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Folder Title:
Global Warming (2 of 2) - 1990 [1]

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Professor Bert Bolin
Department of Meteorology
University of Stockholm
S10691 Stockholm, Sweden

Dear Bert:

At the outset, I want to thank you for your efforts in putting together the July 1990 Draft IPCC Overview and Conclusions Summary. I realize that a wide range of comments had to be taken into account following our meetings in Geneva, and I commend your work.

I have a number of comments, however, to offer on behalf of the United States and think it is important to bring them to your attention prior to the Sundsvall meeting.

There is concern that the careful balance which was struck in the Working Groups and conveyed in their reports has not been maintained in this draft. A summary that does not accurately reflect the three Working Group reports is unacceptable. We recognize that in summarizing the underlying reports of the Working Groups it is necessary to use portions of each rather than the whole. For this reason, you may wish to consider a significantly shorter Overview and Conclusions document, drawing heavily on the three Executive Summaries, to which the underlying Summaries for Policymakers would be attached.

In addition, Section VI, "Strategies for the Future", goes significantly beyond the results of the IPCC assessment effort. If this section is to be retained as part of the consensus document, it should be revised to track more accurately the points contained in the underlying reports of the Working Groups and the Special Committee. Alternatively, we would suggest that a consensus version of this section be moved to the very beginning of the document and be titled IPCC Chairman's Introduction (as is done in the RSWG Summary for Policymakers).

Other comments are outlined below:

Science and Impacts Issues:

- o The current Overview and Conclusions draft still misstates the fundamental scientific uncertainties regarding possible climate change that were included in the Working Group reports (see Policymakers Summary I, page 2). To put the scientific understanding of this issue in perspective, as was done in the Working Group I Report, the fact that there are significant uncertainties regarding the timing, magnitude and regional distribution of climate changes should be highlighted with a separate heading.

- o Scientific findings are expressed with a higher degree of confidence than is warranted (e.g. the words "will" or "would" are substituted throughout rather than "may" or "could" that appeared in the reports) and in some cases worst-case figures are used rather than a mean figure or the full range of figures as listed in the reports (contrast the discussion of sea level rise in the Overview and Conclusions with what appears in PMSIII, page 27).
- o A more extensive discussion of the relative impacts of all the greenhouse gases is needed in the science section. We suggest including the table on Global Warming Potentials (GWPs) from the WGI Policymakers Summary, with appropriate introductory language.
- o In general, the discussion of possible climate change impacts places undue emphasis on the potential negative consequences of climate change, while minimizing the potential for neutral or positive impacts. The underlying Working Group reports give a more balanced view. For example, the balance of the WGII Executive Summary differs significantly from the statement that negative effects will dominate, located on page 9 of the Overview & Conclusions.

Response Options:

- o A continuing concern is that the discussion of WGIII Task A does not reflect the uncertainties surrounding these exercises as stated in the WGIII report. It is important to make clear that these scenarios are not projections or predictions, but are based on varying assumptions. The explanation of how they were formulated should be taken from the WGIII Summary for Policymakers, Sections 3.1 and 3.2 and be placed in a separate section at the beginning of the document (not in an appendix).
- o The draft does not adequately address the uncertainties and lack of information policy makers face in dealing with climate change as indicated in the underlying reports (see PMSIII, section 4). To place the issue in perspective, it is important to include the language contained in the RSWG report that:

"The information available to make sound policy analyses is inadequate because of: (a) remaining scientific uncertainties regarding the magnitude, timing, rate, and regional consequences of potential climate change; (b) uncertainty with respect to how effective specific response options or groups of options would be in actually averting potential climate change; and (c) uncertainty with respect to the cost,

effects on economic growth, and other economic and social implications of specific response options or groups of options. The potentially serious consequences of climate change on the global environment, however, give sufficient reasons to begin by adopting response strategies that can be justified immediately even in the face of such significant uncertainties."

- o There is little discussion of the fact that the RSWG did not have time to consider the vital social and economic issues which are necessary for devising sound policies to address climate change. For example, the IPCC did not analyze the socioeconomic cost of potential climate change impacts or the costs and effectiveness of various response options. This point should be set forth prominently at the beginning of the Overview and Conclusions paper to place the IPCC's work in its proper perspective.
- o Some of the economic concepts are not accurately stated. For example:
 - The definition of "no regrets" policies on page 31 is incorrect. The current wording implies that such policies include actions which have any benefits beyond those related to climate change, whereas the WGIII report refers to those actions which are justified in their own right.
 - The discussion of the comprehensive approach does not describe its benefits. We suggest drawing from the WGIII Summary for Policymakers (p. 38, lines 10-13) to make clear that such an approach would advance environmental protection and minimize economic costs.
 - The description of the "tragedy of the commons" on page 30 (lines 12-16) is flawed as written. This section would be substantially improved if restated along the following lines:

"If individual countries can continue to pollute while others pay the costs of global pollution control, this opportunity to act as "free riders" will encourage nations to avoid mutually advantageous cooperative action."
- o Given the target audience, it is important to specify throughout the draft the baselines being used: Are the emissions changes calculated from present levels or from projected future growth levels? Do they refer to the total flux or the anthropogenic flux? The underlying reports do a better job of stating baselines

and assumptions. Note the difference between the listing on page 4, lines 6-11 and PMSIII, page 6, lines 44-45.

- o The draft does not adequately address the important role of sinks and the possibilities either for expanding sink resources or for implementing adaptation strategies. This was briefly reported in the WGI Summary for Policymakers on page 11.
- o The current draft overstates the ability of the industrialized countries to reduce global emissions and to stabilize atmospheric concentrations regardless of events in the rest of the world. The language from the WGIII Summary for Policymakers that "Developing countries should, within the limits feasible, take measures to suitably adapt their economies" needs to be included in the Executive Summary.
- o The discussion of "narrowing the gap between the industrialized and developing world" would be more accurately characterized as follows:

"Improved economic performance and living standards in the developing world are important to developing a full global partnership to deal with the climate change issue."

These are some of the main comments I would like to bring to your attention as you continue preparations for the Sundsvall meeting. In order to assist in this process, the United States is developing more extensive comments and specific proposed wording changes.

I look forward to working together to develop a final IPCC paper which reflects the findings of the IPCC Working Groups. I am optimistic that the IPCC report will promote a reasoned and effective international response to this important issue.

Very best regards,

Frederick M. Bernthal

Side By Side Review
of
**The Intergovernmental Panel On Climate Change (IPCC)
"Overview & Conclusions" and "Policymakers Summaries"
for Working Groups I, II, & III.**

General Criticisms of the "Overview & Conclusions" Document

What follows is a side by side comparison of the "Overview & Conclusions" document drafted for consideration and adoption at the final plenary session of the Intergovernmental Panel On Climate Change (IPCC) in Sundsvall, Sweden on August 27-30, 1990, and the summaries of the three working groups (Working Group I on Science, Working Group II on Potential Impacts, and Working Group III on Response Strategies) which formed the basis of the IPCC's actual work. The comparison shows that the "Overview & Conclusions" document is not a simple summary of the work and conclusions of the three working groups (as was intended), but rather contains new conclusions and a different emphasis from the underlying documents from which it was to have been drawn.

- In several instances, the "Overview & Conclusions" document reports that the natural greenhouse effect "keeps the earth warmer than it would otherwise be." ("Overview & Conclusions" Executive Summary, page i). Working Group I pointed out, however, that naturally occurring greenhouse gases are vital to "keep the Earth warm enough *to be habitable*." (Working Group I, "Policymakers Summary", page 7, paragraph 1, emphasis added).
- Throughout the document, Scenario A is referred to as "Business As Usual." This moniker can be misleading. Scenario A "assumes that few or no steps are taken to limit greenhouse gas emissions. Energy use and clearing of tropical forests continue and fossil fuels, in particular coal, remain the world's primary energy source. The Montreal Protocol comes into effect [e.g., a 50% reduction of CFCs], but without strengthening and with less than 100 percent compliance." ("Overview & Conclusions" Appendix). Scenario A is the base case reference for all calculations. Unfortunately, some of its assumptions are already outdated. The Montreal Protocol has already been strengthened (to provide for 100% phase out of CFCs) and some steps have already been taken to limit emissions.
- The document uses the words "predict" and "prediction" rather than "estimate" and "estimation." While a layman or reporter would have a hard time defining these words differently, a scientist could attach entirely different meanings to them.
- The "Overview & Conclusions" features underlining of text that appears unemphasized in the original Policymakers Summaries. The function of the "Overview & Conclusions" is to report as briefly as is prudent the findings of the Working Group reports, not to add emphasis or create different conclusions. The document is seriously flawed in this respect.
- The inclusion of tables and graphs is helpful, but can be misleading. The slope of curves is determined by the scaling of the axes in the graphs. To the authors' credit, time series graphs have consistently scaled X axes. However, there is no similar consistency among the Y axes. The result is greenhouse gas trendlines which appear to reach alarming rates of increase. This could be more accurately reported by taking the logarithm of the data or plotting the data on a log-log scale graph. This criticism applies to both the "Overview & Conclusions" and the "Policymakers Summary" documents.

Some of the specific criticisms in the pages that follow are a result of poor word selection which unintentionally alters the meaning of portions of the Policymakers Summaries. However, some of the quotations appear sufficiently selective to reveal bias.

PMS I -- Policymakers Summary of the Working Group I report.

PMS II -- Policymakers Summary of the Working Group II report.

PMS III -- Policymakers Summary of the Working Group III report.

"Overview & Conclusions"

Page i, lines 6, 20-23.

"We are certain of the following:" "the total increase of greenhouse gas concentrations attributable to human activities is at present equivalent to an increase of carbon dioxide since pre-industrial times (about 200 years ago) by about 50%."

Page ii, lines 10-11.

"... and higher northern latitudes warm more than the global mean."

Page ii, lines 37-39.

"global mean surface temperature has increased by 0.3 to 0.6°C over the last 100 years..."

Page iii, lines 11-18.

"Already a rise of sea level by 30-50 cm would affect the habitability of low-lying coastal regions significantly and a one metre rise (possibly towards the end of next century as estimated in the Scenario A) would impact 360,000 km of coastline, render some island countries uninhabitable, displace tens of millions of people, threaten low-lying urban areas, flood productive land and contaminate fresh water supplies."

Page iii, lines 20-25.

"Although studies have not yet conclusively determined whether on average global agricultural potential would increase or decrease, changes of climate would have important effects regionally. Decline in production might be expected in regions of high present-day vulnerability, where ability to adjust is low."

Page iii, lines 32-35.

"Similarly other natural terrestrial ecosystems would be markedly influenced because the rates of climate changes are likely to be faster than the ability of some species to adjust."

"Policymakers Summary"

PMS I, page 1, paragraphs 1-2.

The second quote does not appear in the original document. PMS I lists two, not three certainties. The two are reproduced faithfully in the "Overview & Conclusions" on page i, lines 8-18.

PMS I, page 2, paragraph 3.

"... and higher northern latitudes warm more than the global mean *in winter*." [Emphasis added].

PMS I, page 3, paragraph 1.

"Global-mean surface *air* temperature has increased by 0.3°C to 0.6°C over the last 100 years..." [Emphasis added].

PMS III, page 27, lines 47-49.

"Under the 2030 high emissions scenario [Scenario A], global climate change is predicted to raise global mean sea level 65 cm (with an uncertainty range of 30 to 100 cm) by the year 2100." [100 cm = 1 metre. Note: the one metre rise is the upper bound of Scenario A, not the expected value].

PMS II, page 2, paragraph 10.

"Horticultural production in mid-latitude regions may be reduced. On the other hand, cereal production could increase in northern Europe. Policy responses directed to breeding new plant cultivars, and agricultural management designed to cope with changed climate conditions, could lessen the severity of regional impacts."

PMS I, page 3, paragraph 4.

"Rapid changes in climate will change the composition of ecosystems; some species will benefit while others will be unable to migrate or adapt fast enough and may become extinct."

PMS II, page 3, paragraph 2.

"Flora and fauna would lag behind these climatic shifts, surviving in their present location and, therefore, could find themselves in a different climatic regime. These regimes may be more or less hospitable and, therefore, could increase productivity for some species and decrease that of others."

"Overview & Conclusions"

Page 4, lines 6-11.

"... (Scenario A or Business as Usual Scenario), the increase of greenhouse gas concentrations in the atmosphere would be the equivalent of a doubling of the carbon dioxide concentration by about 2025..."

Page 4, lines 11-13 and table 2.

"Estimated anthropogenic emissions in 1985 and those projected in 2025 in the Scenario A (Business as Usual Scenario) are given in Table 2 below:"

	<u>1985</u>	<u>2025</u>
Carbon dioxide (Gtc)	7.5	13
Methane (Tg)	350	550
Nitrous Oxide (Tg)	4	7
CFCs and HCFCs (Mt)	740	1900

Page 7, lines 28-32.

"We know from observations that the global mean temperature has increased between 0.3°C and 0.6°C, since the middle of last century and that most of this change has occurred primarily during two periods, i.e., the first four decades of this century and since 1975."

"Policymakers Summary"

PMS III, page 6, lines 44-45.

"Under this scenario, the equivalent of a doubling of *pre-industrial* CO₂ levels occurs by around 2030." [Emphasis added].

PMS III, page 8, table 1.

"Anthropogenic Greenhouse Gas Emissions From Working Group III Scenarios

2030 High Emissions Scenario" [Scenario A]

	<u>1985</u>	<u>2025</u>
CO ₂ Emissions (BtC)	5.9	11.5
CH ₄ Emission (TgCH ₄)	362	582
[Total less Natural]		
N ₂ O (TgN)	12.5	16.4
CFCs (Gg) [Includes Halon]	740.5	1914.0

[Note: the magnitudes and units are inconsistent].

PMS I, page 3, paragraph 1.

"*Our judgement* is that: Global-mean surface *air* temperature has increased by 0.3°C to 0.6°C over the last 100 years, with the five global-average warmest years being in the 1980s." [Emphasis added].

PMS I, page 29, paragraph 5.

"The instrumental record of surface temperature is fragmentary until the mid-nineteenth century, after which it slowly improves. Because of different methods of measurement, historical records have to be harmonised with modern observations, introducing some uncertainty. Despite these problems we believe that a real warming of the globe of 0.3°C - 0.6°C has taken place over the last century; any bias due to urbanisation is likely to be less than 0.05°C." [Emphasis original].

"Overview & Conclusions"

Page 9, lines 35-37.

"A climate change will bring with it both positive and negative impacts, although the negative ones will dominate (cf Working Group II)."

"Policymakers Summary"

Working group II did not conclude that negative impacts will dominate. A sample of conclusions from the PMS II Executive Summary follows.

Page 2, paragraph 9, Agriculture and Forestry.

"Sufficient evidence is now available from a variety of different studies to indicate that changes of climate would have an important effect on agriculture and livestock. Studies have not yet determined whether, on average, global agricultural potential will increase or decrease."

Page 2, paragraph 10.

"On balance, the evidence suggests that in the face of estimated changes of climate, food production at the global level can be maintained at essentially the same level as would have occurred without climate change; however, the cost of achieving this is unclear."

Page 4, paragraph 1, Natural terrestrial ecosystems.

"The socioeconomic consequences of these impacts will be significant, especially for those regions of the globe where societies and related economies are dependent on natural terrestrial ecosystems for their welfare. Changes in the availability of food, fuel, medicine, construction materials and income are possible as these ecosystems are changed. Important fibre products could also be affected in some regions."

Page 4, paragraph 2, Hydrology and water resources.

"It appears that many areas will have increased precipitation, soil moisture, and water storage, thus altering patterns of agricultural, ecosystem and other water use. Water availability will decrease in other areas, a most important factor for already marginal situations, such as the Sahelian zone in Africa."

Page 4, paragraph 3, Human settlements, energy, transport, and industrial sectors, human health and air quality.

"The most vulnerable human settlements are those exposed to natural hazards, eg coastal or river flooding, severe drought, landslides, severe wind storms and tropical cyclones."

Page 5, paragraph 2.

"Global warming and increased ultraviolet radiation resulting from depletion of stratosphere ozone may produce adverse impacts on air quality such as increases in some polluted urban areas."

Page 5, paragraph 3, Oceans and coastal zones.

"Global warming will accelerate sea-level rise, modify ocean circulation and change marine ecosystems, with considerable socioeconomic consequences."

Page 6, paragraph 1, Seasonal snow cover, ice, and permafrost.

"Changes in the volume of snow cover, or the length of the snow cover season, will have both positive and negative impacts on regional water resources (as a result of changes in the volume and the timing of runoff from snowmelt); on regional transportation (road, marine, air and rail); and on recreation sectors."

"Overview & Conclusions"

Page 11, lines 29-35.

"Turning next to the more difficult question of impacts of climate change on land, water and ecosystems, a warmer climate may have many benefits, if precipitation is adequate and the rate of change is slow. However, if precipitation is inadequate or the rate of change is rapid, climate change could have many negative impacts on society, and especially ecosystems. Change in ecosystems could result in a loss of certain plant species."

Page 11, lines 37-39.

"It is likely, however, that the distribution of precipitation would change and that soil moisture could decrease in some regions."

Page 12, lines 3-6.

"Although not analyzed more specifically, the supply of food would become more vulnerable to disturbances caused by changes of climate in a world with a rapidly growing population."

"Policymakers Summary"

PMS I, page 33, paragraph 4.

"Ecosystems will respond to local changes in temperature (including its rate of change), precipitation, soil moisture and extreme events. Current models are unable to make reliable estimates of changes in these parameters on the required local scales."

Page 33-34, paragraph 7.

"Because species respond differently to climatic change, some will increase in abundance and/or range while others will decrease. Ecosystems will therefore change in structure and composition. Some species may be displaced to higher latitudes and altitudes, and may be more prone to local, and possibly even global, extinction; other species may thrive."

PMS II, page 19, paragraph 10.

"The direct effects of increased atmospheric concentrations of CO₂ may increase plant growth, water use efficiency and tolerance to salinity, though this positive effect could be reduced over time by ecosystem feedbacks. Enhanced levels of air pollution could also reduce this positive effect."

PMS I, page 33, paragraph 4.

"Ecosystems will respond to local changes in temperature (including its rate of change), precipitation, soil moisture and extreme events. Current models are unable to make reliable estimates of changes in these parameters on the required local scales."

PMS II, page 4, paragraph 2.

"It appears that many areas will have increased precipitation, soil moisture, and water storage, thus altering patterns of agricultural, ecosystem and other water use. Water availability will decrease in other areas, a most important factor for already marginal situations, such as the Sahelian zone in Africa."

PMS II, page 2, paragraph 10.

"On balance, the evidence suggests that in the face of estimated changes of climate, food production at the global level can be maintained at essentially the same level as would have occurred without climate change; however, the cost of achieving this is unclear."

"Overview & Conclusions"

Page 12, lines 21-29.

"Natural terrestrial ecosystems would be markedly influenced because the rates of projected climatic change are likely to be faster than the ability of some species to respond. Flora and fauna would lag behind these climatic shifts and could find themselves in a different climatic regime. Major vegetation zones could face severe disturbances and disruptions, influencing plant and associated animal populations'. 'Species could disappear and lead to substantial reduction in biological diversity'."

Page 13, lines 14-22.

"The global areal extent and volume of elements of the terrestrial cryosphere (seasonal snow cover, near-surface layers of permafrost and some masses of ice) will be substantially reduced. These reductions, when reflected regionally, could have significant impacts on related ecosystems and social and economic activities. Compounding these impacts in some regions is that, as a result of the associated climatic warming positive feedbacks, the reductions could be sudden rather than gradual."

"Policymakers Summary"

PMS II, page 3, paragraph 2.

"Natural terrestrial ecosystems could face significant consequences as a result of the global increases in the atmospheric concentrations of greenhouse gases and the associated climatic changes. Projected changes in temperature and precipitation suggest that climatic zones could shift several hundred kilometres towards the poles over the next fifty years. Flora and fauna would lag behind these climatic shifts, surviving in their present location and, therefore, could find themselves in a different climatic regime. *These regimes may be more or less hospitable and, therefore, could increase productivity for some species and decrease that of others.* Ecosystems are not expected to move as a single unit, but would have a new structure as a consequence of alterations in distribution and abundance of species." [Emphasis added].

Paragraph 3.

"The rate of projected climate change is the major factor determining the type and degree of climatic impacts on natural terrestrial ecosystems. These rates are likely to be faster than the ability of some species to respond and responses may be sudden or gradual."

Paragraph 4.

"Some species could be lost owing to increased stress leading to a reduction in global biological diversity. Increased incidence of disturbances such as pest outbreaks and fire are likely to occur in some areas and these could enhance projected ecosystem changes."

PMS II, page 5, paragraph 5.

"The global areal extent and volume of elements of the terrestrial cryosphere (seasonal snow cover, near-surface layers of permafrost and some masses of ice) will be substantially reduced. These reductions, when reflected regionally, could have significant impacts on related ecosystems and social and economic activities. Compounding these impacts in some regions is that, as a result of the associated climatic warming positive feedbacks, the reductions could be sudden rather than gradual."

Paragraph 6.

"The areal coverage of seasonal snow and its duration are projected to decrease in most regions, particularly at mid-latitudes, with some regions at high latitudes possibly experiencing increases in seasonal snow cover. Changes in the volume of snow cover, or the length of the snow cover season, will have both positive and negative impacts on regional water resources (as a result of changes in the volume and the timing of runoff from snowmelt); on regional transportation (road, marine, air and rail); and on recreation sectors."

"Overview & Conclusions"

Page 15, lines 8-12.

"For later analysis of possible measures to be implemented it is of interest also to give the relative contributions to the enhanced radiative forcing during the decade of the 1980s and the projected distribution for the period 2000-2025 by sector (see Table 4 below).

Page 20, lines 20-25.

"A major program of reforestation as considered by the Noordwijk Ministerial Conference in November 1989 would play some role in slowing down the rate of increase of carbon dioxide in the atmosphere, but would at most reduce it by 5-10%, if fossil fuel use would continue to increase in accordance with Scenario A (Business as Usual Scenario)."

Page 27, lines 2-7.

"Establishing and upgrading regional environmental research centres to assist regions with common cultures and environmental problems to develop indigenous [sic] technology and expertise and to conduct environmental education programmes to tackle those problems in a manner appropriate for the region;"

Page 27, lines 29-35.

"The framework convention should recognize that developing nations will have to achieve an improved level of economic development in order for them to participate meaningfully in global warming response. Consequently the framework convention should be structured in such a way as to encourage actions which serve to narrow the 'poverty gap' and should recognize a minimum level of economic development below which response options will not be expected."

Page 30, lines 12-19.

"If individual countries can optimize their benefits by letting other countries share their costs (i.e. pay for pollution) without they themselves taking the necessary precautions (reducing pollution), the economy of the total system becomes unstable and a catastrophic development may occur ('the law of the commons'). We must also recognize the vast differences in economic strength between the players on the international scene, i.e., the nations and the large multinational companies in the world."

"Policymakers Summary"

PMS III, page 6, lines 1-10.

"However, because of the inherent limitations in our ability to estimate future rates of population and economic growth, etc, there is some uncertainty in the projections of greenhouse gas emissions, individual behavior, technological innovation, and other factors which are crucial for determining emission rates over the course of the next century. This lends uncertainty to projections of greenhouse gas emissions over several decades or longer. Reflecting these inherent difficulties, the RSWG's work on emissions scenarios are the best estimates at this time covering emissions over the next century but further work needs to be done."

The feasibility of the Noordwijk forestry target will be analyzed in the future by Working Group III. No analysis of the Noordwijk remit appears in any of the Policy Makers Summaries.

PMS III, page 39, lines 32-51.

This bullet does not appear in the original document. All text immediately before and after this bullet was extracted from PMS III, page 39, lines 32-51.

This discussion is not part of any of the Working Group reports.

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Policy Design for Climate Change: Comprehensive and Market-Based Approaches

Richard B. Stewart and Jonathan B. Wiener¹

The world community is moving toward a framework convention on climate change: the first negotiating session will be hosted by the United States in February 1990. What should be the approach of any international agreement on climate change? Many have called for immediate controls on greenhouse gas emissions. The discussion to date has been dominated by proposals to restrict carbon dioxide (CO₂) emissions, especially from sources in the energy sector of the economy. Proposals have tended to focus on rigid reduction targets with strict timetables, imposed internationally, to be met uniformly by all nations, and on technology-based standards such as "best available control technology."

Following these suggestions would amount to reinventing the square wheel. They rely on clumsy, outworn environmental policy designs -- piecemeal, command-and-control, technology-based, centrally administered, inflexible approaches that ignore relevant costs and benefits. These proposals concentrate myopically on what is deemed currently "understood" or "achievable." They fail to use incentives that will advance long-run economic and environmental goals. They hobble innovation and investment. Their piecemeal character is self-defeating, undercutting environmental progress by inducing shifts in economic activities from regulated sectors to other, unregulated sectors.

Issues for policy

Potential climate change is an issue of enormous complexity. The "greenhouse gases" -- CO₂, methane, nitrous oxide, tropospheric ozone, halocarbons like chlorofluorocarbons (CFCs), and others -- are numerous and are emitted by myriad

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different sources. Each greenhouse gas ("GHG") has a different capacity to trap heat in the atmosphere, called its "relative radiative forcing." Each also has other direct (chemical) effects on the atmosphere and on plant and animal life; for example, CO₂ enhances plant photosynthesis and water use efficiency, while CFCs deplete the stratospheric ozone layer. One GHG or another is emitted or affected by virtually every ecological and socioeconomic activity in every sector of every nation. Several of the gases are removed from the atmosphere by "sinks"; for example, CO₂ is removed in the photosynthesis carried on by trees, crops, grasses, and oceanic phytoplankton, and stored in plant material, soils, and the deep ocean. Any change in average annual global temperature would be a product of complex interactions and feedbacks among the composition of the atmosphere, cloud formation, ocean circulation, terrestrial sinks of GHGs, albedo (reflectivity), and other phenomena, and would in turn affect patterns of local temperature, precipitation, sea level, soil moisture.

The debate over policy approaches to potential climate change presents at least four basic kinds of issues:

1. To what extent and when will climate change occur? The recent First Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) collects the best evidence scientists have on this question. While it finds that anthropogenic increases in GHGs are likely to yield increases in atmospheric temperature, it concludes that major uncertainties frustrate our ability to forecast the magnitude, timing, or regional patterns of any climate change.

2. What are the costs and benefits of climate change, and of measures to limit or adapt to it? In light of these costs and benefits, what actions, if any, are warranted now? Scant analysis has explored these questions. Information on the impacts of potential climate change -- and on the costs of response measures -- is difficult to develop. A key issue on which not enough is known is finding the appropriate combination of preventive measures, to limit GHG emissions or expand GHG sinks, and adaptive measures, to anticipate and minimize adverse effects of climate change. Meanwhile, the United States is taking actions that make sense in their own right (for other environmental or economic reasons) but that also reduce GHG emissions or preserve or expand sinks. Examples include phasing out CFCs by 2000; the President's initiative to plant a billion trees annually; and the conservation incentives in the acid rain provisions of the proposed Clean Air Act.

3. If limitation efforts are warranted -- whether through actions that make sense in their own right, development of new low-emitting technologies and practices, or otherwise -- should they be confined to CO₂ emissions and limited to

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particular sectors, such as energy, or should they address all GHGs, sources and sinks?

4. Should any domestic or international limitation measures employ traditional command-and-control regulations, or make use of market-based economic incentive tools?

This article focuses on the third and fourth issues identified above. It argues that a piecemeal, gas-by-gas, source-by-source, command-and-control approach is both ecologically unsound and economically imprudent. If limitations investments or measures are to be implemented -- a big "if" that can only be decided based on a more extended look at scientific uncertainties and at costs and benefits of action and inaction -- then they should take a "comprehensive" approach and use market-based economic incentives. We are addressing not "how much" action to take, if any, but "how to" implement any decision to limit GHGs.

Better approaches

Experience has shown the inadequacy of employing piecemeal command-and-control approaches in environmental policy. For example, under the old Clean Air Act, scrubbers were mandated for most utility plants, thus imposing costs on society that could have been saved by allowing the least-cost solution at each plant, discouraging investments in fuel conservation, and, ironically, reducing emissions of one gas -- sulfur dioxide -- while impairing fuel efficiency and thereby increasing emissions of another -- CO₂. Similarly, piecemeal control of residuals in different environmental media (land, air, water) have often simply shifted these residuals around, rather than encouraging a net reduction in total pollution. Comprehensive, incentive-based approaches to deal with the array of environmental problems are now deservedly finding increased favor. For example, the tradeable credits system in the Clean Air bill proposed by the Administration would apply market-based incentives to reduce sulfur emissions, and encourage energy conservation, reducing CO₂ emissions markedly while saving about \$_____ billion annually in control costs.

The need for fresh thinking is acute in climate policy design. Given the interrelationship of climate variables and the wide range of activities that generate greenhouse gases, repeating the old mistakes in the climate arena would be seriously environmentally counterproductive and economically disruptive. Piecemeal approaches would probably move GHGs around in a conjurer's shell game, never achieving claimed reductions.

Whatever level of climate protection the international community may choose to purchase, it ought to implement its

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choice according to a comprehensive approach that embraces all the greenhouse gases ("GHGs"), their sources and sinks. Even in the absence of an international agreement, a comprehensive approach provides the best basis for identifying appropriate actions that make sense on other grounds and also affect GHGs, and for targeting investments in technologies that would affect GHG emissions. From the climate perspective, the environmental variable of concern is not narrowly definable as emissions of CO₂, or carbon content of fuels, or energy efficiency. It is the net emissions (sources less sinks) of all greenhouse gases, weighted by their relative impacts on the environment. Policy designs must be as comprehensive as the ecological reality they seek to address. In climate perhaps more than anywhere else, squeezing the balloon at one end just bulges it out at another.

In addition, any climate policy should harness market incentives to achieve environmental goals, rather than using command-and-control techniques that would needlessly raise the already formidable costs of achieving substantial reductions and would stagnate vital innovation. Because the costs of different response measures will be different in different places -- for example, the cost of curtailing CO₂ emissions in a nation with brand new power plants will likely be more than the cost of the same percentage reduction in a nation with old, retirement age plants, or a nation with abundant afforestation opportunities -- it makes no sense for everyone to adopt uniformly the same specific technologies or percentage reductions. Nor does it make sense to specify and thereby entrench current techniques and discourage innovation of better new techniques.

Carboncentric thinking

Those proposing immediate GHG reductions typically focus on limits, often through adoption of specific "best available" technology, on CO₂ emissions from fossil fuel combustion. Many such proposals are made by nations who would enjoy a comparative competitive advantage under such policies -- those who rely on non-carbon or low-carbon energy sources (such as nuclear, hydropower, or natural gas) or who expect to conserve energy more cheaply than their trading rivals. But such a narrow focus is neither warranted by the factual information about greenhouse gases, nor by sound policy.

First, it is clear that the greenhouse effect is not a question of CO₂ alone. CO₂ is portrayed as the chief culprit in potential global warming because of past accumulations of CO₂ and its large volumetric abundance in current total output. But CO₂ is, molecule for molecule, the weakest of the anthropogenic greenhouse gases. Because any limitation policies must necessarily address future increments of net GHG emissions, it is the comparative impact of additional amounts of each gas that

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must be addressed. Estimates of the "relative radiative forcing" of the various greenhouse gases (their ability to trap heat in the atmosphere) /Chart on GHGs' residence time, relative radiative forcing/ show that a unit of CO₂, notwithstanding its long typical residence time in the atmosphere, is the least potent contributor to potential warming. Moreover, because there is already so much CO₂ in the atmosphere (about 80% of it due to natural emissions), the band of the electromagnetic spectrum that CO₂ molecules block is already almost fully occluded, and additional molecules of CO₂ confront the "saturation effect" -- a sort of atmospheric rule of diminishing marginal returns -- meaning that the incremental radiative forcing of the next CO₂ molecule emitted will be measurably less than that of the previous molecule and thus the current relative potencies shown in /chart above/ tend to overstate the impact of future CO₂ compared to the other GHGs. And the amount of CO₂ in the atmosphere is not growing as rapidly as that of other GHGs; the atmospheric concentration of CO₂ is growing at about 0.3% per year, while methane is growing at about 1% per year and CFCs at over 4% per year.

Meanwhile, CO₂ provides significant non-warming benefits that the other greenhouse gases do not. CO₂ is the grist of photosynthesis. Empirical studies repeatedly show that higher concentrations of CO₂ in the atmosphere substantially improve plant productivity and increase the efficiency with which plants use water. The other greenhouse gases confer no such benefits, and some pose serious non-warming threats; CFCs, for example, deplete the stratospheric ozone layer. In order to provide a sound guide to policy choices, the relative radiative forcing index shown above in chart X should be expanded to incorporate the full environmental impacts of each GHG. CO₂ would receive a credit for enriching plant growth while CFCs received a debit for ozone depletion.

The upshot is that, unit-for-unit, CO₂ is the most environmentally benign of the greenhouse gases. If society and the biosphere had to accept any given amount of predicted warming, then on purely environmental grounds and abstracting from the costs of limitation strategies, it would prefer to have as much of the warming due to CO₂ and as little due to other GHGs. CO₂ is in a sense the last gas, on environmental grounds, whose incremental additions one would want to restrict.

Of course, any extensive measures to limit net GHG emissions -- even under a comprehensive approach -- would mean some efforts to limit emissions of CO₂, the most prevalent anthropogenic GHG. But the extent of limitations on CO₂ or any other specific GHG should not be mandated by international fiat. The costs of limiting each GHG would probably vary considerably among nations, and a uniform restriction on one GHG -- such as a rule requiring a 20% reduction in CO₂ alone -- would impose undue

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costs on nations who could achieve the same net GHG result through policies or technologies affecting other gases. Accordingly, each nation should enjoy the flexibility to adopt whatever mix of policies relating to different GHGs it finds least costly and burdensome, so long as it achieves its goal in terms of net weighted GHG limitations.

Second, focus on the energy sector alone is inappropriate. Certainly the energy sector produces a large share of global anthropogenic CO₂, CO, VOCs and NO_x. But the greenhouse gases arise from a variety of sources in every sector of activity, including agriculture, where rice paddies and ruminant livestock discharge enormous amounts of methane, and fertilized fields release nitrous oxide; forestry, where tree-cutting and soil disruption liberate about 25 to 33% of global anthropogenic CO₂; industry, which emits large amounts of CFCs, VOCs, CO, and NO_x; transportation, which yields CO, VOCs, and CFCs, in addition to CO₂; and the residential and commercial sector, which also produce VOCs and CFCs. /chart on sources & sectors/

Third, sinks deserve serious attention. It is net emissions that must be addressed. The net flux of greenhouse gases into the atmosphere is the result of both emissions from surface sources and removal by surface sinks, including ocean mixing, oceanic phytoplankton, trees, grasses, soil biota, crops, and tropospheric chemical reactions. Plants remove carbon dioxide from the atmosphere during photosynthesis; thus preserving and properly managing forests and other vegetation, or protecting phytoplankton from anthropogenic injury, can help sequester carbon released from surface sources.

The Comprehensive Approach

Any climate policy design must be "comprehensive" to match the diverse character of GHGs, their sources and sinks. Any choice of GHG-relevant actions that are justified in their own right, investment in new technologies, or design of limitations strategies, should be based on net GHG emissions, encompassing all GHGs, sources and sinks, and weighting GHGs according to an index of their comparative environmental impacts, similar to the index of relative radiative forcing in chart I above. This comprehensive design would ensure that no important GHG is ignored, while, as described above, providing incentives to limit the most environmentally damaging GHGs first rather than fixing narrow-mindedly on one gas or sector.

The comprehensive approach would also cure the bane of piecemeal approaches: unwanted shifts to unregulated activities that continue to produce environmental degradation. For example, under a CO₂-only approach, utilities would likely be encouraged

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to undertake fuel switching from coal to natural gas, because with current combustion techniques coal burning produces almost twice as much CO₂ per BTU as burning natural gas. But use of natural gas leads to methane emissions, because methane leaks from natural gas mining and transportation systems. One recent study estimates that a 3-6% rate of methane leakage from natural gas transport would fully offset all the CO₂ savings from switching from coal to natural gas. Such leakage rates are probably at the high end of the average in many advanced industrialized countries, but may be typical elsewhere. A swift expansion of natural gas transport capacity to comply with a stiff CO₂ reduction strategy could well mean use of hastily designed new facilities, or older facilities in disrepair, with leakage rates higher than today's. The net result could be greater net GHG emissions than in the absence of the CO₂ reduction effort. Even if the methane leakage rate only offset, say, 50% of the CO₂ savings, the CO₂-only policy would be severely undermined. The comprehensive approach, on the other hand, would encompass methane emissions and thereby ensure that methane leakage is included in a nation's net GHG emissions inventory and in the incentives and efforts to limit net GHG emissions.

An even more obvious inadvertent shift would attend efforts to restrict fossil fuel consumption that were applied piecemeal to one group of nations (such as OECD countries). Those nations would most likely respond by limiting imported fuels first, thus lowering prices for those fuels on world markets and raising the quantity consumed in other nations. Depending on the sensitivity of consumption to prices and the efficiency of fuel combustion in the various countries, total GHG emissions might even rise. Over the slightly longer term, unilateral or industrialized-only restrictions could induce GHG-emitting industries to move to unregulated locations. These concerns point up the need for wide international cooperation on any limitations strategies.

Each of these shifts would undercut or even cripple the effectiveness of the piecemeal policy. The experience of past piecemeal approaches indicates that it is often the unanticipated shifts -- whether from air pollutants to solid wastes, or from launcher numbers to MIRVed warheads -- that can most effectively render narrow policy thinking obsolete.

The "net emissions" aspect of the comprehensive approach would also provide significant benefits by encouraging sink expansion, through enhanced forest growth and preservation, and protection of phytoplankton habitats from pollution. In addition to limiting net GHG emissions, these activities would provide side benefits in biodiversity, oceanic food webs, reduced soil erosion, and better timber management.

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The comprehensive approach would also deliver important economic benefits. It allows each nation the flexibility to devise its own cost-effective policy mix. Because the marginal costs of abatement will vary by gas, source, sink, technique and across nations, this flexibility will enable the diverse responses needed to ensure an overall least-cost response. For example, the least-cost policy option for limiting net emissions in one nation may be switching from coal to natural gas, while for another nation it may be changing agricultural practices to reduce methane and nitrous oxide emissions, and for another it may be reducing deforestation and ensuring sustainable forest management. Put another way, reducing emissions of CO2 from fossil fuel combustion (or stopping deforestation, or any other single tactic) might be the cheapest way to limit overall net GHG emissions in one nation, but the most expensive in another. Global costs of limiting GHGs would be significantly reduced by allowing the flexibility afforded under the comprehensive approach.

Applying the comprehensive approach

Any initial convention on climate change should promote a cooperative scientific research and reporting agenda that follows the comprehensive approach by examining all GHGs, sources and sinks. It should also provide that a future protocol (if any) containing limitations obligations must follow a comprehensive approach. The convention could even state that any actions taken after a chosen baseline date will count toward any eventual limitation obligations under a future protocol (if any), relying on a provisional index of relative GHG impacts annexed to the convention. This would assure nations that their own actions, including actions justified in their own right and steps taken pursuant to both domestic policy and other international agreements, would receive "credit" if and when limitations are agreed upon. Without such advance assurances, nations will be discouraged from taking even GHG-limiting steps justified on other grounds; they would hesitate lest the protocol negotiation refuse to give credit for such prior actions, and would hold them in abeyance pending protocol negotiations.

The major objection that has been raised to the comprehensive approach is that the current science is not up to monitoring certain sources and sinks, such as non-point sources of methane and nitrous oxide. The objectors say that we should "do what we can now" and wait until later to design a comprehensive approach. Monitoring many such emissions is not easy. But it is not beyond our reach, if we focus current research efforts to support a comprehensive approach. Moreover, experience belies the suggestion that piecemeal initiatives can eventually be transformed into a comprehensive strategy. Piecemeal measures tend to create constituencies with vested

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interests that ensure their perpetuation. For example, the overbroad Prevention of Significant Deterioration (PSD) provisions in the Clean Air Act limit industrial development in many regions of the nation, often without environmental justification. But other regions oppose efforts to relax these limits for fear that industrial and economic development will shift to regions now subject to PSD controls. Similarly, any initial global climate agreement (whether pursued through obligations to limit GHGs or to invest in new technologies) that aimed at energy sector CO2 limitations would benefit certain nations relative to others. The favored nations would resist development of a more comprehensive approach that would treat all nations with an even hand. It is accordingly vital to ensure a "level playing field" by adopting a comprehensive approach at the outset.

The pertinent question is not what is immediately "feasible," but whether the costs of proceeding with a flawed policy design are less than the costs of doing the necessary groundwork to develop and implement a comprehensive approach. One need not wait for perfection; in the interim, proxy-based estimates of difficult-to-measure emissions could be used. The framework convention or other agreement could provide incentives to develop and improve monitoring by offering credit for reductions in difficult-to-monitor GHGs upon a demonstration of the relevant monitoring techniques to an expert panel. Nations who see such reductions as to their benefit (either where the measures are justified in their own right or taken under an agreed limitation obligation) -- and entrepreneurs looking to contract with those nations -- would invest in developing the monitoring capabilities required.

Market-based incentives

The virtues of market-based economic incentives for environmental protection are increasingly well-recognized. Market-based tools include fees or taxes, tradeable allowances, and deposit-refund programs. They have demonstrated success in several important environmental applications, including the tradeable credits program used to phase out lead in gasoline -- achieved at about half the cost (amounting to hundreds of millions of dollars) of a traditional non-trading regulatory program -- and efforts to reduce litter of glass and aluminum containers. Both fees and tradeable allowances are now being used in the U.S. program to eliminate CFC use under the Montreal Protocol; and tradeable allowances have been proposed for the acid rain reduction provisions of the new Clean Air Act, with projected national savings of \$_____ billion annually as compared to a command-and-control program. We have meanwhile learned a great deal about the drawbacks of traditional regulatory approaches, in terms of their cost, obstacles to innovation and

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resource use efficiency, ecological shortsightedness, and administrative burdens. The common feature of the new tools is that they respond to market-failure -- such as pollution -- by redirecting and harnessing market forces to correct the problem. They provide powerful incentives for socially and environmentally responsible behavior. At the same time, they allow flexibility among market actors, promote decentralized decisionmaking about response tactics, further least-cost solutions by allowing those who can fix the problem most cheaply to do so first, and stimulate efficient resource use and broad-scale innovation in technologies and practices.

Market-based techniques are especially well-suited to implementing limitation measures, if any are adopted, for GHGs. Because GHG emissions arise from so many diverse and pervasive sources, the costs of abatement are bound to vary widely among emitters. Market-based mechanisms use that variation to social advantage by imposing some restraint on total emissions -- a limit on the net quantity emitted, or a fee on each unit emitted -- but then letting the market allocate the burden of mitigative measures to those who can most easily shoulder it.

In the climate context, two main economic instruments have been suggested: tradeable emissions allowances, and emissions taxes. Tradeable allowances set a total limit on net emissions, issue that sum of allowances to emitters, and let emitters trade them. Those for whom emissions reductions or sink expansions are relatively more expensive will buy allowances, while those who can achieve them cheaply will sell allowances. This gives an incentive to each emitter to develop new means of limiting emissions at less cost than its competitors, so that it can sell its allowances at a profit. Emissions controls, efficient use of fuels and other inputs, and innovation of new emissions limitations techniques become profit centers for the emitter. The market allocates abatement actions to those who do so at least cost, reducing the overall cost to society. Such a technique could be used to limit net GHG emissions through emissions trading. Domestically, governments could issue allowances for amortized net GHG emissions. Allowances would count toward net emissions of GHGs. Those issued allowances, such as electric utilities, could meet their allowance limits through energy conservation, fuel switching, reducing methane leaks from energy systems, arranging for tree planting, or arranging for reductions in other GHGs by other actors. The value of activities relating to different gases would be calculated according to an index of the comparative environmental impacts of the GHGs. Government clearinghouses, private brokers, and banks could act to facilitate trading among disparate parties and across periods of time.

International reallocations of national obligations through trades would also be advantageous. Such trades could

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consist of informal, bilateral reallocations of obligations to limit GHGs. One nation could satisfy its obligations by investing in response actions in another. For example, Nation A could provide new energy technology to Nation B, in return for all or part of the value of B's reduction in emissions. Or Nation C could plant and manage trees in D's territory while offering agricultural aid to compensate for the reduced available arable land in D. Nation E might earn the opportunity to record certain emissions reductions achieved in Nation F in return for debt forgiveness promised to F. Given significant international variations in marginal costs of limitation, such trades would likely enable the world economy to realize substantial cost savings. These arrangements would demonstrate the power of applying Adam Smith's lessons of comparative advantage to global environmental resources.

Trading could also be more formalized, with allowances issued to nations according to negotiated allocations. Allowances could be made of limited duration, or leasable, to relieve fears of hoarding or other distortions due to exercise of market power. Such trading in GHG limitations would also serve as a market-based, decentralized vehicle for introducing needed low-GHG-emitting technology into the developing world. It would point technology toward those who needed it most, and stimulate innovation by industrialized nations of technologies useful in developing nations. At the same time this framework would obviate creation of a heavily bureaucratized, centralized regulatory authority and technology assistance fund, with attendant opportunities for waste and misallocation of benefits.

Emissions taxes for net GHG emissions are another important option. The tax rate could be geared to the GHG index value of the emissions activity. Like emissions trading, emissions taxes offer a least-cost solution that promotes innovation and efficient resource use. Such a plan could make excellent sense domestically, especially where the focus is on specifying the cost of a GHG limitation program more precisely than the quantity of emissions avoided, or where revenue raising is a major goal. International application of a tax would raise many more difficult questions: Would nations cede their sovereignty to an international tax authority? How would the tax be set? How would the potentially enormous revenues raised be allotted and expended?

Conclusion.

[to add]

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BOX A

List of international events

Intergovernmental Panel on Climate Change (IPCC), including its recent First Assessment Report and its structure for pursuing further research.

Conference of OECD Environment Ministers in January 1991

Second World Climate Conference in November 1990

Bergen Conference in May 1990

Washington Conference on Science and Economics Relating to Global Change in April 1990

Cairo Conference in December 1989

Noordwijk Conference in October 1989

Toronto Conference in June 1988

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NEWS REVIEW

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Bryan Appleyard **Page 7**

Conspiracy in the air?

Jeremy Young





Sun city: but the odd swelter does not make a permanent summer, and the fact that it is always hotter in urban areas — where weather stations are usually located — than in the countryside, has led to unrealistic assessments of climatic conditions

A cold, hard look at 'global warming'

The greenhouse effect heralds a catastrophe that threatens to engulf the world. From an almost benign start — a hardly perceptible change in global temperature — the earth, it is claimed, will suddenly topple into crisis, reducing large tracts of arable land to desert and wreaking havoc on our culture.

It is easy, as Britain swelters in a seemingly endless heatwave, to imagine that our torrid temperatures are evidence of global warming. But impressions of what is happening to the weather are wholly unreliable.

Thus far, this summer has been no warmer than average and significantly cooler than last year. The hottest summer

on record is still 1976. Publicity given to the greenhouse effect encourages us all to explain every baking day as a consequence of global warming. What is the scientific evidence?

The theory is not one put forward by cranks. Nor is it the esoteric province of geophysical Cassandras. Instead it has become the conventional wisdom of our times, endorsed by the great and the good, by politicians and scientists alike. It has spawned an industry of governmental agencies and

pressure groups, television programmes and radio phone-ins. There is only one problem: the mounting evidence that it is not true.

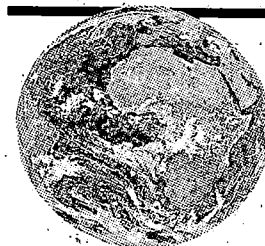
Supporters of the greenhouse effect point first to the earth's climate record over the past century, showing a rise in global temperature and an increase in sea level; and second, to the theoretical predictions of the climate models, which show an increase of between 2C and 5C in global temperature for every doubling in the volume of carbon dioxide. On closer inspection, this evidence turns out to be flawed.

The earth's temperature record comes from thousands of individual measurements taken every hour of every day at weather stations throughout the world. These measurements (60,000 a day, 22m a year) provide the data for claims that the earth has warmed by 0.5C in the past century.

This thermometer record is beset with problems. Weather stations are not evenly distributed over the globe. There are more in the heavily populated regions of the northern hemisphere than in the southern hemisphere, while the three-quarters of the earth's surface that is covered by oceans is almost unrepresented.

More importantly, most weather stations are found in towns, and, as anyone who lives in London will be aware, towns are hotter than the surrounding countryside. In Phoenix, Arizona, the centre of the city is often 10 degrees warmer than the suburbs. As towns have grown, so the temperature has gone up — not because of global warming, but because of the so-called heat-island effect.

Recent studies have shown that urban heat-island effects can be discerned in villages with a population as small as 300, and can produce localised urban



As Britain bakes, it is easy to imagine that the 'greenhouse effect' is to blame. But this summer has been no warmer than average; indeed, June was cooler than usual. So why, though there is no reliable scientific evidence of global warming, do we go on believing in it, asks Hilary Lawson

rise in temperature in the past century took place in the first 50 years, so it is certainly not a case of a continuously rising global temperature.

We do not have accurate records to enable us to extend the graph back beyond the past 100 years, but medieval records indicate there was a warm period when vines were grown throughout Britain, and Vikings grew crops in a country they named "Greenland". It is quite possible that if we could extend the temperature graph back 1,000 years, it would show an overall decline rather than an increase.

Given the doubts over the data and problems with the time base, it is not surprising that Dr Sherwood Idso, at the United States Water Conservation Laboratories, who has studied the effects of carbon dioxide on climate for the past 20 years, is dismissive of claims that the world is warming. "Some people claim there may have been 0.5C warming over the last 100 years. This is tenuous. If we look at the real world we find there has been no significant warming."

Such doubts are supported by those at the heart of the scientific establishment. Richard Lindzen, professor of dynamic meteorology at the Massachusetts Institute of Technology (MIT) in Boston, says: "Most scientists I know feel it would be very difficult to say anything about this record as it stands. I am reasonably confident that, given the record alone, few people would plausibly say that this indicates man has created warming."

BUT if there is no evidence of an increase in temperature, what about increases in sea level? After all, perhaps even more than global temperature rise, it has been predictions of whole landmasses disappearing

impact of waves on the readings. But there is an underlying theoretical problem when measuring sea level. Are you measuring the level of the sea or the level of the land? If the land moves up, the sea appears to fall and vice versa. If the sea level is rising, you might expect it to rise everywhere, but the pattern across the globe is not consistent. Even within the British Isles, for purely geological reasons, the sea level is rising in the southeast and falling in the north of Scotland.

Dr David Aubrey is in charge

of coastal research at the Woods Hole Oceanographic Institute (one of the most influential organisations studying the sea), a few hundred miles north of Manhattan, and is convinced there is no cause for anxiety. "People have averaged different stations, and different time periods and come up with different answers," he says. "You can come up with whatever answer you want, in effect. No useful conclusions about the future can be drawn from the record. There is no evidence that the sea level is rising due to global warming."

In addition to reports of islands sinking beneath the waves (we have not heard about

continued on back page ➔

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1989	INDUSTRIALISED COUNTRIES	DEVELOPING COUNTRIES
POPULATION	1	11
ENERGY	100	10
2020	INDUSTRIALISED COUNTRIES	DEVELOPING COUNTRIES
POPULATION	1	11
ENERGY	100	100

Energy consumption worldwide has grown some twenty fold since 1850. There is a view that energy demand for the industrialised world will double by 2020.

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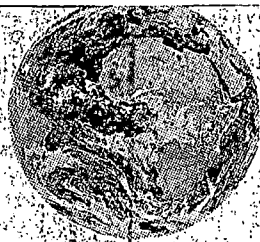
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Recent studies have shown that urban heat-island effects can be discerned in villages with a population as small as 300, and can produce localised urban warming of as much as 0.3C per decade — almost as much as global warming is supposed to have produced in a century.

Although attempts have been made to allow for the heat-island effect in analyses of temperature change over the past century, several recent studies have concluded that the size of the effect has been significantly underestimated.

In 1989, Dr Robert Balling, director of climatology at Arizona State University, found a warming bias in one of the standard temperature analyses in excess of 0.5C. Once again, this is more than the entire increase said to have occurred in 100 years.



As Britain bakes, it is easy to imagine that the greenhouse effect is to blame. But this summer has been no warmer than average; indeed, June was cooler than usual. So why, though there is no reliable scientific evidence of global warming, do we go on believing in it, asks Hilary Lawson

In the past few months we have had evidence to suggest that the thermometer data is even more doubtful. Dr Roy Spencer, of the Nasa space centre in Huntsville, Alabama, has analysed satellite data to produce a graph of global temperature change over the past decade. This satellite data is exceptionally accurate. Unlike the thermometer data, it is evenly spread over the globe and does not suffer from the urban heat-island effect.

From his data, Spencer concludes: "Over the entire 10-year period there was no net warming or cooling. The trend of the thermometer data is only about one to two tenths of a degree, which doesn't sound much but is significant when set against the satellite indication of no trend at all."

EVEN if we ignore problems with the data, the temperature record is still ambiguous. Whether there has been an increase in temperature or not depends on the time period you happen to choose. During the past 50 years, there has been little or no change in temperature. If you take the years from 1930 to 1970, there was a fairly steep decline.

Almost all of the half-degree

century took place in the first 50 years, so it is certainly not a case of a continuously rising global temperature.

We do not have accurate records to enable us to extend the graph back beyond the past 100 years, but medieval records indicate there was a warmer period when vines were grown throughout Britain and Vikings grew crops in a country they named "Greenland". It is quite possible that if we could extend the temperature graph back 1,000 years, it would show an overall decline rather than an increase.

Given the doubts over the data and problems with the time base, it is not surprising that Dr Sherwood Idso, at the United States Water Conservation Laboratories, who has studied the effects of carbon dioxide on climate for the past 20 years, is dismissive of claims that the world is warming. "Some people claim there may have been 0.5C warming over the last 100 years. This is tenuous. If we look at the real world we find there has been no significant warming."

Such doubts are supported by those at the heart of the scientific establishment. Richard Lindzen, professor of dynamic meteorology at the Massachusetts Institute of Technology (MIT) in Boston, says: "Most scientists I know feel it would be very difficult to say anything about this record as it stands. I am reasonably confident that, given the record alone, few people would plausibly say that this indicates man has created warming."

BUT if there is no evidence of an increase in temperature, what about increases in sea level? After all, perhaps even more than global temperature rise, it has been predictions of whole landscapes disappearing beneath the waves that have given rise to fears of impending catastrophe. As with temperature change, a closer look at the evidence tells a different story. Although the popular press has carried reports of increases in sea level of up to 20 metres, respectable scientific predictions have been closer to 0.5m during the next century. Since this is the height of a small wave, it is not easy to detect over 100 years.

Evidence of sea-level change comes from tide gauges normally found in harbours or on jetties. By taking thousands of measurements throughout the year and averaging them, one can hope to eradicate the

ings. But there is an underlying theoretical problem when measuring sea level. Are you measuring the level of the sea or the level of the land? If the land moves up, the sea appears to fall, and vice versa. If the sea level is rising, you might expect it to rise everywhere, but the pattern across the globe is not consistent. Even within the British Isles, for purely geological reasons, the sea level is rising in the southeast and falling in the north of Scotland.

Dr David Aubrey is in charge

People have averaged different stations and different time periods and come up with different answers," he says. "You can come up with whatever answer you want, in effect. No useful conclusions about the future can be drawn from the record. There is no evidence that the sea level is rising due to global warming."

In addition to reports of islands sinking beneath the waves (we have not heard about

continued on back page

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◆ continued from front page

the islands, such as the Shetlands, that are rising), it was widely reported last year that sea ice was melting. Submarines passing under the poles had reported that the ice at specific points was less deep than it had been 10 years earlier.

Julian Paren, of the British Antarctic Survey, is sceptical. "Data from submarines comes from just two snapshots 10 years apart. The submarine observations are contradicted by the only reliable evidence coming from satellites which, for the last 15 years, have given us a daily picture of sea ice extent in the Arctic and Antarctic which shows no change."

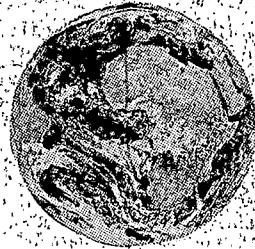
The actual climate record of the earth lacks concrete evidence of an increase in global temperature or a rise in sea level. As a result, under scrutiny, supporters of the greenhouse theory abandon the data and rely instead on the predictions of the climate models. But these turn out to be as shaky as the empirical data.

THOUGH superficially similar, the climate models are radically different in character from the models used to provide daily weather forecasts. The climate models do not start from the current weather at all but try to simulate the entire climate of the earth from first principles. The computer is given the amount of heat arriving from the sun, the laws of physics which describe how heat radiates and the radiation properties of the atmosphere. It then calculates such variables as the temperature of the earth, wind speeds and rainfall.

The climate models predict increases in global temperature of between 2C and 5C for a doubling of the level of carbon dioxide. But before we can trust the predictions of these models, we must first be convinced that they accurately describe our climate. Accuracy is not a word that immediately comes to mind when examining the models' simulation of the world's climate.

Steve Schneider, of the US National Centre for Atmospheric Research and one of the world's leading global warming theorists, says: "A congressman once said to me: 'Do you mean to say that you guys have spent a billion dollars of our money telling us that winter is cold and summer is hot?' And my answer was 'Yes, sir, and we're very proud of that.'"

Conspiracy in the air?



climate model in Britain at the Meteorological Office. According to the published predictions of the model, as much rain falls on central Sahara in summer as Ireland or Scotland.

The sole remaining support for the greenhouse effect comes from the assumption that we understand the underlying physics of the atmosphere and know for certain that carbon dioxide contributes to a warming of the planet. Even this, it turns out, is not the case.

ONE thing is certain: carbon dioxide levels are rising. It is also true that carbon dioxide is a greenhouse gas. It is not the only greenhouse gas, nor the most important — which is water vapour. But the term "greenhouse gas" is misleading.

These gases not only trap heat, they also radiate it. Like all good absorbers of radiation, they are also good emitters. They emit as much radiation as they absorb. Furthermore, the way in which each of the greenhouse gases absorbs and emits radiation depends on its position in the atmosphere. The radiative process is a highly complex one in which the effect

of an increase in any one gas is dependent on its effect on all the others and where this takes place in the atmosphere. As a result, there is no simple relationship between more greenhouse gas and more heat.

Moreover, Reginald Newell, professor of meteorology at MIT, argues that the primary mechanism for heating the atmosphere is not radiation but the latent heat released when water vapour turns to rain. His conclusion is that not only might an increase in carbon dioxide not cause a warming, but that it could cause an actual cooling.

Newell is not alone in this view. In a recent paper on the effects of carbon dioxide, Professor Walter Ellsaesser of the

Lawrence Livermore laboratories, a major American government research establishment in California, concluded that a doubling of carbon dioxide would "have little or no effect on the temperature at the surface and, if anything, might cause the surface to cool".

The greenhouse theory, assumed almost everywhere to be undeniably true, turns out to be entirely speculative. It does not have empirical evidence to back it up and it is theoretically flawed.

But even if there is no reason for believing that carbon dioxide threatens climatic disaster, it is still easy to regard it as a pollutant. Carbon dioxide is the life-giving gas for all plant life, a plant's equivalent of oxygen. Extensive experiments have been able to demonstrate that increases in carbon dioxide levels are positively beneficial to plant growth.

For the past three years Dr Sherwood Idso, of the US Water Conservation Laboratories, has been growing sour orange trees in enclosures with double the normal concentration of carbon dioxide. These

trees are now twice the height of the control group of trees with 180% more biomass. Similar improvements in plant growth have been found in hundreds of experiments. Even 50 years ago commercial nurseries were already enriching their air with carbon dioxide to enhance crop production, as they continue to do today.

Judged on the time-scale of the earth, current levels of carbon dioxide are at an all-time low. Plants developed at a time when carbon dioxide was five to 10 times above its current level. Dr Idso believes that even if we burnt all the fossil fuels in the crust of the earth, the consequences would be entirely beneficial for plants and would have no deleterious effect on the climate. Furthermore, he argues that with the world's rapidly growing population we may need the increased vegetation growth that will flow from higher levels of carbon dioxide.

If there is concrete evidence of the benefits of carbon dioxide, and if the detrimental effects are, at the very least, questionable, how have we been

led to talk so seriously of catastrophe?

THERE has been a coalition of interests, between scientists who have needed funds and the media who wanted a good story. The common perception of science is of a disinterested pursuit of truth. The reality is rather different. Scientists are no different from any other professional group. In order to pursue their work, they require funding. If you are working in climatology, a good way of attracting interest and backing is to predict an apocalypse.

Fifteen years ago, the apocalypse was not global warming but global cooling. Many scientists who are now championing global warming were, just over a decade ago, predicting a forthcoming ice age. Steve Schneider wrote in his first book: "A cooling trend has set in — perhaps one akin to the little ice age."

At the Nasa Space Centre, Dr Spencer takes it for granted that scientific conclusions are influenced by funds: "It's easier to get funding with disasters. It used to be ice age scenario. In 10 years' time, who knows what it will be? Sure, science benefits from some scary scenarios."

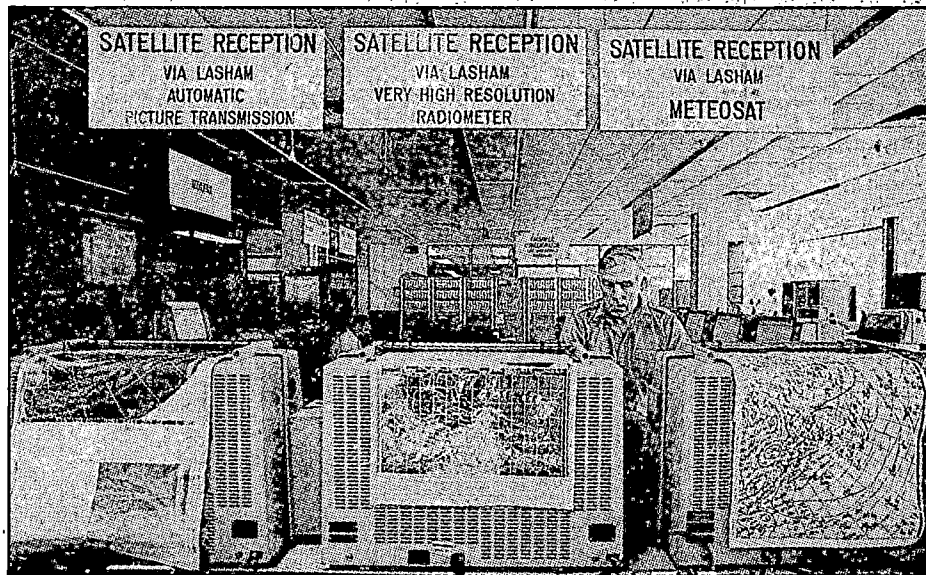
But as the bandwagon has gathered pace, it has not only improved the funds of global warming theorists, it has also made it difficult for scientists who disagree to voice their opinions.

Professor Lindzen, of MIT describes the global warming hysteria as a new McCarthyism. If you don't espouse the cause, you are at risk of being ostracised. "There are statements made of such overt unreality that I feel embarrassed. I feel it discredits my science. I think there could arise problems where one will need to depend on scientific judgment, and by ruining our credibility now, we leave society with a diminished resource."

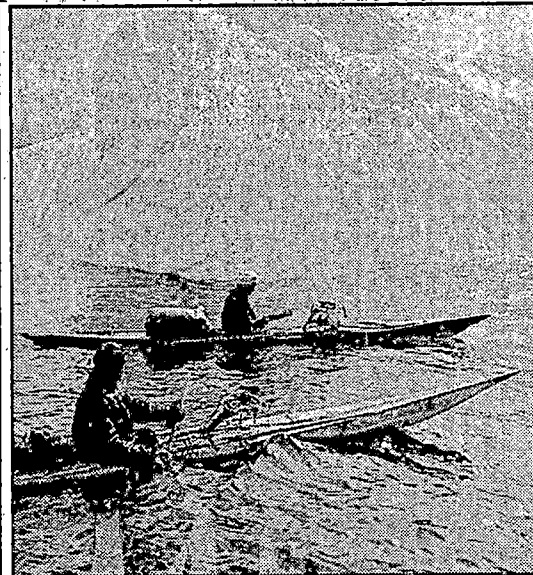
Of course, it has not only been the scientists and the media who have promoted the greenhouse theory; politicians have not been slow to see the advantages. What could be less controversial than government action to save Mother Earth?

As for the rest of us, is it the coming millennium that encourages notions of an apocalypse or just that, in a world without ideals, we need a catastrophe to give us something to believe in?

● Equinox: The Greenhouse Conspiracy will be transmitted at 7pm today on Channel 4



Data base: satellites relay world weather information to the Meteorological Office at Bracknell



No sign of a greenhouse effect in Greenland

Bush may be lonely on global warming, but he's also right

By now all Americans of sound mind and pure heart must be overcome with shame at their government's policy on the greenhouse effect, which is alleged to be turning the planet into a sauna with no off switch. Instead of joining with all the other industrial democracies in pledging to do thrillingly noble deeds, the Bush administration has stuck to its party-poopng insistence on counting costs and nailing down facts.

This is highly unsatisfying to European heads of government, particularly West Germany's Helmut Kohl, whose citizens are a pushover for every environmentalist fashion. It's also infuriating to American environmental groups, who this week were accusing President Bush of nothing more serious

Stephen Chapman

than "killing our world."

Don't send a wreath just yet. The Bush administration may have a hard case to sell politically, but it clearly has the best of the scientific and economic arguments. European governments are more willing to vow a crusade against global warming partly because they know it will cost them a lot less than it will cost us.

The global warming alarmists, like most alarmists, behave as if all the important questions were already settled. In fact, we don't know whether carbon dioxide emissions will raise the atmospheric temperature. If so, we don't know by how much. And, if it does so by a substantial amount, we don't know how damaging the results will be.

If carbon dioxide emissions cause warming, we should already be sweating. But over the past century, scientists have found, temperatures have risen only by a tiny amount, or possibly not at all—despite a sharp increase in the level of carbon dioxide and other greenhouse gases in the atmosphere.

Even many scientists who believe the mercury will climb sooner or later think it won't go nearly as high as environmentalists claim. Those scary predictions of huge increases in ocean levels have already been scaled back, making it unlikely that New Yorkers and Houstonians will need canoes to get to work.

Other experts note that a warming trend, if it happens, will have some benefits—such as boosting harvests, lengthening growing seasons and reducing January gas bills in Chicago. It may also help head off a new ice age, a catastrophe that the green lobby was confidently predicting just a few years ago. Global warming, if it happens, will create some problems, but not the apocalyptic threat to human survival that is often advertised.

The Europeans, who have historically been more allergic to free markets than Americans have, have been forced to retreat from socialism in its various forms. Luckily for them—and for the American left—the greenhouse threat arrived just in time to give unreconstructed statists a new excuse for meddling in the lives of ordinary people. They aren't going to let a few facts get in their way.

It probably hasn't escaped the notice of Helmut Kohl and Francois Mitterrand that the heaviest burden of limiting greenhouse emissions will not fall on Germany and France. Carbon dioxide is produced mainly by burning fossil fuels, which the U.S. uses in far greater quantities than Europeans do.

One reason for the difference is nuclear power. France gets 29 percent of its energy from nuclear plants. West Germany and the European Community as a whole get 12 percent. The United States gets just 6 percent. So Americans will have to spend a lot more money to reduce greenhouse pollutants than Europeans.

How much? A study by Alan Manne of Stanford and Richard Richels of the Electric Power Research Institute estimates if the U.S. wants to cut total emissions 20 percent by 2020, it will eventually have to cough up about 3 percent of its gross national product annually—the equivalent of about \$160 billion a year in today's dollars.

That would make the savings and loan bailout look like a blue light special. The other Western industrial nations would have to spend only about half as much as we would, which may explain why they're about twice as enthusiastic. But, of course, what their leaders demand won't require any real sacrifices for about 20 years. By that time Kohl and his colleagues will be comfortably retired from politics.

President Bush has taken the reasonable position that he won't commit the U.S. government to a vast and expensive intrusion into the nation's economy and its citizens' personal lives without more convincing proof of the need. That's only common sense, a commodity scarcer than the spotted owl.

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3

THE OCEANIC SINK FOR EXCESS ATMOSPHERIC CARBON DIOXIDE

Berrien Moore III

Complex Systems Research Center
University of New Hampshire
Durham, New Hampshire

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ABSTRACT

The concentration of atmospheric CO₂ has increased at least 20% during the last 100 y. The increase is a result of burning fossil fuels and of changing patterns of

Ref

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land use resulting in a reduction of carbon stored in terrestrial biota and in soil. At present, our ability to interpret the carbon cycle and hence to predict future CO_2 concentrations is stymied by unresolved imbalances in the carbon budget. Simply stated, the annual budget equation does not balance unless: (1) fertilization effects, either terrestrial or aquatic, equal deforestation-regrowth; (2) the problem vanishes (for example, deforestation equals regrowth); or (3) the oceanic uptake is grossly underestimated. In order to understand better the third possibility, this chapter reviews the chemical, biological, and physical processes that control uptake of CO_2 in the ocean: the largest sink for excess atmospheric CO_2 .

3.1. INTRODUCTION

The effects of human interferences, such as burning fossil fuel, harvesting forests, and converting land to agriculture, with the natural cycling of carbon are reflected most clearly by the phenomenon of increasing concentration of atmospheric CO_2 (Fig. 3.1). If the current trend continues, the atmospheric CO_2 concentration will exceed 600 parts per million by volume (ppm) by the year 2050—more than two times the preindustrial level. The increase in CO_2 is important because, in contrast to atmospheric O_2 and N_2 , CO_2 absorbs infrared radiation emitted by the earth and prevents the escape of some of the normally outgoing radiation. This is popularly known as the greenhouse effect.

An increase in the amount of CO_2 will result in even greater atmospheric reten-

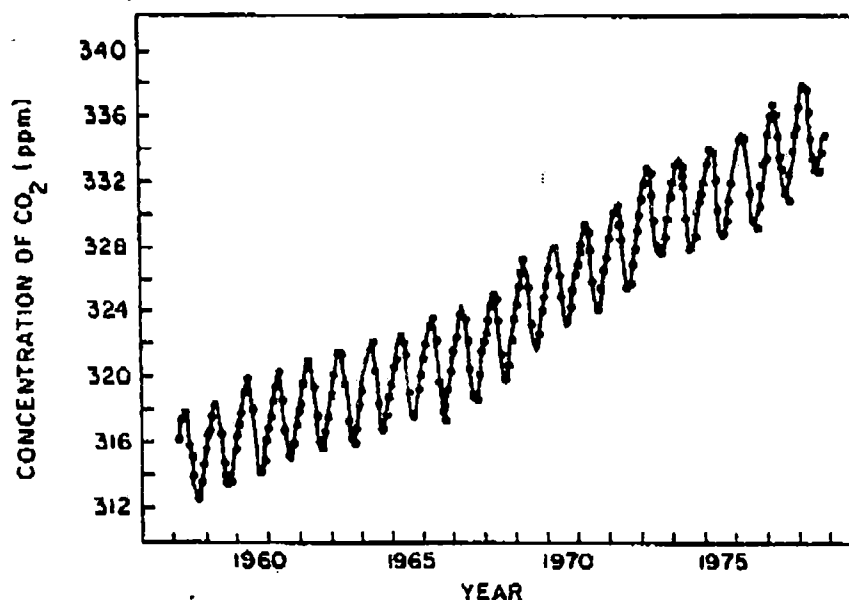


Figure 3.1. Concentration of atmospheric CO_2 at Mauna Loa Observatory, Hawaii (19.5°N , 155.6°W). Dots indicate monthly averages based on continuous measurements. (From Bacastow and Keeling, 1981; Keeling et al., 1982.)

3.1. Introduction 97

tion of radiant heat from the sun and a higher equilibrium temperature for the earth as a whole. If the atmospheric concentration of CO_2 rises to 600 ppm, then the increase in temperature is expected to be important; it can be $2-4^\circ\text{C}$ for the entire earth with an increase of approximately 8°C at the poles (Manabe and Wetherald, 1975; Gates, 1979; Dickinson, 1982). More importantly, the rainfall pattern could be affected dramatically; this could alter the global distribution of agriculture (Cooper, 1982).

At present, our ability to interpret the carbon cycle and thus predict the future CO_2 concentration is stymied by unresolved imbalances in the carbon budget (Bolin, 1977; Woodwell and Houghton, 1977; Moore et al., 1981; Houghton et al., 1983; Woodwell et al., 1983). Simply stated, the annual budget equation for CO_2 (Table 3.1) does not balance unless:

1. Fertilization effects, either terrestrial or aquatic, equal deforestation-regrowth.
2. The problem vanishes; for example, deforestation equals regrowth.
3. The oceanic uptake is grossly underestimated.

In order to appreciate the constraints upon these possibilities, this chapter reviews generally the basic global carbon budget (Fig. 3.2), and in particular considers the chemical, biological, and physical processes that control oceanic uptake of CO_2 .

3.1.1. Atmospheric Carbon Dioxide

The 1984 concentration of carbon as CO_2 in the atmosphere is about 340 ppm, or 728×10^{15} g of carbon (Waggoner, 1984). Within 1 y, seasonal differences in photosynthesis and respiration within the biosphere create an oscillation in the atmospheric CO_2 concentration, with an amplitude of roughly 5 ppm, or 10.6×10^{15} g y^{-1} of carbon (Fig. 3.1). A few attempts have been made to detect changes in the amplitude of this oscillation as a way to infer changes in the size of the pools of carbon in the biosphere; however, the results have been inconclusive (Hall et al., 1975; Pearman and Hyson, 1980; Fraser et al., 1983; Pearman et al., 1983).

There are three important isotopic forms of carbon in the atmosphere: ^{12}C , ^{13}C , and ^{14}C in an approximate ratio of $1:10^{-2}:10^{-12}$. The former two forms are stable, whereas the latter is a radioactive β -emitter with a half life ($t_{1/2}$) of 5730 y.

Measurements of the $^{13}\text{C}:^{12}\text{C}$ ratio are extremely valuable for providing insight into the potential source of the CO_2 sink in the biosphere. When taking up CO_2

Table 3.1. Annual Carbon Budget

Input (g y^{-1} of carbon)		Uptake (g y^{-1} of carbon)	
Fossil-fuel burning	5×10^{15}	Atmospheric increase	3×10^{15}
Deforestation-regrowth	$(1-3) \times 10^{15}$	Oceanic uptake	$(2-3) \times 10^{15}$
Total	$(6-8) \times 10^{15}$	Fertilization effects	?
		Total	$[(5-6) + ?] \times 10^{15}$

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during photosynthesis, plants fractionate against ^{13}C ; consequently, vegetation, humus, and fossil fuels are depleted of ^{13}C . When we know information such as the period of fossil fuel combustion (Rotty, 1981; Tans, 1981), a record of atmospheric ^{13}C : ^{12}C ratio (Freyer, 1979c), the uptake of CO_2 by the ocean (Bacastow and Keeling, 1973; Oeschger et al., 1975; Oeschger and Siegenthaler, 1978; Björkström, 1979; Bolin et al., 1983), and the ^{13}C : ^{12}C fractionation during CO_2 transfer from air to sea and from air to terrestrial vegetation (Siegenthaler and Munnich, 1981; Keeling, 1981), then it is possible to estimate the history of the source of the net release or uptake of CO_2 by terrestrial biota and soil.

Estimates of this type have been based on analyzing the isotopic forms of carbon in tree rings as an atmospheric record (Freyer, 1978; Stuiver, 1978; Siegenthaler et al., 1978; Freyer, 1979b; Keeling et al., 1980; Tans and Mook, 1980; Freyer and Belacy, 1983; Peng et al., 1983). However, inferring atmospheric fluxes is not straightforward. Trees may fractionate carbon differently during different phases of growth or under different nutrient or water regimes (Francey, 1981; Francey and Farquhar, 1982). The effect on atmospheric CO_2 of photosynthesis and respiration of a surrounding or nearby forest will alter the concentration of atmospheric ^{13}C and thereby disturb the record. Extreme caution must be used in interpretation of the record, but even a conservative view would indicate that between the years 1860-1970 the biosphere had a net total release of CO_2 to the atmosphere of $(100-150) \times 10^{15}$ g of carbon (Freyer, 1979a, 1979b; Peng et al., 1983). This total release over the period 1860-1970 is consistent with direct estimates; however, it is not consistent with most current views of oceanic uptake of CO_2 , nor is it consistent with the view that carbon accumulation during regrowth has offset completely the loss due to deforestation, nor is the release rate per year from 1860 to 1970 necessarily consistent with direct estimates.

3.1.2. Carbon in Terrestrial Biota and Soil

The range of estimates of the amount of carbon in living organic matter on land is $(450-900) \times 10^{15}$ g of carbon (Ajtay et al., 1979; Olson, 1982; Houghton et al., 1983; Mathews, 1983). Estimates of total primary production, respiration, and detrital decay rates vary greatly. There are three major reasons for this uncertainty: (1) the definition of biomass is ambiguous in that it does not include below-ground production; (2) the method of scaling from selected local sites of measurement to biome-wide estimates is not rigorous; and (3) uncertainties exist about the geographic extent of different ecosystems.

Although soil organic matter, humus, is a major active reservoir in the global carbon cycle, there is little known about its extent and the rate of activity. Estimates range from $(700-1800) \times 10^{15}$ g of carbon (Schlesinger, 1977; Ajtay et al., 1979; Post et al., 1982; Olson, 1982; Houghton et al., 1983; Schlesinger, 1984). The total amount of carbon (1200×10^{15} g) shown in Fig. 3.2 includes human disturbance and revised estimates on the geographical range of various systems; it excludes the slower turnover pools of carbon in deep humus and peat.

The magnitude of the net release of carbon from vegetation and soils of the world as a result of changes in land use remains unknown. The problem of calculating this

3.1. Introduction 99

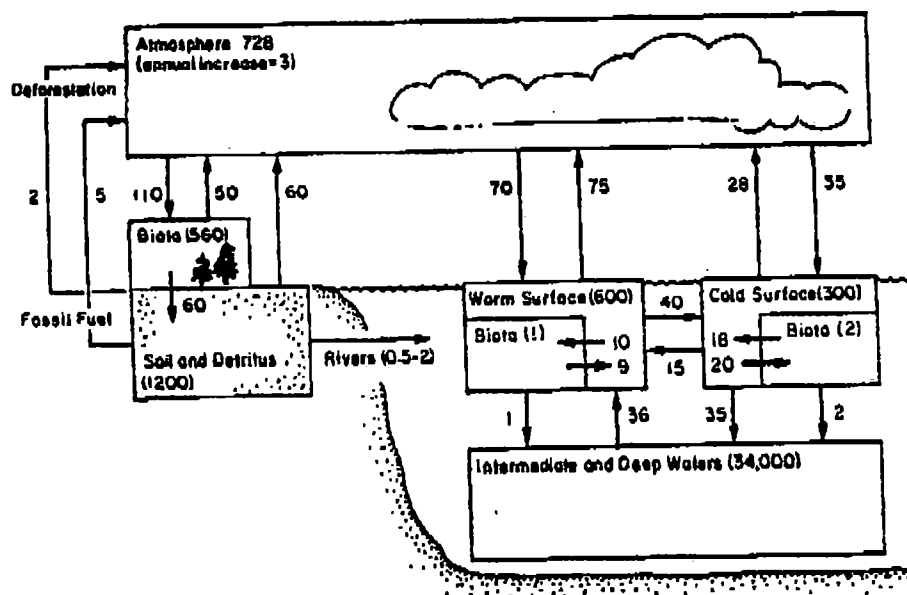


Figure 3.2. Major carbon reservoirs (in 10^{15} g) and fluxes (in 10^5 g y^{-1}) involved in the global carbon cycle. (From de Vooy, 1979.)

release centers on two factors: the rate of change in land use and the response of the biota to disturbances. Current estimates of the rate of conversion of closed canopy tropical forests to agriculture vary from 3.5×10^{10} to 15×10^{10} m^2 y^{-1} (Houghton et al., 1983; Woodwell et al., 1984). Analysis of the biotic response to such disturbance has been equally difficult; improved description of biotic responses requires rigorous measurements of net ecosystem production and *in situ* measurements of carbon stocks following disturbance.

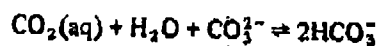
Direct calculations of the net amount of carbon released from the biosphere have accounted for various estimates of disturbances and the uncertainties of biotic response. From 1860 to 1980 the estimated mean total release is 150×10^{15} g, with a current annual release of $(1.5-4.5) \times 10^{15}$ g y^{-1} , of carbon (Hampicke, 1979; Moore et al., 1981; Houghton et al., 1983; Woodwell et al., 1983). The average value of 2×10^{15} g y^{-1} given in Fig. 3.2 and the range $(1-3) \times 10^{15}$ g y^{-1} of carbon given at the beginning of this chapter reflect my current view based on recent published and unpublished studies. These calculations for the period 1860-1980 are consistent with most conclusions about the strength of a biospheric source of CO_2 based on $^{13}C:^{12}C$ ratios. However, without far more refined information about disturbance rates and ecosystem responses, it will be impossible to appraise with confidence the role of the biosphere in the global carbon cycle (Woodwell et al., 1984).

3.1.3. Oceanic Carbon Dioxide

The ocean is the largest active reservoir of carbon. Recent estimates of the total amount of dissolved inorganic carbon (DIC) are $(35,000-38,000) \times 10^{15}$ g (Fig.

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3.2). Only a small part of this is CO_2 (mole fraction of 0.5%); at the prevailing oceanic pH of 8, HCO_3^- dominates the concentration at 90%, and CO_3^{2-} is slightly less than 10%. As CO_2 is taken up by surface seawater, the buffering reaction



1

is driven to the right, consuming CO_3^{2-} and lowering seawater pH.

Although the ocean is the largest active reservoir of carbon, the total marine biomass is only 3×10^{15} g of carbon, or just over 0.5% of the amount of carbon stored in terrestrial vegetation. On the other hand, total primary production in the oceans is $(20-45) \times 10^{15}$ g y^{-1} of carbon, the upper estimate being almost 50% of terrestrial total primary production (Fig. 3.2). Only a small portion of this production results in stored carbon, primarily by way of the sinking of particulate organic carbon (POC). This downward flux has been estimated to be only 10% of surface production (Broecker, 1974).

Linked to these biologically mediated controls on CO_2 are the processes of the physical transport and mixing of oceanic water masses. In particular, turbulent mixing and the penetrative convection of surface water during deepwater formation in polar regions creates a sink for CO_2 in high latitudes, and the balancing upwelling in low latitudes creates a balanced source for CO_2 . Estimates of the magnitude of these net meridional exchanges range as high as 30 ppm, and a comparison of individual cold and warm zones reflects differences as great as 100 ppm (Takahashi et al., 1980, 1981).

In sum, calculations of the net flux of atmospheric CO_2 into the ocean remain uncertain though most models indicate that between 40 and 50% of the CO_2 produced in fossil-fuel combustion is taken up by the ocean (Bacastow and Björkström, 1981; Killough and Emanuel, 1981). If these modelling calculations reflect actual oceanic uptake, then, as the imbalance implies, this result is inconsistent with the magnitude of source for CO_2 in the biosphere estimated either directly from land-clearing or indirectly from tree ring records of $^{13}\text{C}:^{12}\text{C}$ ratios.

This chapter does not resolve that imbalance. Rather, it discusses the particular chemical, biological, and physical processes that govern the largest sink for CO_2 : the ocean (see also Broecker and Peng, 1982).

3.2. THE OCEAN AS A CARBON DIOXIDE SINK

The change in atmospheric CO_2 concentration resulting from fossil-fuel combustion, land-management activities, and other human-induced disturbances of the global carbon cycle is strongly governed by carbon exchange between the atmosphere and ocean (Machta, 1972; Revelle and Munk, 1977; Bolin et al., 1979; Broecker and Peng, 1982). The ocean is a large sink for atmospheric carbon; however, the rate of CO_2 uptake by the ocean is limited by the chemical and biological properties of the oceanic surface and by the various patterns of mixing and circulation that determine the amount of carbon transported from surface waters to the deep ocean, where long-term carbon storage occurs.

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The exchange of CO_2 between the ocean and the atmosphere is controlled primarily through diffusion at the air-sea interface and hence is governed by the difference in CO_2 partial pressure between the atmosphere and the sea surface. One way to view this two-way exchange is to consider the two components separately: (1) the flux of CO_2 from the atmosphere to the sea (F_{as}), and (2) the flux of CO_2 from the sea surface to the atmosphere (F_{sa}).

Though our concern is the uptake of atmospheric CO_2 by the ocean, we shall focus for the moment on the F_{sa} flux, based on two considerations:

1. The atmosphere-to-sea flux (F_{as}) can be represented as a first-order process dependent only upon the residence time of carbon in the atmosphere (t_a) and the mass of carbon as atmospheric CO_2 (N_a). The values of t_a and N_a are reasonably well established (Bolin et al., 1981).

2. Our actual focus in this discussion is $F = F_{as} - F_{sa}$; the uncertainty about the net exchange resides in F_{sa} . Furthermore, F_{sa} for a unit area A of the ocean is written as:

$$F_{A_{sa}} = \frac{A}{A_m} \times \frac{N_{a0}}{P_{a0}} \times \frac{P_A}{t_a} \quad 2$$

where A_m is the surface area of the oceans ($3.6 \times 10^{14} \text{ m}^2$), and N_{a0} is the mass of carbon in the atmosphere as CO_2 at some initial time with partial pressure P_{a0} ; the established value for N_{a0}/P_{a0} is $2.13 \times 10^{15} \text{ ppm}^{-1}$ of carbon where P_A is the average partial pressure of CO_2 in a surface area A of the ocean. Therefore, the essential uncertainties are the distribution of the partial pressure of CO_2 in the surface of the ocean and the factors controlling this distribution.

From the perspective of the global carbon cycle, one could consider the partial pressure of CO_2 in seawater as a linear function of the concentration of CO_2 in seawater (see Fig. 9.2 of Wagener, 1979). However, CO_2 dissociates in seawater at a rate that is itself a function of CO_2 concentration. Further complicating this chemical phenomenon are the dynamics of biological processes; primary production consumes CO_2 and respiration and decay processes produce CO_2 . Each process affects the chemical equilibrium. Similarly, carbonate mineral formation and dissolution alter alkalinity, which affects the partial pressure of CO_2 in seawater. The physical processes of advection and eddy diffusion continually adjust the total inorganic carbon concentration throughout the ocean and thereby continually alter the distribution of the CO_2 partial pressure in the surface waters of the ocean.

Although chemical, biological, and physical processes are combined in the marine environment, this chapter discusses separately the principal attributes of each process.

3.2.1. Chemical Processes

Because CO_2 is not conservative in seawater, a practical conceptual construct is the total concentration (ΣC) of total DIC species. This is defined as

$$\Sigma C = m_{\text{CO}_2} + m_{\text{HCO}_3^-} + m_{\text{CO}_3^{2-}} \quad 3$$

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where m denotes molal concentration. The difficulty with this construct is that the functional relationship between ΣC and the partial pressure, P , is only locally linear, whereas P is essentially a globally linear function of m_{CO_2} . However, the conservative character of ΣC means that the increased complexity of the relationship between P and ΣC is not too difficult to explore. In fact, one can treat the exploration as the answer to two questions: (1) what is the current relationship between ΣC and P , and (2) how does this relationship change with future and perhaps far greater changes in ΣC ?

At constant temperature, salinity, and alkalinity, and for small changes in ΣC , the major aspects of the current relationship are captured by the linear function:

$$P = \frac{10P_0}{\Sigma C_0} \Sigma C - 9P_0 \quad 4$$

where P_0 is the preindustrial partial pressure exerted by surface water prior to the widespread use of fossil fuel, and ΣC_0 is the sum of the molal concentrations of CO_2 , HCO_3^- , and CO_3^{2-} at an initial preindustrial time. Rewriting this linear expression as a normalized ratio of the change in P against the change in ΣC yields a more familiar expression:

$$\frac{(P - P_0)/P_0}{(\Sigma C - \Sigma C_0)/\Sigma C_0} = 10 \quad 5$$

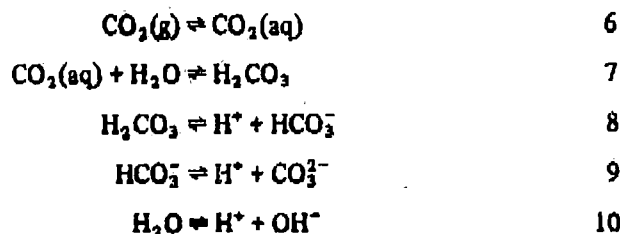
This ratio, usually denoted R and termed the Revelle factor (Broecker and Peng, 1982), was measured as part of the Geochemical Ocean Sections Study (GEOSECS) program (Takahashi, 1977), with a range from 8 for the warmest surface waters to 15 for the coldest. Considering the surface area of these waters, the ratio of 10 is an acceptable weighted average value.

The importance of this factor is best expressed by an example that uses current data. The atmospheric concentration of CO_2 has increased by at least 20% since 1860 (Broecker and Peng, 1982); however, in light of equation 4 the increase in surface concentration of ΣC would be only 1.7%. This is important when we recall that the size of the DIC pool in surface waters was approximately that of the atmosphere in a preindustrial period (Bolin, 1977). The value 900×10^{15} g given for surface DIC (Fig. 3.2) reflects a deeper surface layer, 125 m versus 75 m (Bolin et al., 1979), and thus a reservoir size larger than the atmospheric pool. For an interesting variation of this observation, see Broecker et al. (1979).

A direct calculation may clarify further not only the locally linear relationship expressed by equation 4 and the essentially nonlinear behavior of P against ΣC , which is important in carbon cycling when ΣC increases, but also the influence of temperature-dependent solubility of ΣC . This calculation explicitly refers to ionic equilibria, and hence it may describe more precisely the underlying relations between the P of CO_2 in the surface waters and its solubility at different temperatures, ΣC , the concentration of hydrogen ions, and the total alkalinity. A more thorough and yet easily grasped picture of carbonate-borate chemistry is given by Baes (1982).

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The ionic composition of CO_2 in seawater is determined largely by the carbonate and borate systems. The underlying carbonate system of seawater is expressed through the following equilibrium reactions:



and the borate system is expressed by



If P denotes the partial pressure of CO_2 in seawater, then the ratio of the concentration of $\text{CO}_2(\text{aq})$ to P is the solubility, K_0 , of CO_2 . Similarly,

$$K_1 = \frac{a_{\text{H}^+} m_{\text{HCO}_3^-}}{m_{\text{CO}_2}} \quad 12$$

and

$$K_2 = \frac{a_{\text{H}^+} m_{\text{CO}_3^{2-}}}{m_{\text{HCO}_3^-}} \quad 13$$

where K_1 and K_2 are the first and second apparent dissociation constants of H_2CO_3 , respectively. At 19.59°C and a salinity of $34.76^\circ/_{\text{oo}}$ average value for K_0 , K_1 , and K_2 are 0.3347×10^{-1} , 0.9952×10^{-6} , and 0.7076×10^{-9} , respectively [values for K_1 and K_2 and derived from Mehrbach et al. (1973), and values for K_0 are from Weiss (1974)].

A direct calculation yields the relationship between ΣC and m_{CO_2}

$$m_{\text{CO}_2} = \frac{a_{\text{H}^+} \Sigma C}{(a_{\text{H}^+})^2 + [\text{H}^+] K_1 + K_1 K_2} \quad 14$$

Consequently, if given ΣC and if a_{H^+} is determined from equation 2, then it is possible to calculate m_{CO_2} , P , and hence F_{at} .

With changes in m_{CO_2} and hence ΣC , a_{H^+} is altered through the carbonate reactions; furthermore, the production of carbonic acid and its dissociation perturbs the boric acid speciation in seawater, and hence a_{H^+} , because the carbonate ions compete with the borate ions for the available hydrogen ions. If one assumes that the carbonate-borate alkalinity (Alk) were to remain constant (Keeling, 1973), where

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Alk is defined by

$$Alk = m_{HCO_3^-} + 2m_{CO_3^{2-}} + m_{H_2BO_3^-} + m_{OH^-} - a_{H^+} \quad 15$$

it is then possible to use the dissociation coefficients of carbonic acid, boric acid, and water to determine a_{H^+} , given ΣC . Specifically, let

$$K_B = \frac{a_{H^+} m_{H_2BO_3^-}}{m_{H_3BO_3}} \quad 16$$

and

$$K_W = a_{H^+} a_{OH^-} \quad 17$$

where K_B and K_W are the dissociation coefficients for boric acid and water, respectively, and let total borate (ΣB) be denoted as

$$\Sigma B = m_{H_3BO_3} + m_{H_2BO_3^-} \quad 18$$

The typical value for K_B is 0.1881×10^{-9} , for K_W it is 0.6463×10^{-14} , and for ΣB it is 0.4 millimolal. Values for K_B and ΣB are derived from Almgren et al. (1975) and K_W is taken from Hansson (1973).

From equations 16 and 18, we obtain the relation

$$m_{H_2BO_3^-} = \frac{K_B \Sigma B}{a_{H^+} + K_B} \quad 19$$

By employing equations 3, 17, and 19, we can rewrite equation 15 as

$$Alk = \Sigma C - m_{CO_2} + m_{CO_3^{2-}} + \frac{K_B \Sigma B}{a_{H^+} + K_B} + \frac{K_W}{a_{H^+}} - a_{H^+} \quad 20$$

By using equations 12 and 13 to express $m_{CO_3^{2-}}$ in terms of m_{CO_2} , and the relationship (equation 14) between ΣC and m_{CO_2} , we can write equation 20 as

$$Alk = \frac{a_{H^+} K_1 + 2K_1 K_2}{(a_{H^+})^2 + a_{H^+} K_1 + K_1 K_2} \Sigma C + \frac{K_B \Sigma B}{a_{H^+} + K_B} + \frac{K_W}{a_{H^+}} - a_{H^+} \quad 21$$

This expression is not as awkward as it may seem, since by algebraic manipulations it reduces to a fifth-degree polynomial in a_{H^+} :

$$P(a_{H^+}) = \sum_{n=0}^5 D_n (a_{H^+})^n = 0 \quad 22$$

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where

$$D_0 = -K_1 K_2 K_B K_W,$$

$$D_1 = [(Alk - 2 \Sigma C - \Sigma B) K_2 K_B - (K_2 + K_B) K_W] K_1,$$

$$D_2 = [(Alk - 2 \Sigma C + K_B) K_2 + (Alk - \Sigma C - \Sigma B) K_B] K_1 - (K_1 + K_B) K_W,$$

$$D_3 = (Alk - \Sigma B + K_1) K_B + (Alk - \Sigma C + K_2) K_1 - K_W,$$

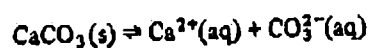
$$D_4 = Alk + K_1 + K_B, \text{ and}$$

$$D_5 = 1$$

Although there is no general algorithm for solving polynomials of degree 5 or greater, the solutions can be approximated by Newton's rule. It should be noted that when solving for a_{H^+} repeatedly as C is increased over time, care must be given in the application of Newton's rule (Bacastow, 1981).

Finally, by comparing equations 14 and 21 and the solubility relationship between P and m_{CO_2} , it is apparent that given any two of the four variables P , ΣC , pH , and Alk , the remaining two terms are determined. This interplay is shown in Fig. 3.3.

As carbon from human activities accumulates in the sea, there is an additional geochemical issue at the opposite end of the carbonate system: the possible increased dissolution of calcium carbonate minerals in sediment above the lysocline. The inorganic equilibrium of importance is



23

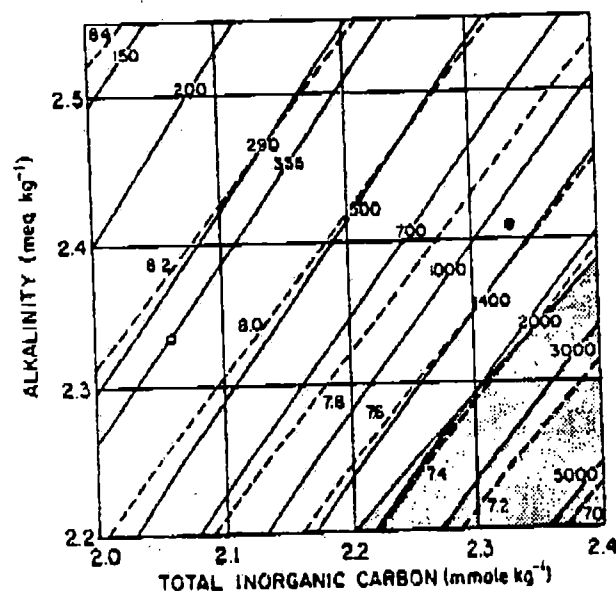


Figure 3.3. Carbon dioxide composition diagram for ocean surface waters at 15°C. The solid lines denote compositions with the same value of P_{CO_2} in microatmospheres; the dotted lines denote compositions with the same pH; the shaded region is undersaturated and the unshaded region is supersaturated with respect to calcite. Surface water and average ocean compositions are also indicated (from Baes, 1982). (○) Surface water; (●) average oceanic composition.

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Currently, the water that interacts with these bottom sediments is saturated or supersaturated with the minerals, and hence the reaction in equation 23 is being driven to the left rather than the right. But, in the future, there is the possibility that as CO_2 -enriched and hence CO_3^{2-} -depleted water (equation 1) penetrates ocean bottom water, the equilibrium reaction in equation 23 would be driven to the right. The increased rate at which the sediments might dissolve, and thereby disrupt the steady-state, appears to be small even when the atmospheric CO_2 concentration increases by 2 to 3 times that of current values. Disruptions of the steady-state at this part of the bottom boundary of the ocean-carbon system are not explored in this chapter; for additional discussion, see papers by Broecker and Takahashi (1977), Peng et al. (1977), and Takahashi and Broecker (1977). The central finding regarding CO_3^{2-} production from the dissolution of carbonate bottom sediments is that enough CO_3^{2-} could be produced for the ocean to accommodate eventually the CO_2 that would be produced by the combustion of all fossil fuel reserves. For other aspects of this question, see papers by Berner and Morse (1974), Brewer et al. (1975), Chen (1978), and Chen and Pytkowicz (1979).

3.2.2. Biological Processes

In regard to anthropogenic disturbances of the carbon cycle, one question that must be resolved is how much additional carbon is being stored by the marine biotic system. Because of the small standing stock of carbon (3×10^{15} g; Fig. 3.2) in marine biomass, the only apparent possibility for increased carbon removal by marine organisms would be an increase in total primary production (Tables 3.2 and 3.3), with a corresponding increase in the flux of POC into deepwater. This would result in a delay of decades before this carbon would be returned to the atmosphere. As mentioned earlier, the amount of POC that falls out of the mixed layer is only approximately 10% of the surface production (Table 3.4). It might appear that increasing the baseline POC flux of roughly 3×10^{15} g y^{-1} of carbon would be just as difficult as increasing the biomass pool; the difference is that the storage must occur each year. Consequently, altering a flux is far more advantageous than increasing a standing active pool.

Table 3.2. Estimates of Annual Total Primary Production in the Ocean^a

Primary Production (10^{15} g y^{-1} of carbon)	Reference
15	Steemann Nielsen (1953)
20	Ryther (1969)
23	Koblentz-Mishke et al. (1970)
44	Bruevich and Ivanenkov (1971)
60-80	Sorokin (1973)
31	Platt and Rao (1975)

^aFrom de Vooy (1979).

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Table 3.3. Estimates of Annual Total Primary Production^a by Individual Oceans

Ocean	Area (10 ¹⁰ m ²)	Fluxes (10 ¹⁵ g y ⁻¹)		
		Koblentz- Mishke et al. (1970)	Bruevich and Ivanenkov (1971)	Platt and Rao (1975)
Indian	73.9	6.01	12.9	6.60
Atlantic	92.6	7.15	14.2	9.76
Pacific	177.6	7.67	16.6	11.40
Antarctic	11.8			3.30
Arctic	13.1		0.3	0.013
North Polar Ocean and other waters		2.28		
Total	368.8	23.11	44.0	31.10

^a From de Vooy (1979).

Peterson (1981) has explored the question of whether nutrients from agricultural runoff and sewage could have increased primary production in the ocean, thereby increasing POC flux and marine carbon storage. His argument involves two themes: (1) the classical observation about atomic ratios in organic matter (Redfield et al., 1963), linking carbon with the nutrients of nitrogen and phosphorus, and (2) a twofold conceptual classification dividing biotic production into new production and regenerated production, depending on the source of the nutrients consumed in carbon fixation (Eppey and Peterson, 1979). The second theme will be discussed first.

In any particular area of the ocean, there are endogenous and exogenous sources of nutrients. The endogenous source is particulate and dissolved compounds derived from excretion by marine animals and the metabolism of heterotrophic micro-

Table 3.4. Estimates of Percentage of Primary Production Sinking Out of the Photic Zone^a

%	Reference
0	Strickland (1965)
<15	Bolin (1970)
1	Lisitzin (1972)
4	Menzel (1974)
2-10	Degens and Mopper (1976)
3	Wong et al. (1976)

^a From de Vooy (1979).

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organisms. Production fueled by this source is called regenerated production. Ignoring for the moment human input, exogenous sources of nutrients are continental runoff and oceanic upwelling. Production supported by these external sources of nutrients is called new production. These external nutrient sources compensate for the nutrient material lost through fecal pellet fallout and the small amount lost due to the downward flux of dissolved nutrients $(0.044-0.15) \times 10^{15} \text{ g y}^{-1}$ of nitrogen. Stated another way, the amount of new production is the amount of production that can be exported from the system without causing the deterioration of nutrient stocks.

In order to estimate the size of these nutrient sources and the potential for human activity to affect them, it is necessary to consider the relationship in organic matter between carbon, nitrogen, and phosphorus. The atomic ratio of the average elemental composition of C:N:P in organic material in surface seawater is 120:15:1 (Broecker, 1974). Expressed in weight, these atomic ratios are 46:6.8:1. Consequently, if phytoplankton fix $40 \times 10^{15} \text{ g y}^{-1}$ of carbon, then roughly $6 \times 10^{15} \text{ g y}^{-1}$ of nitrogen and $0.9 \times 10^{15} \text{ g y}^{-1}$ of phosphorus are also required. There are two ways to estimate the amount of nitrogen and phosphorus coming from exogenous sources: indirectly, by estimating either the amount of new production or the amount lost from the system; or directly, by calculating the actual nutrient input from upwelling and runoff.

If one assumes seawater concentrations of $35 \mu\text{mole liter}^{-1}$ of nitrogen and $2.3 \mu\text{mole liter}^{-1}$ of phosphorus, then an upwelling rate of 2 m y^{-1} would supply $0.31 \times 10^{15} \text{ g y}^{-1}$ of nitrogen and $0.046 \times 10^{15} \text{ g y}^{-1}$ of phosphorus, which could fuel $2.1 \times 10^{15} \text{ g y}^{-1}$ of carbon of new production. The continental nutrient runoff input is two orders of magnitude below these values and will not be considered here.

The indirect calculations tend to set a slightly higher range for exogenous sources. For example, Eppley and Peterson (1979) estimated new production to be in the range of $(3.4-4.7) \times 10^{15} \text{ g y}^{-1}$ of carbon. As they note, this is compatible with an estimated POC loss in the range of $(2.0-4.5) \times 10^{15} \text{ g y}^{-1}$ of carbon, which is 10% of the surface production.

The concern is whether or not, from the perspective of total oceanic primary production, humans have altered appreciably the amount of exogenous nutrients in the system. It is appropriate, therefore, to compare human input to the lower estimates for external input; if anthropogenic effects are insignificant when compared to the smaller estimate, they also will be insignificant when compared to the larger. In other words, short-term (years to decades) increases in open ocean primary production and carbon storage can occur only if the anthropogenic source of nutrients is comparable to $0.3 \times 10^{15} \text{ g y}^{-1}$ of nitrogen and $0.05 \times 10^{15} \text{ g y}^{-1}$ of phosphorus.

Estimates of nutrient loading by humans are given in Table 3.5. It appears that the anthropogenically created potential nutrient sources are at least one order of magnitude below the point of importance. In addition, these sources are only potentially available to enhance oceanic primary production. For example, between 1960 and 1973, $5 \times 10^{12} \text{ g y}^{-1}$ of phosphorus were applied to agricultural soils worldwide; however, only 5-6% may run off and perhaps 50% of this runoff would

Table 3.5. Anthropogenic and Background Loading of Nitrogen and Phosphorus^a

Nutrient Source	Nitrogen (form) (10 ¹² g y ⁻¹)	Phosphorus (form) (10 ¹² g y ⁻¹)	Reference
Upwelling	314 (NO ₃ ⁻)	46 (H ₂ PO ₄ ⁻ + HPO ₄ ²⁻ + PO ₄ ³⁻)	Broecker (1974)
Runoff		0.5 (H ₂ PO ₄ ⁻ + HPO ₄ ²⁻ + PO ₄ ³⁻)	Broecker (1974)
		1.8 (H ₂ PO ₄ ⁻ + HPO ₄ ²⁻ + PO ₄ ³⁻)	Stumm (1973)
	19 (Total dissolved)	2.2 (Total dissolved)	Emery et al. (1955)
	35 (Total)	12.0 (Sediment)	
	13.24 (Total)	0.7	Delwiche and Likens (1977)
Precipitation onto the ocean (total)	20 (Total)		Soderlund and Svensson (1975)
	30 (Total)		McElroy (1976)
	18 (Total)		Sweeney et al. (1978)
	20-50 (NH ₄ ⁺ + NO ₃ ⁻)		U.S. NAS ^b (1978)
	30-83 (NH ₄ ⁺ + NO ₃ ⁻)		Soderlund (1976)
	20 (NH ₄ ⁺ + NO ₃ ⁻)		Soderlund and Svensson (1975)
	15 (NH ₄ ⁺ + NO ₃ ⁻)		McElroy (1976)
	17-24 (NH ₄ ⁺ + NO ₃ ⁻)		Sweeney et al. (1978)
Phosphate mining		4.0 (Total)	U.S. NAS (1978)
		2.6-3.5 (Total)	Delwiche and Likens (1977)
	59 (NH ₄ ⁺ + NO ₃ ⁻)		Pierrou (1976)
		5.0 (Total)	Emery et al. (1955)
Nitrogen fertilizer		10.0 (Total)	Peterson (1981) ^c
			Stumm (1973)
		10.4 (Total)	(1970 U.N. Yearbook)
Fossil-fuel emissions			Pierrou (1976)
	40 (NH ₄ ⁺ + NO ₃ ⁻)		(1974 U.N. Yearbook)
	36		Delwiche and Likens (1977)
	40		Soderlund and Svensson (1975)
	35		McElroy (1976)
Plant material combustion	49		Sweeney et al. (1978)
			U.S. NAS (1978)
	21		U.S. NAS (1978)
	18 (NO _x)	0.5 (Total)	Delwiche and Likens (1977)
	19		Soderlund and Svensson (1975)
Sewage ^d	40		McElroy (1976)
	15		Sweeney et al. (1977)
	50	2.5 (Total)	Delwiche and Likens (1977)
	10-200		U.S. NAS (1978)
	15 (Total)	3 (Total)	

^aFrom Peterson (1981).^bU.S. National Academy of Sciences.^cAverage for the years 1960-1974.^dBased on 4 × 10⁹ people. The assumptions are 10.8 g of nitrogen and 2.18 g of phosphorus per capita d⁻¹.

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become available to phytoplankton. Assuming that all new production due to this phosphorus source results in stored carbon, the increase would be only $0.007 \times 10^{15} \text{ g y}^{-1}$ of carbon. This example (Peterson, 1981) is typical in character of the estimates in the increase in open ocean biotic storage; total increase of carbon in the ocean due to anthropogenic nutrient runoff from human activities is at least one order of magnitude below natural variations in the carbon cycle.

Perhaps if we focus on coastal seas where production density is greatest, where nutrients are rapidly recycled, and where human effects are most pronounced, then the results may be different. Table 3.6 summarizes the upper estimate of the level of loading by man of nutrients in coastal zones. Assuming that exogenous nutrient loading would be recycled 10 times, it is possible that baseline nitrogen could increase from 0.55×10^{15} to $0.75 \times 10^{15} \text{ g y}^{-1}$, and phosphorus could increase from 0.09×10^{15} to $0.12 \times 10^{15} \text{ g y}^{-1}$. Even this substantial increase would cause the storage of only an additional $0.14 \times 10^{15} \text{ g y}^{-1}$ of carbon, assuming that 10% of the surface production is transferred to long-term residence pools.

As Peterson (1981) notes, Emery and Rittenberg (1952) have shown that nitrogen and phosphorus are released preferentially to carbon during early diagenesis (Degens and Mopper, 1976), and that this could raise the number where the effects begin to be appreciable to $\sim 0.3 \times 10^{15} \text{ g y}^{-1}$ of carbon. This may be an estimate on the high side; however, we should mention two viewpoints on either side of this estimate. First, J. Walsh (personal communication) at the Brookhaven National Laboratory believes the potential storage increase of carbon in coastal seas may be closer to $1 \times 10^{15} \text{ g y}^{-1}$. On the other hand, Peterson and Melillo have returned recently to this issue and lowered Peterson's upper estimate of the fertilization effect in the coastal seas to $0.05 \times 10^{15} \text{ g y}^{-1}$ of carbon (B. J. Peterson and J. M. Melillo, personal communication). For the open ocean their estimate of increased carbon storage is also $0.05 \times 10^{15} \text{ g y}^{-1}$. They do find a potential carbon sink of $0.3 \times 10^{15} \text{ g y}^{-1}$ due to possible fertilization effects in terrestrial systems; therefore,

Table 3.6. Potential Input of Mankind on Coastal Productivity

	Element (10^{15} g y^{-1})		
	Carbon	Nitrogen	Phosphorus
Primary productivity (required nitrogen and phosphorus)	3.6	0.54	0.087
Human input of nutrients		0.02	0.003
Recycling nutrient input 10 times		0.20	0.03
Increment to productivity	1.37		
Percent enhancement	38%		
Increment to carbon burial (10% of production)	0.14		

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they report a total potential fertilization effect of $0.4 \times 10^{15} \text{ g y}^{-1}$, which leaves the carbon system still unbalanced (Melillo and Gosz, 1983; Bolin, 1983).

Aside from Walsh's hypothesis, it appears that the role of the marine biota in the 10- to 100-y global carbon cycle is so small compared to other uncertainties that it could be ignored. This might be true, except that marine biota have a profound effect on the distribution of chemical constituents and, therefore, both a direct and indirect effect on the partial pressure of CO_2 in seawater. Furthermore, in some approaches, this distribution of chemical species is critical to the determination of the patterns of advection and turbulence. As such, it is important to separate the effects of the biota on chemical tracers from the effect caused by the movement of water (Brewer, 1978). Consequently, before discussing the physical mixing properties of the ocean, we should review briefly some additional aspects of the combined biotic and chemical system of the ocean.

More than 97% of the carbon in the oceans is in the form of the dissolved inorganic species CO_2 , HCO_3^- , and CO_3^{2-} . The total inorganic carbon is not uniform with depth; ΣC in surface waters is 10–15% less than in deeper waters (Fig. 3.4). This is the result of the photoassimilation of DIC by living organisms, the production of inorganic detritus, the continued downward flux of both organic and inorganic detrital carbon, and carbonate mineral dissolution at great depths. There is a corresponding depletion of phosphorus, as well as nitrogen, in surface water, even in areas of intense upwelling, due to biological uptake and the loss of POC (Fig. 3.5).

The fate of the carbon that falls from the surface waters depends, in part, upon its characteristics. If it is organic material, then it is oxidized at intermediate depths, resulting in an oxygen minimum (Fig. 3.5) and a carbon and phosphorus maximum (Figs. 3.4 and 3.6). If the material is carbonate mineral, it dissolves only at great depths, where the waters are not saturated with respect to CaCO_3 . The dissolution of CaCO_3 obviously affects ΣC , but it also raises alkalinity (Fig. 3.7).

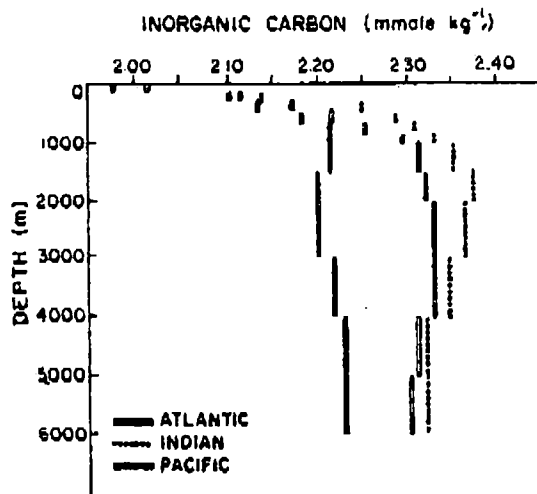


Figure 3.4. Vertical distribution of dissolved inorganic carbons (mmole kg^{-1}) in the Atlantic, Pacific, and Indian Oceans according to GEOSECS observations given by Takahashi et al. (1981) and Bolin et al. (1983).

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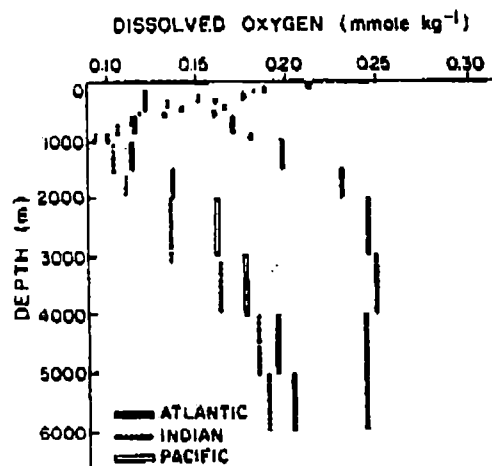


Figure 3.5. Vertical distribution of oxygen (mmole kg^{-1}) in the Atlantic, Pacific, and Indian Oceans according to GEOSECS observations given by Takahashi et al. (1981) and Bolin et al. (1983).

Each change in alkalinity or in the concentration of phosphorus, total inorganic carbon, and oxygen is mediated by biological processes. By quantifying the biological processes through chemical reactions or Redfield ratios (Redfield et al., 1963), or both, and by exploiting oceanic chemical profiles given in the GEOSECS (Bainbridge, 1981a, 1981b; Craig et al., 1981; Broecker et al., 1982; Spencer et al., 1982), Transient Tracers in the Ocean (TTO), and other programs, we can better understand the spatial and temporal distribution and the rate of oceanic processes such as biological production and physical mixing. The rate at which the ocean removes human-produced CO_2 from the atmosphere is and will continue to be primarily a function of the rate and character of oceanic mixing (Chapter 1).

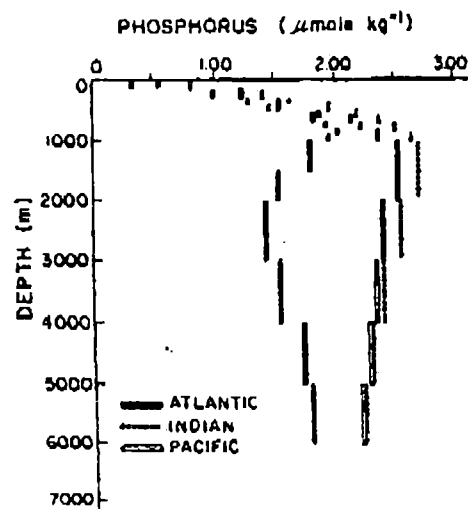


Figure 3.6. Vertical distribution of phosphorus ($\mu\text{mole kg}^{-1}$) in the Atlantic, Pacific, and Indian Oceans according to GEOSECS observations given by Takahashi et al. (1981) and Bolin et al. (1983).

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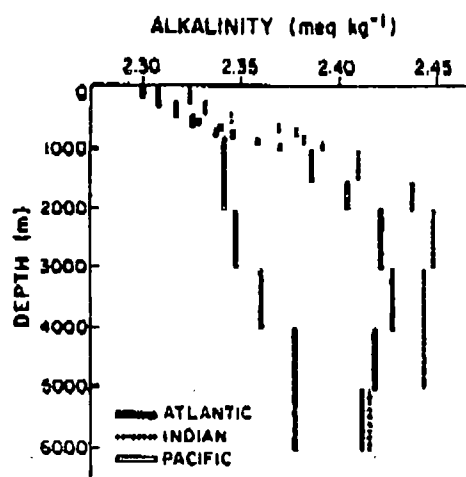


Figure 3.7. Vertical distribution of alkalinity (meq kg⁻¹) in the Atlantic, Pacific, and Indian Oceans according to GEOSECS observations given by Takahashi et al. (1981) and Bolin et al. (1983).

3.2.3. Physical Processes

In polar regions, ice formation results in very dense surface water. These cold surface waters penetrate the thermocline and renew deep oceanic waters; as such, they also have the potential to form, in effect, a pipeline for transferring atmospheric CO₂ to the large reservoir of the abyssal water, which has long residence times. This dynamic pattern coupled with biotic production in high latitudes is the primary reason that the ocean is a more effective sink for CO₂ than is suggested by purely thermodynamical considerations in an abiotic ocean. For a perspective on modelling of this pipeline phenomenon, see reports by Siegenthaler and Oeschger (1978), Björkström (1979), Broecker et al. (1980), Bacastow and Björkström (1981), Broecker and Peng (1981), Killough and Emanuel (1981), Enting and Pearman (1982), Bolin et al. (1983), and Siegenthaler (1983). An early stage in the development of models of deepwater formation and its effect on carbon exchange is given by Plesset and Dugas (1967).

Estimates of the penetrative convection of Antarctic waters are $(1.9-2.4) \times 10^{15} \text{ m}^3 \text{ y}^{-1}$ (Munk, 1966; Gordon, 1971), divided approximately evenly between the Indian-Pacific intermediate waters and Atlantic intermediate waters. There appears to be greater uncertainty about the penetrative connection into North Atlantic deepwater; recent estimates vary from 0.32×10^{15} to $0.95 \times 10^{15} \text{ m}^3 \text{ y}^{-1}$ (Broecker, 1979).

These polar advective fluxes and corresponding turbulent exchanges correspond to a deep equatorial flow of $4-6 \text{ m y}^{-1}$ and a deep-sea turnover time of 600-1000 y (Bolin et al., 1981). Stuiver et al. (1983) conclude that ¹⁴C distributions in abyssal waters indicate somewhat shorter replacement times; for waters deeper than 1500 m in the Pacific, Indian, and Atlantic oceans the turnover times are 560, 230, and 175 y, respectively (Stuiver, 1976; Östlund and Stuiver, 1980; Stuiver, 1980; Stuiver et al., 1981), and Broecker (1979) concludes that the average residence time of water in the deep sea is 450-550 y.

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Obtaining an accurate view of the advective and turbulent exchanges and the associated residence times within different regions of the ocean appears to be at the heart of understanding the CO_2 cycle. Central to obtaining this view will be the distributions of a variety of chemical constituents, in addition to ^{14}C .

It is classical oceanography to use the heterogeneous distributions of chemical elements in the ocean to deduce features of oceanic circulation. For example, the tongue of low salinity in the thermocline region extending northward from the Antarctic circumpolar convergence zone has been interpreted as water that flows northward, in which the magnitude of the advective flow relative to that of turbulent flux can be determined from the salinity profile. Similarly, the outflow of the Mediterranean water into the Atlantic Ocean can be followed by identification of a region of high salinity. In recent years the use of radioactive tracers, particularly ^{14}C and ^3H , has resulted in important information on the water exchange between the surface layers, the intermediate waters, and the deep sea (Broecker et al., 1960; Munk, 1966; Craig, 1969; Kuo and Veronis, 1970; Keeling, 1973; Oeschger et al., 1975; Östlund and Fine, 1979; Jenkins, 1980; Fine et al., 1981).

Keeling and Bolin (1967, 1968) studied the problem of using simultaneously six tracers (salinity, oxygen, DIC, ^{14}C , alkalinity, and phosphorus) for developing a three-box (warm surface water, cold surface water, and deep water) model of the ocean. The primary production of organic matter and the precipitation of carbonate structure and the subsequent bacterial decomposition and chemical dissolution were included as internal source and sink terms for the chemical compounds considered. Exchanges of oxygen, inorganic carbon (as CO_2) and ^{14}C (as $^{14}\text{CO}_2$) between the atmosphere and the sea were also described. They found that the vertical turbulent exchange was primarily between the cold surface water and the deep sea, and the total fluxes of particulate inorganic and organic carbon were 1.0×10^{15} and $1.7 \times 10^{15} \text{ g y}^{-1}$, respectively. The turnover time for the deep water, determined by the ^{14}C difference between the surface water and the deep water, was 1100 y.

Recently Bolin et al. (1983) again used concentrations of DIC, alkalinity, phosphorus, oxygen, and ^{14}C to develop a plausible model of steady-state advection and turbulence patterns, as well as the rates of biotic production and decomposition or dissolution (Fig. 3.8). When this model was subjected to the transient response test (Fig. 3.9) of forcing the system with a time series of atmospheric CO_2 (representing fossil-fuel consumption), the model differed little from previous two- and three-box models. This reflects the fact that spatial detail of the 12-box model is similar to the simpler, more aggregated models.

Results obtained with such crude representations (using less than 12 to 15 boxes in exchange with each other through first-order processes) of the ocean should be considered only as preliminary estimates of the real processes that the models are intended to describe. Furthermore, the results from these models are particularly inadequate because ordinary oceanographic data cannot be used for validation, nor can the results be used to answer the question about the role of the ocean in the global carbon cycle.

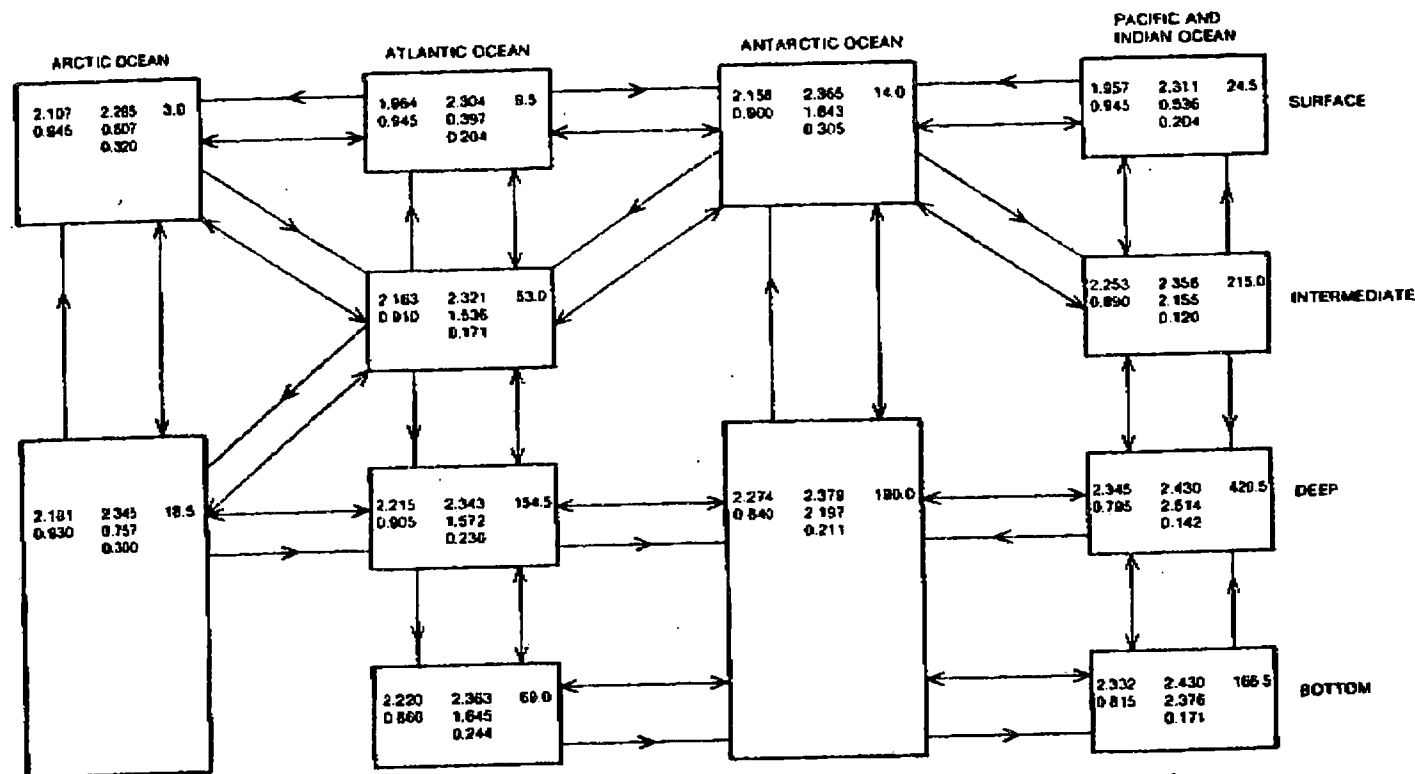


Figure 3.8. Concentrations assigned to the boxes and patterns of advective and turbulent exchanges (Bolin et al., 1983). Each box has three columns of numbers. The first number in the left-hand column is the amount of carbon (mmole kg⁻¹); the second number is the ratio of $^{14}\text{C}/^{12}\text{C}$ expressed as a fraction of the corresponding ratio in the preindustrial atmosphere. The first number in the middle column is alkalinity (meq kg⁻¹); the second number is phosphorus (μmole kg⁻¹); the third number is oxygen (mmole kg⁻¹). The number in the right-hand column is the volume of the respective ocean in 10¹⁵ m³.

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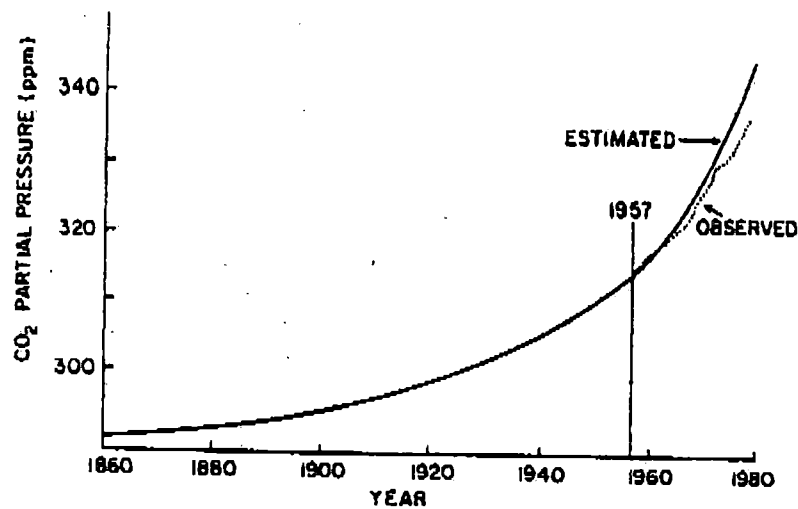


Figure 3.9. Computed change of atmospheric CO_2 from 1860 to 1980 due to fossil-fuel emissions as estimated by Rotty (1981). Dashed line from 1957 to 1979 shows the observed changes at Mauna Loa, according to Bacastow and Keeling (1981).

3.3. CONCLUSIONS

In order to understand thoroughly the global carbon cycle as a whole, and the oceanic sink in particular, it is becoming evident that the heterogeneity of the various components must be considered (Bolin et al., 1981). Past models of the major subsystems within the cycle (for example, the ocean or terrestrial biota) using a few boxes linked by simple kinetics have been wrung dry of information. Progress in this area will require the consideration of spatial heterogeneity and hence more spatially detailed models (Viecelli et al., 1981; Fiadeiro, 1983).

Preliminary versions of spatially detailed models of the terrestrial system have been developed (Moore et al., 1981; Houghton et al., 1983) and refinements in this trend should be continued. Models that describe the terrestrial ecosystem of the world and their alteration by humans are needed at a grid scale of $0.5^\circ \times 0.5^\circ$ in latitude and longitude.

From the other side of the budget, oceanic models whose components represent actual oceanic regions are necessary. This requires methods that are appropriate for systems with hundreds of boxes as well as techniques to extract consistent information from diverse data sets. The existence and use of data is fundamental to progress; higher-resolution oceanic models must be built upon extensive, consistent oceanographic data.

Fortunately, both ingredients, methods and data, may soon be available. Methods, such as the use of pseudo-inverses for matrices, are being refined through application (Wunsch, 1978; Fiadeiro and Veronis, 1982; Wunsch and Minster, 1982; Bolin et al., 1983). Extraordinarily rich data sets of GEOSECS (Bainbridge, 1981a, 1981b; Broecker et al., 1982; Craig et al., 1981; Spencer et al., 1982) are being explored with perhaps even richer data sets (at least for the North Atlantic) of TTO in the near future (Chapter 1). It is, therefore, reasonable to hope that during the next

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decade we will resolve the imbalances in the present model of the carbon budget. This is important since it seems less likely that during the next decade we will reduce the rate at which we influence the global carbon cycle.

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NATIONAL ACADEMY OF SCIENCES
NATIONAL ACADEMY OF ENGINEERING INSTITUTE OF MEDICINE
COMMITTEE ON SCIENCE, ENGINEERING, AND PUBLIC POLICY

PANEL ON POLICY IMPLICATIONS
OF GREENHOUSE WARMING

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**NAS/NAE/IOM Study on
Policy Implications of Greenhouse Warming**

At the request of Congress, the U.S. Environmental Protection Agency commissioned a study on policy implications of greenhouse warming. The study panel plans to produce a short, readable report of findings and recommendations, and a longer support document with more detailed technical and scientific analyses. Both are expected to be available in February 1991.

Potential warming of the global climate is now of concern to governments throughout the world. It is hard, however, to assess the costs and benefits of environmental policies, much less to achieve international agreement on what to do about the human activities with the greatest potential impact on global climate: stationary and mobile burning of fossil fuels, use of chlorofluorocarbons (CFCs), deforestation, and various releases of methane.

In light of growing domestic and international concern, the study is reviewing research and analysis relevant to greenhouse warming. A careful assessment is being made of existing data and what must be done to improve current understanding of the underlying phenomena. The report will include, if appropriate, recommendations for actions that would be needed to mitigate and adapt to greenhouse effects if such actions be warranted. It will examine both the underlying phenomena and the expected efficiency and effectiveness of policy interventions.

Although the study will be addressed in large part to U.S. policy officials, many of the options to be assessed may require multinational effort. The study is expected to contribute a careful, technically-sound review that will be of use to the Congress as well as to the Executive Branch and the international community.

The study's "Synthesis" panel is chaired by the Honorable Daniel J. Evans, until 1988 U.S. Senator from the State of Washington. Senator Evans, a registered civil engineer and former college president, was Governor of the State of Washington from 1965-77. He chaired the Pacific Northwest Power and Conservation Planning Council from 1981-83. Among other activities he is a member of the Board of Directors of the Nature Conservancy.

In carrying out its charge, the Synthesis panel membership is augmented by three groups looking at three interrelated sets of issues.

[A] Direction and rate of change

The "Effects" group is assessing current knowledge about climate change and predictions of physical effects. The objective is to judge the adequacy of present research, uncertainties in that research, and ways our understanding could be improved. The quality of the data record, uncertainties in the evidence, and time and effort required to reduce uncertainties all need to be examined. It may also be necessary to interpret existing information in terms of new indices of warming (e.g., degree-years, peak temperature), not just change in mean global temperature.

[B] Mitigation policies and their effectiveness

The "Mitigation" group is examining the range of policy interventions that might mitigate changes in the earth's radiative balance, assessing these options in terms of their expected impacts, costs, and at least in qualitative terms, their relative cost-effectiveness. This analysis attempts to identify options that could be implemented with reasonable confidence within a decade, more speculative possibilities requiring substantial additional development, and proposals that are not worth pursuing because of faulty physics, chemistry, or biology.

[C] Adaptation strategies

The "Adaptation" group is examining both the consequences of climate change and strategies for adapting to those changes. The group is attempting to develop appropriate indices and units of measurement; considerations include rates of change, peak stresses, regional distribution, and timing. The analysis examines the vulnerability of systems or subsystems, their capacity to adapt or adjust to changes, the speed with which this natural adjustment can be accomplished, and possible interventions that would help systems cope with anticipated changes. The group is considering costs and benefits of such interventions and attempting to set the stage for choosing among alternatives, including examination of what will be done locally and privately and what should be done by government, should actions be warranted.

The list of individuals participating in the study is attached.

Rob Coppock
Staff Director
May 21, 1990

PANEL ON POLICY IMPLICATIONS OF GREENHOUSE WARMING

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POLICY IMPLICATIONS OF GLOBAL WARMING

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The Administrator
Washington, D.C. 20460

August 31, 1990

NOTE TO: Honorable John H. Sununu
Chief of Staff
The White House

I thought you might be interested in seeing a copy of the article that appeared in Science Magazine. It deals with the Science Advisory Committee's comparative risk study that I discussed with you. I am scheduled to release the study at the end of September.

A handwritten signature in black ink, appearing to read "Bill", is positioned above the printed name.

William K. Reilly

Attachment

Counting On Science at EPA

William Reilly is trying to give science a bigger role in EPA policy and wants to focus on the worst environmental problems, not just the most visible. It may be an uphill struggle

WILLIAM REILLY, THE ADMINISTRATOR of the Environmental Protection Agency, and his top advisers are plotting a quiet revolution. They have embarked on a process that could fundamentally change the way EPA does business: an attempt to focus the agency's resources on the environmental problems that pose the biggest risks rather than those that have attracted the most political attention. "It's an effort to inject science more prominently into the policy process," says Hank Habicht, deputy administrator of the agency and Reilly's right-hand man.

That may not sound revolutionary, but Reilly is trying to reverse nearly 20 years of piecemeal environmental policy-making. Congress, reflecting public concerns, has written numerous laws instructing EPA to deal with individual environmental problems—hazardous waste one year, toxic substances or pesticides another, and medical

wastes still another. The result: EPA's budget and priorities have been shaped more by "what the last phone call from Capitol Hill or the last public opinion poll had to say" than by a scientific assessment of risk, says Frederick Allen of EPA's office of policy analysis.

Now, Reilly has asked his Scientific Advisory Board to tell him which problems pose the biggest environmental or public health threats. The board's analysis, a draft of which has been obtained by *Science*, reveals that the environmental problems that dominate public concerns—and EPA's budget—are often not those that Reilly's scientific advisers deem the biggest threats (see table below). Radon and climate change, for example, are at the top of the list for EPA but near the bottom in the public's view.

But turning the agency around would be no mean feat, and even within EPA, opinion

is divided on whether Reilly can pull it off. Without question, he starts with several strikes against him. For one thing, the EPA administrator has very little discretion in allocating funds: most of the agency's budget is needed just to implement the major environmental laws, like Superfund, already on the books. And for another, Reilly faces inertia from within EPA, a bureaucracy that has a vested interest in maintaining the status quo. And then there is the public, which EPA is beholden to, whether or not it agrees with the latest scientific study. Reilly's new effort is "laudable," says Richard Morgenstern, director of the office of policy analysis and an old hand at EPA. "I am bullish on it. But I wouldn't bet the store on it."

But Terry Davies, assistant administrator for policy, planning and evaluation and one of the architects of the new plan, voices no doubts. "We're already doing it," he exclaims. "We are changing the way the agency thinks." But not even the optimists expect major shifts overnight. Deputy administrator Habicht, for instance, talks about "a rapid evolutionary change, not a revolutionary one," but he is convinced that it will be a different agency—if they can pull it off.

The new effort actually had its origins before Reilly came to EPA, in a much discussed 1987 report, *Unfinished Business*. In that tome, EPA staff tried, for the first time, to take a broad look at all the environmental problems the agency deals with and figure out which pose the greatest risk to human health and the environment. Risk ranking, per se, was nothing new—people often ranked one air pollutant against another, for example. And EPA had even attempted to rank the cancer risks within small geographic areas, like Philadelphia and Silicon Valley. But this was different: it was an attempt to look at toxic air pollutants versus pesticides versus global warming.

The task proved to be a methodological nightmare, given the paltry data, uncertain techniques, and value-laden questions such as how to rank loss of wetlands against, say, visibility degradation. But Morgenstern, who directed the study, and 75 senior staff plunged in nonetheless, using whatever data they could muster and falling back on pro-

EPA's Top 11 (not in rank order)	Public Concerns (in rank order)
Ecological Risks Global climate change Stratospheric ozone depletion Habitat alteration Species extinction and biodiversity loss Health Risks Criteria air pollutants (e.g. smog) Toxic air pollutants (e.g. benzene) Radon Indoor air pollution Drinking water contamination Occupational exposure to chemicals Application of pesticides Stratospheric ozone depletion	1. Active hazardous waste sites (67%) 2. Abandoned hazardous waste sites (65%) 3. Water pollution from industrial wastes (63%) 4. Occupational exposure to toxic chemicals (63%) 5. Oil spills (60%) 6. Destruction of the ozone layer (60%) 7. Nuclear power plant accidents (60%) 8. Industrial accidents releasing pollutants (58%) 9. Radiation from radioactive wastes (58%) 10. Air pollution from factories (56%) 11. Leaking underground storage tanks (55%) 12. Coastal water contamination (54%) 13. Solid waste and litter (53%) 14. Pesticide risks to farm workers (52%) 15. Water pollution from agricultural runoff (51%) 16. Water pollution from sewage plants (50%) 17. Air pollution from vehicles (50%) 18. Pesticide residues in foods (49%) 19. Greenhouse effect (48%) 20. Drinking water contamination (46%) 21. Destruction of wetlands (42%) 22. Acid rain (40%) 23. Water pollution from city runoff (35%) 24. Nonhazardous waste sites (31%) 25. Biotechnology (30%) 26. Indoor air pollution (22%) 27. Radiation from x-rays (21%) 28. Radon in homes (17%) 29. Radiation from microwave ovens (13%)

Scientists and the public draw different conclusions about the seriousness of various environmental problems. Above: the worst environmental problems, as identified by EPA's Scientific Advisory Board. Right: the public's top concerns, as reflected in a March 1990 Roper Poll. (Figures in parentheses are the percentages that rated each problem "very serious;" highlighted items also appear on EPA's list.)

fessional judgment when they couldn't. They ended up with a list of 31 problems, essentially in rank order. To their credit, they never pretended scientific rigor; they never claimed, for instance, that problem number 2 was definitely worse than problem 3, but said that it was certainly worse than 13, and 13 in turn was worse than 26.

Their list showed that the old assumptions were wrong. Many of the things that the public was most concerned about—and that EPA was devoting vast resources to—like hazardous waste and underground storage tanks, posed relatively small risks, while the biggest problems, like radon and climate

change, were being virtually ignored. In 1987 the agency was spending several billion dollars for waste cleanup, for example, as opposed to several million for indoor air pollution and climate change.

"*Unfinished Business* revolutionized how people thought," says Jonathan Lash, a former environmental activist with the Natural Resources Defense Council who is now the secretary of natural resources in Vermont.

But while *Unfinished Business* may have changed thinking, it didn't change practice much at EPA, mostly because "you don't turn a tanker on a dime," says Morgenstern. Its impact was also limited by the fact that

many in the agency saw the study as an "unscientific" first cut—not the kind of hard analysis on which to force a change in environmental policy.

But the study did influence Reilly. Soon after he was appointed but before he was confirmed as EPA administrator, Reilly was sitting around the World Wildlife Fund Conservation Foundation headquarters with his colleagues, including Terry Davies and Dan Beardsley, a deputy assistant administrator for policy at EPA who was then on loan to the conservation group, talking about what he should do at EPA, and how. All were frustrated with the "chemical of the

Ranking the Risks Proves Contentious

If the deliberations of EPA's Scientific Advisory Board committee are any indication, then ranking environmental risks, as William Reilly is proposing to do, will not be easy. Indeed, the committee members almost came to academic blows over just how far they were willing to go on admittedly squishy data. The scientists fell out basically along subcommittee lines, with the ecological group taking a bolder or more foolhardy stance, depending on your perspective. But this says as much, if not more, about the personalities of the two subcommittee chairmen as it does about the nature of the problems they were wrestling with.

William Cooper, an ecologist at Michigan State who headed the subcommittee looking into ecological effects, dove right in. His group discarded the methodology of the earlier report, *Unfinished Business*, as unscientific and divided up the universe in a new way, and then promptly ranked the problems. His group came up with a complex set of matrices for evaluating risk, but the bottom line, says Cooper, is that problems are worse if they affect a broad area and have a long "time horizon"—in Cooper's words, a measure of how long it takes, once you shut off the stress, for the ecosystem to recover. According to their new scheme, global climate change and stratospheric ozone depletion came out way on top, as they did in *Unfinished Business*, and so did two other problems the earlier committee did not even consider: habitat alteration and destruction, such as deforestation, and species extinction and loss of biodiversity. Second rank, or relatively high ecological risks, were airborne toxics, toxics in surface water, and pesticides and herbicides.

While Cooper's group bulldozed through the uncertainties, a subcommittee on health effects, headed by Arthur Upton of the Institute for Environmental Medicine at New York University Medical Center, got bogged down early on in the problems of missing data and inconsistent assumptions. The upshot was they declined to rank anything. "It was not scientifically feasible. It was more than a committee of scientists could do on a part-time basis over a few months," says Upton, especially since they were given the unenviable task of somehow combining cancer and noncancer risks. Instead, they laid out in great detail how one

would go about ranking risks in a scientifically defensible way, if one had the time and money to do so. And central to that, they say, is separating out individual agents, like lead, instead of lumping it in with other "criteria air pollutants."

Their cautious stance was immensely frustrating to some committee members, like Jonathan Lash, secretary of natural resources in Vermont, and Fred Hansen of Oregon's Department of Environmental Quality, who pointed out that EPA and state agencies do not have the luxury of waiting for the definitive study but have to make decisions now. But Upton sticks to his guns. "In many cases, we simply don't have the data, either on human exposure to various agents or their toxicity," Upton recently chaired the National Academy of Sciences report, known as BIER V, which wrestled over the effects of ionizing radiation. "When you turn to chemicals, the

information is even more incomplete," says Upton. "Unless one gets more data, these assessments will remain highly uncertain. Sure, one can rank risks, but the confidence one has in the rankings will not be great." And though Upton thinks comparative risk assessment is a good tool for setting priorities, he cautions that "you can carry it to absurd extremes."

The committee reached a compromise of sorts, with Upton's group identifying seven problems that would rank high by almost any reckoning: criteria air pollutants (for example, smog), toxic air pollutants (for example, benzene), radon, other indoor air pollutants, drinking water, worker exposure to chemicals, and worker application of pesticides. And though the data were "less robust," they threw in stratospheric ozone depletion as well, because it looms so large compared with other problems. For all of these high-risk problems, the common denominator was direct exposure, says Upton, not something passed up through the food chain.

Upton cautions that this is not the final word; other problems—such as pesticide residues in food or exposure to consumer products, which were described as high risk in the earlier report—might also rank high if more data were available. But until they are, Upton's committee has "no problem" with Reilly giving extra attention to the seven they have identified. ■ L.R.



Bold and cautious. William Cooper (right) was willing to rank problems, but Arthur Upton wasn't.

month" phenomenon and the sense that EPA was not spending its money as wisely as it could, recalls Davies. They wanted to find a way to focus the agency's resources where they would get the biggest payoff—which means, as Davies says, factoring in not only how risky a problem is but how feasible and costly the various "fixes" are.

They decided upon a two-part strategy: take another look at *Unfinished Business* and the whole issue of comparative risk; and at the same time, get the senior managers at EPA to start thinking about what actions would have the biggest payoff in terms of reducing the most significant problems.

Reilly wasted little time. Soon after he arrived at EPA he asked the agency's Scientific Advisory Board (SAB) to essentially peer review *Unfinished Business*—to go over the data again, see whether they agreed with the methodology and rankings, and, if not, to come up with their own. The board set up a committee of 45 experts, mainly scientists but a few people from state government as well, like Vermont's Jonathan Lash and Fred Hansen, director of Oregon's Department of Environmental Quality, to keep the effort focused on political reality. Lash and Raymond Loehr, an environmental engineer at the University of Texas, Austin, cochair the committee.

That committee, in turn, divided itself into three subcommittees: one headed by William Cooper, an ecologist at Michigan State University, to look at ecological, economic, and aesthetic effects; another, headed by Arthur Upton, director of the Institute for Environmental Medicine at New York University Medical Center, to look at health risks; and a third, chaired by Alvin Alm, director and senior vice president of Science Applications International and a former deputy administrator of EPA under William Ruckelshaus, to look at strategies for reducing the major risks.

The SAB committee spent more than a year sifting through studies, all the while bemoaning the scanty data and uncertain analytical techniques, which make accurately characterizing a risk, much less ranking it against another, a tenuous business at best. Though they applauded *Unfinished Business* for its pioneering work, the committee had lots of problems with it, from the fact that the EPA staff had divided up the universe into problem areas that essentially reflect the agency's existing programs—which "makes no damn scientific sense," says Cooper—to some of its conclusions, which they call "provisional."

But for all their complaints, the SAB committee concluded that *Unfinished Business* was not that far off in its conclusions. Most of the "baddies" identified in the

report—like climate change, stratospheric ozone depletion, air pollution, and radon—still looked bad. The earlier group had, however, overlooked a couple of big ones, habitat destruction and species extinction, which the SAB committee added. And once again, the things the public cares the most about, like hazardous waste, ended up in the middle or at the bottom of the heap.

Not everyone in the group, however, was willing to follow their predecessors out onto a scientific limb and actually rank the problems. Cooper's ecological effects group was perfectly willing to rank them, but Upton's health effects group wasn't, which led to some tussles on the committee (box, p.



Focusing on risk. If William Reilly has his way, EPA will spend its money differently.

617). In the end, they agreed to simply list the 11 problems that everyone agreed were high risk—with the caveat that this is not an inclusive list.

Some of these problems, like the loss of biodiversity, do not fit handily into EPA's statutory mandate, but the committee urged EPA to exert leadership anyway. The committee also urged EPA to give greater weight to ecological risks, which they say have been given short shrift while EPA has concentrated on combating pollutants that pose a threat to public health. And perhaps most important, in terms of the agency's overall direction, the SAB committee gave its scientific seal of approval to comparative risk assessment, flawed as it is, as the best way to set priorities. They recommended that EPA set up a permanent process for comparing risks and then make its policy and budgetary decisions, as much as possible, on the basis of those risks. And, they said, EPA should move beyond the conven-

tional "end-of-the-pipe" approaches and use alternatives, such as pollution prevention and market incentives.

The committee's final report will go to Reilly in late September. At this stage, it is not at all clear how the public and the environmental community will receive it because in the Reagan era, at least, "setting priorities was a euphemism for cutting," says Jonathan Lash. "I don't see that happening here," he adds.

But Reilly and his aides have already embraced the report; in fact, they are using it in shaping the agency's 1992 budget. Their problem, of course, is that 80% of the budget is essentially cast in stone, estimates Dan Beardsley of the policy office. EPA must spend these dollars implementing the laws, paying salaries and rent, and so on. The administrator technically has discretion over perhaps 15% of the budget, but in reality, that too is sacrosanct. "You would be out of your political mind to exercise it," says Beardsley, since Congress has clearly indicated, if not insisted on, how that money ought to be spent.

That leaves only 5% of the budget that is truly flexible. While working to wrest more discretion and more flexibility from Congress, Reilly's aides are concentrating on that 5%. Last November, Reilly and Habicht asked the heads of the various programs to submit 4-year plans, describing where they want to go and how they are going to get there. The guiding principle, they were told, should be risk reduction—and not, say, how to meet the latest court-ordered deadline. In identifying the big risks, the program heads were to take direction first from *Unfinished Business*, and then, when it became available, the SAB report.

By all accounts, the first round "engendered grave suspicions," as Don Barnes, director of the SAB, puts it. "Any time a program is challenged, people wonder if the real goal is to take money away," he says. The plan did cause some resentment, concedes Habicht. But after some initial grumbling most, if not all, have come around.

But if this new thinking is really going to make a difference—if Reilly is really to get the greater flexibility and discretion he wants—then he and his aides will have to change the culture not only at EPA but in Congress and the Office of Management and Budget. Proponents of the effort point to some encouraging signs from Congress, such as rising budgets for global climate change and radon, while funding for hazardous waste has remained relatively steady.

"It is a big agenda, but you have to start somewhere," says Habicht. "We are planting seeds, most of which won't bear fruit until after we have left." ■ **LESLIE ROBERTS**

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NATIONAL ACTION STRATEGY ON CLIMATE CHANGE**ANNOTATED OUTLINE**

This document is a draft outline of a national action strategy on climate change for consideration by provinces and territories. It is proposed that elements of federal and provincial/territorial action programs be developed in the context of the strategic framework outlined in this draft, and be incorporated in the strategy over time.

August 10, 1990

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CHAPTER 1: INTRODUCTION

- Over the past decade, world has been increasingly alerted to possibility that earth's temperature is rising as a result of human activity. Potentially significant impacts - physical, socio-economic, cultural.
- Problem being addressed in number of fora. Internationally, IPCC has been principal focus of activity. Report submitted to governments at recent Second World Climate Conference.
- Domestically, have had reports of Energy Ministers' Task Force; Green Plan consultations; provincial consultations; Parliamentary Standing Committee. Will be key component of Green Plan.
- Effective response to the problem must be international in scope. Similarly, the Canadian contribution to that response must be national and coordinated, and involve all levels of government as well as industry, consumers etc.
- Accordingly, at their meeting during Globe '90 in March, Canadian Environment Ministers
 - agreed that climate change demands the full attention of the Council on a priority basis
 - agreed that international initiatives provide the appropriate forum for establishing national and global targets for greenhouse gases
 - noted the extensive consultation activities underway in Canada
 - recognized their responsibilities in assuming a leadership role in developing a comprehensive national action strategy
 - instructed a steering committee of environment deputies to develop the strategy, in cooperation with energy deputies and other sectoral ministries.
- This paper proposes such a strategy.

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CHAPTER 2: NATURE OF PROBLEM**2.1 SCIENTIFIC EVIDENCE**

- Throughout 1980s, increasing awareness of possibility of climate change. Led to establishment of IPCC in 1988 under auspices of WMO and UNEP.
- IPCC reported in summer. Provide summary of IPCC report on scientific assessment of climate change and on its likely impacts.
- Information from Canadian scientific research program, especially with respect to impacts of climate change on Canada.

2.2 CANADIAN DIMENSION

- Situate Canada relative to other major countries in terms of CO₂ emissions
 - Canada a high emitter of CO₂ on a per capita and per unit of GNP basis
 - [Table showing leading emitters of CO₂ internationally on a per capita and per unit of GNP basis].
- Relatively high rank in terms of CO₂ emissions result of high level of energy intensity - Canada one of most energy intensive countries in world
 - [Chart comparing energy intensity of major industrialized countries on per capita and per unit of GDP basis].
- However, Canada's energy consumption relatively low in terms of carbon intensity - role of hydro and nuclear.
- Reasons for high energy intensity include
 - climate
 - distance
 - resource endowment/industrial structure
 - lower taxes.

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- Situate Canada relative to other countries in terms of emissions of other greenhouse gases.
- Situate Canada relative to other countries in terms of aggregate greenhouse gas emissions.
- Situate Canada relative to total world emissions of
 - CO₂
 - produce 2%
 - other greenhouse gases
 - greenhouse gas aggregate.
- Message: we are only a small part of total picture. Therefore, while intend to be responsible and show leadership, must recognize that acting alone we can have little impact.
- As efforts to achieve an international agreement continue, it makes sense for Canada to adopt those measures to reduce greenhouse gas emissions which are economic or which also assist in achieving other policy objectives. At the same time we can establish a framework for future, more ambitious response strategies.

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CHAPTER 3: THE INTERNATIONAL CHALLENGE

- Canada participating with other countries in exploring ways to achieve a coordinated approach to global climate change.
- Difficulties in reaching international agreement to coordinated approach in this area similar to those encountered in other areas. Ozone depletion, for example, also had to be addressed in face of some degree of scientific uncertainty, and required means to facilitate participation by developing countries in solution.
- However, difficulties more severe in case of climate change. Activities giving rise to greenhouse gas emissions more deeply integrated into our economic structure, implications of taking action to reduce emissions more complicated than reducing use of ozone-depleting substances.
- Key international meetings on climate change: Toronto, The Hague, Noordwijk, Bergen.
 - **Bergen Declaration**
 - All ECE countries committed to "establish national strategies and/or targets and schedules following the report of the IPCC and no later than the start of the negotiations of a framework convention on climate change to limit or reduce CO₂ emissions and other greenhouse gas emissions as much as possible and to stabilize them".
 - Most ECE countries (including Canada) expressed the view that "such stabilization at the latest by the year 2000 and at present levels must be the first step".
- Key element in process has been work of IPCC. Report submitted to Second World Climate Conference. Developments at SWCC.
- Expected that UNEP, in cooperation with WHO, will organize formal negotiations of framework convention on climate change following SWCC. Convention will seek umbrella agreement to reduce impacts on global climate. Will likely be accompanied, simultaneously or later, by protocols with binding commitments to specific action.
- An important aspect of Convention will be issue of technological and financial assistance to developing countries.

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- Convention could be ready for signature at 1992 U.N. Conference on Environment and Development.
- Progress also being made internationally on greenhouse gases in context of negotiations whose immediate focus is a different environmental problem
 - CFCs/ozone depletion - London conference
 - phase-out CFCs by 2000 - developing countries on board
 - 16 countries including Canada - phase-out by 1997
 - tropospheric ozone/LTAP.

CHAPTER 4: THE DOMESTIC CHALLENGE

- [Graph showing historical path of CO₂ emissions in Canada, and projections to 2000/2005. Similar graphs for other greenhouse gases (may be difficult for some gases).]
- Discussion of historical path (CO₂) - consistent growth with exception of early 1920s, early 1930s, and early 1980s. More detailed discussion of last 20 years.
- Discussion of factors underlying CO₂ and other projections (economic growth, oil prices, energy efficiency etc.).
- [Table/pie chart showing distribution of emissions by province for 1990(?) and 2000.]
- Discussion of distribution of emissions by province.
- [Table/pie chart showing distribution of emissions by sector (residential, commercial, industrial etc.) for 1990(?) and 2000.]
- Discussion of distribution of emissions by sector.

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CHAPTER 5: FRAMEWORK FOR RESPONSE

Response strategy has three key components: reducing uncertainties, adaptation and limitation.

5.1 REDUCING UNCERTAINTIES

- Although there is a general consensus among scientists that climate change will occur and that it will have serious consequences, there are still many uncertainties. These uncertainties include the magnitude, timing, rate and regional distribution of climate change.
- International research programs have been established to address these uncertainties. Canada intends to play its part in these programs, focusing on those areas of specific interest to Canada and where we have special expertise.

5.2 ADAPTATION

- Regardless of the effectiveness of control programs, the world will experience a global warming of at least 0.1 C per decade. It will be necessary to adapt to these future climates.
- Steps must be taken to assist Canadians in adapting to that component of climate change which is inevitable.

5.3 LIMITATION

- As well as seeking a better understanding of the problem of climate change, and adapting to that component of climate change which is inevitable, there is a growing consensus internationally that actions to limit emissions of greenhouse gases must begin now.
- The national action strategy sets out the approach Canada is taking domestically to reduce emissions.

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CHAPTER 6: REDUCING UNCERTAINTIES

[It is proposed that elements of federal and provincial/territorial action programs consistent with the strategic framework be incorporated over time.]

- Although there is a general consensus among scientists that climate change will certainly occur and that it will have serious consequences, there are still many uncertainties. These uncertainties include the magnitude, timing, rate and regional distribution of climate change.
- International research programs such as the World Climate Research Program and the International Geosphere Biosphere Program have been established to address these uncertainties. Canada will play its part in these programs, focusing on those of specific interest to Canada and where we have special expertise.
- Areas where Canada has specific interests include the rate of climate change, the hydrological cycle and precipitation, atmosphere/forest interactions, methane emissions from wetlands and atmospheric composition.
- Areas where Canada has special expertise include its world class general circulation model.
- Infrastructure arrangements to focus and coordinate research will be important.

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CHAPTER 7: ADAPTATION

[It is proposed that elements of federal and provincial/territorial action programs consistent with the strategic framework be incorporated over time.]

- Regardless of the effectiveness of those greenhouse gas limitation initiatives which may be introduced, the world will experience a global warming of at least 0.1 C per decade. Canada will experience significantly greater warming, especially in the north.
- It will be necessary to adapt to these future climates. The development of appropriate policies requires an understanding of current climates and how they will change, and of the socio-economic implications of these changes.
- Strategically adaptation initiatives must focus on:
 - regional and national climate monitoring
 - integrated evaluations of the impact of future climates on regional ecological and socio-economic systems
 - development of adaptation strategies for regional ecological and socio-economic systems
 - evaluation and communications aimed at both the general public and decision-makers.

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CHAPTER 9: LIMITATION STRATEGY**9.1 PRINCIPLES**

- Limitation strategy based on three principles
 - comprehensive approach
 - international context
 - flexibility.
- Comprehensive approach means that our response must address all the major greenhouse gases
 - carbon dioxide
 - methane
 - nitrous oxide
 - ozone
 - CFCs.
- Will also address the important CO₂ sink of forests.
- Global problem requires global solution. While Canada must and will accept our responsibilities, our response must be developed in context of international efforts to deal with problem.
- Principle of flexibility recognizes that
 - scientific understanding of problem not yet complete
 - international consensus on addressing problem not yet reached
 - we cannot be certain of impact of measures we take (both impact on reducing emissions and on economy).
- Therefore our limitation strategy must be phased and progressive, giving us flexibility to respond to new information/developments over time.

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8.2 ELEMENTS

8.2.1 International convention and protocols

- Canada actively supporting efforts to achieve coordinated international approach to global climate change. In 1988, Canada hosted the first major conference at which policy makers and scientists came together to consider the implications of human activity on the atmosphere. The Toronto Conference led policy makers worldwide to recognize seriousness of problem.
- Have participated actively in subsequent international meetings. Significant contributor to work of IPCC.
- Canada will continue active support for international efforts. Pressing for conclusion of Convention on Climate Change, and if possible some implementing protocols, in time for signature at 1992 U.N. Conference on Environment and Development.

- - - Targets and schedules

- Scientific and economic uncertainties about magnitude, timing and impact of climate change remain. However, general consensus that risks associated with inaction on greenhouse gas emissions are too great to wait upon results of further research before commencing first actions. This consensus led to expression of precautionary principle at Bergen - "lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation".
- As indicated at Bergen
 - first step is stabilization of emissions of CO₂ and other greenhouse gases at 1990 levels by 2000.
- Will consider more ambitious targets as scientific evidence firms up and in context of joint international action.
- [Graph showing projected emissions to 2000 or 2005, 1990 levels, and implied "gap". If possible, emissions will be in terms of a greenhouse gas aggregate; otherwise will provide graphs for CO₂ and other gases for which data is available, with qualitative discussions for remaining gas(es).]
- Next step is to implement measures to close the gap.

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8.2.3 Phased approach

- Do those things first which make sense in their own right or which also help to achieve other policy objectives - first step measures.
- However, changes in way we use energy that are more far-reaching than those resulting from first step measures may be required to bring us to stabilization or beyond. Strategy establishes process to commence immediate examination of these changes and of the more difficult measures that may be required to bring them about.
- The possible introduction of these measures will depend on results of this examination, success of first step measures, developments in scientific understanding of problem, and developments in reaching agreement on concerted international action.
- Goal is to put Canada in position to respond quickly and appropriately to new information and developments as they occur over time.

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CHAPTER 9: LIMITATION - FIRST STEPS

[It is proposed that elements of federal and provincial/territorial action programs consistent with the strategic framework be incorporated over time.]

9.1 ENERGY - MEASURES

- As noted earlier, Canada's relative high rank internationally in terms of CO₂ emissions largely result of high degree of energy intensity, partially offset by low level of carbon intensity in energy consumption.
- In short term, little scope for substitution away from fossil fuels in energy mix. Moreover, hydro, nuclear have their own environmental impacts. Immediate emphasis, therefore, must be on scope for general energy efficiency improvements. Moreover, considerable evidence that many of these economic in own right.
- Indeed, important for Canadian industry to seize all economically-viable opportunities to improve energy efficiency. Helpful in maintaining Canadian competitiveness in world marketplace over time. Also important in the identification and development of new Canadian technologies and business opportunities. In short, improved energy efficiency is a challenge, but it is also an opportunity for Canada.
- Federal government considering initiatives based on integrated approach. Has three main features.
- First, all sectors of the economy are addressed - there are opportunities to improve efficiency in all sectors.
- Second, integrated set of policy instruments are used - R&D, information/suasion, regulation. Instruments are complementary
 - standards remove least efficient products from market
 - information encourages people to use more efficient products
 - R&D develops new options to reduce CO₂, to save energy and to increase Canadian competitiveness and economic growth.
- Third, approach is dynamic. Puts in place processes which can be built upon over time.

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Equipment

Minimum energy efficiency standards for household appliances and equipment.

- Appliance and equipment labelling and information and demonstration programs.

Buildings

- Updated energy efficiency building codes.
- Enhanced information and education programs for building industry/related services.

Industry

- Process to identify opportunities and initiatives to improve energy efficiency in industrial sector.

Transportation

- New fuel consumption targets.
- Expanded training and information programs.

Alternative energy

- Initiatives to promote market penetration of alternative energy, particularly transportation fuels.

Research and development

- All initiatives have R&D component. Focus on co-funding and joint ventures with private sector.

Federal government operations

- Identify and facilitate economically attractive measures to improve energy efficiency in federal government.

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9.2 ENERGY - CHALLENGE

- Governments have identified large number of areas where room for improvement in energy efficiency. These areas are addressed by measures set out in 9.1.
- However, governments don't have all the answers. There are likely opportunities for improving energy efficiency that governments are not aware of.
- Federal government therefore sending out challenge to Canadians to find these opportunities and take advantage of them.
- The federal government considering establishing a process to bring together the various levels of government and representatives of target sectors.

9.3 CFCs

- CFCs important greenhouse gas. In London in June, Canada committed to phase out CFCs by 1997.

9.4 AGRICULTURE

- Reduce nitrous oxide and methane emissions in agricultural sector.

9.5 OTHER METHANE

- Measures to reduce methane emissions from non-agricultural sources, e.g. landfill sites.

9.6 FORESTRY

- Reforestation initiatives to provide carbon sinks.

9.7 OZONE

- Contribution of tropospheric ozone to radiative forcing, while difficult to quantify, may be significant. NO_x and VOCs are precursors to tropospheric ozone.

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- Canada signed international NO_x protocol, is participating in negotiation of a VOC protocol. Canada developing a management plan to reduce NO_x and VOC emissions by about 15% below 1985 levels in 2005. Includes "California" emission standards for 1994 model-year cars.

9.8 INFORMATION

- Initiative to educate and inform Canadians.

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CHAPTER 10: LIMITATION - BEYOND FIRST STEPS**10.1 IMPACT OF FIRST STEPS****10.1.1 Carbon dioxide**

- [Graph showing reference case emissions to 2000, the gap between this and stabilization, and the extent to which the gap is expected to be closed by first step measures.]
- Discussion of graph/gap.
- Discussion of energy intensity. First step measures bring us to x% annual improvement in energy intensity. To reach stabilization, would require y% annual improvement.
- Our estimate of x% is prudent - many observers think we can do better, and we expect that we may do better as a result of processes that will be put in place.
- However, may not be able to reduce emissions in 2000 to 1990 level, or to keep them there. Moreover, may need to adopt more ambitious targets as scientific understanding of problem evolves, and as international consensus develops on need for concerted action.
- Need therefore to commence examination of more difficult, and sometimes more costly, measures we may need to introduce to bring about more far-reaching changes in way we use energy. These measures, and process for examining them, are set out below.

10.1.2 Other greenhouse gases

- [Where possible, graph for each of the other principal greenhouse gases, in turn, showing reference case emissions, stabilization, and the impact of initial measures. Where not possible, qualitative discussion of impact.]

10.2 MEASURES

- Measures outlined in this section are considerably more far-reaching in their implications than first step measures announced above.

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- Some measures, as well as affecting lifestyle, could have important regional and economic impacts. They therefore require a process of detailed consideration by the Canadian public. Some measures could only be contemplated in the context of joint and coordinated international action as negotiated over the coming years.
- Discussion below provides brief description of these measures, and of process for examining them. It is important that this examination begins now.
- Some measures are under federal jurisdiction, others are under provincial or municipal jurisdiction. Depending on the specific measure, therefore, the federal government or provincial governments will take the lead in coordinating the review process. In most cases, however, it will be important that all the partners be involved in the process.
- Ultimate introduction of these measures will, of course, depend on results of these processes of examination, success of first step measures, developments in scientific understanding of the scope of the climate change problem, and developments in reaching agreement on concerted international action.

10.2.1 Control strategies

- Depending on international and domestic developments, it may be necessary for Canada to adopt increasingly stringent control measures for reducing CO₂ and other greenhouse gas emissions. A regulatory system addressing all major emission sources, and possibly setting sectoral emission ceilings, could be necessary.
- If it becomes necessary to introduce such a control system, the federal and provincial governments would want to ensure that it was designed in a way that would meet Canadian emissions goals in as flexible and least-cost a manner as possible. In particular, there could be role for emissions trading system as part of an overall regulatory strategy.
- Clearly, a program for the regulation of carbon and other emissions, including one that incorporates tradeable permits, would have important economic, regional and lifestyle implications. Also would have a number of difficult design issues associated with it.

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Process - Federal and provincial governments will work with industry and other interested stakeholders on the feasibility and design of a CO₂ emissions control program, including a carbon permit trading system. Key consideration would be linkage to control programs for other greenhouse gases, e.g., ground level ozone (NO_x/VOCs) and CFCs. The federal government will also release a discussion paper in the spring on the use of economic instruments to achieve environmental objectives in Canada. It will contribute to a public discussion of the possible use of trading systems in Canada.

10.2.2 Tax strategies

- Use of the tax system is another means of inducing a reduction in CO₂ and other greenhouse gas emissions. For example, an energy tax could be applied to all forms of energy to promote greater efficiency of energy use and, hence, reduce CO₂ emissions.
- Preliminary evidence suggests that effective energy taxes could involve substantial price increases [illustrative examples]. Moreover, as in case of regulatory/emissions trading system, could have important economic, regional and lifestyle considerations. Administration could also be complex.
- **Process** - Tax strategies will also be addressed in economic instruments discussion paper.

10.2.3 Electric utility incentive structure

- Electricity accounts for about x% of end use demand for energy in Canada. Moreover, about y% of electricity is generated from fossil fuels.
- For that reason, any attempt to bring about a significant change in the way energy is used in Canada must address the electric utility sector.
- Many provincial utilities have launched aggressive demand-side management (DSM) programs. The energy efficiency improvement process described in Chapter 9 will explore further potential in this area.

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- However, concerted action on CO₂ may require even stronger measures addressing issues such as:
 - marginal cost and peak load pricing
 - symmetry in utility incentives for system supply, off-system supply, and DSM.
- Process - Provincial led review process.

10.2.4 Urban infrastructure

- Changes in the way our cities function could play an important role in reducing carbon dioxide emissions arising from gasoline consumption.
- Measures that could be taken in this context include measures to
 - promote the use of urban mass transit
 - improve the flow of urban traffic
 - reduce traffic density.
- Such measures, as well as involving economic costs, also imply changes in Canadians' lifestyles.
- Process - Provincial led review process, working with municipalities.

10.2.5 Nuclear option

- Nuclear energy provides electricity with no CO₂ emissions, but has its own environmental risks.
- If serious about longer-term targets, however, increased reliance on nuclear may have to be considered. Given long lead times, clearly a post-2000 option.
- Last October, federal energy and environment ministers noted usefulness of encouraging broad public discussion of national and provincial energy policies and role of nuclear energy within these policies; indicated would be considering most effective way of launching discussion.
- Process - Announce structure and mandate of nuclear/electricity environmental review.

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CHAPTER 11. CONCLUSION

- Scientific and economic uncertainties about climate change remain. However, risks of inaction are so great that must commence first actions.
- International problem which requires international solution. Canada working for international solution, but in meantime federal and provincial governments believe have responsibility to act nationally.
- Canadian response strategy has three elements: limitation, adaptation, and reducing uncertainties.
- With respect to limitation, national action strategy adopts phased, progressive approach. Sets target to stabilize CO₂ and other greenhouse gas emissions at 1990 levels by 2000 - committed to achieving this.
- First step measures will take us part of the way towards stabilization. These are measures which help us achieve our goals; but make economic sense in their own right and/or achieve other policy goals. Many of them are good for the Canadian economy and provide opportunities for Canadian business.
- More far-reaching changes in way we use energy may be required to bring us to stabilization and beyond. Strategy establishes process to commence immediate examination of the more difficult measures that may be required.
- Strategy also sets out process for adapting to that climate change which is inevitable, and measures Canada is taking to reduce scientific uncertainties related to climate change.
- Overall, strategy establishes process for continually monitoring developments, reducing uncertainty and putting Canada in position to respond appropriately at every step of the way.

Withdrawal/Redaction Sheet

(George Bush Library)

Document No. and Type	Subject/Title of Document	Date	Restriction	Class.
03. Outline	Re: Major Issues Regarding Global Warming (1 pp.)	7/19/90	P/5	

Collection:

Record Group: Bush Presidential Records
Office: Chief of Staff, White House Office of
Series: Sununu, John, Files
Subseries: Issues Files
WHORM Cat.:
File Location: Global Warming (2 of 2) - 1990 [1]

Open on Expiration of PRA
(Document Follows)

By JP (NLGB) on 10/28/05

Date Closed:	12/17/2004	OA/ID Number:	29158-001
FOIA/SYS Case #:	1998-0004-F[1]	Appeal Case #:	
Re-review Case #:	2005-0426-S	Appeal Disposition:	
P-2/P-5 Review Case #:		Disposition Date:	
AR Case #:		MR Case #:	
AR Disposition:		MR Disposition:	
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 (b)(6) Release would constitute a clearly unwarranted invasion of personal privacy [(b)(6) of the FOIA]
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 (b)(8) Release would disclose information concerning the regulation of financial institutions [(b)(8) of the FOIA]
 (b)(9) Release would disclose geological or geophysical information

July 19, 1990

MAJOR ISSUES

Paragraph

- 8. References to global warming as an unprecedented environmental threat
- 9. Call for immediate action by industrialized Countries and assistance to develop countries
- No 17. Precautionary principle
- 19. Goal -- stabilize and reduce GHG concentrations
- No 20. 1st step -- stabilize emissions
- No 21. Stabilization of emissions by 2000
- No 22. 20 percent reduction by 2005 - 2010
- No 23. Negotiate protocols concurrently with framework convention
- No 24. Special targets and financial assistance to developing countries
- No 26. Consideration of Green Fund
- 34. Endorse Noordwijk target of net 12 million hectares forest growth
- 37. Call for initiation concurrent negotiation of framework convention and associated protocols
- 39. Call for initiation of discussion of an energy protocol in early 1991

RAPHAEL G. KAZMAN

231 Duplantier Blvd.
Baton Rouge, LA 70808

(504) 766-0694

August 14, 1990

Editor, SCIENCE
1333 H Street NW
Washington, D.C. 20005

Dear Sir:

The latest "greenhouse" consensus (3 Aug. 1990, p.481) would be laughable if it were not so serious. We have a clear example of a group of specialists trying to impose a scientific truth on society, not by argument, not by presenting data, but by a majority vote! Democratic methods are not appropriate to determining scientific truths, only theory backed up by evidence. One man and the truth constitute a majority. We have even seen how, now and then, two theories account for the evidence (as witness the argument about the source of the K-T boundary and mass extinctions). The argument about plate tectonics achieved a consensus forty years after it was proposed. It took evidence that could not be incorporated into then-current theories to change everybody's mind and there are still a few hold-outs.

In the story "The Greenhouse Consensus" (boxed) the first three items are conclusions based on assumptions. Only the fourth item (temperature rise of from 0.3-0.6 degrees Centigrade in the last 100 years) has any supporting data - and even this is not definitive. The fifth item is laughable: it will take a decade of waiting before the greenhouse warming can be detected with high confidence that something has been found! If you're not reasonably sure that you are right, based on the evidence, why all the jumping up and down, beating your chest, and yelling that the world is coming to an end?

In the meantime, how are the findings by glaciologists to be fitted into the "warming" scenario: the Woods' assessment (1) that the proportion of glaciers that are advancing increased from about 5.7% in 1960 to more than 57% in 1980; the paper in SCIENCE (Zwally, et. al., (2) that the elevation of the Greenland ice cap increased by about 0.2 meters per year between 1978 and 1985; and the statement by Bentley (3) that the accumulation of Antarctic snow is outpacing the rate at which its ice cap is discharged into the ocean - he thinks that sea level might actually be falling. Finally there is the new "plant hardiness zone map" issued by the Department of Agriculture that shows the controlling cold temperatures as far as plant survival is concerned: the 1990 map (4) shows that the zones shown in the preceding, 1965, map (5) are now from 5 to 10 degrees F colder than they were. At this rate, we'll be in a new ice age in about a century.

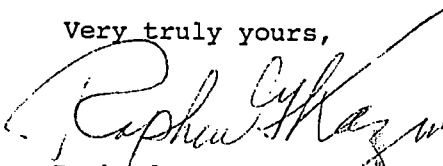
For people who enjoy anecdotal evidence, let me refer to Mark Twain's *LIFE ON THE MISSISSIPPI* concerning Natchez (Chapter 39). He agreed with Trollope's 1827 description of the beauty of the city and its outstanding features one of which is that "Natchez is the furthest point to the north at which oranges ripen in the open air or endure the winter without shelter." This is no longer true, Louisiana oranges were commercially grown south of New Orleans from the early 1940's but the last commercial grove was destroyed by frosts in the 1980's. The climate is changing, getting colder.

The available data and other evidence do not support the hypotheses and the results of the computer models used by the Panel on Climate Change, if my summary of their findings is correct. It follows that while we wait for some actual data to support their speculations, we should devote our attention to something useful, like repairing our roads, building the SDI's "brilliant pebbles", and disposing of garbage. There is nothing like taking a little time before distorting the operation of an entire system of industrial production based on a hypothesis that is unsupported by facts. The available data indicate that the "Global Warming" hypothesis is so inadequate as to be completely wrong.

REFERENCES

- 1.F.B. Woods, 1989, in *Arctic and Alpine Research in 1988*. U. Colorado, Boulder, p.404.
- 2.H.J. Zwally, A.C. Brenner, J.A. Major, R.A. Bindschadler, J.G. Marsh, 1989, *Science* v.246, p.1587.
3. C.R. Bentley, 1989, *Trans. Am.Geophys. Union*, v.70, p.1002.
- 4.Dept. of Agriculture, 1990, *Plant Hardiness Zone Map*, Misc. Pub. 1175
- 5.Dept. of Agriculture, 1965, *Plant Hardiness Zone Map*, Misc. Pub. 814.

Very truly yours,



Raphael G. Kazmann
(Prof. Emer. La. State Univ.)

Carl D. Hanley
Route 5, Box 2517 B
Edinburg, Texas 78539

NAN

FROM
GRANDPA'S
DESK

Chief 5-15-90
& Pres:

Please refer to this
source as you master
your global-warming
models; Thanks

Regards

Carl H.

THE GREENHOUSE ROSTER

50 Highest Emitters of Major Heat-Trapping Gases

Carl D. Hanley
Route 5, Box 2517 B
Edinburg, Texas 78539

Source: World Resources Institute.
Map by Dave Herring

MAP KEY

SCALE

100,000,000

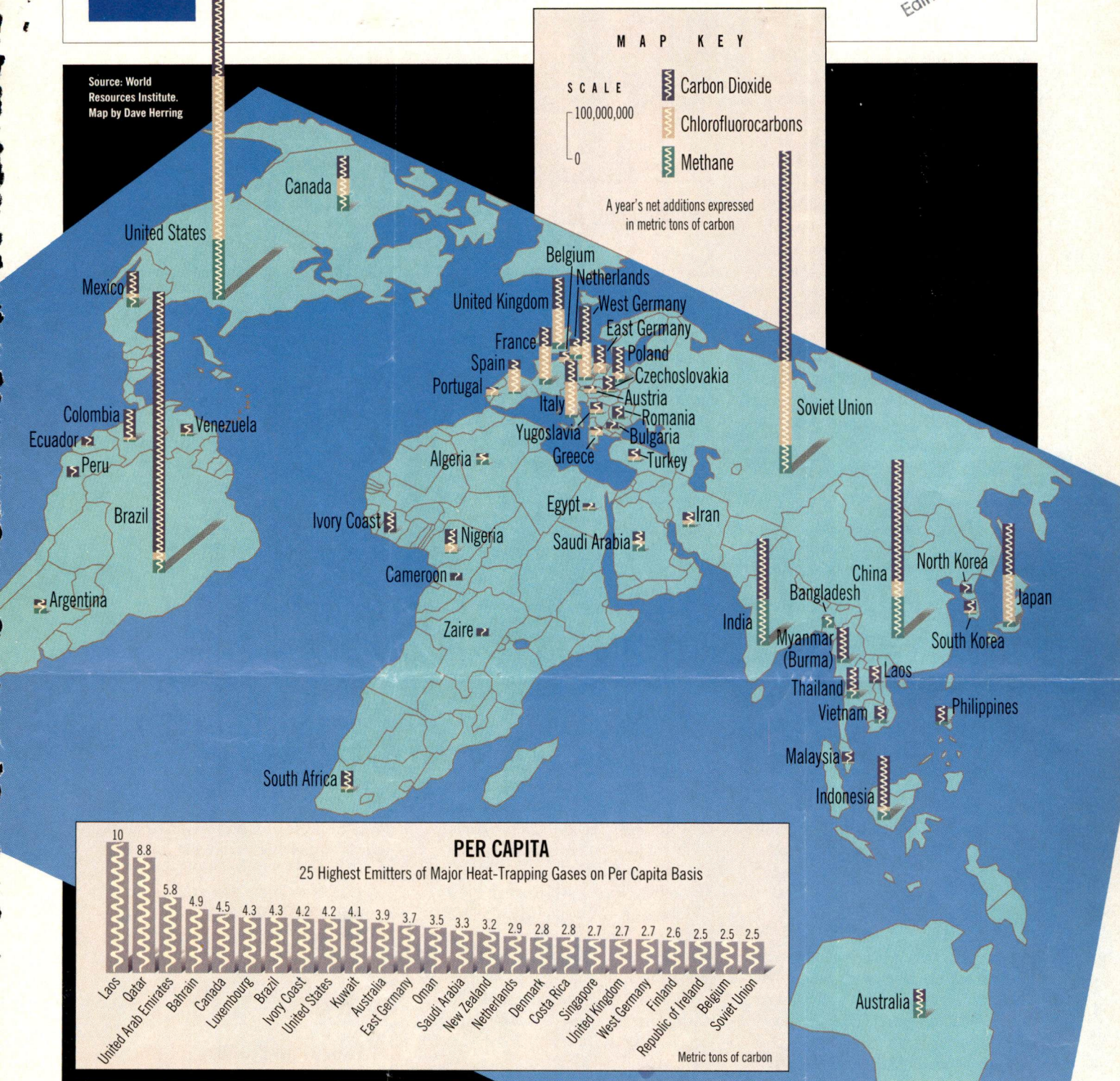
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Carbon Dioxide

Chlorofluorocarbons

Methane

A year's net additions expressed
in metric tons of carbon



Three major heat-trapping gases—carbon dioxide, methane, and chlorofluorocarbons—combine to account for 86% of the greenhouse effect, current global warming attributable to human activity, according to the World Resources Institute in Washington. Using latest (1987) figures, researchers describe all the gases in terms of the equivalent heating effect of CO₂, expressed in metric tons of carbon. The ranking of nations by the year's net addition to emissions (map), with US, USSR leading, contrasts with ranking per capita (chart). Such factors as a high rate of deforestation account for elevated per capita emissions in Laos and the Ivory Coast; gas flaring, which accompanies oil production, boosts ranking of United Arab Emirates.

THE WORLD

Remember the Law of the Sea?

INTERNATIONAL MINING OF THE RICHES of the seabed is inching closer with Law of the Sea meetings like the one this month (Aug. 13-31) in New York. Working-group members are reportedly impressed by a four-year French study outlining profitable mining of manganese nodules from the ocean floor on the basis of an annual capacity of 1.5 million tons of dry nodules. A self-propelled collector would recover the nodules. They would be processed in a French plant for extracting nickel, cobalt, and copper as well as manganese. France is one of the four RPIs (registered pioneer investors). The others are India, Japan, and the Soviet Union. During the Reagan administration the United States pulled back from its early support of an international Law of the Sea treaty for equitable use and protection of the world's seas. The treaty negotiations culminated in the 1982 United Nations Convention on the Law of the Sea. Now it has been ratified by more than 40 of the 60 nations necessary to bring it into force. Meanwhile, at meetings such as the one last March in Kingston, Jamaica, and the one this month in New York, the preparatory commission for the convention continues to work out such matters as how to keep seabed mining from harming the exports or economies of land-based developing nations producing minerals.

Inflation Comparisons

GLOBAL INFLATION APPEARS TO BE ON the rise from last year's rate of 18%. That figure, calculated by the International Monetary Fund (IMF), was already 5 percentage points higher than 1988 and 9 points higher than the 9% inflation of 1987. Within the overall figures are enormous disparities. In 1989 the rate in developing countries as a whole rose to 86%. In Latin America it went to 350%. Bringing down the overall rate is the United States, with about 4.5%, lower than Britain, Italy, Switzerland, or Sweden.

NOTES

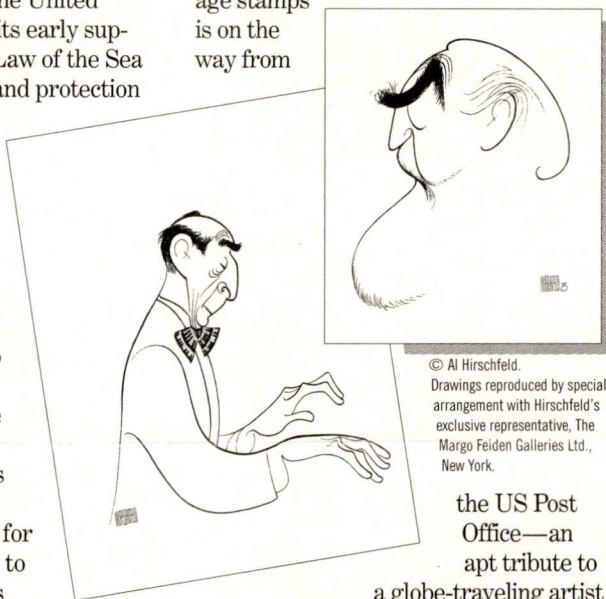
F R O M

PRACTICALLY EVERYWHERE

UNITED STATES

Hirschfeld for All

SOON EVERYONE WILL BE ABLE TO OWN a "Hirschfeld" for a few cents in contrast with the hundreds and thousands of dollars the works of Al Hirschfeld regularly go for: A series of Hirschfeld postage stamps is on the way from



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the US Post Office—an apt tribute to

a globe-traveling artist known for watercolors of Bali as well as caricatures of Broadway, among many other subjects (such as those above, pianist Vladimir Horowitz and the artist himself in a recent self-portrait). For many decades Hirschfeld has been celebrating the world as seen by his artist's eye. Right now 67 of his etchings and lithographs are touring the US in an exhibition that is scheduled into 1992 when it will be at the Pensacola Museum of Art, Pensacola, Florida, Jan. 26-March 8, and the Nelson-Atkins Museum of Art, Kansas City, Missouri, June 20-Sept. 6. On this current year's itinerary: Parkersburg Art Center, Parkersburg, West Virginia, Aug. 26-Oct. 7; Arnot Art Museum, Elmira, New York, Nov. 4-Dec. 29. Among dates in 1991: University of Western Illinois Museum/Gallery, Macomb, Illinois, April 7-May 19; Leigh

Yawkey Woodson, Wausau, Wisconsin, June 16-July 28; Portland Museum of Art, Portland, Maine, Aug. 25-Oct. 6; Palm Springs Desert Museum, Palm Springs, California, Nov. 3-Dec. 29.

CHINA

Insider's Insights

WHAT CAUSED THE STIRRINGS AMONG the Chinese people last year? The main force has been repeated mistakes by the Chinese Communist Party and the corruption it has allowed to flourish, according to a leading Chinese writer, Liu Binyan, in his forthcoming book "China's Crisis, China's Hope." In 1987 Liu was himself expelled from the party, which had earlier rehabilitated him after punishment with hard labor following a series of articles on bureaucratic corruption. This year he is writer in residence at Trinity College in Hartford, Connecticut. His book is due in October from Harvard University Press.

AUSTRIA

International Mozart Competition

YOUNG PIANISTS, SINGERS, AND VIOLINISTS of professional level and of all nationalities may enter the fifth international Mozart Competition to be held in Salzburg Jan. 25-Feb. 5, 1991. It is open to singers born after Jan. 15, 1957, and pianists and violinists born after Jan. 15, 1959. Entry forms, due by Oct. 1, 1990, may be obtained through the Austrian Press and Information Service, 31 East 69th St., New York, NY 10021, or Internationaler Mozart-Wettbewerb, A-5020 Salzburg, Mirabellplatz 1, Austria.

POLAND

Privatization Pioneer

THE RISE OF PRIVATIZATION OF INDUSTRY in Eastern Europe may see some of its earliest success in Poland, according to Kazimierz Poznanski, a University of Washington professor of international studies who lectured to the Institute for East-West Security Studies earlier this year. Poland is unusual among East bloc

132718

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12 April 1990

Dr. John H. Sununu
Chief of Staff
White House
Washington, DC 20500

Dear John:

I enjoyed meeting with you, Allan Bromley, and Dan Albritton on 30 March. I hope we are making progress in answering your questions about climate models. Your comments are well taken on the need for adequate vertical, as well as horizontal, resolution in climate models.

If I recall correctly, you wanted to know what happens, in terms of slowing down greenhouse warming, when we increase the depth of the upper ocean (where most of the additional heat goes). The atmospheric radiative forcing part of the model allows for solar and infrared radiation with clouds (Kiehl et al., 1987). Solar radiation is generally broken down into two regions—one is between 0–0.9 μm and is usually denoted ultraviolet and visible; the other is 0.9–4.0 μm and is denoted near-infrared. In the present calculation, we make this division into 0.0–0.9 μm and 0.9–4.0 μm intervals. The model includes fractional clouds, absorption by gases in the ultraviolet, absorption by ozone in the visible spectral regions, carbon dioxide, water vapor, oxygen, cloud-level liquid water, and albedos (that is, reflectance of clouds and the surface).

After averaging out horizontal effects, we set forth the basic physics of the climate model (see enclosed reprint by Dickinson, 1981), where steady-state global temperature change ΔT , due to a change in external heating ΔQ in the climate system, gives

$$\Delta T = \frac{\Delta Q}{\lambda}, \quad (1)$$

where λ is the feedback describing the change of outgoing thermal and reflected solar radiation at the top of the atmosphere. If λ is large, then the temperature change is small and vice versa. Various National Academy studies estimate that (approximately) $\lambda \simeq 2 \text{ W m}^{-2} \text{ K}^{-1}$.

In time-dependent form, (1) becomes

$$C \frac{\partial T}{\partial t} + \lambda T = \Delta Q, \quad (2)$$

where C is the heat capacity of atmosphere-ocean climate system. Because the climate system has several sub-systems, such as the atmosphere and the oceans with different heat capacities, it is better to separate them into two equations for each medium, that is,

$$C_a \frac{\partial T_a}{\partial t} + \lambda_{am}(T_a - T_m) + \lambda T_a = \Delta Q, \quad (3)$$

$$C_m \frac{\partial T_m}{\partial t} + \lambda(T_m - T_a) = 0, \quad (4)$$

where T_a and T_m are atmospheric temperature and ocean mixed-layer temperature; C_a and C_m are heat capacities of the atmosphere and ocean mixed layer; λ_{am} is the feedback parameter between the atmosphere and ocean mixed layer (estimated $\simeq 50 \text{ W m}^{-2} \text{ K}^{-1}$). The latter term allows transfer of heat for the atmosphere and ocean. The following table provides quantitative measures of the parameters:

Medium	Mass ($\times 10^3 \text{ Kg m}^{-2}$)	Heat Capacity ($\text{W m}^{-2} \text{ year K}^{-1}$)
Atmosphere	14	$C_a = 0.45$
Ocean mixed layer (81 m)	81	$C_m = 10$

The solution to (3) and (4) can be simplified by combining the two first-order ordinary differential equations into one second-order ordinary differential equation that can be solved by a simple Runge-Kutta numerical method incorporated into the computer program.

In determining climate change in this simple model, we first estimated λ from a radiative column model by using, say, a vertical profile of tropical atmospheric temperature. The climate sensitivity factor is obtained from variations of the net radiative flux at the tropopause due to changes in temperature and moisture. Thus,

$$\lambda = \frac{dF^N}{dT} = \frac{\partial F}{\partial T} + \frac{\partial F}{\partial q} \frac{dq}{dT} + \frac{\partial S}{\partial q} \frac{dq}{dT}. \quad (5)$$

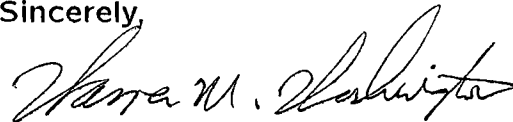
The quantities $\partial F/\partial T$, $\partial F/\partial q$, and $\partial S/\partial q$ are obtained from the column radiation model. dq/dT is estimated from the assumption of fixed relative humidity. Calculations from the column model yield a value of $\lambda \simeq 2 \text{ W m}^{-2} \text{ K}^{-1}$. Once λ has been determined, it can be used in (4) to obtain a change in the ocean mixed-layer temperature for a given forcing ΔQ . For example, a doubling of carbon dioxide yields $\Delta Q \simeq 4 \text{ W m}^{-2}$. Thus, from (1) the equilibrium temperature change would be expected to be $\Delta T \simeq 2^\circ\text{K}$.

The time-dependent evolution of ΔT can be obtained from the computer model of the mixed-layer temperature change described above. The column radiation model can also be used to calculate ΔQ for other carbon-dioxide concentrations. A note of caution, however—Figures 2.12 and 2.13 (enclosed) show that the upper mixed layer of the ocean is approximately 70 m or so. Our knowledge of the ocean's thermal structure indicates that, except in the high latitudes, only the upper mixed layer of the ocean is involved in greenhouse warming. The latest 3-D climate models support this. In fact, in the greenhouse warming scenario, the ocean becomes more statically stable and contains less coupling between the top and bottom, except for some regional features in the high latitudes.

Several sample computations with the 1-D model with different ocean depths are enclosed.

Next week I will be attending meetings in Washington, DC, including the White House Conference on Science and Economics Research Related to Global Change. I will bring along a floppy disk containing a 1-D model with interactive oceans, and, at your convenience, I could install the model on your computer.

Sincerely,



Warren M. Washington, Director
Climate & Global Dynamics Division

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Fax: (303) 497-1137

E-Mail: warren.washington@ncar.ucar.edu

Enclosures:

1. Figures 2.12 and 2.13
2. Documentation of the column radiation and cloud model
3. Reprint by Robert Dickinson on simple climate model

cc: D. Allan Bromley
Nancy Maynard
Daniel Albritton

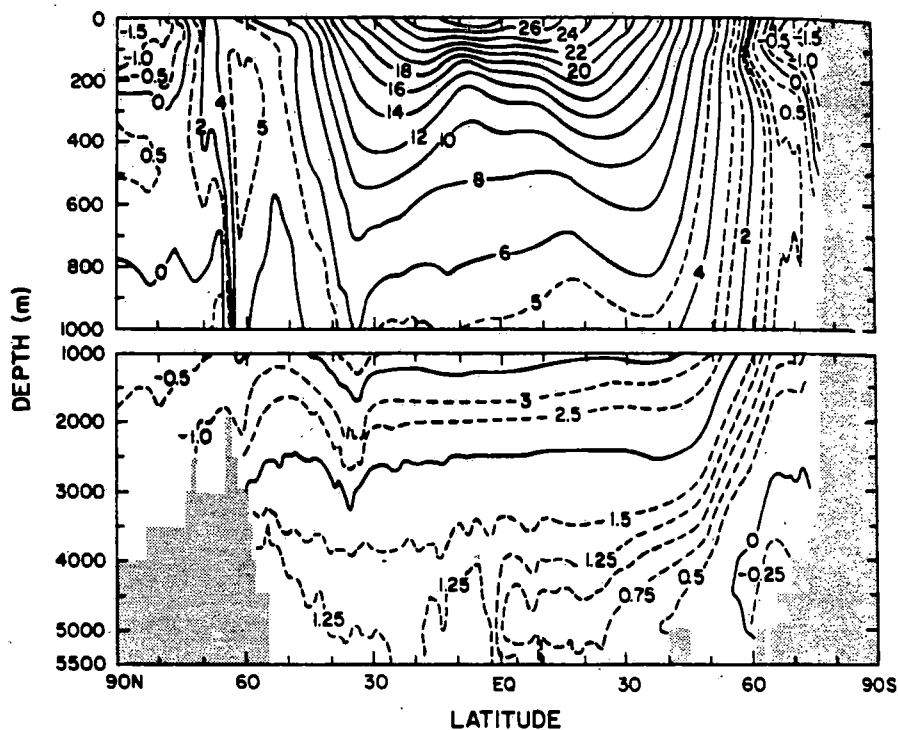


Fig. 2.12 Annually averaged ocean potential temperature (in $^{\circ}\text{C}$) as a function of latitude and depth. [Redrawn from Levitus (1982).]

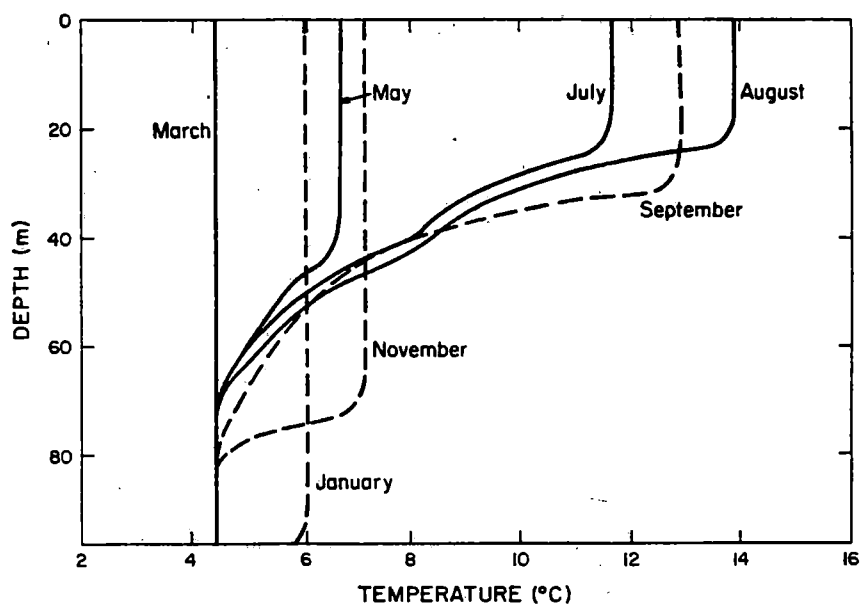


Fig. 2.13 Standard ocean temperature profiles in the Northern Hemisphere mid-latitudes in January, March, May, July, August, September, and November. [After Knauss (1978).]

166376

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7 August 1990

Dr. John H. Sununu
Chief of Staff
White House
Washington, DC 20500

John
Dear John:

Enclosed is a copy of part of my presentation to Prime Minister Margaret Thatcher during her visit to the National Center for Atmospheric Research on 3 August 1990. The material contains some new results not yet published that may be of interest to you on the subject of regional climate change. Obviously, the research should be viewed as preliminary until published.

Sincerely,



Warren M. Washington, Director
Climate & Global Dynamics Division

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E-Mail: ccm@ncar.ucar.edu

Enclosure

SUMMARY OF PRESENTATION TO
PRIME MINISTER MARGARET THATCHER
OF THE UNITED KINGDOM

3 August 1990

By Warren M. Washington and Gerald A. Meehl
Climate and Global Dynamics Division
National Center for Atmospheric Research
Boulder, Colorado U.S.A.

A BRIEF DESCRIPTION OF NEW NCAR RESULTS
ON REGIONAL CLIMATE CHANGE CAUSED BY
INCREASING GREENHOUSE GASES

In a cooperative effort,¹ scientists from Australia, the United Kingdom, NCAR, and NOAA/GFDL have intercompared meridional differences between model simulations and observed temperature changes. Figure 1 shows the observed annually averaged temperature change from the ten-year period 1978–1988 minus 1963–1973. Note the general pattern of warming in the lower atmosphere (below 300 mb, about 10 km) and cooling in the stratosphere (above 100 mb). This pattern can be compared with computer simulations of the final (equilibrium) greenhouse effect for doubled carbon dioxide (CO₂) from model simulations by GFDL, NCAR and UKMO shown in Figure 2. Although the magnitudes are quite different (as expected, owing to possible errors in the data and because CO₂ has not doubled), the overall regional pattern of the simulations has some correspondence to the observed. Clearly, the observed changes cannot be connected uniquely with the changes due to increased greenhouse gases.

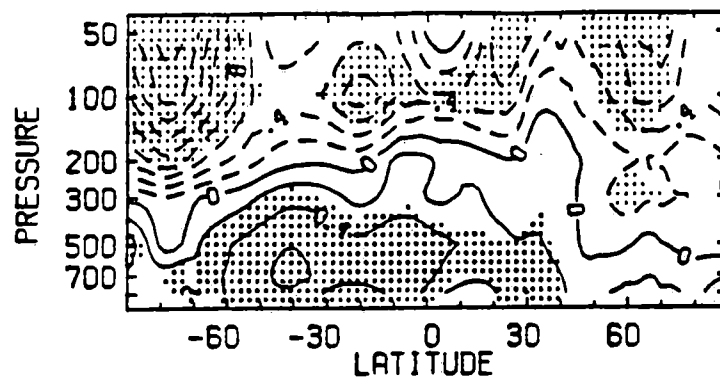
We have recently extended our coupled atmosphere-ocean climate model experiment with slowly increasing CO₂ to nearly 50 years (see our earlier study in *Climate Dynamics*, 4, 1–38, 1989). This extension allows further examination of global and regional surface air temperature changes. We have calculated five-year seasonal means from year 26 to year 45 to determine whether or not clear regional warming is evident for particular seasons. Five-year means were used rather than individual one-year seasonal means because the tropical Pacific El Niño and La Niña events produced by the coupled model can profoundly affect mid- and high-latitude regional patterns on the scale of individual years.

¹David J. Karoly, Jennifer A. Cohen (Centre for Dynamical Meteorology, Monash University, Clayton VIC 3168, Australia), Gerald A. Meehl (NCAR, Boulder, CO 80307), John F.B. Mitchell (Hadley Climate Prediction and Research Centre, Bracknell, Berkshire, UK), Abraham H. Oort, Ronald J. Stouffer (NOAA/GFDL, Princeton University, Princeton, NJ 08542).

The following figures show the regional five-year differences between the gradually (1% per year) increased CO₂ experiment and the control with a constant concentration of CO₂ at 330 ppm. (One percent per year roughly accounts for the combined heating effect of all greenhouse gases, such as CO₂, methane, chlorofluorocarbons, and nitrous oxide, etc.) Figure 3 shows the summer and winter differences and Figure 4 the spring and autumn differences. Winter, spring, and autumn seasons have the greatest warming. There is, however, regional cooling over parts of the globe even with five-year mean patterns. T. Karl of the National Oceanic and Atmospheric Administration provided Figure 5, which exhibits the largest absolute difference in five-year averaged December, January, February observed surface air temperatures (taken from 1945 to 1984). As depicted in this figure, the observed five-year means are capable of large differences of roughly the same magnitude as those from the model. Recently, K. Trenberth of NCAR (*Bull. Amer. Meteorol. Soc.*, Vol. 71, No. 7, 988-993, July 1990) has shown large regional changes in the observed interdecadal surface temperatures over the Northern Hemisphere. These observed studies underscore the difficulty we face in identifying the "fingerprint" of greenhouse warming from short climatic records.

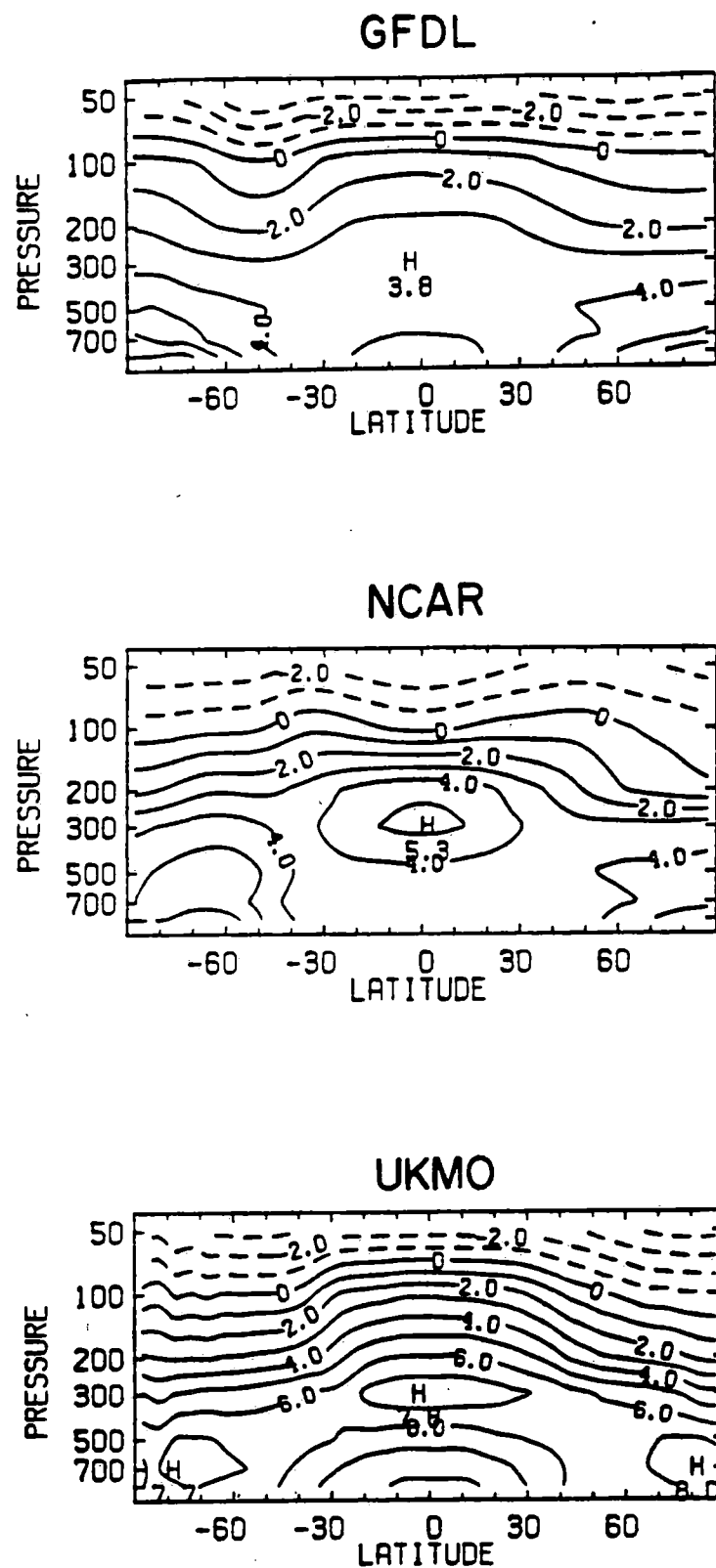
In Figure 6, a ten-year (31-40) annual mean temperature difference simulated in our transient CO₂ experiment shows general warming, especially at high northerly latitudes for this period. Also shown in Figure 6 are annual mean differences for the ten-year period (years 31-40) from an experiment in which CO₂ is instantaneously doubled (2×CO₂) at year 1. The 2×CO₂ difference from the control shows approximately the same regional pattern as the transient experiment. It is interesting that consistent regional warming patterns are evident in the longer averaged annual means but not in the seasonal five-year means.

The new results suggest that, in order to observe the regional greenhouse-effect signal, we may have to consider changes in seasonal means only for periods substantially longer than five years. Changes over shorter periods may reflect natural variability much more than the transient greenhouse buildup. Future climate models with increased resolution and improved treatment of climate processes, such as clouds, will have to contend with the large natural variability of five-year or, perhaps, decadal time scales of regional patterns. This will make establishment of clear and consistent regional and seasonal greenhouse effects more difficult than previously believed. In addition, these results hint at the possibility that identification of regional greenhouse effects in the observed data may also be more difficult to verify on a seasonal basis than on an annual basis.



OBSERVED (OORT, 1983)
TEN YEAR ANNUAL MEANS
1978-88 MINUS 1963-73

Figure 1. Observed zonal mean temperature differences between ten-year averages for period 1978-1988 minus 1963-1973 from the global analysis data set of Oort (1983). Solid lines are warming and dashed lines are cooling. Contours are 0.2°C.



ANNUAL MEAN TEMPERATURE DIFFERENCE

Figure 2. Zonal mean annual atmospheric temperature differences between equilibrium doubled CO₂ and control climate model simulations with (a) GFDL, (b) NCAR, and (c) UKMO models. The contour interval is 1°C and negative contours are dashed.

TRANSIENT MINUS CONTROL CLIMATE MODEL EXPERIMENT
(5 Year Means Temperature Difference - °C)

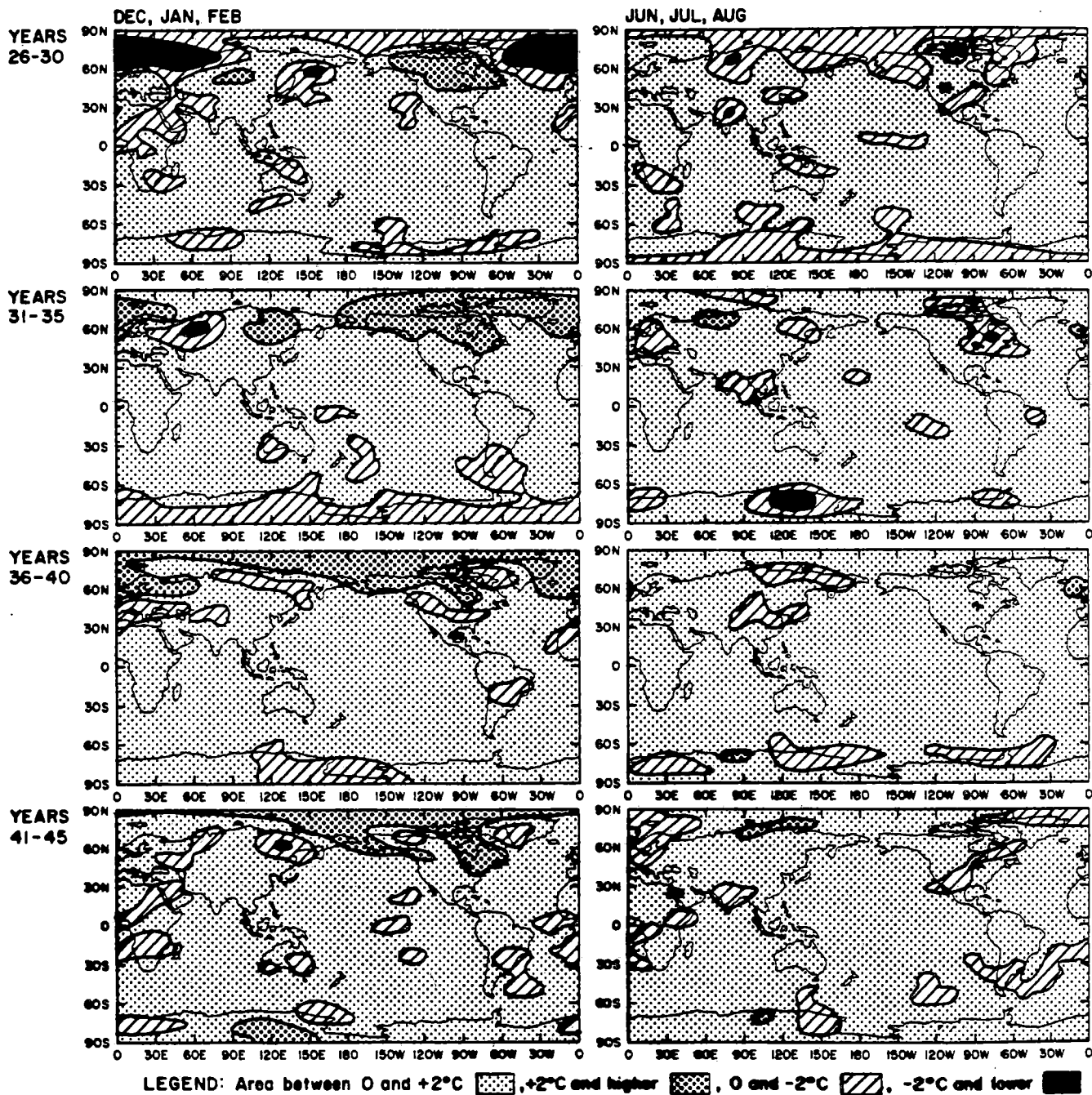


Figure 3

TRANSIENT MINUS CONTROL CLIMATE MODEL EXPERIMENT
(5 Year Means Temperature Difference - °C)

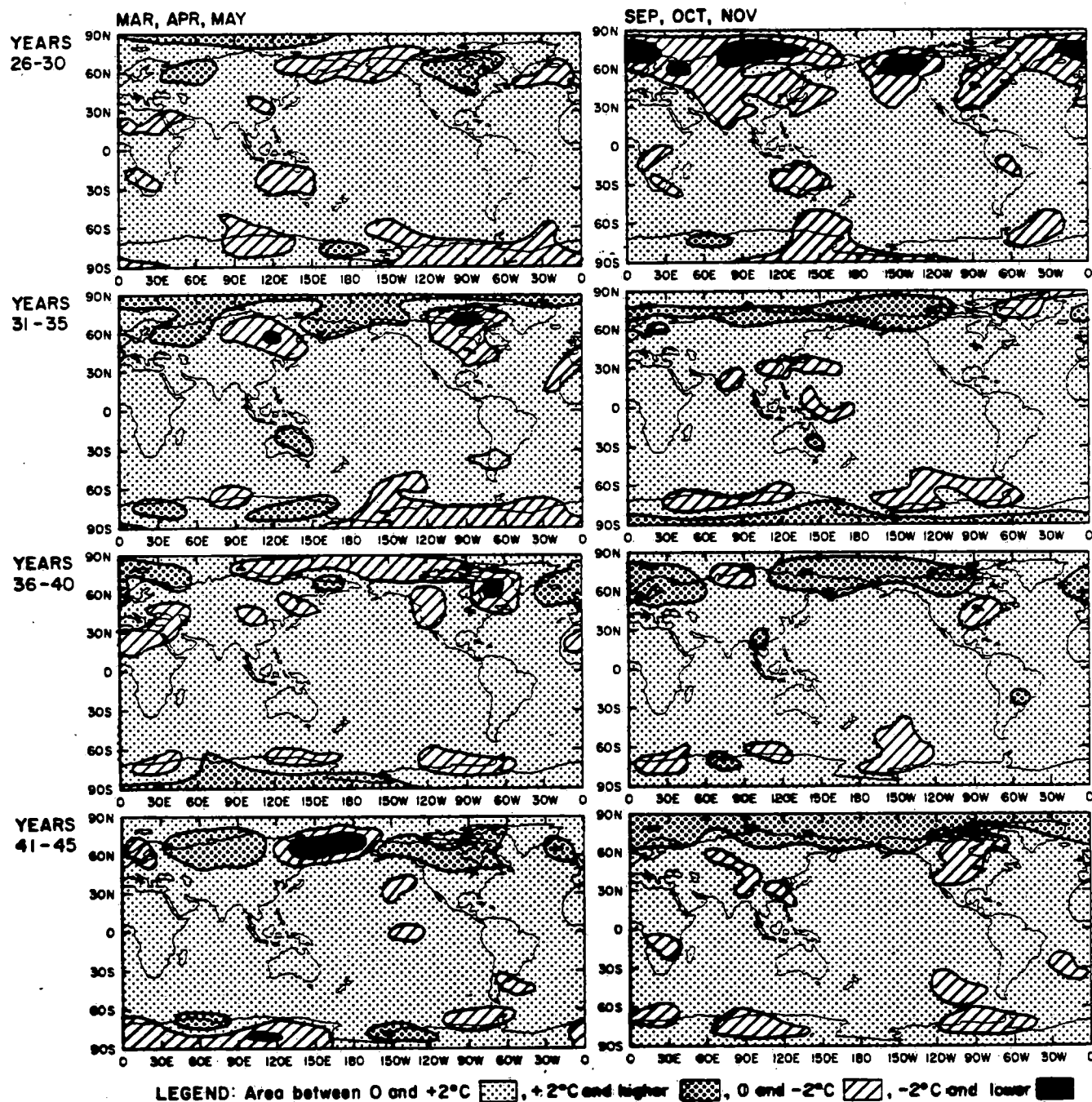
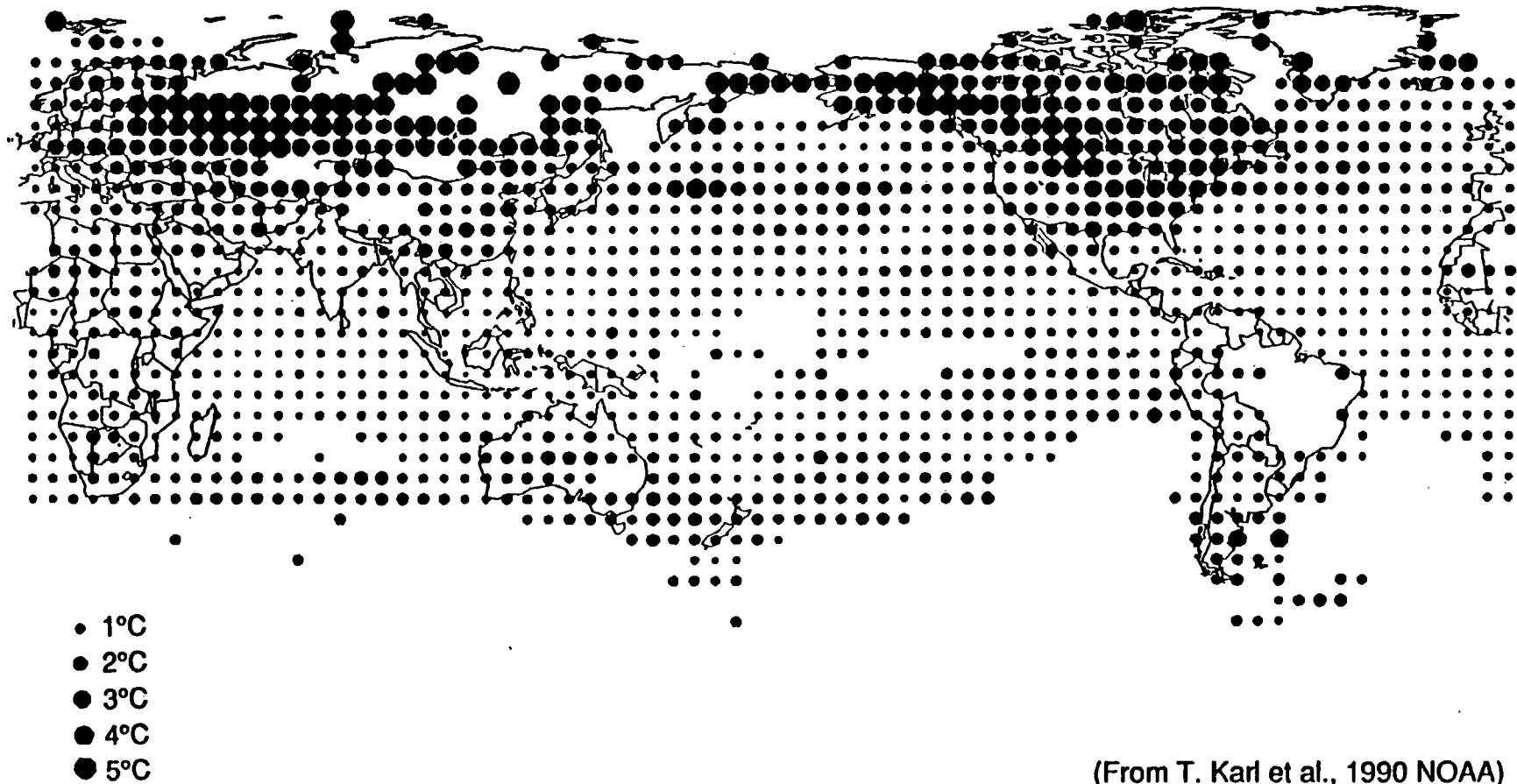


Figure 4

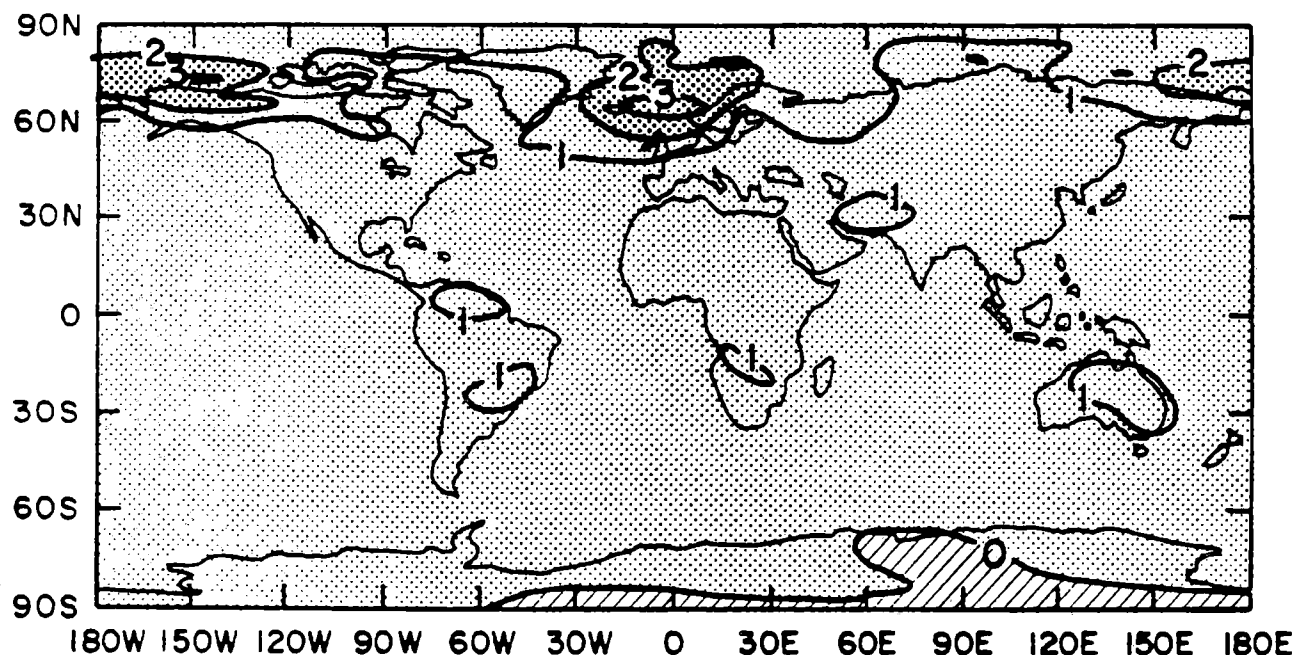
OBSERVED DATA
Largest Absolute Differences Between Five-Year Averages
Between 1945 and 1984, December, January, February



(From T. Karl et al., 1990 NOAA)

Figure 5

**TRANSIENT MINUS CONTROL EXPERIMENTS
10 YEAR MEAN (years 31-40)**



**2x CO₂ MINUS CONTROL EXPERIMENTS
10 YEAR MEAN (years 31-40)**

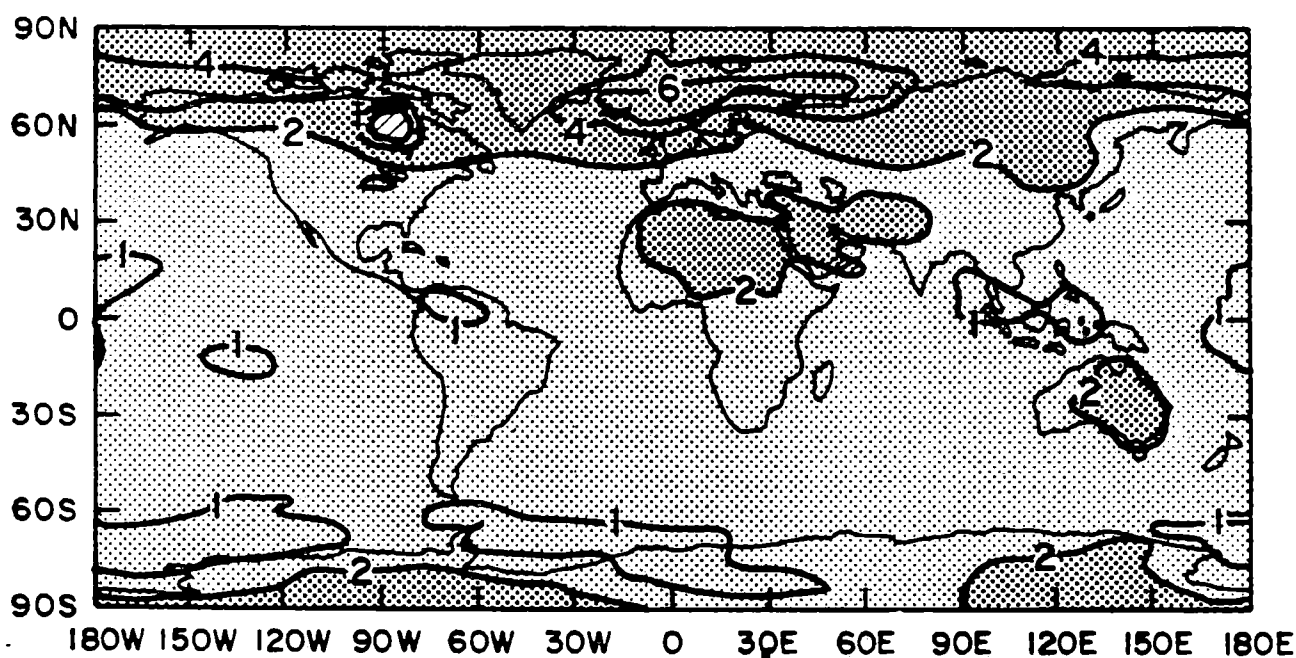


Figure 6

Sea Level and Climate Change

ERIC J. BARRON

Pennsylvania State University

STARLEY L. THOMPSON

National Center for Atmospheric Research

INTRODUCTION

It has long been suggested that a change in global sea level produces a change in climate. This hypothesis receives substantial support from the geologic record of sea-level change. Over a broad range of time scales (10^4 to 10^7 yr), eustatic sea level and continental flooding are well correlated with paleoclimatic data, particularly during the past 100 million yr (m.y.).

The relationship between sea level and climate has three components. First, climate directly influences sea-level variations largely through the processes that control the growth and decay of continental ice. At peak glaciation 18,000 yr ago, approximately one-sixth of the planet was covered by ice and continental glaciation, and sea level was lower by 85 to 130 m than it is at present (CLIMAP, 1976).

Second, a variety of physical mechanisms exist whereby sea-level changes can directly affect global climate. By changing the nature of the atmosphere-surface interface, sea-level changes can alter the transfer of heat, moisture, and momentum between the surface and the atmosphere. In addition, sea level can alter ocean currents by introducing or removing geographic barriers. Ocean currents are a principal means of transferring heat from the tropics to polar regions and play a crucial role in controlling some regional climates of the present. Other potential direct influences of sea level on climate include effects on ice

sheet size, ocean chemistry, and atmospheric content of carbon dioxide and other trace gases.

Third, the correlation between sea level and climate during Earth history may be the product of an indirect association. One plausible indirect link is a relationship between increased volcanism, higher atmospheric carbon dioxide levels, and high global sea level caused by rapid sea-floor spreading (Berner *et al.*, 1983). In this case, climate change would be directly related to changes in carbon dioxide levels, and the correlation of climate change with sea level would not be indicative of a direct cause-and-effect relationship.

Only the direct influence of sea level on climate and the indirect association between sea level and climate are considered here. The direct influences of climate on sea level, through land ice volume or ocean temperature change, are considered in Chapters 10 and 13 (this volume), respectively. Simulations with global dynamical climate models and examples from the paleoclimatic record provide insight into the importance of various physical mechanisms and the explanations of correlation between climate and sea-level variations during earth history.

DIRECT EFFECTS OF SEA LEVEL ON CLIMATE

The potential direct effects of sea level on climate can arise from physical mechanisms that fall into at least five categories: (1) regional changes in atmosphere-surface

coupling, (2) changes in ocean circulation, (3) changes in surface heat capacity, (4) changes at ice sheet-ocean margins, and (5) changes in ocean-atmosphere chemical composition. The mechanisms are listed roughly in order of increasing uncertainty, although insufficient work has been completed in the investigation of the climatic effect of sea-level changes in every category. Hence the discussion that follows will necessarily rely heavily on work not originally conducted with an eye to sea-level change. In some cases, educated speculation will have to suffice until more research specific to the problem of sea level and climatic change is conducted.

More is known about atmosphere-surface coupling than the other four categories, perhaps because atmospheric and oceanographic scientists have studied and modeled the general problem for many years. Ocean circulation modeling has also been conducted for many years, but the level of detail required for comprehensive study of the global effects of sea-level change has exceeded the capability of even the largest computers. [Current global ocean models use about a 500-km grid. Typical sea-level changes (over geologic time) produce coast line changes on the order of 100 to 1000 km. Thus sea-level changes are either subgrid scale or, at best, barely resolvable (hence poorly treated) by current global ocean models.] Changes in ice sheet volume are usually thought of as influencing sea level; interest in the influence of sea level on ice sheets is relatively recent. Likewise, it is uncertain how sea-level changes can have a direct impact on ocean-atmosphere chemical composition, but such composition changes, if they exist, could cause substantial changes in global climate by altering the "greenhouse" effect.

Atmosphere-Surface Coupling

Virtually every facet of Earth's climate is controlled or affected by the transfer of heat, moisture, and momentum between the atmosphere and the underlying surface. For example, most of the heat that drives the atmospheric circulation is first absorbed as solar energy at the surface and then made available as sensible heat (direct temperature change) and latent heat of condensation (heat released when evaporated moisture condenses to form rain or snow). Furthermore, the long-term circulation of the atmosphere is constrained to conserve absolute angular momentum. Momentum transferred to the Earth when the atmosphere "rubs" against the surface must be balanced by a reverse momentum transfer elsewhere arising from changes in wind speed and direction. Surface easterly winds represent absolute momentum transfer from the Earth to the atmosphere, and surface westerlies vice versa. Changes in the regional distribution of surface "roughness" can di-

rectly affect local surface winds and, owing to the momentum conservation constraint, global wind patterns as well.

Surface Heat and Moisture Balance Heat balances typical of three surface types are shown in Figure 11.1. In general, the surface of the Earth receives a net positive flux of radiant energy (a gain of solar energy minus a loss of infrared energy) that is balanced by sensible heat and evaporative losses. Land in the subtropics is relatively dry and has a relatively high albedo, that is, reflectivity for solar energy. Most of the net radiative gain is balanced by sensible heat loss owing to the lack of moisture to be evaporated. In contrast, the adjacent subtropical oceans have low albedo and lose heat almost exclusively by evaporation. Changing subtropical land to ocean, e.g., by a sea-level increase, would produce a major change in the amount of heat and moisture received by the overlying atmosphere, perhaps producing a change in regional climate. As Figure 11.1 shows, near equatorial land is qualitatively similar to ocean because abundant vegetation makes it relatively dark and moist. Thus changing equatorial-type land to ocean would produce a smaller climatic effect than changing subtropical land to ocean.

A local change in albedo of the surface can produce a large effect on the local surface energy balance, but what effect can it have on global-scale climate? A simple analy-

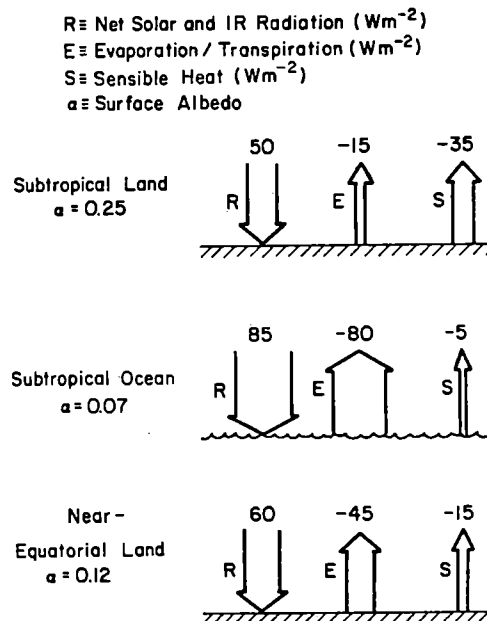


FIGURE 11.1 Heat balances for some representative surface types. On average, net radiative heating of the surface is balanced by evaporative and sensible heat loss. Evaporation is the preferred mode of heat loss at warm temperature; thus subtropical oceans lose heat mainly through evaporation.

sis based on our current understanding of global climate theory suggests that a global change in surface albedo of 0.01 will produce about a 1°C change in surface temperature. The effect of less than global-scale changes in surface albedo will be smaller in general, but requires detailed modeling calculations to determine the actual sensitivity.

We can now make a rough estimate of the effect of sea-level change on surface albedo and temperature. Suppose that in a latitude zone with an initial land fraction of 0.4, a sea-level rise reduces the land area fraction to 0.3 (a rather large change, probably requiring a sea-level increase well in excess of 100 m). Assume also that the difference in surface albedos between the covered land and the ocean is 0.1. The average change in surface albedo in the zone is thus $(0.4 - 0.3) \times 0.1 = 0.01$. The predicted rise in surface temperature of the zone (assuming no interaction with adjacent zones or other effects) is about 1°C . Thus a major change in sea level is not likely to cause a large change in global-scale surface temperature from an albedo effect only. This approximate result is confirmed by more detailed calculations by Thompson and Barron (1981) that examined the effect on albedo of shifting the continents to the positions they had 100 m.y. ago (Ma). Factor of 2 changes in land area in the subtropics produced a change of only a few watts per square meter (W/m^2) in the surface energy budget of the zone.

Referring again to Figure 11.1, we see that plausible changes in surface wetness can produce much larger changes in the surface energy balance than can plausible changes in albedo. Sea-level change provides an ideal way to produce an extreme change in surface wetness. No calculations have been done with global climate models in which sea level has been changed and only surface wetness has been allowed to vary (i.e., no albedo changes or other effects). Thus it is difficult to say just how important changes in wetness are compared to albedo changes, but we can get some indication from simulation studies that have changed land surface properties to investigate other problems. Shukla and Mintz (1982) performed two simulations with a global climate model: one in which all land was assumed to be completely dry (no evaporation allowed) and the other assuming land to be completely wet (like the ocean). Thus the simulations can give an indication of what might happen if very dry desert were changed to ocean without any albedo change. The calculations showed the dry land case producing summer land surface temperatures 10° to 20°C higher than the wet case. Clearly, evaporation from the surface can have a powerful cooling effect.

Moisture flux from the surface not only transports heat but causes changes in atmospheric water vapor content that can affect cloudiness and precipitation. Yeh *et al.*

(1984) have done simulations with a global climate model in which soil moisture was perturbed to see the effect on surface temperature and rainfall. They found, in general, that increased surface evaporation led to increased precipitation, but not necessarily in the same region as the increased evaporation. Increasing evaporation in a surface divergence region (a region of downward air motion) led to increased precipitation in adjacent convergence regions, but not locally. The explanation of the effect is that it is difficult to form precipitation in regions of downward motion regardless of the amount of water vapor in the air. Excess humidity in subsidence regions is moved by winds to regions of upward motion and then rained out. More recently, Gordon and Hunt (1987) have further emphasized the role of simulated surface hydrology and precipitation patterns.

From the above discussion, it can be concluded, for example, that replacing land with ocean in the normally dry subtropics might not lead to any local rainfall increase, but might instead produce increased equatorial rainfall. Aside from noting these potential local and nonlocal mechanisms, more specific statements cannot be made about the effects of sea-level change on rainfall without more-detailed global climate model calculations.

What happens if surface albedo and moisture availability are changed simultaneously? Henderson-Sellers and Gornitz (1984) performed climate model experiments in which the effects of Amazon deforestation were examined. The deforestation was simulated by changing the surface albedo from 0.11 to 0.19 and by greatly decreasing the potential for surface evaporation and transpiration. These changes are similar to what one would expect from a sea-level drop, i.e., replacing sea with land. The researchers found that there was no net surface temperature change in the deforested area. The surface albedo and wetness changes for this particular case produced nearly complete compensating effects. There was, however, a local decrease in rainfall of about 10 percent over the deforested area, as expected from the discussion above. There were no global-scale climate effects that could be reliably detected above the normal model variability. Even though these results are only suggestive, they do indicate that the direct climate effect of large sea-level changes may not be large even on regional scales.

Surface Roughness The transfer of heat, moisture, and momentum between the atmosphere and surface is proportional to the surface drag coefficient (C_D), a nondimensional quantity that expresses the proportionality between the friction force per unit area at the surface and the square of the surface wind speed. The value of C_D is strongly dependent on the "roughness" of the surface as measured by the characteristic height of surface protrusions such as

TABLE 11.1 Typical Values of Surface Drag Coefficient, C_D ($\times 10^{-3}$) (from Garratt 1977)

	C_D
Ocean	
Wind speed 5 m/s	1
Wind speed 20 m/s	2
Land	
Desert	3
Tropical forest	25
Typical	10

rocks or plants. Typical values of C_D for land and ocean are given in Table 11.1. In general, the drag coefficient over ocean is an order of magnitude smaller than it is over land. This has the effect of (a) tending to produce decreased surface fluxes over ocean and (b) producing a higher surface wind speed over ocean by way of compensation. [Substantial momentum transfer between the Earth and the atmosphere is also created by large-scale orography, the so-called "mountain pressure torque" (see Holton, 1979, pp. 264–265). It is unlikely that reasonable sea-level changes alone would produce climatologically important changes in topographic heights relative to sea level.]

It is not clear what effect a change in sea level could have on large-scale climate through a change in C_D . Some sensitivity studies with climate models (e.g., Hansen *et al.*, 1983) have shown that the simulated climates are not very sensitive to C_D . On the other hand, it is well known that changes in momentum exchange at the surface can have a substantial effect on atmospheric circulation systems (Holton, 1979, p. 260). It is not possible at this time to say how important sea-level-induced changes in surface roughness are in relation to changes in albedo or wetness.

Combined Surface Effects Barron and Washington (1984) performed two climate model simulations for continental positions of 100 Ma. One case was for present day sea levels and the other included a sea level estimated to be 330 m higher than the present that is thought to have occurred during the Cretaceous period. This is a massive sea-level increase that would have caused a 20 percent decrease in global land area. Barron and Washington found that the sea-level change produced systematic local climate changes only in the subtropics and tropics. In these regions, changing land to ocean produced local cooling (the evaporation increase outweighed the albedo decrease) and slight warming elsewhere. Zonally averaged temperatures changed by less than 2°C at any latitude (see Figure 11.2). The global net effect on surface tem-

perature was small. The postulated change in Cretaceous sea level produced a smaller global climate effect than did correspondingly large changes in topography and continental positions.

Ocean Circulation

In a number of instances, sea-level changes have been invoked as a mechanism of modifying the ocean surface and thermohaline circulations. The sea-level ocean circulation mechanism involves bathymetric control of current directions, importance of barriers in basin-basin communication, and the role of shallow epicontinental seas and marginal basins in the formation of deep water. Each example cited below illustrates the potential for sea-level changes to influence climate, but none of the studies to date provides quantitative links between sea-level-induced circulation changes and climate change.

The high-velocity core of the Gulf Stream scours the Blake Plateau, producing a 50- to 75-km-wide band of erosional topography. Pinet and Popenoe (1982) used seismic stratigraphy and a series of drill holes to show that the axis of the Gulf Stream has shifted hundreds of kilometers repeatedly during the past 20 m.y. The position of the Gulf Stream axis is well correlated with sea-level

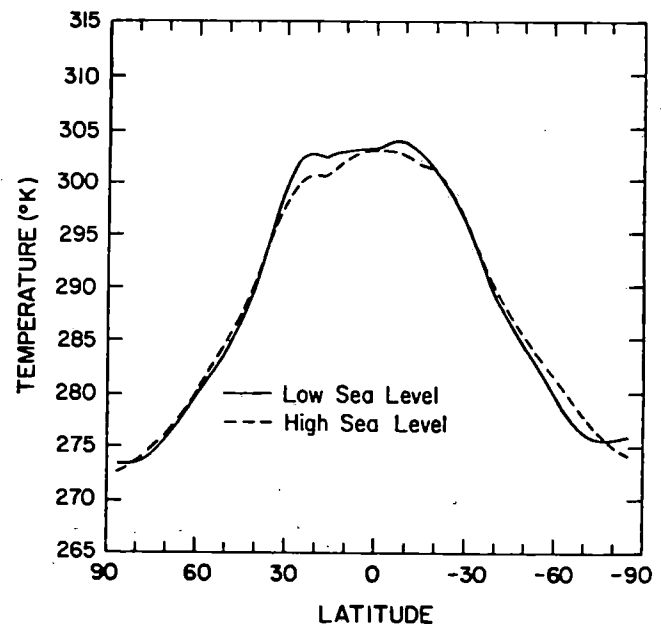


FIGURE 11.2 A comparison of the zonally averaged surface temperature for a general circulation model experiment with Cretaceous continental positions with low sea level (present-day total area) and no topography and an experiment with Cretaceous continental positions with high sea level (about 20 percent of continental area flooded) and no topography.

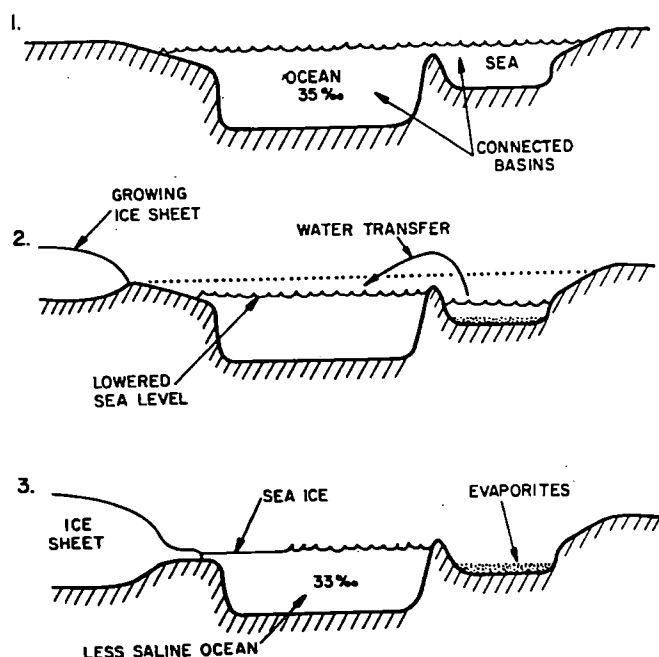


FIGURE 11.3 A hypothetical example of the potential for sea-level change to affect climate through a mechanism that relies on isolation of ocean basins. (1) The world ocean and a subtropical sea communicate across a shallow strait. (2) A global climate change induces ice sheets to grow. Lowered sea level isolates the subtropical sea, which begins to evaporate. Fresh water is transferred to the world ocean by precipitation. (3) Lower salinity of the world ocean promotes a sea ice increase, which acts as a positive feedback to the global cooling.

variations. During lowstands of sea level, a broad bathymetric bulge, called the Charleston bump, deflects the Gulf Stream offshore to a position across the Blake Plateau and along the steep continental slope just north of the Blake Spur. During sea-level highstands, the Gulf Stream parallels the Florida-Hatteras Slope. The Gulf Stream has a notable impact on regional climates, thus the potential for climate change. However, the extent of possible climatic change due to such movements in current direction in response to sea-level variation is unknown.

The elevation of a barrier above sea level or subsidence of a ridge below sea level has been cited as a mechanism of climatic change in numerous instances. The subsidence of the Greenland-Iceland-Faeroe Ridge (about 38 Ma) probably resulted in a significant interaction between the Arctic and Atlantic oceans; subsidence of the Walvis Ridge off South Africa (about 20 Ma) greatly influenced the Benguela current system; and formation of the Isthmus of Panama (about 2.3 Ma) eliminated equatorial Atlantic-Pacific flow (Berggren, 1982). Berggren stressed the role of ocean gateways in modifying heat transport by the oceans. Sea-level variations have the potential to have

breached or created surface circulation barriers during Earth history, but few instances related specifically to sea level are documented, and in every case the climatic implications are qualitative.

Sea-level change can isolate or reconnect small basins. Particularly in subtropical high-evaporation zones or regions where precipitation greatly exceeds evaporation, isolation of a basin from the main ocean can result in large density contrasts (i.e., hypersalinity or freshening of the basin). Thierstein and Berger (1978) hypothesized that reconnection of a temporarily isolated basin can result in an injection event that favors either abyssal stratification or surface stratification depending on the salinity characteristics. Brass *et al.* (1982) showed that deep water can form in marginal seas in the subtropics due to high evaporation (warm, salty bottom water). These authors suggest that changes in the size and configuration of marginal seas in the subtropics owing to sea-level change may have controlled deep-water formation during different periods of earth history. Deep water tends to form in semirestricted basins or marginal seas because the isolation allows the water mass to obtain different density characteristics, through atmospheric interaction, in comparison with the main ocean. These marginal seas are certainly susceptible to sea-level variations that may modify their size and configuration. Basin isolation and induced salinity variations may also result in climate change because fresh water freezes more readily (see hypothetical example in Figure 11.3). The potential of this mechanism to modify climate is largely unexplored.

Annual Temperature Cycle

The heat capacity or thermal inertia of the surface is a strong determinant of the annual cycle of temperature at a given latitude. The thermal inertia of the ocean is dependent on the depth of the mixed layer, ranging from tens of meters to in excess of 200 m. In contrast, the thermal inertia of land is roughly equivalent to a 1.0-m depth of water. Extensive continental flooding is likely to modify the local thermal inertia, and hence influence the annual cycle of temperature.

In experiments using the seasonal zonal energy balance climate model of Thompson and Schneider (1979) to investigate the contrast between the climate of the Cretaceous and that of the present (Barron *et al.*, 1981), the changes in land fraction associated with Cretaceous geography resulted in a 3° to 5°C reduction in the amplitude of the annual cycle of surface temperature in the Northern Hemisphere mid-latitudes (i.e., the summers were cooler and winters warmer than present). The mid-latitude ocean fraction increased by approximately 20 percent in the Cretaceous case. In this model the zonal thermal inertia

was computed from an area-weighted harmonic mean assuming no land-sea heat transfer within a zone.

More recently, the general circulation model experiments with Cretaceous geography and mean annual isolation of Barron and Washington (1984) have been extended to a seasonal mixed-layer experiment. The zonally averaged amplitude of the annual cycle of surface temperature in the Northern Hemisphere mid-latitudes was reduced 4° to 8°C in comparison with a present-day control experiment. The largest component of this zonally averaged difference is regions that were land initially but become oceanic when the sea level was increased. If this component of the zonal average is removed, the change in amplitude is 1° to 3°C.

The above two simulations illustrate the potential for sea-level fluctuations to produce changes in seasonality. However, each experiment described above includes a number of variables that could influence seasonality (e.g., ice-albedo feedback), and consequently the importance of thermal inertia has not been isolated.

Ice Sheets

The influence of sea level on ice sheets became a topic of interest when the potential instability of the present West Antarctic Ice Sheet became widely known. This ice sheet is the smaller of two major ice masses covering Antarctica. Unlike the East Antarctic Ice Sheet, the western ice sheet is mostly grounded below where sea level would be if the ice were removed. Apparently, the ice sheet exists only because floating ice shelves at its edge act as buttresses to prevent the ice sheet from quickly flowing out into the ocean. These ice shelves are themselves stabilized by friction against protruding islands, underwater rises, and the sides of the bays in which the shelves sit. Such marine ice sheet-shelf systems have been shown to be potentially unstable to perturbations such as ocean warming or sea-level rise (Thomas *et al.*, 1979).

Evidence and modeling studies (Thomas and Bentley, 1978) indicated that the West Antarctic Ice Sheet was much larger 18,000 yr ago during the height of the last glacial episode. This increased size was made possible by the almost 100-m lower sea level at that time. The hypothesis is that the rise in sea level associated with the melting of the great Northern Hemisphere ice sheets caused a substantial collapse of the large West Antarctic Ice Sheet until it stabilized at its present size. A further sea-level rise could presumably act to unpin the buttressing ice shelves that allow the remnant ice sheet to exist.

Although the massive East Antarctic Ice Sheet is in no danger of total collapse, it too has undergone fluctuations in size associated with sea-level changes. During the last glacial maximum this ice sheet probably extended 75 to 90

km farther onto the continental shelf than at present (Alley and Whillans, 1984). The rise in sea level at the end of the Ice Age produced a rapid retreat response at the ice sheet edge that propagated as a wavelike reduction of ice sheet thickness to the interior of the ice sheet.

Although the basic link between large sea-level changes and ice sheet growth and decay is fairly clear, it is not obvious that small sea-level changes in isolation have a substantial effect on global climate. The principal effect on climate would probably arise from the change in area of the ice sheet and associated sea ice. A further regional climatic effect would come from changes in ice sheet topography. If large glacio-climatic changes in sea level are needed to have significant effects on ice sheets, then any sea-level-induced ice sheet changes would act only as positive climatic feedbacks rather than actual driving forces for large climatic changes. The level of positive feedback could be quite small, e.g., a 50-cm rise in sea level due to ocean thermal expansion could cause such a small reduction in ice sheet size that any positive feedback on ocean temperature would be negligible.

Ocean Chemistry

The most uncertain potential direct effect of sea level on climate involves the conjectured relation between sea level, ocean-atmosphere chemistry, and the greenhouse effect. Studies of cores drilled in ice sheets have shown that atmospheric CO₂ concentration was about two thirds of its present value during the last glacial maximum. Since CO₂ is a greenhouse gas, the change in atmospheric composition apparently acted to substantially augment the postglacial warming (Thompson and Schneider, 1981).

It is not clear what caused the atmospheric CO₂ increase at the time of deglaciation, but it is known that the changes must have originated in the oceans (Broecker, 1984). An initial hypothesis (Broecker, 1982) was that increased sea level due to melting Northern Hemisphere ice sheets covered previously exposed continental shelf. Increased sedimentation of organic matter onto the shelf would have removed phosphorous from the ocean. Since phosphorous is a limiting nutrient, such a loss would decrease ocean phytoplankton productivity, reduce the uptake of CO₂ in surface water, and hence produce an atmospheric CO₂ increase. A second hypothesis (Berger, 1982) was that the postglacial sea-level rise encouraged deposition of carbonate sediments on the shelf, an action that would have generated an increased CO₂ content in the surface water and the atmosphere. The source of carbonate to be deposited, and hence CO₂, would have been dissolution of deep-sea sediments. However, more recent hypotheses of the glacial to interglacial CO₂ change have not directly involved sea-level changes (Broecker, 1984).

Whether sea-level changes can directly affect atmospheric CO_2 concentration is an unresolved question.

INDIRECT SEA-LEVEL AND CLIMATE ASSOCIATIONS

The global cooling trend over the past 70 m.y. is well correlated with a gradual decline in global sea level or increase in global land area. The global cooling from the Cretaceous to the present day has been estimated to be in the range of 6° to 12°C in globally averaged surface temperature (Barron, 1983). The decrease in global sea level is estimated to be as much as 300 to 400 m (Hardenbol *et al.*, 1982) and an increase in total land area of 20 percent (Barron *et al.*, 1980). Early comparisons between sea-level variations associated with this long-term trend and paleotemperature (e.g., Damon, 1968) have been used to infer a strong causal relationship between sea level and climate over the past 100 m.y.

Barron and Washington (1984) performed an extreme sea-level sensitivity experiment with a general circulation model of the atmosphere. This experiment compared mean annual simulations for Cretaceous geography with flooded continents and with present land area (nonflooded continents), which were described earlier. The globally averaged surface temperature response to increased sea level and decreased land area in the model was -0.2°C (Figure 11.2). In the subtropics, where the majority of the flooding occurred, increased evaporative cooling (about 60 W/m^2) and a small increase in cloud cover (2.5 percent) compensated for the surface albedo change.

The results of the sea-level climate model sensitivity experiment bring into question the direct explanation of the global cooling trend as a function of sea-level and surface-albedo variations. The alternative possibilities are (1) inadequate model sensitivity, most likely because of a lack of a seasonal cycle or a fully resolved coupled ocean model, or (2) an indirect association of sea level and paleotemperatures. Point (1) is discussed in detail by Barron and Washington (1984), and here we will introduce only one plausible indirect association between sea level and paleotemperatures.

Berner *et al.* (1983) and Lasaga *et al.* (1985) performed calculations with a geochemical model based on the carbonate-silicate geochemical cycle to test the possibility of atmospheric CO_2 concentration changes on time scales of 1 m.y. over the past 90 m.y. On this time scale, CO_2 removal from the atmosphere is largely dependent on weathering of exposed silicate rocks (with higher sea level this area decreases). One explanation of higher global sea levels is increased rates of seafloor spreading (see Harrison, Chapter 8, this volume). If seafloor spreading rates are high, then a logical implication is greater volcanism

and hence higher CO_2 input into the atmosphere (see Arthur *et al.*, 1985, for a discussion on substantially higher volcanic input estimates for the Cretaceous). Berner *et al.* (1983) suggested that this substantially higher volcanic input of CO_2 cannot be compensated by increased rate of weathering of exposed silicate rocks. In this scenario, high paleotemperatures would result from a CO_2 -induced warming that would be associated with high sea level, but the warming would not be a direct response to sea-level variations.

The problems with the atmospheric CO_2 model of Berner *et al.* (1983) include estimating actual rates of CO_2 degassing through time, estimating actual seafloor spreading rates (Berner *et al.* used four different estimates of seafloor spreading variations), and determination of how directly weathering of silicate and carbonate rocks responds to the level of atmospheric CO_2 concentrations (Berner and Barron, 1984). In addition, Shackleton (1985) suggested that the carbon isotope record may limit the potential variability of atmospheric CO_2 . Despite some unresolved problems, the CO_2 model of Berner *et al.* (1983) and Lasaga *et al.* (1985) would solve the problem of explaining the long-term correlation between sea level and paleotemperatures in light of small climate model sensitivity to large-scale continental flooding, and is a good example of a potential indirect association between sea level and climate.

SUMMARY

The direct effects of sea level on climate include changes in atmosphere-surface coupling, ocean circulation, thermal inertia, ice sheet-ocean interactions, and changes in ocean-atmosphere chemical composition. In only a few cases has the direct effect of a specific variable been isolated. In the majority of the climate model simulations, the model experiments provide insight into the importance of various physical mechanisms, but a series of sensitivity experiments should be conducted to isolate the importance of variables such as surface albedo, surface wetness, surface roughness, and thermal inertia. Many of the arguments presented for the importance of various mechanisms (e.g., ocean gateways that influence oceanic heat transport) are purely qualitative. The first steps toward placing these concepts on a more firm physical foundation must be taken if we are to demonstrate the potential role of sea level in climate change.

Further, correlations between sea level and climate in the geologic record may not be a product of the direct mechanisms described here. The possibility exists, for example, that the causes of sea-level change may influence climate (e.g., tectonic control on sea level and vol-

canic CO₂ emissions), and the paleoclimatic associations with sea level may be indirect.

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Withdrawal/Redaction Sheet

(George Bush Library)

Document No. and Type	Subject/Title of Document	Date	Restriction	Class.
04. Memo	From D. Allan Bromley to John Sununu Re: Issues on the Framework Convention Organizational Meeting and the Second World Climate Conference (2 pp.)	9/24/90	P -5	

Collection:

Record Group: Bush Presidential Records
Office: Chief of Staff, White House Office of
Series: Sununu, John, Files
Subseries: Issues Files
WHORM Cat.:
File Location: Global Warming (2 of 2) - 1990 [1]

Open on Expiration of PRA
 (Document Follows)
 By JP (NLGB) on 10/28/05

Date Closed: 12/17/2004	OA/ID Number: 29158-001
FOIA/SYS Case #: 1998-0004-F[1]	Appeal Case #:
Re-review Case #: 2005-0426-S	Appeal Disposition:
P-2/P-5 Review Case #:	Disposition Date:
AR Case #:	MR Case #:
AR Disposition:	MR Disposition:
AR Disposition Date:	MR Disposition Date:

RESTRICTION CODES

Presidential Records Act - [44 U.S.C. 2204(a)]

P-1 National Security Classified Information [(a)(1) of the PRA]
 P-2 Relating to the appointment to Federal office [(a)(2) of the PRA]
 P-3 Release would violate a Federal statute [(a)(3) of the PRA]
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 P-6 Release would constitute a clearly unwarranted invasion of personal privacy [(a)(6) of the PRA]

C. Closed in accordance with restrictions contained in donor's deed of gift.

PRM. Removed as a personal record misfile.

Freedom of Information Act - [5 U.S.C. 552(b)]

(b)(1) National security classified information [(b)(1) of the FOIA]
 (b)(2) Release would disclose internal personnel rules and practices of an agency [(b)(2) of the FOIA]
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 (b)(7) Release would disclose information compiled for law enforcement purposes [(b)(7) of the FOIA]
 (b)(8) Release would disclose information concerning the regulation of financial institutions [(b)(8) of the FOIA]
 (b)(9) Release would disclose geological or geophysical information

THE WHITE HOUSE
WASHINGTON

September 24, 1990

THE CHIEF of STAFF
has seen

MEMORANDUM FOR GOVERNOR SUNUNU

FROM: D. ALLAN BROMLEY *Alan*
SUBJECT: ISSUES ON THE FRAMEWORK CONVENTION
ORGANIZATIONAL MEETING AND THE SECOND WORLD
CLIMATE CONFERENCE

Background

The President offered to host the first negotiating session for a Framework Convention on global climate change at Malta last year, and reiterated the invitation at the White House Conference on the Science and Economics of Global Change. In May of this year a tentative decision was made to begin the negotiations in the first week of February 1991, preceded by a preparatory committee meeting or meetings this fall. The first preparatory meeting will be held September 24 to 26. Organizational issues for the first negotiating session will be discussed at that time.

The Second World Climate Conference is scheduled for October 29 to November 7 in Geneva. It will focus on scientific issues, including the IPCC report. A ministerial session has been scheduled for the final two days of the conference, which will produce a Ministerial Declaration. A preparatory committee meeting will be held September 27 to 29 in Geneva.

The Global Change Strategy Task Force (a steering group of the DPC Global Change Working Group) met last Tuesday to address some minor, outstanding organizational issues for the first negotiating session and substantive issues in the proposed Ministerial Declaration for the Second World Climate Conference. Unanimous agreement was reached on the organizational issues for the Framework Convention, and this was relayed to the U.S. delegation. General agreement was reached on the Second World Climate Conference issues. A summary of the discussion and recommendations follows.

Framework Convention Negotiations - Organizational Issues

The Strategy Task Force recommended the following guidance for our representatives at the preparatory committee meeting with respect to the starting date, length, and location of the first negotiating session:

The U.S. strongly prefers a one-week session beginning February 4 in Washington, D.C.. However, if there is strong international pressure for a two-week meeting, we would agree to a ten-day meeting as a fallback position.

The group had considered either Washington, D.C., or Dallas, Texas as alternate locations. A paper comparing the suitability of the two cities was circulated to Task Force members and the group decided on Washington. This was based on cost considerations, the availability of appropriate facilities, press coverage, the amount of influence a U.S. delegation could have in the process, and the potential for a Presidential appearance.

Second World Climate Conference

The State Department has compiled interagency comments on a draft ministerial declaration produced by the Second World Climate Conference Secretariat. The Strategy Task Force discussion focused on a limited number of issues on which the U.S. would not be prepared to negotiate. These include:

- o We should not agree to specific targets and timetables for reducing greenhouse gas emissions;
- o There should be no provision for "new and additional" funding (for developing countries);
- o There should be no mention of separate protocols to a framework convention;
- o The comprehensive approach, which addresses all greenhouse gases, their sources and sinks, must be an integral part of the approach;
- o The declaration must accurately describe the scientific context and uncertainties associated with potential climate change;

The Task Force prepared alternate language for these and other issues of particular interest, as well as fallback modifications of existing language which could be used in negotiating final language during the September 27 to 29 preparatory meeting. A more comprehensive briefing on these issues can be scheduled for you, if you would like.

State and Commerce will represent the U.S. at the September preparatory meeting. The Strategy Task Force strongly recommends that Dr. John Knauss, Undersecretary of Commerce, head the U.S. delegation to the ministerial portion of the conference in October. An immediate announcement of the Knauss appointment will tend to discourage head of state participation by other countries as well as prevent speculation on any appearance by higher level U.S. representatives. In addition, it reinforces our continuing commitment to focusing the climate change discussions on science and decreases the opportunity for rhetoric, as was characteristic of Noordwijk. Therefore, the Task Force recommends that Dr. Knauss be appointed to head the delegation as soon as possible.

Comments: _____

THE WHITE HOUSE

AC/ER

WASHINGTON

October 1, 1990

THE CHIEF of STAFF
has seen

MEMORANDUM FOR GOVERNOR SUNUNU

FROM: EDE HOLIDAY 

SUBJECT: Preparations for Second World Climate Conference
and Framework Climate Change Convention
Negotiations

You received a memorandum from Allan Bromley last week outlining the results of a recent meeting of the Global Change Strategy Task Force that discussed the above subjects. We are working closely with Allan and members of his staff to emphasize the strategic nature of the work of his group in overseeing preparation of U.S. policy positions for the upcoming Second World Climate Conference and the February 1991 opening of negotiations on a framework global climate change convention, a need highlighted to you recently by Secretary Watkins (see attached memo). The State Department-led PCC will continue the staff-level preparatory work, with Allan's group resolving conflicts between departments and ultimately reviewing and approving final positions. The Domestic Policy Council may also be asked to review the U.S. opening position for the first negotiating session on the framework convention.

Withdrawal/Redaction Sheet

(George Bush Library)

Document No. and Type	Subject/Title of Document	Date	Restriction	Class.
05. Memo	From James Watkins to John Sununu Re: Impressions of the DOE Delegation to the IPCC Fourth Plenary Session (2 pp.)	9/6/90	P/5	

Collection:

Record Group: Bush Presidential Records
Office: Chief of Staff, White House Office of
Series: Sununu, John, Files
Subseries: Issues Files
WHORM Cat.:
File Location: Global Warming (2 of 2) - 1990 [1]

Open on Expiration of PRA
 (Document Follows)
 By JP (NLGB) on 10/28/05

Date Closed: 12/17/2004	OA/ID Number: 29158-001
FOIA/SYS Case #: 1998-0004-F[1]	Appeal Case #:
Re-review Case #: 2005-0426-S	Appeal Disposition:
P-2/P-5 Review Case #:	Disposition Date:
AR Case #:	MR Case #:
AR Disposition:	MR Disposition:
AR Disposition Date:	MR Disposition Date:

RESTRICTION CODES

Presidential Records Act - [44 U.S.C. 2204(a)]

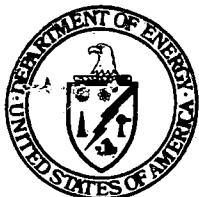
P-1 National Security Classified Information [(a)(1) of the PRA]
 P-2 Relating to the appointment to Federal office [(a)(2) of the PRA]
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Freedom of Information Act - [5 U.S.C. 552(b)]

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The Secretary of Energy

Washington, DC 20585

September 6, 1990

ER - INFO

MEMORANDUM FOR THE HONORABLE JOHN H. SUNUNU
CHIEF OF STAFF TO THE PRESIDENT

SUBJECT: IMPRESSIONS OF THE DOE DELEGATION TO THE IPCC
FOURTH PLENARY SESSION

John:

This is a follow-up to your telephone conversation on August 31 with Assistant Secretary John Easton regarding the outcome of the IPCC Fourth Plenary Session held in Sundsvall, Sweden from August 27-31. We have today received the draft of the IPCC First Assessment Report Overview, reflecting amendments and modifications made in Sundsvall. While we are still reviewing this draft to ensure that it is an accurate reflection of the debate last week, I wanted to share with you the general impressions of the DOE delegation.

In the view of the DOE delegation, the negotiated text of the revised Overview is a substantial improvement over the Draft Overview and Conclusions which formed the basis for last week's discussions. It better reflects the uncertainties facing policy makers, is consistent with the U.S. comprehensive approach, and clearly indicates that response measures will vary depending on national circumstances and require careful analysis. Moreover, the IPCC First Assessment Report in its entirety will include not only this Overview, but the underlying policymakers summaries and the full working group reports. This is valuable from a U.S. perspective because the full reports better reflect the uncertainties than the summary sections on science, impacts and response strategies incorporated in the Overview.

The key results of a protracted and often difficult debate in Sundsvall were:

- o The U.S. successfully resolved our key concerns leading into Sundsvall by removing particularly objectionable portions of the original draft and having language from the underlying policymakers' summaries reinserted. The U.S. was successful primarily because Saudi Arabia and other key developing countries (notably Brazil and Mexico) expressed many similar concerns.
- o In particular, U.S. and other Delegations inserted additional language emphasizing the uncertainties surrounding climate change; the need for a global response and actions on the part of both industrialized and developing countries; and describing the most effective response measures as those which are, inter alia, beneficial for reasons other than climate change, justifiable in their own right and economically efficient and cost effective. The report further states that the degree to which various response options are viable will depend on national circumstances and that determination of the best options will require careful analysis.

- o The U.S. managed to replace one section of the report which could have been read as an endorsement of CO2 emissions reduction targets. Draft language calling for nations to initiate actions to stabilize and later reduce emissions with the aim to "define targets for carbon dioxide and other greenhouse gases" was replaced, at U.S. insistence, with compromise language from the Working Group III Policymakers' Summary.
- o This language states that: "Subject to their particular circumstances, individual nations may wish to consider taking steps now to attempt to limit, stabilize or reduce the emission of greenhouse gases resulting from human activities and prevent the destruction and improve the effectiveness of sinks. One option that governments may wish to consider is the setting of targets for CO2 and other greenhouse gases."
- o The developing countries are increasingly insistent on acknowledgment of their need for financial assistance, technology transfer on preferential terms, and on the lead responsibility of the industrialized countries in addressing climate change. This effort is led by Brazil and supported by Mexico, the PRC and India. Reflecting their apprehension over the IPCC report serving as a basis for subsequent negotiations, Brazil inserted a disclaimer in the report's preface: "It should be noted that the report reflects the technical assessment of experts rather than government positions, particularly those governments which could not participate fully in all IPCC Working Group meetings."
- o The U.S. is increasingly isolated among the industrialized countries in stressing the remaining uncertainties and in resisting endorsement of CO2 and other greenhouse gas reduction goals or targets.

The IPCC Plenary presages the very difficult negotiating process which lies ahead for the U.S. Other industrialized countries will seek more drastic response measures now. Also, the developing countries are likely to resist any action on their part without additional financial and technology assistance. It will be necessary, therefore, for the U.S. to have a well-defined position and strategy before the upcoming negotiations on a framework convention.

It will also be necessary to prepare carefully for the Second World Climate Conference to be held from October 29-November 7. As you know, the draft ministerial declaration for this conference is unacceptable. The modest successes we were able to achieve in Sundsvall could be lost depending on how this conference chooses to receive and act on the IPCC report. We need to arrive at a strategy for this conference quickly so that we can work the attending delegations well in advance.

James D. Watkins
Admiral, U.S. Navy (Retired)

* Under the strategic planning for this is appreciatively pursued now and includes your strong top-down guidance periodically, 2000.

Withdrawal/Redaction Sheet

(George Bush Library)

Document No. and Type	Subject/Title of Document	Date	Restriction	Class.
06. Memo	From D. Allan Bromley to John Sununu Re: Letter from Dr. J.F. Kenney Concerning the Role of "Juvenile Methane" in the Greenhouse System and more (1 pp.)	9/7/90	P 5	

Collection:

Record Group: Bush Presidential Records
Office: Chief of Staff, White House Office of
Series: Sununu, John, Files
Subseries: Issues Files
WHORM Cat.:
File Location: Global Warming (2 of 2) - 1990 [1]

Open on Expiration of PRA
(Document Follows)
By JP (NLGB) on 10/28/05

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RESTRICTION CODES

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THE WHITE HOUSE
WASHINGTON

September 7, 1990

THE CHIEF of STAFF
has seen

MEMORANDUM FOR GOVERNOR SUNUNU

FROM: D. ALLAN BROMLEY 

SUBJECT: THE LETTER YOU RECEIVED FROM DR. J. F. KENNEY
CONCERNING THE ROLE OF "JUVENILE METHANE" IN
THE GREENHOUSE SYSTEM - AND MORE

Just before we left on vacation you gave me a copy of this letter with its very surprising conclusion. Because I was intrigued by it I asked Berrien Moore of the University of New Hampshire (who is one of the world experts in this area) and Bob Watson of NASA to take a close look at Kenney's assertions which would, obviously, be very important - if correct. I enclose herewith the resulting memorandum from Moore and Watson because I thought that you would find it interesting. I also enclose a somewhat revised illustration of the global carbon cycle.

At the same meeting in your office you raised the question of whether current climate models assumed a linear relationship between greenhouse gas concentrations and resulting infra-red radiation absorption. Bob Correll and a number of associates have researched this for me and again I enclose their memorandum. The answer, in brief, is no but I thought that you would be interested in the background for that answer.

We had a meeting of the Global Climate Change Strategy Committee yesterday to review what happened at the Sundsvall IPCC meeting and to plan for the forthcoming international meetings. In brief, although the IPCC meeting was chaotic in the extreme, the outcome was relatively in our favor. The draft Bolin report that was reviewed in your office was scrapped and replaced with a relatively brief overview, to which was appended the policymaker's summaries of the three IPCC working groups.

We will move forward to coordinate preparation for the forthcoming meetings and keep you well informed. Should it be of interest to you, I would be happy to arrange for Bernthal and Watson to brief you on what actually happened in Sweden.

Among the interesting aspects were:

- a) The fact that the Northern Europeans backed off their extreme positions,
- b) the fact that Brazil, with more or less overt support from India, China and the developing countries tried to derail the entire process so that there would be no report from the IPCC.

Please let me know if you wish to hear more details.

Critique of J.F.Kenney Letter to J.H.Sununu

Although most of the scientific and technical information presented in Dr. J. F. Kenney's letter is correct, the author draws a totally erroneous conclusion about the source of the increase of atmospheric carbon dioxide. Juvenile methane is not the cause of the recent (since pre-industrial times) increase in atmospheric carbon dioxide. All of the information presented in this letter was available, and taken into account, during the IPCC scientific review. This memo will present the correct interpretation of the carbon cycle.

While there is no dispute that the carbon cycle is complex, and the magnitude of many of the reservoirs and gross fluxes between reservoirs are quite uncertain (i.e., by about 20% or more), there is little doubt about the following facts:

CARBON DIOXIDE

- (1) The current (1990) average mixing ratio (often referred to as atmospheric concentration) of carbon dioxide is 353 ppmv (750×10^{15} g C)--known to better than 0.5%. This contrasts to the pre-industrial (1750-1800) atmospheric mixing ratio of carbon dioxide of about 280 ppmv (594×10^{15} g C)--decadal averages for a period of about one thousand years prior to 1750 were constant to within about $\pm 2\%$, i.e., about ± 5 -6 ppmv. Therefore, the atmospheric mixing ratio of carbon dioxide has increased by about 25% since the pre-industrial era.
- (2) The atmospheric loading of carbon dioxide is currently increasing at an annual rate of 1.8ppmv (3.8×10^{15} g C). This is three times greater than the annual rate of increase of 0.6 ppmv (1.3×10^{15} g C) in 1958 when precise atmospheric measurements began.
- (3) The interhemispheric gradient of carbon dioxide abundances between the northern and southern hemispheres has increased from about 1 ppmv in 1960 to about 3 ppmv today.
- (4) The annual gross fluxes of carbon dioxide between the atmosphere and the oceans are about 90×10^{15} g C, and the annual gross fluxes of carbon dioxide between the atmosphere and the terrestrial biosphere are about 100×10^{15} g C. In each case the fluxes are probably only known to about 30%. As stated earlier, the ice core record shows that the atmospheric concentration of carbon dioxide prior to 1750 was constant to within about $\pm 2\%$ (± 5 -6ppmv) indicating that the gross fluxes of carbon dioxide between the atmosphere and the oceans and between the atmosphere and the terrestrial biosphere were in a quasi-steady state. The contemporary net fluxes are smaller and better known (see next three points) than the gross natural fluxes, hence the uncertainty about the current carbon cycle is less than one might suppose by examination of only the gross fluxes and their associated uncertainties.
- (5) The current annual emissions of carbon dioxide from the combustion of fossil fuel are about 6×10^{15} g C per year (last accurate assessment was $5.7 \pm 0.5 \times 10^{15}$ g C in 1987). The cumulative release of carbon dioxide from the combustion of fossil fuels is estimated at $200 \pm 20 \times 10^{15}$ g C between 1850 and 1987.
- (6) The annual emissions of carbon dioxide from "tropical deforestation" were estimated (IPCC) to be between 0.6 and 2.5×10^{15} g C in 1980, i.e., ($1.5 \pm 1.0 \times 10^{15}$ g C). Recent increases in the rate of tropical deforestation suggest that the lower limit is too low, and that the most likely current value is towards the central or upper end of the range. The

cumulative release of carbon dioxide from tropical and extratropical deforestation is estimated at $115 \pm 35 \times 10^{15}$ g C between 1850 and 1985.

- (7) The sum of the current annual emissions of carbon dioxide from tropical deforestation and the combustion of fossil fuels is $7.5 \pm 1.2 \times 10^{15}$ g C, of which only about 3.5×10^{15} g C remain in the atmosphere. The remaining $4 \pm 1.2 \times 10^{15}$ g C is being taken up by the oceans and terrestrial biosphere, but the relative proportions are poorly quantified.
- (8) The net annual uptake of carbon dioxide by the oceans is $(2 \pm 1 \times 10^{15}$ g C).
- (9) The net annual uptake of carbon dioxide by "non-tropical" terrestrial ecosystems is highly uncertain ($0-3 \times 10^{15}$ g C), and it has been suggested that it may have increased in recent decades through a number of plausible mechanisms, including enhanced productivity due to a warmer climate, carbon dioxide and/or nitrogen fertilization, and improved forest management.

CARBON 14

- (10) ^{14}C (half-life of 5700 years) is produced in the atmosphere through the partial conversion of ^{14}N by cosmic radiation.
- (11) Because of the rapid exchange of carbon dioxide (about $190 \pm 40 \times 10^{15}$ g C per year) between the atmosphere and the terrestrial biosphere and ocean waters, ^{14}C is rapidly equilibrated throughout the atmosphere, terrestrial biosphere and surface waters of the ocean.
- (12) The ^{14}C content of atmospheric carbon dioxide resulting from the combustion of fossil fuels (coal, natural gas, or oil) is zero, because the age of fossil fuels greatly exceeds the half-life of ^{14}C .
- (13) The atmospheric abundance of $^{14}\text{CO}_2$ was approximately constant prior to 1750, then decreased approximately 25% over the 200 year period prior to nuclear bomb testing and nuclear power plant operation. This pattern (known as the Suess effect) is due primarily to emission of ^{14}C -free fossil fuel CO_2 , which diluted the pre-industrial ^{14}C content of the atmosphere. The burning of biomass also contributed to this dilution since vegetation is partly depleted, relative to the atmosphere, in ^{14}C because of fractionation against the heavier isotope at the air-leaf interface. The atmospheric concentration of ^{14}C increased rapidly after 1952, reaching a peak in 1963/4, from which it has decreased to a value about 40% above the 1952 value.

METHANE

- (14) The atmospheric loading of methane is known to about 1%. The current (1990) average mixing ratio of methane is 1.72 ppmv (3.7×10^{15} g C), compared to a pre-industrial value of about 0.6 to 0.8 ppmv (1.3 to 1.7×10^{15} g C). Note that the corresponding contemporary and pre-industrial values for CO_2 are 750 and 594×10^{15} g C, respectively.

- (15) The atmospheric loading of methane is currently increasing at an annual rate of 0.014 to 0.017 ppmv (0.03 to 0.036×10^{15} g C).
- (16) The current annual emissions of methane from both natural and anthropogenic sources is between 0.3 and 0.5×10^{15} g C, of which about 60 to 70% is believed to be due to anthropogenic activities. The ice core record suggests that the natural sources of methane were relatively stable for several centuries prior to 1850.
- (17) The magnitude of the sources is largely constrained by knowledge of the atmospheric sink, primarily removal by reaction with tropospheric hydroxyl radicals. The atmospheric lifetime is about 10 to 12 years, with an uncertainty of about 20-30%.
- (18) The magnitude of the individual anthropogenic and human-influenced sources of methane are quite poorly quantified, including rice paddies, cattle rearing, biomass burning, landfills, permafrost, natural wetlands, coal mining and venting of natural gas, e.g., the annual flux of methane from rice paddies is estimated to range from 0.019 to 0.13×10^{15} g C.
- (19) Methane from coal mining, and venting of natural gas, as well as "juvenile methane emissions" (if any), would contain no ^{14}C , where-as methane emissions arising from biological sources would contain a modern day ^{14}C signature. The best estimate of the percentage of methane emissions with no ^{14}C signature has recently been determined to be about 20%, although some estimates reach as high as 32%.

Conclusions:

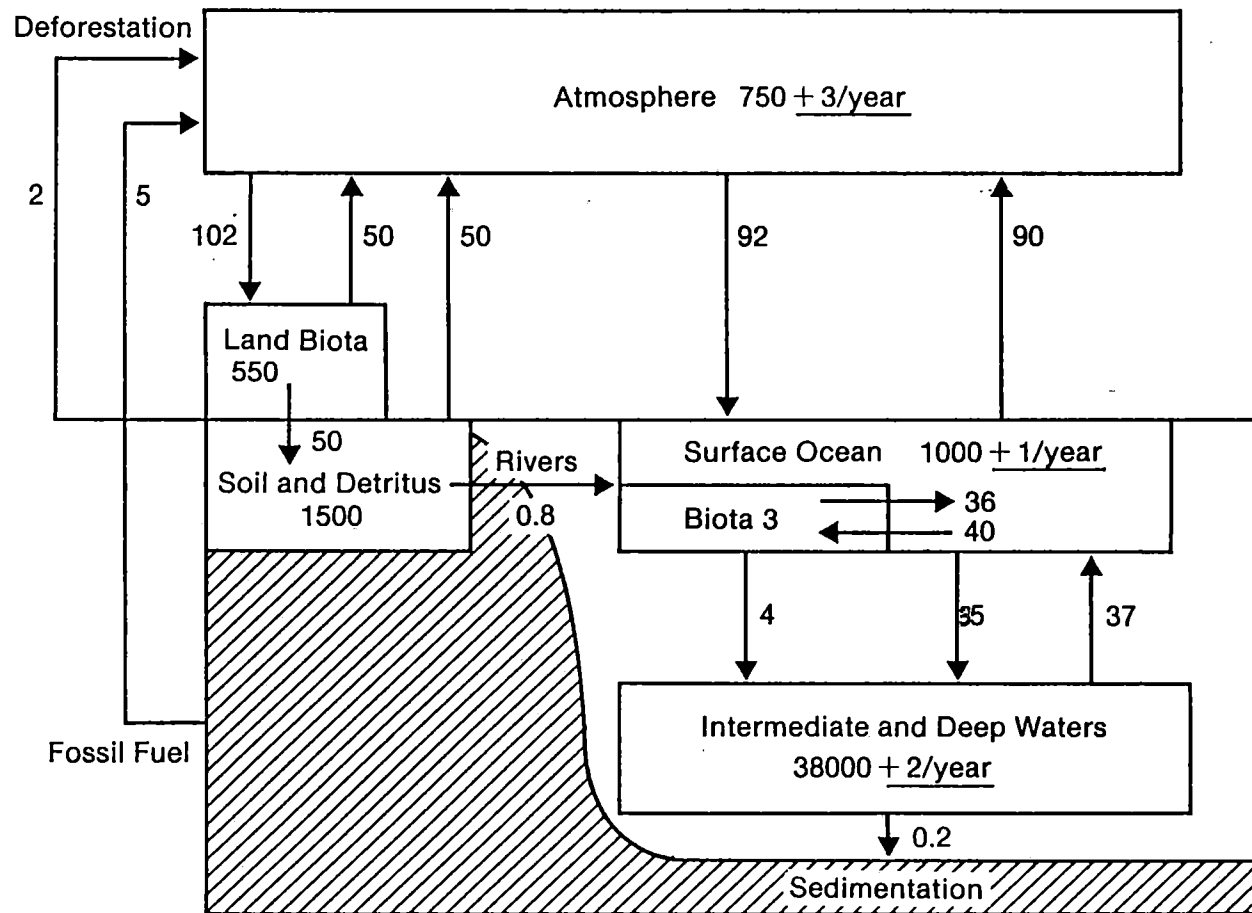
The total annual flux of atmospheric carbon dioxide arising from natural and anthropogenic methane emissions is between 0.3 and 0.5×10^{15} g C, of which about 60 to 70% are thought to arise from the direct influence of human activities, i.e., 0.18 to 0.35×10^{15} g C. It is clear that this annual flux is relatively unimportant, in terms of total carbon, compared to the annual fluxes of carbon dioxide arising from the combustion of fossil fuels ($5.7 \pm 0.5 \times 10^{15}$ g) and tropical deforestation (0.6 and 2.5×10^{15} g C).

The observed decrease, prior to 1952, in the atmospheric abundance of $^{14}\text{CO}_2$, compared to $^{12}\text{CO}_2$, over the last 200 years is consistent with the source of atmospheric carbon dioxide containing no ^{14}C , i.e., from the combustion of fossil fuels (completely depleted of ^{14}C) and the atmospheric oxidation of ^{14}C free CH_4 (the magnitude of this source, $<0.15 \times 10^{15}$ g C per year, is only a few percent of the fossil fuel source).

The observed change in the interhemispheric gradient in carbon dioxide over the past 30 years parallels the increased combustion of fossil fuels in the northern hemisphere.

The anthropogenic fluxes of carbon dioxide are much smaller (factor of about 25) than the natural sources and sinks, but are still large enough to perturb the natural carbon cycle and account for the observed ~25% increase in atmospheric carbon dioxide since pre-industrial times. The ice core record suggests that the atmospheric concentrations of carbon dioxide and methane were in quasi-steady state (natural sources and sinks balanced) prior to the industrial revolution, with rapid increases thereafter.

The sum of the annual emissions of carbon dioxide from tropical deforestation and the combustion of fossil fuels is between 6 and $9 \times 10^{15} \text{g C}$, of which only about $3.5 \times 10^{15} \text{g C}$ remain in the atmosphere. The remaining 2 to $5.5 \times 10^{15} \text{g C}$ is being taken up by the oceans and terrestrial biosphere, but the relative proportions are poorly quantified. The lack of a quantitative knowledge of the sinks, hence atmospheric lifetime, of carbon dioxide means that there is uncertainty associated with our understanding of the relationship between future emissions and atmospheric concentrations of carbon dioxide.



Question: Do climate models assume a linear relationship between changes in the atmospheric concentrations of greenhouse gases and changes in the absorption of infra-red (terrestrial) radiation, i.e., changes in radiative forcing.

Answer: No.

Climate models do not assume a linear relationship between changes in the atmospheric concentrations of greenhouse gases and changes in radiative forcing. Changes in radiative forcing due to changes in the atmospheric concentration of species A depends upon the spectral properties of species A, the atmospheric concentration of species A, and the concentration of other gases with spectrally overlapping bands.

The forcing of some atmospheric species (most notably carbon dioxide, methane, and nitrous oxide) is markedly non-linear in absorber amount. Therefore, changes in radiative forcing are critically dependent on the concentrations for which the calculations are performed.

Carbon dioxide: The atmospheric concentration is currently about 353 ppmv. There is a logarithmic dependence between changes in atmospheric concentrations of carbon dioxide and changes in radiative forcing (in Wm^{-2}), that can be expressed by the following simple (approximate) relationship:

* $\Delta \text{Forcing} = 6.3 \ln (C/C_0)$, where C is CO_2 in ppmv for $C < 1000 \text{ ppmv}$.

Methane and Nitrous Oxide: The atmospheric concentrations of methane and nitrous oxide are currently 1.7 ppmv and 0.31 ppmv, respectively. There is a square root dependence between changes in the atmospheric concentrations of methane and nitrous oxide and changes in radiative forcing (in Wm^{-2}), that can be expressed by the following simple (approximate) relationships:

* $\Delta \text{Forcing} = 0.036 (M^{0.5} - M_0^{0.5}) - (f(M, N_0) - f(M_0, N_0))$
where M is CH_4 in ppbv for $M < 5 \text{ ppbv}$.

* $\Delta \text{Forcing} = 0.14 (N^{0.5} - N_0^{0.5}) - (f(M_0, N) - f(M_0, N_0))$
where N is N_2O in ppbv for $N < 5 \text{ ppbv}$.

The second term in each equation is due to the fact that the spectral bands of methane and nitrous oxide are significantly overlapped, therefore this has to be taken into account with the following overlap term:

$$f(M, N) = 0.47 \ln [1 + 2.01 \times 10^{-5} (MN)^{0.75} + 5.31 \times 10^{-15} M (MN)^{1.52}];$$

Chlorofluorocarbons (CFCs): Because of the low (a few parts per billion by volume (ppbv)) atmospheric concentrations of CFCs 11 and 12, and the fact that they absorb in a "spectrally transparent" region of the spectrum, there is a linear relationship between changes in atmospheric concentrations of CFCs 11 and 12 and changes in radiative forcing that can be simply expressed:

* $\Delta \text{Forcing (CFC-11)} = 0.22 (X - X_0)$, where X is CFC-11 in ppbv $< 2 \text{ ppbv}$

* Delta Forcing (CFC-12) = $0.28 (Y - Y_0)$, where Y is CFC-12 in ppbv < 2 ppbv

Ozone: The relationship between changes in the atmospheric concentrations of tropospheric and stratospheric ozone and changes in radiative forcing are somewhat more complex than for the long-lived, well mixed gases, such as discussed above. Changes in radiative forcing are sensitive, with a linear response, to changes in the vertical distribution of ozone, particularly near the tropopause.

Global Warming Potentials:

It should be noted that the concept of global warming potentials (GWPs) requires an understanding of not only the dependence of the radiative forcing of a gas on its concentration and the concentration of other gases with spectrally overlapping bands, but also of:

- (1) the atmospheric lifetimes of the various gases
- (2) the specification of the most appropriate time period over which to perform the integration

The reference gas for the table of GWPs listed by IPCC is carbon dioxide, yet the atmospheric lifetime of carbon dioxide is quite poorly defined because of uncertainties associated with understanding its sources and sinks. This limitation, which was recognized by IPCC means that significant research will be needed before relative GWPs can be determined with confidence.

THE CHIEF of STAFF
has seen

THE WHITE HOUSE
WASHINGTON

90 SEP 17 PM 2:03

September 17, 1990

MEMORANDUM FOR THE PRESIDENT

FROM: D. ALLAN BROMLEY 
SUBJECT: THE U.S. GLOBAL CHANGE RESEARCH PROGRAM

Last year, at the Paris Economic Summit, you made available to your G-7 colleagues copies of a report outlining the U.S. Global Change Research Program that had been prepared by the Committee on Earth Sciences, a component of the Federal Coordinating Council for Science, Engineering and Technology (FCCSET). The report was apparently very well received and a number of countries have looked on it as a model for their own activities.

During the past year, this FCCSET committee--now renamed as The Committee on Earth and Environmental Sciences, one of seven such committees now functioning under a revitalized FCCSET--has revisited the entire U.S. governmental global change program in light of new data, new understanding and new circumstances.

We touched on this briefly when you joined us during the last PCAST meeting and I thought that you might find the attached summary of the new 1991 plan (now at the printers so that it can accompany your FY 91 formal budget submission to the Congress) of interest. In my opinion, this 1991 report and research plan will mark a very significant advance over the already excellent 1990 one. I shall, of course, be happy to provide any further information that might be useful to you, or arrange for a more complete briefing on any of these topics that you might select.

In parallel with the ongoing CEES activities related to the science and technology of global change, the Domestic Policy Working Group on Global Change (WGGC) is monitoring activities of the United Nations' Intergovernmental Panel on Climate Change (IPCC). The IPCC has just completed the first phase of its activities and evaluation of the science on effects of, and political responses to, global change. The WGGC is making preparations for effective U.S. participation in the several international conferences on this topic that will take place later this year and prior to the first negotiating session for the Global Change Framework Convention that you have agreed to host here in Washington in February 1991.

Cooperation between the CEES and the WGGE continues to be exemplary and will, in my opinion, effectively support your international leadership in this important area of global stewardship.

Attachment

AN OVERVIEW OF THE U.S. GLOBAL CHANGE RESEARCH PROGRAM

What is Driving the U.S. Global Change Research Program ?

World leaders are taking an increased interest in the economics and social implications of global environmental changes, both natural and human-induced. The 1988 midwestern U.S. drought underscored the potential effects of a warm, dry summer, just as the climate of recent decades in the Sahel starkly reveals the human tragedy that can occur in marginal-subsistence zones of a changing planet. Furthermore, the very recent linking of the antarctic ozone "hole" to man-made chlorofluorocarbons (CFC's) and the current debate over humanity's role in the "greenhouse effect" have placed the environment high on the national and international agenda. In virtually all these issues, the salient feature is the significant scientific uncertainty associated with predicting the behavior of the coupled ocean-atmosphere-land Earth system. *The substantial costs associated with addressing environmental changes require policy decisions be based on adequate scientific knowledge. To provide this knowledge, the U.S. Global Change Research Program (US/GCRP) has been developed as a precursor component of the U.S. Government's overall approach to global environmental change.*

What is the U.S. Strategy for the US/GCRP ?

The US/GCRP has been developed through the Committee on Earth and Environmental Sciences (CEES) of the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET). *The program is driven by carefully established priorities, and by key scientific questions that must be addressed to establish sound national and international policies for addressing issues such as the "greenhouse effect", global climate change, and ozone depletions.* The Program was developed as a government-wide and integrated research program. It has been established in cooperation with the U.S. and international scientific communities, through the National Academy of Sciences (NAS) and internationally through the International Council of Scientific Unions (ICSU). The Program is also linked internationally to a substantial number of other government agencies (though the International Group of Funding Agencies for Global Change Research) and to the relevant intergovernmental organizations of the United Nations.

What are the Overall Goals and Objectives of the US/GCRP ?

The Goal:

To establish the scientific basis for national and international policy making relating to natural and human-induced changes in the global Earth system.

This goal will be implemented through three overall US/GCRP objectives:

The Objectives:

- o Establish an integrated, comprehensive long-term program of documenting the Earth system on a global scale.
- o Conduct a program of focused studies to improve our understanding of the physical, geological, chemical, biological, and social processes that influence Earth system processes and trends on global and regional scales.
- o Develop integrated conceptual and predictive Earth system models.

What are the Key Areas of Scientific Uncertainty ?

Hydrological cycle: primarily cloud-radiation and land surface-atmosphere interactions. These uncertainties affect the predicted rate (magnitude at a given time) of "climate change".

Role of the oceans: the exchange of energy between the ocean and the atmosphere, and between the upper layers of the ocean and the deep ocean. These uncertainties affect the predicted rate of climate change, especially at the regional scale.

Trace gases: quantification of the uptake and release of carbon dioxide by the oceans and terrestrial biosphere, and quantification of the individual sources of methane and nitrous oxide. These uncertainties affect our understanding of how the climate system will be "forced", hence the rate of predicted climate change. These uncertainties also limit the formation of control strategies.

Predictions of regional climate change: limitations in computer resources (spatial resolution and physical sophistication), coupled with an inadequate understanding of several key processes (e.g., the exchange of water and energy between vegetative surface and the atmosphere) limit the accuracy of regional climate change predictions at the scale required for impact assessments to be performed (sub-continental).

Detection of global change: trends in a number of climatically important parameters, coupled with a quantified understanding of natural variability, are needed to differentiate between human-induced changes in the environment from those that occur naturally. This will require long-term observations of climatically important parameters and forcing functions, as well as careful development of time-dependent coupled ocean-atmosphere GCM's.

What Scientific Research does US/GCRP Address to Reduce Scientific Uncertainties ?

The US/GCRP seeks, through the FY 1991 Program, to improve our current understanding of:

- (i) The natural and human-influenced processes that control climate and global change, and
- (ii) The impacts of climate and global change at the regional scale.

More specifically, the US/GCRP in FY 1991 seeks to document the natural variability of the Earth's climate, and to improve our understanding and modeling of:

- (i) Cloud-radiation feedbacks;
- (ii) The exchange of energy between the atmosphere and the surface waters of the ocean, and between the surface and deep waters of the ocean;
- (iii) The cycling of carbon and other key elements between the atmosphere, land and oceans;
- (iv) The exchange of water and energy between land surfaces and the atmosphere; and
- (v) The current structure and functioning of ecosystems and their response to changes.

How will the US/GCRP be implemented ?

The FY 1991 President's Budget requests \$1,034 million for the US/GCRP, an increase of 57% over the FY 1990. The US/GCRP is managed through nine agencies (DOC, DOD, DOE, DOI, EPA, NASA, NSF, SMITHSONIAN, and US/DA), and is conducted in cooperation with a substantial number (over 20) other countries. The U.S. is contributing about 50% of the total international effort, and is providing the leadership in virtually every case. The US/GCRP is a government-wide integrated scientific research program that seeks to provide the scientific basis for national and international policy making relating to natural and human-induced changes in the global Earth system. A summary of current understanding and recent scientific developments is attached.

Climate Change - Summary of Current Understanding and Recent Developments

The Climate System:

The Earth's climate is controlled by the input energy from the sun, by the radiative balance of the atmosphere, and by internal processes within the climate system. The radiative balance depends upon the input of solar radiation and the atmospheric concentrations of radiatively active trace gases (i.e., greenhouse gases), clouds and aerosols. To predict changes in the climate system requires an understanding of future changes in the atmospheric concentrations of greenhouse gases and aerosols, and the processes that control the response of the climate system to natural and human-influenced changes in the radiation balance.

Contemporary Changes in the Forcing of the Climate System:

Current Understanding: Natural greenhouse gases, primarily water vapor and carbon dioxide, and to a lesser extent, methane, nitrous oxide and ozone, keep the Earth much warmer than it would otherwise be. It is well documented that since the industrial revolution the atmospheric concentrations of carbon dioxide, methane, nitrous oxide and industrially produced chlorofluorocarbons (strong greenhouse gases) have been increasing primarily due to human activities. However, there are many uncertainties concerning the magnitudes of the sources and sinks of these greenhouse gases. The time atmospheric carbon dioxide takes to adjust to changes in sources is of order 50-200 years, hence, carbon dioxide emitted into the atmosphere today will influence the atmospheric abundance of carbon dioxide for centuries into the future.

Recent Developments: The most significant recent scientific development is the suggestion that the oceans are only a minor sink (possibly only one half of the previously estimated oceanic uptake) for anthropogenic carbon dioxide, and that the most significant sink for anthropogenic carbon dioxide is most likely uptake by extratropical terrestrial ecosystems.

Historic Changes in the Forcing of the Climate System:

Current Understanding: The most reliable information on past atmospheric carbon dioxide and methane concentrations is obtained by the analysis of air trapped in polar ice cores, which shows a strong correlation between changes in temperature and changes in the atmospheric concentrations of carbon dioxide and methane.

Recent Developments: About 11,000 years ago, rapid changes in atmospheric temperatures and carbon dioxide concentrations were observed (a period known as the Younger-Dryas). Recently, it has been suggested that these changes are linked to abrupt and large-scale changes in the interplay between biological, chemical and physical processes in the oceans.

Predictions of Climate Change:

Current Understanding: General Circulation Models (GCM's) are currently the best available tools with which to predict changes in the Earth's climate in response to a change in the atmospheric concentrations of trace gases or aerosols, solar activity, or surface albedo. The current GCM's have substantial limitations, in particular, they are very sensitive to the treatment of cloud-radiation interactions. Different cloud-radiation models lead to significant differences (up to a factor of 3) in the magnitude of the predicted global warming. Predictions of regional climate changes are very uncertain. They are particularly sensitive to the treatment of ocean dynamics and ocean-atmosphere interactions and to the terrestrial vegetation-atmosphere interactions. Further, current computer capabilities severely limit the spatial resolution of the GCMs. Therefore, the predictions of the magnitude and timing of climate changes, especially at the regional level, are considerably uncertain. However, given these limitations, GCM's suggest that: (i) the equilibrium increase in global mean surface temperature should lie between 1.5 and 4.5 degrees centigrade; (ii) between 60 and 80% of the equilibrium warming should be realized at the time of "equivalent doubling"; (iii) global mean precipitation should increase; (iv) sea-ice extent should decrease; and (v) the predicted warming in the northern polar winter should be greater than the global mean.

Observations of Temperature Changes:

The instrumental record of surface temperatures suggests an increase of between 0.3 and 0.6 degrees centigrade since the mid-nineteenth century, with an undetermined, but probably small (less than 0.05 degrees centigrade) artificial component due to urbanization. Temperatures have not increased smoothly with time, nor uniformly throughout the world, i.e., (i) the majority of the temperature increase occurred before 1940, prior to most of the anthropogenic increase in the atmospheric concentrations of greenhouse gases; (ii) there is little evidence that the continental U.S. has warmed since 1900; (iii) the northern hemisphere cooled between 1940 and the early 1970s, while the southern hemisphere continued to warm; (iv) there have been significant differences in regional changes, especially in the northern hemisphere since 1950; and (v) from 1975 to 1982 a more general warming occurred, followed by little global warming since 1982.

Detection of the "Anthropogenic Greenhouse" Signal:

The Earth's climate is inherently variable on all time scales, both regionally and globally. The challenge is to detect an "anthropogenic greenhouse" signal amidst the natural variability of the system. Current GCM's and observations cannot confirm the presence or absence of an "anthropogenic greenhouse" signal.

Sea Level:

Although the data are difficult to interpret, the best scientific assessment is that over the past 100 years, sea level has risen at an average rate of rise of 1.0-2.0 mm/yr. The uncertainties are large, but the principal causes of this rise are consistent with the expected thermal expansion of the oceans and the melting of mountain glaciers. Regional values differ considerably from global values and predicting future conditions is even more uncertain. If the global mean surface temperature increases, then sea level is predicted to rise, primarily due to the thermal expansion of the oceans and to a melting of some land-ice. The current predicted range of sea level increase lies between about 10 and 30 cm, at the time of an equivalent doubling of carbon dioxide (sometime during the middle of the next century).

Ecological Systems:

Biological Productivity: Warming of soils will tend to increase nutrient availability to plants with potential for increased productivity. Further, increased temperature will affect respiration more than photosynthesis, possibly reducing carbon stored in terrestrial ecosystems resulting in a positive feedback on atmospheric carbon dioxide concentrations. Higher atmospheric carbon dioxide concentrations can increase photosynthesis with potential increases in net production, but the duration of "carbon dioxide fertilization effects" is unknown. However, while there is some knowledge of the responses of biological production processes to changes in parameters of the physical environment, how these integrate over the life cycle of even one species interacting in a complex of other species is unknown.

Ecosystem Composition: Species will respond differently to changes in temperature, precipitation and atmospheric carbon dioxide, either singly or in some combination. However, exactly what these responses will be is not known. Also unknown are the changes that will occur among species, including plant-animal and plant-microbe interactions.

Marine Ecosystems: The historic record leaves little doubt that global warming will have an impact on marine planktonic organisms. The structure and productivity of marine ecosystems are strongly influenced by ocean circulation and mixing, with such physical parameters tightly linked with climate. While there is considerable knowledge of specific processes and specific parts of the global oceans, the integration of this knowledge is incomplete and significant gaps in understanding exist.