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**Discussion**

# Today's Debate on Global Climate Change: Searching for the Scientific Truth

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**List of Abbreviations**

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|---|---|
| AOGCM | Atmosphere-Ocean General Circulation Models |
| CA | California |
| cm | Centimeter |
| $CO_2$ | Carbon dioxide |
| DOE | Department of Energy |
| GHGs | Greenhouse gases |
| GNP | Gross national product |
| ppmv | Parts per million volume |
| SSTs | Sea surface temperatures |
| UN | United Nations |
| UNEP | United Nations Environmental Programme |
| US | United States |
| WMO | World Meteorological Organization |

# Introduction

In the last few months, I have made a substantial effort to learn more about global issues and the role that increasing atmospheric concentrations of $CO_2$ may play in generating global warming. This is a subject that I have followed with interest since the early 1980s, when I published a review paper on this matter for an Italian scientific magazine [Zannetti 1982]. At that time, the subject was not very fashionable; today, global change is at the top of scientific and political agendas worldwide.

I would like to share with readers some scientific considerations and observations based upon my recent reading. As a person who has worked in environmental sciences for more than 25 years, I have always followed the scientific method and I am somewhat disturbed by certain aspects of the current scientific debate on this topic. I hope readers will comment on my observations, provide constructive criticism, and send me additional information to expand this analysis and, if needed, correct any unclear or erroneous statements of mine.

I also feel obliged to state in advance that this work was performed as a personal scientific endeavor, with no pre-conceived agenda and no direct financial support from any group or organization. I wish this clarification were not needed, but probably it is, in the current hot political climate where ad-hominem attacks against scientists seem frequently based on their affiliation and sponsorship entities instead of the contents of their scientific arguments.

# The Emergence of Global Concern

Scientists have often debated, in the last few decades, the possible role of anthropogenic activities in changing the composition of the atmosphere and affecting the climate. We know that, on local and urban scales, climate has been affected by urbanization. For example, meteorologists have known for many decades that urban areas create a warm region, called "urban heat island" [Stern *et al.* 1984], which at the surface remains a few degrees higher than surrounding rural regions. Also, we have evidence that decades of urban development with swimming pools and golf courses, as well as agriculture, in desert areas (e.g., Palm Spring, CA) have affected the local climate by increasing the average relative humidity.

The presence of anthropogenic effects on climate at larger scales (e.g., the continental and global scale) is more difficult to assess. The reason is that continental and global climate is very complex and affected by a very large number of parameters, including chaotic components. Climate changes can be detected, but the attribution of causes is a formidable challenge since observed changes can be due to either natural variability or human-induced effects – or both.

One of the main reasons why concern about global changes and discussions on global warming are popular today is illustrated in Figure 1, which shows combined land-surface and sea-surface, annual temperature anomalies from 1861 to 1994 over the entire globe. If you cover with your hand the temperature data after 1980, hardly any evidence could be found of increasing global warming. But if you look at the temperature trend in this century and the effects of the two warming periods of 1910-1940 and 1975-1994, an average warming trend may be inferred. If this warming is then interpreted as just the initial phase of a large trend caused by accumulation of greenhouse gases (GHGs), such as carbon dioxide ($CO_2$), then there is clearly reason for concern.

In the last few years, an increasingly larger segment of the scientific world has studied global issues. The increasing number of publications, computer simulation efforts, and monitoring activities is impressive (see, for example, the list of Internet sites provided at the end of this article). Furthermore, the political and economic implications of global change have attracted the interest of the media and the common citizen. Many scientists, even those who do not have direct expertise in global climate or environmental matters, have felt the need to express public opinions and support, agreements and disagreements. These events, of course, are good and bad at the same time.

The positive aspect is the increasing worldwide support to scientific research aiming at understanding and simulating the physical and chemical mechanisms of the earth. Environmental sciences are still “young” and the danger associated with possible future global warming is clearly triggering interest and support for this emerging area of study. The negative aspect is the politicization of the scientific debate and the intrusion of non-scientific (or anti-scientific) methods, especially from activist groups with pre-defined agendas.

In this climate, the reader of scientific literature must be extra cautious and try to identify and give maximum credence to those authors that appear to be unbiased, without pre-conceived opinions, and adopt without reservation the scientific method.

## The Two Sides of the Issue

In a nutshell, there are two main groups of scientists dealing with global change: the believers and skeptics. Of course, this is a gross parameterization of a large spectrum of ideas and thoughts. Many scientists, actually, consider themselves as “uncommitted”. However, at least initially, this basic subdivision is useful.

The first group – the believers – basically state that, today, there is enough evidence to suggest a discernible human influence on global climate and, more specifically, a warming trend that is unlikely to be entirely natural in origin. In other words, modern science was not only able to detect global warming, but also to attribute its cause(s) to human activities, i.e., the anthropogenic emission of greenhouse gases (GHGs), such as $CO_2$. Global warming is expected to cause several adverse effects, e.g., a rise in global mean sea level. The most important piece of literature for this group is Houghton *et al.* [1996] – an impressive and comprehensive report, published under the umbrella of the World Meteorological Organization (WMO) and the United Nations (UN) Environmental Programme (UNEP).

The second group – the skeptics – are an increasingly large number of scientists who express caution and challenge some or most of the statements of the first group. Some statements are challenged as scientifically untrue, others as inappropriate and premature in light of all known uncertainties on this matter which are, indeed, quite large. Their publications appear periodically in reputable scientific journals and conference proceedings. They are not operating, at least today, in an organized fashion under dedicated institutional umbrellas. The recent conference* "Countdown to Kyoto" in Canberra, Australia, represents perhaps the first comprehensive effort to create a "home" and an organized voice for this group.

Both groups include moderates and extremists, with the extremists – not surprisingly – being the most politicized segment of the two communities. The media have tended, so far, to give more space and credibility to the first group, even though voices from the second group are increasingly heard. Needless to say, there are excellent scientists in both groups, with many also occupying a position that can only be described as "in between" the two. There is no doubt that, eventually, in a few decades, the scientific method will prevail by confirming only those theories and conclusions that are fully supported by scientific evidence.

## The First Group's Argument

The first group's arguments [Houghton *et al.* 1996] can be basically summarized in nine (9) items:

1. *$CO_2$ increase in the atmosphere is the most important factor affecting changes in global radiative forcing*+ .

> This statement is summarized in Figure 2 which illustrates the role of $CO_2$ in comparison with all other known factors which affect the change of radiative forcing from pre-industrial times to the present day. In other words, the increase in atmospheric $CO_2$ has recently been (and is expected to be) the single, most important factor in causing global temperatures to increase on the earth.

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* 'Countdown to Kyoto': The Consequences of the Mandatory Global Carbon Dioxide Emissions Reductions, Australian APEC Study Centre, Canberra, Australia, 19-21 August 1997. (http://www.arts.monash.edu.au/ausapec/kypaps.htm).

+ Radiative forcing is the perturbation to the energy balance of the Earth-atmosphere system, expressed in watts per square meter [$Wm^{-2}$]

2. *Anthropogenic $CO_2$ emissions are increasing worldwide.*

   Figure 3 provides an estimate of the growing anthropogenic emissions of $CO_2$ from 1860 to present day. $CO_2$ emissions have increased by a factor of 4 in the second half of this century. In 1991, approximately 6,200 million metric tons of carbon, was emitted to the atmosphere as a result of fossil fuel burning, cement manufacturing, and gas flaring.

3. *As a consequence of $CO_2$ emissions, atmospheric concentrations of $CO_2$ are increasing worldwide.*

   Figure 4 gives an atmospheric $CO_2$ record for the past 200 years, showing an increase of $CO_2$ concentrations, from a pre-1800, pre-industrial value of about 280 ppmv to the current value of about 360 ppmv. Figure 5 illustrates the longest continuous record of atmospheric $CO_2$ measurements available in the world, from about 315 ppmv in the 1950s to about 360 ppmv today.

4. *The $CO_2$ concentration increase is causing global temperatures to increase; "fingerprints" of $CO_2$-caused global warming have been found on spatial patterns.*

   Figure 1 indicates that global temperatures have increased during this century. There is an evident correlation between $CO_2$ and temperature increase, illustrated in Figure 6. More importantly, unlike the previous computer models, the current generation of global models (i.e., Atmosphere-Ocean General Circulation Models*, AOGCM) simulate well the temperature increase in this century when the direct effect of sulfates is taken into account (see Figure 7). The simulation of the AOGCM proves that the increase of global temperature is mostly due to the increase of GHGs.

   Recent studies, instead of focusing on global means, have compared observations with the spatial patterns of temperature changes predicted by AOGCM. These studies show significant correspondence between the observations and model predictions and, thus, indicate human influence on global climate. A summary of these observed climatic trends is illustrated in Figure 8.

5. *$CO_2$ concentrations are expected to double in the next century.*

   The IS92 emission scenarios [IPCC 1992] provide projections of future emissions of GHGs and aerosol precursors and the proportion of emissions remaining in the atmosphere. The projected $CO_2$ emissions and resulting atmospheric $CO_2$

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* In coupling atmospheric and ocean general circulation models, typically the model atmosphere only sees the sea surface temperatures (SSTs) and sea ice, while the model ocean sees the surface wind stress, the freshwater flux (precipitation minus evaporation), and the heat fluxes [Trenberth 1996]. An alternative approach to the utilization of hydrologic models in the context of climate change simulations is discussed by Pielke *et al*. [1997].

concentrations are illustrated in Figure 9. Both $CO_2$ emissions and ambient $CO_2$ concentrations are expected to double in the next century.

6. *Current global AOGCM are reliable tools for forecasting climate change when simulations include the likely effect of aerosols in addition to GHGs.*

   As illustrated in Figure 7, the most recent computer simulations using AOGCM include the cooling effect of sulfate aerosols and, by doing so, are able to simulate correctly the global warming in this century. This successful validation gives us confidence in using the same models for forecasting future impacts of increasing $CO_2$ concentrations in the next century.

7. *Global model forecasts indicate that, as a consequence of increasing $CO_2$ concentrations in the next century, global temperatures will increase a few degrees Celsius.*

   Figure 10 illustrates the extreme range of possible global temperature increases in the next century, from 0.8°C to 4.5°C, as simulated by the current AOGCM using the projections presented in Figure 9.

8. *Global model forecasts indicate that, as a consequence of temperature increase, serious adverse effects will be experienced.*

   Several adverse effects can be attributed to the expected temperature increase in the next century. For example, Figure 11 shows the projected global mean sea level rise from 1990 to 2100, in the range from 38 cm to 56 cm. The rise is expected to continue after 2100, as illustrated in Figure 12, depending upon the different, achievable stabilization values for atmospheric $CO_2$.

   Other possible adverse effects include terrestrial and marine biotic responses.

9. *To avoid or minimize adverse effects, government action and international treaties are needed to curb $CO_2$ emissions and, eventually, stabilize $CO_2$ concentrations.*

   GHGs emissions have long-term ramifications because GHGs have long lifetimes (e.g., $CO_2$ has a lifetime of over a century). Figure 13 illustrates the needed reduction in anthropogenic $CO_2$ emissions required to stabilize atmospheric $CO_2$ at pre-defined levels. $CO_2$ stabilization in the atmosphere can only be achieved by, first, decreasing the growth rate of $CO_2$ emissions, and then stabilizing $CO_2$ emissions at levels well below the current ones.

## The Second Group's Arguments

The second group's arguments are not found in comprehensive reports, with perhaps the exception of the proceedings of the conference "Countdown to Kyoto" mentioned before. Publications and statements from the second group are more "reactive" in nature, since they focus on criticism (both constructive and destructive) of the first group's statements and calculations.

I will make an effort to illustrate some of the opinions of the second group (plus some general observations that may help put the first group's arguments into a different perspective), in reference to the nine items used for the first group.

1. *$CO_2$ increase in the atmosphere is the most important factor affecting changes in global radiative forcing.*

   Global radiative forcing is still poorly understood. The estimates presented in Figure 2 are very uncertain and could change radically with new knowledge acquired in the next few years. In particular, the global mean radiative forcing due to GHGs could be much lower that the values presented in Figure 2.

   Parameters such as solar variation [Hoyt and Schatten 1997] and albedo changes may be very important and, perhaps, more important than all the other factors combined. Land use plays a significant role on local, regional, and global climate [Pielke 1997; Copeland *et al*. 1996].

   Minor relative variations in atmospheric water vapor are more important than major relative changes in $CO_2$ concentrations. In fact, the role of water vapor as a greenhouse gas is much more important than all the anthropogenic GHGs. It has been estimated that an increase in low cloud cover of only about 4% would have the same magnitude temperature forcing as doubling $CO_2$; and that a decrease in cloud droplet size from 10 to about 8.5 $\mu$m would also match the radiative forcing from doubling $CO_2$ [Slingo 1990; Trenberth 1996].

   Recent studies [Lee 1992; Kerr 1995; Hoyt and Schatten 1997] (see Figures 14 through 16) make a good case that the sun's radiant output varies over decades and longer time scales and that these variations are playing a significant role in climate change. Also, since the 1920s, climate variations are consistent with a cyclic solar forcing of 10-11 years [Hoyt and Schatten 1997].

   Even the moon can affect the climate. In fact, most precipitation and proxy precipitation records have much stronger cyclic variation (18-22 years) than the solar cycles, implying lunar tidal influences [Hoyt and Schatten 1997].

2. *Anthropogenic $CO_2$ emissions are increasing worldwide.*

   $CO_2$ emissions are increasing, but at very different rates in different countries. As illustrated in Figure 17 [Begley 1997], the US, Canada, and Western Europe seem to have reached a plateau at an emission of about 2.5 billion metric tons of $CO_2$ per year and show a low relative growth. The rest of the world instead is growing fast with current emissions of about 4 billion metric tons of $CO_2$ per year and a growth rate of roughly 1 billion metric tons of $CO_2$ per decade.

In spite of all changes and developments in the last half century, global $CO_2$ emission per capita have remain relatively constant at 1 metric ton of C per person per year ± about 30%, as illustrated in Figure 18. This seems to indicate that population control, more than anything else, should be seen as the main strategy for controlling global $CO_2$ concentrations.

Some countries have an alarming exponential growth. Charts for the Peoples Republic of China, India, and South Korea are shown, respectively, in Figures 19 through 21.

As illustrated in Figure 22, France is the only (accidental) success story in achieving a decrease of $CO_2$ emissions, due to nuclear power generation. This issue should cause a re-thinking of the future role of nuclear energy throughout the world and, perhaps, help in redefining the nuclear energy policy for the next century.

3. *As a consequence of $CO_2$ emissions, atmospheric concentrations of $CO_2$ are increasing worldwide.*

The causes of atmospheric $CO_2$ increase worldwide are not fully clear. In spite of the high increase of anthropogenic emissions in the last decades, as illustrated in Figures 3 and 18, the growth rate of $CO_2$ concentration has been relatively constant at about 1-1.5 ppmv/year, as illustrated in Figure 23, with even a (unexplained) decline in the early 1990s.

There is, then, a contradiction between the increasing global $CO_2$ emissions in Figure 18 and the relatively constant growth rate of atmospheric $CO_2$ in Figure 23 – a factor that may indicate a strong non-anthropogenic component.

4. *The $CO_2$ concentration increase is causing global temperatures to increase; "fingerprints" of $CO_2$-caused global warming have been found on spatial patterns.*

According to Figure 1, most of the warming in this century occurred before 1940, before $CO_2$ concentrations increased significantly. This is not consistent with the theory of a global warming caused by GHGs.

The warming illustrated in Figure 1 is obtained from data recorded at surface stations. As observed by Christy [1997] and many others, these data are from sparse stations with uneven global coverage. Moreover, land-based temperature records are contaminated by urban-warming and other land-use changes. Consequently, stations located in the middle of city growth areas can produce a warming totally unrelated to any global factor. Corrections have been made to account for these phenomena, but many scientists believe that the temperature time series are still contaminated by non-climatic effects tending to show a spurious warming.

The rise in surface air temperatures in the last 100 years is concentrated in the 1917-1940 period, which may be related to minimal volcanic activity. This increase seems largely due to natural variations and urbanization [Christy 1997].

Global temperatures have been measured since 1979 from satellites. The method consists of basing global temperatures on the measurement of microwave emissions from molecular oxygen. This method has been fully validated and has shown precision on monthly values of ± 0.04°C [Spencer and Christy 1990]. This temperature monitoring system is truly global, truly homogeneous, and measures the entire lower troposphere (from surface to about 7 km altitude) instead of just the surface. Satellite data from 1979 to 1996 shows a slight cooling of about 0.04°C per decade which cannot be reconciled with the warming monitored in the surface stations (Figure 24). Christy [1995] provides a justification of this inconsistency – between satellite and surface data – by claiming that satellite data showing a slight cooling are correct, while data from surface networks are affected by inhomogeneity and disproportionate representation of extratropical continental regions. In conclusion, the 1975-1994 global warming trend in Figure 1 is not confirmed by, and actually inconsistent with, reliable temperature measurements from satellites.

5. *$CO_2$ concentrations are expected to double in the next century.*

These calculations of $CO_2$ concentration trends are not included in the AOGCM simulations but are independently performed using carbon cycle models, which are still primitive and very uncertain. To be more credible, carbon cycle models must be used in conjunction with AOGCM, validated against collected data, and be capable of incorporating many more processes, such as biological carbon fixation, and remineralization and sedimentary interaction.

The growth rate of ambient $CO_2$ concentrations has not increased substantially in recent years (Figure 23). This seems to indicate that a doubling of $CO_2$ concentration in the next century may not occur.

6. *Current global AOGCM are reliable tools for forecasting climate change when simulations include the likely effect of aerosols in addition to GHGs.*

The current climate models (AOGCM) have focussed on the physical climate system. In the simulations, the concentrations of constituents, such as ozone and $CO_2$, are either fixed or pre-specified as a function of time [Trenberth 1997]. In this respect, these models are not real "$CO_2$ models", since the $CO_2$ concentration does not depend on the climate changes. Similarly, land surface, biological, ecological, and chemical processes are oversimplified or not included at all.

Current AOGCM are very uncertain, especially in the treatment of clouds, the hydrological cycle, and land surface. Probably the single greatest uncertainty in climate models is the treatment of clouds [Trenberth 1997]. But clouds play a key role in affecting global temperature – a role which is much more important than any GHG. Unresolved phenomena in AOGCM include the process of moist convection by which heat and moisture are transported vertically, the hydrological processes that determine the moisture in the soil, and many of the dynamic processes in the ocean [Jacoby and Prinn 1994].

The main uncertainties in AOGCM are [Santer *et al.* 1996]:

1. errors in simulating current climate in uncoupled and coupled models,
2. inadequate representation of feedback,
3. flux-correction problems,
4. signal estimation problems,
5. “missing forcing” and uncertainties in space-time evolution of forcing, and
6. the cold-start effect.

The treatment of positive and negative feedback in AOGCM is inadequate and highly uncertain. Without the positive feedback of water vapor, no current model would predict warming in excess of 1.7°C for a doubling of $CO_2$ [Lindzen 1997]. But the way current models handle factors, such as clouds and water vapor, is disturbingly arbitrary. Indeed, there is compelling evidence for all the known feedback to be negative. An example of the complexity of feedback mechanisms is the ice-albedo case: warming may reduce the amount of sea ice, leading to reduced albedo and, therefore, enhanced warming; but more open water also provides a source of moisture that may compensate for the change in albedo [Cess *et al.* 1991; Trenberth 1996].

The interactive coupling between atmosphere and ocean in AOGCM is numerically incorrect and generally leads to simulating a climate drift into a new unrealistic state. This error is somehow accounted for by special ad-hoc corrections. However, the confidence in AOGCM predictions will remain low as long as climate drifts are found. Simply stated, coupled ocean-atmosphere climate models cannot reproduce current climatic conditions without adjustments that suggest fundamental flaws in the physical understanding and representation of the coupled ocean-atmosphere processes [Jacoby and Prinn 1994].

AOGCM are capable of simulating this century’s (annual mean) warming only by introducing the cooling effect of increasing concentrations of sulfate aerosols (see Figure 7). However, no measurements support the assumption of increasing atmospheric aerosols. On the contrary, a vast body of measurements available from 1900 onward indicate that atmospheric transmission is remarkably constant, as illustrated in Figure 25. This means that anthropogenic aerosols have not increased sufficiently to influence climate as much as claimed in the recent runs of AOGCM. Consequently, the global warming associated to $CO_2$ increase is over-estimated and AOGCM-based simulations of temperature in this century do not fit the actual measurements.

When further investigated, the apparently successful validation of AOGCM presented in Figure 7 appears to be troublesome. It is true that, on a global scale, the inclusion of sulfate concentrations improves the simulation of global mean temperature. However, as illustrated in Figure 26, the simulation over North America and Europe is not improved [Mitchell *et al.* 1995]. So, the success for global temperatures may just be the effect of error cancellation and not a true improvement of the simulation performance of the model. As correctly observed by Trenberth [1996] and many others, it is often possible to tune a model to achieve an apparent success, if the focus is only one quantity. However, changes in a model that improves one aspect may often adversely affect other variables, which seems to be the case illustrated in Figure 26. Models require comprehensive validation, not just calibration and tuning.

The role of aerosols in the forcing of climate is very complex [Charlson and Heintzenberg 1995]. Three categories of connections can be defined:

1. direct forcing (i.e., the theory of influence of aerosols on radiation),
2. indirect forcing, and
3. influences on heterogeneous chemistry.

Of these, only direct forcing is well understood. Also, the response to stratospheric aerosol forcing (e.g., during volcanic eruptions) is better understood than the one due to tropospheric aerosols.

Satellite-based observation (Figure 24) do not show any temperature increase since 1979; therefore, the validation of AOGCM-based simulations of temperature in this century (Figure 7) does not fit satellite measurements. This conclusion indicates that the global warming associated to $CO_2$ increase, as simulated by the current AOGCM, is over-estimated.

The Arctic, according to AOGCM simulations, is very sensitive to man-made greenhouse effect. Still, there is no sign of Arctic warming in the satellite-based data [Baliunas 1994].

The range of uncertainty for AOGCM is wider that one would estimate based on the spread of the models' outputs themselves [Jacoby and Prinn 1994].

Current state-of-the-art AOGCM simulations can only run for a few days because of computer limitations. Compromise solutions have to be made for the long (decade to century) runs needed for climate simulations [Trenberth 1996].

The planetary surface temperature is simply not as responsive to small changes in natural greenhouse effect as it was once thought (modeled) to be [Michaels 1997].

7. *Global model forecasts indicate that, as a consequence of increasing $CO_2$ concentrations in the next century, global temperatures will increase a few degrees Celsius.*

   Current AOGCM are not reliable tools for this type of forecast. They provide only a subset of possible future climate conditions and represent sensitivity experiments, not predictions [Pielke and Zeng 1994].

   Current AOGCM largely over-estimates the global warming associated with $CO_2$ increase.

   AOGCM must be able to replicate this century's temperature before being used with confidence in projecting future changes.

8. *Global model forecasts indicate that, as a consequence of temperature increase, serious adverse effects will be experienced.*

   Forecasts of temperature increases are not reliable.

   Adverse effects calculations are questionable.

   $CO_2$ increases have some positive effects. For example, enhanced $CO_2$ levels increase some plant growth and productivity [Jacoby and Prinn 1994; Boese *et al.* 1997].

   Temperature increases have some positive effects, especially because most of the forecasted warming is expected to occur in winter, at night, and in cold regions.

9. *To avoid or minimize adverse effects, government action and international treaties are needed to curb $CO_2$ emissions and, eventually, stabilize $CO_2$ concentrations.*

   Today, we should not rely on computer models to judge global warming [Pielke 1994]. Also, a delay in the implementation of $CO_2$ controls, while waiting for new evidence provided by better science, would have almost negligible effects. A recent analysis by Wigley *et al.* [1996] concluded that there is little difference between immediate (1995) emission cuts and initiation of cuts in 2020. Both scenarios lead to the same stabilized $CO_2$ concentration of approximately 550 ppmv, with the 25-year delay causing an additional, insignificant, global temperature rise of 0.2°C in 2100.

> The cost of $CO_2$ controls may be prohibitive and much below the benefits. For example, Baliunas [1994] estimates that stabilizing GHG concentrations could cost about one-fourth of the GNP of the US on an annual basis. Moreover, countries like China, India, Indonesia, and Brazil seem unlikely to stimulate voluntary $CO_2$ abatement; therefore, rich countries will probably have to pay poor countries to stabilize GHG concentrations. This would imply massive international transfers of wealth on a scale well beyond anything in recorded history [Jacoby *et al.* 1997].
>
> By allocating funds to $CO_2$ controls with uncertain benefits, we may penalize other environmental programs with higher potential benefits (e.g., reduction of population exposure to air toxics). Furthermore, $CO_2$ controls may cause a possible increase of indoor concentrations associated with decreased air exchange to save energy.

Other observations from the second group could be mentioned. And, of course, many of the second group's arguments have been commented upon and criticized by scientists in the first group. For example, Nicholls *et al*. 1996, state that the warming observed at surface stations cannot be attributed to urbanization, since it is also found in ocean temperatures and reflected in indirect temperature measurements (see Figure 8). I certainly cannot provide a summary of the entire debate here, since my main goal is just to present the main thoughts in the two sides.

## A Preliminary, Personal Conclusion

My (very) preliminary, (very) personal conclusion on this matter will focus on four (4) main items.

1. *The sun factor.*

   I believe, after reading the recent book by Hoyt and Schatten [1997], that the sun plays an important role in climate change and this role cannot be dismissed as negligible (as implied in Figure 2) in comparison with that of GHGs. Only the recent satellite measurements provide truly accurate solar-irradiance monitoring. These data must be carefully examined in the next few decades to verify possible long-term variations in solar irradiance and their relation with climatic changes.

2. *The global warming in the last two decades.*

   Satellite measurements of global temperature since 1979 do not show any global warming (Figure 24). This is in disagreement with surface temperature data shown in Figure 1. Unless convincing evidence is raised which challenges the validity of satellite data and provides a convincing argument against the discussions of Christy [1995, 1997], satellite measurements indicate that surface stations are not a good indicator of global temperature. If this is true, the entire validation effort of the most recent AOGCM depicted in Figure 7 is wrong and the sensitivity of global temperature to changes in GHG concentrations is much lower that the values presented in Figure 2. Consequently, projections of temperature increases in the next century may be highly over-estimated. The clarification of this item, in rigorous terms, should be a top priority issue for the scientific community.

3. *The positive feedbacks.*

Positive feedback occurs when a temperature increase causes variations that tend to further increase global temperature. For example, it is often assumed that, with warmer climate, the earth may have less snow and ice cover; thus, reducing the albedo and intensifying the warming. Also, at higher temperature the lower atmosphere contains more water vapor, which is a potent greenhouse gas. These positive feedback's magnify the 1.2°C gain that would be expected from direct radiation alone under a doubling of $CO_2$ concentrations [Jacoby and Prinn 1994].

One of the reason why AOGCM project large temperature increases in the next century is the presence of positive feedbacks, which are highly uncertain and difficult to quantify (for example, the cloud feedback is both positive and negative). I find it hard to accept that the earth may be in a situation of "unstable" equilibrium where a perturbation (temperature increase) is followed by an amplification of the signal. Based on scientific intuition, I would be inclined to think that, while we may certainly have positive and negative feedback, the total feedback can only be negative, i.e., in opposition to the signal, or absent at all. Otherwise, the earth's history would have been characterized by larger fluctuations and instabilities.

4. *The role of sulfates.*

As an expert in air pollution, I find it very difficult to accept the selective inclusion of sulfates, as performed in the most recent AOGCM simulations, to account for a cooling effect. Sulfates are only a fraction (and often a small fraction) of the total mass of aerosols that affect global radiative forcing. A vast body of measurements is available from 1900 onward showing that atmospheric transmission is remarkably constant [e.g., Hoyt and Frohlich 1983]. These data simply cannot be ignored.

A candid analysis of Figure 7 indicates that the role of sulfates in the most recent AOGCM simulations is absolutely critical for trusting these models. It is only because of the increasing cooling caused by sulfates after 1920, that the models are capable of simulating a correct global temperature trend in this century (even though continental trends remain incorrect, as illustrated in Figure 26). But, as mentioned before, atmospheric transmission measurements do not support an increase of atmospheric aerosols since 1920.

> If the treatment of sulfate concentrations in AOGCM simulations is incorrect, we find again that the sensitivity of global temperature to changes in GHG concentrations must be much lower that the values presented in Figure 2. Consequently, projections of temperature increases in the next century may be highly over-estimated. The clarification of this item, in rigorous terms, should be a top priority for the scientific community.

So, am I a skeptic? Perhaps. But my skepticism is based upon scientific data and facts. The most shocking experience for me is to encounter many scientists who, with little or no knowledge in atmospheric sciences, have convinced opinions on this issue! Also, I share many of the observations and comments provided by Lindzen [1997] and find it extremely disturbing to see hundreds of scientists and many Nobel Laureates, with no qualifications nor technical experience on this matter, signing petitions.

I remain, however, a partial believer, in the sense that I have no doubt that the computer modeling approach to this problem is a sound scientific endeavor and that the current AOGCM are useful tools. As correctly observed by Trenberth [1997], models can be used and abused and, certainly, they do not offer the certainties that policy-makers would like. The scientific community as a whole, however, must achieve a consensus on the proper use of these models, the quantification of their projections, and the calculation of the uncertainty bounds of these projections.

The scientific community must resist political, economic, and militant pressures from any direction. Let's examine, for example, Figure 27, a case in which Michaels and Knappenberger [1996] expose and criticize Santer *et al.* [1996a] for selecting only a subset of observational data in order to prove a sulfate + greenhouse hypothesis. If the accusation is correct, this represents a very disturbing event (and if the accusation is not correct, this is very disturbing too). All data and scientific evidence must be used, without exception; they can be criticized but not ignored. One scientific side must listen to the other side and debate the arguments using, as the sole arbiter, the scientific method. Also, the recent effort in trying to disqualify scientific opinions on subjective considerations (e.g., the authors' political affiliation or sponsors) instead of objective considerations, is very dangerous to the scientific community.

# Addendum

In the last few months, I have circulated a preliminary draft of this chapter in the scientific community. This draft generated interest and comments from many readers, who have also provided additional information on this subject. Some selected comments are presented below.

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Q.: My only question, personally, is about France being the only accidental success story - would not Germany (via reunification), England (via switch to NG) and the former Soviet States all qualify as well?

A.: France is the only country that, in the last few decades, has shown a strong decline in $CO_2$ emissions. The other countries you mentioned made progress too, but more in reducing their increasing trend.

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Following is a reference relating to the comparison of the surface and satellite temperature data:

Hansen et al (1997) "Forcings and chaos in interannual to decadal climate change". J. Geophysical Research 102(D22), 25679-25720.

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A few references on satellite-based temperature measurements:

Hurrell, J. W., and K. E. Trenberth, 1997: Spurious trends in the satellite MSU temperature record arising from merging different satellite records. Nature 386, 164--167.

and the followup correspondence and rebuttal: Trenberth, K. E., and J. W. Hurrell, 1997: How accurate are satellite `thermometers'. Nature 389, 342--343.

Hurrell, J. W., and K. E. Trenberth, 1997: Difficulties in obtaining reliable temperature trends: Reconciling the surface and satellite MSU 2R trends. J. Climate.

Trenberth, K. E., 1997: Global Warming: It's happening. article 9. http://naturalscience.com/ns/articles/01-09/ns_ket.html (Electronic journal).

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Frederick Seitz, Past President of the National Academy of Sciences, USA, and President Emeritus of the Rockfeller University has launched a petition to reject the global warming agreement that was written in Kyoto in December 1997. For more information, contact Petition Project, PO BOX 1925, La Jolla, CA 92038-1925 (USA).

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# Comments on "Todays Debate on Climate Change: Searching for the Scientific Truth, by P Zannetti"

*By*
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*Griffith University*
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I have read the paper by Zannetti (1998) with considerable interest. I came to most of these conclusions some 10 years ago and stood in conferences and said so. At the time, the scientific method seemed to be forgotten as the ' believers in the greenhouse ' entered the fray in earnest: how dare I challenge the established mantra???  The debate is still going today and the science is still inconclusive as to the nature and extent of the Greenhouse Effect.  This paper, Zannetti (1998), is a useful contribution to that debate, and a call for the proper use of the Scientific method.

The body of the paper is appropriate and well presented, but the conclusions seem to underplay and not fully represent the first part. Some additional features which could be mentioned, include

### *1) The Sun.*

The sun is not a constant but is variable in its outputs. The Solar Constant is the measure of the radiative flux from the sun at a distance equivalent to the radius of the earth's orbit. The name is misleading as we know that this flux varies (Kelly and Wigley, 1992). We do not have accurate output measures from the sun in the long term although satellites have observed and measured the sun's radiative output since about 1978 when the Nimbus satellite was launched for that purpose. The Marshall Report (1989) discusses some of the results and indicates the variability in the solar constant.

One point is the variation in sunspot activity as a measure of solar activity. Sunspot activity has been observed by the Chinese for some 3000 years or more, as slaves were forced to look at the sun and observe and count sunspots. The records are by no means reliable and the level of resolution is quite problematic. The telescope arrived in about 1610, which was the start of the Maundler minimum in sunspot activity, and permitted better techniques for observation. These techniques were eventually superceded by the satellites. This Maundler period lasted until about 1700 and sunspot activity has been increasing since then [but also oscillating on a 10-11 and 22 year cycle]. In addition, the little ice age coincided with this period, and temperatures have increased since but fluctuating of course. This should not be construed as an assumption of cause and effect.

However, one feature of the current Greenhouse debate is the lack of attention to the main input of radiant energy to the earth. This is an area deserving of scientific attention.

### *2) The Models.*

Zannetti (1998) raises several questions about the models which are in use for predicting climate change, but does not follow through on how to improve them. Braddock et al.(1994) have managed to write IMAGE , one of the simpler climate models, as a mathematical system and studied it for equilibria, stability and chaotic behavior. They also considered the sensitivity of the model to variation in the values of a small range of the parameters, considered some of the stochastic properties and the application of control theory for achieving targets on atmospheric composition while minimizing some economic cost function. This form of analysis needs to be extended to other climate models although there are serious problems in computer resources to tackle the calculations both mathematical and numerical.

The current models need to better handle the physics of water vapor, clouds etc, as well as the interactions with ice. The carbon cycle needs to be improved, as do the other models [nitrogen cycle and heat cycle] as these all affect the biosphere. The relationships and interactions with the atmosphere and ocean are also not well modeled. In a GCM, the basic modeling of other parts of the system needs to be brought to the same level of sophistication as that for the atmosphere.

### *3) Other Modeling Issues.*

There is a range of models of differing complexity and sophistication from 'back of the envelope to GCM', for each component of the integrated models. This raises a question as to the suitability of the match between models where the atmosphere [say] is but a module of a larger integrated [world?] model What are the error propagation of one crude model feeding information into a more sophisticated one, and vice versa. These aspects certainly need to be explored.

I would like to see a modeling situation where several models of differing sophistication and complexity can be incorporated into the integrated [Greenhouse] simulator Then we could compare the predictive power of the simulator at different levels of resolution, sophistication and complexity. Some advanced form of sensitivity analysis may give some idea as to which of the sub-models for each cycle [heat, carbon etc] are required to achieve various levels of resolution and precision, and which need to be improved. Such a study could also investigate the information flow and transformations, and consider how they interact as errors propagate through the integrated whole.

### 4) Climate Relationships

Barnola et al. (1987) have discussed the link between the gas concentrations in ice bores and atmospheric temperatures, and found good correlation between the two. They also put the records through a spectral analyzer and found significant periods of 105000 years, 43-44000 years, and 21000 years. All of these periodic cycles coincide with the periods of variation of the earth's orbital and axial parameters. The variation in the radiative input from the sun does seem to have an effect on climate.

I have repeated their calculations and confirm their results. I also attempted to find a lag effect between the temperature, methane and carbon dioxide records from the Vostok Ice Cores. The data contains errors in the dating of the measurements, and Barnola et al. (1987) suggest errors of measurement of up to 10000 years in the record, especially for the older data. I used cross correlation and least squares fitting of lagged records to try to identify time lags between the temperature and gas concentrations. The lags seem to vary through the record but are of the order of 1400 years with the gas signal lagging the temperature.

I attempted the same exercise with the historical sea level record as investigated by Chappell (1982) using geomorphological techniques in the Huon Gulf region in Papua New Guinea. The timing errors are worse than for the ice core data, and there are significant errors in the estimated sea levels. Again, cross correlations were used to identify a range of lags with most being in the range 2000-6000 years with the sea level lagging the temperature record. I have not attempted to publish the work as the calculated lags all lie within the error range of the basic data, and the R-squared values are less than 0.6 for all of the fits.

There is still considerable politics going on in scientific circles, over the cause and effects of the greenhouse, as Kyoto and its prelude showed. There is evidence of politics within the scientific community over funding and influence. There is also evidence of a selective use of science in the political world. I believe the scientific community needs to return to the scientific methods and traditions.

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Zannetti, P., 1998, Today’s Debate on Climate Change:Searching for the Scientific  Truth, http://www.envirocomp.org/html/publish/GlobalWarming/GWreport_x_EC.pdf

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I note in your latest issue of ENVIRONews that several references are given concerning the satellite temperature record. Please see the other point of view at:
http://wwwghcc.msfc.nasa.gov/temperature/
and the links contained therein.

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I would like to suggest two additional sources: one is 'Energy Policy' (Elsevier) p.439-444: 'A winning coalition of advocacy: climate research, bureaucracy and alternative fuels’, March 1997, which is based on a four year study of the IPCC and its internal politics and science. The second is a 1997 book by Nigel Calder, ‘The Manic SUN’, which tells the human story of the Danes trying to get work on the solar hypothesis.

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There are two other sources of information about “skeptics”. There is a British group which includes scientists at the Institute for Economic Affairs  in London, 2 Lord North Street, Westminster London SW1P3LB (iea@iea.org.uk  or http://www.iea.org.uk). They have published 2 books on this subject. There is also the European Academy for Environmental Affairs, under Prof. Dr. H. Metzner), phone: 07071 787 83; Fax 07071 72939.

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## Some Internet Resources and Information on Global Warming

Climate Countdown – National Environmental Trust
http://www.envirotrust.com/climate.html

'Countdown to Kyoto': The Consequences of the Mandatory Global Carbon Dioxide Emissions Reductions, Australian APEC Study Centre, Canberra, Australia, 19-21 August 1997
http://www.arts.monash.edu.au/ausapec/kypaps.htm

Global Climate Information Project
http://www.climatefact.org/

Greenhouse gases section of the Energy Information Administration's (EIA) Worldwide Web Server
http://www.eia.doe.gov/oiaf/1605/frntend.html

U.S. Global Change Research Program
http://www.usgcrp.gov/

Carbon Dioxide Information Analysis Center – The primary global-change data and information analysis center of the U.S. Department of Energy (DOE)
http://cdiac.esd.ornl.gov/

Massachusetts Institute of Technology – Joint Program on the Science and Policy of Global Change
http://web.mit.edu/globalchange/www/

U.S. Geological Survey Global Change Research Program
http://GeoChange.er.USGS.gov/index.html

Union of Concerned Scientists – Compact section on global warming
http://www.ucsusa.org/warming/index.html

George C. Marshall Institute
http://www.marshall.org/globalfax.html

Global Warming – New York Times
http://www.nytimes.com/library/national/warming-index.html

White House Initiative on Global Climate Change
http://www.whitehouse.gov/Initiatives/Climate/main.html

The Environmental Protection Agency – The Global Warming section
http://www.epa.gov/globalwarming/

Global Warming Information Page – Maintained by Consumer Alert
http://www.globalwarming.org/index.htm

Environmental News Network
http://www.enn.com/climate/

Global Warming: Focus on the Future
http://www.envirolink.org/orgs/edf/

United Nations Intergovernmental Panel on Global Warming
http://www.ipcc.ch/

World Wildlife Fund's Climate Change Campaign
http://www.panda.org/climate/

Add Up Your Carbon Dioxide Emissions – Games site
http://www.envirolink.org/orgs/edf/games/index.html

Global Climate Coalition – A coalition of private companies and trade associations
http://www.worldcorp.com/dc-online/gcc/tech.html

Sierra Club Global Warming and Energy Campaign
http://www.sierraclub.org/global-warming/home.html

Global Warming: Understanding the Forecast – From the Environmental Defense Fund
http://www.edf.org/pubs/Brochures/GlobalWarming/index.html

The UNFCCC Official Web Site of the Climate Change Secretariat
http://www.unfccc.de/fccc/conv/file01.htm

Global Warming Central
http://www.law.pace.edu/env/energy/globalwarming.html

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# Figures

In this chapter, I took the liberty of scanning the figures below to provide the readers with useful information on the subject. Full credits are provided for each figure.

**Figure 1.** Figure 3.3 c, p. 143, Nicholls *et al*. (1996)

**Figure 2.** Figure 2.16, p. 117, Schimel *et al*. (1996)

**Figure 3.** From p. 497, Boden *et al*. (1994)

**Figure 4.** From p. 12, Neftel *et al*. (1994)

**Figure 5.** From p. 18, Keeling and Whorf (1994)

**Figure 6.** Figure 1, Trenberth (1997) – (I apologize for the poor quality of this scanning)

**Figure 7.** Figure 6.3, p. 297, Kattenberg *et al*. (1996) - (I apologize for the poor quality of this scanning)

**Figure 8.** Figure 12, p. 29, Houghton *et al*. (1996) - (I apologize for the poor quality of this scanning)

**Figure 9.** Figure 5, p. 23, Houghton *et al*. (1996)

**Figure 10.** Figure 6.24, p. 323, Kattenberg *et al*. (1996)

**Figure 11.** Figure 20, p. 40, Houghton *et al*. (1996)

**Figure 12.** Figure 25, p. 45, Houghton *et al*. (1996)

**Figure 13.** Figure 7, p. 25, Houghton *et al*. (1996)

**Figure 14.** Figure 5.11, Hoyt and Schatten, 1997 (from Lee 1992, p. 121)

**Figure 15. a)** Figure 10.21, p. 196, Hoyt and Schatten (1997). **b)** Figure 10.13, p. 186, Hoyt and Schatten (1997) (from Friis-Christensen and Lassen, 1991)

**Figure 16.** From Kerr 1995

**Figure 17.** Figure, p. 50, Newsweek, October 20, 1997

**Figure 18.** From p. 507, Marland *et al*. (1994)

**Figure 19.** From p. 541, Marland *et al*. (1994)

**Figure 20**. From p. 550, Marland *et al*. (1994)

**Figure 21**. From p. 568, Marland *et al*. (1994)

**Figure 22**. From p. 560, Marland *et al*. (1994)

**Figure 23**. Figure 2.2, p. 81, Schimel *et al*. (1996)

**Figure 24**. Figure 5, Christy (1997)

**Figure 25**. Figure 11.3, p. 211, Hoyt and Schatten (1997), [Hoyt and Frohlich 1983]

**Figure 26**. Figure 2, Mitchell *et al*. (1995)

**Figure 27**. Figure 5, Michaels (1997)

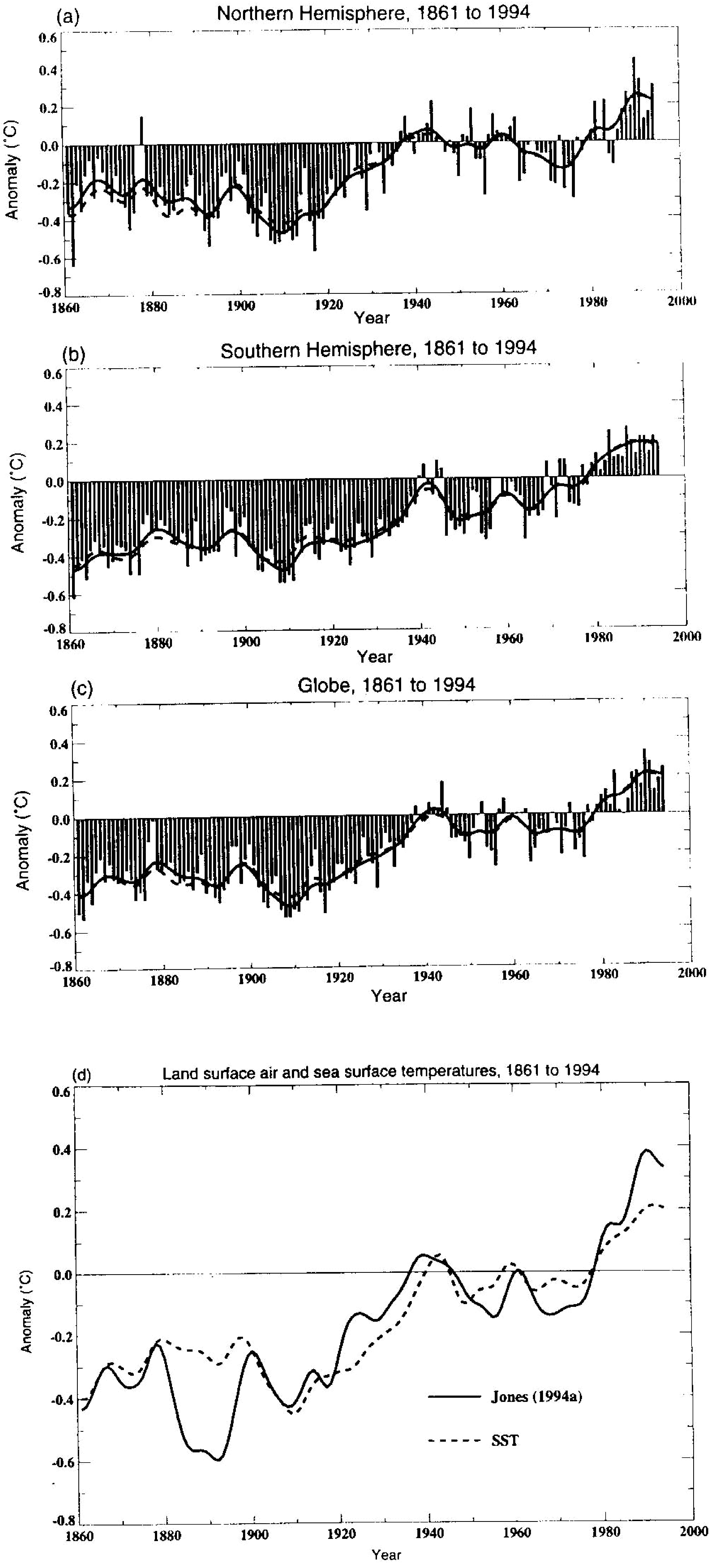


**Figure 3.3:** Combined annual land-surface air and sea surface temperature anomalies (°C) 1861 to 1994, relative to 1961 to 1990 (bars and solid smoothed curves): (a) Northern Hemisphere; (b) Southern Hemisphere; (c) Globe. The dashed smoothed curves are corresponding results from IPCC (1992), adjusted to be relative to 1961 to 1990. (d) Global land-surface air temperature (solid line) and SST (broken line).

Figure 1. Figure 3.3 c, p. 143, Nicholls *et al.* (1996)

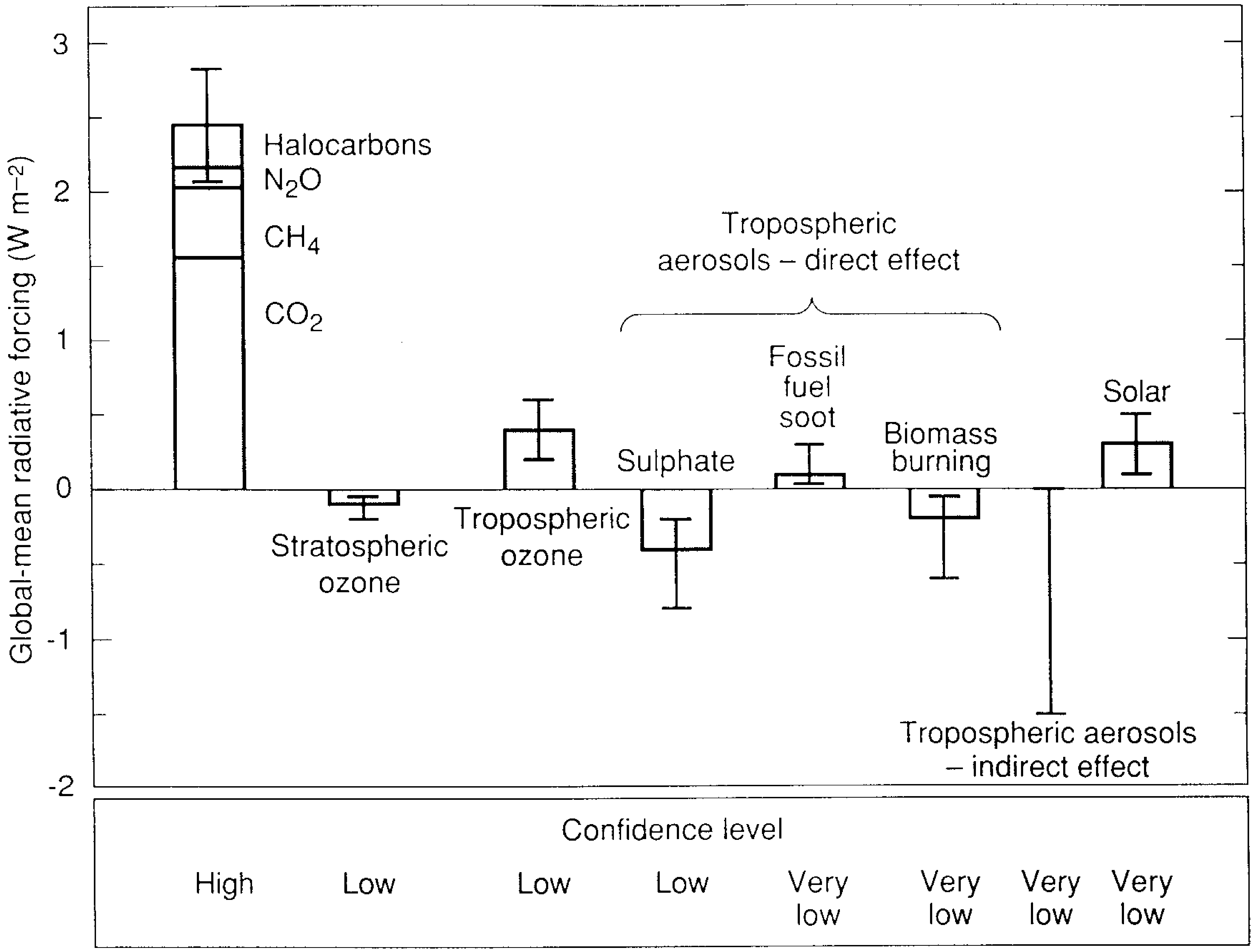
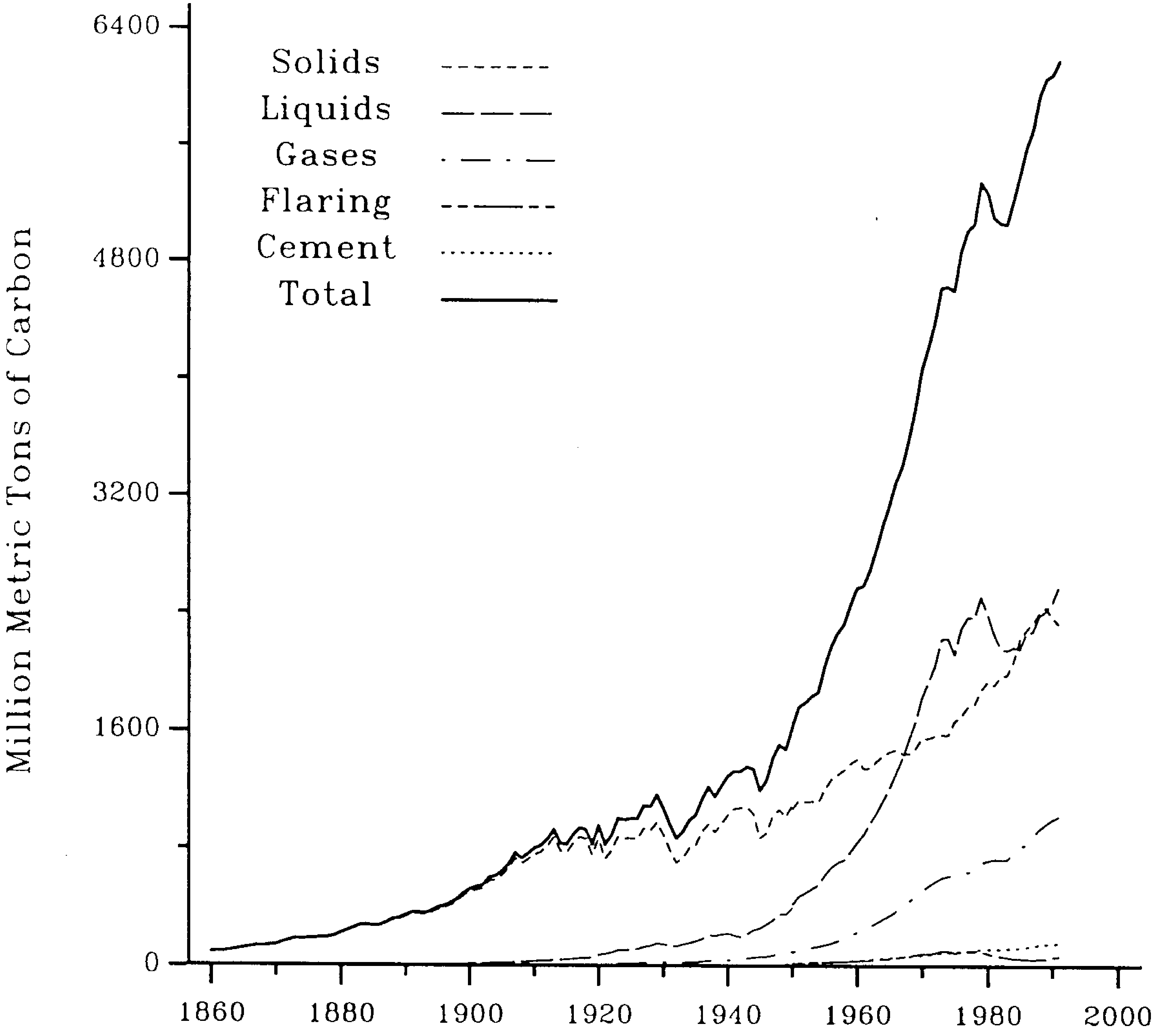


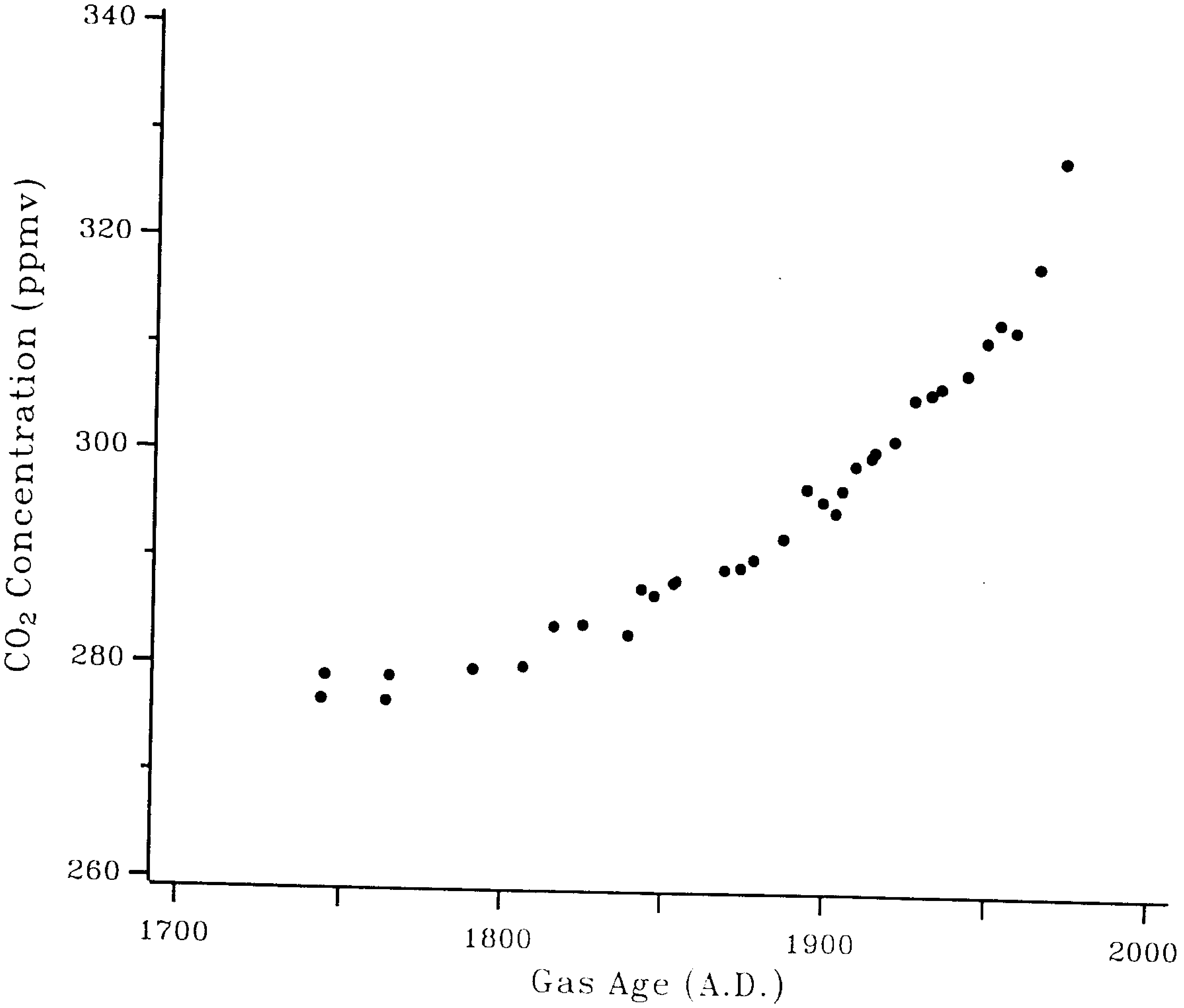
**Figure 2.16:** Estimates of the globally and annually averaged anthropogenic radiative forcing (in $Wm^{-2}$) due to changes in concentrations of greenhouse gases and aerosols from pre-industrial times to the present day and to natural changes in solar output from 1850 to the present day. The height of the rectangular bar indicates a mid-range estimate of the forcing whilst the error bars show an estimate of the uncertainty range, based largely on the spread of published values; our subjective confidence that the actual forcing lies within this error bar is indicated by the "confidence level". The contributions of individual gases to the direct greenhouse forcing is indicated on the first bar. The indirect greenhouse forcings associated with the depletion of stratospheric ozone and the increased concentration of tropospheric ozone are shown in the second and third bar respectively. The direct contributions of individual tropospheric aerosol components are grouped into the next set of three bars. The indirect aerosol effect, arising from the induced change in cloud properties, is shown next; our quantitative understanding of this process is very limited at present and hence no bar representing a mid-range estimate is shown. The final bar shows the estimate of the changes in radiative forcing due to variations in solar output. The forcing associated with stratospheric aerosols resulting from volcanic eruptions is not shown, as it is very variable over this time period; Figure 2.15 shows estimates of this variation. Note that there are substantial differences in the geographical distribution of the forcing due to the well-mixed greenhouse gases ($CO_2$, $N_2O$, $CH_4$ and the halocarbons) and that due to ozone and aerosols, which could lead to significant differences in their respective global and regional climate responses (see Chapter 6). For this reason, the negative radiative forcing due to aerosols should not necessarily be regarded as an offset against the greenhouse gas forcing.

Figure 2. Figure 2.16, p. 117, Schimel *et al.* (1996)



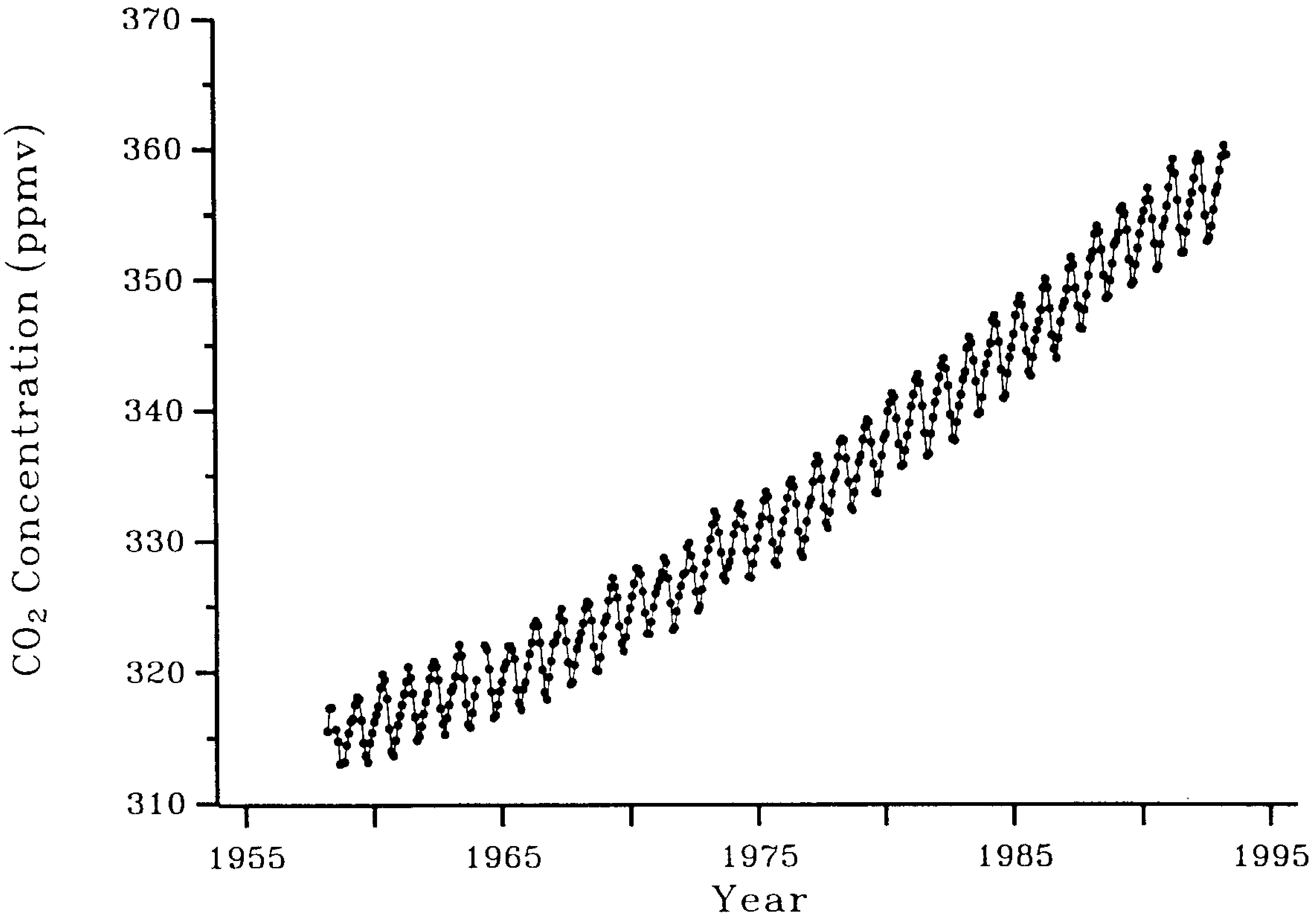
*Global $CO_2$ emissions from fossil fuel burning, cement production, and gas flaring, 1860–1991.*

Figure 3. From p. 497, Boden *et al.* (1994)



*Atmospheric $CO_2$ derived from the Siple ice core.*

Figure 4. From p. 12, Neftel *et al.* (1994)



*Monthly atmospheric $CO_2$ concentrations at Mauna Loa.*

Figure 5. From p. 18, Keeling and Whorf (1994)

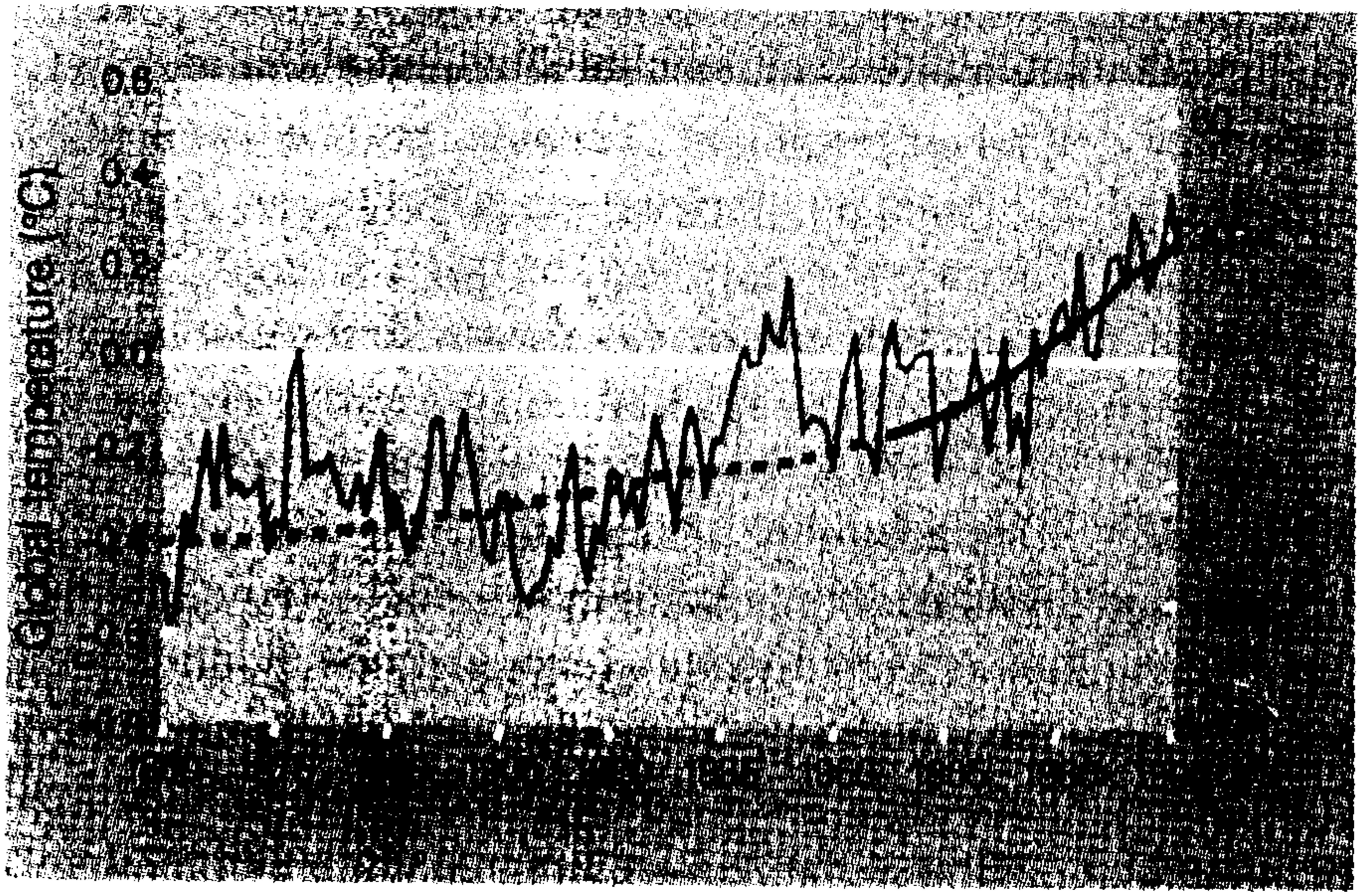


Figure 1 **Estimated changes in annual global mean temperatures[5] (red) and carbon dioxide (green) over the past 137 years relative to a 1961–90 base period. Earlier values for carbon dioxide are from ice cores[3] (dashed line), and for 1957 to 1995 from direct measurements made at Mauna Loa, Hawaii[2]. The scale for carbon dioxide is in parts per million by volume (p.p.m.v.) relative to a mean of 333.7 p.p.m.v.**

Figure 6. Figure 1, Trenberth (1997)

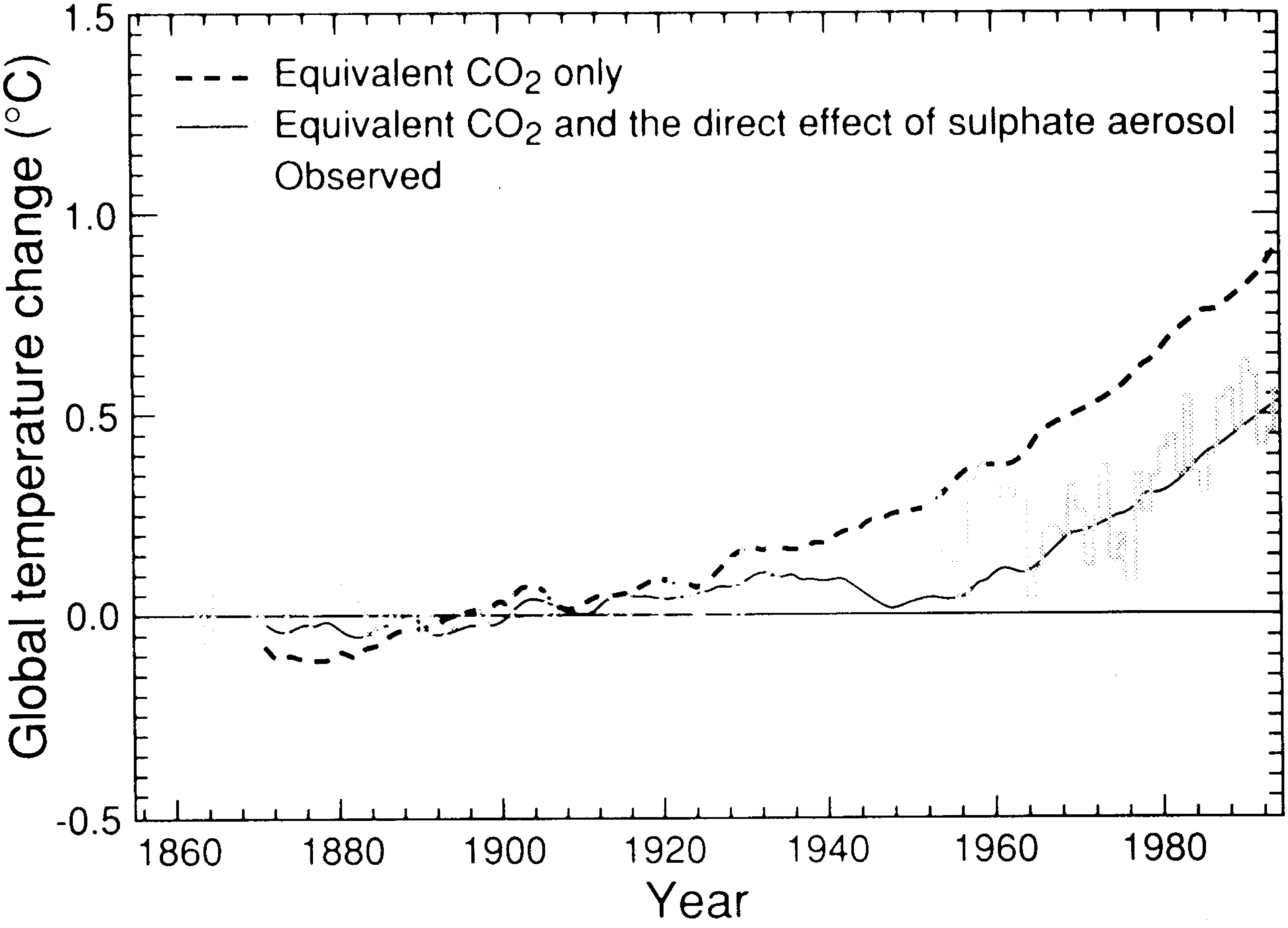
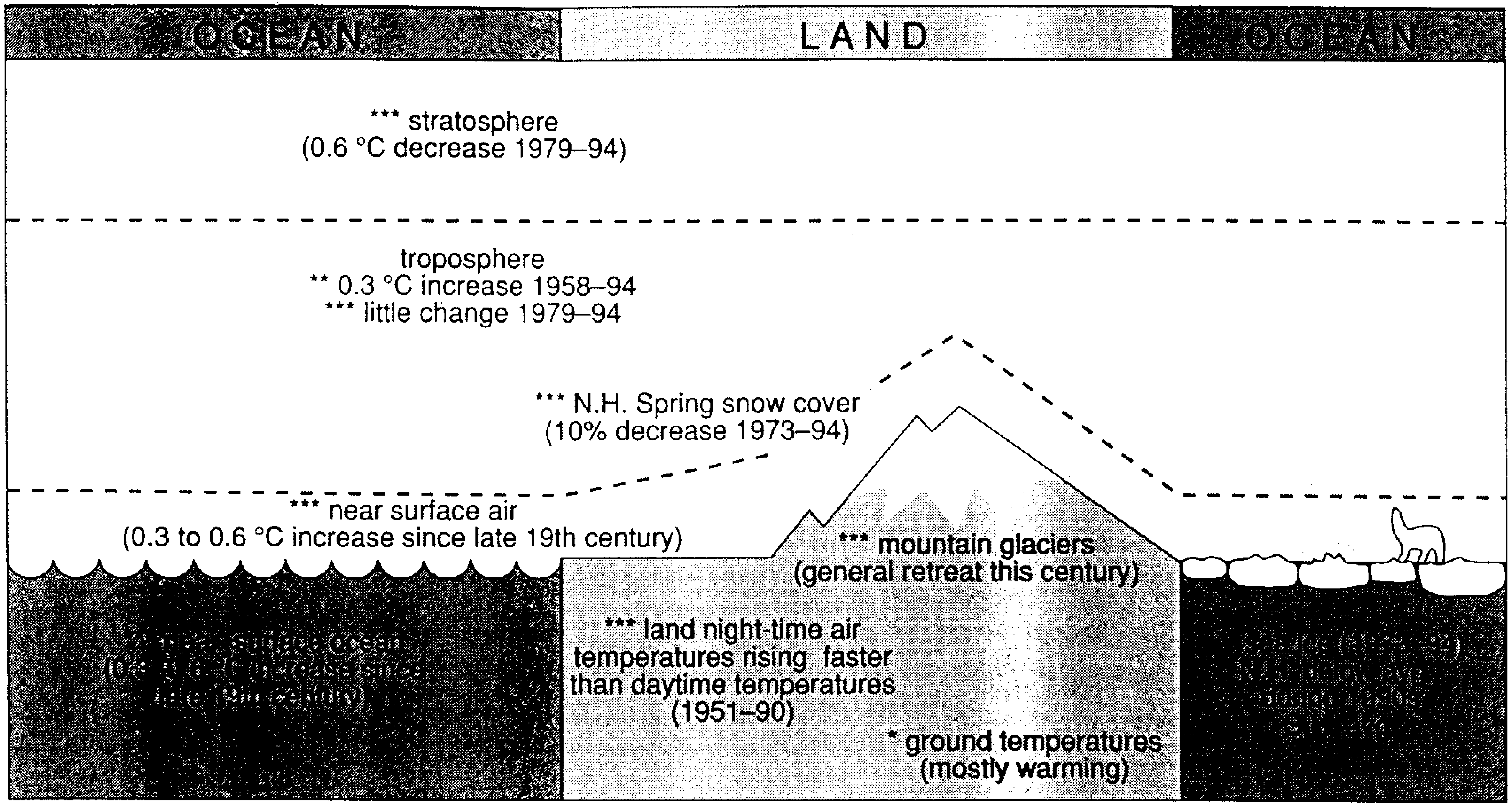


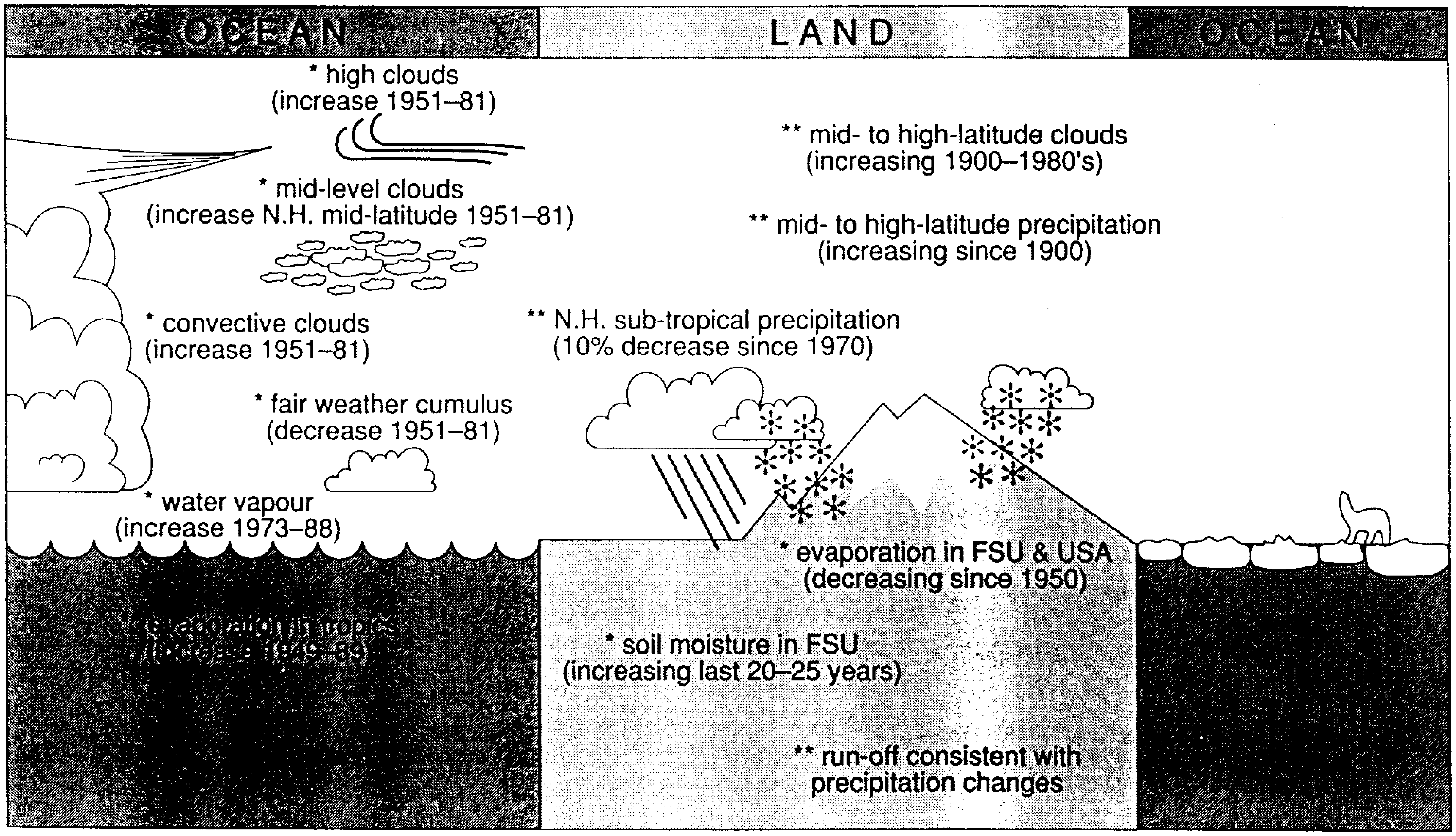
**Figure 6.3:** Simulated global annual mean warming from 1860 to 1990, allowing for increases in equivalent $CO_2$ only (dashed curve) and allowing for increases in equivalent $CO_2$ and the direct effects of sulphates (flecked curve) (Mitchell *et al.*, 1995a). The observed changes are from Parker *et al.* (1994). The anomalies are calculated relative to 1880–1920.

Figure 7. Figure 6.3, p. 297, Kattenberg *et al.* (1996)

(a) **Temperature indicators**



(b) **Hydrological indicators**



**Asterisk indicates confidence level (i.e., assessment): *** high, ** medium, * low**

Figure 12: Summary of observed climatic trends during the instrumental period of record.

Figure 8. Figure 12, p. 29, Houghton *et al.* (1996)

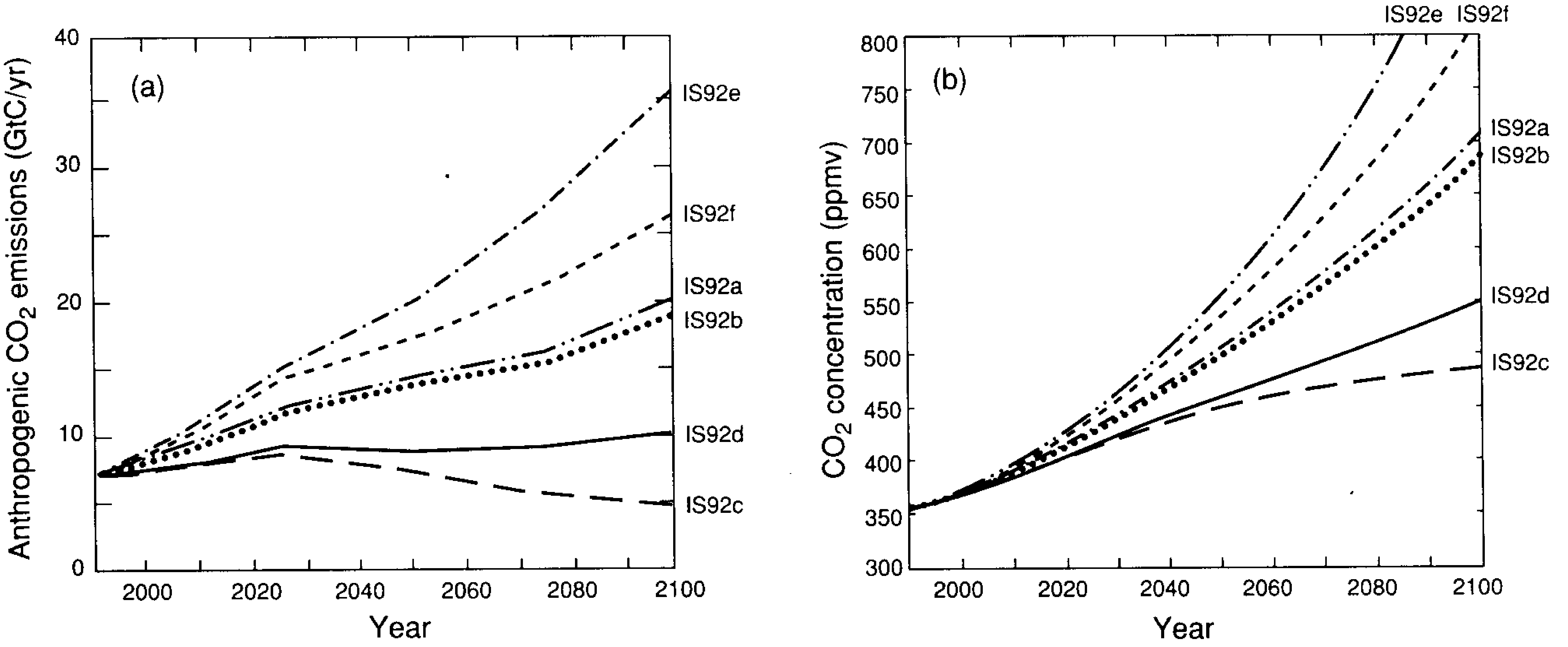


**Figure 5:** (a) Total anthropogenic $CO_2$ emissions under the IS92 emission scenarios and (b) the resulting atmospheric $CO_2$ concentrations calculated using the "Bern" carbon cycle model and the carbon budget for the 1980s shown in Table 2.

Figure 9. Figure 5, p. 23, Houghton *et al.* (1996)

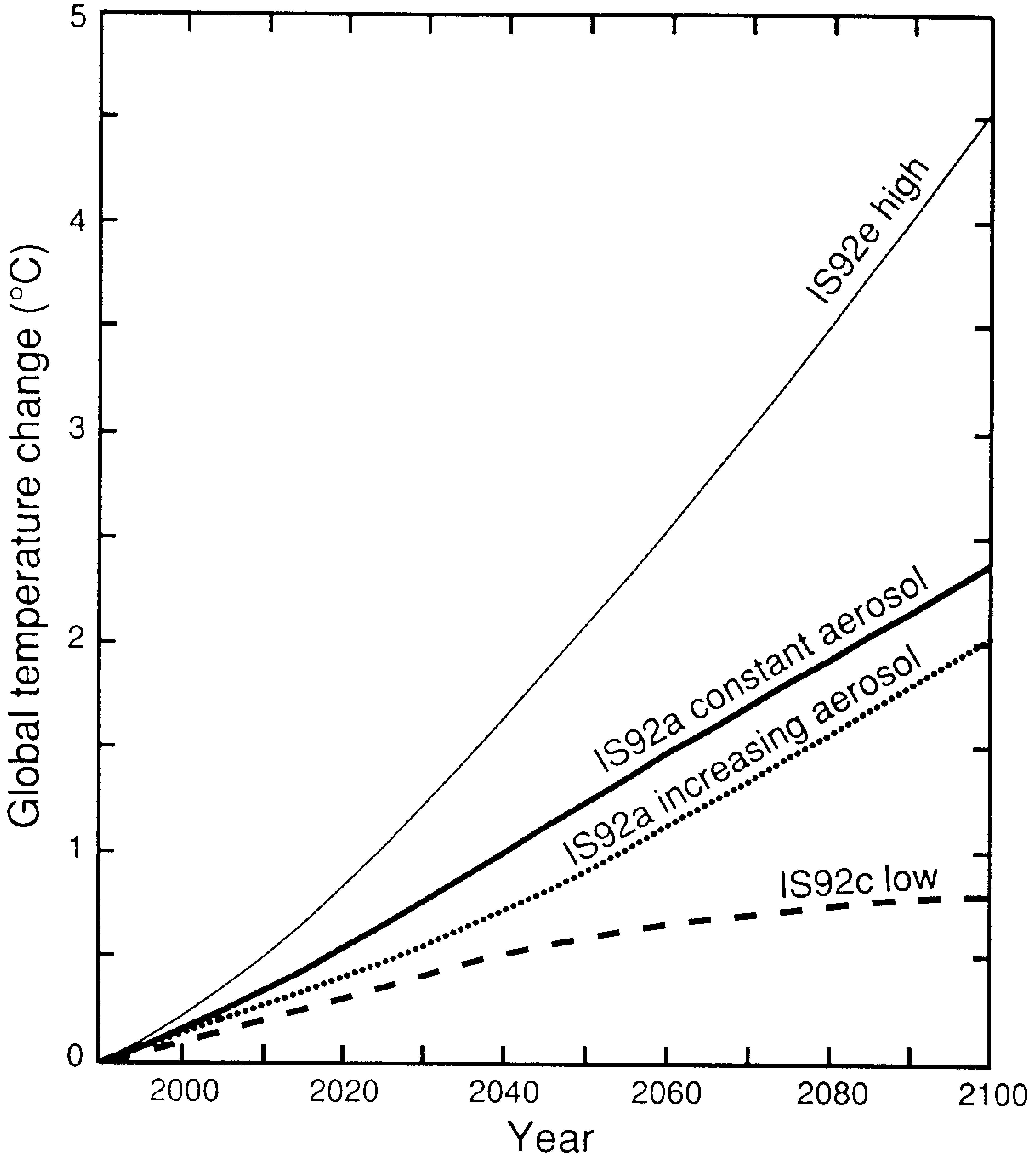


**Figure 6.24:** Extreme range of possible changes in global mean temperature. The topmost curve is for IS92e assuming constant aerosol concentrations beyond 1990 and a high climate sensitivity ($\Delta T_{2\times} = 4.5°C$); the lowest curve is for IS92c, also assuming constant aerosol concentrations beyond 1990, but with a low climate sensitivity ($\Delta T_{2\times} = 1.5°C$). Results for IS92a are shown for comparison, both with and without changing aerosols.

Figure 10. Figure 6.24, p. 323, Kattenberg *et al.* (1996)

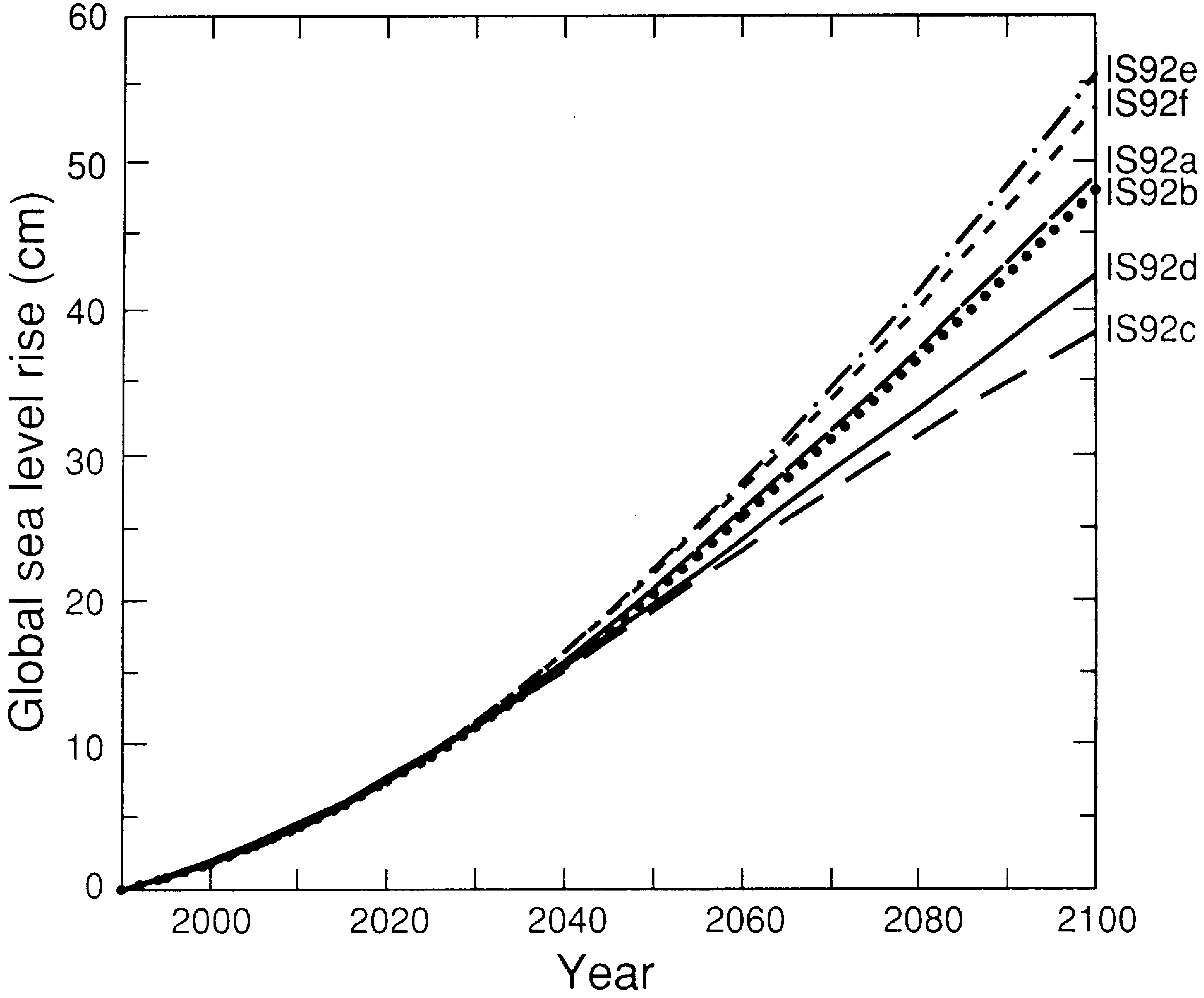


**Figure 20:** Projected global mean sea level rise from 1990 to 2100 for the full set of IS92 emission scenarios. A climate sensitivity of 2.5°C and mid-value ice melt parameters are assumed.

Figure 11. Figure 20, p. 40, Houghton *et al.* (1996)

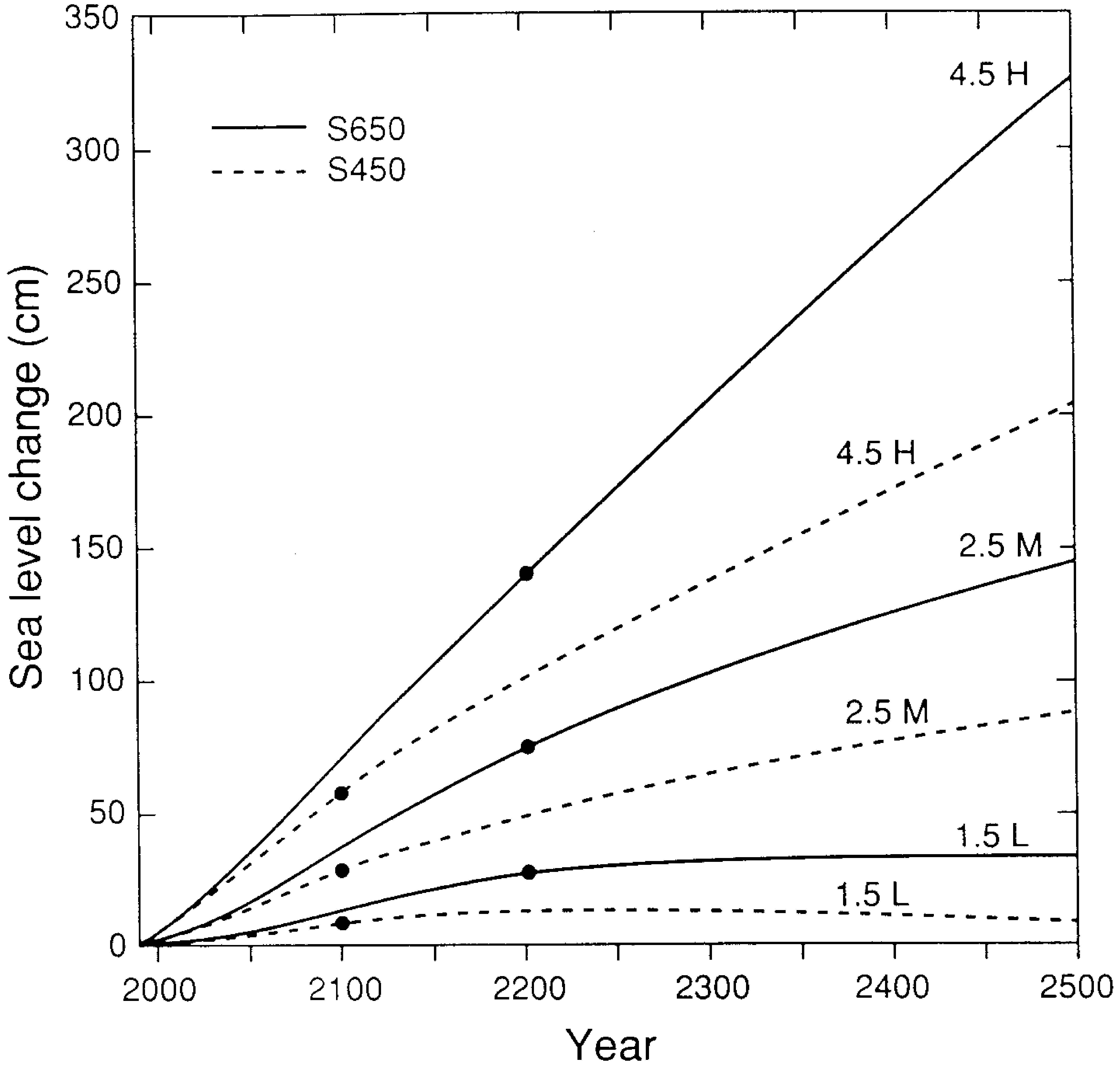


**Figure 25:** The global mean sea level response to the $CO_2$ concentration pathways leading to stabilisation at 450 (dashed curves) and 650 (solid curves) ppmv (see Figure 7a) for a climate sensitivity of 1.5, 2.5 and 4.5 °C. The changes shown are those arising from $CO_2$ increases alone. The date of concentration stabilisation is indicated by the dot. Calculations assume the "observed" history of forcing to 1990, including aerosol effects and then $CO_2$ concentration increases only beyond 1990.

Figure 12. Figure 25, p. 45, Houghton *et al.* (1996)

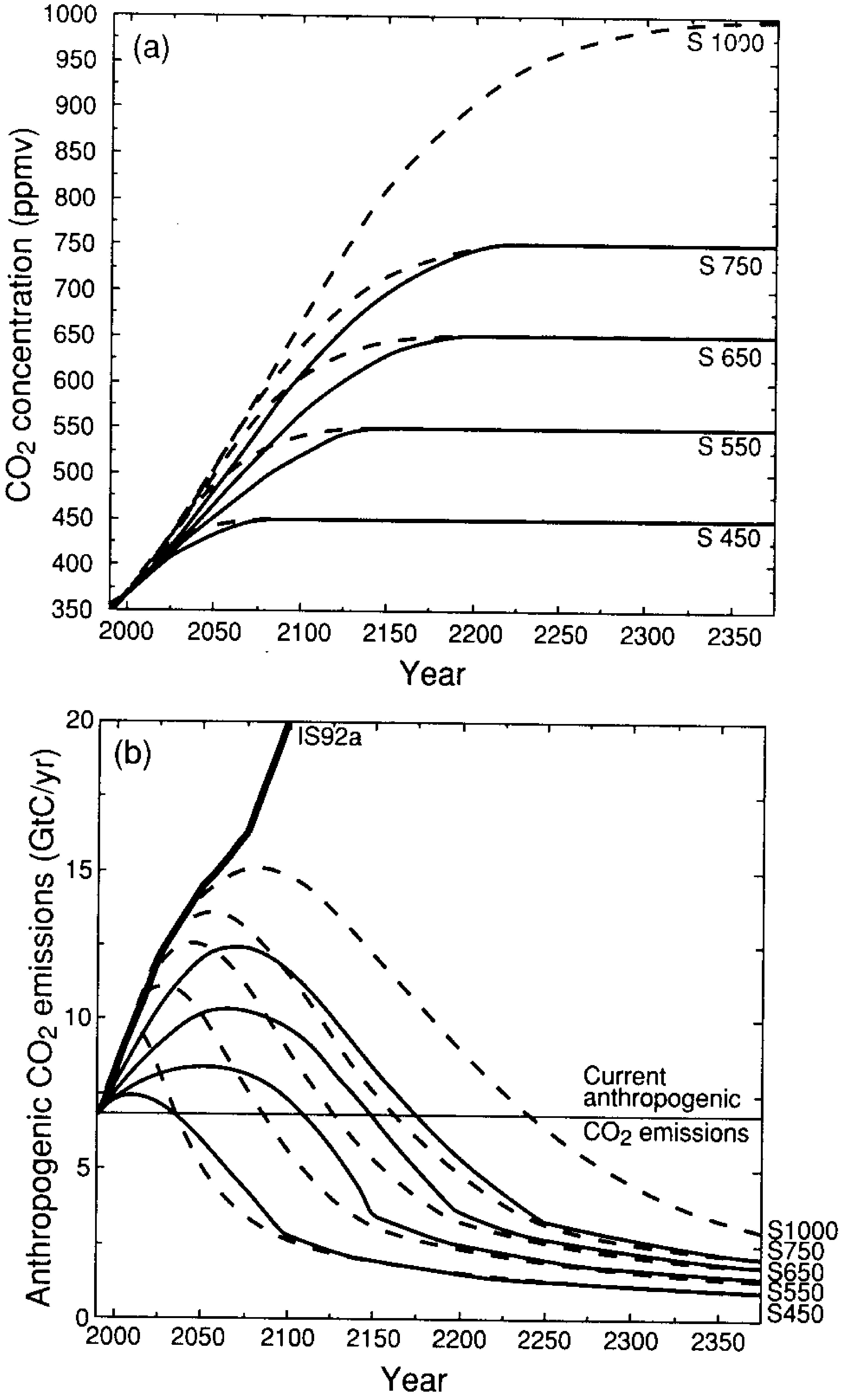


**Figure 7:** (a) $CO_2$ concentration profiles leading to stabilisation at 450, 550, 650 and 750 ppmv following the pathways defined in IPCC (1994) (solid curves) and for pathways that allow emissions to follow IS92a until at least 2000 (dashed curves). A single profile that stabilises at a $CO_2$ concentration of 1000 ppmv and follows IS92a emissions until at least 2000 has also been defined. (b) $CO_2$ emissions leading to stabilisation at concentrations of 450, 550, 650, 750 and 1000 ppmv following the profiles shown in (a). Current anthropogenic $CO_2$ emissions and those for IS92a are shown for comparison. The calculations use the "Bern" carbon cycle model and the carbon budget for the 1980s shown in Table 2.

Figure 13. Figure 7, p. 25, Houghton *et al.* (1996)

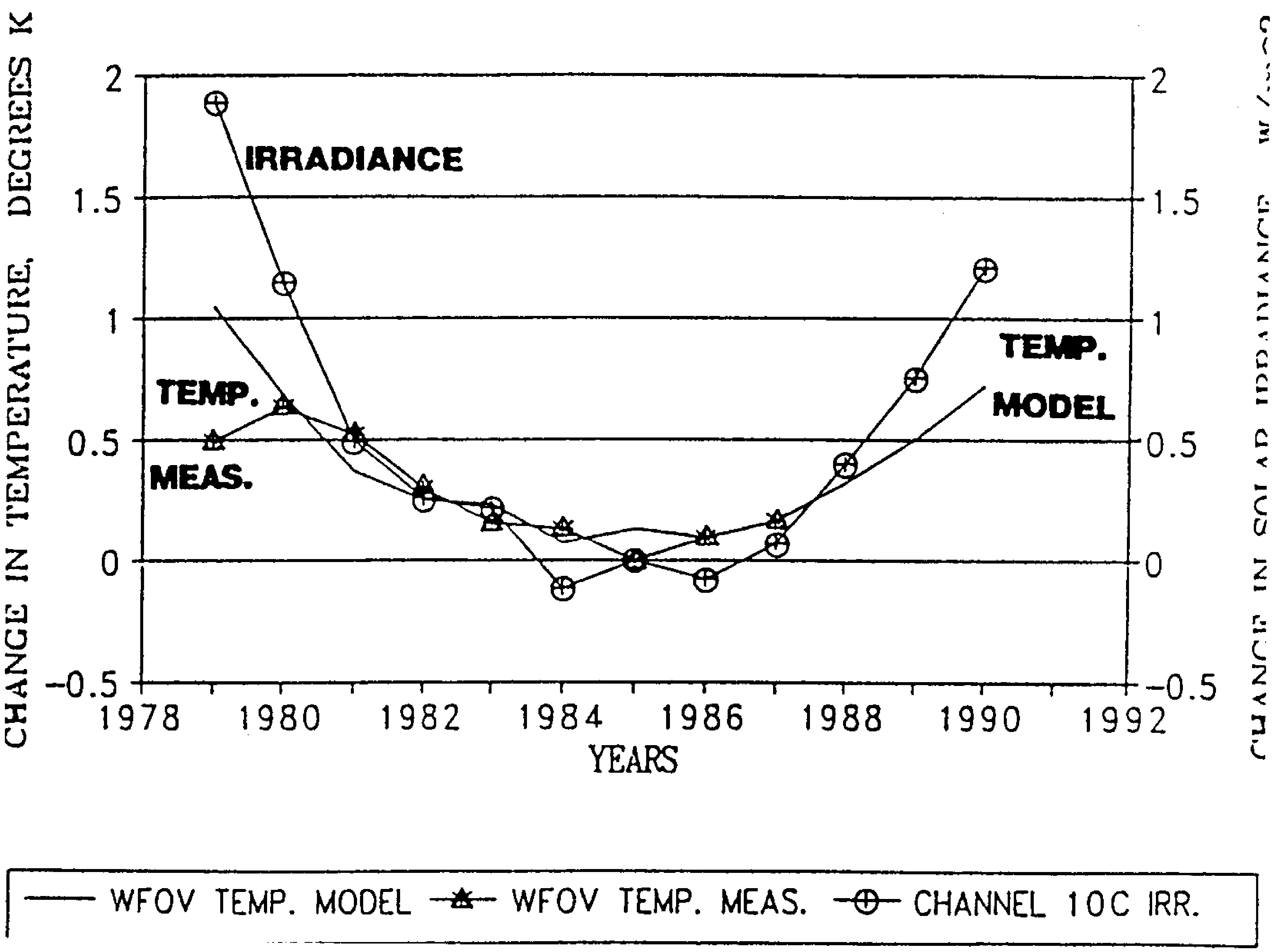


FIGURE 5.11 The yearly mean Nimbus-7 solar total irradiance values are plotted along with the temperatures deduced from thermal radiation measurements on board Nimbus-7 (the wide-field-of-view [WFOV] temperature measurements). Both curves parallel each other, suggesting a cause-and-effect relationship. (From Lee, 1992, with permission.)

Figure 14. Figure 5.11, Hoyt and Schatten, 1997 (from Lee 1992, p. 121)

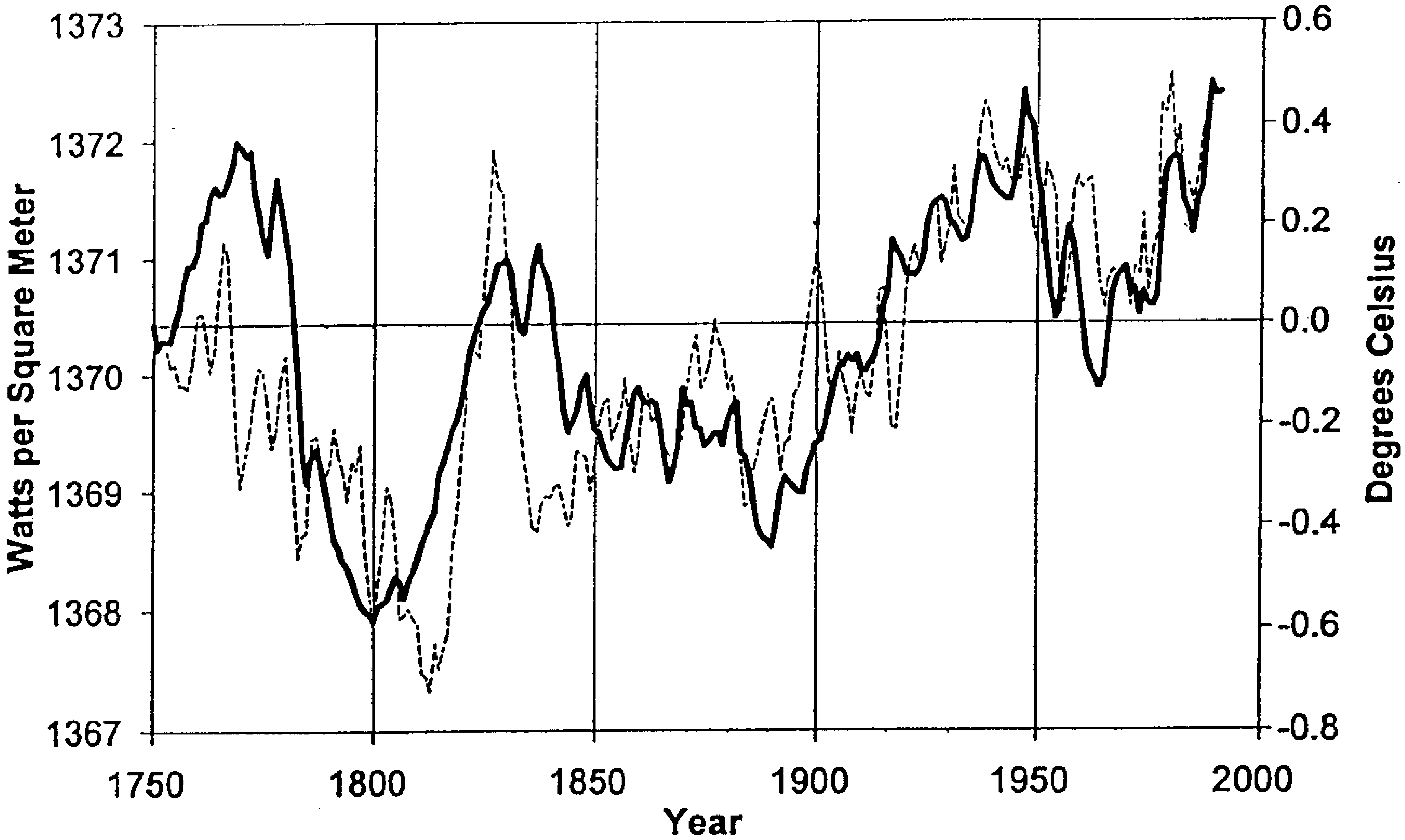


FIGURE 10.21 The annual mean Northern Hemisphere (NH) temperature variations for 1700–1879 from Groveman and Landsberg (1979) and for 1880 to the present from Hansen and Lebedeff (1988), after being smoothed by an 11-year running mean *(lighter line)*. The model irradiances are overlain to show their similarity. Only a slight divergence of the two curves exists for the last few decades.

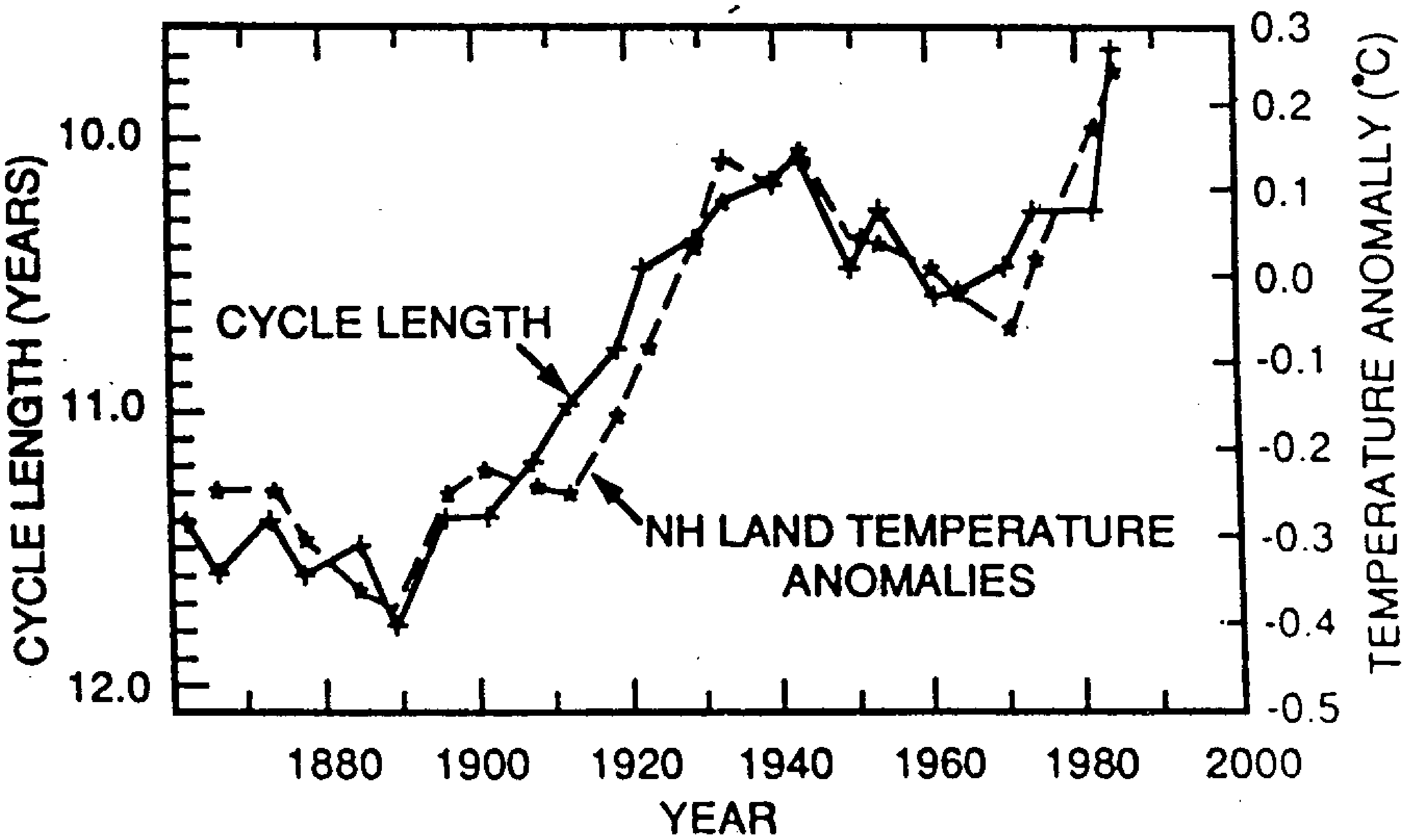
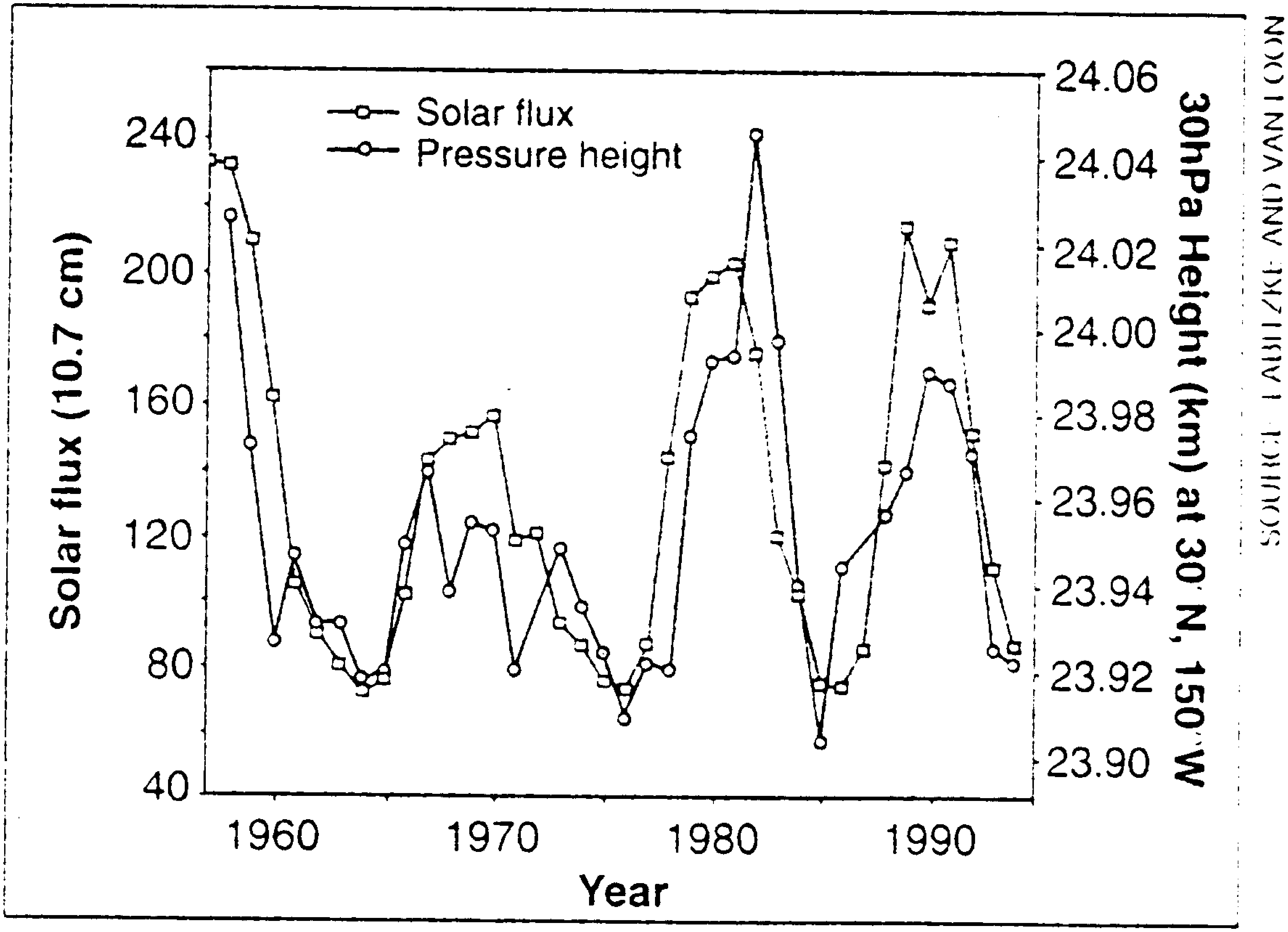


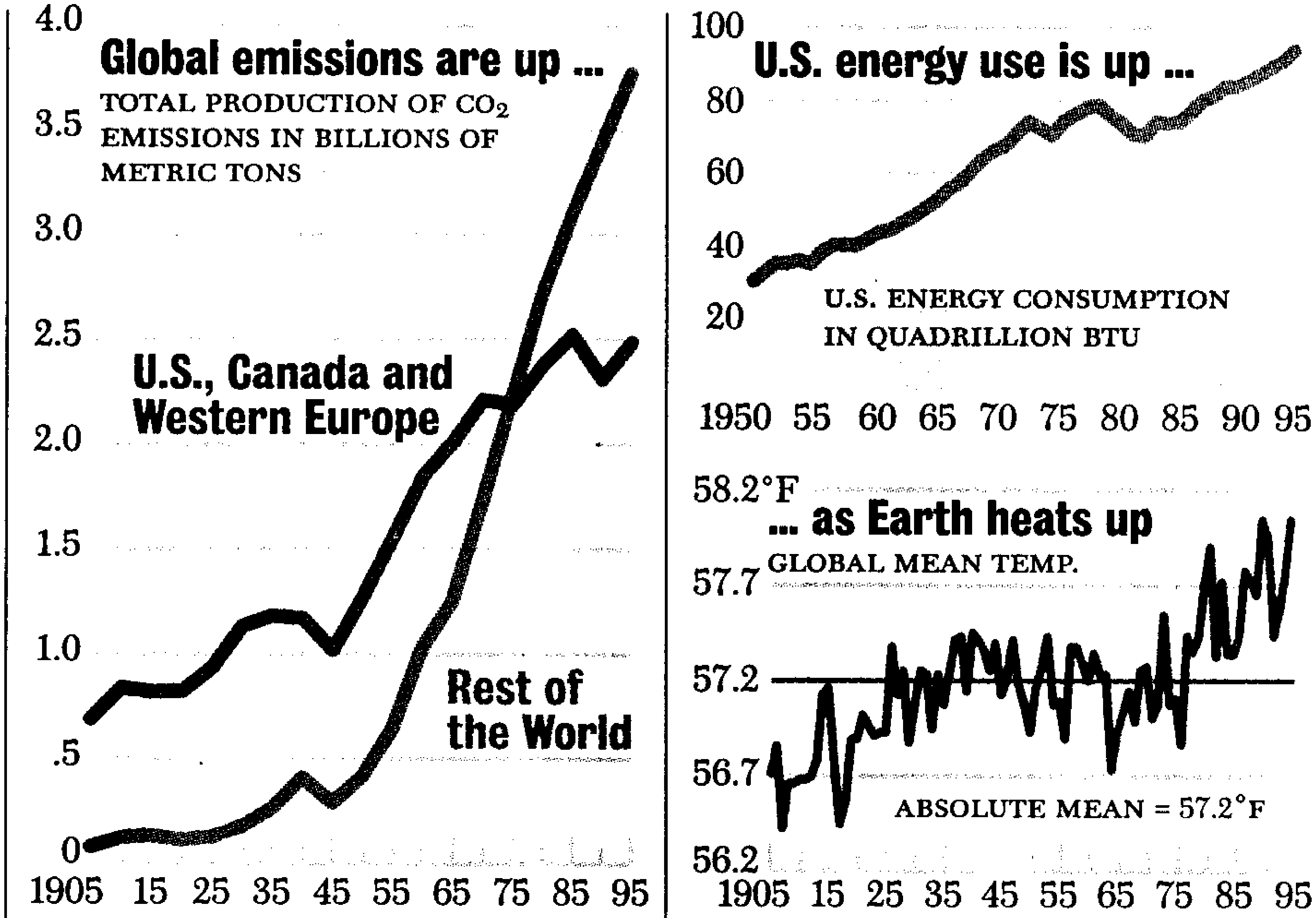
FIGURE 10.13 Variations in solar-cycle length and Northern Hemisphere temperature anomalies. The two plotted variables parallel each other quite remarkably (from Friis-Christensen and Lassen, 1991, with permission). Also note that the solar-cycle length variations are similar in form to Indiana's temperature extreme frequencies as plotted in Figure 4.5.

Figure 15. a) Figure 10.21, p. 196, Hoyt and Schatten (1997). b) Figure 10.13, p. 186, Hoyt and Schatten (1997) (from Friis-Christensen and Lassen, 1991)



**Coincidence or causation?** Climate in the middle atmosphere (as traced by pressure changes) has followed the solar cycle (traced by radio emissions) for 37 years.

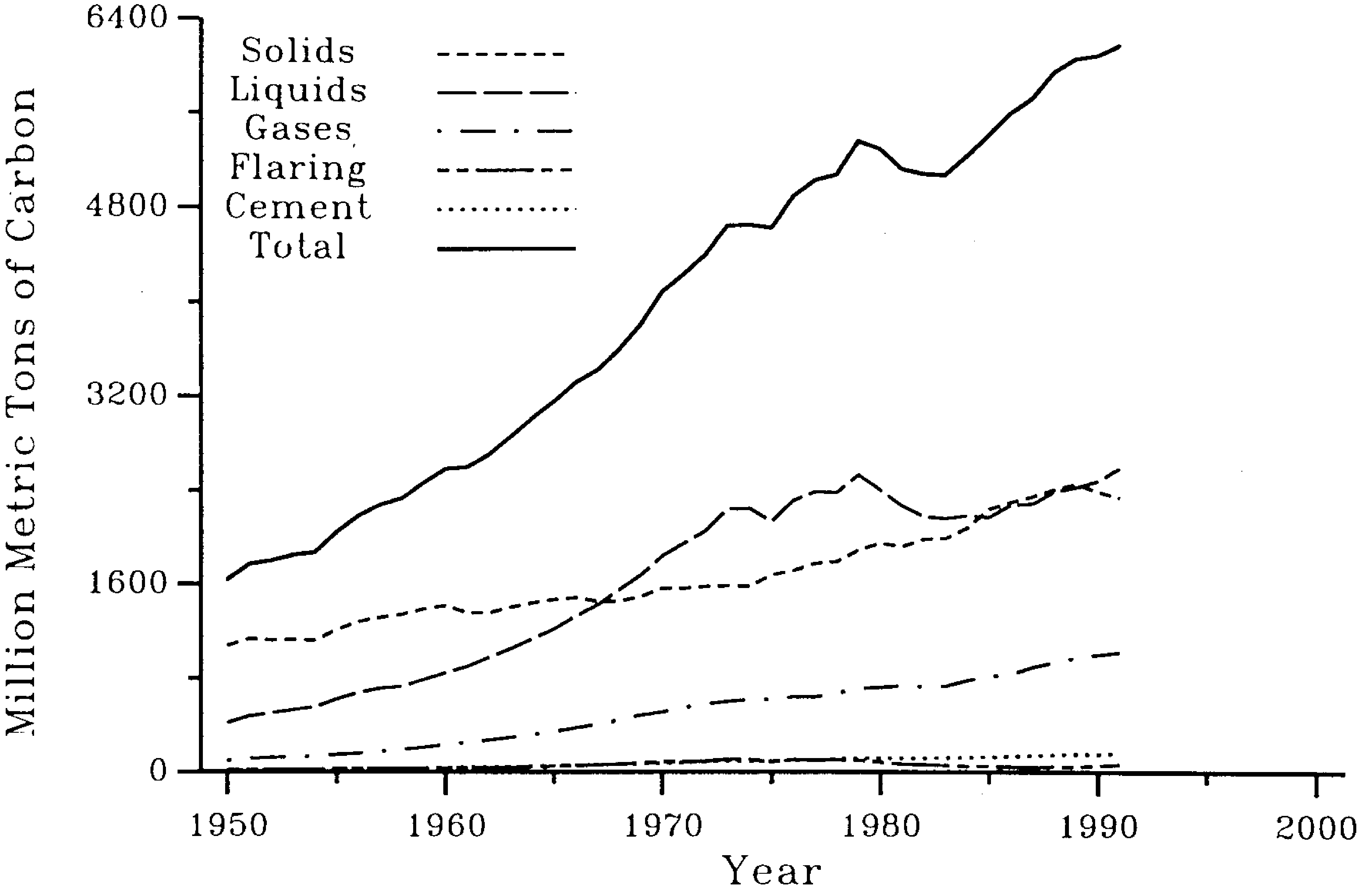
Figure 16. From Kerr 1995



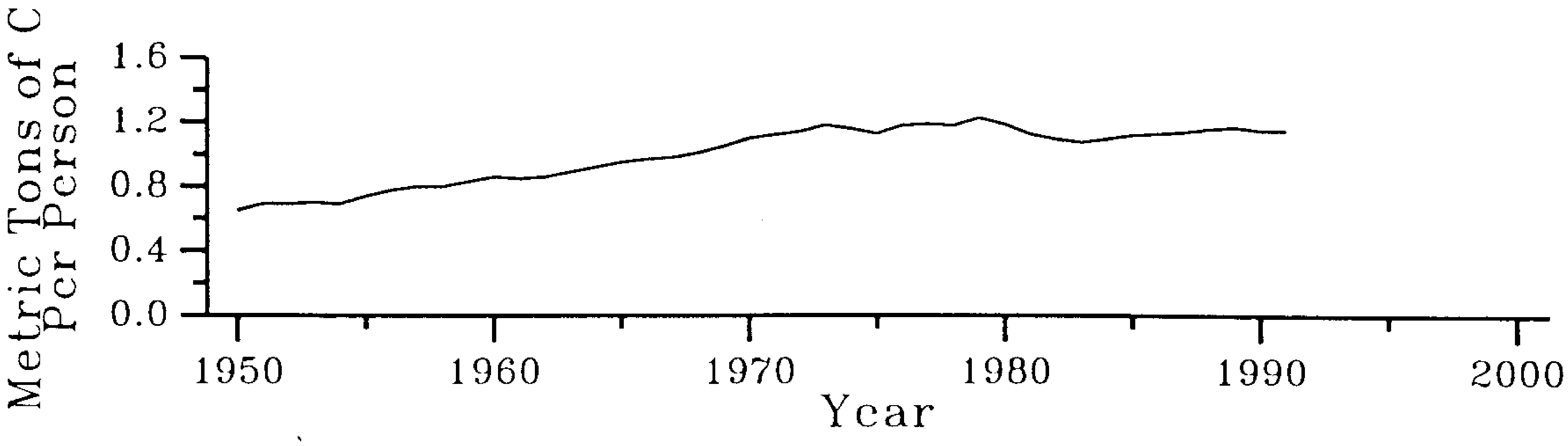
Worldwide carbon-dioxide emissions are rising. After stablizing output for 30 years, Western countries' emissions are on the rise. Levels for all countries are expected to double by 2100.

Despite a drop during the 1970s energy crisis, Americans continue to use more gas, oil and coal. Meanwhile global temperatures rise: the four warmest years on record have all been in the 1990s.

Figure 17. Figure, p. 50, Newsweek, October 20, 1997

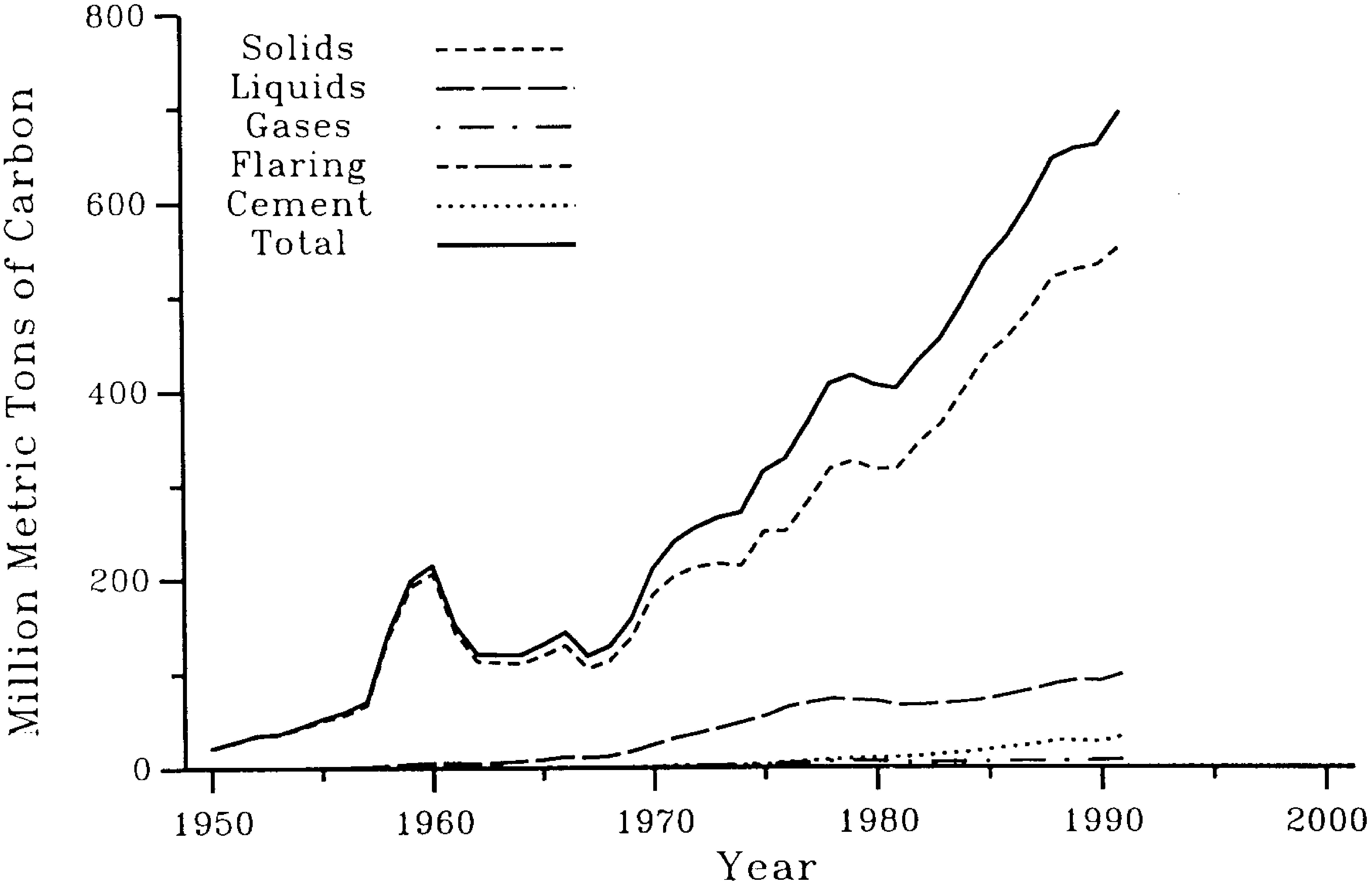


*Global $CO_2$ emissions from fossil fuel burning, cement production, and gas flaring for 1950–91.*

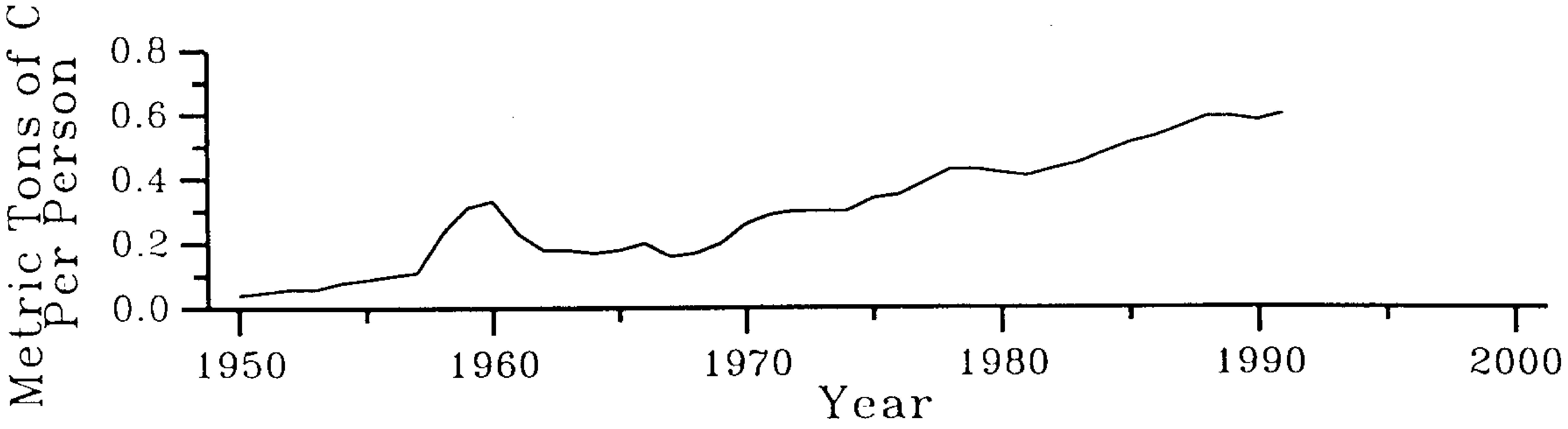


*Global per capita $CO_2$ emission estimates.*

Figure 18. From p. 507, Marland *et al*. (1994)

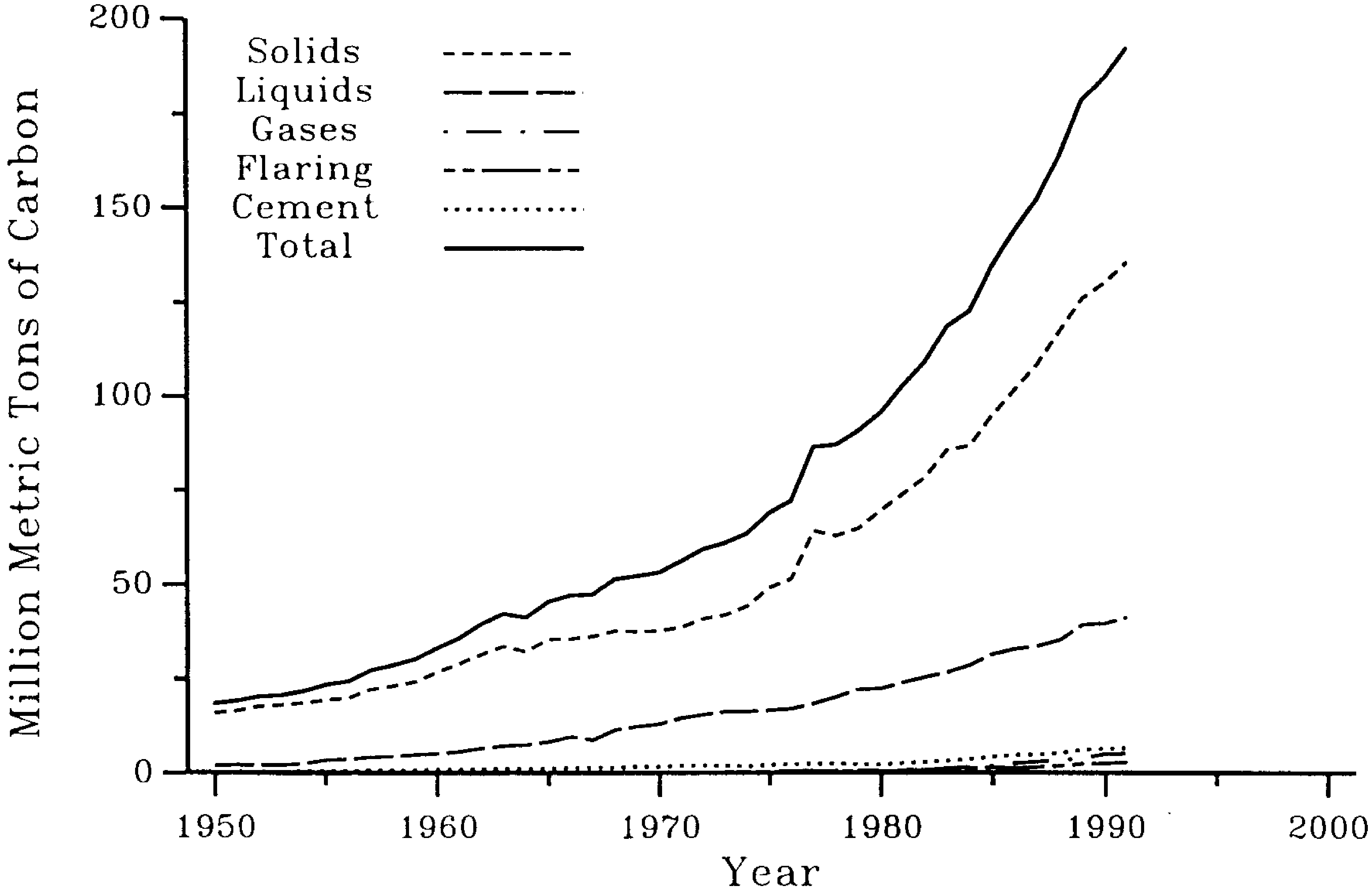


*CO$_2$ emissions from the Peoples Republic of China.*

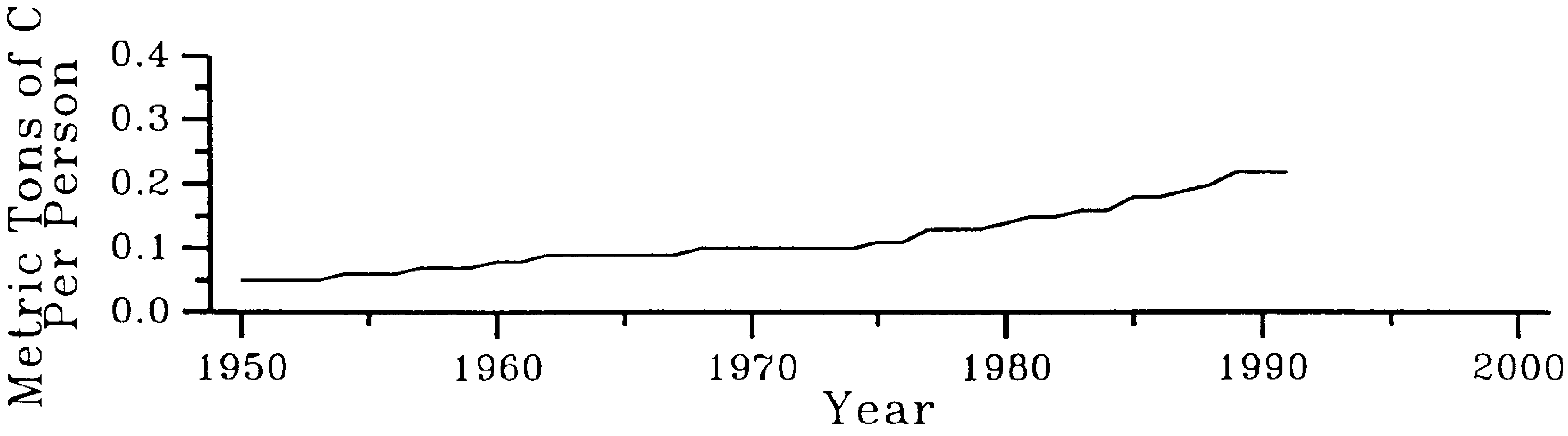


*Per capita CO$_2$ emission estimates for the Peoples Republic of China.*

Figure 19. From p. 541, Marland *et al.* (1994)

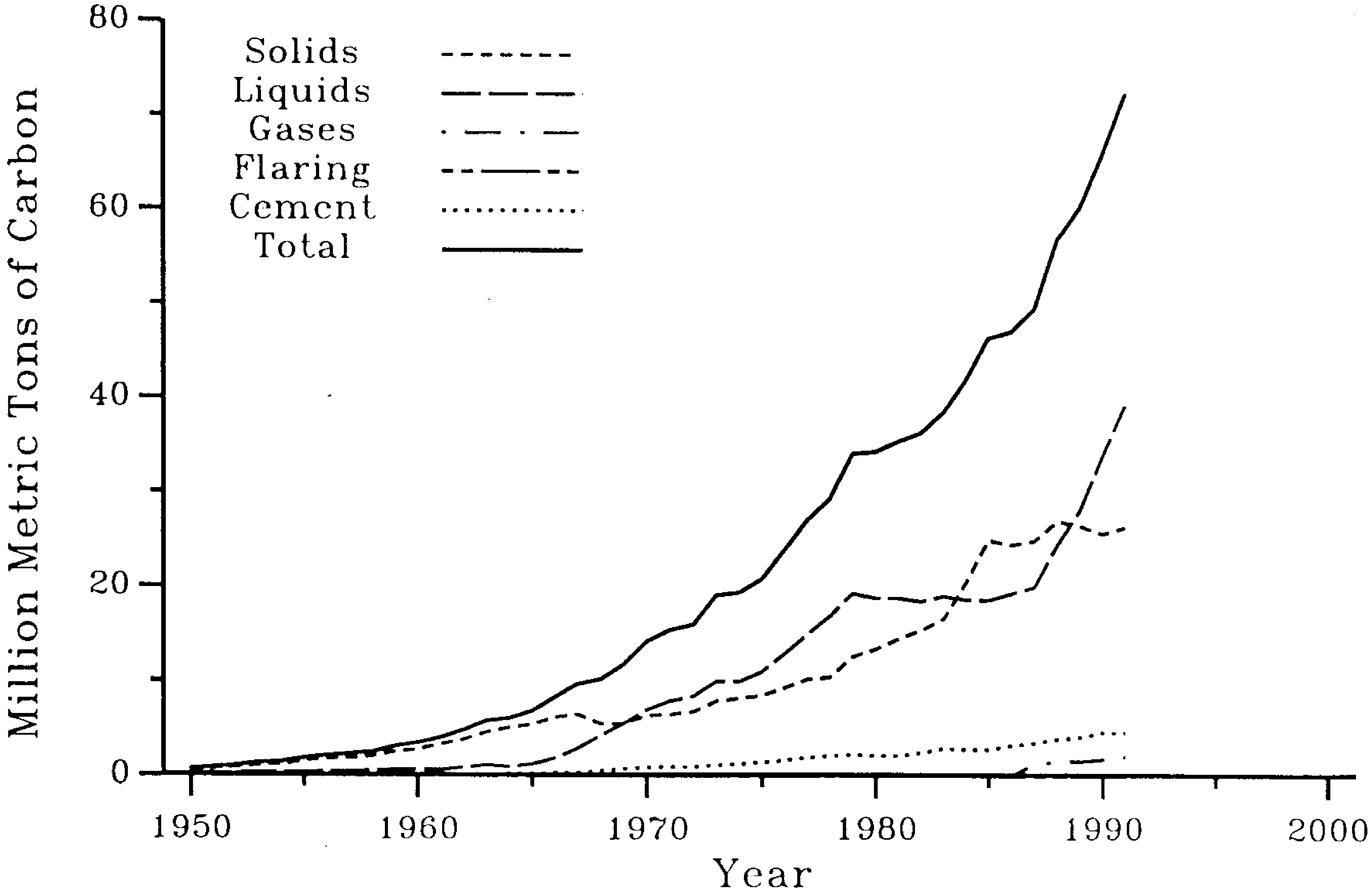


*$CO_2$ emissions from India.*

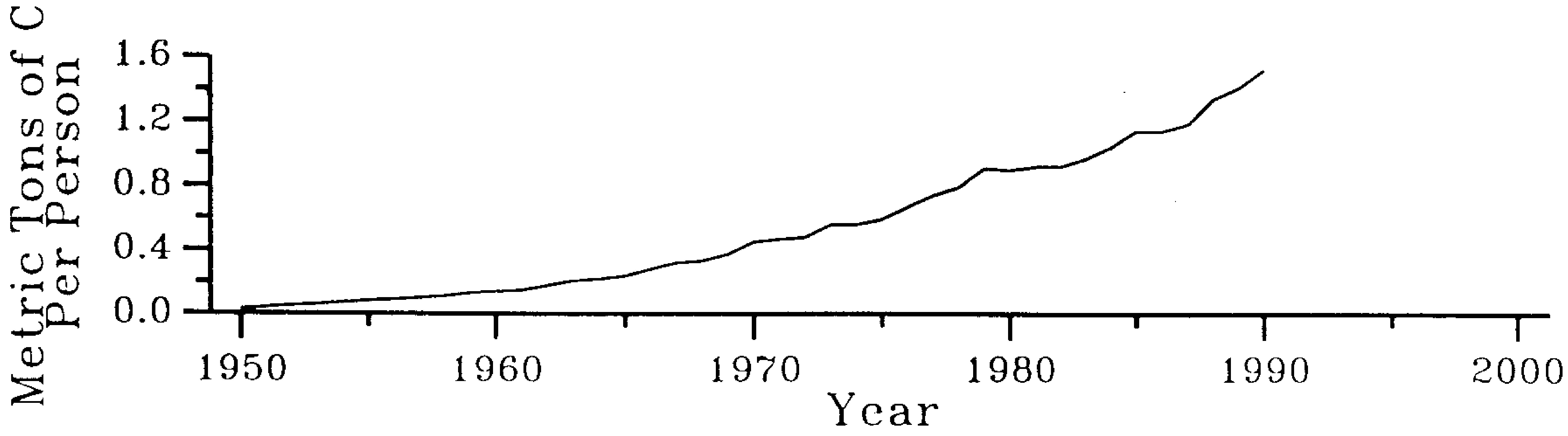


***Per capita $CO_2$ emission estimates for India.***

Figure 20. From p. 550, Marland *et al.* (1994)

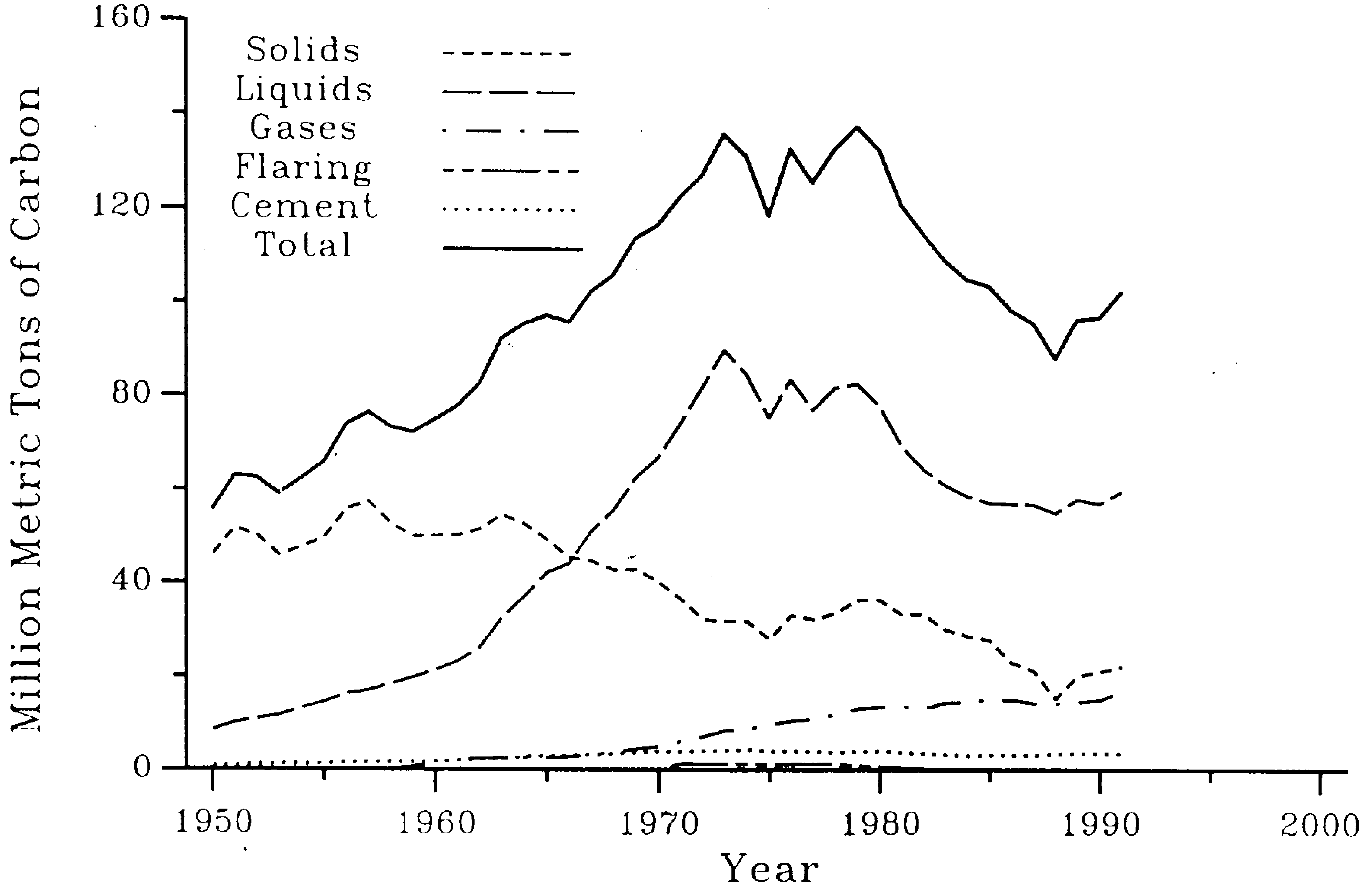


*CO$_2$ emissions from South Korea.*

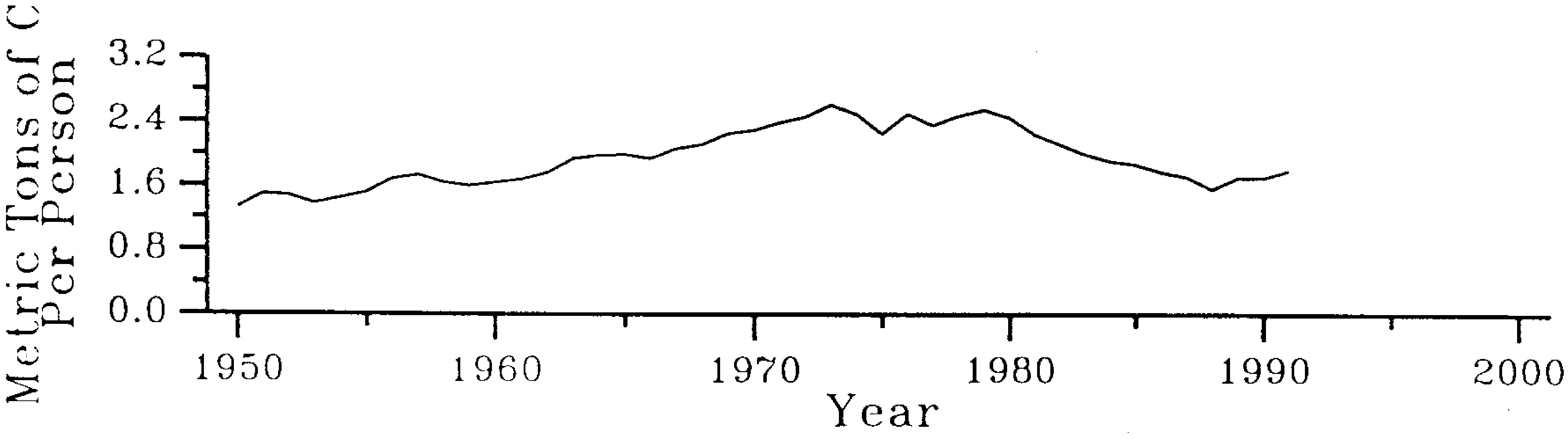


*Per capita CO$_2$ emission estimates for South Korea.*

Figure 21. From p. 568, Marland *et al.* (1994)



*$CO_2$ emissions from France.*



*Per capita $CO_2$ emission estimates for France.*

Figure 22. From p. 560, Marland *et al.* (1994)

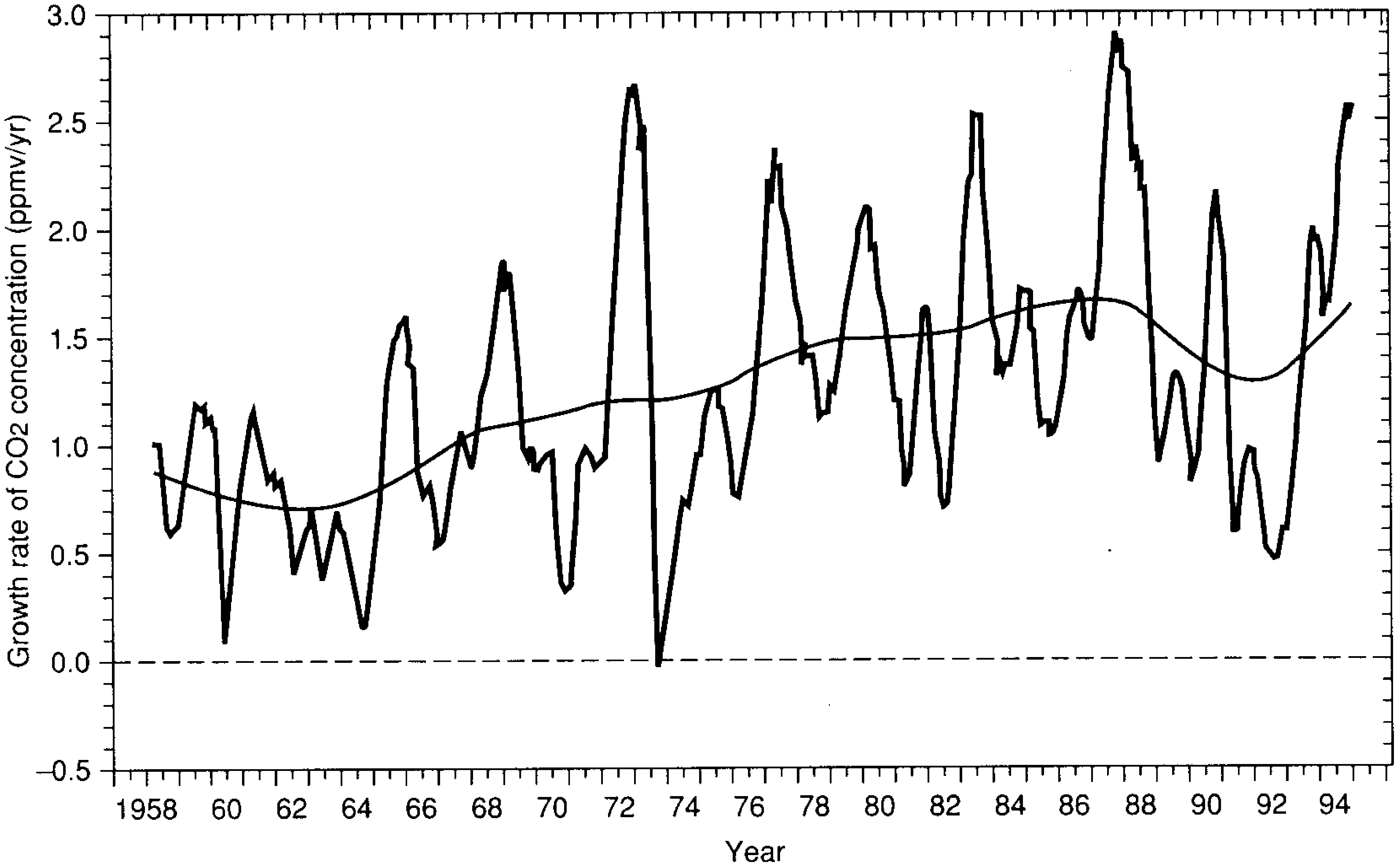


**Figure 2.2**: Growth rate of $CO_2$ concentrations since 1958 in ppmv/year at the Mauna Loa, Hawaii station. The high growth rates of the late 1980s, the low growth rates of the early 1990s, and the recent upturn in the growth rate are all apparent. The smoothed curve shows the same data but filtered to suppress variations on time-scales less than approximately 10 years. (Sources: C.D. Keeling and T.P. Worf, Scripps Institute of Oceanography, and P. Tans, NOAA CMDL. The Keeling and NOAA results are in close agreement. The Mauna Loa Observatory is operated by the NOAA.)

Figure 23. Figure 2.2, p. 81, Schimel *et al* .(1996)

Figure 5: **Annual variations in global temperatures for the troposphere for two baloon-based data sets and the satellite data set (top) and annual variations of 'global' surface temperatures from three surface-based data sets (bottom)**

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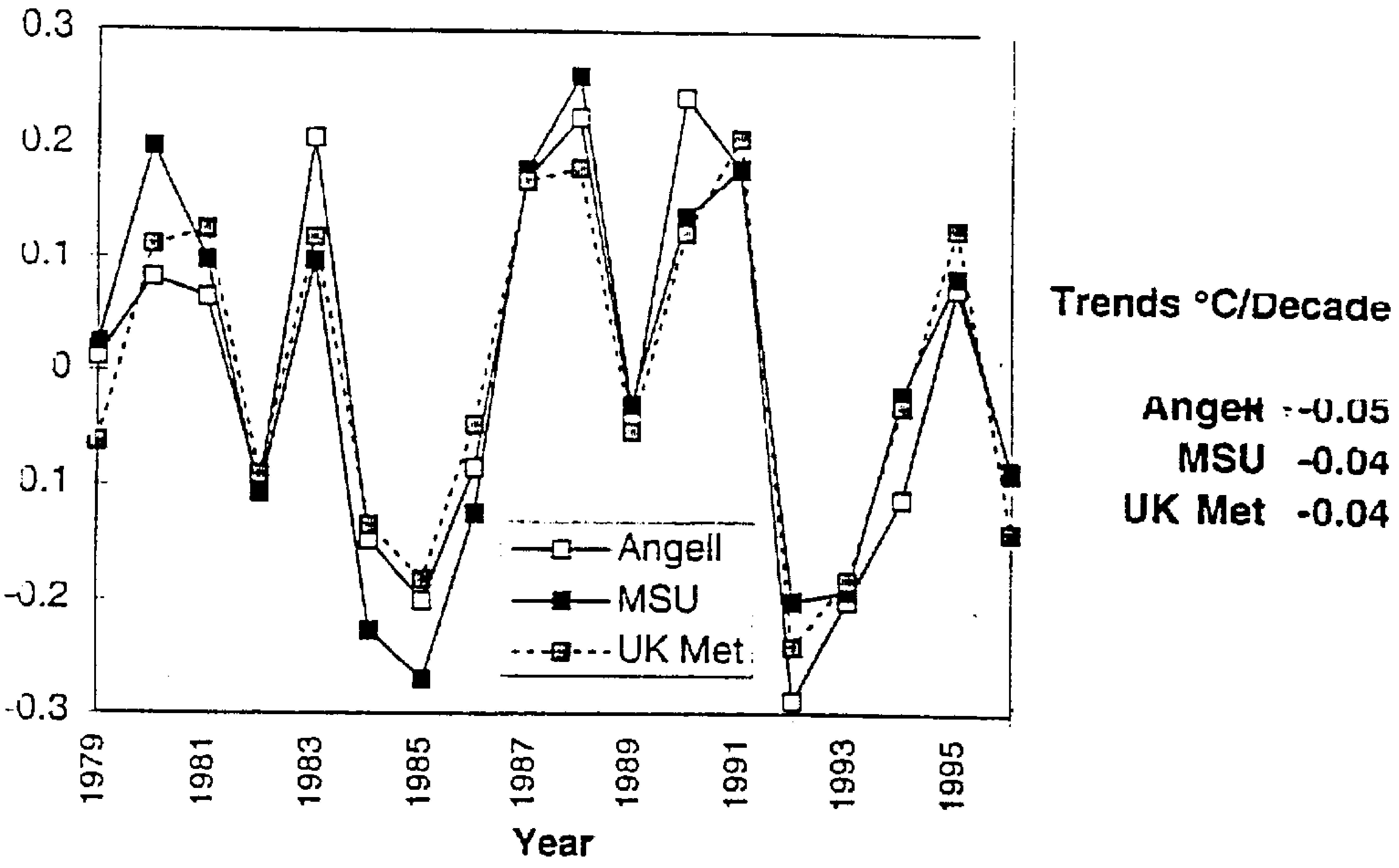
Global annual tropospheric temperatures (°C)



Global annual surface temperatures (°C)

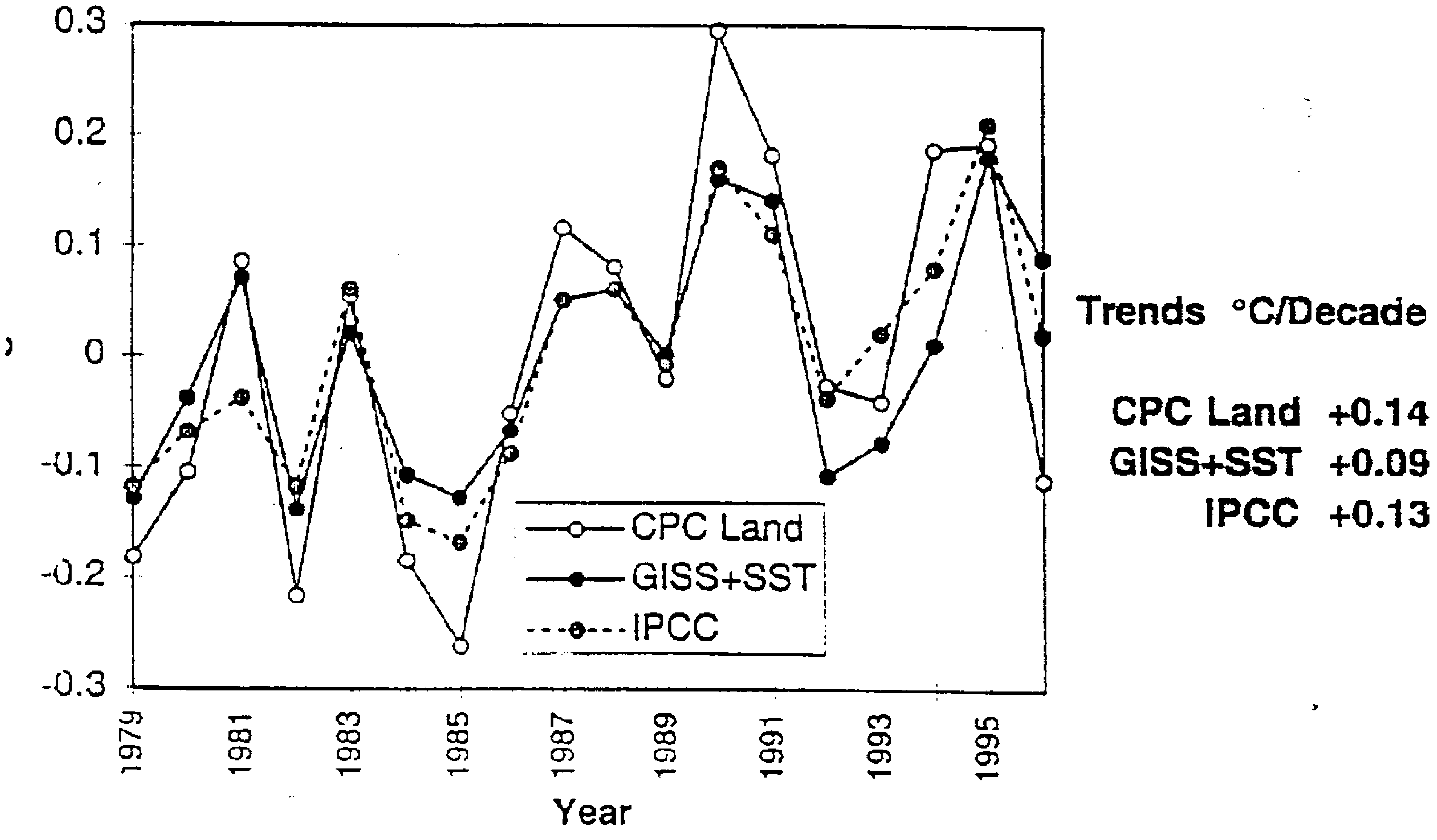


Figure 24. Figure 5, Christy (1997)

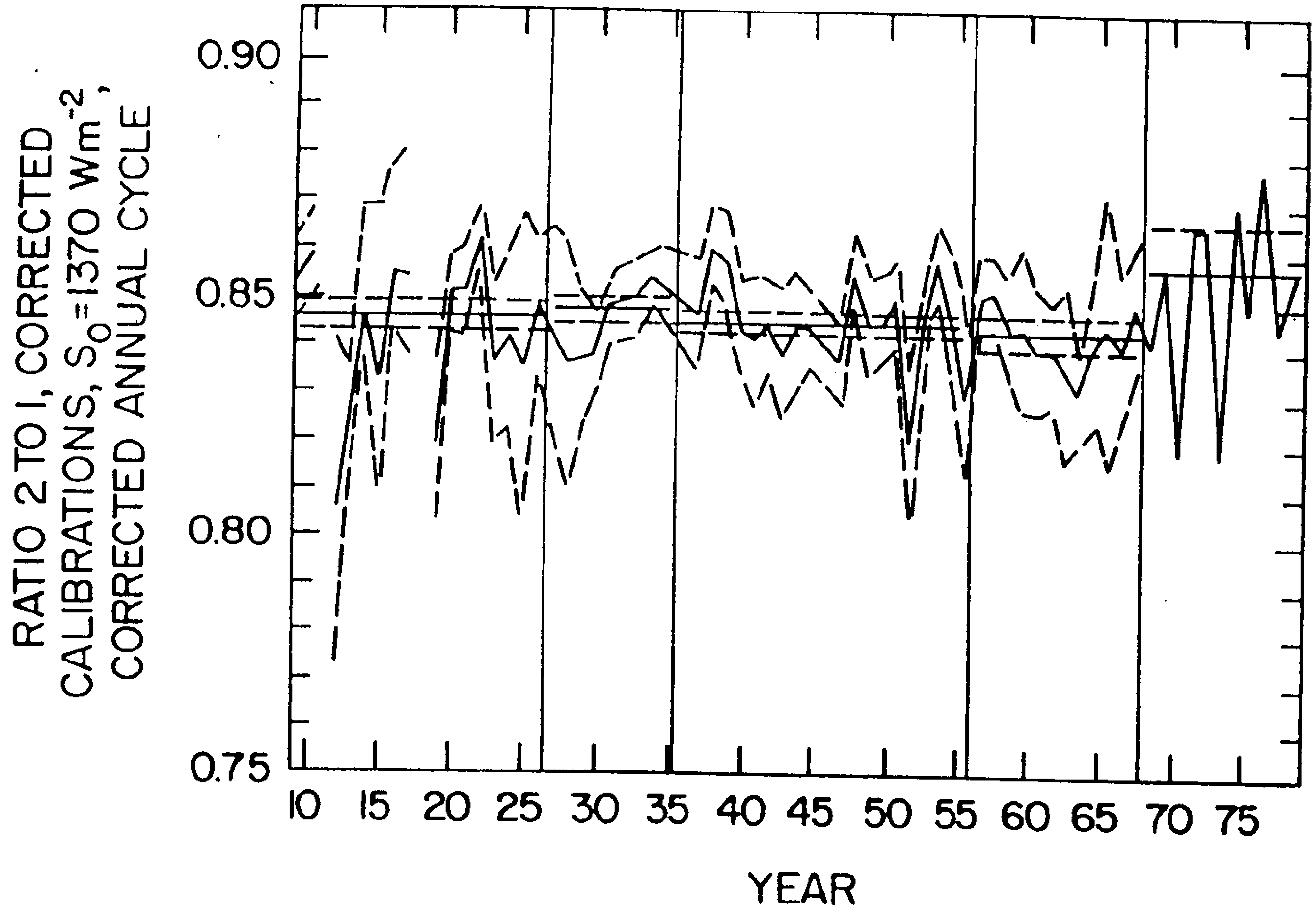


FIGURE 11.3 Atmospheric transmission at Davos, Switzerland, from 1909 to 1979 using the atmospheric ratioing technique. Except for a few large volcanic eruptions, atmospheric transmission at this central European site has remained remarkably stable, with no significant trend. The discontinuity after 1968 arises from a change in sampling during the day and not from any atmospheric alteration. (From Hoyt and Frohlich, 1983.)

Figure 25. Figure 11.3, p. 211, Hoyt and Schatten (1997), [Hoyt and Frohlich 1983]

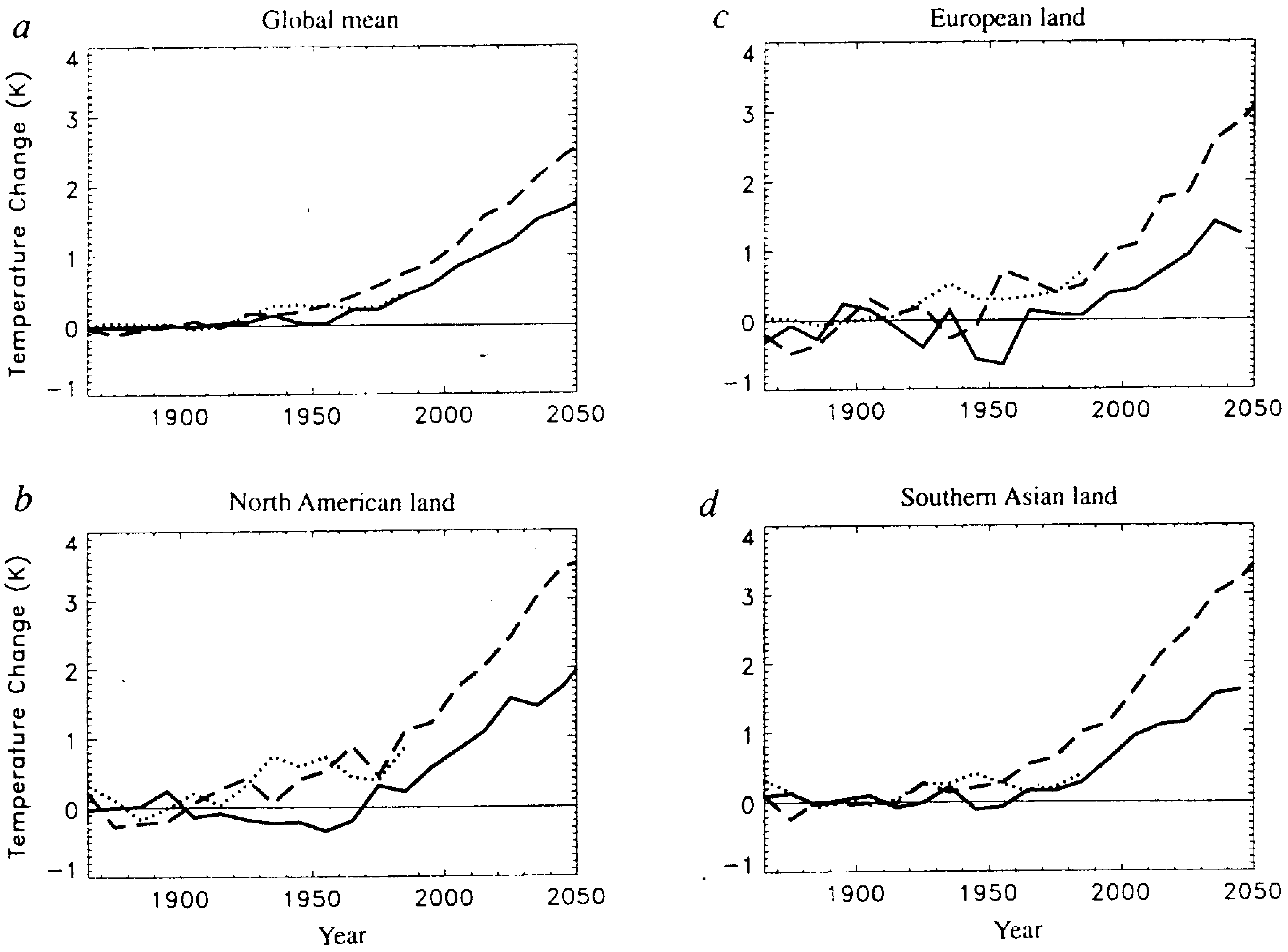


FIG. 2 Changes in area-average decadal mean temperature at 1.5 m, relative to the 1880–1920 mean. Observed[4] (dotted curve), GHG (dashed curve), SUL (solid curve). *a*, Global mean; *b*, mean over North America; *c*, mean over Europe; *d*, mean over southern Asia. Areas defined as in Fig. 1.

Figure 26. Figure 2, Mitchell *et al.* (1995)

Figure 5: **Observed warming in Santer et al. (1996) from 1963 to 1987 (top). The highlighted region in the Southern Hemisphere shows the strong observed warming. The entire temperature history over the same region from 1957 to 1995 shows no significant warming trend (bottom). However, the period that was chosen for study by Santer et al. (filled circles) warms dramatically.**

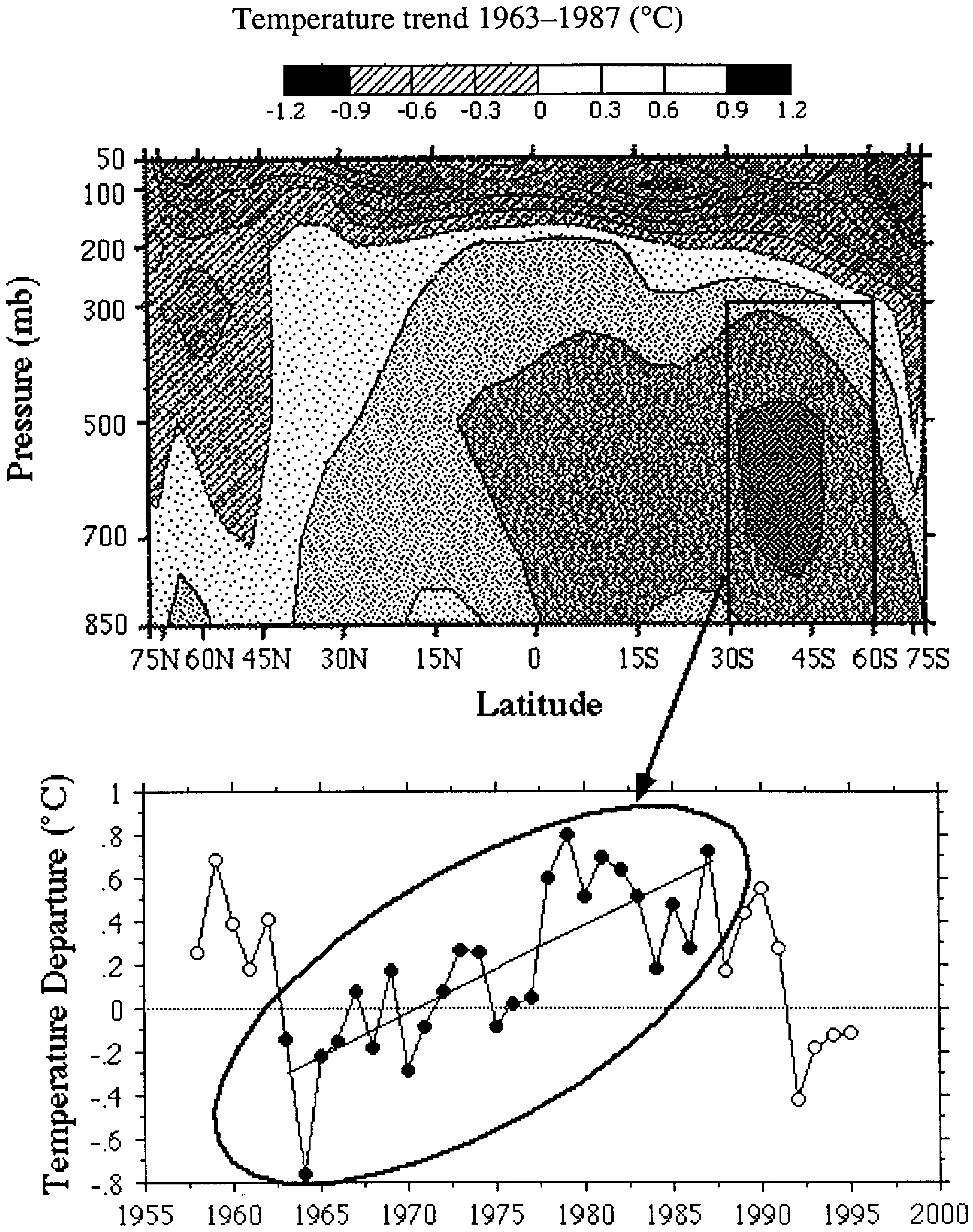


Figure 27. Figure 5, Michaels (1997)