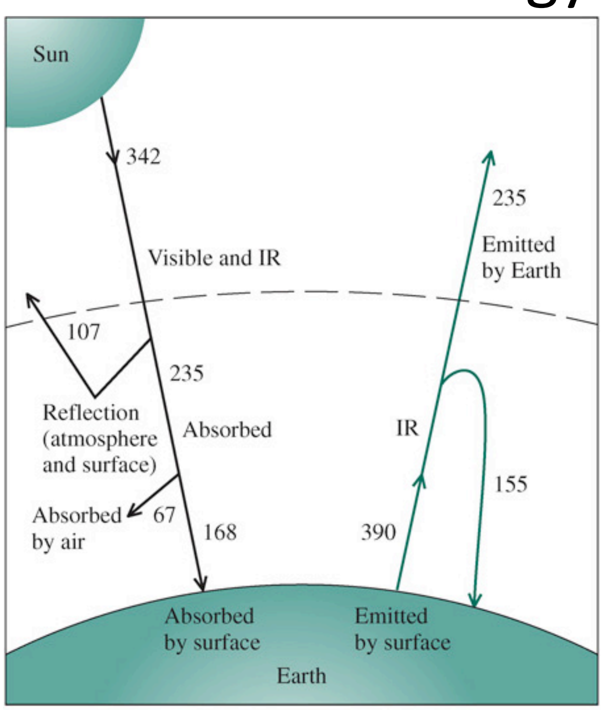
Review of Major Climate Change Science Findings and Observed Climate Impacts

May 2010

Reminder of Earth's Energy Balance

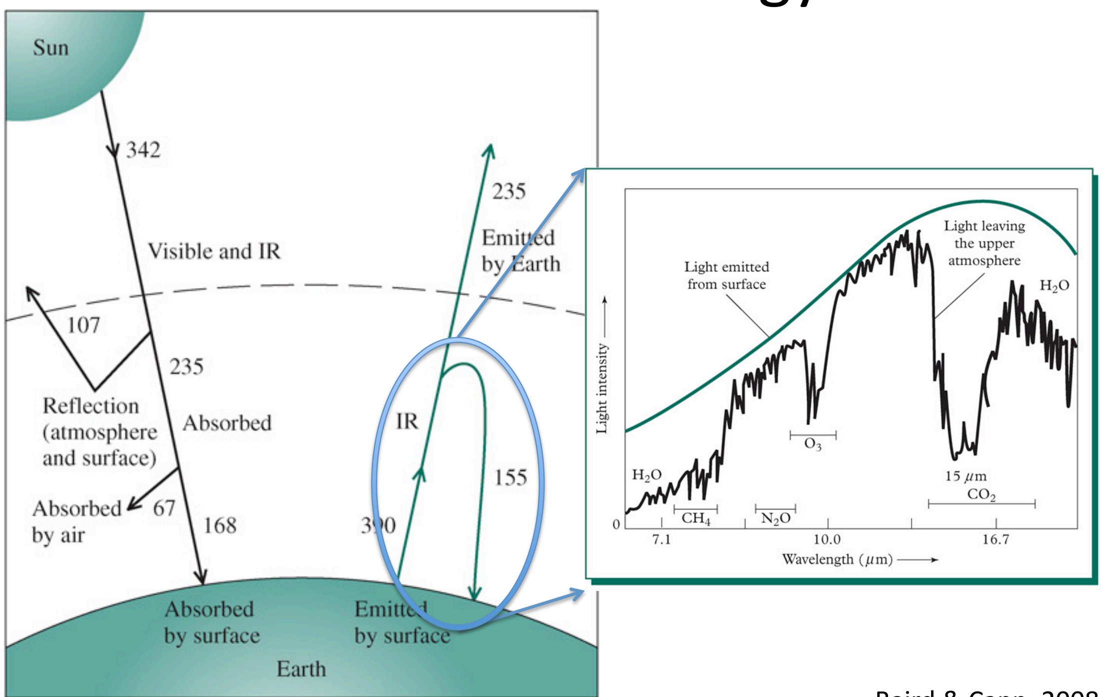


~ 30% reflected

Radiative fluxes in W m^{-2}

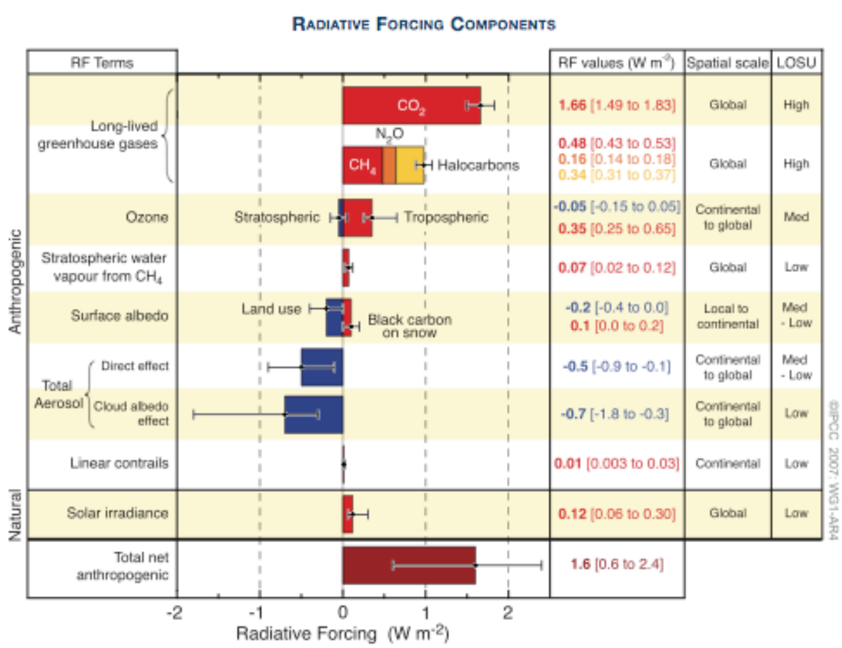
Baird & Cann, 2008

Reminder of Earth’s Energy Balance



Baird & Cann, 2008

What’s doing the greenhouse-ing?



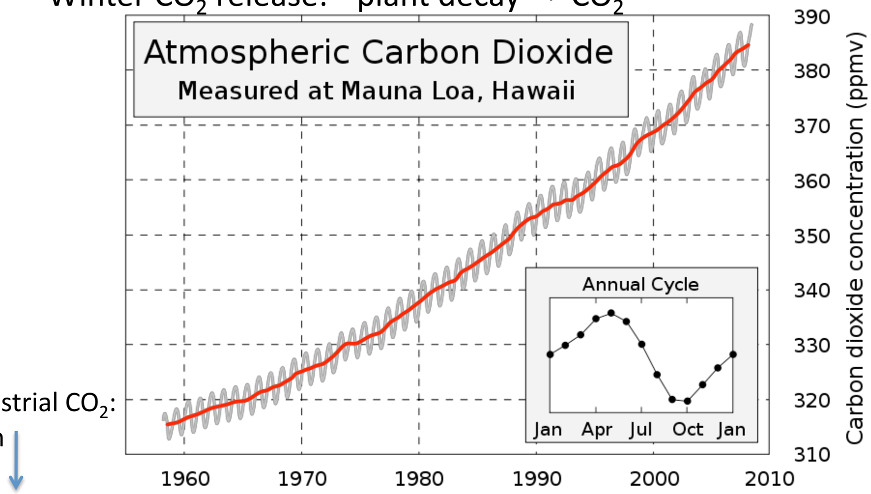
IPCC, 2007

Figure SPM.2. *Global average radiative forcing (RF) estimates and ranges in 2005 for anthropogenic carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and other important agents and mechanisms, together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding (LOSU). The net anthropogenic radiative forcing and its range are also*

The elephant in the atmosphere: CO_2

- 2010 peak CO_2 at Mauna Loa: 391 ppm
- Seasonal wiggle of about 2 ppm: biosphere "breathing"
  - Summer CO_2 drawdown:
    CO_2 + H_2O + sunlight → O_2 + plant biomass (photosynthesis)
  - Winter CO_2 release: plant decay → CO_2

Pre-industrial CO_2: 280 ppm

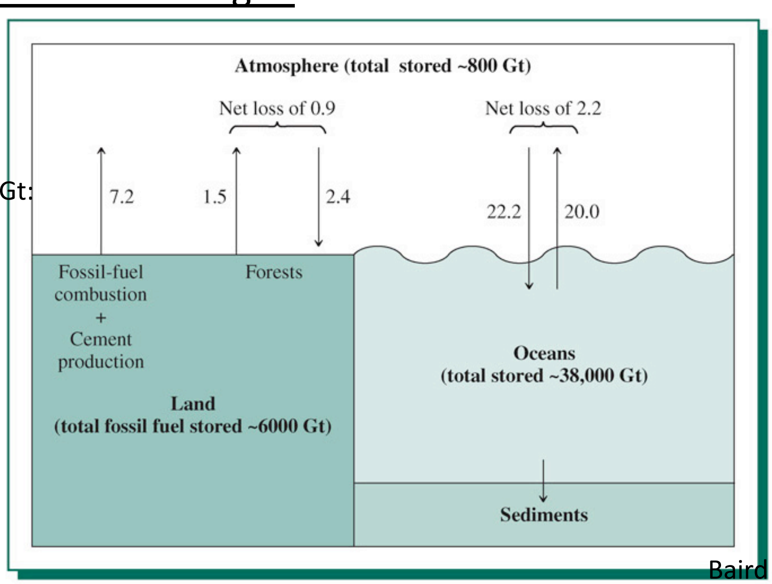


Fate of atmospheric CO_2

Annual anthropogenic CO_2 inputs ~ 7 Gt C per year, of which only ~ 4.7 Gt remains in atmos.

<u>Where does the rest go?</u>

Annual fluxes in Gt:



Baird & Cann, 2008

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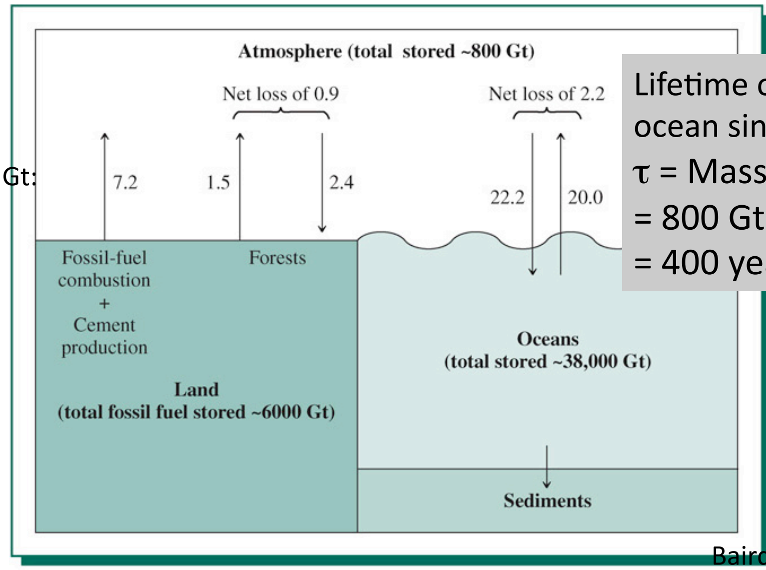


Lifetime of CO_2 w.r.t. ocean sink:
τ = Mass/Flux
= 800 Gt / 2.2 Gt yr^{-1}
= 400 years!

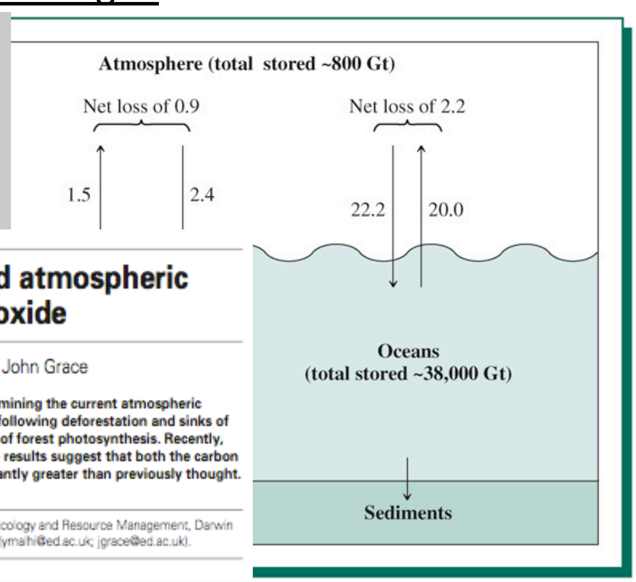
Baird & Cann, 2008

Fate of atmospheric CO_2

Annual anthropogenic CO_2 inputs ~ 7 Gt C per year, of which only ~ 4.7 Gt remains in atmos.

<u>Where does the rest go?</u>

CO_2 sink to forests is poorly quantified! Varies with tree age; lifetime in biomass poorly constrained



Tropical forests and atmospheric carbon dioxide

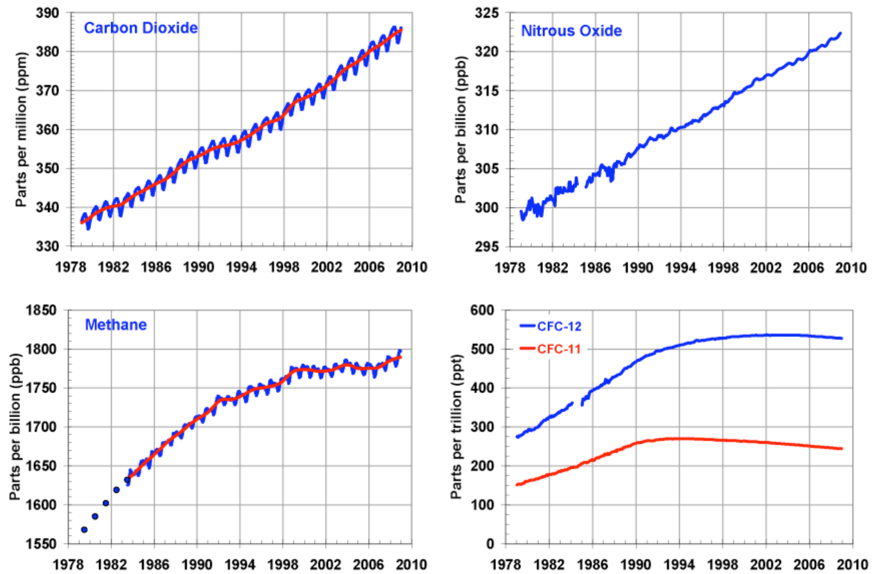
Yadvinder Malhi and John Grace

Tropical forests play a major role in determining the current atmospheric concentration of CO_2, as both sources of CO_2 following deforestation and sinks of CO_2 probably resulting from CO_2 stimulation of forest photosynthesis. Recently, researchers have tried to quantify this role. The results suggest that both the carbon sources and sinks in tropical forests are significantly greater than previously thought.

Yadvinder Malhi and John Grace are at the Institute of Ecology and Resource Management, Darwin Building, University of Edinburgh, UK EH9 3JU (ymalhi@ed.ac.uk; jgrace@ed.ac.uk).

TREE, 2000

The warming components:
Empirical understanding of GHG radiative forcing
1. Concentrations



http://www.esrl.noaa.gov/gmd/aggi/

The warming components:
Empirical understanding of GHG radiative forcing
2. Formulae

Table 1. Expressions for Calculating Radiative Forcing*

Trace Gas	Simplified Expression Radiative Forcing, ΔF (Wm^{-2})	Constant
CO_2	$\Delta F = \alpha \ln(C/C_o)$	$\alpha = 5.35$
CH_4	$\Delta F = \beta(M^{½} - M_o^{½}) - [f(M,N_o) - f(M_o,N_o)]$	$\beta = 0.036$
N_2O	$\Delta F = \varepsilon(N^{½} - N_o^{½}) - [f(M_o,N) - f(M_o,N_o)]$	$\varepsilon = 0.12$
CFC-11	$\Delta F = \lambda(X - X_o)$	$\lambda = 0.25$
CFC-12	$\Delta F = \omega(X - X_o)$	$\omega = 0.32$

*IPCC (2001)

The subscript "o" denotes the unperturbed (1750) concentration

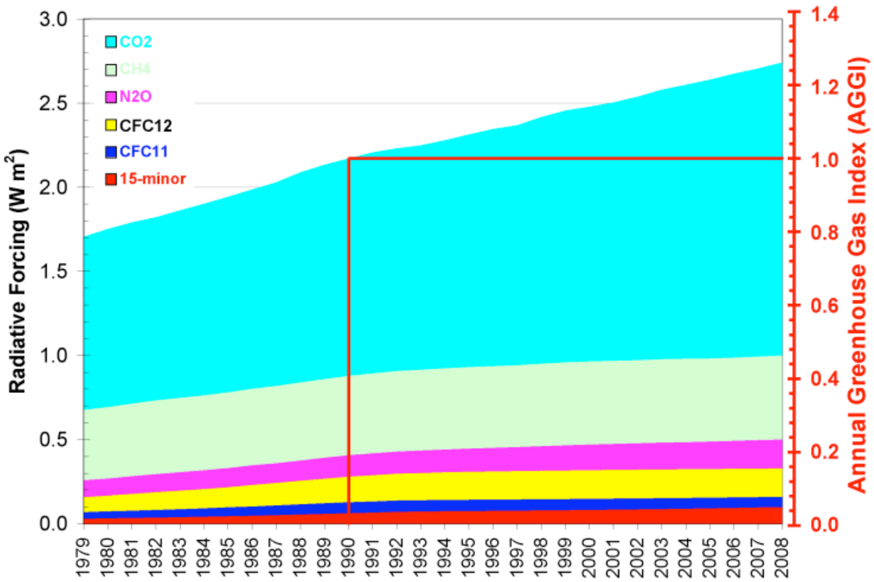
$f(M,N) = 0.47\ln[1 + 2.01\times10^{-5} (MN)^{0.75} + 5.31\times10^{-15}M(MN)^{1.52}]$

C is CO_2 in ppm, M is CH_4 in ppb
N is N_2O in ppb, X is CFC in ppb

C_o = 278 ppm, M_o = 700 ppb, N_o = 270 ppb, X_o = 0

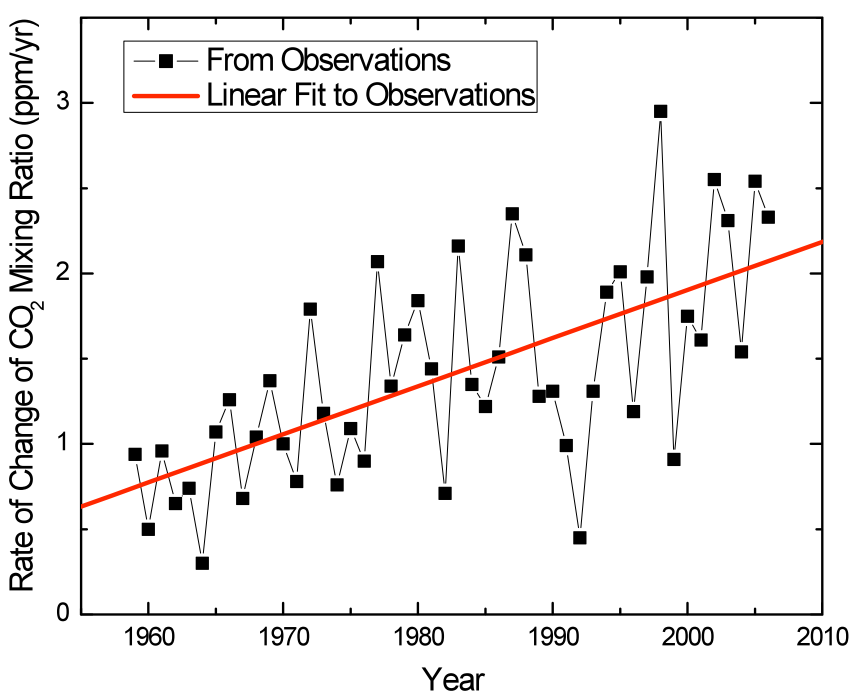
http://www.esrl.noaa.gov/gmd/aggi/

The warming components:
Empirical understanding of GHG radiative forcing
3. Historical forcing trends



http://www.esrl.noaa.gov/gmd/aggi/

Rate of change of [CO_2] increasing



CO_2: biggest driver. How much warming? "Climate sensitivity"

= Expected equilibrium T increase if $[CO_2]$ levels off at double pre-industrial (550ppm)

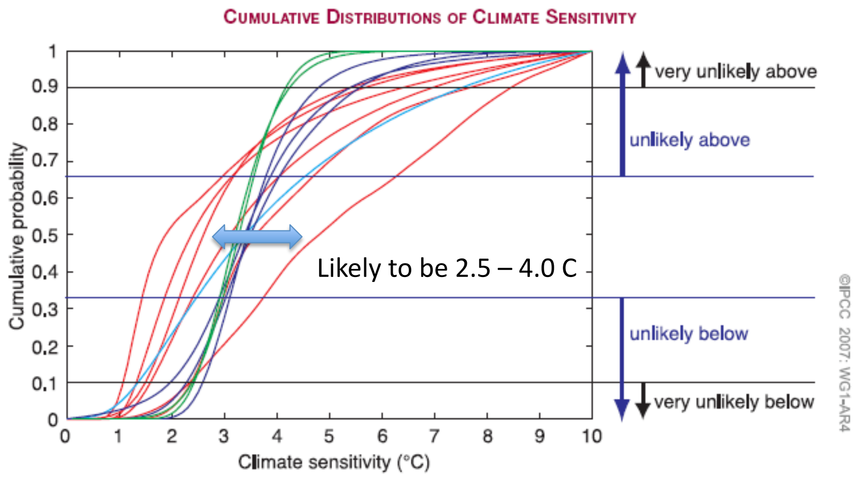


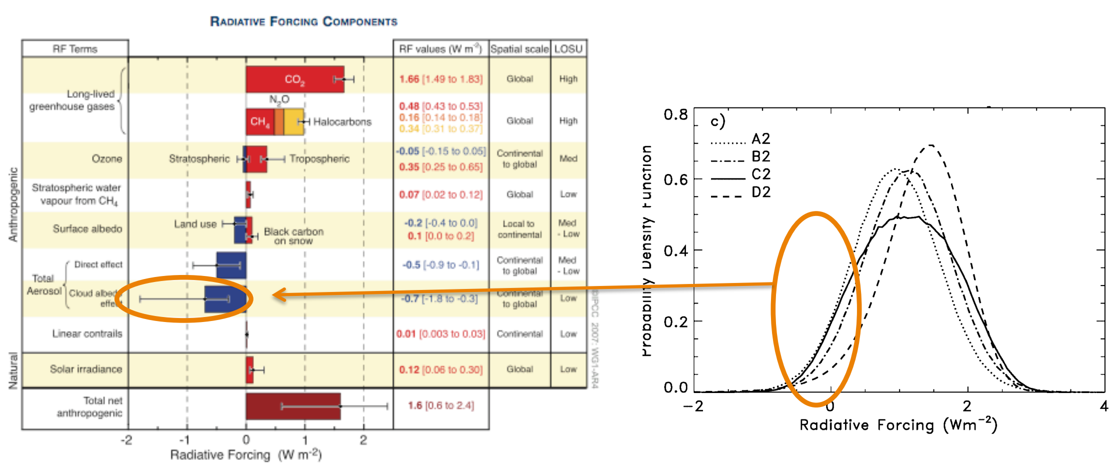
Figure TS.25. *Cumulative distributions of climate sensitivity derived from observed 20th-century warming (red), model climatology (blue), proxy evidence (cyan) and from climate sensitivities of AOGCMs (green). Horizontal lines and arrows mark the boundaries of the likelihood estimates defined in the IPCC Fourth Assessment Uncertainty Guidance Note (see Box TS.1). {Box 10.2, Figures 1 and 2}*

__Equilibrium climate sensitivity (ECS):__ "Global annual mean surface air temperature change experienced by the climate system after it has attained equilibrium in response to a doubling of atmospheric CO_2."

IPCC, 2007

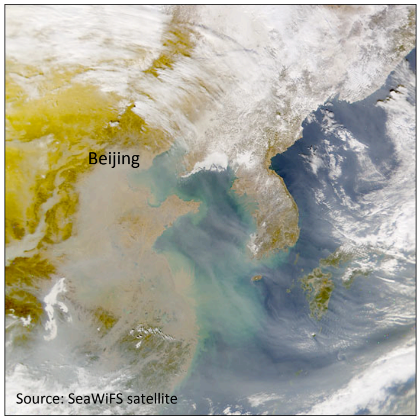
What limits accuracy of climate sensitivity estimates using 20th century temperature trends?

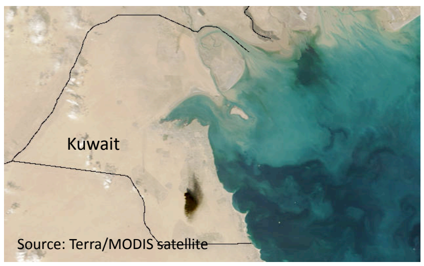
➔ **Uncertainty in aerosols!**

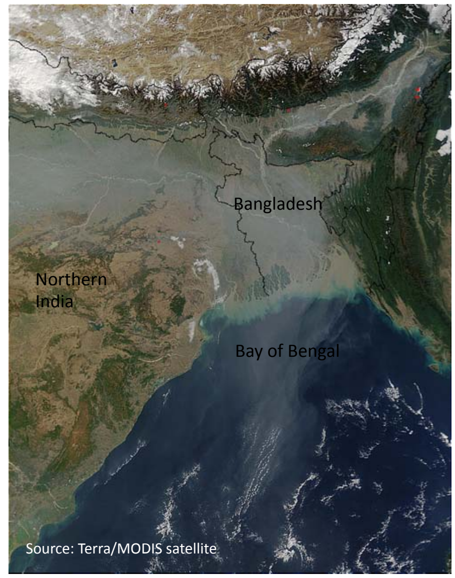


CO_2 and other GHG warming has been offset by an highly uncertain aerosol forcing in the __cooling__ direction.

Different types of Aerosols

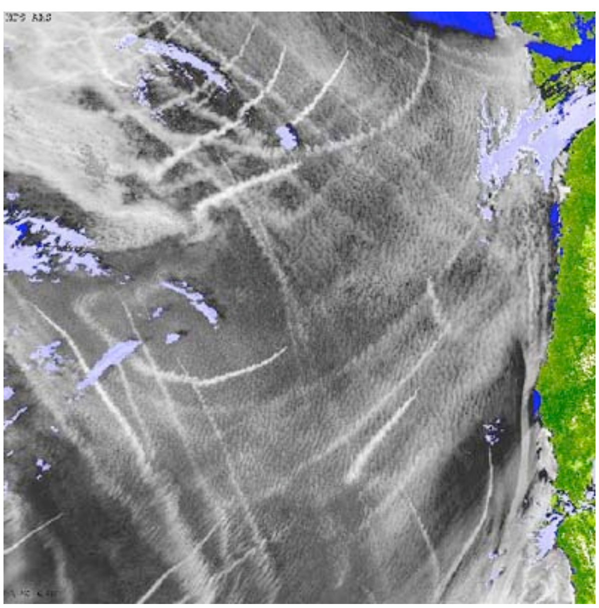






http://visibleearth.nasa.gov

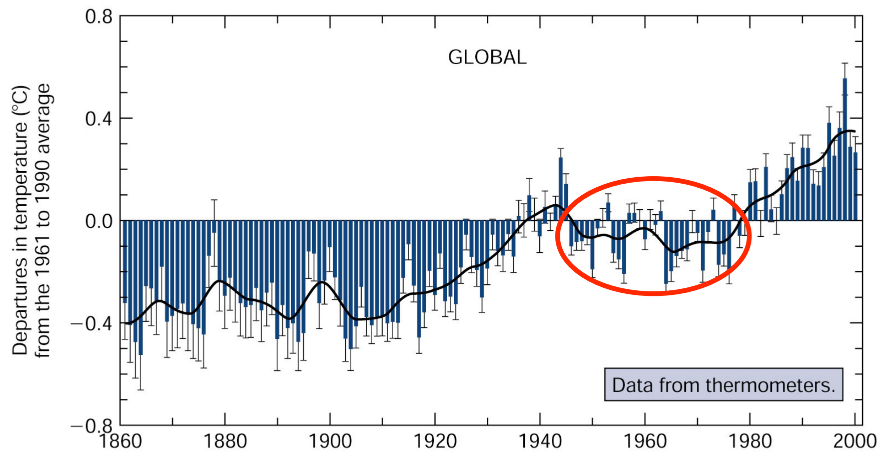
Ship Tracks and Contrails



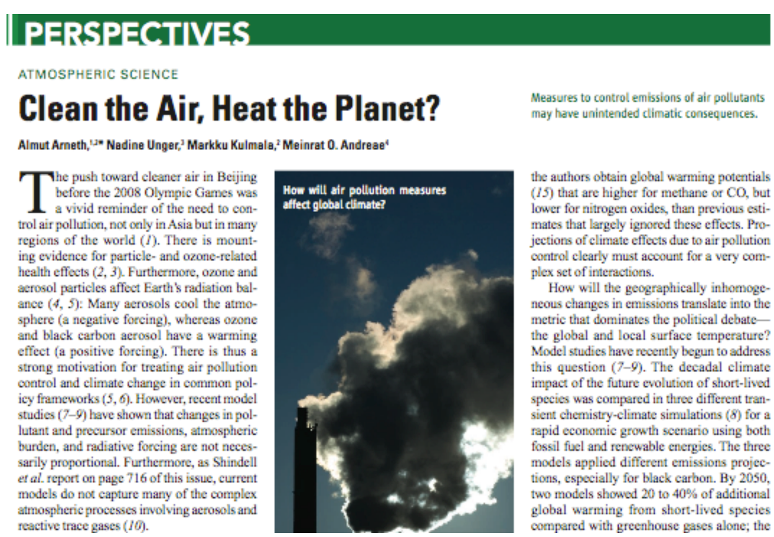
Examples of Aerosol Indirect Effects on Clouds

Sulfate Cooling Mid 20th Century

Aerosol direct effect thought to explain temporary hiatus in T increase



Could cleaning up airborne particulates accelerate warming?



PERSPECTIVES

ATMOSPHERIC SCIENCE

Clean the Air, Heat the Planet?

Measures to control emissions of air pollutants may have unintended climatic consequences.

Almut Arneth,[1,2*] Nadine Unger,[3] Markku Kulmala,[2] Meinrat O. Andreae[4]

The push toward cleaner air in Beijing before the 2008 Olympic Games was a vivid reminder of the need to control air pollution, not only in Asia but in many regions of the world (*1*). There is mounting evidence for particle- and ozone-related health effects (*2*, *3*). Furthermore, ozone and aerosol particles affect Earth's radiation balance (*4*, *5*): Many aerosols cool the atmosphere (a negative forcing), whereas ozone and black carbon aerosol have a warming effect (a positive forcing). There is thus a strong motivation for treating air pollution control and climate change in common policy frameworks (*5*, *6*). However, recent model studies (*7*–*9*) have shown that changes in pollutant and precursor emissions, atmospheric burden, and radiative forcing are not necessarily proportional. Furthermore, as Shindell *et al.* report on page 716 of this issue, current models do not capture many of the complex atmospheric processes involving aerosols and reactive trace gases (*10*).

the authors obtain global warming potentials (*15*) that are higher for methane or CO, but lower for nitrogen oxides, than previous estimates that largely ignored these effects. Projections of climate effects due to air pollution control clearly must account for a very complex set of interactions.

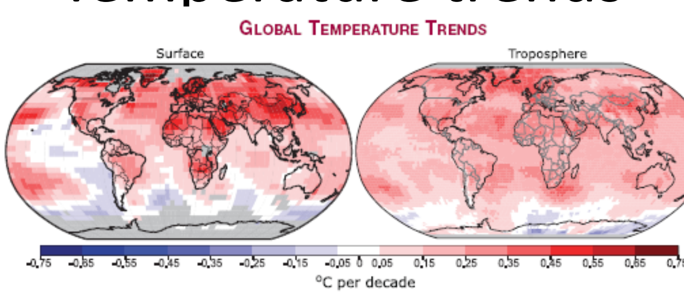
How will the geographically inhomogeneous changes in emissions translate into the metric that dominates the political debate—the global and local surface temperature? Model studies have recently begun to address this question (*7*–*9*). The decadal climate impact of the future evolution of short-lived species was compared in three different transient chemistry-climate simulations (*8*) for a rapid economic growth scenario using both fossil fuel and renewable energies. The three models applied different emissions projections, especially for black carbon. By 2050, two models showed 20 to 40% of additional global warming from short-lived species compared with greenhouse gases alone; the

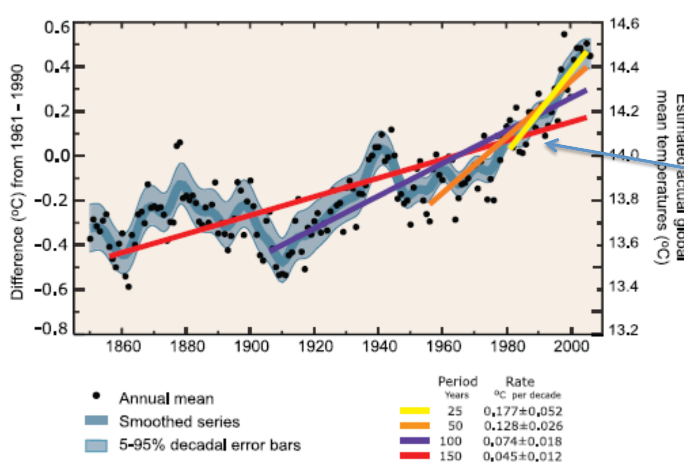
Might we want to keep those particles aloft?? Or even … add more?

Observations of a changing climate

Temperature trends

Land warming faster than oceans (recall thermal inertia)

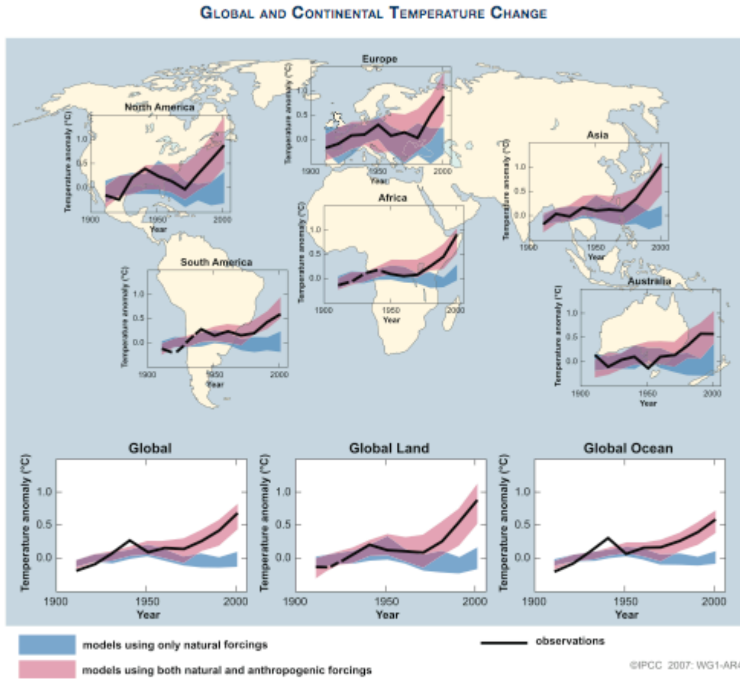




Rate of warming *doubled* in later half of 20th century

IPCC, 2007

Attribution: Temperature trend can only be modeled with anthropogenic contribution



Cryosphere trends

NH Changes in Snow Cover

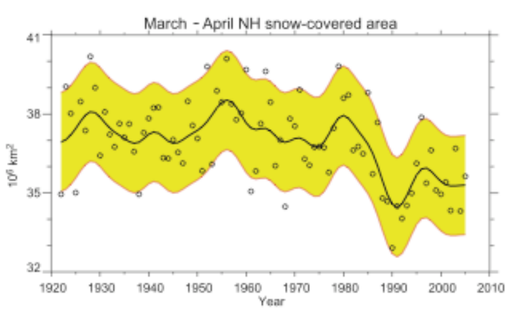


Figure 4.2. *Update of NH March-April average snow-covered area (SCA) from Brown (2000). Values of SCA before 1972 are based on the station-derived snow cover index of Brown (2000); values beginning in 1972 are from the NOAA satellite data set. The smooth curve shows decadal variations (see Appendix 3.A), and the shaded area shows the 5 to 95% range of the data estimated after first subtracting the smooth curve.*

Hemispheric Changes in Sea Ice Extent

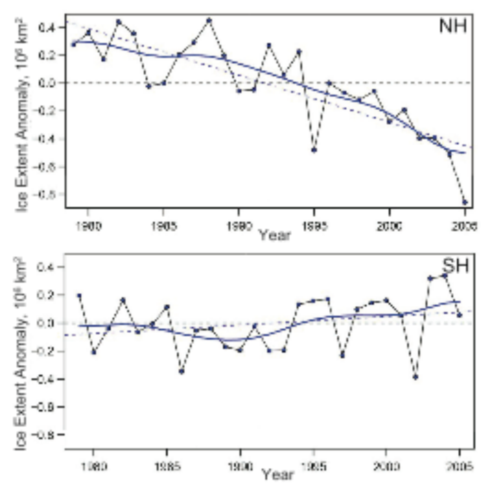
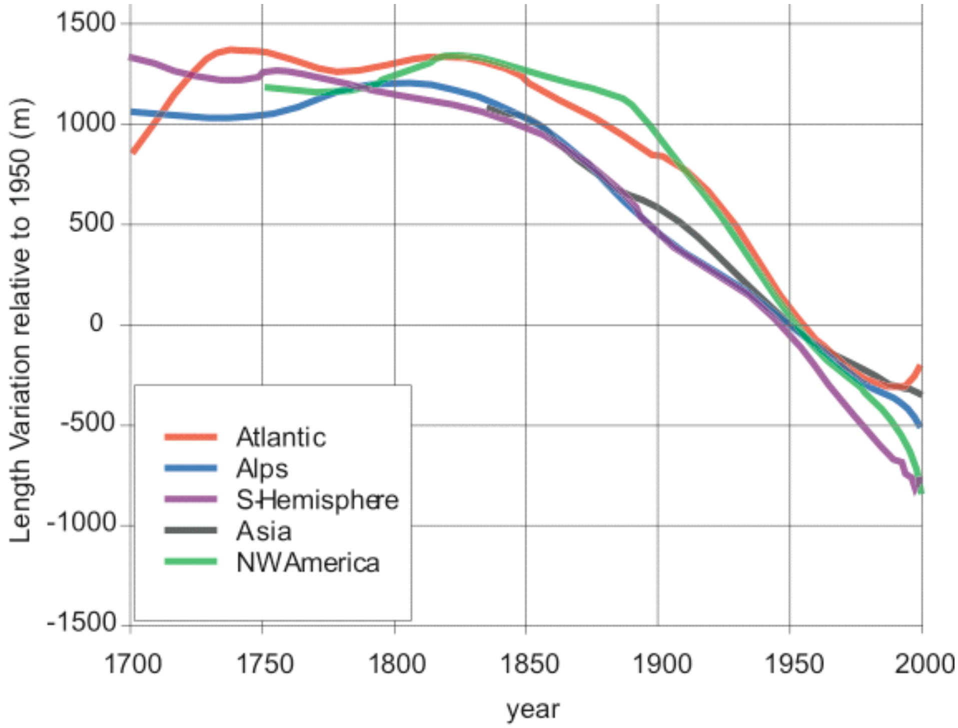


Figure 4.8. *Sea ice extent anomalies (computed relative to the mean of the entire period) for (a) the NH and (b) the SH, based on passive microwave satellite data. Symbols indicate annual mean values while the smooth blue curves show decadal variations (see Appendix 3.A). Linear trend lines are indicated for each hemisphere. For the Arctic, the trend is $-33 \pm 7.4 \times 10^3$ km^2 yr^{-1} (equivalent to approximately –2.7% per decade), whereas the Antarctic results show a small positive trend of $5.6 \pm 9.2 \times 10^3$ km^2 yr^{-1}. The negative trend in the NH is significant at the 90% confidence level whereas the small positive trend in the SH is not significant (updated from Comiso, 2003).*

Glacier Lengths



Tropical Glaciers

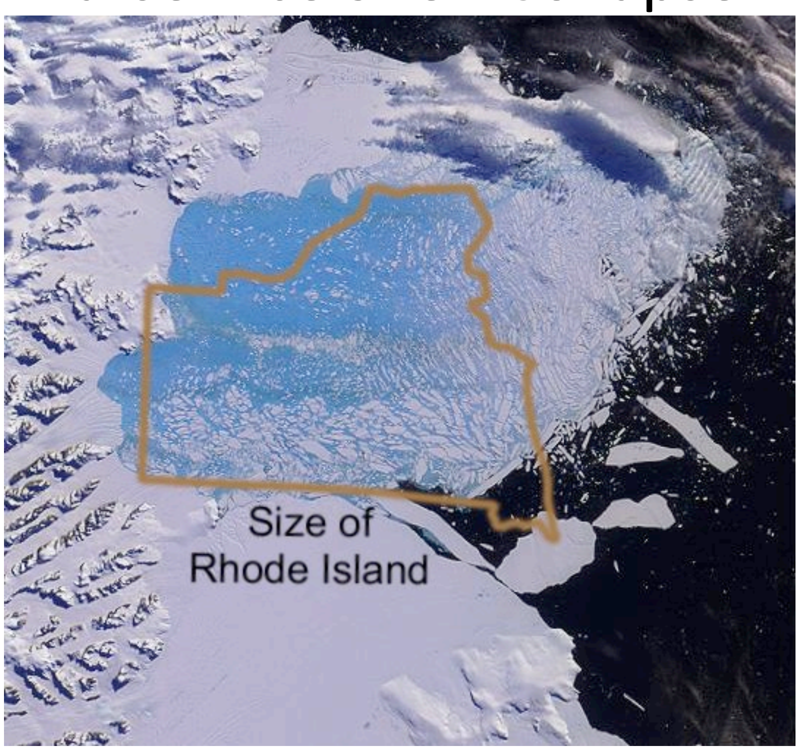
Qori Kalis

Snows of Kilimanjaro

February 17, 1993

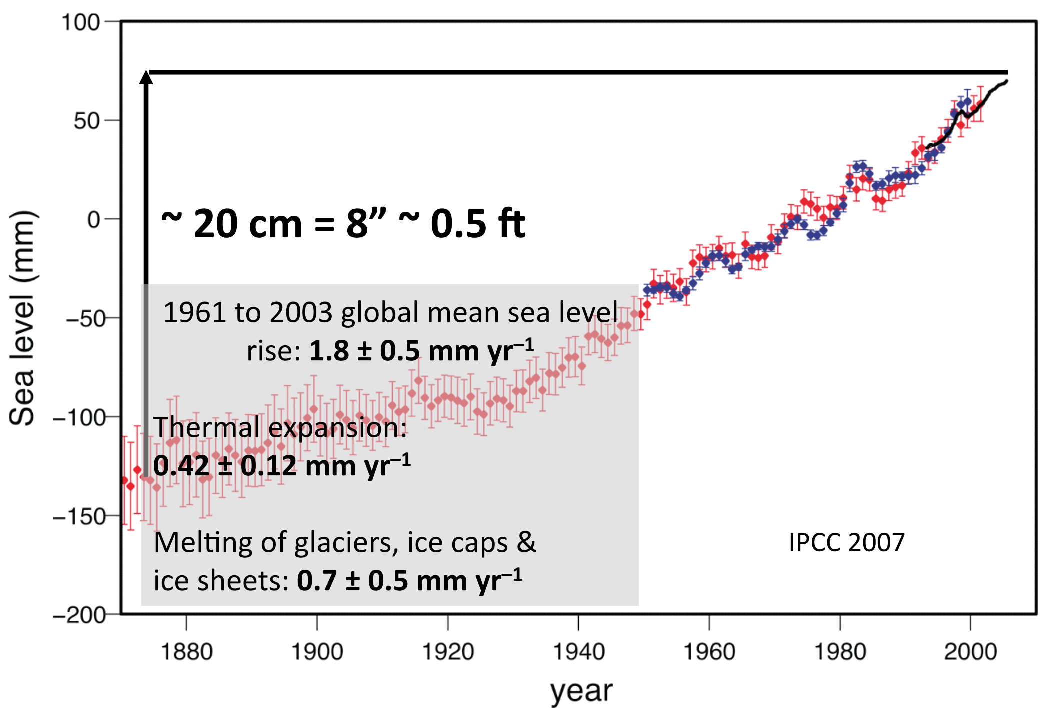
February 21, 2000

Larsen Ice Shelf Collapse



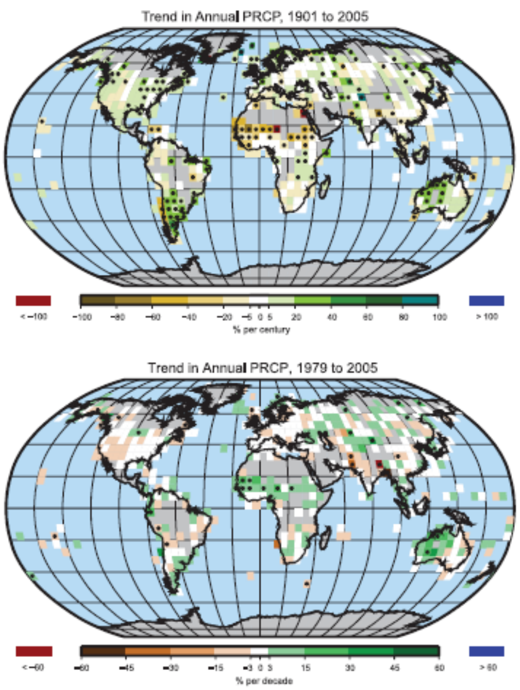
Shrinking polar ice caps

Global Mean Sea Level Measurements



Precipitation trends

GLOBAL MEAN PRECIPITATION



Over the 20th century:

wetter eastern North America and southern South America, western Australia, northern Europe and northern and central Asia

dryer Sahel (Africa), southern Europe, southern Africa and parts of southern Asia

Extreme precipitation:

Warmer sea surface temperatures in the Atlantic are correlated with increasing intense tropical cyclone activity.

ANNUAL SEA-SURFACE TEMPERATURE ANOMALIES

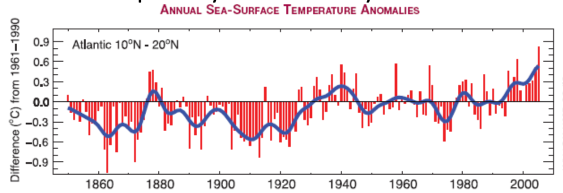
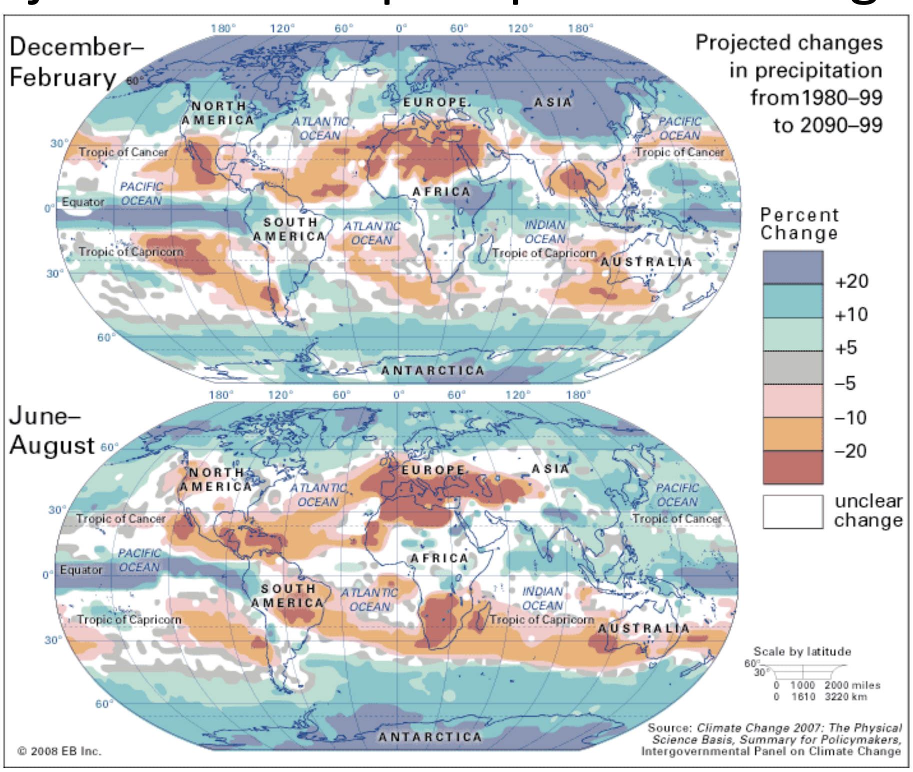


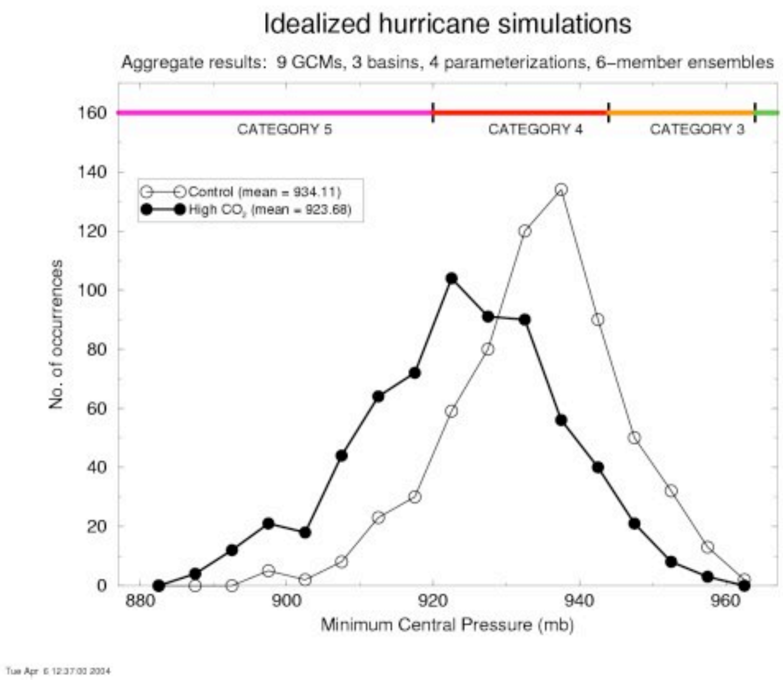
Figure TS.11. *Tropical Atlantic (10°N–20°N) sea surface temperature annual anomalies (°C) in the region of Atlantic hurricane formation, relative to the 1961 to 1990 mean. {Figure 3.33}*

IPCC, 2007

Projected future precipitation changes

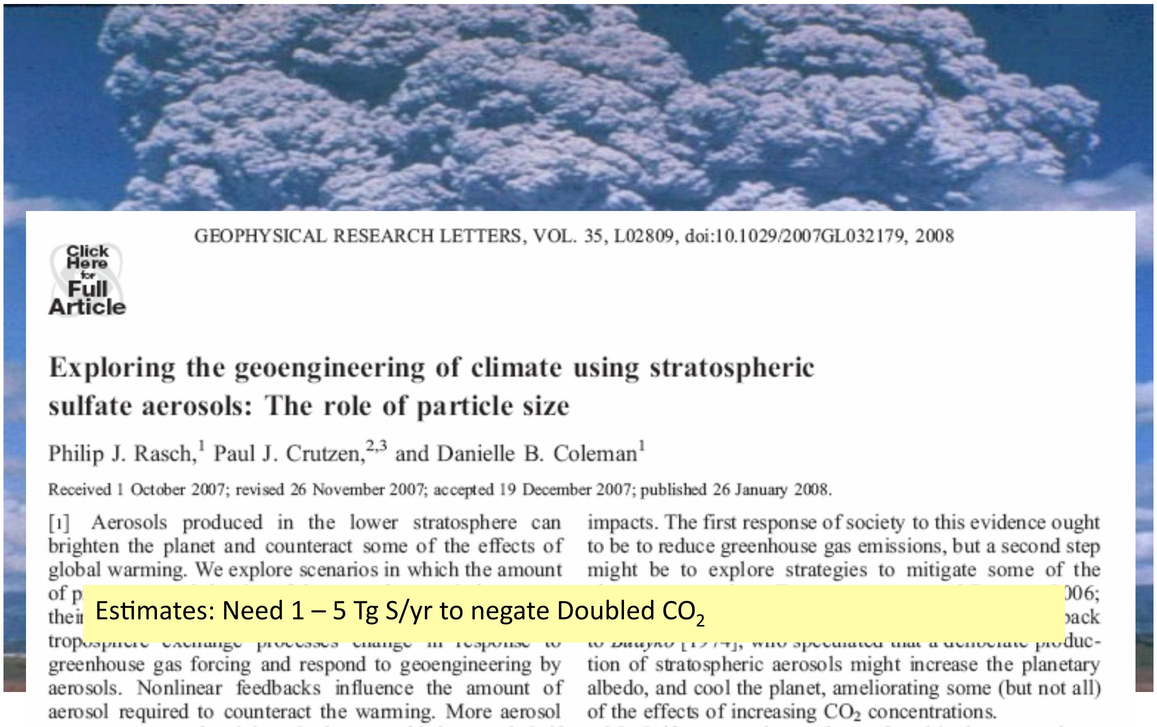


Hurricane Intensity Change



but …. areas downwind of Iceland have recently cooled …

So …. is this an option?



GEOPHYSICAL RESEARCH LETTERS, VOL. 35, L02809, doi:10.1029/2007GL032179, 2008

Click Here for Full Article

Exploring the geoengineering of climate using stratospheric sulfate aerosols: The role of particle size

Philip J. Rasch,[1] Paul J. Crutzen,[2,3] and Danielle B. Coleman[1]

Received 1 October 2007; revised 26 November 2007; accepted 19 December 2007; published 26 January 2008.

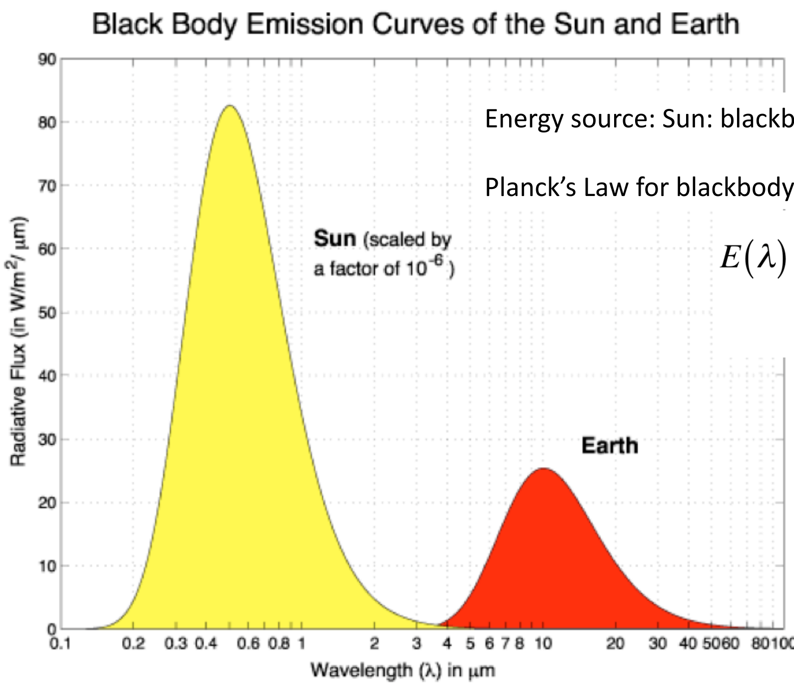
[1] Aerosols produced in the lower stratosphere can brighten the planet and counteract some of the effects of global warming. We explore scenarios in which the amount of p… thei… tropo… greenhouse gas forcing and respond to geoengineering by aerosols. Nonlinear feedbacks influence the amount of aerosol required to counteract the warming. More aerosol

impacts. The first response of society to this evidence ought to be to reduce greenhouse gas emissions, but a second step might be to explore strategies to mitigate some of the …006; …back … tion of stratospheric aerosols might increase the planetary albedo, and cool the planet, ameliorating some (but not all) of the effects of increasing CO_2 concentrations.

Estimates: Need 1 – 5 Tg S/yr to negate Doubled CO_2

Extras

Reminder of Earth's Energy Balance

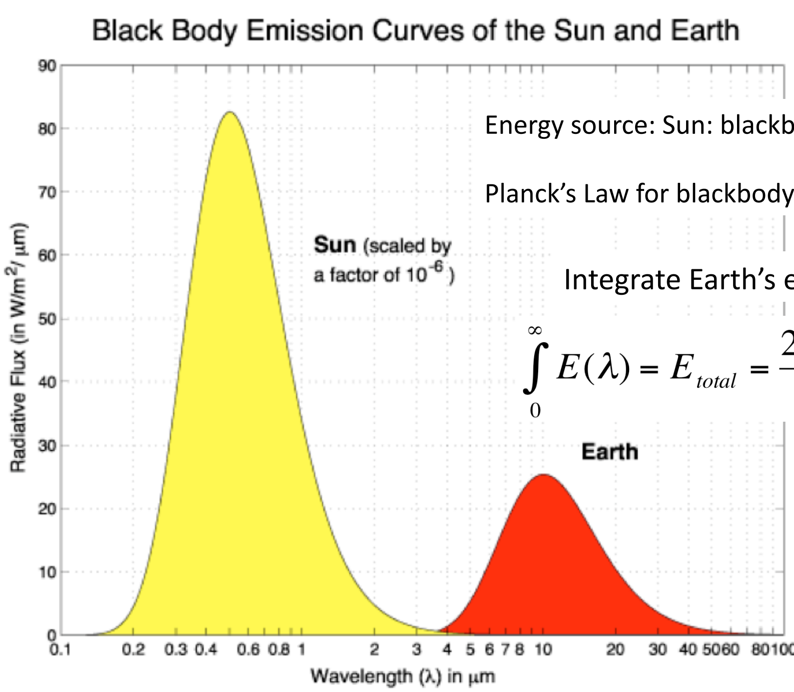


Energy source: Sun: blackbody @ T_{sun} ~ 5800 K

Planck's Law for blackbody radiation:

$$E(\lambda) = \frac{2\pi hc^2\lambda^{-5}}{\exp\left(\frac{hc}{\lambda k_B T}\right) - 1}$$

Reminder of Earth's Energy Balance



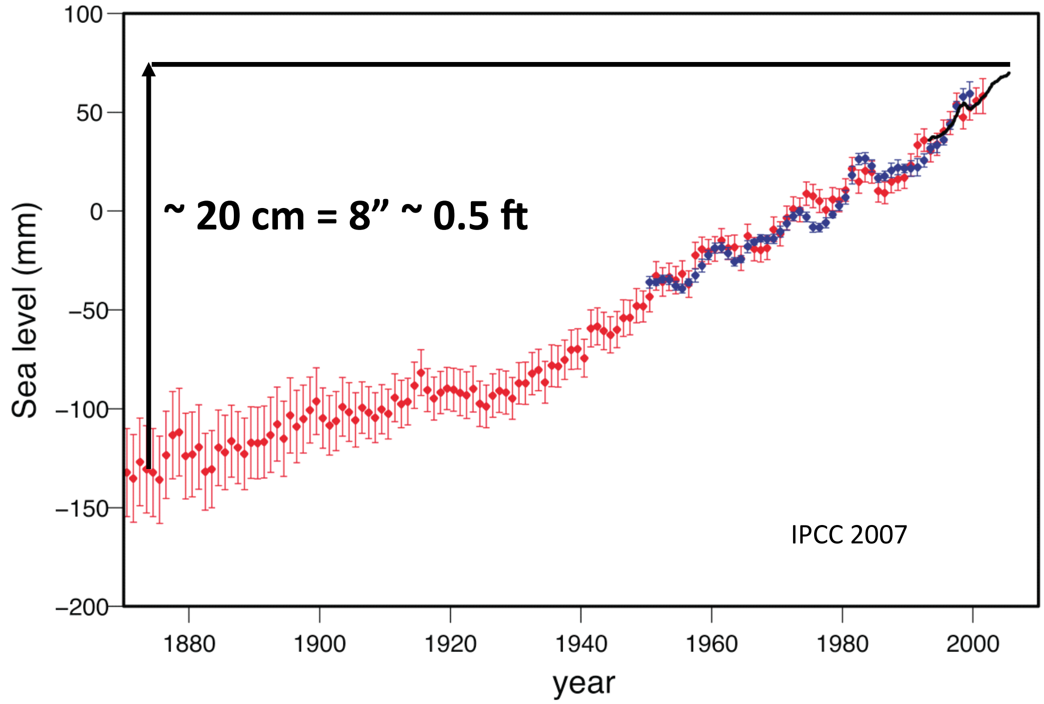
Energy source: Sun: blackbody @ T_{sun} ~ 5800 K

Planck's Law for blackbody radiation:

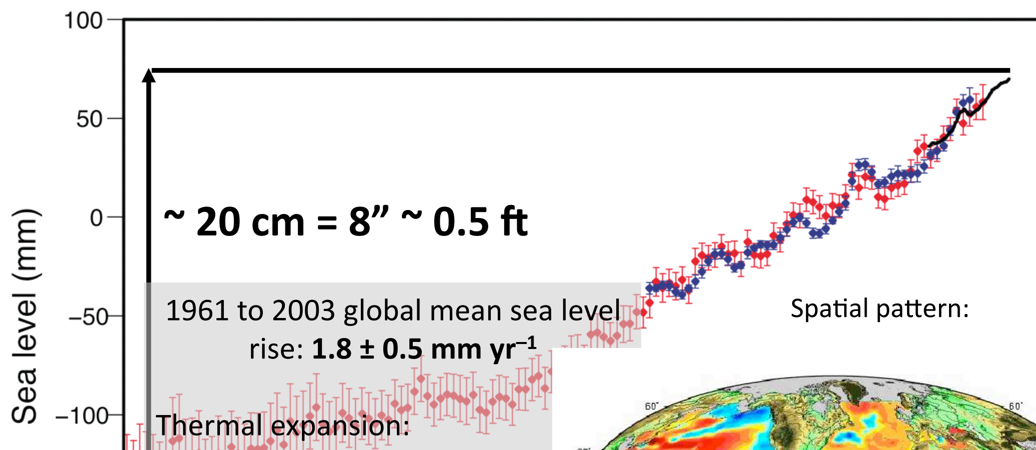
Integrate Earth's energy output:

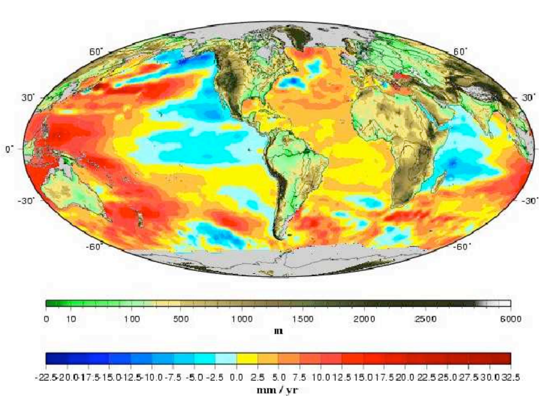
$$\int_0^\infty E(\lambda) = E_{total} = \frac{2\pi^5 k_B^4 T^4}{15c^2h^3} = \sigma T^4$$

Global Mean Sea Level Measurements

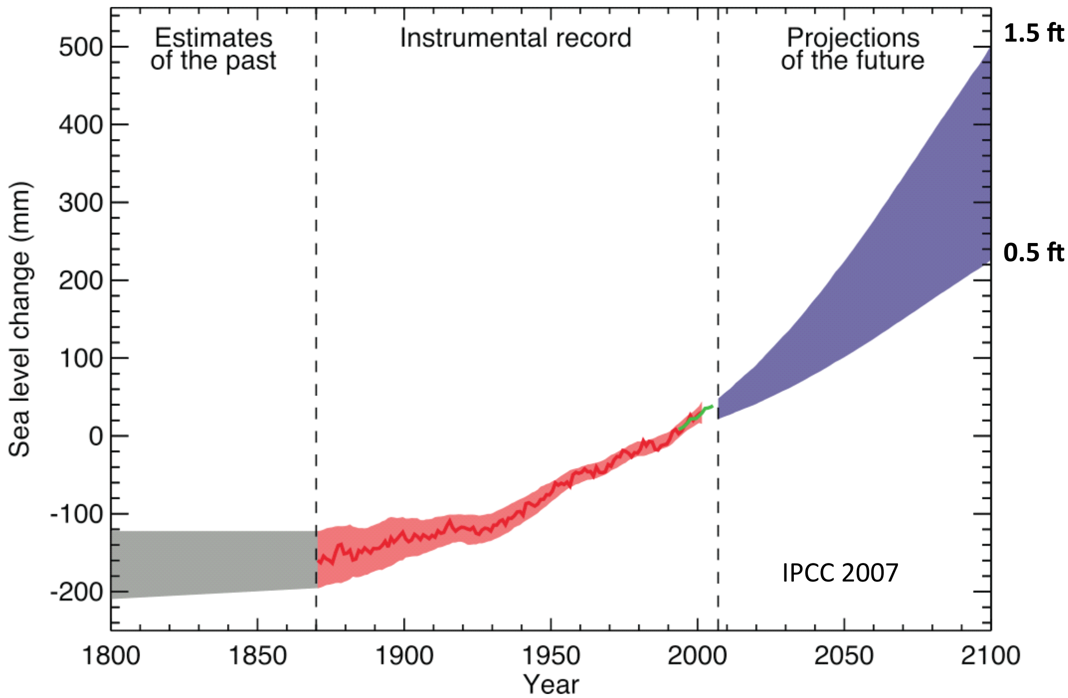


Global Mean Sea Level Measurements

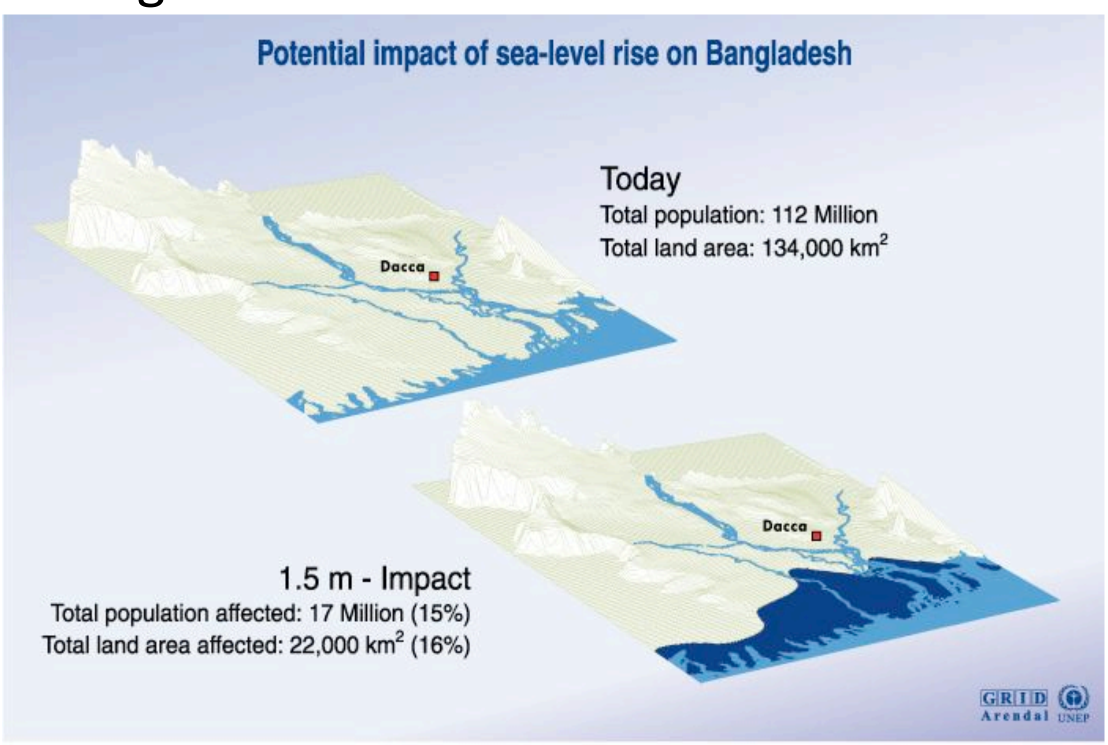




Sea Level Projections

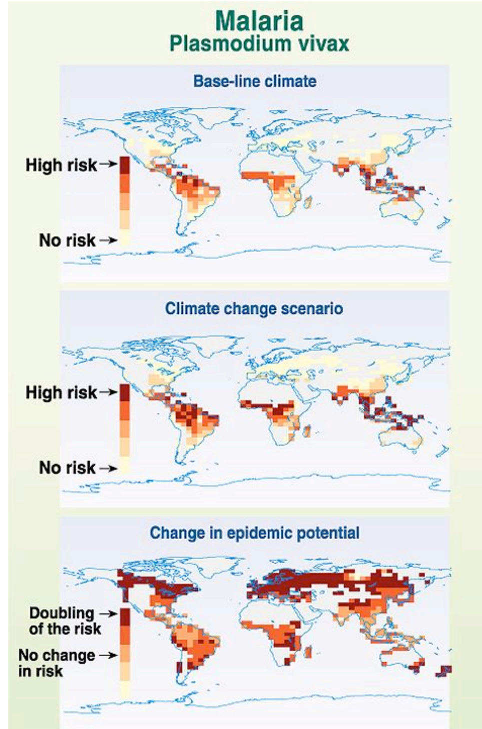


Bangladesh Under 1 Meter Sea Level Rise



Source : UNEP/GRID Geneva; University of Dacca; JRO Munich; The World Bank; World Resources Institute, Washington D.C.

Mosquito-borne diseases



Potential malaria risk areas for base-line climate conditions (1831-1980) and for a global mean temperature increase of 1.16°C (based on the climate patterns generated by the ECHAM1-A GCM) and changes in average annual "epidemic potential" (EP), a measure of vectorial capacity, relative to base-line climate, for P. vivax.

Source: Martens, P. et al. (1995). Potential impacts of climate change on malaria risk. Environme
Health Perspectives, 103(5), 458-464.