Geoengineering: Might it Serve As A Societal Insurance Policy?

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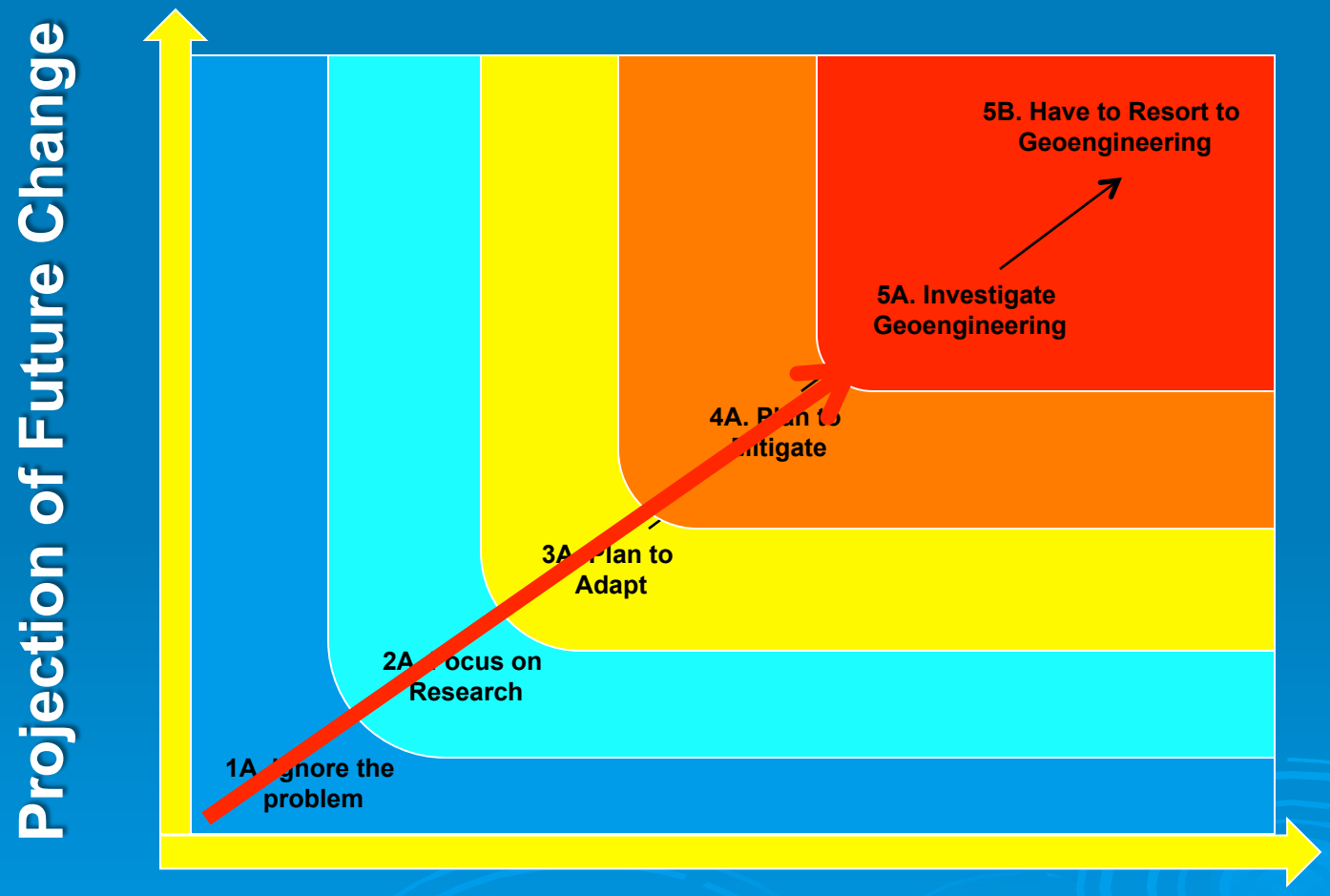
Climate Institute
Washington DC

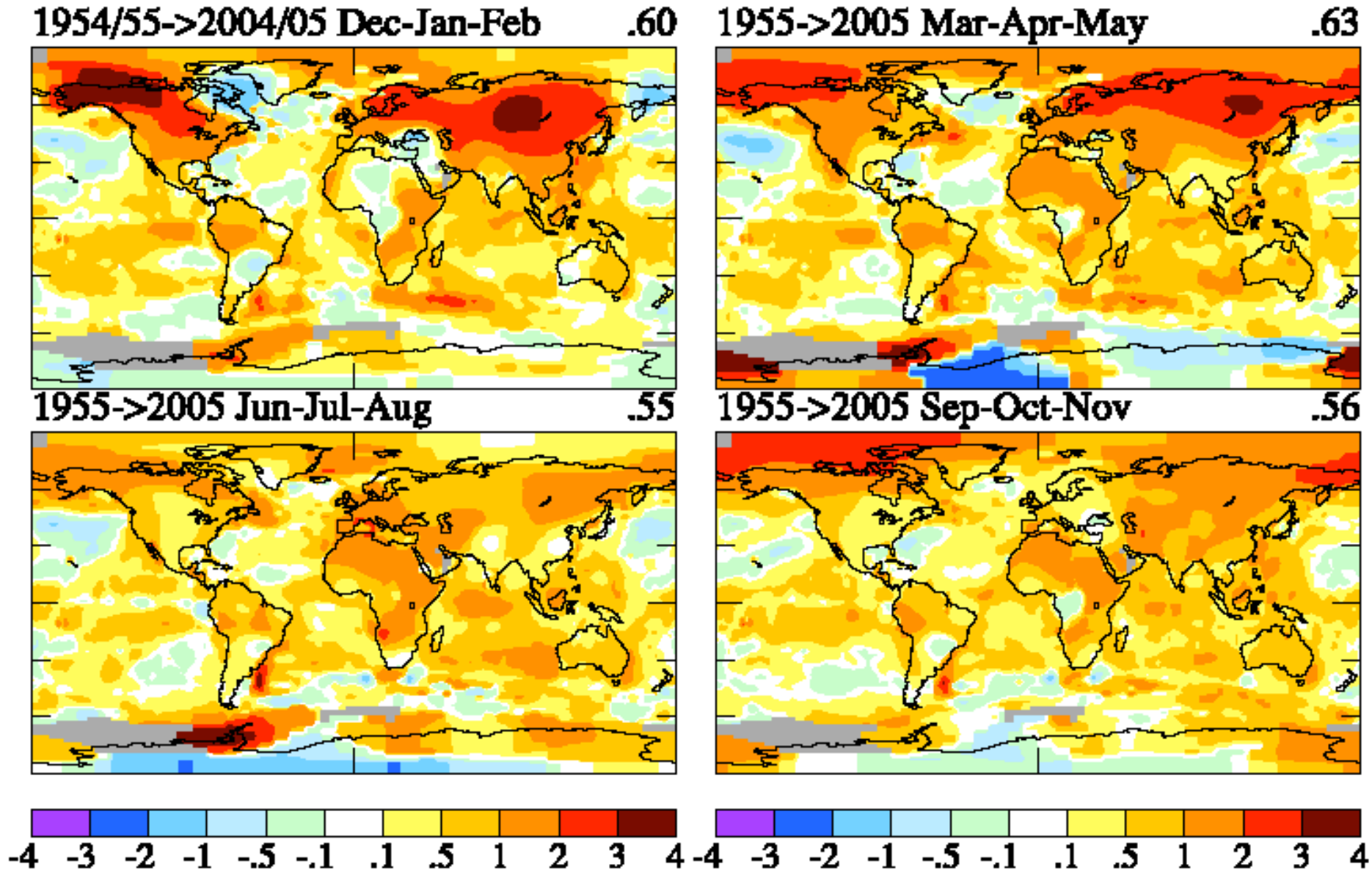
13 November 2008
Mexico City, Mexico

The Successive Stages of Climate Change Policy? Geoengineering as a Possible Ultimate Step

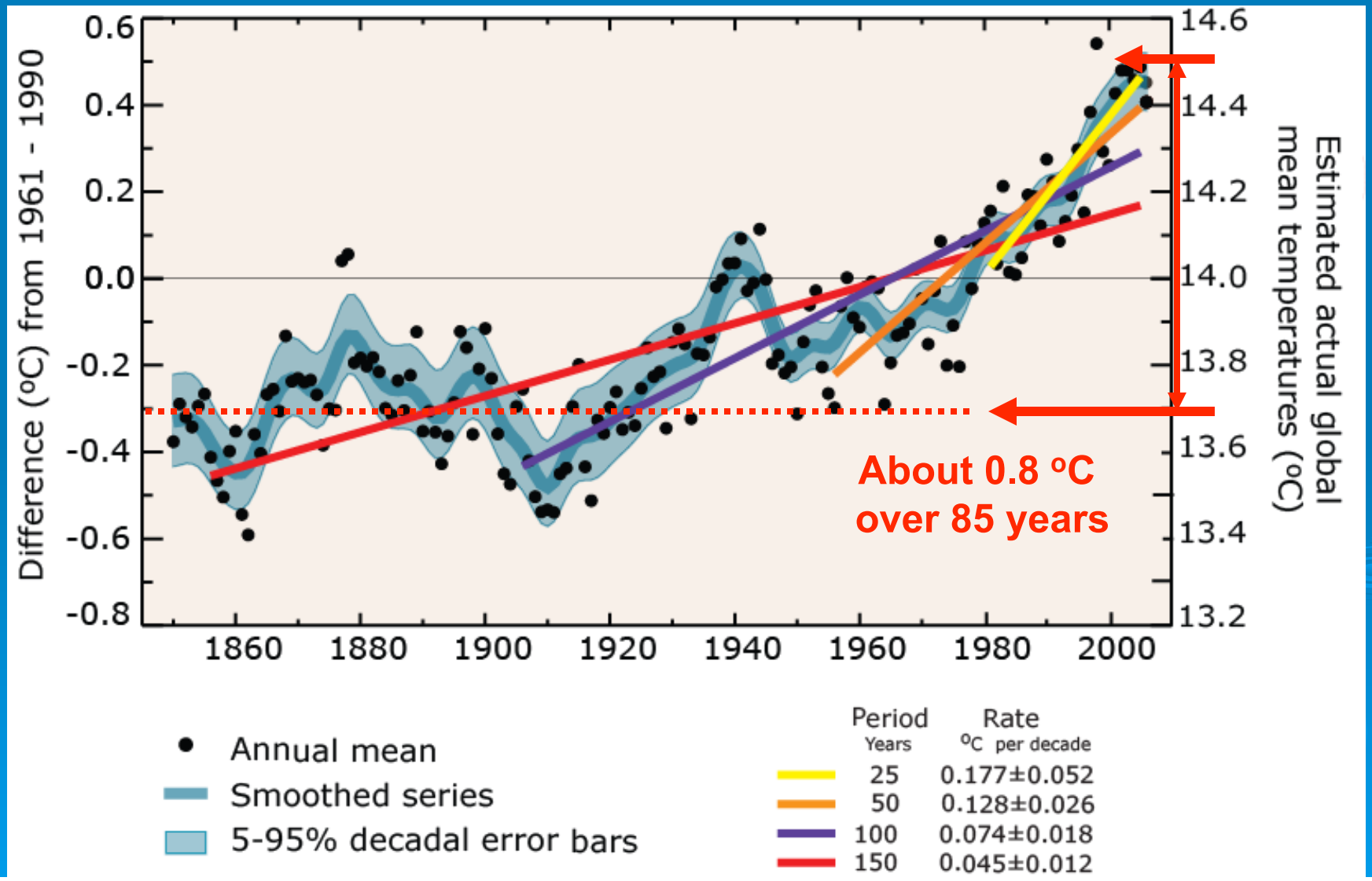


We have been experiencing warming has in all four seasons over the past 50 years

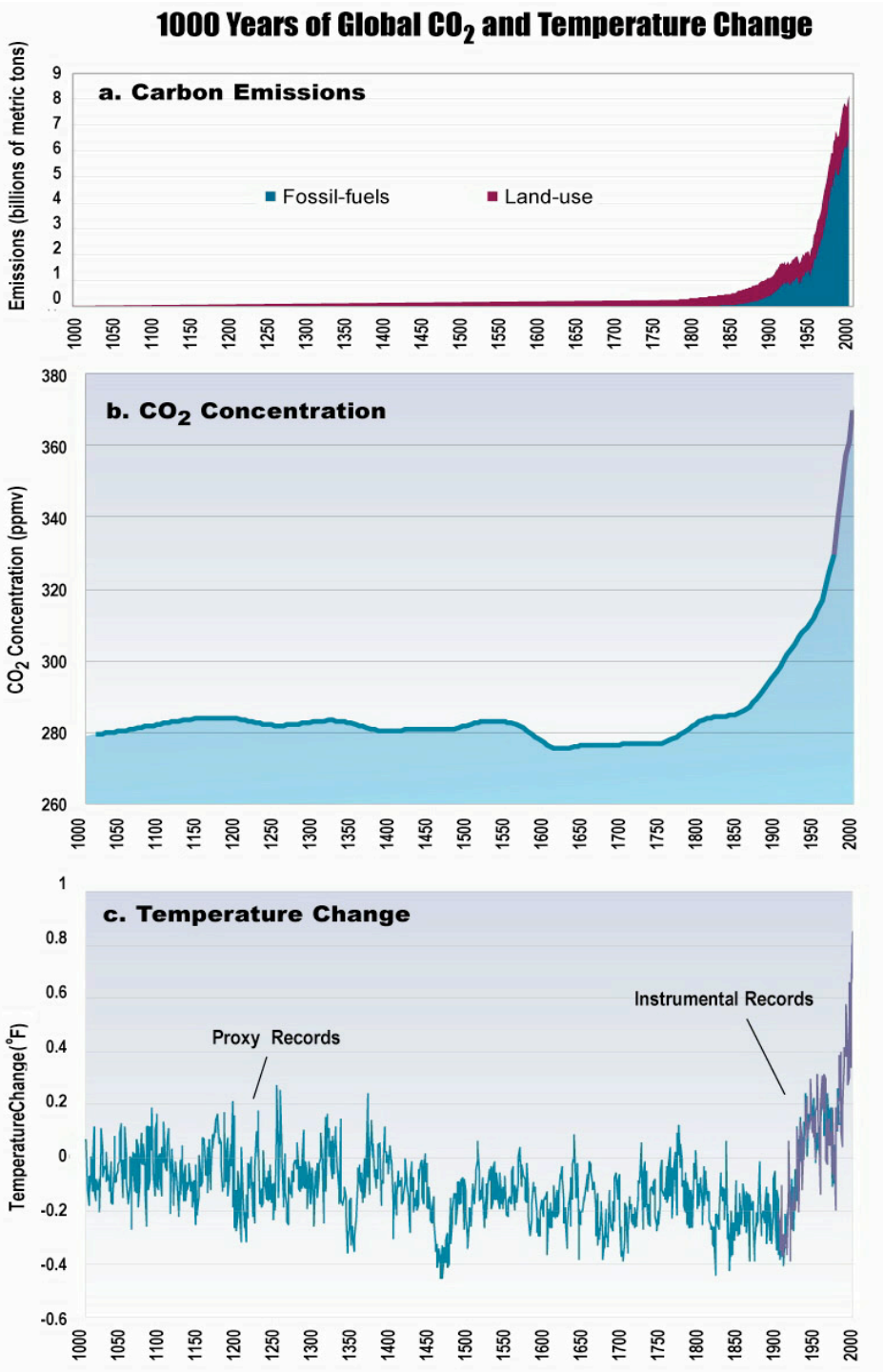
Source: GISS, 2006



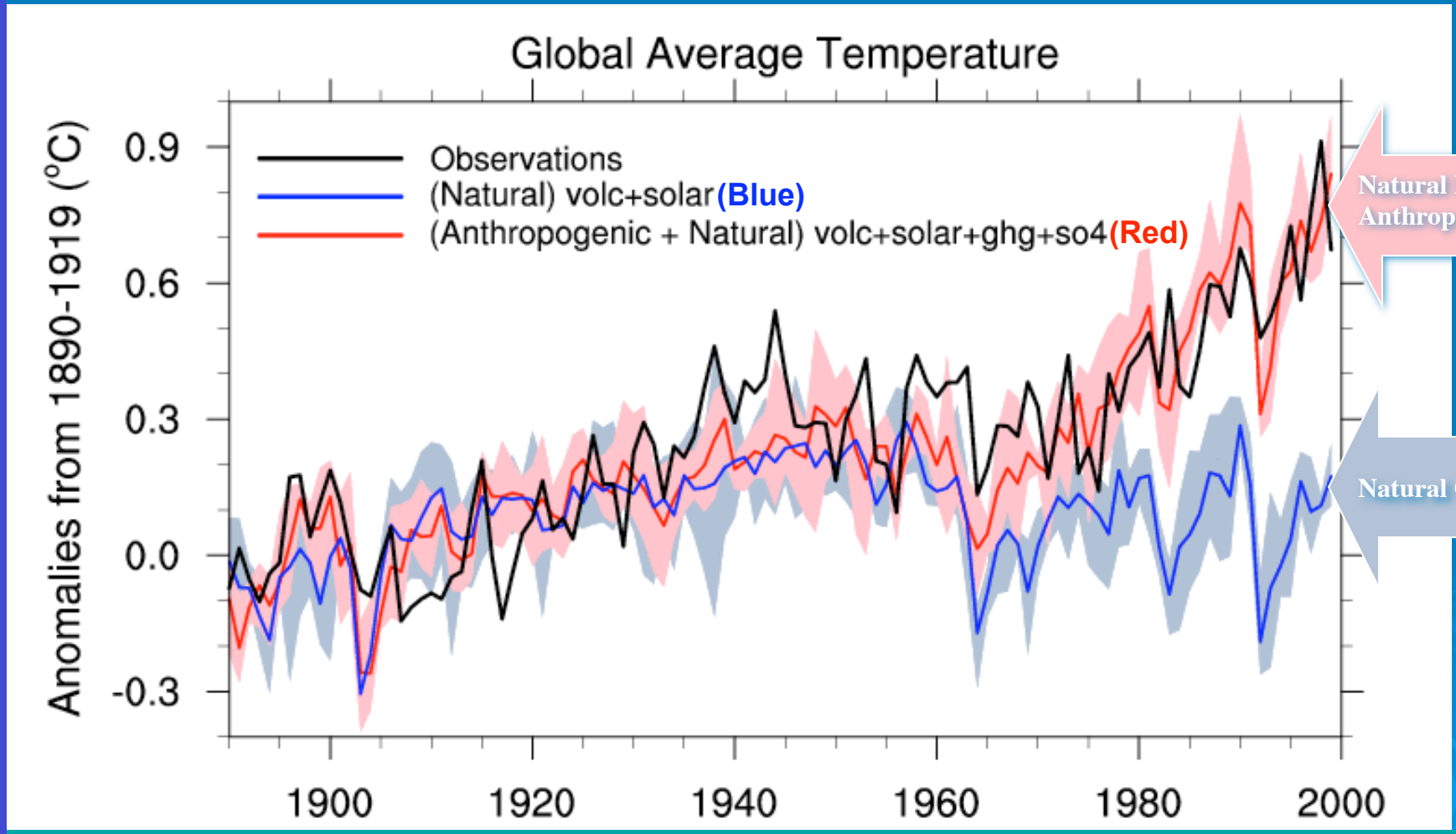
23 of the 24 warmest years since records began in 1850 have occurred since 1980!



Over the past 150 years, CO_2 emissions, the CO_2 concentration, and global average surface temperature have begun to increase at very rapid rates, clearly indicative of a growing human influence



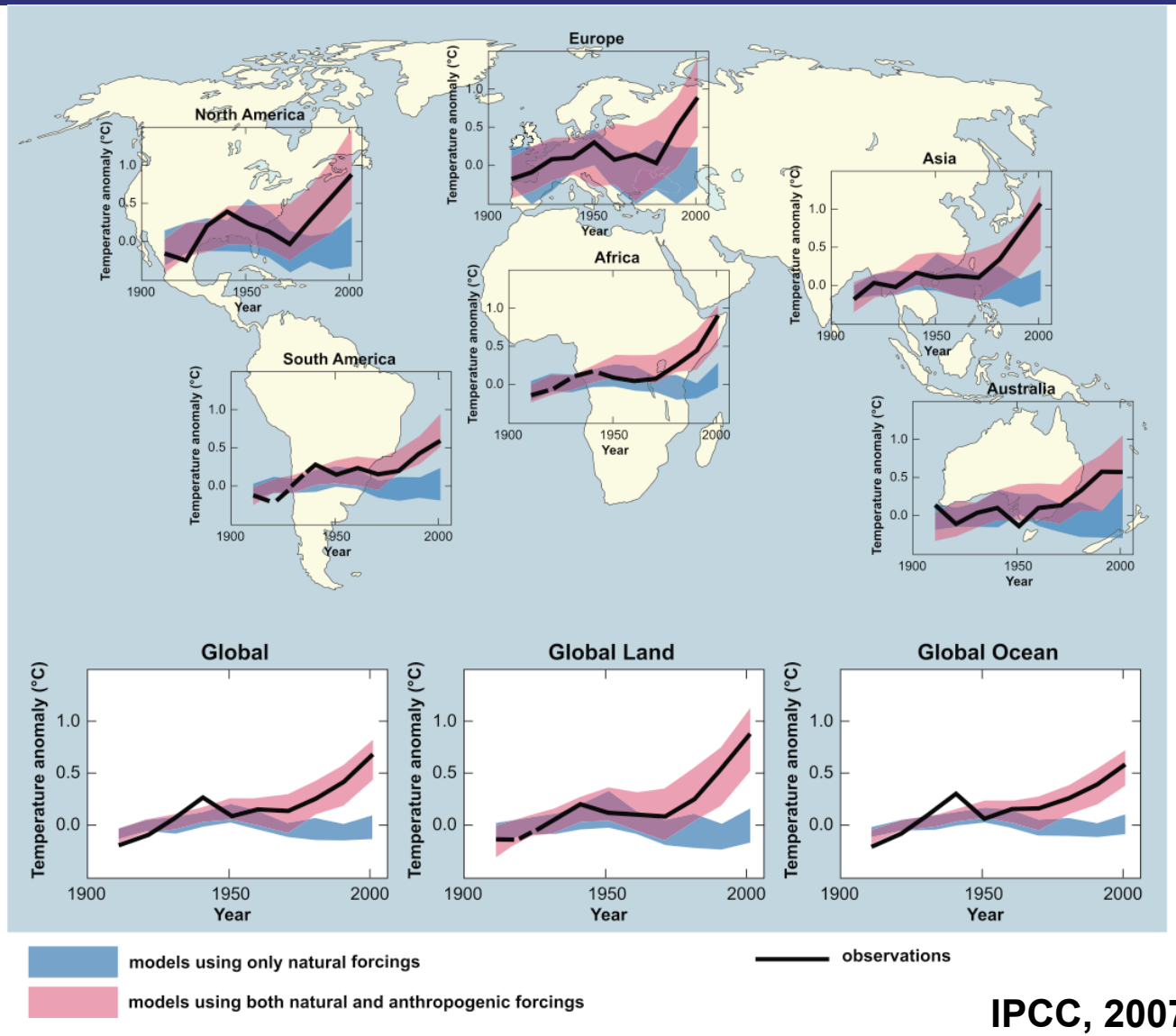
The models reasonably represent climate change over the last 100 years, when the effects of both natural and human forcings are included



NCAR Climate Simulations

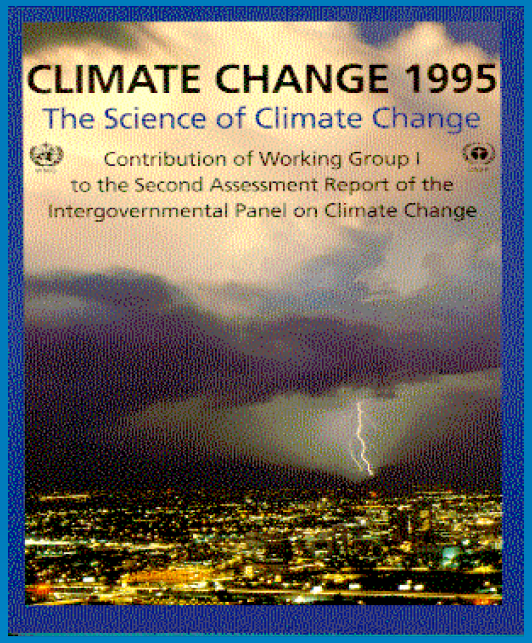
Comparisons of observations with model simulations including all forcings (pink) and just natural forcings (blue), for 20th century and providing global and regional coverage

The model results appear as a band because (1) the results are for multiple models, and (2) the model simulations account for the natural variability of the climate, unlike the observations which, although averaged over a decade, represent a single pass through climatic history. Observations also include biases due to changing spatial coverage and measurement errors.

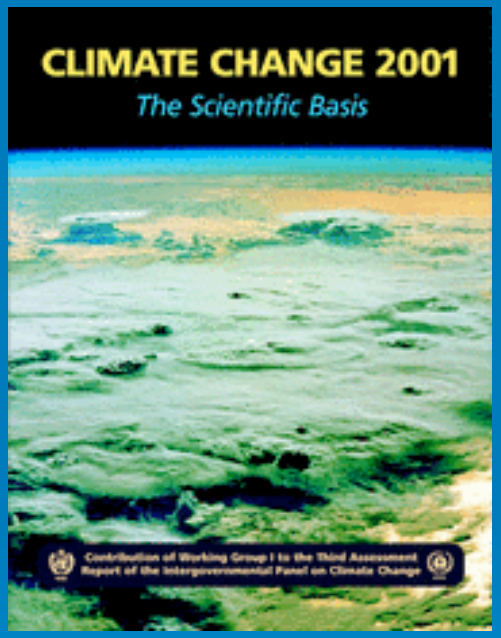


IPCC, 2007

Over its series of assessments, the IPCC has concluded that the evidence for human influences on climate is getting stronger



"The balance of evidence suggests a discernible human influence on global climate"



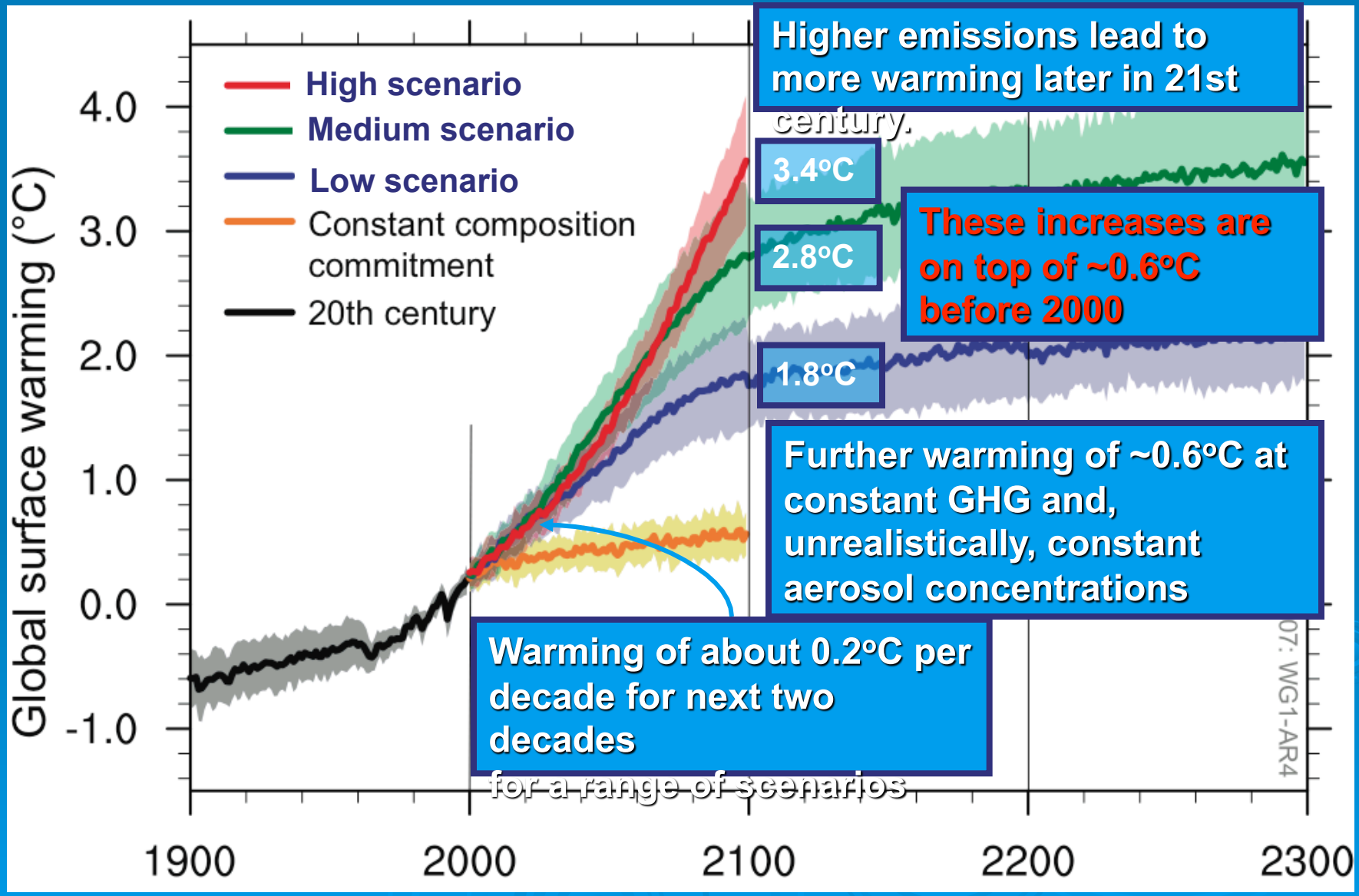
"There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities"

IPCC
CLIMATE CHANGE 2007

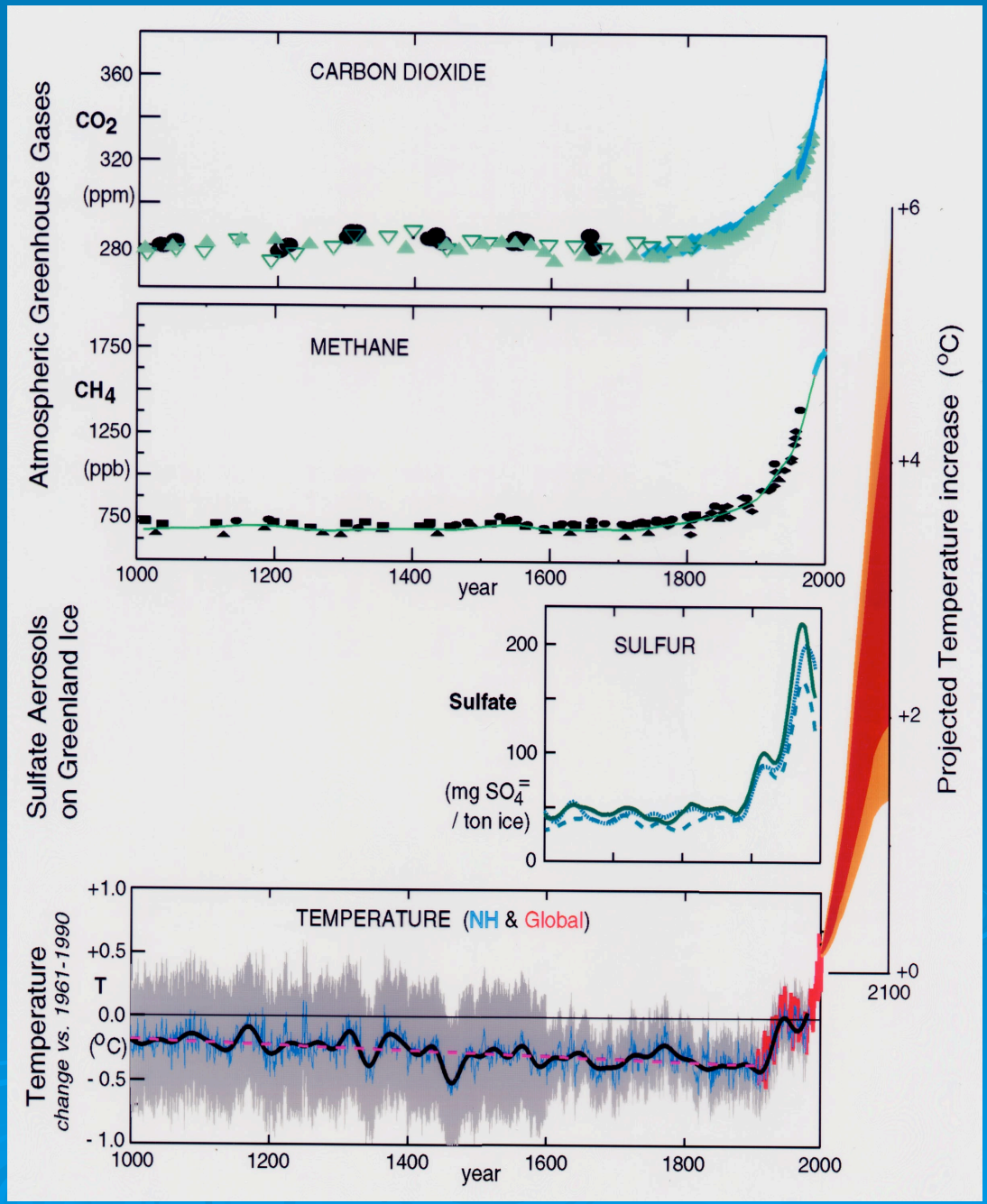
Available at www.ipcc.ch and Cambridge University Press

"Warming of the climate system is unequivocal….Most of the observed increase in globally-averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations."

Projections of global average warming after 2000 for different assumptions about emissions of GHGs



The projected increase in global average temperature could result in global temperatures being much higher than during the history of civilization and higher than they have been in tens of millions of years



Source: IPCC TAR, 2001 and M. Prather

Climate change is likely to lead to a range of important environmental and societal impacts

Adapted from EPA

Carbon Dioxide and Climate Changes

CO_2 and GHGs

Temperature

Precipitation

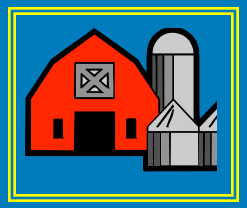
Sea Level Rise

Societal Impacts

Indigenous peoples and developing nations
Exacerbated impacts on the poor
Dramatically different situation for future generations

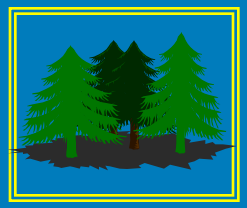
Health Impacts

Weather-related mortality/heat stress
Infectious diseases
Air quality-induced respiratory effects



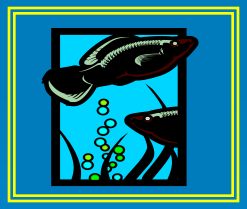
Agriculture Impacts

Crop yields and commodity prices
Irrigation demands
Pests and weed



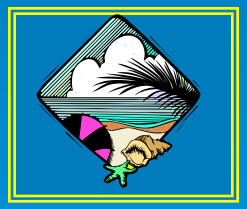
Forest Impacts

Change in forest composition
Shift geographic range of forests
Forest health and productivity



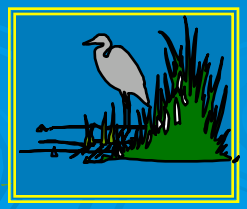
Water Resource Impacts

Changes in water supply and timing
Water quality
Increased competition for water



Coastal Area Impacts

Erosion of beaches
Inundation of coastal wetlands
Costs to defend coastal communities



Ecosystem Impacts

Shifts in ecological zones
Loss of habitat and species
Coral reefs threatened

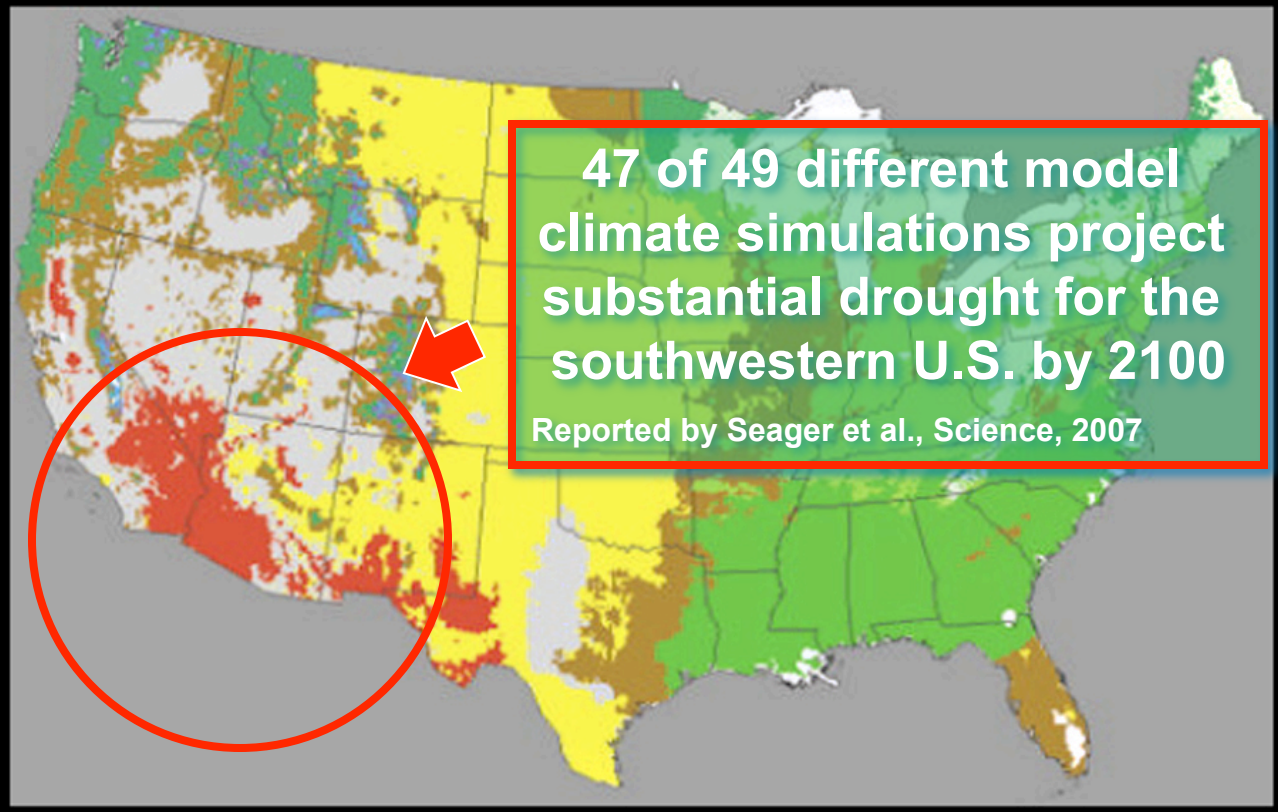
In the U.S. Southwest, increases in CO_2 and water use efficiency allow ongoing growth of xeric species, setting the stage for more intense and frequent wildfire

Maps of current and projected potential vegetation distribution for the conterminous US. Potential vegetation means the vegetation that would be there in the absence of human activity. Changes in vegetation distribution by the end of the 21st century are in response to two climate scenarios, the Canadian and the Hadley. Output is from MAPSS (Mapped Atmosphere-Plant-Soil System).

- Tundra
- Taiga / Tundra
- Conifer Forest
- Northeast Mixed Forest
- Temperate Deciduous Forest
- Southeast Mixed Forest
- Tropical Broadleaf Forest
- Savanna / Woodland
- Shrub / Woodland
- Grassland
- Arid Lands

Ecosystem Models

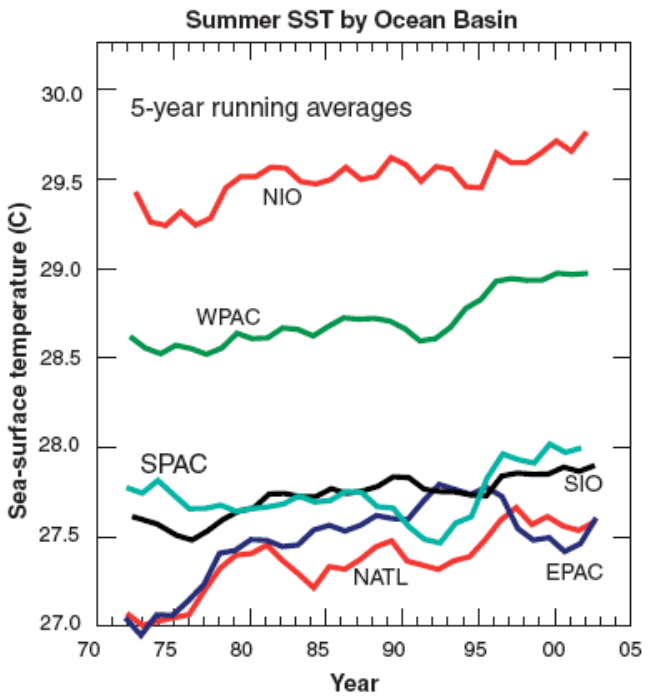
Current Ecosystems



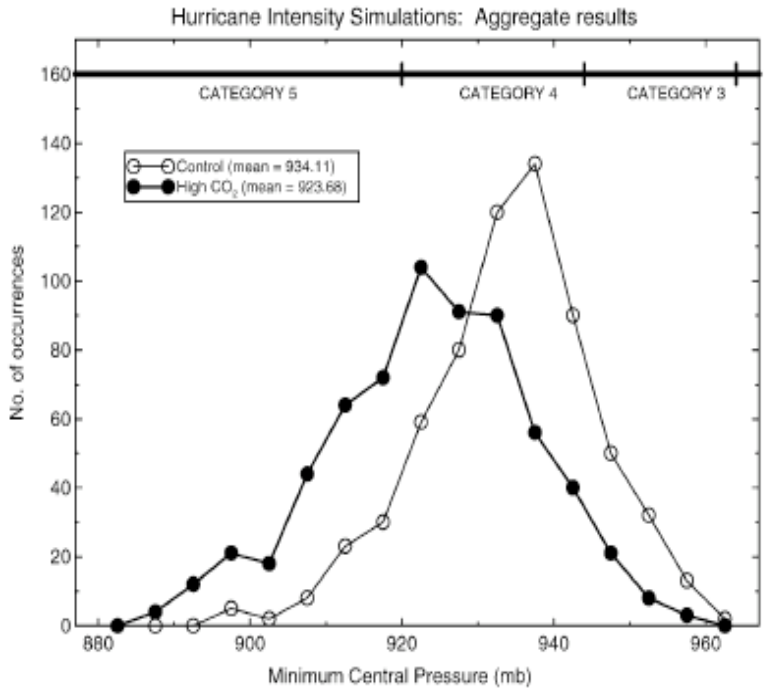
47 of 49 different model climate simulations project substantial drought for the southwestern U.S. by 2100

Reported by Seager et al., Science, 2007

An increase in the intensity of extreme weather is likely to worsen many types of disasters

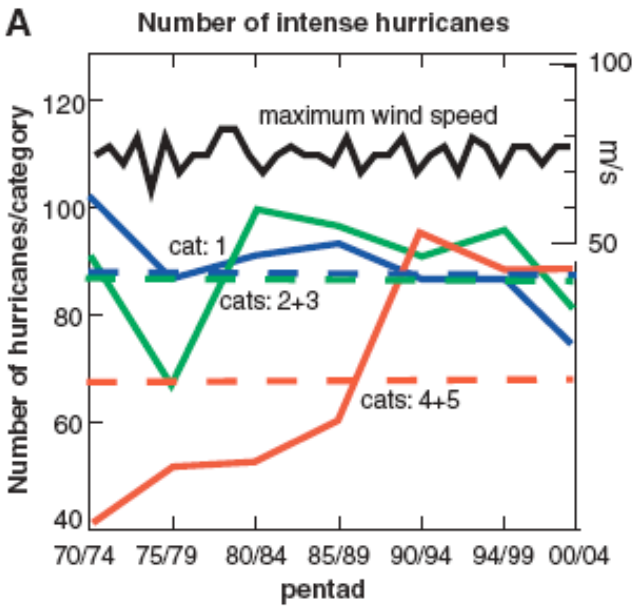


Hurricanes appear to be intensifying and releasing more energy, and society has become more vulnerable due to more coastal residents and buildings



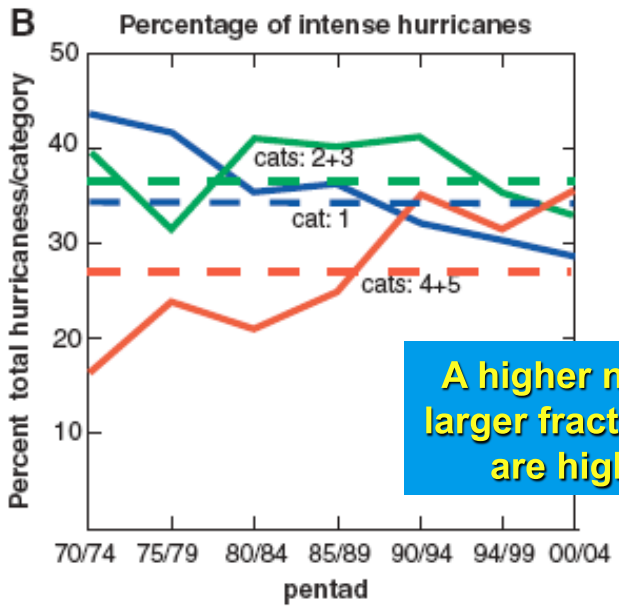
Ocean temperatures are rising

Source: Webster et al., Science, 2005



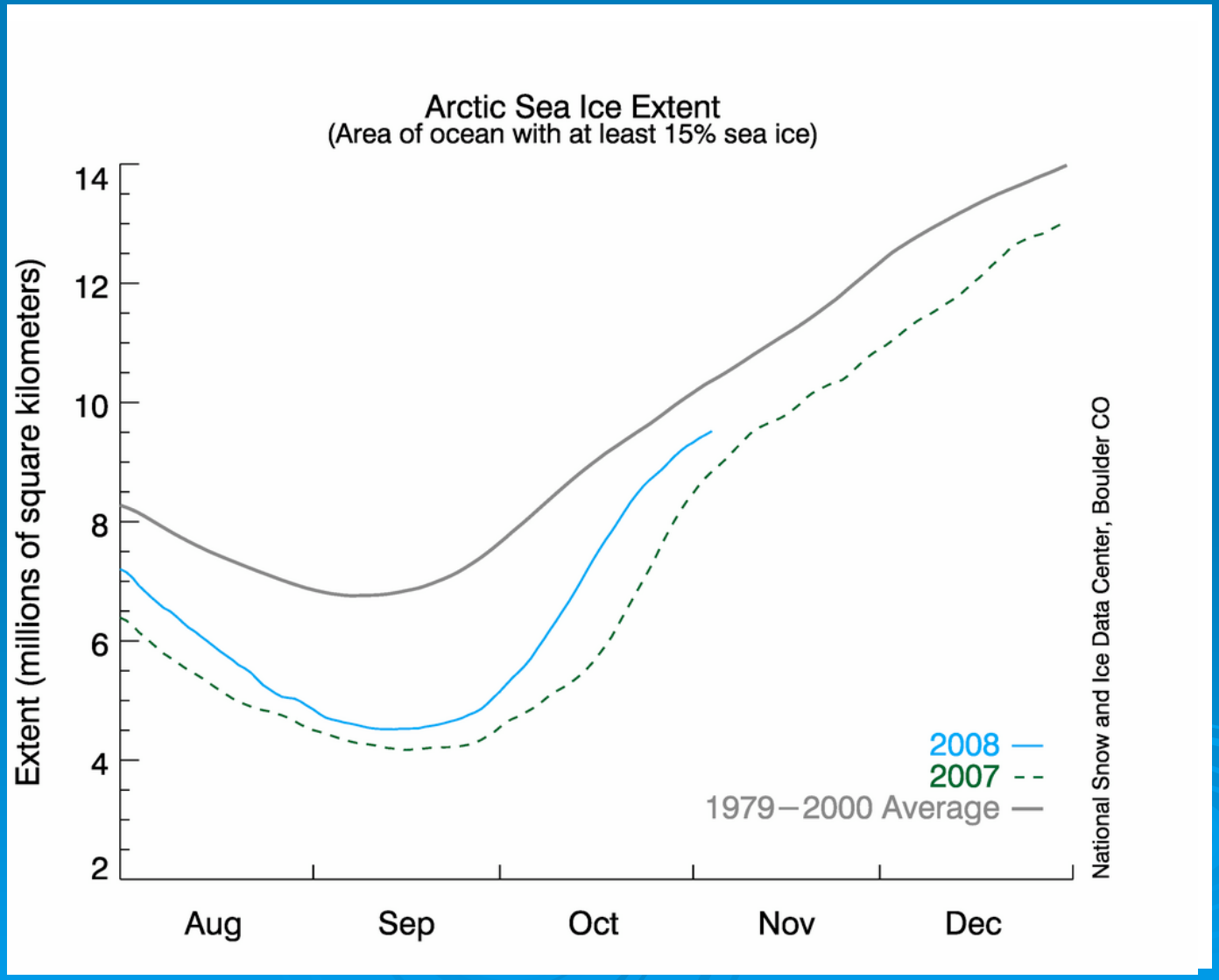
Projections are for more powerful hurricanes and more drenching rains

Source: Knutson and Tuleya, Science, 2004



A higher number and a larger fraction of storms are high intensity

Average Arctic sea ice extent has been declining in all seasons, and especially rapidly in 2007 and 2008



The world system is interconnected-- a warmer Arctic will also have significant impacts on mid-latitude weather

- In the fall and early winter, little really cold air can be generated until the sea ice is 1-2 m thick, letting the warm subtropical air push northward--and can create large, wet snowstorms.
- In the spring and summer, less cool, dry air is generated that can undercut the moist tropical air and trigger thunderstorms, shifting their occurrence further to the north.

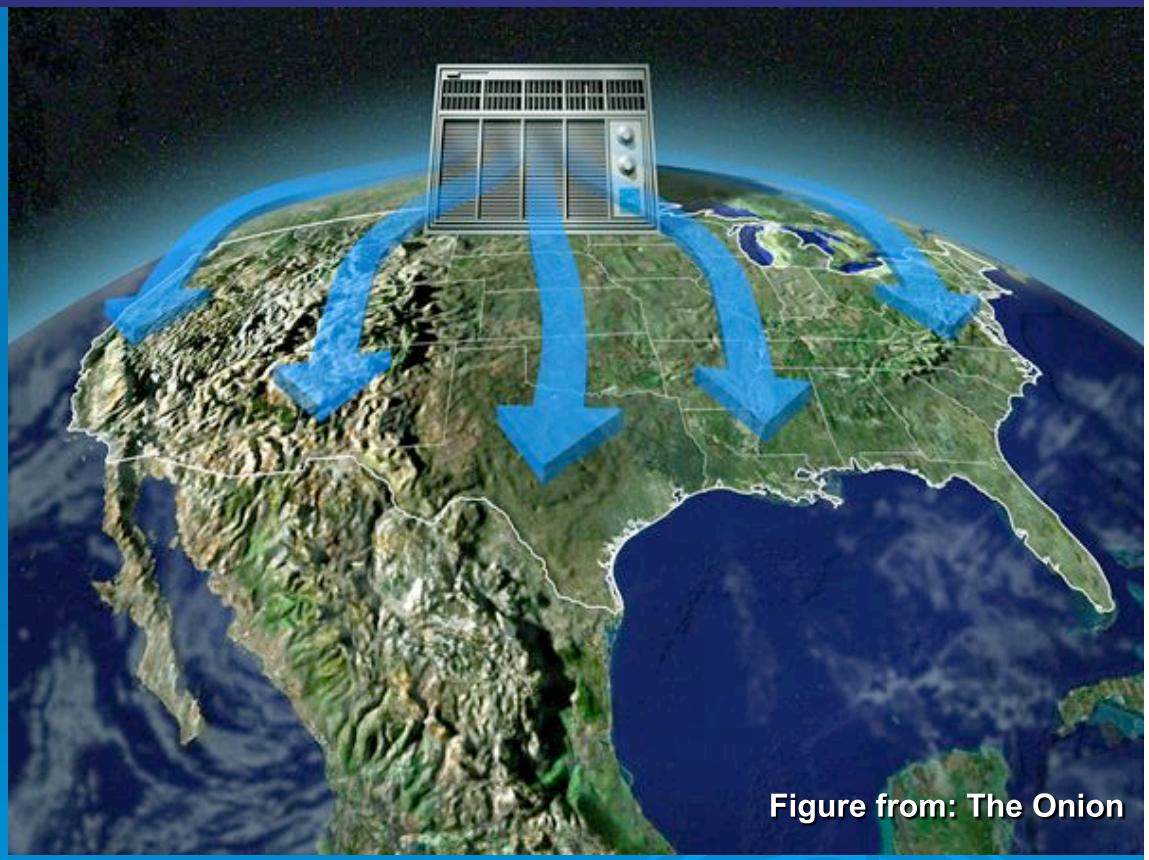
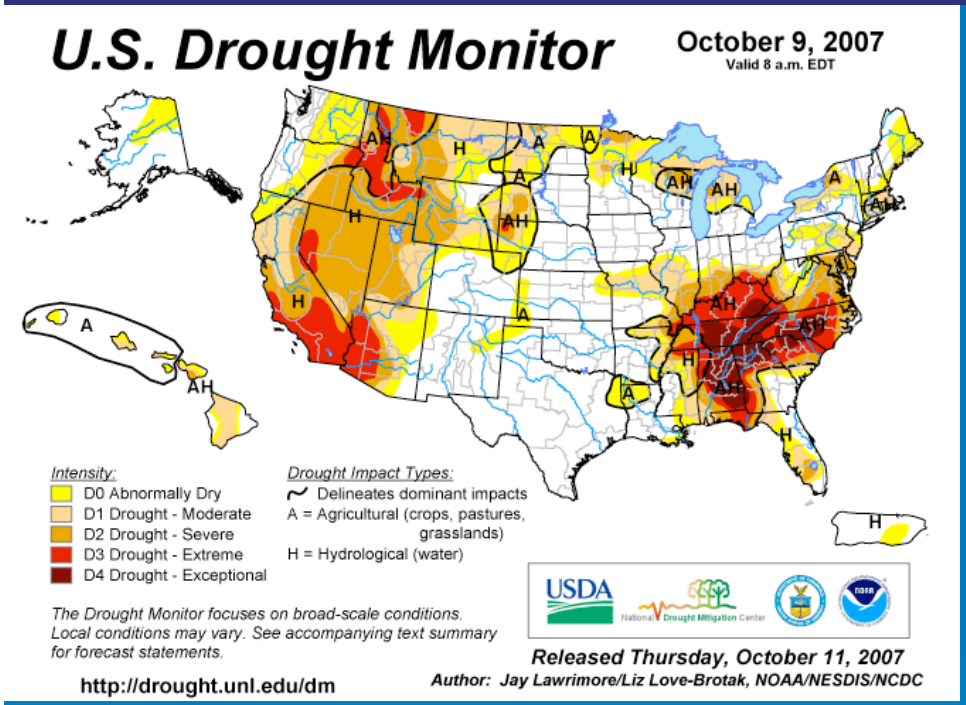


Figure from: The Onion

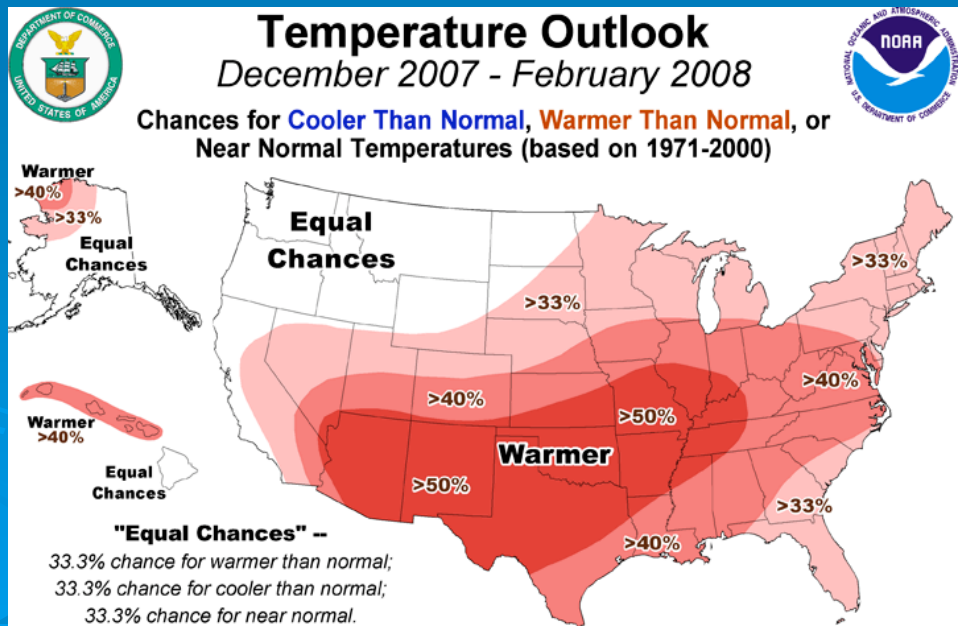
The efficiency of the Northern Hemisphere's natural "air conditioner" will be sharply reduced

With less cold air coming out of the Arctic and northern Canada, tropical air pushes north



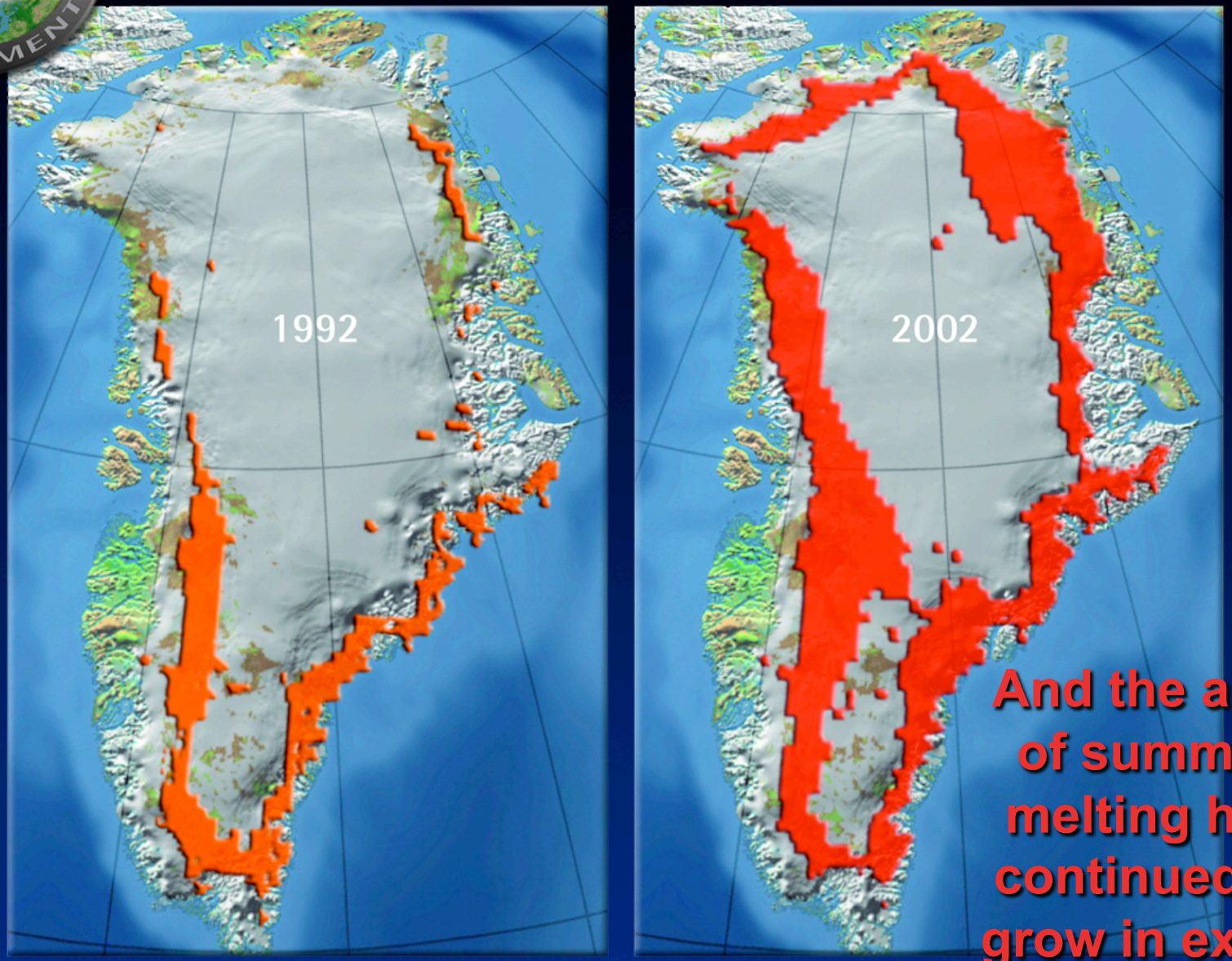
Warm season thunderstorms require the presence of warm, moist air, plus a trigger such as a cool front from northern Canada. Weak fronts get blocked by the Appalachians, leaving their southeastern side drier--and the area hoping for hurricane rains.

Until Arctic sea ice 1-2 meters thick insulates the air from the ocean, really cold winter air masses cannot form and warm, moist air pushes north into the US; the resulting clash can yield violent weather



IMPACTS OF A WARMING ARCTIC

Greenland Ice Sheet Melt Extent



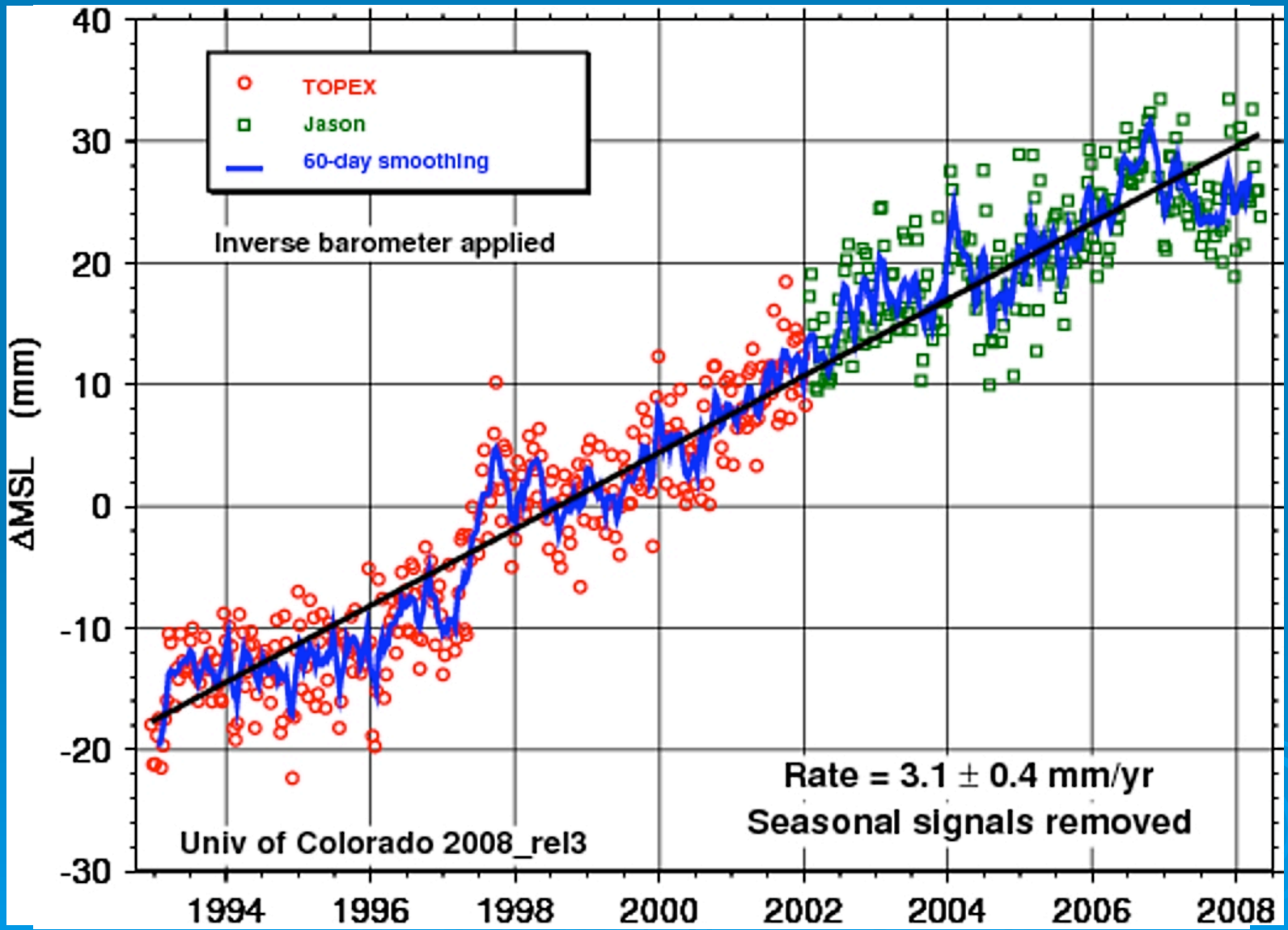
And the area of summer melting has continued to grow in extent

The Greenland Ice Sheet is melting more rapidly than accounted for in available models as a result of processes not yet accounted for-- namely moulins carrying meltwater (and its heat) deep into the glacier and at the base lubricating ice sheet movement.

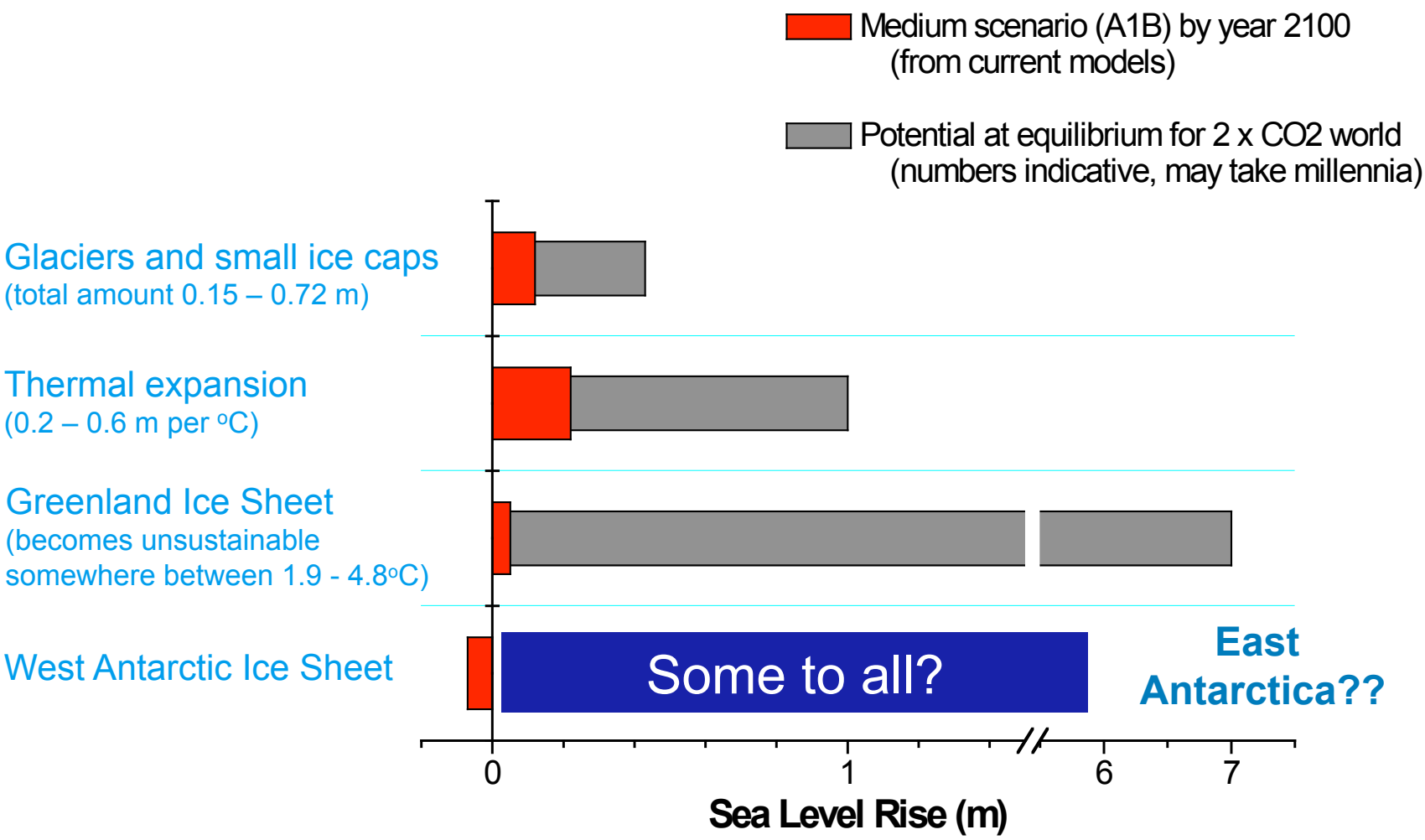
Recent satellite observations are showing increasing loss of ice sheet mass

Source: Business Week Aug. 2004

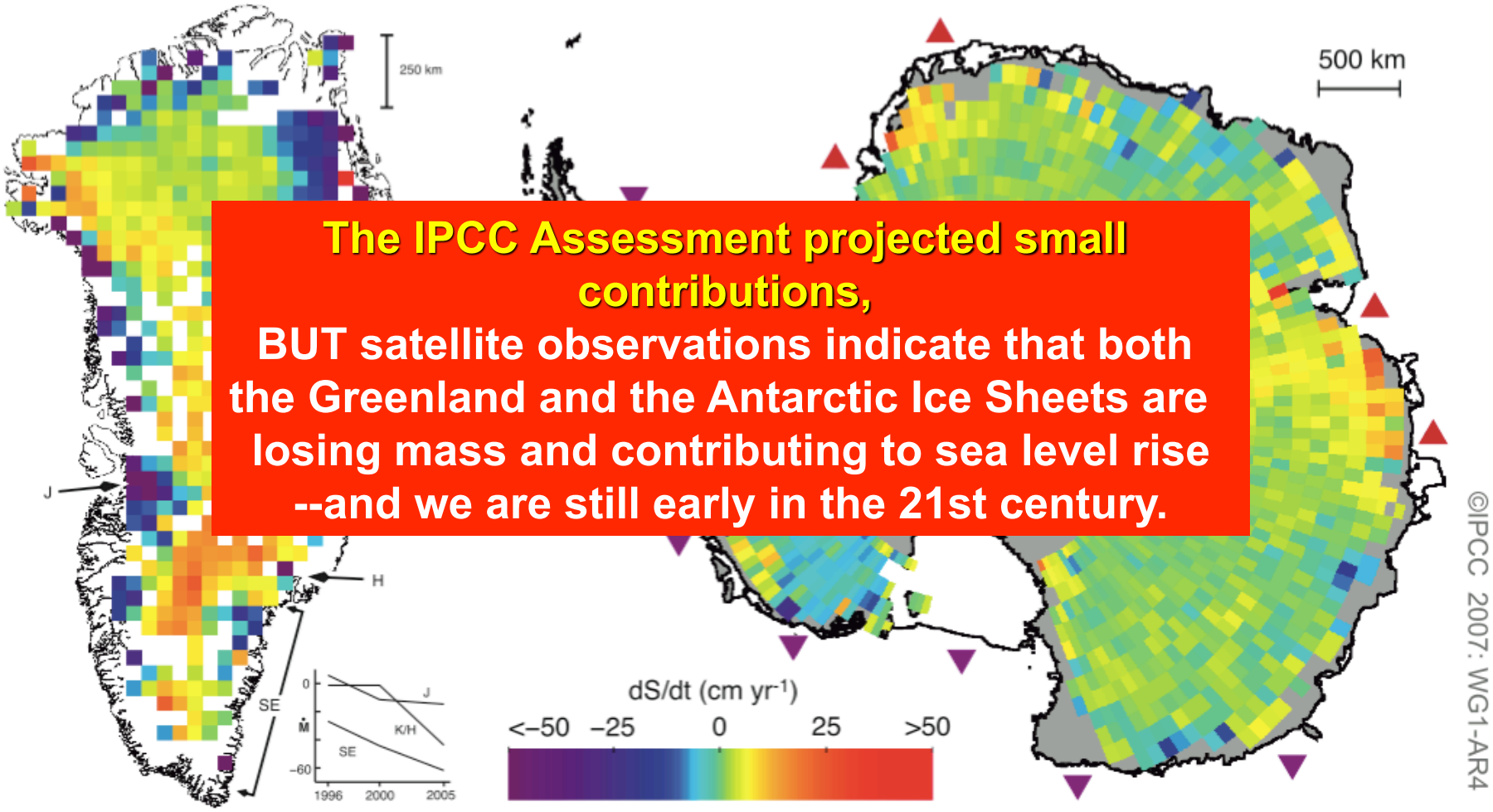
Tide gauge and satellite data on sea level indicate that the rate of rise is increasing



Sea level rise:
The long term potential is very large



The Greenland and Antarctic Ice Sheets both show loss around the edges, somewhat offset by interior thickening



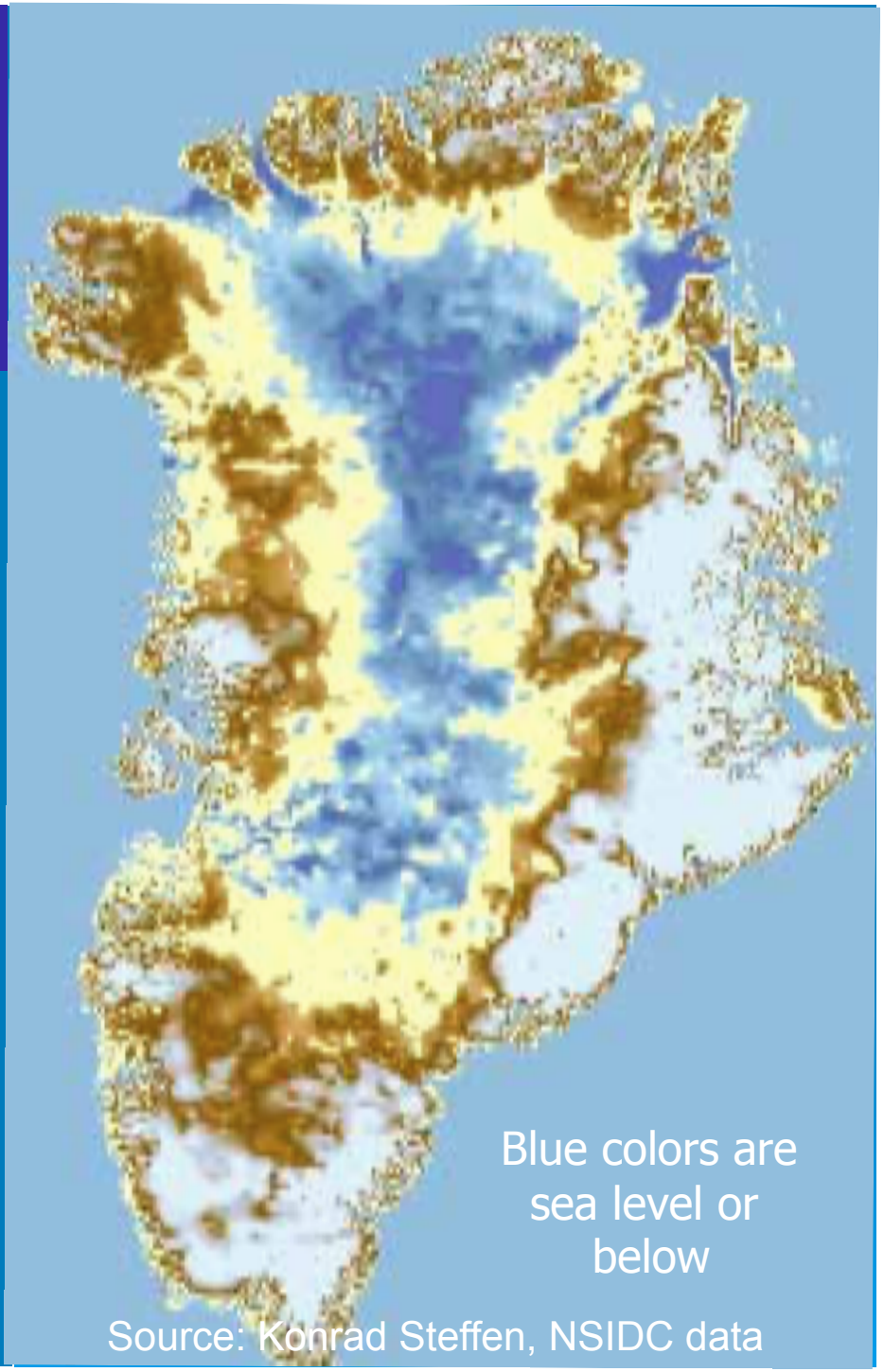
The IPCC Assessment projected small contributions,

BUT satellite observations indicate that both the Greenland and the Antarctic Ice Sheets are losing mass and contributing to sea level rise --and we are still early in the 21st century.

Greenland's underlying topography suggests the Ice Sheet is very vulnerable

Contrary to the prevailing view, much of the Greenland Ice Sheet in interior areas is grounded ***below*** sea level (the land has been depressed by the ice), so ocean waters can carry heat underneath and help lift the ice sheet.

In addition, fjords connect the ice sheet to the surrounding seas along the west and northern coasts, enabling more rapid movement of the ice from the interior to the ocean



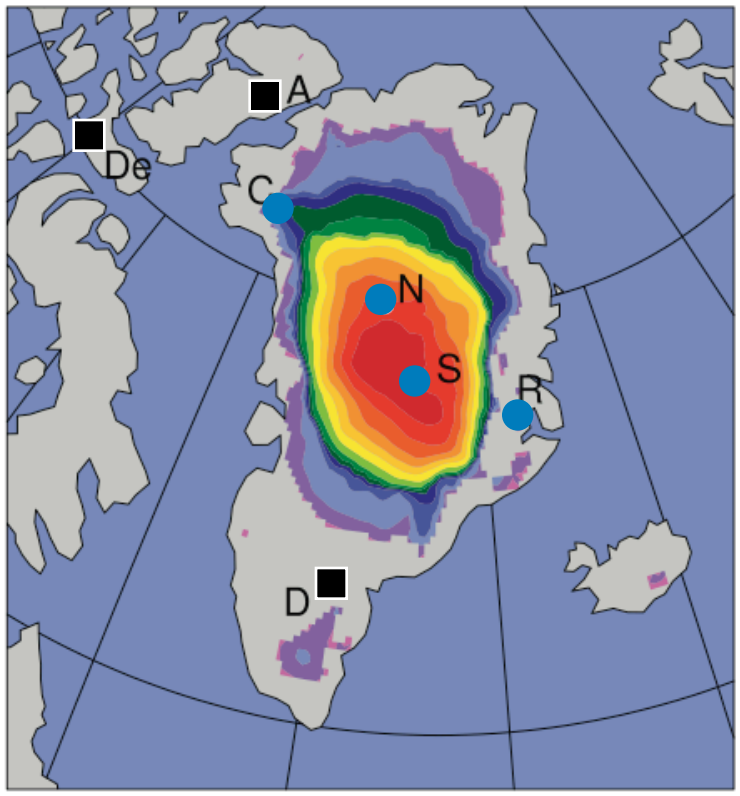
Corings indicate the Greenland Ice Sheet was much smaller during the Eemian interglacial

Contours are from average of three ice sheet models.

Circles show drill sites that had ice.

Squares show sites that did not have ice.

The last time polar regions were significantly warmer than present for an extended period (about 125,000 years ago), reductions in polar ice volume led to 4 to 6 m of sea level rise.



Worst Case Storm-surge Inundation for Hurricane Categories 1-4 (Metro East Coast Assessment)

The Dec 11-12, 1992 nor'easter reached 8.5 feet above mean sea level, about 1-2 feet below rail and subway entrances

LaGuardia airport had levees put in after a 1950s storm caused flooding--it can happen

Limiting climate change will require significant emissions reductions: The 1992 UN Framework Convention on Climate Change (UNFCCC) set an objective of atmospheric stabilization

Objective 2 of the UNFCCC calls for:

- Stabilization of the greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.
- Such a level should be achieved within a time-frame sufficient
  - to allow ecosystems to adapt naturally to climate change,
  - to ensure that food production is not threatened, and
  - to enable economic development to proceed in a sustainable manner.

Earth Summit, Rio de Janeiro, 1992

(adopted widely by the world community and ratified by the US Senate in 1992)

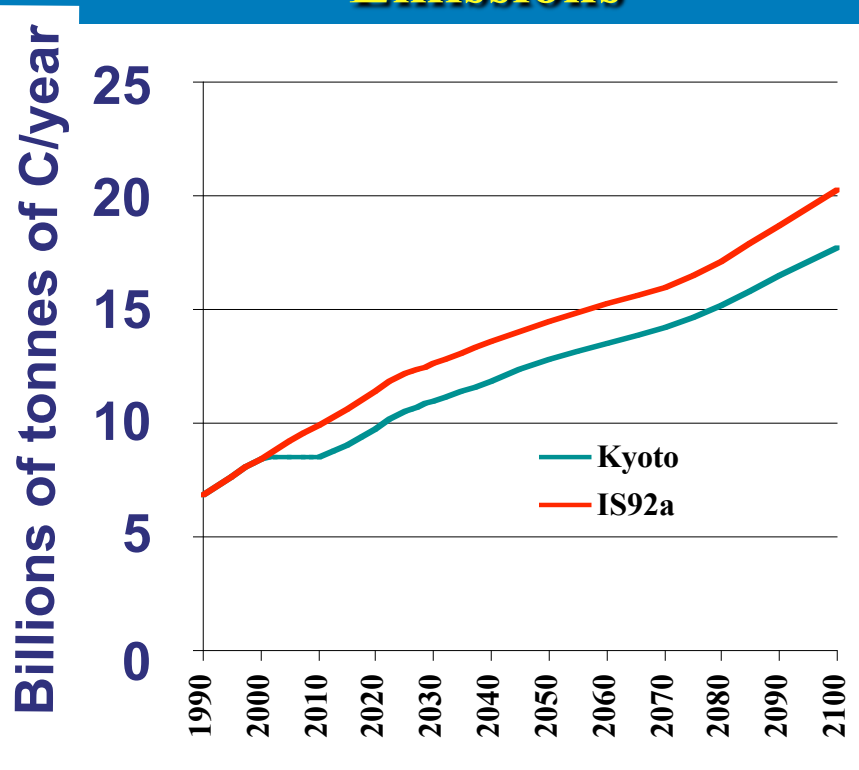
While slowing the rate of climate change will require significant reductions in emissions, pressures are in the opposite direction

Future emissions will be the product of four terms:

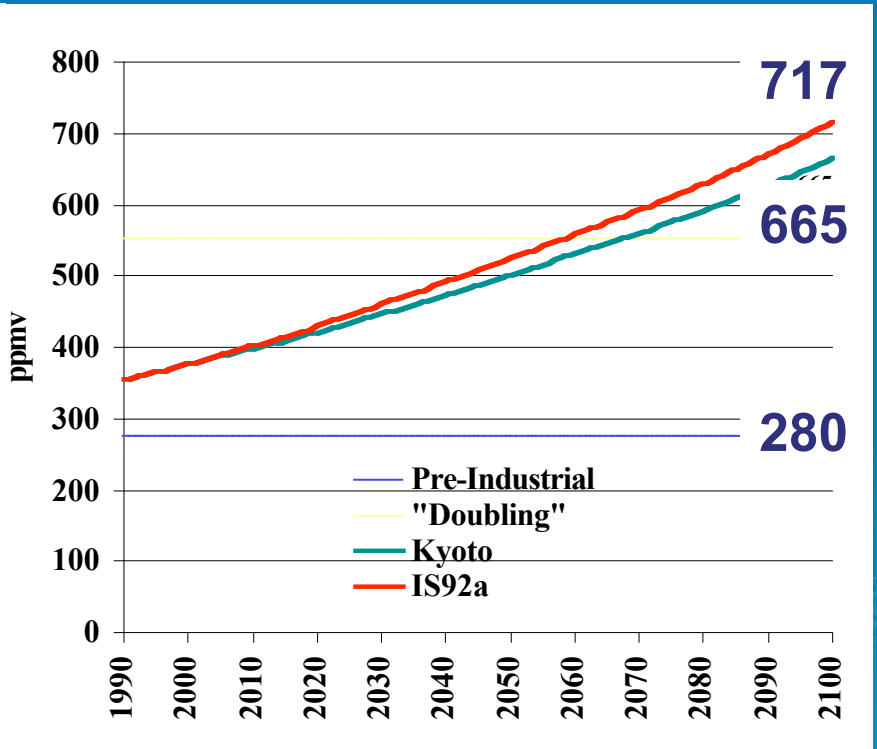
• The global population	⇨	Rising
• Energy use per person (related to standard of living)	⇨	Rising
• Fraction of energy coming from fossil fuels	⇨	Depends on choice of technology
• Amount of carbon from fossil fuel generation of energy	⇨	Will rise if go to coal, unless sequester

The Kyoto Protocol, even if fully implemented, would have only a very modest effect-- challenging as it may be, it can only be a first step

Emissions



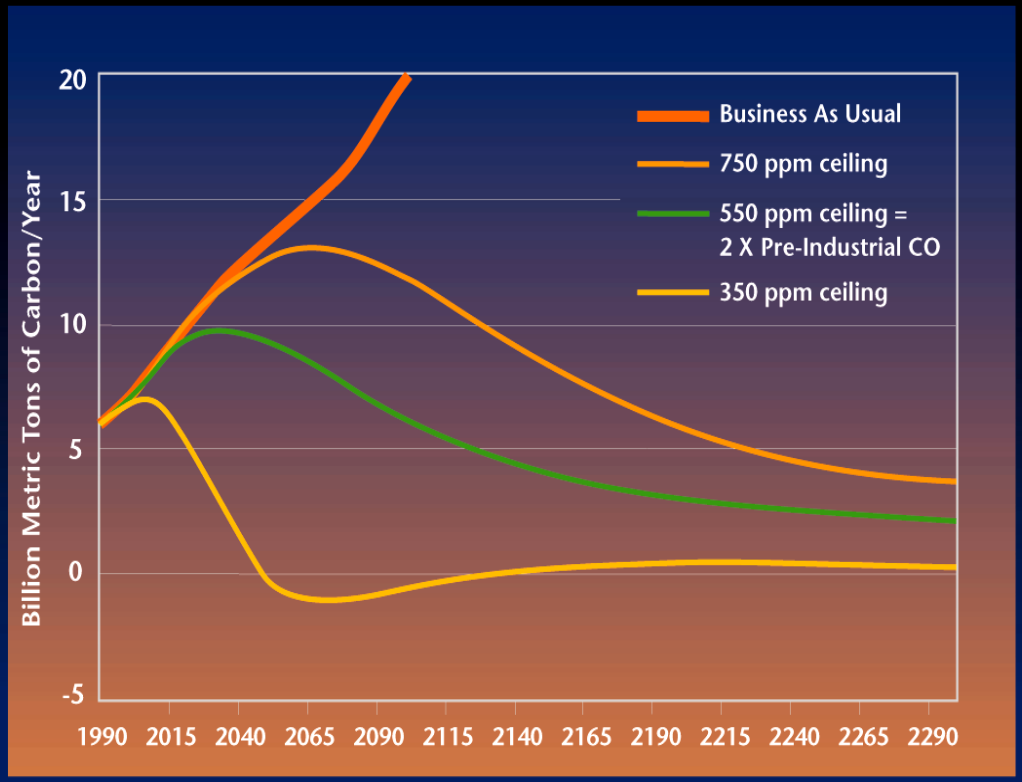
Concentrations



P.S.--And the explanations of the need for the US to withdraw have been very poorly explained, hurting the US image abroad and confusing policy development here in the US.

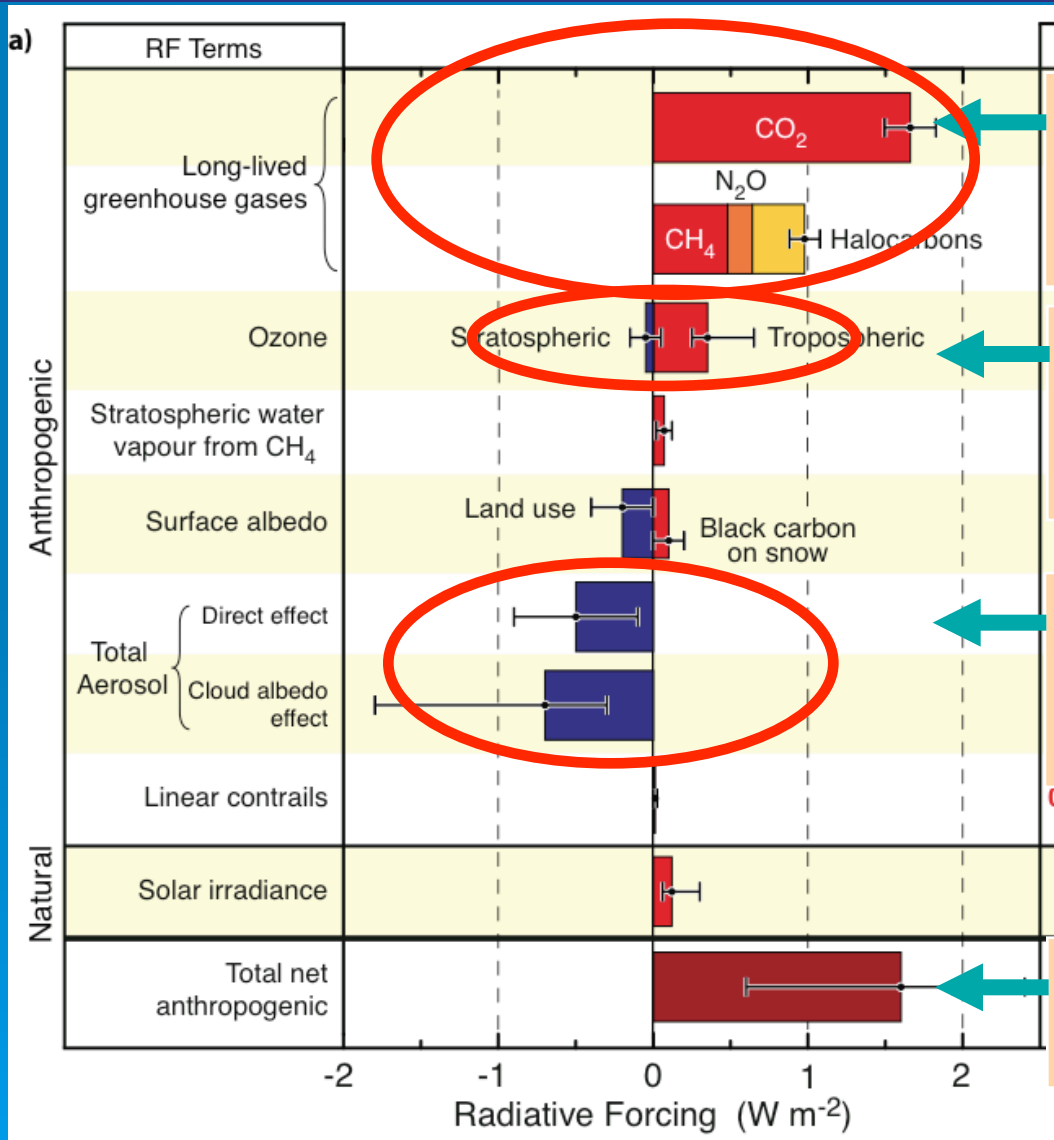
As the international community of nations (including the US) agreed in ratifying the UN Framework Convention on Climate Change, stabilizing the climate will require that the world stabilize atmospheric composition

Atmospheric Stabilization Emissions Paths



But stabilization at a low enough CO_2 level will require very large, global cutbacks in emissions over the next several decades

Present greenhouse gas forcing is equivalent to a CO_2 concentration of at least 455 ppm, ~80 ppm of which is offset by sulfate aerosols



CO_2-eq is really 455 ppm for long lived greenhouse gases

Adding short-lived gases worsens the situation (CCSP report 3.2--2008)

Offset cooling by aerosols is removed within weeks of emission

CO_2-eq of 375 ppm for net human activities

As a result of the accelerating changes in climate, the world faces a very serious dilemma

- If the present CO_2e concentration of 375 ppm, including the aerosol offset, is causing severe impacts in some regions and has apparently started the deterioration of the southern section of the Greenland Ice Sheet, with consequent large sea level rise;
- If cutting emissions will eliminate the aerosol offset and the greenhouse gas CO_2e concentration is already 455 ppm and headed up at least another 100 ppm; and
- If a CO_2 concentration of as little as 450 ppm would further acidify the oceans, seriously threatening coral reefs and atolls as well as many marine organisms

Might we need to consider going beyond mitigation and taking control of the climate through advertent action--namely *geoengineering the climate* and *ocean composition* to counter-balance the effects of adding greenhouse gases?

Geoengineering: Approaches to Mitigating or Counterbalancing Inadvertent Greenhouse-Gas Induced Climate Change

1. Reducing the quantities of greenhouse gases in the atmosphere (and reducing the CO_2 concentration would help limit ocean acidification)

2. Offsetting the radiative forcing of greenhouse gases

3. Altering the processes that lead to the climate change and impacts

Both Inadvertent and Advertent Changes are the Subject of International Protocols

- Inadvertent change is now governed by the *UN Framework Convention on Climate Change* (and for some by the *Kyoto Protocol*).
- Advertent (and maybe inadvertent) climate change may be subject to the *UN Convention on the Prohibition of Military or any Other Hostile Use of Environmental Modification Techniques* agreed to in 1978 (and the US ratification was filed on January 17, 1980).

Provisions of the Convention on the Prohibition of Military or any Other Hostile Use of Environmental Modification Techniques

Article I.1: Each State Party to this Convention undertakes not to engage in military or any other hostile use of environmental modification techniques having widespread, long-lasting or severe effects as the means of destruction, damage or injury to any other State Party.

Article I.2: Each State Party to this Convention undertakes not to assist, encourage or induce any State, group of States or international organization to engage in activities contrary to the provisions of paragraph 1 of this article.

Approaches to limiting or reducing greenhouse gas concentrations

- Reducing the extent of the activity (reducing emissions, i.e., *mitigation*)
- Expanding and/or enhancing biospheric uptake of GHGs on land (e.g., reforestation, fertilizing forests, changing agricultural practices)
- Enhancing oceanic uptake and/or storage of GHGs (e.g., iron fertilization to enhance biospheric pump, genetically engineer phytoplankton or algae, sinking tree trunks, accelerate weathering to increase alkalinity, artificially enhance ocean overturning, etc.)
- Capturing GHGs at the point of emission and sequestering them (e.g., deep underground, in the deep ocean)
- Scrubbing GHGs from the atmosphere and storing or sequestering them (e.g., underground, in the deep ocean)

Venture capital companies are already testing the potential for fertilizing the ocean to increase C uptake--but there are concerns

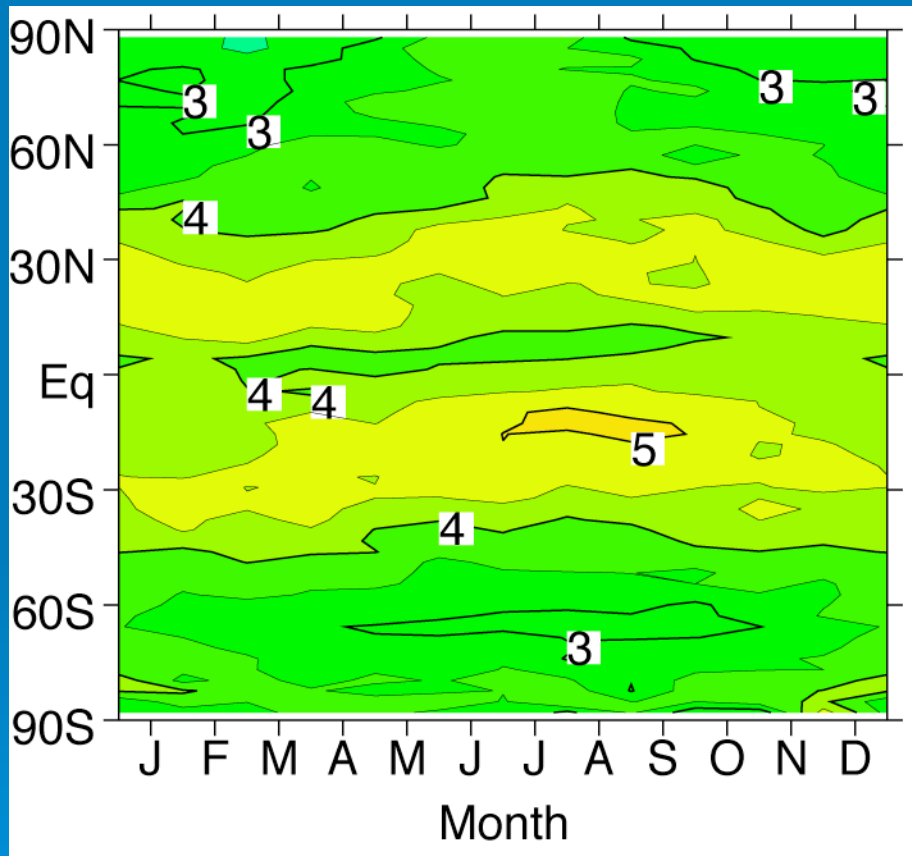
The SOLAS (Surface Ocean- Lower Atmosphere Study) scientific team has offered the following statement on proposed large scale commercial ocean fertilisation:

- Large-scale fertilisation of the ocean is being actively promoted by various commercial organisations as a strategy to reduce atmospheric CO_2 levels. However the current scientific evidence indicates that this will not significantly increase carbon transfer into the deep ocean, nor will it lower atmospheric CO_2. Furthermore there may be negative impacts of iron fertilization including dissolved oxygen depletion, altered trace gas emissions that affect climate and air quality, changes in biodiversity, and decreased productivity in other oceanic regions. It is then critical and essential that robust and independent scientific verification is undertaken before large-scale fertilisation is considered. Given our present lack of knowledge, the judgment of the SOLAS SSC is that ocean fertilisation will be ineffective and potentially deleterious, and should not be used as a strategy for offsetting CO_2 emissions.

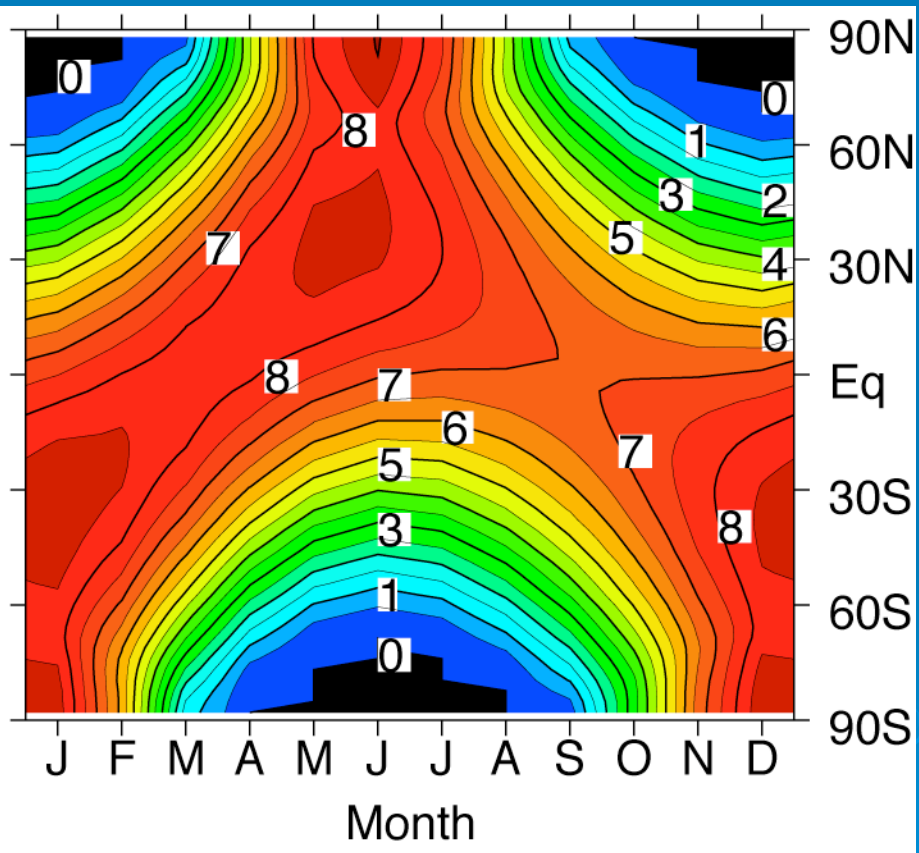
Approaches other than iron fertilization may be available (for example, bringing deep nutrients up to the surface via wave-powered pumps

Solar radiation management is based on offsetting additional trapping of IR radiation

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



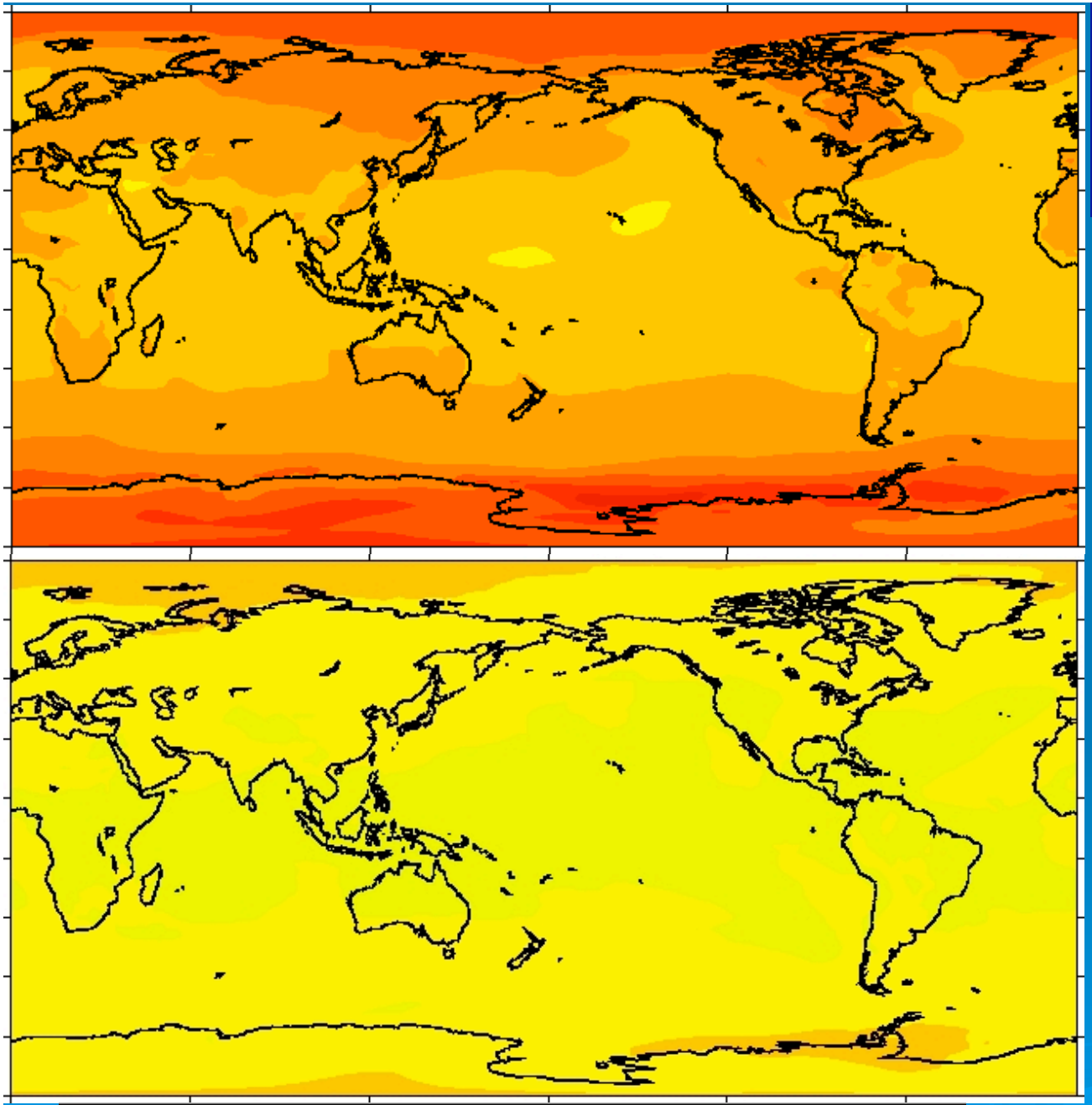
Radiative forcing from 1.8% reduction in solar intensity (W / m^2)



Key Question: Will the climatic responses to these very different forcings really cancel ?

Govindasamy and Caldeira, GRL, 2000

Temperature responses



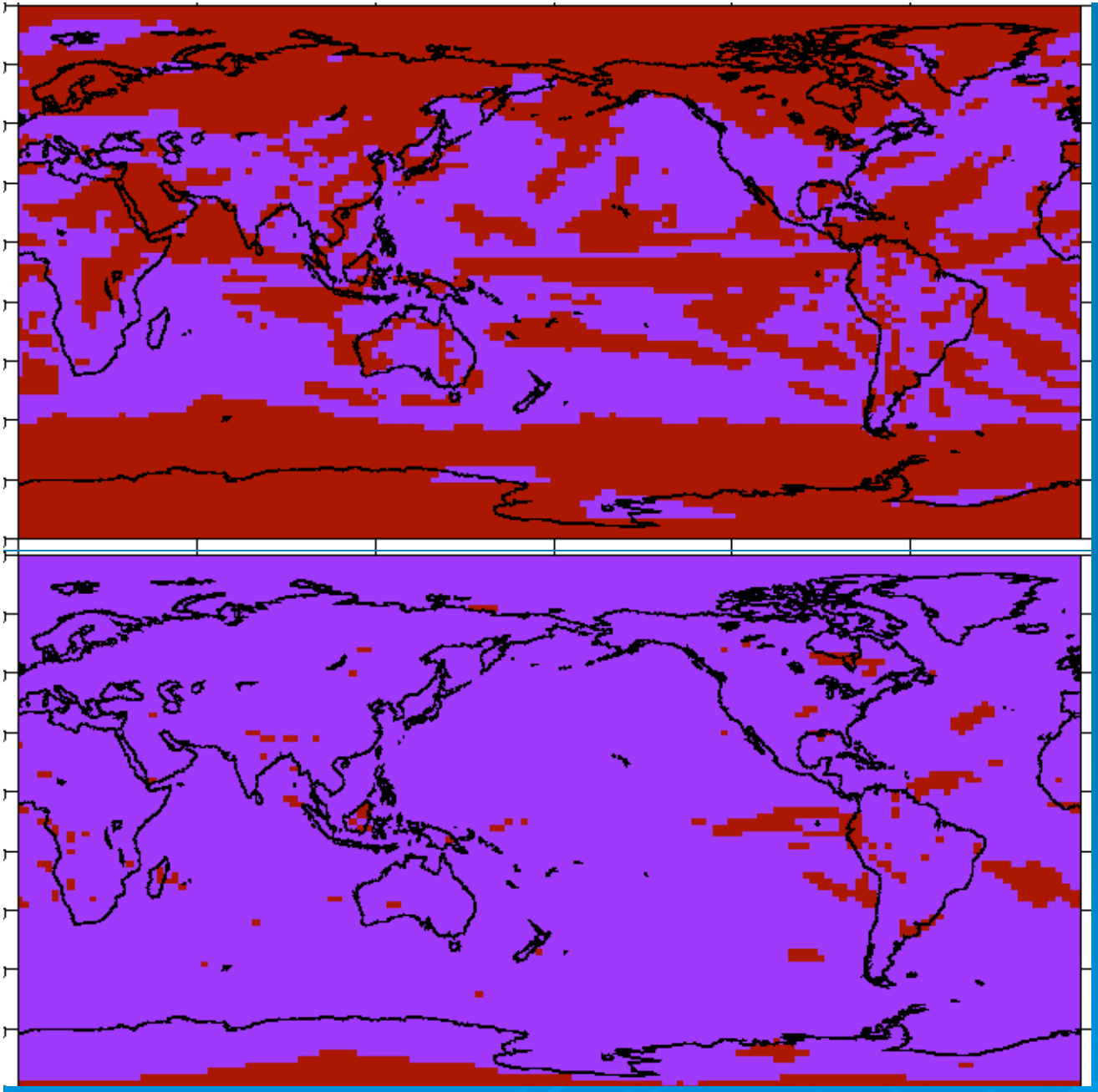
-6 -4 -2 0 2 4 6 ºC

2 x CO_2

2 x CO_2
and
1.8% reduction in solar intensity

Caldeira and Wood, 2008

Precipitation response



2 x CO_2

(Significant over 47 % of Earth's area)

2 x CO_2
and
1.8% reduction in solar intensity

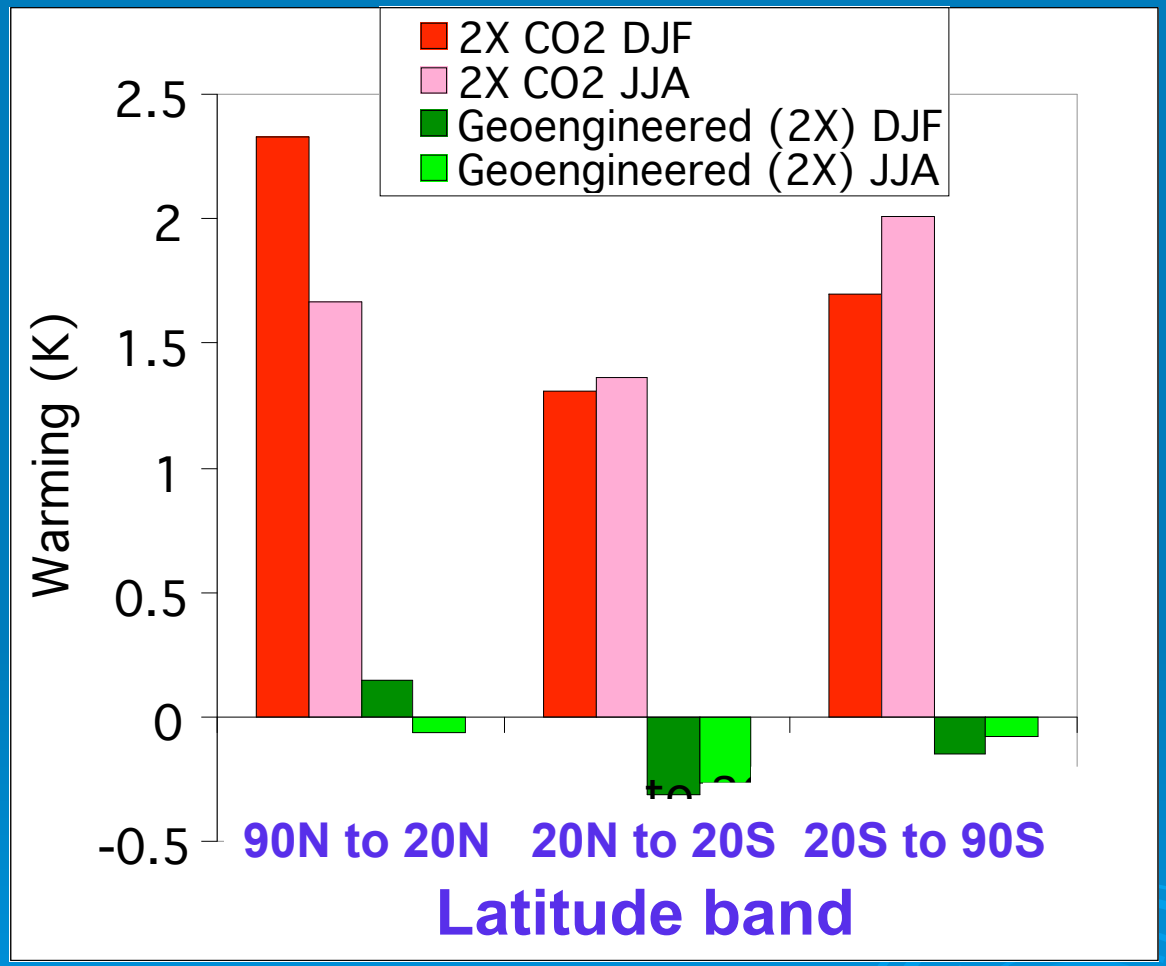
(Significant over 4 % of Earth's area)

Area where change is significant at 0.05 level based on 30-yr climatology

Caldeira et al., in prep, 2007

So, it appears that counter-balancing of the effects of greenhouse gases is workable

Seasonal and latitudinal temperature change



Amazingly, the cancellation is nearly complete, and closer agreement might be possible

Research question: So, how did orbital elements then cause the ice ages

Govindasamy and Caldeira 2000

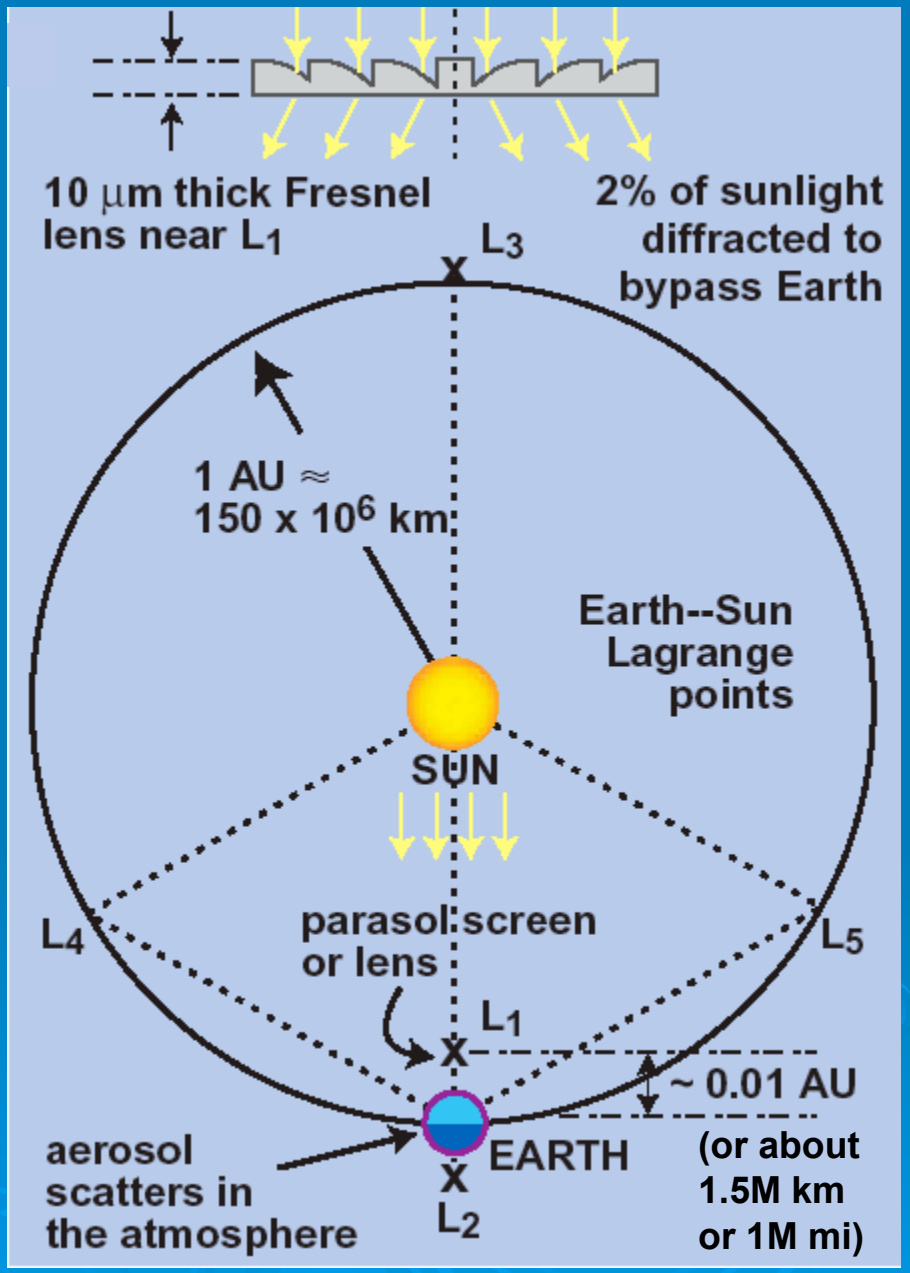
So, how could it be done? There are several proposed approaches for reducing the amount of solar radiation

- Solar radiation deflector(s) at the First Lagrange point (L1)
- Mirror-like satellites in low-Earth orbit
- Stratospheric aerosols or other reflector particles
- Tropospheric aerosols
- Brightening the albedo of clouds, particularly marine stratus
- Increasing the reflectivity of the land or ocean surface

Deflector(s) at the Lagrange Point

Options:

1. A single deflector about 1400 km in diameter, manufactured and launched from the Moon (Early, 1989)
2. A cloud of smaller deflectors lofted from Earth over up to a few decades by 20M electro-magnetic launches, each with 800k reflectors, and carried to position by ion propulsion (Angel, 2006)



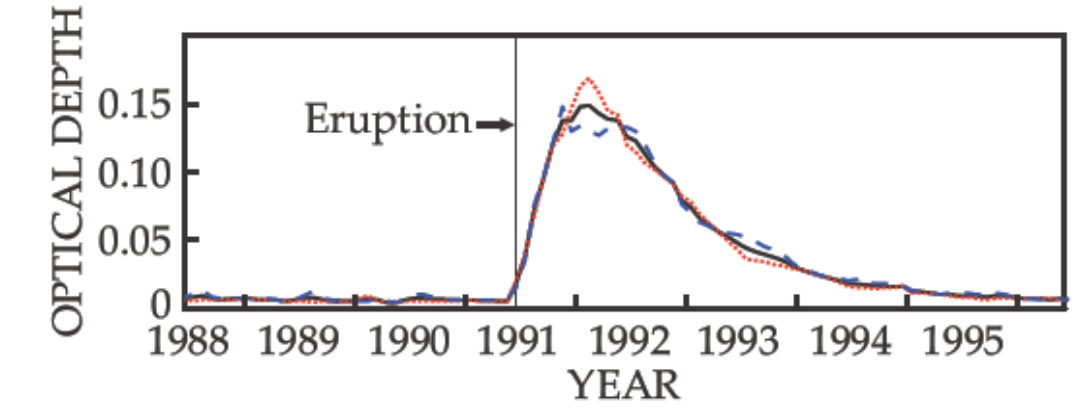
Hoffert et al., 2002

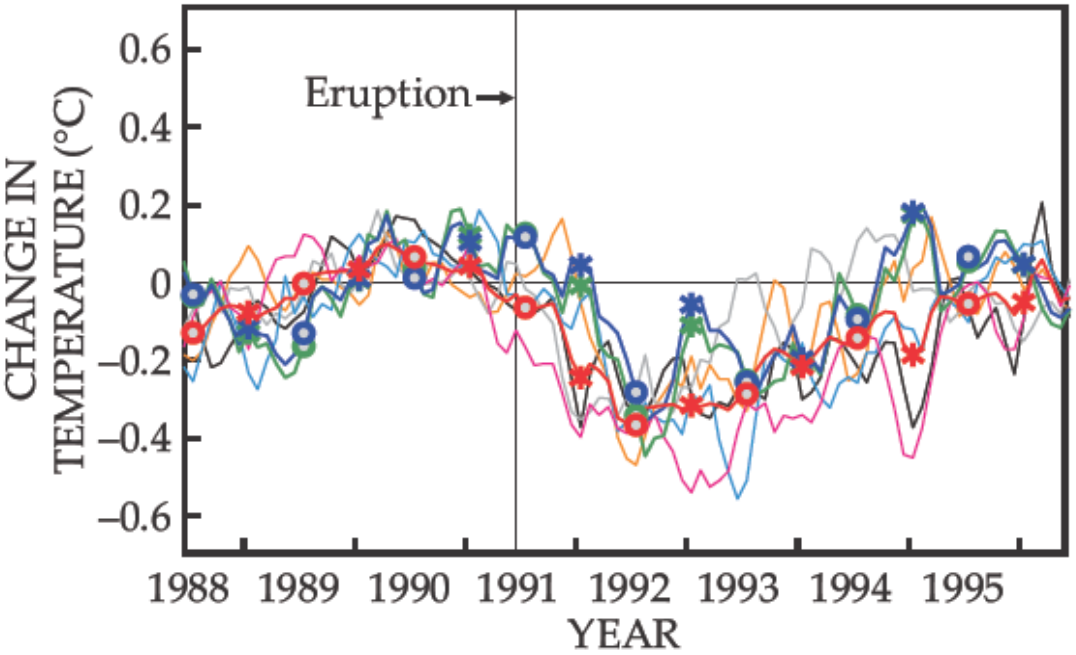
Place Mirrors in Near-Earth Orbit

- NAS (1992) panel report estimated it would require 55,000 orbiting mirrors, each covering and area of 100 square kilometers:
  - The Sun would be obscured with numerous mini-eclipses
  - Would be hard to deal with space debris
  - Could cut number in half if actively aligned

Create a Stratospheric Parasol Roughly Equivalent to Mt. Pinatubo, 15 June 1991

T Alipalo/UNEP/Topham





Engineering options for placing aerosols in the stratosphere

- **Increasing stratospheric sulfate loading is most studied**
  - "Hose to the stratosphere" carrying SO_2
    - Skinny pipe/hose, ground to ~25 km-high HAA (DoD)
  - Artillery (shooting barrels of sulfate particles into stratosphere)
    - "…surprisingly practical" – NAS Study, 1992
  - High-altitude transport aircraft venting gas or aerosol
    - "Condor/Global Hawk, with a cargo bay"
    - Half-dozen B-747s deploy 10^6 tonnes/year of engineered aerosol; towed lifting-lines/bodies for height-boosting the sprayer-dispenser an additional 5-10 km above normal cruising ceilings

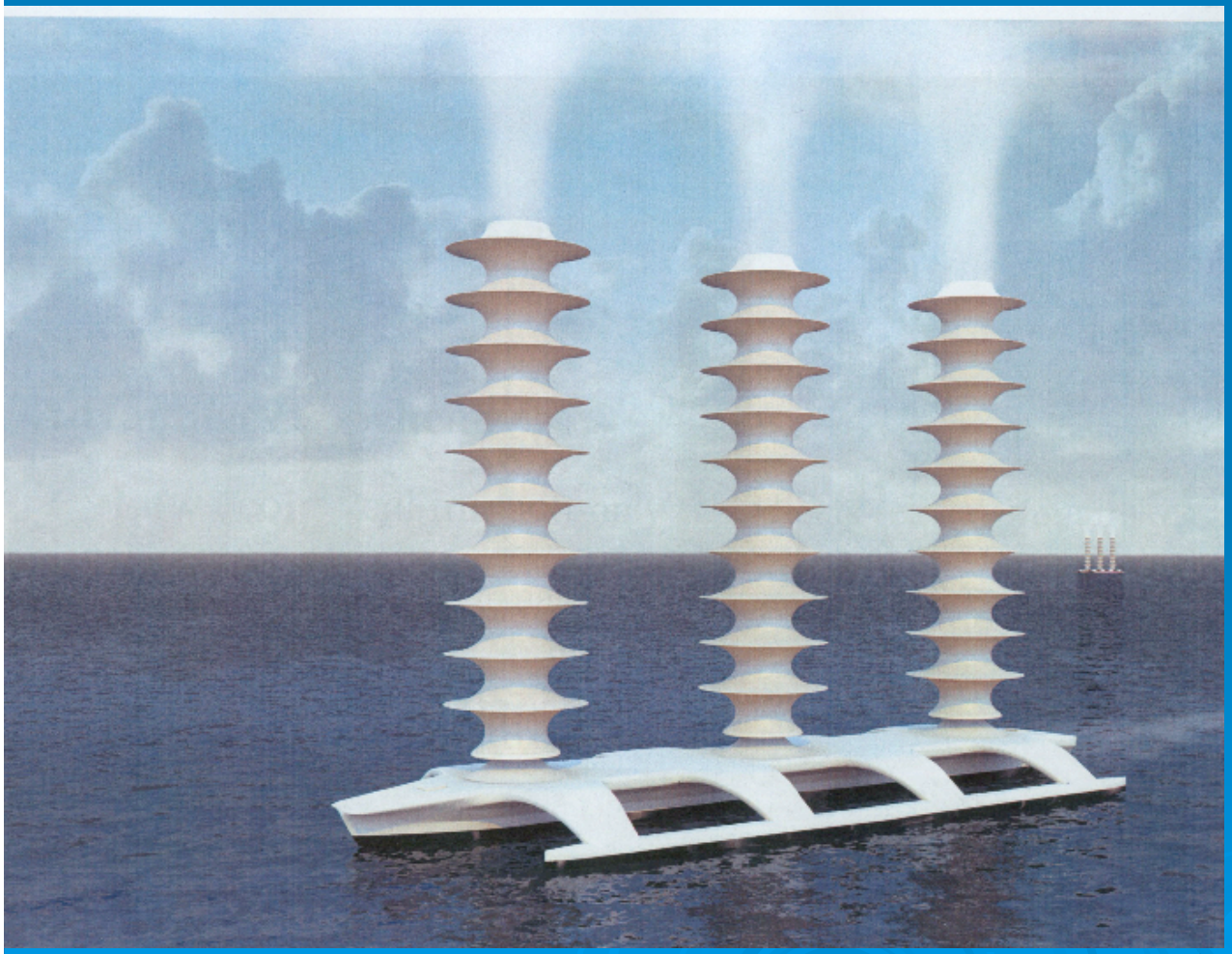
- **Other approaches to increasing high-altitude reflectivity**
  - Lofting of balloons into the stratosphere (possibly micro-scale and shaped as corner reflectors to reduce problems of light scattering)
  - Using particles other than sulfates to reduce scattering (e.g., photophoretic—self-lofting—particles, and going above the stratosphere)
  - Anthropogenically induced volcanoes (e.g., created by explosions)
  - Tethered (set-of-) lifting-bodies – a set of high-tech kites

Modified from original by Lowell Wood

Increasing tropospheric reflectivity requires altering cloud albedo/amount or aerosol loading

- **Enhance the sulfate aerosol loading**
  - The present sulfate aerosol loading likely offsets about 0.5 C of warming through direct and indirect effects on clouds
  - Additional sulfate aerosol loading may result from increased emissions from coal-fired power plants in China and elsewhere
  - *While sulfate aerosols do have health and environmental consequences, perhaps the emissions should be intentionally increased to limit global warming*
- **Increase the reflectivity of marine stratus clouds by injecting sea water droplets (Latham and Salter, 2006)**

Latham and Salter propose controlled enhancement of the albedo and longevity of low-level maritime clouds



- The ships, roughly the size of a three-masted sailing ship, would be wind-powered
- They would loft a spray of very fine sea water that would be carried up into low clouds, brightening their albedo
- The approach would work best in pristine areas
- Ship locations could shift with the seasons
- Roughly 50 new 200-ton trimarans would be needed per year

Increasing surface reflectivity requires altering the albedo over large regions

- Brightening urban areas would help in that area, but generally a pretty limited area, so would mainly help with the heat island of urban areas
- Covering desert areas with a reflecting material would require large areas and likely modify regional weather
- Selecting or genetically engineering vegetation to make it brighter might be possible, but very problematic to do over large area
- Increasing ocean albedo with a floating reflector would require a continental size area, allowing for cloud obscuring effects
- New ideas for changing ocean albedo are emerging

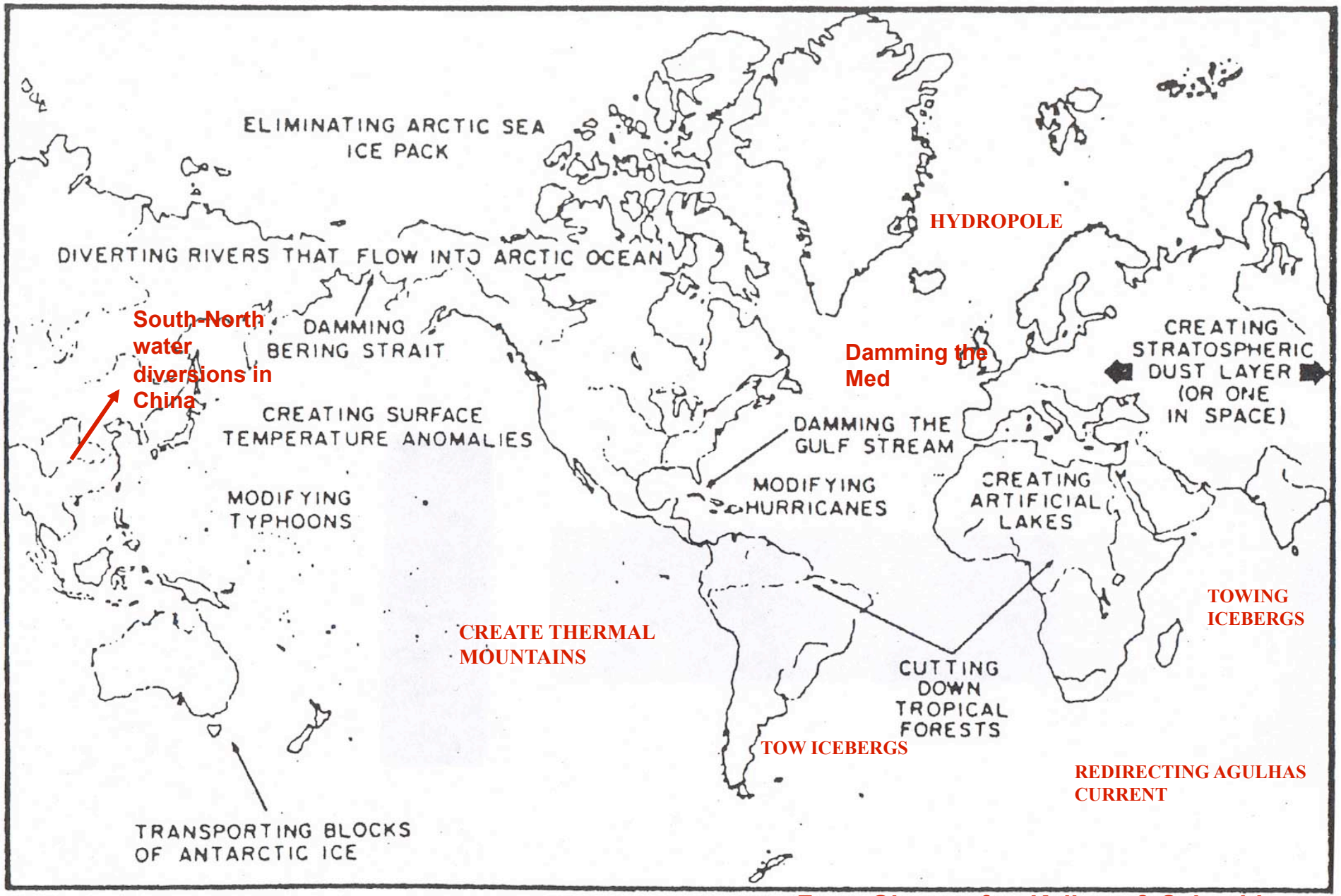
Whatever the approach, global geoengineering would likely bring significant costs and implications

- **Environmental impacts** to consider include shifting direct to diffuse radiation (limiting some direct solar electric technologies), modifying sky color, biospheric impacts, altering carbon storage rate, and increasing ozone depletion
- Reducing incoming solar radiation **would not slow the build-up of CO_2 itself**, thus would do nothing to alleviate the imminent threat of ocean acidification
- As a substitute for mitigation, maintaining the solar shield would require a **permanent, increasing commitment** for many generations
- System failure or a decision to halt its ongoing operation would commit the world to a period of **even more rapid warming** than is ongoing today
- Coming to international agreement on a **governance structure** for optimizing the global climate, and paying for system operation, is almost beyond comprehension

Rather than trying to change the global environment, counterbalancing GHG-induced climate impacts could be set as the objective for geoengineering

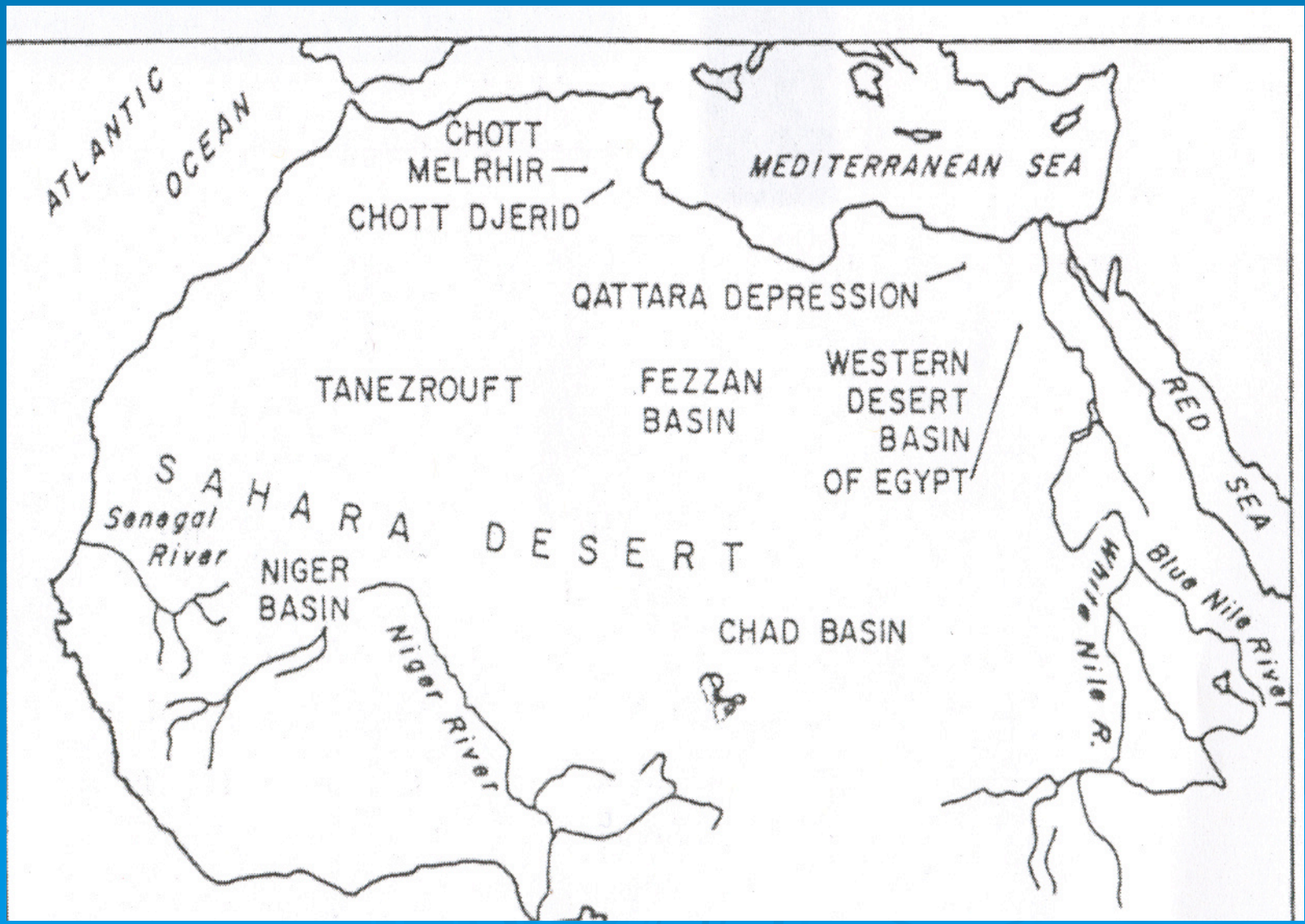
- Could we limit Arctic warming and the contribution to sea level rise of melting glaciers and ice sheets? Proposals have included:
  - Redirecting Russian rivers,
  - Damming the Bering Strait (and perhaps directed pumping of waters)
  - Insulating glaciers (in some regions)
  - Reducing solar heating by significantly increasing aerosol loading of the Arctic lower stratosphere
- Could we limit the increasing strength, and perhaps the track, of hurricanes and typhoons? Proposals have included:
  - Enhancing cloud albedo to limit warming of the ocean in the regions where they form and/or intensify
  - Oceanic films to limit heat transfer
  - Redirection of solar energy using orbiting mirrors

Proposed engineering schemes to modify or control climate



From Glantz, after Kellogg & Schneider

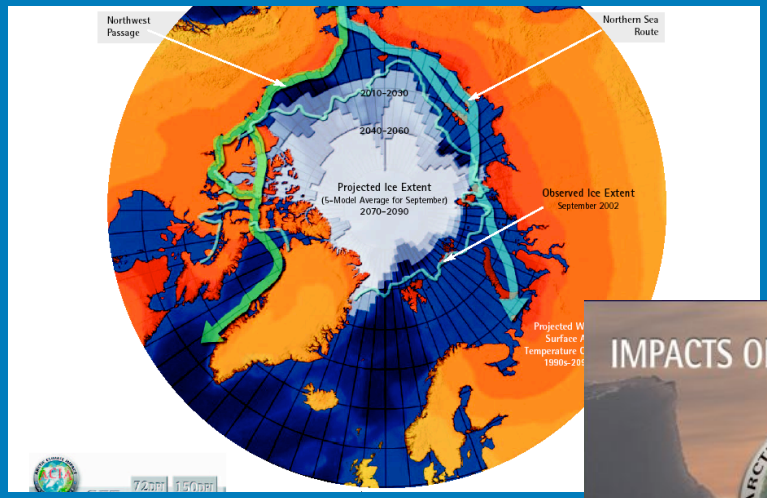
Filling depressions in Africa has been proposed for generating energy and helping to limit sea level



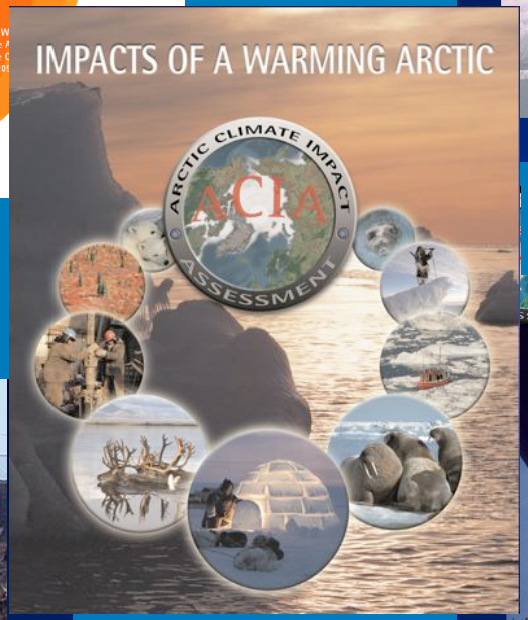
From Glantz

Reductions in Arctic Sea Ice are already having significant effects within the region—and beyond

Access to the region will increase, leading to sovereignty claims and challenges for ensuring safety and environmental quality

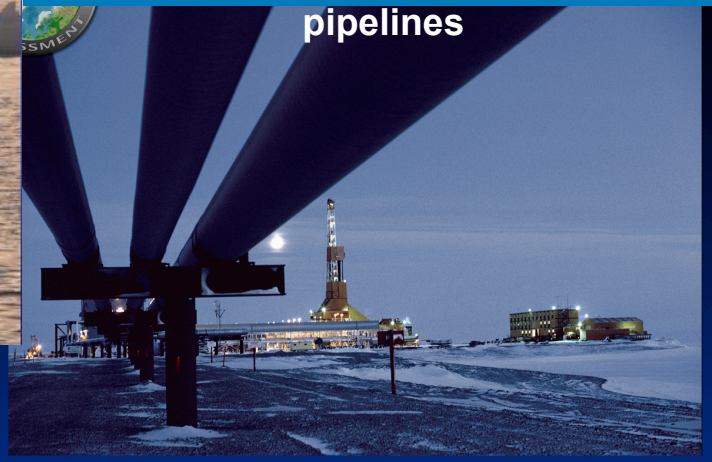


Adverse impacts on Arctic ecosystems and species (e.g., polar bear)

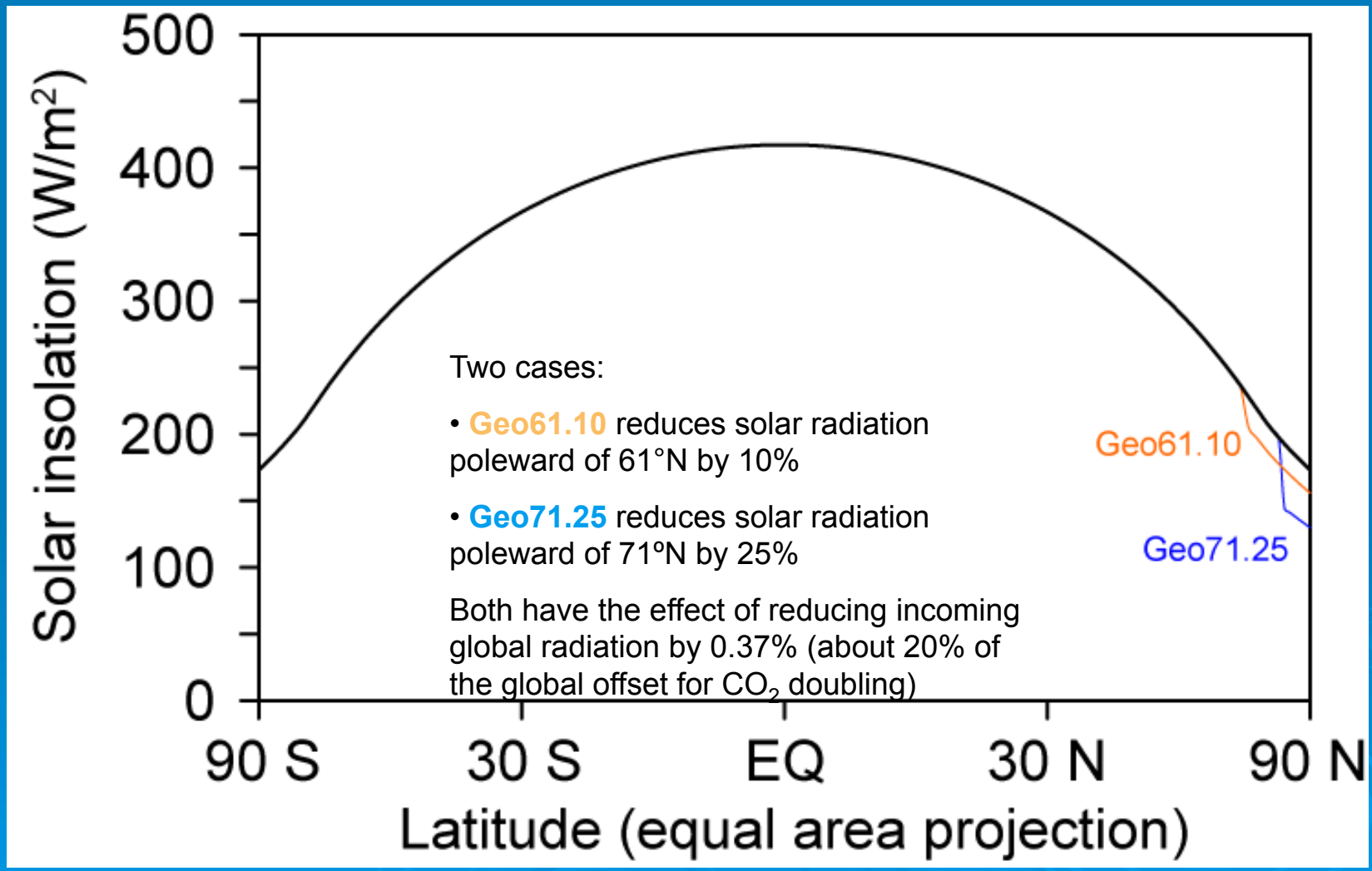


Sea ice loss allows increased coastal erosion, which will force relocation of about 150 Indigenous communities

Melting of permafrost weakens soils and foundations for buildings and pipelines



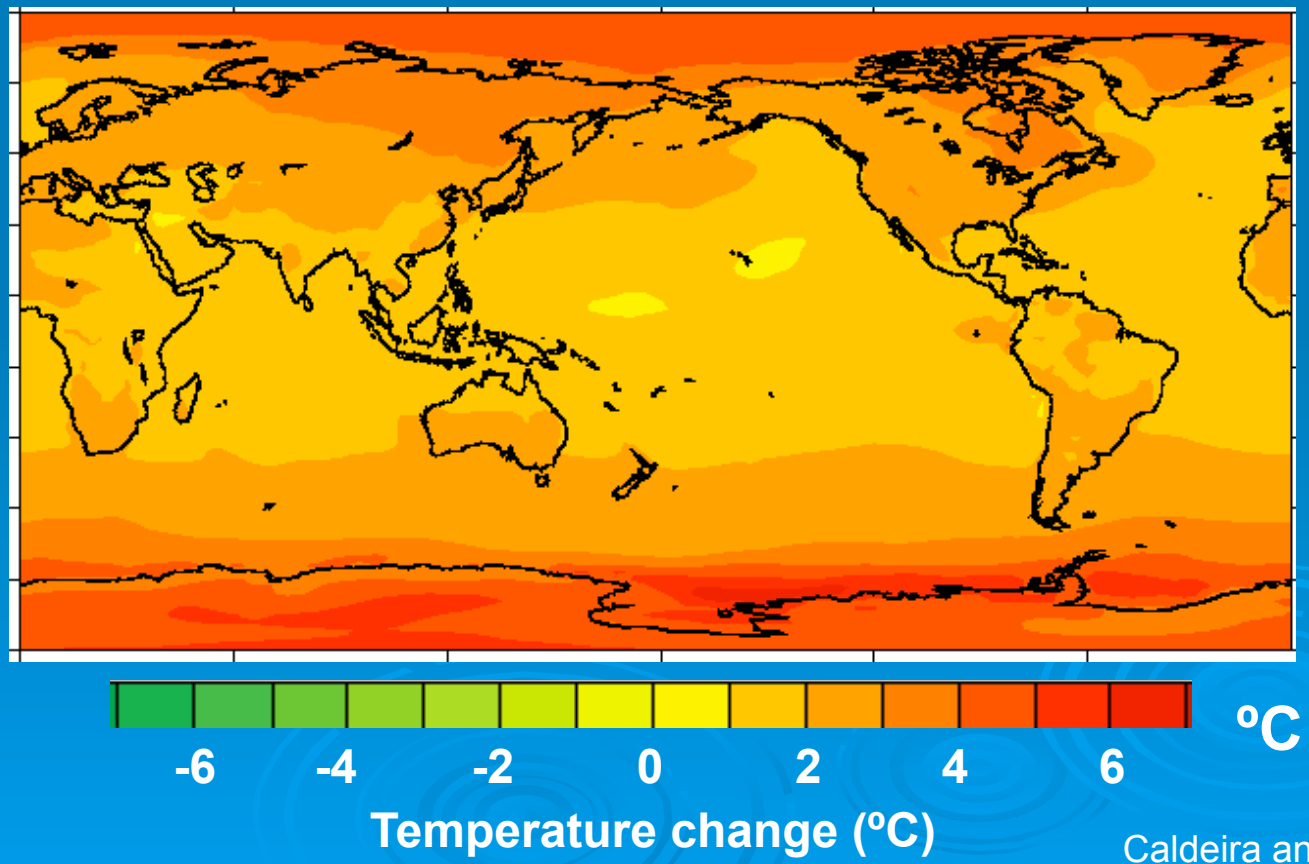
Might it be reasonable to consider reducing solar radiation only in the Arctic



Suggestion of MacCracken at DOE, 2001 workshop

Annual mean temperature response

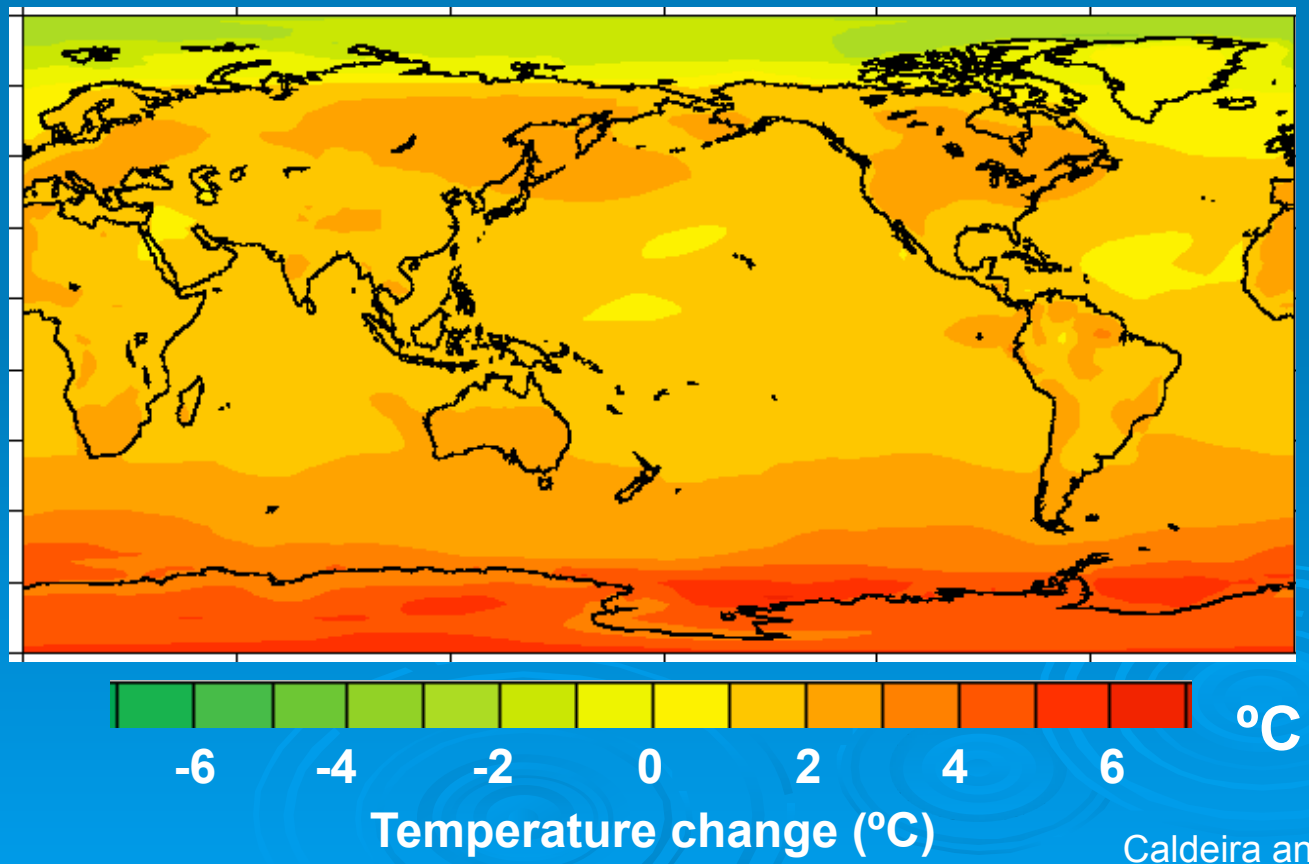
- $2xCO_2$
  - 560 ppm CO_2, normal solar radiation



Caldeira and Wood, 2008

Annual mean temperature response

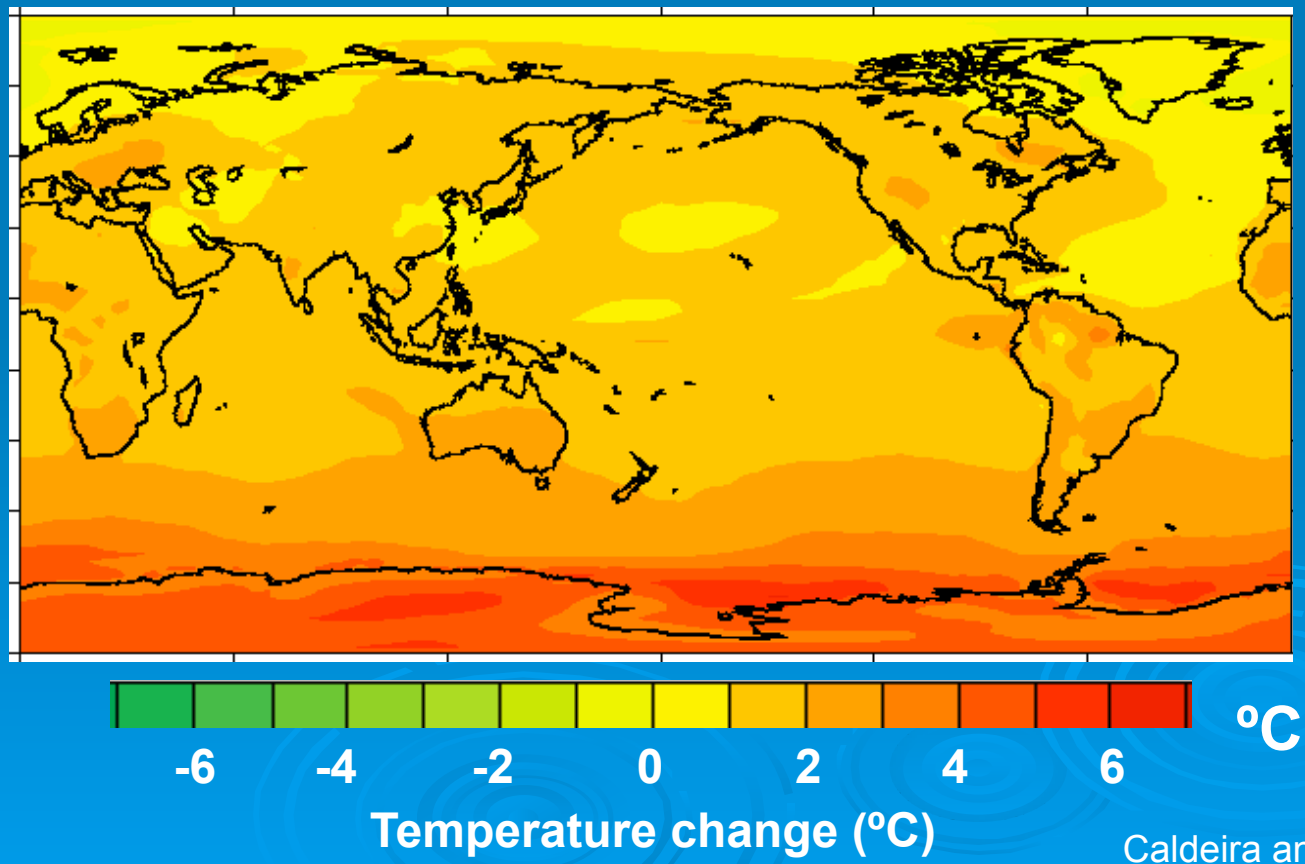
- Geo71.25
  - 560 ppm CO_2, 25% solar reduction north of 71ºN



Caldeira and Wood, 2008

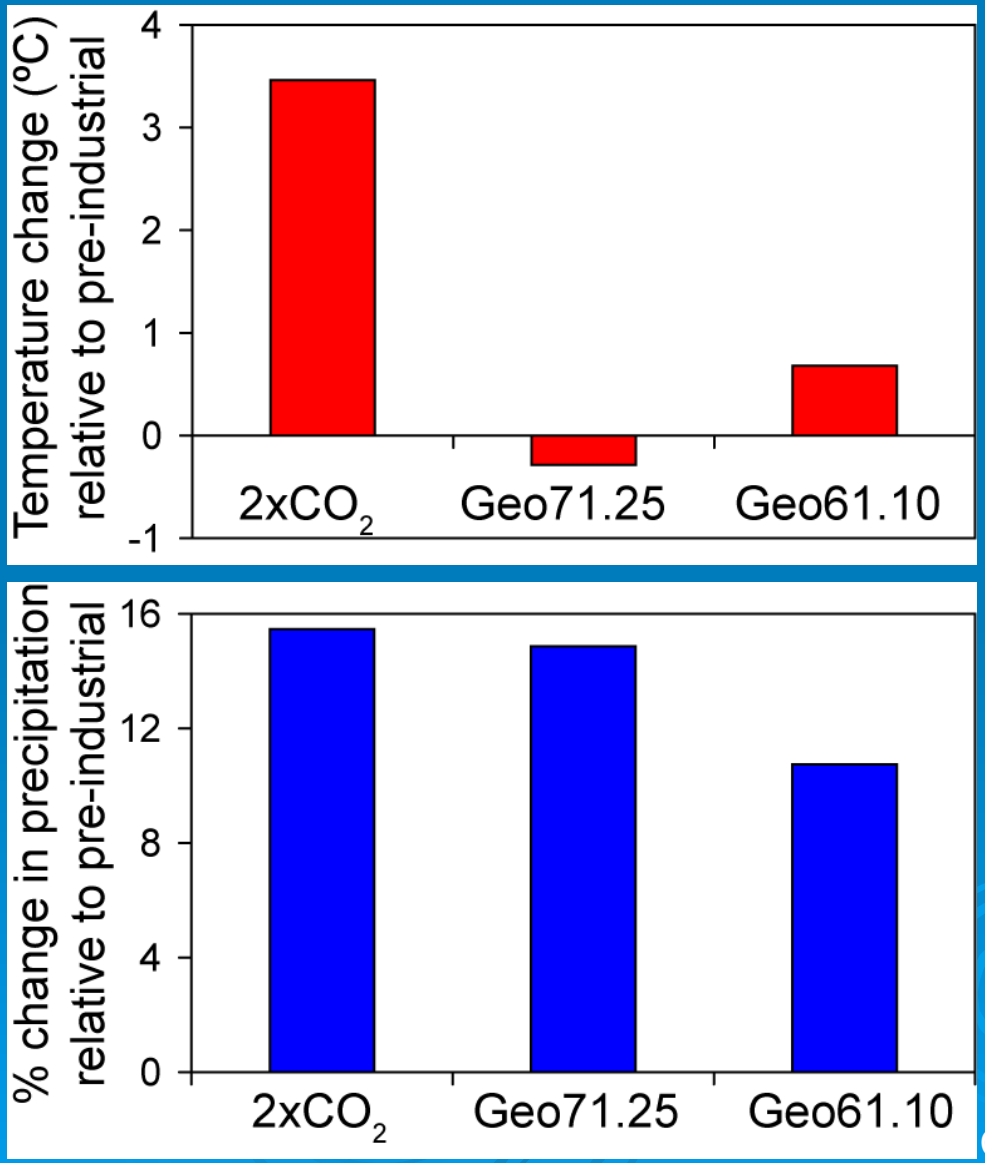
Annual mean temperature response

- Geo61.10
  - 560 ppm CO_2, 10% solar reduction north of 61ºN



Caldeira and Wood, 2008

Arctic geoengineering reverses temperature effects but not increased precipitation



Caldeira and Wood, 2008

Limiting Arctic warming would likely generate overall benefits--locally and for the world

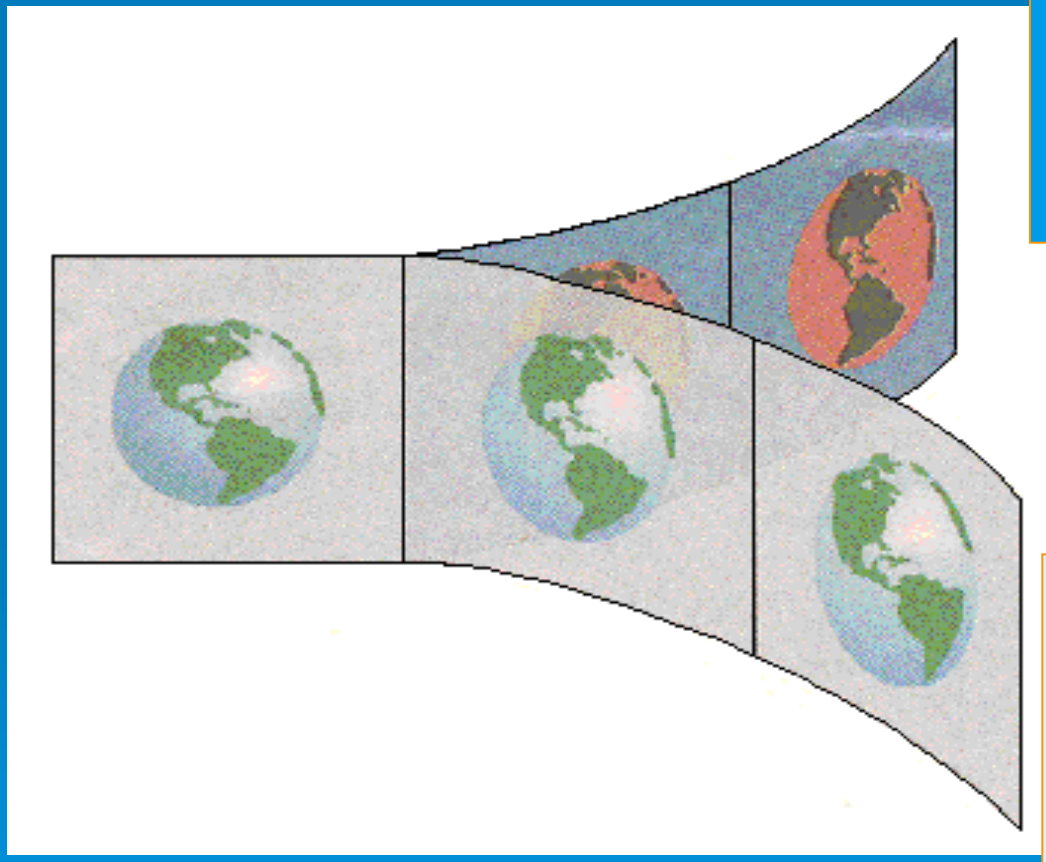
Within the Arctic:

- Building up the sea ice and enhancing river ice would help save Arctic megafauna
- Colder conditions would help preserve Indigenous culture and endangered villages
- Inserting aerosol low enough could limit ozone depletion, and choosing right type of particle could more than offset UV increase
- Preventing permafrost melting would limit structural damage, help preserve forests (and cold would help kill off pests), extend travel times, and help retain soil carbon
- Increased snowfall would help restore glacial extent, sustaining tourism interest
- Reduced light conditions would not affect many people
- The process is testable, stoppable, and inexpensive

Beyond the Arctic:

- Cooling of the Arctic would moderate the warming for much of the Northern Hemisphere, reversing the delay in onset of winter and halting the advance in springtime warm-up (it might also reduce precipitation)
- Continued generation of the cold, dry air masses that have traditionally formed in the Arctic would help to sustain characteristic mid-latitude weather regimes (from winter storms to the generation of summer thunderstorms)
- Reversing melting of mountain glaciers and Greenland would greatly slow the prospective increase in sea level
- Quite possibly help to sustain the global Thermohaline Circulation
- Limiting Arctic warming would reduce the pace at which species would need to shift poleward

Geoengineering may offer us a choice…



…growth with ever increasing environmental and societal risk

. . . or develop approaches that allow growth and development while diminishing environmental and societal risk

Five initial steps to explore geoengineering aimed at both addressing problems and building capabilities for global action, if needed

1. To limit ocean acidification: Pursue ocean pumping where bring own nutrients to the surface
2. To limit Arctic (and mid-latitude) warming, glacial and ice sheet melting, and consequent sea level rise: Explore, develop, and test Arctic aerosol injection; including testing reflectors other than sulfates
3. To limit hurricane and typhoon intensification: Try Salter and Latham approach in cyclone intensification regions
4. To maintain (and even enhance) the sulfate aerosol offset: Evaluate the potential for managing SO_2 emissions from India, China and Australia
5. To build the legal framework for potential geoengineering: Investigate and propose potential intergovernmental control mechanisms and policies

And, of course, intensive mitigation efforts are also needed

Thus, we face a moral quandary

What if we continue to emit greenhouse gases, and Arctic and other species are threatened with extinction?

Which is worse?

– let her (& other species) die, or

– geoengineer global climate, or

– geoengineer Arctic climate?

There is, of course, much research to be done, and significant potential for surprises, but do we simply sit and wait?

Article II: As used in Article I, the term "environmental modification techniques" refers to any technique for changing -- through the deliberate manipulation of natural processes -- the dynamics, composition or structure of the Earth, including its biota, lithosphere, hydrosphere and atmosphere, or of outer space.

Article III.1: The provisions of this Convention shall not hinder the use of environmental modification techniques for peaceful purposes and shall be without prejudice to the generally recognized principles and applicable rules of international law concerning such use.

Article III.2: The States Parties to this Convention undertake to facilitate, and have the right to participate in, the fullest possible exchange of scientific and technological information on the use of environmental modification techniques for peaceful purposes.

Article IV: Each State Party to this Convention undertakes to take any measures it considers necessary in accordance with its constitutional processes to prohibit and prevent any activity in violation of the provisions of the Convention anywhere under its jurisdiction or control.

Understanding Relating to Article I

It is the understanding of the Committee that, for the purposes of this Convention, the terms, "widespread", "long-lasting" and "severe" shall be interpreted as follows:

- (a) "widespread": encompassing an area on the scale of several hundred square kilometres;
- (b) "long-lasting": lasting for a period of months, or approximately a season;
- (c) "severe": involving serious or significant disruption or harm to human life, natural and economic resources or other assets.
- It is further understood that the interpretation set forth above is intended exclusively for this Convention and is not intended to prejudice the interpretation of the same or similar terms if used in connexion with any other international agreement.

Understanding Relating to Article II

- It is the understanding of the Committee that the following examples are illustrative of phenomena that could be caused by the use of environmental modification techniques as defined in Article II of the Convention: earthquakes, tsunamis; an upset in the ecological balance of a region; changes in weather patterns (clouds, precipitation, cyclones of various types and tornadic storms); changes in climate patterns; changes in ocean currents; changes in the state of the ozone layer; and changes in the state of the ionosphere.

- It is further understood that all the phenomena listed above, when produced by military or any other hostile use of environmental modification techniques, would result, or could reasonably be expected to result, in widespread, long-lasting or severe destruction, damage or injury. Thus, military or any other hostile use of environmental modification techniques as defined in Article II, so as to cause those phenomena as a means of destruction, damage or injury to another State Party, would be prohibited.

- It is recognized, moreover, that the list of examples set out above is not exhaustive. Other phenomena which could result from the use of environmental modification techniques as defined in Article II could also be appropriately included. The absence of such phenomena from the list does not in any way imply that the undertaking contained in Article I would not be applicable to those phenomena, provided the criteria set out in that article were met.

[Emphasis added]

However: Understanding Relating to Article III

- It is the understanding of the Committee that this Convention does not deal with the question whether or not a given use of environmental modification techniques for peaceful purposes is in accordance with generally recognized principles and applicable rules of international law.

Unresolved Questions (in my view):

1. Would this convention be applicable in the case of advertent changes in the climate if some party considers them to have an adverse (hostile) influence on them?
2. Is intentionally not taking an action to limit inadvertent changes in the climate subject to this convention if it has an adverse (hostile) influence on another party?