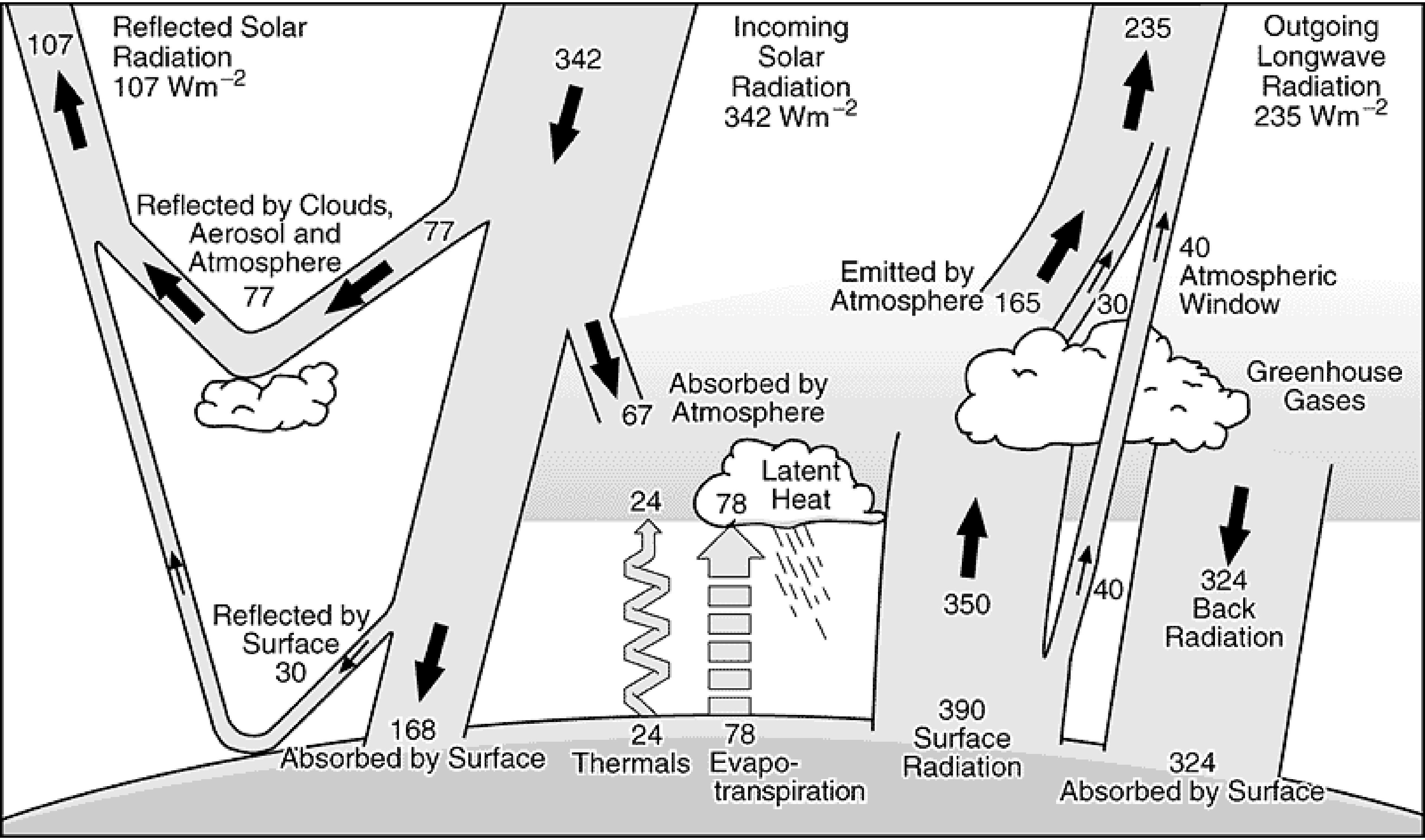
Global Climate Change: Data, Issues and Concerns


107
Reflected Solar Radiation 107 Wm^{-2}
342
Incoming Solar Radiation 342 Wm^{-2}
235
Outgoing Longwave Radiation 235 Wm^{-2}
Reflected by Clouds, Aerosol and Atmosphere
77
77
Emitted by Atmosphere
165
30
40
40 Atmospheric Window
Absorbed by Atmosphere
67
Greenhouse Gases
Latent Heat
24
78
350
40
324 Back Radiation
Reflected by Surface 30
168 Absorbed by Surface
24 Thermals
78 Evapo-transpiration
390 Surface Radiation
324 Absorbed by Surface

The "natural greenhouse effect" warms global surface temperature to approximately 33 °C above -18 °C, a temperature without any greenhouse effect, so that the current global surface temperature of the Earth is about 15 °C.

However, there is no doubt that too much human-enhanced greenhouse effect may cause unwanted global warming.

Here are some headlines from IPCC-2013 summary:

1. Warming of the climate system is **unequivocal**, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased.
2. Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. In the Northern Hemisphere, 1983–2012 was likely the warmest 30-year period of the last 1400 years.
3. Ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010. It is virtually certain that the upper ocean (0−700 m) warmed from 1971 to 2010, and it likely warmed between the 1870s and 1971.
4. Over the last two decades, the Greenland and Antarctic ice sheets have been losing mass, glaciers have continued to shrink almost worldwide, and Arctic sea ice and Northern Hemisphere spring snow cover have continued to decrease in extent.
5. The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia. Over the period from 1901 to 2010, global mean sea level rose by 0.19 meters.
6. The atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have increased to levels unprecedented in at least the last 800,000 years. Carbon dioxide concentrations have increased by 40% since pre-industrial times, primarily from fossil fuel emissions and secondarily from net land use change emissions. The ocean has absorbed about 30% of the emitted anthropogenic carbon dioxide, causing ocean acidification.
7. Total radiative forcing is positive, and has led to an uptake of energy by the climate system. The largest contribution to total radiative forcing is caused by the increase in the atmospheric concentration of CO2 since 1750.
8. Human influence on the climate system is clear. This is evident from the increasing greenhouse gas concentrations in the atmosphere, positive radiative forcing, observed warming, and understanding of the climate system.
9. Climate models have improved since the AR4. Models reproduce observed continental-scale surface temperature patterns and trends over many decades, including the more rapid warming since the mid-20th century and the cooling immediately following large volcanic eruptions (very high confidence).
10. Human influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in global mean sea level rise, and in changes in some climate extremes (see Figure SPM.6 and Table SPM.1). This evidence for human influence has grown since AR4. It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century.

Future Aspects:

11. Continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system. Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions.
12. Global surface temperature change for the end of the 21st century is likely to exceed 1.5°C relative to 1850 to 1900 for all RCP scenarios except RCP2.6. It is likely to exceed 2°C for RCP6.0 and RCP8.5, and more likely than not to exceed 2°C for RCP4.5. Warming will continue beyond 2100 under all RCP scenarios except RCP2.6. Warming will continue to exhibit interannual-to-decadal variability and will not be regionally uniform.
13. Changes in the global water cycle in response to the warming over the 21st century will not be uniform. The contrast in precipitation between wet and dry regions and between wet and dry seasons will increase, although there may be regional exceptions.
14. The global ocean will continue to warm during the 21st century. Heat will penetrate from the surface to the deep ocean and affect ocean circulation.
15. It is very likely that the Arctic sea ice cover will continue to shrink and thin and that Northern Hemisphere spring snow cover will decrease during the 21st century as global mean surface temperature rises. Global glacier volume will further decrease.
16. Global mean sea level will continue to rise during the 21st century. Under all RCP scenarios, the rate of sea level rise will very likely exceed that observed during 1971 to 2010 due to increased ocean warming and increased loss of mass from glaciers and ice sheets.
17. Climate change will affect carbon cycle processes in a way that will exacerbate the increase of CO2 in the atmosphere (high confidence). Further uptake of carbon by the ocean will increase ocean acidification.
18. Cumulative emissions of CO2 largely determine global mean surface warming by the late 21st century and beyond. Most aspects of climate change will persist for many centuries even if emissions of CO2 are stopped. This represents a substantial multi-century climate change commitment created by past, present and future emissions of CO2.

Box SPM.1: Representative Concentration Pathways (RCPs)

They are identified by their approximate total radiative forcing in year 2100 relative to 1750:

2.6 W m-2 for RCP2.6,
4.5 W m-2 for RCP4.5,
6.0 W m-2 for RCP6.0, and
8.5 W m-2 for RCP8.5.

For the Coupled Model Intercomparison Project Phase 5 (CMIP5) results, these values should be understood as indicative only, as the climate forcing resulting from all drivers varies between models due to specific model characteristics and treatment of short-lived climate forcers. These four RCPs include one mitigation scenario leading to a very low forcing level (RCP2.6), two stabilization scenarios (RCP4.5 and RCP6), and one scenario with very high greenhouse gas emissions (RCP8.5).

Human-enhanced greenhouse effect can change the climate

Greenhouse effect is important and it influences the global climate. The "natural greenhouse effect" warms global surface temperature to approximately 33 °C above -18 °C, a temperature without any greenhouse effect.

Parameter	**CO_2**	**CH_4**	**CFC-11 ($CFCl_3$)**	**CFC-12 (CF_2Cl_2)**	**N_2O**
Pre-industrial atmospheric concentration (1750-1800)	**280 ppmv**	**0.8 ppmv**	**0**	**0**	**288 ppbv**
Current atmospheric concentration (1990)	**353 ppmv**	**1.72 ppmv**	**280 pptv$_2$**	**484 pptv**	**310 ppbv**
Current rate of annual atmospheric accumulation	**1.8 ppmv (0.5%)**	**0.015 ppmv (0.9%)**	**9.5 pptv (4%)**	**17 pptv (4%)**	**0.8 ppbv (0.25%)**
Atmospheric lifetime (years)	**(50-200)**	**10**	**65**	**130**	**150**
Radiative forcing factors	**1**	**21**	**12400**	**15800**	**206**

Key Greenhouse Gases Influenced by Human Activities

Parameter	CO_2	CH_4	CFC-11 ($CFCl_3$)	CFC-12 (CF_2Cl_2)	N_2O
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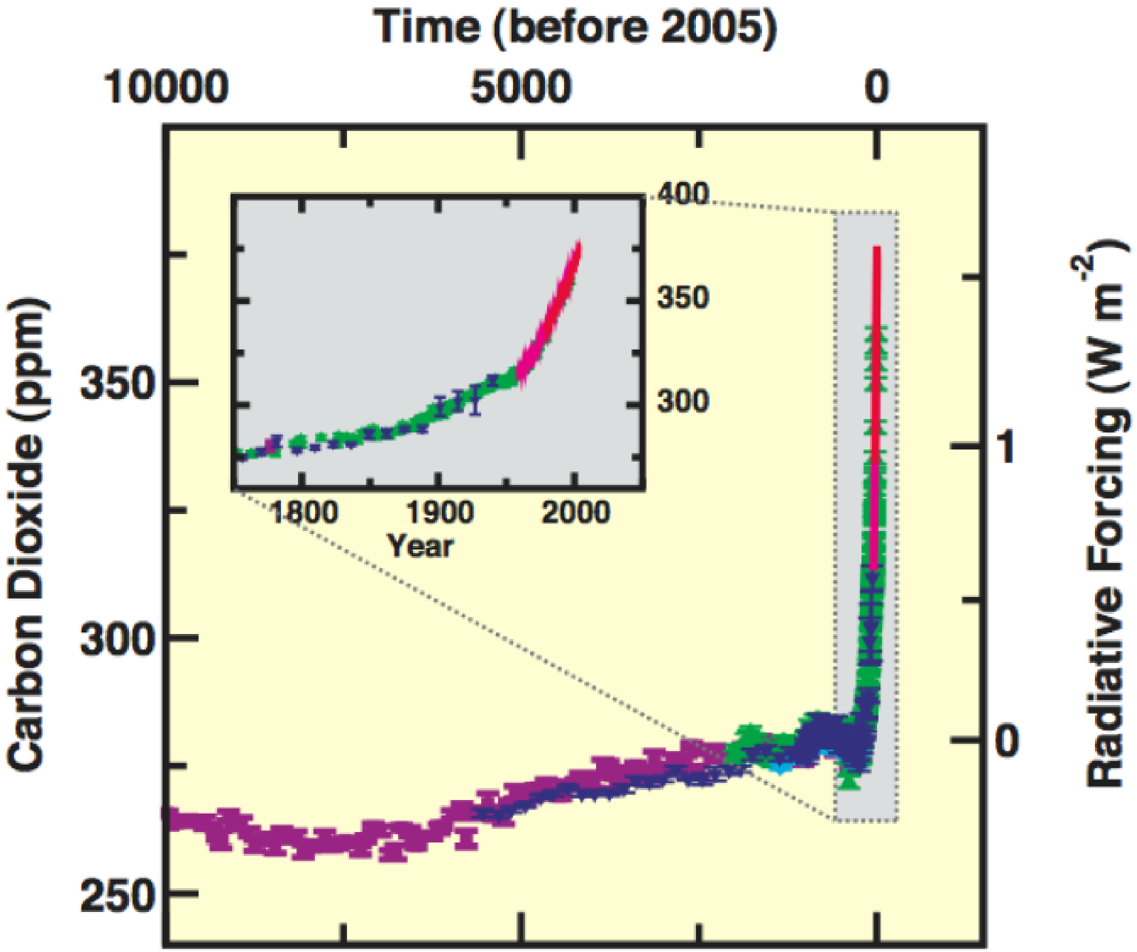
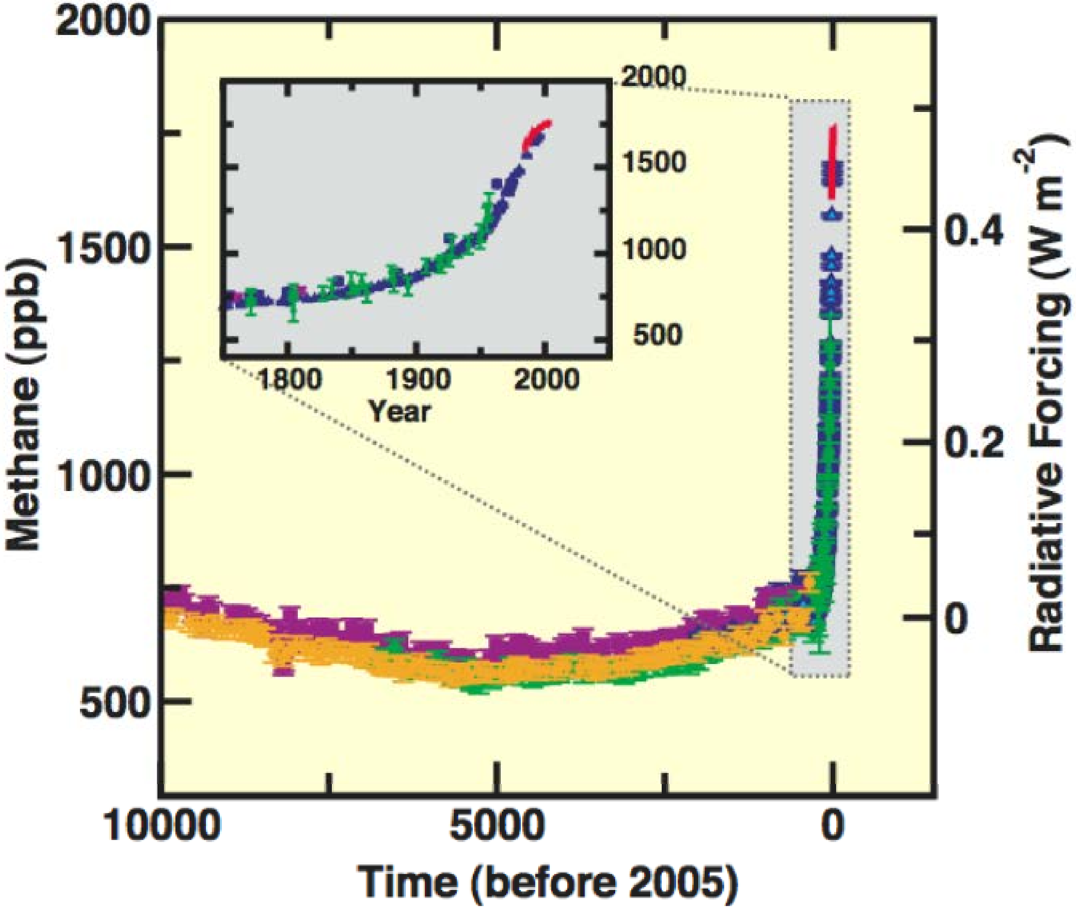
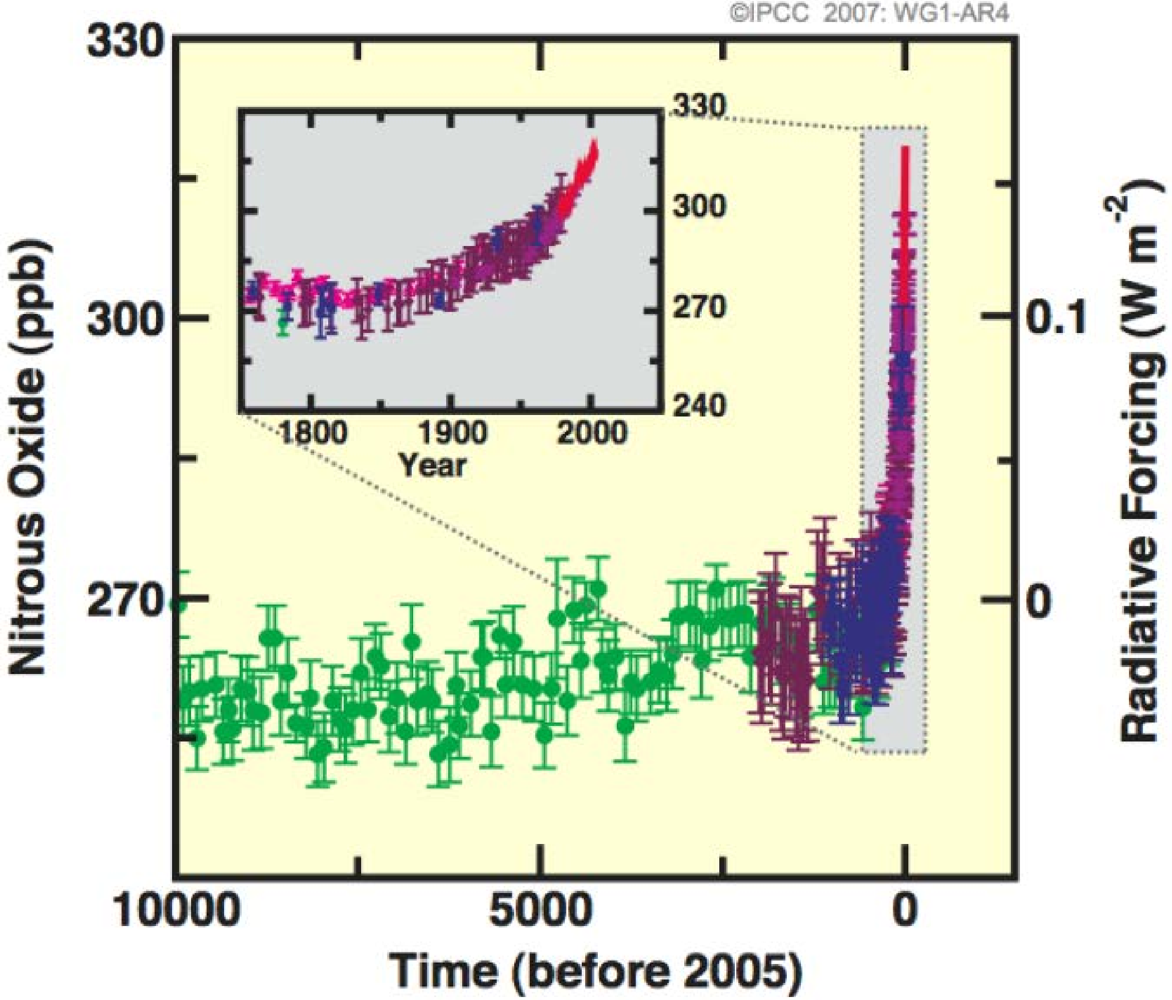
Radiative forcing factors	1	21	12400	15800	206

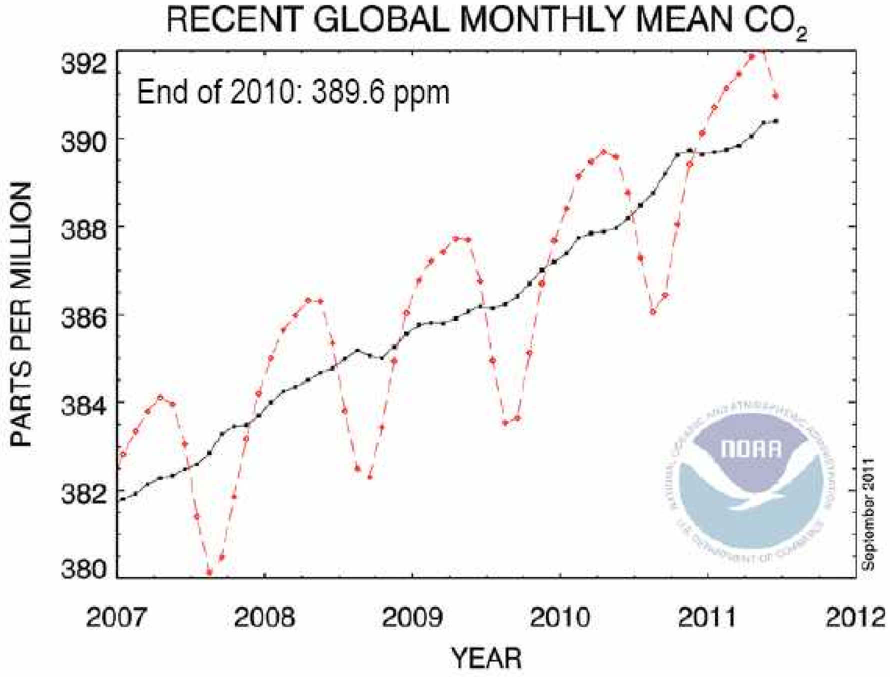
Changes in Greenhouse Gases from ice-Core and Modern Data




2000
1500
1000
500
Methane (ppb)
10000
5000
0
Time (before 2005)
0.4
0.2
0
Radiative Forcing (W m^{-2})
2000
1500
1000
500
1800
1900
2000
Year


©IPCC 2007: WG1-AR4
330
300
270
Nitrous Oxide (ppb)
0.1
0
Radiative Forcing (W m^{-2})
10000
5000
0
Time (before 2005)
330
300
270
240
1800
1900
2000
Year

Atmospheric CO_2 Concentration



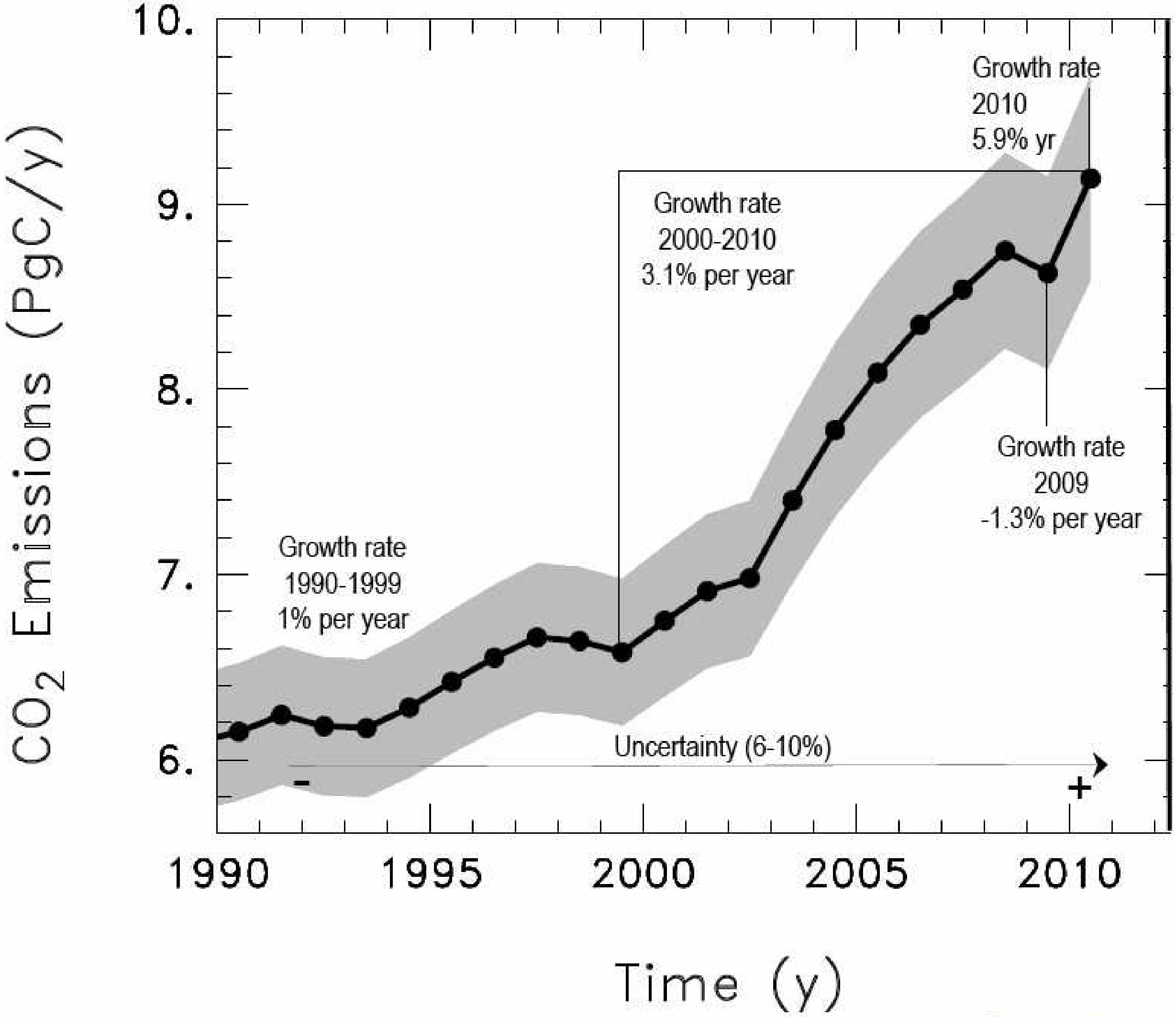
Annual Mea	Growth Rate (ppm y^{-1})
2010	2.36
2009	1.63
2008	1.81
2007	2.11
2006	1.83
2005	2.39
2004	1.58
2003	2.20
2002	2.40
2001	1.89
2000	1.22

Annual Growth Rates
(decadal means)

1970 – 1979: 1.3 ppm y^{-1}
1980 – 1989: 1.6 ppm y^{1}
1990 – 1999: 1.5 ppm y^{-1}
2000 – 2010: 1.9 ppm y^{-1}

Data Source: Thomas Conway, 2011, NOAA/ESRL + Scripts Institution

Fossil Fuel & Cement CO_2 Emissions



Peters et al. 2011, Nature CC; Data: Boden, Marland, Andres-CDIAC 2011; Marland et al. 2009

Fate of Anthropogenic CO_2 Emissions (2010)

9.1 ± 0.5 PgC y^{-1}

+

0.9 ± 0.7 PgC y^{-1}

5.0 ± 0.2 PgC y^{-1}

50%

2.6 ± 1.0 PgC y^{-1}

26%

Calculated as the residual
of all other flux components

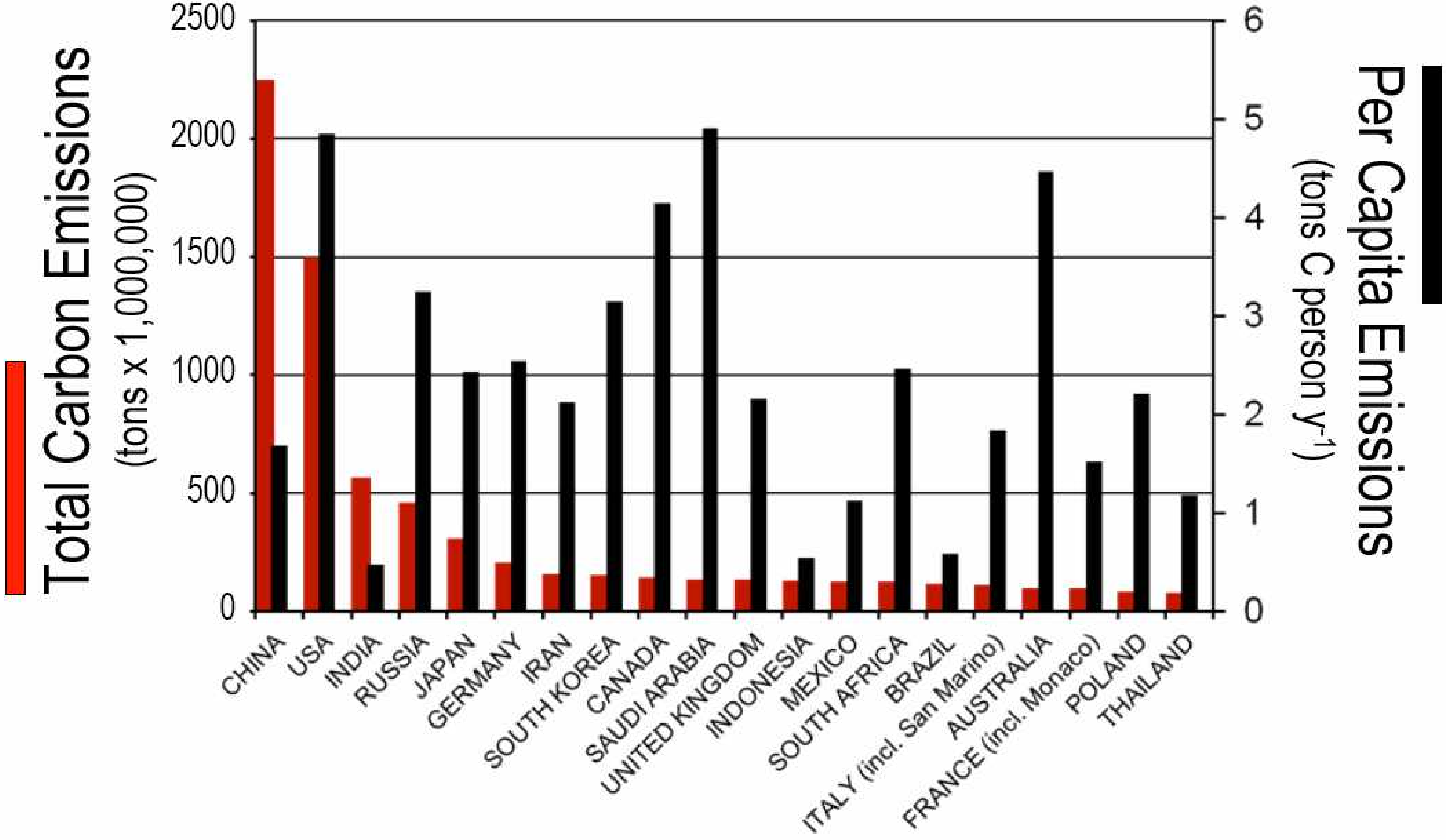
24%

2.4 ± 0.5 PgC y^{-1}

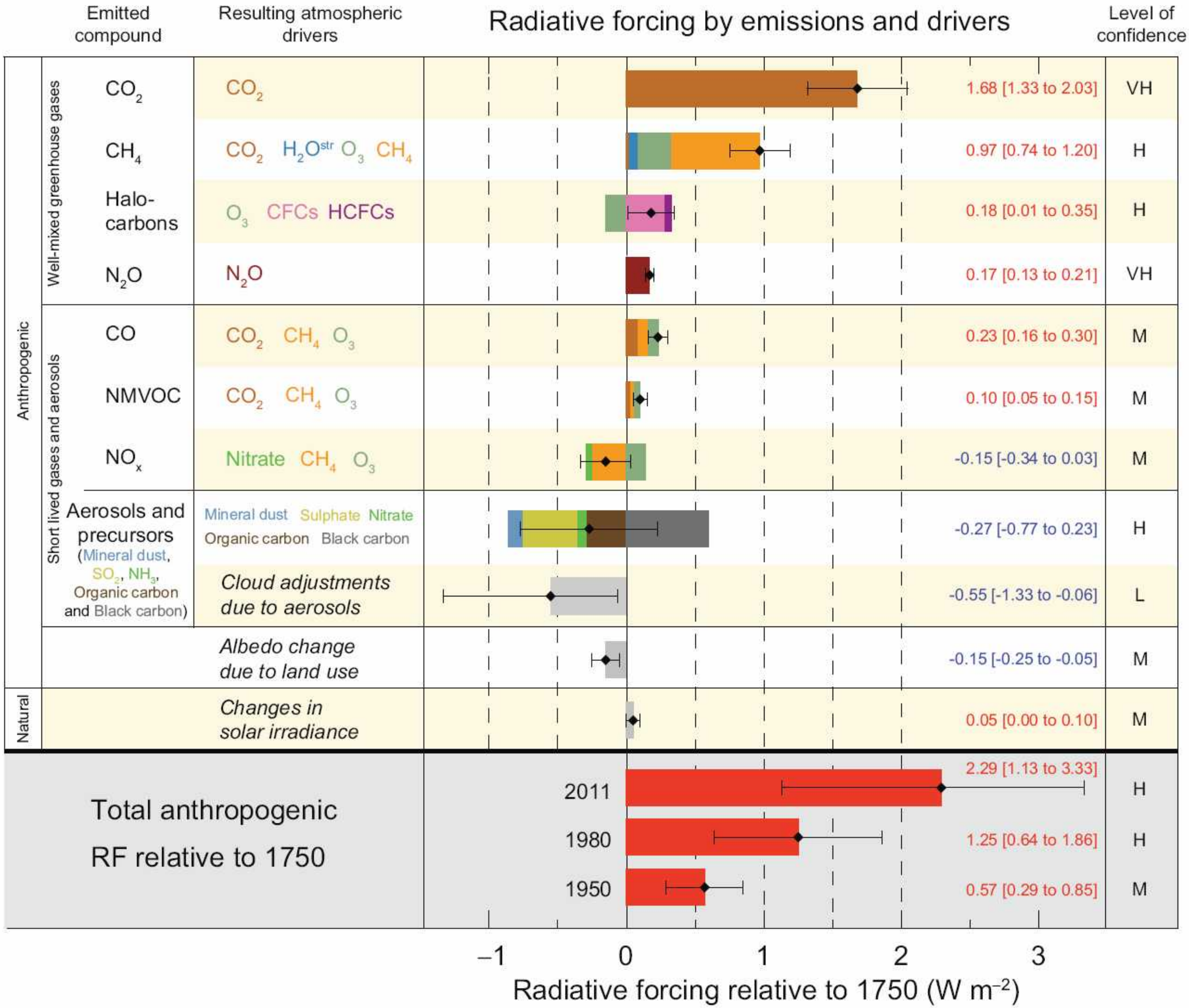
Average of 5 models

Global Carbon Project 2010; Updated from Le Quéré et al. 2009, Nature Geoscience; Canadell et al. 2007, PNAS

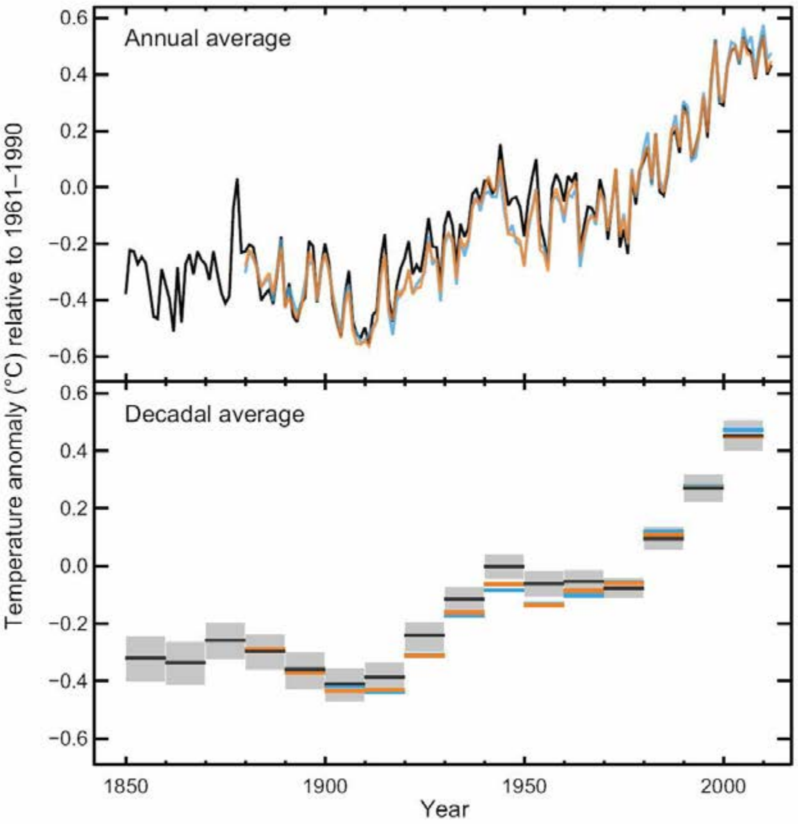
Top 20 CO_2 FF Emitters & Per Capita Emissions 2010



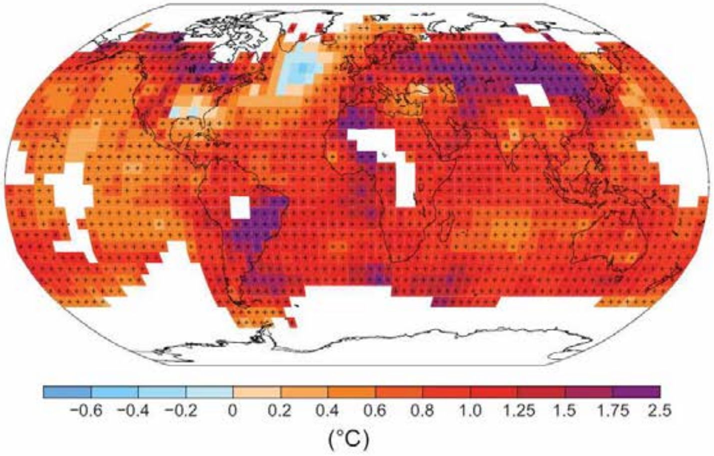
Global Carbon Project 2011; Data: Boden, Marland, Andres-CDIAC 2011; Population World Bank 2011


Emitted compound
Resulting atmospheric drivers
Radiative forcing by emissions and drivers
Level of confidence
Anthropogenic
Well-mixed greenhouse gases
CO_2
CO_2
1.68 [1.33 to 2.03]
VH
CH_4
CO_2 H_2O^{str} O_3 CH_4
0.97 [0.74 to 1.20]
H
Halo-carbons
O_3 CFCs HCFCs
0.18 [0.01 to 0.35]
H
N_2O
N_2O
0.17 [0.13 to 0.21]
VH
Short lived gases and aerosols
CO
CO_2 CH_4 O_3
0.23 [0.16 to 0.30]
M
NMVOC
CO_2 CH_4 O_3
0.10 [0.05 to 0.15]
M
NO_x
Nitrate CH_4 O_3
-0.15 [-0.34 to 0.03]
M
Aerosols and precursors (Mineral dust, SO_2, NH_3, Organic carbon and Black carbon)
Mineral dust Sulphate Nitrate Organic carbon Black carbon
-0.27 [-0.77 to 0.23]
H
Cloud adjustments due to aerosols
-0.55 [-1.33 to -0.06]
L
Albedo change due to land use
-0.15 [-0.25 to -0.05]
M
Natural
Changes in solar irradiance
0.05 [0.00 to 0.10]
M
Total anthropogenic RF relative to 1750
2011
2.29 [1.13 to 3.33]
H
1980
1.25 [0.64 to 1.86]
H
1950
0.57 [0.29 to 0.85]
M
−1
0
1
2
3
Radiative forcing relative to 1750 (W m^{-2})

(a) Observed globally averaged combined land and ocean surface temperature anomaly 1850–2012



(b) Observed change in surface temperature 1901–2012



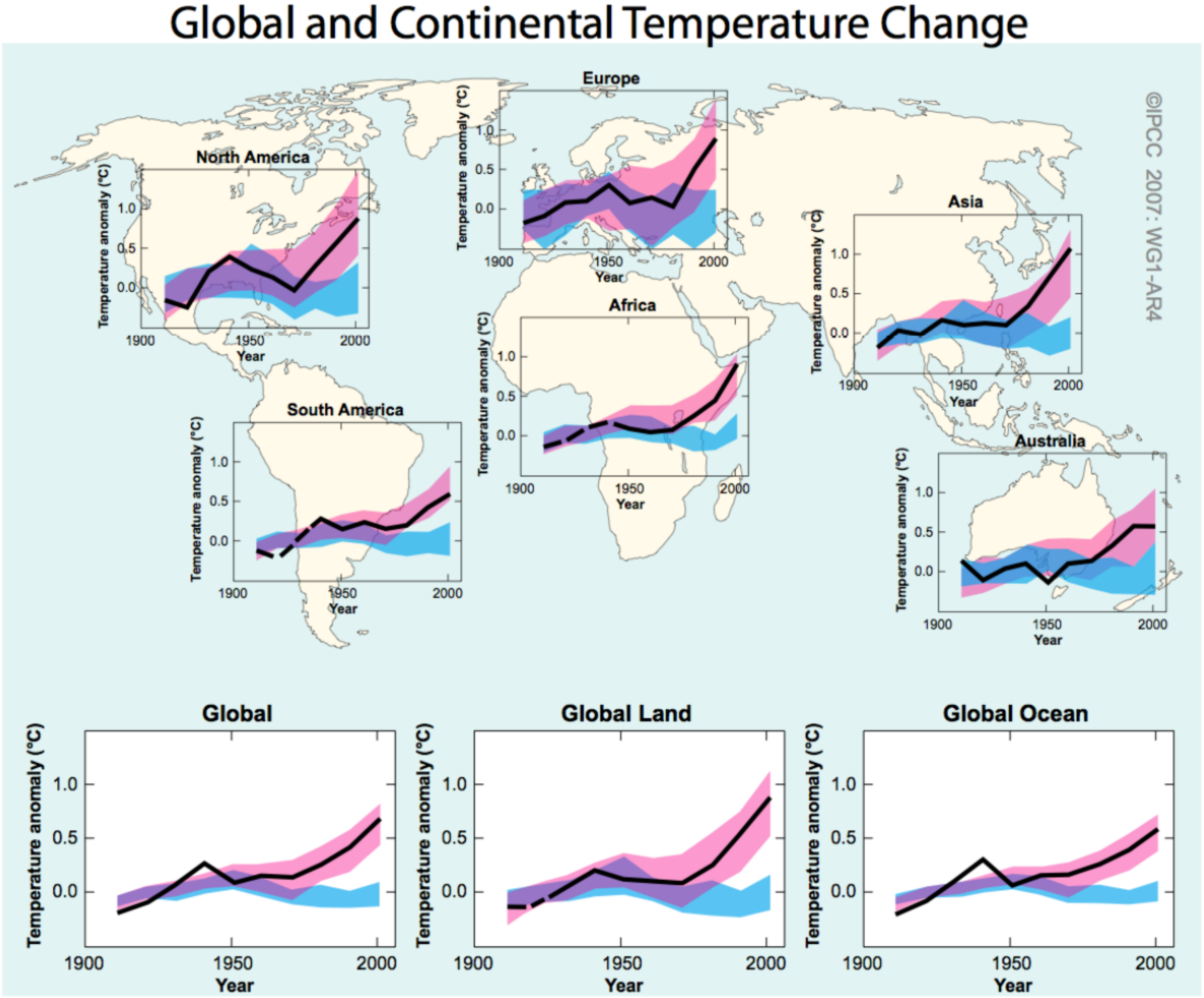
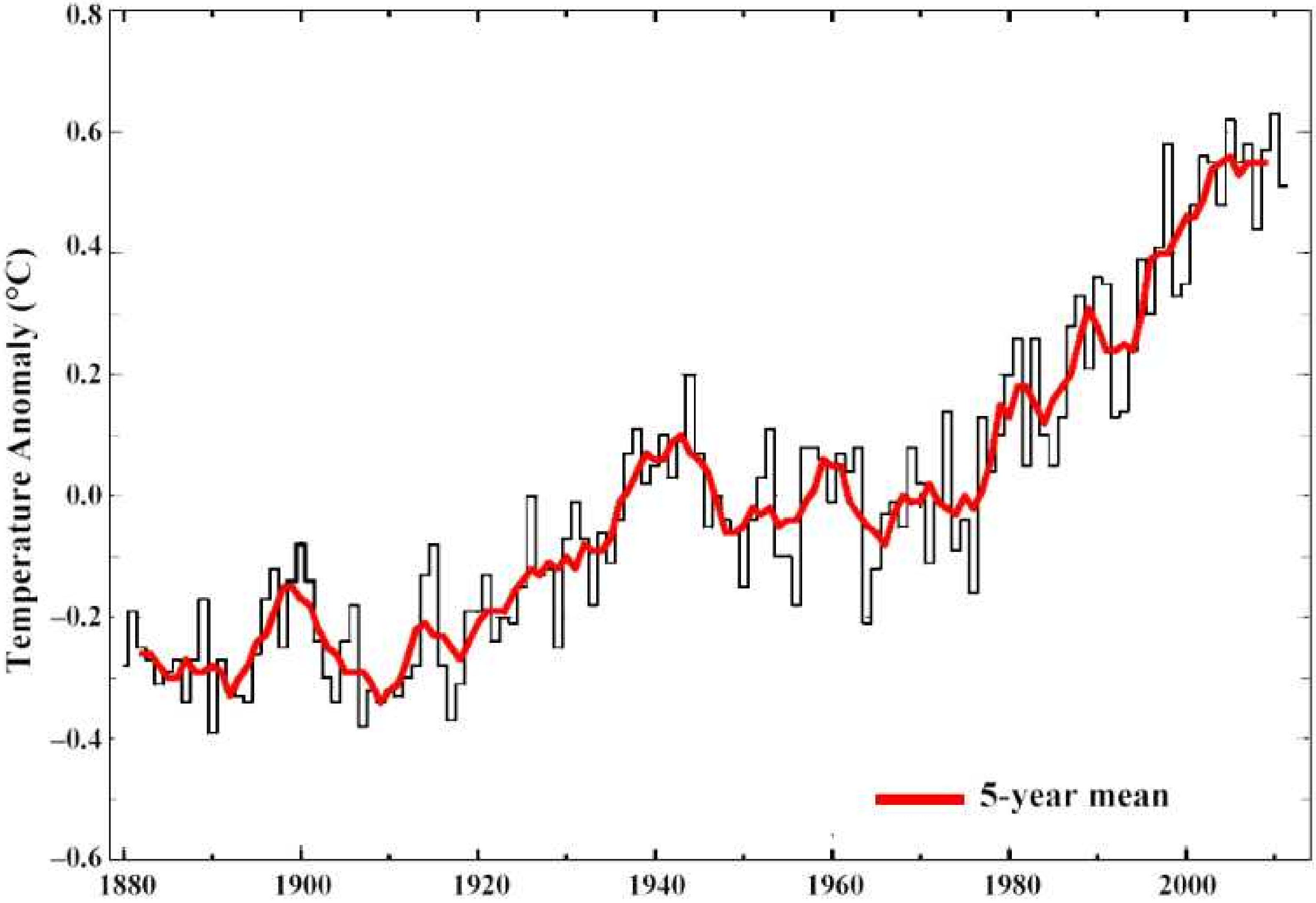


FIGURE SPM-4. Comparison of observed continental- and global-scale changes in surface temperature with results simulated by climate models using natural and anthropogenic forcings. Decadal averages of observations are shown for the period 1906–2005 (black line) plotted against the centre of the decade and relative to the corresponding average for 1901–1950. Lines are dashed where spatial coverage is less than 50%. Blue shaded bands show the 5–95% range for 19

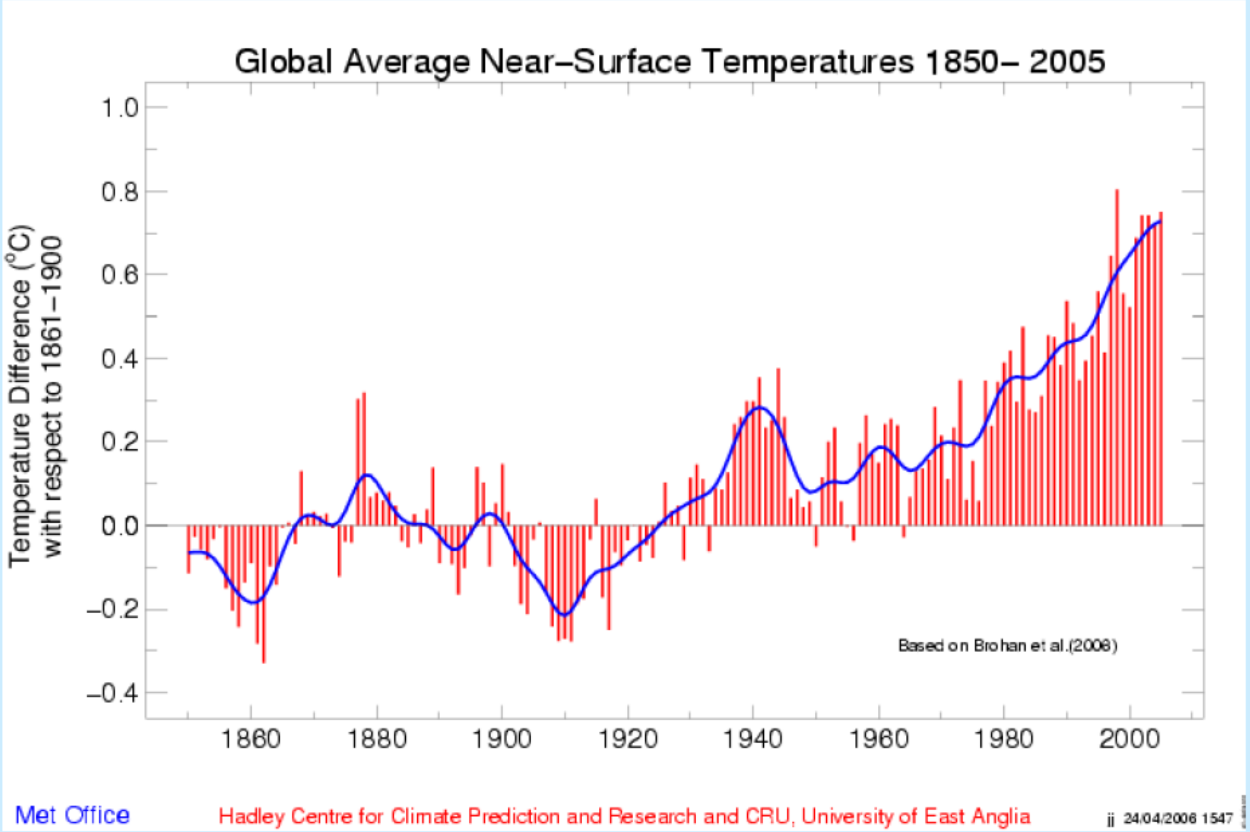
Global Temperature Anomalies (1880-2011)
(Land + Ocean)



Source: J.E. Hansen, R. Ruedy, M. Sato, and K. Lo
NASA Goddard Institute for Space Studies

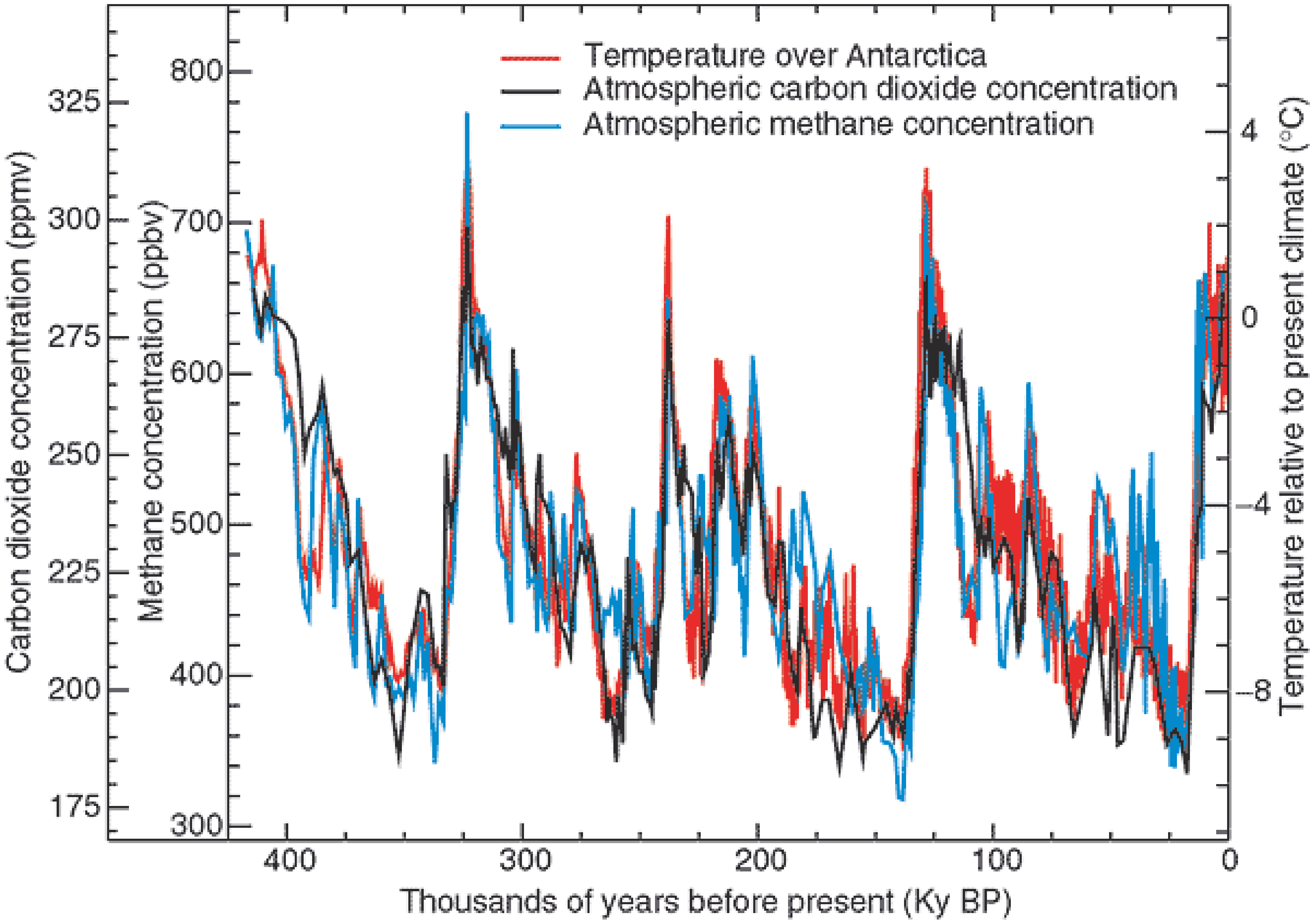
Figure 1.3 The Earth has warmed 0.7°C since around 1900.

The figure below shows the change in global average near-surface temperature from 1850 to 2005. The individual annual averages are shown as red bars and the blue line is the smoothed trend. The temperatures are shown relative to the average over 1861 – 1900.



Source: Brohan et al. (2006)

From the Stern Report, Chapter 1


Temperature over Antarctica
Atmospheric carbon dioxide concentration
Atmospheric methane concentration
Carbon dioxide concentration (ppmv)
325
300
275
250
225
200
175
Methane concentration (ppbv)
800
700
600
500
400
300
Temperature relative to present climate (°C)
4
0
−4
−8
400
300
200
100
0
Thousands of years before present (Ky BP)

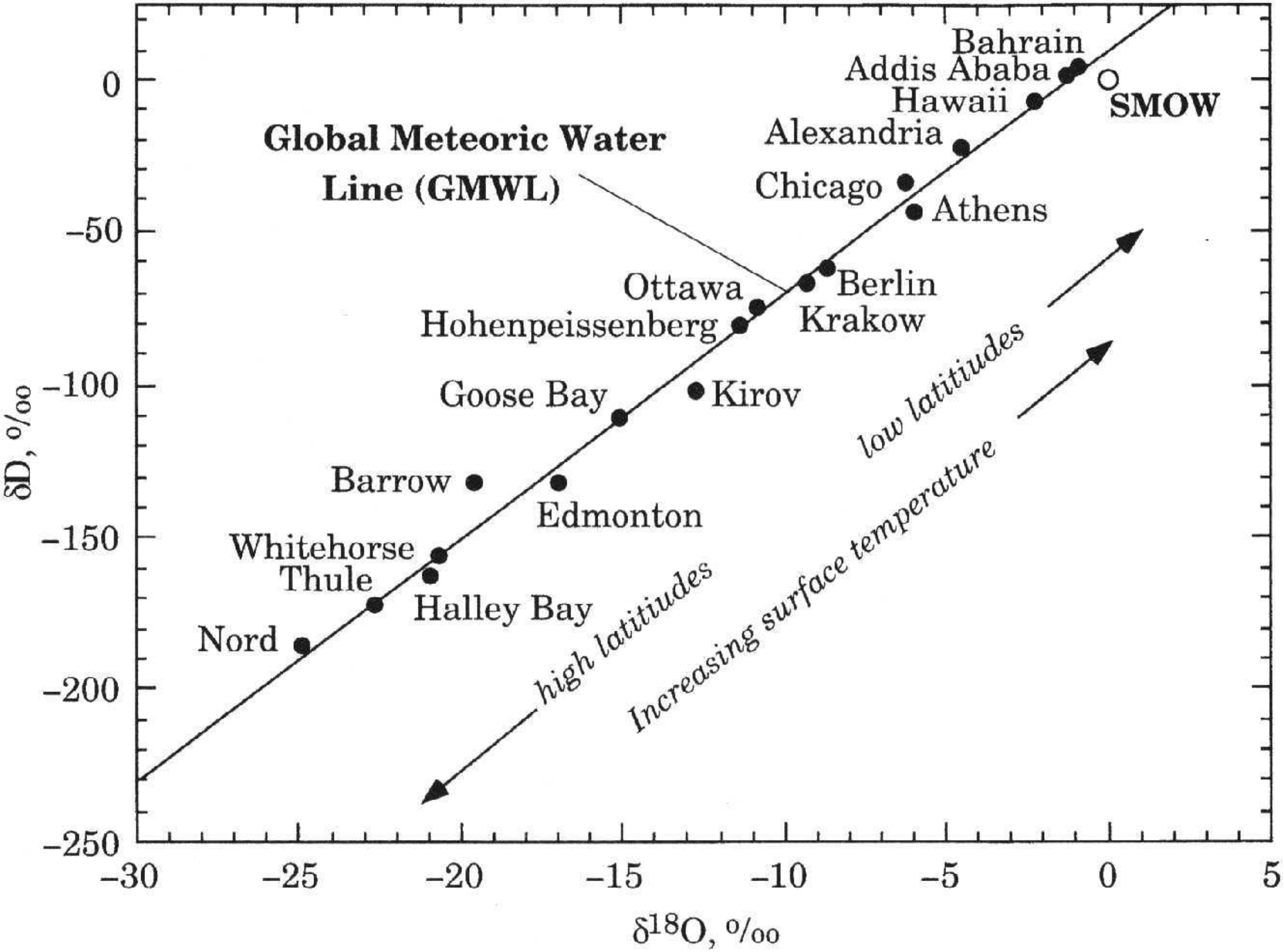


FIGURE 11-2 Relationship between δD and $\delta^{18}O$ for meteoric water that is ultimately derived from ocean water (SMOW). (From data compiled by Rozanski et al., 1993.)

Thermodynamic isotope fractionation: $\ln(P_{16}/P_{18}) = 7.88/T - 0.0177$; (from Faure 1977) Where P_{16} is equilibrium vapor pressure of ^{16}O water; P_{18} is for ^{18}O water; T is Kelvin temperature (°C+273.16)

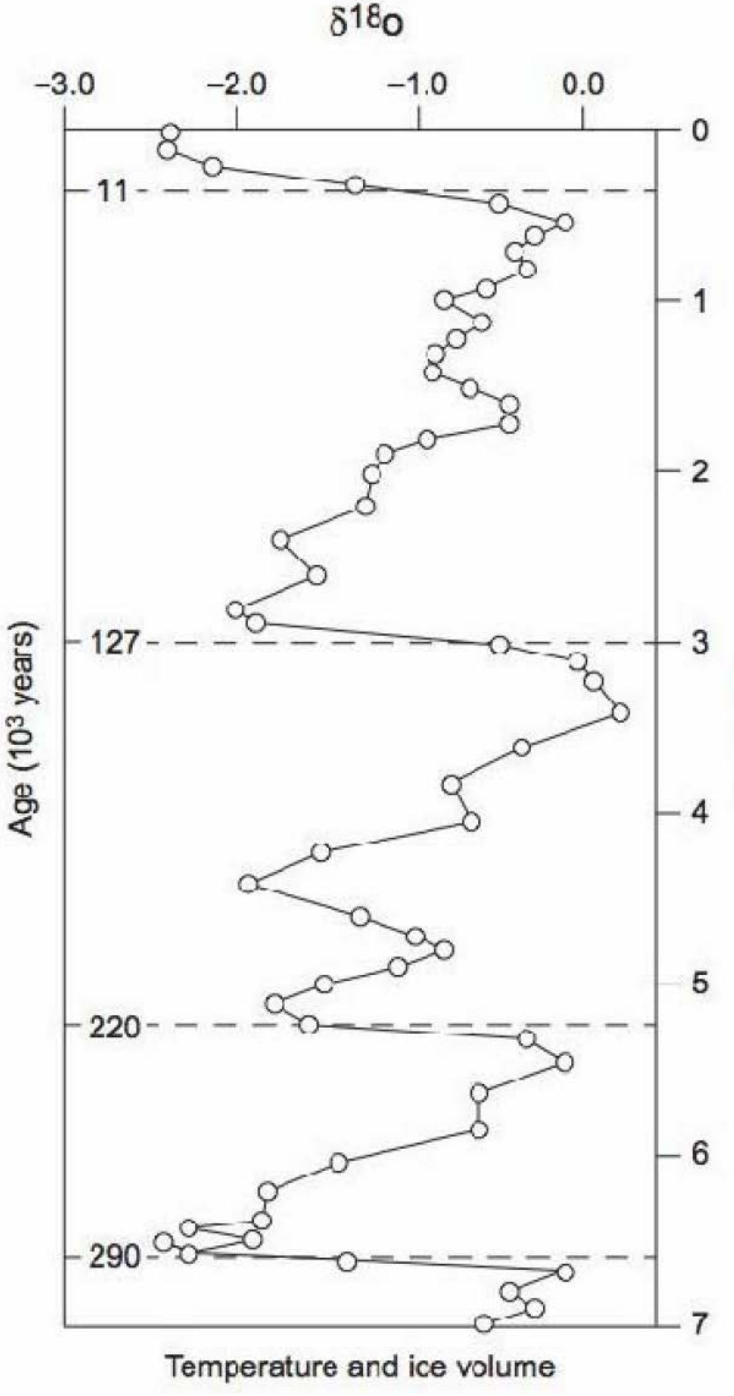


FIGURE 9.31 Changes in the δ^{18}O in sedimentary carbonates of the Caribbean Sea during 300,000 years. Enrichment of δ^{18}O during the last glacial epoch (20,000 years ago) is associated with lower sea levels and a greater proportion of $H_2{}^{18}O$ in seawater. *Source: From Broecker (1973).*

Box 1.3 Changes in the earth system that could amplify global warming

Weakening of Natural Land-Carbon Sinks: Initially, higher levels of carbon dioxide in the atmosphere will act as a fertiliser for plants, increasing forest growth and the amount of carbon absorbed by the land. A warmer climate will increasingly offset this effect through an increase in plant and soil respiration (increasing release of carbon from the land). Recent modelling suggests that net absorption may initially increase because of the carbon fertilisation effects (chapter 3). But, by the end of this century it will reduce significantly as a result of increased respiration and limits to plant growth (nutrient and water availability).[28]

Weakening of Natural Ocean-Carbon Sinks: The amount of carbon dioxide absorbed by the oceans is likely to weaken in the future through a number of chemical, biological and physical changes. For example, chemical uptake processes may be exhausted, warming surface waters will reduce the rate of absorption and CO_2 absorbing organisms are likely to be damaged by ocean acidification[29]. Most carbon cycle models agree that climate change will weaken the ocean sink, but suggest that this would be a smaller effect than the weakening of the land sink[30].

Release of Methane from Peat Deposits, Wetlands and Thawing Permafrost: Thawing permafrost and the warming and drying of wetland areas could release methane (and carbon dioxide) to the atmosphere in the future. Models suggest that up to 90% of the upper layer of permafrost will thaw by 2100.[31] These regions contain a substantial store of carbon. One set of estimates suggests that wetlands store equivalent to around 1600 $GtCO_2e$ (where Gt is one billion tonnes) and permafrost soils store a further 1500 $GtCO_2e$[32]. Together these stores comprise more than double the total cumulative emissions from fossil fuel burning so far. Recent measurements show a 10 – 15% increase in the area of thaw lakes in northern and western Siberia. In northern Siberia, methane emissions from thaw lakes are estimated to have increased by 60% since the mid 1970's[33]. It remains unclear at what rate methane would be released in the future. Preliminary estimates indicate that, in total, methane emissions each year from thawing permafrost and wetlands could increase by around 4 – 10 $GtCO_2e$, more than 50% of current methane emissions and equivalent to 10 – 25% of current man-made emissions.[34]

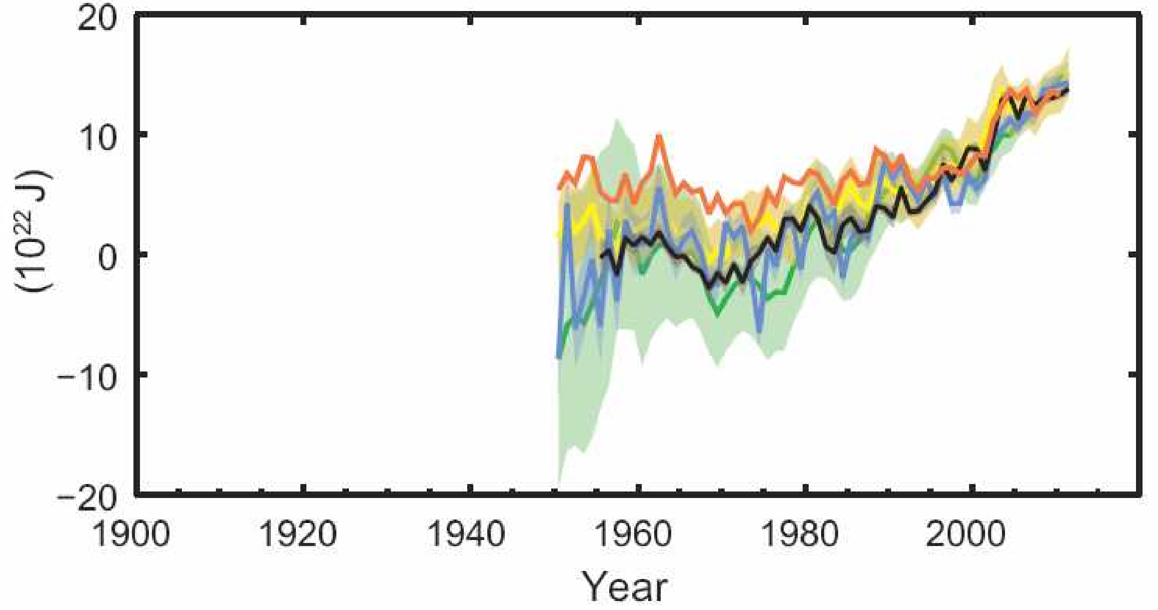
Release of Methane from Hydrate Stores: An immense quantity of methane (equivalent to tens of thousands of $GtCO_2$, twice as much as in coal, oil and gas reserves) may also be trapped under the oceans in the form of gas hydrates. These exist in regions sufficiently cold and under enough high pressures to keep them stable. There is considerable uncertainty whether these deposits will be affected by climate change at all. However, if ocean warming penetrated deeply enough to destabilise even a small amount of this methane and release it to the atmosphere, it would lead to a rapid increase in warming.[35] Estimates of the size of potential releases are scarce, but are of a similar scale to those from wetlands and permafrost.

From: Stern Report, Chapter 1

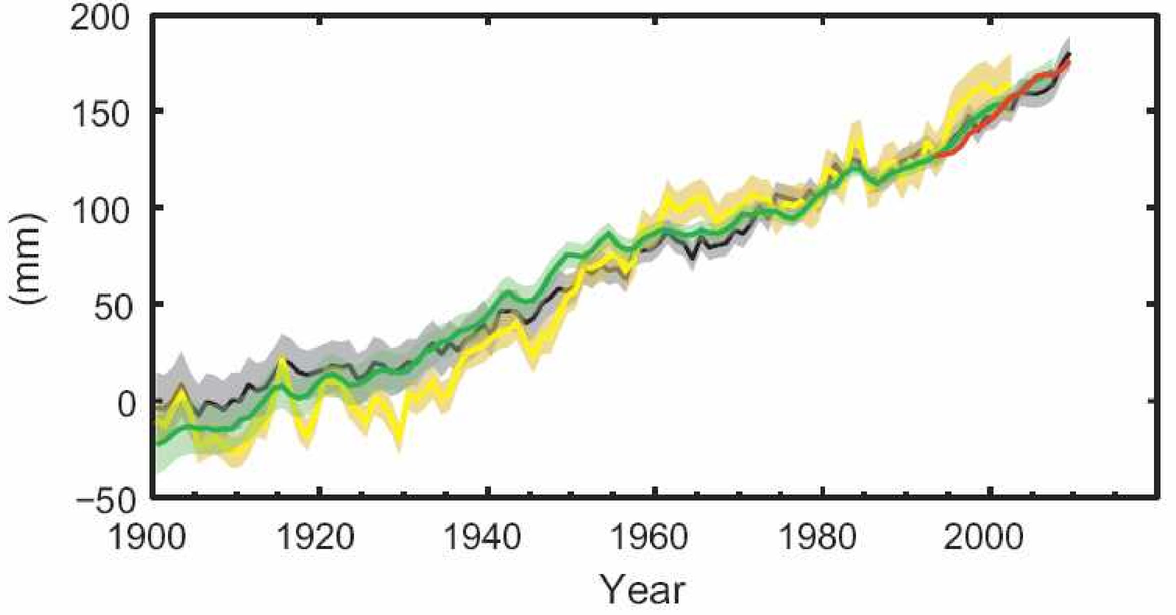
How much might the sea level rise?

Sea level refers to the ocean's average level over a long time. In many parts of the world, sea level changes gradually as the coast or the ocean floor rises or falls due to natural geological changes or human actions such as pumping large amounts of oil out of the ground.

In addition to these often large local changes, over the past century the average sea level has been rising at a rate of between 0.4 to 0.8 inches (0.5 to 1 cm) per decade. Scientists are uncertain why this is occurring.



(c) Change in global average upper ocean heat content



(d) Global average sea level change

Table SPM-1. Observed rate of sea level rise and estimated contributions from different sources. {5.5, Table 5.3}

	Rate of sea level rise (mm per year)	
Source of sea level rise	**1961 – 2003**	**1993 – 2003**
Thermal expansion	0.42 ± 0.12	1.6 ± 0.5
Glaciers and ice caps	0.50 ± 0.18	0.77 ± 0.22
Greenland ice sheet	0.05 ± 0.12	0.21 ± 0.07
Antarctic ice sheet	0.14 ± 0.41	0.21 ± 0.35
Sum of individual climate contributions to sea level rise	1.1 ± 0.5	2.8 ± 0.7
Observed total sea level rise	1.8 ± 0.5[a]	3.1 ± 0.7[a]
Difference (Observed minus sum of estimated climate contributions)	0.7 ± 0.7	0.3 ± 1.0

Table note:

[a] Data prior to 1993 are from tide gauges and after 1993 are from satellite altimetry.

Sea level in the future?

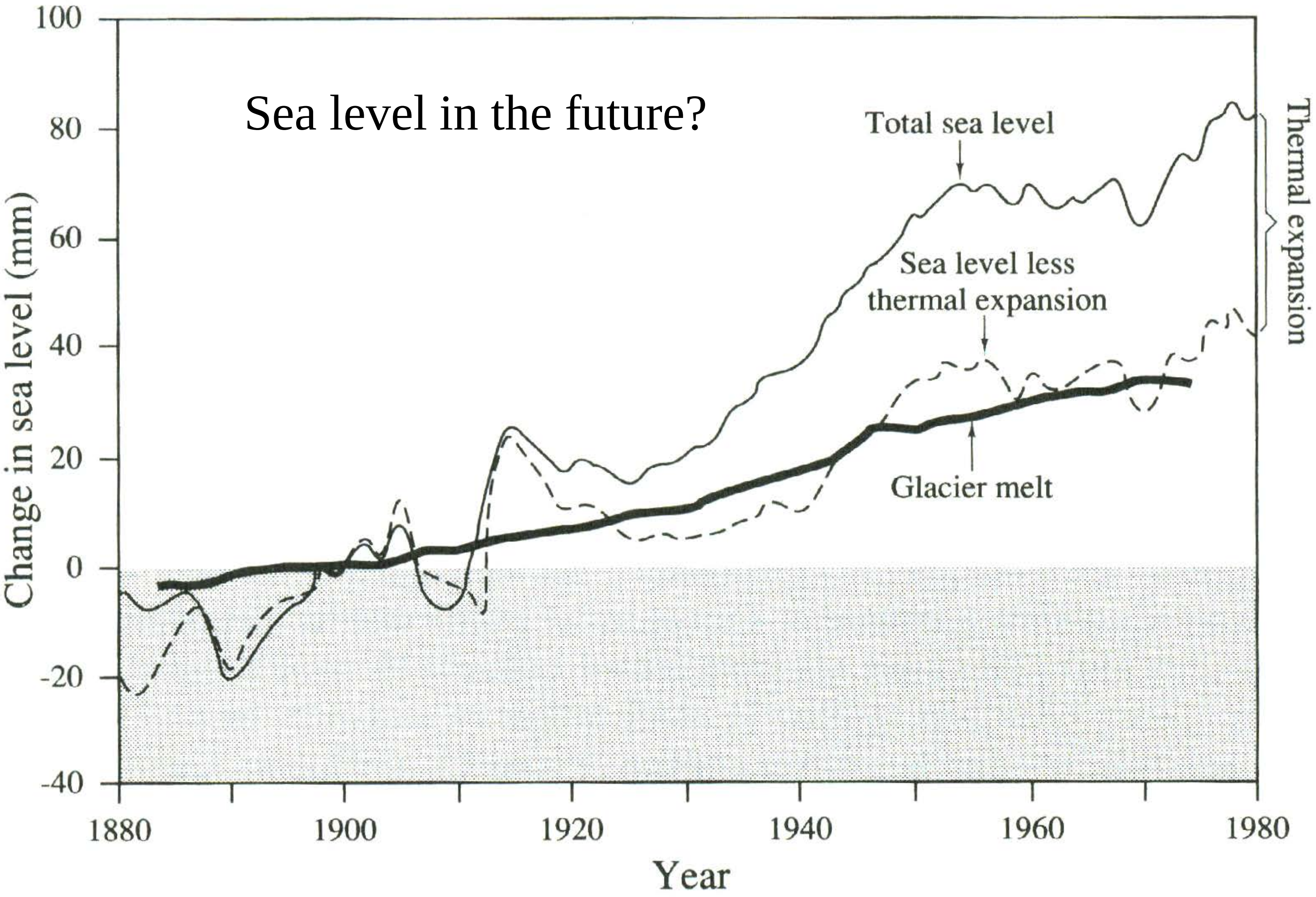
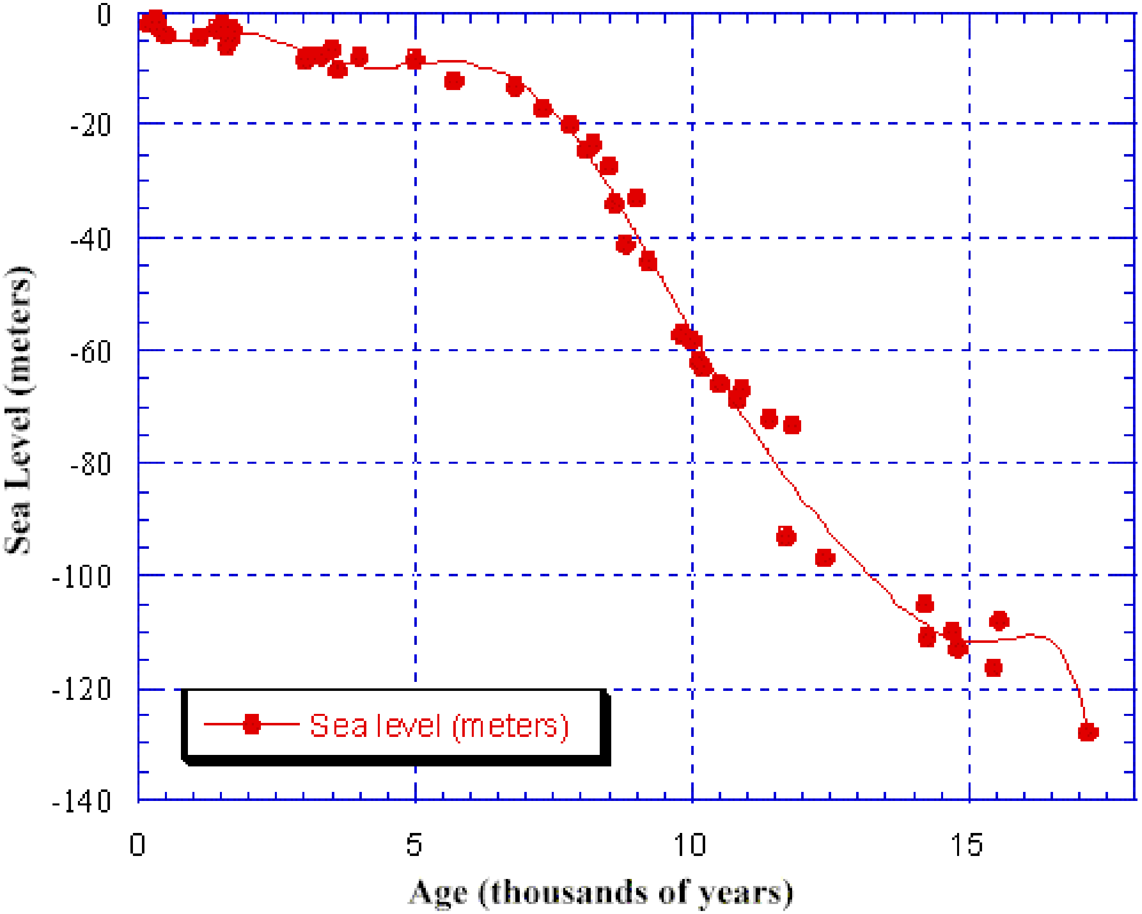
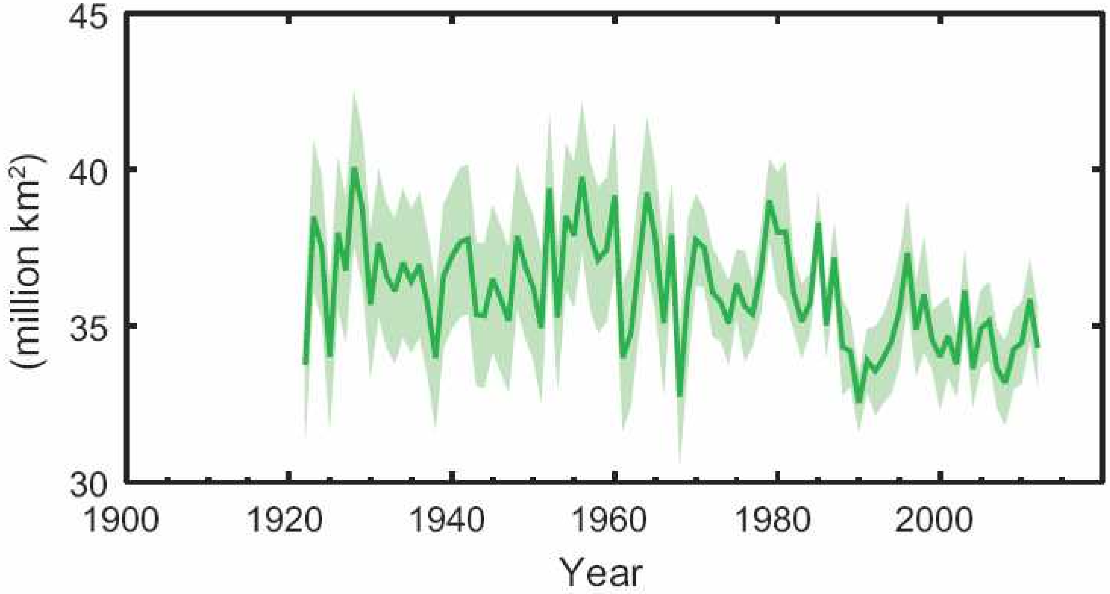


Figure 10.3 Changes in sea level during the last century (Gornitz et al. 1982), indicating the proportion due to thermal expansion of the oceans and that due to melting of glaciers. From Jacobs (1986), after Meier (1984). Copyright 1984 by the AAAS.

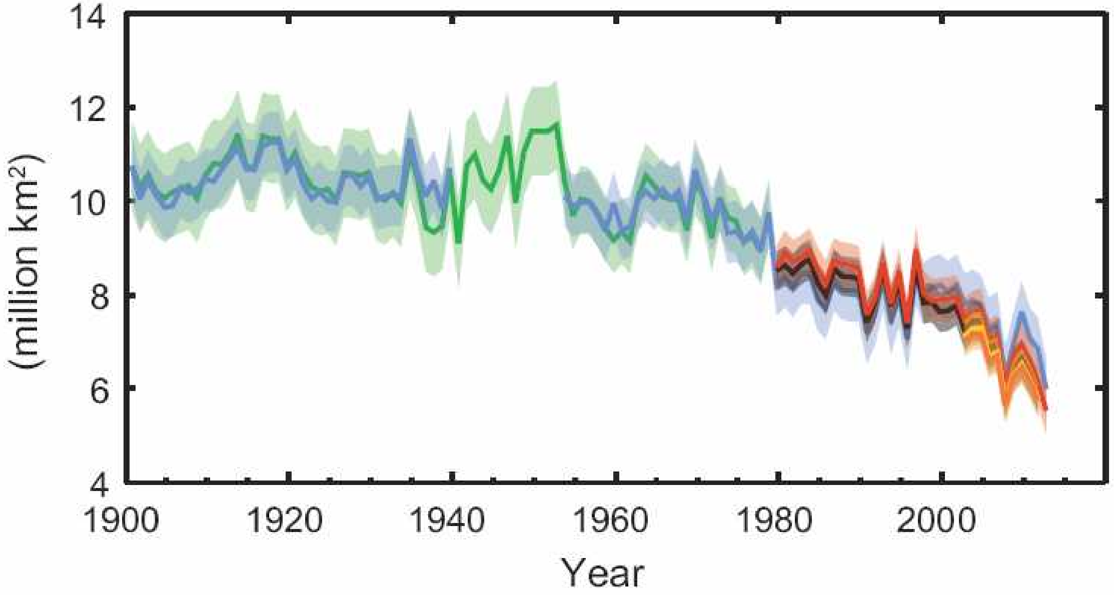
Sea level change of the last 17,000 years based on AMS ^{14}C dating of Barbados coral-reefs and ^{18}O data.
(From: RG Fairbanks, Nature, 1989, 342:637-642)

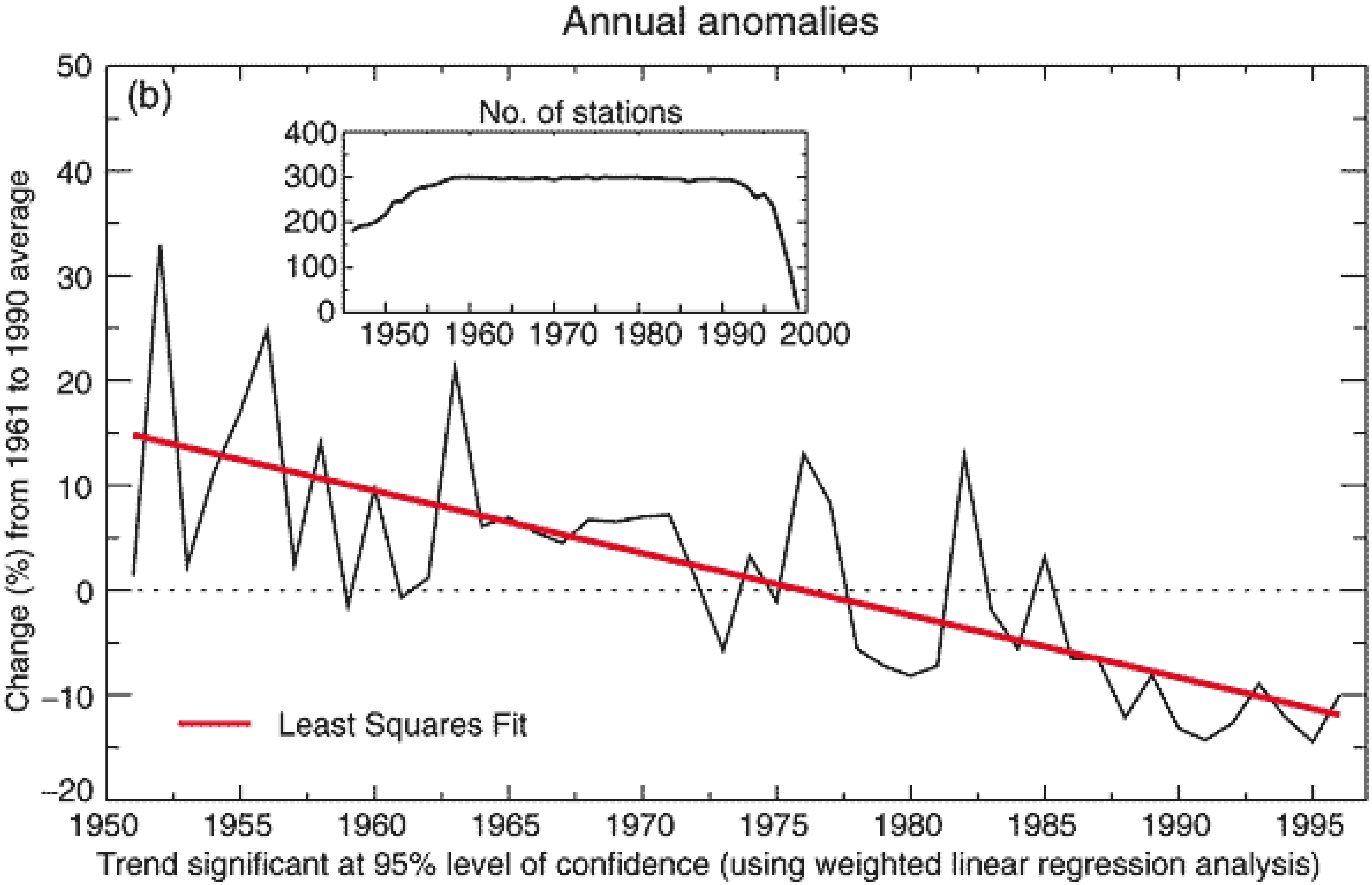


(a) Northern Hemisphere spring snow cover



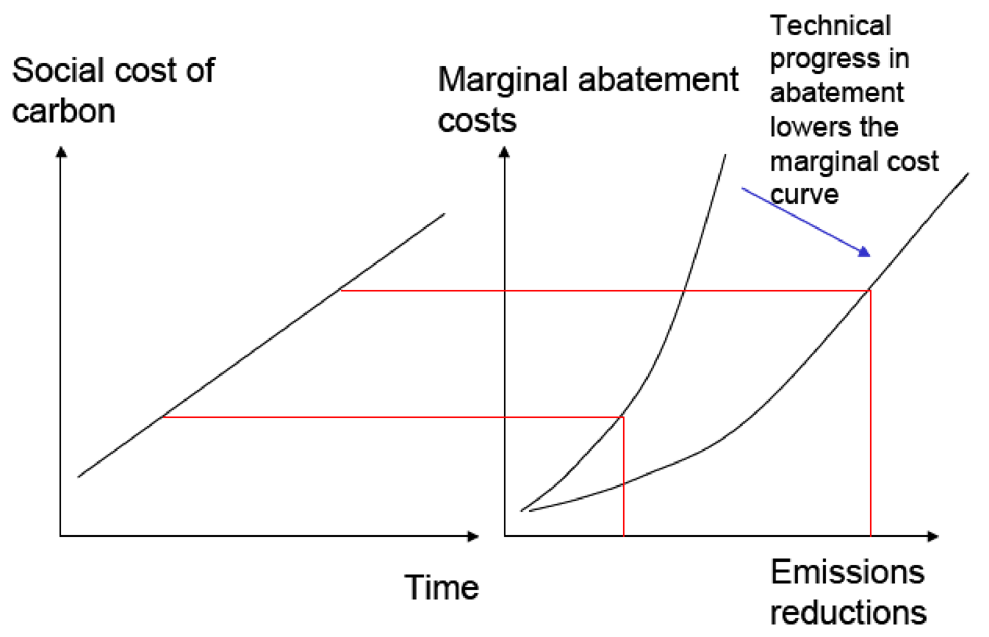
(b) Arctic summer sea ice extent





Change in the number of frost days

Box 13.2 The relationship between the social cost of carbon and emissions reductions

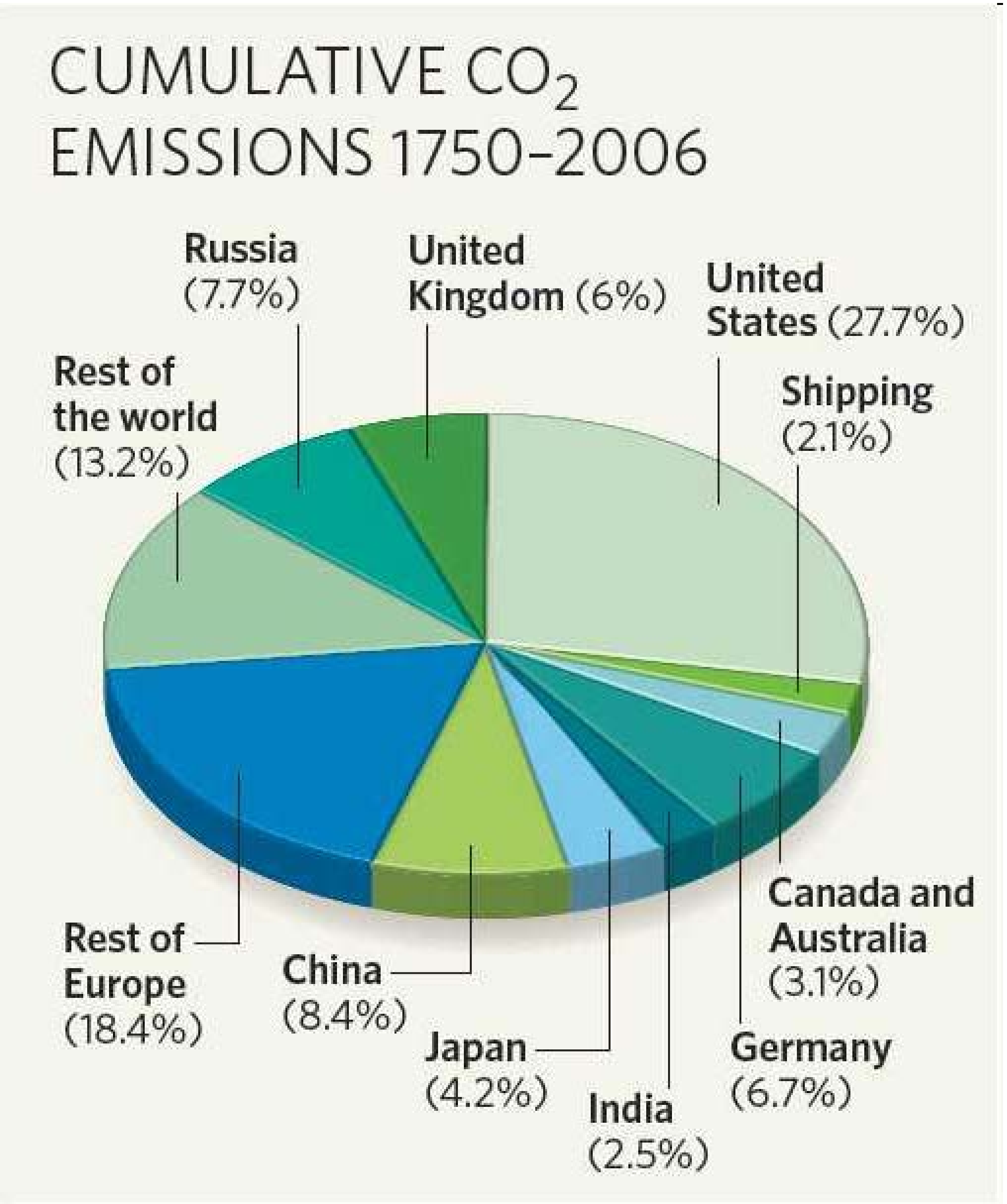


Up to the long-run stabilisation goal, the social cost of carbon will rise over time because marginal damage costs do so. This is because atmospheric concentrations are expected to rise and damage costs are expected to be convex in temperature (i.e. there is increasing marginal damage); these effects are assumed to outweigh the declining marginal impact of the stock of gases on global temperature at higher temperatures.

The price of carbon should reflect the social cost of carbon. In any given year, abatement will then occur up to this price, as set out in the right-hand panel of the diagram above. Over time, technical progress will reduce the total cost of any particular level of abatement, so that at any given price there will be more emission reductions.

The diagram reflects a world of certainty. In practice, neither climate-change damages nor abatement costs can be known with certainty in advance. If the abatement-cost curve illustrated in the right-hand panel were to fall persistently faster than expected, that would warrant revising the stabilisation goal downwards, so that the path for the social cost of carbon in the left-hand panel would shift downwards.

From: Stern Report, Chapter 13



Source: CO_2 Information Analysis Center, Oak Ridge National Lab.

Summary

The issue of global warming is discussed by focusing on several contributing factors such as (1) solar radiation/orbital factors, (2) albedo, and (3) greenhouse effect.

Effects of global warming are explored:

(1) temperature changes,
(2) frosting days,
(3) El Nino, and
(4) sea level rise.