.greenland-guide.gl/icecap/default.htm

Appendix I:
Greenland's Disappearing Icecap
Icecap and Sea-level Calculations

Calculation: Greenland's Icecap and Sea-Level			
De	12,756.30	[km]	Approximate diameter of Earth
SAearth	5.1121E+08	[km^2]	Approximate surface area of Earth at mean sea level
SAearthoceans	3.5785E+08	[km^2]	Approximate surface area of Earth's oceans
Area of Greenland's icecap	1.80E+06	[km^2]	
Average thickness of Greenland ice	1.5	[km]	
Volume of Greenland icepack:	2.70E+06	[km^3]	Volume of ice divided by area of oceans
Calculated sea-level rise for 100% melt:	7.55	[metres]	Assuming that all of Greenland's ice is above sea-level of 2006ce
Published maximum sea-level rise for 100% melt:	7.00	[metres]	
2005 annual rate of icepack loss:	213	[km^3/annum]	in 2005 (satellite / gravity observation
Time till flooding	1811	[years]	time for one meter rise - assuming a stable icepack

Credit: NCP
Reference: www.Wikipedia.com

Solar Shield Program
A Proposal to Mitigate Global Warming

Appendix II:

Technologies Required to Implement a Solar Shield

Appendix II:

Technologies Required to Implement a Solar Shield

The solar shield requires existing technologies and extensions of existing technologies to be ready for production.

Four major technologies should be refined for the application and then proven in small to production-scale testing:

(1) nanoparticle design

(2) mass production of the reflecting nanoparticles

(3) delivery of the particles to altitude, and

(4) efficient deployment at altitude.

The four major technologies are briefly considered in the next few pages.

Appendix II:

Technologies Required to Implement a Solar Shield

Technology 1/4: Nanoparticle Design

The design of the nanoparticles requires a number of resources, from manpower to semiconductor fab hardware. Here is a list of some of the required resources:

(1) 3D EM computer aided-design
(2) Access to advanced nanowire fabrication:
    (1) Grown nanowire structures are typically 200 nm long and 0.51 nm wide
        - cross-section of 2x2 gold atoms
(3) Mechanical strength of nanowire research and design input
    (1) What kind of self-support structure is necessary and sufficient for the gold nanowire dipoles?
(4) Design for cost-efficient volume fabrication
    (1) Consult with industry leaders and research labs
(5) Design for efficient deployment
    (1) Interface with group studying deployment at altitude
    (2) Nanotech packaging
    (3) Consider eventual production in low Earth orbit

Technology 1/4: Nanoparticle Design, continued

(6) Design for efficient orientation
- Scattering advantage of being more or less horizontal
- Interface with atmospheric modelling groups
- Interaction with Earth's magnetic field

(7) Design for proper half-life
- What should the half-life be?
- What drives the half life? UV exposure?
- Special design / material requirement?

(8) Ecologically safe design
- (1) Safe to handle in bulk or in accidental environmental releases
  - (1) No negative effect on pulmonary or ocular functions
- (2) Safe to release to atmosphere
  - (1) No effect on ozone etc

(9) Nanotech particle storage
- (1) Is there a shelf-live for finished packaged nanotech particles?
- (2) Is there a requirement to lubricate the packaged nanotech particles?

Appendix II:

Technologies Required to Implement a Solar Shield

Technology 1/4: Nanoparticle Design, continued

(10) Can we seriously consider metals other than gold?
(11) Can thin gold nanowires (0.51 nm thick) effectively reflect the light? Quantum conduction in thin-metal scattering.
(12) Supercomputer modelling of the long-term effects
   (1) Ocean-atmosphere coupling
   (2) Stratospheric coupling?

Appendix II:

Technologies Required to Implement a Solar Shield

Technology 2/4: Mass Production of the Reflecting Nanotech Particles

(1) Develop techniques to produce never-before-seen quantities of nanotech particles

(2) Design of efficient small, medium large and production scale prototype nanotech factories

(3) Test of small, medium volume etc factory efficiencies
  (1) Repeated re-examinations of fabrication process and efficiencies of scale
  (2) Feedback fabrication results into next fab-run and next-generation factory design

(4) Consider manufacture in space: simply launch the raw materials and avoid packaging and special machines for deployment

(5) Industry and government partnership
  (1) Intel, USA's DARPA
  (2) European agencies
  (3) Japanese agencies
  (4) Others

Technology 3/4: Delivery of the Nanotech Particles to Altitude

(1) Decide on a deployment altitude
  - (1) The stratosphere (50-60 km up)?
  - (2) Low Earth Orbit (200 km up)?

(2) How do we deliver one-metric tonne packages of nanotech particles to the deployment altitude?
  - (1) Rockets? Rocket Planes? Space shuttle?
  - (2) Balloons?

(3) Development of a system to support 100+ launches per year

(4) A commercial rocket & launch facility that can deliver a one metric tonne payload to low Earth orbit costs about $5 million US dollars (equivalently four tonnes of nanotech + one tonne packaging for $20 million US dollars)
  - (1) Volume price reduction?

(5) Selection of launch facilities: For example, we could choose from Russian, US, or French facilities.
  - (1) Tradeoffs to consider: cost, services, US-gov ITAR restrictions.
  - (2) Governmental or commercial service provider?
  - (3) Distance from rocket factory

Appendix II:

Technologies Required to Implement a Solar Shield

Technology 4/4: Efficient Deployment of Nanotech Particles at Altitude.

(1) Test multiple packaging options for nanotech particles

(2) Machines: we need to design and build special machines to deploy the nanotech particles

(3) Do the nanotech particles need to be lubricated in packaging or during deployment?

(4) Consider manufacture of the nanotech dipoles in space: simply launch the raw materials and avoid packaging and special machines for deployment

(5) Electrostatics: is deployment efficiency effected by static buildup by the machine or by the nanotech particles sliding over each other?

(6) Altitude feedback: is deployment more efficient in the stratosphere or in low Earth orbit?
  (1) Does the thin atmosphere in low Earth orbit interfere with the tiny nanotech particles?
  (2) What advantages might we see in atmospheric (stratosphere) dispersal?
  (3) Do the nanotech particles accrete onto each other?

Solar Shield Program
A Proposal to Mitigate Global Warming

Appendix III:

Properties of Gold

Appendix III:

Properties of Gold

For an initial proposal for a solar shield, gold is selected as the nominal metal for fabricating the scattering / reflecting nanoparticles. It may be possible to change to another noble metal or material if there is an adequate incentive, either economic or technical.

Gold is selected as a starting point because of a number of properties.

(1) Noble property: Gold is the most noble metal: it won’t oxidize at altitude
(2) Eco-safe property: Gold usually has a minimum impact with the environment
(3) Reflecting property: Gold is an excellent reflector of optical and infra-red light
(4) Economy property: Gold can be reliably applied in layers only a few atoms thick
(5) Weight property: thin Gold layers will weigh less than the other possible metals
(6) Microlithography, semiconductor and nanowire industry practice: Gold is well understood

The properties of gold are listed in the spreadsheet on the next page.

Appendix III:

Properties of Gold

Density_Au	19.30	[gram/cm^3]	Density of gold metal at room temperature		
Atomic Mass_Au	197.00	[gram/mole]	Atomic mass of gold atoms		
Atomic Radius_Au	1.74E-08	[cm]	Atomic radius_of_gold		
Atomic_Diameter_Au_estimate	2.57E-08	[cm]	Atomic diameter of gold estimated from molar mass and density		
	0.0101	[microinches]			
Production_Au_2001	2604.00	[tonnes]	Mass of gold produced on Earth in calendar year 2001 (a low production year)		
	2.60E+09	[grams]			
	83,720,544	[Troy ounces]			
Example commercial production:	1,136,300	[Troy ounces]	www.goldcorp.com	2005 production, from all GoldCorp sources	
London Gold Fixing	$715.50	[$USD/Troy ounce]	London Gold Fixing of 2006_05_11 (a local high)		
Gold extraction costs	$238.00	[$USD/Troy ounce]	Average gold mining and extraction costs (cy2006)		

Appendix III:

Properties of Gold

Material in the Solar Shield: Gold or an Alternative

The cost of the solar shield program might be reduced if the gold nanotech particles were fabricated from a lighter-weight material or materials.

Alternative material: buckytubes

Buckytubes are efficient and potentially are much lighter in weight. However there are some drawbacks to releasing large amounts of buckytubes:

- small quantities of buckytubes are poisonous to humans when inhaled (not so with gold)
- the carbon surface of buckytubes may be very reactive in the high atmosphere and cause damage to chemicals like ozone (not so with gold: gold is mostly inert)

Conclusion: gold seems to be superior to buckytubes.

Appendix III:

Properties of Gold

Materials Science

The selection of the optimum material is a major research topic for the solar shield program.

More study is needed since metallic gold can act like a catalyst.   We don’t want the solar shield to activate a significant volume of undesireable chemical reactions in the atmosphere.

Palladium, platinum and perhaps other metals may be viable alternatives. More research and study.

On the other hand, non-conductive sulphate crystals might be superior scatterers over metallic half-wave dipoles. Yet more research and study.

Solar Shield Program
A Proposal to Mitigate Global Warming

Appendix IV:

Optical Chaff (“Window”) Theory

Appendix IV:

Optical Chaff (“Window”) Theory

A piece of electromagnetic chaff is a (metal) half-wave dipole. The effective area of a classic conjugated-matched half-wave dipole antenna is equal to Ae:

$$Ae = \frac{(\text{Power Gain}) * \lambda^2}{4\pi}$$

…where the power gain of a dipole is 1.63 (or 2.12 dBi).

This assumes that the dipole is oriented to match the polarity of the incident light.

The dipoles are resonant to tbd wavelengths typically in the range 300-1200 nm: from the visible into the near infra-red.

Appendix IV:

Optical Chaff (“Window”) Theory

Optical chaff – the half-wave dipole – exhibits an electromagnetic footprint (effective area) “Ae” that is substantially larger than the physical cross-sectional area “Ap” presented to the electromagnetic wave.

“ Ap” is physical area of a rectangle defined by a physical cross-sectional area “Ap” of half-wave dipole:

$$Ap = \lambda/2 \times \lambda/30 = \lambda^2 / 60$$

… where one assumes that the antenna is 15 times longer than it is wide.

Therefore the ratio Ae/Ap of a half-wave dipole (1:15) is:

$$Ae/Ap = 4.8 * (\text{Power Gain}) = 7.82 \text{ (dipole power gain = } 1.63 \text{ or } 2.12 \text{ dBi)}$$

A conjugate-matched dipole dimensioned 1:15 will scatter light over almost eight times its physical area.

Appendix IV:

Optical Chaff (“Window”) Theory

For reasons of reducing cost of the solar shield program it is desireable to reduce the amount of gold required to do the job. This means increasing the ratio Ae/Ap. In an initial design there are two methods that can reduce the amount of gold.

Method 1: increase antenna gain

Increased scatterer gain is impractical because it requires (a) a more sophisticated microscopic antenna (b) greater manufacturing costs and (c) a requirement to align the more sophisticated antenna towards the sun

Method 2: decrease the amount of metal per dipole

Decreased scatterer mass is practical because it is possible to form gold nanowires with only a few atoms of cross-section. The length of the dipole remains the same.

Appendix IV:

Optical Chaff (“Window”) Theory

For a nanowire dipole resonant at 600nm with a 2x2 average atomic cross-section (0.51nm x 0.51nm), the ratio of width-to-length (form factor) is 1:590.

Ae/Ap = 150.

Therefore the half-wave nanowire dipole scatters 150 times more energy than you would expect based solely on the mechanical dimensions.

form factor 1:15	->	Ae/Ap	= 7.82	power gain of 1.63, 2.12 dBi
form factor 1:590	->	Ae/Ap	= 150.0	power gain of 1.63, 2.12 dBi

For example, if Ae/Ap = 150, then you need only one square kilometer of two atom thick gold (processed into nanowire dipoles and deployed in the sky) to effectively cover 150 square kilometers of sky on a planet with10000 square kilometers of sky (and in doing so deliver a 1.5 percent reduction of insolation).

Appendix IV: Optical Chaff ("Window") Theory Dipole Design

Some basic considerations for optical chaff design:

1. Dipole Orientation

The dipoles are expected to be free-floating. Therefore one needs to deploy about three times as many dipoles as you would otherwise need to implement the solar shield.

Research topic: might the dipoles become non-free-floating and somehow polarized in space, possibly forced by the Earth's magnetic field?

2. Dipole Match

The nanowire dipoles are designed with zero load (short-circuit). As a result twice the amount of light should be scattered, unless quantum conduction phenomena modify with the dipole physics. Until this doubling is confirmed the solar shield model will assume scattering as a normal half-wave dipole with conjugate match.

3. Dipole Structural Mechanics

Nanowire dipoles are flimsy, especially with width-to-length form factors of about 1:600. Is there a requirement to strengthen them during storage and transport? What about durability when deployed?

Appendix IV: Optical Chaff (“Window”) Theory Dipole Design

Basic solar considerations for optical chaff design:

1. Solar Light Spectrum

The spectrum of solar light can be seen from exoatmospheric measurements of the solar irradiance spectrum. The peak is near 480 nm (green) with significant tails below 220 nm and above 2200 nm. One dipole design can cover a small fraction that range. A dipole’s half-power scattering bandwidth is nominally +-5%, for example from 600 nm to 662 nm, centred on 631nm. Therefore there is a design choice: either use…

(a) One wavelength design: concentrate on insolation reduction at one wavelength (near the green) or else use…

(b) Multiple wavelengths, multiple designs: reduce insolation over a wide band of perhaps ten wavelengths

2. Solar Light Polarization

Solar light can be of any polarization. All polarizations are adequately scattered with the free-floating randomly oriented dipoles.

Appendix IV:

Optical Chaff (“Window”) Theory

Advantages of half-wave metal chaff made of a noble metal (for example, gold):

- gold reflects and scatters ultra-violet, visible and infra-red light better than most alternative materials
- low resistivity / low loss / minimum unintentional resistive conversion of optical EM energy into heat energy
- gold can be fabricated into nanowires with cross-sections as thin as one or 2x2 atoms.
- gold has very low chemical / environmental reactivity
- gold has minimum interaction with the environment
- gold is non-magnetic and should not interfere with the Earth’s magnetic field.
    - research topic: dipole interaction with the Earth’s magnetic field: physical orientation?
- durability under UV-light and exposure to free radicals in the high atmosphere
- dipoles fabricated from gold nanowire:
    - reduced mass, reduced cost
    - some mechanical stiffening may be required, that is a topic for research
    - printed metal on substrates is not required with gold nanowires

<u>Solar Shield Program</u>
<u>A Proposal to Mitigate Global Warming</u>

<u>Appendix V:</u>

Key Altitudes above the Earth

Appendix V:

Key Altitudes above the Earth

Above the troposphere (13 km) there are a number of possible locations for deploying the solar shield. Potential deployment altitude varies from 50 km up (just below the stratosphere) to about 200 km up (a minimum low Earth orbit). At these altitudes the solar constant is much higher: closer to 1366 Watts per square meter instead of 680± Watts per square meter at sea level (the ± indicates that the solar energy reaching sea level depends on cloud-cover, water vapour, time of year etc.). Consequently a high altitude solar shield reflects much more energy than a low altitude (tropospheric) solar shield.

A number of key altitudes are listed in the spreadsheet on the next page.

Early in the solar shield program there need to be cost-benefit tradeoff studies on the optimum altitude to deploy the solar shield. For example:

- 30 km up might be a bad idea because that it is the middle of the ozone layer.
- 50 km up might be a good idea because it’s above the ozone layer and less energy is needed to get there (compared with low Earth orbit)
- 200 km up (low earth orbit) might be a good idea because it is a weightless and mostly atmosphere-free environment: the nanoparticles could be deployed slowly, smoothly and very efficiently.

Appendix V:

Key Altitudes above the Earth

Spreadsheet listing the diameter of the Earth plus several significant altitudes above mean sea level.

Variable Name	Altitude		Description
De	12,756.30	[km]	Approximate diameter of Earth
Etrop	13.00	[km]	Elevation of troposphere above mean sea level
Eozon	24.00	[km]	Elevation of ozone layer (maximum concentration) above mean sea level
Eballoon_manned	34.67	[km]	Elevation of highest ascent of a manned balloon (1961 - Ross & Prather)
Eballoon_unmanned	51.80	[km]	Elevation of highest ascent of an unmanned balloon (1972 - Chico, CA-USA)
Estrat	60.00	[km]	Elevation of stratosphere above mean sea level
Ethermo(min)	80.00	[km]	Elevation of thermosphere above mean sea level (minimum)
E_X15	108.00	[km]	Elevation of X-15 rocket plane above mean sea level (maximum)
E_spaceshipone	112.00	[km]	Elevation of SpaceShipOne flight 17P of 2004_10_04 (maximum achieved)
Eshuttle(min)	185.00	[km]	Elevation of US Space Shuttle above mean sea level (minimum orbit)
E_LEO(min)	200.00	[km]	Elevation of LEO satellites above mean sea level (minimum)
Eiss	360.00	[km]	Elevation of ISS (International Space Station) above mean sea level
Ethermo(max)	500.00	[km]	Elevation of thermosphere above mean sea level (maximum)
Eexosph(min)	500.00	[km]	Elevation of exosphere above mean sea level (minimum)
Eshuttle(max)	1,000.00	[km]	Elevation of US Space Shuttle above mean sea level (maximum orbit)
E_LEO(max)	1,200.00	[km]	Elevation of LEO satellites above mean sea level (maximum)
E_GEO(min/max)	35,786.00	[km]	Elevation of GEO satellites above closest equatorial sea level
E_lune	384,403.00	[km]	Average elevation of the Moon above the Earth
E_L1	1,500,000.00	[km]	"Elevation" of the L1 Lagrangian point above the Earth (0.01 AU)
E_sol	150,000,000.00	[km]	Mean distance between the Earth and the Sun (1.00 AU or 8.3 light-minutes)

Solar Shield Program
A Proposal to Mitigate Global Warming

Appendix VI:

List of Other Proposed Techniques to Mitigate Global Warming

Appendix VI:

List of Other Proposed Techniques to Mitigate Global Warming

To the best of this author's understanding, **no responsible organization has publicly spearheaded the world's requirement** to manage global warming in the time that we have available. It seems that we only have a few decades before the possibility of catastrophic climate changes.

At the same time I have heard many **status quo techniques** for managing the results of climate change. They seem to be either **too passive or else too drastic**. On one hand, passive techniques accept global warming, rising sea levels and the resulting economic and social problems as unavoidable "act(s) of God". On the other hand, drastic techniques require painful social and economic restructuring in a very few short years.

The solar shield program is different. **The solar shield is a way to manage the climate while avoiding the most undesireable climate changes.** The program permits active management of Earth's climate over the long term instead of choosing between either passive acceptance of uncertain fate or unrealistically fast social and economic changes.

The solar shield gives mankind more time to reduce greenhouse gas emissions and develop alternative fuel sources like nuclear power.

Appendix VI: List of Other Proposed Techniques to Mitigate Global Warming Viable Proposals from Others

When I looked I was pleased to discover that some independent researchers are quietly investigating methods to perform adaptive climate control. There are cost-effective proposals to address eliminate global warming now – and a few decades later to avert global cooling and a new ice age.

"Scientists use creativity to fight global warming" By Fred Pearce, Boston Globe Correspondent, 1/20/2004

CAMBRIDGE, England -- At a meeting here this month top climate scientists and technologists from both sides of the Atlantic reached an extraordinary consensus:

Ideas for curing global warming that were once dismissed as screwball now need to be taken seriously."

Reference:

www.boston.com/news/globe/health_science/articles/2004/01/20/scientists_use_creativity_to_fight_global_warming/

Appendix VI: List of Other Proposed Techniques to Mitigate Global Warming Viable Proposals from Others

“Ideas for curing global warming that were once dismissed as screwball now need to be taken seriously.”

Ideas such as:

- filling the stratosphere with billions of silver balloons to reflect the sun's rays

- spraying the oceans with iron to make the plankton suck up the CO_2 gases causing global warming

    - can be dangerous: “What if the CO_2 leaked? Eighteen years ago (in 1986), 1,700 people in the African state of Cameroon died of asphyxiation after a huge bubble of natural carbon dioxide erupted from Lake Nyos.”

These technologies “ should be developed as a safety net, they said. Some even felt the technology should be adopted regardless of need, because it would create a better world in which we could twiddle with the planet's temperature like a domestic thermostat.”

Reference:

www.boston.com/news/globe/health_science/articles/2004/01/20/scientists_use_creativity_to_fight_global_warming/

Appendix VI: List of Other Proposed Techniques to Mitigate Global Warming Active Control of Insolation

The next few pages draw on a paper that addresses active control of insolation from the below-quoted symposium. The paper discusses prevention of global warming AND prevention of a new ice age.

The authors are:

Edward Teller(†), Roderick Hyde, Muriel Ishikawa, John Nuckolls and Lowell Wood

University of California, Lawrence Livermore National Laboratory, Livermore CA 94551-0808, and Hoover Institution, Stanford University, Stanford CA 94305-6010;

lowellwood@comcast.net , (925) 422-7286 [voice]; (925) 423-1243 [fax]

Source: Symposium on Macro-Engineering Options For Climate Change Management and Mitigation, Isaac Newton Institute, Cambridge, England, 7-9 January 2004.

Reference: www.tyndall.webapp1.uea.ac.uk/events/past_events/

Appendix VI:
List of Other Proposed Techniques to Mitigate Global Warming
Active Control of Insolation

Active Control of Insolation:

“Controlled scattering of incoming sunlight back into space, by injecting sub-microscopic minimum-feature-size particles into the stratosphere:

– Dielectrics	– e.g., ~100 nm sulfate aerosol-spherules
– Metals	– e.g., “UV chaff,” super-P metal balloon-ettes
– Resonant scatterers	– e.g., coated dye molecules”

In addition to eliminate global warming, the symposium saw parallel proposals to eliminate the possibility of global cooling and the start of a new ice age after the year 2100…

Source: Symposium on Macro-Engineering Options For Climate Change Management and Mitigation, Isaac Newton Institute, Cambridge, England, 7-9 January 2004.

Appendix VI: List of Other Proposed Techniques to Mitigate Global Warming Advanced Insolation Control: Ice Age Prevention

Ice Age prevention: “Three approaches to “inexhaustible” greenhouse

(1) “LWIR chaff”: 10 μm mesh Al screen & 0.1 μm ‘ribs’

- Comparable area mass-density as “UV chaff”
- Annual stratospheric lofting requirements of ~0.1 MT/year for +4 K mean global temperature-increase: ~$0.4 B annual cost

(2) Semiconductor (e.g., Si)-walled super-P balloon-ettes

- Again, pass optical insolation; reflect Earth-sourced LWIR

(3) Near L-1 Lagrangian Point [1.5 million km towards the Sun] diffractive screen [3000 metric tonnes, 100 km x 100 km] moves aside from Earth-Sun axis, scatters ‘missed’ insolation onto the Earth

- the same screen can stop [global warming]
- “Tacks” a bit differently into Sun’s radiation + gravitational pressure
- Agricultural benefit retained –photosynthetic light enhanced

Source: Symposium on Macro-Engineering Options For Climate Change Management and Mitigation, Isaac Newton Institute, Cambridge, England, 7-9 January 2004.

Appendix VI: List of Other Proposed Techniques to Mitigate Global Warming Advantages of CO_2 Emissions + Solar Shield

"Human interests clearly demand active technical (vs. bureaucratic) management of 'global warming'

– twice as great land-plant 'primary productivity' is on-offer

- the 'green side' of 2x increased atmospheric [CO_2]
- better nutrition for the 21st century's greatly increased population –without more food-production miracles being required

– more-&-better food gained for the same effort, cost, land-use, water, …

– greatly reduced "sun damage" to humans-&-property, plants,…

–enhanced atmospheric aesthetics: sunrises/sunsets, sky-blueness,…"

Source: Symposium on Macro Engineering Options For Climate Change Management and Mitigation, Isaac Newton Institute, Cambridge, England, 7-9 January 2004.

Appendix VI: List of Other Proposed Techniques to Mitigate Global Warming Summary

Summary of proposed techniques to mitigate global warming…

Large-Scale Macro-Engineering:

- solar shield-style scattering techniques (including sulphate crystals in the stratosphere)
- iron-dumping in the oceans to speed-up the capture of CO_2 by algae
- gigawatt solar power stations in geostationary orbit

-**More Conservative Techniques:**

- reduced reliance on fossil-fuels
- improved vehicular efficiencies (hybrid vehicles, electric cars, public transport systems)
- more wind farms, solar cell farms, and nuclear power plants
- improved solar cells (quantum dots)
- convert coal-fired electric power stations into natural-gas power stations
- efficient lighting and appliances, good thermal insulation for buildings
- short-term focus on reducing methane emissions

Solar Shield Program
A Proposal to Mitigate Global Warming

Appendix VII:

Earth’s Energy Budget

Appendix VII: Earth's Energy Budget Incoming Power: 174 petawatts

Incoming power: 174000 terawatts

The total flux of power entering the Earth's atmosphere is estimated at 174000 terawatts. The input power consists of four elements:

Element 1/4: solar radiation (99.978%, or nearly 174000 petawatts; or about 340 W/m^2)

This is equal to the product of the solar constant, about 1366 watts per square metre, and the area of the Earth's disc as seen from the Sun, about 1.28×10^{14} square metres (πR^2), averaged over the Earth's spherical surface area ($4\pi R^2$) - which is of course four times larger. The solar flux averaged over just the sunlit half of the earth's surface is about 680 W/m^2.

Element 2/4: geothermal energy (0.013%, or about 23 terawatts; or about 0.045 W/m^2)

This is produced by stored heat and heat produced by radioactive decay leaking out of the Earth's interior.

Appendix VII: Earth's Energy Budget Incoming Power: 174 petawatts

Incoming power: 174000 terawatts

Element 3/4: Tidal Energy (0.002%, or about 3 terawatts; or about 0.0059 W/m^2)

This is produced by the interaction of the Earth's mass with the gravitational fields of other bodies such as the Moon and Sun.

Element 4/4: Fossil Fuel Consumption (about 0.007%, or about 13 terawatts; or about 0.025 W/m^2).

All of the energy from fossil fuel consumption ends up as environmental heat.

Note that **Element 1** the solar 'constant' varies by approximately 0.1% over an eleven-year solar cycle. The value is not known absolutely to within better than about one watt per square metre. Hence the geothermal and tidal contributions are less than the uncertainty in the solar power.

Reference: http://en.wikipedia.org/wiki/Earth%27s_energy_budget

Appendix VII: Earth's Energy Budget Outgoing Power: 174 petawatts

Earth's Energy Budget is Balanced: Incoming Power = Outgoing Power = 174 petawatts

The average albedo (reflectivity) of the Earth is about 0.3, which means that 30% of the incident solar energy is reflected back into space, while 70% is absorbed by the Earth and reradiated as infrared. The planet's albedo varies from month to month, but 0.3 is the average figure. It also varies very strongly spatially: ice sheets have a high albedo, oceans low. The contributions from geothermal and tidal power sources are so small that they are omitted from the following calculations.

30% reflected energy consists of:

- 6% reflected from the atmosphere
- 20% reflected from clouds
- 4% reflected from the ground (including land, water and ice)

70% absorbed energy is eventually reradiated:

- 64% by the clouds and atmosphere
- 6% by the ground

Reference: http://en.wikipedia.org/wiki/Earth%27s_energy_budget

Appendix VII:
Earth's Energy Budget
Anthropogenic Contribution: 2.4 watts/m^2

Emission of greenhouse gases, and other factors (such as land-use changes), modify the energy budget slightly but significantly. The IPCC (Intergovernmental Panel on Climate Change) provides an estimate of these forcing functions, insofar as they are known.

The largest and best known are from the well-mixed greenhouse gases (CO_2, CH_4, halocarbons, etc.), totalling an increase in forcing of 2.4 W/m^2 relative to the year 1750 CE. These are less than 1% of the exoatmospheric solar input (1366 W/m^2), but it still contributes to the observed increase in atmospheric and oceanic temperatures.

Credit: IPCC, "Climate Change 2001: Working Group I: The Scientific Basis

Reference: http://en.wikipedia.org/wiki/Earth%27s_energy_budget

www.grida.no/climate/ipcc_tar/wg1/figspm-3.htm

Solar Shield Program
A Proposal to Mitigate Global Warming

Appendix VIII:

Economic Impact of Global Warming / Rising Sea Level

Appendix VIII
Economic Impact of Global Warming / Rising Sea Level

Yohe (1989) estimated that:

- a one-half-meter rise in sea level would place $185 billion of property and infrastructure in jeopardy by 2100
- a one-meter rise in sea level would place $429 billion in jeopardy by 2100.

Credit: Yohe, G. 1989. “The cost of not holding back the sea: Toward a national sample of economic vulnerability.” Coastal Management 18:403-431.

Reference: www.pewclimate.org

Appendix VIII
Economic Impact of Global Warming / Rising Sea Level

Titus and Greene (1989) estimated that:

- the financial cost of protecting all developed areas from a half-meter sea-level rise would be $50 to $66 billion
- protecting against a one-meter sea-level rise would cost $115 to $174 billion.

Credit: Titus, J.G. and M.S. Greene. 1989. “An Overview of the Nationwide Impacts of Sea Level Rise.“ In The Potential Effects of Global Climate Change on the United States. Appendix B: Sea Level Rise. Smith, J.B., and Tirpak, D. (eds). U.S. Environmental Protection Agency, EPA-230-05-89-052, Washington, DC.

Reference: www.pewclimate.org

Solar Shield Program
A Proposal to Mitigate Global Warming

Appendix IX:

Greenhouse Gases

Appendix IX

Greenhouse Gases

Greenhouse gases increase the temperature of the Earth by trapping heat and increasing the effective insolation.

As of the year 2001ce, greenhouse gases (CO_2, CH_4, halocarbons, N_2O etc.) have increased the power entering the Earth's ecosystem by 2.4 W/m^2 relative to the year 1750ce.

The Earth's ecosystem compensates with an equivalent 2.4 W/m^2 increase in brown-body radiation out of the ecosystem into space.

Increased brown-body radiation requires an increase in the Earth's mean temperature. The compensatory increase in Earth's mean temperature is the basis of the phenomenon that we call "global warming".

Credit: IPCC, "Climate Change 2001: Working Group I: The Scientific Basis

Reference: http://en.wikipedia.org/wiki/Earth%27s_energy_budget

www.grida.no/climate/ipcc_tar/wg1/figspm-3.htm

Appendix IX
Greenhouse Gases
Atmospheric CO_2, Past and Future

"Before the Industrial Era, circa 1750, atmospheric carbon dioxide (CO_2) concentration was 280 ± 10 ppm for several thousand years. It has risen continuously since then, reaching 367 ppm in 1999…

"There is sufficient uptake capacity in the ocean to incorporate 70 to 80% of foreseeable anthropogenic CO_2 emissions to the atmosphere [emissions in 2000ce are ~6 gigatonnes per year], this process takes centuries due to the rate of ocean mixing.

"As a result, even several centuries after emissions occurred, about a quarter of the increase in concentration caused by these emissions is still present in the atmosphere.

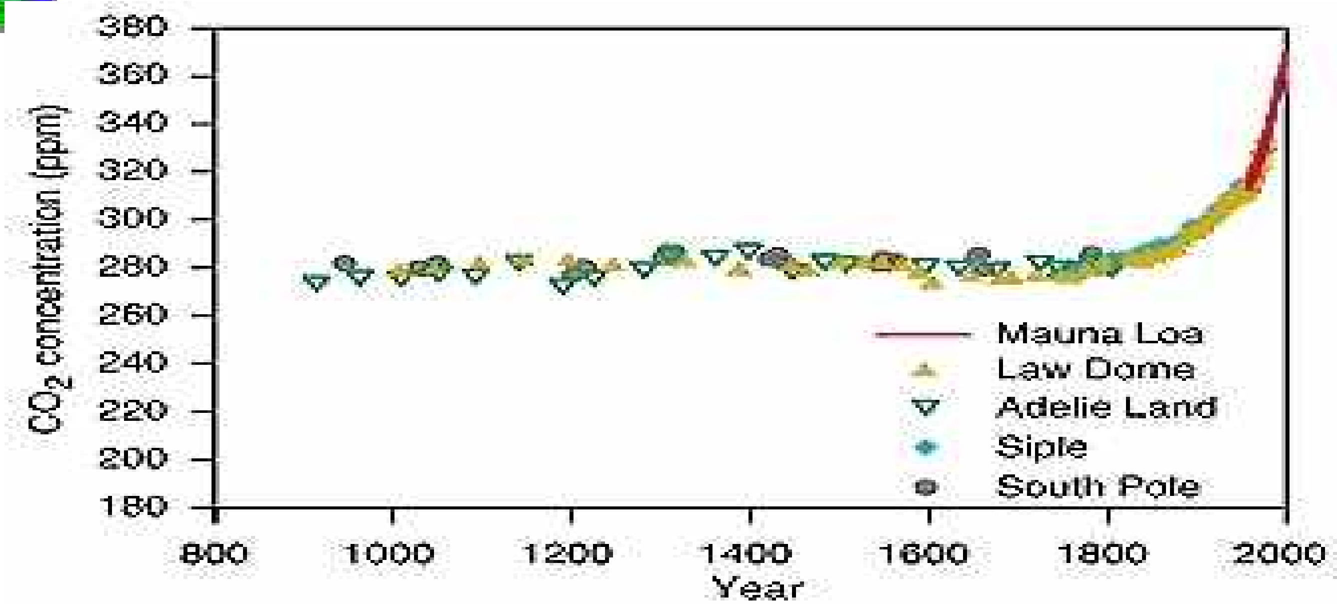
"CO_2 stabilisation at 450, 650 or 1,000 ppm would require global anthropogenic CO_2 emissions to drop below 1990 levels, within a few decades, about a century, or about two centuries respectively, and continue to steadily decrease thereafter."

Credit: IPCC, "Climate Change 2001: Working Group I: The Scientific Basis

Chapter 3, The Carbon Cycle and Atmospheric Carbon Dioxide, Executive Summary

Reference: www.grida.no/climate/ipcc_tar/wg1/095.htm

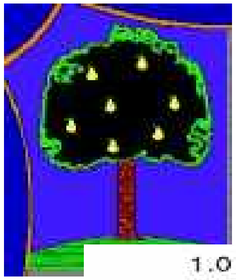
Appendix IX
Greenhouse Gases
Atmospheric CO_2 from 800 to 2000ce



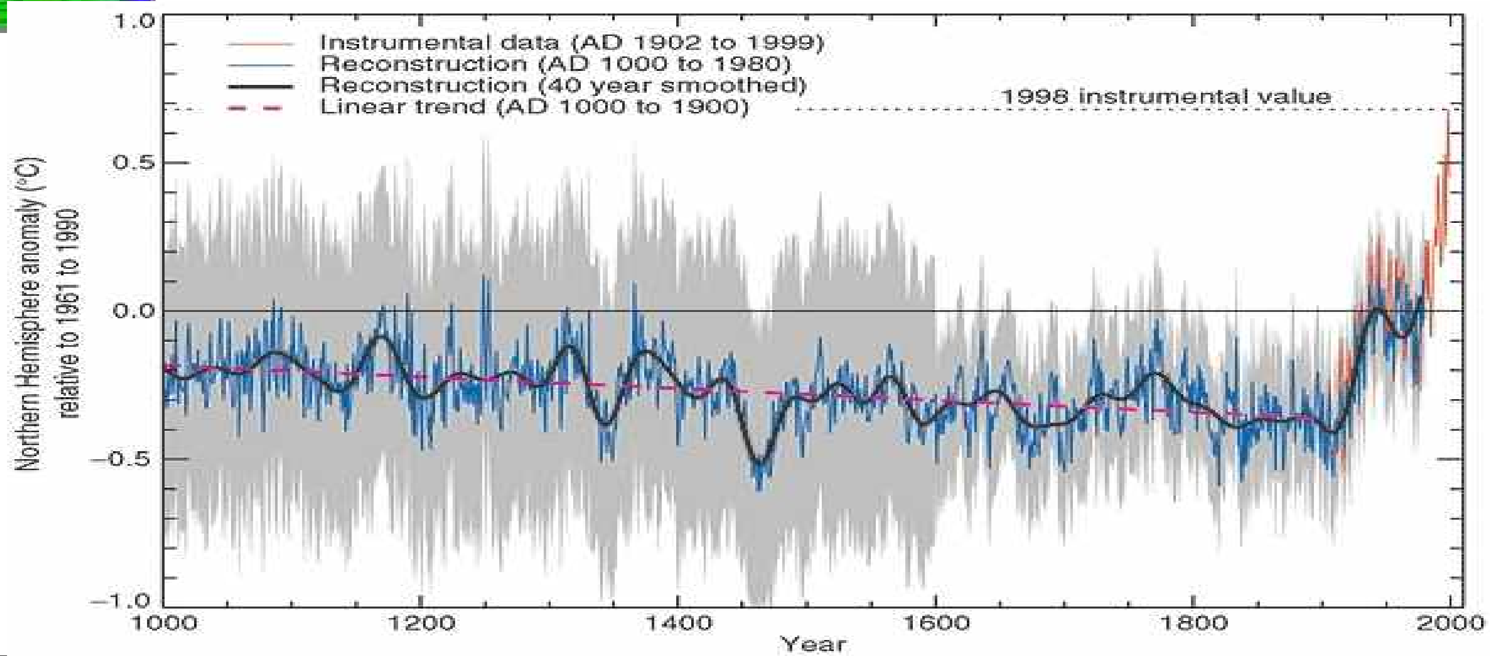
"Variations in atmospheric CO_2 concentration... CO_2 concentration in Antarctic ice cores for the past millenium (Siegenthaler et al., 1988; Neftel et al., 1994; Barnola et al., 1995; Etheridge et al., 1996). Recent atmospheric measurements at Mauna Loa (Keeling and Whorf, 2000) are shown for comparison."

Credit: © IPCC 2001 Figure 3.2 b of IPCC WG1 TAR, "Climate Change 2001: Working Group I: The Scientific Basis"

Reference: www.grida.no/climate/ipcc_tar/wg1/105.htm



Appendix IX
Greenhouse Gases
Mike Mann's Hockey Stick *– remove and replace with what?*



"Millennial Northern Hemisphere (NH) temperature reconstruction (blue) and instrumental data (red) from AD 1000 to 1999, adapted from Mann et al. (Penn State University) (1999). Smoother version of NH series (black), linear trend from AD 1000 to 1850 (red-dashed) and two standard error limits (grey shaded) are shown."

Credit: © IPCC 2001Figure 2.20 of IPCC WG1 TAR, "Climate Change 2001: Working Group I: The Scientific Basis"

Reference: www.grida.no/climate/ipcc_tar/wg1/563.htm

Solar Shield Program
A Proposal to Mitigate Global Warming

Appendix X:

Tradeoffs: Advantages and Disadvantages

Appendix X

Tradeoffs: Advantages and Disadvantages

The solar shield program for macro-engineering the world’s climate trades off advantages and disadvantages.

The main advantage is reduced risk of rapid (Type II) climate change over the next hundred years.

The solar shield has the following beneficial side-effects:

- stable annual temperatures
- sea-level communities are stable
- boost in commercial nanotech industry and the commercial aero-space industry
- fewer international conflicts caused by economic and resource allocation (as compared with the conflicts associated with a sea-level rise of one or more metres).

Appendix X

Tradeoffs: Advantages and Disadvantages

Advantage: Flexible Scattering Spectrum

The solar shield is made out of a nominally ten different dipole designs – corresponding to a ten different resonant frequencies.

The proposed attenuation of the solar constant is quite small, only two percent (0.1 dB). However, if we discovered that we were attenuating needed light, it is simple to modify the fabrication of one or more of the dipoles to produce less attenuation of the needed light while still maintaining the solar shield.

On the other hand, it is possible that research discovers that an optical wavelength is causing unwanted climate phenomena. It is again simple to modify the fabrication and increase production or even introduce a new design to address the problem wavelength.

Appendix X

Tradeoffs: Advantages and Disadvantages

There are three non-technical challenges in a viable solar shield program: funding, management and support. The three challenges are hurdles, not disadvantages.

Funding: more than one nation funds the program (during production, $10 billion US dollars per annum)

Management: politics and international relations: someone has to manage the solar shield technical development and the international negotiations.

- who would be involved? OECD, the UN, the USA, the EU, Russia, India, China…
- model for the technical organization: perhaps CERN
- what if some other groups or countries opposed the program?

Support: can support be found?

Appendix X

Tradeoffs: Advantages and Disadvantages

Disadvantage: Lack of Detailed Knowledge of Earth's Ecosystem

Mankind does not yet clearly understand the Earth's ecosystem and the many coupled systems and the subtle sometimes unexpected feedback mechanisms. Do we understand enough to do no harm in implementing a solar shield? Clearly a solar shield project should be subject to years of climate research and modelling. The project also should be evaluated with small-scale testing scenarios looking for unexpected ecological feedbacks even before production. Examples of important things we don't know:

- for example: only recently have computer models coupled stratospheric winds to the troposphere and the modelled the observed anomalous arctic warming associated with the 0.1% variation in the solar constant in the 11-year sunspot cycle. Reference:

- for example: the hypothesis of a global climate switch based on north Atlantic environment & a worldwide system of ocean currents (the Ocean Conveyor) was developed by Wally Broecker of Lamont-Doherty Earth Observatory in the last half century. The hypothesis is still under test.

- for example: the hypothesis of a global climate switch based in the tropics has been put forward Mark Cane (Lamont –Doherty) and Lonnie Thompson (Ohio State) in the last 20 years. The hypothesis is still under test.

Appendix X

Tradeoffs: Advantages and Disadvantages

Miscellaneous Disadvantages:

(1) Potential Impact on Astronomy

Gold dipoles in low Earth orbit will decay one-by-one and fall back into Earth's atmosphere within a few years. The annual mass of dipoles falling back to Earth in full production is small in comparison to meteor dust. The maximum mass of dipoles falling back to Earth is between 0.1 and 1.0 percent of the mass rate of meteor & cosmic dust entering Earth's atmosphere. The 0.1-1.0 percent variability is due to the variability of published estimates of meteor / cosmic dust entering Earth's atmosphere.

The potential impact – while apparently small – should be addressed. The optical, radio, and milli-metre-wave astronomy communities should be consulted.

Solar Shield Program
A Proposal to Mitigate Global Warming

Appendix XI:

Nanowire Technology

Appendix XI

Nanowire Technology

Nanowire Dipoles for the Solar Shield

The solar shield program might use nanowire-based dipoles to scatter unwanted light away from Earth. Much of this solar shield proposal is based on nanowire technology, although there are alternatives.

Typical nanowire dipole lengths:

- from 200 nm to 700 nm

Typical nanowire dipole average cross-section:

- 2x2 gold atoms (0.51nm x 0.51nm)

Gold nanowires with similar dimensions have already been fabricated in research organizations. However, as of 2006 there has been no large-scale commercial manufacture of the required nanowire.

Appendix XI

Nanowire Technology

Current Capabilities of Nanowire Technology

"A nanowire is a wire of dimensions of the order of a nanometer (10^{-9} meters). Alternatively, nanowires can be defined as structures that have a lateral size constrained to tens of nanometers or less and an unconstrained longitudinal size…"

- "inorganic molecular nanowires (Mo_6S_9-xI_x) have a diameter of 0.9 nm, and can be hundreds of micrometers long. "

- quantum conductance: "integer values of $2e^2/h \approx 12.9\ k\Omega^{-1}$" = $0.0129\ \Omega^{-1}$ so the quantum resistance is 77.5 Ω.

- monatomic gold nanowires have been fabricated (Robert N. Barnett, Hannu Ha1kkinen, Andrew G. Scherbakov, and Uzi Landman, "Hydrogen Welding and Hydrogen Switches in a Monatomic Gold Nanowire", Nano Letters, vol. 4, no. 10, 2004 pages 1845-1852)

Reference: Wikipedia http://en.wikipedia.org/wiki/Nanowire

Appendix XI

Nanowire Technology

Quantum Conductance

Due to the quantum nature of the nanowire conductance it is probably necessary to re-derive the half-wave dipole scattering cross-section.

In particular, can we model the nanowire half-wave dipole as a conventional dipole with a short-circuited load? If so, great. Larger short-circuited half-wave dipoles typically have double the scattering cross-section of a conjugate-matched dipole. Therefore one could reduce the required amount of nanotech dipoles by fifty percent. However, until I re-derive the dipole scattering cross-section with quantum conductance, I continue to assume we need the full quantity of dipoles.

Resistive Loss

Is the resistive loss in the quantum-conduction dipole significant to the solar shield? Presumably not since resistive loss turns to heat. Half the heat is radiated away from the Earth, just as half the scattered optical photons are scattered away from the Earth.

- still, it is a topic for research

Appendix XI

Nanowire Technology

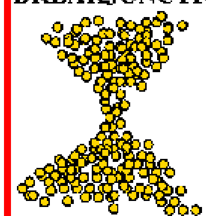
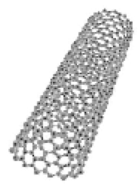
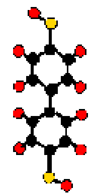
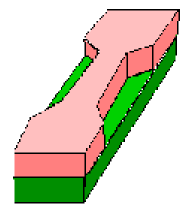
	BREAKJUNCTION 	NANOTUBE 	MOLECULAR WIRE 	QUANTUM WIRE 
Composition	Cu, Ag, Au . .	C	C,N,H,S	GaAs/AlGaAs
Geometry	?	Tubular	Fixed by Q.M.	Planar (2-D)
Width	atomic	1-20 nanometers	~ 1 nm	100's of nanometers
Length	1 - 1000 nm	1 - 20μ m	few nanometers	2 - 20 μ m
External Connections	Easy	Problematic	Challenging	Straightforward
Fabrication	Contact Mechanics	Carbon Arc	Test Tube	High Resolution Lithography
Conduction Mechanism	Quasi-ballistic	?	?	Ballistic

Figure x: Types of nanowire: breakjunction (i.e., the gold nanowire dipole), nanotube, molecular wire and quantum wire.

Credit: Elton D. Graugnard, Purdue University, Dept. of Physics

Reference: www.physics.purdue.edu/nanophys

<u>Solar Shield Program</u>
<u>A Proposal to Mitigate Global Warming</u>

<u>Appendix XII:</u>

Marine Ecosystem Coupling with Atmospheric CO_2

Appendix XII

Marine Ecosystem Coupling with Atmospheric CO_2

The air temperature couples to the surface waters of the oceans. There is a lot of water in the oceans, even if we restrict ourselves to consider the first hundred metres of depth. And water has a large specific heat compared with air. Therefore warming the surface ocean temperature lags the increase in air temperature. Because of mixing of the upper hundred metres of surface waters, the ocean acts as a large thermal capacitor – for now, the ocean moderates changes in world temperature. The ocean's thermal response lags the increase of average air temperature by decades, and acts to cool the troposphere's average air temperature below what we might otherwise observe.

There are at least two problems associated with high atmospheric CO_2 and increased temperature of marine surface waters:

Problem 1: Reduced Biomass of Marine Algae, and
Problem 2: Increased Acidity of Earth's Oceans

The solar shield helps reduce both of these problems.

These problems are described on the next few pages.

Appendix XII

Marine Ecosystem Coupling with Atmospheric CO_2

Problem 1: Reduced World Biomass of Marine Algae

At present the world biomass of marine algae is shrinking due to the slowly increasing temperature of the ocean surface waters (the upper hundred metres or so).

Marine algae prefer water temperature around 12°C for a number of reasons. That is why the Gulf Stream is blue – there is little algae in tropical waters. And why other waters of the North Atlantic Ocean are murky – the cooler surface waters contain an abundance of algae.

However, as the marine surface waters slowly warm, the regions of cooler oceans that teem with algae shrink.

How does the solar shield help the problem with marine algae?

By cooling the Earth, the solar shield cools the ocean surface temperature, thereby increasing the biomass of algae and the ocean's rate of uptake of atmospheric CO_2 .

Appendix XII

Marine Ecosystem Coupling with Atmospheric CO_2

Problem 2: Increased Acidity of Earth's Oceans

The solar shield does not help immediately with the ecological problem of the acidification of the surface marine ecosystems caused by increasing levels of atmospheric CO_2 .

However, the solar shield's cooling of the atmosphere and reduced insolation at sea-level will help reduce atmospheric CO_2 by increasing the marine uptake of CO_2 . By cooling the Earth, the solar shield cools the ocean surface temperature.

How does the solar shield help mitigate the problem of ocean acidification?

By cooling the oceans, the solar shield causes two desireable processes that each reduce acidity:

(a) It increases the biomass of algae that biochemically assimilates carbon from the carbonate ion CO_3^{-2} , and…

(b) It increases the biomass of plankton that in addition use the carbonate ion CO_3^{-2} to make tiny calcium carbonate structures.

Appendix XII

Marine Ecosystem Coupling with Atmospheric CO_2

Problem 2: Increased Acidity, continued…

Today, acidification of marine ocean surface waters occurs through increased CO_2 (gas) absorption at the air-water interface and the increasing accompanying carbonate ion CO_3^{-2} in aqueous solution.

The marine surface waters are critical for much of Earth's plant and animal life, both large and microscopic.

If the water chemistry changes significantly, we should see changes in fisheries and possibly in the rate of CO_2 uptake.

Appendix XII

Marine Ecosystem Coupling with Atmospheric CO_2

Problem 2: Increased Acidity, continued…

The chemistries of interest are:

- CO_2 (gas) in aqueous solution
  - the current forcing function for carbon chemistry in the ocean

- carbonate ion CO_3^{-2} in aqueous solution
  - dependent variable proportional to aqueous CO_2 (gas) concentration

- calcium carbonate Ca_2CO_3 (a solid usually laid down by organic matter)
  - dependent variable inversely proportional to carbonate ion CO_3^{-2} concentration

N.B.: acidification properties:

- acid readily dissolves calcium carbonate
- dissolving calcium carbonate into the oceans presumably slows the ocean's uptake / absorption of atmospheric CO_2

Appendix XII

Marine Ecosystem Coupling with Atmospheric CO_2

Problem 2: Increased Acidity, continued…

Today, marine acidification is steadily increasing…

Current (2006ce) measured marine pH change from 1750ce pH levels:

- -0.1 pH units (corresponds to year 2006ce’s 380 ppm of atmospheric CO_2)
- ΔpH=-0.1 means 25% more acid (in year 2006ce)

Future (2100ce) modelled marine pH change from 1750ce pH levels:

- -0.4 pH units (corresponds to the predicted 2100ce 800 ppm of atmospheric CO_2)
- ΔpH=-0.4 means 150% more acid (in year 2100ce)

A Simple Linear Model?:

Doubling the atmospheric CO_2 from year 2006ce to year 2100ce appears to increase the ocean acidity by a factor of two.

Appendix XII

Marine Ecosystem Coupling with Atmospheric CO_2

Problem 2: Increased Acidity, continued…

The beneficial increase in agricultural production that is induced by greater quantities of CO_2 in the atmosphere must be balanced against the increased of the oceans.

In recent years the pH of the oceans has fallen by about 0.1.

The increased acidity attacks some sensitive creatures that build solid calcium carbonate structures like corals, sea shells and some plankton.

The steady increase in acidification will have “negative impacts on corals and other marine organisms that build calcium carbonate shells and skeletons”.

Credit: “Impacts of Anthropogenic CO_2 on Ocean Chemistry and Biology”, Kathy Tedesco, Richard A. Feely, Christopher L. Sabine, Cathrine E. Cosca, NOAA 2005-10-03

Reference: http://www.oar.noaa.gov/spotlite/spot_gcc.html

Solar Shield Program
A Proposal to Mitigate Global Warming

Appendix XIII:

Questions and Some Answers

Appendix XIII

Questions and Some Answers

The proposed solar shield program would be a cooperative international initiative to mitigate some of the worst results of global warming. During research, development, production and operation, the program would be a large technical venture drawing upon human, industrial and financial resources of many nations.

Still - there are many questions about the program. This appendix is an attempt to list and address some of the questions.

Appendix XIII

Questions and Some Answers

List of Questions

Q1: Should the solar shield program be a cooperative international program? A European program? an American program?

Q2: Can I personally support the solar shield program?

Q3: How will a solar shield program effect my tax rate?

Q4: How will a solar shield program effect my family?

Q5: Will a solar shield impede the launch of satellites and other space activity?

Q6: Are there any negative ecological side-effects caused by a solar shield?

Q7: Will a solar shield interfere with radio communication?

Q8: Will a solar shield interfere with air travel?

Q9: Is there an ecological risk due to gold dipoles re-entering Earth's atmosphere?

Q10: Will a solar shield fabricated of gold dipoles place a significant demand on the world gold supply?

Q11: In low Earth orbit there are some energetic gas molecules. Are nanowire dipoles strong enough to withstand an occasional high-speed collision with a gas molecule?

Q12: Is a solar shield program required if we contain and reduce global CO_2 emissions in the near future?

Appendix XIII

Questions and Some Answers

Addressing the Questions

Q1: Should the solar shield program be a cooperative international program? A European program? an American program?

A: The solar shield effects the world and should be a cooperative international program. It is reasonable to expect as a minimum the participation of the OECD, the UN, the USA, the EU, Russia, India, China… among others.

Q2: Can I personally support the solar shield program?

A: Yes – positive and negative feedback are welcome. Most properly educated people do not know about this and other macro-engineering options to mitigate global warming. However as of 2006 there is no government, organization, or company promoting this or any other macro-engineering research program that might help mitigate global warming.

Q3: How will a solar shield program effect my tax rate?

A: A solar shield program has a negligible effect on your tax rate. The maximum cost of the program in full production is $10 billion dollars annually. If the USA assumed one third of the financing, the obligation would be 0.083% of the $12000 billion dollars of the US gross domestic product in 2005.

Appendix XIII

Questions and Some Answers

Addressing the Questions

Q4: How will a solar shield program effect my family?

A: A solar shield program – when in full production – will mitigate some of the worst side-effects of global warming. Most significantly, the ecology stabilizes somewhat: air and sea temperatures will decrease (in general) and the remaining icecaps on Greenland and the icecaps / ice shelves of west Antarctica will stop melting. That will stop the sea-level from rising further and help the world's economy. One can expect two socially and commercially important spin-offs: (a) accelerated commercial & medical research into the promising field of nanotechnology and (b) an improved commercial aerospace industry.

Q5: Will a solar shield impede the launch of satellites and other space activity?

A: No. A solar shield in low Earth orbit will obstruct satellite launch by less than the obstruction caused by meteor dust in the atmosphere. The solar shield would be allocated its own set of orbits. Other space business can avoid orbits assigned to the solar shield's dipoles made of gold nanowires.

Appendix XIII

Questions and Some Answers

Addressing the Questions

Q6: Are there any negative ecological side-effects caused by a solar shield?

A: So far there are no known ecological problems introduced by a solar shield. If deployed above the atmosphere the solar shield should be especially inert and isolated from the Earth's living troposphere.

However the Earth's ecology is complex and there is much we don't know. Therefore the solar shield program is required to perform continuous small-scale studies, supercomputer climate modelling and hardware tests from the beginning of any work to investigate the possibility of unwelcome side-effects. The small scale studies lead into larger studies and hardware tests as equipment and techniques are developed. During production and operation, long-term environmental and human exposure tests and supercomputer modelling are required to continue, while the world monitors the technical performance of the solar shield.

Appendix XIII

Questions and Some Answers

Addressing the Questions

Q7: Will a solar shield interfere with radio communication?

A: ‘Short wave’ long distance communications should improve (3-30 MHz). The maximum impact (<0.1 dB) is small even at the worst case wavelengths, the design optical wavelength(s). The impact is even less on microwave, milli-metre wave and infra-red optical data links with satellites.

Q8: Will a solar shield interfere with air travel?

A: No positive or negative effect is anticipated on air-travel. The average rate of microscopic gold dust falling from the sky into the passenger airspace is less than one percent the mass rate of meteor dust falling into the same space.

Q9: Is there an ecological risk due to gold dipoles re-entering Earth’s atmosphere?

A: One might expect that the gold falling into the atmosphere will become stable compounds of gold (gold dust), but that area needs research for confirmation and elaboration.

Appendix XIII

Questions and Some Answers

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Q10: Will a solar shield fabricated of gold dipoles place a significant demand on the world gold supply?

A: The solar shield program in full production would require nominally five percent of the world's annual production of gold. This should increase the demand for gold (and possibly the cost!). The cost of gold already experiences significant annual fluctuations. The solar shield would introduce a very steady predictable demand on gold. Therefore the solar shield could act as a stabilizing element in the world gold market.

Q11: In low Earth orbit there are some energetic gas molecules. Are nanowire dipoles strong enough to withstand an occasional high-speed collision with a gas molecule?

A: I don't know and it is a concern - an area for research and design should the program be funded. I have yet to calculate the probability of the very sparse gas molecules in low Earth orbit significantly impacting on the cloud of gold nanowire dipoles on a year-to-year basis. If the impact is statistically too significant then it might be prudent to request a higher low Earth orbit for the solar shield.

Appendix XIII

Questions and Some Answers

Addressing the Questions

Q12: Is a solar shield program required if we contain and reduce global CO_2 emissions in the near future?

A: A solar shield is still required because without a solar shield - even meeting difficult targets for reduced greenhouse emissions - we still anticipate a sustained long term increase in temperature and (among other temperature-enabled phenomena) an associated destructive rise in sea level.

If mankind succeeds (for example, by the decade 2020-2030ce) in reducing global CO_2 emissions to below 1990 levels, the atmosphere will contain about 450 ppm CO_2.

450 ppm CO_2 is 170 ppm greater than the historical steady state of 280 ppm +-10 ppm.

Global mean temperatures certainly will continue to be historically high and possibly still increasing unless there is a continuing program to force annual reductions in CO_2 emissions to far below 1990 levels. The most optimistic projections estimate that the process will take decades.

The huge reservoir of excess CO_2 in the atmosphere is persistent over centuries because of slow (but hopefully (!) steady) uptake in the oceans.

Solar Shield Program
A Proposal to Mitigate Global Warming

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Figures 6: Computer Climate Models

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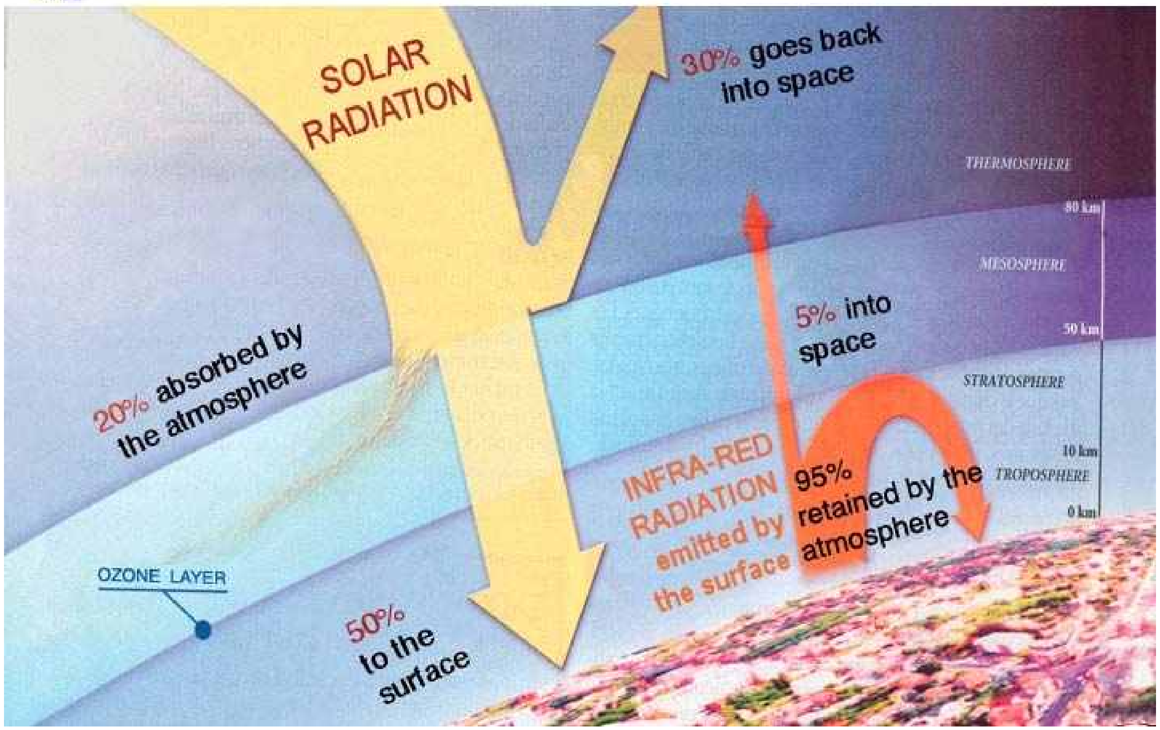


Figure 1a: Simplified Model of Earth's Energy Budget

Credit: "Science et l'Avenir" 2006, translation by Mlle. Robinson of EFN – Environmentalists for Nuclear Energy

Reference: www.ecolo.org

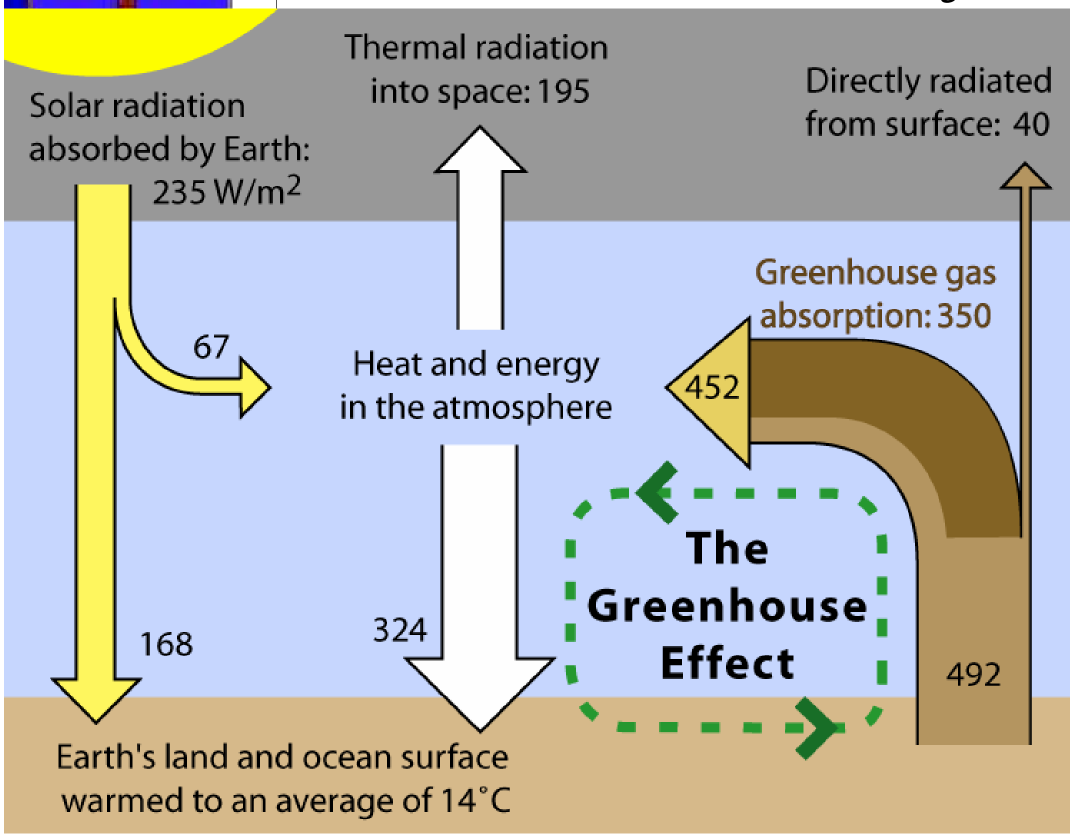


Figure 1b: Simplified Model of Earth's Energy Budget in the Troposphere. Notice that the solar radiation absorbed by the Earth (235 W/m^2) is far less than the energy available in the solar constant outside the atmosphere (about 1400 W/m^2)

Credit: Robert A. Rohde from published data and is part of the Global Warming Art project (2006)
Reference: http://en.wikipedia.org/wiki/Earth%27s_energy_budget

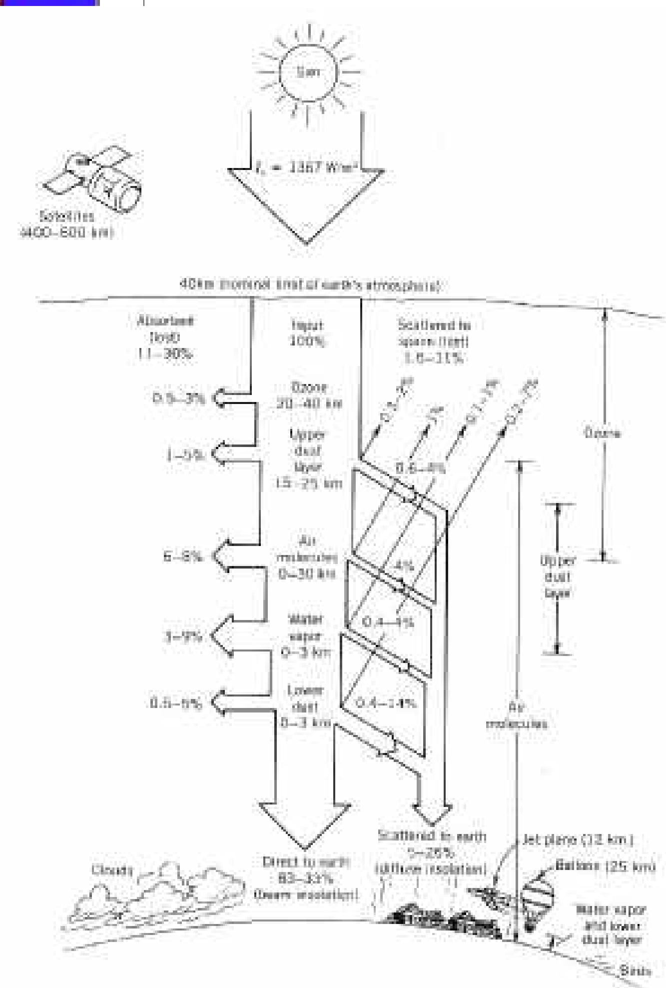


Figure 1c: Clear sky absorption and scattering of incident solar energy. Values are typical for one air mass.

Credit: Watt, A. D. (1978), "On the Nature and Distribution of Solar Radiation." U.S. Department of Energy Report HCP/T2552-01, March.

Reference:
www.powerfromthesun.net/chapter2/Chapter2.htm

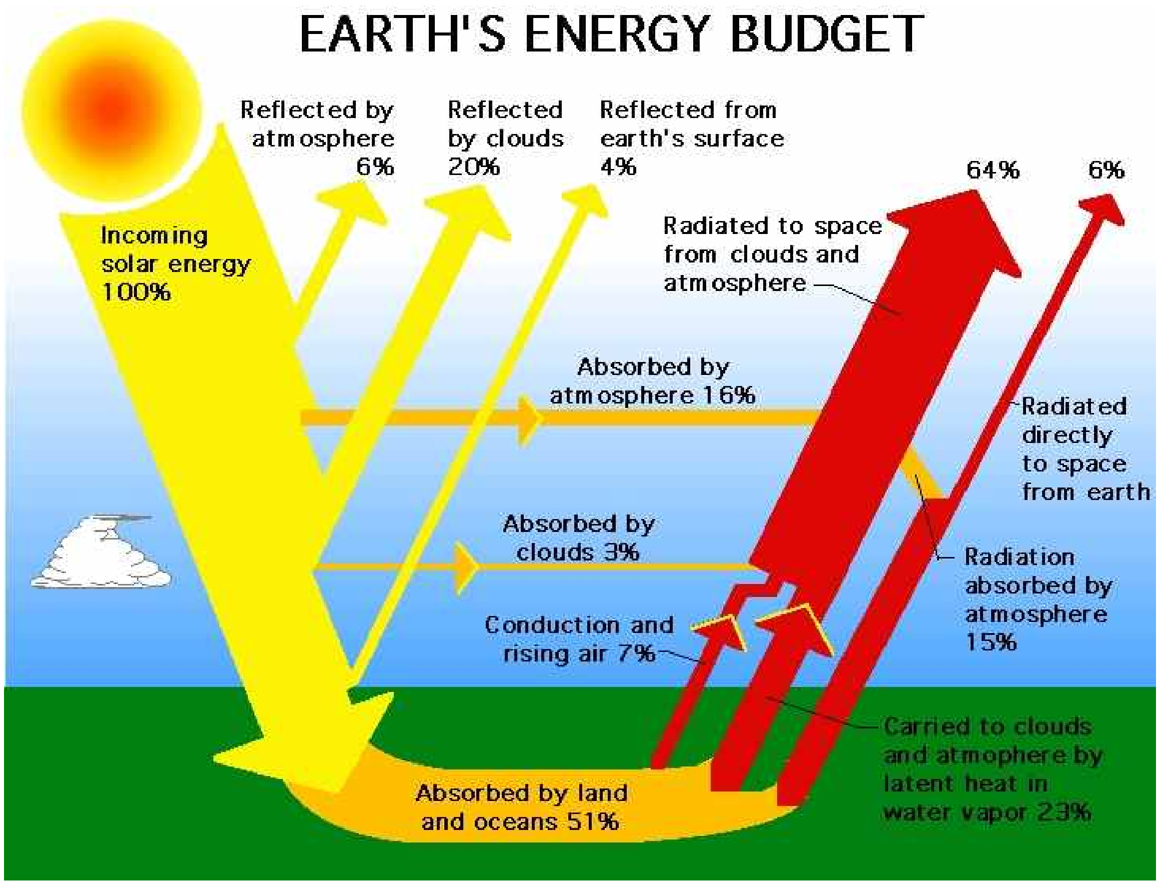


Figure 1d: Earth's energy budget by NASA / ERBE (2006)

Credit: NASA / Earth Radiation Budget Experiment (ERBE) (2006)

Reference:
http://asd-www.larc.nasa.gov/erbe/components2.gif

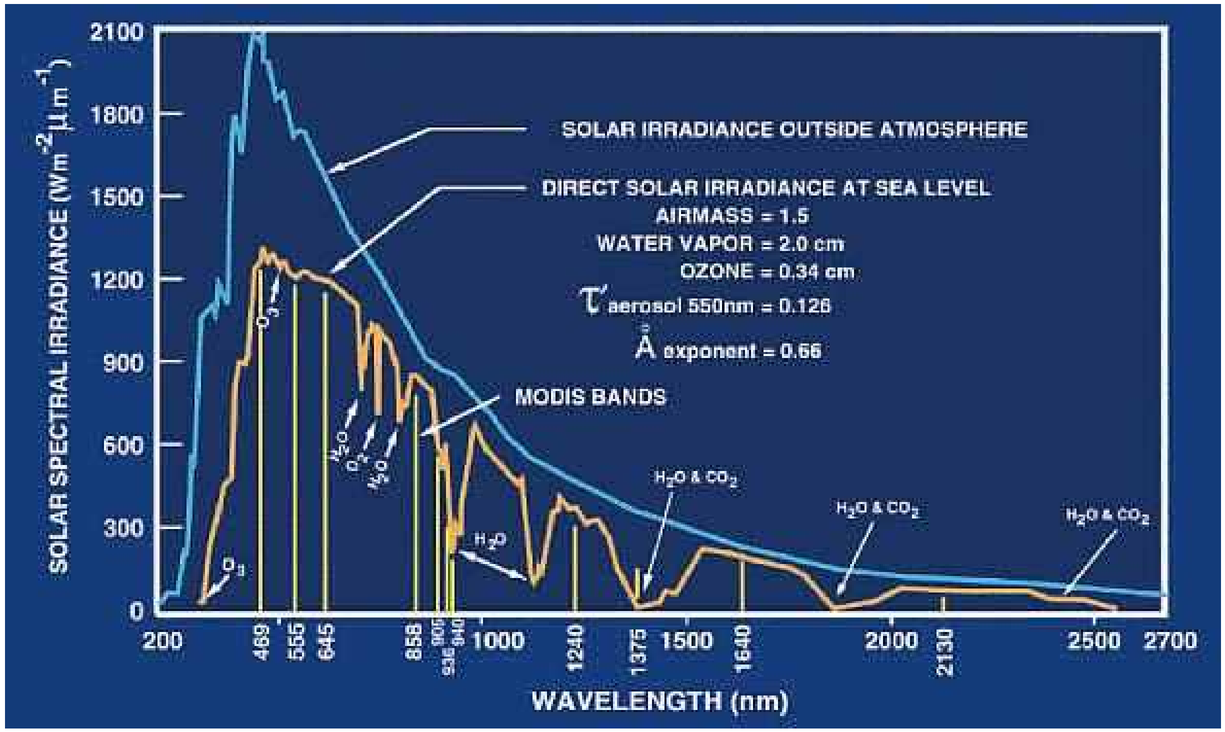


Figure 2a: Solar Spectral Irradiance: by far the most significant forcing function for Earth's climate. The peak of the spectrum is around 480 nm… the colour green.

Credit: NASA / MODIS (Moderate-resolution Imaging Spectroradiometer) (2006)
Reference: http://Wikipedia - MODIS

Normalized Nanowire Dipole Scattering Cross-Section - one dipole

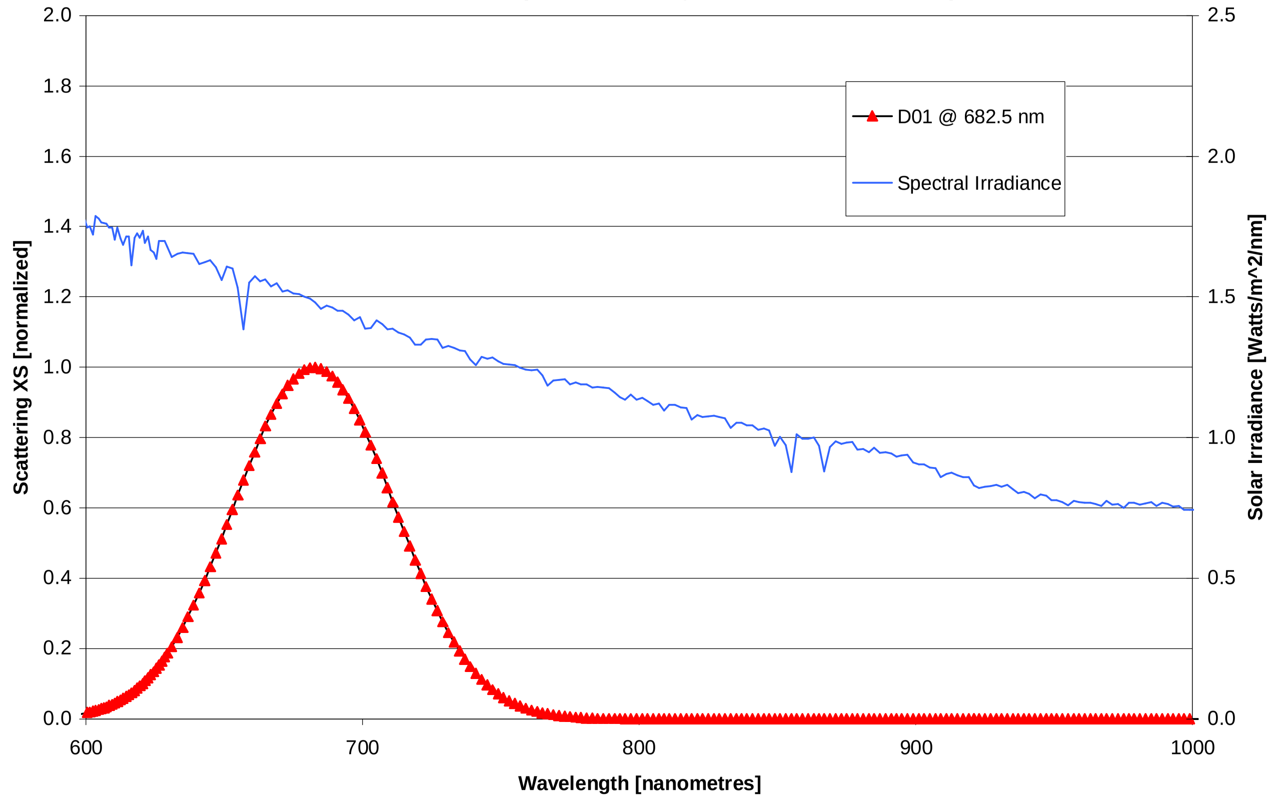


Figure 2b: Normalized scattering cross-section of a nanowire half-wave dipole resonant at 682.5 nm (near infra-red), and the solar irradiance curve. The dipole's half-power scattering cross-sectional bandwidth is approximately +-5%. Credit: NCP, 2000 ASTM Standard Extraterrestrial Spectrum Reference E-490-00, RReDC - Renewable Resource Data Center. Reference: http://rredc.nrel.gov/solar/spectra/am0/ASTM2000.html

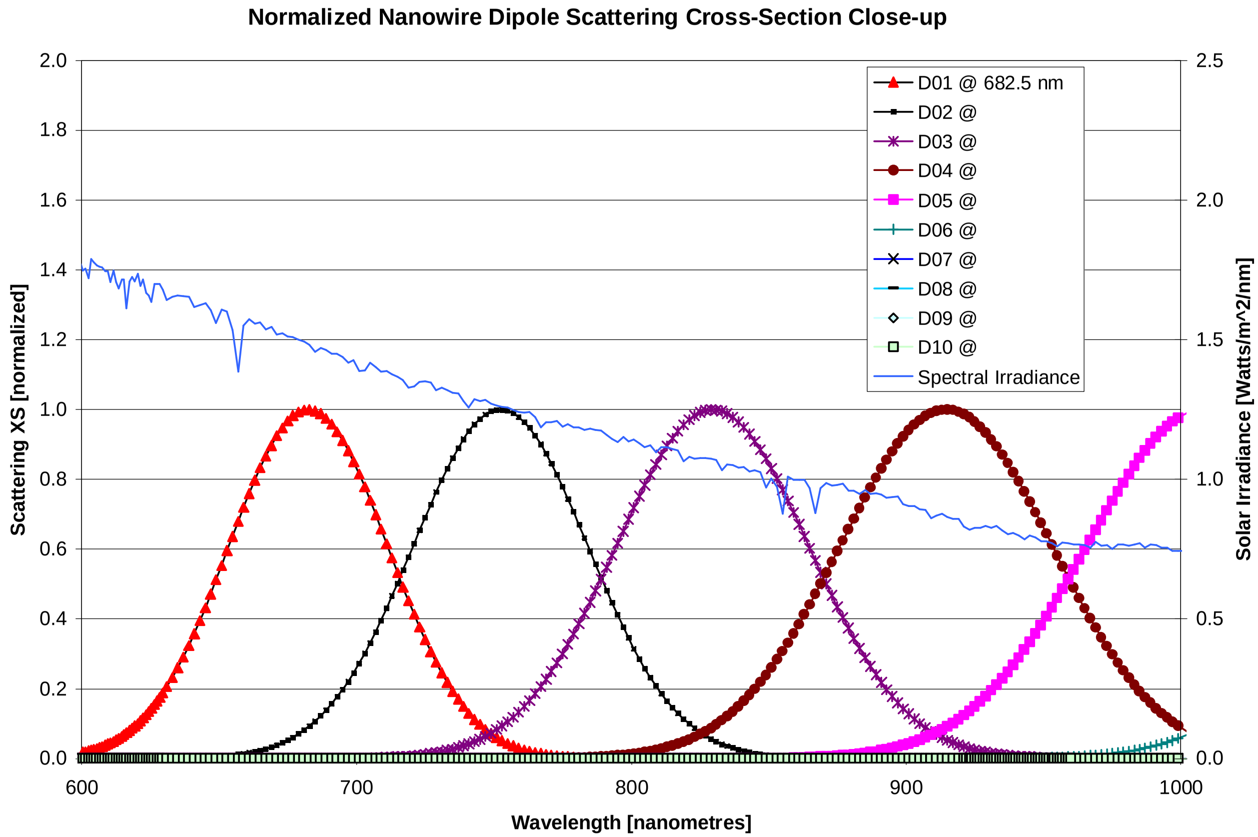


Figure 2c: Normalized scattering cross-section of a several nanowire half-wave dipoles with different resonant wavelengths and the solar irradiance curve. The scattering cross-sections are designed to intersect at the half-power scattering points.
Credit: NCP, 2000 ASTM Standard Extraterrestrial Spectrum Reference E-490-00, RReDC - Renewable Resource Data Center. Reference: http://rredc.nrel.gov/solar/spectra/am0/ASTM2000.html

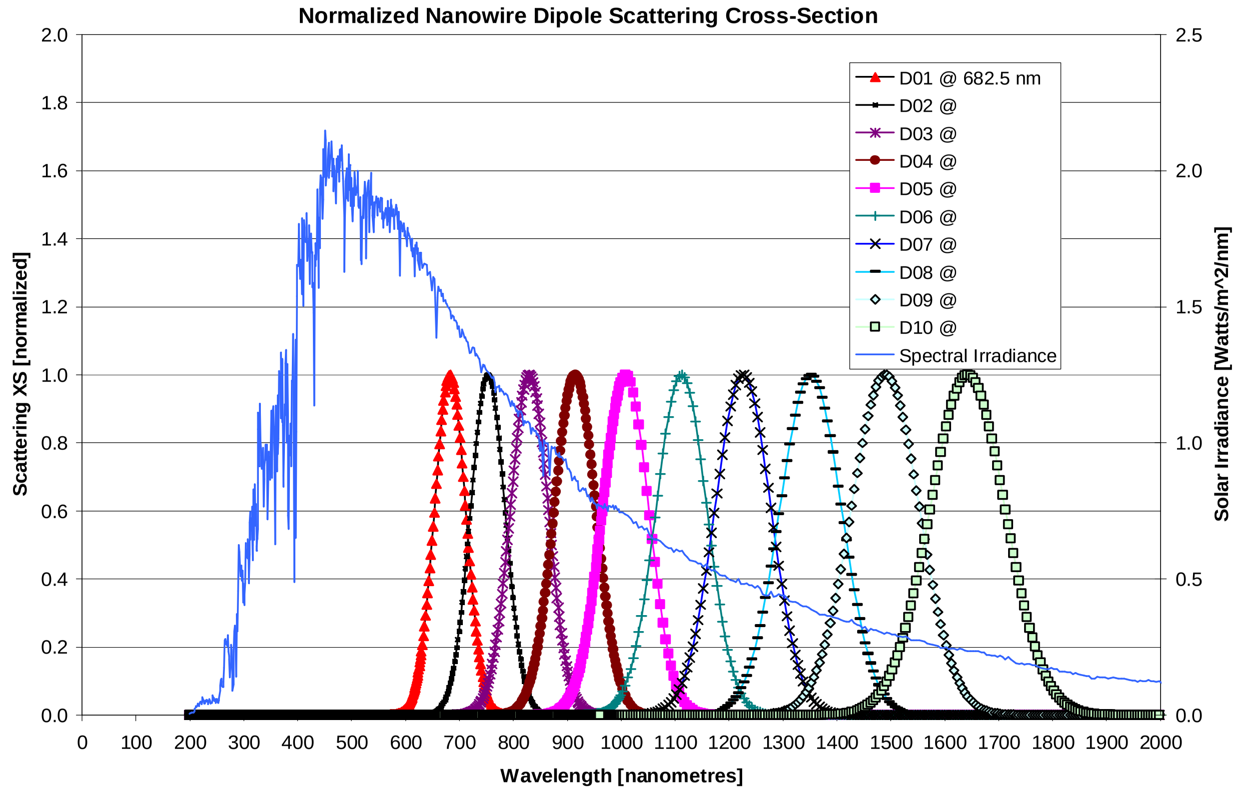


Figure 2d: Normalized scattering cross-section of ten nanowire half-wave dipoles with different resonant wavelengths and the solar irradiance curve.
Credit: NCP, 2000 ASTM Standard Extraterrestrial Spectrum Reference E-490-00, RReDC - Renewable Resource Data Center. Reference: http://rredc.nrel.gov/solar/spectra/am0/ASTM2000.html

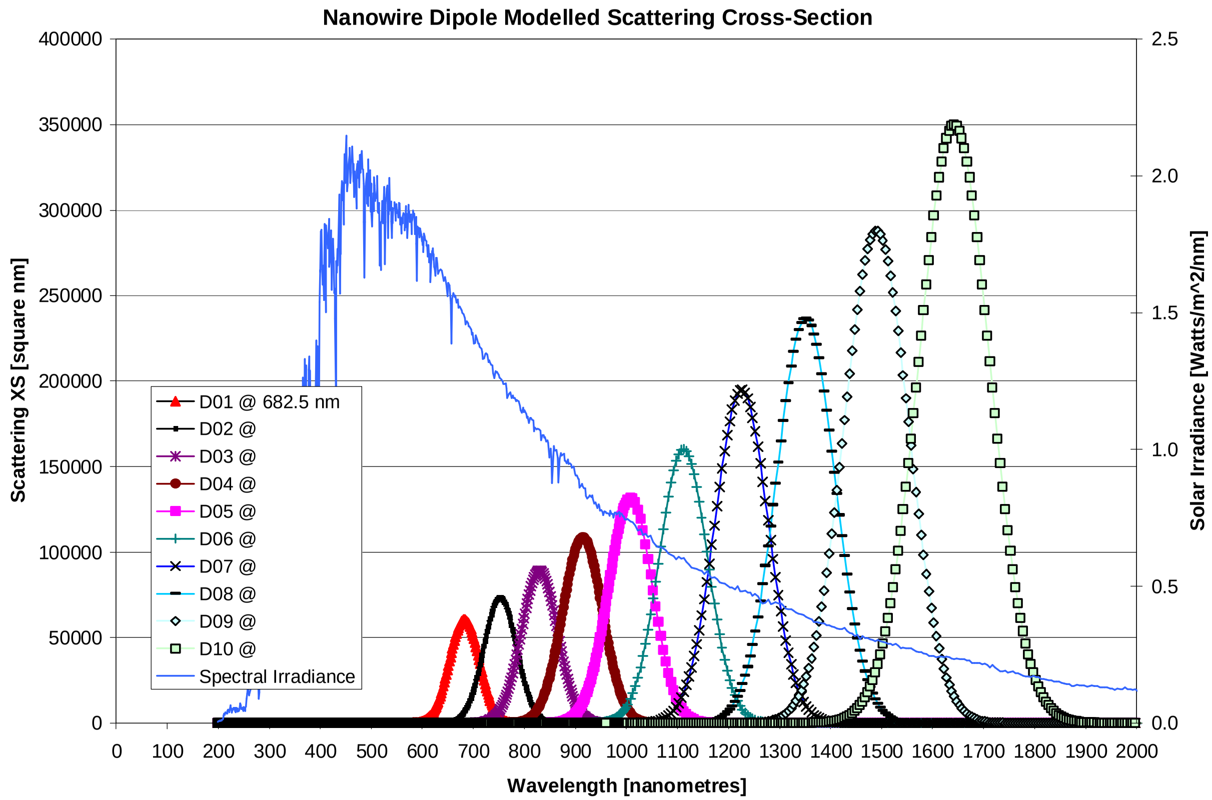


Figure 2e: Modelled scattering cross-section of ten nanowire half-wave dipoles with different resonant wavelengths and the solar irradiance curve. By correlating the modelled dipole cross-sections against the solar irradiance spectrum one can find a minimum cost implementation.

Credit: NCP, 2000 ASTM Standard Extraterrestrial Spectrum Reference E-490-00, RReDC - Renewable Resource Data Center. Reference: http://rredc.nrel.gov/solar/spectra/am0/ASTM2000.html

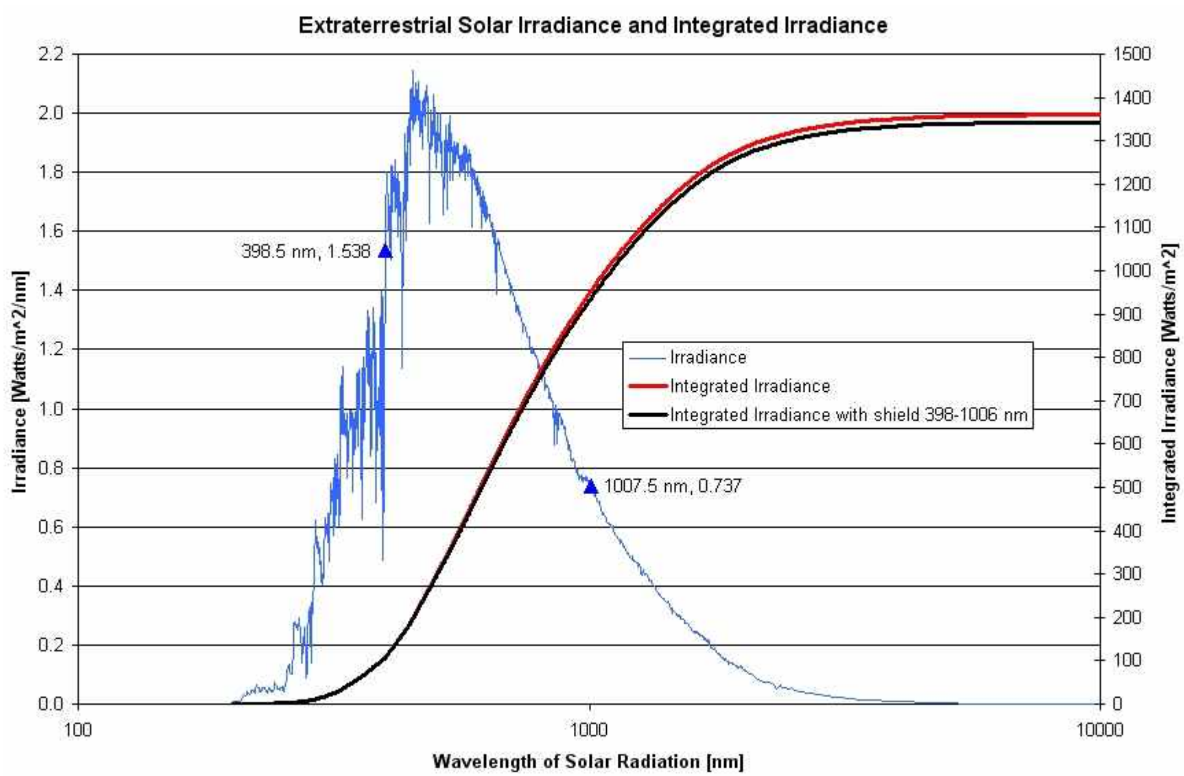


Figure 2f: One possible design for a solar shield: solar irradiance spectrum, the integrated solar irradiance spectrum, and the integrated solar irradiance spectrum as-modified by a 2% solar shield consisting of ten dipole wavelengths covering 398-1006 nm.

Credit: NCP, 2000 ASTM Standard Extraterrestrial Spectrum Reference E-490-00, RReDC - Renewable Resource Data Center. Reference: http://rredc.nrel.gov/solar/spectra/am0/ASTM2000.html

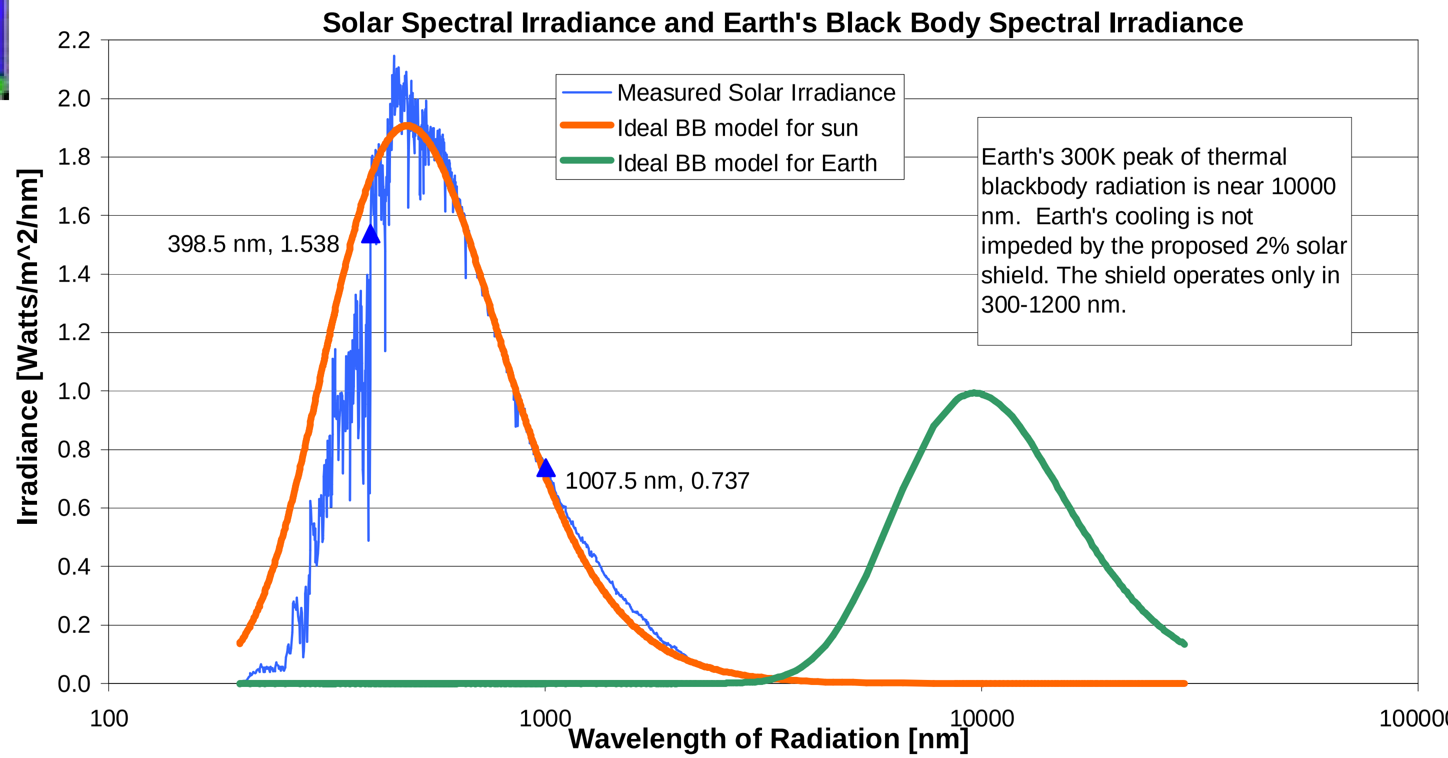


Figure 2g: The solar shield's dipole scatterers do not hold the Earth's heat in because they are designed to work well in the visible and near infra-red light (300 to 1200 nm). These dipoles scatter Earth's radiant heat very ineffectively because Earth radiates mostly in the far infra-red (3000 to 25000 nm) (the peak of the blackbody spectrum at 300ºK is near wavelength 10000 nm per Wien's displacement law).
Credit: NCP, 2000 ASTM Standard Extraterrestrial Spectrum Reference E-490-00, RReDC - Renewable Resource Data Center. Reference: http://rredc.nrel.gov/solar/spectra/am0/ASTM2000.html

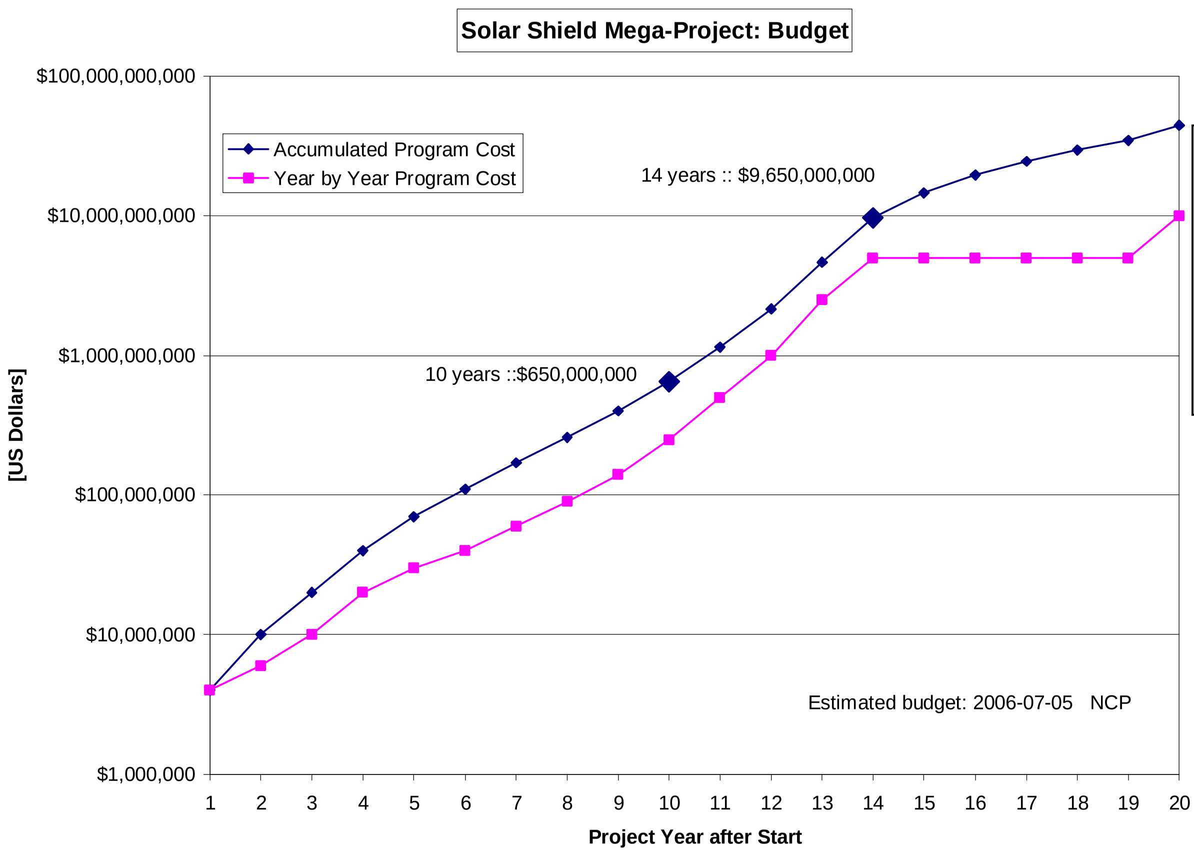


Figure 3a: Solar Shield Project Budget

Credit: NCP (2006)

Reference:

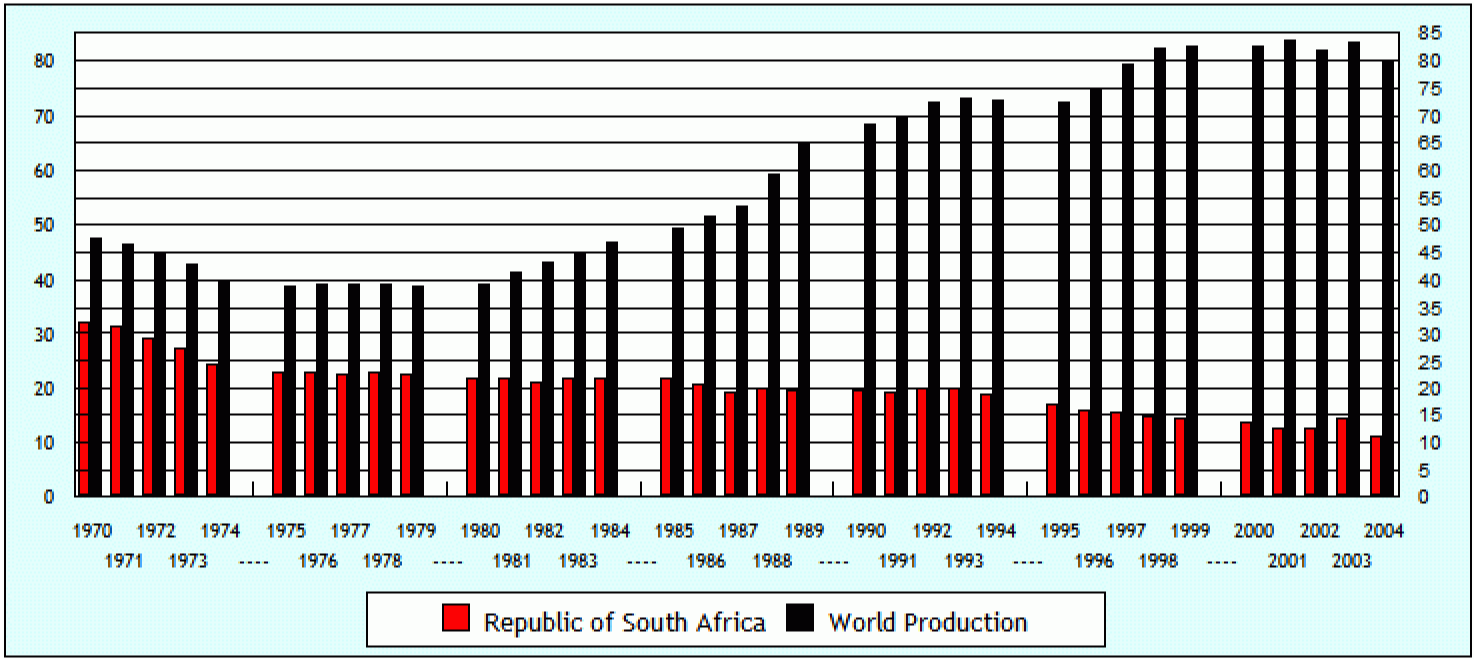


Figure 3b: World Gold Production, 1970-2004.
Scale: the Y-axis is in units of millions of troy ounces.
Credit:
Reference: www.goldsheetlinks.com/production.htm

Figure 3c: Daily Gold Prices per Troy Ounce: OHLC from 2005-10-06 until 2006-07-12

Credit: The Bullion Desk (2006)

Reference:
www.thebulliondesk.com

Figure 4: Currently proposed governmental and institutional responses to global warming: (1) enact expensive laws to force industry and automotive sectors to quickly reduce greenhouse emissions, (2) prepare infrastructure for world disaster management, and (3) accept rising sea levels should they in fact rise.

The solar shield program eliminates the rising seas, eliminates the requirement for planetary disaster management and adapts to the greenhouse gases so there is no global warming. Greatly reduced greenhouse emissions are still *absolutely required* but it's more practical (less harmful) to stretch the transition out over more decades (lowered costs to industry).

Image credit: DILBERT by Scott Adams (2006)
Reference: www.dilbert.com

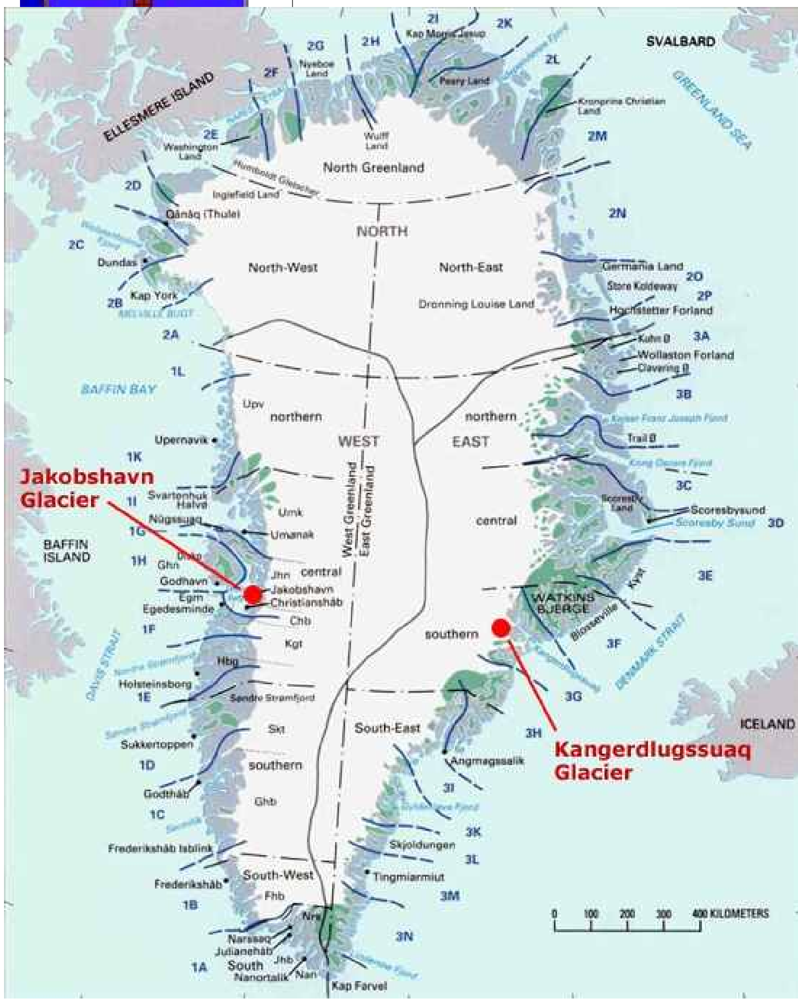


Figure 5a: “Two glaciers that bring about 10 percent of the Greenland Ice Sheet to the ocean—the Jakobshavn Glacier on the west coast and the Kangerdlugssuaq Glacier on the east coast— have flowed two to three times faster in recent years. (Local ice caps and ice domes are shown in green. Ice-free areas are shown in dark gray).”

Credit: Sarah Das, Woods Holes Oceanographic Institution (2006)

Reference:
www.whoi.edu/oceanus/viewArticle.do?id=9126

Figure 5b: “Supraglacial lakes, several kilometers long, form in summer from melted ice atop the Greenland Ice Sheet”

Credit: Sarah Das, Woods Holes Oceanographic Institution (2006).
Reference: www.whoi.edu/oceanus/viewArticle.do?id=9126

Figure 5c: “Supraglacial lakes may concentrate water so that it causes the ice to fracture and water to be injected directly to the bed, where the ice meets the ground. Added water would reduce friction between the ice and the ground, causing the ice sheet to flow faster to the ocean.”

Credit: Sarah Das, Woods Holes Oceanographic Institution (2006).
Reference: www.whoi.edu/oceanus/viewArticle.do?id=9126

Figure 5d: Meltwater stream flowing into a large moulin in the ablation zone (area below the equilibrium line) of the Greenland ice sheet… image from Summer 2002

Credit: Roger J. Braithwaite, The University of Manchester, UK (2006)

Reference:
www.gsfc.nasa.gov/topstory/20020606greenland.html

http://icesat.gsfc.nasa.gov/

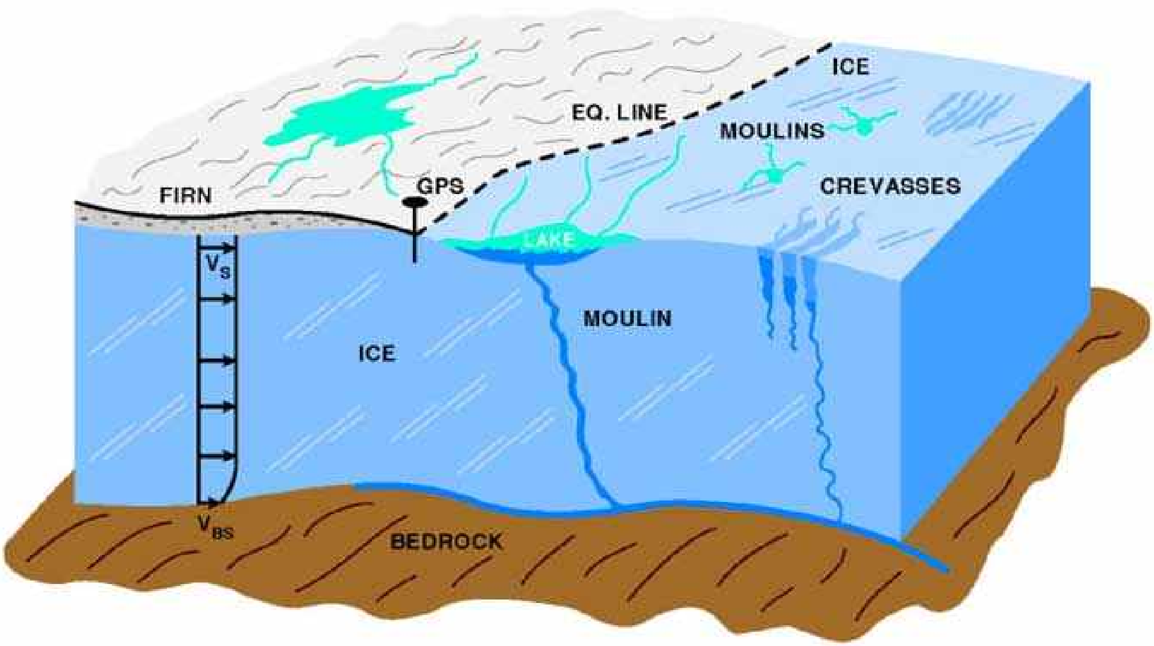


Figure 5e: “Glaciological features of the [Greenland] ice sheet including surface lakes, crevasses, and large openings called moulins, that stretch up to 10 meters in diameter and drain to the bedrock. Meltwater descends through the moulins, down to the bedrock, contributing to the movement of the ice sheet.”

Credit: Jay Zwally, NASA/GSFC 2006
Reference: www.gsfc.nasa.gov/topstory/20020606greenland.html
http://icesat.gsfc.nasa.gov/

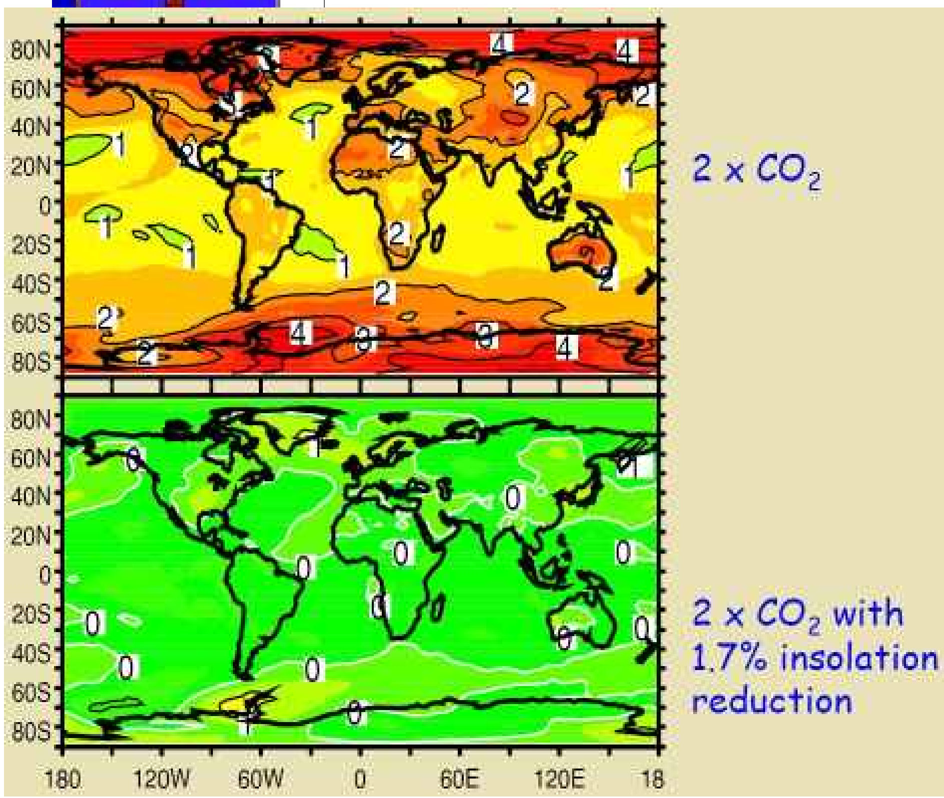


Figure 6a: LLNL supercomputer climate models compare two worlds with double the pre-industrialized levels of CO_2: one world without insolation control and the other world with active insolation control. Without insolation control (upper map) results in polar temperatures increasing by 3-4 degrees C. Reduced insolation by ~1.7% (lower map) results in about uniform temperatures worldwide (negligible tropospheric warming).

Temperature units are degrees Celsius.

Credit: Govindasamy B. and Caldeira K., "Geoengineering Earth's radiation balance to mitigate CO_2-induced climate change," Geophys. Res. Lett. 27, #14, 2141 (2000)
Reference: E. Teller et. al., Symposium on Macro-Engineering Options For Climate Change Management and Mitigation, Isaac Newton Institute, Cambridge, England, 7-9 January 2004.
www.tyndall.ac.uk, www.llnl.gov, www.tyndall.ac.uk/events/past_events/cmi.shtml

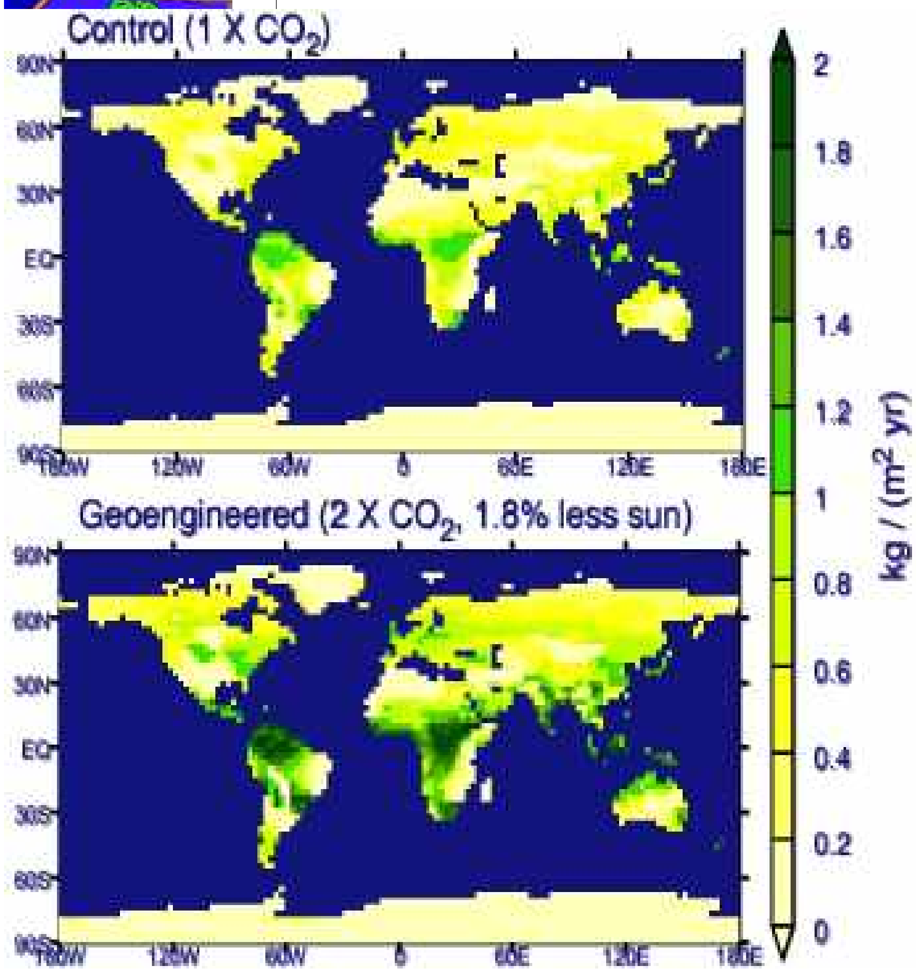
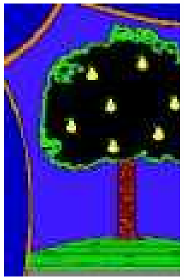


Figure 6b: LLNL supercomputer climate model - "Net primary (plant) productivity of the terrestrial land-masses, as modeled by the IBIS code with slab ocean, used in conjunction with the Community Climate Model CCM3. The upper panel depicts the Earth with a pre-industrial atmospheric CO_2 concentration (280 ppm), while the lower panel depicts the Earth with a CO_2 concentration 2x that of the pre-industrial one (560 ppm) and with 1.8% less insolation.

The lower panel's globally-aggregated land-plant productivity is nearly twice that of the upper panel, which implies an agricultural crop value gain of the order of 1 trillion dollars/year for the enriched-CO_2 case."

Credit: Govindasamy B., Caldeira K., and Duffy PB, "Geoengineering Earth's radiation balance to mitigate change from a quadrupling of CO_2" , Global and Planetary Change (2002)
Reference: E. Teller et. al., Symposium on Macro-Engineering Options For Climate Change Management and Mitigation, Isaac Newton Institute, Cambridge, England, 7-9 January 2004.
www.tyndall.ac.uk, www.llnl.gov, www.tyndall.ac.uk/events/past_events/cmi.shtml



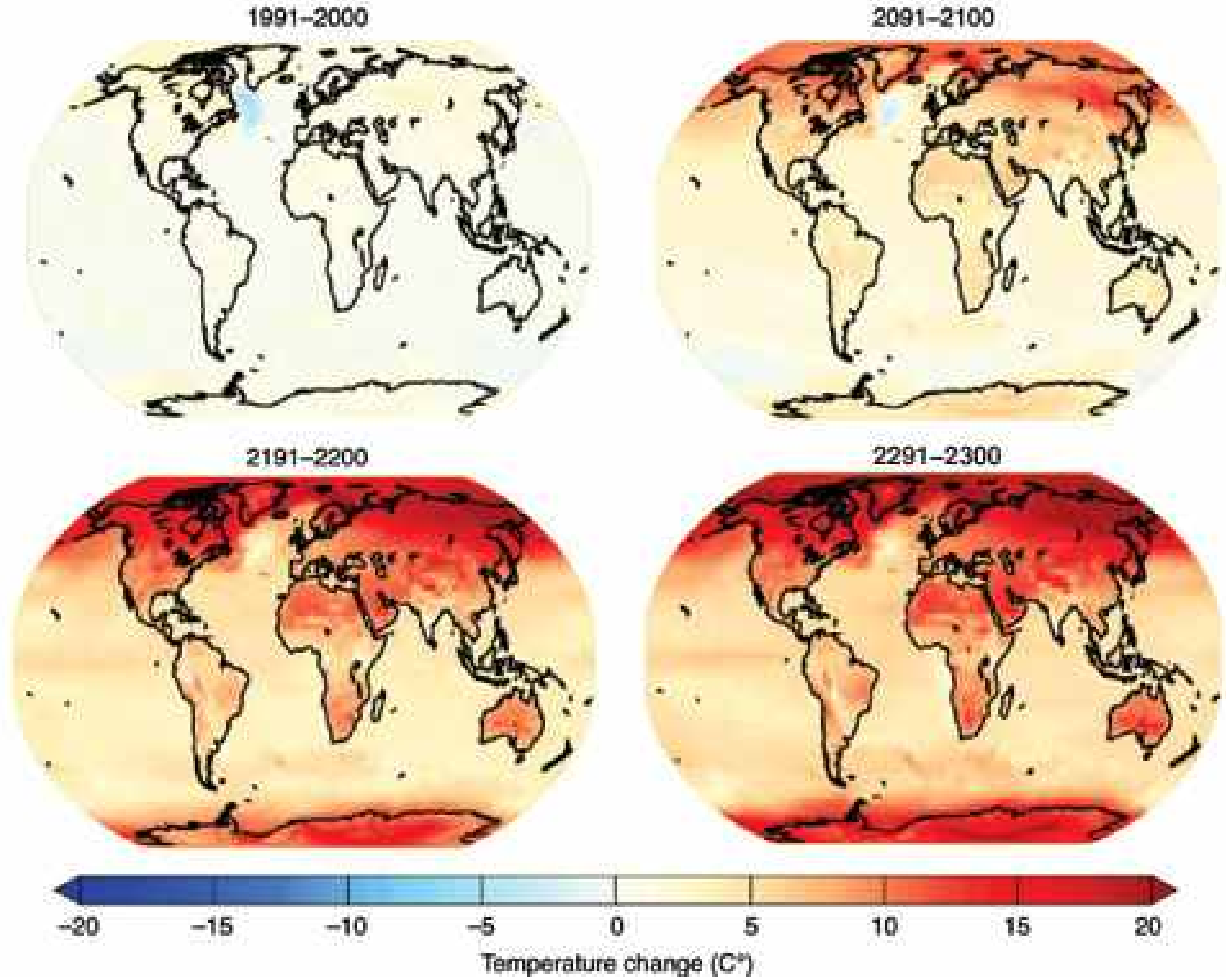


Figure 6c: The future without a solar shield: LLNL model - “Computer modeling data of the global surface-temperature change over the next 300 years indicate the Arctic will be warmer by 20°C in 2300. All plots are referenced to preindustrial times (1891–1900). ”
Credit: Bala Govindasamy, “Too Hot to Handle”, LLNL Science & Technology Review Magazine, June 2006
Reference: www.llnl.gov/str//June06/Govindasamy.html, www.llnl.gov

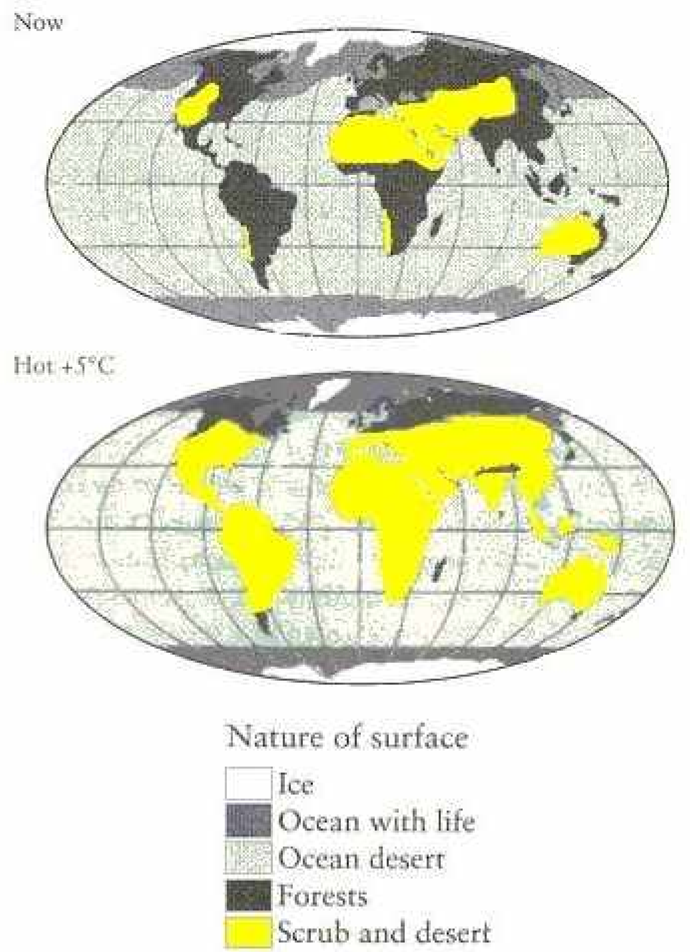
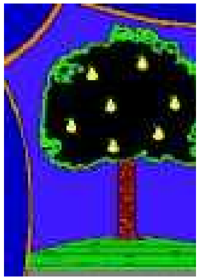


Figure 6d: The future without a solar shield: “A geographic model for changes to the Earth’s micro-climates with a global five degree Celsius increase in temperature”

The model depicts tropical seas as “ocean desert”. This is because the most fertile parts of the ocean are the plankton-rich cooler arctic and antarctic waters. N.B.: CO_2 gas uptake absorption by cooler sea water is much faster than in warmer waters.

Credit: James Lovelock, "The Revenge of Gaia" (2006), page 63.

Reference: www.tnr.fr



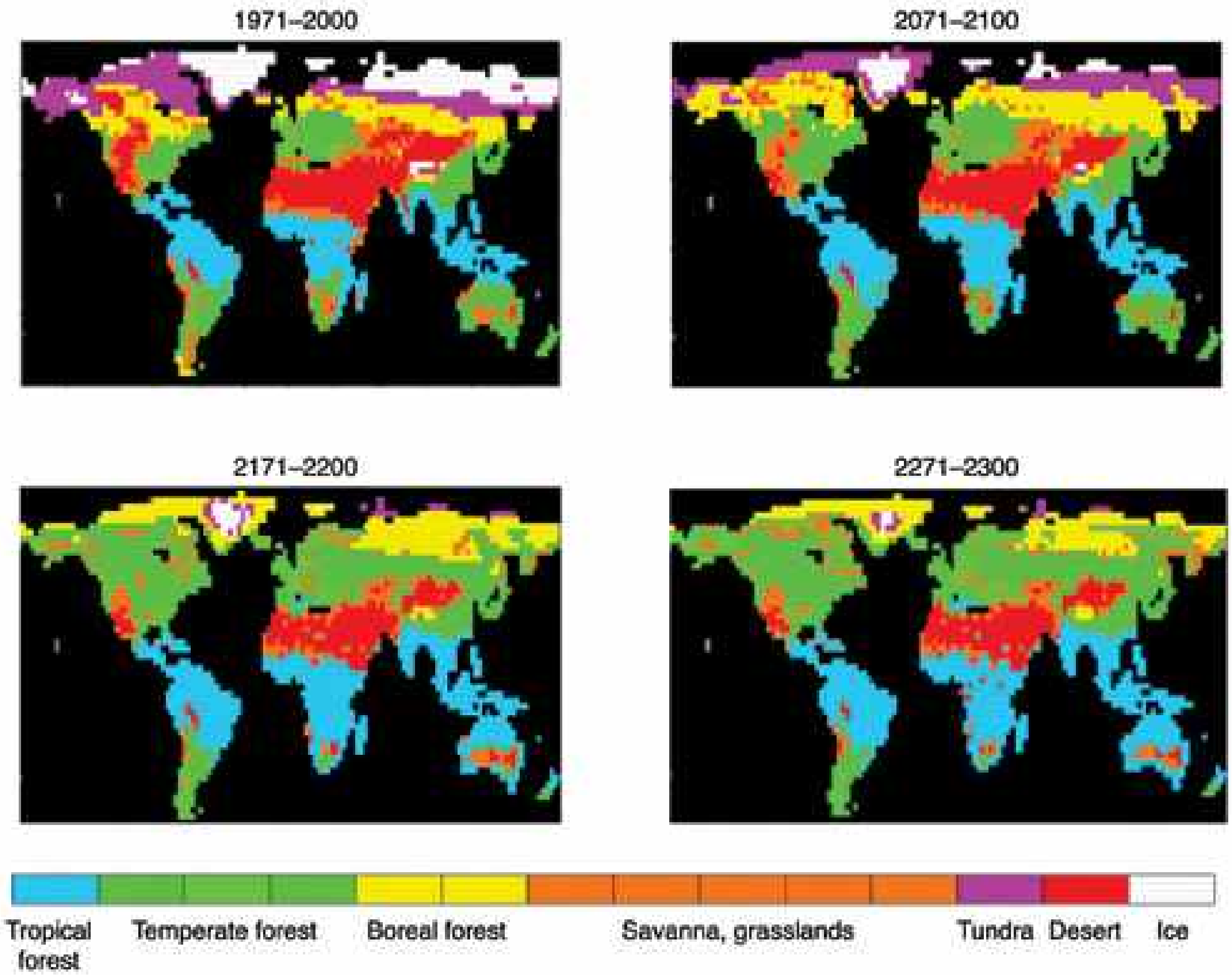


Figure 6e: The future without a solar shield: LLNL climate model - “Simulations of the changes in global dominant vegetation types show that northern ice caps will begin vanishing this century and tundra regions will disappear within 200 to 300 years.”
Credit: Bala Govindasamy, “Too Hot to Handle”, LLNL Science & Technology Review Magazine, June 2006
Reference: www.llnl.gov/str//June06/Govindasamy.html , www.llnl.gov

Figure 6f: Coastline changes for sea level rises of one, seven, and fourteen metres.
Credit:
Reference:

Mike Mann's Hockey Stick *– remove and replace with what?*

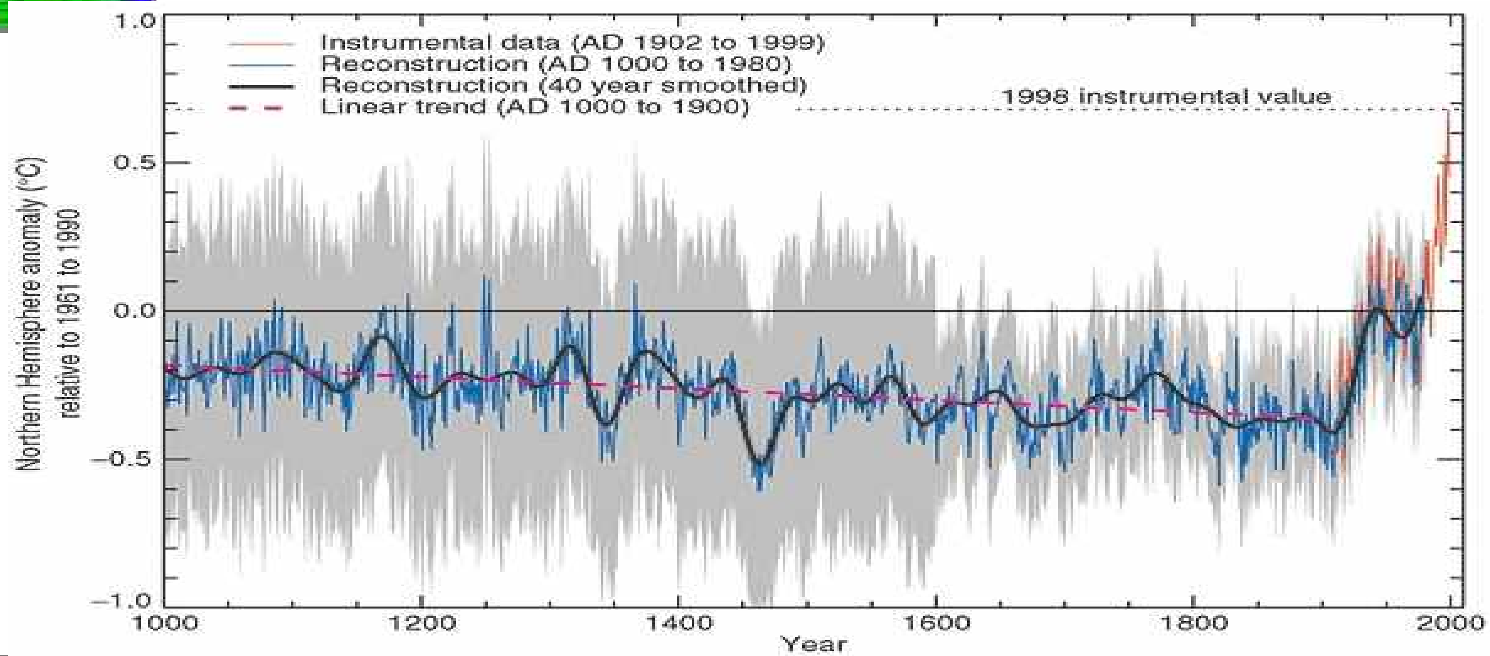


Figure 7a: "Millennial Northern Hemisphere (NH) temperature reconstruction (blue) and instrumental data (red) from AD 1000 to 1999, adapted from Mann et al. (1999). Smoother version of NH series (black), linear trend from AD 1000 to 1850 (red-dashed) and two standard error limits (grey shaded) are shown."

Credit: © IPCC 2001Figure 2.20 of IPCC WG1 TAR, "Climate Change 2001: Working Group I: The Scientific Basis"

Reference: www.grida.no/climate/ipcc_tar/wg1/563.htm

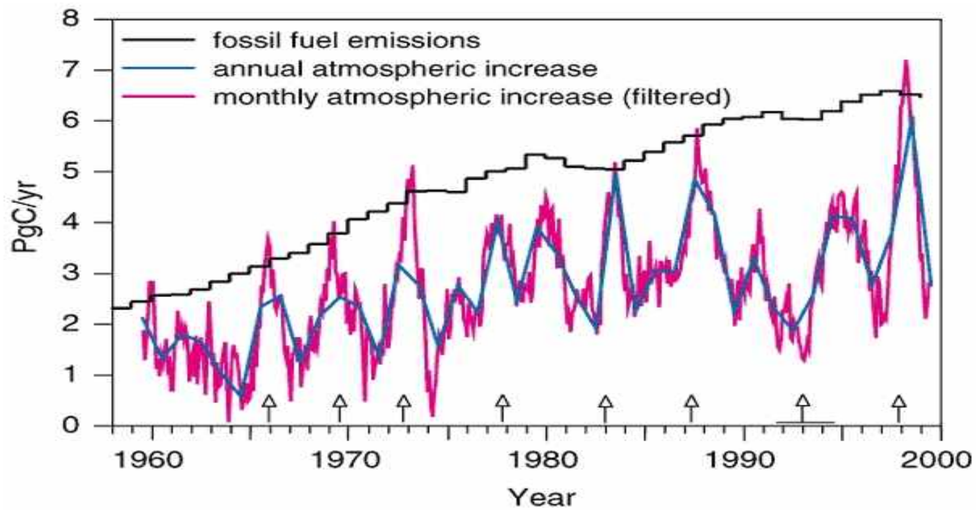


Figure 7b: 1960-2000ce: “Fossil fuel emissions and the rate of increase of CO_2 concentration in the atmosphere. The annual atmospheric increase is the measured increase during a calendar year. The monthly atmospheric increases have been filtered to remove the seasonal cycle. Vertical arrows denote El Niño events. A horizontal line defines the extended El Niño of 1991 to 1994. Atmospheric data are from Keeling and Whorf (2000), fossil fuel emissions data are from Marland et al. (2000) and British Petroleum (2000), see explanations in [referenced] text.”

Units: “PgC” = petagrams of carbon, where one PgC equals one gigatonne of carbon
Credit: © IPCC 2001 Figure 3.3 of IPCC WG1 TAR, “Climate Change 2001: Working Group I: The Scientific Basis”
Reference: www.grida.no/climate/ipcc_tar/wg1/107.htm

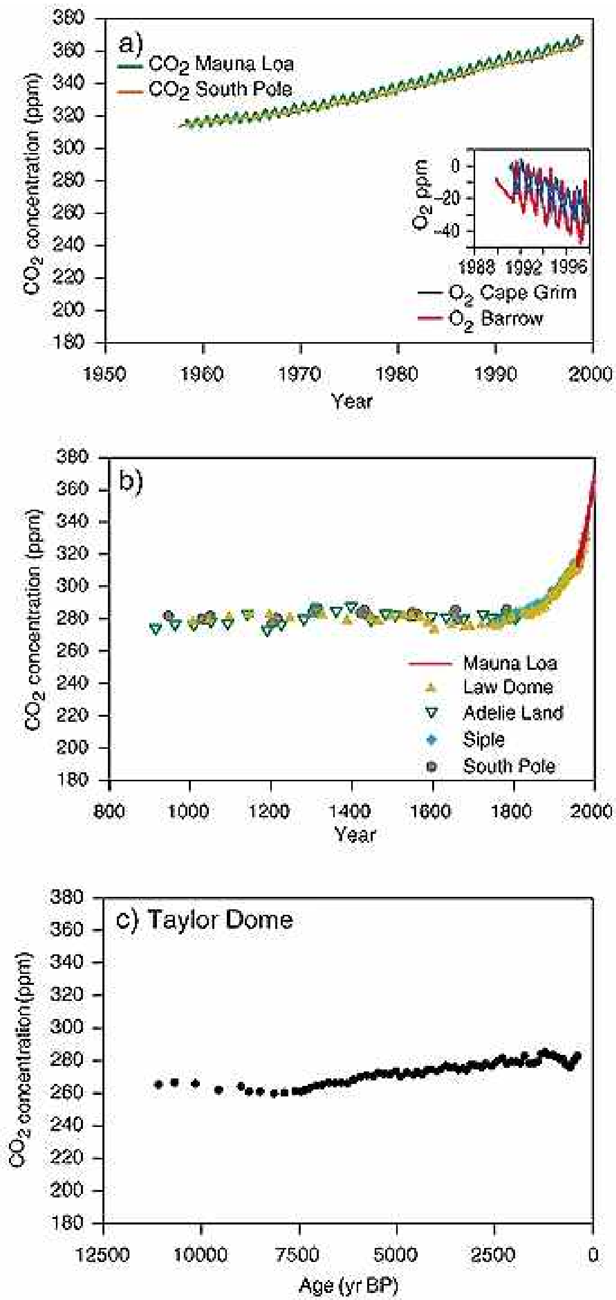


Figure 7c: "Variations in atmospheric CO_2 concentration on different time-scales. (a) Direct measurements of atmospheric CO_2 concentration (Keeling and Whorf, 2000), and O_2 from 1990 onwards (Battle et al., 2000). [Oxygen] O_2 concentration is expressed as the change from an arbitrary standard. (b) CO_2 concentration in Antarctic ice cores for the past millenium (Siegenthaler et al., 1988; Neftel et al., 1994; Barnola et al., 1995; Etheridge et al., 1996). Recent atmospheric measurements at Mauna Loa (Keeling and Whorf, 2000) are shown for comparison. (c) CO_2 concentration in the Taylor Dome Antarctic ice core (Indermühle et al., 1999)."

Credit: © IPCC 2001 Figure 3.2 a, b, and c of IPCC WG1 TAR, "Climate Change 2001: Working Group I: The Scientific Basis"

Reference: www.grida.no/climate/ipcc_tar/wg1/105.htm

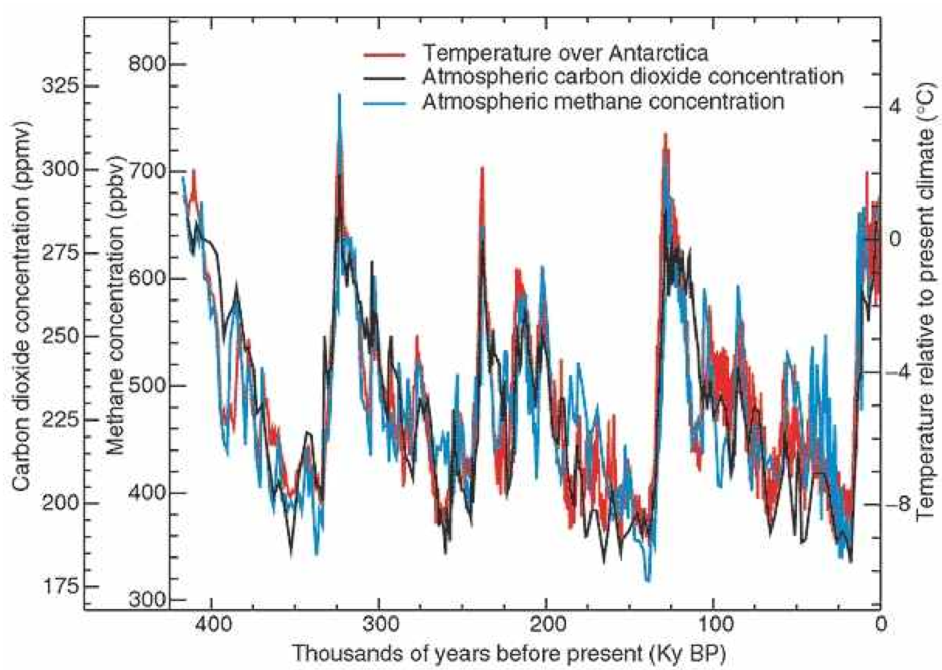


Figure 7d: Variations of temperature, methane, and atmospheric carbon dioxide concentrations derived from air trapped within ice cores from Antarctica (adapted from Sowers and Bender, 1995; Blunier et al., 1997; Fischer et al., 1999; Petit et al., 1999).

Credit: © IPCC 2001 Figure 2.22 of IPCC WG1 TAR, "Climate Change 2001: Working Group I: The Scientific Basis"

Reference:
www.grida.no/climate/ipcc_tar/wg1/563.htm

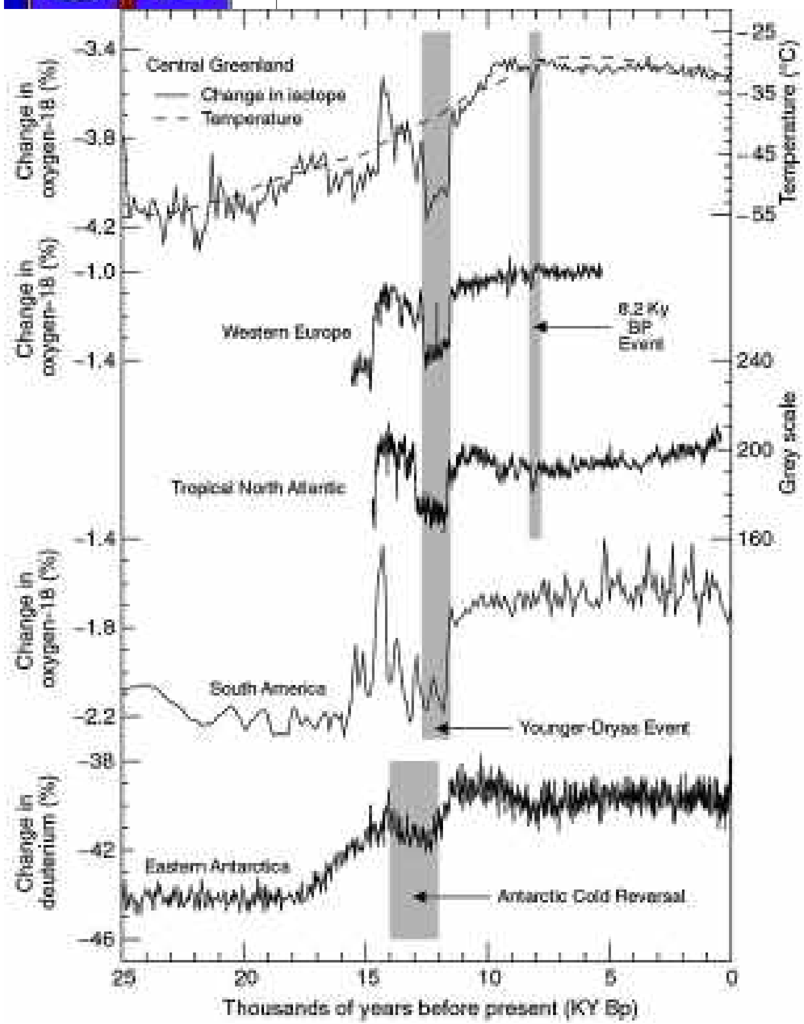


Figure 7e: Records of climate variability during the Holocene and the last climatic transition, including the 8.2 ky BP event (adapted from Johnsen et al., 1992; Hughen et al., 1996; Thompson et al., 1998; von Grafenstein et al., 1999; Jouzel et al., 2001). The shaded areas show the 8.2 ky BP event, the Younger Dryas event and the Antarctic Cold Reversal. The grey scale used in the Tropical North Atlantic record is a measure of sea surface temperature, deduced from the colour of plankton rich layers within an ocean sediment core.

Reference:
www.grida.no/climate/ipcc_tar/wg1/563.htm

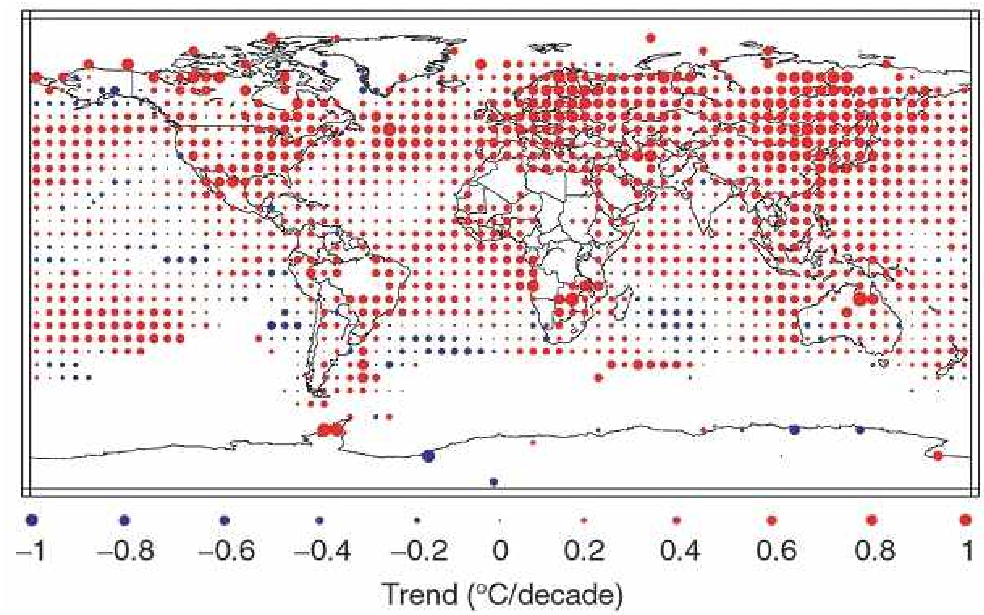


Figure 7f: World annual surface temperature trends for the 1976 to 2000 in units of °C/decade.

Credit: : © IPCC 2001 Figure 2.9 of IPCC WG1 TAR, "Climate Change 2001: Working Group I: The Scientific Basis"

Reference: www.grida.no/climate/ipcc_tar/wg1/057.htm

Figures

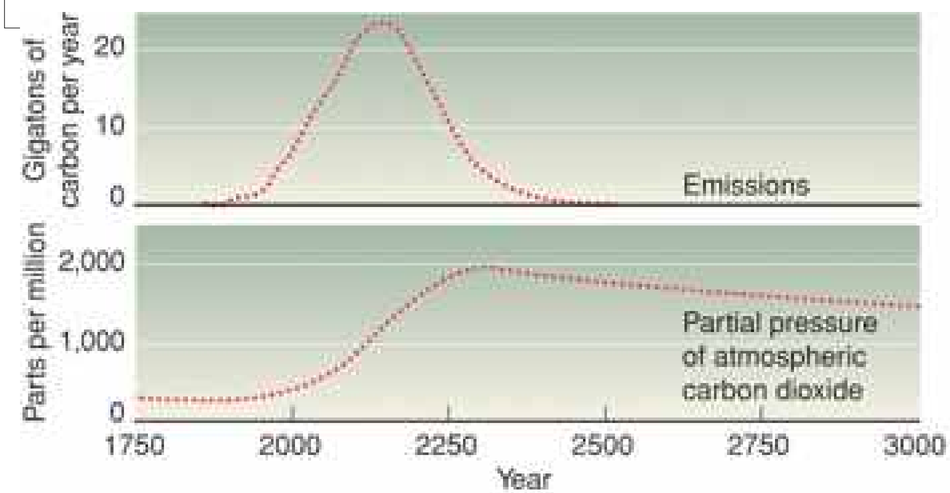


Figure 8a: model for CO_2 versus time, 1750 to 3000ce. "Determining how large the concentrations of atmospheric carbon dioxide will be in the future depends on how much fossil fuel is emitted. The top curve shows the emission rate of carbon dioxide and supposes all the estimated conventional fossil-fuel resources will be depleted by the year 2500. The bottom curve shows the resulting carbon dioxide concentrations up to year 3000. Ocean absorption of carbon dioxide is taken into account, but climate and land carbon changes are not."

Credit: Bala Govindasamy, "Too Hot to Handle", LLNL Science & Technology Review Magazine, June 2006

Reference: www.llnl.gov/str//June06/Govindasamy.html, www.llnl.gov

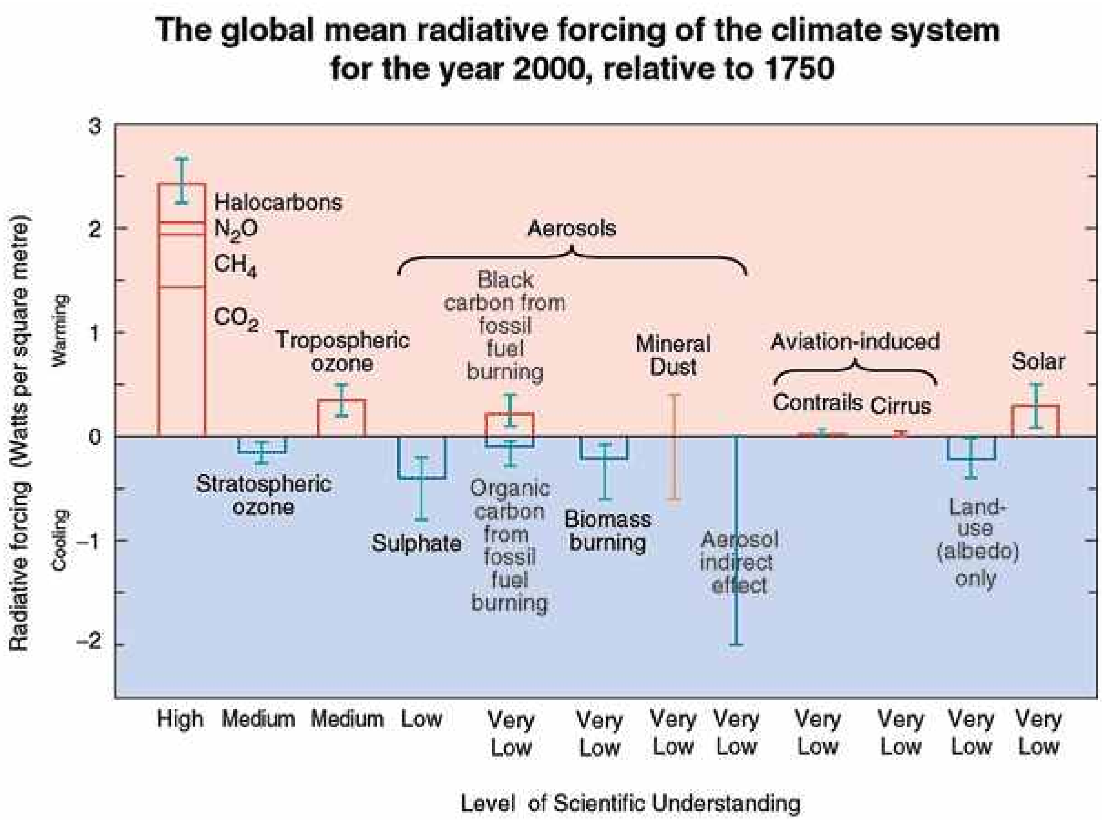


Figure 8b: Global mean forcing of Earth's climate for 2000ce, relative to 1750ce.

Credit: IPCC, "Climate Change 2001: Working Group I: The Scientific Basis"

Reference:
www.grida.no/climate/ipcc_tar/wg1/figspm-3.htm