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THE WHITE HOUSE

August 6, 90

Gen. John Dunnington:
Dear John:

I thought you might find the
enclosed reprint by Jesse Ausubel
of Rockefeller of interest.

Sincerely
Duan

James Hansen

4

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Draft 4/1/90

Conventional Wisdom about Impacts of Global Climate Change

Jesse H. Ausubel
The Rockefeller University

What difference does it make if the climate becomes hotter, drier, wetter, or windier? Now that the issue of the greenhouse effect has been prominent in the media for a few years, a collection of images and concerns about life on a warmer earth has started to form. In this paper I will review what might be described as the conventional wisdom about the impacts of climate change. I will explore eight hypotheses which, taken together, I believe constitute the core of the conventional wisdom, as found in magazine articles, statements by politicians, and treatments of the issue in the arts, as well as in communications by scientists. These hypotheses are tested against research findings from the literature about climate impacts, which has burgeoned since the late 1970s. In conclusion, a revised set of hypotheses is offered.

The reason for this approach is twofold. One is simply that it is important to recognize the fundamental picture on which the society is implicitly relying for its decision-making. Over a period of time, a picture of an issue tends to settle into the public mind. A few images and sound-bites monopolize our thinking. In the case of the greenhouse gas issue, these images for Americans are probably parched crops in the

THE WHITE HOUSE
WASHINGTON

May 2, 1990

MEMORANDUM FOR JOHN H. SUNUNU

FROM: D. ALLAN BROMLEY 

SUBJECT: CARBON PROBLEM

I am sorry that it has taken as long as it has to get back to you on this carbon question, but it has turned out to be more complicated than I had previously anticipated. With very substantial help from Bob Watson of NASA, Bob Corell of NSF, Berrian Moore of the University of New Hampshire, and Nancy Maynard of my office, I now believe that I have a reasonably detailed understanding of what is going on and how the various numbers fit together.

I would propose to lay out in this memorandum my understanding of how the numbers are being put together in current publications up to and including the IPCC Working Group Reports. As a reference that ties the rough numbers together, I would suggest that you use the enclosed figure. One that I supplied to you previously.

First of all, a general comment may be in order. As you will see in the following notes, there is a fair degree of definitional confusion that is being used to the advantage of activists in the field. I shall try to be as specific as possible concerning these matters of definition.

o It has become traditional in the field when discussing doubling to use the preindustrial situation as the base but this is rather infrequently mentioned. The preindustrial burden of carbon in the atmosphere was with reasonable certainty, 600 Gt.

o In all discussions of doubling, one must understand that there is a missing word. What is being discussed is in fact effective doubling, i.e., one includes all other greenhouse gases, such as methane, nitrous oxide, and ozone, with carbon dioxide and then asks when the total radiative forcing brought about by this mixture of greenhouse gases, will be twice that caused by the pre-industrial atmospheric loading.

o The increase of carbon dioxide in the atmosphere is perhaps the best known single datum in the whole discussion resulting from the pioneering measurements of Keeling of the Scripps Oceanographic Institution beginning in 1957 in Hawaii as part of the U.S. participation in the International Geophysical Year. These data show that in 1990 the best figure for the atmospheric burden of carbon is 750 Gt (this is larger than the 740 Gt shown in the figure but is a more correct number for the present day situation). Given this number, it is then clear that the carbon content of the atmosphere has increased by 25% with respect to the pre-industrial base.

o However, at the present time, the other greenhouse gases, i.e., methane, nitrous oxide, and ozone together have almost precisely the same radiative forcing impact as does the anthropogenic carbon dioxide which then raises the total radiative forcing by another 25% and leaves us with a radiative forcing term in the atmosphere that is 50% above the preindustrial value.

There is an obvious weakness in this whole argument in that we know relatively less about the methane and nitrous oxide situation in the preindustrial period so that our base is perhaps a little weak but the argument is that the uncertainties that reflect these other gases in the preindustrial period are relatively small.

Despite such questions it is very clear that these numbers represent, by far, the hardest data in the whole carbon cycle.

o In order to do its work the Working Group #1 of IPCC required information on the future emission profile for greenhouse gases and requested such information from Working Group #3. As nearly as I can determine, the three scenarios that are being studied in the IPCC are the result of a rather arbitrary selection of the dates 2025, 2050, and 2090 as representing high emission, medium emission, and low emission scenarios and then working backwards from those arbitrarily selected numbers. There has simply been no very credible, complete attempt to build these effective doubling dates from the bottom up.

Perhaps the most effective study is the one that has been done by EPA and Dutch workers at the request of the IPCC Working Group #3, but in this study only the carbon dioxide emissions have been considered (omitting methane, nitrous oxide, and the like) and the preliminary results of these studies, although not yet released, would seem to suggest that an effective doubling would occur perhaps by 2020, although there is very substantial uncertainty associated with this estimate.

Unfortunately, the IPCC groups in at least the first revision of their working group documents have chosen, instead of presenting analyses based on all three of their scenarios, simply to pick the high emission one with an effective doubling date of 2025 and have also agreed to refer to this as the "business as usual" scenario.

Let me now turn to the question of how the numbers get put together.

o In all the IPCC work, it is assumed that carbon dioxide contributes between 50 and 60% of the total radiative forcing.

o The dominant source of anthropogenic carbon is that resulting from the combustion of fossil fuel shown in the figure as 6 Gt per year. Evidence over the past few years indicates that after more than a decade of relatively constant emissions, our fossil fuel combustion rate has begun to grow again and the assumption is that by the 2020 to 2035 period fossil fuel combustion will correspond to between 7 and 8 Gt a year.

All this being assumed, we are then defining an effective doubling as corresponding to the situation where we have 900 Gt of carbon in the atmosphere—carbon up by 50% over the preindustrial value with the other greenhouse gases contributing an additional 50%. This is obviously a misleading situation because in fact the carbon is only increasing by 50% and yet everyone is talking about doubling without making it at all clear that other greenhouse gases are involved.

- o Given that we are now at 750 Gt in the atmosphere, we then require only another 150 Gt.

- o It is always assumed, however, that 50% of the anthropogenic carbon is removed from the atmosphere so that we would then require an emission of 300 Gt and at an emission rate of 6 Gt per year from fossil fuel combustion, we come up by simple arithmetic with effective doubling in 50 years, i.e., by 2040. Obviously if we agree with the IPCC that the emission rate from fossil fuel combustion will rise between now and that time, the date at which effective doubling occurs will be earlier. If it were to average say 7.5 Gt per annum, we would be talking reaching the effective doubling point in 2030.

Contrary to what I mentioned to you earlier, the carbon release from the manufacture of Portland Cement through dehydration of calcium carbonate, contributed only a few percent of that due to fossil fuel combustion and is not considered in most of these discussions. It had been raised in earlier papers as being potentially a much more serious contributor but the more quantitative estimates of the last few years have reduced its importance.

There is obviously another source of carbon release from the earth's surface through deforestation. In the figure this is indicated at 2 Gt per year, but a very detailed estimate carried out in 1980 could only put the number at somewhere between 0.6 and 2.5 Gt per annum. The number is very poorly known and in most current calculations it is taken as 1.6 Gt per year, or frequently rounded as here to 2 Gt per year.

- o The above mentioned Hawaiian data allow us to say with considerable certainty that we are adding between 3 and 3.5 Gt of carbon to the atmosphere each year at the present time.

- o We are then faced with a open question. If we add up the deforestation and fossil fuel contributions and set them equal to 7.5 Gt per year, and if 3.5 Gt, let us say, stays in the atmosphere, where does the remaining 4 Gt per year go?

- o Classically, it has always been assumed in recent calculations that the ocean uptake is 2.5 Gt per year, but this number could be anywhere between 1 and 3 Gt per year and the IPCC has chosen to use a value of 2 Gt per year in its calculations. The measurements of carbon dioxide partial pressure in the oceanic surface waters has been extremely spotty and limited to only some parts of the ocean so that our knowledge of its present value is relatively uncertain.

o However, when we add up these numbers, we come up with something like 2 Gt per year carbon that is missing. Some assume that it must be taken up by the terrestrial biosphere in mid-latitudes and others assume that for unspecified reasons, the deforestation contribution must be very close to zero rather than the usually assumed 2 Gt per year. It is quite clear that there is no good scientific basis for either of these suggestions and it is also clear that those in the field are simply working backwards and trying to explain this missing carbon in some plausible fashion.

o The question of the possible sequestering in mid-latitude terrestrial biota raises the question of one of the many feedback loops that have not been adequately considered. We know that over the past 50 years there has been a regrowth of forests in the mid-latitudes largely because of a migration from rural to urban societies, and it is entirely possible that the nitrous oxide, and to a lesser extent, sulphur dioxide, released from industrial processes could have acted as fertilizer and thus stimulated biomass carbon sequestration. Indeed, the mere presence of more CO_2 could itself have acted as a fertilizer and increased growth rates.

o It has become quite clear in the recent past that the controlling factor in ocean sequestration of carbon is not in the atmosphere ocean interface but rather in the effectiveness of the translation mechanism which carries carbon from the surface to the much deeper water. However, these transport mechanisms are very poorly understood.

o Given all of the above, you have some feeling for some of the uncertainties involved and, I hope, a better feeling for the basic thrust of the IPCC calculations as to effective doubling times.

o Having established a doubling time, one then turns to the global circulation models to try to establish what impact the increase in radiative forcing would have on global temperatures and the like. The best IPCC estimate at the moment lies in the range of 1.4 to 2.9 degrees centigrade relative to the preindustrial situation.

o These models would also predict that today's global temperature should have increased between 0.5 and 1.1 degrees centigrade relative to that in say, 1750. There is general agreement in the scientific community that on average there has been something like a 0.5 degree centigrade in the mean global temperature over this period. And this would, therefore, fall at the low end of the model predictions if all of the warming could be attributed to anthropogenic carbon. Obviously it cannot.

o There are several possibilities. The observed warming could be attributed to purely natural fluctuations and there is clear evidence in the paleoecological ice core data of such fluctuations in the past, although these data are not sufficiently accurate to really pin this down with satisfactory precision. Alternatively, the observed increase could result from the superposition of an anthropogenic signal and a natural one and, since we have no way of knowing apriori what the natural signal is, we are left with substantial uncertainty. It is quite clear, however, that we are not talking about the 5 degrees centigrade predictions that have gained substantial publicity.

o As something of a footnote, and simply to illustrate some of the difficulties here, it should be noted that in the IPCC calculations it is assumed that we retain 50% of our current CFC emissions in the industrialized world plus some estimate of growing use in the developing world. Whereas, given present indications it is entirely possible that a very large fraction of the most potent CFCs will be removed from the atmosphere by about 2000. If this is the case, of course, the IPCC calculations overestimate the future radiative forcing but the effect is not all that large. If one were to assume that the CFCs were removed effectively by the year 2000, then we move the effective doubling time back by between 10 and 15 years.

This is typical of the uncertainties that lurk throughout this entire question, not to mention the whole series of feedback loops that are only beginning to be examined.

I am enclosing herewith the third draft of a section of the first IPCC Working Group Report that deals with greenhouse gases and aerosols and, as you will note, considers in section 1.2.7 a number of the possible oceanic and terrestrial feedback mechanisms. This at least represents a start in the right direction. This particular chapter has, like all the others, not been scrubbed by any of the IPCC participating governments but it has been prepared by a group led by Bob Watson and I think is a workman-like job in general.

I hope that this is helpful. I've concluded that relatively few people who have been engaged in the global warming discussions really understand what is going on with the numbers and I have attempted to spell out my best understanding here.

Enclosures

SECTION 1

Greenhouse Gases and Aerosols

3rd Draft
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LEAD AUTHORS: R. WATSON
H. RODHE
H. OESCHGER,
U. SIEGENTHALER

CONTRIBUTORS:

M. Andreae; R. Charlson; R. Cicerone; J. Coakley; R. Derwent;
J. Elkins; F. Fehsenfeld; P. Fraser; R. Gammon; H. Grassl;
R. Harriss; M. Heimann; R. Houghton; V. Kirchoff; G. Kohlmaier;
S. Lal; P. Liss; J. Logan; L. Merlivat; K. Minami; G. Pearman;
S. Penkett; D. Raynaud; E. Sanhueza; P. Simon; W. Su;
A. Thompson; A. Watson; M. Whitfield; P. Winkler; S. Wofsy.

SECTION 1: GREENHOUSE GASES AND AEROSOLS

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EXECUTIVE SUMMARY

The Earth's climate is dependent upon the radiative balance of the atmosphere, which in turn depends upon the input of solar radiation and the atmospheric abundances of radiatively active trace gases (i.e., greenhouse gases), clouds and aerosols.

Since the industrial revolution the atmospheric concentrations of several greenhouse gases, i.e., carbon dioxide (CO₂), methane (CH₄), chlorofluorocarbons (CFCs), nitrous oxide (N₂O), and tropospheric ozone (O₃), have been increasing, primarily due to human activities. Several of these greenhouse gases have long atmospheric lifetimes, decades to centuries, which means that their atmospheric concentrations respond slowly to changes in emission rates. In addition, there is evidence that the concentrations of tropospheric aerosols have increased at least regionally.

Carbon Dioxide: The atmospheric CO₂ concentration, at 353 ppmv in 1990, is now about 25% greater than the pre-industrial (1750-1800) value of about 280 ppmv, and higher than at any time in at least the last 160,000 years. Carbon dioxide is currently rising at about 1.8 ppmv (0.5%) per year due to anthropogenic emissions. Anthropogenic emissions of CO₂ are estimated to be 5.7±0.5 Gt C (in 1987) due to fossil fuel burning, plus 0.6 - 2.5 Gt C (in 1980) due to deforestation. The atmospheric increase during the past decade corresponds to (48±8)% of the total emissions during the same period with the remainder being taken up by the oceans and land. Indirect evidence suggests that the land and oceans sequester CO₂ in roughly equal proportions, though the mechanisms are not all well understood. The time taken for atmospheric CO₂ to adjust to changes in sources or sinks is of order 50-200 years, determined mainly by the slow exchange of carbon between surface waters and deeper layers of the ocean. Consequently, CO₂ emitted into the atmosphere today will influence the atmospheric concentration of CO₂ for centuries into the future. Three models have been used to estimate that even if anthropogenic emissions of CO₂ could be kept constant at present day rates, atmospheric CO₂ would increase to 415 - 480 ppmv by the year 2050, and to 460 - 560 ppmv by the year 2100. In order to stabilize concentrations at present day levels, an immediate reduction in global anthropogenic emissions by 60-80 percent would be necessary.

Methane: Current atmospheric CH₄ concentration, at 1.72 ppmv, is now more than double the pre-industrial (1750-1800) value of about 0.8 ppmv, and is increasing at a rate of about 0.015 ppmv (0.9%) per year. The major sink for CH₄, reaction with hydroxyl (OH) radicals in the troposphere, results in a relatively short atmospheric lifetime of about 10 years. Human activities such as rice cultivation, domestic ruminant rearing, biomass burning, coal mining, and natural gas venting have increased the input of CH₄ into the atmosphere, which combined with an possible decrease in the concentration of tropospheric OH, yields the observed rise in global CH₄. However, the quantitative importance of each of the factors contributing to the observed increase is not well known at present. In order to stabilize concentrations at present day levels, an immediate reduction in global anthropogenic emissions by 15-20 percent would be necessary.

Chlorofluorocarbons: The current atmospheric concentrations of the anthropogenically produced halocarbons, CCl₃F (CFC-11), CCl₂F₂ (CFC-12), C₂Cl₃F₃ (CFC-113) and CCl₄ (carbon tetrachloride) are about 280 pptv, 484 pptv, 60 pptv, and 146 pptv, respectively. Over the past few decades their concentrations, except for CCl₄, have increased more rapidly (on a percentage basis) than the other greenhouse gases, currently at rates of at least 4% per year. The fully halogenated CFCs and CCl₄ are primarily removed by photolysis in the stratosphere, and have atmospheric lifetimes in excess of 50 years. Future emissions will, most likely, be eliminated or significantly lower than today's because of current international negotiations to strengthen regulations on chlorofluorocarbons. However, the atmospheric concentrations of CFCs 11, 12 and 113 will still be significant (30 - 40% of current) for at least the next century because of their long atmospheric lifetimes.

1 **Nitrous Oxide:** The current atmospheric N_2O concentration, at 310 ppbv, is now about 8%
2 greater than in the pre-industrial era, and is increasing at a rate of about 0.8 ppbv (0.25%) per
3 year. The major sink for N_2O , photolysis in the stratosphere, results in a relatively long
4 atmospheric lifetime of about 150 years. It is difficult to quantitatively account for the source
5 of the current increase in the atmospheric concentration of N_2O but it is thought to be due to
6 human activities. Recent data suggest that the total annual flux of N_2O from combustion and
7 biomass burning is much less than previously believed. Agricultural practices may stimulate
8 emissions of N_2O from soils and play a major role. In order to stabilize concentrations at
9 present day levels, an immediate reduction of 70 - 80% of the additional flux of N_2O that has
10 occurred since the pre-industrial era would be necessary.
11

12 **Ozone:** Ozone is an effective greenhouse gas especially in the middle and upper troposphere
13 and lower stratosphere. Its concentration in the troposphere is highly variable because of its
14 short lifetime. It is photochemically produced in-situ through a series of complex reactions
15 involving carbon monoxide (CO), CH_4 , non-methane hydrocarbons (NMHC), and nitrogen
16 oxide radicals (NO_x), and also transported downward from the stratosphere. The limited
17 observational data support positive trends of about 1% per year for O_3 below 8 km in the
18 northern hemisphere (consistent with positive trends in several of the precursor gases,
19 especially NO_x , CH_4 , and CO) but probably close to zero trend in the southern hemisphere.
20 There is also evidence that O_3 has decreased by a few percent globally in the lower stratosphere
21 (below 25 km) within the last decade. Unfortunately, there are no reliable long-term data near
22 the tropopause.
23

24 **Aerosol particles:** Aerosol particles have a lifetime of at most a few weeks in the
25 troposphere and occur in highly variable concentrations. A large proportion of the particles that
26 influence cloud processes and the radiative balance is derived from gaseous sulphur emissions.
27 Due to fossil fuel combustion, these emissions have more than doubled globally, causing a
28 large increase in the concentration of aerosol sulphate especially over and around the
29 industrialized regions of Europe and North America. Future concentrations of aerosol sulphate
30 will vary in proportion to changes in anthropogenic emissions. Aerosol particles derived from
31 natural (biological) emissions may contribute to climate feedback processes. During a few
32 years following major volcanic eruptions the concentrations of natural aerosol particles in the
33 stratosphere can be greatly enhanced.
34

1.1 INTRODUCTION

The Earth's climate is dependent upon the radiative balance of the atmosphere, which in turn depends upon the input of solar radiation and the atmospheric abundances of radiatively active trace gases (i.e., greenhouse gases), clouds and aerosols. Consequently, it is essential to gain an understanding of how each of these climate "forcing agents" varies naturally, and how some of them might be influenced by human activities.

The chemical composition of the Earth's atmosphere is changing, largely due to human activities (Table 1). Air trapped in Antarctic and Greenland ice shows that there have been major increases in the concentrations of radiatively active gases such as carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O) since the beginning of the industrial revolution. In addition, industrially produced chlorofluorocarbons (CFCs) are now present in the atmosphere in significant concentrations, and there is evidence that the concentrations of tropospheric O₃ and aerosols have increased at least regionally. Atmospheric measurements indicate that in many cases the rates of change have increased in recent decades. Many of the greenhouse gases have long atmospheric life-times, decades to centuries, which implies that their atmospheric concentrations respond slowly to changes in emission rates.

TABLE 1
Summary of Key Greenhouse Gases Influenced by Human Activities ¹

Parameter	CO ₂	CH ₄	CFC-11	CFC-12	N ₂ O
Pre-industrial atmospheric concentration (1750-1800)	280 ppmv ²	0.8 ppmv	0	0	288 ppbv ²
Current atmospheric concentration (1990) ³	353 ppmv	1.72 ppmv	280 pptv ²	484 pptv	310 ppbv
Current rate of annual atmospheric accumulation	1.8 ppmv (0.5%)	0.015 ppmv (0.9%)	9.5 pptv (4%)	17 pptv (4%)	0.8 ppbv (0.25%)
Atmospheric lifetime ⁴ (years)	(50-200)	10	65	130	150

1 Ozone has not been included in the table because of lack of precise data.

2 ppmv = parts per million by volume;

ppbv = parts per billion by volume;

pptv = parts per trillion by volume.

3 The current (1990) concentrations have been estimated based upon an extrapolation of measurements reported for earlier years, assuming that the recent trends remained approximately constant.

4 For each gas in the table, except CO₂, the "lifetime" is defined here as the ratio of the atmospheric content to the total rate of removal. This time scale also characterizes the rate of adjustment of the atmospheric concentrations if the emission rates are changed abruptly. CO₂ is a special case since it has no real sinks, but is merely circulated between various reservoirs (atmosphere, ocean, biota). The "lifetime" of CO₂ given in the table is a rough indication of the time it would take for the CO₂ concentration to adjust to changes in the emissions (see section 1.2.1 for further details).

The effectiveness of a greenhouse gas in influencing the Earth's radiative budget is dependent upon its atmospheric concentration and its ability to absorb outgoing long-wave terrestrial radiation. Tropospheric water vapour is the single most important greenhouse gas, but its atmospheric concentration is not significantly influenced by direct anthropogenic emissions. Of the greenhouse gases that are affected by human activities, CO₂ has the largest radiative effect, followed by the CFCs, CH₄, tropospheric O₃, and N₂O. Although the present rate of increase in the atmospheric concentration of CO₂ is about a factor of 70,000 times greater than that of CCl₃F (CFC-11) and CCl₂F₂ (CFC-12) combined, and a factor of about 120 times greater than that of CH₄, its contribution to changes in the radiative forcing during the decade of the 1980s was about 55%, compared to 17% for CFCs (11 and 12), and 15% for CH₄ (see Section 2). Other CFCs and N₂O accounted for about 8%, and 5%, respectively, of the changes in the radiative forcing. While the contribution from tropospheric O₃ may be important, it has not been quantified because the observational data is inadequate to determine its trend. This pattern arises because of differences in the efficiencies of the gases to absorb terrestrial radiation.

Aerosol particles play an important role in the climate system because of their direct interaction (absorption and scattering) with solar and terrestrial radiation, as well as through their influence on cloud processes and thereby, indirectly, on radiative fluxes.

There is a clear need to document the historical record of the atmospheric concentrations of greenhouse gases and aerosols, as well as to understand the physical, chemical, geological, biological and social processes responsible for the observed changes. A quantitative understanding of the atmospheric concentrations of these gases requires knowledge of: the cycling and distribution of carbon, nitrogen and other key nutrients within and between the atmosphere, terrestrial ecosystems, oceans and sediments; and the influence of human actions on these cycles. Without knowledge of the processes responsible for the observed past and present changes in the atmospheric concentrations of greenhouse gases and aerosols it will not be possible to predict with confidence future changes in atmospheric composition, nor therefore the resulting changes in the radiative forcing of the atmosphere.

1.2 CARBON DIOXIDE

1.2.1 The Cycle of Carbon in Nature

Carbon in the form of CO₂, carbonates, organic compounds, etc. is cycled between various reservoirs, atmosphere, oceans, land biota and marine biota, and on geological time scales, also sediments and rocks (Figure 1.1; for more detailed reviews see Sundquist, 1985; Bolin, 1981, 1986; Trabalka, 1985; Siegenthaler, 1986). The largest natural exchange fluxes occur between the atmosphere and the terrestrial biota and between the atmosphere and the surface water of the oceans. By comparison, the net inputs into the atmosphere from fossil fuel combustion and deforestation are much smaller, but are large enough to modify the natural balance.

The turnover time of CO₂ in the atmosphere, measured as the ratio of the content to the fluxes through it, is about 4 years. This means that on average it takes only a few years before a CO₂ molecule in the atmosphere is taken up by plants or dissolved in the ocean. This short time scale must not be confused with the time it takes for the atmospheric CO₂ level to adjust to a new equilibrium if sources or sinks change. This adjustment time, corresponding to the lifetime in Table 1, is of the order of 50 - 200 years, determined mainly by the slow exchange of carbon between surface waters and the deep ocean. The adjustment time is important for the discussions on global warming potential, cf. Section 2.2.7.

Because of its complex cycle, the decay of excess CO₂ in the atmosphere does not follow a simple exponential curve, and therefore a single time scale cannot be given to characterize the whole adjustment process toward a new equilibrium. The two curves in Figure 1.2, which represent simulations of a pulsed input of CO₂ into the atmosphere using atmosphere-ocean models (one box model and one General Circulation Model (GCM)), clearly show that the

1 initial response (governed mainly by the uptake of CO₂ by ocean surface waters) is much more
2 rapid than the later response (influenced by the slow exchange between surface waters and
3 deeper layers of the oceans). For example, the first reduction by 50 percent occurs within
4 some 50 years, whereas the reduction by another 50 percent (to 25 percent of the initial value)
5 requires approximately another 200 years. The concentration will actually never return to its
6 original value, but reach a new equilibrium level; about 15 percent of the total amount of CO₂
7 emitted will remain in the atmosphere.

9 1.2.1.1 The role of the atmosphere

10 The mean annual concentration of CO₂ is relatively homogeneous throughout the troposphere
11 because the troposphere is mixed on a time scale of about 1 year. The pre-industrial
12 atmospheric CO₂ concentration was about 280 ppmv, as reconstructed from ice core analyses
13 (c.f. Section 1.2.4.1), corresponding to an atmospheric amount of 594 Gigatonnes of carbon
14 (GtC: 1 Gt = 10⁹t = 10¹⁵g; 1 ppmv CO₂ of the global atmosphere equals 2.12 GtC and 7.8 Gt
15 CO₂); today, the level is about 353 ppmv (Figures 1.3 and 1.4). The atmospheric increase has
16 been monitored since 1958 at a growing number of stations (Keeling and Heimann, 1986;
17 Keeling et al., 1989a; Beardsmore and Pearman, 1987; Conway et al., 1988).

19 1.2.1.2 The role of the ocean

20 On time scales of decades or more, the CO₂ concentration of the unperturbed atmosphere is
21 mainly controlled by the exchange with the oceans, since this is the largest of the carbon
22 reservoirs. There is a continuous exchange of CO₂ in both directions between the atmosphere
23 and oceans. The net flux into (or out of) the ocean is driven by the difference between the
24 atmospheric partial pressure of CO₂ and the equilibrium partial pressure of CO₂ (pCO₂) in
25 surface waters.

26
27 The exchange of carbon between the surface and deeper layers is accomplished mainly through
28 transport by water motions. Ventilation of the thermocline (approximately the uppermost km
29 of the ocean) is particularly important for the downward transport of anthropogenic CO₂. The
30 deep circulation is effective on time scales of 100-1000 years.

31
32 The natural carbon cycle in the ocean and in particular pCO₂ in surface ocean water are strongly
33 influenced also by biological processes. The marine biota serve as a "biological pump",
34 transporting organic carbon from surface waters to deeper layers as a rain of detritus at a rate
35 of about 4 GtC per year (Eppley and Peterson, 1979), which is balanced by an equal upward
36 transport of carbon by deeper water richer in CO₂ than surface water. This "biological pump"
37 has the effect of reducing surface pCO₂ very substantially: without the biological pump ("dead
38 ocean") the pre-industrial CO₂ level would have been higher than the observed value of 280
39 ppmv, at perhaps 450 ppmv (Wenk, 1985; Bacastow and Maier-Reimer, 1990). Alterations in
40 the marine biota due to climatic change could therefore have a substantial effect on CO₂ levels
41 in the future. Note, however, that the "biological pump" does not help to sequester
42 anthropogenic CO₂ (see Section 1.2.4.2).

44 1.2.1.3 The role of terrestrial vegetation and soils

45 The most important processes in the exchange of carbon are those of photosynthesis,
46 autotrophic respiration (i.e., CO₂ production by the plants) and heterotrophic (i.e., essentially
47 microbial) respiration converting the organic material back into CO₂ mainly in soils (c.f.
48 Section 10 for a detailed discussion). Net primary production (NPP) is the net annual uptake
49 of CO₂ by the vegetation; NPP is equal to the gross uptake (gross primary production, GPP)
50 minus autotrophic respiration. In an unperturbed world, NPP and decomposition by
51 heterotrophic respiration are approximately balanced on an annual basis; formation of soils and
52 peat corresponds to a (relatively small) excess of NPP.

53
54 The carbon balance can be changed considerably by the direct impact of man (land use
55 changes, particularly deforestation), by climate changes, and by other changes in the
56 environment, e.g., atmospheric composition. Since the pools and fluxes are large (NPP 50-60
57 GtC per year, GPP 90-120 GtC per year; Houghton et al, 1985b), any perturbations can have a
58 significant effect on the atmospheric concentration of CO₂.

1.2.2 Anthropogenic Perturbations

The concentrations of CO₂ in the atmosphere are primarily affected by two anthropogenic processes: release of CO₂ from fossil fuel combustion, and changes in land use such as deforestation.

1.2.2.1 Historical fossil fuel input

The global input of CO₂ to the atmosphere from fossil fuel combustion, plus minor industrial sources like cement production, has shown an exponential increase since 1860 (about 4% per year), with major interruptions during the two world wars and the economic crisis in the thirties (Figure 1.5). Following the "oil crisis" of 1973, the rate of increase of the CO₂ emissions first decreased to approximately 2% per year, and after 1979 the global emissions remained almost constant at a level of 5.3 GtC per year until 1985, when they started to rise again, reaching 5.7 GtC per year in 1987 (Figure 1.5). The cumulative release of CO₂ from fossil fuel use and cement manufacturing from 1850 to 1987 is estimated at 200 GtC $\pm$ 10% (Marland, 1989).

Ninety five percent of the industrial CO₂ emissions are from the northern hemisphere, dominated by industrial countries, where annual releases reach up to about 5 tC per capita (Rotty and Marland, 1986). In contrast, CO₂ emission rates in most developing countries lie between 0.2 and 0.6 tC per capita per year. However, the relative rate of increase of the CO₂ emissions is much larger in the developing countries (ca 6% per year), showing almost no slowing down after 1973 in contrast to Western Europe and North America where the rate of increase decreased from about 3% per year (1945-72) to less than 1% per year (1973-84).

1.2.2.2 Historical land use changes

The vegetation and soils of unmanaged forests hold 20 to 100 times more carbon per unit area than agricultural systems. The amount of carbon released to the atmosphere compared to that accumulated on land as a result of land use change depends on the amounts of carbon held in biomass and soils, rates of oxidation of wood products (either rapidly through burning or more slowly through decay), rates of decay of organic matter in soils, and rates of regrowth of forests following harvest or abandonment of agricultural land. The heterogeneity of terrestrial ecosystems makes estimation of global inventories and fluxes difficult.

The total release of carbon to the atmosphere from changes in land use, primarily deforestation, between 1850 and 1985 has been estimated to be about 115 GtC (Houghton and Skole, 1990), with an error limit of about $\pm$ 35 GtC. The components of the flux to the atmosphere are: (1) burning associated with land use change; (2) decay of biomass on site (roots, stumps, slash, twigs etc.); (3) oxidation of wood products removed from site (paper, lumber, waste etc.); (4) oxidation of soil carbon; minus (5) regrowth of trees and redevelopment of soil organic matter following harvest. Although the greatest releases of carbon in the nineteenth and early twentieth centuries were from lands in the temperate zone (maximum 0.5 GtC per year), the major source of carbon during the past several decades has been from deforestation in the tropics, with a significant increase occurring since 1950. Over the entire 135 yr period, the release from tropical regions is estimated to have been 2-3 times greater than the release from middle and high latitudes. Estimates of the flux in 1980 range from 0.6 to 2.5 GtC (Houghton et al. 1985a, 1987, 1988; Detwiler and Hall, 1988): virtually all of this flux is from the tropics. The few regions for which data exist suggest that the annual flux is higher now than it was in 1980.

1.2.3 Long-Term Atmospheric Carbon Dioxide Variations

The most reliable information on past atmospheric CO₂ concentrations is obtained by the analysis of polar ice cores. The process of air occlusion lasts from about 10 up to 1000 years, depending on local conditions (e.g., precipitation rate), so that an air sample in old ice reflects the atmospheric composition averaged over a corresponding time interval.

Measurements on samples representing the last glacial maximum (18,000 yr before present) from ice cores from Greenland and Antarctica (Neftel et al, 1982, 1988; Delmas et al., 1980) showed CO₂ concentrations of 180-200 ppmv, i.e., about 70 percent of the pre-industrial value. Analyses on the ice cores from Vostok, Antarctica, have provided new data on natural variations of CO₂, covering a full glacial-interglacial cycle (Figure 1.6; Barnola et al., 1987). Over the whole period there is a remarkable correlation between polar temperature, as deduced from deuterium data, and the CO₂ profile. The glacial-interglacial shifts of CO₂ concentrations must have been linked to large-scale changes in the circulation of the ocean, and in the whole interplay of biological, chemical and physical processes, but the detailed mechanisms are not yet very clear. The CO₂ variations were large enough to potentially contribute, via the greenhouse effect, to a substantial (although not the major) part of the glacial-interglacial climate change (Hansen et al., 1984; Broccoli and Manabe, 1987).

Ice core studies on Greenland ice indicate that during the last glaciation, CO₂ concentration shifts of the order of 50 ppmv may have occurred within less than 100 years (Stauffer et al., 1984), parallel to abrupt, drastic climatic events (temperature changes of the order of 5°C). These rapid CO₂ changes have not yet been identified in ice cores from Antarctica (possibly due to long occlusion times; Neftel et al., 1988), therefore, it is not yet clear if they are real or represent artefacts in the ice record.

1.2.4 The Contemporary Record of Carbon Dioxide - Observations and Interpretation

1.2.4.1 The carbon dioxide increase from pre-industrial period

Relatively detailed CO₂ data have been obtained for the last millennium from Antarctic ice cores (Neftel et al, 1985a; Friedli et al, 1986; Siegenthaler et al., 1988; Raynaud and Barnola, 1985, Pearman et al., 1986). They indicate that during the period 1000 to 1800, the atmospheric concentration was between 270 and 290 ppmv. The relative constancy seems surprising in view of the fact that the atmosphere exchanges about 30 percent of its CO₂ with the oceans and biota each year. This indicates that the sensitivity of atmospheric CO₂ levels to minor climatic changes such as the Little Ice Age (lasting from the end of the 16th to the middle of the 19th century), where global mean temperatures probably decreased by about 1°C, is small.

A precise reconstruction of the CO₂ increase during the past two centuries has been obtained from an ice core from Siple Station, Antarctica (Figure 1.3; Neftel et al., 1985a, Friedli et al., 1986). These results indicate that CO₂ started to rise around 1800 and had already increased by about 15 ppmv by 1900. Precise direct atmospheric measurements started in 1958, when the level was about 315 ppmv and the rate of increase 0.6 ppmv per year. The present atmospheric CO₂ level has reached 353 ppmv, and the mean growth rate has now reached about 1.8 ppmv per year (Figure 1.4; Keeling et al, 1989a).

1.2.4.2 Uptake by the ocean

The ocean is an important reservoir for taking up anthropogenic CO₂. The relative increase of dissolved inorganic carbon (total CO₂) in ocean water is smaller than in the atmosphere (only 2-3 percent until now, see below). Precise measurements of dissolved inorganic carbon can be made with present analytical tools. However, an accurate determination of the trend in dissolved inorganic carbon is difficult because of its variability in time and space. Hence, repeated transects and time series will be required to assess the total oceanic CO₂ uptake with good precision.

The net flux of CO₂ into (or out of) the ocean is given by the product of a gas transfer coefficient and $\Delta p\text{CO}_2$ (the CO₂ partial pressure difference between ocean and atmosphere). The gas transfer coefficient increases with increasing wind speed and also depends on water temperature. Therefore, the net flux into the ocean can be estimated from a knowledge of the atmospheric CO₂ concentration, $p\text{CO}_2$ in surface water (for which the data are still sparse), the global distribution of wind speeds over the ocean as well as the relation between wind speed and gas transfer coefficient (which is known to $\pm 30\%$ only). There have been several

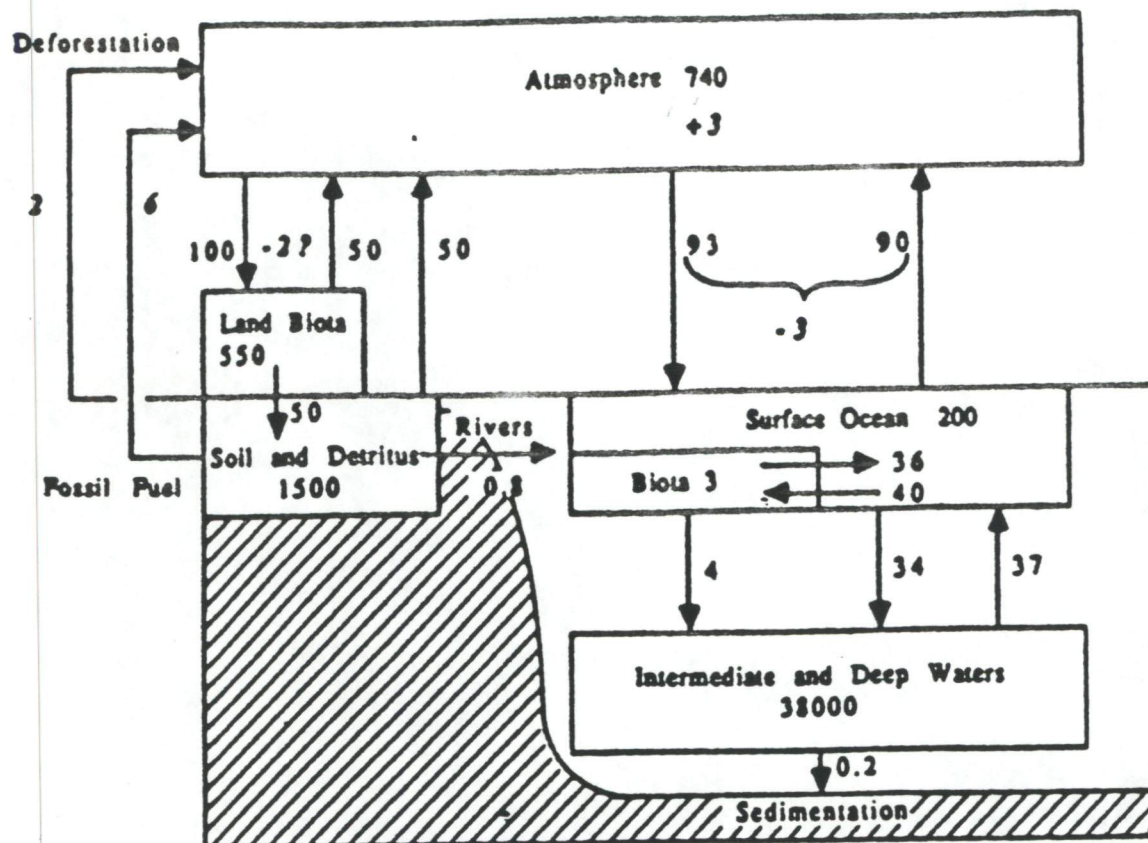


Figure 1: Global carbon reservoirs and fluxes. The numbers apply for the present-day situation and represent typical literature values. Fluxes, e.g. between atmosphere and surface ocean, are gross annual exchanges. Numbers in bold-face italics indicate net annual perturbation fluxes to the atmosphere and annual atmospheric CO_2 increase due to human action. Units are gigatons of carbon (GtC; 1 Gt = 10^9 metric tons = 10^{12} kg) for reservoir sizes and GtC yr^{-1} for fluxes. More details and discussions are found in several reviews (Sundquist, 1985; Trabalka, 1985; Bolin, 1986; Siegenthaler, 1986).

estimates of the global net uptake of CO₂ by the oceans using observations (e.g., Enting and Pearman, 1982, 1987). The most recent estimate yields 1.6 GtC per year (Tans et al., 1990); the error of this estimate is, according to the authors, not easy to estimate.

Estimates of oceanic CO₂ uptake, in the past and in the future, require models of the global carbon cycle that take into account air-sea gas exchange, aqueous carbonate chemistry and the transport from the surface to deep ocean layers. The aqueous carbonate chemistry in sea water operates in a mode that if the atmospheric CO₂ concentration increases by e.g., 10%, then the concentration of dissolved inorganic carbon in sea water increases by only about 1% at equilibrium. Therefore, the ocean is not such a powerful sink for anthropogenic CO₂ as might seem first when comparing the relative sizes of the reservoirs (Figure 1.1).

The rate at which anthropogenic CO₂ is transported from the surface to deeper ocean layers is determined by the rate of water exchange in the vertical. It is known from measurements of the radioactive isotope ¹⁴C that on average it takes hundreds to about one thousand years for water at the surface to penetrate to well below the mixed layer of the major oceans (e.g., Broecker and Peng, 1982). Thus, in most oceanic regions only the top several hundred metres of the oceans have at present taken up significant amounts of anthropogenic CO₂. An exception is the North Atlantic Ocean where bomb-produced tritium has been observed even near the bottom of the sea, indicating the active formation of new deep water.

The rain of biogenic detrital particles, which is important for the natural carbon cycle, does not significantly contribute to a sequestering of excess CO₂, since the marine biota do not directly respond to the CO₂ increase. Their activity is controlled by other factors, such as light, temperature and limiting nutrients (e.g., nitrogen, phosphorus, silicon). Thus, only the input of fertilizers (phosphate, nitrate) into the ocean through human activities may lead to an additional sedimentation of organic carbon in the ocean; different authors have estimated the size of this additional sink between 0.04 and 0.3 GtC per year (see Baes, 1985). It seems thus justified to estimate the fossil fuel CO₂ uptake to date considering the biological flux to be constant, as long as climatic changes due to increasing greenhouse gases, or natural causes, do not modify the marine biotic processes. Although this appears a reasonable assumption for the past and present situation, it may well not be so in the future.

The carbon cycle models used to date to simulate the atmosphere-ocean system have often been highly simplified, consisting of a few well-mixed or diffusive reservoirs (boxes) (e.g., Oeschger et al. 1975; Broecker et al., 1980; Bolin, 1981; Enting and Pearman, 1987; Siegenthaler, 1983). Even though these box models are highly simplified they are a powerful means for identifying the importance of the different processes that determine the flux of CO₂ into the ocean (e.g., Broecker and Peng, 1982; Peng and Broecker, 1985). The results of these models are considered to be reasonable because, as long as the ocean circulation is not changing, the models need only simulate the transport of excess CO₂ from the atmosphere into the ocean, but not the actual dynamics of the ocean. In the simple models, the oceanic transport mechanisms, eg., formation of deep water, are parameterized. The transport parameters (e.g., eddy diffusivity) are determined from observations of transient tracers that are analogs to the flux of anthropogenic CO₂ into the ocean. If a model reproduces correctly the observed distribution of, e.g., bomb-produced ¹⁴C, then it might be expected to simulate reasonably the flux of CO₂ into the ocean. A 1-D box-diffusion model yields an oceanic uptake of 2.4 GtC per year on average for the decade 1980 - 1989, and an outcrop-diffusion model (both described by Siegenthaler, 1983) 3.6 GtC per year. The latter model most probably overpredicts the flux into the ocean, because it includes an infinitely fast exchange between high-latitude surface waters and the deep ocean.

However, it is obviously desirable to use 3-dimensional (3-D) general circulation models of the oceans for this purpose. At this time, only a few modeling groups have started to do this. One 3-D model (Maier-Reimer and Hasselmann, 1987) gives a similar CO₂ uptake as a 1-D box-diffusion model of Siegenthaler (1983), as illustrated by the model response to a pulse input of CO₂ (Figure 1.2). In a recent revised version of this model (Maier-Reimer et al., personal communication) the ocean takes up less CO₂, about 1.2 GtC per year on average for the decade 1980 - 1989. The GFDL 3-D ocean model (Sarmiento et al., 1990) has an oceanic uptake of

1.9 GtC per year for the same period. 3-D ocean models and especially coupled atmosphere-ocean models are the only means to study in a realistic way the feedback effects that climate change may have on atmospheric CO₂ via alteration of the ocean circulation (cf. Section 1.2.7.1). However, models need to be constrained by more data than are presently available.

The oceanic uptake of CO₂ for the decade 1980 - 1989, as estimated based on carbon models (e.g., Siegenthaler and Oeschger, 1987; Maier-Reimer et al., personal communication, 1990; Goudriaan, 1989; Sarmiento et al., 1990) is in the range 2.0 ± 0.8 GtC per year.

1.2.4.3 Redistribution of anthropogenic carbon dioxide

During the period 1850 to 1986, 195 ± 20 GtC were released by fossil fuel burning and 117 ± 35 GtC by deforestation and changes in land use, adding up to a cumulative input of 312 ± 40 GtC.

Atmospheric CO₂ increased from about 288 ppmv to 348 ppmv during this period, corresponding to $(41 \pm 6)\%$ of the cumulative input. This percentage is sometimes called the "airborne fraction", but that term should not be misunderstood: all CO₂, anthropogenic and non-anthropogenic, is continuously being exchanged between atmosphere, ocean and biosphere. Conventionally, an "airborne fraction" referring to the fossil input only has often been quoted, because only the emissions due to fossil fuel burning are known with good precision. However, this may be misleading, since the atmospheric increase is a response to the total emissions. We therefore prefer the definition based on the latter. The airborne fraction for the period 1980 - 1989 (see calculation below) corresponds to $(48 \pm 8)\%$ of the cumulative input.

In model simulations of the past CO₂ increase, using estimated emissions from fossil fuels and deforestation, it has generally been found that the simulated increase is larger than that actually observed. An estimate for the decade 1980-1989 is:

Emissions from fossil fuels into the atmosphere (Figure 1.5)	5.4 ± 0.5 GtC per yr
Emissions from deforestation and land use	1.6 ± 1.0
Accumulation in the atmosphere	3.4 ± 0.2
Uptake by the ocean	<u>2.0 ± 0.8</u>
Net imbalance	1.6 ± 1.4

The result from this budget and from other studies is that the estimated emissions exceed the sum of atmospheric increase plus model-calculated oceanic uptake by a significant amount. The question therefore arises whether an important mechanism has been overlooked. All attempts to identify such a "missing sink" in the ocean have, however, failed so far. A possible exception is that a natural fluctuation in the oceanic carbon system could have caused a decreasing atmospheric baseline concentration in the past few decades; this does not appear likely in view of the relative constancy of the pre-industrial CO₂ concentration. There are possible processes on land, which could account for the missing CO₂ (but it has not been possible to verify them). They include the stimulation of vegetative growth by increasing CO₂ levels (the CO₂ fertilization effect), the possible enhanced productivity of vegetation under warmer conditions, and the direct effect of fertilization from agricultural fertilizers and from nitrogenous releases into the atmosphere. It has been estimated that increased fertilization by nitrogenous releases could account for a sequestering of up to a maximum of 1 GtC per year in terrestrial ecosystems (Melillo, private communication, 1990). In addition, changed forest management practices may also result in an increase in the amount of carbon stored in northern mid-latitude forests. The extent to which mid-latitude terrestrial systems can sequester carbon before becoming saturated and ineffective is unknown. As mid-latitude terrestrial systems become close to becoming saturated, and hence ineffective in sequestering carbon, this would allow more of the CO₂ to remain in the atmosphere.

A technique for establishing the global distribution of surface sources and sinks has been to take global observations of atmospheric CO₂ concentration and isotopic composition and to invert these by means of atmospheric transport models to deduce spatial and temporal patterns of surface fluxes (Pearman et al., 1983; Pearman and Hyson, 1986; Keeling and Heimann,

1986). The observed interhemispheric CO₂ concentration difference (currently about 3 ppmv) is smaller than one would expect given that nearly all fossil releases occur in the northern hemisphere. The results of this approach suggest that there is an unexpectedly large sink in the northern hemisphere, equivalent to more than half of the fossil fuel CO₂ release (Enting and Mansbridge, 1989; Tans et al., 1990; Keeling et al., 1989b). Furthermore, it has been concluded that the oceanic uptake compatible with oceanic and atmospheric CO₂ data and with a 3-dimensional atmospheric transport model is at most 1 GtC per year (Tans et al., 1990). Thus, a significant terrestrial sink, possibly larger than the oceanic uptake, is suggested by these model analyses.

1.2.4.4 Seasonal variations

Atmospheric CO₂ exhibits a seasonal cycle, dominated by the seasonal uptake and release of atmospheric CO₂ by land plants. Its amplitude is small (1.2 ppmv peak-to-peak) in the southern hemisphere and increases northward to a maximum of order 15 ppmv peak-to-peak in the boreal forest zone (55-65° N).

The amplitude of the seasonal cycle has been observed to be increasing (e.g., Pearman and Hyson, 1981; Bacastow et al., 1985; Thompson et al., 1986). For example, at Mauna Loa, Hawaii, the seasonal amplitude has increased by nearly 20% since 1958. The increase has however, not been monotonic, and different evaluation methods yield somewhat different values; still, it is statistically significant. This increasing amplitude could point to a growing productivity (NPP) of the terrestrial ecosystems, and to a sequestering of carbon by a growing biomass, provided the increase in biomass is not fully compensated by respiration. It is important to note that such a change does not necessarily indicate increased productivity or increased storage of carbon (Pearman and Hyson, 1981; Kohlmaier et al., 1989; Houghton, 1987); it could also be due to, e.g., accelerated soil respiration in winter.

1.2.4.5 Interannual variations

Small imbalances in natural exchange fluxes are reflected in interannual CO₂ concentration fluctuations (± 1 ppmv over 1-2 years). They are correlated with the El Niño-Southern Oscillation (ENSO) phenomenon (Thompson et al., 1986; Keeling et al., 1989a), which suggests a relation to changes in the equatorial Pacific Ocean, where normally the upwelling causes a high pCO₂ peak and outgassing of CO₂ into the atmosphere. However, a closer inspection shows that this cannot be the dominating mechanism, since during El Niño, the equatorial pCO₂ peak disappears (Feely et al., 1987), while atmospheric CO₂ grows more strongly than normally. Alternatively, processes in the land biosphere, perhaps in response to climatic events connected with ENSO events, may be responsible. This explanation is supported by one set of stable carbon isotope data on atmospheric CO₂ (Keeling et al., 1989a); but not supported by a second set (Goodman and Francey, 1988).

1.2.4.6 Temporal variations of carbon isotopes

The release of CO₂ from biospheric carbon and fossil fuels, both having lower ¹³C/¹²C ratios than atmospheric CO₂, has led to a decrease of the isotope ratio ¹³C/¹²C in the atmosphere by about 1‰. The man-made emissions of ¹⁴C-free fossil fuel CO₂ have likewise caused a decrease of the atmospheric ¹⁴C concentration (measured on tree-rings) of the order of 2% from 1800 to 1950. Both isotopic perturbations can be used to constrain the history of the anthropogenic release of CO₂. The observed decreases of ¹³C, as observed in air trapped in ice cores (Friedli et al., 1986) and ¹⁴C, observed in tree rings, agree, within experimental uncertainty, with those expected from model calculations with the same carbon cycle models as used for studying the CO₂ increase (Stuiver and Quay, 1981; Siegenthaler and Oeschger, 1987). The interpretation of ¹³C trends in tree rings has proven to be difficult because of plant physiological effects on isotope fractionation (Francey and Farquhar, 1982).

1.2.5 Evidence that the Contemporary Carbon Dioxide Increase is Anthropogenic

1 How do we know that in fact human activity has been responsible for the well documented
2 25% increase in atmospheric CO₂ since the early 19th century? Couldn't this rise instead be
3 the result of some long-term natural fluctuation in the natural carbon cycle? Simple arguments
4 allow us to dismiss this possibility.
5

6 First, the observational CO₂ records from ice cores with good time resolution clearly show that
7 the maximum range of natural variability about the mean of 280 ppmv during the past 1000
8 years was small (10 ppmv over a 100 year timescale), that is an order of magnitude less than
9 the observed rise over the last 150 years. A value as high as the current level of 353 ppmv is
10 not observed anywhere in the measured ice core record for the atmospheric history during the
11 past 160,000 years; the maximum value is 300 ppmv during the previous interglacial, 120,000
12 years ago.
13

14 Second, the observed rate of CO₂ increase closely parallels the accumulated emission trends
15 from fossil fuel combustion and from land use changes (c.f. Section 1.2.2). Since the start of
16 atmospheric monitoring in 1958, the annual atmospheric increase has been smaller each year
17 than the fossil CO₂ input. Thus, oceans and biota together must have been a global sink rather
18 than a source during all these years. Further evidence is provided by the fact that the north-to-
19 south CO₂ concentration difference has been observed to increase from 1 ppmv in 1960 to 3
20 ppmv in 1985, parallel to the growth of the (northern hemisphere) fossil fuel combustion
21 sources (Keeling et al., 1989a).
22

23 Third, the observed isotopic trends of ¹³C and ¹⁴C agree qualitatively with those expected due
24 to the CO₂ emissions from fossil fuels and the biosphere, and they are quantitatively consistent
25 with results from carbon cycle modelling.
26
27

28 1.2.6 Sensitivity Analyses for Future Carbon Dioxide Concentrations

29
30 Future atmospheric CO₂ concentrations depend primarily on emission rates from energy use
31 and deforestation, and on the effectiveness of the ocean and land biota as CO₂ sinks. For the
32 sake of illustration, several schematic scenarios are shown in Figures 1.7 and 1.8. Those of
33 Figure 1.7 are based on prescribed total CO₂ emission rates after 1990, for those in Figure 1.8
34 atmospheric concentrations after 1990 were prescribed and the corresponding emission rates
35 were calculated to fit these concentrations. A box-diffusion model of the global cycle was used
36 for these simulations (Enting and Pearman, 1982, 1987), with an oceanic eddy diffusivity of
37 5350 m²year⁻¹ and an air-sea gas exchange rate corresponding to an exchange coefficient of
38 0.12 year⁻¹. The calculations assume no biospheric-climate feedbacks, and also assume that
39 after 1990 the net biospheric input of CO₂ is zero, i.e., the input of CO₂ from tropical
40 deforestation is balanced by uptake of CO₂ by terrestrial ecosystems.
41

42 In case a (all emissions stopped; Figure 1.7), the atmospheric concentration declines, but only
43 slowly (from 351 ppmv in 1990 to 331 ppmv in 2050 and 324 ppmv in 2100), because the
44 penetration of man-made CO₂ to deeper ocean layers takes a long time. Even if the emissions
45 were reduced by 2% per year from 1990 on (case b), atmospheric CO₂ would continue to
46 increase for several decades. Case c (constant emission rate after 1990) gives CO₂ levels of
47 about 450 ppmv in 2050 and 520 ppmv in 2100. A constant relative growth rate of 2% per
48 year (case d) would yield 575 ppmv in 2050 and 1330 ppmv in 2100. Comparison of cases b,
49 c and d clearly shows that measures to reduce emissions will result in slowing down the rate of
50 atmospheric CO₂ growth.
51

52 Cases b' and c', in comparison to b and c, schematically illustrate the effect of reducing
53 emissions in 2010 instead of in 1990.
54

55 If an (arbitrary) threshold of 420 ppmv, i.e., 50% above pre-industrial, is not to be exceeded
56 (case e, Figure 1.8), then CO₂ production rates should slowly decline, reaching about 50% of
57 their present value by 2050 and 30% by 2100. In order to keep the concentration at the present

level (case f), emissions would have to be reduced drastically to 30% of present immediately and to less than 20% by 2050.

The results of scenario calculations with a 3-D ocean-atmosphere model (Maier-Reimer and Hasselmann, 1987; Maier-Reimer et al., personal communication, 1990--revised model) give higher concentrations than those obtained with a box-diffusion model shown in Figure 1.7. For instance, about 480 ppmv in the year 2050 and about 560 ppmv in the year 2100 for scenario c, compared to about 450 ppmv and 520 ppmv in Figure 1.7. On the other hand, calculations with a box model that includes a biospheric CO₂ sink (Goudriaan, 1989) yields somewhat lower concentrations than shown in Figure 1.7, for instance about 415 ppmv in the year 2050 and 460 ppmv in the year 2100 for scenario c.

1.2.7 Feedbacks from Climate Change into the Carbon Dioxide Cycle

As increasing greenhouse gas concentrations alter the Earth's climate, changing climate and environmental conditions in their turn act back on the carbon cycle and atmospheric CO₂. The climate change Earth has experienced in the recent past is still within the range of natural short-term variability, and so are probably, therefore, the feedback effects of anthropogenic climate change. However, as the changes in the climate become larger than natural climatic variation the magnitude of the feedback effects should begin to have a significant effect. These feedbacks could in general be either positive (amplifying the initial changes) or negative (attenuating them).

1.2.7.1 Oceanic feedback effects

The following are possible feedback effects on the ocean-atmosphere carbon system:

1.2.7.1.1 Ocean temperature: Ocean temperature changes can affect sea water CO₂ chemistry. Surface-water pCO₂ will increase with increasing temperature, tending to decrease the net uptake by the oceans. The future atmospheric CO₂ increase may be amplified by something like 5 percent due to this effect (Lashof, 1989).

1.2.7.1.2 Ocean circulation: The ocean circulation may change in response to climatic change. As a consequence of increasing surface water temperatures, the thermocline may become more resistant to vertical mixing and slow down the uptake of anthropogenic CO₂. Modified wind stress may affect ocean circulation. However, the overall change in ocean dynamics, and consequently in CO₂ uptake, due to a climatic change cannot be estimated from simple considerations; a proper evaluation of such an effect can only be done using dynamical ocean models. Studies on Greenland ice cores indicates that during the last glaciation, significant CO₂ concentration shifts may have occurred within less than 100 years (c.f. Section 1.2.3), probably caused by strong changes of large-scale ocean circulation. Therefore, the possibility that, due to climatic changes, unexpected abrupt events may take place in the natural carbon system cannot be excluded.

1.2.7.1.3 Gas exchange rates: A change in the global wind pattern could influence the gas transfer from the atmosphere to the sea surface. Carbon cycle models show that the net CO₂ uptake by the global ocean is not sensitive to the gas transfer coefficients (because it is controlled mainly by vertical mixing, not by gas exchange; Oeschger et al., 1975; Broecker et al., 1980; Sarmiento et al., 1990), so this effect would probably be of minor influence.

1.2.7.1.4 Modification of oceanic biogeochemical cycling: The rain of dead organic particles corresponds to a continuous export flux of carbon (and nutrients) out of the ocean surface, which under non-perturbed conditions is balanced by an equal upward transport of dissolved carbon (and dissolved nutrients) by water motion. In polar regions and strong upwelling zones, where productivity is not limited by nitrogen or phosphorus, the balance could become disturbed consequent on variations in ocean dynamics (c.f. Section 1.2.7.1.2), so as to influence atmospheric CO₂. As a result of climate change, the distribution of marine ecosystems and species composition could change, which could affect pCO₂ in surface waters. It is not possible at present to predict the direction and magnitude of such effects.

2 Warming of the oceans might lead to accelerated decomposition of dissolved organic carbon,
3 converting it into CO₂, and thus amplify the atmospheric increase (Brewer, personal
4 communication, 1990).

5
6 *1.2.7.1.5 UV-B radiation:* A reduction in stratospheric O₃ would increase the intensity of
7 UV-B radiation at the Earth's surface. This might have negative effects on the marine biota due
8 to a decrease of marine productivity and thus on the biological carbon pump. This could lead to
9 an increase in the concentration of CO₂ in surface waters and consequently in the atmosphere.

10 11 **1.2.7.2 Terrestrial biospheric feedbacks**

12 The following are probable feedback effects on the terrestrial biosphere-atmospheric carbon
13 system:

14
15 *1.2.7.2.1 Carbon dioxide fertilization:* Short-term experiments under controlled conditions
16 with crops and other annuals, as well as with few perennials, show an increase in the rates of
17 photosynthesis and growth in most plants under elevated levels of CO₂ (Strain and Cure,
18 1985). If elevated levels of CO₂ increase the productivity of natural ecosystems, more carbon
19 may be stored in woody tissue or soil organic matter. Such a storage of carbon will withdraw
20 carbon from the atmosphere and serve as a negative feedback on the CO₂ increase. Of
21 particular importance is the response of forests (Luxmoore et al., 1986), given that forests
22 conduct about 2/3 of global photosynthesis (50% of this cycles annually through leaves, while
23 50% is stored in woody tissue). However, it is not clear whether the increases in
24 photosynthesis and growth will persist for more than a few growing seasons, whether they
25 will occur at all in natural ecosystems and to what degree they will result in an increased
26 storage of carbon in terrestrial ecosystems.

27
28 *1.2.7.2.2 Eutrophication and toxification:* The increased availability of nutrients such as
29 nitrate and phosphate from agricultural fertilizers and from combustion of fossil fuel may
30 stimulate the growth of plants. It has been estimated that the effect of eutrophication, both on
31 land and in the oceans, could be as large as 1 GtC per year (Melillo, private communication,
32 1990). However, it should be noted that the greater availability of nutrients has often been
33 associated with increasing levels of acid precipitation and air pollution, which have been
34 associated with a reduction in the growth of terrestrial biota.

35
36 *1.2.7.2.3 Temperature:* Under non-tropical conditions, photosynthesis and respiration by
37 plants and by microbes both tend to increase with increasing temperature; but respiration is the
38 more sensitive process, so that a warming of global air temperature is likely to result in an
39 initially increased release of carbon to the atmosphere. Estimates indicate that the additional
40 flux might be significant, perhaps as large as one or a few GtC per year (Woodwell, 1983;
41 Kohlmaier, 1988; Lashof, 1989; Houghton and Woodwell, 1989). This temperature-enhanced
42 respiration would be a positive feedback on global warming.

43
44 *1.2.7.2.4 Water:* Changes in soil water may affect carbon fixation and storage. Increased
45 moisture can be expected to stimulate plant growth in dry ecosystems and to increase the
46 storage of carbon in tundra peat. There is a possibility that stresses brought about by climatic
47 change may be alleviated by increased levels of atmospheric CO₂. At present however, it is not
48 possible to predict reliably either the geographical distribution of changes in soil water or the
49 net effect of these changes on carbon fluxes and storage in different ecosystems. Changes in
50 climate are generally believed to be more important than changes in the atmospheric
51 concentration of CO₂ in affecting ecosystem processes (c.f. Section 10.)

52
53
54
55 *1.2.7.2.5 Change in geographical distribution of vegetation types:* In response to
56 environmental change, structure and location of vegetation types may change. If the rate of
57 change is slow, plant distributions may adjust. If, however, the rate of change is fast, large
58 areas of forests might not be able to adapt rapidly enough, hence be negatively affected with a
59 subsequent release of CO₂ to the atmosphere.

1.2.7.2.6 UV-B radiation: A reduction in stratospheric O₃ would increase the intensity of UV-B radiation at the Earth's surface. Increased UV-B may have a detrimental effect on many land biota, including crops (Teramura, 1983), thus affecting the strength of the biospheric sink of CO₂ over land.

1.2.8 Conclusions

The atmospheric CO₂ concentration is now about 353ppmv, 25% higher than the pre-industrial (1750-1800) value and higher than at any time in at least the last 160,000 years. This rise, currently amounting to about 1.8 ppmv per year, is beyond any doubt due to human activities. Anthropogenic emissions of CO₂ were 5.7±0.5 GtC due to fossil fuel burning in 1987, plus 0.6 to 2.5 GtC due to deforestation (estimate for 1980). During the last decade (1980 - 1989) about 48% of the anthropogenic emissions have stayed in the atmosphere, the remainder has been taken up by the oceans and possibly by land ecosystems. Our qualitative knowledge of the global carbon cycle is, in view of the complexity of this cycle, relatively good. However, the current quantitative estimates of sources and of sinks of CO₂ do not balance; the atmospheric increase is less rapid than expected from carbon cycle models (in which CO₂ fertilization or environmental responses of the biosphere are not included). This, and model analyses of the interhemispheric CO₂ gradient, indicate that the northern hemisphere terrestrial ecosystems may act as a significant sink of carbon. Such a sink has, however, not been directly identified. To summarize: the total annual input of anthropogenic CO₂ is currently (1980-1989) about 7.0±1.1 GtC, assuming a central value for the input of CO₂ from tropical deforestation; the annual uptake by the oceans is estimated (based on the box models, GCMs and Tans et al, 1990) to be about 2.0±1.0 GtC; and the annual atmospheric accumulation is about 3.4±0.2 GtC. Thus, the annual sequestering by the terrestrial biosphere should be about 1.6±1.5 GtC. While several mechanisms have been suggested that could sequester carbon in terrestrial ecosystems, it is difficult to account for the total required sink. Therefore, it appears likely that, (i) the uptake of CO₂ by the oceans is underestimated, (ii) there are important unidentified processes in terrestrial ecosystems that can sequester CO₂, and/or (iii) the amount of CO₂ released from tropical deforestation is at the low end of current estimates.

If the land biota presently act as a sink of carbon due to a fertilization effect, then they might get saturated with respect to this fertilization some time in the future. This means that we cannot assume, that the terrestrial sink, which may be active currently, will continue to exist unchanged through the next century.

In order to avoid a continued rapid growth of CO₂ in the atmosphere, severe reductions on emissions will be necessary. The time taken for atmospheric CO₂ to adjust to changes in sources or sinks is of the order of 50-200 years, determined mainly by the slow exchange of carbon between surface waters and deeper layers of the ocean. Even if all anthropogenic emissions of CO₂ were halted, the atmospheric concentration would decline only slowly, and it would not approach its pre-industrial level for many hundreds of years. Thus, any reductions in emissions will only become fully effective after a time of the order of a century or more. Based on some model estimates, which neglect the feedbacks discussed earlier, the atmospheric concentration in the year 2050 would be between 530 - 600 ppmv for a constant relative growth of the annual anthropogenic emissions by 2% per year, and between 415 - 480 ppmv (increasing to 460 - 560 ppmv by the year 2100) for a constant anthropogenic emission rate at the 1990 level. In order not to exceed 420 ppmv (50% above pre-industrial), annual anthropogenic emissions would have to be reduced continuously to about 50% of their present value by the year 2050. In order to stabilize concentrations at present day concentrations (353 ppmv), an immediate reduction in global anthropogenic emissions by 60-80 percent would be necessary. The size of the estimated reduction depends on the carbon cycle model used.

During the millennium preceding the anthropogenic CO₂ growth, the concentration was relatively constant near 280 ppmv, with a variability of less than ± 10 ppmv. This indicates that the sensitivity of atmospheric CO₂ levels to minor climatic changes such as the Little Ice Age, where global mean temperatures probably decreased by about 1°C, is within this range.

However, the anticipated climatic and environmental changes may soon become large enough to act back on the oceanic and terrestrial carbon cycle in a more substantial way. A close interaction between climate variations and the carbon cycle is evidenced by the glacial-interglacial CO₂ variations. The ice-core record shows that CO₂ concentrations during the coldest part of the last glaciation were about 30% lower than during the past 10,000 years. The glacial-interglacial CO₂ variations were probably due to changes in ocean circulation and marine biological activity, and were correlated to variations in global climate. There is some (not fully clear) evidence from ice cores that rapid changes of CO₂, ca. 50 ppmv within about a century, occurred during and at the end of the ice age.

If global temperatures increase, this could change the natural fluxes of carbon, thus having feedback effects on atmospheric CO₂. Some of the identified feedbacks are potentially large and could significantly influence future CO₂ levels. They are difficult to quantify, but it seems likely that there would be a net positive feedback, i.e., they will enhance the man-made increase. On the longer term, the possibility of unexpected large changes in the mechanisms of the carbon cycle due to a human-induced change in climate cannot be excluded.

1.3 METHANE

Methane is a chemically and radiatively active trace gas that is produced from a wide variety of anaerobic (i.e., oxygen deficient) processes and is primarily removed by reaction with hydroxyl radicals (OH) in the troposphere. Oxidation of CH₄ by OH in the stratosphere is a significant source of stratospheric water (H₂O) where it is an important greenhouse gas.

1.3.1 Atmospheric Distribution of Methane

1.3.1.1 Paleo atmospheric record of methane

There are good data on the atmospheric concentration of CH₄ (Figure 9) from Antarctic and Greenland ice cores for the period between 10,000 and 160,000 years ago (Raynaud et al. 1988; Stauffer et al. 1988; Craig and Chou, 1982; Chappellaz et al. 1989). The minimum concentration during the last glacial periods (about 20,000 and 150,000 years ago) was around 0.35 ppmv, and rose rapidly, in phase with the observed temperature increases, to about 0.65 ppmv during the glacial-interglacial transitions (about 15,000 and 130,000 years ago). The atmospheric concentrations of CH₄ decreased rapidly, prior to, and during the last deglaciation period about 10,000 - 11,000 years ago (the Younger Dryas period when there were abrupt temperature decreases in Greenland and northern Europe), and increased rapidly thereafter.

Because of the brittle nature of the ice cores, data on the atmospheric concentrations of CH₄ are reliable only during the last 2,000 years of the Holocene period (last 10,000 years)

1.3.1.2 Contemporary record of methane

Ice core data (Figure 1.10) indicate that the atmospheric concentrations of CH₄ averaged around 0.8 ppmv between two hundred and two thousand years ago, increasing to 0.9 ppmv one hundred years ago (Craig and Chou, 1982; Rasmussen and Khalil, 1984; Stauffer et al. 1985; Pearman and Fraser, 1988; Pearman et al., 1986; Etheridge et al., 1988). Since then, the atmospheric concentration of CH₄ has increased smoothly to present levels, highly correlated with global human population. Analysis of infrared solar spectra has shown that the atmospheric concentration of CH₄ has increased by about 30% over the last 40 years (Rinsland et al. 1985; Zander et al. 1990).

Atmospheric concentrations of CH₄ have been measured directly since 1978 when the globally averaged value was 1.51 ppmv (e.g., Rasmussen and Khalil, 1981; Blake and Rowland, 1988). Currently the value is 1.72 ppmv, corresponding to an atmospheric reservoir of about 4900 Tg (1 Tg = 10¹² g) and it is increasing at a rate of 14 to 17 ppbv per year (40 to 48 Tg per year), i.e., 0.8 to 1.0% per year (Blake and Rowland, 1988; Steele et al. 1987). The atmospheric concentration of CH₄ in the Northern Hemisphere is 1.76 ppmv, compared to 1.68 ppmv in the Southern Hemisphere (Figure 1.11). The magnitude of the seasonal

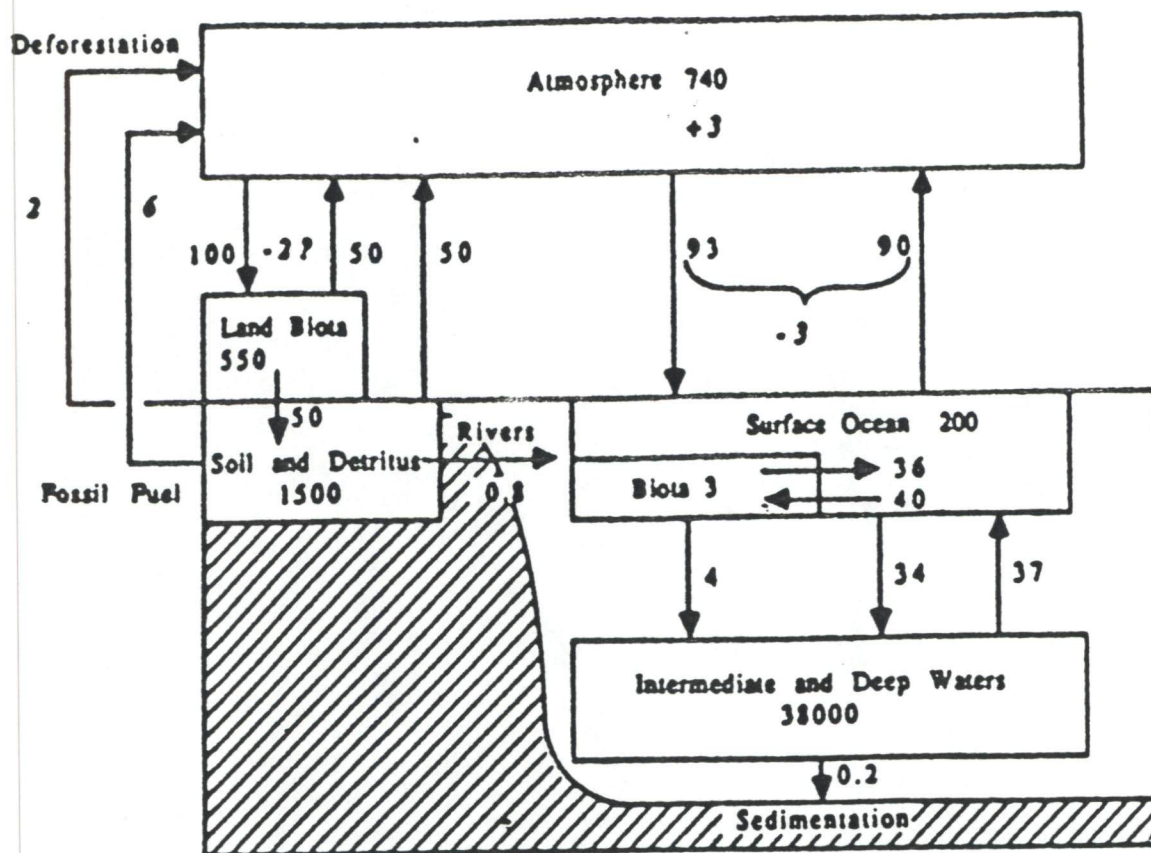


Figure 1: Global carbon reservoirs and fluxes. The numbers apply for the present-day situation and represent typical literature values. Fluxes, e.g. between atmosphere and surface ocean, are gross annual exchanges. Numbers in bold-face italics indicate net annual perturbation fluxes to the atmosphere and annual atmospheric CO₂ increase due to human action. Units are gigatons of carbon (GtC; 1Gt = 10⁹ metric tons = 10¹²kg) for reservoir sizes and GtC yr⁻¹ for fluxes. More details and discussions are found in several reviews (Sundquist, 1985; Trabalka, 1985; Bolin, 1986; Siegenthaler, 1986).

variability varies with latitude (Steele et al. 1987; Fraser et al. 1984), being controlled by the temporal variability in source strengths and atmospheric concentration of OH radicals,

1.3.1.3 Isotopic composition of methane

Methane is produced from different sources with distinctive proportions of carbon ^{12}C , ^{13}C , and ^{14}C , and hydrogen isotopes H, D (^2H), and T (^3H). Similarly, the rates of processes that destroy CH_4 depend upon its isotopic composition. Consequently, the CH_4 budget can be constrained by knowledge of the isotopic composition of atmospheric CH_4 , the extent of isotopic fractionation during removal, and the isotopic signatures of CH_4 from different sources. Recent work to elucidate the sources of CH_4 has proceeded through an analysis of carbon isotopic signatures (Cicerone and Oremland, 1988; Wahlen et al., 1989; Lowe et al., 1988; and references therein). One example of this is an analysis of ^{14}C data which suggests that about 100 Tg CH_4 per year may arise from fossil sources (Cicerone and Oremland, 1988; Wahlen et al., 1989). Such a distinction is possible because CH_4 from fossil sources is ^{14}C -free, while that from other sources has essentially the ^{14}C concentration of modern carbon.

1.3.2 Sinks of Methane

The major sink for atmospheric CH_4 is reaction with OH in the troposphere, the OH concentration being controlled by a complex set of reactions involving CH_4 , CO, NMHC, NO_x , and tropospheric O_3 (discussed in Section 1.7; Sze, 1977; Crutzen, 1987). Based on the reaction rate coefficient between CH_4 and OH, and the estimated tropospheric distribution of OH, an atmospheric life-time for CH_4 of between 8 and 11.8 years has been estimated (Prinn et al. 1987). This estimate is supported by the fact that models of global OH are tested by analyses of the budgets for CH_3CCl_3 (Logan et al., 1981; Fraser et al., 1986a; Prinn et al., 1987) and ^{14}CO (Appendix to WMO, 1989b). The reaction between CH_4 and OH currently represents a sink of 400 to 600 Tg of CH_4 per year. The efficiency of this sink may, however, have decreased during the last century because the atmospheric concentration of OH in the troposphere may have decreased, hence the lifetime of CH_4 would have increased, in response to increasing concentrations of CO, NMHC, and CH_4 (Sze, 1977).

Soils may represent a removal mechanism for CH_4 . The magnitude of this sink has been estimated (this assessment) to be 30 ± 15 Tg CH_4 per year from the work of Harris et al., 1982 and Seiler and Conrad, 1987.

1.3.3 Sources of Methane

Methane is produced from a wide variety of anaerobic sources (Cicerone and Oremland, 1988). Two main pathways for CH_4 production have been identified: (i) reduction of CO_2 with hydrogen, fatty acids or alcohols as hydrogen donors, or (ii) transmethylation of acetic acid or methyl alcohol by CH_4 -producing bacteria. Table 2 summarizes identified sources of CH_4 with ranges of likely annual emissions. The total annual CH_4 source must equal the atmospheric sink of about 500 (400 to 600) Tg CH_4 per year, the possible soil sink of about 30 (15 to 45) Tg CH_4 per year, and the annual growth of 40 to 48 Tg CH_4 in the atmosphere. The sum of the present best estimates of the sizes of the individual sources identified in Table 2 equal 525 Tg CH_4 per year. It should be noted that the newest data for rice paddies, biomass burning, and coal mining sources suggest that the values may be even less than those of Table 2, possibly indicating a missing source of CH_4 , or an overestimate of the sink for CH_4 .

Table 2		
ESTIMATED SOURCES AND SINKS OF METHANE		
	Annual Release (Tg CH ₄)	Range (Tg CH ₄)
Source		
Natural Wetlands (bogs, swamps, tundra, etc)	115	100 - 200
Rice Paddies	110	25 - 170
Enteric Fermentation (animals)	80	65 - 100
Gas Drilling, venting, transmission	45	25 - 50
Biomass Burning	40	20 - 80
Termites	40	10 - 100
Landfills	40	20 - 70
Coal Mining	35	17 - 50
Oceans	10	5 - 20
Freshwaters	5	1 - 25
CH ₄ Hydrate Destabilization	5	0 - 100
Sink		
Removal by soils	30	15-45
Reaction with OH in the atmosphere	500	400 - 600
Atmospheric Increase	44	40 - 48

1.3.3.1 Natural wetlands

Significant progress has been made in quantifying the magnitude of the source of CH₄ from natural wetlands (Svensson and Rosswall, 1984; Sebacher et al. 1986; Whalen and Reeburgh, 1988; Moore and Knowles, 1987; Mathews and Fung, 1987; Harris et al. 1985; Crill et al. 1988; Andronova, 1989; Harris and Sebacher, 1981; Burke et al, 1988; Harris et al, 1988; Aselmann and Crutzen, 1989). Recent data support earlier estimates of a global flux of 110 - 115 Tg CH₄ per year, but reverses the relative importance of tropical and high latitude systems. The data base, which is still quite limited (no data from Asia), suggests 55 Tg CH₄ per year (previously 32 Tg CH₄ per year) from tropical wetlands, and 39 Tg CH₄ per year (previously 63 Tg CH₄ per year) from high latitude wetlands. Since CH₄ is produced through biological processes under anaerobic conditions, any factors affecting the physical, chemical or biological characteristics of soils could affect CH₄ emission rates.

1.3.3.2 Rice paddies

Rice paddies are an important source of CH₄ with estimates of the globally averaged flux ranging from 25 - 170 Tg CH₄ per year (Neue and Scharpenseel, 1988; Yagi and Minami, 1989; Holzapfel-Pschorn and Seiler, 1986; Cicerone and Shetter, 1981; Cicerone et al. 1983). The flux of CH₄ from rice paddies is critically dependent upon several factors including: (i) agricultural practices (e.g., fertilization, water management, density of rice plants, double cropping systems, application of manure or rice straw), (ii) soil / paddy characteristics (soil type, acidity, redox potential, temperature, nutrient availability, substrate, profile of anaerobic environment), and (iii) time of season. One difficulty in obtaining accurate estimates is that almost 90% of the world's harvested area of rice paddies is in Asia, and of this about 60% are in China and India from which no detailed data is available. The annual production of rice since 1940 has approximately doubled as a result of double cropping practices and an increased area of cultivation. It is likely that CH₄ emissions have increased proportionally as well.

1.3.3.3 Biomass burning

Biomass burning in tropical and sub-tropical regions is thought to be a significant source of atmospheric CH_4 , with estimates of global emission rates ranging from 20 to 80 Tg CH_4 per year (Andreae et al. 1988; Bingemer and Crutzen, 1987; Crutzen et al. 1979; Crutzen et al. 1985; Crutzen, 1989; Greenberg et al. 1984; Stevens et al. 1990; Quay et al. 1990). Improved estimates require an enhanced understanding of: (i) CH_4 emission factors, (ii) the amount, by type, of vegetation burnt each year on an area basis, and (iii) type of burning (smouldering vs flaming). Current estimates indicate that over the last century the rate of forest clearing by burning has increased (cf. Section 1.2.2.2).

1.3.3.4 Enteric fermentation (animals)

Methane emissions from enteric fermentation in ruminant animals, including all cattle, sheep and wild animals, is estimated to provide an atmospheric source of 65 - 100 Tg CH_4 per year (Crutzen et al. 1986; Lerner et al., 1988). Methane emissions depend upon animal populations, as well as the amount and type of food. It is difficult to accurately estimate the change in this source over the last century because the significant increase in the number of cattle and sheep has been partially offset by decreases in the populations of elephants and North American bison. One estimate suggests that the magnitude of this source has increased from 21 Tg CH_4 per year in 1890 to 78 Tg CH_4 per year in 1983 (Crutzen et al. 1986).

1.3.3.5 Termites

There is a large range in the magnitude of the estimated fluxes of CH_4 from termites; 10 - 100 Tg CH_4 per year (Cicerone and Oremland, 1988; Zimmerman et al. 1982; Rasmussen and Khalil, 1983; Seiler et al. 1984; Fraser et al. 1986b). The values are based on the results of laboratory experiments, applied to estimates of global termite populations and the amount of biomass consumed by termites, both of which are uncertain, and field experiments. It is important to determine whether the global termite population is currently increasing, and whether it is likely to respond to changes in climate.

1.3.3.6 Landfills

The anaerobic decay of organic wastes in landfills may be a significant anthropogenic source of atmospheric CH_4 , 20 - 70 Tg CH_4 per year. However, several factors need to be studied in order to quantify the magnitude of this source more precisely, including amounts, trends, and types of waste materials, and landfill practices (Bingemer and Crutzen, 1987).

1.3.3.7 Oceans and freshwaters

Oceans and freshwaters are thought to be a minor source of atmospheric CH_4 . The estimated flux of CH_4 from the oceans is based on a limited data set, taken in the late 1960's / early 1970's when the atmospheric concentration of CH_4 was about 20% lower. They showed that the open oceans were only slightly supersaturated in CH_4 with respect to its partial pressure in the atmosphere. There are inadequate recent data from either the open oceans or coastal waters to reduce the uncertainty in these estimates (Cicerone and Oremland, 1988).

1.3.3.8 Coal mining

Methane is released to the atmosphere from coal mine ventilation, and degassing from coal during transport to an end-use site. A recent unpublished study estimated the flux of CH_4 from coal mining, on a country basis, for the ten major coal producing countries, and deduced a global minimum emission of 17 Tg CH_4 per year. Global CH_4 fluxes from coal mining have been estimated to range from 10 - 50 Tg CH_4 per year (Cicerone and Oremland, 1988, and recent unpublished studies by others).

1.3.3.9 Gas drilling, venting and transmission

CH_4 is the major component of natural gas, hence leakage from pipelines and venting from oil and gas wells could represent a significant source of atmospheric CH_4 (Cicerone and Oremland, 1988). The global flux from these sources is estimated, based on limited data of questionable reliability, to range from 25 - 50 Tg CH_4 per year.

1.3.4 Feedbacks from Climate Change into the Methane Cycle

Future atmospheric concentrations of CH₄ will depend on changes in the strengths of either the sources or sinks, which are dependent upon social, economic, and political, and also environmental factors and in particular changes in climate. Methane emissions from wetlands are particularly sensitive to temperature and soil moisture, and hence future climatic changes could significantly change the fluxes of CH₄ from both natural wetlands and rice paddies. Tropospheric OH, which provides the atmospheric sink for CH₄, is dependent upon a number of factors, including the intensity of UV-B radiation, and the ambient concentrations of H₂O, CO, CH₄, reactive nitrogen oxides, and tropospheric O₃ (See Section 1.7) (Crutzen, 1987; Isaksen and Hov, 1987; Thompson and Cicerone, 1986).

1.3.4.1 Tropical methane sources

The major sources of CH₄ in tropical regions (natural wetlands and rice paddies) are quite sensitive to variations in soil moisture. Consequently, changes in soil moisture, which would result from changes in temperature and precipitation, could significantly alter the magnitude of these large sources of atmospheric CH₄. Increased soil moisture would result in larger fluxes, whereas a decrease in soil moisture would result in smaller fluxes.

1.3.4.2 High latitude methane sources

Methane fluxes from the relatively flat tundra regions would be sensitive to changes of only a few centimetres in the level of the water table, with flooded soils producing a factor of 100 more CH₄ than dry soils (Whalen and Reeburgh, 1988; Crill et al. 1988). Similarly, emissions of CH₄ are significantly larger at warmer temperatures, due to accelerated microbiological decomposition of organic material in the near-surface soils. Consequently, an increase in soil moisture and temperatures in high latitude wetlands would result in enhanced CH₄ emissions, whereas warmer drier soils might have decreased CH₄ emissions.

Higher temperatures could also increase the fluxes of CH₄ at high northern latitudes from; (i) CH₄ trapped in permafrost, (ii) decomposable organic matter frozen in the permafrost, and (iii) decomposition of CH₄ hydrates (Cicerone and Oremland, 1988; Kvenvolden, 1988). Quantifying the magnitudes of these positive feedbacks is difficult. Timescales for thawing the permafrost, located between a few centimetres to metres below the surface, could be decades to centuries, while the time for warming the CH₄ hydrates could be even longer, although one study (Kvenvolden, 1988) estimated that the flux of CH₄ from hydrate decomposition could reach 100 Tg CH₄ per year within a century.

1.3.5 Conclusions

Current atmospheric CH₄ concentrations, at 1.72 ppmv, are now more than double the pre-industrial value (1750-1800) of about 0.8 ppmv, and are increasing at a rate of 0.9% per year. The ice core record shows that CH₄ concentrations were about 0.35 ppmv during glacial periods, and increased in phase with temperature during glacial-interglacial transitions. The current atmospheric concentration of CH₄ is greater than at any time during the last 160,000 years.

Reaction with OH in the troposphere, the major sink for CH₄, results in a relatively short atmospheric lifetime of 10±2 years. The short lifetime of CH₄ implies that atmospheric concentrations will respond quite rapidly, in comparison to the longer lived gases such as CO₂, N₂O, and CFCs, to changes in emissions. In order to stabilize concentrations at present day levels, an immediate reduction in global man-made emissions by 15-20 percent would be necessary (this and other scientific sensitivity analyses are discussed in the Annex). Global concentrations of OH are dependent upon the intensity of UV-B radiation, and the concentrations of gases such as H₂O, CO, CH₄, NO_x, NMHC, and O₃, and may have declined during the 20th century due to changes in the atmospheric concentrations of these gases.

The individual sources of atmospheric CH₄ have been qualitatively identified, but there are significant uncertainties in the magnitude of their strengths. Human activities such as rice cultivation, rearing of domestic ruminants, biomass burning, coal mining, and natural gas venting have increased the input of CH₄ into the atmosphere, and these combined with an apparent decrease in the concentration of tropospheric OH, yields the observed rise in global CH₄. However, the quantitative importance of each of the factors contributing to the observed increase is not well known at present.

Several potential feedbacks exist between climate change and CH₄ emissions, in both tropical and high latitude wetland sources. In particular, an increase in high latitude temperatures could result in a significant release of CH₄ from the melting of permafrost and decomposition of CH₄ hydrates.

1.4 HALOCARBONS

Chlorine and bromine containing halocarbons have been shown to deplete O₃ in the stratosphere. In addition, it has been recognized that they are important greenhouse gases. Their sources, sinks, atmospheric distributions, and role in perturbing stratospheric O₃ and the Earth's radiative balance have been reviewed in detail (WMO 1985, 1989a, 1989b). Many governments, recognizing the harmful effects of halocarbons on the environment, signed the "Montreal Protocol on Substances that Deplete the Ozone Layer" (UNEP, 1987) in 1987 to limit the production and consumption of a number of fully halogenated CFCs and halons. The control measures of the Montreal Protocol freeze the production and consumption of CFCs 11, 12, 113, 114, and 115 in developed countries at their 1986 levels from the year 1990, a reduction to 80% of their 1986 levels from the year 1993, with a further reduction to 50% of their 1986 levels from the year 1998. Developing countries, with a per capita use of CFCs of less than 0.3 kg per capita, are allowed to increase their per capita use up to this limit and can delay compliance with the control measures by 10 years. All major producing and consuming developed countries, and many developing countries, have signed and ratified the Montreal Protocol.

1.4.1 Atmospheric Distribution of Halocarbons

The mean atmospheric concentrations of the most abundant radiatively active halocarbons are shown in Table 3. The atmospheric concentrations of the halocarbons are currently increasing more rapidly on a global scale (on a percentage basis) than the other greenhouse gases (Figure 1.12). The concentrations of the fully halogenated chlorofluorocarbons (CFCs), slightly greater in the northern hemisphere than in the southern hemisphere, are consistent with the geographical distribution of releases (>90% from the industrialized nations), a 45 °N - 45 °S mixing time of about 1 year, and their very long atmospheric lifetimes.

1.4.2 Sinks for Halocarbons

There is no significant tropospheric removal mechanism for the fully halogenated halocarbons such as CCl₃F (CFC-11), CCl₂F₂ (CFC-12), C₂Cl₃F₃ (CFC-113), C₂Cl₂F₄ (CFC-114), C₂ClF₅ (CFC-115), carbon tetrachloride (CCl₄), and halon 1301 (CBrF₃). They have long atmospheric lifetimes, decades to centuries, and are primarily removed by photodissociation in the mid - upper stratosphere. There is currently a significant imbalance between the sources and sinks giving rise to a rapid growth in atmospheric concentrations. To stabilize the atmospheric concentrations of CFCs 11, 12 and 113 at current levels would require reductions in emissions of approximately 70-75%, 75-85%, and 85-95%, respectively (see Annex).

Non-fully halogenated halocarbons containing a hydrogen atom such as methyl chloride (CH₃Cl), methylchloroform (CH₃CCl₃), CHClF₂ (HCFC-22), and a number of other HCFCs and HFCs being considered as substitutes for the current CFCs (c.f. Section 1.4.4) are primarily removed in the troposphere by reaction with OH. These hydrogen containing species

1 have atmospheric lifetimes ranging from about one to forty years, much shorter on average
2 than the fully halogenated CFCs. To stabilize the atmospheric concentrations of HCFC-22 at
3 current levels would require reductions in emissions of approximately 40-50%.

TABLE 3
Halocarbon Concentrations and Trends (1990) †

Halocarbon		Mixing Ratio pptv	Annual Rate of Increase pptv %		Lifetime Years
CCl ₃ F	(CFC-11)	280	9.5	4	65
CCl ₂ F ₂	(CFC-12)	484	16.5	4	130
CClF ₃	(CFC-13)	5			400
C ₂ Cl ₃ F ₃	(CFC-113)	60	4-5	10	90
C ₂ Cl ₂ F ₄	(CFC-114)	15			200
C ₂ ClF ₅	(CFC-115)	5			400
CCl ₄		146	2.0	1.5	50
CHClF ₂	(HCFC-22)	122	7	7	15
CH ₃ Cl		600			1.5
CH ₃ CCl ₃		158	6.0	4	7
CBrClF ₂	(halon 1211)	1.7	0.2	12	25
CBrF ₃	(halon 1301)	2.0	0.3	15	110
CH ₃ Br		10-15			1.5

† There are a few minor differences between the lifetimes reported in this table and the equivalent table in WMO 1989b. These differences are well within the uncertainty limits. The 1990 mixing ratios have been estimated based upon an extrapolation of measurements reported in 1987 or 1988, assuming that the recent trends remained approximately constant.

1.4.3 Sources of Halocarbons

Most halocarbons, with the notable exception of CH₃Cl, are exclusively of industrial origin. Halocarbons are used as aerosol propellants (CFCs 11, 12, and 114), refrigerants (CFCs 12 and 114, and HCFC-22), foam blowing agents (CFCs 11 and 12), solvents (CFC-113, CH₃CCl₃, and CCl₄), and fire retardants (halons 1211 and 1301). The atmospheric concentration of methyl chloride is about 0.6 ppbv, and is primarily released from the oceans and during biomass burning. There is no evidence that the atmospheric concentration of CH₃Cl is increasing. Methyl bromide (CH₃Br) is produced by oceanic algae, and there is evidence that its atmospheric concentration has been increasing in recent times due to a significant anthropogenic source (Penkett et al., 1985; Wofsy et al., 1975).

1.4.4 Future Atmospheric Concentration of Halocarbons

Future emissions of CFCs 11, 12, 113, 114, and 115 will be governed by the Montreal Protocol on "Substances that Deplete the Ozone Layer" as discussed in Section 1.4. In addition, international negotiations are currently in progress that will likely (i) result in a complete global phase-out of production of these chemicals by the year 2000, and (ii) enact limitations on the emissions (via production and consumption controls) of CCl₄, and CH₃CCl₃. However, even with a complete cessation of production of CFCs 11, 12 and 113 in the year 2000 their atmospheric concentrations will still be significant for at least the next

century because of their long atmospheric lifetimes. It should be noted that emissions of these gases into the atmosphere will continue for a period of time after production has ceased because of their uses as refrigerants, foam blowing agents, fire retardants, etc.

A number of hydrofluorocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs) are being considered as potential replacements for the long-lived CFCs (11, 12, 113, 114, and 115) that are regulated under the terms of the Montreal Protocol. The HFCs and HCFCs primarily being considered include: HCFC-22, HCFC-123 (CHCl_2CF_3), HCFC-124 (CHClFCF_3), HFC-125 (CHF_2CF_3), HFC-134a (CH_2FCF_3), HCFC-141b ($\text{CH}_3\text{CCl}_2\text{F}$), HCFC-142b (CH_3CClF_2), HFC-143a (CH_3CF_3), and HFC-152a (CH_3CHF_2). The calculated atmospheric lifetimes of these chemicals are controlled primarily by reaction with tropospheric OH and range between about 1 and 40 years. It has been estimated (UNEP, 1989) that a mix of HFCs and HCFCs will replace the CFCs currently in use at a rate of about 0.4 kg of substitute for every kg of CFCs currently produced, with an annual growth rate of about 3%. Because of their shorter lifetimes, and expected rates of substitution and emissions growth rates, the atmospheric concentrations of HFCs and HCFCs will be much lower for the next several decades than if CFCs had continued to be used, even at current rates. However, continued use, accompanied by growth in the emission rates, of HFCs and HCFCs for more than several decades would result in atmospheric concentrations that would be radiatively important.

1.4.5 Conclusions

The atmospheric concentrations of the industrially produced halocarbons, primarily CCl_3F , CCl_2F_2 , $\text{C}_2\text{Cl}_3\text{F}_3$, and CCl_4 are about 280 pptv, 484 pptv, 60 pptv, and 146 pptv, respectively. Over the past few decades their concentrations (except CCl_4) have increased more rapidly (on a percentage basis) than the other greenhouse gases, currently at rates of at least 4% per year. The fully halogenated CFCs and CCl_4 are primarily removed by photolysis in the stratosphere, and have atmospheric lifetimes in excess of 50 years.

Most halocarbons, with the notable exception of methyl chloride, are exclusively anthropogenic and their sources (solvents, refrigerants, foam blowing agents, and aerosol propellants) are well understood.

To stabilize, and then reduce, the current atmospheric concentrations of the fully halogenated CFCs (e.g., 11, 12 and 113) would require approximate reductions in emissions of 70-75%, 75-85%, and 85-95%, respectively. Future emissions of CFCs and CCl_4 will, most likely, be eliminated or be significantly lower than today's because the stringency, scope, and timing of international regulations on chlorine and bromine containing chemicals, i.e., the Montreal Protocol on Substances that Deplete the Ozone Layer, are currently being renegotiated. However, the atmospheric concentrations of CFCs 11, 12 and 113 will still be significant (30 - 40% of current) for at least the next century because of their long atmospheric lifetimes.

1.5 NITROUS OXIDE

Nitrous oxide is a chemically and radiatively active trace gas that is produced from a wide variety of biological sources in soils and water and is primarily removed in the stratosphere by photolysis and reaction with electronically excited oxygen atoms.

1.5.1 Atmospheric Distribution of Nitrous Oxide

The mean atmospheric concentration of N_2O in 1990 is about 310 ppbv, corresponding to a reservoir of about 1500 Tg N, and increasing at a rate of 0.2 - 0.3% per year (Figure 1.13; Weiss, 1981; Prinn et al. 1990; Robinson et al. 1988; Elkins and Rossen, 1989; Rasmussen and Khalil, 1986). This observed rate of increase represents an atmospheric growth rate of about 3 to 4.5 Tg N per year. The atmospheric concentration of N_2O is higher in the northern

hemisphere than in the southern hemisphere by about 1 ppbv. Ice core measurements show that the pre-industrial value of N_2O was relatively stable at about 285 ppbv for most of the past 2000 years, and started to increase around the year 1700 (Figure 1.14; Pearman et al., 1986; Khalil and Rasmussen, 1988a; Etheridge et al. 1988; Zardini et al. 1989). Figure 1.14 shows that the atmospheric concentrations of N_2O may have decreased by a few ppbv during the period of the mini ice-age.

1.5.2 Sinks for Nitrous Oxide

The major atmospheric loss process for N_2O is photochemical decomposition in the stratosphere, and is calculated to be 10 ± 3 Tg N per year (Table 4). Nitrous oxide has an atmospheric lifetime of about 150 years. The observed rate of growth represents a 30% imbalance between the sources and sinks (Hao et al. 1987). Tropospheric sinks such as surface loss in aquatic and soil systems are considered to be small (Elkins et al. 1978, Blackmer and Bremner, 1976).

1.5.3 Sources of Nitrous Oxide

1.5.3.1 Oceans

The oceans are a significant, but not dominant source of N_2O (McElroy and Wofsy, 1986). Based on measurements of the concentration gradients between the atmosphere and surface waters (Butler et al. 1989, and NOAA GMCC unpublished data), and on estimates of the gas exchange coefficient, the current estimate of the magnitude of the ocean source ranges from 1.4 - 2.6 Tg N per year, significantly lower than earlier estimates (Elkins et al. 1978; Cohen and Gordon, 1979; Cline et al. 1987). An accurate determination of the global annual ocean flux is difficult because of uncertainties associated with quantifying the gas exchange coefficient and because the partial pressure of N_2O in the surface waters is highly variable, both spatially and temporally. The partial pressure of N_2O in surface waters varies considerably, ranging from being supersaturated by up to 40% in upwelling regions to being undersaturated by a few percent in areas around Antarctica and within gyres. Data suggest that during El Niño events, where upwelling in the Pacific ocean is suppressed, the ocean fluxes of N_2O are significantly lower (Cline et al. 1987; Butler et al. 1989). It is still unclear whether N_2O is primarily produced from nitrification in near surface waters, or denitrification in oxygen deficient deep waters. Based on vertical profile measurements of oceanic N_2O (NOAA GMCC, unpublished) the oceanic reservoir has been estimated to be between 900 and 1100 Tg N, comparable to the atmosphere. Consequently, changes in the exchange fluxes of N_2O between the ocean and the atmosphere could significantly impact its atmospheric concentration.

1.5.3.2 Soils

Denitrification in aerobic soils is thought to be a dominant source of atmospheric N_2O (Keller et al. 1986; Matson and Vitousek, 1987; Matson and Vitousek, 1989; Slemr et al. 1984). Nitrification under anaerobic conditions could, however, produce higher yields of N_2O per unit of transformed nitrogen. Quantification of global N_2O emissions from soils is difficult because of the heterogeneity of terrestrial ecosystems and the variability in environmental conditions that control the fluxes of N_2O .

Estimates of global fluxes of N_2O from tropical forests range from 2.2 - 3.7 Tg N per year. The impact of deforestation on the emissions of N_2O from tropical soils is unclear, with some studies suggesting that the emissions of N_2O from deforested land are enhanced by as much as a factor of three (Luizao et al. 1989), whereas other studies concluded that N_2O fluxes decreased if vegetation did not return (Robertson and Tiedje, 1988).

Quantifying the roles of temperate forest soils and grasslands in the N_2O budget is difficult because of the paucity of data, and conflicting results. Estimates of N_2O fluxes from temperate forest soils range from 0.7 - 1.5 Tg N per year in one study (Schmidt et al. 1988), to almost none in another study (Bowden et al. 1989). One study also reported that deforestation in temperate forests would lead to enhanced emissions of N_2O (Bowden and Bormann, 1986).

Reliable global N_2O fluxes from grasslands are impossible to derive from the fragmented data available. One study (Ryden, 1981) concluded that English grassland soils, with no fertilization, are a sink for N_2O , whereas limited studies of tropical grasslands and pastures suggest that they may be a moderate to significant source of N_2O (Luizao et al. 1989; Robertson and Tiedje, 1988).

1.5.3.3 Combustion

Until recently, the combustion of fossil fuels was thought to be an important source of atmospheric N_2O (Pierotti and Rasmussen, 1976; Weiss and Craig, 1976; Hao et al. 1987). However, a recent study has shown that the earlier results are incorrect because N_2O was being artificially produced in the flasks being used to collect N_2O from combustion sources (Muzio and Kramlich, 1988). The latest estimate of the global flux of N_2O from combustion sources is between 0.1 and 0.3 Tg N per year, compared to earlier values which were as high as 3.2 Tg N per year.

1.5.3.4 Biomass Burning

Biomass burning is now thought to be a minor source of atmospheric N_2O with a global flux of less than 0.2 Tg N per year (Muzio and Kramlich, 1988; Crutzen 1989; Elkins et al. 1990; Winstead et al. 1990; Griffith et al. 1990). This value is 1-2 orders of magnitude less than previous estimates (Crutzen et al. 1979, 1985) which were influenced by artifacts involving N_2O analysis (Crutzen et al., 1985) and N_2O production in sampling flasks (Muzio and Kramlich, 1988).

1.5.3.5 Fertilizer / Ground-Water

Nitrous oxide production from the use of nitrate and ammonium fertilizers is difficult to quantify because the N_2O fluxes are dependent upon numerous factors including type of fertilizer, soil type, soil temperature, weather, and farming practices (e.g., ploughing, sowing, irrigating). Conversion of fertilizer N to N_2O ranges from 0.01 - 2.0% (Conrad et al. 1983; Bremner et al. 1981). This range, coupled with a global fertilizer production of 55 Tg N per year in 1980, results in a total N_2O emission of between 0.01 - 1.1 Tg N per year (Conrad et al. 1983). Leaching of nitrogen fertilizers from soils into groundwater may result in additional fluxes of N_2O up to 1.1 Tg N per year (Conrad et al. 1983; Ronen et al. 1988). Consequently, a range of 0.01 - 2.2 Tg N per year can be derived for the flux of N_2O from fertilizer use.

1.5.4 Conclusions

Nitrous oxide is a greenhouse gas whose atmospheric concentration, at 310 ppbv, is now about 8% greater than in the pre-industrial era, and is increasing at a rate of about 0.2 - 0.3% per year, corresponding to about 3 - 4.5 Tg N per year. This represents an excess of 30% of current global emissions over current sinks. The major sink for N_2O is photolysis in the stratosphere, resulting in a relatively long atmospheric lifetime of about 150 years. The magnitude of the sink for N_2O is relatively well known ($\pm 30\%$). In order to stabilize concentrations at present day levels, an immediate reduction of 70 - 80% of the additional flux of N_2O that has occurred since the pre-industrial era would be necessary.

Quantification of the various natural and anthropogenic sources is uncertain. Since the latest studies indicate that the total combined flux of N_2O from combustion and biomass burning is between 0.1 to 0.5 Tg N per year, in contrast to earlier estimates of about 5 Tg N per year, and production of N_2O from fertilizer (including groundwater) is believed to be less than or equal to 2.2 Tg N per year, it is difficult to account for the annual increase based on known sources. Stimulation of biological production due to agricultural development may account for the missing anthropogenic emissions. Estimates of the removal rate of N_2O by photodissociation in the stratosphere range from 7 - 13 Tg N per year. Therefore, the total source needed to account for the observed annual atmospheric growth is 10 - 17.5 Tg N per year against a flux of N_2O from known sources of 4.4 - 10.5 Tg N per year. These data suggest that there are missing sources of N_2O , or the strengths of some of the identified sources have been underestimated. Despite these uncertainties, it is believed that the observed increase in N_2O concentrations is caused by human activities.

1

TABLE 4	
Estimated Sources and Sinks of Nitrous Oxide	
	Range (TgN per year)
Source	
Oceans	1.4 - 2.6
Soils (tropical forests)	2.2 - 3.7
(temperate forests)	0.7 - 1.5
Combustion	0.1 - 0.3
Biomass burning	0.02 - 0.2
Fertilizer (including ground-water)	0.01 - 2.2
TOTAL:	4.4 - 10.5
Sink	
Removal by soils	?
Photolysis in the stratosphere	7 - 13
Atmospheric Increase	3 - 4.5

1.6 STRATOSPHERIC OZONE

Stratospheric O₃ is an important constituent of the Earth's atmosphere. It protects the Earth's surface from harmful solar ultraviolet radiation and it plays an important role in controlling the temperature structure of the stratosphere by absorbing both incoming solar ultraviolet radiation and outgoing terrestrial (longwave) radiation. Part of the absorbed outgoing longwave radiation is then re-radiated back to the surface-troposphere system. Reductions in stratospheric O₃ can modify the surface temperature via two competing processes: more solar radiation is transmitted to the surface-troposphere system, thereby contributing to a surface warming; on the other hand, the cooler stratosphere (due to decreased solar and long-wave absorption) emits less to the troposphere which would tend to cool the surface. The solar warming (a function of total column amount of O₃) and longwave cooling (a function of the vertical distribution of O₃) are similar in magnitude. Therefore, the magnitude as well as the sign of the change in surface temperature depends critically on the magnitude of the O₃ change, which in turn is depends strongly on altitude, latitude and season.

The concentration and distribution of stratospheric O₃ is controlled by dynamical, radiative and photochemical processes. Stratospheric O₃ is photochemically controlled by chemically active species in the (i) oxygen, (ii) hydrogen, (iii) nitrogen, (iv) chlorine, and (v) bromine families. The precursors for the photochemically active species are (i) O₂, (ii) H₂O and CH₄; (iii) N₂O; (iv) CFCs, CCl₄, CH₃CCl₃, CH₃Cl, and (v) halons and CH₃Br, respectively.

1.6.1 Stratospheric Ozone Trends

1.6.1.1 Total column ozone trends

The Antarctic ozone hole, which formed during the mid to late 1970s recurs every springtime. To determine O₃ trends more widely, data from the ground-based Dobson network have been re-evaluated, station by station, and used to determine changes in total column O₃ over the past two decades. Unfortunately, the network and data are adequate for only a limited geographical

region, i.e., 30 - 64°N. They are inadequate to determine total column O₃ changes in the Arctic, tropics, subtropics, or southern hemisphere apart from Antarctica. Satellite data can provide the desired global coverage, but the current record is too short (about one solar cycle, 1978 to present), to differentiate the effects of natural and human-influenced processes on O₃. The re-evaluated data was analysed for the effects of known natural geophysical processes [seasonal variation, the approximately 26-month quasi-biennial-oscillation, and the 11-year solar cycle] and possible human perturbations. After allowing for natural variability, the analyses, using a variety of statistical models and assumptions, showed measurable zonal mean O₃ decreases in the range 3.4% to 5.1% between 30 and 64°N latitude for the winter months (December - March) between 1969 and 1988, with the larger decreases at the higher latitudes (WMO, 1989a,b). No statistically significant zonal trends were found for the summer period (May - August). Lastly, within longitudinal sectors, regional differences in the O₃ trends were indicated, with the largest values over North America and Europe and the smallest over Japan.

1.6.1.2 Changes in the vertical distribution of ozone

Substantial uncertainties remain in defining changes in the vertical distribution of O₃. Analysis of SAGE I and II satellite data, averaged over 20 to 50°N and S latitudes, indicates that near 40 km O₃ decreased by $3 \pm 2\%$ between February 1979 - November 1981 and October 1984 - December 1988 (WMO, 1989b). Because the SAGE record is so short (i.e., less than one solar cycle), no attempt has been made to distinguish between solar-induced and human-influenced contributions to these changes. A thorough analysis of data from 10 ground-based Umkehr stations in the Northern Hemisphere for the period 1977 to 1987 indicates a statistically significant decrease in O₃ between 30 and 43 km. The decrease near 40 km of $4.8 \pm 3.1\%$, after allowing for seasonal and solar-cycle effects and correcting the data for aerosol interferences, is broadly consistent with theoretical predictions. Based on satellite, ground-based, and ozonesonde data, there are indications of a continuing stratospheric O₃ decrease since the late 1970s of a few percent at 25 km and below. Photochemical models, which do not take into account heterogeneous processes) do not predict these changes, but the measurements are qualitatively consistent with those required for compatibility with the total column measurements.

1.6.2 Future Changes

Future changes in stratospheric O₃ are critically dependent upon future emissions of CFCs, other halocarbons, CH₄, N₂O, and CO₂. Assuming that the current regulatory measures agreed under the Montreal Protocol are not strengthened, then the chlorine loading of the atmosphere is predicted to reach about 9 ppbv by the year 2060, about three times today's level, and a bromine loading of about 30 pptv, about twice today's level. Models predict column O₃ reductions of 0 to 4% in the tropics, and from 4 to 12% at high latitudes in late winter. These predictions do not include the effects of heterogeneous processes, which play a critical role in the formation of the Antarctic ozone hole. Consequently, models that include the effects of heterogeneous processes would predict larger O₃ depletions, at least in polar regions. Ozone is predicted to decrease by 25 - 50% at 40 km and result in stratospheric temperature decreases of 10 to 20 K. If, as expected, the Montreal Protocol is modified to eliminate the emissions of CFCs 11, 12, 113, 114, 115, halons 1211 and 1301, and restrict the emissions of CCl₄ and CH₃CCl₃, by the year 2000, then the chlorine loading of the atmosphere by the year 2060 will probably lie between 2.5 and 4 ppbv (depending upon the emissions of CCl₄ and CH₃CCl₃, and HCFCs). Models that do not include heterogeneous processes predict that global O₃ levels would be similar to today. However, if the atmospheric chlorine loading approaches 4 ppbv the implications for polar O₃, and its subsequent impacts on O₃ at mid-latitudes, are unknown.

1.7 TROPOSPHERIC OZONE AND RELATED TRACE GASES (CARBON MONOXIDE, NON-METHANE HYDROCARBONS, AND REACTIVE NITROGEN OXIDES).

1.7.1 Tropospheric Ozone

Tropospheric O₃ is a greenhouse gas, of particular importance in the ^{middle and} upper troposphere ^{and the lower stratosphere} in the tropics and sub-tropics. Its distribution is controlled by a complex interplay between chemical, radiative, and dynamical processes. Ozone is: (i) transported down into the troposphere from the stratosphere; (ii) destroyed by vegetative surfaces; (iii) produced by the photo-oxidation of CO, CH₄, and NMHC in the presence of reactive nitrogen oxides (NO_x), and (iv) destroyed by uv-photolysis and by reaction with hydrogen oxide radicals (HO₂) (Danielsen, 1968; Mahlman and Moxim, 1978; Galbally and Roy, 1980; Crutzen, 1974; Isaksen et al., 1978). Chemical processes in clouds could have a strong influence on O₃ production and destruction rates (Lelieveld and Crutzen, 1990).

Consequently, while CO, NMHC, and NO_x are not important greenhouse gases in themselves, they are important precursors of tropospheric O₃ and they are therefore treated in some detail in this subsection.

1.7.1.1 Atmospheric distribution

Ozone in the troposphere has a lifetime of at most several weeks, hence its concentration varies with latitude, longitude, altitude and season (Chatfield and Harrison, 1977; Logan, 1985). Near the surface monthly mean concentrations (30 - 50 ppbv) are highest in spring and summer at northern mid-latitudes (Figure 1.15). In the middle troposphere at northern mid-latitudes values are highest also in spring and summer, 60 - 65 ppbv. The summer maximum results from photo-oxidation of O₃ precursors from fossil fuel combustion and industrial activity (Isaksen et al., 1978; Fishman et al., 1985; Logan 1985). Ozone values are highest in winter and spring at other latitudes, in part because the stratospheric source is largest then (Levy et al., 1985). There is 35% more O₃ at 40°N than at 40°S, in the middle troposphere (Logan, 1985).

Concentrations of O₃ tend to be smaller in the tropics than in mid-latitudes, except in the dry season, when emissions of O₃ precursors from biomass burning provide a photochemical source (Delany et al., 1985; Crutzen et al., 1985; Logan and Kirchoff, 1986; Fishman et al., 1990). Ozone values during the southern spring over South America can reach almost as high values as found over the industrialized mid-latitudes in summer. Large regions of the tropical troposphere appear to be influenced by sources of O₃ from biomass burning (Fishman et al., 1990). Remote marine air and continental air during the wet season may provide a photochemical sink for O₃ in the tropics; mean surface concentrations as low as 4 - 12 ppbv have been measured (Liu et al., 1980; Oltsmans and Komhyr, 1986; Kirchoff, 1990).

1.7.1.2 Trends

Most long-term measurements of O₃ have been made at northern mid-latitudes, from surface sites and from balloons. Only sporadic data are available before the 1970s. A comparison of data obtained in Paris from 1876-1910 (Volz and Kley, 1988) with rural data from the present day from Europe and North America (Logan, 1985, 1989) suggests that surface O₃ has increased by a factor of 2 - 3 on average; the increase is largest in summer, the factor then being 4 - 6 (Figure 1.15). Ozone values in Europe in the 1970s appear to be about twice those found between 1930 and 1950 (Crutzen, 1988). Data from Europe suggest an increase of 1 - 2% per year from the mid 1950s to the early 1980s, with increases in winter and summer (Feister and Warmbt, 1987; Bojkov, 1988). Since the mid-1970s O₃ has increased by 0.8% per year at remote sites in Alaska and Hawaii; shown no annual trend at Samoa, but has decreased by 0.5% per year at the South Pole (Oltmans et al., 1988). Decreases of 1.8% per year are found at both Samoa and South Pole in summer. Trend data are lacking for tropical continental sites.

Ozonesonde data for northern mid-latitudes between 1965 and 1986 suggest that O₃ has increased by about 1% per year below 8 km, primarily over N. Europe and Japan (Angell and Korshover, 1983; Logan 1985; Tiao et al., 1986; WMO, 1989a,b), but there are no clear trends in the upper troposphere. By contrast, O₃ has decreased in the lower stratosphere (below 25 km), the crossover in the trend being near the tropopause. There is no trend in O₃ at the single sonde station at southern mid-latitudes, and long term sonde data are lacking in the tropics.

1.7.1.3 Relationships between ozone and its precursors

The concentration of tropospheric O_3 is dependent in a very non-linear manner on the atmospheric concentrations of its precursor gases, i.e., CO , CH_4 , NMHC, and, in particular NO_x ($NO_x = NO + NO_2$). Nitrogen oxide concentrations and trends control changes in the concentration of O_3 (Dignon and Hameed, 1985). At low NO_x concentrations (where NO_x is less than 5 - 30 pptv; this threshold depends on the concentrations of O_3 and hydrocarbons) increases in CO , CH_4 , and NMHC lead to a decrease in O_3 , whereas at high NO_x concentrations increases in CO , CH_4 , and NMHC lead to significant enhancements in O_3 . Therefore, no simple relationship exists between increases in the precursor gases and changes in tropospheric O_3 . Several model calculations have been performed to investigate the sensitivity of O_3 changes to changes in the precursor gases, both individually and collectively. All models that have attempted to simulate changes in O_3 during the past century have calculated increases in Northern Hemisphere O_3 by up to a factor of two, broadly consistent with observations, depending upon the assumptions made regarding the initial concentration, distribution, and changes in precursor gas concentrations, particularly NO_x .

Understanding the feedbacks among O_3 and its precursor gases is essential to understand tropospheric OH, which controls the atmospheric lifetimes of CH_4 and the NMHCs. The global concentration of OH, which determines the oxidizing capacity of the troposphere, can be either enhanced because of elevated levels of tropospheric O_3 , NO_x or water vapour (associated with a global warming) or suppressed because of increases in CH_4 , CO , and NMHC (Crutzen, 1987; Thompson et al., 1989). Prediction of regional and global trends in OH concentrations requires an understanding of regional emissions of CH_4 , CO , NMHC and NO_x , as well as transport of O_3 between its source regions and the remote troposphere. One key point is that a continued increase in levels of CO would reduce the global concentration of OH because NO_x is too short-lived to counteract that effect over much of the globe. This would increase the atmospheric lifetime of CH_4 .

1.7.2 Carbon Monoxide

1.7.2.1 Atmospheric distribution of carbon monoxide

The atmospheric concentration of CO exhibits significant spatial and temporal variability because of its short atmospheric lifetime (2 - 3 months). The short atmospheric lifetime, coupled with an inadequate monitoring network, means that the global spatial variability and long-term trends in CO are not well documented. The limited observational data base (Heidt et al. 1980; Dianov-Klovov and Yurganov, 1981; Seiler and Fishman, 1981; Seiler et al. 1984; Khalil and Rasmussen, 1984, 1988a; Fraser et al. 1986 a, c; Newell et al. 1989; Zander et al., 1989; Kirchoff and Marimho, 1989; Kirchoff et al., 1989) has demonstrated that the concentration of CO , (i) is about a factor of two greater in the Northern than in the Southern Hemisphere where the annual average is about 50 - 60 ppbv, (ii) increases with latitude in the northern hemisphere, (iii) exhibits strong seasonal variations in both hemispheres at mid to high latitudes, and (iv) decreases with altitude. CO appears to be increasing at about 1% per year in the northern hemisphere, but the evidence for increases in the southern hemisphere is ambiguous.

1.7.2.2 Sources and sinks for carbon monoxide

The total annual source of CO is about 2400 Tg CO , being about equally divided between direct anthropogenic (incomplete combustion of fossil fuels and biomass) and atmospheric (oxidation of natural and anthropogenic CH_4 and NMHC) sources (Logan et al. 1981; Cicerone, 1988). Atmospheric concentrations of CO may have increased in the northern

hemisphere because of the fossil fuel source, and because of changes in the rate of oxidation of CH_4 , whose atmospheric concentration has increased since pre-industrial times. Fossil fuel sources of CO are presently decreasing in North America (EPA, 1989) and possibly in Europe, but may be increasing elsewhere.

The major removal process for atmospheric CO is reaction with OH (Logan et al. 1981). The observed seasonal variability in the southern hemisphere, distant from seasonally varying sources, can be explained by the seasonal variability in the concentration of tropospheric OH. Soils may provide a minor sink for CO (Conrad and Seiler, 1985).

1.7.3 Reactive Nitrogen Oxides

The key constituents of tropospheric NO_y , defined as the sum of all nitrogen oxide species except for N_2O , are NO_x , nitric acid (HNO_3), peroxyacetylnitrate (PAN: $\text{CH}_3\text{CO}_3\text{NO}_2$), and organic nitrates. Most primary sources of nitrogen oxides release NO_x (mainly NO); the other species are produced by photochemical reactions in the atmosphere. While the atmospheric lifetime of NO_x is short (about 1 day), the atmospheric lifetime of NO_y can range up to several weeks. Thus NO_y can transport nitrogen compounds away from source regions to more remote locations, where photolysis of HNO_3 and PAN, and thermal decomposition of PAN, can regenerate NO_x .

1.7.3.1 Atmospheric distribution of nitrogen oxides

The atmospheric concentrations of NO_x exhibit significant spatial and temporal variability, reflecting the complex distribution of sources and the short atmospheric lifetime. The near surface and free tropospheric concentrations of NO_x each vary by several orders of magnitude, highly influenced by the proximity of source regions. Near surface concentrations of NO_x range from as low as 0.001 ppbv in remote maritime air to as high as 10 ppbv in Europe and Eastern N. America (excluding urban areas), while free tropospheric concentrations range from 0.02 ppbv in remote regions to more than 5 ppbv over populated areas (Fehsenfeld et al., 1988).

The spatial inhomogeneity, coupled with a sparsity of measurements, means that the spatial and temporal distribution and long-term trends in NO_x and NO_y are not adequately documented, although reconstructed emissions inventories of NO_x suggest large increases throughout this century (Dignon and Hameed, 1989). Data from a Greenland ice core have shown that the concentration of nitrate ions (dissolved nitrate from HNO_3) remained constant from 10,000 years ago to about 1950, then doubled by the late 1970's, consistent with the increase in industrial emissions (Neftel et al. 1985b). Data from glacier ice in Switzerland indicates that nitrate ions increased by a factor of 4 - 5 between 1900 and the 1970's in Western Europe (Wagenbach et al. 1988).

1.7.3.2 Sources and sinks of nitrogen oxides

The sources of atmospheric NO_x are about equally divided between anthropogenic (combustion of fossil fuels: 21 Tg N per year, and biomass burning: 2 - 5 Tg N per year), and natural (microbial processes in soils: 20 Tg N per year; lightning: 2 - 8 Tg N per year, and transport from the stratosphere: 1 Tg N per year) (Galbally, 1989). Emissions of NO_x (6.3 Tg N per year) from the combustion of fossil fuels have not increased in N. America since 1970 (EPA, 1989). Soil emissions of NO are stimulated by agricultural activity (e.g., addition of fertilizer, manure, etc.), hence, agricultural soil emissions may provide significant sources of NO_x in many areas.

The dominant removal processes for NO_x are (i) conversion to HNO_3 , PAN, and organic nitrates by photochemical mechanisms, (ii) reactions involving NO_3 radicals, and possibly (iii) deposition of NO_2 on vegetation. The resulting NO_y species are then removed from the atmosphere by wet and dry deposition, or by conversion back to NO_x .

1.7.4 Non-Methane Hydrocarbons

1.7.4.1 Atmospheric distribution of non-methane hydrocarbons

The NMHC can be classified by atmospheric lifetime: (i) relatively long-lived (lifetimes > week) where the highest concentrations (up to 3 ppbv for ethane) are observed at middle to high northern latitudes; (ii) more reactive (lifetimes between half a day and one week) such as $C_2 - C_5$ alkenes whose concentrations exhibit significant temporal and latitudinal variability from <0.1 ppbv in remote areas to a few ppbv close to source regions, and (iii) extremely short lived (lifetimes of hours) such as terpenes or isoprene whose local concentrations may reach about 10 ppbv very close to their sources. Trends in the atmospheric concentrations of NMHC have not been established due to a lack of measurements.

1.7.4.2 Sources and sinks for non-methane hydrocarbons

The oceans are a major source of NMHC, mainly alkenes. Estimates of the source strength of ethene and propene range from 26 Tg C per year (Bonsang et al., 1988) to as high as 100 Tg C per year (Penkett, 1982). Emissions of NMHC from terrestrial vegetation are dependent upon environmental factors as well as the type of vegetation. Isoprene is primarily emitted from deciduous plants, whereas conifer trees are primarily a source of terpenes. Isoprene and terpene emission rates are very large, about 500 Tg per year for each (Rasmussen and Khalil, 1988). The source strength of NMHC from anthropogenic activities such as biomass burning, solvents and fossil fuel combustion has been estimated to be about 100 Tg per year.

The dominant loss mechanism for most NMHC is rapid (much faster than CH_4) reaction with OH. The products of these reactions are capable of forming O_3 in the presence of NO_x .

1.7.5 Feedbacks Between Climate and the Methane / Non-Methane Hydrocarbon / Carbon Monoxide / Oxides of Nitrogen / Tropospheric Ozone System

There are numerous potentially important feedbacks between climate change and tropospheric O_3 and OH. Changes in cloud cover, precipitation, and circulation patterns, as well as changes in the biospheric source strengths of CH_4 , CO, NMHC and NO_x , will induce changes in homogeneous and heterogeneous reactions controlling O_3 and OH. In addition, changes in stratospheric O_3 may induce changes in tropospheric processes, through changes in ultraviolet radiation. Stratospheric O_3 depletion is likely to increase tropospheric O_3 when the levels of CO, NO_x , and NMHC are high, but reduce it in regions of very low NO_x . The importance of these feedback processes remains to be determined.

1.7.6 Conclusions

Tropospheric O_3 is a greenhouse gas that is produced photochemically through a series of complex reactions involving CO, CH_4 , NMHC and NO_x . Hence, the distribution and trends of tropospheric O_3 depend upon the distribution and trends of these gases whose atmospheric concentrations are changing.

The short atmospheric lifetimes of O_3 (several weeks), and many of its precursor gases, coupled with inadequate observational networks, leave their distributions and trends inadequately documented. Most data support positive trends of about 1% per year for O_3 below 8 km altitude in the Northern Hemisphere (consistent with positive trends in several of the precursor gases, especially NO_x , CH_4 , and CO), and a similar trend for CO in the Northern Hemisphere, but not in the Southern Hemisphere. While there is no systematic series of data that allow quantitative estimates of trends in NMHC and NO_x to be made, their atmospheric concentrations are likely to have increased during the past few decades because of increased anthropogenic sources. The ice core records of nitrate levels provide indirect evidence for a Northern Hemisphere increase in atmospheric NO_x .

1.8 AEROSOL PARTICLES

1.8.1 Concentrations and Trends of Aerosol Particles in the Troposphere

Aerosol particles play an important role in the climate system because of their direct interaction (absorption and scattering) with solar and terrestrial radiation, as well as through their influence on cloud processes and thereby, indirectly, on radiative fluxes. These processes are discussed in more detail in Sections 2.3.2 and 2.3.3. Two separate issues should be identified. The first is the effect of increasing or decreasing anthropogenic emissions of aerosol particles and their precursors in regions impacted by these emissions. The second is the role of feedback processes linking climate change and natural (biological) production of particles in unpolluted regions, especially over the oceans (cf. Section 10.8.3).

Total suspended particulate matter in air varies from less than $1 \mu\text{g m}^{-3}$ over polar ice caps or in the free mid ocean troposphere to 1 mg m^{-3} in desert dust outbreaks or in dense plumes from e.g., forest fires. In a typical sample of continental air mineral dust, sulphuric acid, ammonium sulphate as well as organic material and elemental carbon (soot) may be found both as pure or mixed particles. Most of the soluble particles become solution droplets at relative humidities above 80%; thus the radiative properties of aerosol particles even vary with relative humidity at constant dry aerosol mass.

A large part of the aerosol mass in submicron size particles is derived from gas-to-particle conversion through photochemical processes involving gaseous sulphur and hydrocarbon compounds. Such conversion may take place through photochemical processes involving the oxidation of sulphur dioxide (SO_2) and other sulphur gases to sulphuric acid (H_2SO_4) by reaction with OH. The H_2SO_4 so formed, having a low equilibrium vapour pressure, immediately condenses onto existing aerosol particles or forms new ones. Transformation to sulphuric acid and sulphate also takes place in cloud droplets, the majority of which eventually evaporate leaving the sulphate in the aerosol phase. Trends in the emission of these gaseous precursors, especially the sulphur gases, are therefore of great importance for the regional aerosol burden and thereby potentially for climate.

Large quantities of aerosol particles are also emitted from the burning of savannas and forests in tropical regions. The directly emitted particles consist largely of carbonaceous materials including black carbon (soot) (Andreae et al., 1988). In addition, particles are formed from precursor gases like SO_2 and hydrocarbons emitted by fires.

The average tropospheric life time of aerosol particles, and of their precursor gases, is of the order of only days or weeks. This is much shorter than the lifetime of most greenhouse gases. It implies that the atmospheric loading at any one time reflects the emissions that have taken place during the past few weeks only. No long-term accumulation in the troposphere is thus possible and any reduction in anthropogenic emissions will immediately result in a corresponding reduction in tropospheric concentrations. The short lifetime also implies large spatial and temporal variability in the concentrations of aerosol particles.

It has been established from analyses of Greenland ice cores that the amounts of sulphate, nitrate and trace metals, derived mainly from atmospheric aerosols, have been increasing since industrialisation began (Nefel et al., 1985 b; Mayewsky et al., 1986). However, there are almost no long-term, continuous direct observations of aerosol parameters in the atmosphere outside urban and industrial areas (Charlson, 1988). Indirect evidence from visibility observations indicates that the concentration of submicron aerosols over much of the eastern part of the U.S. has increased during the period 1948-1978 (Husar et al., 1981).

Another example of a trend analysis of atmospheric aerosols is due to Winkler and Kaminski (1988), who concluded that submicrometer aerosol mass outside Hamburg has increased by a factor of nearly two between 1976 and 1988 due to long range transport from industrialized centres in the region.

The hypothesis by Charlson et al. (1987) of a connection between climate and phytoplankton activity in ocean surface waters is based on the role played by soluble aerosol particles in determining the microphysical properties of clouds. The proposed climate-phytoplankton feedback rests on the facts that cloud condensation nucleus (CCN) concentrations in air are low over oceans far from land, that the CCN available in clean maritime air are composed almost totally of sulphate particles, and that this sulphur originates almost entirely from emissions of reduced sulphur gases (principally dimethylsulphide (DMS)) from the ocean surface. There is a significant non-linearity in the effect on cloud microphysics of given changes in CCN concentration, depending on the starting CCN concentration characteristics of clean oceanic air.

There is abundant evidence in the literature to confirm the role played by CCN concentration in determining cloud droplet size distribution. However, at this stage neither the sign nor magnitude of the proposed climate feedback can be quantitatively estimated, though preliminary calculations based on plausible scenarios indicate that this hypothesis merits careful consideration. Preliminary attempts to test this hypothesis using existing historical data of various types have been inadequate and have yielded only equivocal conclusions.

1.8.2 The Atmospheric Sulphur Budget

Current estimates of the global sulphur cycle show that anthropogenic emissions of SO_2 are likely to be at least as large as natural emissions of volatile sulphur species, cf. Table 5 (based essentially on Andreae, 1989). Within the industrialized regions of Europe and North America, anthropogenic emissions dominate over natural emissions by about a factor of ten or even more (Galloway et al., 1984; Rodhe, 1976). The anthropogenic SO_2 emissions have increased from less than 3 TgS per year globally in 1860, 15 in 1900, 40 in 1940 and about 80 in 1980 (Ryaboshapko, 1983). It is evident from these numbers that the sulphur fluxes through the atmosphere have increased very substantially during the last century, especially in the Northern Hemisphere. During the past decade the anthropogenic sulphur emissions in North America and parts of Europe have started to decline.

TABLE 5

Estimates of global emission to the atmosphere of gaseous sulphur compounds †

Source	Annual Flux (TgS)
Anthropogenic (mainly SO_2 from fossil fuel combustion)	80
Biomass burning (SO_2)	7
Oceans (DMS)	40
Soils and plants (H_2S , DMS)	10
Volcanoes (H_2S , SO_2)	10
Total	147

† The uncertainty ranges are estimated to be about 30% for the anthropogenic flux and a factor of two for the natural fluxes.

Small amounts of carbonyl sulphide (COS) are also emitted into the atmosphere. They do not significantly affect the sulphur balance of the troposphere but they are important in maintaining an aerosol layer in the stratosphere.

1 Because of the limited atmospheric lifetime of most sulphur compounds, the augmentation of
2 the sulphur concentrations brought about by industrialization is not evenly distributed around
3 the globe. This is illustrated by Figure 1.16, which shows an estimate of how much more
4 aerosol sulphate there is at present in the lower atmosphere (900 hPa level) than in the pre-
5 industrial situation (Langner and Rodhe, 1990). Over the most polluted regions of Europe and
6 North America the sulphate levels have gone up by more than a factor of 10. Smaller increases
7 have occurred over large parts of the oceans.
8
9

10 1.8.3 Aerosol Particles in the Stratosphere

11
12 The vertical profile of aerosol particle concentration normally exhibits a marked decline up
13 through the troposphere followed by a secondary maximum in the lower stratosphere at around
14 20 km. The stratospheric aerosol layer is maintained by an upward flux of gaseous precursors,
15 mainly carbonyl sulphide (COS). Concentrations may be greatly enhanced over large areas for
16 a few years following large volcanic eruptions, such as El Chichon in 1982. No significant
17 trends have been detected in the global background aerosol layer in the stratosphere during
18 periods of low volcanic activity (WMO, 1989a). The potential impact on climate of
19 stratospheric aerosols is discussed in Section 2.3.2.
20

21 1.8.4 Conclusions

22
23
24 Aerosol particles have a lifetime of at most a few weeks in the troposphere and occur in highly
25 variable concentrations. A large proportion of the particles which influence cloud processes
26 and for the radiative balance, are derived from gaseous sulphur emissions. These emissions
27 have more than doubled globally, causing a large increase in the concentration of aerosol
28 sulphate especially over and around the industrialized regions in Europe and North America. If
29 anthropogenic sulphur emissions are indeed a major contributor to cloud condensation nuclei
30 concentrations on a global scale, then any climate prediction must take account of future trends
31 in regional and global anthropogenic sulphur emission, which may be quite different from
32 those of the greenhouse gases.
33

34 Aerosol particles derived from natural (biological) emissions may contribute in important ways
35 to climate feedback processes. During a few years following major volcanic eruptions the
36 concentration of aerosol particles can be greatly enhanced.
37

Section 1

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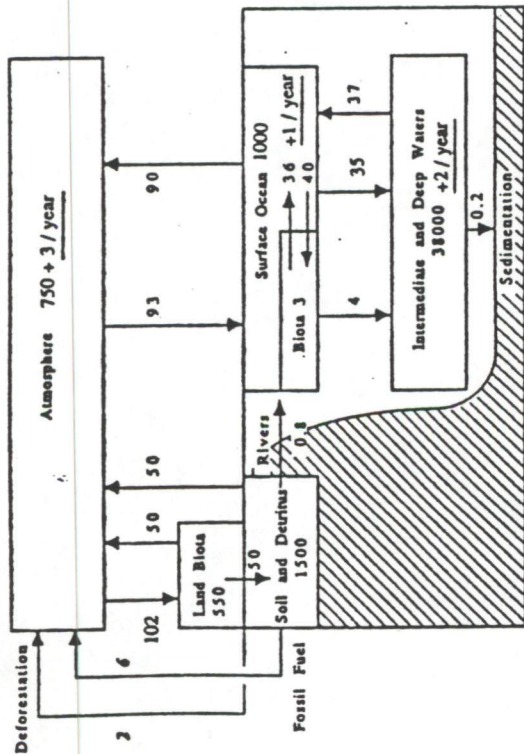


Figure 1: Global carbon reservoirs and fluxes. The numbers apply for the present-day situation and represent typical literature values. Fluxes, e.g. between atmosphere and surface ocean, are gross annual exchanges. Numbers underlined indicate net annual CO_2 accumulation due to human action. Units are gigatons of carbon (GtC ; $1 \text{ Gt} = 10^9$ metric tons $= 10^{12} \text{ kg}$) for reservoir sizes and GtC yr^{-1} for fluxes. More details and discussions are found in several reviews (Sundquist, 1985; Trabalka, 1985; Bolin, 1986; Siegenthaler, 1986).

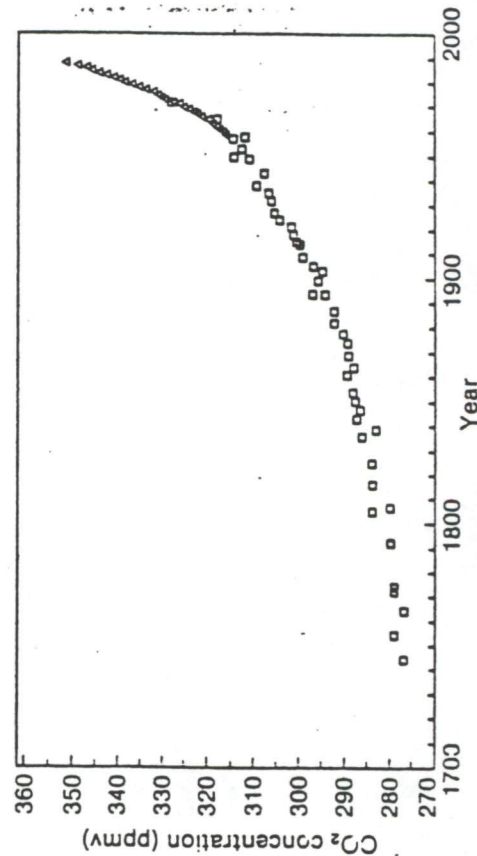


Figure 3: Atmospheric CO_2 increase in the past 250 years, as indicated by measurements on air trapped in ice from Siple Station, Antarctica (squares; Neftci et al., 1985a; Friedli et al., 1986) and by direct atmospheric measurements at Mauna Loa, Hawaii (crosses; Keeling et al., 1989a).

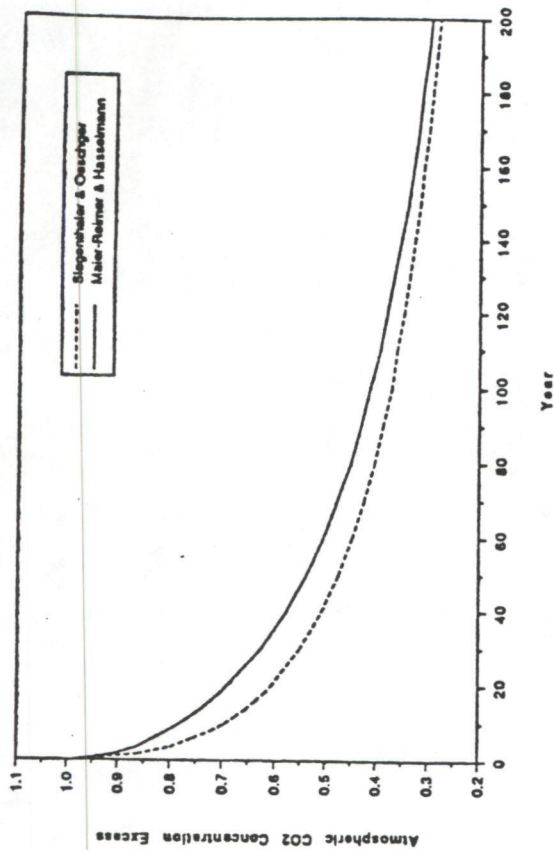


Figure 2: Atmospheric CO_2 concentration excess after a pulse input at time 0 (initially doubling the atmospheric CO_2 concentration), as calculated with two ocean-atmosphere models. Solid line: 3-dimensional ocean-circulation model of Maier-Reimer and Hasselmann (1987); dashed line: 1-dimensional box-diffusion model of Siegenthaler and Oeschger, 1987). The adjustment towards a new equilibrium does not follow an exponential curve; it is very fast during the first decade, then slows down more and more. The concentration excess does not go to zero; after a long time, a new equilibrium partitioning between atmosphere and ocean will be reached, with about 15 percent of the input residing in the atmosphere.

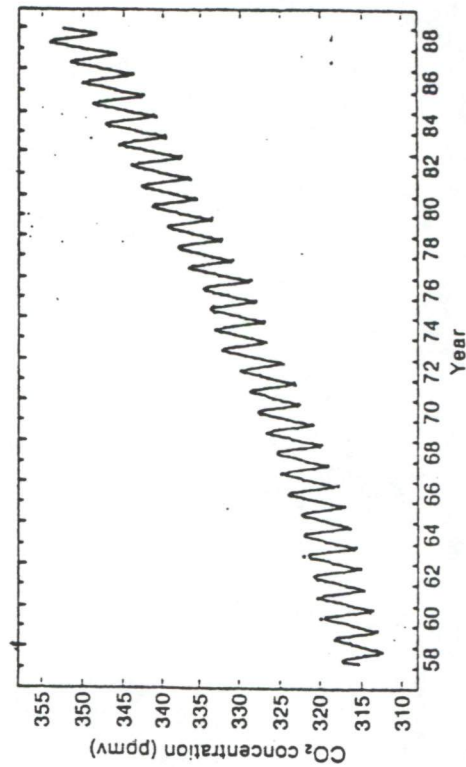


Figure 4: Monthly average CO_2 concentration in parts per million of dry air, observed continuously at Mauna Loa, Hawaii (Keeling et al., 1989a). The seasonal variations are due primarily to the withdrawal and production of CO_2 by the terrestrial biota.

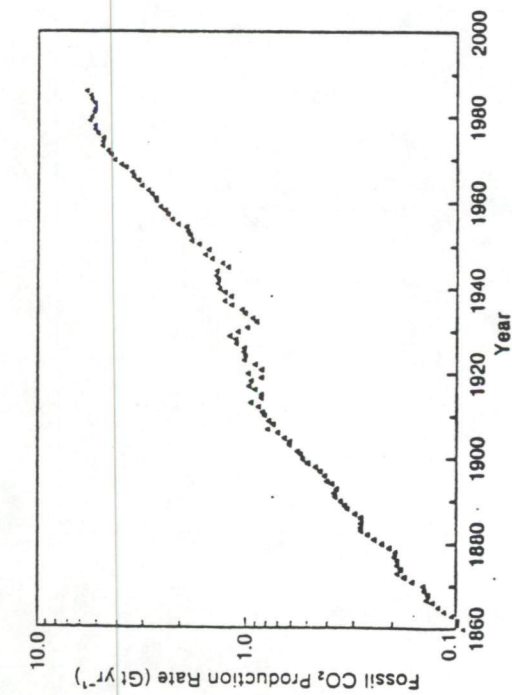


Figure 5: Global annual emissions of CO₂ from fossil fuel combustion and cement manufacturing, expressed in GtC yr⁻¹ (Rotty and Marland, 1986; Marland, 1989). The average rate of increase in emissions between 1860 and 1910 and between 1950 and 1970 is about 4% per year.

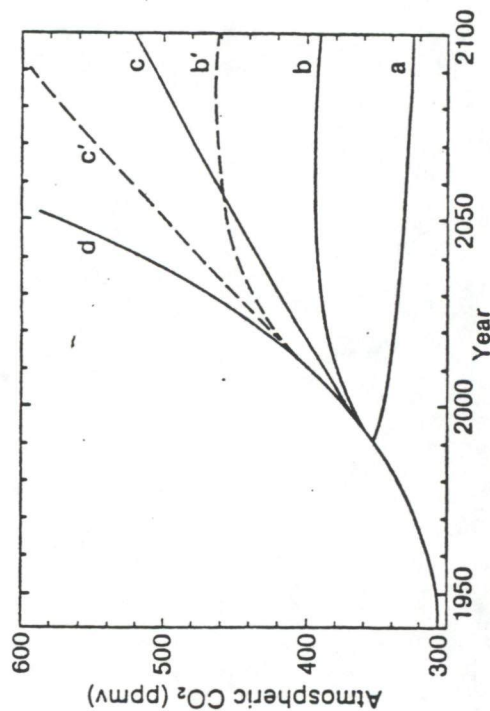


Figure 7: Future atmospheric CO₂ concentrations as simulated by means of a box-diffusion carbon cycle model (Enting and Pearman, 1982, 1987) for the following scenarios: a) - d): anthropogenic CO₂ production rate p prescribed after 1990 as follows: a) $p = 0$; b) p decreasing by 2% per year; c) $p = \text{constant}$; d) p increasing at 2% per year. Scenarios b') and c'): p grows by 2% per year from 1990-2010, then decreases by 2% per year (b') or is constant (c'). Before 1990, the concentrations are those observed (cf. Figure 3), and the production rate was calculated by to fit the observed concentrations.

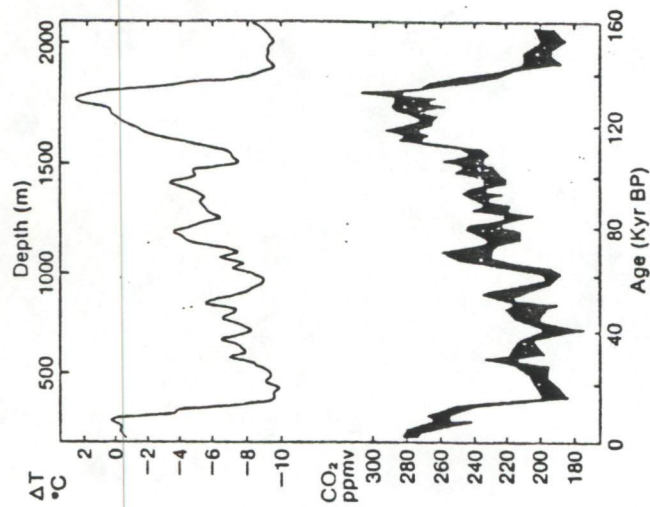


Figure 6: CO₂ concentrations (bottom) and estimated temperature changes (top) during the past 160,000 years, as determined on the ice core from Vostok, Antarctica (Bernola et al., 1987). Temperature changes were estimated based on the measured deuterium concentrations.

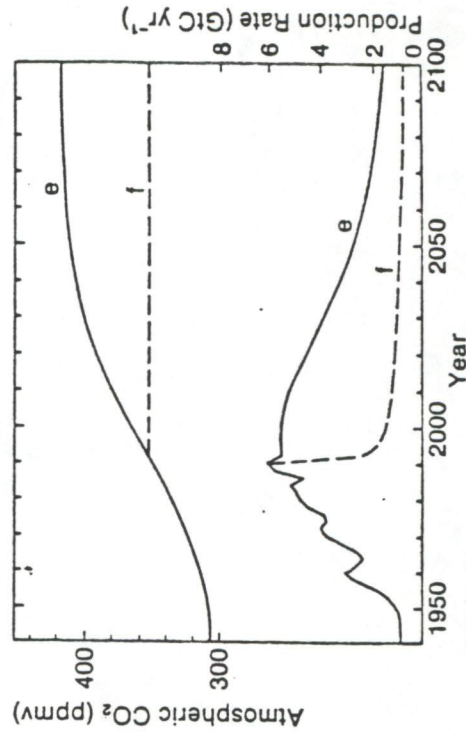


Figure 8: Future CO₂ production rates calculated by means of a box-diffusion carbon cycle model (Enting and Pearman, 1982, 1987) so as to yield the prescribed atmospheric CO₂ concentrations after 1990. e) concentration increasing steadily (logistic function of time). 420 ppmv. f) concentration constant after 1990.

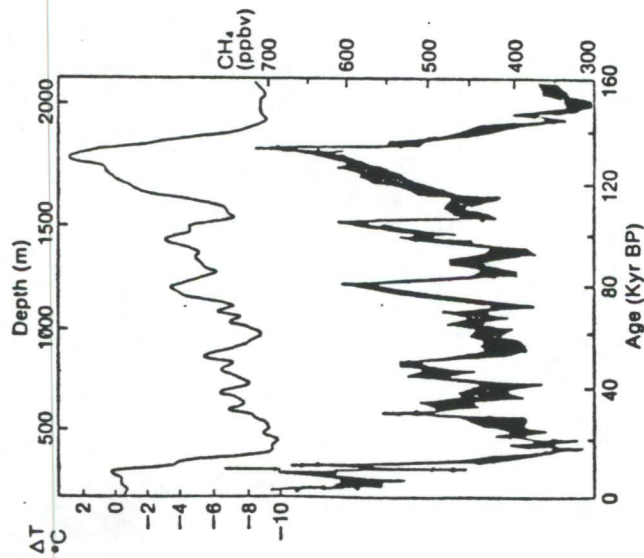


Figure 9: Methane concentrations (bottom) and estimated temperature changes (top) during the past 160,000 years as determined on the ice core from Vostok, Antarctica (Chappellaz et al., 1990). Temperature changes were estimated based on the measured deuterium concentrations.

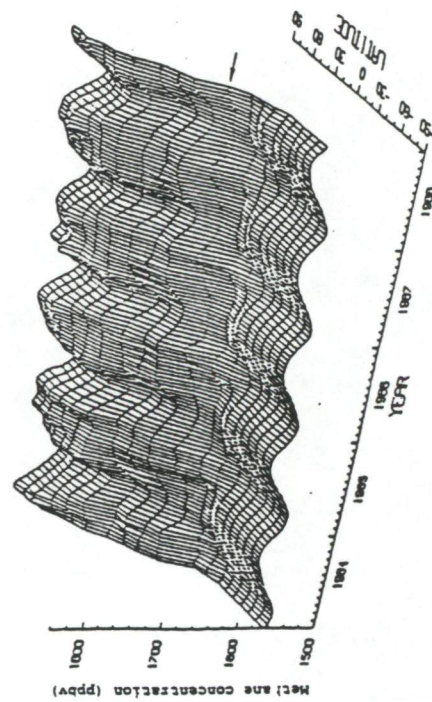


Figure 11: The global distribution, seasonality, and trend of methane from the GMCC network (Steele et al., 1987, and unpublished data)

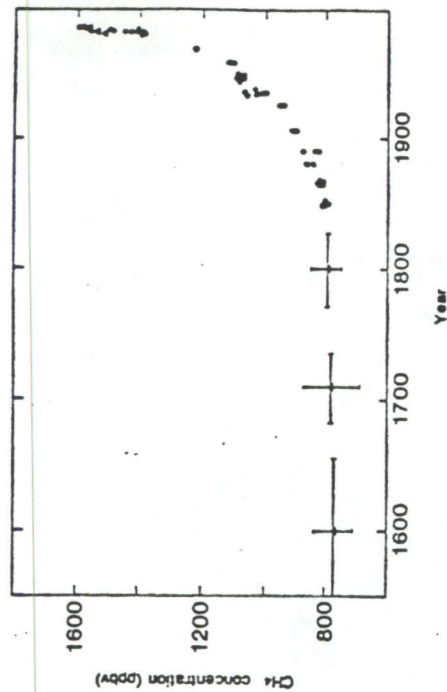


Figure 10: Atmospheric methane variations in the past few centuries measured from air in dated ice cores (Etheridge et al., 1988; Pearman and Fraser, 1989).

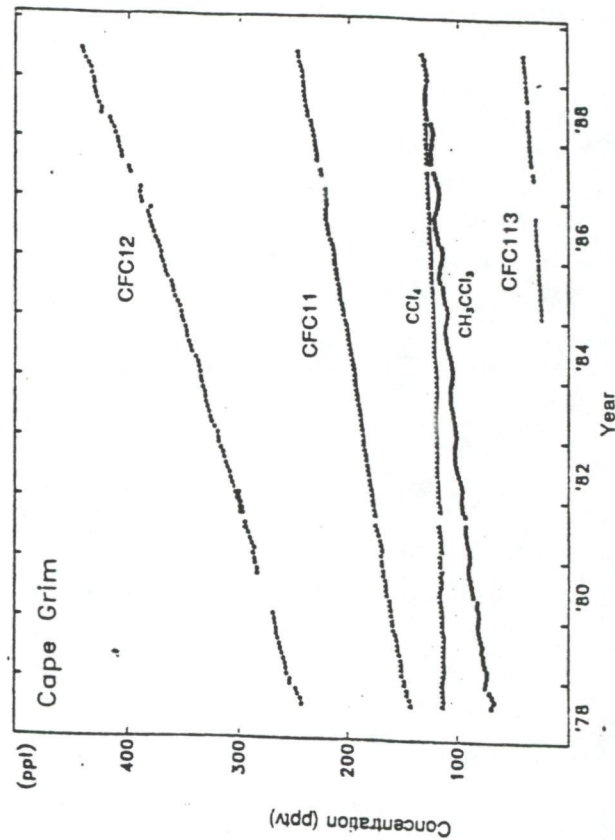


Figure 12: Halocarbon concentrations measured at Cape Grim, Tasmania during the period 1978-1989 (Fraser and Derek, 1989, and unpublished data).

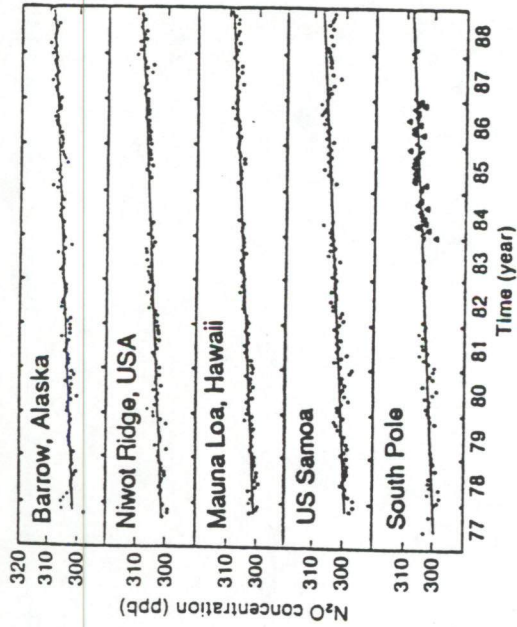


Figure 13: Atmospheric measurements of nitrous oxide from the NOAA/GMCC network (Elterre and Rossen, 1989).

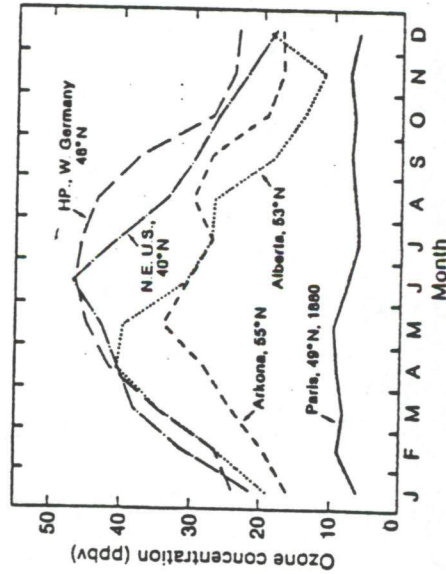


Figure 15: The seasonal variation of surface ozone. The solid line shows data from Montsouris, France, for 1876-86 (Volz and Kley, 1988). All other data are from the 1970s and 1980s: dashed line, Arkona, GDR (Feister and Warmbt, 1987); dotted line, Ellerslie, Alberta, Canada (Angle and Sandhu, 1986); dot-dash line, average of eight rural sites in the northeastern U.S., the SURE sites (Logan, 1988); long dashed line, Hohenpeissenberg, FRG (Logan, 1985). All the recent data are shown as monthly means of daily average values.

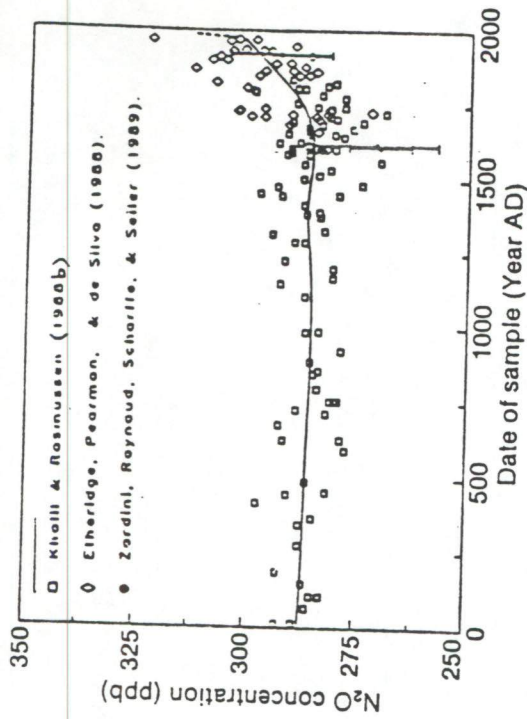
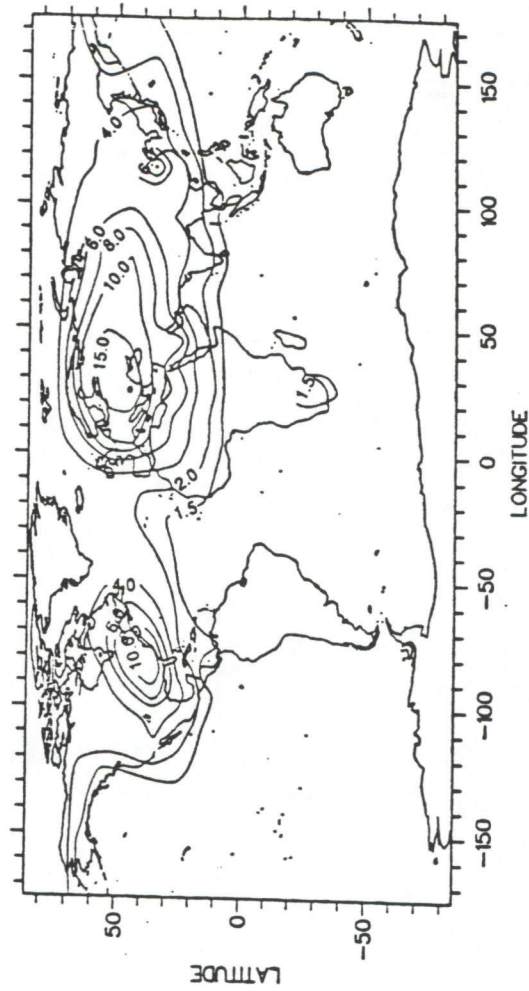


Figure 14: Nitrous oxide measurements from ice-core samples.



THE WHITE HOUSE
WASHINGTON

July 2, 1990

Memo to: John Sununu
From: Allan Brinkley
Re: IPCC Summary Report.

As you recall, Bob Watson and
Fred Bernthal went to Europe two weeks
ago to work with Bert Bolin to draft
an IPCC final summary report. Bolin had
prepared a good draft and the assumption
was, on our part, that the working group
chairmen, each with a backup (Watson
in our case) would work with Bolin to
massage the draft and include suggestions
such as those Sam Stier had made.

In the event, Bolin lost control of
the meeting and instead of finalizing
a draft for presentation at the IPCC
Plenary in early August, the entire

Structure and content of the report were opened up without too much agreement or conclusion.

At the end of the meeting Balin was sent off to try again. I am enclosing herewith a copy of the second draft that we have just received from Balin. I have not yet read it but am told that the deadline for comments is COB today (Thursday).

I feel certain that this can be stretched for a day or so.

I shall be happy to try to inject any comments you may have into the system - but realize that you have many other things on your mind.

Best regards.

Alan
(Sent by FAX, July 2)

THE WHITE HOUSE

WASHINGTON

June 14, 1990

MEMORANDUM FOR JOHN H. SUNUNU

FROM:

D. ALLAN BROMLEY *DB*

SUBJECT:

SEA LEVEL CHANGE AND ENVIRONMENTAL MATTERS

Like all else in the global warming arena the calculation of sea level change is much more complicated than it appears. First some general comments:

1. Assuming for the moment a rise in atmospheric temperature there are two determining constants at work. First is that at the atmosphere-ocean interface, i.e., how much thermal energy is transferred to the water and at what rate? Second is that of the internal ocean transport mechanisms that carry this thermal energy into the bulk ocean.
2. Considering the Atlantic, as an example, thermal energy transferred to the Gulf Stream is carried northward and in the Greenland-Iceland region it splits with something like 90 percent remaining on the surface and continuing its clockwise surface circulation. This involves the upper 100-200 meters at most. The remainder (about 10%) is carried downward and flows again southward at much greater depth. What this means is that the thermal expansion of the ocean from the bulk of the ocean--depths greater than 100-200 meters-- is delayed by something between 50 and 100 years as compared to that of this 100-200 meter surface layer.
3. It is important to note that for salinity greater than 24.7 permil, the density of sea water increases with decreasing temperature all the way to the freezing point, i.e., there is no maximum in the liquid density vs temperature plot as is the case with fresh water. Also counterintuitively, the coefficient of thermal expansion of sea water increases with increasing pressure i.e., depth.
4. The simple minded expansion calculation--in zeroth order follows from the hydrostatic equation

$$p = \rho g h \quad \text{where } p = \text{pressure, } \rho = \text{density} \\ g = \text{acceleration due to gravity} \\ h = \text{depth}$$

and $a = -\frac{1}{\rho} \frac{d\rho}{dT}$ where T is the temperature and
a is the thermal expansion coefficient

5. As water expands the sea levels rises but $\partial p = 0$

$$\partial p = \partial \rho g h + \rho g \partial h = 0 \text{ so } \rho g h \partial T = \rho \partial h \text{ and } \partial h / \partial T = \alpha h$$

Here in the zeroth order we simply take an average depth $\langle h \rangle \sim 3800$ m on the assumption (wrong!) of complete thermal equilibrium and set

$$\alpha(T, p, s) \sim (10 \text{ to } 20) \times 10^{-3} / ^\circ\text{C} \text{ where } s \text{ is the salinity, and so find}$$
$$\partial h / \partial T \sim 60 \text{ cm}/^\circ\text{C}$$

6. From this we see that a 0.10C rise in temperature corresponds to 6 cm sea level rise as indeed would a 0.4 C rise in the top 1000m and no temperature change in the lower levels. But this is a very crude model.

7. In the IPCC WG 1 report that predicts an effective CO2 doubling by 2030, the predicted sea level rise is 18cm. This is composed of the following contributions

(a) Thermal expansion--10 cm. The report discusses in some detail an up-to-date box diffusion model that does take into account the variations of salinity and of temperature. The authors of this particular section of the report are publishing a book later this year on their calculation and perhaps reflecting that, their discussions in the IPCC report are not as clear as they might be in places. Indeed one could (as I did) read the policymaker's summary as suggesting that the 10 cm figure came from a linear extrapolation of historical data on sea levels to the 2030 temperature predicted by the GCM models. I find however that the more complex box model calculations were actually used.

(b) Melting of land based glacier ice--7 cm. Here I am quite confident that this number results from simple linear extrapolation of the recent historical data on the retreat of mountain glaciers.

Note: Such extrapolations are on shaky grounds. The association of past historical behavior with the atmospheric temperature--on a single parameter basis--has very little justification. Similarly, there is little justification for linear extrapolations. The global circulation models give static, point-in-time predictions but no insight into the path from one of these states to the next. The historical record suggests substantial fluctuations about any average. Finally, my earlier memo on the carbon cycle raises its own questions regarding the assumption of effective doubling in 2030.

(c) Melting of the Greenland ice cap--2 cm. All GCM's predict that polar regions will experience greater greenhouse warming than equatorial ones in any warming scenario.

(d) Sequestering of water in Antarctica--(-1) cm. Because of its much greater area and predicated increased snowfall it is anticipated that Antarctica will actually

sequester water in a warming scenario. It bears noting that melting of 0.1% of the Antarctic ice corresponds roughly to a 1 meter change in global sea level.

Adding up all these contributions then leads to the quoted 18 cm prediction for sea level rise in 2030.

What we really need is a solid scientific look at this entire question, recognizing that it is difficult and that many of our input data are fuzzy. I am hoping to interest NOAA and NSF in doing such a study. We can do better!

I share your concern, and Dick Darman's, that by focussing on the anthropogenic greenhouse gas sources and sinks in the policymaker's summary--and the executive summary--and by omitting much mention of the 20 times greater natural fluxes, the authors end up with a distorted perspective even though both anthropogenic and natural fluxes are treated quite well in the body of the main report--which relatively few people will ever read!

I am also concerned that if we appear to accept IPCC WG 1 as ultimate truth then to some extent we have been effectively coopted into accepting the recommendations of the IPCC WG 2 and 3 which may well be substantially different from what we had in mind.

Let me turn then to a different topic.

The June 8 UNEP and RSWG (IPCC WG 3) meetings in Geneva, in my opinion, were particularly important in demonstrating that we are increasingly seen as occupying a centrist position with the EC (Netherlands, FRG, etc.) as the extremists. It will be important for us to continue fostering this view as more and more nations begin to recognize that they were overly hasty and even emotional in their willingness to sign up for targets and timetables last November in Noordwijk. Sanity is returning slowly to this field!

I believe that the President's leadership in this entire global change area is increasingly being recognized--albeit reluctantly in some communities--and that by injecting economics directly into the discussions at the White House Conference we have achieved much more than the international press was prepared to admit at the time.

It will be very important for us to develop our positions in the entire global change and environmental areas as soon as possible because in the face of the rather ridiculous number of conferences, workshops, ministerials, etc., upcoming, in the absence of such firm and generally agreed upon positions, we tend to get ratcheted toward positions that are not in our best interests.

Your suggestions and comments would be most welcome.

THE WHITE HOUSE
WASHINGTON

DATE: February 13, 1990

TO: Dr. Allan Bromley

FROM: GOVERNOR JOHN H. SUNUNU

Your comments, please.

*See earlier response
please.*

THE WHITE HOUSE

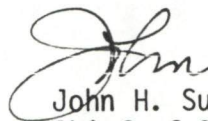
February 13, 1990

Dear Miro,

Thanks for the note.

I will be talking to Allan Bromley about your recommendation. I appreciate you taking the time to write and will follow up next time we meet.

Regards,



John H. Sununu
Chief of Staff

THE WHITE HOUSE

WASHINGTON

Dr. Miro M. Todorovich
410 Riverside Drive, Apt. 82A
New York, New York 10025

bcc: Dr. Allan Bromley

MIRO M. TODOROVICH
410 Riverside Drive, Apt. 82A
New York, New York 10025

February 9, 1990

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

Dear John:

In quick succession, the New York Times and other media noted (1) the toning down of the President's speech on global atmospheric concerns, (2) wetland's regulation relaxation, and (3) the one nuclear engineer in the White House allegedly responsible for these deeds.

While in more than full agreement with what was decided, I worry about your exposure to attack (remember Bork, etc.).

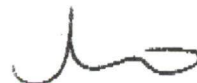
For more than a year now, I have held the belief that impeccably-crafted groups of prominent scientific experts (à la Seabrook panel) whom you would ask for council on specific issues could remove the lightning rod from above your head and guide hostile electricity to harmless neutralization.

You should be seen as a skillful executor of the best scientific/economic understanding held by competent people -- not portrayed as a capricious individual imposing his idiosyncratic predilections, via the President, onto a docile society.

Fred and I could assemble fully believable panels in support of any scientifically defensible decision. I strongly believe that it would be politically very wise that you lean visibly on such scientific validation.

Waiting to hear your reaction.

Cordially,



Miro M. Todorovich

THE WHITE HOUSE

WASHINGTON

October 26, 1990

MEMORANDUM FOR THE PRESIDENT

FROM: D. ALLAN BROMLEY *Anan*
SUBJECT: Second World Climate Conference

This will provide additional information on the Second World Climate Conference (SWCC), supplementing Roger Porter's memo to you of October 23.

Preparations for SWCC

The U.S. positions for SWCC have been developed through a working level group headed by the State Department, which has reported to the DPC Global Change Strategy Task Force that I chair. The task force has developed our positions on the five major issues in the draft Ministerial Declaration, reviewed and approved the alternative draft declaration discussed below, and reviewed the opening statement of NOAA Administrator Dr. John Knauss, who will head the U.S. delegation to the Ministerial portion of the meeting. Throughout this process I have kept Governor Sununu fully apprised of developments.

SWCC is controversial

SWCC is one of many international conferences held to address global climate change issues. These conferences generally have as their goals: heightening the visibility of the issues, encouraging scientific and economic inquiry into climate phenomena, and, in many instances, international political positioning.

The first part of SWCC will be a review of scientific information, including materials compiled through the U.N. sponsored Intergovernmental Panel on Climate Change (IPCC), which has been endorsed by the U.S. government as the appropriate channel to consider climate change science. It will provide a forum for discussions that connect scientific understanding with the continuing policy debate. There are no official "delegations" to the scientific discussions.

A ministerial meeting will occur during the second week of the conference, increasing the political tone of the event. There will be pressure to begin negotiations on greenhouse gas emissions reductions. The U.S. does not recognize SWCC as the forum for substantive climate change negotiations, so Dr. Knauss was chosen to head the U.S. delegation to emphasize our view of the meeting as science-focused.

The U.S. position is that this meeting should discuss the scientific issues and preserve any negotiations for the February 1991 framework convention meeting, hosted

by the U.S. in Washington. The delegation will also try to gather support for our "comprehensive approach" to emissions reductions, which takes into account characteristics of all greenhouse gases and their effects on the environment. Some countries will seek to push agreement on elements to be included in a framework convention, but the U.S. delegation plans to hold firm in deferring such issues to the negotiations.

There are five major issues in the controversial draft Ministerial Declaration

The draft Declaration is highly controversial. Major issues for the U.S. in the draft, along with the U.S. positions, are:

- (1) Targets and Timetables. We should not commit to specific targets and timetables for reducing greenhouse gases. Instead, we should take actions that are justified for other reasons. All actions should be within the context of the comprehensive approach to greenhouse gas limits.
- (2) Content of a Convention. The Ministerial Declaration should not prejudice the negotiations which are to begin in Washington in February.
- (3) Financial Assistance. The U.S. will not commit to providing new, additional international assistance which increases the overall budget. Existing resources and mechanisms must be fully utilized before new monies can be considered.
- (4) Climate Change Science. The declaration must be accurate in describing the scientific context and uncertainties associated with potential climate change.
- (5) Precautionary Principle. The U.S. will assert, as was spelled out in the Houston Economic Summit declaration, that lack of full scientific certainty is no excuse to postpone actions which are justified in their own right.

The U.S. may be isolated on a number of issues

The U.S. does not agree with many countries' broad interpretation of the precautionary principle, or their calls for targets and timetables and financial assistance. Other countries interpret the precautionary principle as urging immediate action for the prevention of environmental degradation, regardless of the extent of scientific uncertainty. The Soviet Union and Saudi Arabia may be our allies on this issue.

Press interest in the conference may be intense for a period of time because of pressure from a growing number of countries to set targets and timetables. Japan will highlight its recently developed strategy for stabilizing CO₂ at current levels by the year 2000. Australia will also be discussing its strategy to reduce all greenhouse gases 20% by the year 2005. The U.S. could be portrayed as stalling on greenhouse gas emissions reductions. In fact, actions that the U.S. is taking or planning to take are estimated to stabilize our net greenhouse gas emissions at 1987 levels by the year 2000, a significant reduction (approximately 20%) from previously anticipated levels.

An alternative declaration will be proposed by the U.S. delegation

To decrease the possibility of isolation, the U.S. has prepared an alternative draft Ministerial Declaration, which is shorter, less technical and more ministerial in tone. It will probably not be readily accepted in its entirety by SWCC participants. However, it should influence the discussions and could encourage support for the U.S. position by a number of countries uncomfortable with the current draft Ministerial Declaration. This is likely to result in greater leverage for our delegation and a compromise final declaration acceptable to the U.S..

THE WHITE HOUSE
WASHINGTON

October 5, 1990

MEMORANDUM FOR GOVERNOR SUNUNU

FROM: D. ALLAN BROMLEY *Duan*
EDE HOLIDAY
SUBJECT: Global Change Strategy Task Force Meeting

The Global Change Strategy Task Force met on Wednesday, October 3. The State Department provided a debriefing on last week's preparatory meetings in Geneva on the framework convention negotiations and the Second World Climate Conference. In addition, the Department of Justice outlined the draft report of the Comprehensive/Incentives Task Force.

Framework Convention Negotiations: The United Nations Environment Programme and the World Meteorological Organization held a September 24-26 preparatory meeting to consider organizational issues for the first negotiating session and the schedule for future negotiating sessions.

The meeting produced several consensus recommendations:

- o Negotiations will begin in Washington on February 4 and continue for nine working days. The lawyers will produce a first draft of a convention during the meeting, but actual negotiations will be deferred. Nine days are considered necessary for this process, which the U.S. should be able to influence.
- o No draft convention will be distributed prior to February. It is clear that governments, and not Mostafa Tolba, will control the negotiating process.
- o Decisions on the convention will be made by consensus, effectively giving all parties a veto.
- o There will be a single negotiating forum, avoiding the prospect of the convention being renegotiated by the U.N. General Assembly. (LDCs will move this Fall to have the convention actually negotiated by the General Assembly; as this would likely doom chances of having a convention ready for signature at the June 1992 U.N. environment conference in Brazil, little support is anticipated.)

0 No agreement was reached on the timing of the negotiation of protocols, although it appears the prevailing sentiment is to work toward a simple, pure framework convention for 1992.

0 The IPCC First Assessment Report and supporting documents, including its legal measures paper, will serve as the primary documents for the negotiations. Political declarations such as those signed at Noordwijk and Bergen, will merely provide non-binding background information. The IPCC will provide "objective scientific and technical advice" to the negotiating process, with its exact role to be decided in February.

0 After the first session, most meetings will be held in Geneva, with at least one meeting in Nairobi. Meetings should be no longer than two weeks and will be held at three month intervals (May, August, and November 1991, with additional meetings in 1992.)

0 Non-governmental organizations (NGOs) with a "substantive interest" will be allowed to attend the negotiations as observers, but will be excluded from certain sessions.

A full list of recommendations from the meeting can be found at Tab A. A proposed agenda for the February Washington meeting can be found a Tab B.

Second World Climate Conference: State and Commerce led the U.S. delegation to the September 27-29 preparatory meeting. The draft ministerial declaration was considered and almost all of the language bracketed, which will make it difficult to produce a final declaration. State will propose an alternative draft declaration that is much shorter and more "ministerial" in tone and defers the substantive issues to the negotiations. Norway proposed a similar, though more political, draft in Geneva that was rejected, but State believes that its version may receive a warmer reception. The draft, a copy of which can be found at Tab C, is undergoing interagency review.

Thatcher, Mitterand and Kohl have tentatively accepted invitations to address the ministerial portion of the conference. Mulroney is considering going, but may defer to the U.S. lead. State sent a cable last week indicating that Dr. John Knauss will represent the U.S. at the ministerial.

Comprehensive/Incentives Task Force Report: Dick Stewart from Justice briefed on the draft "Interim Report: Research and Analysis to Support the Comprehensive and Incentives Approaches" (found at Tab D). The report discusses the correlation of the economic incentives approach and the comprehensive global change index based approach. The scope of the report is confined to issues of "how to" rather than "how much." Stewart also obtained approval for a set of priorities to accomplish the support work necessary to implement this approach (found at Tab E).

THE WHITE HOUSE

WASHINGTON

October 24, 1990

MEMORANDUM FOR GOVERNOR SUNUNU

FROM: D. ALLAN BROMLEY

SUBJECT: Global Change Strategy Task Force Meeting

October 29 to November 7 in Geneva

The Global Change Strategy Task Force met on Tuesday, October 23, 1990 to review the negotiation strategy on the Ministerial Declaration for the Second World Climate Conference (SWCC) and discuss preparations for framework convention negotiations.

Second World Climate Conference:

Heads of state from some European countries are expected to attend the SWCC. Although Thatcher and Kohl have accepted the invitation, they may reconsider and confirmation of their attendance will likely be delayed until days before the Conference. Mitterand has withdrawn an earlier acceptance of the invitation and may send his environmental minister. Heads of African, Asian and Latin-American countries are not expected to be in attendance. Press stories are anticipated from this conference portraying the U.S. as stalling on greenhouse gas emissions reductions. However, the U.S. delegation plans to hold firm on important policy issues and a compromise may be reached that is acceptable to the U.S.. Preparations for the SWCC include:

(1) Development of an alternative draft Ministerial Declaration.

The draft Ministerial Declaration prepared at the Geneva Preparatory Committee meeting last month is lengthy and contains much controversial, bracketed language. As a result, it may be difficult for the participants to agree on final declaration language. The Department of State sent a wire to all diplomatic posts last week expressing the U.S. concerns with the Geneva draft and suggesting that an alternative could be produced reflecting sentiments held by all ministers (Tab A).

To address U.S. concerns, and counter the possible introduction of other documents containing even more difficult language, an alternative draft declaration has been prepared consistent with U.S. positions on key issues. Interagency review produced a final version, which was approved at Tuesday's meeting. That document is written in standard ministerial language and tone to increase its chances of acceptance and to minimize the number of non-substantive changes (Tab B).

The draft U.S. alternative will probably not be readily accepted in its entirety by SWCC participants. However, it will influence the discussions and could encourage support for the U.S. position by a number of countries uncomfortable with the current draft Ministerial Declaration produced in Geneva.

(2) Priority U.S. policy issues.

As you know, the Strategy Group had previously outlined the U.S. position on the five most important issues in the SWCC draft Ministerial Declaration to insure clear guidance for the U.S. delegation as well as cleared language for substitution wherever necessary. A copy of the five major issues, along with a summary of the U.S. government positions and approved language are attached (Tab C).

(3) Opening Statement for Dr. John Knauss

A draft opening statement by Dr. John Knauss for the SWCC was distributed prior to the meeting and, with a few changes, approved by the Task Force. (Tab D)

Framework Convention on Climate Change:

The U.S. will host the first negotiating session (February 4, 1991) in Washington, sponsored by the United Nations Environmental Programme and World Meteorological Organization. Preparations for the framework convention are underway in an interagency State Department group coordinated through the Strategy Task Force. A list of major products needed for the negotiations in February will be forthcoming at the next interagency meeting.

Other Business:

An informational briefing on the Japanese climate change strategy report was presented by the Department of State. This report outlines the Japanese strategy for achieving stabilization of CO₂ at 1987 levels for the year 2000 and thereafter. It is being interpreted as a major new policy statement. An October 24th Washington Post article indicated that this policy statement left the U.S. as one of the few developed countries not to commit to greenhouse gas emissions reduction targets.

The Japanese strategy involves two targets: one based on current energy technology, and the other based on new energy technology. Emissions are measured on a per capita basis and are allowed to increase with population growth, thereby eliminating the difficulty of achieving stabilization due to population increases. These and other qualifications make it a clever political statement with little substance upon which to conclude that the Japanese could actually achieve firm reductions.

Recommendation:

The draft declaration (Attachment B) and the opening statement (Attachment D) are strongly supported by the Global Change Strategy Task Force. Unless there are objections, we will instruct U.S. delegations to proceed with the strategy outlined above.

October 25, 1990

MEMORANDUM FOR THE PRESIDENT

FROM: D. Allan Bromley
Ede Holiday

SUBJECT: The Second World Climate Conference

This will provide additional information on the Second World Climate Conference (SWCC).

Significance of the Second World Climate Conference

The SWCC is one of many international conferences held in the past two years to address the issues surrounding global climate change. These conferences have served to heighten the visibility of the issues, for political positioning, and to encourage scientific and economic inquiry into climate phenomenon.

This meeting will review scientific information, including materials compiled through the Intergovernmental Panel on Climate Change (IPCC). The IPCC has been endorsed by the U.S. government as the appropriate channel to consider climate change scientific research, the effects of climate change and possible responses to these effects. However, a ministerial portion has been added at the end of this conference, giving a political tone to the meeting. As a result, there will be pressure to begin negotiations on greenhouse gas emissions reductions.

The meeting will be of interest to the press for a short time and the U.S. will probably be portrayed as stalling on greenhouse gas emissions reductions. However, this meeting will be overshadowed by the first negotiating session on climate change, which you agreed to host in February 1991 in Washington, D.C.

Japan will officially announce their strategy for stabilizing CO₂, a major greenhouse gas, at 1987 levels by the year 2000. Australia will also announce their strategy to stabilize.

Because the U.S. does not consider this to be the forum for substantive climate negotiations, Dr. John Knauss, Administrator of the National Oceanic and Atmospheric Administration, was selected to head the delegation to the Ministerial portion. European head of state are interested because the meeting is in Europe. Asian, African and Latin-American heads of state will not attend, but will send their environmental ministers.

The U.S. position for this meeting is to discuss the issues but preserve any negotiations for the February meeting in Washington.

Draft Ministerial Declaration

A draft Ministerial Declaration prepared for this meeting is highly controversial. The five major issues for the U.S. in the declaration, along with the U.S. positions, are:

- (1) **Targets and Timetables.** We should not commit to specific targets and timetables for reducing greenhouse gases. Instead, we should take actions that are justified for other reasons; and a "comprehensive" approach to greenhouse gas limits (considering all gases) should be taken.
- (2) **Content of a Convention.** The Ministerial declaration should not prejudice the negotiations which are to begin in Washington in February.
- (3) **Financial Assistance.** The U.S. will not commit to providing new and additional funding which increases the overall budget. The environment already has a higher priority in our bilateral and multilateral assistance funding. Existing resources and mechanisms must be fully utilized before new monies can be considered.
- (4) **Climate Change Science.** The declaration must be accurate in describing the scientific context and uncertainties associated with potential climate change.
- (5) **Precautionary Principle.** Lack of full scientific certainty is no excuse to postpone actions which are justified in their own right.

The U.S. may be isolated on this last issue. Other countries interpret this principle as urging immediate action for the prevention of environmental degradation, regardless of the extent of scientific uncertainty. The Soviet Union and Saudi Arabia may be our allies on this. Because most of the developed countries have proposed strategies for climate change, they will have no need to disagree with the precautionary principle.

Alternative Declaration to be Proposed by the U.S.

The U.S. has prepared an alternative draft ministerial declaration, which is shorter, less technical and more ministerial in tone. It will probably not be readily accepted in its entirety by SWCC participants. However, it will influence the discussions and could encourage support for the U.S. position by a number of countries uncomfortable with the current draft Ministerial Declaration.

**Central Issues
for the
FY 1992 U.S. Global Change Research Program**

1. **The NASA Budget Run-Out Issue:** The Critical Issue is to Develop a US/GCRP Budget Run-Out for the Total Program that Maintains the Integrity of the US/GCRP while Providing Agency Level Budget Run-Outs that fit within the Agreements that are being made in the Budget Summits. The Central Problem is Accommodating the NASA Component of the US/GCRP (i.e. Earth Probes and Eos).
2. **Several Technical and Program Questions:** Address the Program and Budget Questions Raised By OSTP and OMB. The Questions, a Draft Copy of which is Attached, are in Summary:
 - a. **NRC Report:** Several Questions on the Program and Eos that Arise out of the NRC Report.
 - b. **Management Strategy:** A Question About the Management Strategy for the US/GCRP.
 - c. **The ARM Program:** A Clarification Question About DOE's ARM Program and Eos.
 - d. **Relationship to the HCP Initiative:** A Question About the Relationship Between US/GCRP and the HPC Initiative.
 - e. **Several Questions on the Budget:** These Include; Constant Dollar Run-Outs for the Program, Differences Between OMB and CEES Envelopes, and Resolving the Differences Between CEES and Agency Submissions.
 - f. **Alternate Funding Levels:** A Request for an Analysis for an Option 2 AND 2+ Budget Scenario

Command?

Command? read 76

Posted: Fri, Oct 12, 1990 6:23 PM EDT
From: J.FELLOWS
To: r.corell
CC: j.fellows
Subj: CEES Qs

Msg: AGJA-4435-5837

BOB: Share these with your small group,
unless you feel we need another round. I
tried my best to accomodate your needs. Jack

U.S. Global Change Research Program

1. Please provide responses and proposed mechanism to address the issues highlighted in the bullets on pages 1-7 of the NRC FY 1991 USGCRP assessment report.
2. One of the NRC bullets recommends that a comprehensive observational strategy be developed. This comprehensive strategy should be extended to all aspects of the program. Please develop a comprehensive, integrated strategy for the USGCRP (i.e., the USGCRP management plan showing the programmatic and temporal dependencies of all the observation, process studies, and modeling efforts and how they focus on a common goal of an integrated Earth system model). We understand that such an effort has begun. We would like to make this a formal request for such a management strategy and develop a schedule for its completion.
3. What is the best way to characterize DOE's ARM to distinguish it from many of the data observations being made by NASA's EOS program?
4. Attached you will find a copy of the FY 1992 High Performance Computing notebook produced by the FCCSET/Physical, Mathematics, and Engineering Science Committee. Why aren't more USGCRP programs incorporated into the HPC effort (e.g., NASA's EOSDIS, DOE's CHAMMP, etc.)? The HPC effort states that it will provide timely computer hardware and software improvements for climate modeling. How is the USGCRP dependent on the HPC effort?
5. Please provide the graph, and associated data table, shown at the OMB-CEES budget hearing that shows the constant year dollar FY 91-96 run-out of the recommended option.
6. Please provide an explanation of why the funding level of the USGCRP FY 1992 budget options are higher than those requested in Robert Grady's 8/2/90 letter. In particular, why is the CEES FY 92 option 3 inconsistent with the OMB option 3 (the runout of the FY 1991 budget)?
7. Could the science community needs for Landsat data be satisfied with EOS data? If not, what are the issues? Could Landsat sensors replace HIRIS?
8. See attached Information on Alternative Funding Levels.
9. Please provide an explanation of the differences between the FY 1992 CEES Recommendation and Agency Request in the attached table. Information on Alternative Funding Levels

the recent budget agreement has made the budget environment even more uncertain. We were anticipating such a situation when we requested options 1 and 2. It seems improbable that we can spend over a billion dollars annually and not make meaningful progress in the research that supports our understanding of global change issues. The goals and pace may have to change, but we must have some lower, but still integrated funding options.

Thus, we would like the CEES to provide an analysis of what progress could be achieved, as well as the impacts, on the USGCRP goals, objectives, and related policy questions at FY 1992 funding levels of \$1,075 million (inflation only) and \$1,200 million (15 percent growth).

These funding levels, especially the outyears, are heavily dependent on EOS assumptions. Please don't just assume a years delay for EOS. Because many of the pressing policy questions are related to global warming and the NRC discussion on simultaneity requirements, we anticipate having to answer very difficult questions about why a smaller, EOS-precursor global warming mission or different EOS configuration couldn't be flown sooner. Thus, we must be prepared to answer the following questions and show they could be accommodated in the two funding levels discussed above.

Suppose a platform is flown (1) supporting only those instruments that need congruent measurement (e.g., AIRS, AMSU, CERES-IN, OSP, HIMSS, MISR, MODIS-N/T, HIRIS, and supporting instruments) or (2) just a EOS precursor system that satisfies global warming data needs:

Could we fly these instruments on an existing spacecraft? What foreign and domestic launch vehicles could launch such a spacecraft? How does such a spacecraft compare to what the Europeans and Japanese are developing? If they are comparable, could the three nations all use the same spacecraft and launch method? What flight options would be available for the remaining EOS instruments?

Is the climate satellite proposed in the attached Hansen article an effective EOS precursor global warming satellite?

ERBE, in particular, has been cited as being important in the first detection of global warming. What are our options for flying ERBE? Please do not limit ERBE alternatives to NASA approaches. Could ERBE fly on any existing NOAA, DOD, Private Sector, Foreign, etc? Do not omit a possible option because of policy or legal issues. If important, these barriers can be altered.

What changes would be made in the ground-based USGCRP to complement this new space-based approach?

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ction?

ommand? bye

This mail session is now complete.

Question 1. Please provide responses and proposed mechanism to address the issues highlighted in the bullets on pages 1-7 of the NRC FY 1991 USGCRP assessment report.

A. ASSESSMENT OF THE FY 1991 USGCRP

NRC: While the USGCRP includes observations, process studies and modeling, the FY 1991 program emphasizes observational programs because of the initiation of the Earth Observing System and Earth Probes series and the expense of space-based observing systems. The heavy emphasis on observations, necessary to initiate long-lead time, space-based capability, should be balanced as the program develops in the future by increased emphasis on process studies and modeling.

We concur with the Academy Panel's assessment of the need to continue to maintain an appropriate balance between the the long-term investments in synoptic-scale satellite observational programs and the associated ground-based observations, research, modelling/analytical, and information management efforts which will comprise an effective U.S. Global Change Research Program. We like the Academy Panel, believe that an early commitment to addressing the costs of a COMPREHENSIVE global observing system (EOS, Earth probes, operational satellites, and a complementary program of intensive, IN SITU measurements) is essential to the ultimate success of a Program whose goal is to provide a PREDICTIVE UNDERSTANDING OF THE (ENTIRE) EARTH SYSTEM. The CEES believes that the FY 1991 Program proposed by the President represented an appropriate first-step. A comprehensive Program requires a global-scale observing system and, as the Academy Panel points out, the costs of satellite-based platforms and instruments are high. Unless we intend to restructure and descope the USGCRP from the broad-based Program currently proposed, we simply must accept the costs associated with the synoptic-scale observations required.

The CEES program development and review process will ensure a continuous commitment to a well-balanced Program. The CEES recommended Program for FY 1992-1996 builds on the EOS-based strategy adopted by the President in FY 1991 and, therefore, continues to reflect the outyear costs of a primarily space-based observational program. To complement this observing program, the CEES recommendation includes significant increases in USGCRP process studies, ling, and information management. Since the comprehensive, global observing program was considered to have been addressed satisfactorily in FY 1991, the CEES was able to focus our FY 1992 planning and program development efforts on high-priority proposals in the area of Earth system modelling and research into key Earth systems as recommended by the Academy Panel.

NRC: The program would benefit from a better definition of the required national Earth system modeling capability and a workable plan for interpreting and delivering the results in forms useful to policymakers. These omissions should be addressed soon if the program is to meet its announced objectives.

We agree with the need for a more sharply-focused and aggressive programmoThe CEES recommended program for FY 1992 reflects our commitment to such a program by identifying Earth system modelling, primarily focuse climate system, as an overarching integrating theme for the next five years. The FY 1992 recommendation reflects the results of considerable scientific deliberations and program development discussions both within the CEES and with the Academy's Committee on Global Change.

USGCRP documentation, inclalproject descriptions, continue to highlight the need to implement an effective, broad-based, interagency approach to developing a national Earth system modelling capability. In fact, the NOAA Modelling and Analytical Centers initiative, combined

with the DOE modelling initiative are specifically c as the first steps in the evolution of an integrated CEES approach to the problem.

Until recently, detailed advice from the scientific community to define and support the development of agency initiatives in Earth system modelling has been lacking. In fact, the Modelling Chapter of the still unpublished report of the Ademmittee on Global Change represents the first comprehensive attempt at a comprehensive strategy statement on the part of the global change research community.

Even in the absence of such comprehensive guidance, CEES agencies have supported scientific planning meetings on the subject of climate and Earth system modelling and resulting initiatives like the NOAA Modelling and Analytical Centers project represent significant contributions to the evolving national and international effort.

NRC: The USGCRP is organized around seven scientific priorities. We conclude that the ranking of science priorities is consistent with the goals of the program and the consensus of the scientific community involved in global change research. The program would be strengthened if the science element focused on the study of how human activities influence and are influenced by global change ("human interactions") were better defined and more adequately funded. Priorities within the USGCRP must be kept flexible so that the program can remain responsive to research findings and unanticipated needs.

The CEES concurs with the Panel's assessment of the need to further define an effective scientific program in the area of Human Interactions. The FY 1991 proposal for the USGCRP reflected the limited level of scientific planning in the area of a "Human Interactions" element of global change research that existed at the time that agencies began to develop FY 1991 initiatives. CEES Working Group representatives have been working closely over the past year with members of the Academy Committee on Global Change to more clearly delineate a research strategy in this important area; the results of that interaction are reflected in both the Academy Committee's most recent submission to IGBP and in the CEES FY 1992 Recommended Program where the Human Interactions element receives more than a doubling of available resources. We, like the Academy Committl Change, believe that this science element should continue to receive considerable scientific planning and program development attention in the future and we believe that the current cooperation between the CEES and the Committee on Global Change provides an appropriate mechanism to provide that attention.

The CEES agrees wholeheartedly that the USGCRP must remain responsive to new scientific insights and unanticipated needs. By adopting the comprehensive (inclusive) research strategy embodied in the current USGCRP, the CEES believes we have developed a Program which allows the gratest flexibility in the national response to environmental problems. We concur with the Academy's sense that there is considerable risk in the alternative, reduced approach which directs Earth system research exclusively toward today's perceived policy problems; to do so fls to anticipate tomorrow's unforeseen problems. The programmatic priorities adopted by the CEES in any given year will always be evolutionary. In fact, how those priorities change in response to new insights and future scientific/technological developments will, itself, be a measure of the success of the Program. The FY 1992 CEES recommendation demonstrates how effective the CEES process can be at maintaining a strong, broad-based research Program while focusing FY 1992 efforts on addressing the highest-priority needs identified by the scientific consensus process embodied in the IPCC.

NRC: The collaboration among agencies involved in the USGCRP has thus far been exemplary regarding definition and planning at the program level. The CEES has been an effective

mechanism for this collaboration. The next challenge is to extend the collaborative approach to the specific activities of projects at the level of the Task Groups that now define activities or projects at the level of the Task Groups that now define activities within the science elements of the program. An ideal would be a "zero-based" project definition within each science element to discourage the re-labeling of prior agency initiatives only peripherally related to the goals of the program.

The identification of Integrating Themes for the USGCRP as part of the FY 1992 budget development process has helped the CEES Working Group take steps to develop a more effective program development and management approach for the USGCRP. Task Group reviews of agency proposals in light of their contributions to the highest priority USGCRP scientific needs provided a more advanced level of programmatic focus and refinement than was possible in FY 1991. Task Groups DID look at both ongoing and proposed activities related to both the identified Integrating Themes and the research priorities identified in each of Program's science elements and have agreed to continue this programmatic evaluation throughout the coming year. The Working Group is committed to adopting a management strategy for the USGCRP which allows for routine and periodic evaluation of key elements of the Program, the identification of gaps, and the provision of specific recommendations to address those gaps either through new enhancements or programmatic redirection.

NRC: USGCRP planning documents distinguish between "focused" (i.e., central) and "contributing" (i.e., supportive) programs. The focused elements do not represent the entirety of the required research, and many contributing programs and complementary activities in the President's budget must also be sustained if the program is to succeed. These contributing programs should be identified in a consistent manner.

The CEES agrees with the need to more clearly and consistently define the nature and value of "Contributing" programs which agencies began for other purposes but which clearly support the overall goal and objectives of the U.S. Global Change Research Program. CEES has already begun effort to re-evaluate and re-define, where necessary and appropriate, the specific agency programs and projects included as either "Focused" or "Contributing" elements of the U.S. Global Change Research Program. Initial results of this effort, in fact, will be reflected in the FY 1991 Research Plan to be released shortly. This effort is part of CEES' evolving plans for USGCRP program management, evaluation and review.

NRC: International collaboration on global change is required both to secure data on a global scale and to share human and financial resources. Cooperation with developing countries in global change research should be strengthened to ensure their involvement. U.S. support for international efforts, including an appropriate share of the support of program and project offices, should be made an explicit element of annual budgets.

Explicit funding for high-priority projects within the World Climate Research Program (e.g., WOCE, TOGA, GEWEX) and core projects of the IGBP like IGAC and JGOFS, and Past Global Changes IS provided in a number of agency contributions to the FY 1991 USGCRP--particularly those of NSF, NASA, and NOAA and continued support for such projects remains high for the CEES in FY 1992. For many agencies, support for an individual project includes explicit identification of resources to support national and/or international program/project offices (e.g., NOAA's support for the national and international TOGA project offices and evolving plans for multi-agency support of an international GEWEX project office to be housed at NASA). Agencies include explicit support for national and international scientific planning/coordination offices like the IGBP Secretariat in Stockholm in their annual budget requests.

Similarly, programs like the Tropical Ocean-Global Atmosphere Program include explicit partnerships with other nations, including developing nations, often implemented through bilateral or multilateral agreements. In addition, plans for global-scale observing efforts like NASA's EOS and Earth Probes programs include consideration of related efforts on the part of other countries and international research programs like those of the WCRP.

Established LINKAGES to interagency, other national INTERNATIONAL programs is used as an explicit project evaluation criteria during the CEES program development process.

*[CORELL: NEED A SENTENCE OR TWO OR THREE ON THE STATE OF OUR INTERNATIONAL FUNDING AGENCY EFFORTS]

NRC: The role of the scientific community outside the participating agencies in providing for independent scientific review of the overall program should be more clearly defined, including the role of the NRC, and mechanisms for carrying out the reviews should be established.

We concur with the need for continuous, objective scientific review of the USGCRP. Many CEES agencies have already established scientific advisory and/or review panels to provide specific guidance on their individual contributions to UGCRP. In terms of the overall Program, we have always assumed that the Academy, primarily through its Committee on Global Change (CGC), would continue to serve as a focal point for such review and look forward to working with the CGC and the NRC leadership to establish appropriate mechanisms for regular scientific evaluation of the Program.

NRC: The USGCRP must strengthen the involvement and support of the academic research community, preferably through explicit programs of extramural support in each of the agencies, to meet the long-term need for new scientists and technicians in the program and to ensure the participation of an adequate base of research scientists.

CEES recognizes that an strong USGCRP must be based on a effective partnership between scientists both inside the Federal Government and in the broad academic research community. That partnership must reflect the unique talents and special capabilities of each party as well as the identifiednsibility of each participating agency.

In some cases, a given Agency's role in the USGCRP may be most appropriately implemented through in-house capabilities while in others the support of extramural researchers will dominate. While the specific mix of in-house vs extramural research may differ across agencies, the CEES reom a USGCRP that effectively entrains the broad scientific community.

CEES agrees with the Panel's assessment that the distribution of fundinhouse and extramural efforts should be more explicitly addressed/described in future Program descriptions and plans.

CEES strongly agrees with the need to actively promote the developmenof additional human/intellectual resources to support the USGCRP and the FY 1991 Program includes initial investments on two major global change education initiaeso address this need. These resources will be supplemented in succeeding years and education is expected to continue to be a high-priority for the CEES and the USGCRP.

The CEES Working Group on Global Change has established a Task Group on Education charged with addressing this important aspect of the USGCRP in close collaboration with the Academy'sitteon Global Change.

NRC: Agencies with the programs in the "focused" category (e.g., those programs included in the budget whose goals are regarded by CEES as central to the USGCRP) should be guided by extramural advisory panels to ensure appropriate focus and flexibility.

The CEES agrees with the need to ensure the continuous involvement of the entire community in the development of specific agency contributions to the USGCRP. In fact, the CEES Evaluation Criteria related to SCIENTIFIC ME requires that each proposed project must be the product of a documented scientific planning and review process.

The specific nature of that scientific planning and review process will vary depending on the specific nature of a given Agency's role in the USGCRP. Many agencies, including NOAA and NASA, for example, have chosen to establish standing advisory panels for their focused program contributions to the USGCRP. The NSF Science Board has served in a similar capacity for the Foundation. Other agencies, like DOE and DOI, for example, have chosen ad hoc review panels at key points in program development. While the CEES has an obligation to ensure sufficient scientific planning and review of the Program as a whole, individual agencies should be given maximum flexibility in developing appropriate mechanisms to review their specific contributions.

B. THE EARTH OBSERVING SYSTEM IN THE CONTEXT OF THE USGCRP

NRC: EOS will not provide all the space-based measurements required for understanding global change and must be viewed in the context of other space-based measurement systems of both the US and other nations that will fly either before or during the proposed measurement period.

EOS scientific planning has considered the precursor missions planned by the US and other nations, as well as the plans of ESA and Japan for polar platforms. Missions such as UARS, TOPEX/POSEIDON, the European ERS-1, and the Japanese JERS-1 will make important contributions to the long term datasets needed for global change research. In addition, the international constellation of operational polar orbiting and geostationary meteorological satellites (NOAA, GOES, METEOSAT, GMS, and INSAT) are essential for defining the state of the global atmosphere at times not viewed from the EOS platforms. The Earth Probes will help insure continuity in critical measurements such as ozone (TOMS), and serve to implement new capabilities for measuring precipitation in the tropics (TRMM), and wind stress at the oceans surface (NSCATT).

NRC: Documenting global change will require both space-based and in situ measurements in the atmosphere, on the surface of the earth, and on and in the oceans. There is yet no comprehensive observational strategy that relates the US measurement program to international efforts, both space-based and in situ.

While there is no comprehensive national or international strategy yet to fully study the Earth as integrated system, strategies do exist, and await funds for implementation, of many facets of the Earth system. There are carefully formulated strategies for studying the atmosphere, oceans, and atmosphere-ocean interactions. However, comparable plans do not exist to study the terrestrial system or land-atmosphere interactions. This situation exists partly due to the differences in maturity levels of the many scientific disciplines involved in the USGCRP. For the physical climate elements of the program NASA has been an active participant, along with NOAA and NSF, in planning and implementing the major research elements of the World Climate Research

Program. Ongoing projects such as the Tropical Ocean Global Atmosphere (TOGA) and World Ocean Circulation Experiment (WOCE) exemplify the approach to combining satellite and in situ data in understanding the complex processes which control the Earth's climate system. The newly emerging Global Energy and Water Cycle Experiment (GEWEX), planned for the next decade, will coincide with the launch of EOS and is dependant on its successful deployment. GEWEX will provide much of the needed in situ data for validation of EOS remote sensing data products. For the biogeochemical dynamics elements of the program projects such as the Joint Global Ocean Flux Study (JGOFS) are also well formulated and await the launch of a satellite ocean color sensor (SeaWiFS) before the global aspects of the study can be implemented. A similar situation exists for progress to be made in studies of tropospheric chemistry, i.e, an integrated program of ground and space observations requires an enhancement of funds and a commitment to fly satellite sensors.

NRC: Certain sets of data should be collected simultaneously, e.g., the role of clouds in climate and the fluxes of trace gases in biogeochemical cycles. We are not aware of similar arguments for other scientific objectives of the USGCRP that demand the breadth of simultaneity.

The simultaneity argument has driven the process for selecting instruments to be flown on the EOS-A series. There is no doubt that the core instrument payload for EOS-A (HIRIS, ITIR, MISR, MIMR, MODIS-N/T, STIKSCAT, AIRS/AMSU, CERES, and EOSP) needs to be flown on a single platform, either because the instruments provide complementary scientific data or the data from one instrument is needed to correct the data from another instrument. The approach proposed for EOS-B has been primarily driven by cost and schedule considerations.

NRC: For the two high priority areas described above, we concluded that the number of instruments that must fly together requires at least one large satellite. Dividing the proposed instruments among several smaller satellites, although technically feasible, still requires a launch vehicle larger than the Delta rocket.

NASA agrees and are examining alternative measurement strategies for EOS-B, maintaining essential instrument groupings.

NRC: EOS plans call for a 15-year record of observations using a series of identical satellites, each with a 5-year lifetime, for each set of measurements. It seems likely that scientific understanding and technical capabilities will change during the course of the EOS program. Although NASA is designing the instruments and spacecraft to have common interfaces for interchangeability, the program contains no process that would enable it to evolve to new scientific understanding, concepts, or technology as they emerge during the life of the EOS program.

The suite of long-term measurements planned for EOS are essential to understanding the myriad of key physical, chemical, and biological processes involved in global change. A 15-year spatially and temporally consistent record is important for separating natural from man induced changes. These basic measurement requirements are not expected to change drastically during the the EOS timeframe. The Earth Probe family of satellites provides the flexibility to respond to new scientific issues as they arise.

NRC: Scientific arguments for simultaneity in terms of the other USGCRP research objectives of the second proposed satellite series, EOS-B, have not been developed by NASA; it currently appears that that these objectives could also be achieved with a number of smaller independant satellites. NASA's assessment of comparative costs suggests thhat flying the projected EOS-B

instruments on a large spacecraft is the least expensive option. In principle, the science investigations proposed for EOS-B could be done by a suite of smaller satellites. Since a number of the instruments do not require extensive development, these could perhaps be launched sooner.

NASA agrees and is studying the EOS-B payload options. Earlier launch considerations would be dictated primarily by budget constraints.

NRC: Prior to the launch of EOS in 1998 significant opportunities exist for gathering key global change data through a number of US and foreign research and operational satellites (e.g., UARS, TOPEX/POSEIDON, ERS-1, Earth Probes). A gap is noted in the critical area of earth radiation budget. In some cases the precursor missions are prerequisites, not substitutes for the EOS measurements. If budget constraints arise, it would be more desirable to delay the launch of EOS rather than to forego or diminish the effectiveness of the near-term missions.

NASA agrees that the precursor missions are critical to the USGCRP. While there is no doubt that Earth radiation budget data is very important it should be recognized that it is only one aspect of the climate change (global warming) issue. It should be noted that the French/Soviet SCARAB project will begin collecting data in late 1991 to help bridge the gap in measurements of the Earth radiation budget. Further, NASA is studying the possibility of adding a CERES instrument to the Tropical Rainfall Measurement Mission (TRMM) satellite for launch in 1996/1997 timeframe, and is being investigated for consideration for JPOP should JPOP be moved to a non-polar orbit.

NRC: The continuity and reliability of data used to monitor global change as it occurs are particularly important. NASA needs a more thorough contingency plan in the event of failures. Considering the potential long-term drift in instruments, it is clear that the issue of calibration warrants continuing attention.

NASA has identified three instruments as being of critical importance to the program (MODIS-N, CERES, and AMSU). For MODIS-N, consideration will be given to equipping EOS-B with a copy; the instrument RFP will reflect this contingency. CERES has been approved for flight aboard the European EPOC and as an attached payload to the Space Station, and is being investigated for consideration for JPOP should JPOP be moved to a non-polar orbit. AMSU will fly on EOS-A for simultaneity reasons but will also fly on the NOAA operational satellite. With respect to calibration, NASA recognizes the criticality of this issue. Therefore, each flight instrument will have a calibration plan which describes the methodology to be employed in establishing a clear record of instrument performance and documents any changes in its characteristics.

NRC: The preeminent challenge to global change research is the synthesis of diverse types of information from many different sources. The EOSDIS will be a pioneering effort in this regard: the intended scope of the system far exceeds that of any existing civilian data management system.

NASA agrees; as an example, this is one important reason why the information management functions of EOSDIS, which must provide EOSDIS users with a coherent view of the many kinds of data and information involved, will be implemented in a progressive, evolutionary manner, with continuous input and feedback from users. Such a capability can not be defined a priori, and must evolve as lessons are learned from experience with early versions.

NRC: Investing in the early development of EOSDIS is appropriate and necessary for the long-term success of the program. Investment does not guarantee success. While relevant experience for developing EOSDIS exists, no operational paradigm for the management and dissemination of such large scientific datasets currently exists.

NASA agrees; early investment in EOSDIS and early deployment of initial versions of EOSDIS that can be used and tested long before EOS-A launch is essential if NASA, with the advice of its user community, is to succeed. Work on the first version of EOSDIS, based on drawing together existing systems and including initial prototyping and standards development and testing, has begun in FY90 and will accelerate in FY91. This in-house effort will feed directly into the contracted EOSDIS development and implementation as soon as an EOSDIS contract has been awarded.

NRC: EOSDIS is planned as and must be an evolving entity. NASA should not attempt to define the total system specifications of EOSDIS at the onset and then assume that they will not be altered throughout the remainder of the program.

NASA agrees. EOSDIS will be implemented in a progressive, evolutionary manner, which will allow for continuous and interactive user participation, and ongoing review, allowing the requirements, specifications, and design of EOSDIS to be changed based on user experience and reaction to early versions of system elements. EOSDIS will be implemented as a series of progressively more capable versions, beginning as soon as possible, with major upgrades prior to the launch of EOS-A and EOS-B, and continuing for the full life of the EOS mission. NASA views this approach as absolutely essential; a priori definition of specifications for EOSDIS is not possible. NASA will begin with a set of specifications as a starting point for the progressive, evolutionary process outlined briefly above.

NRC: EOSDIS should include and accomodate more than just data from EOS sensors to meet the needs of the USGCRP. The agencies involved in data collection and dissemination - NASA, NOAA, NSF, and USGS - have a special responsibility to work together and with the international community to assure that all relevant data and information are available to EOSDIS for global change research.

NASA agrees. NASA plans to involve other agencies in the EOSDIS effort to ensure that all relevant data and information are available to global change researchers. NASA has working agreements with NOAA and USGS regarding long term roles with the EOS program, and plans to establish NOAA and other agency data centers as EOSDIS Affiliated Data Centers linked into EOSDIS so that their data is readily available. NASA is working with NOAA and other agencies on Pathfinder Data Set efforts to ensure that data sets that are essential for global change research are identified, put into a readily accessible form, and that new long term derived products needed for global change research are produced and made available through early versions of EOSDIS.

NRC: The management of very large data bases with provisions for browsing and other capabilities should be viewed as a research issue. Current understanding of how to meet the challenge is not mature. A program of research and prototyping is needed to guide the evolution of the proposed data management capabilities.

NASA plans to offer user access to precomputed browse products as an EOSDIS service. NASA agrees regarding dynamic or interactive browse; plans for EOSDIS include prototyping efforts in interactive browse and related capabilities, and migration of successful prototypes to the working EOSDIS environment once they have proven their usefulness and practicality to the user

community and NASA. EOSDIS will be designed to accomodate addition of interactive browse capabilities that result from prototyping.

NRC: We welcome NASA's policies regarding access to EOSDIS data products which are aimed at making them equally available tio all users and researchers at nominal costs of reporduction and delivery. Means should be found to include Landsat data in EOSDIS.

NASA working with USGS, will, to the fullest extent permitted by current law, facilitate access by researchers to Landsat data.

NRC: Because the implementation of EOSDIS poses significant continuing challanges, EOSDIS should have an ongoing mechanism for acquiring independant advise from the user community. The EOS Investigators' Science Advisory Panel for EOSDIS should be continued and should be augmented to include some scientists who are not EOS investigators, but who are active in fields within the range of scientific disciplines involved in global change research. as well as in research on data and information management.

NASA will continue the EOS Investigators' Science Advisory Panel, and will ensure that it is representative of the full earth science community as well as the EOS investigators. In addition, each of the EOSDIS Distributed Active Archive Centers will form its own science advisory panel to provide advice on each center's activities as well as to provide, in coordination with the overall group, advice on EOSDIS as a whole. NASA regards continuing and strengthening mechanisms for securing science advice on EOSDIS as essential.

Question 2: One of the NRS bullets recommends that a comprehensive observational strategy.....

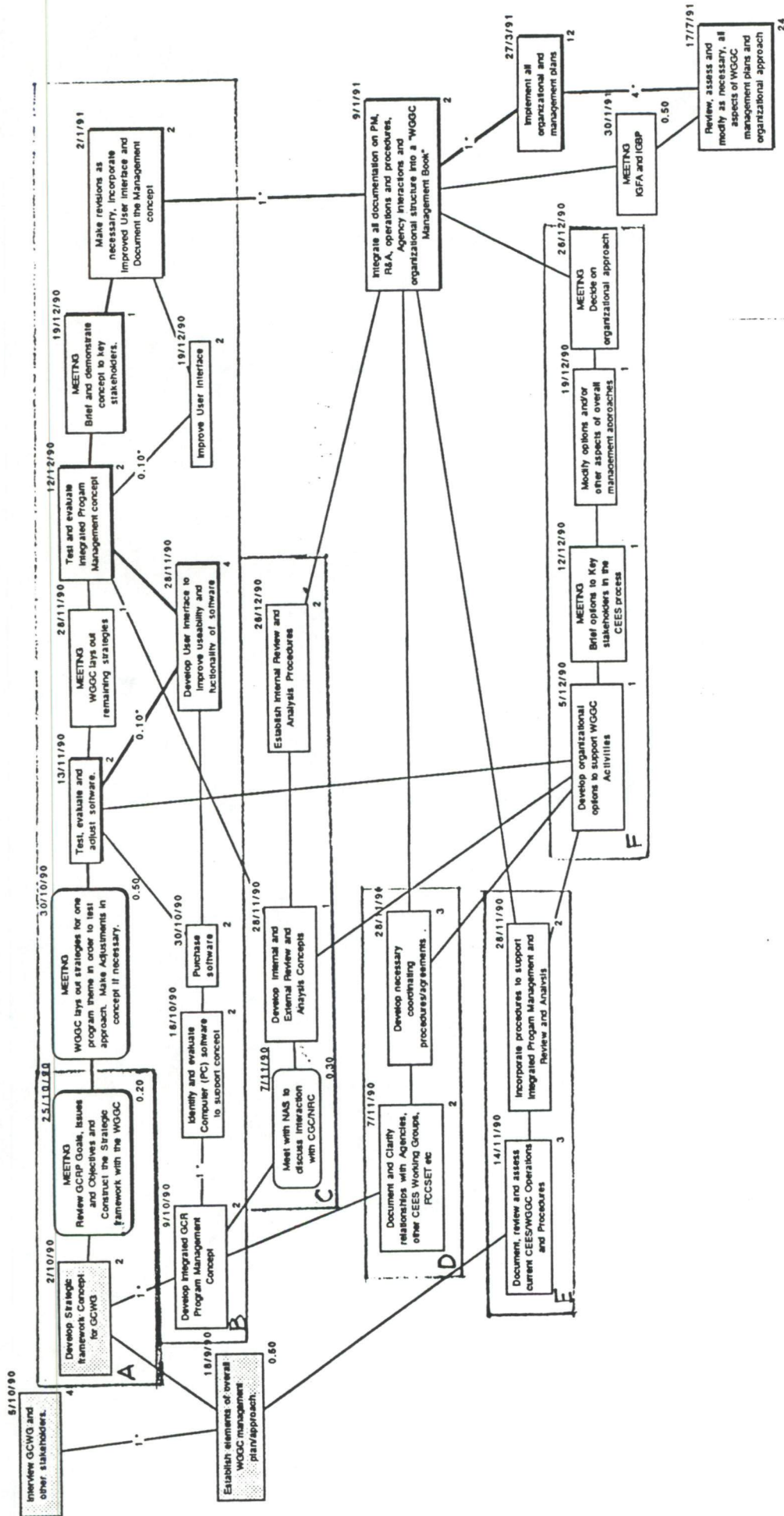
The CEES/WGGC is moving aggressively to develop a management approach for the USGCRP. The WG staff has recently been augmented to enable more efficient coordination of the interagency planning and implementation and has dedicated an individual to developing a USGCRP management plan by the end of the year (see attached schedule).

The complete management plan would involve not only the internal (domestic, within the CEES/CGC structure) management of the USGCRP, but also the external (international, in concert with CGC, ie., the U.S. National IGBP committee, ICSU's IGBP-WCRP efforts, and intergovernmental efforts, eg., IPCC, etc.) coordination to ensure that the USGCRP is a truly focussed, efficiently managed research effort. In addition, the CEES has taken a leadership role in establishing the IGFA (International Group of Funding Agencies for Global Change) group to coordinate the funding of the international global change research effort. The evolving plan of the management of the USGCRP would taken into account all above facets and be ready for implementation by February 1991.

The proposed elements of a GCWG Management plan/approach are:

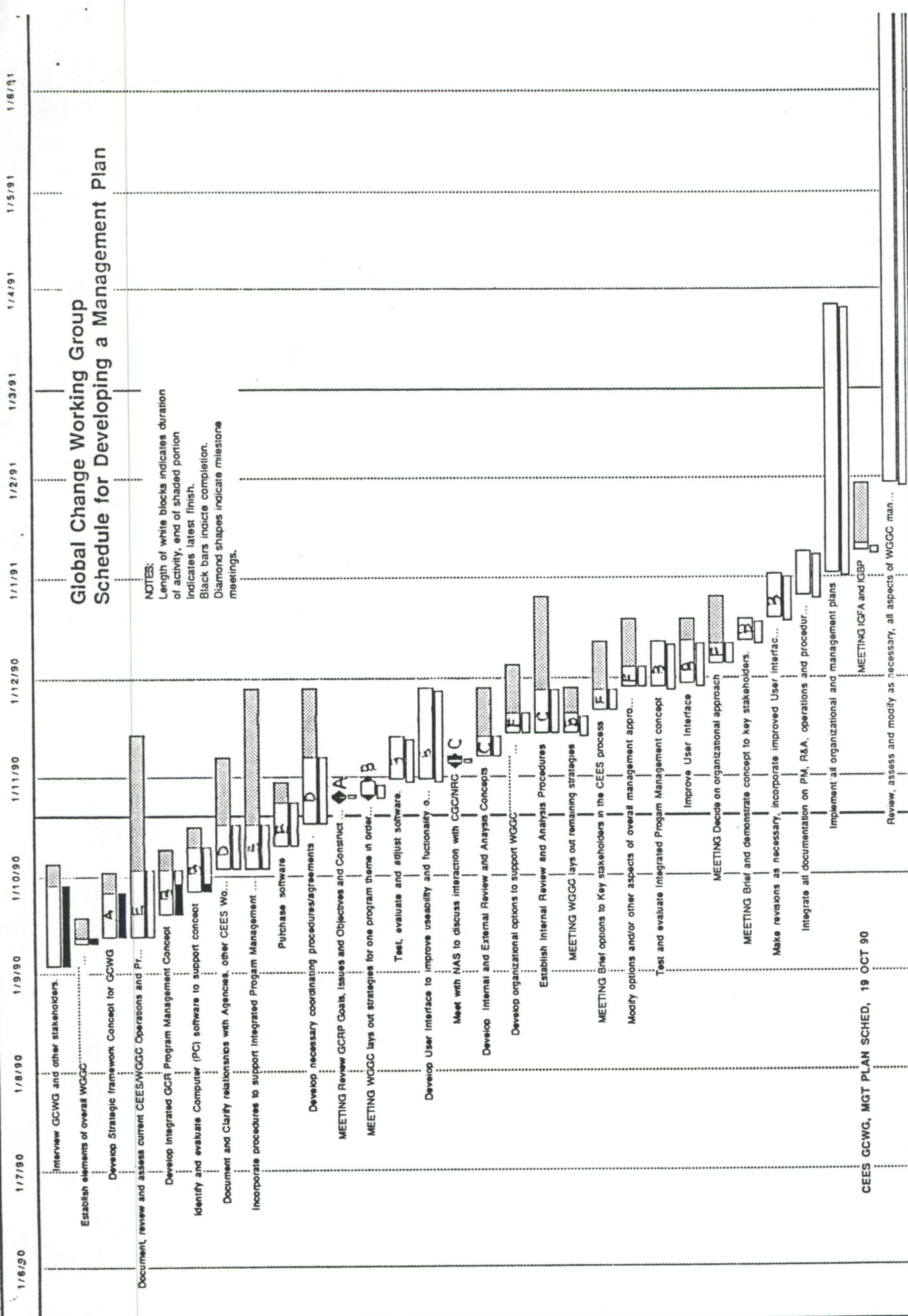
1. Strategic framework
A strategic frame work showing the programmatic and temporal dependencies ie., the USGCRP goal/vision, research issues and meta research questions (objectives). The prototype will use the integrating themes (issues) to define the objectives and to construct the research program.
2. Integrated Program Management
The integrated program is the research that constitutes the strategies by which the objectives are reached. The integrated program shows the dependances and/or linkages between the research projects and the strategic objectives. This management model gives the Working Group and the Agencies a tool to focus review, analysis, discussion and decision making on the key science and programmatic issues in the most efficient way possible.
3. Review and analysis, internal/external
Describes how and by whom programmatic and science review, evaluation and progress is undertaken and how it is reported.
4. Agency Interactions
Describes the necessary coordination procedures and agreements between agencies, other CEES working groups, FCCSET, etc. This also includes international and intergovernmental coordination.
5. CEES/GCWG operations and procedures
Describes the internal CEES/WGGC operations, procedures and logistics required to support such activities as preparing budget submissions, coordinating interagency participation in the development of research strategies, and other activities driven by program management.
6. Organizational construct
Describes the organizational strategies, roles and responsibilities within CEES/WGGC, the participating agencies and others required to support all of the activities described above.

Global Change Working Group Schedule for Developing a Management Plan



- A. Strategic framework
- B. Integrated Program Management
- C. Review and analysis, internal/external
- D. Agency roles and interactions
- E. CEES/WOGC operations and procedures
- F. Organization construct to support activities

Notes: Dates shown are late finish dates.
Durations are in weeks.
Shaded activities are complete



Global Change Working Group Schedule for Developing a Management Plan

NOTES:
Length of white blocks indicates duration of activity, end of shaded portion indicates latest finish.
Black bars indicate completion.
Diamond shapes indicate milestone meetings.

Question 3: ARM/EOS

DOE's ARM Program was designed as a stand-alone, ground-based program to quantitatively describe the radiation balance from the surface of the Earth to the top of the atmosphere and to determine the atmospheric characteristics responsible for this balance, including the formation and evolution of clouds. The focus of the research is the acquisition of high quality radiation measurements in the atmospheric column and the atmospheric characteristics responsible for the radiative balance in order to improve the parameterization of general circulation models used for climate prediction. Current predictions of climate change due to an enhanced greenhouse effect have a large uncertainty due to the unknown effects of cloud feedbacks on the Earth's radiation balance.

ARM would be complemented by space-based measurements (as space-based truthing of the ground-based measurements) but it is not dependent on such measurements. Such space-based measurements could be provided by instruments planned for EOS-A, some of the meteorological satellites proposed by NOAA, and existing satellites flown by the Soviet Union and France. Depending on the launch schedule for EOS-A, ARM may not overlap with EOS.

Ultimately, the understanding of cloud-radiation effects and successful model parameterization of cloud-climate feedback processes for GCMs requires accurate global observations of the three-dimensional cloud fields including essential parameters such as cloud amounts, top and base heights, optical depths, effective particle size, and phase along with observations of the radiation and meteorological variables. Such detailed information will only be possible with a very comprehensive, satellite-based program such as the Earth Observing System (EOS). To make progress in the time period leading to EOS, various agencies have embarked on field programs to advance methods of describing clouds in climate models. The First ISCCP Regional Experiment (FIRE) is an on-going field program designed to promote the development of improved cloud and radiation parameterizations for use in climate models, and to provide for assessment and improvement of International Satellite Cloud Climatology Project (ISCCP) data products. FIRE is a NASA-lead, multi-agency effort with support from NASA, NSF, ONR, DOE, NOAA, USAF, and other elements of the DOD. Although FIRE is principally a U. S. national project, it benefits from important contributions from scientists from the United Kingdom and France. The strategy of FIRE has been to combine modeling activities with satellite, airborne, and surface observations to study two types of climatically important cloud systems: cirrus and marine stratocumulus through intensive, regional field observations. The first five years of FIRE have included highly successful intensive field observational periods for both cloud systems and has yielded significant progress toward its objectives. Based on results of Phase I, FIRE is now moving into Phase II which focuses on the formation, maintenance, and dissipation of both cloud systems and includes observations necessary to include large-scale modeling results in the analyses. The emphasis in FIRE is on approximately one-month long intensive field observations, but does include limited studies over many years (5 years or more) and extended regions (approximately 1000km) with satellite observations.

The evolving DOE Atmospheric Radiation Measurement (ARM) Program has an overall objective of providing an experimental testbed for the study of important atmospheric effects, particularly cloud and radiation processes for use in atmospheric models. The ARM Program seeks to supplement on-going cloud climatology and satellite cloud-radiation projects by contributing critical data and analyses from an intensive ground-based measurement and modeling program. The strategy of ARM is to conduct long-term (approximately 10 years) ground-based measurements at a few (1-6) sites that are carefully chosen based on their climatological significance. Each site would include a central hub where an extensive array of advanced instrumentation would be located and an outlying network of less specialized instrumentation which can operate in an autonomous mode. At the central hub, instrumentation would include advanced lidar, radar, high resolution spectrometers, and significant calibration and support

facilities. To enhance these more specialized measurements, the ARM program includes advanced instrument development in addition to the observational and modeling segments.

Thus, the FIRE and ARM programs are complementary with each providing key observations and analyses for improving the understanding of cloud-climate processes and for validating satellite cloud data products. FIRE provides relatively short duration and intensive regional processes studies with sampling through the atmospheric column for two critical cloud types. Whereas, ARM will concentrate on localized and intensive observation at the ground to provide climatological observations covering all cloud types at a given location.

Question 4: Attached you will find a copy of the FY 1992 High Performance Computing notebook ...

Some parts of the High Performance Computing Initiative (HPCI) are relevant to the Global Change Research Program. However, the Global Change Research Program is not dependent for its success upon HPCI. As with other potential technology development or acceleration programs, if the HPCI is successful it will enhance the capability of the science community to carry out the Global Change Research Program (GCRP) especially its modeling aspects.

Within the HPCI there is an effort to accelerate the pace of supercomputer development. Under normal levels of government and private sector development, super computers have been increasing in effective processing speed by about a factor of three every roughly three years. HPCI aims to produce growth in computer speed of a factor in the range of one hundred to one thousand in five years and to make this increase in hardware capability readily accessible to users through the development of appropriate software techniques. The GCRP can accomplish its mission within the constraints of the normal pace of super computer improvement, but it would clearly exploit faster increases in computing power by moving to finer model resolution and the inclusion of more phenomena in models sooner than would otherwise be possible.

The useful element within HPCI for Global Change Research is the development of the National Research and Education Network (NREN). GCRP requires effective electronic networking of the participating US scientists. Ties to equivalent science networks in other countries is also needed. If NREN is put in place it can serve this need for the GCRP. If NREN is not put in place or the effort focuses on technology development rather than implementation, GCRP agencies will have to provide effective networking for the subset of the community that is involved in GCRP. While providing this networking is a key element within the infrastructure required by the GCRP it is just a small part of EOSDIS and other new and on-going agency programs that comprise the US GCRP.

Question 6: Please provide an explanation of why the funding level of the USGCRP FY 1992 budget options are higher than those requested in Robert Grady's 8/2/90 letter. In particular, why is the CEES FY 92 option 3 inconsistent with the OMB option 3 (the run-out of the FY 1991 budget)?

In the June 2, 1990 letter from Robert Grady, Associate Director natural Resources, Energy, and Science OMB, to Dallas Peck, Chairman of the Committee on Earth and Environmental Sciences, five budget options were developed for analysis by the CEES. These budget options provided by OMB are outlined as follows:

(Dollars in Millions)

	1990	1991	1992	1993	1994	1995	1996
1	659	1,034	931	931	931	931	931
2	659	1,034	1,034	1,237	1,453	1,664	1,666
3	659	1,034	1,358	2,257	2,675	2,800	2,800
4	659	1,034	1,402	2,442	2,886	3,065	3,065
5	659	1,034	1,726	2,770	3,270	3,452	3,600

- 1 10% cut from FY 1991 PB
- 2 Freeze (EarthProbes/Ground Based Enhancement, no EOS)
- 3 FY 1991 President's Budget
- 4 FY 1991 Option 3
- 5 Full FY 1992 Request

The CEES report of the President's FY 1991 budget, Option 3, is inconsistent with that option as provided by the OMB. The CEES Options for FY 1990-1996 are as follows:

CEES Budget Options

(Dollars in Millions)

	1990	1991	1992	1993	1994	1995	1996
1							
2							
3	659	1,035	1,391	2,316	2,758	2,904	3,033
4	659	1,035	1,469	2,534	3,017	3,240	3,378
5	659	1,035	1,623	2,821	3,317	3,529	3,695
6	659	1,035	1,606	2,786	3,260	3,464	3,628

- 1
- 2
- 3 FY 1991 President's Budget
- 4 FY 1991 Option 3
- 5 Full FY 1992 Request
- 6 CEES Recommended Program

Discrepancies between the budget options provided by OMB and those provided by the CEES may be explained as follows:

(Dollars in Millions)

	1991	1992	1993	1994	1995	1996	
Total Discrepancy +	1.0	33.0	59.0		83.0	104.0	233.0
Smithsonian ++	5.5	8.8	13.2		14.1	15.1	15.9
Dept. of Defense ++		6.3	6.6		6.8	7.1	7.4
EPA *	-4.1	-3.2	-2.4		-1.5	-0.7	-0.1
DOE **	-0.1	14.1	26.9		42.7	50.0	47.9
Allowance for Inflation (DOC,DOI,USDA; NASA FY95,96)		7.4	14.7		21.4	32.2	161.7
Total Delta	1.3	33.4	59.0		83.5	103.7	232.8

- + Discrepancy between OMB Budget Option 3 and CEES Budget Option 3. The "Total Delta" refers to the delta between the OMB and CEES Option 3 totals that is accounted for in the above explanation.
- ++ The FY 91-96 USGCRP base provided the CEES did not include Focused research conducted by the Smithsonian Institution and the Department of Defense, both new participants in the USGCRP.
- * EPA states that their USGCRP budget included programs focused on mitigation and adaptation research that have been removed from USGCRP and placed in the MARS program. Discussion between EPA and OMB continue regarding this redirection.
- ** DOE -- Following post budget review of the ARM and CHAMMP Programs a decision was made to adjust the amount of base funding to include these Programs.

7. Could the science community needs for Landsat data be satisfied with EOS data? If not, what are the issues? Could Landsat sensors replace HIRIS?

No. EOS will provide data that are complementary to, but not substitutes for, the data provided by Landsat. The Landsat observing capability provides the only data that cover a broad spectral range throughout the visible, near infra-red, and thermal infra-red bands at the appropriate spatial resolution (30 - 80 meters) required to continuously monitor the Earth's surface.

Landsat data are complementary to data to be returned from the NASA EOS polar platform sensors. The primary EOS land-observing sensors are the pointable High Resolution Imaging Spectrometer (HIRIS), the Thermal Infrared Radiometer (ITIR), and the Moderate Resolution Imaging Spectrometers (MODIS-N and -T). HIRIS and ITIR will acquire relatively narrow field of view, hyperspectral, high spatial resolution data, and MODIS will acquire moderate spatial resolution, wide field of view data. No EOS sensors will return data similar in characteristics to Landsat, i.e., high spatial resolution, broad spectral bands, and wide-area coverage.

Landsat, data will also be needed to develop, test, and validate EOS data processing algorithms prior to and after the launch of EOS.

The EOS was conceived and designed assuming the continuation of Landsat data. Since terrestrial vegetation undergoes observable changes during the day, Landsat makes its observations in the morning at a time when cloud cover is at a minimum. EOS is intended to fly in the early afternoon to observe terrestrial revealing the potential for ecosystem change due to such stress. Therefore, the HIRIS and its Japanese-provided companion instrument, ITIR, have been designed for EOS as highly flexible research tools to study local processes at specific sites around the globe while the Landsat TM serves as a survey instrument for global monitoring.

Specifically, Landsat has a 185-km swath width, fixed nadir viewing, six channels for reflected sunlight and one channel for thermal emission, and provides mapping of the global surface every 16 days, limited only by atmospheric conditions such as cloud cover. HIRIS will have a 24-km swath, both along-track and cross-track pointing, and 192 spectral bands for reflected sunlight. These characteristics are intended to enable detection of small shifts in ecosystem boundaries, the study of inland lakes and estuaries, and the examination of processes in vegetation. ITIR provides complementary capabilities for thermal emission measurements with five channels.

On EOS, the frequent global survey of coarse resolution vegetation conditions will be provided by the MODIS which will provide global coverage every 1 to 2 days but at 500-1000 m resolution. As with the data from NOAA's advanced Very High Resolution MODIS will enable greatly improve observations of the of land vegetation at finer temporal resolution than TM but without the ability to distinguish the spatial detail associated with agricultural practices. The afternoon measurements of MODIS on EOS will be complemented by the morning observations of the Medium Resolution Imaging Spectrometer (MERIS) flying on the European Space Agency platform.

HIRIS is designed to provide a major increase in our ability to remotely sense biological processes and geological properties of the Earth's surface. Neither Landsat, SPOT, nor ITIR are capable of replacing HIRIS either individually or collectively. HIRIS is a spectrometer while all previous high resolution sensors are radiometers working at a few selected spectral bands.

Question 8: Information on Alternative Funding Levels:

The answer to this question has several components: (A) general comments regarding the USGCRP and the overall scientific and political consequences of options 2 and 2+; (B) the CEES recommendations for options 2 and 2+; and (C) implementation of EOS.

A. General comments:

The U.S. Global Change Research Program is driven by carefully-established priorities associated with the key scientific questions that must be addressed to establish sound national and international policies related to global environmental issues, particularly global climate change. The Program was developed as a Government-wide, integrated research effort and was established in cooperation with the U.S. and international scientific communities. In particular, the USGCRP responded to an evolving scientific paradigm referred to as "Earth System Science." The foundation of Earth System Science is the belief that sound scientific information on global change must be derived from a comprehensive, integrated view of the interactions among key components of the Earth system. In particular, the highest priority information is whether, and to what extent, changes in the global climate system justify significant energy and environmental policy changes. Such a predictive understanding requires an enhanced capability to document, understand and anticipate natural and human-induced variability in the Earth's climate system, particularly on timescales of years to decades. In this context, CEES relied on the information needs delineated by the IPCC Scientific (Working Group 1) and Impacts (Working Group 2) Assessments. Specifically, the CEES adopted an FY 1992-1996 USGCRP Budget Strategy designed to:

(I) Enhance scientific research efforts, such as the World Climate Research Program and the International Geosphere-Biosphere Programme, that seek to reduce the following scientific uncertainties identified by the IPCC:

1. sources and sinks of greenhouse gases, which affect predictions of future concentrations;
2. clouds and radiative balance, which strongly influence the magnitude of climate change at global and regional scales;
3. oceans, which influence the timing and patterns of climate change;
4. land-surface hydrology, which affects regional climate change and water availability;
5. polar ice-sheets, which affect predictions of global sea level changes; and
6. ecological dynamics, which are impacted by and respond to climate change; and

(II) Enhance scientific research to support the development and implementation of a comprehensive approach for greenhouse gas emissions reductions (e.g., sources, sinks and behavior of greenhouse gases).

To address these questions, CEES has adopted a program strategy that focuses agency contributions on five FY 1992-1996 Integrating Themes: (i) Climate Modelling and Prediction; (ii) the Global Water and Energy Cycles; (iii) the Global Carbon Cycle; (iv) Ecological Systems and Population Dynamics; and (v) Sea Level Change. Regardless of funding levels, the USGCRP must apply its resources towards improving (as rapidly as possible) our ability to improve future predictive assessments of climate change in support of policy deliberations.

The level of funding available under Options 2 and 2 1/2 raises first-order questions about the nature of the scientific approach to the problem. The scientific program embodied in the current Presidential initiative assumes a comprehensive, inclusive approach to documenting, understanding and predicting Earth System change and its regional implications on a global scale. The salient feature of the EOS-based research strategy is its comprehensive global observing system: the combination of NASA EOS instruments, operational satellite missions, and the program of intensive IN SITU measurements provided by other CEES agencies. This critical characteristic of

the currently-approved Program allows the research strategy to be directed toward a "predictive understanding of the (entire) Earth system." There is considerable risk in a reduced approach which directs Earth system research exclusively toward today's perceived policy problems; to do so fails to anticipate tomorrow's unforeseen problems. The CEES and the Nation met this challenge by proposing an inclusive (comprehensive) research strategy to allow the greatest flexibility in the national response to environmental problems.

In particular, the Program strategy was consciously designed to more effectively integrate and focus scientific projects which have traditionally been developed and implemented on a more piecemeal basis--pursuing an understanding of individual Earth System problems in discrete projects where scientific and program integration is more a function of coincidence or personality than design. Such an "incisive", approach, aimed at elucidating a single hypothesis, will certainly improve our understanding of the Earth system (as it has in the past) but it does not allow for the comprehensive documentation of change on a global scale nor is it likely to produce timely and significant improvements in our understanding of the key system interactions which drive changes in the Earth's climate system. Certainly, good science can be done but not the highly-focused, integrated global change research program promised by the Presidential initiative. By adopting the strategy reflected in the President's FY1991 proposal, CEES and the Administration rejected the piecemeal approach because the associated risk is too great.

At the heart of distinguishing between these two approaches to the problem is the NASA Earth Observing System (EOS) program. With a comprehensive observing system based on an EOS approach, the U.S. can pursue the fully integrated, broadly-based USGCRP currently supported by the President. Without EOS, the U.S. must formally revise our approach to the problem to a more traditional, piecemeal scientific attack on individual elements of the Earth's climate system. Given current international commitments, such a decision should be made now; additional delay will only continue to raise expectations and put the Administration in an even-more dangerous political position.

With or without EOS, there are considerable risks associated with an Administration decision to pursue a funding profile for the U.S. Global Change Research that falls below at least Option 4 of the CEES Recommendation. These risks include:

- o The President has publicized and taken great pride in an aggressive, comprehensive U.S. Global Change Research Program as the centerpiece of his response to the issues raised by real and anticipated changes in the global environment; a reversal of that position will place the President and the United States in a difficult (if not untenable) negotiating position during upcoming "framework convention" and related policy deliberations;
- o The U.S. position to pursue a comprehensive emissions tradeoff option is only viable with a strong, comprehensive research program that provides a predictive understanding of not only the sources, sinks and behavior of key greenhouse gases but of the interactive Earth system processes that will determine the response of the Earth's climate system to changes in the concentrations of those gases;
- o The current comprehensive program demonstrates the Administration's commitment to address the scientific, technologic and public policy issues associated with global environmental change; this commitment is the principal mechanism available to forestall potentially costly or unnecessary action and provide a strong, scientific foundation for future legislative and regulatory actions;
- o Foreign governments and the national and international scientific communities have applauded U.S. leadership in global change research and many international commitments to support complementary observational (e.g., satellites), data exchange, research, and modelling

activities are based on the anticipation of the strong U.S. support implied by the President's announcement of the USGCRP. If the U.S. reduces its commitment to a significant enhancement in its research effort, it is likely that other countries will as well, in particular the Europeans and Japanese would most likely re-examine their polar platform programs;

- o The CEES recommended Program of \$1.6 billion in FY 1992 actually represents a small investment when compared to the multi-billion, and perhaps trillion, dollar decisions associated with the major changes in U.S. and international energy policy implied by current international negotiations;

- o Severe reductions in planned USGCRP efforts, particularly those associated with new satellite programs like EOS, eliminate a prime opportunity for the U.S. to regain the competitive edge in science and technology by eliminating an incentive for U.S. industry to invest in the development and application of state-of-the-art technologies--an incentive which currently encourages innovation and promises to strengthen the U.S. scientific and technological infrastructure;

- o Limiting U.S. global change research to a narrowly-defined effort designed to predict only whether and how the Earth's physical climate system will change, carries significant societal, economic, public policy and national security risks; doing so means not only failing to anticipate and mitigate the impacts of such change, but, perhaps more importantly, failing to anticipate tomorrow's unforeseen environmental and natural resource problems;

- o Reversing the current position of support for an aggressive and well-funded USGCRP would severely threaten the ability of the Administration to maintain leadership on this issue in Congressional negotiations;

- o Adopting a USGCRP funding profile below Option 4 is a significant reversal of the much-publicized Administration commitment to: (i) the run-out budget for the approved new start for the NASA Mission to Planet Earth program (EOS is a major component of Mission to Planet Earth), and (ii) growth within the Geosciences division within NSF (as part of the Government's commitment to double that Agency's budget).

B. CEES Recommendations for Options 2 and 2+:

Funding Levels:

The two funding levels considered for FY 92 for the USGCRP are \$1075 million (option 2) and \$1200 million (option 2+). These numbers should be compared to: (i) \$1034 million (FY 91), (ii) \$1358 million (option 3); (iii) \$1402 million (option 4); and (iv) \$1606 million (CEES recommended level). Option 2 represents a \$41 million increase over FY 91 (inflation), while option 2+ represents a \$166 million increase over FY 91.

While options 2 and 2+ do not allow the CEES USGCRP to proceed in a timely fashion with a comprehensive Earth Sciences program that will form the basis for informed policy formulation, they do allow for an enhanced understanding of certain aspects of the Earth system. The following discussion outlines what can be achieved with these levels of funding and what cannot.

Background Information:

The IPCC identified six high priority areas of research that need to be studied in order to reduce the scientific uncertainties associated with climate change (global warming). The following list links the high priority research areas with the CEES integrating themes:

- | | | |
|----|--|---|
| 1. | Sources and sinks of greenhouse gases: | Global carbon cycle |
| 2. | Clouds and radiative balance: | Global water and energy cycles |
| 3. | Oceans: | Global water and energy cycles |
| 4. | Land-surface hydrology: | Global water and energy cycles |
| 5. | Polar ice sheets: | Global water and energy cycles; Sea level change, and |
| 6. | Ecological dynamics: | Ecological systems and population dynamics. |

CEES carefully considered the IPCC report in formulating its FY 92 program, i.e. the CEES focussed its attention on an improved understanding of climate change (global warming), not all Earth science issues (e.g., stratospheric ozone depletion, loss of biodiversity). CEES also proposed an overarching integrating theme of climate modeling and prediction, consistent with the recommendation of the IPCC. *The key point to note is that the CEES recommended FY 92 augmentations and new initiatives are focussed on the climate change (global warming) issue.*

The CEES also considered the need to enhance the scientific research needed to support the development and implementation of a comprehensive approach for greenhouse gas emissions reductions.

Strategy for Options 2 and 2+:

a. Allocation between Space-based and non-space-based research:

For simplicity, we will equate the space-based program with NASA, although it should be recognized that about 24% (\$158.4 million) of the NASA program in FY 91 is non-space-based research, and we will equate the non-space-based research with the other agencies (DOC/NOAA, DOE, DOI, EPA, NSF, and USDA). While option 2 is viewed as a budget increase to deal with inflation, the CEES does not recommend allocating the increase in proportion to the size of the FY 91 agency budgets. The CEES recommends that: (a) under option 2 NASA is allocated \$21 million (in contrast to a pro-rated inflation increase of \$26.2 million), while the other agencies are allocated \$20 million (in contrast to a prorated inflation increase of \$14.8 million), and (b) under option 2+ NASA is allocated \$83 million, while the other other agencies are allocated \$83 million. These augmentations should be compared to the CEES recommended augmentation levels of \$264.6 million for NASA, and \$233.9 million for the other agencies (reflects the current DOI position).

b. Summary of budget allocation for options 2 and 2+ by agency and by integrating theme:

BUDGET BY AGENCY

Agency	FY 91	FY 92 Delta Option 2	FY 92 Delta Option 2+	FY 92 Delta Option 6
DOC/NOAA	87.0	11.0	31.3	89.9
DOE	65.9	2.0	12.1	16.2
DOI	43.7	0.0	2.4	2.4*
EPA	21.9	0.0	6.0	20.1

NASA	661.0	21.0	83.0	264.6
NSF	102.8	7.0	27.7	83.5
USDA	47.5	0.0	3.5	12.2
TOTAL	1035.0	41.0	166.0	498.5*
DOD#	0.0	n/a	n/a	6.3
SMITH#.	5.5	n/a	n/a	3.3

* Reflects DOI's current position regarding no augmentations or new initiatives.

DOD and the Smithsonian were not part of the FY 91 CEES budget process, therefore CEES believes that OMB must decide how to deal with their requested FY 92 budgets. It should be noted that the Smithsonian budget requests are primarily aimed at aspects of the global carbon cycle and the ecological systems and population dynamics, which CEES is not recommending augmentating at levels 2 and 2+.

BUDGET BY INTEGRATING THEME

non-space-based research*

Theme	FY 91	FY 92 Delta Option 2	FY 92 Delta Option 2+	FY 92 Delta Option 6
Climate modelling	34.0	20.0	22.4	26.7
Carbon cycle	102.2	0.0	27.8	81.3
Water and energy	135.6	0.0	32.8	108.6
Ecological systems	77.5	0.0	0.0	56.1
Sea level	28.0	0.0	0.0	27.7

* These numbers do not include the following FY 91 NASA ground-based research programs: Climate modelling--\$7.4 million; Carbon cycle--\$32.9 million; Water and energy --\$ 58.8 million; Ecological systems--\$2.9 million; Sea level--\$2.4 million;

c Non-spaced based component of USGCRP (does not include NASA's non-spaced programs):

Option 2:

There are two approaches that can be taken under option 2 with respect to the non-space based component of the USGCRP program. The first is to allocate the budget increase across the board. The second, and CEES recommended approach, is to allocate all of the increase to initiating the three requested climate modelling and prediction initiatives.

Climate modeling and prediction

**	DOE	CHAMMP	\$2.0 million
**	NOAA	Climate Modeling and Analysis	\$11.0 million
**	NSF	ICMAP	\$7.0 million
		sub-total	\$20.0 million

Option 2+:

There are two approaches that can be taken under option 2+ with respect to the non-space based component of the USGCRP program. The first is to delay the initiation of all new initiatives and enhance all requested FY 92 augmentations by about 15%. The second, and CEES recommended approach, is to target a number of specific programs for the full, or close to full, FY 92 requested level (augmentations and new initiatives), and to keep all other programs at their FY 91 levels. Clearly, all agencies will re-examine their base programs to ensure that the FY 92 funds are most efficiently utilized, hence there could be some internal redistribution of budget allocations among base programs. The critical question is which augmentations and new initiatives are given highest priority.

The CEES recommendations for option 2+ are presented within the structure of the five integrating themes. The CEES recommends the following combination of augmentations and new initiatives for option 2+ (\$86 million increase above FY 91):

Climate modeling and prediction

**	DOE	CHAMMP	\$2.1 million
**	NOAA	Climate Modeling and Analysis	\$12.8 million
**	NSF	ICMAP	\$7.5 million
sub-total			\$22.4 million

The CEES recommendation of \$22.4 million for augmentations and new initiatives under option 2+ builds upon a FY 91 base of \$34.0 million, and is 84% of the requested enhancement of \$26.7 million. Under option 2+ we recommend that are:

- * Three major new initiatives in climate modeling and prediction. These are essential for developing more reliable global and regional scale predictions of climate change.

Global carbon cycle

**	DOE	Ocean Research	\$2.0 million
**	NOAA	Ocean Circulation and Biogeochemistry	\$3.0 million
**	NSF	U.S. JGOFS	\$4.3 million
**	NSF	Global Tropospheric Chemistry	\$3.8 million
**	NOAA	Atmospheric Chemistry	\$3.8 million
**	EPA	Tropospheric Chemistry	\$0.2 million
**	EPA	terrestrial	\$5.8 million
**	DOI	terrestrial	\$1.4 million
**	USDA	terrestrial	\$3.5 million
sub-total			\$27.8 million

The CEES recommendation of \$27.8 million for augmentations and new initiatives under option 2+ builds upon a FY 91 base of \$102.2 million, but is only 34% of the requested enhancement of \$81.3 million. Under option 2+ we recommend that are:

- * Three key augmentations for studies of ocean carbon. These programs will improve our understanding of the role of the oceans in the uptake and release of carbon dioxide, and will provide critical data needed for the "U.S. Comprehensive Emissions and Trading Approach". In addition, these augmentations are critical for implementation of the U.S. contribution to JGOFS, and complement the NASA SeaWiFS program that will provide global observations of ocean color (primary productivity).
- * Two augmentations for tropospheric chemistry. These programs are needed to improve our understanding of tropospheric ozone and the lifetimes of key greenhouse gases such as methane. A key uncertainty identified by IPCC is the contribution of tropospheric ozone to changes in the radiative forcing of the atmosphere (i.e., global warming). This data is needed for the "U.S. Comprehensive Emissions and Trading Approach".
- * Three augmentations for terrestrial carbon studies. The role of the terrestrial biosphere in the sequestration of anthropogenic carbon is a critical issue identified by IPCC. These programs will provide an initial modest effort towards understanding the "missing carbon". Formulation and implementation of the "U.S. Comprehensive Emissions and Trading Approach" requires a significant improvement in our understanding of the terrestrial biosphere.
- * There are no augmentations in carbon cycle model development, or the human dimensions component of the global carbon cycle.

Global water and energy cycle

**	NOAA	TOGA	\$2.9 million
**	NSF	TOGA	\$3.5 million
**	NOAA	Ocean Circulation and Biogeochemical	\$4.2 million
**	NSF	WOCE	\$4.6 million
**	DOE	Atmospheric Radiation Measurements	\$8.0 million
**	NSF	Role of Clouds	\$1.5 million
**	NOAA	Clouds, Energy and Water Cycle	\$4.6 million
**	NSF	GEWEX	\$2.5 million
**	DOI	terrestrial	\$1.0 million
sub-total			\$32.8 million

The CEES recommendation of \$32.8 million for augmentations and new initiatives under option 2+ builds upon a FY 91 base of \$135.6 million, but is only 30% of the requested enhancement of \$108.6 million. Under option 2+ we recommend that are:

- * Two augmentations for TOGA. These augmentations are critical for the U.S. contribution to TOGA, which will lead to improvements in our understanding of the exchange of energy and chemicals between the atmosphere and the ocean.
- * Two augmentations for WOCE. These augmentations are critical for the U.S. contribution to WOCE, which will improve our understanding of ocean circulation.

- * Four augmentations for understanding the role of clouds in the climate system. Clouds are the single largest uncertainty associated with the prediction of global temperature change.
- * No augmentations or new initiatives for studying land-surface hydrological processes, which play a key role in the prediction of regional climate change, and in the management of water resources.
- * No augmentations or new initiatives for studying polar ice-sheets, which play a critical role regional climate and sea level change.
- * No augmentations or new initiatives for studying the human dimensions component of global change, which has been identified by NAS and this Administration as an area of research that must be enhanced.
- * No augmentations or new initiatives for paleo-climate studies, which are crucial for testing models and understanding natural variability.

Ecological systems and population dynamics

\$0

The CEES recommendation is no augmentations and new initiatives under option 2+. The FY 91 base is \$77.5 million, and the requested enhancement was \$56.1 million. Under option 2+ we recommend that are:

- * No augmentations or new initiatives for ecological systems and population dynamics studies. Current scientific uncertainties associated with these issues are unacceptably large, as noted by IPCC.

Sea level change

\$0

The CEES recommendation is no augmentations and new initiatives under option 2+. The FY 91 base is \$28.0 million, and is 79.1% of the requested enhancement of \$27.3 million. Under option 2+ we recommend that are:

- * No augmentations or new initiatives for studies of sea level change. Current scientific uncertainties associated with the role of polar ice sheets is large.

TOTAL

\$86.0 million

d. Space-based Component of USGCRP (includes NASA's non-spaced-based programs):

NASA is committed to a space-based program that is responsive to scientific and policy needs. Since the NAS review of the USGCRP and EOS, NASA has undertaken feasibility studies of different approaches to implement EOS B, and to fly CERES and SAGE earlier than EOS A (for Earth radiation budget studies). NASA and CEES believe that the currently planned EOS and Earth Probes programs are essential components of the scientific program required to provide the scientific information required for policy formulation with respect to key environmental issues. It should be noted that if EOS is descoped to focus soley on the climate change (global warming) issue it would still require the following instruments currently under consideration for EOS A (HIRIS; ITIR; MISR; MIMR; MODIS Nadir/Tilt; STIKSCAT; AIRS/AMSU; CERES; SAGE; EOSP; MOPPITT/TRACER, and HIRDLS), and the following instruments curently under

consideration for EOS B (ALT; TES; and GLRS). The only instruments that cannot be justified would be instruments devoted to stratospheric ozone (it should be noted that stratospheric ozone changes could affect tropospheric climate) and secondary science. This means that all of the currently planned EOS A instruments, and a significant portion of the EOS B instruments are needed for understanding climate change, i.e., the current EOS configuration is a global warming satellite. The following list tracks EOS instruments to the areas of scientific uncertainty identified by IPCC:

1. sources and sinks of greenhouse gases, which affect predictions of future concentrations--
AIRS/AMSU; HIRDLS; HIRIS; ITIR; MIMR; MODIS-N/T; MOPPITT/TRACER; SAGE; STIKSCAT; and TES;
2. clouds and radiative balance, which strongly influence the magnitude of climate change at global and regional scales--
ACRIM; AIRS/AMSU; CERES; EOSP; MIMR; MISR; and MODIS-N.
3. oceans, which influence the timing and patterns of climate change--
ALT; CERES; MIMR; MISR; MODIS-N/T; and STIKSCAT.
4. land-surface hydrology, which affects regional climate change and water availability--
HIRIS; ITIR; MIMR; MISR; and MODIS-N.
5. polar ice sheets, which affect predictions of global sea level changes--
ALT; GGI; and GLRS; and
6. ecological dynamics, which are impacted by and respond to climate change--
AIRS/AMSU; HIRIS; ITIR; MISR; and MODIS-N/T.

In FY 91 NASA allocated \$426 million for non-EOS programs, and \$235 million for EOS. NASA would continue its non-space-based, and satellite-related programs (UARS, TOPEX, Mission Operations and Data Analysis, etc.) initiated prior to FY 91 as recommended by CEES, and would augment its Earth Probes program as requested (\$25 million in FY 91 to \$68.3 million in FY 92) under options 2 and 2+. This would mean that NASA would allocate \$463.6 million to non-EOS programs, and \$218.4 million (option 2) or \$280.4 million (option 2+) for EOS (science plus platform) in FY 92 in contrast to \$235 million in FY 91 and the requested FY 92 level of \$462.0 million.

Program	FY 91	FY 92 option 2	FY 92 option 2+	FY 92 option 6
EOS	235.0	218.4	280.4	462.0
non-EOS	426.0	463.6	463.6	463.6
Total	661.0	682.0	744.0	925.6

The option 2 budget, inflated at 15% per year thereafter, would not allow EOS to be developed. Therefore, EOS would have to be discontinued and an augmented Earth Probes line would be developed that would address specific aspects of Earth sciences but would never allow a

comprehensive approach to be taken as advocated by IPCC, WCRP, or IGBP. At present it is unclear what additional Earth Probes would be flown.

If EOS were funded at the option 2 level in FY 92, and then the requested run-out profile starting in FY 93, then NASA would continue development of EOS at a minimum level in FY 92, and delay the launch of the EOS A and EOS B series by about one year.

If EOS were funded at the option 2+ level in FY 92, and then the requested run-out profile starting in FY 93, NASA would continue to develop EOSDIS and fund the scientific investigations at the planned rate, coupled with a continuation of EOS phase B instrument definition studies and platform development at a low level. This option would allow the EOSDIS to be completed in the currently planned timeframe in order to allow the scientific community to analyse and interpret existing data sets in a timely fashion. The launch of EOS would then be delayed by about one year. Without the EOS budget run-out profile EOS (even descope to only study climate change/global warming) would not be viable.

As stated earlier, EOS was given a new start in FY 91 with an approved run-out budget. Any funding level less than the CEES recommendation will be viewed by the national and international scientific and policy communities as a significant departure from President Bush's public position regarding his commitment to Mission to Planet Earth, and the need to reduce scientific and economic uncertainties associated with climate change prior to policy formulation. The budget required for full implementation for EOS should be viewed in context of the likely growth in the total NASA budget and that share allocated to OSSA, i.e., EOS implementation could largely be accommodated within the expected growth in these budgets.

e. Basis for CEES recommendation:

The CEES recommendation for option 2 (an enhancement of approximately \$41 million) would allow augmentation of NASA Earth Probes program, continuity in NASA's level of effort in non-space-based programs and ongoing satellite programs, but a cut-back in NASA's EOS program. The CEES recommendation would also allow initiation of three modelling initiatives, but no augmentations or new initiatives in any other non-space-based programs. This budget will not allow programs to be augmented or initiated that are required to reduce the key scientific uncertainties identified by IPCC in a timely manner.

The CEES recommendation for option 2+ (an increase above the FY 91 level of approximately \$86 million for non-space-based research and \$80 million for space-based research) would allow progress to be made in several key areas identified by IPCC, but not in others (remember CEES recommended that a comprehensive approach to reducing the key uncertainties associated with climate change (global warming) would require a budget enhancement between FY 91 and FY 92 of \$306.4 million for non-space-based research, and \$264.6 for space-based research). The recommended augmentations and new initiatives for option 2+ in the global carbon cycle and global water and energy cycle are primarily focussed on the atmosphere, oceans and ocean-atmosphere exchange, because these areas of research are more mature than those associated with the terrestrial biosphere and atmosphere-terrestrial biosphere exchange. The recommended efforts support U.S. contributions to key ongoing international programs (WOCE, TOGA, JGOFS, IGAC, and aspects of GEWEX) that have been endorsed by the IPCC as critical for reducing some of the key uncertainties associated with climate change. The non-space-based programs have also been selected because of synergism with NASA's precursor EOS space programs, i.e., TOPEX (contributes to WOCE), NSCAT (contributes to TOGA), SeaWiFS (contributes to JGOFS), TRMM (contributes to GEWEX), and the possible early flight of SAGE and CERES (feasibility studies to fly SAGE and CERES in conjunction with TRMM are underway), which will contribute to an improved understanding of clouds.

Clearly other programs could be supported under option 2+, but some of the currently recommended programs would have to be eliminated. The recommended program of no enhancements in impact studies and economics research is clearly unacceptable, but so would a program with no enhancements in the global carbon cycle or clouds.

C. EOS Implementation:

Question: Suppose a platform is flown (1) supporting only those instruments that need congruent measurement (e.g., AIRS, AMSU, CERES, EOSP, HIMSS, HIRIS, MISR, MODIS-N/T, and supporting instruments) or (2) just an EOS precursor system that satisfies global warming data needs:

- * Could we fly these instruments on an existing spacecraft? What foreign.....

As discussed earlier, there seems to be a misconception that a satellite to study climate change (global warming) is a sub-set of EOS A instruments. A satellite system to study global warming includes all EOS A instruments (i.e., those instruments which need congruent measurements (AIRS/AMSU; CERES; EOSP; HIRIS; MIMR (to replace HIMSS); MISR; MODIS nadir/Tilt; and STIKSCAT) plus HIRDLS; MOPPITT/TRACER; and SAGE), plus a sub-set of the EOS B instruments (ALT; GGI; GLRS; and TES) and LAWS. Understanding global warming also requires flight of CERES, SAGE, and the TRMM payload in a non-sun-synchronous orbit.

The set of instruments needing congruent measurements cannot be accommodated on any existing spacecraft. Of the six additional instruments needed to study global warming, only HIRDLS or SAGE can be accommodated on the EOS-A series platforms, so additional spacecraft are needed to accommodate ALT, TES, GLRS and LAWS. The flight of these other instruments would generally require a spacecraft size consistent with the launch capabilities of the Atlas II-AS. Such a spacecraft would be slightly smaller than the planned Japanese and European platforms. A satellite of this size could make use of some existing spacecraft subsystems and could use some of the modules of the EOS-A platform in principle. The Japanese H-II rocket and the European Ariane IV and V rockets are all at least as capable as the Atlas II-AS and could serve this purpose.

The overall international mix of instruments, and platforms or satellites needed to study global change (global warming) requires that one platform be developed which is capable of supporting the congruent measurement set (current EOS A). The remainder of the program requires additional platforms and satellites. At present, the ESA M series of platforms is targeted at flying a subset of the congruent measurements at a second time of day. This will provide a better sample of diurnal variations and meet operational requirements. The ESA N series might serve as a vehicle for an advanced SAR, but there is no consensus in Europe as to which complement of instruments should fly on this series. The international community is currently encouraging Japan to fly its platform in a 55 degree orbit (non-sun-synchronous) with a payload consisting of LAWS, CERES, and a follow-on to the TRMM mission. There is no indication abroad of any willingness to fund additional platforms. If the US were to decide to use foreign means of launch and satellites designed for these vehicle, it would presumably have to pay for them.

While it might seem reasonable to suppose that one international partner would focus on providing launch vehicles while another focused on the development of satellites, the aerospace industrial aspirations of the US, Japan and Europe are for a capability in both launchers and satellites. This makes it impractical for all three partners (ESA, Japan, NASA) to use the same launch vehicle or satellite.

- * Is the climate satellite proposed in the attached Hansen article an effective EOS precursor global warming satellite?

No! CLIMSAT only addresses a small, although important, part of the global warming issue, i.e., climate forcing, feedback and diagnostic processes associated with detecting the purely radiative consequences of enhanced greenhouse gas concentrations. It does not address most aspects of the climate change (global warming) issue identified by the IPCC, e.g., role of the oceans, greenhouse gases, land-surface hydrological processes, sea level change, etc. It will not establish cause and effect between greenhouse gas emissions and changes in the Earth's climate, either globally or regionally, let alone provide the information needed for the development and implementation of the comprehensive and emissions trading approach to greenhouse gas emissions.

The CLIMSAT concept incorporates three basic instruments (SAGE, EOSP, and ERBE), coupled with auxiliary data to be provided by either ground-based systems or operational satellites. It should first be noted that the complement of data provided by CLIMSAT is already available from prior flights of ERBE and SAGE, coupled together with ground-based and operational satellite data. Therefore, no new insights about the climate system and its feedbacks will be learned.

NASA agrees with Hansen that Earth radiation budget data are critical, therefore, NASA is currently examining the feasibility of placing CERES and SAGE instruments aboard the joint US/Japanese TRMM mission, which will be launched prior to EOS A in the 1996/1997 timeframe. The desirability of an early pre EOS A launch of the "experimental" EOSP is less clear and is being studied.

EOS is designed to address one of the key weakness identified by J. Hansen in our previous approach to Earth sciences, i.e., a program that does not provide continuity in critical data sets, including Earth radiation budget measurements. The pre-EOS NASA approach to Earth science was to design a single exploratory mission of limited duration with no, or limited follow-on plans (options 2 and 2+ would force NASA to return to this unacceptable mode of operation). EOS has been designed to provide a 15 year data set of the critical parameters required to address the broader issues of natural and human-induced climate change, and will, in conjunction with the ground-based component of the USGCRP, reduce the scientific uncertainties identified by IPCC.

- * ERBE, in particular, has been cited as being important in the first detection of global warming. What are...

While NASA agrees that ERBE data is important, it should be noted that no single instrument will detect "enhanced" global warming in a manner acceptable to policymakers that want to establish a cause and effect relationship between increases in the atmospheric concentrations of greenhouse gases and quantitative changes in the Earth's climate, globally and regionally.

NASA has discussed the possibility of flying an ERBE type instrument aboard NOAA, DOD and foreign satellites. Both NOAA and DOD have stated that there are no suitable opportunities pre EOS A.

With respect to opportunities to fly an ERBE type instrument aboard a foreign satellite, NASA is, as stated above, examining the feasibility of flying CERES with TRMM aboard a Japanese satellite in the 1996/1997 timeframe. NASA is also exploring the possibility of flying a CERES instrument aboard a German satellite, ATMOS, which should be launched in the

1995/1996 timeframe. There are also plans to fly a Soviet/French SCAROB instrument aboard two Meteor satellites in 1991. SCAROB should provide, if properly calibrated, data comparable to ERBE narrow field-of-view data.

- * What changes would be made in the ground-based USGCRP to complement this new space-based approach?

Until a decision is made with respect to the satellite program, it is impossible to speculate how the ground-based USGCRP would have to be modified. The current ground-based program has been designed to complement the planned satellite program, e.g., GEWEX has been designed assuming EOS, the European and Japanese polar platforms, and the operational satellite programs will be implemented as currently planned. Elimination of EOS will almost certainly affect the polar platforms programs of ESA and Japan, hence the goals of programs such as GEWEX could not be achieved.

Question 9: Please provide an explanation of the differences between the FY 1992 CEES recommendation and the agency request in the attached table?

Option 5, the Agency budget request to OMB for USGCRP, is not consistent with the Option 5 as reported by the CEES. The following table outlines these discrepancies:

(Dollars in Millions)					
FY 1992					
	FY 1991	OMB Plan	CEES Recommend	CEES Opt. 5	Agency Request
DOC/NOAA	87.0	87.0	176.9	183.7	176.9
DOD	0.0	0.0	6.3	6.3	6.3
DOE	66.0	68.0	82.1	82.1	67.4
DOI	43.7	44.0	118.7	126.1	46.4
EPA	26.0	26.0	42.0	2.0	43.4
NASA	661.0	939.6	925.6	925.6	925.6
NSF	103.0	146.0	186.3	188.3	186.3
SMITHSONIAN	0.0	0.0	8.8	8.8	8.0
USDA	47.4	47.0	59.7	59.7	59.7
TOTAL	1,034.1	1,357.6	1,606.0	1,623.0	1,520.0

The difference between the OMB Plan and the CEES Recommendation may be explained on a project by project basis through a review of materials contained in "Our Changing Planet: The FY 1992-1996 Budget Recommendations" a report prepared by the CEES and delivered to OMB on September 14, 1990.

The difference between the CEES "Recommendation" and the USGCRP budget requested by most agencies is quite similar. The reason for such close agreement is quite simply a reflection of the CEES review process and communication back to the agencies of actions taken through those deliberations.

The CEES review of proposals and development of budget recommendations for the USGCRP began in March 1990. At that time the CEES Working Group on Global Change in partnership with the agencies outlined the research priorities and began the development of special integrating themes that would be emphasized during the FY 1992-1996 budget period. During the late spring and early summer frequent meetings of the Working Group and its Task Forces further defined program needs for FY 92 and began preliminary reviews of proposals. By July 15, 1990 all agencies had submitted to the CEES proposals for USGCRP FY 1992-1996. Task Groups reviewed all USGCRP, both the base and augmentation, using the CEES Evaluation Criteria (p. 6 of CEES Budget Recommendation). A numerical rating, 0 (lowest)- 5 (highest) was assigned to each project based upon the review criteria. Of the # programs submitted to the CEES Task Groups for review, 23 of the proposals were rejected immediately because they were not focused on the goals and objectives of the USGCRP. Funding was considered for those programs receiving an average numeric rating of 2.5 or greater.

Initial budget decisions concerning project level funding was discussed individually with agency representatives during the week of August 6-10. Final CEES recommendations were delivered to the Agencies from the Working Group on August 17.

The August 17 date had been negotiated with the Agencies in order to ensure the Agencies adequate time to adjust their Agency budget requests to reflect the recommendation of the CEES.

The consistency between the CEES Recommendation and the Agency Requests for DOC, DOD, NASA, NSF, and USDA reflects the decision by these agencies to request only that amount for USGCRP that would be recommended for their Programs by the CEES.

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THE WHITE HOUSE

WASHINGTON

September 21, 1990

file

MEMORANDUM FOR D. ALLAN BROMLEY
DAVID DEMAREST
ROBERT GRADY
ROGER PORTER
RICHARD SCHMALENSEE

FROM: EDE HOLIDAY *[Signature]*

SUBJECT: Bill Reilly Speech to National Press Club

On September 26, Bill Reilly will address the National Press Club. His speech will focus on the Administration's environmental record, and more importantly will unveil the comparative risk study prepared by EPA's independent Science Advisory Board. The study emphasizes risk reduction in establishing priorities for environmental protection, and is expected to receive significant attention. Reilly will also mention EPA's upcoming report to Congress on Environmental Investments: The Cost of a Clean Environment.

A draft of Reilly's remarks is attached for your review. Please provide any comments you might have on the speech to Barry McBee of my staff (x2800 or by fax at x2223) by noon on Monday.

Attachment



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

2nd DRAFT
SEPT. 20, 1990

DRAFT

THE ADMINISTRATOR

AIMING BEFORE WE SHOOT:

THE "QUIET REVOLUTION" IN U.S. ENVIRONMENTAL POLICY

Address by

WILLIAM K. REILLY

Administrator

U.S. Environmental Protection Agency

THE NATIONAL PRESS CLUB

**Washington, DC
September 26, 1990**

DRAFT

As EPA approaches its 20th Anniversary, the whirlwind of environmental stock-taking that was fanned by the Earth Day celebration this past April has by no means abated. It used to be that when other national concerns arose -- energy or budgetary issues, for example -- the environment had to take a back seat. That is no longer the case; and that fact attests, I think, to the authenticity of the current environmental spirit.

Today I want to spend a few minutes reviewing our progress to date on the environmental front. And then I want to describe what I see as an urgent need for some new approaches -- some smarter, clearer ways of thinking and acting -- to deal with the problems that continue to confront us. In the process, I will be discussing an important new report, being released today, which makes a number of far-reaching suggestions for how we can begin moving toward those new approaches.

My intention today is to help stimulate and intensify a broad national dialogue on a fundamentally important question: How can our society most effectively use its resources to achieve the greatest possible benefits to human health and to the planet that sustains us? The answers to the environmental policy questions we pose today will help to determine just how green the next decade will be.

Keeping Our Promises: A Report Card

Of course, I am seen by some as ^{me of} the "green^{out} members of the Bush Administration; and as Kermit the Frog says, "It's not easy being green."

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But no Green in government has ever had the support from a President that our environmental efforts have received from President Bush. While much remains to be done, this Administration has moved the environmental agenda farther, faster than in any previous 20-month period in history. That is not just my view, but the conclusion of a number of people who are thoroughly familiar with the history of the Agency. We may have moved in fits and starts. We may not have always communicated our policies well. But despite what you may hear from some of our critics, the progress, the momentum, is undeniable.

On international issues, the President has redefined U.S. foreign policy to give environmental concerns much greater prominence than in the past. Just three weeks ago I was in Budapest, Hungary, to participate in the opening the new Regional Environmental Center for Eastern and Central Europe, proposed by President Bush on his trip there last year. This Center symbolizes the President's decision to make environmental improvement the cornerstone of our efforts to help nurture democracy in that part of the world.

Across Eastern Europe, the Center is known as the "Bush Center." And our contribution to helping that region deal with its truly catastrophic environmental and economic problems has evoked tremendous expressions of gratitude.

The President also has been out in front on other major global environmental issues: On ozone depletion, he was among the first to call for a complete phase-out of chlorofluorocarbons by the year

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2000. On protection of tropical rain forests, he proposed a visionary international forestry agreement -- long a goal of conservationists worldwide -- at the July economic summit in Houston. On urban pollution, besides our Eastern Europe center and the technical assistance we are providing Poland in air monitoring and water quality improvement, the United States has signed a bilateral agreement with Mexico to help improve Mexico City's air; and next month this country's first environmental attache will arrive at our embassy there, a further indication of the elevation of environmental issues as a key foreign-policy concern.

Early on, the President banned exports of hazardous waste absent safeguards in the receiving country; and the Administration helped develop and then signed the Basel Convention governing transboundary shipments of such wastes. There was the ban on imports of ivory, which President Bush started and the European Community followed, with very encouraging early results for elephant conservation, especially in East Africa.

The President's "Enterprise for the Americas" program, announced earlier this month, includes a groundbreaking debt-for-environment initiative to help establish Environmental Funds in Latin America and the Caribbean, using the interest payments of renegotiated public debt. This program, which has been exceptionally well received in Latin America, could significantly increase local funds going to environmental protection.

On climate change, as you know, we've taken some flak -- but I would invite you to do a little digging behind all the rhetoric

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and posturing, by folks in this country and abroad, to see where the action really is on that issue.

The fact is that with respect to climate change, the United States is putting its money where other peoples' mouths are. While others talk about ambitious -- and perhaps unattainable -- carbon dioxide emissions reductions in the future, the United States will be spending more than \$1 billion in the coming fiscal year to learn more about the scope, causes, effects, and responses to the problem.

This research will provide much of the scientific basis underlying international negotiations next year on a climate change framework convention -- the opening session of which President Bush offered to host last May?

Nor are we sitting on our hands waiting for the science to jell. We already are committed to a series of actions that make sense in their own right and will yield benefits should climate change prove to be, as some have suggested, a problem of serious consequence. (It is also possible, as White House Science Advisor D. Allen Bromley points out in a soon-to-be-published article, that other global issues such as ozone depletion, deforestation and loss of genetic diversity "may...turn out to be more serious in terms of human impact than global climate change.") By passing a new Clean Air Act, phasing out CFCs, carrying out the President's "America the Beautiful" reforestation initiative, tightening landfill controls on methane, and promoting energy conservation, we can hold U.S. greenhouse gas emissions at 1987 levels through

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the year 2000.

The next time you feel the urge to write about climate change, you might ask yourself: "How many other countries can point to real action on this issue -- and back it up?" How many others have laid before the public the details -- if these even exist -- of how they plan to cut greenhouse gas emissions while maintaining economic growth? Here's a little-publicized fact: Many European countries are banking on France's excess nuclear capacity to enable them to meet their carbon dioxide reduction commitments.

The nation's environmental progress on the domestic front has also been substantial, and satisfying.

The President's leadership has brought a sweeping, comprehensive and ambitious new Clean Air Act to the brink of passage. Our efforts to promote pollution prevention, recycling and consumer education are beginning to take root.

The resources devoted to hazardous waste control and cleanup have increased substantially, including 500 new staff positions for Superfund enforcement. In fact, we had a record performance on enforcement last year -- in orders to the Justice Department, in recoveries from responsible parties, in cleanups and settlements. Some \$35.1 million in civil penalties was assessed in fiscal year 1989 -- the second highest amount in the Agency's history -- and \$12.5 million in criminal fines, an Agency record.

On ecosystem protection, we've continued to work toward the President's goal of "no net loss" of wetlands despite some tough questions that the issue raises -- the protection of private

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property rights foremost among them.

Furthermore, the acid rain provisions of the Clean Air Act will greatly reduce ecologically damaging sulfur oxide emissions; and we are now negotiating an accord with Canada to ensure comparable reductions on their side of the border. The Administration has moved to block several water development projects that would have unacceptable potential effects on wetlands, wildlife and recreation, and to phase out ocean dumping of sewage sludge by June of 1992.

EPA has taken steps to limit public exposure to toxic substances like asbestos, dioxin, benzene and lead. The President has proposed sweeping pesticide reforms, to enhance public confidence in the food supply; he's also proposed a substantial strengthening of the laws to help prevent oil spills.

By any objective measure, it is clear that this Administration is serious, determined, and dedicated to the pursuit of a credible, innovative environmental agenda. We have created high expectations, and for the most part, we are meeting them. In short, President Bush has moved the environment from the margins to the mainstream. The opportunities for genuine environmental progress have never been greater than they are today.

The Cost of a Clean Environment

At the same time, this Administration is profoundly conscious of the need to achieve continued environmental progress in harmony with the nation's economic aspirations. The Administration's

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policies are firmly grounded in the recognition that we do not have to choose between a healthy environment and a healthy economy. We can, and must, have both.

Our country's environmental gains over the past two decades -- in cleaner air and water, in strict controls on hazardous waste, in protection of wildlife and valuable ecosystems -- have not come cheaply. Within the next few weeks EPA will make public a report to Congress showing that total annual costs for pollution control in the United States increased, in constant dollars, from \$27 billion in 1972 to \$85 billion in 1987, slightly more than the other Western industrialized nations for which we have data. For this year, we estimate that the public and private sectors are spending more than \$100 million, in today's dollars, for pollution control.

This increase in spending has been accompanied by, has in fact been made possible by, the nation's robust economic growth over much of the same period -- compelling evidence that environmental quality and economic expansion, far from being mutually exclusive, go hand in hand.

Our report also will show that by the year 2000, pollution control costs from programs now in place will grow to about \$155 billion a year, or about 2.7 percent of GNP. That is the net "cost of clean," without taking into account any of the benefits from this investment; our economists are now looking at ways to add up the benefits of pollution control as well. Most of the growth in the next ten years will not be in the traditional areas of air and

- 8 -

water pollution control, but instead will be in expenditures for cleaning up pollution on land -- primarily from hazardous waste sites, Federal facilities, and leaking underground storage tanks.

Piecemeal Policy-Making

Given these substantial and growing costs, it seems only prudent to ask ourselves: Are we spending all this money on the right things? Are we spending it in the most effective possible way? Are society's resources being used in ways that will contribute most directly to the health and well-being of our citizens and our environment?

Not long after my EPA appointment was announced, I made the customary rounds of the members of the Senate Environment and Public Works Committee, to whom it would fall to consider my nomination.

One of my most memorable visits was with Senator Pat Moynihan; as I expect many of you know, conversations with Senator Moynihan are always memorable.

He sat me in a very nice Windsor chair, about which he said, "This is a Republican chair...this is appropriate, I think, for the new EPA Administrator to sit in."

Then he perched his little half-reading glasses down on his nose, and he fixed these two fingers, picador-like, on me...

And looking over his glasses, he said, "Above all...above all...do not allow your agency to become transported by middle-class enthusiasms!"

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Well, I assured him that wouldn't happen; and later I came to a conclusion about what he meant. What he meant, I decided, was, "Respect sound science; don't be swayed by the passions of the moment." 

All too often in the past, I think, the guiding principle for making environmental policy has been what some of my colleagues at EPA call the "ready-fire-aim" principle. Perhaps some of you have played a somewhat primitive, pre-Nintendo video game called "Space Invaders." In that game, whenever you see an enemy ship on the screen, you blast at it with both barrels -- typically missing the target at least as often as you hit it.

The last two decades of environmental policy in this country have been similar in some ways to that video game: Every time we saw a blip on the radar screen, we unleashed a virtual arsenal of control measures to eliminate it. In the late 1960s we saw that we had an air pollution problem, so we enacted ambitious clean air laws. At about the same time, we became aware of serious water pollution and passed an equally challenging clean water act. We saw that exposure to toxic chemicals was causing human health problems and passed a sweeping law to control toxic substances. And so it went through the 1970s and 1980s: drinking water, radiation, pesticides, hazardous waste, medical wastes --each problem dealt with essentially in isolation, without reference to all the others.

As I noted, many of those efforts have been successful -- up to a point. But the upshot of this piecemeal approach to pollution

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control has been that we have set our pollutant- and medium-specific goals over the last 20 years without adequately addressing our overall environmental quality objectives. Rarely did we evaluate the relative importance of individual chemicals or individual environmental media. We didn't assess the combined effects on ecosystems and human health from the total loadings of pollutants deposited through different media, through separate routes of exposure, and at various locations. We have never been directed by law to seek out the best opportunities to reduce environmental risks, in toto; nor to employ the most efficient, cost-effective ways of proceeding.

As a result of this fragmentation, today more than 80 congressional committees and subcommittees dip their spoons into the broth of environmental policy. EPA is pulled in many directions at once by Congress, other agencies of government, the public, constituency groups, the courts, and of course the news media. We answer to many taskmasters. Many problems, such as local land-use issues, are not even in our jurisdiction, yet we tend to be held responsible for solving all of them. For its part, the press sometimes tends to focus on the "pollutant of the week," regardless of its importance relative to other environmental problems -- or to other social problems, for that matter. This kind of crisis management is certainly not unique to the environment -- but when we're dealing with critical issues of public health and safety every day, at significant economic cost, I think it's imperative that we step back from time to time and

- 11 -

take a broader view.

Setting Risk-Based Priorities

As we gear up to deal with the environmental problems of the 1990s and beyond, I think the time has come to start taking aim before we open fire. We must begin to recognize that not all environmental problems are equally urgent, equally in need of attention, or equally responsive to the same control strategy. And the most visible problems -- or the ones that generate the most sound and fury -- may well not be the most serious when judged on the basis of real risks. Moreover, the problems are much too daunting, and their solutions far too expensive, to be dealt with all at once. We will run out of ammunition long before we run out of problems. We need to work smarter -- to target our efforts where they will do the most good.

In short, we have to find a better way of setting environmental priorities. And this is where sound science comes in. Sound science can help us fix priorities and allocate resources based on risk, to the extent that statutory mandates allow. Obviously there are a number of other important factors that go into shaping our priorities -- public values and perceptions, economic constraints -- but sound science is our most reliable anchor in a turbulent sea of environmental policy and regulation.

Risk is a common metric that lets us distinguish the environmental heart attacks and broken bones from indigestion or

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bruises. Despite the uncertainties inherent in -- and continuing controversies over -- how to assess risk, comparative risk assessment is still one of the best indicators of where we should be directing our resources.

Four years ago my predecessor, Lee Thomas, recognized the need to do a better job of setting priorities across the range of EPA's programs. He instructed EPA's in-house scientists and environmental managers to look at a range of environmental problems and to try to rank them based on risk. The result of this exercise was a visionary report published in 1987 under the title, Unfinished Business: A Comparative Assessment of Environmental Problems.

The Unfinished Business report, a responsible and in many ways courageous first step toward a methodology of risk-based priority setting, revealed that expert and public opinions about the seriousness of many environmental problems differed markedly. Moreover, in the words of the report, "EPA's priorities appear more closely aligned with public opinion than with estimated risk." Opinion polls at the time of the study, for example, showed relatively little public concern for the risks of global climate change and indoor air pollution; yet we know these to be potentially among the most important problems we face.

Given the significance of this groundbreaking effort, one of my first actions as Administrator was to ask EPA's Science Advisory Board, a distinguished and objective panel of independent scientists and engineers, to review Unfinished Business, assess its

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rankings applying the best technical and scientific knowledge available, and suggest ways to improve the comparative risk assessment process.

I also asked the scientists to extend the original analysis and to identify risk reduction strategies that could be particularly effective for specific problems, or that could help to mitigate multiple problems at the same time.

The science board has done its job with great patience and perseverance, and it has produced a thoughtful and fundamentally significant contribution to the debate over the future of environmental protection in this country. Let me take a moment to express my special thanks to the co-chairmen of this study: Dr. Ray Loehr of the University of Texas, who is the chairman of the Science Advisory Board, and Jonathan Lash, until recently the Secretary of the Agency of Natural Resources for the State of Vermont and now director of the Environmental Law Center at Vermont Law School.

The new report, which is being distributed today, is called, Reducing Risk: Setting Priorities and Strategies for Environmental Protection. It builds on the pioneering work of the "Unfinished Business" report in comparing disparate environmental problems according to the degree of risk they pose. But the new report goes well beyond the earlier effort by spelling out a set of fundamental principles for achieving broader, more integrated, and more carefully targeted environmental policy-making. Taken together, these principles provide a basic framework for addressing some of

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the daunting environmental problems of the 1990s and beyond.

Targeting Resources for Risk Reduction

The report's first and most basic recommendation reflects the point I made a moment ago: We must do a better job of setting environmental priorities. We -- EPA and society at large -- must locate and focus our attention on the most promising opportunities for reducing risk to the environment and to human health and welfare.

To help us move toward that goal, the Science Advisory Board carefully reviewed the risk comparisons in the Unfinished Business study. Within the constraints of the limited information and crude analytical methodology now available -- and we clearly need to do a great deal of work to improve both -- the board identified several problems that continue to pose relatively high risks to human health or the environment despite the progress of the last two decades. The human health risks highlighted in the report, based primarily on overall degree of direct public exposure to known toxic agents, are ambient air pollution, worker exposure to chemicals in industry and agriculture, indoor air pollution, and drinking water pollution. Additional data, which EPA is now working to gather and analyze, may reveal other areas of equally high risk -- pesticide residues in food, for example, or chemicals in consumer products.

The report also identifies specific high-risk ecological problems, based primarily on their geographic scope and the amount

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of time it will take to reverse them: habitat alteration and destruction, species extinction and loss of genetic diversity, stratospheric ozone depletion, and global climate change. ||

The report makes special mention of the need for EPA to address ecological risks with the same level of effort that we have devoted in the past to human health risks. This is in recognition of the intimate relationship between productive natural ecosystems and human health and welfare. The report also recommends, and I concur, that we need to find better ways of determining the true value of natural resources and factoring long-term environmental effects into national economic accounting systems.

Some of the issues identified in the report, such as ozone depletion and global climate change, already are receiving a great deal of emphasis both in the United States and internationally. Others, however -- indoor air pollution, species loss, habitat destruction -- have received less attention from either government, where jurisdiction is a question, or the public, where significance is a question.

The Reducing Risk report, like Unfinished Business before it, raises many provocative issues with far-reaching public-policy implications. For example, as I mentioned the report emphasizes that indoor air pollution, especially radon, is among the most urgent environmental problems facing the country in terms of overall risk. Exposure to elevated levels of radon is estimated to be the second-leading cause of lung cancer in the United States; for the average American, living in a house with a level of radon ||

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at which EPA recommends remedial action is equivalent to receiving no fewer than 400 chest X-rays a year. Yet the public continues to rank radon and indoor air pollution low on its list of concerns; only a small percentage of Americans have even tested their homes for radon, let alone taken remedial action. By the way, EPA later this year may have more to say about another prevalent indoor air pollutant: passive smoking. //

Partly because of a lack of reliable information about the extent of public exposure, the health risk associated with hazardous waste is given a relatively low ranking compared to indoor air pollution in both the old and the new studies. Yet the nation's expenditures on cleaning up abandoned hazardous waste sites are many times greater than the resources devoted to indoor air pollution -- and as the "Cost of Clean" report points out, that discrepancy will grow even larger in the next ten years.

When the relative risk of the problems we address -- in the the best professional judgment of ecologists, engineers and other scientists from both inside and outside EPA -- is out of synch with the resources we deploy toward them, the obvious question is: What if anything should be done about it? Should we as a society continue to expend substantial resources on environmental problems that appear to be relatively low-risk to the population as a whole, even though they may pose high risks to a relatively small number of individuals? Who should make such decisions? What is the appropriate role of the Federal government in dealing with the problems? How can decisions be better informed by science? What

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weight should be given to scientific factors compared to other important factors, such as public perceptions, justice, and equity? How in a democracy do we balance the legitimate public demands for action to reduce risk and protect the environment with our professional judgment about how best to achieve these goals? In short, how can risk-based decision-making help us to move the environmental agenda forward in the most cost-effective way?

Toward Integrated Environmental Policy

Let me be clear: the Science Advisory Board is not suggesting, nor am I, that conventional approaches to environmental problems such as hazardous wastes should be abandoned. EPA is, in fact, firmly committed to continued, intensified enforcement of the environmental laws already on the books, as evidenced by EPA's record enforcement figures last year. But we do need to think carefully about where our limited resources can most effectively be spent.

That brings me to a second basic principle discussed in the Relative Risk report: how we spend our resources is as important as what we spend them on. As I noted earlier, the traditional approach to environmental protection -- prescriptive, command-and-control regulations -- has brought us a long way. But by themselves, technology-based regulations are no longer sufficient to do the job before us. In some cases, they can actually be counterproductive, serving only to inhibit innovation and to discourage regulated industries from going beyond minimum legal

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requirements.

These limitations are particularly evident in the emerging areas of challenge and concern -- problems ranging from pollution in the household and pesticide residues in food to threats to the planet's atmosphere and climate. To address these "new" concerns, we need to take a broader, more integrated look at the range of environmental programs we administer, and the response tools available to us, with an eye toward finding the most efficient and effective ways to reduce risk. Among the tools identified by the Science Advisory Board are research, public education, technical assistance, and market incentives. And above all, we need to mobilize a national effort to prevent pollution before it's created in the first place.

Clearly, this is not something EPA can do by itself. All parts of government and all sectors of society must participate. The quality of the environment is directly affected by energy extraction and use, by agriculture, by transportation, by our relations with other nations, by our trade policies, by our tax policies. Government, for its part, must pay much more attention to environmental considerations at the outset of policy-making, just as we now do with economic concerns. This is not to suggest that I want to see EPA getting into every other agencies' business; rather I'm suggesting that all the other agencies need to be getting into our business, the business of protecting the environment.

In the private sector, the educational system can participate

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by building environmental principles into curricula at all levels, from elementary and high school to professional training -- engineering, public policy, business, law, foreign policy.

But as I said, EPA can't do it all; government can't do it all. Effective national responses to many of our environmental problems will be mounted only through countless individual acts of stewardship; only through the constant adaptations of millions of citizens and thousands of companies to new information; and in the end, only through the inspired leadership and continuous learning of individual citizens.

Ultimately, every American must feel empowered and enabled to act on behalf of the environment.

Rethinking the Environmental Agenda

I am today, therefore, calling for a broad, robust national dialogue on the Science Advisory Board's findings and recommendations -- including hearings before the relevant Congressional committees, and wide-ranging discussions by environmental and industry groups, scientists, academicians, and citizens everywhere. Clearly any effort to set environmental priorities based on relative risk -- to rethink the environmental agenda for the 1990s and the 21st Century -- is going to be difficult and contentious. There are many uncertainties inherent in such a process. But this report takes an essential first step. Much more information is needed; but now at least we have a better idea of what we do need, as well as some basic principles that can

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help us to better target our resources.

Changing the nation's environmental agenda will not be easy, and it won't happen overnight -- but I'm pleased to note that many of the science board's principles and recommendations already are being adopted by EPA and other government agencies. What Science Magazine recently called a "quiet revolution" in the way EPA does business is in fact well under way.

All EPA programs are conducting a broad strategic planning effort which is aimed at focusing our attention and resources on areas of greatest risk and greatest potential for risk reduction.

Our budget decisions already are being guided by the risk reduction principles of EPA's long-term strategic planning process. Some regulatory decisions, such as the recent decision on radionuclides in drinking water, reflect the Agency's new emphasis on risk reduction. We are actively looking for ways to improve economic analysis to incorporate the costs of production and disposal. And to help improve the state of environmental literacy in this country, I have opened an EPA Office of Environmental Education. This new office is a long-term wager whose real payoff will arrive in the next century.

Pollution prevention has become the watchword for all EPA programs, from municipal wastewater treatment to toxic air pollution to stronger, carefully targeted multi-media enforcement strategies. The Agency is placing much greater emphasis on ecology, in recognition of the fact that the health of natural systems is the foundation for economic health and the well-being

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of society at large.

Economic incentives, highlighted by the Science Advisory Board as an innovative option, have been central to the Administration's efforts to craft a cost-effective environmental policy -- for example, in the groundbreaking emissions trading and alternative fuels provisions of the President's Clean Air Act amendments.

And there is a growing government-wide recognition that almost every aspect of public policy affects environmental quality. EPA has been working closely with the departments of State, Energy, Agriculture, Interior, Treasury, and Commerce to coordinate our activities and strengthen the environmental component of government policy-making.

Environmental Stewardship for a Sustainable Future

Last year in this room I asserted that the Bush Administration has a clear, ambitious and unambiguous environmental vision:

-- A vision of a nation moving steadily to provide a greater measure of protection for human health and for natural systems;

-- A vision of a public informed and knowledgeable about its realistic choices in an industrialized, economically developed society;

-- A vision of a people infused with an ethic of environmental stewardship, working to secure the vital link between sound, sustainable economic growth and a healthy, productive environment.

The broad review and re-evaluation of the nation's environmental agenda that I am calling for today can play a central

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role in turning that vision into reality. The decisions about how best to go about the task of environmental protection and risk reduction must be discussed and debated in the kitchens of American homes, in school classrooms, in the halls of Congress, the boardrooms of industry, the conference rooms of our vigorous environmental groups, in policy councils at all levels of government.

From those discussions and debates will emerge a new approach to environmental policy, and a new generation of environmental programs -- programs that will carry the nation forward through the 1990s and into the 21st Century.

The questions we are raising today can give us the answers we will need to safeguard our environmental legacy to future generations.

Thank you.

"CORRESPONDENCE TRACKING"

TYPE: Action Item

DOCUMENT NUMBER: 9023593

FROM: Reilly, William: EPA

TO: Bromley

DATE OF
CORRESPONDENCE: 09/26/90

SUBJECT: Speech to National Press Club

ASSIGNED TO: D. Allan Bromley

ACTION REQUIRED: direct reply

SENDER'S DUE DATE: OSTP DUE DATE: 10/15/90

DATE COMPLETED: -----

COPIES TO:

WHITE HOUSE TRACKING #:

CONTACT PERSON:

REMARKS:

DATE RECEIVED: 09/26/90

FILE: NEOB



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

SEP 26 1990

THE ADMINISTRATOR

Dr. D. Allan Bromley
Science Advisor to the President
and Director
Office of Science and Technology Policy
The White House
Washington, D.C. 20500

Dear Allan:

I am writing to share with you a speech I delivered to the National Press Club on September 26th where I unveiled a year-long study conducted by EPA's Science Advisory Board titled, Reducing Risk: Setting Priorities and Strategies for Environmental Protection. A copy of the executive summary of this new SAB report is enclosed.

In 1987, the Environmental Protection Agency had published a report titled, Unfinished Business. That report, based on the limited data available, for the first time had attempted to rank in a comprehensive fashion a wide spectrum of environmental problems according to the risk posed to the environment and to human health. The new report takes us the next step forward: it raises some provocative questions about environmental priorities.

I hope you will read the enclosed and join me in promoting a broad, robust public dialogue that can help policy makers at all levels of government and the many others concerned about environmental policy meet the difficult challenges ahead.

Sincerely yours,

A handwritten signature in cursive script, appearing to read "Bill", is written over the typed name.

William K. Reilly

Enclosure

THE WHITE HOUSE

WASHINGTON

November 26, 1990

Dear Bill:

Many thanks for sending me a copy of the speech you presented at the National Press Club on September 26. I apologize for the delay in responding, but as you understand, October was a disastrous month for me.

I read the speech with great interest and I am entirely in agreement with you that we need a much deeper dialogue than we have had in the Administration thus far concerning the whole wide spectrum of environmental problems and our response to them.

I am convinced that it is essential that we take a more proactive stance in matters environmental and, in particular, in the global change area prior to our initiation of the negotiations next February heading toward a framework convention on global change.

I feel that in many ways we have not served the President as well as we might. He has not received anywhere near the credit that is his due for the commitment that he has made, not only to understanding environmental phenomena through a solid scientific research program, but also through specific actions that go beyond what any other nation can currently claim despite the enormous amount of public relations and political clamor that we are hearing particularly from our European friends.

I will be actively pursuing these and other issues with you in the DPC Working Group on Global Change as we prepare for the upcoming global change negotiating session. I also look forward to preparations for the 1992 Brazilian Conference. Roger Porter and I will be working on these and a number of other environmental issues in both the GCWG and the EPRG.

Your input will be absolutely crucial in these discussions.

Again, congratulations on the talk and with all best wishes.

Sincerely yours,

A handwritten signature in dark ink, appearing to read "D. Allan Bromley", with a stylized, flowing script.

D. Allan Bromley
Assistant to the President
for
Science and Technology

The Honorable William K. Reilly
Administrator
Environmental Protection Agency
Room 1200 - West Tower
401 M Street, Southwest
Washington, D.C. 20460

"CORRESPONDENCE TRACKING"

TYPE: Action Item

DOCUMENT NUMBER: 9023057

FROM: Reilly, William: EPA

TO: Bromley

So design de

**DATE OF
CORRESPONDENCE:** 08/02/90

SUBJECT: Opening of Regional Environmental Center in
Budapest, 9/6/90.

ASSIGNED TO: D. Allan Bromley

ACTION REQUIRED: direct reply

SENDER'S DUE DATE:

OSTP DUE DATE: 08/22/90

DATE COMPLETED:

COPIES TO:

WHITE HOUSE TRACKING #:

CONTACT PERSON:

REMARKS:

DATE RECEIVED: 08/03/90

FILE: NEOB



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

August 2, 1990

Dr. D. Allan Bromley
Assistant to the President
Office of Science and Technology Policy
Executive Office of the President
Washington, DC 20506

THE ADMINISTRATOR

Dear Allan:

By now you should have received a formal invitation to attend the official opening of the Regional Environmental Center for Central and Eastern Europe in Budapest, Hungary, on Thursday, September 6, 1990. I very much hope you can join me in Budapest for this important event.

When President Bush first proposed the establishment of this Regional Center one year ago, no one could have predicted the tremendous sweep toward democratic reform in Eastern Europe that we have witnessed in this past year. These dramatic changes have catapulted environmental issues to the forefront of public attention and to the top of the list of challenges which the new governments of the region must face. Environmental degradation in the region attests to the urgency of assisting these emerging democracies in developing environmentally sound policies which will sustain their long-term economic growth.

The Regional Center will build on the momentum by serving as a focal point for multinational environmental cooperation through information dissemination, technical training, and public outreach. Clearly, a coordinated regional effort is crucial to address effectively the severe pollution problems which transcend national boundaries and which threaten human and economic health in the region.

Please join me on September 6 at the opening of the Regional Center to help spark the beginning of what we hope will be a brighter, cleaner future for Central and Eastern Europe. Let's give direction and inspiration to realize President Bush's vision for the Regional Center. I look forward to seeing you in Budapest.

Sincerely yours,

A handwritten signature in dark ink, appearing to read "Bill", is written below the "Sincerely yours," text.

William K. Reilly

THE WHITE HOUSE
WASHINGTON

August 17, 1990

Dear Bill:

Many thanks for your note reinforcing the formal invitation to attend the official opening of the Regional Environmental Center for Central and Eastern Europe in Budapest scheduled for Thursday, September 6, 1990.

Under normal circumstances this is an occasion that I would have been delighted to be part of but, as you may know, my wife has been extremely ill for some time and I have therefore very much curtailed my travel outside of the Washington area.

From all accounts, this new Center is off to an excellent start and can play a very important role in bridging our activities with those in Eastern Europe. I very much appreciate your note and invitation and wish that it were possible for me to join you.

With all best wishes,

Sincerely yours,



D. Allan Bromley
Assistant to the President
for
Science and Technology

The Honorable William K. Reilly
Environmental Protection Agency
401 M Street, Southwest
Washington, D.C. 20460

THE WHITE HOUSE

WASHINGTON

January 31, 1990

Dear Mr. Flavin:

Thank you for your letter and copies of your Worldwatch report and testimony. This letter is also in response to a letter sent from you to John Sununu dated October 25. I appreciate your concern on this important subject, but you should be aware that the United States is currently doing more than any other country to understand and address the problem of global change, including global warming. In addition, there is no question that the President is committed to a course of events that will give us both the understanding needed to make wise decisions and the international consensus necessary to implement those decisions.

First of all, an ongoing high priority for this Administration is to develop a sound global change research program that will serve the decision-making process. The President's FY 1991 budget devotes special attention to the U.S. Global Change Research Program, an interagency research effort to monitor, understand, and predict changes in the global earth system.

Secondly, we now have a forum for developing domestic policy. President Bush has asked me to chair a Cabinet-level Working Group on Global Change under the White House Domestic Policy Council. The working group is developing government-wide U.S. policy on global climate change and other environmental issues based on the soundest scientific and economic understanding. The working group has called for federal agencies to study the economic impacts of global climate change, the activities of the private sector in the United States that affect climate change, and the legal precedents for international agreements and conventions on the environment. Using this information, the group provides information and advice to the President and contributes to international deliberations on global warming.

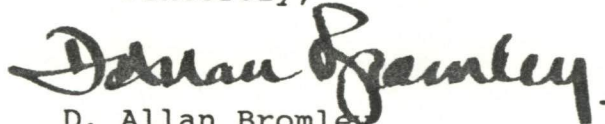
In addition to the activities of the Working Group on Climate Change, the President has asked me, together with the Chairman of the Council of Economic Advisors and the Administrator of the Environmental Protection Agency, to organize an international White House meeting of the senior science, economics, and environmental officials from a number of countries in the spring of this year. The meeting will focus on the kinds of data and analytical tools needed to understand the economic as well as the scientific aspects of global climate change, and develop policies to deal with it.

The U.S. government also continues to support the work of the Intergovernmental Panel on Climate Change sponsored by the United Nations and the World Meteorological Organization. The three working groups of the IPCC will be meeting in Washington in February to prepare their reports on the scientific aspects, response strategies, and mitigation options for global change. The final papers will be presented in August, shortly before the Second World Climate Conference in November.

All of these activities will contribute to the negotiation of a Framework Convention that the President has offered to host following the Second World Climate Conference. The goal of the Framework Convention will be to develop an international process that will lead to the stabilization of greenhouse emissions within a given time frame. By drawing upon the best scientific and economic understanding available, such a convention will be both economically realistic and politically feasible.

I believe that the actions described above constitute a thorough and responsible approach to the very serious problem of global change. I hope that we can count upon your support as this administration moves forward on this difficult issue.

Sincerely,

A handwritten signature in dark ink, appearing to read "D. Allan Bromley", written in a cursive style.

D. Allan Bromley
Assistant to the President
for
Science and Technology

Mr. Christopher Flavin
Vice President for Research
Worldwatch Institute
1776 Massachusetts Avenue, N.W.
Washington, D.C. 20036

6W

"CORRESPONDENCE TRACKING"

TYPE: Priority Presidential Correspondence DOCUMENT NUMBER: 8920259

FROM: SALLY KELLEY
PRESIDENTIAL CORRESPONDENCE

TO: OSTP

DATE OF
CORRESPONDENCE: 10/30/89

SUBJECT: MR. CHRISTOPHER FLAVIN ENCLOSURES FOR GOVERNOR
SUNUNU'S REVIEW A PAPER ENTITLED "SLOWING GLOBAL
WARMING: A WORLDWIDE STRATEGY"

ASSIGNED TO: Nancy Maynard

ACTION REQUIRED: APPROPRIATE RESPONSE

SENDER'S DUE DATE: 11/17/89 OSTP DUE DATE: 11/17/89

DATE COMPLETED: 11/30/90

COPIES TO: JUDY BOSTOCK

REMARKS:

DATE RECEIVED: 11/07/89

FILE: NEOB

"CORRESPONDENCE TRACKING"

TYPE: Action Item

DOCUMENT NUMBER: 8920498

FROM: Worldwatch Institute
Christopher Flavin

TO: Bromley

DATE OF
CORRESPONDENCE: 11/21/89

SUBJECT: Global Change meeting and study enclosed "Slowing
Global Warming: A World Wide Strategy"

ASSIGNED TO: Nancy Maynard

ACTION REQUIRED: Response for
DAB signature

*Thoughtful SOB with the
Remind me to exclude him
from our list of interview
DAB*

SENDER'S DUE DATE:

OSTP DUE DATE: 12/15/89

DATE COMPLETED: 1/30/90

COPIES TO: D. Allan Bromley
Judy Bostock

*per. too, 8920259 (also from
Flavin)*

REMARKS: DAB and JB - copy of letter and Testimony only NM - sent study
to her NEOB - ltr and testimony only in files

DATE RECEIVED:

FILE: NEOB

THE WHITE HOUSE

WASHINGTON

February 16, 1990

Dear Jim:

As you are already aware, President Bush has appointed me, Michael Boskin, and Michael Deland as co-chairmen of his Conference on Scientific and Economics Research Related to Global Change.

I have asked Dr. Robert Corell of NSF to act as Conference Director and Dr. Franmarie Keel to act as Conference Coordinator. They have identified key requirements and I would ask your help in meeting one specific need of office space to house their conference staff.

Dr. Keel has spoken to Mr. Anthony Ewing and Dr. William Mills of the Oak Ridge Associated Universities, which is located at 1019 19th Street, N.W. As you know ORAU holds a Department of Energy integrated contract. They have offered to allow the staff for this White House Conference the use of a suite of offices for the cost of approximately \$6,000 a month or a total of \$18,000 for the duration of the Conference activity lasting through April 30, 1990.

In light of the fact that this is a Presidential Conference, I would ask that your Department cover the cost of the office space and make the necessary arrangements with the Oak Ridge Associated Universities.

I shall much appreciate your help.

Sincerely,



D. Allan Bromley
Assistant to the President
for
Science and Technology

The Honorable James D. Watkins
Secretary of Energy
1000 Independence Avenue, S.W.
Washington, D.C. 20585

THE WHITE HOUSE
WASHINGTON

February 20, 1990

Dear Admiral Watkins:

On December 4, 1989, in Malta during his meeting with President Gorbachev and again on February 5, 1990, at the Plenary Session of the Intergovernmental Panel on Climate Change, President Bush announced his intention to host a White House Conference on Science and Economics Research Related to Global Change. This will be an important and visible symbol of the President's commitment to extending U.S. leadership in advancing understanding of this important phenomena and the implications of possible policy responses. It will be the first major White House Conference, and thus will be closely watched for this reason as well.

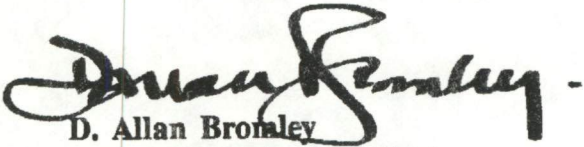
As you may know, the President has requested that we co-chair this important meeting. In this capacity, we are delighted to invite your participation in the Conference. Please reserve the dates of April 17 and 18 on your calendar.

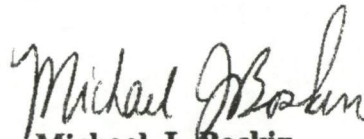
It is traditional that to fund an effort such as this each participating agency contributes to defraying the cost. On behalf of the President, we are, therefore, requesting that you make provisions for transferring \$100,000 to the Council on Environmental Quality Management Fund so that we can proceed with preparations to make this Conference a success. The budget for this Conference will be about \$800,000. We will be pleased to make a copy of this budget available to you.

We would further request that your comptroller who is responsible for performing this transaction notify Norman Hartness at the Office of Management and Budget (395-6840) no later than Tuesday, February 20, to enable us to begin the contracting procedures necessary for this Conference.

Thank you for your kind consideration of this request. The President is most appreciative of your assistance in helping to make this important undertaking a success.

Sincerely,


D. Allan Bromley
Assistant to the President
for Science and Technology


Michael J. Boskin
Chairman
Council of Economic Advisers


Michael R. Deland
Chairman
Council on Environmental Quality

The Honorable James D. Watkins
Secretary of Energy
1000 Independence Avenue, S.W.
Washington, D.C. 20285

THE WHITE HOUSE

WASHINGTON

December 19, 1990

MEMORANDUM FOR GOVERNOR SUNUNU

FROM: D. ALLAN BROMLEY *W. J. ...*
SUBJECT: HUD'S LEAD-BASED PAINT REPORT

It is difficult for me to comment about the specifics of the HUD report on lead-based paint without having participated in the briefing arranged by Cabinet Affairs or having had a chance to review the report.

HUD's strategy outlined in the last paragraph of Daniel Casse's memorandum of November 20 seems a rational one. Considering the recent national publicity regarding EPA's draft report on carcinogenesis of electromagnetic fields, I would suggest a carefully planned strategy relative to public release of the HUD report's findings.

Would it be possible for my office to receive a copy of the report? I also would appreciate knowing exactly when the report is (or was) released.