Anthropogenic climate modification & dangerous climate change

John Noble
Meteorology 205B
April 22, 2008
(Updated)

Outline

- Introduction
  - Carbon cycle
  - Climate feedbacks
  - Uncertainties

- Metrics for “dangerous” change

- Climate–biosphere emergency
  - Carbon cycle is perturbed
  - Ocean acidification

- Anthropogenic Climate Modification (ACM)
  - Historical overview
  - Inadvertent Climate Modification (Pollution)
  - Deliberate Climate Modification (Geoengineering)

- References

Carbon cycle

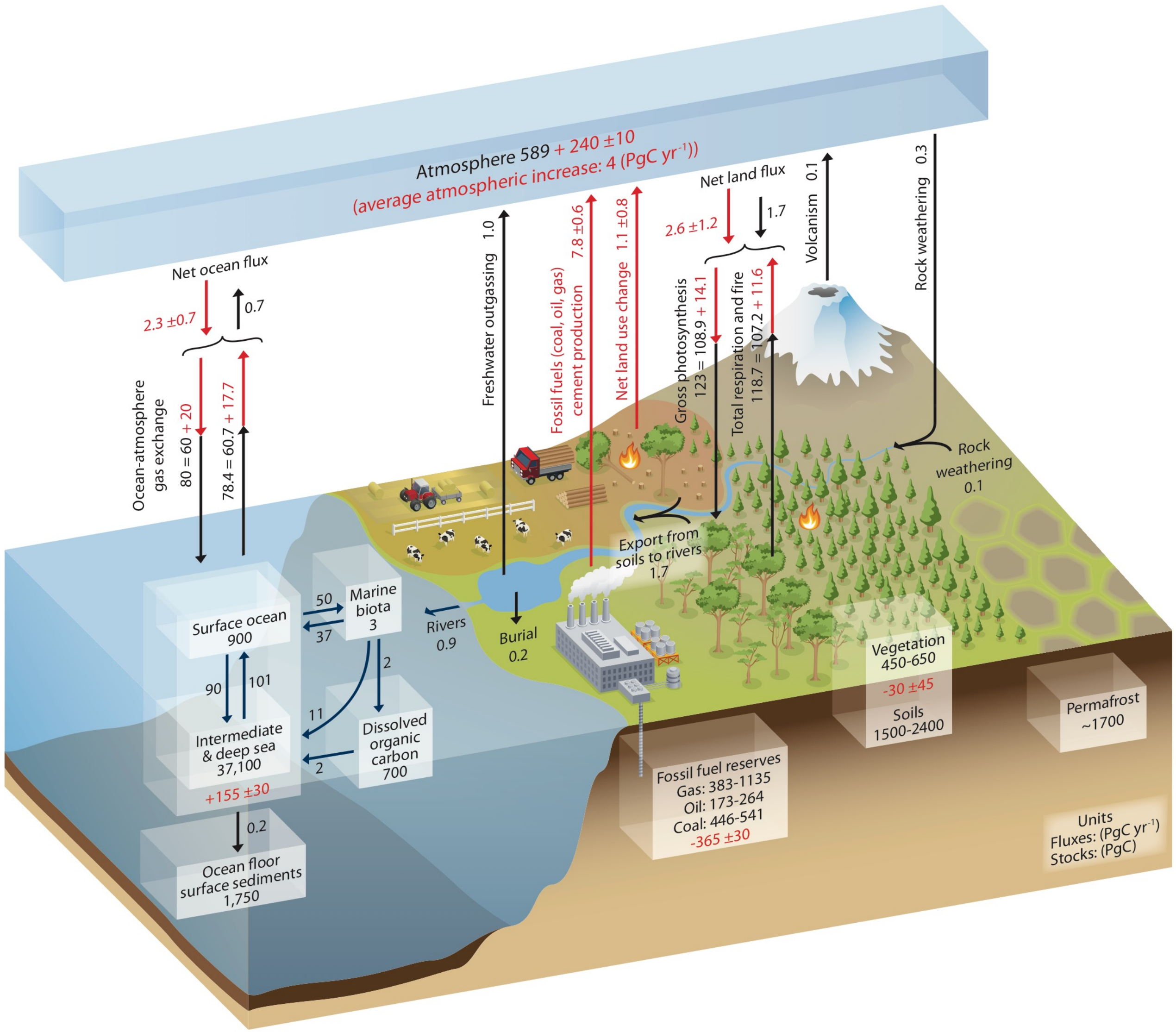


Figure 6.1 | Simplified schematic of the global carbon cycle. Numbers represent reservoir mass, also called carbon stocks in PgC (1 PgC = 10^{15} gC) and annual carbon exchange fluxes (in PgC yr^{-1}). Black numbers and arrows indicate reservoir mass and exchange fluxes estimated for the time prior to the Industrial Era, about 1750... Red arrows and numbers indicate annual anthropogenic fluxes averaged over the 2000–2009 time period.

(IPCC 2013)

Carbon cycle and climate feedbacks

Climate feedbacks diminish or amplify forcing.

These lead to accelerated warming:

- Ice-albedo feedback
- Drying of tropics ⇒ reduces carbon uptake
- Fossil fuel emissions are faster than land/ocean uptake
- Improving air quality could lead to decadal 4 K surface increase in Arctic (Crutzen 2006)

⇒ Positive feedbacks overwhelm negative

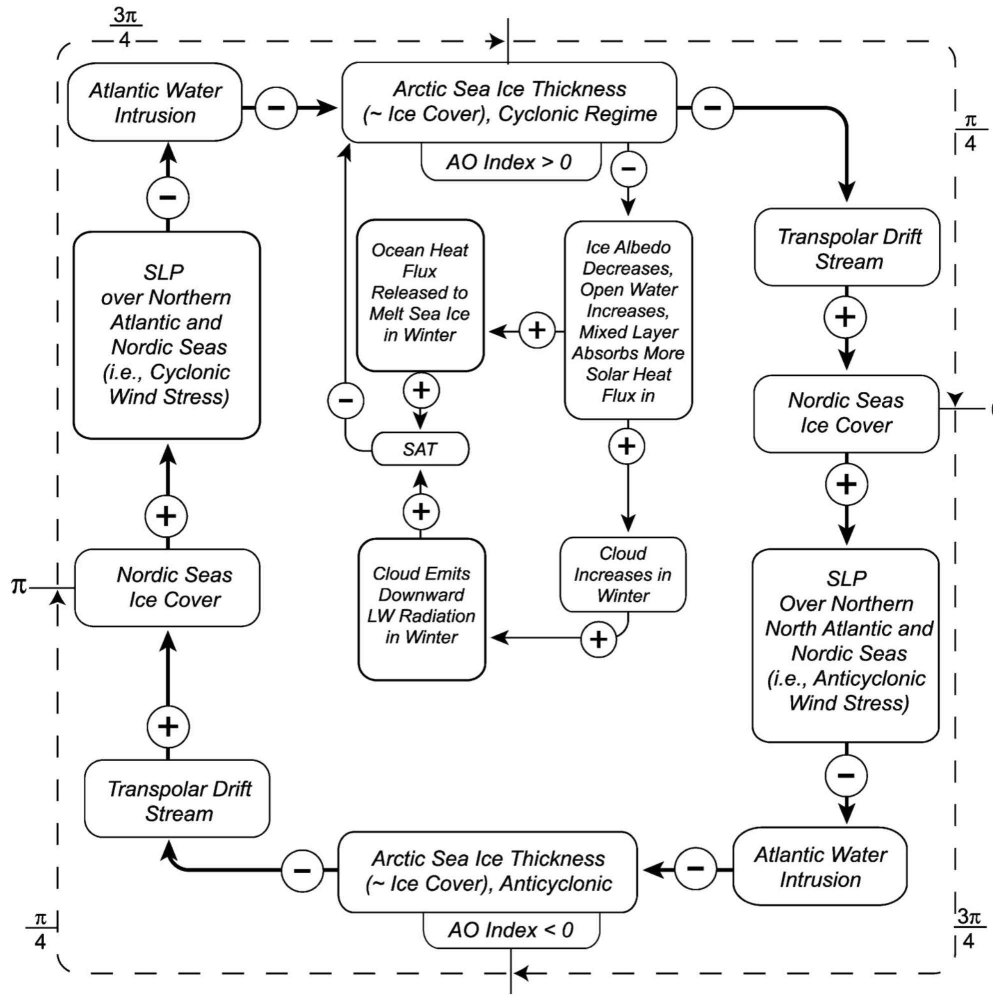


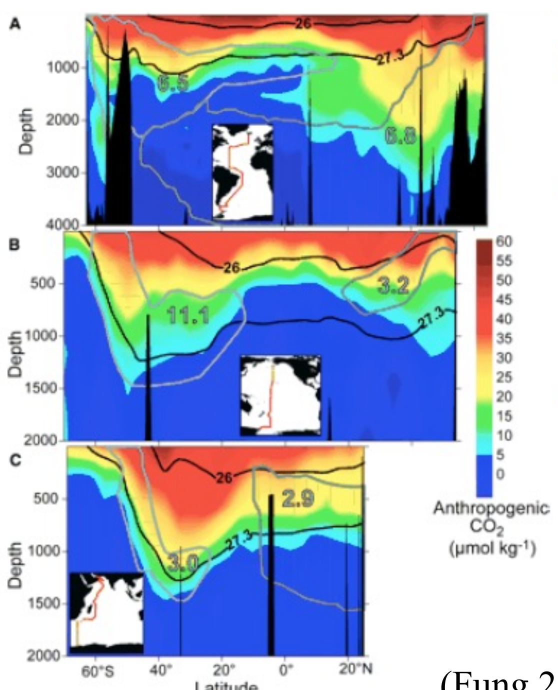
Fig. 13 The proposed modified feedback loop for the observed decadal Arctic climate cycle and the observed long-term downward trend due to a positive feedback of sea ice and clouds. An arrow with a plus sign between *box A* and *box B* means that a positive (negative) anomaly in *A* would cause a positive (negative) anomaly in *B* after a certain delay, while an arrow with a minus sign would results in a negative (positive) anomaly in *B*. (Wang *et al.* 2005)

Climate feedbacks

Fossil fuel emissions:
~50% in atmosphere
~50% in land & ocean

Bottleneck to warming: Oceans

- 4000 m of water, heated from above
- Stably stratified
  - Very slow diffusion of chemicals and heat to deep ocean
- Fossil fuel CO_2:
  - 200 years emission
  - Penetrated to upper 500–1000 m



(Fung 2006)

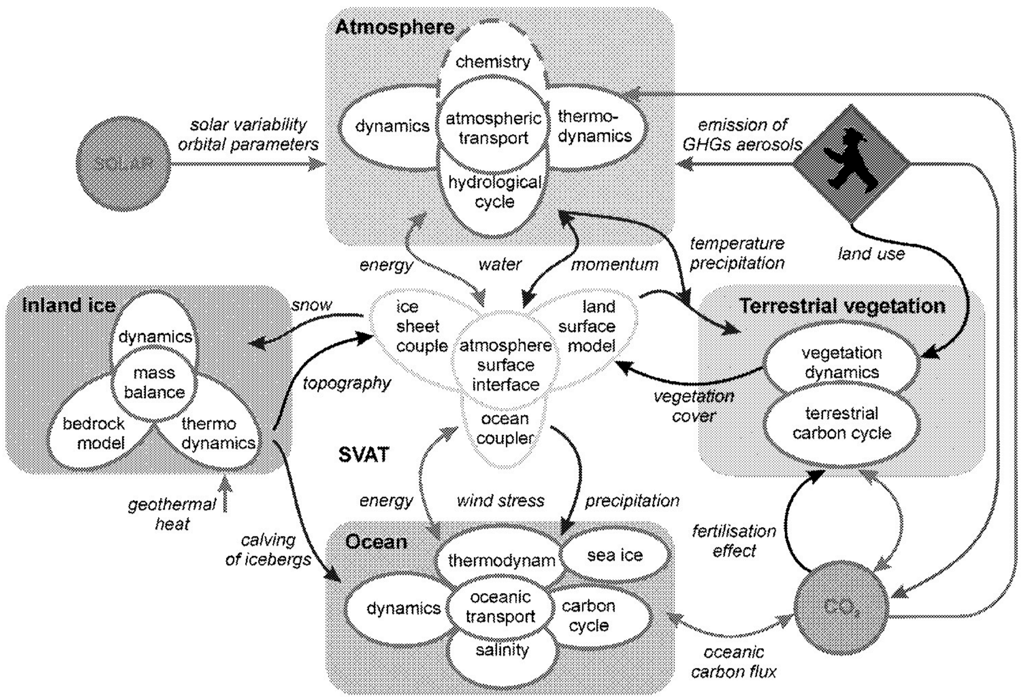


Figure 1. Structure of CLIMBER-2, an Earth System Model of Intermediate Complexity (EMIC; Claussen et al., 2002). The model consists of four modules which describe the dynamics of the climate components atmosphere, ocean, terrestrial vegetation, and inland ice. These components interact via fluxes of energy, momentum (e.g., wind stress on the ocean), water (e.g., precipitation, snow, and evaporation), and carbon. Also, the land-surface structure is allowed to change in the case of changes in vegetation cover or the emergence and melting of inland ice masses, for example. The interaction between climate components is described in a so-called Soil Vegetation Atmosphere Transfer Scheme (SVAT). CLIMBER-2 is driven by insolation (which can vary owing to changes in the Earth orbit or in the solar energy flux), by the geothermal heat flux (which is very small, but important in the long run for inland ice dynamics), and by changes imposed on the climate system by human activities (such as land use or emission of greenhouse gases (GHG) and aerosols).

(Rial *et al.* 2004)

Uncertainties

- Climate-carbon cycle sensitivity
- Magnitude and time scale of future carbon cycle feedbacks
- Carbon storage capacity of the ocean and land
- Change in storage rate with time
- Atmosphere-ocean-biogeochemical coupling

Metrics for "dangerous" change

Extermination of Animal & Plant Species

1. Extinction of Polar and Alpine Species

2. Unsustainable Migration Rates

Ice Sheet Disintegration: Global Sea Level

1. Long-Term Change from Paleoclimate Data

2. Ice Sheet Response Time

Regional Climate Change

1. General Statement

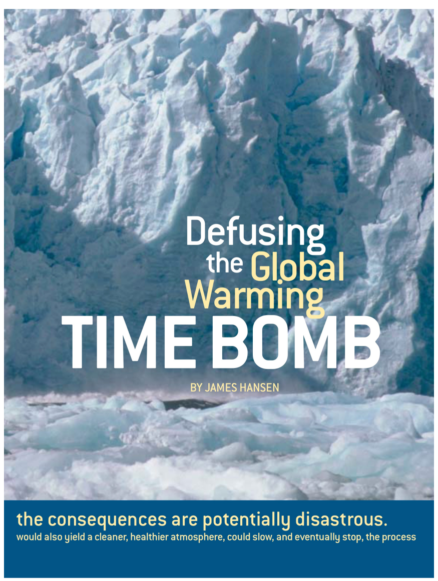
2. Droughts/Floods

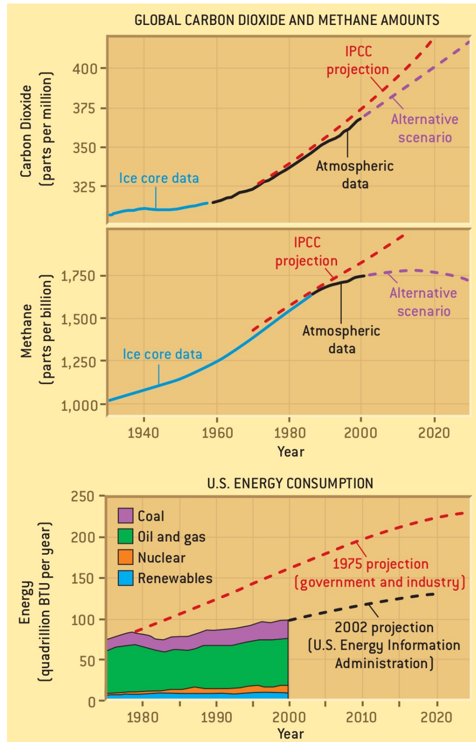
(Hansen 2007)

Abrupt climate change

Evidence of accelerating warming and non-linear coupling
(Hansen, 2004; Schellnhuber *et al.,* 2006; Fung 2006)

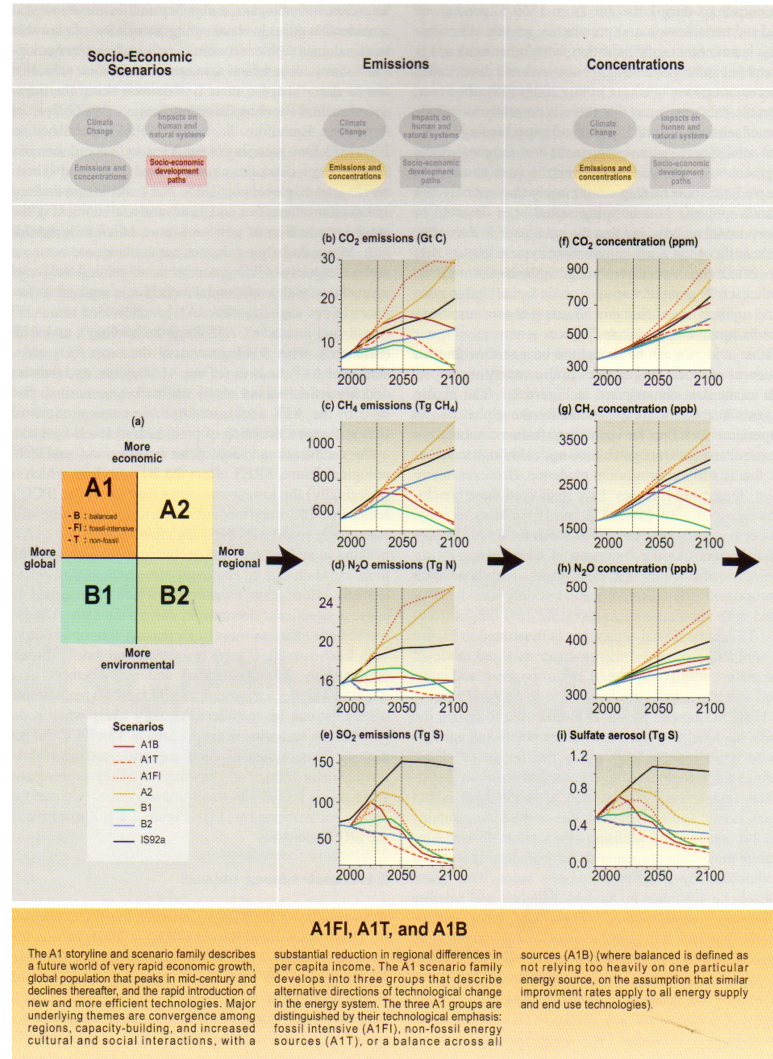
“Is it time to start working on a climate emergency response system”
(Caldeira 2008)





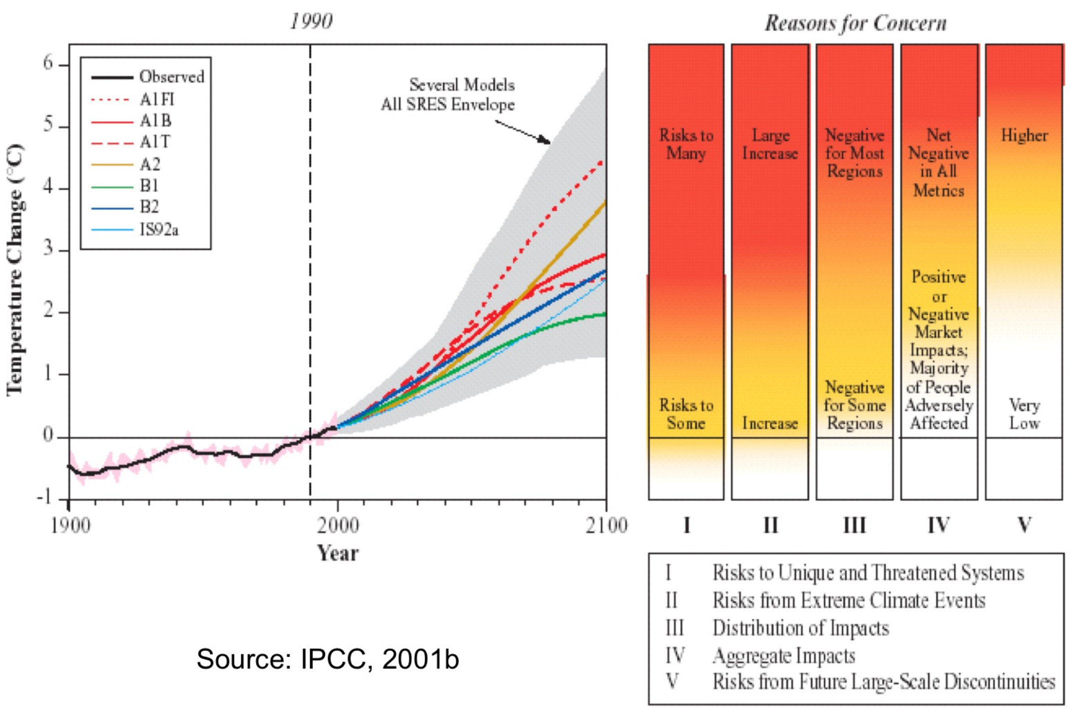
OBSERVED AMOUNTS of carbon dioxide and methane (*top two graphs*) fall below IPCC estimates, which have proved consistently pessimistic. Although the author's alternative scenario agrees better with observations, continuation on that path requires a gradual slowdown in carbon dioxide and methane emissions. Improvements in energy efficiency (*bottom graph*) have allowed energy use in the U.S. to fall below projections in recent decades, but more rapid efficiency gains are needed to achieve the carbon dioxide emissions of the alternative scenario, unless nuclear power and renewable energies grow substantially.

(Hansen 2004)



Abrupt climate change

- CO_2 stabilization requires a 60–80% reduction in current anthropogenic CO_2 emissions
- Emissions increased by 2% from 2001 to 2002 (Marland *et al.,* 2005)
- Current CO_2 emissions are 30–40% larger than at at any time during the past 650,000 years. (Crutzen 2006)



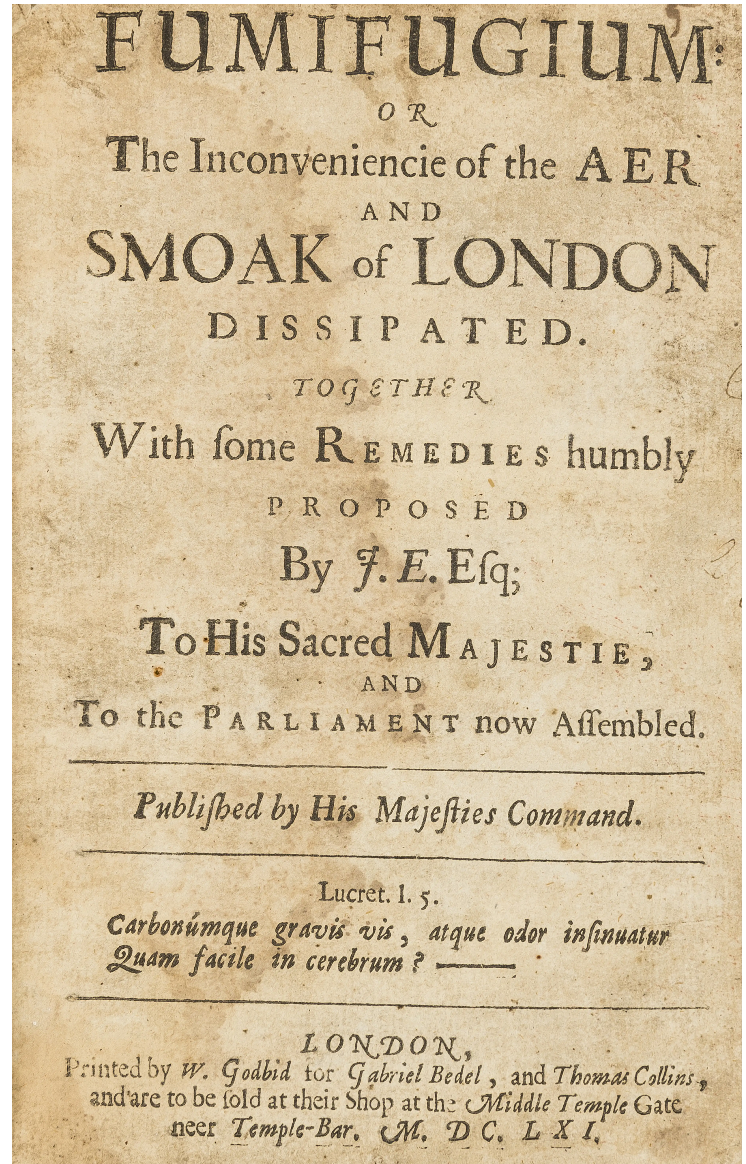
Source: IPCC, 2001b

(Schneider and Lane 2006)

Historical overview

Fumifugium (Evelyn 1661)

- One of the earliest papers on fossil fuel pollution.
- Describes the effects of pollution on London and its populace.
- Calls for pollution mitigation.
- Recommends moving industry outside of the city.
- Recommends creating greenbelts around the city's periphery.


FUMIFUGIUM:
OR
The Inconveniencie of the AER
AND
SMOAK of LONDON
DISSIPATED.
TOGETHER
With ſome REMEDIES humbly
PROPOSED
By *J. E.* Eſq;
To His Sacred MAJESTIE,
AND
To the PARLIAMENT now Aſſembled.

Publiſhed by His Majeſties Command.

Lucret. l. 5.
Carbonúmque gravis vis, atque odor inſinuatur
Quam facile in cerebrum? ——

LONDON,
Printed by *W. Godbid* for *Gabriel Bedel*, and *Thomas Collins*, and are to be ſold at their Shop at the *Middle Temple* Gate neer *Temple-Bar*. *M. DC. LXI.*

Geoengineering – 1965

Report predicts:

- 25% Atmospheric CO_2 increase
- Possible melting (partial or total) of Greenland and/or Antarctica

- Geoengineering is the sole recommendation.
- No emphasis on emissions reduction

~~~~~~

RESTORING THE QUALITY

OF

OUR ENVIRONMENT

Report of The

Environmental Pollution Panel

President's Science Advisory Committee

THE WHITE HOUSE

NOVEMBER 1965

THE WHITE HOUSE

WASHINGTON

November 5, 1965

Ours is a nation of affluence. But the technology that has permitted our affluence spews out vast quantities of wastes and spent products that pollute our air, poison our waters, and even impair our ability to feed ourselves. At the same time, we have crowded together into dense metropolitan areas where concentration of wastes intensifies the problem.

Pollution now is one of the most pervasive problems of our society. With our numbers increasing, and with our increasing urbanization and industrialization, the flow of pollutants to our air, soils and waters is increasing. This increase is so rapid that our present efforts in managing pollution are barely enough to stay even, surely not enough to make the improvements that are needed.

Looking ahead to the increasing challenges of pollution as our population grows and our lives become more urbanized and industrialized, we will need increased basic research in a variety of specific areas, including soil pollution and the effects of air pollutants on man. We must give highest priority of all to increasing the numbers and quality of the scientists and engineers working on problems related to the control and management of pollution.

I am asking the appropriate Departments and Agencies to consider the recommendations and report to me on the ways in which we can move to cope with the problems cited in the Report. Because of its general interest, I am releasing the report for publication.
~~~~~~

Anthropogenic climate modification

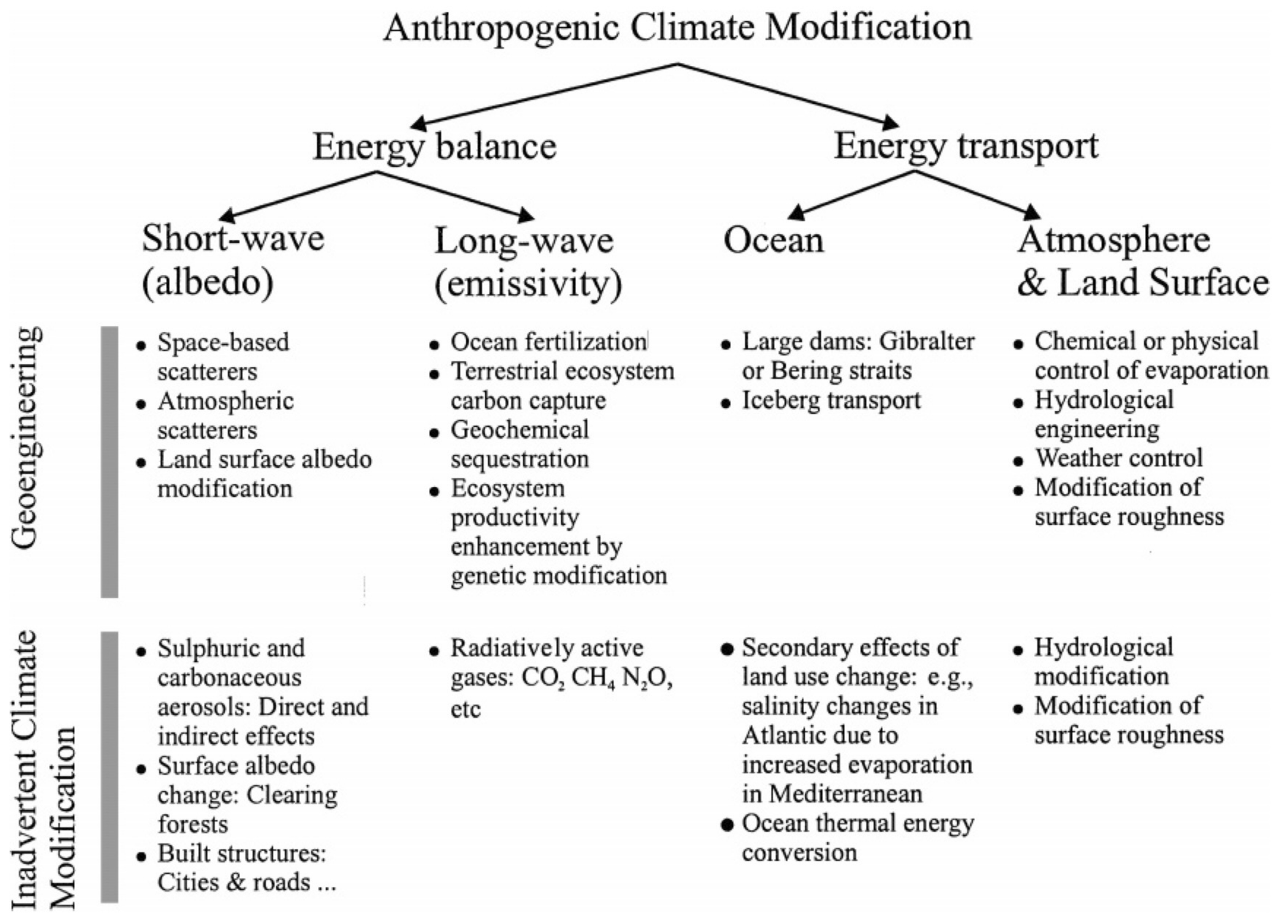
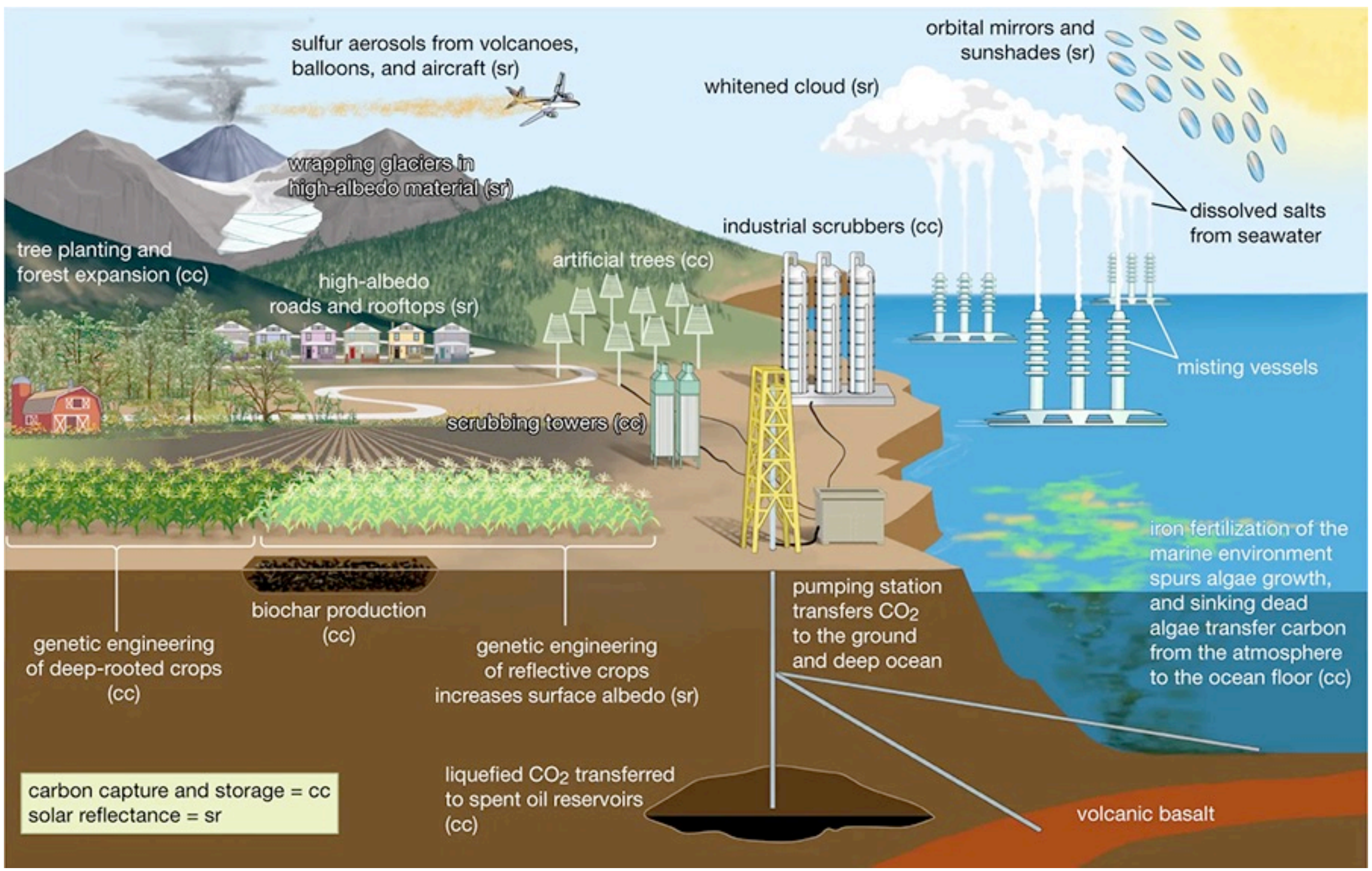


Figure 3 Taxonomy of climate modification. The taxonomy organizes the modes of climate modification—equivalently, possibilities for anthropogenic forcing of climate—both deliberate and inadvertent. The modes of climate modification listed as geoengineering have been proposed with the primary aim of climate modification. Note that some modes appear both as geoengineering and as inadvertent climate modification.

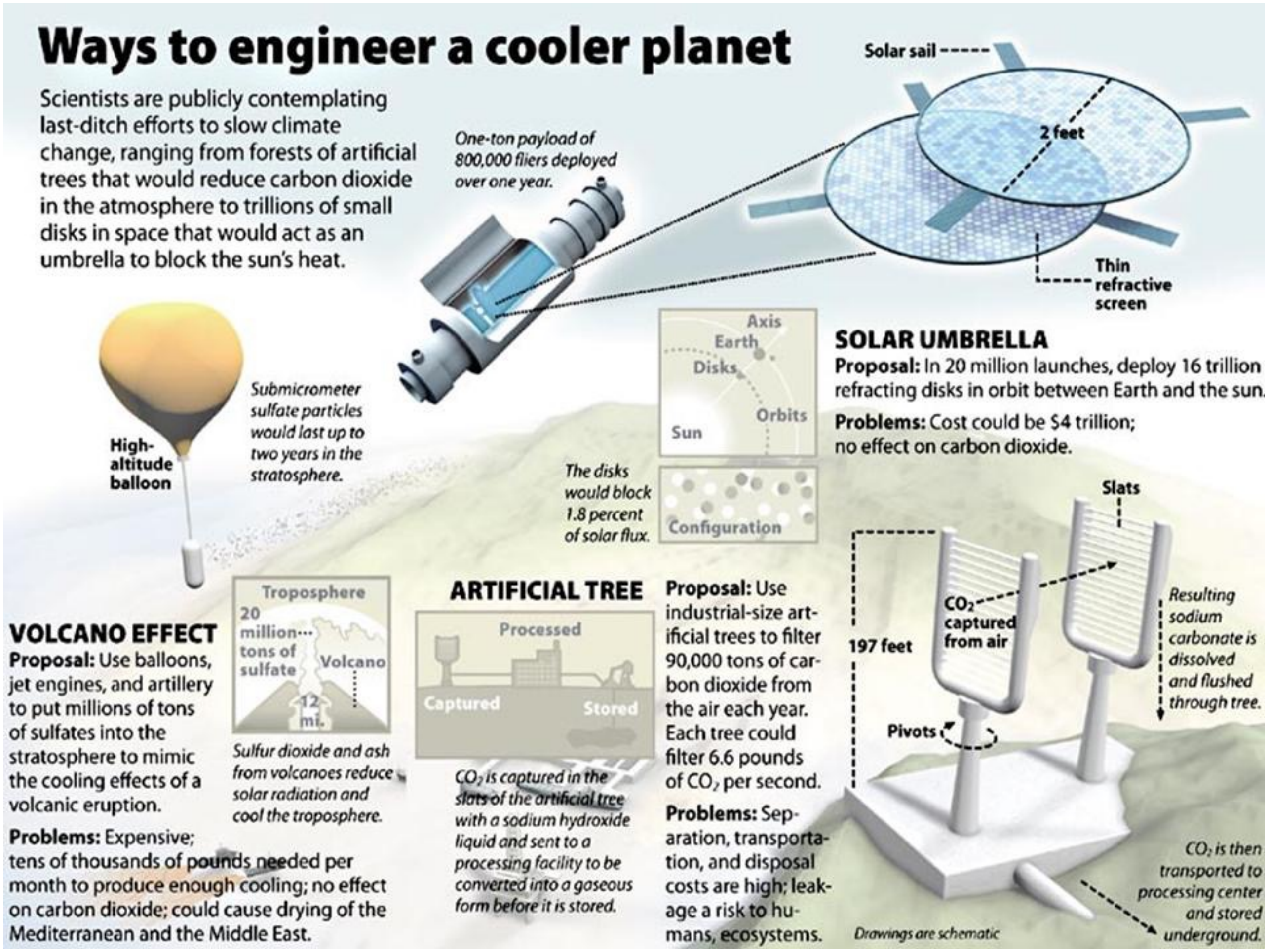
(Kieth 2000)

Geoengineering

- Numerous proposals have & are being considered
- Questions:
  - Reversibility
  - Consequences for ecosystems
- 'Moral hazard': knowledge of its possibilities may reduce concern about abrupt climate change and weaken commitments to cutting emissions



Geoengineering considerations



Stratospheric sulfur injections

Crutzen (2006) argues:

- Efforts towards emissions reductions have been grossly unsuccessful.
- Stratospheric injections of sulfur in the form of S_2 or H_2S to produce SO_2
- 1–2 year residence time in stratosphere vs. ~1 week in troposphere
- Hansen *et al.* (1992) calculated radiative cooling of 4.5 W/m^2 from 6 Tg S
- Sulfate climate cooling efficiency of 7.5 W/m^2 per Tg S in stratosphere.
- Cost: ~ $25 billion/year (NAS 1992)
- Amount needed is ~2– 4% of current input of 55 Tg S/year
- Permit rapid remedial response.

Sulfate aerosol simulations

Matthews and Caldeira (2007) conducted transient climate–carbon simulations of planetary geoengineering to assess stabilizing global temperatures if CO_2 emissions are allowed to continue unabated.

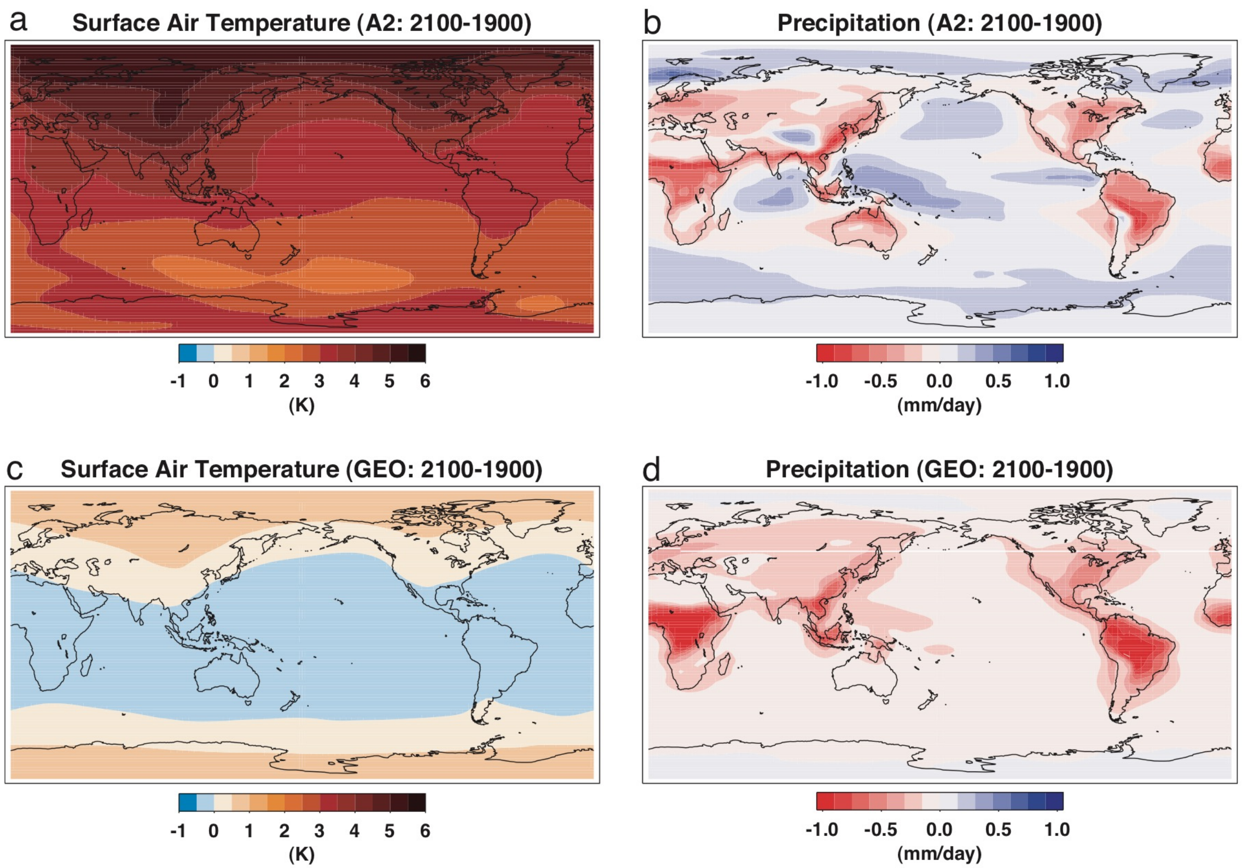


Fig. 1. Simulated changes in surface air temperature (*a* and *c*) and precipitation (*b* and *d*) at 2100 relative to 1900 for model runs A2 (*a* and *b*) and GEO (*c* and *d*). Plots show differences in 10-year averages centered on 2095 and 1895, respectively.

Sulfate aerosol simulations

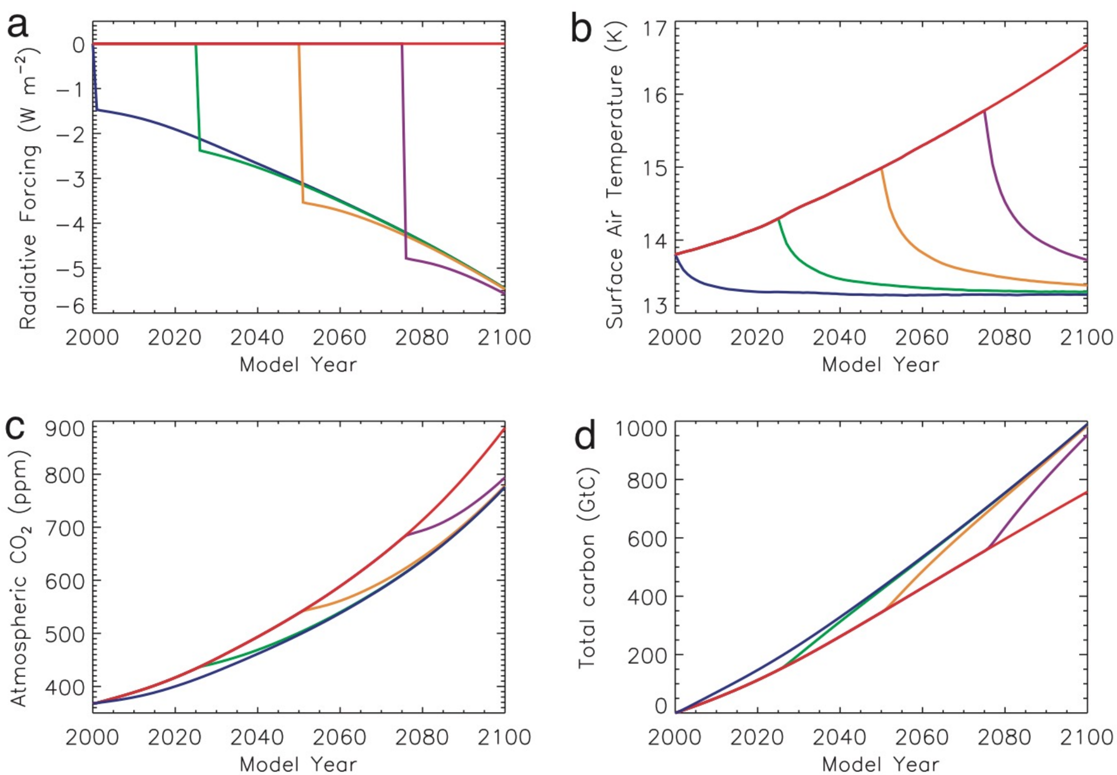


Fig. 2. Prescribed geoengineering radiative forcing (*a*), simulated globally averaged surface air temperature (*b*), simulated atmospheric CO_2 (*c*), and simulated change in combined land and ocean carbon storage (*d*) for runs A2 (red), GEO (blue), ON_2025 (green), ON_2050 (orange), and ON_2075 (purple).

(Matthews and Caldeira 2007)

Sulfate aerosol simulations

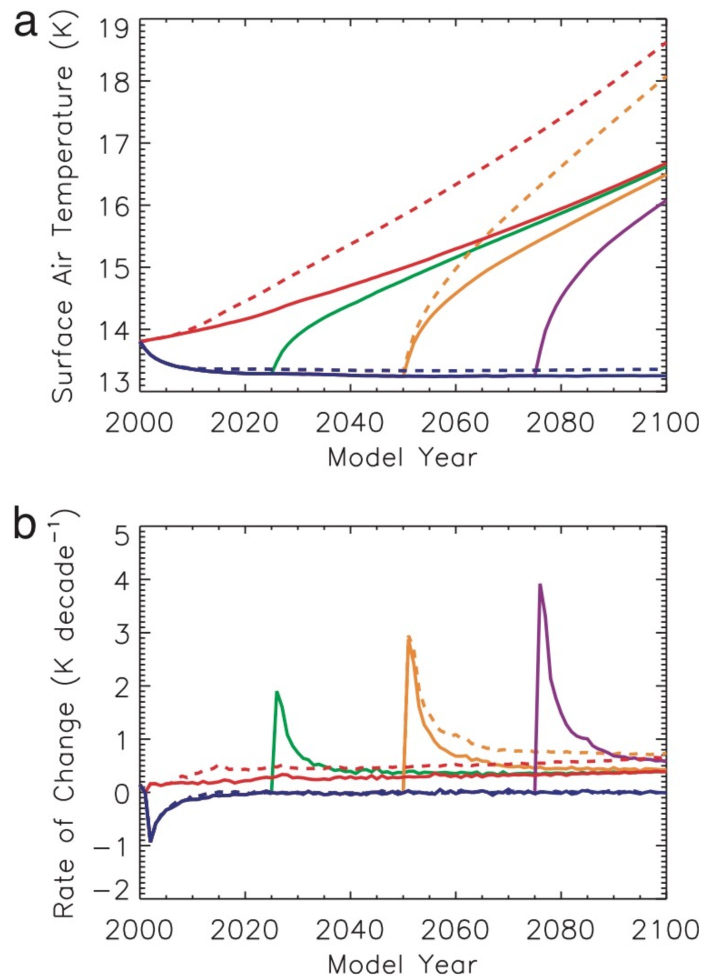


Fig. 3. Simulated surface air temperature (*a*) and annual rate of temperature change (*b*) for runs A2 (red), GEO (BLUE), OFF_2025 (green), OFF_2050 (orange), and OFF_2075 (purple). Runs with doubled climate sensitivity (A2+CS, GEO+CS, and OFF_2050+CS) are plotted as dashed lines.

(Matthews and Caldeira 2007)

Sulfate aerosol simulations

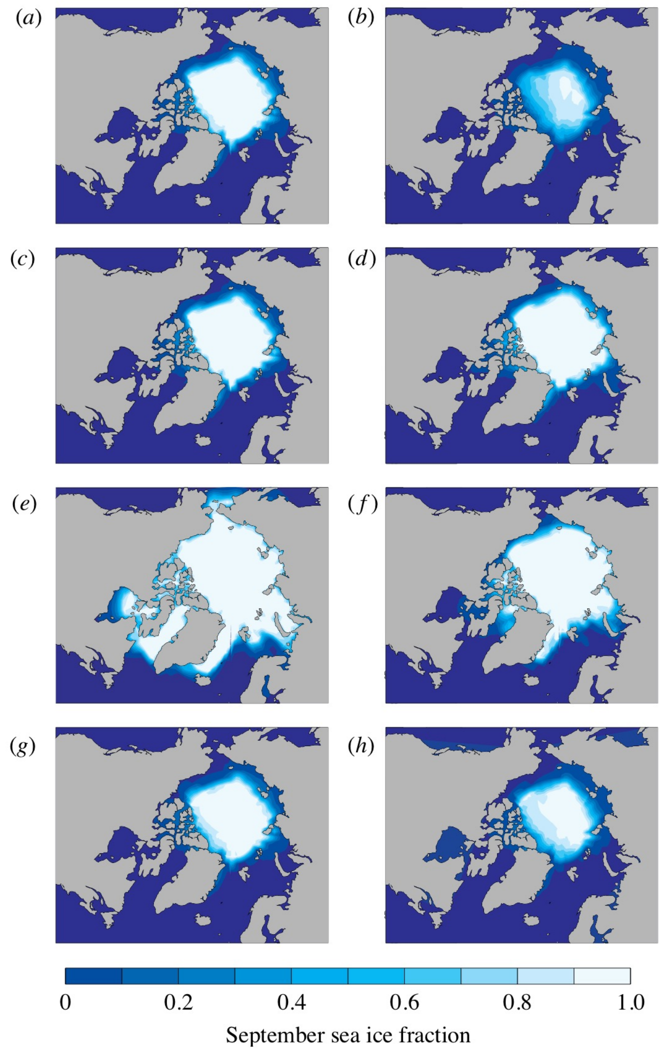


Figure 4. September sea ice fraction. Depending on the amount of insolation reduction and where it is reduced, simulated sea ice extent at the annual minimum can be adjusted at will. (*a*) $1\times CO_2$, (*b*) $2\times CO_2$, (*c*) Arctic61_0.37, (*d*) Arctic71_0.37, (*e*) Arctic61_1.84, (*f*) Arctic71_0.73, (*g*) Global_1.84, (*h*) Global_0.73.

(Caldeira and Wood 2008)

Caldeira *et al.* results

Geoengineering may be a promising strategy for counteracting climate change.

– It may not be necessary to replicate the exact radiative forcing patterns from greenhouse gases to largely negate their effects.

- However, subtle changes in the distribution of solar luminosity associated with the Milankovitch cycles (Imbrie *et al.,* 1984) may have produced large climate change on time scales >104 years, after ocean circulation and ice sheets adjusted to the slightly modified new climate.

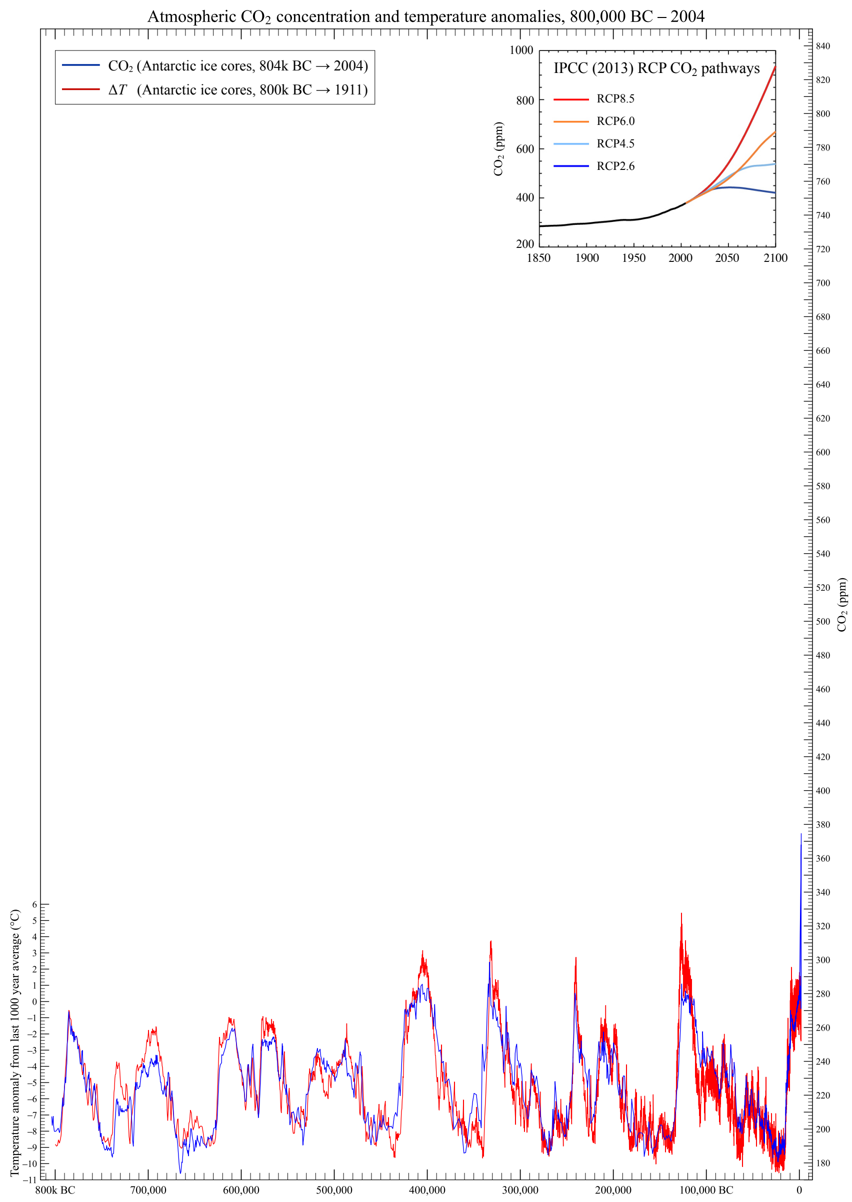
- Even if geoengineering schemes could largely compensate for the climate change induced by a CO_2 doubling or quadrupling on short time scales, there is no guarantee that long-term climate would remain relatively unaffected.

- For instance, the uptake of CO_2 by the biosphere will increase at elevated levels of atmospheric CO_2, irrespective of whether we implement geoengineering schemes or not.

CO_2 direct air capture

- First successful demonstration of CO_2 air capture technology (Lackner 2003, 2007)
- Sorbents such as sodium hydroxide (NaOH) capture CO_2 molecules from free-flowing air and release them as a pure stream of CO_2 for sequestration.
- Device with an opening of one square meter can extract about 10 tons of carbon dioxide from the atmosphere each year.

800,000-year CO_2 & temperature record



(Noble 2024)

References

Andreae, M. O., C. D. Jones, and P. M. Cox, 2005: Strong present-day aerosol cooling implies a hot future, *Nature*, **435**, 1187–1190.

Bruckner, T. and Schellnhuber, H. J., 1999: Climate Change Protection: The Tolerable Windows Approach, *IPTS Report,* **34.**

Caldeira, K. and Wood, L., 2008: Global and Arctic climate engineering: numerical model studies, *Phil. Trans. R. Soc. A*., **366**, 4039–4056.

Cicerone, R. J., 2006: Geoengineering: Encouraging Research and Overseeing Implementation. *Climatic Change*, **77**, 221-226.

Crutzen, P., 2006: Albedo enhancement by stratospheric sulfur injections: a contribution to resolve a policy dilemma? *Climatic Change*, **77**, 211–220.

Evelyn, J., 1661: Fumifugium, or, The inconveniencie of the aer and smoak of London dissipated: together with some remedies humbly proposed by J.E., Esq., to His Sacred Majestie and to the Parliament now assembled. London.

Fung, I., 2006: Climate Model Predictions. UC Berkeley, 23 May 2006.

Govindasamy, B. and Caldeira, K., 2000: Geoengineering Earth's radiative balance to mitigate CO_2-induced climatic change, *Geophys. Res. Lett*. **27**, 2141–2144.

Hansen, J., 2004: Defusing the Global Warming Time Bomb, *Sci Amer*, March 2004, 68–77.

Hansen, J., 2007: Global Warming: Connecting the Dots from Causes to Solution, National Press Club & American University, Washington, DC, 26 Feb. 2007.

IPCC 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge Univ. Press.

Kieth, D. W., 2000: Geoengineering the Climate: History and Prospect. *Annu. Rev. Energy Environ*. **25**, 245–84.

Lackner, K.S., 2003. A guide to CO2 sequestration. *Science*, **300**, pp.1677–1678.

Matthews, H. D. and Caldeira, K., 2007: Transient climate–carbon simulations of planetary geoengineering, *PNAS*, **104**, 9949–9954.

Noble, J., 2024: Visualization of atmospheric CO_2 datasets (software development). jnoble.org/climate.

References

Panel, E.P., United States President's Science Advisory Committee and President's Science Advisory Committee, 1965: Restoring the quality of our environment. The White House.

Rial, J.A., *et al.,* 2004: Nonlinearities, Feedbacks and Critical Thresholds within the Earth's Climate System. *Climatic Change*, **65**, 11–38.

Schneider, S. H. and Lane, J., 2006: An Overview of 'Dangerous' Climate Change. Avoiding Dangerous Climate Change, Schellnhuber, H. J. *et al.,* Eds., Cambridge Press, 7–23.

Wang, J., *et al.,* 2005: Linking the northern hemisphere sea-ice reduction trend and the quasi-decadal arctic sea-ice oscillation. *Climate Dynamics,* **24**, 115–130.