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REMARKS:

Allan -

FYI, per our conversation. The letter went out about the 20th despite the absence of a date!

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13 February 1990

Professor George F. Carrier
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Dear George,

I am sorry that I am not able to attend the meeting, but the dates selected ruled me out. Also, because of a breakdown in communication, you didn't receive my answer to your questions dealing essentially with the issue of atmospheric stabilization. The EPA report by Moore and Ringo (which my office has sent to Rob Coppock; he will give you that short note plus two other papers: one for popular consumption and the other a somewhat dated review of the carbon cycle--also not very technical) does address the questions you posed. Simply put, if one assumes a pre-existing steady-state (which most models do assume and which the ice core data support), then adding CO₂ to the atmosphere as a forcing makes the atmosphere increase no matter how small the addition (the ocean-atmosphere system is nearly linear--if one sets climate change aside). They only exceptions to this "rule" are two: one obvious and one speculative.

The obvious one is if one adds a lot (read spike) of CO₂ and then much less then the atmosphere goes up and then comes down "even though one is still adding CO₂." See the relaxation of the atmosphere in the Moore and Ringo paper after we hit the system with a Gaussian-like input function. The reason, simply put, is that the ocean runs further and further "behind" the atmosphere the more rapidly the atmospheric CO₂ increases. Folks tend to get that confused with stabilizing the atmosphere--note in the EPA report what happens when we cut "emissions" by 50% over an interval that policy-makers are currently considering.

The speculative one requires the introduction of another sink like an expanding terrestrial biosphere. This actually could bear upon the policy debate, but in a somewhat indirect manner and one which skirts the actual issue of stabilization.

Suppose there has been another (net) sink for atmospheric CO₂ like temperate vegetation. Then the ocean "may" have been more "inefficient" in taking up CO₂ than previously believed--since some was going into this "unknown" terrestrial sink. However, this sink has far less capacity than the oceans to take up CO₂, and could become "saturated" in the fossil fuel era leaving only an unsuspectedly inefficient ocean to deal with fossil fuel CO₂. There is some recent evidence that suggests that this is, in fact, what is happening.

Missing
CO₂

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Let me now turn to the issues and associated questions and hopefully the above might serve as background.

1. The CO₂ record and its credibility.
2. State of understanding of the carbon cycle.

Issue #2 opens more avenues than #1; furthermore, they are linked so let me treat them jointly.

****What are the zeroth order conclusions that one can draw from the atmospheric CO₂ record over the timeframe 1700 to the present?**

The published record begins in 1740 based on ice core records; the longest direct atmospheric record that is acceptable is based upon the daily observations from atop the Mauna Loa in Hawaii. These measurements were begun in 1957 by C. David Keeling, and the record is consistent with other shorter records such as South Pole and Point Barrow. Since 1980 the Geophysical Monitoring for Climate Change division of NOAA has been collecting air samples in flasks for CO₂ analysis from more than 20 sites (this is the so-called "Flask Program").

The records are consistent and the ice core record overlaps the direct atmospheric observation. The records show a linear increase from about 270 ppm(v) in 1744 to 290 in 1860, and then a more exponentialish increase from 1860 to a present value of about 350. The record shows an erratic pattern from 1925 to 1950 (depression and war) and an almost linear (rather step) from 1950 to the present. Small departures occur during the late 70's because of the oil shocks.

****What are the principal forcing terms and how well do we know them?**

The combustion of fossil fuel and production of cement has contributed approximately 200 BMT-C as CO₂ over the interval 1860 to the present (BMT=Billion Metric Tons). The 1987 value was (I believe) 5.57. The record is fuel specific and country specific. I would guess the error bars are something like +/-10%. This record is often called the Rotty Record after Ralph Rotty, who with G. Marland (at Oak Ridge National Lab) produced the timeseries. (e.g. See Tellus 37B, 243, 1985.)

The record of carbon release due to land use change (deforestation) is much less certain. The total release from 1700 to the present is something like 100-150 BMTs. The current annual release is 1-1.5 BMT/a. The error is +/-30%? (e.g. See Houghton et al., Tellus 39B, 122, 1987).

**** What is the principal sink for CO₂ and how well do we know it?**

This will be a bit long-winded but it may help the Panel:

The oceans are by far the largest active reservoir of carbon. Recent estimates of the total amount of dissolved inorganic carbon (DIC) are in the area of 38,000 BMTs or roughly four times the total carbon stored in estimated recoverable fossil fuel resources. Only a small fraction of DIC is carbon dioxide (0.5%); the bicarbonate ion at 90% and the carbonate ion at slightly less than 10% are the

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major forms of dissolved inorganic carbon. There is far less dissolved organic carbon; however, there is also recent evidence that suggests that previous measurements of the concentration of dissolved organic carbon may have missed a substantial fraction (25-50%) because the material was quite recalcitrant.

Although the oceans are the largest active reservoir of carbon and cover almost 70% of the globe, the total marine biomass contains only 3-6 BMTs of carbon, or just about 0.5-1.0% of the carbon stored in terrestrial vegetation. On the other hand, total primary production of marine organisms is 30-40 BMTs per year, corresponding to 30-40% of the gross primary production of the total terrestrial biosphere. However, only a relatively small proportion of this production is actually removed from surface waters and "stored" in deeper layers. This fraction is now in some dispute as a result of the controversy over the concentration of dissolved organic carbon. (Oceanographers "back-out" the new production from geochemical profiles such as DIC.)

The net flux of atmospheric carbon into the oceans remains uncertain, although most models suggest that between 30 and 50% of the fossil fuel emissions are taken up by the oceans. The higher end of this scale would just balance the difference between the fossil fuel carbon dioxide release and the atmospheric buildup; however, if the oceans are not that "efficient" a sink for CO_2 or if there are additional sources, such as net carbon release due to deforestation, then there must be other unaccounted for sinks for carbon dioxide.

Interestingly, there is recent evidence (Tans, Fung, Takahashi--to appear Science) that supports both conditionals and the conclusion: the oceans may well be less "efficient;" deforestation is a net source to the atmosphere of perhaps slightly more than 1 BMT-C as CO_2 , and there may be an unaccounted for sink. The sink is estimated from indirect evidence to be in temperate terrestrial ecosystems; there is no direct evidence that such a sink exists; moreover, if it exists, it is not certain for how long it will continue to function.

The evidence is the result of comparing distributions of the partial pressure of CO_2 in the ocean and with atmospheric distributions; add to this mix the fossil fuel source terms; stir the source fluxes with an atmosphere GCM and compare. Result: need at 1 BMT source in the tropics ("deforestation") and a 2 BMT terrestrial sink (per year) between 20 and 40 degrees north latitude.

This captures lots of questions:

****What is the role of terrestrial vegetation in the carbon cycle? Are terrestrial ecosystems increasing the storage of carbon in response to increases in atmospheric CO_2 ? If so, will it continue; at what rate; what are climate changes?**

****What is the role of episodic events in ocean uptake of CO_2 --are we missing the ocean role by looking at annual averages?**

****Finally, the hard one--will the ocean uptake of CO_2 relative to the atmospheric concentration change substantially if climate changes??**

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The discussion above touches on some of these questions; with respect to the last question: I do not know--other than the simple caution of opening a warm soft drink!

I wish I could be with you and stand ready to help in the future.

Best regards,



Berrien Moore III
Director
Institute for the Study of
Earth, Oceans, and Space

cc: R. Coppock

3

THE OCEANIC SINK FOR EXCESS ATMOSPHERIC CARBON DIOXIDE

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ABSTRACT

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

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

3.1. INTRODUCTION

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

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

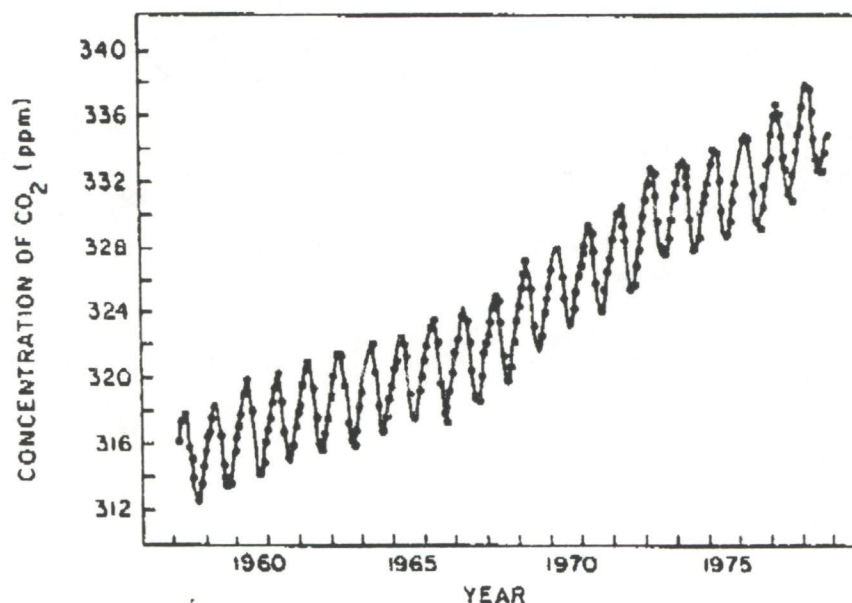


Figure 3.1. Concentration of atmospheric CO_2 at Mauna Loa Observatory, Hawaii (19.5°N , 155.6°W). Dots indicate monthly averages based on continuous measurements. (From Bacastow and Keeling, 1981; Keeling et al., 1982.)

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

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

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

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

3.1.1. Atmospheric Carbon Dioxide

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

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

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

Table 3.1. Annual Carbon Budget

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

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

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

3.1.2. Carbon in Terrestrial Biota and Soil

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

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

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

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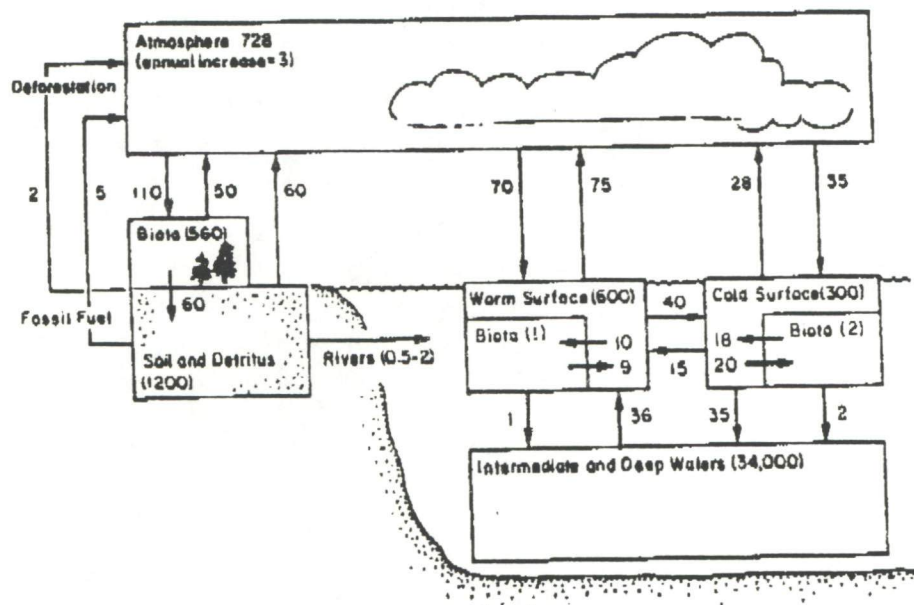


Figure 3.2. Major carbon reservoirs (in 10^{15} g) and fluxes (in 10^{15} g y^{-1}) involved in the global carbon cycle. (From de Vooy, 1979.)

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

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

3.1.3. Oceanic Carbon Dioxide

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

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



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

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

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

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

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

3.2. THE OCEAN AS A CARBON DIOXIDE SINK

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

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

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

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

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

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

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

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

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

3.2.1. Chemical Processes

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

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

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

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

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

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

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

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

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

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

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



and the borate system is expressed by



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

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

and

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

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

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

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

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

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

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Alk is defined by

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

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

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

and

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

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

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

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

From equations 16 and 18, we obtain the relation

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

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

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

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

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

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

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

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where

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

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

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

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

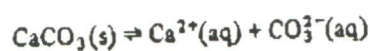
$$D_4 = Alk + K_1 + K_B, \text{ and}$$

$$D_5 = 1$$

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

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

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



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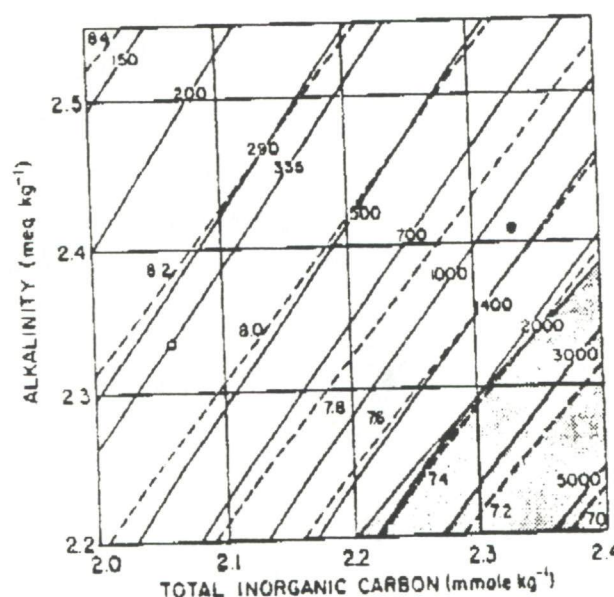


Figure 3.3. Carbon dioxide composition diagram for ocean surface waters at 15°C. The solid lines denote compositions with the same value of P_{CO_2} in microatmospheres; the dotted lines denote compositions with the same pH; the shaded region is undersaturated and the unshaded region is supersaturated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

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

3.2.2. Biological Processes

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

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

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

^a From de Vooy (1979).

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

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

^a From de Vooy (1979).

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

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

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

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

^a From de Vooy (1979).

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

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

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

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

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

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

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

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

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

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

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

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

Table 3.6. Potential Input of Mankind on Coastal Productivity

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

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

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

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

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

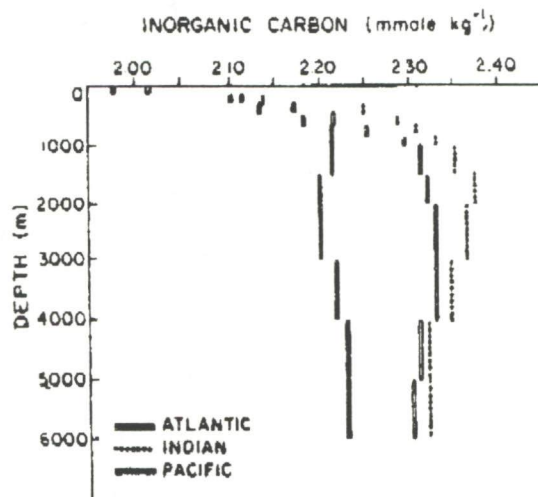


Figure 3.4. Vertical distribution of dissolved inorganic carbons (mmole kg^{-1}) in the Atlantic, Pacific, and Indian Oceans according to GEOSECS observations given by Takahashi et al. (1981) and Bolin et al. (1983).

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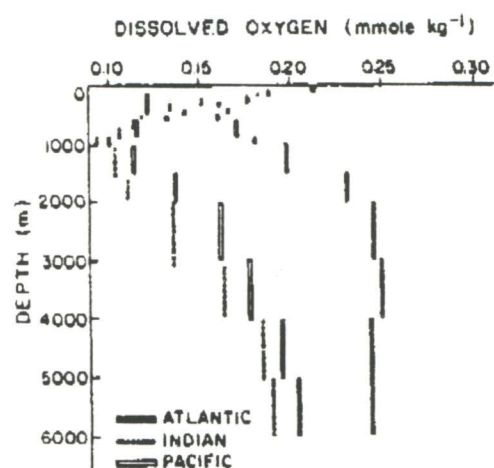


Figure 3.5. Vertical distribution of oxygen (mmole kg^{-1}) in the Atlantic, Pacific, and Indian Oceans according to GEOSECS observations given by Takahashi et al. (1981) and Bolin et al. (1983).

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

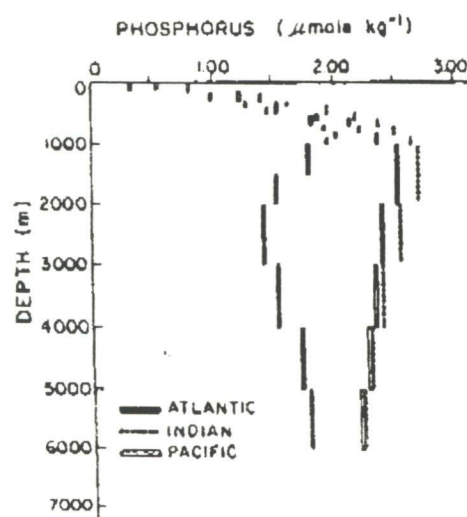


Figure 3.6. Vertical distribution of phosphorus ($\mu\text{mole kg}^{-1}$) in the Atlantic, Pacific, and Indian Oceans according to GEOSECS observations given by Takahashi et al. (1981) and Bolin et al. (1983).

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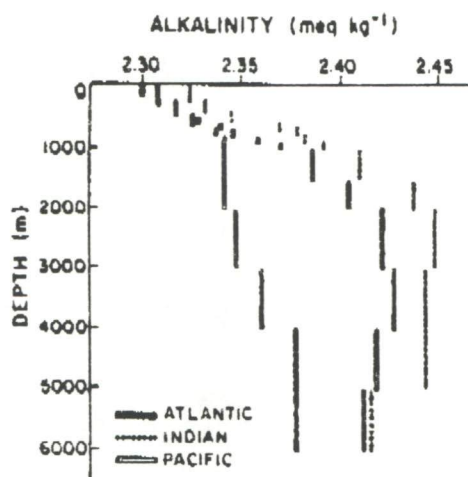


Figure 3.7. Vertical distribution of alkalinity (meq kg^{-1}) in the Atlantic, Pacific, and Indian Oceans according to GEOSECS observations given by Takahashi et al. (1981) and Bolin et al. (1983).

3.2.3. Physical Processes

In polar regions, ice formation results in very dense surface water. These cold surface waters penetrate the thermocline and renew deep oceanic waters; as such, they also have the potential to form, in effect, a pipeline for transferring atmospheric CO_2 to the large reservoir of the abyssal water, which has long residence times. This dynamic pattern coupled with biotic production in high latitudes is the primary reason that the ocean is a more effective sink for CO_2 than is suggested by purely thermodynamical considerations in an abiotic ocean. For a perspective on modelling of this pipeline phenomenon, see reports by Siegenthaler and Oeschger (1978), Björkström (1979), Broecker et al. (1980), Bacastow and Björkström (1981), Broecker and Peng (1981), Killough and Emanuel (1981), Enting and Pearman (1982), Bolin et al. (1983), and Siegenthaler (1983). An early stage in the development of models of deepwater formation and its effect on carbon exchange is given by Plesset and Dugas (1967).

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

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

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

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

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

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

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

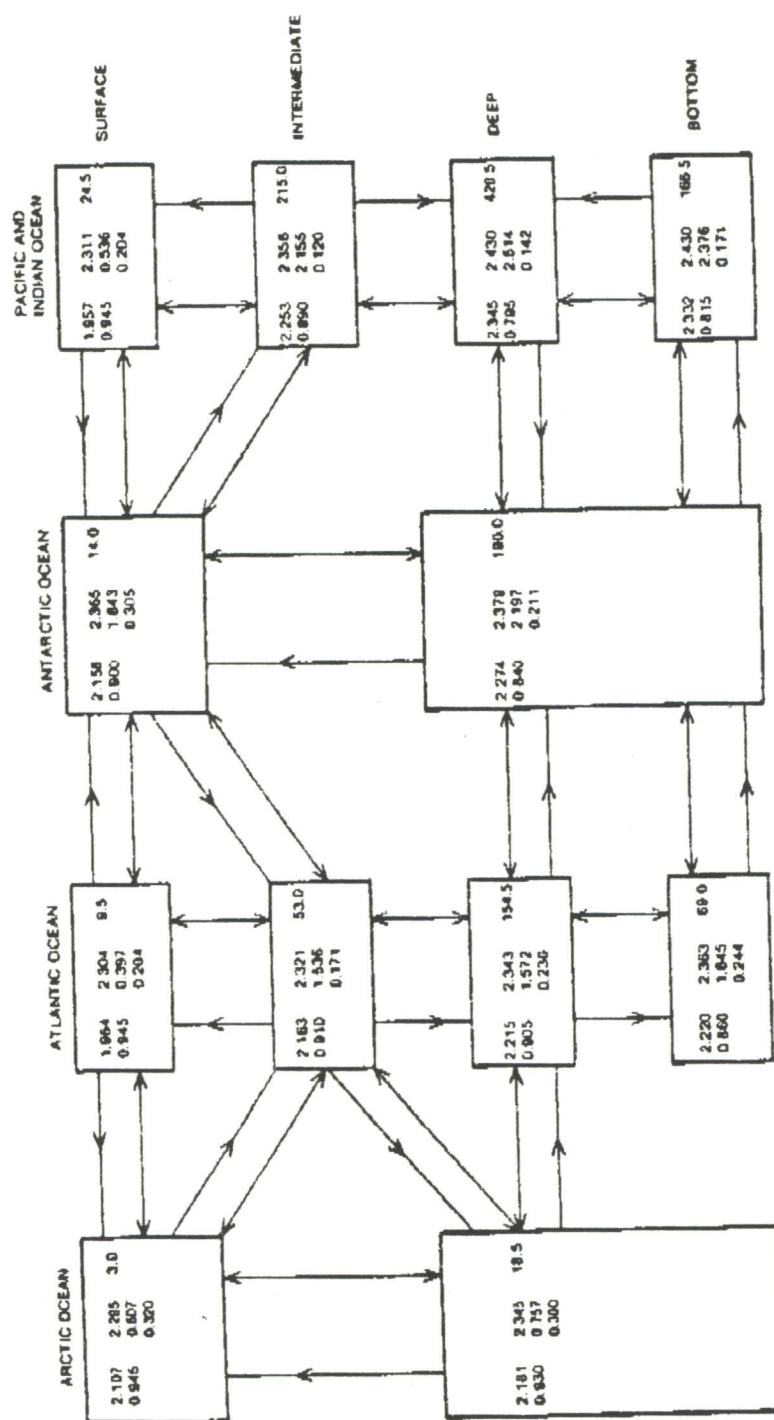


Figure 3.8. Concentrations assigned to the boxes and patterns of advective and turbulent exchanges (Bolín et al., 1983). Each box has three columns of numbers. The first number in the left-hand column is the amount of carbon (mmole kg^{-1}); the second number is the ratio of ^{14}C : ^{12}C expressed as a fraction of the corresponding ratio in the preindustrial atmosphere. The first number in the middle column is the corresponding ratio in the preindustrial atmosphere. The first number in the right-hand column is oxygen (mmole kg^{-1}). The number in the right-hand column is the volume of the respective ocean in 10^{15} m^3 .

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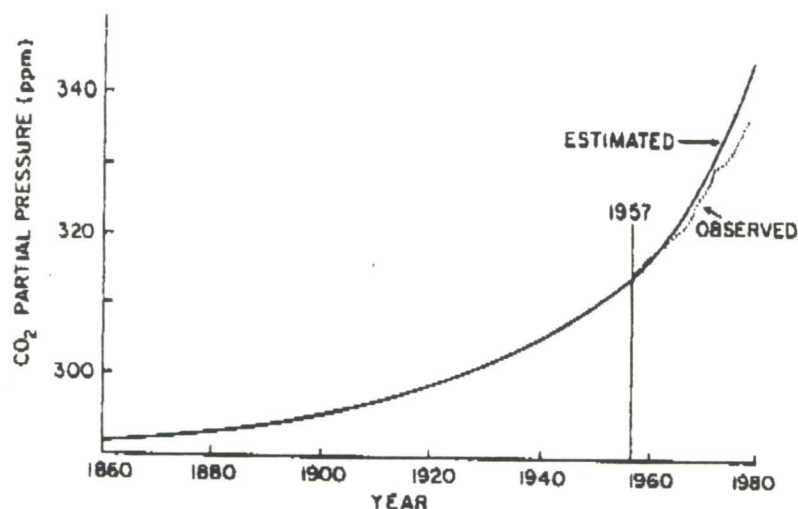


Figure 3.9. Computed change of atmospheric CO_2 from 1860 to 1980 due to fossil-fuel emissions as estimated by Rotty (1981). Dashed line from 1957 to 1979 shows the observed changes at Mauna Loa, according to Bacastow and Keeling (1981).

3.3. CONCLUSIONS

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

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

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

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

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

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Four Ocean Carbon Models

Report to the Environmental Protection Agency
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Ref

FOUR OCEAN CARBON MODELS

Berrien Moore III and Chris Ringo

The change in atmospheric CO_2 concentration resulting from fossil-fuel combustion, land-management activities, and other human-induced disturbances of the global carbon cycle is strongly governed by the CO_2 exchange between the atmosphere and ocean. The ocean is the largest sink for atmospheric CO_2 ; however, the rate of CO_2 uptake by the ocean is limited by the chemical and biological processes within the oceanic surface layer and by the various patterns of advection and mixing that determine the amount of carbon transported from the surface to the deeper layers, where longer-term carbon storage occurs.

Future atmospheric concentrations of CO_2 will depend on the rate of industrial CO_2 emissions, the exchanges between the atmosphere and the terrestrial biosphere, and the rate of uptake by the oceans. The Environmental Protection Agency (EPA) has been asked by Congress to assess strategies for limiting the build up of atmospheric CO_2 . To respond to this request it is necessary to use reasonable models to calculate the likely range of the future oceanic uptake given different scenarios of CO_2 emissions.

This paper briefly reviews the key processes that determine oceanic CO_2 uptake and describes the work undertaken by The Institute for the Study of Earth, Oceans, and Space (EOS) at the University of New Hampshire (UNH) where in cooperation with W. Emanuel at the Oak Ridge National Laboratory (ORNL), we have organized a set of representative ocean-atmosphere carbon exchange models for interactive use in policy analysis at EPA and elsewhere.

OCEAN MODELLING

The oceanographic community has already a rich history that parallels the atmospheric modelling advances in seeking the development of general ocean circulation models (GCMs), in which the steady-state circulation of the oceans may be deduced in response to a given external forcing, i.e. specification of sources and sinks at the ocean surface of momentum, energy, and water. The efforts and accomplishments are significant but lag behind atmospheric GCMs primarily because the data for the oceans is far more sparse and the turn-over constants span a much greater range. From a long-term perspective this undoubtedly is the most rational approach for improving our understanding of the general circulation of the oceans and of dealing with the issue of atmosphere-ocean carbon exchanges; however, these

models have only recently begun to incorporate carbon dynamics, and as such, they are not yet sufficiently well-developed or sufficiently well-understood for use at this time in a policy context.

An approach to studying the general circulation of the ocean including carbon exchanges that has been taken by chemical oceanographers is, however, useful now for trying to bracket ocean-atmosphere carbon exchanges. For quite some time, they have been exploring the questions: what are the transfer processes due to water motions and biological activity needed in order to explain the quasi-steady distribution of chemical compounds in the ocean? What can we learn about the biochemistry of the sea by the simultaneous use of several tracers? How do we extract information about the ocean from the observed transient tracers, particularly tritium, ^{14}C and chlorofluorocarbons that are now invading the world ocean due to man-made emissions into the atmosphere?

The basic idea is to make use of the fact that the distributions of chemical and physical properties (e.g. concentrations of inorganic carbon or the varying pattern of temperature) are a reflection of the water motions (advective and turbulent) and perhaps biological activities (e.g. new production, decomposition, carbonate formation, and dissolution) as well as different distributions of sources and sinks.

For example, Craig (1957) recognized that the distribution of ^{14}C in the sea could be used to determine the rate of renewal of the deep waters of the oceans, and this led to the development of simple ocean models to interpret available ^{14}C data. The simultaneous use of ^{14}C and more traditional marine tracers was first attempted by Bolin and Stommel (1961) and further developed by Keeling and Bolin (1967). These early developments were based on very simple (usually 2-box) ocean models. Oeschger et al. (1975) recognized the need to resolve the vertical structure of the oceans in more detail to better depict reality, and thereby, formulated the box-diffusion model. Siegenthaler (1983) further elaborated on this same idea by also considering the isopycnal ventilation of the deep sea through the cold polar regions (the out-crop model). Bjorkstrom (1979) also incorporated cold polar regions in a 12-box model of the global ocean that also distinguished intermediate waters from deeper ones and included advection as well as eddy diffusion. This model also contained biological processes (organic and carbonate) as well as a full treatment of ocean surface carbon chemistry.

Peng and Broecker (1982) have also made extensive use of tracers in the study of the biogeochemistry of the oceans. Their concept of large-scale mixing of major water masses ("end members") are used to interpret the observed distributions. These formulations are, however, mathematically indeterminate (i.e. there are an infinite

number of solutions), and it is not generally clear how to select a single solution out of the many that are possible, particularly in light of the fact that the present interest is on the time dependent aspects of the solution. Therefore, these formulations are difficult to apply in a scenario manner.

In a deterministic setting, Bolin et al. (1983) have employed five tracers in their study of the global ocean circulation, namely total dissolved inorganic carbon, alkalinity, radioactive carbon, oxygen, and dissolved inorganic phosphorus and imposed the condition of water continuity. A coarse resolution model was used, i.e. 12 reservoirs for the global ocean. The fluxes of organic and inorganic detrital matter from the surface layers into the thermocline region and the deep sea were considered, and these fluxes became additional unknowns. The source and sink terms for the biologically important tracers were interrelated by assuming constant values for the Redfield ratios (the ratios of carbon to nitrogen to phosphorus to oxygen in organic matter). No deposition of detrital matter on the sea bottom was permitted. The inverse problem was formally overdetermined, and a condition of minimizing the errors of the conservation equations was employed, as well as a set of inequality constraints requiring that turbulent transfer be along the concentration gradient of the tracers and that detrital matter forms in surface reservoirs and is dissolved or decomposed in deeper layers of the ocean. The deduced circulation pattern generally agreed with the current view of the gross features of the global ocean circulation.

KEY PROCESSES CONTROLLING OCEAN-ATMOSPHERE EXCHANGES

The oceans are a large sink for atmospheric carbon; however, the rate of carbon uptake by the oceans is limited by surface ocean chemistry and biology, and by the various patterns of mixing and circulation which determine the amount of carbon transported from surface waters to the deep ocean, where long-term carbon storage occurs.

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

The flux F_{am} can be represented as a first order process dependent only upon the residence time of carbon in the atmosphere (T_a) and the mass of carbon as atmospheric CO_2 (N_a). The values of T_a and N_a are reasonably well-established.

For the flux F_{ao} , let us consider a unit area (A) of ocean, then the flux from the ocean to the atmosphere across A can be expressed as:

$$F_{ao} = (A/A_o)(N_{ao}/P_{ao})(P_A/T_a) \quad (1)$$

where A_o is the surface area of the oceans ($3.6 \times 10^{14} \text{ m}^2$), and N_{ao} is the mass of carbon in the atmosphere as CO_2 at some initial point in time with partial pressure P_{ao} ; the established value for N_{ao}/P_{ao} is $2.1314921 \times 10^{15} \text{ g C (ppmv)}^{-1}$. The key "unknown" is P_A , the partial pressure of CO_2 in the surface area A . Thus, the essential uncertainties are the distribution of the partial pressure of CO_2 in the surface of the ocean and the factors controlling this distribution.

From the perspective of the global carbon cycle one might consider the partial pressure of CO_2 in seawater as a linear function of the concentration of CO_2 in seawater (Broecker, 1974; Bjorkstrom, 1979); however, CO_2 dissociates in seawater at a rate that is itself a function of CO_2 concentration. Further complicating this chemical phenomenon are the dynamics of biological and physical processes. Primary production consumes CO_2 ; respiration and decay processes produce CO_2 . Each process affects the chemical equilibrium. Additionally, carbonate formation and dissolution alters alkalinity which affects the partial pressure of CO_2 in seawater. The physical processes of advection and eddy diffusion continually adjust the total inorganic carbon concentration throughout the ocean and thereby continually alter the CO_2 partial pressure distribution in the surface waters of the ocean.

Although chemical, biological, and physical processes are combined in the marine environment, we shall discuss separately (and briefly) the principal attributes of each process.

Chemical Processes. Since CO_2 is not conservative in seawater, a practical conceptual construct is the concentration (Σ) of total dissolved inorganic carbon. This is defined as

$$\Sigma \text{C} = [\text{CO}_2] + [\text{HCO}_3^-] + [\text{CO}_3^{2-}] \quad (2)$$

where "[]" indicates molar concentration. The difficulty with this construct is that the functional relationship between ΣC and the partial pressure P is only locally linear, whereas P is essentially a globally linear function of $[\text{CO}_2]$. However, the conservative character of ΣC means that the increased complexity of the

relationship between P and ΣC is not too difficult to explore. In fact, one can treat the exploration as the answer to two questions:

1. What is the current relationship between ΣC and P ?
2. How does this relationship change with future and perhaps far greater changes in ΣC ?

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

$$P = (10P_0/\Sigma C_0) \Sigma C - 9P_0 \quad (3)$$

where P_0 and ΣC_0 is the preindustrial partial pressure exerted by surface water, (ΣC_0 is the sum of the concentrations of CO_2 , HCO_3^- and $^{*2}\text{CO}_3$ at an initial preindustrial point). Rewriting this linear expression as a normalized ratio of the change in P against the change in ΣC yields a more familiar expression:

$$((P - P_0)/P_0)/((\Sigma C - \Sigma C_0)/\Sigma C_0) = 10 \quad (4)$$

This ratio, usually denoted R and termed the Revelle factor, was measured as part of the GEOSECS program (see Takakashi, 1977), with a range from 8 for the warmest surface waters to 15 for the coldest. Considering the surface area of these waters, 10 is a good weighted average value. This expression, with a Revelle factor of 10, is used in the Oeschger et al. (1975) model at the air-sea interface.

The importance of this factor is best expressed by an example that uses current data. Since the atmospheric concentration of CO_2 has increased by at least 25% over the last 125 years since 1860, then in light of equation 4, the increase in surface concentration of total dissolved inorganic carbon would be only 2.3% (assuming the surface layer remains in equilibrium with the atmosphere). Consequently, the biological and mixing processes must have removed from surface waters whatever additional carbon dioxide entered the ocean.

A direct calculation may clarify further not only the locally linear relationship expressed by equation 4 and the essentially nonlinear behavior of P against ΣC , which is important in carbon cycling as CO_2 increases, but also we need to consider formally the role of chemical solubility because it is temperature dependent. This calculation explicitly exploits ionic equilibria, and hence it describes more precisely the underlying relations between the partial pressure of CO_2 in the surface waters and its solubility at different temperatures, ΣC ,

concentration of hydrogen ions, and total alkalinity. A more thorough and yet easily grasped picture of carbonate-borate chemistry is given by Baes (1982).

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



and the borate system is expressed by



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

$$K_1 = [\text{H}^+][\text{HCO}_3^-] / [\text{CO}_2] \quad (11)$$

and

$$K_2 = [\text{H}^+][\text{CO}_3^{2-}] / [\text{HCO}_3^-] \quad (12)$$

are the first and second dissociation constants of H_2CO_3 , respectively. (Actually, K_1 is the apparent first dissociation constant for H_2CO_3 . In other words, it is the product of the inverse of the equilibrium constant for the hydration process of $\text{CO}_2(\text{aq})$ and the first dissociation coefficient of H_2CO_3 .)

A direct calculation yields the relationship between ΣC and $[\text{CO}_2]$

$$[\text{CO}_2] = [\text{H}^+] \Sigma\text{C} / ([\text{H}^+]^2 + [\text{H}^+]K_1 + K_1K_2) \quad (13)$$

Consequently, if one had ΣC and $[\text{H}^+]$ then it is possible to calculate $[\text{CO}_2]$, P , and hence F_{mg} . However, with changes in $[\text{CO}_2]$ and hence ΣC , $[\text{H}^+]$ is altered through the carbonate reactions; furthermore, the production of carbonic acid and its dissociation perturbs the boric acid speciation in seawater, and hence $[\text{H}^+]$, since the carbonate ions compete with the borate ions for the available hydrogen ions. If one assumes that the carbonate-borate alkalinity, denoted by A , remain constant (Keeling, 1973), where A is defined by

$$A = [\text{HCO}_3^-] + 2[\text{CO}_3^{2-}] + [\text{H}_2\text{BO}_3^-] + [\text{OH}^-] - [\text{H}^+] , \quad (14)$$

it is then possible to use the dissociation coefficients of carbonic acid, boric acid, and water to determine $[^+H]$ given only EC. In fact, given any two of the following four variables: P, EC, $[^+H]$, and A, the remaining two terms are determined. It is these relationships that are used in both the Bjorkstrom and the 12-box model of Bolin et al. (1983) to handle ocean carbon chemistry.

Biological Processes. Although the oceans are the largest active reservoir of carbon and cover almost 70 percent of the globe, the total marine biomass contains only about 3 Pg ($Pg = 10^{15}$ g) of carbon or just about 0.5 percent of the carbon stored in terrestrial vegetation. On the other hand, total primary production of marine organisms is 30 to 40 Pg per year, corresponding to 30 to 40 percent of the total primary production of terrestrial vegetation. However, only a relatively small portion of this production results in a sink for atmospheric carbon, primarily through the sinking of particulate organic carbon, which decomposes in deeper layers or is incorporated into sediments.

The consumption of CO_2 in primary production in biologically active surface water, and the enrichment of the deep water in EC as the result of the decomposition and dissolution of detrital matter that originates from biological processes in the surface waters, taken together are often referred to as the "biological pump"; the biology pumps carbon to the bottom. The most obvious pumping is the incorporation into living organisms of CO_2 that is dissolved in surface waters, either in tissue or as carbonate in shells. This lowers the partial pressure of CO_2 , followed by the "shipping" of some of the CO_2 to the bottom "packed" in the remains of dead marine organisms.

As a consequence of the "biological pump," the concentration of total dissolved inorganic carbon is not uniform with depth; the concentration in surface waters is 10 to 15 percent less than deeper waters. There is a corresponding depletion of phosphorus (and nitrogen) in surface water, even in areas of intense upwelling, as the result of biological uptake and the loss of the detrital material, which also contains phosphorus (and nitrogen) as well as carbon.

The fate of the carbon that falls from the surface waters depends, in part, upon its characteristics. If it is organic materials, then it is oxidized at intermediate depths, which results in an oxygen minimum and a carbon and phosphorus maximum. If the material is carbonate it dissolves, raising both alkalinity and the concentration of carbon, primarily at great depths where the high pressure increases the solubility of calcium carbonate.

Thus, where active, the biological pump lowers the partial pressure of CO_2 in surface waters and enhances the partial pressure in deep water not in contact with the atmosphere. It is as if the biological pump moves the partial pressure around in a way that allows carbon dioxide to work its way into the ocean. In areas of low production the partial pressure is often greater than that of the atmosphere and CO_2 is released from the sea surface. In the natural pre-industrial quasi-steady state, the overall pattern was however in near balance; the net exchange was essentially zero.

Further, each change in alkalinity or in the concentration of phosphorus, total inorganic carbon, and oxygen is mediated by biological processes as well as by the motion of the water masses. By quantifying the biological processes and by exploiting oceanic chemical profiles (for example, data from the Geochemical Ocean Section Study and the Transient Tracers in the Ocean Program) marine geochemists have been able to determine the pattern of biological production and respiration, the strength of the biological pump, and to a degree, the rates of circulation and mixing. This is the basic philosophy behind the parameterization of the 12-box model of Bolin et al. (1983).

Physical Processes. The role of the oceans in the carbon cycle is much dependent on their rate of overturning (the meridional circulation) and mixing. In polar regions, ice formation leaves much of the salt "behind", still in solution. The result is an increase in salinity in these already cold waters and hence an increase in density. As a consequence, these cold surface waters sink; as such, they also have the potential to form, in effect, a pipeline or conveyor belt for transferring atmospheric CO_2 to the large reservoirs of abyssal waters which have long residence times.

This downward convection of surface waters in polar regions during "bottom water formation" creates a sink for carbon dioxide in high latitudes, but the balancing upwelling of carbon-rich waters in low latitudes creates a source. In other words, what goes down (cold polar water with CO_2) must come up (warm equatorial water with excess CO_2). In addition to the bottom water formation in polar regions, there is water exchange between surface waters and intermediate waters due to vertical exchange in association with the surface ocean currents, like the Gulf Stream. These different exchange processes maintained by water motions renew the abyssal part of the oceans in a matter of a few hundred years in the Atlantic Ocean, while the age of Pacific deep water is up to about 1500 years. Intuitively we realize

that this rather slow rate of oceanic turn-over limits the oceans as a sink for carbon dioxide.

OCEAN CARBON MODELS FOR THE POLICY CONTEXT

Models are required to capture the net effect of these interwoven chemical, biological, and physical processes. As discussed above, GCMs that incorporate carbon dynamics are still under development and are not yet appropriate for use in a policy context. Rather, we have selected a set of geochemical based ocean models from the published literature that capture a broad range of ocean-atmosphere carbon dynamics:

1. Box-Diffusion Model (BD): the turnover of carbon below 75 m is represented by a diffusion equation. A constant coefficient of diffusivity is estimated to match an idealized profile of natural carbon-14 (Oeschger et al., 1975).
2. Advective-Diffusive Model (AB): the first of a number of models whose structures are meant to be more realistic than the simple diffusive assumption. The surface ocean is divided into cold and warm compartments. Water downwells directly from the cold surface compartment into intermediate and deep layers (Bjorkstrom, 1979).
3. 12-Compartment Regional Model (12B): the Atlantic and Pacific-Indian Oceans are each divided into surface, intermediate, deep and bottom water compartments. The Arctic and Antarctic Oceans are divided into surface and deep water compartments. The model is calibrated against multiple tracer distributions (Bolin et al., 1983).
4. Outcrop-Diffusion Model (OC): allows direct ventilation of the intermediate and deep oceans at high latitudes by incorporating outcrops for all sublayers into the box-diffusion formulation (Siegenthaler, 1983).

These models are relatively simple compared to work in development today, including GCMs that incorporate ocean chemistry and biology. The models have, naturally, much in common: they are all diagnostic rather than prognostic, each uses

carbon-14 in the parameterization process, each includes ocean carbon chemistry (buffer or Revelle factor), and some form of ocean mixing. There are, however, major differences: ocean biology is included only in two (AB, 12B); deep water formation is not explicitly considered in the box-diffusion model; ocean chemistry varies in complexity; in the box-diffusion and outcrop-diffusion models all of the physics is captured by a single constant eddy diffusivity term, whereas, in the Bjorkstrom model the system is primarily advective (eddy diffusivities can be incorporated); the Bolin model has both advection and eddy diffusivities; and, perhaps most importantly the geometrical configurations are quite different (Table 1). In addition, there are a host of smaller differences: ocean volume and surface area, parameterization procedures, carbon-14 profiles, initial conditions, atmospheric residence time. As a result of these large and small differences, we find a range of responses; briefly, the outcrop-diffusion model is the most efficient in taking up CO_2 ; the box-diffusion model, the Bjorkstrom model, and the Bolin model all tend toward less carbon uptake.

We should note (see next section) that their relative responses are in part a function of the forcing term, and in this study, we consider only past and various future fossil fuel emission scenarios without any terrestrial release. Rapidly increasing emissions generally leads to a decreasing percentage going into the ocean model; whereas, a decreasing emission has the opposite effect. Capturing these changes is why models are preferable to a constant multiplier or percentage for varying emission scenarios.

BASIC RESULTS

In this study, we first employ three forcing functions representing past and future fossil fuel emissions of CO_2 ; later we consider another slightly more policy oriented forcing term. These initial emission scenarios do not reflect any particular energy future; rather they are chosen to reflect a broad range of responses. The three forcing functions are:

1. The actual fossil fuel record (i.e., Rotry Record for the period 1860-1986 as supplied by the Carbon Dioxide Information Analysis Center at the Oak Ridge National Laboratory) to 1986 and then constant at the 1986 value (5.56 Gt/yr) for the period 1987-2200.

2. The actual fossil fuel record to 1986 and then the best fit straight line to the 1977-1986 data for the period 1987-2200 (see Figure 1).

3. A Gaussian-like fit (see Chapter 2, SCOPE 16, Bacastow and Björkstom, 1981) to the Rotty Record such that a) it has the same total input for the period 1860-1986; b) it passes through the 1986 data point; and c) the total integral is eight times the amount of CO_2 as in the pre-industrial atmosphere (see Figures 1, 2, and 3).

We use the four models discussed earlier and actually include two parameterizations for the OC model. One uses steady-state ^{14}C to parameterize the dynamic processes in the model, and the other uses bomb ^{14}C (see Siegenthaler, 1983). Hence, for each forcing term, there are actually five responses. The results are shown in Figures 4, 5, and 6. In using the Gaussian-like input functions, we extend the time frame to 2500 in order to show how the atmosphere-ocean system begins to relax as the forcing term (Figure 3) goes to zero. In all cases, the OC model, in either parameterization, is by far the most efficient in taking up carbon dioxide.

This range of models certainly includes what is the currently accepted role of the ocean in the global carbon cycle; however, it does not include a model that is sufficiently "efficient" so as to allow for the uptake of the currently accepted deforestation-produced CO_2 (Houghton et al., 1987; Houghton et al., 1985; Palm et al., 1986; and Houghton and Skole in press), though the OC model would come the closest. Therefore, either 1) the current understanding of the oceans is insufficient, or 2) the current estimates of land use-derived CO_2 are in error, or 3) there are important missing processes. It is likely that all three are true. One intermediate approach in testing the sensitivity of CO_2 projections is to include the mismatch as a "donor-controlled" sink in atmospheric concentrations when one includes as a forcing term the deforestation produced CO_2 with the fossil fuel derived CO_2 .

Finally, in light of a recent editorial by Firor (1988), we tested the four models using an emission senario investigated by Maier-Reimer and Hasselman (1987), the results of which are referenced by Firor. In this scenario, fossil fuel use decreases at 2% per year until it reaches half the current (1986) level of 5.56 BMT/yr; a graph of this forcing function is given in figure 7. In his editorial, Firor concerns himself with a quantity called the "airborne fraction" (see e.g., Bolin, 1986; Keeling, 1982; Nordhaus and Yohe, 1983), defined in his work as the

fraction of a year's fossil fuel that remains in the atmosphere after one year. The airborne fraction of the Maier-Reimer/Hasselmann model drops to 0.15 in the emissions scenario just mentioned, and because of this result and its consistency with other studies (reviewed in Bolin, 1986), Firor suggests that society may be able to "come close to stabilizing the atmospheric burden of CO_2 with a 50% reduction in fossil fuel use."

The responses of the four models to this emissions scenario are given on the graph of figure 8a, and the airborne fractions of each are plotted versus time on the graph of figure 8b. Although the behavior of the airborne fraction appears rather complicated, it can be seen from the graph that these models generally take up less of the excess CO_2 than does the Maier-Reimer/Hasselmann model. And, even though the airborne fraction does drop as the input function drops, it begins to rise again for each model after the input function becomes constant. More importantly though, after the input function becomes constant, the rise in atmospheric CO_2 concentration averages between 0.4 ppm/yr (for the outcrop model) and 0.5 ppm/yr (for the box-diffusion model). Admittedly, this rise is considerably less than the approximately 1 ppm/yr rise that is presently occurring, but it does not constitute a stable atmosphere. Tests of the responses of the four models to similar emissions scenarios indicate that emissions would have to be cut to approximately one-tenth of the present level to bring about something close to stabilization (a 0.05 ppm/yr rise).

This topic and other related questions raised by Firor (1988) are the subject of further investigation by the present authors, the results of which will be submitted to the scientific literature.

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Table 1

Model	Biology	Chemistry	Physics
BD	None	Constant buffer	Single eddy diffusivity
OC	None	Fit to data	Single eddy diffusivity with polar outcrop
AB	New production decays exponentially with depth. Similar for carbonate	Full carbonate-borate equilibrium system	Primarily advective with polar outcrop
12B	New production and decay determined by chemical tracers. Similar for carbonate	Full carbonate-borate equilibrium system	Advective-diffusive system with outcrops in both the Arctic and Antarctic regions

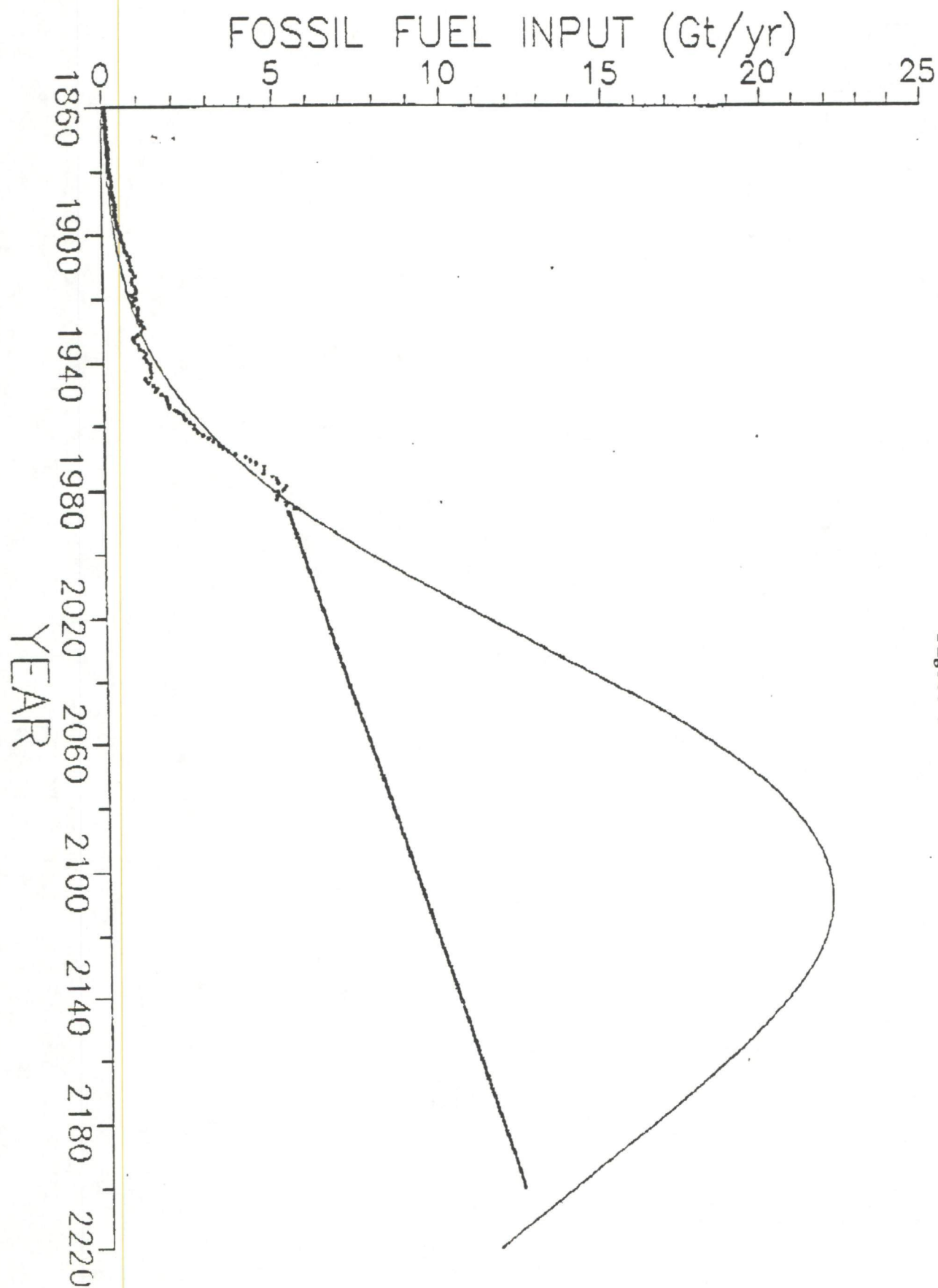


Figure 1

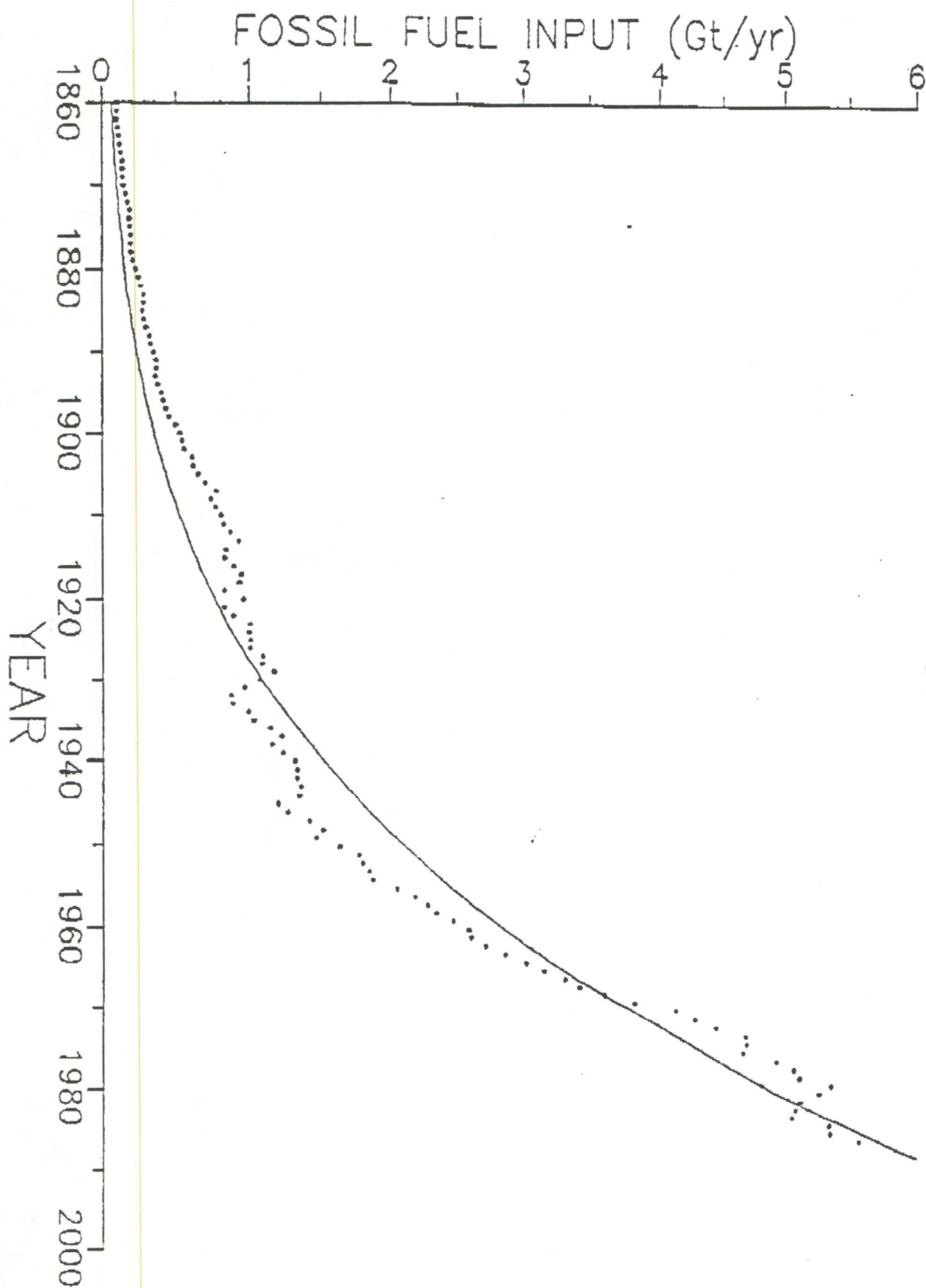


Figure 2

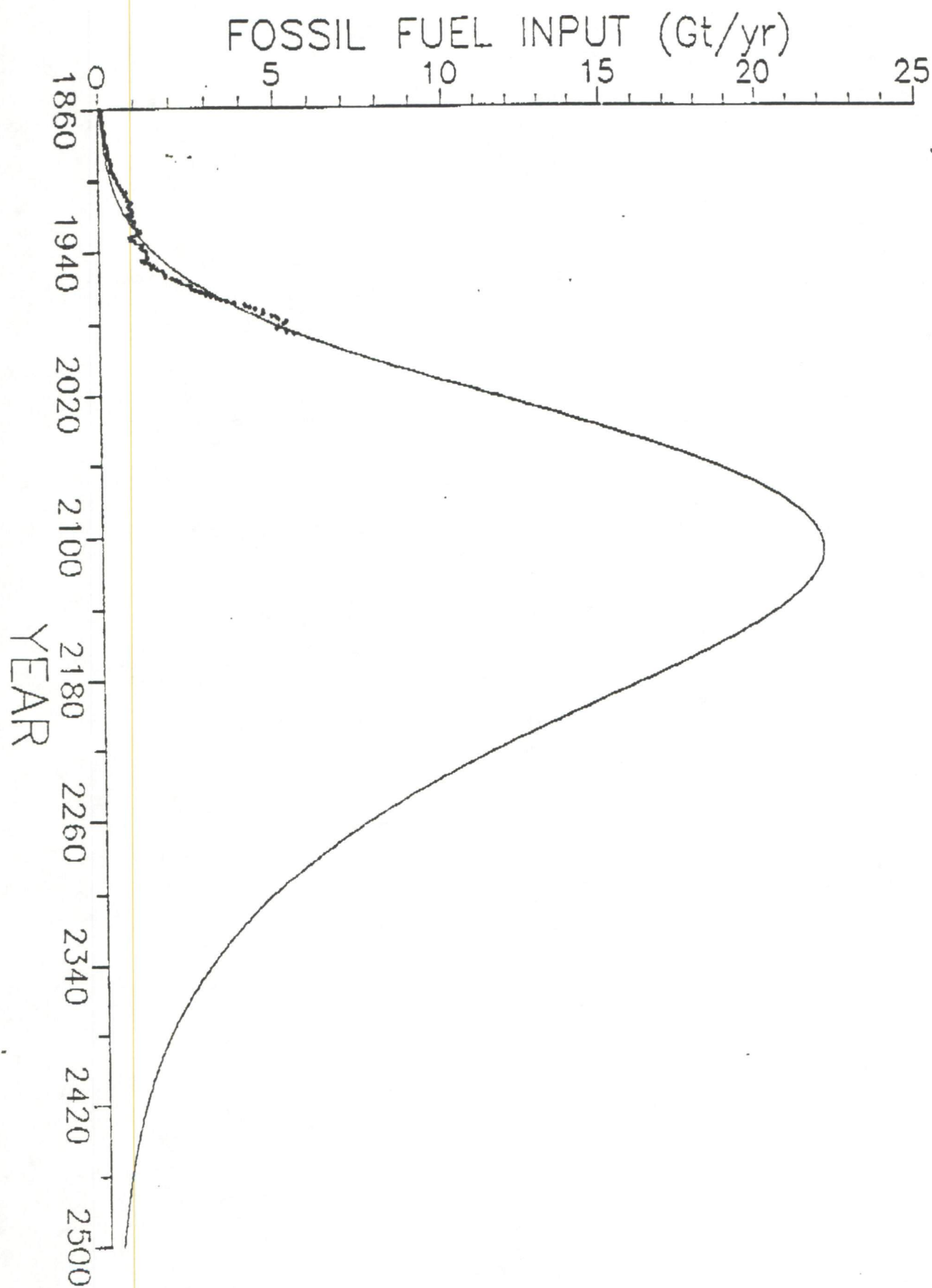
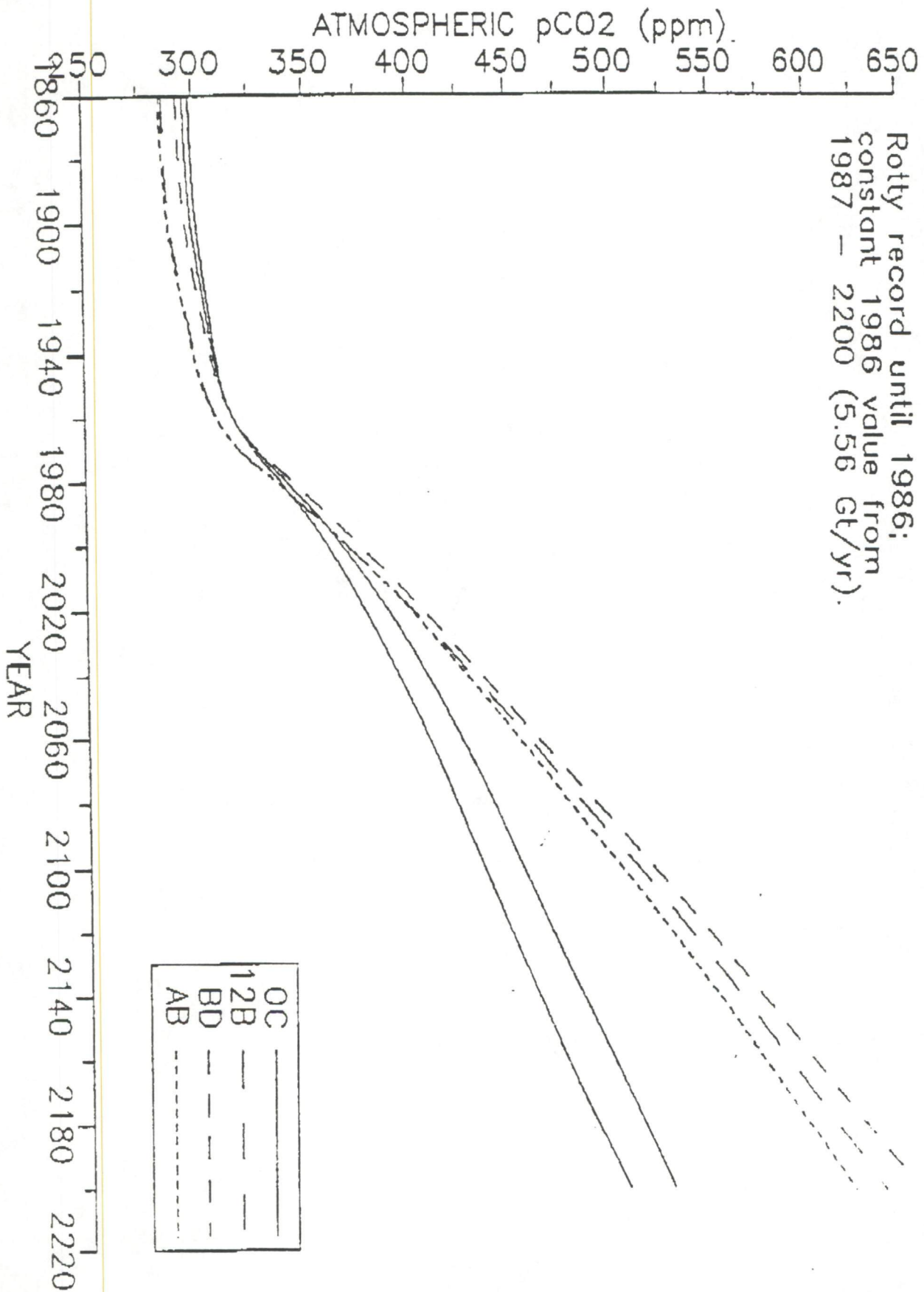
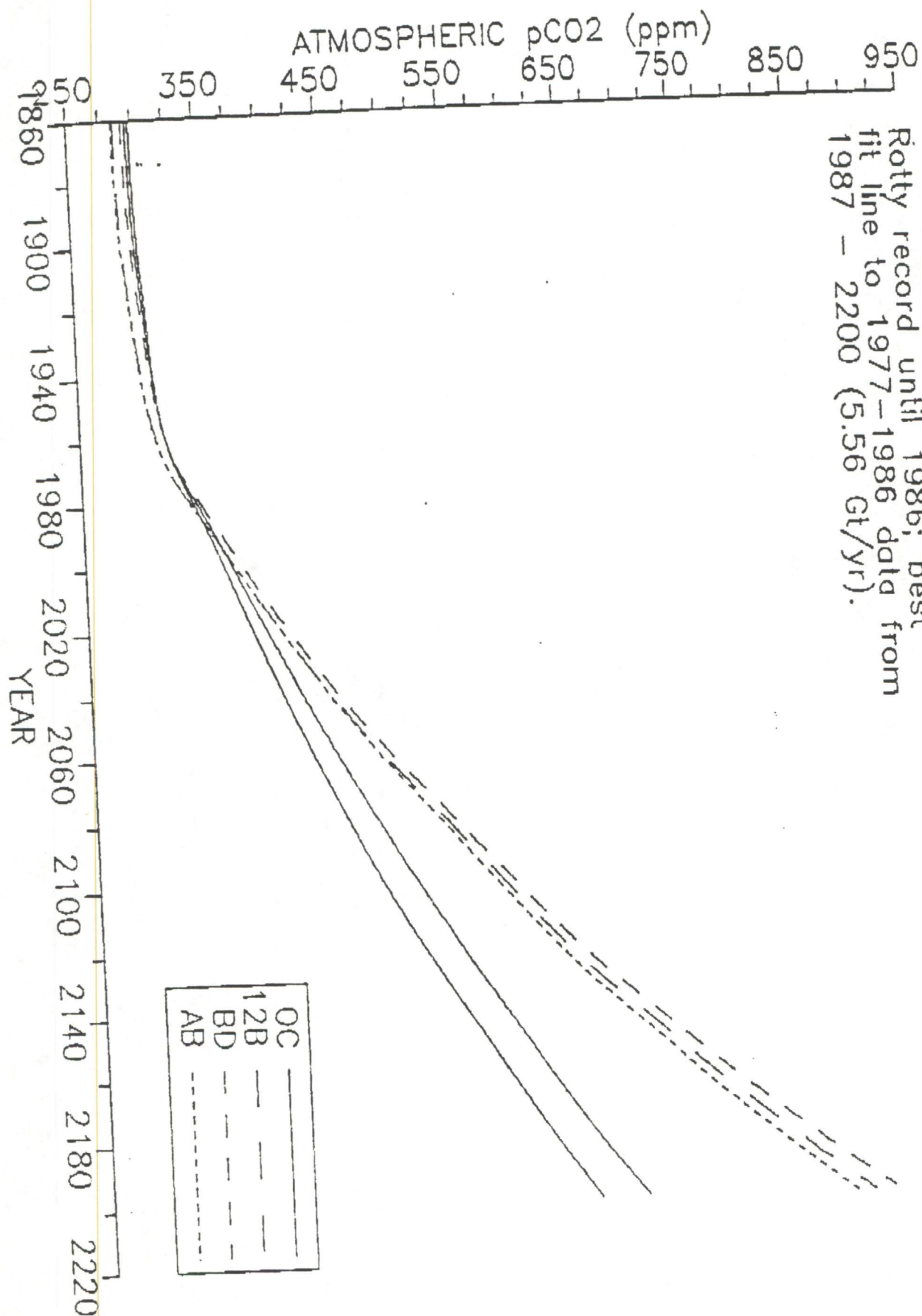
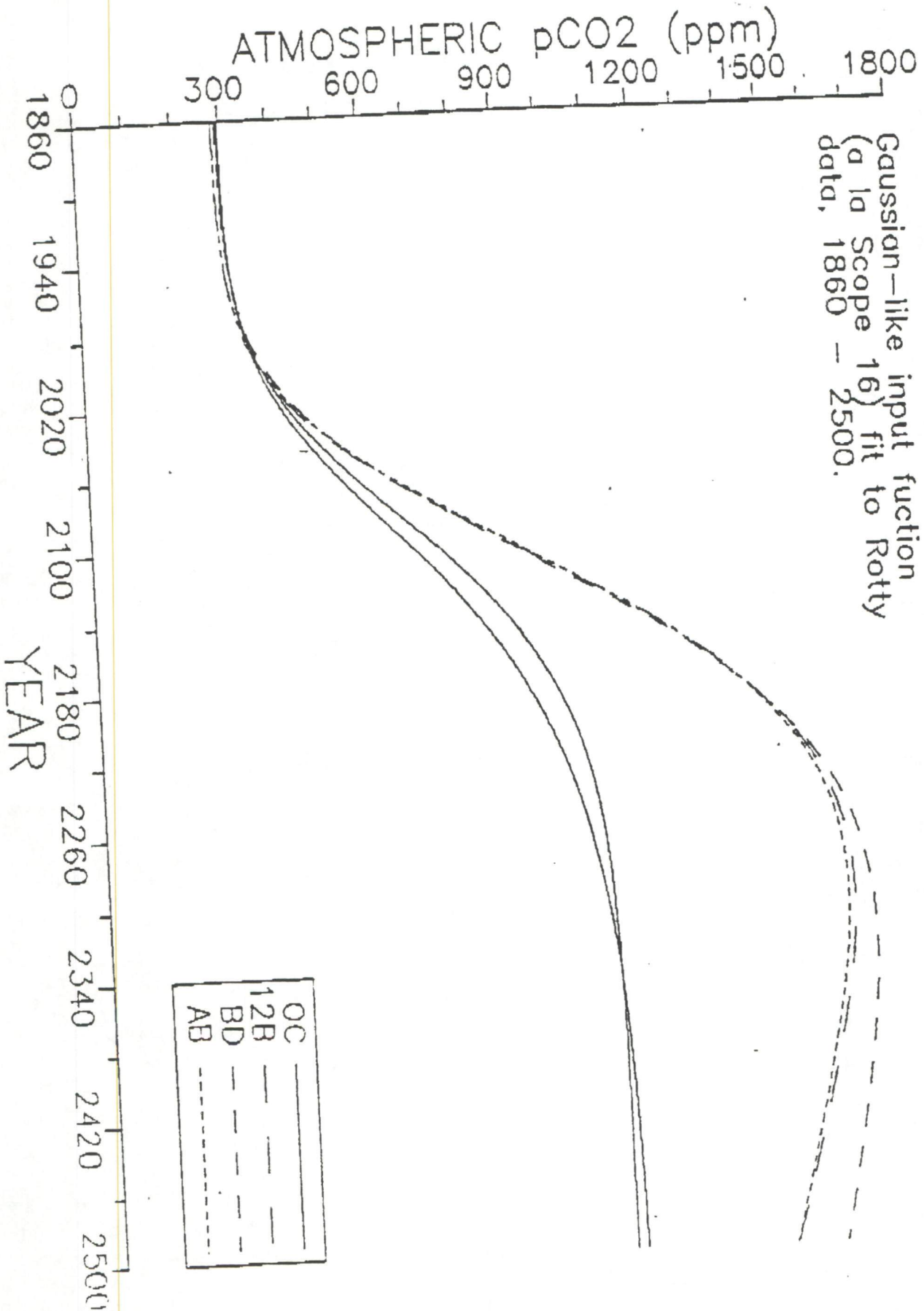


Figure 3







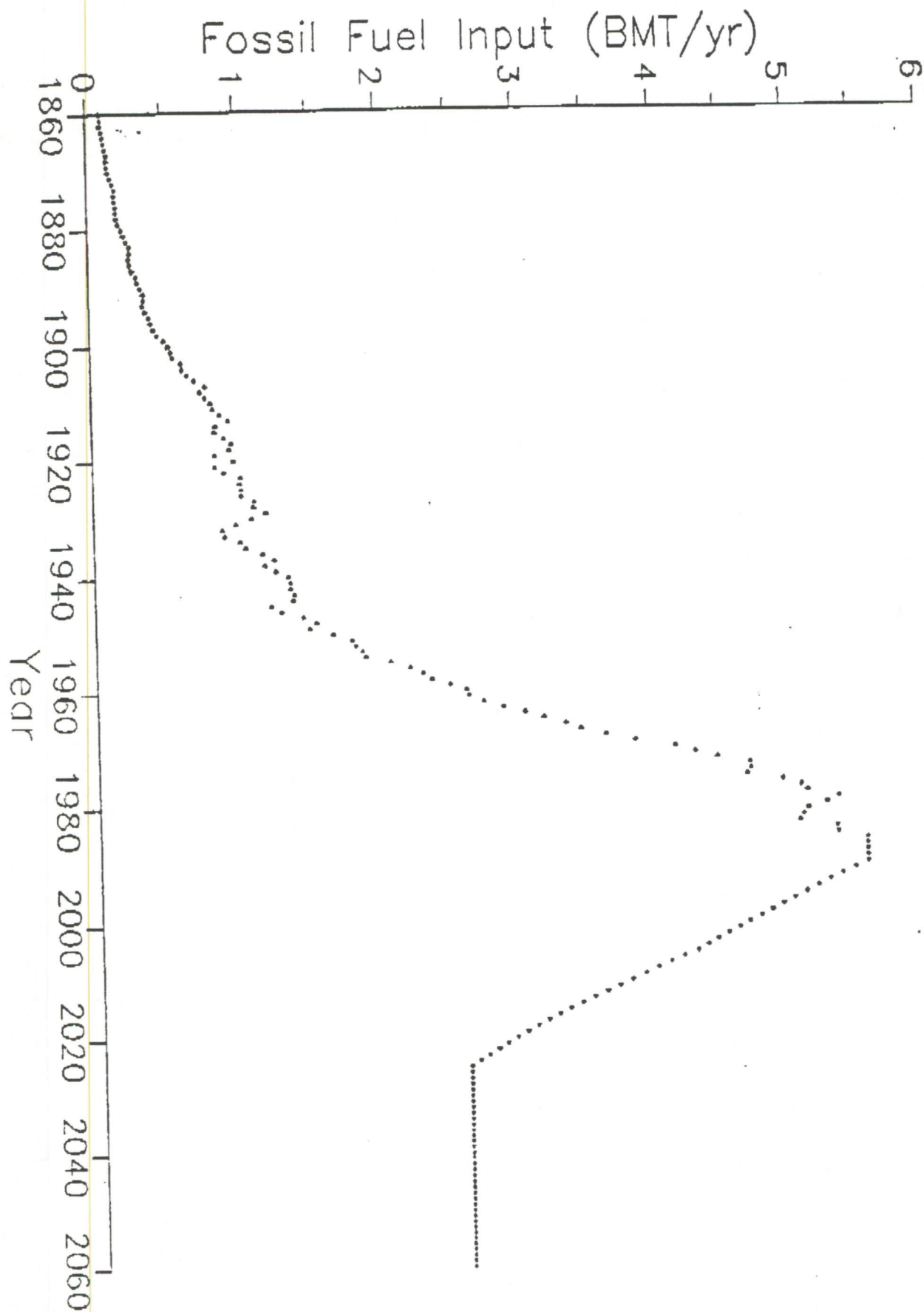


Figure 7

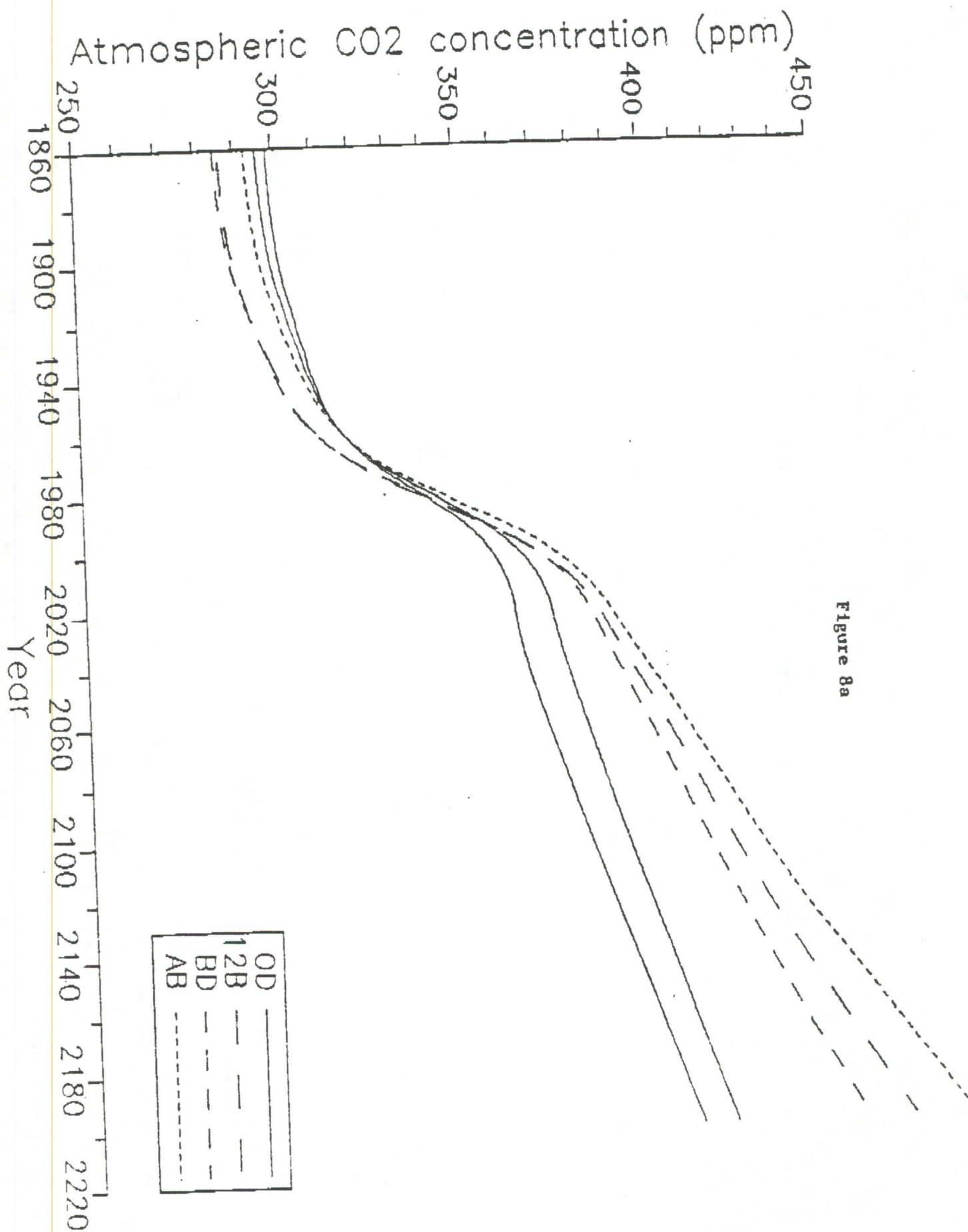


Figure 8a

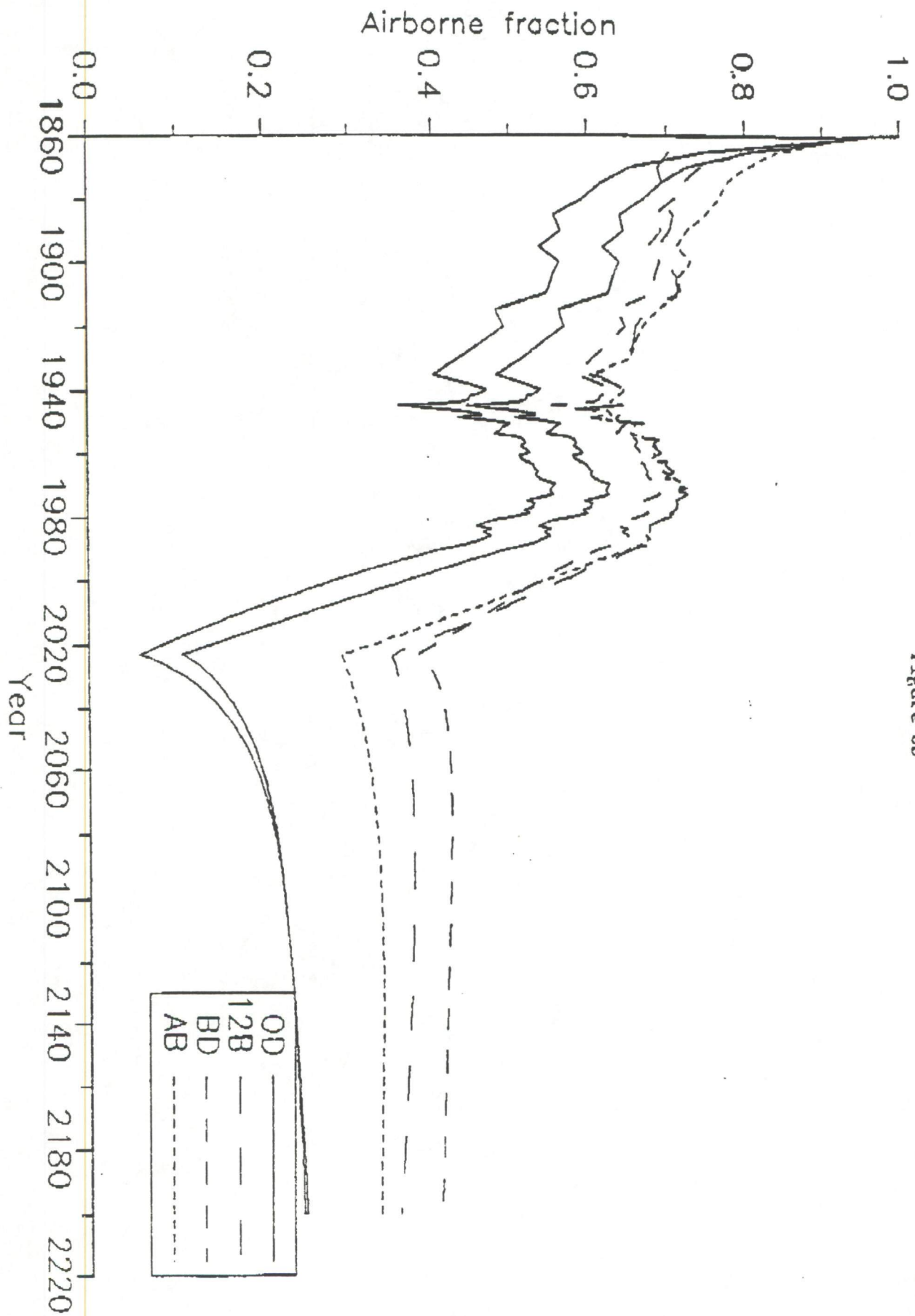


Figure 8b

THE WHITE HOUSE

WASHINGTON

May 25, 1990

MEMORANDUM FOR FRED BERNTHAL
CHRIS DAWSON
MIKE DELAND
THERESA GORMAN
BOB GRADY
HENSON MOORE
BILL REILLY
DICK SCHMALENSEE

FROM: ALLAN BROMLEY
STEVE DANZANSKY

SUBJECT: Global Change Strategy Task Force

The next meeting of the Global Change Strategy Task Force will be on Wednesday, May 30, at 4:00 p.m. in Room 180 of the Old Executive Office Building.

At the meeting we will discuss various options relating to the negotiations for a global climate change convention. An options paper is being prepared by the State Department that will address the issues of (a) the timing of the negotiations' commencement, (b) the basic structure of the negotiating process and its products (e.g., a comprehensive convention, a framework convention with a comprehensive protocol, or a framework convention with a series of protocols), and (c) the appropriate level of the U.S. negotiator. The paper should be distributed late this afternoon or Tuesday morning. As was noted in our meeting earlier this week, Dr. Mostafa Tolba will be convening a meeting in Geneva on June 8, following the Response Strategies Working Group meeting, to begin discussions regarding the preparations and planning for the negotiation process. It will be helpful if the U.S. representative at that meeting (a subject which will also be discussed next week) has at least some preliminary indications of U.S. positions on the broader issues outlined above.

In the interim, we would appreciate your review of and comments on the Policymakers Summary of the Response Strategies Working Group, which will taken up at Geneva the week of June 4, and on the statement of U.S. Global Climate Change Policy, both of which were distributed with our memorandum of May 21. Comments should be directed by COB May 29 to Barry McBee at 456-2800 or Nancy Maynard at 456-6202 so that they can be submitted to the U.S. delegation going to Geneva.

THE WHITE HOUSE
WASHINGTON

DATE: July 10, 1990

TO: *Steve*
Ken Yale ✓

FROM: *EDE* EDE HOLIDAY
Assistant to the President
and Secretary of the Cabinet

*Steve/
Ken -*

*I would like
your thoughts as
to how we would
view his proposal*

EJH

2. page

wrote to you

*our assessment of situation
what doing to remedy it.*



The Secretary of Energy
Washington, DC 20585

July 10, 1990

MEMORANDUM FOR: The Honorable John H. Sununu
The Chief of Staff
The White House

FROM: James D. Watkins *Jim Watkins*
Secretary of Energy

SUBJECT: Domestic Policy Council
Direction in Global Climate

John:

In the next few months, there will be a flurry of international meetings to discuss responses to global warming. These include the Fourth Plenary Intergovernmental Panel on Climate Change (IPCC) meeting in late August, the Second World Climate Conference in late October and early November and the commencement of framework convention negotiations later this year or early next year. Preparing for these meetings must be made a major priority of the Administration.

There is no time to lose. By the end of July, we will need a fully considered U.S. Government position on the IPCC Final Report on Global Climate Change. As you know, John, the U.S. has placed heavy reliance on the IPCC work. This "policymakers' summary" is crucial. It is all anyone will ever read. It will be a primary agenda item for the Second World Climate Conference and will be the foundation for the framework convention negotiations.

I believe that the U.S. position on global climate change is not being adequately reflected in the IPCC Summary Report. Nor does the Summary Report accurately reflect the results of the scientific research reported in the base document. Currently DOE and other agency staff are reviewing the document and supplying line-by-line comments to the State Department. However, there appears to me to be no overall U.S. strategy for the IPCC plenary meeting in August and the follow-on meetings. We still do not seem to have an agenda. Instead, we are reacting, fighting off proposals that advocate immediate action on targets and timeframes for reducing CO₂. As you know, the potential implications to the U.S. economy of adopting premature commitments such as this are tremendous.

We need a better game plan for coordination and development of a U.S. strategy on global climate. Please consider the following:

- o A reaffirmation of the Administration's climate change policy to help assure that we have a strategy that clearly supports this policy. I believe we have a sound policy which needs to be articulated in a positive way.
- o We need more White House guidance and control of the decisionmaking process. I would propose that decisions regarding global climate change policy should be made only after deliberations by the Domestic Policy Council.
- o The DPC should focus on a two-year horizon, coinciding with the 1992 U.N. Conference on Environment and Development. More specifically, we need a comprehensive strategy that anticipates the Fourth IPCC Plenary meeting, the negotiations on a climate change framework convention, and carries us out to the 1992 U.N. Conference, where a framework convention will be signed.
- o Additionally, after the establishment of our policies and positions, we must begin to articulate our posture through the preparation of our draft Ministerial declarations, executive summaries and other international documents. We need to stop merely reacting to other countries' documents and start getting our own positions on the table, early.

I believe that you share my view that we stand at a critical juncture in the global climate change debate. I am convinced that your active personal involvement is essential if we are to succeed in managing this issue properly. I recommend that you chair a special committee of the DPC on developing a long-term strategy on global climate change. We are prepared to commit whatever resources are necessary to assist you in this effort.

DEPARTMENT OF ENERGY
The Office of Policy, Planning and Analysis

DATE: July 10, 1990

TO: Edy Holiday

ORGANIZATION: _____

PHONE NUMBER: 456-2174

FAX: 456-2878

**SUBJECT/
COMMENTS:**

NUMBER OF PAGES
(INCLUDING COVER SHEET) 3

FROM: Linda C. Stuntz, **DOE Policy, Planning
and Analysis**

PHONE NUMBER: (202)-586- 5316

THE WHITE HOUSE
WASHINGTON

August 15, 1990

MEMORANDUM FOR RICHARD SCHMALENSEE

FROM: D. ALLAN BROMLEY *Allan*
SUBJECT: REPORT ON THE ECONOMICS OF GLOBAL CHANGE

I am in general agreement with the suggestion in your memorandum of August 3. However, I would hope that you would ensure that Bob Corell provides you a reasonably complete summary so that the reader at least has a basis for understanding the science that underlies many of the economic discussions that are central to the report.

I remain convinced that this will be a very useful document and look forward to its publication. Let me again thank you for the outstanding job that you have done in pulling all this material together in what is really the first believable analysis.

"CORRESPONDENCE TRACKING"

TYPE: Action Item

DOCUMENT NUMBER: 9023081

FROM: Schmalensee, Richard: Council of Economic Advisors

TO: Bromley

**DATE OF
CORRESPONDENCE: 08/03/90**

SUBJECT: Science subject in final report

ASSIGNED TO: D. Allan Bromley

ACTION REQUIRED: as appropriate

SENDER'S DUE DATE: OSTP DUE DATE: 08/25/90

DATE COMPLETED:

COPIES TO: Nancy Maynard

WHITE HOUSE TRACKING #: CONTACT PERSON:

REMARKS:

DATE RECEIVED: 08/06/90

FILE: NEOB



COUNCIL OF ECONOMIC ADVISERS
EXECUTIVE OFFICE OF THE PRESIDENT
WASHINGTON

August 3, 1990

MEMBER OF THE COUNCIL

MEMORANDUM FOR TASK FORCE ON THE ECONOMICS OF GLOBAL CHANGE

FROM: RICHARD SCHMALENSEE *RS*
SUBJECT: Science in our report

I would like to suggest a change in the focus of our final report -- a change that will, I think, both simplify our revision task and lessen any problems that might be caused by the report's public unveiling. Specifically, I propose to reduce substantially the space devoted to describing the state of the relevant science.

You will recall that we decided initially to include a fairly extensive discussion of the science both to lay out and justify a set of assumptions to be employed in the impact analysis and to make the document more or less self-contained. You will also recall how much effort our group, mainly composed of non-scientists, spent haggling over the description of the state of the science (particularly the description of the uncertainties), even though we agreed fairly easily on the range of plausible magnitudes that should be considered.

I propose that we draw on the considerable public discussion of the science that has occurred since March and stick more closely to our economic knitting. Thus I think we should have a one-page science section that mainly repeats ranges that the IPCC and others have made public, with full citation of all important sources, and cut out all discussions of GCMs, clouds, and oceans. Beyond numbers, I would merely note that considerable research is under way to resolve substantial uncertainties of various sorts and that all models suggest a considerable lag between changes in trace gas concentrations and warming of the earth system. These points seem both relevant to our discussion and (relatively) non-controversial.

If I don't get any howls of outrage early next week, I'll look to Bob Corell for a condensed science section. If there are production problems at Bob's end, CEA will attempt the task.

Note from
Bob Farrell
8/30/90

Global change file

Iron Fertilization History (Neil Andersen)

During the 1980's a group of oceanographers, studying the vertical transport and cycling of carbon (i.e. the NSF supported VERTEX Program), became interested in ocean iron availability since this element is required by plants for the synthesis of chlorophyll. After several years of method development they finally were able to overcome the severe analytical problems associated with measuring the very low concentrations of dissolved and particulate iron occurring in open ocean waters. With this success they were surprised to learn that most of the iron required for plant growth had to come from the fall out of wind-born dust blowing away from the continents out over the ocean.

There are vast areas of the ocean such as the Antarctic and equatorial Pacific that have large amounts of unused plant nutrients. These regions are far from terrestrial iron-rich dust sources and it was logical to suspect a limitation of plant growth resulting from iron deficiency. As a result, Dr. John Martin and co-workers from Moss Landing Marine Laboratories recently went to these regions and determined that indeed, iron concentrations were very low. Furthermore, they found that the addition of very small quantities of iron greatly stimulated plant growth.

These observations led Dr. Martin to speculate that it might be possible for man to fertilize these ocean regions with small amounts of iron which would create massive plant blooms that would in turn stimulate the removal of the greenhouse-gas carbon dioxide from the atmosphere. Soon thereafter the Board on Biology of the NRC convened a meeting in December, 1989 to discuss the issue for the purpose of determining whether or not more in depth consideration of the topic was warranted. Then late in May, 1990, this idea caught the fancy of the media. From various accounts it could have well appeared to the casual observer that a basis had been created and the establishment of an effort for iron fertilization of the ocean to remove atmospheric CO₂ was a fait accompli. However, in reality it remains no more than an idea, albeit a very controversial one. Meetings are being planned to debate the issues and will be held this fall and in early 1991. An expected result will be the beginning of the planning of large scale experiments, possibly to be carried out within the U.S. JGOFS, as well as other appropriate research groups. With the knowledge gained in these large scale studies it will be possible to decide whether iron fertilization is, or is not, a realistic method to actively stimulate the removal of CO₂ from the atmosphere if the need arises.

THE WHITE HOUSE
WASHINGTON

September 17, 1990

MEMORANDUM FOR THE PRESIDENT

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

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

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

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

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

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

Attachment

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

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

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

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

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

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

The Goal:

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

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

The Objectives:

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

What are the Key Areas of Scientific Uncertainty ?

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

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

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

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

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

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

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

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

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

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

How will the US/GCRP be implemented ?

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

Climate Change - Summary of Current Understanding and Recent Developments

The Climate System:

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

Contemporary Changes in the Forcing of the Climate System:

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

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

Historic Changes in the Forcing of the Climate System:

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

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

Predictions of Climate Change:

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

Observations of Temperature Changes:

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

Detection of the "Anthropogenic Greenhouse" Signal:

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

Sea Level:

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

Ecological Systems:

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

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

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

"THE GLOBAL CHANGE RESEARCH ACT OF 1990"

AMENDMENT IN THE NATURE OF A SUBSTITUTE FOR S. 169

STAFF DRAFT

Strike all after the enacting clause and insert in lieu thereof the following:

SHORT TITLE. This Act may be cited as the "Global Change Research Act of 1990."

TITLE I – UNITED STATES GLOBAL CHANGE RESEARCH PROGRAM

SEC. 101. FINDINGS, PURPOSES, AND DEFINITIONS.

(a) **FINDINGS.**—The Congress makes the following findings:

(1) Industrial, agricultural, and other human activities, coupled with an expanding world population, are contributing to processes of global change that may significantly affect the habitability of the Earth within a few human generations.

(2) Such human-induced changes, in conjunction with natural phenomena, may lead to significant global warming and thus alter world climate patterns and increase global sea levels. Over the next century, these consequences could adversely affect productivity of the world's agriculture, forests, and fisheries; coastal habitability; biological diversity; human health; and global economic and social well-being.

(3) The release of chlorofluorocarbons and other stratospheric ozone-depleting substances is rapidly reducing the ability of the atmosphere to screen out harmful ultraviolet radiation, which could adversely affect human health and ecological systems.

(4) Development of effective policies to abate, mitigate, and cope with global change will rely on a comprehensive national research program to improve scientific understanding of global environmental processes and to help distinguish human-induced from natural global changes.

(5) New developments in interdisciplinary Earth sciences, global observing

systems, and computing technology make possible significant understanding and prediction of these global changes and their effects.

(6) Although significant Federal global change research efforts are underway, a productive Federal research program will require effective interagency coordination, and coordination with the activities of State, private, and international entities.

(b) PURPOSES.—The purposes of this Title are—

(1) to provide for development and implementation of a comprehensive United States research program which will help the nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change; and

(2) to integrate and coordinate the global change research activities of the United States.

(c) DEFINITIONS.—As used in this Act, the term —

(1) "Committee" means the Committee on Earth and Environmental Sciences established under Section 102.

(2) "global change" means: (a) the interactive physical, chemical, and biological processes that regulate the Earth system; (b) the unique environment that the Earth provides for life; (c) changes occurring in the Earth system which may influence the future habitability of the Earth, including changes in climate, the atmosphere, land productivity, oceans or other water resources, or ecological systems; and (d) the manner in which such system, environment, and changes are influenced by human actions.

(3) "global change research" means study, monitoring, assessment, prediction, and information management concerning global change;

(4) "Program" means the United States Global Change Research Program established under section 103 of this Act; and

(5) "Plan" means the National Global Change Research Plan developed under

section 104 of this Act, or any revision thereof.

SEC. 102. COMMITTEE ON EARTH AND ENVIRONMENTAL SCIENCES.

(a) **ESTABLISHMENT.**—The President shall establish a Committee on Earth and Environmental Sciences within the Federal Coordinating Council on Science, Engineering, and Technology (hereinafter in this Act referred to as the "Council"). The Committee shall consist of at least one representative each from—

- (1) the National Science Foundation;
- (2) the National Aeronautics and Space Administration;
- (3) the National Oceanic and Atmospheric Administration;
- (4) the Environmental Protection Agency;
- (5) the Department of Energy;
- (6) the Department of State;
- (7) the Department of Defense;
- (8) the Department of the Interior;
- (9) the Department of Agriculture;
- (10) the Department of Transportation;
- (11) the Office of Management and Budget;
- (12) the Office of Science and Technology Policy;
- (13) the Council on Environmental Quality;
- (14) the National Institute of Environmental Health Sciences; and
- (15) such other agencies of the United States as the President considers

appropriate.

Such representatives shall be high-ranking officials of their agency or department, wherever possible the head of the agency or department, or the portion thereof that is most relevant to the purpose of the Committee described in subsection (c) of this section.

(b) CHAIRPERSON.—The Director of the Office of Science and Technology Policy, with the approval of the Committee, biennially shall select one of the Committee representatives to serve as Chairperson. Representatives of the same agency or department may not serve as Chairperson for consecutive terms. For the period between the date of enactment of this Act and January 1, 2000, the Chairperson shall represent one of the following agencies:

- (1) The National Aeronautics and Space Administration.
- (2) The National Oceanic and Atmospheric Administration.
- (3) The National Science Foundation.
- (4) The United States Geological Survey.

(c) PURPOSE.—The purpose of the Committee relative to global change is to increase the overall effectiveness and productivity of Federal global change research. In fulfilling this purpose, the Committee shall address significant global change research priorities which affect more than one agency.

(d) FUNCTION.—A primary function of the Committee shall be to plan and coordinate the United States Global Change Research Program established under section 103 of this Act, by—

- (1) serving as the lead entity responsible for development and oversight of the implementation of the Plan;
- (2) coordinating the global change research activities of Federal agencies and departments;
- (3) providing budgetary advice as specified in section 107 of this Act;
- (4) working with academic, State, industry, and other groups conducting global change research, to coordinate such research and to provide for periodic public and peer review of the Program;
- (5) cooperating with the Secretary of State in —

(A) providing representation at international meetings and conferences on global change research in which the United States participates; and

(B) coordinating the Federal activities of the United States with international global change programs, including the International Geosphere-Biosphere Program, programs of other nations, and programs of international organizations such as the International Council of Scientific Unions, the World Meteorological Organization, and the United Nations Environment Program;

(6) entering into an agreement with the National Academy of Sciences under which the National Academy of Sciences shall—

(A) evaluate the scientific content of the Plan; and

(B) provide information and advice obtained from United States and international sources, and recommended priorities for future global change research;

(7) consulting with actual and potential users of the results of the Program to ensure that such results are useful in developing national and international policy responses to global change;

(8) reporting at least annually to the President and the Congress, through the Chairman of the Committee, on Federal global change research priorities, policies, and programs.

(e) EXECUTIVE SECRETARY.—An Executive Secretary shall be appointed by the Chairperson of the Committee, with the approval of the Committee, from among the permanent employees of one of the agencies represented on the Committee, and shall remain in the employ of such agency or department.

(f) SUPPORT.—The Office of Science and Technology Policy shall provide support necessary for administering the activities of the Committee. The Chairperson shall have the authority to make all personnel decisions regarding the support and administrative staff of

the Committee. The Committee shall make arrangements for the interagency transfer of funds from agencies and departments represented on the Committee to the Office of Science and Technology Policy for administering the activities of the Committee.

SEC. 103. UNITED STATES GLOBAL CHANGE RESEARCH PROGRAM.

The President shall establish an interagency United States Global Change Research Program aimed at understanding global change. The Program will be implemented by the Plan developed under Section 104.

SEC. 104. UNITED STATES GLOBAL CHANGE RESEARCH PLAN.

(a) IN GENERAL.—The President, through the Committee, shall develop a United States Global Change Research Plan for the implementation of the Program. The Plan shall contain recommendations for Federal global change research.

(b) SUBMISSION OF PLAN.—The Committee shall submit the Plan to Congress within one year after the date of enactment of this section and a revised Plan shall be submitted once every three years thereafter.

(c) CONTENTS OF PLAN.—The Plan shall—

(1) establish, for the 10-year period beginning in the year the Plan is submitted, the goals and priorities for Federal global change research which most effectively advance scientific understanding of global change and provide usable information on which to base policy decisions relating to global change;

(2) describe specific activities, including research activities, data collection and analysis, predictive modeling, participation in international research efforts, and information management, required to achieve such goals and priorities;

(3) provide for identification and coordination of the relevant programs and activities of the following agencies and departments —

(A) the Department of Commerce, particularly the National Oceanic

and Atmospheric Administration;

- (B) the National Science Foundation;
- (C) the National Aeronautics and Space Administration;
- (D) the Department of the Interior;
- (E) the Department of Energy;
- (F) the Department of Agriculture;
- (G) the Environmental Protection Agency;
- (H) the Department of Defense, particularly the Department of the

Navy;

- (I) the Department of Transportation;
- (J) the Department of State;
- (K) the National Institute of Environmental Health Sciences; and
- (L) such other agencies of the United States as the President considers

appropriate.

(4) set forth the role of each participating Federal agency or department in implementing the Plan;

(5) include consideration, as appropriate, of reports and studies conducted by Federal agencies and departments, the National Research Council, and other entities;

(6) recommend allocations of Federal funding among specific global change research activities, in a manner which avoids redundancy and maximizes efficiency among Federal programs;

(7) provide for, to the fullest extent possible, participation in international projects to –

(A) create globally accessible formats for data collected by various international sources; and

(B) combine and interpret data from various sources to produce information readily usable by policymakers attempting to formulate effective strategies for preventing, mitigating, and adapting to the effects of global change.

(8) make recommendations for the coordination of the global change research activities of the United States with such activities of other nations and international organizations, including—

(A) a description of the extent and nature of necessary international cooperation;

(B) the development by the Committee, in consultation with the National Space Council, of proposals for cooperation on major capital projects, including space systems;

(C) bilateral and multilateral proposals for improving worldwide access to scientific data and information; and

(D) methods for improving participation in international global change research by developing nations;

(9) provide for the following research elements:

(A) Global measurements for establishing worldwide observations necessary to document global changes on all relevant spatial and time scales, including standardization of measurement techniques.

(B) Basic and applied research to understand the nature of and interactions among the physical, chemical, biological, and social systems related to global change.

(C) Studies of past changes in the Earth system, using historical evidence from the geological and fossil record.

(D) Predictions, using quantitative models of the Earth system, to

identify and simulate global environmental processes and trends, and the regional implications of such processes and trends.

(E) Development of new and conceptual numerical models of the Earth system.

(F) Development of a national information base, including necessary management systems which will promote consistent, efficient, and compatible transfer and use of data.

(d) PUBLIC COMMENT ON THE PLAN -- Not later than 90 days before the Committee submits the Plan to Congress, the Committee shall publish a proposed Plan in the Federal Register for a public comment period of not less than 60 days, and shall consider any comments received before drafting and publishing the Plan or revision.

SEC. 105. SCIENTIFIC ASSESSMENTS.

On a periodic basis (not less frequently than every three years), the Committee shall prepare and submit to the President and the Congress an assessment which--

(a) integrates, evaluates, and interprets the findings of the Program and discusses the scientific uncertainties associated with such findings;

(b) analyzes the effects of global change on the natural environment, agriculture, energy production and use, land and water resources, transportation, human health and welfare, human social systems, and biological diversity;

(c) analyzes current trends in global change, both human-induced and natural, and projects major trends for the subsequent 25 to 100 years; and

(d) provides information useful for developing policy decisions and recommendations that improve the ability to prevent or adapt to global change.

SEC. 106. CONSULTATION WITH INDUSTRY, ACADEMIC, AND ENVIRONMENTAL GROUPS AND REPRESENTATIVES.

In developing the Plan and the periodic assessment documents specified in sec. 105, the Committee shall regularly consult with academic, State, industry, and environmental groups and representatives. To fulfill this requirement, the Committee may create one or more advisory boards comprised of representatives from these groups.

SEC. 107. BUDGET.

(a) COMMITTEE GUIDANCE.— The Committee shall each year provide general guidance to each Federal agency or department participating in the Program with respect to the preparation of requests for appropriations for activities related to the Program.

(b) SUBMISSION OF REPORTS WITH AGENCY APPROPRIATIONS REQUESTS.—

(1) Working in conjunction with the Committee, each Federal agency involved in global change research shall include with its annual request for appropriations submitted to the President under section 1108 of Title 31, United States Code, a report which—

(A) identifies each element of the proposed global change research activities of the agency;

(B) specifies whether each element—

(i) contributes directly to the Program; or

(ii) contributes indirectly but in important ways to the

Program; and

(C) states the portion of its request for appropriations allocated to each element of the Program.

(2) Each agency that submits a report under paragraph (1) shall submit such report simultaneously to the Committee.

(c) CONSIDERATION OF PLAN IN PRESIDENT'S BUDGET.—

(1) Before submitting each annual budget to the Congress under Section 1105 of Title 31, United States Code, the President shall provide to the Committee an opportunity to

review and comment on the budget estimate for each agency in the context of the Plan;

~~(2) At the time of the submission of each annual budget to the Congress, the President shall make the results of such review and comments available to the Congress and to each agency represented on the Committee.~~

(2)
(3) The President shall identify in each annual budget submitted to the Congress under section 1105 of Title 31, United States Code those items in each agency's annual budget which are elements of the Program.

SEC. 108. ANNUAL REPORTS.

Each year at the time of submission to the Congress of the President's budget, the Committee shall submit to the Congress a report on the activities conducted by the Committee pursuant to this Act, including—

(1) a summary of the achievements of the Program during the period covered by the report and of priorities for future global change research;

(2) an analysis of the progress made toward achieving the goals of the Plan;

(3) recommendations by the President concerning—

(A) changes in agency roles needed to better implement the Plan; and

(B) additional legislation which may be required to achieve the purposes of this Act; and

(4) expenditures required by each agency for carrying out its portion of the Program, including—

(A) the amounts spent during the fiscal year most recently ended;

(B) the amounts expected to be spent during the current fiscal year;

and

(C) the amounts requested for the fiscal year for which the budget is being submitted.

SEC. 109. NATIONAL REMOTE SENSING ADVISORY COMMITTEE

Not Later than 60 days after the enactment of this Act, the Director of the Office of Science and Technology Policy shall establish a permanent National Remote Sensing Advisory Committee made up of representatives of remote sensing data users, data vendors, technology developers, system operators, information management and telecommunications specialists, and social scientists from the Government and the private sector. Such Committee shall:

(a) provide advice and policy recommendations to the President, the President's Science Advisor, and relevant Committees of the United States Congress on the development of an integrated remote sensing policy that would be responsive to both user needs and global developments, in terms of—

(1) coordinating land, oceanic, and atmospheric remote sensing systems, including ground stations;

(2) coordinating research and development, applications, and commercial remote sensing activities;

(3) fostering effective integration of satellite, aerial, and in situ data; and

(4) assessing current institutional arrangements for the management, exploitation, and sharing of both real-time and archived data.

(b) provide recommendations on the conduct of cooperative test and applications demonstration projects designed to manage environmental pollution and the use of natural resources; and

(c) coordinate with the Program on issues of mutual concern.

SEC. 110. EFFECT ON FEDERAL RESPONSE ACTIONS

Nothing in this title shall be construed, interpreted, or applied to preclude or delay the planning or implementation of any Federal action designed, in whole or in part, to identify, prevent, mitigate, adapt to, or otherwise respond to the effects of global change.

TITLE II—INTERNATIONAL COOPERATION IN GLOBAL CHANGE RESEARCH

SEC. 201. SHORT TITLE.

This title may be cited as the "International Cooperation in Global Change Research Act of 1990."

SEC. 202. FINDINGS AND PURPOSES.

(a) **FINDINGS.**—The Congress makes the following findings:

(1) Pooling of international resources and scientific capabilities will be essential to a successful international global change program.

(2) While international scientific planning is already underway, there is currently no comprehensive intergovernmental mechanism for planning, coordinating, or implementing research to understand global change and to mitigate its adverse effects.

(3) An international global change program will be important in building future consensus on methods for reducing global environmental degradation.

(4) The United States, as a world leader in environmental and Earth sciences, should help provide leadership in developing and implementing an international global change research program.

(b) **PURPOSES.**—The purposes of this Title are:

(1) to promote international, intergovernmental cooperation on global change research;

(2) involve scientists and policymakers from developing nations in such cooperative global change research programs; and

(3) promote international efforts to provide technical and other assistance to developing nations which will facilitate improvements in their domestic standard of living while minimizing damage to the global or regional environment.

SEC. 203. INTERNATIONAL DISCUSSIONS.

(b) **ENERGY RESEARCH.**—The President shall direct the Secretary of State (in cooperation with the Secretaries of Energy and Commerce, the United States Trade Representative, and appropriate agencies represented on the Committee) to initiate discussions, to the fullest extent possible, with other nations leading toward an international research protocol for cooperation on the development of energy technologies which have minimally adverse effects on the environment. Such discussions shall include the following issues:

(1) Creation of an international cooperative program to fund research related to energy efficiency, solar and other renewable energy sources, and passively safe and diversion-resistant nuclear reactors.

(2) Creation of an international cooperative program to develop low cost energy technologies which are appropriate to the environmental, economic, and social needs of developing nations.

(3) Exchange of information concerning environmentally safe energy technologies and practices, including those described in subparagraphs (1) and (2).

SEC. 204. GLOBAL CHANGE INFORMATION OFFICE

Not more than 180 days after the date of enactment of this section, the President shall, in consultation with the Committee and all relevant Federal agencies, establish an Office of Global Change Information. The purpose of the Office shall be to disseminate to foreign governments, businesses and institutions, as well as the citizens of foreign countries, information available in the United States which would be useful in identifying, preventing, mitigating, or adapting to the effects of global change. Such information shall include methods and technologies to—

(A) reduce energy consumption through conservation and energy efficiency;

(B) promote the use of solar and renewable energy sources which reduce the amount of

greenhouse gases released into the atmosphere;

(C) develop replacements for chlorofluorocarbons, halons, and other ozone-depleting substances which exhibit a significantly reduced potential for depleting stratospheric ozone;

(D) promote the conservation of forest resources which help reduce the amount of carbon dioxide in the atmosphere;

(E) assist developing countries in ecological pest management practices and in the proper use of agricultural and industrial chemicals; and

(F) promote recycling and source reduction of pollutants in order to reduce the volume of waste which must be disposed of, thus decreasing energy use and greenhouse gas emissions.

TITLE III - NATIONAL CLIMATE PROGRAM ACT AMENDMENTS

The National Climate Program Act is amended—

- (1) in section 2(6) (15 U.S.C. 2901(6)) by striking "lacks" and inserting in lieu thereof "needs";
- (2) in section 3 (15 U.S.C. 2902(3)) by striking "man-induced" and inserting in lieu thereof "human induced";
- (3) in section 4 (15 U.S.C. 2903) by—
 - (A) striking paragraphs (1), (2), and (4);
 - (B) redesignating paragraph (3) as paragraph (1); and
 - (C) inserting a new paragraph as follows:

"(2) The term "Committee" means the Committee on Earth and Environmental Sciences established pursuant to section 102 of the Global Change Research Act of 1989."
- (4) in section 5(a) (15 U.S.C. 2904) by—
 - (A) striking "President" and inserting in lieu thereof "Committee"; and
 - (B) Inserting "Such Program shall be integrated with and maintained as an identifiable programmatic unit within the National Global Change Research Program established pursuant to section 103 of the Global Change Research Act of 1989." after "findings and purposes of this Act."
- (5) by amending section 5(b) (15 U.S.C. 2904(b)) to read as follows:

"(b) Duties.—The Committee shall—

 - (1) ensure promulgation of the 5-year plans described in subsection (d)(9);
 - (2) define the roles in the Program of Federal agencies represented on the Committee, recognizing in particular the important role of the National Oceanic and Atmospheric Administration within the Department of Commerce in conducting climate-related

research and providing climate services;

(3) provide for Program coordination with the Global Change Research Program established pursuant to section 103 of the Global Change Research Act of 1989; and

(4) cooperate and participate, to the fullest extent possible, with foreign, international, or domestic organizations and agencies involved in climate-related activities, as necessary to carry out the Program."

(6) in section 5(c) (15 U.S.C. 2904(c))—

(A) by striking "National Climate Program Office.—" and inserting in lieu thereof "Financial Assistance.—";

(B) by striking paragraphs (1), (2), and (4); and

(C) in paragraph (3)—

(i) by striking "(3)";

(ii) by striking "The Secretary may provide, through the Office" and inserting in lieu thereof "The Federal agencies represented on the Committee may provide"; and

(iii) by striking "if such goals" and all that follows through "department, agency, or instrumentality."

(7) in section 5(d)(2) (15 U.S.C. 2904(d)(2)), by striking "man-induced" and inserting in lieu thereof "human-induced";

(8) in section 5(d)(7) (15 U.S.C. 2904(d)(7)),

(A) by redesignating clauses (A) through (E) as clauses (B) through (F), respectively;

(B) by inserting before clause (B), as so redesignated, the following new clause: "(A) establishment of regional climate centers;";

(C) by striking "The Secretary" and inserting in lieu thereof "In carrying out subparagraphs (A) through (F) of this section, Federal agencies represented on the Committee"; and

(D) by striking "group of States, which grants" and inserting in lieu thereof "group of States. Such grants".

(9) by striking section 5(e) (15 U.S.C. 2904(e));

(10) by striking section 5(f) (15 U.S.C. 2904(f));

(11) by striking section 5(g) (15 U.S.C. 2904(g));

(12) by redesignating section 7 as section 6;

(13) in section 6, as so redesignated—

(A) by striking "The Secretary" and all that follows through "March 31 of each year," and inserting in lieu thereof "As part of the annual reports required under Sec. 106 of the Global Change Research Act of 1989, the Committee, in consultation with the Secretary of Commerce, shall prepare";

(B) by inserting "and" at the end of paragraph (c);

(C) by striking paragraph (d); and

(D) by redesignating paragraph (e) as paragraph (d);

(14) by striking section 8 (15 U.S.C. 2907); and

(15) by striking section 9 (15 U.S.C. 2908).

Amend the title to read as follows: "To require the establishment of a Global Change Research Program aimed at understanding and responding to global change, including the cumulative effects of human activities and natural processes on the environment, to require the initiation of discussions toward international protocols in global change research, and for other purposes."

1 (6) promote recycling and source reduction of
2 pollutants in order to reduce the volume of waste which
3 must be disposed of, thus decreasing energy use and
4 greenhouse gas emissions.

5 TITLE III--NATIONAL CLIMATE PROGRAM ACT AMENDMENTS

6 SEC. 301. NATIONAL CLIMATE PROGRAM.

7 Section 5 of the National Climate Program Act (15 U.S.C.
8 2904(b)) is amended--

9 (1) by striking subsection (b);

10 (2) in subsection (d)--

11 (A) by striking paragraph (6);

12 (B) by redesignating paragraphs (7), (8), and

13 (9) as paragraphs (6), (7), and (8); and

14 (C) in paragraph (8), as so redesignated, by
15 striking "period," and all that follows and
16 inserting in lieu thereof "period."; and

17 (3) by striking subsection (g).

18 SEC. 302. ANNUAL REPORT.

19 Section 7 of the National Climate Program Act (15 U.S.C.

20 2906) is amended--

21 (1) in subsection (b) by adding "and" at the end;

22 (2) by striking subsections (c) and (d); and

23 (3) by redesignating subsection (e) as subsection

24 (c).

(a) GLOBAL CHANGE RESEARCH.—The President shall direct the Secretary of State, in cooperation with the Committee, to initiate discussions, to the fullest extent possible, with other nations leading toward international protocols and other agreements to coordinate global change research activities. Such discussions shall include the following issues:

(1) Allocation of costs in global change research programs, especially with respect to major capital projects, with a goal of avoiding redundancy and maximizing efficiency.

(2) Coordination of global change research plans with those developed by international organizations such as the International Council on Scientific Unions, the World Meteorological Organization, and the United Nations Environment Program.

(3) Establishment of global change research centers and training centers for scientists, especially those from developing nations.

(4) Development of innovative methods for management of international global change research, including—

(A) use of new or existing intergovernmental organizations for the coordination or funding of global change research; and

(B) creation of a limited foundation for global change research.

(5) The prompt establishment of prototype international projects to—

(A) create globally accessible formats for data collected by various international sources; and

(B) combine and interpret data from various sources to produce information readily usable by policymakers attempting to formulate effective strategies for preventing, mitigating, and adapting to the effects of global change.

(6) Establishment of international offices to disseminate information useful in identifying, preventing, mitigating, or adapting to the effects of global change.

October 21, 1990

MEMORANDUM FOR D. ALLAN BROMLEY

FROM: KEN YALE *KY*
SUBJECT: Global Change Meeting

Attached are materials that were distributed in anticipation of the Global Change Strategy Task Force meeting on Tuesday afternoon. Nancy and Vickie have done an excellent job of coordinating this meeting. Before the meeting takes place we should discuss the agenda. I believe a brief 2:30 appointment has been put on your calendar for this purpose.

This meeting will also be mentioned at the environmental breakfast on Tuesday morning. One topic that may also be discussed is the forestry convention paper that is being prepared by EPA at our request. Hank Habicht asked me if that would be the appropriate forum to initially broach the topic, with further explanation at the global change meeting. I said I would seek your direction on that matter.

The EPA paper was completed last week. There are potential pitfalls to getting out ahead of that issue. On the other hand, someone has to show initiative on the issue.

Also, I should mention to you the latest developments on the global change research act. It seems that the process of working with the Hill was very complicated, but the outcome may be the best for all involved. We should discuss this before Sununu's staff meeting in the morning.

THE WHITE HOUSE
WASHINGTON

November 6, 1990

MEMORANDUM FOR RICHARD G. DARMAN
DIRECTOR, OFFICE OF MANAGEMENT AND BUDGET

FROM: D. ALLAN BROMLEY *Alan*

SUBJECT: S. 169, Global Change Research Act

We have been asked to comment on the enrolled bill entitled "The Global Change Research Act" (S. 169). Following is the opinion of the Office of Science and Technology Policy on this legislation.

The substance of the legislation, as well as its effect on the interagency process under the Federal Coordinating Council on Science, Engineering and Technology (FCCSET), would indicate the necessity of a pocket veto. FCCSET is still in an experimental stage and it would be highly problematic to freezing any of its components into legislation as additional improvements are contemplated.

However, political considerations may dictate a conclusion other than a pocket veto at this time. In particular, OSTP is fully supportive of the Committee on Earth and Environmental Sciences and we cannot be perceived as opposing the committee's successful activities in coordinating science and technology programs of the Federal government. Therefore, we take no position at this time and defer to the West Wing, in particular Governor Sununu, to make a decision based on his best political judgement.

"CORRESPONDENCE TRACKING"

TYPE: Information

DOCUMENT NUMBER: 9024213

FROM: Correll, Robert: NSF

TO: Bromley

*global change
file*

DATE OF
CORRESPONDENCE: 11/27/90

SUBJECT: Letter to Bob Grady re: global change program

ASSIGNED TO:

ACTION REQUIRED:

SENDER'S DUE DATE:

OSTP DUE DATE:

DATE COMPLETED: -----

COPIES TO: Maryanne Bach
Nancy Maynard
D. Allan Bromley

WHITE HOUSE TRACKING #:

CONTACT PERSON:

REMARKS:

DATE RECEIVED: 11/29/90

FILE: ENVIRONMENT

NATIONAL SCIENCE FOUNDATION

WASHINGTON, D.C. 20550



OFFICE OF THE
ASSISTANT DIRECTOR
FOR GEOSCIENCES

November 27, 1990

Mr. Robert Grady
Associate Director
Natural Resources Energy and Science
Office of Management and Budget
New Executive Office Building
Washington, D.C. 20503

Dear Mr. Grady:

On behalf of Dr. Dallas Peck, Chairman of the Committee on Earth and Environmental Sciences (CEES), I am conveying to you the CEES Working Group on Global Change (WGGC) responses to follow-on questions raised by the OMB with respect to the U.S. Global Change Research Program (USGCRP). Understanding the need of the OMB to resolve these questions prior to making any final decision concerning the FY 92 Budget, the WGGC is providing a response to all follow-on questions at this time.

The WGGC hopes that this response meets the informational needs of the OMB as they relate to the FY 92 Budget decision. I would welcome the opportunity to further discuss with you the enclosed response, proposed Program options, and their implications to the USGCRP.

Thank you for the opportunity to provide further information concerning the USGCRP.

Sincerely,

Robert W. Corell
Chairman, CEES Working Group
on Global Change

Enclosure

cc:D. Allan Bromley
D. Peck

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.

ANSWER: The CEES Working Group on Global Change (WGGC) concurs with the Academy Panel's assessment of the need to continually evaluate and maintain an appropriate balance between the long-term investments in synoptic-scale satellite observational programs and the associated ground-based observations, process studies, modeling, and information management efforts which will comprise an effective U.S. Global Change Research Program. We believe that an early commitment to a comprehensive global observing system (EOS, Earth probes, operational satellites, and a complementary program of intensive, Earth-based in situ measurements) is essential to the ultimate success of a Program whose goal is to establish the scientific basis for national and international policymaking related to natural and human-induced changes in the global earth system and to achieve a predictive understanding of the entire Earth system. The establishment of integrated, international, comprehensive (satellite and in situ) ocean, atmospheric, and terrestrial observing systems and the improvement of the existing atmospheric system is critical to many of the research elements discussed throughout the USGCRP, both to further the research and to establish the long-term data bases necessary to develop predictive models and to verify them. Complementing this comprehensive observing system will be a number of intensive research projects aimed at understanding and modelling key aspects of the behavior of the Earth system. Resources to support these research and modeling activities will receive continued support over the lifetime of the USGCRP.

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.

ANSWER: The CEES WGGC agrees with the need for a more sharply-focused and aggressive program in Earth system modeling and the need for a workable plan for interpreting and delivering the results in a form useful for policymakers. USGCRP documentation, including individual agency project 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, the NSF Integrated Climate and Modeling, Analysis and Prediction Program (ICMAP), combined with the DOE modelling initiative (Computer Hardware, Applied Mathematics and Model Physics—CHAMMP) are specifically cited as the first steps in the evolution of an integrated CEES approach to the problem.

CEES agencies have supported scientific planning meetings on the subject of climate and Earth system modelling and the new initiatives. These projects represent significant new 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.

ANSWER: The CEES WGGC 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 our initial level of scientific planning in the area of a "Human Interactions" element of global change research. The DOE-CO2 data base on emissions from fossil fuels demonstrates the relationship between human activities and global change. The USDA studies associated with human interactions related to agriculture and forestry are directly focused on how human activities influence global change. CEES WGGC 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 the Academy Committee's most recent submission to IGBP and in the CEES WGGC plans for FY 1992 and beyond. We believe that this science element should continue to receive considerable national and international 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 national mechanism to provide that attention, and that additional international mechanisms must continue to evolve.

The CEES and other interested Agencies are currently concluding an important analysis of the economic research agenda for Global Change. A report is expected to be submitted to the Administration very soon.

The USGCRP will remain responsive to new scientific insights and unanticipated needs, as it recognizes that other surprises such as the discovery of the antarctic ozone hole are likely to continue to occur.

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 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.

ANSWER: The identification of a selected set of "Integrating Themes" for the USGCRP as part of the FY 1992 budget development process has helped the CEES WGGC 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.

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.

ANSWER: The CEES WGGC 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 WGGC has already begun an 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. The 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.

ANSWER: 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, NOAA, and DOE, and continued support for such projects remains a high priority for the CEES. For many agencies, support for an individual project includes explicit identification of resources to support national and/or international program/project offices (e.g., multi-agency 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). Many agencies include support for national and international scientific planning/coordination offices like the IGBP Secretariat in Stockholm in their annual budget requests, although, for practical reasons associated with budget justification procedures, this support is associated with individual programs rather than as "stand-alone" budget line items. The U.S. is the single largest contributor to international research programs, to the needed infrastructure, and to project offices. Some agencies are specifically constrained, by law, from major international research activities.

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 explicit consideration of related efforts on the part of other countries and international research programs like those of the WCRP.

The U.S., particularly the CEES, was instrumental in forging new arrangements to facilitate international collaboration and coordinating mechanisms for government agencies of many countries to jointly plan and implement international programs of Global Change research. Virtually every major Global Change international research program was initiated, nurtured and substantially supported by the U.S. Further, the U.S. was singularly influential in the establishment of the International Group of Funding Agencies for Global Change Research (IGFA), including the chairmanship, secretariat, and substantial staff support. IGFA is essentially the equivalent of an international CEES. It was founded in the summer of 1990 after 18 months of planning, in which the U.S. played the leadership role. Its primary purpose is to facilitate coordinated implementation of global-scale research programs (i.e., WOCE, TOGA, IGAC, PAGES, JGOFS, GEWEX, GLOBEC, etc.) and to explicitly coordinate resource allocations (funding major capital equipment like ships, supercomputers, satellites and scientific manpower requirements). The group will meet semiannually, with the next meeting scheduled for February 1991 in the U.K.

In addition to the active support provided by the US. for international research programs, there has been significant participation by the U.S in the Working Groups of the International Panel on Climate Change (IPCC). The results of the studies from this panel are expected to help direct future US research projects in the area of basic science, as well as in the planning of response strategies and in the assessment of the impacts of global change.

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.

ANSWER: We concur with the need for, and seek, 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 USGCRP. In terms of the overall Program, the CEES Working Group on Global Change will continue to seek the advice and guidance of the Academy, primarily through its Committee on Global Change (CGC). We 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.

ANSWER: CEES recognizes that a 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 identified role/responsibility of each participating agency. It must also be recognized that industrial, state and local funding for global change research must be strengthened to complement federal funding.

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 remains committed to a USGCRP that effectively engages the broad scientific community. The CEES Working Group on Global Change agrees with the Panel's assessment that the distribution of funding between in-house and extramural efforts should be more explicitly addressed/described in future Program descriptions and plans.

The CEES Working Group on Global Change strongly agrees with the need to actively promote the development of additional human/intellectual resources to support the USGCRP. The FY 1991 Program includes initial major investments on two global change education initiatives to address this need. 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's Committee on Global Change. Education initiatives in DOE and NSF, are designed to enhance multi-disciplinary science training for global change research.

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.

ANSWER: The CEES Working Group on Global Change agrees with the need to ensure the continuous involvement of the scientific community in the development of specific agency contributions to the USGCRP. In fact, the CEES Evaluation Criteria related to scientific merit require that each proposed project must be the product of a documented scientific planning and review process. While the CEES has an obligation to ensure sufficient scientific planning and review of the Program as a whole, individual agencies have maximum flexibility in developing appropriate mechanisms to review their specific contributions. 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.

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.

ANSWER: EOS scientific planning has always considered the precursor missions planned by the U.S. and other nations, including 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 data sets 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). In addition, we recognize that satellite measurements alone are not adequate to monitor and understand changes in the global environment, and that in-situ measurements are an absolutely essential and integral component of any global observing system.

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 as yet no comprehensive observational strategy that relates the US measurement program to international efforts, both space-based and in situ.

ANSWER: The USGCRP is designed as part of a comprehensive national and international strategy to study the Earth as integrated system, utilizing in situ, ground-based measurements in conjunction with research satellites (including Earth Probes), the polar platforms (including EOS), and operational satellites. The CEES is committed to that goal and is working domestically and internationally to fully meet that objective, in conjunction with the scientific community. The FY 90 and FY 91 Research Plans outline the initial steps. The CEES WGGC is carefully formulating strategies for studying the atmosphere, oceans, and atmosphere-ocean interactions, and expanding studies of terrestrial systems, and land-atmosphere interactions.

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.

ANSWER: The CEES WGGC agrees that the simultaneity argument has driven the process for selecting instruments to be flown on the EOS-A series. To address the global warming research issue requires an improved understanding of the global water and energy cycles (includes the role of clouds) and the biogeochemical cycles (in particular the global carbon cycle). This requires the core instrument payload proposed for the EOS-A series (HIRIS, ITIR, MISR, MIMR, MODIS-N/T, STIKSCAT, AIRS/AMSU, CERES, and EOSP) 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 design strategy for EOS-B has been driven by economics of scale, cost, and schedule considerations. Within the candidate payload for the EOS-B series there are a few instruments which need to fly together (ALT, GLRS and GGI) and a few that could benefit from flying together (SAFIRE, MLS, and TES). The flight of these instruments on a single platform will enable measurements for improved profiling of glaciers, better determination of sea level and

complementary measurements of different chemical species to better examine the chemical balance of the intervening atmospheric volume.

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.

ANSWER: The CEES WGGC agrees, and NASA is examining alternative measurement strategies for EOS-B, maintaining essential instrument groupings (discussed in the answer to the previous question).

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.

ANSWER: The suite of long-term measurements planned for EOS is 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, which will be both a precursor to EOS and will fly in parallel to EOS, provides the flexibility to respond to new scientific issues as they arise. The continued involvement of the CEES agencies and academic community during the lifetime of EOS will ensure a continuous evaluation of the need for new instrumentation and to develop plans for continuity of observations after EOS.

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 independent satellites. NASA's assessment of comparative costs suggests that 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.

ANSWER: The CEES WGGC agrees and NASA is studying the EOS-B payload options (see answer to earlier question). 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.

ANSWER: The CEES WGGC agrees that the precursor missions are critical to the USGCRP. EOS scientific planning has always considered the precursor missions planned by the U.S. 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). In addition, we recognize that satellite measurements alone are not adequate to monitor and understand changes in the global environment, and that in-situ measurements are an absolutely essential and integral component of any global observing system.

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.

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.

ANSWER: NASA has identified three instruments as being of particularly 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 EPOP 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.

ANSWER: The CEES WGGC agrees; as an example, this is one important reason why the information management functions of USGCRP and 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 cannot be defined a priori, and must evolve as lessons are learned from experience with early versions. EOSDIS involves partnerships with many other agencies (e.g., NOAA, USGS), international organizations, and other countries, and is therefore a high priority in the data management component of the USGCRP.

In turn, it is recognized that the data management programs of other agencies, e.g. NOAA and USGS, Forest Service and National Agriculture Library will be absolutely necessary to both add value to NASA's EOSDIS program and to contribute directly to the documentation, understanding and prediction of global change.

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.

ANSWER: The CEES WGGC 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, began 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. The data management system for USGCRP is being planned by the Interagency Working Group on Data Management for Global Change and the CEES Earth Systems Measurements and Data Management Task Group. It is planned to have the full data management system for USGCRP functioning by 1995.

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.

ANSWER: The CEES WGGC 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 accommodate 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.

ANSWER: The CEES WGGC agrees. NASA has involved other CEES agencies and the international community 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 now 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. USDA will be seeking funding for research to develop "gateways" to enable universities, federal laboratories and other users to utilize "value added and bibliographic data systems".

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.

ANSWER: 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 accommodate addition of interactive browse capabilities that result from prototyping.

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

ANSWER: NASA, working with USGS, will, to the fullest extent permitted by current law, facilitate access by researchers to Landsat data. A CEES task group is currently preparing a report on the value of Landsat data in Global Change research. This report will address questions of access to all users in support of global change research.

The Interagency Working Group on Data Management for Global Change has prepared a Global Change Data Management Policy Statement. It is in final full CEES Principals review, with the intent that it become the overarching policy of data access by the science community. Further it is hoped that this policy statement will become the US policy on these issues and will form the basis for negotiations with other countries to assure more uniform availability by all scientists to all appropriate data.

NRC: Because the implementation of EOSDIS poses significant continuing challenges, EOSDIS should have an ongoing mechanism for acquiring independent advice 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.

ANSWER: 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 be developed. This comprehensive observational 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 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.

The CEES WGGC agrees that (i) a comprehensive observational strategy needs to be developed, and (ii) a USGCRP management plan needs to be developed showing the observation, process studies and modeling efforts and how they focus on a common goal of an integrated Earth system model.

Comprehensive Observational Strategy:

The USGCRP needs a comprehensive national and international strategy to study the Earth as integrated system, utilizing in-situ measurements in conjunction with research satellites (including Earth Probes), the polar platforms (including EOS), and operational satellites. The CEES is committed to the USGCRP's goal and is working domestically and internationally to fully meet the USGCRP's objective, in conjunction with the scientific community (the U.S. NAS has agreed to play an active role in this process). The FY 1990 and FY 1991 Research Plan outlines the initial steps. The CEES WGGC is carefully formulating strategies for studying the atmosphere, oceans, and atmosphere-ocean interactions, and expanding studies of terrestrial ecosystems, and land-atmosphere interactions. There exist differences in maturity levels of the many scientific disciplines involved in the USGCRP. For the physical climate elements of the program, NASA, NSF and NOAA have been an active participants 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 to promote understanding of the complex processes which control the Earth's climate system. The newly emerging Global Energy and Water Cycle Experiment (GEWEX) will utilize the Earth Probes, as well as EOS. 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. A long-term strategy for ground-based and satellite observations will likely emerge from knowledge gained during short-duration projects such as WOCE, TOGA, JGOFS, etc.

The scientific conference statement from the Second World Climate Conference (SWCC) strongly endorsed the formulation and implementation of a Global Climate Observing System. In addition, a possible design for a Global Ocean Observing System, which was presented to the SWCC, will be discussed at the next meeting of scientific funding agencies (IGFA) early next year in Washington DC.

CEES WGGC Management Plan:

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 WGGC/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 WGGC 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 WGGC Management plan/approach are:

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.

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.

Review and analysis, internal/external

Describes how and by whom programmatic and science review, evaluation and progress is undertaken and how it is reported.

Agency Interactions

Describes the necessary coordination procedures and agreements between agencies, other CEES WGGC working groups, FCCSET, etc. This also includes international and intergovernmental coordination.

CEES WGGC 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.

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.

Question 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?

DOE's ARM Program is a 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 process models and parameterizations within general circulation and related models used for climate prediction. ARM will complement, and be complemented by, ground, aircraft, and satellite (operational and research) programs. Space-based measurements could be provided by instruments planned for EOS-A, some of the meteorological satellites proposed by NOAA, and existing and planned satellites flown by the Soviet Union, Japan and France.

The evolving DOE 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 few (5-6) 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.

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. There are basically three complementary approaches to the development of this information, none of which is uniquely suited for providing a complete test of these models. The techniques are satellite based, field campaigns and extended observations. These three approaches are part of an observational triad necessary for understanding the climate system.

Satellites are unique platforms for the observational confirmation of the study of the climate system. The requirement for global information about the climate system will only be met with the establishment of the satellite based Earth Observing system. While satellites are an extraordinary platform for the study of the Earth, they have some limitations. These limitations have been taken into account in the design of the International Satellite Cloud Climatology Program (ISCCP) and the current planning for the Global Energy and Water Experiment (GEWEX). In addition to the satellite component of these programs which produces critical global data, ISCCP and GEWEX have ground-based research components, such as FIRE, the First ISCCP Regional Experiment, whose goals include regional experiments for validation of the climatology, improvement of cloud analysis algorithms, improvement of cloud modeling in climate models, to investigate the role of clouds in the Earth's radiation budget and hydrologic cycle and to derive surface radiation budget data from satellite radiance data.

Field experiments, such as FIRE, give insight into processes whose importance may not have been previously recognized. Since field experiments involve the deployment of aircraft, balloons and direct sampling devices, the phenomenology that is possible in a field experiment is on a physical scale much finer than might be observed with a satellite or last longer than a satellite overpass would provide for observation. The ability to study process and phenomena in more detail than is possible with a satellite points to another critical role of field experiments, satellite ground truth experiments.

In developing ground truth for a satellite, both field experiments (e.g. FIRE) and intensive systematic observations such as ARM) provide validation or methods and results obtained from the satellite observations. The observations are a critical activity for the study of the climate system. It is not possible to put direct sampling systems everywhere making satellites the critical tool for understanding environmental change on a global scale. However, the algorithms used to infer quantities of interest from satellite observations are very complicated and very few satellites carry on-board calibration capabilities. As a result field programs like FIRE and ARM are used to "calibrate" the methods used by satellites to infer global parameters, thereby providing an important link in the validation of climate models. The need for these efforts will continue into the EOS era.

ARM emphasizes the third leg of the triad, that is, continuous and systematic observations from the ground surface to the top of the atmosphere. The goals of ARM are two-fold. First, it will improve the treatment of radiative transport in GCMs for the clear sky, general overcast, and broken cloud cases. Second, it will provide a testbed for cloud parameterization models used in GCMs. The measures of the quality of the models will include their ability to reproduce observed wavelength and direction-dependent fluxes of longwave and shortwave radiation and the time-varying distribution of cloud type and amount.

Of all the subgrid-scale characteristics that affect atmospheric radiation, cloud inhomogeneities and surface albedo variations are among the most important. It is possible that over the next decade model resolution will increase substantially so that single grid cells will have dimensions of a few tens of kilometers. Even so, since clouds can have dimensions less than a kilometer, subgrid parameterization will remain necessary. Uncertainties in climate models will be reduced substantially when a reliable cloud parameterization is developed that will consistently apply under important mean climate conditions. Data that characterizes the statistics of clouds on a subgrid-scale is necessary for the development of improved cloud models, and ARM is designed to produce such data.

ARM will strengthen parameterizations of physical processes of climate models. This includes improved detail in the physics of instantaneous and local energy fluxes. It is a critical requirement for understanding regional effects of climate change.

Thus, the EOS and ARM programs are complementary with each providing key observations for improving the understanding of cloud-climate processes, and for providing critical data for climate modeling. The ground-based program provides systematic and intensive measurements of radiation and cloud processes, which can be used for calibration of space-based observations.

The complementarity among these three programs (EOS, ARM and FIRE) and related programs, such as GEWEX and STORM, does not end with their scientific goals. Basic methods are needed to obtain and interpret observations. A FIRE field program or an ARM site are very much like EOS platforms on the ground. Concurrent observations made with a variety of methods, including satellites, focussed on developing a complete picture of key meteorological and climatological phenomena. Therefore ARM and other programs offer important opportunities to study data processing methods and such critical technologies as four-dimensional data assimilation in the pre-EOS era.

Question 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 CHAMPP, 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?

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, supercomputers have been increasing in effective processing speed by about a factor of three roughly every three years. HPCI aims to increase computer speed by factors in 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 supercomputer 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.

The HPC initiative includes \$3.0 million from DOE's Computer Hardware, Advanced Mathematics and Model Physics (CHAMMP) Program to aid the development of an aAdvanced Climate model (ACM). The ACM will require the use of computers capable of increasing throughput by a factor of at least 10,000, and CHAMMP will develop mathematical formulations and software that utilize the extensive parallelism of the emerging generation of computers, including improved algorithms that have been thoroughly varified using comprehensive sets of field observations.

Question 5: Please provide the graph, and associated data table, shown at the OMB-CEES WGGC budget hearing that shows the constant year dollar FY 91-96 run-out of the recommended option.

CEES WGGC RECOMMENDED PROGRAM
FY 1991-1996
CONSTANT DOLLARS

AGENCY	FY 91	FY 92	FY 93	FY 94	FY 95	FY 96	FY 92-96
DOC/NOAA	87.0	169.0	213.0	243.0	253.0	253.0	1131.0
DOD	0.0	6.1	6.1	6.1	6.2	6.2	30.7
DOE	65.9	78.9	86.0	97.4	103.1	100.3	465.7
DOI	43.7	114.0	151.8	172.0	187.4	189.8	815.0
EPA	21.9	40.3	44.1	54.8	65.2	65.2	269.6
NASA	661.0	876.5	1706.3	1904.8	1878.2	1859.2	8225.0
NSF	102.8	178.3	243.7	264.3	295.2	320.3	1301.8
SI	5.5	8.5	12.2	12.7	13.1	13.4	59.9
USDA	47.5	57.4	57.4	57.4	57.4	57.4	287.0
TOTAL	1035.3	1529.0	2520.9	2812.5	2858.8	2864.8	12586.0

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 WGGC 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 WGGC. These budget options provided by OMB are outlined as follows:

(Dollars in Millions)

	1990	1991	1992	1993	1994	1995	1996
Option 1	659	1,034	931	931	931	931	931
Option 2	659	1,034	1,034	1,237	1,453	1,664	1,666
Option 3	659	1,034	1,358	2,257	2,675	2,800	2,800
Option 4	659	1,034	1,402	2,442	2,886	3,065	3,065
Option 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 WGGC report of the President's FY 1991 budget, Option 3, is inconsistent with that option as provided by the OMB. The CEES WGGC Options for FY 1990-1996 are as follows:

CEES WGGC Budget Options

(Dollars in Millions)

	1990	1991	1992	1993	1994	1995	1996
Option 1							
Option 2							
Option 3	659	1,035	1,391	2,316	2,758	2,904	3,033
Option 4	659	1,035	1,469	2,534	3,017	3,240	3,378
Option 5	659	1,035	1,623	2,821	3,317	3,529	3,695
Option 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 WGGC Recommended Program

Discrepancies between the budget options provided by OMB and those provided by the CEES WGGC 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 WGGC Budget Option 3. The "Total Delta" refers to the delta between the OMB and CEES WGGC Option 3 totals that is accounted for in the above explanation.

++ The FY 91-96 USGCRP base provided the CEES WGGC 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?

The science community needs for Landsat data cannot be satisfied with EOS data. 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 vegetation near the time of maximum thermal and hydrological stress, thereby revealing the potential for ecosystem change due to such stress. 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 spectral bands for reflected sunlight and one band for thermal emission, and can image the Earth's 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 will permit detection of small shifts in ecosystem boundaries, detailed 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 Radiometer (AVHRR), MODIS will enable greatly improve observations of the land vegetation at finer temporal resolution than TM but lacks the ability to distinguish the spatial spectral detail associated with ecosystem changes and agricultural practices.

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 WGGC 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 the scientific basis for 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 issue 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 WGGC relied on the information needs delineated by the IPCC Scientific (Working Group 1) and Impacts (Working Group 2) Assessments. Specifically, the CEES WGGC 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).

The CEES WGGC recommended science elements are explicitly tied to the international research activities where the U.S. has formal or implied agreements that, if not honored, would affect the credibility of the U.S. These activities direct resources to that portion of the Earth system science where scientific understanding appears to be most advanced and can lead to rapid payoff. The CEES WGGC 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. An assumption in this regard is that the recommendations of the Ad Hoc Task Group on Economics research Needs related to Global Change are taken as being considered separately by the OMB. 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 scientific program embodied in the current Presidential initiative assumes a comprehensive, inclusive approach to documenting, understanding and predicting Earth System change and global implications on a regional 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 WGGC 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." 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. 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 WGGC and the Nation met this challenge by proposing an inclusive (comprehensive) research strategy to allow the greatest flexibility in the national response to environmental questions.

In particular, the Program strategy was designed to more effectively integrate and focus scientific projects which have traditionally been developed and implemented on a more piecemeal basis. By adopting the strategy reflected in the President's FY1991 proposal, CEES WGGC 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 its 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 damaging 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 WGGC Recommendation. These risks include:

- 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 regulatory action and provide a strong, scientific foundation for future management approaches and solutions;
- 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 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) approved growth within the Geosciences and Biological and Behavioral Sciences divisions within NSF.

- 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 The CEES WGGC 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 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;

B. CEES WGGC WGGC Recommendations for Options 2 and 2+:

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). CEES WGGC carefully considered the IPCC report in formulating its FY 92 program, i.e. the CEES WGGC 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). The following list links the high priority research areas with the CEES WGGC 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, and Global carbon cycle |

CEES WGGC 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 WGGC recommended FY 92 augmentations and new initiatives are focussed on the climate change (global warming) issue.

The CEES WGGC 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.

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 WGGC recommended level). Option 2 represents a \$41 million increase over FY 91 (inflation), while option 2+ represents a \$166 million increase over FY 91.

Specific impacts of option 2+ are:

Basic investigator-initiated research on interactions among economic systems and other human, ecological and physical systems would be frozen at current levels, just as the program gathers momentum and well below the levels needed.

The opportunity to establish international projects (institutes) focused on economics, social sciences and global change could not occur. Especially critical here are the needs for transnational data.

Elimination of joint research between the socio-economic and physical/biological sciences centered at Long-term Regional Research sites, such as NSF's Long Term Ecological Research Sites, research that would deal with regional issues (e.g., water management, transportation, etc.)

Ecological research on the effects of change (change resulting from climate as well as directed management activities) to natural and managed ecosystems would be held below the levels needed to provide timely scientific input to near and intermediate term policy decisions. In the U.S. ecological research of all types is significantly underfunded, so redirecting resources from the base offers no relief.

Specifically, with respect to ecological research, option 2+ effectively cancels (or at best delays by years) the development and implementation of large scale experimental manipulations of ecological systems. These experiments are necessary to test critical system level hypotheses, the findings from which directly affect management, energy and economic policies.

While options 2 and 2+ do not allow the CEES WGGC 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.

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 WGGC does not recommend allocating the increase in proportion to the size of the FY 91 agency budgets. The CEES WGGC 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 WGGC recommended augmentation levels of \$264.6 million for NASA, and \$233.9 million for the other agencies (reflects the current DOI position).

b 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 WGGC 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 would certainly not allow the USGRCP to proceed in a timely fashion. It would likely result in the cancellation or at best a significant delay in a number of critical international scientific research projects such as WOCE, TOGA, JGOFS, and GEWEX, and would not allow for critical budget augmentations for research areas such as ecological impacts and economics.

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 WGGC 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 WGGC recommendations for option 2+ are presented within the structure of the five integrating themes. The CEES WGGC 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 WGGC 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 WGGC 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 WGGC 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 million

The CEES WGGC 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 million

The CEES WGGC 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

c. 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 WGGC 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 descope to focus solely 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 currently 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 WGGC, 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 not 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 WGGC 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.

d. 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	10.2
TOTAL	1035.0	41.0	166.0	498.5**
DOD#	0.0	0	0	6.3
SMITH#.	5.5	0	0	3.3

* President's FY 91 budget submission to Congress; does not reflect recent Congressional actions.

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

DOD and the Smithsonian were not part of the FY 91 CEES WGGC budget process, therefore CEES WGGC 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 WGGC is not recommending augmenting at levels 2 and 2+.

Although DoD's initial focused program is small compared to other agencies already established in the USGCRP, it represents the crucial first step toward identifying the potential of this new partner to the USGCRP. DoD's capacity to support the USGCRP must be understood and brought quickly to bear in order to optimize its role. To negate DoD involvement in FY 92 would conflict with the emerging interest and early momentum of DoD's Defense and the Environment Initiative and the Strategic Environmental Research Program for DoD and DoE. There is perhaps no better mechanism than the USGCRP in partnership with DoD to address potential national security issues driven by global change. Without such a mechanism, there appears to be no advantage for continued DoD participation in the USGCRP an event that penalizes all concerned.

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;

e. Basis for CEES WGGC approach:

The CEES WGGC approach 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 WGGC approach 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 WGGC approach for option 2+ (an increase above the FY 91 level of approximately \$83 million for non-space-based research and \$83 million for space-based research) would allow progress to be made in several key areas identified by IPCC, but not in others (remember CEES WGGC 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 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?

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 U.S./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 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.**

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 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.

- * What other non-satellite approaches could be used to collect important global change and climate change data (e.g., CONDOR, AURORA, etc.)? Are these of lesser priority than currently planned programs? What would the CEES WGGC recommend regarding the use of these capabilities in the pre-EOS period.**

Aircraft provide unique platforms from which to study certain scientific questions; e.g., aircraft played a critical role in understanding the Antarctic ozone hole. However, it is clear that the current fleet of manned aircraft do not provide all of the operational capabilities required, in particular duration and altitude. Therefore, the CEES WGGC has established a task group charged to examine the scientific return that could be expected from the utilization of unmanned long-duration and/or high altitude aircraft for global change research, i.e, CONDOR, AURORA, etc. This task group will present a short report to CEES WGGC and OMB within two weeks.

Question 9: Please provide an explanation of the differences between the FY 1992 CEES WGGC 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 WGGC. The following table outlines these discrepancies:

(Dollars in Millions)					
FY 1992					
Agency		OMB	CEES WGGC	CEES WGGC	
	FY 1991	Plan	Recommend	Opt. 5	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	42.0	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	57.4
TOTAL	1,034.1	1,357.6	1,606.4	1,622.6	1,520.0

The difference between the OMB Plan and the CEES WGGC 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 WGGC and delivered to OMB on September 14, 1990.

The difference between the CEES WGGC "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 WGGC review process and communication back to the agencies of actions taken through those deliberations.

The CEES WGGC review of proposals and development of budget recommendations for the USGCRP began in March 1990. At that time the CEES WGGC 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 a preliminary review of proposals was initiated. By July 15, 1990, all agencies had submitted to the CEES WGGC proposals for USGCRP FY 1992-1996. Task Groups reviewed all USGCRP, both the base and augmentation, using the CEES WGGC Evaluation Criteria (p. 6 of CEES WGGC Budget Recommendation). A numerical rating, 0 (lowest)- 5 (highest), was assigned to each project based upon the review criteria. Funding was considered for those programs receiving an average numeric rating of 2.5 or greater. Of the 281 proposals submitted to the CEES WGGC Task Groups for review, 252 proposals are included in the CEES WGGC USGCRP Recommendation to the OMB (23 of the proposals were rejected because they were not focused on the goals and objectives of the USGCRP; 6 proposals, based on the evaluation criteria, were removed from further funding consideration). The level of funding for each of the OMB "Options" was determined in large part using the numeric ratings provided through the Task Groups' review.

Initial budget decisions concerning project level funding was discussed individually with agency representatives during the week of August 6-10. Final CEES WGGC 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 WGGC. The consistency between the CEES WGGC 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 WGGC.

Agency budget requests to the OMB that are not consistent with CEES WGGC "Recommendations" or CEES WGGC Option 5 levels may be explained as follows:

DOC/NOAA: Agency request of \$176.9 M was submitted to the OMB in constant, uninflated, dollars. Inflated, the request from NOAA to OMB is \$183.7 M and reflects the CEES WGGC Option 5.

DOE: Agency request of \$67.4 M is inconsistent with the CEES WGGC Recommendation or Option 5. This situation arose due to requirements by DOE to print their budget submission to the OMB prior to receiving the CEES WGGC Recommendation. Admiral Watkins has since sent a letter to the OMB explaining this situation and requesting the OMB to adjust the DOE budget for global change research to \$82.1 M.

DOI: Agency request of \$46.4 M is inconsistent with the CEES WGGC Recommendation or Option 5. DOI submitted to the CEES WGGC a global change program for the Department which totaled \$126.1 M. The CEES WGGC reviewed the program and recommended to the DOI a funding level of \$118.7 M for programs in USGCRP. DOI declined to request additional funding for global change research, above inflation, stating "...the need to reduce the Federal budget deficit precludes full support of the plan". This decision was made after the CEES WGGC submitted their recommendations to the OMB and explains the inconsistency between the CEES WGGC Recommendation, Option 5, and the Agency Request to the OMB. The impact of the DOI decision not to seek additional funding in FY 92 is explained in further detail below.

EPA: The agency request of \$43.4 M reflects post-CEES WGGC submission of Recommendations to the OMB. The amount of \$42.0 M did not include adequate funding for "salaries and expenses" that are required to conduct programs under the USGCRP.

NSF: The agency submission to the OMB was reduced from that amount indicated by the CEES WGGC in Option 5. This decision was made to reflect recommendations made by the CEES WGGC.

SMITHSONIAN: Agency request of \$8.0 M was submitted to the OMB in constant, uninflated, dollars. Inflated, the request from

Smithsonian to OMB is \$8.8 M and reflects the CEES WGGC Option 5.

Impact of Proposed FY 92 DOI Level

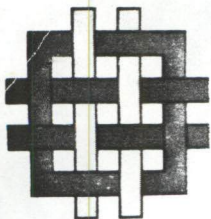
DOI/USGS activities comprise 50% of the Earth System History and Solid Earth Processes components of the U.S. Global Change Research Program, and are central to maintaining an effective land-based component of the overall program. The DOI proposed funding level for FY 1992 will result in a major reduction in research activities associated with these two science elements, thus leading to a serious gap in our research strategy. Hence the U.S. Global Change Research Program will not be as effective or responsive to the need for information to make future policy decisions on the effects of global warming as desired.

Land-surface hydrology is a critical component of the global change program because we do not understand the functioning and dynamics of the global hydrological cycle. Other agencies involved in studying the global water cycle (NASA, NOAA, NSF) have assumed that DOI will provide the land-based research and data collection for these studies. The proposed DOI funding level will not allow DOI to fulfill its role (as supported in the CEES WGGC recommended program), and in particular, will not allow DOI to participate in a continental scale study in North America - an international effort to understand continental hydrology in the global climate system.

Land modeling lags 10 - 15 years behind ocean and atmospheric modeling and is complicated by the extreme variability of the land surface that is in need of characterization and the data resources to support the modeling effort. DOI/USGS is currently being relied on to provide the missing link. At the proposed DOI funding level, valid, credible support for development of national policies and response strategies will be delayed by 10 to 15 years unless some other agency aggressively pursues this critical area of research.

DOI initiatives to assess the impact of global change on ecosystems and ecosystem interactions with environment will be seriously limited through reduction in the number of proposed site monitoring stations, reduced assessment of the impacts of UV-B on biological communities, and studies to determine the economic impact of global change on natural resources will be delayed.

The USGS plays a critical role in ensuring the long-term stability and availability of land-related earth science data, including Landsat data, for global change studies. Landsat provides a relatively complete record of global land cover and land surface conditions since 1972. This represents a sunk-cost investment of \$1.5 billion. At the DOI proposed funding level, 25-30% of this irreplaceable data will be lost due to tape and system degradation.



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Emily:
Pls. stay in
touch w/
Bruce
on all
this.
Nov 30 90 JHS.
JP

Dear Jim

Here is our list of significant international
environmental meetings that represent
risk or opportunity for the Administration
from a public perception viewpoint.

I've started some of the more significant.
Hope this is helpful.

Sincerely,

Bruce

cc Teresa Gorman.

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CALENDAR OF INTERGOVERNMENTAL MEETINGS - DECEMBER 1990 - JUNE 1992

<u>DATE</u>	<u>PLACE</u>	<u>EVENT/ORGANIZATION</u>
<u>1990</u>		
Dec. 4-5	Paris	Organization for Economic Cooperation and Development (OECD) Group of Experts on the Programme on Technology and the Environment Economic Cooperation
Dec. 11-13	Paris	OECD Environment Committee
<u>1991</u>		
Jan. 21-23	Geneva	U.N. Economic Commission for Europe (UNECE) Joint Working Group on Environment and Economics
* Jan. 30-31	Paris	OECD Environment Ministerial
Feb. 1	Paris	OECD Environment and Development Meeting
* Feb.	Washington	U.N. Conference to Begin Drafting Climate Convention
Feb.	Geneva	Nordic Council of Ministers
Feb.	Geneva	U.N. Economic Commission of Europe Meeting of Environment Ministers
* Feb. 25		Meeting of the U.N. Intergovernmental Panel on Climate Change (IPCC)
* Mar. 18-Apr. 5	Geneva	Second Meeting of U.N. Conference on Environment and Development (UNCED) Preparatory Committee
Apr. 23-25	Paris	OECD Environment Committee
* Apr.		Meeting of Parties to the Vienna Convention on the Protection of the Ozone Layer

<u>DATE</u>	<u>PLACE</u>	<u>EVENT/ORGANIZATION</u>
May 20- May 31	Nairobi	U.N.Environment Program Governing Council Meeting
* June		G-7 Economic Summit
* June		World Forestry Conference
July		U.N. Working Group to Prepare a Convention on Climate Change
* Aug. 12-30	Geneva	Fourth Meeting of U.N. Conference on Environment and Development Preparatory Committee
Sept.-Dec.	New York	U.N. General Assembly
Sept.		World Bank/International Monetary Fund Annual Meeting
* Nov.		World Bank Meeting re Global Environment Facility/financial pledges
* Dec.	Paris	OECD meeting on Environment and Development
Dec.		International Energy Agency/Dutch Energy Conference
<u>1992</u>		
* Jan.	New York	Final Meeting of U.N. Conference on Environment and Development (UNCED) Preparatory Committee
* June 1-12	Rio de Janeiro	U.N. Conference on Environment and Development
Nov.	USA	Election

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20506

December 10, 1990

MEMORANDUM FOR D. ALLAN BROMLEY

FROM: NANCY G. MAYNARD)
SUBJECT: Response to J. Hansen Article

Attached is the material you requested from Bob Corell and NASA on the article by James Hansen proposing the Climate Satellites (CLIMSAT). The material was sent over promptly on November 30, but because preparations were underway for your trip to South America, it was suggested that it be made available upon your return. I did, however, provide a one page summary of the material for Tom Ratchford in preparation for his participation in the NASA Director's Review.

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Final
DRAFT
11/30/90

SUMMARY RESPONSE TO JIM HANSEN'S CLIMSAT PROPOSAL

This proposal advocates launch of two identical small satellites in 55 degree and sun-synchronous orbits, respectively, each carrying (Earth Radiation Budget Experiment) ERBE, (Stratospheric Aerosol and Gas Experiment) SAGE and (Earth Observing Scanning Polarimeter) EOSP instruments. The goal is to provide measurements of a few selected environmental parameters important to the global warming issue before EOS.

ISSUES:

The CLIMSAT proposal only addresses the elements of global warming as a simple problem in radiative transfer. While this is a legitimate scientific objective, it does not deal with many of the larger unknowns of global change, (i.e., [1] ocean circulation, [2] role of biosphere and tropical forests, [3] ice, [4] sea level, and [5] cloud feedbacks) nor does it address the cause and effects relationships which drive the overall national program.

The only critical measurements for which scientific consensus exist (i.e., the NRC Global Change Review Committee) are the radiation budget measurements, ERBE (the current version is CERES). A less expensive way to achieve these measurements is to include CERES on the Japanese/US TRMM mission in 1996 and on the German/US ATMOS mission in 1997. A series of similar, but less well calibrated, French-Soviet SCARAB instruments will be launched beginning in 1991. CERES will fly on EOS-A in 1998 and on EPOP in 1997.

No scientific requirements exist for flying SAGE with CERES (i.e., for simultaneous stratospheric aerosol and radiation budget measurements). Also, SAGE is a candidate for EOS-B.

EOSP is an instrument developed by Dr. Hansen's institution. It has been approved for EOS-A in 1998, but has been assigned a low priority by the scientific community.

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RESPONSE
to
"Assessment of Observing Global Climate Change"
a paper by Dr. James Hansen

Dr. Hansen's paper is a strong advocacy for two identical Climate Satellites (CLIMSAT). Specifically, the paper recommends that NASA fly three instruments -- Earth Radiation Budget Experiment (ERBE), Stratospheric Aerosol and Gas Experiment (SAGE), and Earth Observing Scanning Polarimeter (EOSP) -- on small satellites in 55 degree inclination and sun-synchronous orbits. The goal of this action is to deliver them to orbit sooner than EOS because Dr. Hansen feels that taken together, they will provide the "most crucial unmeasured climate quantities".

This proposal does not address many of the major unknowns in the global warming issue, i.e., 1) ocean circulation, 2) role of biosphere and tropical forests, 3) ice, 4) sea level, and 5) cloud feedbacks.

On balance, the argument advanced really raises questions of priority within the Earth Probes Program and between the schedule of EOS and the the total number of Earth Probes that can be afforded before the launch of EOS. The paper does not compare CLIMSAT benefits specifically with any other remote sensing measurements satellite except to argue that because EOS is a large mission, it will be slow in development.

The current priorities of NASA's Earth Probes program are the following four missions:

1. NASA Scatterometer (to be flown on the Japanese ADEOS satellite)
 - NSCAT will measure wind speed at the ocean surface, an important input to understanding air/sea interactions.
2. Total Ozone Mapping Spectrometer (TOMS) (flying on three satellites)
 - TOMS will measure the distribution of stratospheric ozone, important for measurements of ozone depletion (e.g. Antarctic ozone hole.).

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3. Purchase of SeaWIFS Data from a commercial provider
 - SeaWIFS will measure ocean color in support of JGOFS bioproductivity studies.
4. Tropical Rainfall Measurement Mission (TRMM)
 - TRMM will measure the distribution of rainfall in the tropics, an important factor in understanding climate.

From a cost standpoint, the first three of these, or the fourth by itself, would be roughly equal in cost of the proposed CLIMSAT excluding launch costs. The current schedule for EOS calls for launch of the first polar platform during 1998. Funding CLIMSAT at the cost of EOS schedule would be roughly the equivalent of a one year slip in EOS launch. If CLIMSAT could be immediately added to the NASA program, the earliest launch for the first of the satellites could be reasonably expected to be during FY 1996 -- due to review, procurement, design, OMB, and Congressional approval -- roughly two years before EOS. The second satellite could be expected to launch later.

Let's examine the current planning for the three instruments of the proposed CLIMSAT. First, the proposed Earth Radiation Budget sensor (CERES) is the largest, most costly, and arguably most important of the three. What would be flown is the CERES instrument from EOS. CERES is derived from the highly successful Earth Radiation Budget Experiment (ERBE) which has flown since 1984 on NOAA-9 and -10, and on the ERBS satellite, and has provided important information on sources and sinks of radiant energy in the Earth's climate system as well as new insight into the contribution of clouds to the greenhouse effect. CERES is virtually assured flight in sun-synchronous orbit on the first EOS platform in FY 1998 and on the first European Space Agency (ESA) polar platform scheduled for launch in 1997. In addition to these anticipated flights, a French SCARAB instrument patterned on ERBE/CERES designs is scheduled for launch in the early 1990's aboard one or more Soviet spacecraft. This may mitigate the urgency for early flight of CERES, but there are significant concerns about the calibration of this instrument and the length of the data record that this effort may produce due to the normally short lifetime expected for Soviet spacecraft.

The most significant CLIMSAT science benefit would appear to result from an early flight of a CERES-type device in a low inclination orbit.

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This could be achieved by adding this instrument to the payload of the US/Japanese TRMM mission which is technically feasible. TRMM has been planned for a 1996 launch. Planning is also underway for inclusion of CERES on a US/German ATMOS mission.

The second most significant instrument is the Stratospheric Aerosol and Gas Experiment (SAGE) which is at present a candidate for flight on the second EOS polar platform in the year 2000, also in a sun-synchronous orbit. SAGE has a successful record in mapping the aerosol distributions of the stratosphere and providing important information on the vertical profiles of important trace gases since 1979.

Solar and stellar occultation devices which lack flight heritage but which share the measurement objectives of SAGE are currently planned for flight on the Japanese ADEOS mission and the first ESA Polar Platform. There are no simultaneity arguments for a SAGE instrument to be flown on the same spacecraft as an Earth radiation budget type instrument except convenience of implementation. Given this situation, it is not clear that SAGE flights on two small satellites is justified.

The third instrument for CLIMSAT is the Earth Observing Scanning Photopolarimeter (EOSP) from Dr. Hansen's own institution. EOSP would provide measurements of cloud and aerosol microphysical properties and information on vegetation and the land surface. This instrument is a candidate for flight on the first EOS polar platform and was not proposed for flight in low inclination. The argument is that the cost is quite small and the instrument proved useful on a mission to Venus. Venus is completely cloud covered at all times and is not subject to ground based confirmation of the accuracy of results. Given the modest cost, the general disposition of the EOS science community has been to support the inclusion of EOSP on the first EOS platform but at a lower priority than the flight of a number of other instruments. It is natural for Dr. Hansen to feel strong support of EOSP, but there is not a scientific consensus that this is one of the most critical measurements for understanding climate change.

Dr. Hansen's paper is not written from the standpoint of integrated planning for a comprehensive study of global change including both monitoring and increased understanding of the processes which are

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operative in the Earth system. The emphasis is primarily on simply examining one element of climate change as a problem of radiative transfer, i.e. the radiative output of energy from the Earth. This is most evident in the fact that the article views land biota as important only from the standpoint of changes in surface albedo (the amount of sunlight reflected from a surface) and totally ignores the role of vegetation in the transpiration of water vapor and the transport of heat and energy by the ocean. The carbon cycle is also ignored in its entirety. A major uncertainty in all climate predictions is the assumption that carbon dioxide growth will continue to be partially removed from the atmosphere by poorly quantified biological mechanisms involving marine and terrestrial biota and the feedback mechanisms associated with such. Observations of this type are correctly assumed to be provided by EOS but the failure to address priorities directly leaves the reader with the impression that these aspects of global change are much less important.

The CLIMSAT proposal approaches data requirements primarily from the perspective of a prognostic climate modeler. In this area Dr. Hansen is virtually without peer, but this is a very limited view of the Earth system. The approach of the paper is to view the key requirements for data to be monthly averages at 250 km spatial granularity. This is roughly the resolution at which current climate assessment models can be implemented. Policy decisions on responses to global change will have to take into account regional impacts and not just global average changes. The article does acknowledge this, but leaves the data acquisition in support of this to EOS. The nature of the argument is to push for an ability to address one select portion of the global change question first and leave open the question of the pace at which the others can be addressed. This is a perspective which could be adopted by many other researchers, but they would tend to favor their own special interests or satellite missions of similar scope to CLIMSAT but with different instruments and different goals. The EOS planning by NASA is founded on the premise that such piecemeal approaches are inadequate to meet the requirements of understanding global change and supporting intelligent policy formulation and implementation.

Dr. Hansen adopts the view that small satellite missions are less subject to schedule slips than large ones. Although everyone believes that small missions can be individually executed faster than

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large ones, it is less than clear that small missions don't suffer slippage problems to the same degree as large ones. The Cosmic Background Explorer (COBE) is a case in point. Furthermore, the logistics of implementing a set of small missions lead to interference among them wherever they share resources such as satellite fabrication, thermal vacuum testing, and launch facilities.

In conclusion, CLIMSAT is a reasonable idea if viewed in isolation from the integrated question of global change and the inevitable question of competition for resources. If additional funds were available to NASA than is presently anticipated, the maintenance of TRMM launch in 1996, and the addition to its payload of a CERES instrument developed as a virtual copy of the EOS instrument would offer much of the benefit claimed for CLIMSAT at significantly less cost. Such an approach has been discussed within the community and is supported by management. We believe that under current planning constraints, CLIMSAT is less critical than the four currently planned Earth Probe missions on a science per dollar basis and a modest acceleration in the availability of data as proposed for CLIMSAT is not worth an additional schedule delay in EOS.

Ruth,
For NM's
global
change
file!
Thanks,
m

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20506

December 14, 1992

global change file

MEMORANDUM FOR D. ALLAN BROMLEY

FROM: NANCY G. MAYNARD *NGM*

SUBJECT: Results of the Japan Workshop on an Asia-Pacific Network for Global Change Research, December 3-4, 1992

Attached, for your reference, is a report forwarded by Lou Brown describing the results of the "Workshop on an Asia-Pacific Network for Global Change Research (APN/GCR)" which took place 3-4 December 1992 in Tokyo. A short summary follows below:

1. The meeting was very well-attended.
 - . Representatives were present from virtually all of the countries of SE Asia, South Asia, and the South Pacific
 - . Australia sent a large delegation and indicated very strong long-term interest
 - . Many Japanese Government agencies were represented and many participated actively
2. Participating countries welcomed Japan's initiative to host the workshop and from the outset there was consensus that such a Network be established
3. A very different approach than IAI will be taken because so many regional activities are already underway that a better approach for this region would be a "network of networks".
4. It was agreed that while technology is important, it should be undertaken in conjunction with science - not separately
5. A number of specific proposals for action were discussed including a center in the PRC for North Asia, Thailand for the Southeast Asian land mass, Indonesia for the Southwest Pacific, and India for South Central Asia.
6. For next steps, it was decided: (1) to convene a second workshop in mid-1993 (Japan will host if no other offer) and (2) to set up 2 working groups, one on science and one on organization and management. It was also agreed that a small secretariat should be set up.

REPORT
on the
Results of the Workshop on an
Asia-Pacific Network for Global Change Research
(APN/GCR), 3-4 December 1992, Tokyo*

1. OPENING OF THE SESSION

Ambassador Takayo Suto, Foreign Ministry of Japan, opened and chaired the meeting. In his keynote address Ambassador Suto noted that establishment of regional institutes for global change research had been proposed at the White House Conference on Scientific and Economic Research Related to Global Change in April 1990 and that such institutes were specifically suggested for three regions -- the Americas; Asia and the Pacific; and Europe and Africa. The Government of Japan decided that the time had come to initiate discussions regarding establishment of an Asia-Pacific Network for Global Change Research (APN/GCR). To this end they had convened this Workshop.

2. PRESENTATION ON THE IAI

Dr. Robert W. Corell, Chairman of the Implementation Committee (IC) for the Inter-American Institute for Global Change Research (IAI), informed the Workshop on both the IAI planning process and the present status of this effort. He stressed that planning for the IAI has from the outset been driven by scientific needs; planning is being developed by building consensus among IAI members; and it is expected that the IAI will soon become operational.

3. PRESENTATION ON THE EAN

Dr. Friedrich Geiss of the EC Secretariat reported that the EC is currently proposing to its member states the establishment of a Europe-Africa Network for Global Change Research (EAN). An EC group of experts concluded at its initial meeting on 9 September 1992 that global change research in Europe could benefit substantially from improved coordination among the EC countries through a network arrangement such as an EAN. The group of experts will meet again on 11 December in Brussels. Dr. Geiss noted that the EC supports about \$100 million of global change research over a four-year period; these funds complement national efforts of approximately an order of magnitude greater.

* This report was prepared by Louis B. Brown, Chairman of the Working Group on International Coordination and Development of the CEES Sub-Committee on Global Change, 11 December 1992.

4. PARTICIPATION IN THE WORKSHOP

The meeting was very well-attended. Representatives from virtually all of the countries of Southeast Asia, South Asia, and the South Pacific participated in the meeting, most were very active. Australia sent a large delegation to the meeting and indicated very strong long-term interest in regional cooperation in global change research and in the development of the APN/GCR.

Many Japanese Government agencies were represented including the JEA, MITI, STA, Education, Construction, Transportation, and, of course, the Foreign Ministry. Many Japanese scientists spoke during the Symposium and some did so as individuals. This indicates a new level of flexibility in Japan with regard to international scientific meetings, since the Government of Japan has generally in the past operated very much by consensus in such meetings.

5. SUMMARY OF VIEWS ON THE ESTABLISHMENT OF AN APN/GCR

The participating countries very much welcomed Japan's having taken the initiative to host this workshop. There was from the outset a consensus that an Asia-Pacific Network for Global Change Research (APN/GCR) should be established. At the same time, however, most countries pressed to have this network take a very different approach than that taken by the IAI. It was recognized that many regional activities are already underway and it was recommended that the APN/GCR develop a scientific agenda which supports these ongoing regional activities and possibly also promotes their coordination. Thus, it was strongly recommended that the APN/GCR be planned and developed as a "network of networks". The key regional activities already underway or planned that would fit within an APN/GCR rubric are summarized below.

There was a consensus that the APN/GCR should be science driven, but that the planning process will need to determine the extent to which the APN/GCR addresses research, observations, monitoring, analysis, prediction, and data management and the extent to which the APN/GCR goes beyond science to policy issues, technology development, and "countermeasures" to global change.

It was agreed that, although technology development is important, it should be undertaken in conjunction with science -- not separately -- and thus should be an integral part of network's scientific activities. The Workshop concluded that the APN/GCR should promote cooperation within the region and among other relevant regional (or "sub-regional") activities already underway. It was agreed that the APN/GCR would require commitments from governments. The Chairman's report will indicate that the network be "more-or-less" intergovernmental, but there appeared to be some reservations on this point.

5.A. THE PRC: NORTH ASIA

The PRC reconfirmed their earlier offer to host a regional center which would be the hub of a network for global change research in northeast Asia and the northwest Pacific and would focus on study of the Asian monsoon system and the impact of global change on this system.

5.B. THAILAND: SOUTHEAST ASIA

The former Science Minister of Thailand, Mr. Sanga Sabhasri, led a strong presentation from Thailand on their interests in hosting a center for a sub-regional network that would cover primarily the land mass of Southeast Asia with an emphasis on tropical ecosystem and forest processes and their interaction with global change. It was evident that Thailand has already consulted with neighboring countries on this matter, especially Myanmar (Burma).

5.C. INDONESIA: THE SOUTHWEST PACIFIC

Indonesia indicated they are prepared to host a regional center for oceanic and related coastal areas of Southeast Asia which would focus on climate change and El Nino research and prediction and on tropical forests and biodiversity.

5.D. INDIA: SOUTH CENTRAL ASIA

India indicated that they would be prepared to host a regional center for South Central Asia which might focus on the impact of global change on storm surges. Thailand and The Philippines urged that IGBP broaden its present efforts in Southeast Asia beyond the ASEAN group. Thailand indicated a strong interest in hosting a center for studies of terrestrial forests and ecology, with a geographic focus in the Southeast Asia mainland.

6. RELATIONS WITH OTHER ACTIVITIES AND ORGANIZATIONS

The Unesco representative urged that any effort to develop regional cooperation in global change research be made within, rather than outside, established intergovernmental organizations, such as the UN and its specialized agencies. It was agreed, however, that liaison between the APN/GCR and WCRP, IGBP, and HDP is of the highest priority while interaction with interested intergovernmental organizations is also important and should be pursued. It was suggested that the newly-established Asia-Pacific Economic Council could play an important role in promoting regional cooperation, but it was concluded that since APEC is just getting underway, they should not be looked to to provide substantial support for the APN at this time.

7. THE FUTURE APN/GCR PLANNING PROCESS

It was agreed that this first APN workshop should define the process through which a scientific agenda for the APN and organizational options should be developed. It was agreed that two key elements of this process should be to convene a second workshop in mid-1993 and to set up two working groups, one each on science and on organization and management. These working groups could either begin work prior to the workshop or meet in conjunction with the workshop. It was agreed that the APN/GCR would require a small but competent secretariat and that the planning process should address this need. The Chairman invited other countries to consider hosting the second workshop, but indicated that Japan would be prepared to do so if no other country offered.

8. U.S. INTERVENTION

Mr. Louis Brown made the following intervention on behalf of the United States:

"Thank you, Mr. Chairman, for the opportunity to make a few comments. The United States is pleased to have been able to join with other countries of Asia and the Pacific to initiate planning for a network for global change research in this very important region. As you, Mr. Chairman, noted in your keynote speech, the concept of regional institutes for global change research was tabled at the White House Conference on Scientific and Economic Research Related to Global Change in April 1990.

Dr. D. Allan Bromley, the Science Advisor to the President, has long been a strong advocate of regional cooperation in global change research. He has asked that we convey to this Workshop his best wishes and his hope that the development of regional institutes and networks for global change research in Asia and the Pacific; the Americas; Europe and Africa; and others as well will lead to a coordinated and truly global approach to the study of the processes which underlie global change.

Such a global approach will require development of effective interaction, not only among interested countries, but between these countries and interested international organizations as well. The active participation of representatives of such international organizations in this and future workshops can only advance this interaction.

In closing, let me say that the United States has supported and continues to support a broad range of global change research under the aegis of the U.S. Global Change Research Program. We believe that continued U.S. global change research in this region can make a valuable contribution to an APN/GCR and we are fully prepared to promote and support cooperative efforts in this area".