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# Carbon Dioxide and Climate: Summaries of Research in FY 1983 and FY 1984

CO<sub>2</sub>

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## FOREWORD

The Department of Energy is the lead Federal agency for research related to atmospheric carbon dioxide. Its responsibility is to sponsor a program of directed research, and to coordinate this research with relevant activities of other Federal agencies, private concerns, and international efforts.

This Program Summary documents the activities and products of the Carbon Dioxide Research (CDR) Program in Fiscal Years 1983 and 1984. It includes descriptions of all projects funded annually in these years or under multiple-year contracts from Fiscal Year 1982. Also, a brief summary of the CDR Program's goals, objectives, and organization is provided.

The CDR Program of the U.S. Department of Energy is directed by the Carbon Dioxide Research Division, one of six divisions of the Office of Basic Energy Sciences (BES) in the Office of Energy Research. Other divisions of BES are Engineering and Geosciences, Biological Energy Research, Chemical Sciences, Advanced Energy Projects and Material Sciences. Each BES division administers basic, mission-oriented research programs.

F.A. Koomanoff  
Director  
Carbon Dioxide Research Division  
Office of Basic Energy Sciences



## PREFACE

This document, which describes the activities and products of the Carbon Dioxide Research (CDR) Program in Fiscal Years (FY) 1983 and 1984, is organized into four main sections as follows:

SECTION	DESCRIPTION
Introduction	<ul style="list-style-type: none"><li>o Describes overall CO<sub>2</sub> issues</li><li>o Ties CO<sub>2</sub> issues to the research approach, program goals, and objectives</li><li>o Relates each specific research area to the overall goals of the program</li><li>o Shows the level of the Federal effort</li></ul>
Research Areas and Project Descriptions	<ul style="list-style-type: none"><li>o Describes scientific questions in each research area</li><li>o Provides descriptions of individual research projects</li><li>o Shows the research approach or methodology used in each project</li><li>o Lists the expected product for each project</li><li>o Provides indexes of keywords, principal investigators, and research institutions for easy reference</li></ul>
Appendixes	<ul style="list-style-type: none"><li>o Provides more in-depth information on the total research approach</li></ul>
Indexes	<ul style="list-style-type: none"><li>o Provides locator information on subjects, principal investigators, and research institutions for the overall report</li></ul>

Any questions concerning the Carbon Dioxide Research Program or specific projects may be addressed to the Carbon Dioxide Research Division, U.S. Department of Energy, ER-12, Washington, D.C., 20545, or by telephone at (301) 353-3281.



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## INTRODUCTION

Worldwide monitoring indicates that the amount of carbon dioxide (CO<sub>2</sub>) in the earth's atmosphere is gradually increasing. CO<sub>2</sub> has risen from 316 parts per million (ppm) in 1958, when continuous monitoring was initiated, to 343 ppm in 1983. The scientific consensus is that an overall increase of 15% has taken place since the turn of the century, primarily because of the growing use of fossil fuels. This change in atmospheric CO<sub>2</sub> may have substantial effects on climate and vegetation, which could in turn significantly affect agriculture and other human endeavors.

In 1978, Congress enacted the National Climate Program Act to establish a comprehensive national policy for dealing with all climate-related issues. Responsibilities under the Act involve several governmental agencies. The U.S. Department of Energy (DOE) serves as the lead agency for coordinating the Government's research efforts in the area of atmospheric CO<sub>2</sub>. Within DOE, this role is the mission of the Carbon Dioxide Research Division (CDRD) of the Office of Basic Energy Sciences, which is part of the Office of Energy Research. The placement of the Division within DOE is shown in Figure 1.

**Research Program** DOE initiated its research program in 1978. The goal of the research program is the identification of possible policy options for governmental action in response to changes in the atmospheric CO<sub>2</sub> concentration. Achievement of this goal requires increased understanding of CO<sub>2</sub> interactions involving the atmosphere, the biosphere, the oceans, and the cryosphere. The functions assumed by the program to fulfill this goal are to

- o Sponsor specific projects that would either increase the knowledge base or support refinement of the conceptual tools being used to help understand the phenomenon
- o Communicate to the domestic and international research communities potential priority issues and the implications of research findings
- o Perform a continuing technical review of the products of the varied research efforts worldwide to expand the growing knowledge base
- o Coordinate Federal research related to CO<sub>2</sub>

The coordinating effort within DOE began in 1977 with a series of workshops and conferences. This was done so that leading scientists could formulate the questions that needed to be addressed in order to define research needs and reduce uncertainties.

**Carbon Dioxide Research Approach** To increase the knowledge base, DOE has defined the research logic shown in Figure 2. The major efforts of the CDR Program are presently focused on the cross-hatched areas.

The basis for CO<sub>2</sub> research is a scientific understanding of the carbon cycle, that is, the means by which carbon is stored and transferred among the earth's four principal carbon reservoirs--the atmosphere, the oceans, the biosphere, and deposits of fossil fuels. Transfers of carbon among these reservoirs should balance, although actual measurements have failed to capture this balance.

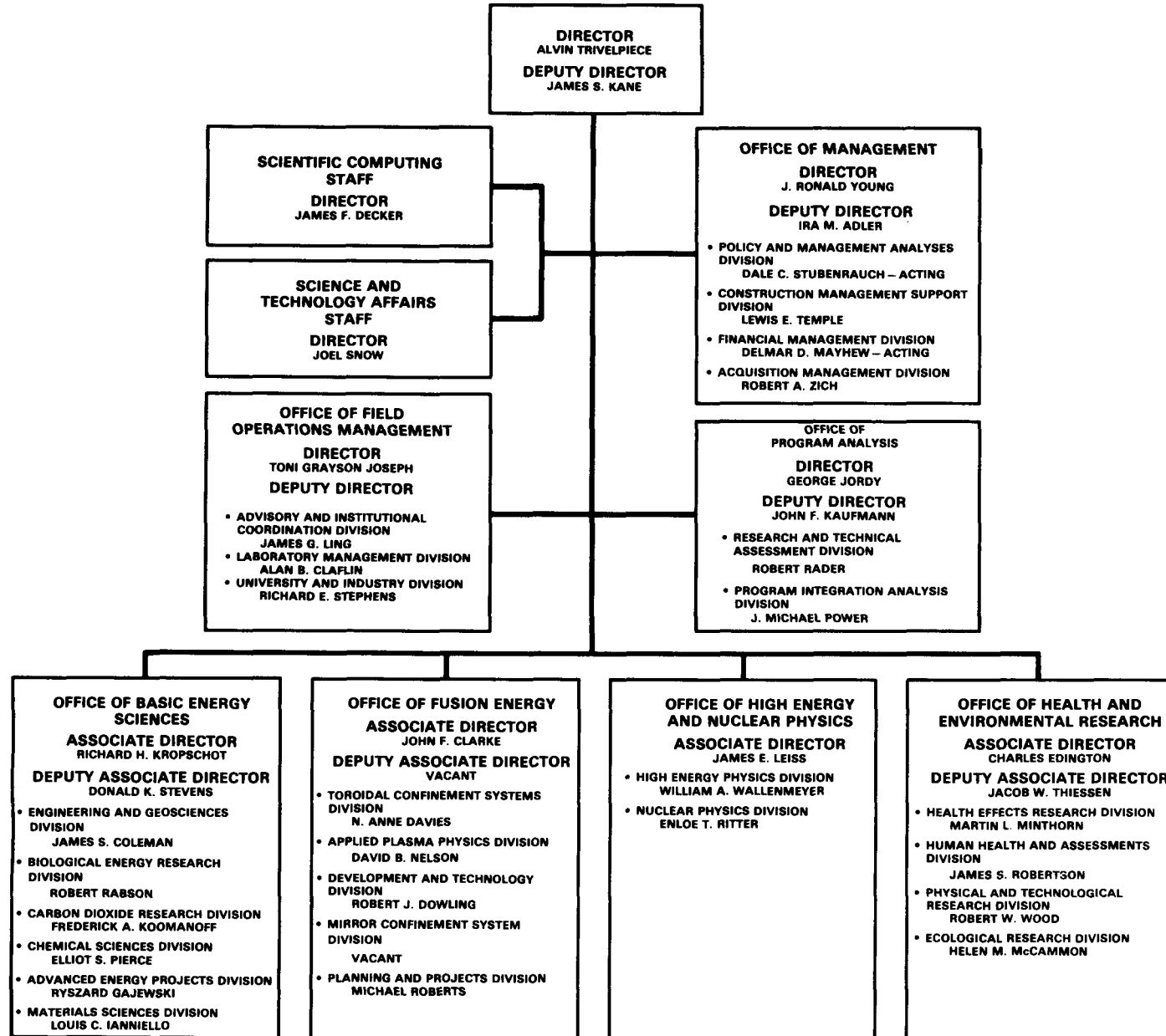
Understanding the global carbon cycle leads to determining what direct effects rising levels of CO<sub>2</sub> will have on climate and vegetation. Research in climate is directed at determining the extent to which rising levels of CO<sub>2</sub> will lead to global and regional climate changes. A major project is to establish when and how climate changes will first be detected against the background of normal climatic cycles and variations. Research in the response of vegetation to rising levels of CO<sub>2</sub> will focus on the role of CO<sub>2</sub> in photosynthesis and plant growth and the corresponding changes in the yields and structure of crops and ecosystems.

These direct effects will in turn cause numerous indirect effects on human activities, health, and welfare. Evaluation of these indirect effects, and of the degree to which modification, adaptation and prevention (MAP) strategies can be pursued, is the purpose of the fourth research area of the research program.

Additional program areas (represented by the boxes to the right of the cross-hatched area of Figure 2) are scientific interface, integration and evaluation, policy options, decisions, and implementation. Scientific interface is the communication of information to interested members of the research and policymaking communities, the cooperation with and coordination of the efforts of these same communities, and program management.

Integration and evaluation concerns publishing the State-of-the-Art (SOA) reports and the Statement of Findings (SOF), as well as performing risk and cost/benefit

**FIGURE 1. OFFICE OF ENERGY RESEARCH**



analyses necessary for future policy option reviews. The SOA reports, to be issued by DOE in 1985, will be definitive, scientific statements about what is and is not known and the uncertainties surrounding data and research results on each of the research areas described above--carbon cycle, climate, vegetation, and indirect effects--plus the study area of first detection listed under climate. The SOF, to be issued by the fall of 1985, will synthesize the SOA reports and other studies and present an integrated systems view of the entire research program needed to reduce uncertainties.

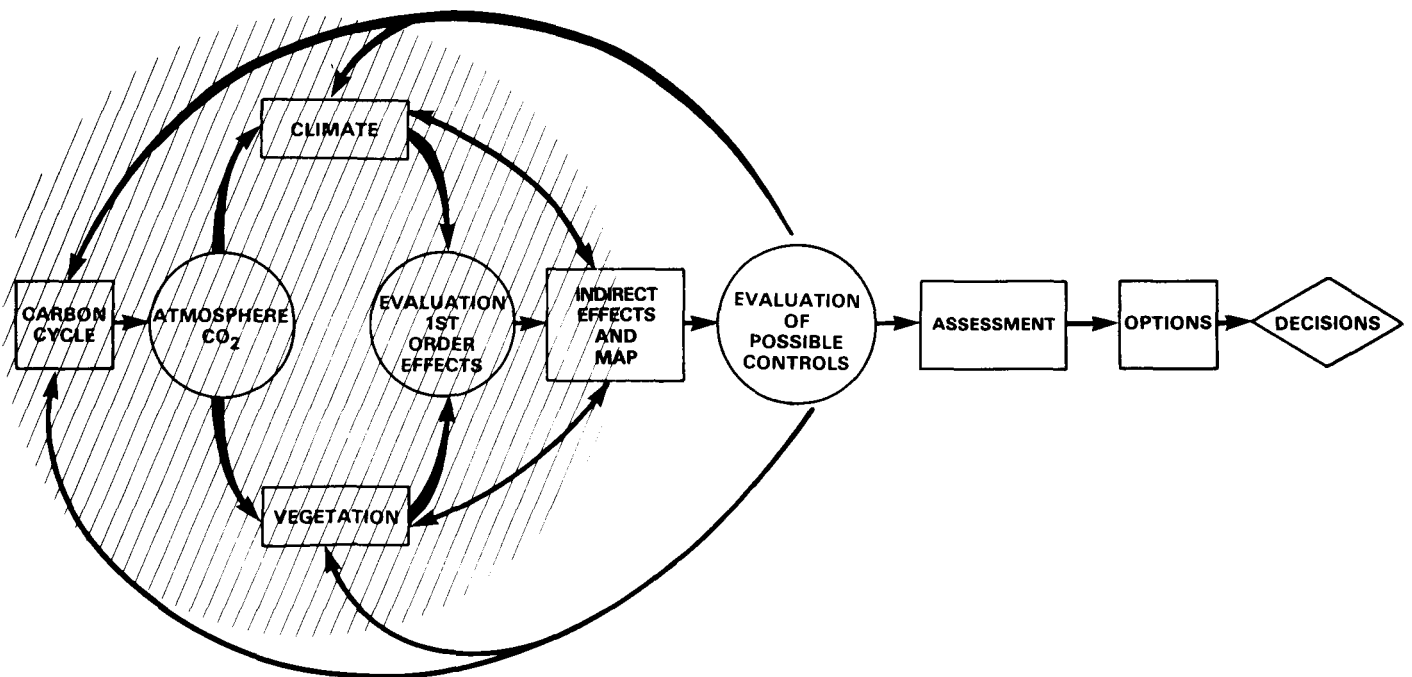
The policy options, decisions, and implementation areas of the research program are currently awaiting the outcomes of further research. Thus, the structure of the CDR Program in these areas remains tentative.

**Distribution of Research** Because of the diverse types of research needed to meet the objectives of the research program, a wide range of research institutions and agencies is participating. DOE is supporting leading scientists in government

agencies such as the National Oceanic and Atmospheric Administration (NOAA), the U.S. Department of Agriculture (USDA), in the national laboratories, and in universities and private industry. The distribution of research funds to types of research institutions by fiscal year and for the overall program is presented in Table 1. To date, universities have received the largest percentage of overall funding, followed by the national laboratories and government agencies.

**Level of Effort** Research sponsored by the CDR Division has increased steadily since its beginning in FY 1978 when \$1,479,000 was made available for program development and research. By FY 1983, the budget was \$9,073,000, and reached \$12,473,000 in FY 1984. During the first years of the program, the research budget was concentrated in the carbon cycle and climate areas, but as of FY 1984 was distributed over six research areas, reflecting the maturing of the program. The distribution of research funds to research areas by fiscal year and for the overall program is presented in Table 2.

FIGURE 2. THE CO<sub>2</sub> PROGRAM



**Organization of the Program Summary** Descriptions are provided for all projects funded by DOE under annual contracts in FY 1983 and/or FY 1984 as well as those funded into these years under multiple-year contracts from FY 1982. (No projects funded under multiple-year contracts from fiscal years earlier than FY 1982 were active as of FY 1983.) Each description contains the project's title, 3-year funding history (in thousands of dollars), the contract period over which the funding applies(d), the name(s) of the principal investigator(s), the institution conducting the projects, and the project's objectives, products and approach. Project descriptions are categorized within the report according to each one's emphasis relative to the six principal program areas: carbon cycle, climate and first detection, vegetation response; indirect effects, scientific interface, and integration and evaluation. Within these categories, the descriptions are grouped alphabetically by principal investigator. Each program area category is preceded by a brief text that defines the program area, states its goals and objectives,

lists principal research questions, and identifies program and/or area managers.

**Indexes and Keywords** A comprehensive system of indexing has been developed for this document to aid in locating research topics, participants, and research institutions in the text and the project descriptions. Each section of the report, beginning with carbon cycle, contains indexes of keywords, principal investigators, and research institutions for project descriptions in that particular section, with the principal investigator and institution indexes preceding and the keyword index following the project descriptions. A maximum of five keywords is included for each project description with words selected to be pertinent to CDR Program interests and not to correlate with other program summaries or references. Comprehensive subject, principal investigator, and institution indexes also are provided at the end of the text. The comprehensive subject index includes keywords from the Introduction and chapter texts in addition to those from the project descriptions.

**Table 1: Distribution of CDRD Research Funds to Institutions by Fiscal Year (in 1000 dollars)**

Type of Institution	FY78	FY79	FY80	FY81	FY82	FY83	FY84	TOTAL	Percent of Program Funding (all fiscal years)
University	955	1,326	3,455	5,357	4,613	3,086	4,092	22,884	43
Laboratory	332	755	1,854	3,177	4,894	4,206	6,059	21,277	40
Government	192	283	75	595	1,790	1,078	1,286	5,299	10
Industry	0	11	40	110	249	510	536	1,456	3
Other	0	528	600	497	460	213	427	2,725	5
Total	1,479	2,903	6,024	9,736	12,006	9,093	12,400	53,641	100
Budget Adjustment	0	0	0	0	(35)	(20)	73	18	
Total Budget	1,479	2,903	6,024	9,736	11,971	9,073	12,473	53,659	

**Table 2:** Distribution of CDRD Research Funds to Research Areas by Fiscal Year  
(in 1000 dollars)

Research Area	FY78	FY79	FY80	FY81	FY82	FY83	FY84	TOTAL	Percent of Program Funding (all fiscal years)
Carbon Cycle	789	1,653	3,798	5,515	5,160	3,389	3,565	23,869	44
CO <sub>2</sub> Climate	348	490	1,050	2,029	3,327	2,073	3,325	12,642	24
Vegetation Response	0	122	238	917	1,688	1,444	2,514	6,924	13
Indirect Effects	0	180	194	45	374	525	1,441	2,759	5
Scientific Interface	0	0	40	65	926	1,082	1,253	3,366	6
Integration Evaluation	202	200	228	679	531	580	302	2,722	5
Program Development Management	140	258	475	486	0	0	0	1,359	3
<b>Total</b>	<b>1,479</b>	<b>2,903</b>	<b>6,024</b>	<b>9,736</b>	<b>12,006</b>	<b>9,093</b>	<b>12,400</b>	<b>53,641</b>	<b>100</b>
Budget Adjustment	0	0	0	0	(35)	(20)	73	18	
<b>Total Budget</b>	<b>1,479</b>	<b>2,903</b>	<b>6,024</b>	<b>9,736</b>	<b>11,971</b>	<b>9,073</b>	<b>12,473</b>	<b>53,659</b>	



## CARBON CYCLE

There are four principal reservoirs, or regions of the earth, in which carbon behaves in a systematic manner. These are the atmosphere, the terrestrial biosphere, the oceans, and the earth's deposits of fossil fuels. Carbon can transfer between reservoirs through a variety of chemical, physical, geological, and biological processes. Reservoirs, or components of reservoirs, that release carbon to other reservoirs, are termed sources. Those that absorb carbon are termed sinks. The rate of carbon exchange between reservoirs is the carbon flux. This overall network of storage and transfer is known as the carbon cycle.

**Research Objectives** The goal of carbon cycle research is the estimation of future atmospheric CO<sub>2</sub> levels. This goal is contingent upon fundamental knowledge of the exchange of carbon between the principal reservoirs. Specific objectives of carbon cycle research are therefore to quantify those exchanges and to estimate the changes in atmospheric CO<sub>2</sub> concentration from past and future anthropogenic (i.e., human) activities. Primary areas of study are atmospheric observations of CO<sub>2</sub> concentrations and trends, fossil fuel emissions, oceans, the biosphere, depositories (sinks), transfers (fluxes) of CO<sub>2</sub>, and modeling of the global carbon cycle.

**Research Questions** Answers to the following questions are needed to achieve the stated objectives:

- o What future releases of CO<sub>2</sub> to the atmosphere from fossil fuel combustion can be expected under alternative levels of use? What is the history of such releases?

- o What is the trend, annual cycle, and geographic variability of atmospheric CO<sub>2</sub>? How has the concentration of CO<sub>2</sub> in the atmosphere changed over the past centuries and millennia? Was there a steady-state condition in the carbon cycle prior to anthropogenic perturbations?
- o Is the terrestrial biosphere a net source or sink (or is it in equilibrium) for atmospheric CO<sub>2</sub>? How large are and what is the nature of exchanges between the atmosphere and different terrestrial ecosystems? What has been the influence of deforestation and cultivation on atmospheric CO<sub>2</sub>? Has the situation changed substantially in the past 100 years?
- o What is the variability over time and over regions of ocean-atmosphere CO<sub>2</sub> exchange? How rapidly is carbon removed from surface water to the deep ocean? What is the globally averaged rate of ocean uptake of atmospheric CO<sub>2</sub>?
- o How can one determine whether there are significant sources or sinks of atmospheric CO<sub>2</sub> not now considered in carbon cycle models? Why have efforts to compute a balanced carbon budget for the carbon cycle as yet been unsuccessful?

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 Oak Ridge, TN 37831  
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**Project Title:**

DEVELOPMENT OF A THREE-DIMENSIONAL MODEL OF THE NATURAL CARBON CYCLE IN THE OCEAN AND ITS PERTURBATION BY ANTHROPOGENIC CARBON DIOXIDE

**Current Contract Period:**

10/01/83-09/30/84

**Funding:** FY1984           63  
          FY1983           0  
          FY1982           0

**Principal Investigator/s:**

BACASTOW, ROBERT B.

**Organization/s:** SCRIPPS INSTITUTION OF OCEANOGRAPHY

**Objectives:** To develop a three-dimensional (3-D) transport model of the natural carbon cycle in the ocean and ultimately to produce a model for the estimation of the uptake of anthropogenic CO<sub>2</sub> by the world's oceans.

**Products:** A model of the partial pressure of CO<sub>2</sub> in ocean surface waters and total CO<sub>2</sub> in surface and subsurface waters. This requires that the alkalinity also be modeled. In addition, tracers such as <sup>14</sup>C and <sup>3</sup>H will be modeled because they are good indications of ocean transport rates.

**Approach:** During the first year of this project, the principal investigator will be working with Klaus Hasselmann and co-workers at the Max-Planck Institute for Meteorology in Hamburg, Federal Republic of Germany. The 3-D transport model to be developed for this project will be based on the ocean circulation model that is being formulated at Hamburg. The model will assume consistent velocity, salinity, and temperature fields. The transport equation for the chemical species involved and sinks of carbon due to formation and decomposition of organic matter will be determined. The sources and sinks will be determined from primary production and particle trap data and by changes in the concentration of trace chemical species, including total CO<sub>2</sub>, O<sub>2</sub>, alkalinity, and NO<sub>3</sub>, as measured by the GEOSECS and TTO expeditions.

**Project Title:**

REGIONAL CARBON DIOXIDE FLUXES

**Current Contract Period:**

10/01/82-09/30/83

**Funding:** FY1984        0  
              FY1983        75  
              FY1982        99

**Principal Investigator/s:**

BINGHAM, GAIL

**Organization/s:** LAWRENCE LIVERMORE NATIONAL LABORATORY

**Objective:** To validate a CO<sub>2</sub> flux sensor and to determine its potential for estimating CO<sub>2</sub> exchange over regional ocean expanses and the terrestrial biosphere. Estimates will be used to document regional and seasonal variability and to evaluate effects of turbulence on atmosphere-ocean exchange of CO<sub>2</sub>.

**Product:** Direct measures of atmosphere-ocean and atmosphere-biosphere CO<sub>2</sub> exchange. For oceans, the term E (gas exchange coefficient) of the net CO<sub>2</sub> flux equation,  $F = E \times \Delta pCO_2 / (pCO_2)_a$ , will be estimated using fast-response CO<sub>2</sub> sensors and eddy correlations to estimate exchange of atmospheric properties with surfaces. For the biosphere, estimates of CO<sub>2</sub> flux will be correlated with net annual CO<sub>2</sub>-cycle photosynthesis or respiration.

**Approach:** Integrated area fluxes will be estimated with a fast-response CO<sub>2</sub> sensor for aircrafts flights over oceans with different pCO<sub>2</sub> properties and over fields and forests instrumented for independent measure of CO<sub>2</sub> flux. The results will be compared with independent estimates obtained indirectly (Rn exchange) for oceans and stationary land-based sites to assess the potential for estimating integrated area net CO<sub>2</sub> exchange.

**Project Title:**ANALYSIS OF ARCHIVED SEA WATER SAMPLES: 1900  
TO THE PRESENT**Current Contract Period:**

08/01/84-07/31/85

**Funding:** FY1984        64  
                  FY1983        0  
                  FY1982        0**Principal Investigator/s:**

BREWER, PETER G.

**Organization/s:** WOODS HOLE OCEANOGRAPHIC INSTITUTION

**Objective:** To explore the use of archived seawater samples to reconstruct early 20th-century atmospheric CO<sub>2</sub> concentrations. This project represents a high-risk, yet high-payoff venture because atmospheric CO<sub>2</sub> concentrations for this time segment are particularly critical for model validation and testing.

**Product:** A record of atmospheric CO<sub>2</sub> concentrations over the last century based on archived seawater samples. This exploratory project provides for a first look at the samples, but not for the extraction of all information. Should this research be successful, further work will be required; however, if the samples yield erratic results requiring large corrections, then it would not be prudent to proceed further.

**Approach:** Seawater samples will be obtained from the Institute of Oceanographic Sciences, Wormly, England, covering the period from 1900 to the present. The samples will be analyzed to determine the chemical and isotopic properties that are relevant to the decoding of the temporal CO<sub>2</sub> signal. Furthermore, a search will be made in England, Denmark, and Norway for all documentation supporting these samples. The samples will be subjected to a variety of analyses yielding information on radiocarbon, oxygen, pH, nutrients, CO<sub>2</sub>, chlorofluorohydrocarbons, tritium, helium, and nitrous oxide levels. The validity of the samples must be questioned and carefully studied because they were collected for determination of salinity, not oceanic CO<sub>2</sub> content. The samples may have been handled in such a way as to influence their CO<sub>2</sub> content; thus, all possible effects of sample preparation must be considered.

**Project Title:**

OCEAN TRACER MODELING: DATA EVALUATION AND  
COMPARISON OF PRELIMINARY MODELS

**Current Contract Period:**

01/01/84-12/31/84

**Funding:** FY1984        62  
              FY1983        60  
              FY1982        60

**Principal Investigator/s:**

BROECKER, WALLACE S.

**Organization/s:** LAMONT-DOHERTY GEOLOGICAL OBSERVATORY

**Objectives:** To place limits on the extent to which changes in the cycling of organic material in the sea have altered the course of the atmosphere's CO<sub>2</sub> content. To determine how well nutrients can be predicted if given the location, depth, potential temperature, and salinity.

**Product:** Atlases of nutrient plots, region by region in every ocean, based on GEOSECS and TTO data sets. Results of model calculations with a variety of relevant scenarios that might influence the production and/or cycling of organic material in the sea.

**Approach:** Various scenarios of changes which might influence the ocean life cycle will be used in model calculations, so that the magnitude of the changes in CO<sub>2</sub> can be tied to the magnitude of the changes in O<sub>2</sub> and the nutrient parameters for thermocline waters. For nutrient predictions, GEOSECS and TTO data will be used to plot PO<sub>4</sub> vs. NO<sub>3</sub>, PO<sub>4</sub> vs. CO<sub>2</sub>, PO<sub>4</sub> vs. Apparent Oxygen Utilization, and Silica vs. Alkalinity region by region in every ocean.

**Project Title:**

CORAL GROWTH RINGS AND THE TEMPORAL HISTORY  
OF NUCLEAR C-14/C AND Sr-90/Sr IN THE  
SURFACE OCEAN

**Current Contract Period:**

06/01/82-05/31/84

**Funding:** FY 1982 227  
(Funded for 24 months)

**Principal Investigator:**

BROECKER, WALLACE S.  
FAIRBANKS, RICHARD G.

**Organization/s:** LAMONT-DOHERTY GEOLOGICAL OBSERVATORY

**Objective:** To obtain time histories of  $^{90}\text{Sr}$  and  $^{14}\text{C}$  of the surface ocean from annual growth bands of head-corals for use in estimating  $\text{CO}_2$  exchange between atmosphere and ocean. The isotopic records will also provide a database for developing or tuning models of ocean circulation and fossil  $\text{CO}_2$  removal by oceans.

**Product:** Data on abundance of  $^{90}\text{Sr}$  and  $^{14}\text{C}$  in growth rings of coral for selected corals of the Pacific and Atlantic Oceans. These data, interpreted in relation to other information from bomb fallout, will provide the basis for regional-scale models of ocean circulation and carbon uptake.

**Approach:** Because of annual growth characteristics of head corals and because they assimilate bomb-tracer information from bodies of waters which bathe them, they can provide time series data about properties and history of circulating water masses for the past 30 years. Coral heads are sectioned, dated, and analyzed for  $^{90}\text{Sr}$  and  $^{14}\text{C}$ . Coral isotopic data are interpreted in relation to ocean input and used as a proxy record of regional circulation patterns (upwelling, downwelling, Eckman pumping).

**Project Title:**

THE ROLE OF TROPICAL FORESTS IN THE GLOBAL  
CARBON CYCLE

**Current Contract Period:**

11/24/83-11/23/84

**Funding:** FY1984        88  
              FY1983        80  
              FY1982        0

**Principal Investigator/s:**

BROWN, SANDRA  
LUGO, ARIEL

**Organization/s:** UNIVERSITY OF ILLINOIS AND UNIVERSITY OF PUERTO RICO

**Objectives:** (1) To investigate the changes in soil carbon pools in tropical forest lands subjected to various intensities and types of land uses; (2) to develop carbon budgets for selected tropical forest life zones in both young and mature stages; and (3) to investigate the present and future role of tropical tree plantations in the global carbon cycle.

**Products:** (1) Documentation of soil carbon changes under tropical land uses; (2) carbon budgets for mature and successional tropical forests; (3) determination of the potential role of tropical forest plantations as sinks of carbon; and (4) a complete report synthesizing all information for reassessment of the role of tropical forests in the global cycle.

**Approach:** Soil samples will be collected and analyzed for their carbon content from areas subjected to known land uses over a known time period from six major life zones (tropical and subtropical dry, moist, and wet forests). These data will provide information on the behavior of the soil compartment during disturbance and recovery to and from various land uses.

Data from the literature and unpublished information from colleagues working in the field will be used to develop carbon budgets of major forest life zones in both mature and successional stages. These data will be supplemented with measurements of tree growth, tree mortality, and storage of litter and dead wood from long-term growth plots in tropical forests in Puerto Rico.

From this project has been produced a data file compiled from the published literature containing data from approximately 500 tropical tree plantations. This will be updated and subjected to an analysis similar to one previously performed for natural tropical forests. This will include the classification of the data into life zones, estimation of the areas of tropical plantations by life zones, and calculation of organic carbon budgets for all tropical plantations to estimate their role in the carbon cycle.

**Project Title:**

ON THE INCREASE OF TOTAL CARBON DIOXIDE IN  
THE WORLD OCEANS

**Current Contract Period:**

01/01/84-12/31/84

**Funding:** FY1984        89  
              FY1983        66  
              FY1982        36

**Principal Investigator/s:**

CHEN, C.-T.

**Organization/s:** OREGON STATE UNIVERSITY

**Objective:** To further quantify oceanic penetration of anthropogenic or excess carbon dioxide by using direct measurements or carbonate data.

**Product:** A reliable carbon chemistry data base for the deep-water formation source in the Southern Ocean. Such information will contribute significantly to parameterization of this process in models of oceanic CO<sub>2</sub> uptake. A synthesis of information on excess CO<sub>2</sub> calculations based on carbonate data will assess the utility of the technique in determining the penetration of anthropogenic CO<sub>2</sub> in the oceans.

**Approach:** The analysis of carbonate chemistry data represents a potentially important approach for quantifying the oceanic distribution of fossil fuel-derived CO<sub>2</sub>. The principal investigator will first fully document his earlier research and data analyses regarding this topic before proceeding with a new field measurement program. The major component of the field research will be to document the effects of seasonal and cross-frontal variations in primary productivity, nutrient dynamics, and the biogeochemical cycles of calcium, carbon, oxygen, and radiotracers in the Southern Ocean (Antarctic). One cruise is scheduled for the fall of 1984, two are scheduled in 1985, and one is scheduled in 1986. Continuous surface samples will be taken, and water column stability will be studied at about 12 specified stations, including nearby GEOSECS stations. The hydrography and biogeochemical nature of the region will also be investigated at about six seep stations. A revisit to the 1981 SOMOV stations and the 1973 GEOSECS Station 89 of the Weddell Sea is tentatively scheduled for 1986. These reoccupations should reveal secular changes in oceanic CO<sub>2</sub> penetration.

**Project Title:**

CARBON DIOXIDE EMISSIONS

**Current Contract Period:**

10/01/83-09/30/84

**Funding:** FY1984      150  
              FY1983      150  
              FY1982      0

**Principal Investigator/s:**

EDMONDS, JAE

**Organization/s:** OAK RIDGE ASSOCIATED UNIVERSITIES

**Objective:** To prepare estimates of CO<sub>2</sub> emissions along with associated uncertainties about these emissions over the period 1975 to 2075. The program will build on work conducted during FY 1983 in which subjective probabilities were assigned by Institute for Energy Analysis, Oak Ridge Associated Universities (IEA/ORAU) analysts from three scenarios.

**Products:** (1) Data base development; (2) model modification; (3) uncertainty analysis; (4) documentation revision; and (5) transfer of model to the Carbon Dioxide Information Center (CDIC).

**Approach:**

A data base of input parameters for the uncertainty analysis will be developed based on previously conducted literature reviews and informal surveys of experts, such as the Oak Ridge Survey of FY 1983.

The IEA/ORAU long-term global energy-CO<sub>2</sub> model will be modified for use with state-of-the-art uncertainty analysis software. This work will build on the sensitivity analysis conducted in FY 1983.

A state-of-the-art Monte Carlo computer package will be used together with the IEA/ORAU long-term global energy-CO<sub>2</sub> model to conduct an uncertainty analysis. At the conclusion of this analysis, an assessment will be made as to the relative need for further data base development and model enhancements.

The document "Global Carbon Emissions From Fossil Fuels, 1975 to 2075," which was completed in FY 1983, will be revised at the conclusion of the documentation review process.

The IEA/ORAU long-term global energy-CO<sub>2</sub> model will be transferred, together with supporting documentation, to CDIC at ORNL.

**Project Title:**

GLOBAL CARBON CYCLES AND CLIMATIC RISKS

**Current Contract Period:**

10/01/83-09/30/84

**Funding:** FY1984      403  
              FY1983      240  
              FY1982      360

**Principal Investigator/s:**

EMANUEL, WILLIAM R.

**Organization/s:** OAK RIDGE NATIONAL LABORATORY

**Objectives:** To extend understanding of the global carbon cycle in order to explain the causes of observed changes in atmospheric CO<sub>2</sub> concentration and to provide a capability to project future changes in CO<sub>2</sub> levels as further fossil fuel use occurs.

**Product:** Papers in the scientific literature describing mathematical models of the global carbon cycle and underlying data, testing, verification, and applications of these models to address carbon cycle issues.

**Approach:** Changes in atmospheric CO<sub>2</sub> concentration are controlled by interactions between the atmosphere and other carbon reservoirs, particularly the oceans and land ecosystems. Current estimates of the oceanic uptake are too low to accommodate the releases of carbon from vegetation and soils thought to have occurred over the past century because of land-use change; however, the analysis is complicated by uncertainty as to the history of atmospheric CO<sub>2</sub> before the beginning of accurate measurements. In the next stages of research, estimates of the rate of carbon uptake by the oceans and reconstructions of the history of changes in carbon storage in vegetation and soil because of land-use change will be refined in order to improve the capability to account for the fate of fossil fuel CO<sub>2</sub>.

A set of digital maps with 0.5° resolution will be used to incorporate geography in the analysis of land use. These maps will underlie models that simulate changes in carbon storage in terrestrial ecosystems. Ocean models are being developed that explicitly treat each major region of the oceans and resolve both depth and latitude, and clearer treatment is being given to the role of marine organisms in carbon cycling and tracer distributions.

New models will be available as the history of atmospheric CO<sub>2</sub> is clarified by data such as ice-core CO<sub>2</sub> measurements. Models will be tested against such independent data and compared against the results from other formulations to determine the attributes that are responsible for differences in response and interpretations.

**Project Title:**

STUDY OF CARBON DIOXIDE SOURCE/SINK  
DISTRIBUTIONS WITH A THREE-DIMENSIONAL MODEL

**Current Contract Period:**

08/01/84-07/31/85

**Funding:** FY1984        140  
              FY1983        67  
              FY1982        60

**Principal Investigator/s:**

FUNG, INEZ Y.-S.

**Organization/s:** LAMONT-DOHERTY GEOLOGICAL OBSERVATORY

**Objective:** To investigate potential information about CO<sub>2</sub> sources and sinks contained in temporal (seasonal and interannual) and geographical variations in atmospheric CO<sub>2</sub>, using a three-dimensional (3-D) atmospheric model.

**Product:** A refined 3-D model of atmospheric CO<sub>2</sub> circulation which treats spatial and temporal exchange of CO<sub>2</sub> between the atmosphere, the biosphere, and the ocean. The model will be used to analyze information on relationships among sources and sinks and deviations from the long-term secular trend of CO<sub>2</sub>.

**Approach:** A 3-D transport model developed by the Goddard Institute for Space Studies will be further refined and used to compute the global distribution of atmospheric CO<sub>2</sub> for specified sources and sinks (biosphere, ocean, humans). The model will be based on first principles or on the best available input data, and the ability of the computed global distribution of CO<sub>2</sub> to account for observed seasonal and interannual variations in CO<sub>2</sub> abundance will be examined. During the next year, refinements will be made to the (1) seasonality of biospheric exchange; (2) scenarios of deforestation release of CO<sub>2</sub>; and (3) monthly maps of pCO<sub>2</sub>, total alkalinity, and total carbon concentrations in the surface waters of the oceans. In addition, the geographic distribution of piston velocity (rate of air-sea exchange) based on observed wind speeds and sea surface temperatures will be investigated.

**Project Title:**

CARBON DIOXIDE IN ARCTIC AND SUBARCTIC  
REGIONS

**Current Contract Period:**

08/01/83-07/31/84

**Funding:** FY1984           0  
              FY1983           60  
              FY1982          150

**Principal Investigator/s:**

GOSINK, THOMAS J.

**Organization/s:** UNIVERSITY OF ALASKA

**Objective:** To identify principal sources and sinks for CO<sub>2</sub> in polar regions and to quantify spatial and temporal CO<sub>2</sub> exchange of ocean and Arctic tundra.

**Product:** Documentation that the Arctic is a net annual sink for CO<sub>2</sub> and that natural sources and sinks located there are the cause of up to 20-40% of the observed large annual cycle of atmospheric CO<sub>2</sub>. Air-sea exchange of CO<sub>2</sub> for northern and southern polar oceans will be compared, supported by field data on effects of pCO<sub>2</sub>, biological productivity, and brine channels of sea ice.

**Approach:** Seasonal investigations are being conducted on the exchange of CO<sub>2</sub> at the interface of the atmosphere with the land, sea, and ice in various polar environments. Some results suggest that the Arctic regions represent a net annual sink for CO<sub>2</sub>, and additional data will be obtained on atmosphere-ocean CO<sub>2</sub> exchange involving Arctic and Subarctic water, CO<sub>2</sub> exchange at the sea-ice boundary, and CO<sub>2</sub> balance of tundra-tiaga regions. Data will be synthesized, interpreted, and modeled to evaluate spatial and temporal effects on the large annual CO<sub>2</sub> cycle.

**Project Title:**

NORTH ATLANTIC STUDY OF THE TRANSIENT TRACERS  
IN OCEAN PROGRAM (NAS/TTO)

**Current Contract Period:**

07/01/83-06/30/84

**Funding:** FY1984        0  
              FY1983        409  
              FY1982        615

**Principal Investigator/s:**

GROSS, M. GRANT

**Organization/s:** NATIONAL SCIENCE FOUNDATION

**Objective:** (1) To study deep ocean circulation and mixing processes using chemical tracers; (2) to study the flux of anthropogenic CO<sub>2</sub> into the ocean through its correlation with a multiplicity of tracers; and (3) to provide a data set to permit testing physically-derived concepts of ocean circulation.

**Product:** (1) Time-series data of bomb-produced tracers for estimating mixing rates of CO<sub>2</sub>-saturated surface with thermocline and deeper ocean water; (2) detailed carbon chemistry data to identify the relative strengths of different ocean regions for removing atmospheric CO<sub>2</sub> (precise total C data will provide a benchmark reference for future estimates of fossil CO<sub>2</sub> removal by oceans); and (3) improved models of carbon transport (a database of all properties is essential for developing and calibrating models of ocean circulation).

**Approach:** Physical and chemical properties of the North Atlantic Ocean will be measured, including carbon (pCO<sub>2</sub>, ΣC, alkalinity), transient tracers (<sup>3</sup>H, <sup>14</sup>C, <sup>85</sup>Kr, freons), steady-state tracers (<sup>39</sup>Ar, <sup>226</sup>Ra, <sup>228</sup>Ra), and hydrographic-nutrient constituents (T, S, O<sub>2</sub>, NO<sub>3</sub>, NO<sub>2</sub>, PO<sub>4</sub>) collected from vertical soundings. The resultant database will be compared with GEOSECS data to determine how rapidly CO<sub>2</sub>-saturated surface water penetrates the deep ocean, and will aid modeling of thermocline penetration and bottom-water formation. Carbon-14 data provide estimates of atmosphere-ocean exchange of CO<sub>2</sub>, and profile distributions are the basis for calibration of ocean-mixing models.

**Project Title:**

INCORPORATING HISTORICAL FACTORS INTO THE  
TROPICAL LAND USE/CARBON MODEL (GLOBC7)

**Current Contract Period:**

01/01/84-12/31/84

**Funding:** FY1984        47  
              FY1983        41  
              FY1982        0

**Principal Investigator/s:**

HALL, CHARLES A. S.

**Organization/s:** CORNELL UNIVERSITY

**Objective:** To continue the assessment of carbon release from human activities for the entire tropics (76 countries). Data from a variety of sources (e.g., FAO and other DOE-funded researchers including Richards, Brown, Lugo, Olson, and Post) will be integrated with a tropical land use/carbon model developed by Hall and colleagues through DOE funding. The country-by-country life zone analysis (with emphasis on Brazil) will also continue.

**Product:** An estimate of carbon exchange and associated uncertainties resulting from land use changes in the tropics. Efforts to reduce the uncertainty of historical estimates of land in agriculture will focus on the period 1960 to 1980.

**Approach:** The existing computer model (GLOBC7) will be combined with various estimates of land use change as well as biomass and soil carbon estimates. Emphasis in research this year will be to add a historical component to the existing analyses, to fill in gaps in the present country-by-country FAO data-based analysis, and to perform an analysis of Brazilian data using the life zone concept.

Data previously obtained by Richards will be used to develop curves representing areas of land in agriculture and forests and, where possible, in other categories such as shifting cultivation and forest fallow. The initial approach to determine biomass of the vegetation being cut will be to use wood volume to carbon conversion values supplied by S. Brown and A. Lugo and the FAO country-by-country estimates of virgin forest volumes (assuming these values are representative for forests of the past). Later work will use life zone analysis if it can be coordinated with Richards and Olson. Such work will be a major undertaking, and only a relatively few countries can be studied in 1984. Land use change in Brazil will be analyzed by methods developed for the analysis of Costa Rica, Panama, Peru, and Bolivia.

**Project Title:**

GEOCHEMICAL AND GEOPHYSICAL MODELS OF THE  
FOSSIL FUEL CARBON DIOXIDE CLIMATE PROBLEM

**Current Contract Period:**

03/08/83-03/07/84

**Funding:** FY1984        81  
              FY1983        76  
              FY1982        67

**Principal Investigator/s:**

HOFFERT, MARTIN

**Organization/s:** NEW YORK UNIVERSITY

**Objective:** To develop and apply a coupled carbon cycle/climate model to provide long period estimates of the effects of the historic and projected CO<sub>2</sub> emissions on global CO<sub>2</sub> concentrations and climate.

**Product:** Preliminary indications of the rate of future warming as CO<sub>2</sub> concentrations rise. This model will be the first to treat the carbon cycle and climate system, including oceanic temperatures and circulation, in a coupled, self consistent manner. Because of the relative simplifications in this model, the calculations can be done relatively quickly, but the estimates must be viewed as preliminary because many model parameterizations are based on statistical calibrations to the present climate. Although the model will not provide estimates of regional and seasonal resolution, it will be the only model able to estimate changes over relatively long periods of time (e.g., 200 years).

**Approach:** An improved energy balance climate model and a carbon cycle model (including marine biosphere, both with latitudinal resolution and coupled to a new two-dimensional ocean transport and storage model will be calibrated using GEOSECS, TTO and climate data. The model will be applied to simulate the climate and CO<sub>2</sub> concentrations of the recent past and to project future values.

**Project Title:**

MATHEMATICAL MODELS FOR USE IN DEFINING THE  
ROLE OF THE TERRESTRIAL BIOTA IN THE GLOBAL  
CARBON CYCLE

**Current Contract Period:**

10/01/83-09/30/84

**Funding:** FY1984        175  
              FY1983        0  
              FY1982        0

**Principal Investigator/s:**

HOUGHTON, RICHARD A.

**Organization/s:** MARINE BIOLOGICAL LABORATORY

**Objectives:** (1) To describe the range of estimates of the net carbon flux between biota and atmosphere that results from different data and assumptions; and (2) to develop a geographically based model to account for changes in and use through time.

**Products:** (1) A comparison of the various estimates of net CO<sub>2</sub> exchange between terrestrial ecosystems and the atmosphere; and (2) a geographically based model (1/2<sup>0</sup> by 1/2<sup>0</sup>) that calculates changes in the carbon stored on land. The matrix of data for the model is based on maps of geology, soil, vegetation, and history of land use.

**Approach:** The MBL/TCM will be used to translate uncertainties or disagreements in data and assumptions into ranges of carbon flux. The model will serve as a common denominator and provide the basis of comparison for different sets of data.

The intersection of geology, soil, and vegetation will define an ecosystem or life zone for which changes in carbon associated with disturbance will be determined from literature or current work by other DOE contractors. Rates of disturbance will be assigned to location on the basis of Richards' work in South and Southeast Asia and on the basis of recent changes in land use in Africa.

**Project Title:**

HIGH ACCURACY STANDARDS AND REFERENCE  
METHODOLOGY FOR CARBON DIOXIDE IN AIR

**Current Contract Period:**  
05/01/83-04/30/84

**Funding:** FY1984        180  
              FY1983        280  
              FY1982        200

**Principal Investigator/s:**  
HUGHES, ERNEST E.

**Organization/s:** NATIONAL BUREAU OF STANDARDS

**Objectives:** To develop a reference set of CO<sub>2</sub>-in-air standards to assist in ensuring traceability to national standards of worldwide atmospheric CO<sub>2</sub> measurements; to demonstrate measurement consistency between NBS standards and the Scripps primary measurement technique; to develop reference methodology for the accurate analysis of samples of CO<sub>2</sub> in air.

**Products:** (1) An initial set of CO<sub>2</sub>-in-air standard reference materials (SRMs) in the range of atmospheric concentrations (nominally 320, 340 and 360 ppm), plus a subsequent set of wider range CO<sub>2</sub>-in-air SRMs or research materials from about 200 to 1000 ppm: (2) Absolute reference analytical methodology for high-accuracy measurements of CO<sub>2</sub>-in-air standards. The former, taken together with a demonstration of consistency in CO<sub>2</sub>-in-air standard measurements between NBS and Scripps, will provide a potential for future measurements of atmospheric CO<sub>2</sub> to be directly traceable to NBS standards, thereby ensuring continuity in long-range stability and intercomparability of atmospheric CO<sub>2</sub> data. The latter will provide a wholly independent, absolute method for ensuring high accuracy measurements of CO<sub>2</sub> in air.

**Approach:** The initial set of CO<sub>2</sub>-in-air SRMs will be prepared by NBS by using gravimetric methods as a basis for accuracy. This preliminary set of standards has been analyzed for a period of over 1 year with a relative uncertainty which does not exceed 0.1% (0.3 ppm). Samples of these primary standards will be reserved for long-term stability studies and measurement compatibility over time. NBS measurements of standards (by gravimetric and isotope dilution methods) will be correlated with the Scripps manometric methods.

**Project Title:**

MONITORING OF ATMOSPHERIC CO<sub>2</sub> AT MAUNA LOA  
OBSERVATORY

**Current Contract Period:**

09/01/84-08/31/85

**Funding:** FY1984      135  
              FY1983      0  
              FY1982      0

**Principal Investigator/s:**

KEELING, CHARLES D.

**Organization/s:** SCRIPPS INSTITUTION OF OCEANOGRAPHY

**Objectives:** (1) To monitor atmospheric CO<sub>2</sub> concentrations at Mauna Loa for a two-year period; and (2) to complete the updates and corrections to the existing Mauna Loa CO<sub>2</sub> record (1958-present) using newly available advances in computer technologies.

**Products:** (1) Hourly atmospheric CO<sub>2</sub> concentrations in preliminary form that have received basic quality assurance evaluations and reports documenting any anomalies or deviations from standard procedures; (2) calibration of existing instrumentation with CO<sub>2</sub>-in-nitrogen gases and CO<sub>2</sub>-in-air gases and inclusion of calibration curves into the quality assurance and editing computer program; and (3) final edited and calibrated hourly atmospheric CO<sub>2</sub> concentration for 1958-present including all known or detected corrections established in products 1 and 2 above.

**Approach:** Continuation the monitoring of atmospheric CO<sub>2</sub> concentrations at Mauna Loa over the next two years. Implementation of computer programs that will incorporate existing quality assurance controls as well as calibration curves to adjust the Mauna Loa record for site and instrumentation errors. Incorporation of all quality assurance controls and calibration techniques, existing and/or developed, into the final reassessed atmospheric CO<sub>2</sub> record.

**Project Title:**

COMPARISON OF CARBON DIOXIDE DATA AND MEASUREMENTS AT THE MAUNA LOA OBSERVATORY BY NOAA AND SIO

**Current Contract Period:**  
01/01/83-12/31/83

**Funding:** FY1984           0  
              FY1983       100  
              FY1982       0

**Principal Investigator/s:**  
KEELING, CHARLES D.

**Organization/s:** SCRIPPS INSTITUTION OF OCEANOGRAPHY

**Objective:** (1) To explain causes of both systematic and random differences of atmospheric CO<sub>2</sub> data collected by SIO and NOAA at the Mauna Loa Observatory (MLO); (2) to recommend procedural changes for achieving convergence of measurements which maintain the long-term integrity of the database; and (3) to recommend institutional responsibility for continuation of atmospheric CO<sub>2</sub> measurements at MLO.

**Product:** Resolution of differences of atmospheric CO<sub>2</sub> at the MLO so that a single measurement program and database can be developed and maintained by a government agency (NOAA).

**Approach:** A comparative study will be carried out evaluating NOAA and SIO past data and methods of CO<sub>2</sub> measurement. Specific functions include correcting and comparing the past data, determining the degree of agreement as well as causes for any differences that may be present, and undertaking a field study of measurements taken simultaneously at MLO by scientists from both NOAA and SIO. A protocol will be worked out to change parameters successively at MLO to see, if possible, which factors may be causing any discrepancy. The detectors used, the sample-handling equipment and procedures, and the data selection procedures will be scrutinized.

**Project Title:**

A STUDY OF THE ABUNDANCE OF CARBON DIOXIDE IN THE ATMOSPHERE

**Current Contract Period:**

01/01/83-06/30/83

**Funding:** FY1984           0  
              FY1983           80  
              FY1982           401

**Principal Investigator/s:**

KEELING, CHARLES D.

**Organization/s:** SCRIPPS INSTITUTION OF OCEANOGRAPHY

**Objective:** (1) To continue CO<sub>2</sub> measurements at the Mauna Loa Observatory in concert with NOAA; (2) to complete measurement and interpretation of atmospheric CO<sub>2</sub> and isotopic ratios; and (3) to summarize interpretations of atmospheric CO<sub>2</sub> data from Pacific locations. This research is a continuation of a long-term study of CO<sub>2</sub> in the atmosphere and relationships among various sources and sinks.

**Product:** A summarized atmospheric CO<sub>2</sub> database for the Mauna Loa Observatory, Christmas Island, Fanning Island, and the South Pole. Evaluations of the comprehensive database will focus on seasonally varying gradients across the Pacific region, exchange of CO<sub>2</sub> between atmosphere and oceanic and biospheric sources and sinks, and empirical determinations of the atmospheric fraction of fossil fuel CO<sub>2</sub>.

**Approach:** Interim support will be provided to assure continuity of CO<sub>2</sub> measurements and data interpretation while responsibility for CO<sub>2</sub> monitoring at Mauna Loa and the promulgation of CO<sub>2</sub> standards shift from SIO to NOAA and NBS, respectively. Interim support will also be used to continue CO<sub>2</sub> and isotopic measurements and data interpretation at other Pacific locations (Christmas Island, Fanning Island, South Pole, and New Zealand) while research related to these locations is considered by the NSF.

**Project Title:**

ABSOLUTE ABUNDANCE AND VARIABILITY OF  
DISSOLVED INORGANIC CARBON IN OCEAN WATER

**Funding:** FY1982 118  
(Funded for 24 months)

**Current Contract Period:**

08/01/82-07/31/84

**Principal Investigator/s:**

KEELING, CHARLES D.

**Organization/s:** SCRIPPS INSTITUTION OF OCEANOGRAPHY

**Objectives:** (1) To obtain high-precision, direct time-series measurements of total C of ocean water; (2) to identify and quantify sources of natural variation of total C at selected ocean locations; and (3) to provide empirically-based estimates of ocean water change of total C in relation to fossil and biosphere CO<sub>2</sub>.

**Product:** Determination of the feasibility of directly measuring the change in total C of oceans in relation to fossil and possible biosphere sources of CO<sub>2</sub>. Direct estimates of the ocean carbon response to human-induced perturbation of the global carbon system will be possible given nominal seasonal and interannual variability of ocean properties.

**Approach:** Monthly samples of ocean water from at least three fixed locations will be analyzed for total C, alkalinity, salinity, and nutrients to provide a 2-year time series of data on variability of these parameters. High-precision total C measurements will be corrected for seasonal biological productivity. Candidate locations to be sampled include ocean areas in the vicinity of Hawaii, Bermuda, Station P of the North Pacific, and the Equatorial Pacific.

**Project Title:**

ACCURATE DETERMINATION OF C-13/C-12 IN CARBON  
DIOXIDE OF PAST ATMOSPHERES

**Current Contract Period:**

08/01/84-07/31/85

**Funding:** FY1984        83  
              FY1983        65  
              FY1982        60

**Principal Investigator/s:**

LONG, AUSTIN

**Organization/s:** UNIVERSITY OF ARIZONA

**Objective:** To develop an accurate atmospheric  $^{13}\text{C}/^{12}\text{C}$  record, representing the contributions of  $\text{CO}_2$  from fossil-fuel burning and changes in the biosphere, back to preindustrial times through  $^{13}\text{C}/^{12}\text{C}$  measurements in tree rings.

**Product:** The main product of this project will be a curve representing the  $^{13}\text{C}/^{12}\text{C}$  changes in atmospheric  $\text{CO}_2$  over the past 150 years. Isotopic effects attributable to such factors as local pollution, "canopy" effect, and most importantly, climate effects on fractionation, will be analyzed. Such a curve will provide key constraints in establishing the role of the biosphere as a  $\text{CO}_2$  source or sink in the recent past.

**Approach:** Our understanding of the factors influencing  $^{13}\text{C}/^{12}\text{C}$  trends will be expanded by analyzing additional sites to determine the regional extent of synchronicity of  $\delta^{13}\text{C}$  trends, by scrutinizing some site conditions which may, in theory, affect  $^{13}\text{C}/^{12}\text{C}$  ratios, and by studying effects of temperature and  $\text{CO}_2$  concentration on tree  $^{13}\text{C}/^{12}\text{C}$  ratios.

Specific tasks include: (1) Expanding the numbers of pinyon pine  $\delta^{13}\text{C}$  chronologies by adding two sites in southwestern New Mexico and/or northern Colorado; (2) sampling additional coastal California pines (single-leaf pinyon, ponderosa, and Bishop pine) to determine if the  $^{13}\text{C}/^{12}\text{C}$  fluctuations in the southwest extend over regions of different climate; (3) examining selected sites to determine the effect of other local influences (e.g., fire, deforestation, defoliation); and (4) developing  $^{13}\text{C}/^{12}\text{C}$  records from upper and lower forest-border bristlecone pines to study how the trees' cellulose responds to environmental and climatic variables such as soil moisture, temperature and  $\text{CO}_2$ .

**Project Title:**

ARGON-39 MEASUREMENTS ON SAMPLES EXTRACTED  
FROM OCEAN WATER

**Current Contract Period:**

08/15/83-08/14/84

**Funding:** FY1984           0  
          FY1983           40  
          FY1982           36

**Principal Investigator/s:**

OESCHGER, HANS

**Organization/s:** UNIVERSITY OF BERN

**Objective:** To measure the abundance of  $^{39}\text{Ar}$  in North Atlantic deep water samples collected by the North Atlantic Transient Tracers in Oceans Program (NA/TTO).

**Product:** Data on the abundance of  $^{39}\text{Ar}$  in deep-water samples collected by the TTO program.

**Approach:** As the surface water penetrates deeper ocean strata, the water mass becomes isolated from the atmospheric source of  $^{39}\text{Ar}$ . Natural decay of the isotope in deep water is measured, and the abundance of  $^{39}\text{Ar}$  in deep water (relative to modern abundance) provides accurate age determination of deep water. The data are used by the Physics Institute, TTO, and other ocean research programs to calibrate models of ocean circulation. Time and sometimes location of deep water formations are estimated from composite  $^{39}\text{Ar}$  and other man-made tracer data.

**Project Title:**

RECONSTRUCTION OF THE HISTORY OF THE  
ATMOSPHERIC CARBON DIOXIDE CONTENT AND  
C-13/C-12 RATIO BY ICE CORE ANALYSIS

**Current Contract Period:**

09/30/82-09/30/84

**Funding:** FY1982 98  
(Funded for 24 months)

**Principal Investigator/s:**

OESCHGER, HANS

**Organization/s:** UNIVERSITY OF BERN

**Objective:** To measure the CO<sub>2</sub> concentration in the atmosphere during the last 10,000 to 100,000 years, and to determine its natural variability, as well as possible causes and climatic effects.

**Product:** A time series on CO<sub>2</sub> concentration of the past atmosphere derived from ice cores. A pre-industrial atmosphere CO<sub>2</sub> value is obtained from the ice-core data, providing unique proxy CO<sub>2</sub> data for a geologic time interval (up to 100,000 years BP) for which no other measurements exist. The time-series data, establish an anchor point for model calculations for CO<sub>2</sub> increase. Insight on naturally occurring, pre-anthropogenic CO<sub>2</sub> cycles will also be provided by the ice-core data.

**Approach:** Samples of atmospheric air are entrapped as air bubbles in cold polar ice at the time of ice formation and stored in a stratigraphical sequence. Ice samples of up to 100,000 years old have been collected by core drilling through the polar ice sheets in Greenland and Antarctica. Further core drillings in East Antarctica may provide ice samples that are several hundred thousand years old, covering several glacial epochs. Methods to extract the air from ice samples and analytical methods have to be improved to increase the overall precision of the measurements, particularly to determine whether the composition of the air enclosed in bubbles is altered by physical or chemical processes during the long storage time. Measurements of the isotopic ratio <sup>13</sup>C/<sup>12</sup>C are therefore important.

**Project Title:**

INDIAN OCEAN RADIOCARBON

**Current Contract Period:**

08/01/84-07/31/85

**Funding:** FY1984        51  
              FY1983        0  
              FY1982        0

**Principal Investigator/s:**

OSTLUND, H. GOTE

**Organization/s:** UNIVERSITY OF MIAMI

**Objective:** To collect radiocarbon data in the Indian Ocean to further quantify the removal of CO<sub>2</sub> from the atmosphere by the ocean.

**Product:** A data base of radiocarbon information from a N-S section in the Indian Ocean. Without a solid and reliable data base for carbon in the source waters of the world oceans, progress in various model studies involving oceanic CO<sub>2</sub> reservoirs cannot be made.

**Approach:** The principal investigator has been invited to participate in the INDIGO 1 Indian Ocean expedition sponsored by the French Government. The cruise is planned for February 1985; analysis of the samples, which is expected to take 6 months, will begin in mid-1985. The <sup>14</sup>C data will be released early to the participating principal investigators for internal use as soon as the information is available, and final data for unrestricted use are expected to be provided to the U.S. Department of Energy's Carbon Dioxide Information Center by 31 December 1985. It is anticipated that total CO<sub>2</sub> data will also be available from this same cruise through the joint efforts of Dr. C.-T. Chen, in a separate proposal, and Dr. A. Poisson and that accompanying tritium measurements and hydrographic data will be supplied by collaborating French scientists.

**Project Title:**

MODELING FACTORS THAT INFLUENCE SOIL CARBON VARIATION

**Current Contract Period:**

10/01/83-09/30/84

**Funding:** FY1984 200  
FY1983 91  
FY1982 340**Principal Investigator/s:**

POST, W. M.

**Organization/s:** OAK RIDGE NATIONAL LABORATORY

**Objective:** To determine the effect of several soil-forming factors, particularly vegetation, on the rates of storage and loss of soil carbon. This includes effects due to both natural variation in vegetation and changes in the soil carbon pool due to management of vegetation by humans.

**Products:**

- o A model of soil organic matter production and decomposition developed and linked with a model of forest production dynamics. The model will evaluate the relationship between vegetation input variability and soil carbon density and turnover time variability.
- o Collection and statistical analysis of data from soil profiles under natural vegetation and managed systems to determine changes in amounts and rates of storage as the result of management practices. Effort will be concentrated in agricultural soils of the midwestern United States from which adequate data are available.
- o Exploration of the feasibility of using  $^{14}\text{C}$  as a tracer in determining soil carbon dynamics. A model will be constructed to determine carbon fluxes between organic fractions, soil horizons, and the atmosphere that are consistent with the  $^{14}\text{C}$  measurements.

**Approach:**

- o A dynamic forest simulation model validated for a variety of ecosystem types will be used to generate a long-term record of vegetation input into a litter and soil carbon model. How realistically the variation in vegetation production affects soil carbon density will be determined. Extensive data from literature sources will be used in model calibration and verification.
- o Soil profile data from undisturbed vegetation under consideration for management, as well as systems already managed for inventory or agricultural resource monitoring, will be statistically analyzed to quantitatively interpret trends in carbon density. A larger data set will be collected and analyzed to determine whether any trends in soil carbon changes can be observed and quantified for different soil types.
- o Samples from each horizon of two soil profiles collected before 1955 (i.e., before significant contamination from atmospheric nuclear weapons testing) have been obtained. Recent collections of soil from the same locations as the two prebomb samples will also be analyzed for comparison. A model will be constructed to estimate the transfer of organic matter consistent with the  $^{14}\text{C}$  data obtained. Recent soil data will be analyzed by using this model to determine whether bomb-produced  $^{14}\text{C}$  can be used as a tracer for organic materials in soils.

**Project Title:**

CARBON STORAGE/POLLUTION EXPORT  
(CASTOR/POLLUX) PROGRAM ANALYSIS OF A  
TRANSIENT BIOLOGICAL SINK FOR CARBON DIOXIDE

**Current Contract Period:**

10/01/83-09/30/84

**Funding:** FY1984        200  
              FY1983        250  
              FY1982        250

**Principal Investigator/s:**

PREMUZIC, EUGENE T.

**Organization/s:** BROOKHAVEN NATIONAL LABORATORY

**Objective:** To obtain data for testing the hypothesis that there has been a transient increase in primary production on continental shelves resulting in a biological sequestering of anthropogenically derived CO<sub>2</sub>.

**Product:** A quantified rate of input of phytoplankton-derived carbon to the sediment on the upper continental slope. The amount of biologically fixed carbon sequestered on the upper slope will be estimated and compared with the amount of missing carbon for which contemporary models of fossil fuel sources and atmospheric, biospheric, and other oceanic sinks cannot account.

**Approach:** Field data will be collected to (1) determine how much of the organic carbon buried on the upper continental slope is of recent marine origin; (2) determine how much of the annual shelf particle flux is deposited on continental slopes; (3) measure changes in in situ C/N ratios, reflecting early diagenesis; (4) determine the rates and routes of organic nitrogen remineralization leading to enhanced CO<sub>2</sub> fixation; and (5) specify how much of the carbon exported to the slope results from eutrophication of the coastal zone. To identify the source of the carbon on the continental margin, material from sediment traps and cores will be analyzed for selected stable and radioisotopic composition, as well as organic and inorganic species. Field measurements are also under way so that seasonal variations in export of organic carbon from the shelf to the upper slope environments can be detected.

**Project Title:**

LAND USE AND VEGETATION CHANGES IN SOUTH AND  
SOUTHEAST ASIA, 1700 to 1980

**Current Contract Period:**

06/01/84-05/31/85

**Funding:** FY1984        202  
              FY1983        155  
              FY1982        0

**Principal Investigator/s:**

RICHARDS, JOHN F.

**Organization/s:** DUKE UNIVERSITY

**Objective:** To compile historical data on patterns of land use and vegetation cover for South and Southeast Asia (20 existing nations) from 1700 to 1980.

**Product:** A time series data base of land-use changes due to human intervention in South and Southeast Asia during the past 280 years. This information will contribute to understanding the perturbation of the natural carbon cycle by land-use changes so that accurate projections of future atmospheric concentrations of CO<sub>2</sub> can be made.

**Approach:** The data will be collected by standard historical research techniques from extant unpublished archival and published original sources. Land use and vegetation cover in the study area will be classified according to nine mutually exclusive categories. Data for early reference dates (1700, 1750, and 1800) will be summarized for the two major regions only (South and Southeast Asia). More detailed information, including a composite picture of land use and vegetation for 10-year intervals, will be compiled for the period 1820 to 1980 for each nation, province, state, and administrative district as available. The data will be adjusted for shifts in boundaries and political changes over time and will be provided in a format that will be compatible with present carbon cycle models. It is expected that this project will be a 3-year study. During the first year, work will be done primarily in residence at Duke University. During the second and part of the third year (if continued), research will focus on the colonial record holdings in London, Paris, and The Hague. The last phase of the project will involve research in the colonial archives of New Delhi, Lahore, Jakarta, and other national capitals and major archives.

**Project Title:**

COMPUTER COST AND PROGRAMMING SUPPORT FOR  
THE STUDY OF CARBON DIOXIDE SOURCE/SINK  
DISTRIBUTIONS WITH A THREE-DIMENSIONAL  
MODEL

**Current Contract Period:**

08/15/83-07/31/84

**Funding:** FY1984        0  
              FY1983        53  
              FY1982        45

**Principal Investigator/s:**

RIND, D.

**Organizations/s:** GODDARD INSTITUTE FOR SPACE STUDIES

This project provides programming support and computer services for Fung, LDGO, "Study of Carbon Dioxide Source/Sink Distributions with a Three-Dimensional Model."

**Project Title:**

ESTIMATE OF CARBON DIOXIDE EMISSIONS FROM  
FOSSIL FUEL

**Current Contract Period:**

10/01/83-09/30/84

**Funding:** FY1984        187  
              FY1983        190  
              FY1982        0

**Principal Investigator/s:**

ROTTY, RALPH M.

**Organization/s:** OAK RIDGE ASSOCIATED UNIVERSITIES

This project involves two tasks: Task 1, Data Development for CO<sub>2</sub> from Fuel Use; and Task 2, Energy Systems and Atmospheric CO<sub>2</sub>.

**Task 1. Objectives:** (1) To provide continued monitoring and updating of data for CO<sub>2</sub> emissions from fossil fuels; (2) to provide data needed by the carbon cycle community in regard to seasonal and spatial distribution of CO<sub>2</sub> emissions from fossil fuels; and (3) to develop a time series of global fuel wood data to be useful both as a retrospective CO<sub>2</sub> source and in projecting fossil energy demands.

**Product:** Estimates of annual rates of CO<sub>2</sub> emission from fossil fuel production, including seasonal and geographical distribution (based on a latitude-longitude grid), and organization of data to show the seasonal and spatial distribution of the emissions.

**Approach:** UN energy production statistics are used as the basis for calculations of annual global emissions. A time series of CO<sub>2</sub> emissions resulting from the use of wood as a fuel will be developed, similar to that prepared for fossil fuels.

**Task 2. Objective:** To review the prospects of several energy supply systems of the 21st century within the context of projected atmospheric CO<sub>2</sub> concentration and evaluate the impact such systems will have on atmospheric CO<sub>2</sub>. Expanded electrification will be emphasized; systems selected for evaluation will be those that produce electricity.

**Product:** A technical evaluation of energy systems which can (or will) have a major impact on future energy supplies affecting CO<sub>2</sub> emissions.

**Approach:** The hypothesis will be tested that there is a global trend toward increased dependence on electricity, which is likely to continue into the next century. This hypothesis will be tested using electric energy data tabulated in the UN Yearbook of World Energy Statistics. Also, a variety of energy supply systems have been suggested to solve the world's future energy problems. This project will assess the individual supply technologies for their feasibility in meeting the needs of the world in the future, especially in regard to electricity. This assessment will review, summarize, and critique strengths and weaknesses of the energy supply technologies selected.

**Project Title:**

CHANGES IN THE FLUX RATES OF SOIL CARBON TO  
THE ATMOSPHERE DUE TO DISTURBANCE

**Current Contract Period:**

01/01/83-12/31/83

**Funding:** FY1984        0  
              FY1983        29  
              FY1982        0

**Principal Investigator/s:**

SCHLESINGER, WILLIAM H.

**Organization/s:** DUKE UNIVERSITY

**Objective:** To compile and review information from the literature and available primary data regarding changes in soil carbon storage when natural ecosystems are converted to managed use.

**Product:** Data collected from paired plots, one natural and one manipulated, for all ecosystems for which information is available and remeasured at intervals over long periods of time. These data will be used to develop a preliminary estimate of the input of carbon into the atmosphere due to the disturbance of natural vegetation.

**Approach:** Soil data will be gathered from the published literature and investigators currently gathering information on soil carbon exchange. These data will be reanalyzed in a format that is useful for considering carbon storage in global ecosystems. Changes in total profile content through time will be plotted as a function of time and the slope of these relations used to determine a loss factor which can be compared among ecosystems and land-use practices.

**Project Title:**

ATMOSPHERIC CARBON DIOXIDE ABUNDANCE - AN  
ARCHIVAL STUDY OF SPECTROSCOPIC DATA

**Current Contract Period:**

10/01/83-09/30/84

**Funding:** FY1984      260  
              FY1983      240  
              FY1982      280

**Principal Investigator/s:**

STOKES, G. M.

**Organization/s:** PACIFIC NORTHWEST LABORATORY

**Objectives:** (1) To extend knowledge of the atmospheric CO<sub>2</sub> burden back as far as possible by using archived solar spectra as the data base; (2) to compare in situ measurements of the modern era with spectroscopic measurements of the modern era; and (3) to evaluate solar spectra as a source of information concerning other trace gases using CO<sub>2</sub> as a test case.

**Product:** A time series of atmospheric CO<sub>2</sub> produced for the period 1920 to 1955. Results from this work may clarify some of the controversy concerning the relative importance of biospheric and fossil fuel contributions to the present CO<sub>2</sub> burden.

**Approach:** Spectroscopic data can produce CO<sub>2</sub> column densities with a precision and accuracy of about 1%, and past records of atmospheric CO<sub>2</sub> will be derived from Smithsonian spectrobolograms. Measurements of the near-infrared solar spectrum containing CO<sub>2</sub> absorption bands have been accumulated since the mid-1890s for use in astronomy. Analysis of these spectra will provide an extension of CO<sub>2</sub> abundance information into the early 20th century. Analysis of new spectroscopic data will be accomplished with the Fournier Transform Spectrometer of the Kitt Peak National Observatory. This analysis will identify possible sources of systematic error that may arise in the study of data which were not specifically collected for the determination of telluric abundances.

**Project Title:**

GEOCHEMICAL DETERMINATION OF BIOSPHERIC  
CARBON DIOXIDE FLUXES TO THE ATMOSPHERE

**Current Contract Period:**

09/01/83-08/31/84

**Funding:** FY1984        0  
          FY1983        158  
          FY1982        158

**Principal Investigator/s:**

STUIVER, MINZE

**Organization/s:** UNIVERSITY OF WASHINGTON

**Objective:** To continue to determine the history of biospheric fluxes to the atmosphere by studying  $^{13}\text{C}/^{12}\text{C}$  and  $^{14}\text{C}/^{12}\text{C}$  isotope ratios in tree-ring cellulose. Research will focus on mechanisms that induce variability in the isotope records and a preliminary investigation of anthropogenic carbon change in the world's oceans will be made based on carbon isotope ratios in coral.

**Product:** A time-series of past  $^{13}\text{C}/^{12}\text{C}$  and  $^{14}\text{C}/^{12}\text{C}$  changes in atmospheric  $\text{CO}_2$  for the current millennium. The record of  $^{13}\text{C}/^{12}\text{C}$  change will be used to derive global atmospheric fluxes using a box-diffusion model, fine-tuned to observed  $^{14}\text{C}/^{12}\text{C}$  changes. The utility of coral  $\delta^{13}\text{C}$  records as an indicator of anthropogenic carbon change in the world oceans will be described.

**Approach:** The variability of the carbon isotope ratios in tree rings will be studied by measuring additional, long-term records of trees under known physiological stress. By choosing different tree species, including U.S. sequoia and bristlecone pine, sections of trees collected from New Zealand, and different environmental conditions, the signal added by the tree can be studied and often eliminated when the theoretical concepts of isotope fractionation are considered. The influence of defoliation on  $\delta^{13}\text{C}$  records will be studied by examining tree sections with years of poor growth rate attributed to insect defoliation. The effects of tree physiology on  $\delta^{13}\text{C}$  will be studied by assuming the ice-core data are correct and investigating the departure of tree-ring data from such records. A preliminary analysis will be made of coral  $\delta^{13}\text{C}$  records as an indicator of anthropogenic carbon change in the world oceans and will include the use of  $^{18}\text{O}$  as a potential "normalization" parameter.

**Project Title:**

ASSESSMENT OF CARBON DIOXIDE SINK/SOURCE IN THE OCEANIC AREAS: SEASONAL AND GEOGRAPHIC VARIABILITY

**Current Contract Period:**

08/01/84-07/31/85

<b>Funding:</b> FY1984	215
FY1983	125
FY1982	90

**Principal Investigator/s:**

TAKAHASHI, TARO

**Organization/s:** LAMONT-DOHERTY GEOLOGICAL OBSERVATORY

**Objective:** To investigate through field observations the seasonal and regional variability of CO<sub>2</sub> chemistry in the major oceanic regimes, including the formation areas of deep waters in high latitudes, temperature gyres, and equatorial upwelling belts.

**Product:** An expanded data base of CO<sub>2</sub> chemistry in the upper layers of major oceanic regions. Such data will aid modelers in understanding the nature of the feedback mechanisms in the coupling of the CO<sub>2</sub>-induced climatic change with the oceanic uptake/discharge of CO<sub>2</sub>.

**Approach:** The basic strategy of this research is to conduct systematic field observations by collecting sea water samples on board various ships of opportunity. The samples will be shipped to the Lamont-Doherty Geological Observatory (LDGO) laboratory for analyses. This will require the using a gas chromatographic system specifically constructed for high-precision analyses of CO<sub>2</sub>.

The sampling program is broken down into the following three tasks:

- o The net CO<sub>2</sub> flux across the air-sea interface will be measured in the central equatorial Pacific using the pCO<sub>2</sub> and Rn-222 methods. The results will be compared with those obtained during the earlier Hawaii-Tahiti studies to see interannual variability of this important oceanic CO<sub>2</sub> source.
- o The pCO<sub>2</sub> and total CO<sub>2</sub> concentration in the surface water will be determined along the 180° meridian in the central Pacific between Hawaii and McMurdo Station, Antarctica. The data will be used to determine (1) the seasonal variability in the surface water CO<sub>2</sub> chemistry between 40° N latitude to the Antarctica in the Pacific; and (2) the secular variation of surface water pCO<sub>2</sub> in the Pacific during the past 10 years by comparing the new data with those obtained along a similar transect during GEOSECS in 1974.
- o The seasonal variability, in particular between the winter and summer values, of the surface water pCO<sub>2</sub> in northern North Pacific Ocean will be investigated using commercial freight ships sailing between Japan and the Northwestern United States as a sampling platform. This area is a known water mass formation area and is a strong CO<sub>2</sub> sink during the summertime. To date, the CO<sub>2</sub> chemistry in this area during the winter season is virtually unexplored.

**Project Title:**

CARBON CYCLE PROGRAM MANAGEMENT

**Current Contract Period:**

10/01/83-09/30/84

**Funding:** FY1984 334  
FY1983 189  
FY1982 227

**Principal Investigator/s:**

TRABALKA, JOHN R.

(\$46K of FY1983 funding was assigned to a task classified under Work Breakdown Structure V.)

**Organization/s:** OAK RIDGE NATIONAL LABORATORY

**Objective:** To provide technical management support to the Carbon Dioxide Research Division of the Department of Energy (DOE) by implementing the DOE Carbon Cycle Research Plan through subcontracted research, updating the plan as necessary, recommending research priorities, monitoring scientific quality of research, establishing program milestones, and interpreting and communicating deliverables to DOE.

**Product:** A state-of-the-art report on the status of knowledge about the global carbon cycle to be prepared and communicated to contractors and the research community in 1984. Management assistance will be provided to the DOE Carbon Dioxide Research Division in their efforts to accurately predict future atmospheric concentrations of CO<sub>2</sub> that will result from releases of carbon dioxide anticipated from the combustion of fossil fuels.

**Approach:** Management support will annually review and evaluate both the technical progress of carbon-cycle-related research and the quality and value of the information provided and bring this perspective to bear when assisting the Carbon Dioxide Research Division's planning process. An additional task will be to prepare topical reports on the technical status of specified program elements. Management support will also assist in communicating the DOE Carbon Dioxide Research Program objectives and accomplishments to the scientific community; assess research objectives and products from other federal agencies, industry, and academia; coordinate needs, progress, and products with other project managers; and integrate the Carbon Dioxide Research Division's program with other national and international activities. To achieve these objectives, Oak Ridge National Laboratory is coordinating with existing federally sponsored research, performing research, and subcontracting to university centers of excellence for research supporting global carbon cycle modeling, including specifically subsystem model development and terrestrial biospheric and oceanic data acquisition.

**Project Title:**

DEVELOPMENT OF A LASER DETECTION SYSTEM FOR ARGON 39 AND APPLICATION TO OCEANOGRAPHIC SAMPLES

**Current Contract Period:**

05/01/83-04/30/84

**Funding:** FY1984           0  
          FY1983           66  
          FY1982           96

**Principal Investigator/s:**

WILLIS, ROBERT D.

**Organization/s:** SCRIPPS INSTITUTION OF OCEANOGRAPHY

**Objective:** To develop a laser detection system (Resonance Ionization Spectroscopy and Single Atom Detection RIS-SAD) for measuring very small quantities of argon 39 in seawater. As an inert chemical, <sup>39</sup>Ar serves as a useful tracer of the mixing of surface water with the deep ocean; its half-life is ideal for determining the time when deep water was last in contact with the surface.

**Product:** A significantly improved <sup>39</sup>Ar detection system. Data will be used to develop and calibrate two- and three-dimensional models of ocean circulation and will provide new <sup>39</sup>Ar data for the 1984 state-of-the-art report.

**Approach:** A measurement system will be developed and first applied to the detection of krypton (a noble gas having a less-difficult ionization scheme), then to <sup>39</sup>Ar from seawater samples. The <sup>39</sup>Ar data will be used in ocean-circulation studies of the penetration of atmospheric and mixed-layer constituents across the thermocline into deep ocean water.

**Project Title:**REMOTE SENSING OF DEFORESTATION IN THE AMAZON  
BASIN**Current Contract Period:**

12/10/83-12/09/84

<b>Funding:</b> FY1984	156
FY1983	0
FY1982	234

**Principal Investigator/s:**

WOODWELL, GEORGE M.

**Organization/s:** MARINE BIOLOGICAL LABORATORY

**Objectives:** To determine (1) the validity of applying a change detection algorithm (developed under previous funding) to tropical forests; (2) the validity of applying the algorithm with NOAA7 data alone and with a combination of NOAA7 and LANDSAT data; and (3) the rates of change in the area of forests and the net flux of carbon from the Amazon Basin over the past years as a prelude to a systematic global survey. Specifically, the objectives are to (1) determine the availability of adequate data for the Amazon Basin; (2) establish a working relationship between the National Aeronautics and Space Administration (NASA) and the Ecosystems Center at the Marine Biological Laboratory to conduct collaborative research on this topic; and (3) determine the rate of change in the area of forests and net flux of carbon in Rondonia over the past 10 years.

**Product:** Determination of whether adequate data are available to determine the net flux of carbon from vegetation to the atmosphere based on remote sensing techniques. Collaboration with scientists from NASA should result in the most effective means of conducting research on this topic.

**Approach:** Purchase of LANDSAT data tapes from the Brazilians will be implemented as soon as possible. Adequacy of the data will be determined by ground truth and by comparing the validity of the algorithm from LANDSAT data with other estimates as data permit. Specific efforts will be made to collaborate with scientists from NASA in the use of satellite imagery for detecting land use changes. This will be accomplished by building on the many formal and informal links already made with NASA. The change detection technique will be applied to the territory of Rondonia to determine the rate of change in the area of forests and its associated net flux of carbon. The work will be supplemented at no cost to the Department of Energy by a joint project through the Jet Propulsion Laboratory in Pasadena, California, to use radar imagery from the shuttle to examine the distribution of forests in Rondonia.

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## CLIMATE AND FIRST DETECTION

The present concentration of atmospheric CO<sub>2</sub>, acting in combination with other infrared-absorbing and emitting gases, plays an important role in maintaining the current climate. Without CO<sub>2</sub> acting to absorb much of the infrared radiation emitted from the earth's surface and reradiating some of the energy back to the surface, global surface temperatures would be substantially cooler. Conversely, increases in CO<sub>2</sub> will fundamentally affect the earth's climate--increasing global surface temperatures. The atmospheric circulation of moisture would be substantially more active, and polar icecaps smaller. At the same time, the stratosphere would be cooler, possibly leading to altered atmospheric dynamics and reduced ozone concentrations. Separating natural variability in climate from CO<sub>2</sub>-induced climate change is vital to the research effort. First detection is the process of evaluating and analyzing data in search of evidence that the predicted CO<sub>2</sub>-induced climate changes are, in fact, occurring.

**Research Objectives** Research in climate and first detection is intended to reduce uncertainties concerning any CO<sub>2</sub>-induced regional and seasonal patterns of climate change, the response of the cryosphere and the oceans, and when and where the first signs of the change may be detected. Specific objectives are to estimate the rate and magnitude of a CO<sub>2</sub>-induced climate change and to establish when a CO<sub>2</sub> signal is first detectable in the climate record. Areas of study covered under this subsystem are climate and geophysical data, climate models and model validation, first detection of climate change caused by increasing CO<sub>2</sub>, climate analogs, and analysis and estimates of CO<sub>2</sub>-induced climate change.

**Research Questions** To determine the climate response to the projected increases in atmospheric CO<sub>2</sub>, climate research will focus on answering the following questions:

- o What seasonally dependent regional and global climatic changes in temperature, precipitation, evaporation, humidity and other factors will be induced by projected changes in the atmospheric CO<sub>2</sub> concentration?
- o How rapidly will the climate changes occur? To what extent will the projected changes depend on the time-dependent characteristics of the climate and the rate of increase of CO<sub>2</sub>?
- o To what extent do the projected changes interact with and depend on other climatically related events and activities of man and nature?
- o What portion of recent past or current climate changes evidenced in the climate record can be attributed to the influence of CO<sub>2</sub>?

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**Project Title:**

LAKE ICE OCCURRENCE AS A POSSIBLE DETECTOR OF  
ATMOSPHERIC CARBON DIOXIDE EFFECTS OF CLIMATE

**Current Contract Period:**

12/01/83-11/30/84

**Funding:** FY1984        47  
              FY1983        46  
              FY1982        0

**Principal Investigator/s:**

BARRY, ROGER C.

**Organization/s:** UNIVERSITY OF COLORADO

**Objective:** To determine whether lake freezeup and breakup data can be used as an additional as well as a proxy indicator of seasonal climate change. Assuming success, scenarios of freezeup and breakup will be posed for comparison with future data to test rates of climate change predicted by climate models.

**Product:** A feasibility assessment for use of lake ice regimes to detect and monitor CO<sub>2</sub>-induced climatic trends, including a projection of anticipated responses of water bodies. If verified, the use of changes in lake ice regimes could be routinely monitored via remote sensing techniques.

**Approach:** The timing of the freezeup and breakup of lakes in the northern continents is identified as a candidate parameter for detecting the predicted first effects of increasing atmospheric carbon dioxide. A substantial data base exists for lakes in Canada and Alaska and there is considerable potential to obtain similar information from northern Europe. Following a survey of previous lake ice-climatological analyses, it is proposed to examine, on a statistical basis, the North American statistics of lake freezeup and breakup in relation to readily available climatic data. The lake data will be stratified according to variables related to the water body and its geographic location.

**Project Title:**

THE CLIMATE OF THE NORTHERN HEMISPHERE, 1851  
TO 1900, COMPARED TO CONTEMPORARY CLIMATE

**Current Contract Period:**

09/15/83-12/31/84

**Funding:** FY1984        40  
              FY1983        138  
              FY1982        157

**Principal Investigator/s:**

BRADLEY, RAYMOND S.

**Organization/s:** UNIVERSITY OF MASSACHUSETTS

**Objective:** To locate and digitize the best available climatic data from the largely prenetwork period of 1851 to 1900 to provide an evaluated climatic data base for the northern hemisphere extending back to the preindustrial period. This data base is required so that CO<sub>2</sub>-induced warming can be detected as early as possible.

**Product:** A high-quality data base extending to the preindustrial period, when fossil fuel emissions were relatively low, that will facilitate early detection of the climatic effects of increasing CO<sub>2</sub> concentrations. The currently available data set begins during the 1880s, which is well after the start of industrialization and, moreover, is during a decade when volcanically induced cooling was probably at its maximum in the last 150 years. Because of its interfering influence, being able to account for volcanic influences is essential if CO<sub>2</sub>-induced warming is to be detected before the end of the century. Extending the data base back to 1850 will allow a more careful estimation of volcanic influences (and natural climate variability) and, therefore, more certain early detection of CO<sub>2</sub>-induced climatic effects.

**Approach:** Meteorological data recorded during the last half of the 19th century in diverse locations will be located, assembled, evaluated, and digitized to develop a northern hemisphere record covering the period 1851 to 1900. Various time and space averages will be performed for comparison with the 20th-century record.

**Project Title:**

SENSITIVITY ANALYSIS OF THE IMPACT OF CARBON  
DIOXIDE ACCUMULATION ON CLIMATE

**Current Contract Period:**

10/01/83-09/30/84

**Funding:** FY1984      260  
              FY1983      260  
              FY1982      197

**Principal Investigator/s:**

CACUCI, D.G.

**Organization/s:** OAK RIDGE NATIONAL LABORATORY

**Objective:** To determine the dependence of climate model results on parameterization coefficients and dynamic variables. This work will assist in the estimation of model sensitivity and uncertainty.

**Product:** Application of the adjoint method for the determination of the dependence of selected model results (functionals) to allow sensitivities to be calculated for the input coefficients and variables.

**Approach:** The adjoint method, used by ORNL to investigate sensitivities of other large-scale models, will be used to determine the sensitivity of climate models to choices of parameterization coefficients and values of dynamic variables. The method has been applied to a relatively simple RCM. Climate models contain many parameterizations that are highly interactive. Normal model verification studies evaluate the performance and sensitivity with respect to relatively few model coefficients and variables. Successful application of the technique to a radiative convective model (RCM) was demonstrated in 1981. Interpretation of the results for the RCM demonstration case will assist in the understanding of model sensitivity. Application of this technique to general circulation models will be pursued to improve understanding of model dynamics and energy balances. Feasibility studies are under way to evaluate its application to a three-dimensional dynamic climate model in FY 1982 to FY 1984.

**Project Title:**

RESEARCH ON THE DYNAMICS OF CLIMATE

**Current Contract Period:**

06/01/84-05/31/85

**Funding:** FY1984      250  
                  FY1983      90  
                  FY1982      400**Principal Investigator/s:**

GATES, W. LAWRENCE

**Organization/s:** OREGON STATE UNIVERSITY

**Objective:** To apply the two-layer OSU general circulation model to study the climatic effects of increasing CO<sub>2</sub> concentrations, with particular attention to development of analysis techniques that will allow determination of regional and seasonal changes for a comprehensive set of climatic variables.

**Product:** Additional information on the seasonal and regional response of climate to increasing CO<sub>2</sub> concentrations. The OSU GCM (the leading university-based GCM) has an interactive dynamic ocean and sea ice prescription, allowing special attention to be paid to climatic effects in polar regions. Of particular importance will be determination of the statistical significance of the predicted regional changes in the context of natural variability. During 1982 and 1983, estimates of the changes due to doubling of CO<sub>2</sub> concentrations were emphasized; in 1984, analysis and comparison of results to other models will permit estimation of the uncertainty due to use of different models.

**Approach:** The two-layer OSU GCM is a relatively rapid-running, two-layer global climate model that has been well tested and documented. This model will be used in a series of perturbation experiments that will allow investigation of the statistical significance of climate changes that are predicted when CO<sub>2</sub> concentrations are increased. Detailed analyses of model results at particular points, in important regions, and by seasons will be performed in 1984.

**Project Title:**

MODEL INTERCOMPARISON

**Current Contract Period:**

02/01/84-01/31/85

**Funding:** FY1984      100  
              FY1983      152  
              FY1982      97

**Principal Investigator/s:**

GATES, W. LAWRENCE

**Organization/s:** OREGON STATE UNIVERSITY

**Objective:** To develop a basis and strategy for intercomparing climate models so that the causes of different results from different models can be determined. Comparison of the CO<sub>2</sub> sensitivities of a two-dimensional and a three-dimensional model will be used to investigate the differences that can arise between models and the mechanisms that contribute to the differences. In FY 1984, techniques developed may be applied to other models so as to further investigate the causes of differences in model results.

**Product:** The causes of the range of results that can occur in climate models will be analyzed in terms of the differences inherent in model structure and the effects caused by different parameterization of the oceanic meridional transport and heat capacity. Understanding the causes of differences in results from different models will allow analysis techniques and sensitivities developed for lower dimension models to be used in interpretation of results from three-dimensional models.

**Approach:** The OSU GCM and the LLNL SDM are being used to develop a strategy for model intercomparison. The three-dimensional OSU model is relatively comprehensive and can be used with several ocean parameterizations. Because of its specialized nature, the two-dimensional LLNL model, which includes most surface and atmospheric processes included in GCMs and a crude representation of the longitudinal dimension, permits detailed analyses of model processes and can be adapted for comparison experiments. A series of control and perturbation experiments will be performed to evaluate the differences in results that exist and the processes contributing to these differences.

**Project Title:**

GEOCHEMICAL AND GEOPHYSICAL MODELS OF THE  
FOSSIL FUEL CARBON DIOXIDE CLIMATE PROBLEM

**Current Contract Period:**

03/08/83-03/07/84

**Funding:** FY1984        84  
              FY1983        76  
              FY1982        68

**Principal Investigator/s:**

HOFFERT, MARTIN

**Organization/s:** NEW YORK UNIVERSITY

**Objective:** To develop and apply a coupled carbon cycle/climate model to provide long period estimates of the effects of the historic and projected CO<sub>2</sub> emissions on global CO<sub>2</sub> concentrations and climate.

**Product:** Preliminary indications of the rate of future warming as CO<sub>2</sub> concentrations rise. This model will be the first to treat the carbon cycle and climate system, including oceanic temperatures and circulation, in a coupled, self consistent manner. Because of the relative simplifications in this model, the calculations can be done relatively quickly, but the estimates must be viewed as preliminary because many model parameterizations are based on statistical calibrations to the present climate. Although the model will not provide estimates of regional and seasonal resolution, it will be the only model able to estimate changes over relatively long periods of time (e.g., 200 years).

**Approach:** An improved energy balance climate model and a carbon cycle model (including marine biosphere, both with latitudinal resolution and coupled to a new two-dimensional ocean transport and storage model will be calibrated using GEOSECS, TTO and climate data. The model will be applied to simulate the climate and CO<sub>2</sub> concentrations of the recent past and to project future values.

**Project Title:**

IMPACT OF CARBON DIOXIDE ON THE CLIMATE  
CHANGE IN NORTH AMERICA DURING THE 20TH  
CENTURY

**Current Contract Period:**

09/01/84-08/31/85

**Funding:** FY1984      150  
              FY1983      152  
              FY1982      0

**Principal Investigator/s:**

KUKLA, GEORGE

**Organization/s:** LAMONT-DOHERTY GEOLOGICAL OBSERVATORY

**Objectives:** (1) To define regional trends in mean, maximum, and minimum surface air temperatures and in precipitation over North America during the 20th century; and (2) to analyze the possible effects of CO<sub>2</sub> on the observed temporal and spatial anomaly patterns.

**Products:** A regional data base for first detection and production of an assessment of probable regional CO<sub>2</sub>-induced climate change. Also obtained will be (1) charts and tapes of differences between the 1951 to 1980 and 1931 to 1960, and 1951 to 1980 and 1941 to 1970 monthly mean surface air temperatures (spatial resolution will include climatic divisions in the United States and 200 to 300 stations in Canada); (2) charts and tapes as described in (1) for monthly precipitation; and (3) charts and tapes of the trend in the monthly minimum, maximum, and mean surface air temperatures and monthly precipitation (spatial resolution will include 400 stations for the period 1931 to 1980 and 100 stations for the period 1895 to 1930). The data will be analyzed to show anomalies and trends. These will be compared with global and hemispheric trend data and model-projected CO<sub>2</sub>-induced climate changes (Northern Hemisphere).

**Project Title:**

VARIATIONS IN ARCTIC CLOUD COVER IN SUMMER

**Current Contract Period:**

03/01/83-02/28/84

**Funding:** FY1984        80  
              FY1983        64  
              FY1982        46

**Principal Investigator/s:**

KUKLA, GEORGE

**Organization/s:** LAMONT-DOHERTY GEOLOGICAL OBSERVATORY

**Objective:** To investigate the variation in cloud cover over the Arctic basin. Generated information will enable improved parameterization of clouds and the resultant radiation transfer in climate models to be used to assess the impact of CO<sub>2</sub>.

**Product:** Digitized charts and extended data to cover additional years of the interval 1974 to 1982. Data of two relatively cold (1978 and 1979) and two relatively warm (1975 and 1977) years will be compared as prospective indicators of a warming regime. Relations of atmospheric circulation outside the Arctic will be analyzed.

**Approach:** Clouds of three different types will be charted in a scale of 1:15,000,000 in 3-day intervals. Shortwave and infrared DMSP satellite imagery and images of the NOAA polar orbiting satellites will be used. Areal proportion of the different cloud types and of the cloud free surface will be measured separately for 10 geographic segments. Attempts are also under way to estimate the cloud top height from the width of the shadow thrown on the ice. Information on the cloud thickness and height will enable refined calculations of the heat exchange at the surface and has tested recognition of different stages of the snow and ice formation and dissipation.

**Project Title:**

CLOUD AND RADIATION INTERACTIONS AND CLIMATE

**Current Contract Period:**

12/01/83-09/30/84

**Funding:** FY1984      300  
              FY1983      0  
              FY1982      0

**Principal Investigator/s:**

LUTHER, FREDERICK M.

**Organization/s:** LAWRENCE, LIVERMORE NATIONAL LABORATORY

**Objectives:** (1) To compare longwave radiation transfer models; (2) to compare short and longwave radiation codes used in general circulation models (GCM); and (3) to compare both sets of models to satellite data and laboratory and atmospheric measurements to establish model and data uncertainty ranges.

**Product:** Establishment of the range of uncertainty between models and between models and the data. These results contribute to development and validation requirements for cloud and radiation interactions in climate models.

**Approach:** The proposed research will build upon an already existing longwave radiation model comparison study. This model comparison currently involves 20 scientists from 12 institutions in the United States, and several European scientists have recently agreed to participate in the study. The five major GCMs in the United States are already included in the study. The comparison study, up to now, has focused primarily on longwave calculations with clear sky conditions (the exception being some GCM sensitivity calculations). This study will be expanded to include cloudy situations for the four cloud regimes being investigated by FIRE. Radiation transfer calculations will be performed for prescribed cloud parameters to evaluate differences in the radiation calculations. The comparison of GCM radiation calculations will include solar algorithms as well as longwave algorithms. The cloud prescriptions routines will also be compared. The intent is to evaluate the relative uncertainty of the radiation transfer routines. Subsets of the satellite data compiled through FIRE will be used to evaluate the models.

**Project Title:**

CARBON DIOXIDE EFFECTS RESEARCH

**Current Contract Period:**

10/01/83-09/30/84

**Funding:** FY1984        865  
              FY1983        673  
              FY1982        716

**Principal Investigator/s:**

MACCRACKEN, MICHAEL C.

**Organization/s:** LAWRENCE LIVERMORE NATIONAL LABORATORY

This project involves four tasks: Task 1, Climate Modeling; Task 2, Model Intercomparison; Task 3, Program Management; and Task 4, State-of-the-Art Report on Climatic Effects of Increasing CO<sub>2</sub>.

**Task 1. Objective:** To understand the factors that contribute to the latitudinal and seasonal sensitivity of climate models to increasing CO<sub>2</sub> concentrations.

**Products:** Determination of the sources of climate model sensitivity, the importance of uncertainties, and limitations in representations of these processes.

**Approach:** A two-dimensional climate model with a crude longitudinal representation, one-dimensional radiation transport and radiative-kinetics models, and a coupled carbon cycle-climate model will be used to investigate interactions and feedback mechanisms involving clouds, sea ice, water vapor, surface albedo, convection, trace gasses, and oceans.

**Task 2.** (Same as Gates, W. Lawrence, OSU, "Model Intercomparison.")

**Task 3. Objective:** State-of-the-art estimates of the climate effects of increasing CO<sub>2</sub> and the extent that such changes have started to occur and to provide technical oversight and coordination of the climate research area.

**Products:** (1) A focal point for CO<sub>2</sub>/climate research undertaken by federal and international climate programs; (2) technical coordination of DOE contract research; (3) Specific, sponsored studies on timely CO<sub>2</sub> climate issues; and (4) state-of-the-art reports in FY 1984 on climate modeling and first detection.

**Approach:** To stimulate the CO<sub>2</sub>/climate issue, and coordinate research sponsored by DOE.

**Task 4. Objective:** Detailed state-of-the-art reports describing (1) the potential climatic effects of increasing CO<sub>2</sub> and (2) an observation-based assessment of whether the projected changes are evident.

**Product:** Support of the preparation of the state-of-the-art reports.

**Approach:** Small workshops of researchers will prepare an outline of the reports. DOE researchers and consultants will prepare a draft report. Workshops will then revise and integrate the sections into the reports.

**Project Title:**

NOAA INITIATIVE ON RADIATIVELY IMPORTANT  
TRACE SPECIES

**Current Contract Period:**  
09/01/84-12/31/85

**Funding:** FY1984        40  
              FY1983        0  
              FY1982        0

**Principal Investigator/s:**  
PETERSON, JAMES T.

**Organization/s:** NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION/GMCC

**Objective:** To initiate a program to establish a record of methane trends from the NOAA flask sampling program.

**Product:** Accelerated development of a certified methane record.

**Approach:** The NOAA researchers will analyze and interpret the methane record as drawn from the NOAA flask network. Calibration, standard gases, and the technique for obtaining the methane sample without affecting the CO<sub>2</sub> analysis will be developed from pilot to near-routine experiments.

**Project Title:**

THE STABILITY OF LOW-LATITUDE SEA-SURFACE  
TEMPERATURE OVER 1,000-100,000 YEARS

**Current Contract Period:**

07/01/83-01/31/84

**Funding:** FY1984        0  
              FY1983        110  
              FY1982        0

**Principal Investigator/s:**

PRELL, WARREN

**Organization/s:** BROWN UNIVERSITY

**Objective:** To establish the stability of the low-latitude, sea-surface temperatures (SST). The resultant data set will form a significant climate-modeling boundary condition.

**Product:** A data set providing a climate-model boundary condition. Climate sensitivity to CO<sub>2</sub> is increased (Hoffert, NYU) if low-latitude SST has varied little over the last 18,000 years. If data accuracy and precision can be established, climate models can use the data as a boundary condition for the verification of climate models.

**Approach:** The research will use two independent (biotic and isotopic) data sets to assess the accuracy and precision of the low-latitude, ocean paleotemperature record. Seasonal and spatial patterns will be analyzed.

**Project Title:**

CARBON DIOXIDE RESEARCH PROJECT ON  
REGIONAL CLIMATE MODELING

**Current Contract Period:**

09/01/84-08/31/85

**Funding:** FY1984        200  
              FY1983        0  
              FY1982        0

**Principal Investigator/s:**

QUINLAN, FRANK T.

**Organization/s:** NATIONAL CLIMATIC DATA CENTER/NOAA

**Objectives:** (1) To develop a complete historical data set to adequately describe the climate of the United States since 1900, providing certified data for at least 900 stations for at least an 80-year period of record; and (2) to update the data set of all available monthly sunshine data in the United States for the period 1891 to 1981, to prepare station and instrument histories, and to certify the data.

**Products:** (1) Certified data sets and station history information on magnetic tape and a final report documenting the certifications and estimating the procedures, historical observation practices, type of instruments used, and selected time series plots of historical interest; and (2) a set of all available U.S. monthly sunshine data for the period 1891 to 1984 on magnetic tape, a final report documenting the station and instrument histories, and selected time series plots of historical interest.

**Approach:** It will be necessary to digitize the data and station history information for 500 stations (the NCDC plans to digitize the monthly temperature, precipitation, and station history information for approximately 700 stations), do spatial and temporal analyses to certify the data sets, and estimate data for any missing months in the time series. The validation process will involve internal consistency checks of the data series and statistical areal comparison checks.

**Project Title:**

THE ROLE OF CARBONACEOUS AEROSOL IN CLIMATE  
MODIFICATION

**Current Contract Period:**

10/01/83-09/30/84

<b>Funding:</b> FY1984	200
FY1983	118
FY1982	182

**Principal Investigator/s:**

ROSEN, HAL J.

**Organization/s:** LAWRENCE BERKELEY LABORATORY

**Objectives:** To determine by the end of FY 1984 for the state-of-the-art report whether the presence of carbon-based aerosols resulting from fossil fuel use measured in the Arctic is a regional phenomenon and whether the potential climatic effects will influence the first detection of a CO<sub>2</sub> signal in the Arctic. If estimates of the climatic effects indicate a significant perturbation, then a plan for the systematic study of aerosols in the Arctic will be prepared.

**Product:** Determination of the spatial extent and temporal variations of the carbonaceous aerosols, extending from the Alaskan through the Canadian to Norwegian Arctic areas. Carbonaceous aerosols from combustion processes are present during late winter and spring in at least two areas in the Arctic. Filter samples from airplanes have indicated that the aerosol is not just at ground level. Preliminary analyses have indicated that present concentrations of the aerosol may cause local radiative effects comparable to doubling CO<sub>2</sub> during the spring. Filter samples were collected primarily in the Alaskan Arctic. Vertical and horizontal distributions will be obtained by an aircraft sampling expedition in March and April 1983. Also, a first estimate of trends will be made by using existing ice-core data. The data base being developed will be used by Lawrence Livermore National Laboratory (LLNL) modelers, who will assess the regional and global climatic effects.

**Approach:** Approximately 300 samples from three sites in the Canadian Arctic (Alert, Igoolik, and Mould Bays) and two sites in the Norwegian Arctic (Spitzbergen and Bear Islands) will be obtained from the Canadian Atmospheric Environment Service and the Norwegian Institute for Air Research, respectively. These samples and approximately 150 size-segregated samples from the Alaskan Arctic will be analyzed and put into a data base useful for modelers. LBL has developed an instrument for the real-time determination of aerosol absorption coefficients. This instrument will be modified and installed in a NOAA WP-3D aircraft to determine the vertical and horizontal distributions of absorption coefficients from March to April 1983. Filter samples will describe the scope of the problem. If a significant regional or global climatic effect is indicated in the associated climate modeling studies, a monitoring plan will be suggested for a follow-up systematic study of the aerosols.

**Project Title:**

HUMIDITY AND CLOUD RADIATION FEEDBACK AND  
POSSIBLE CLIMATIC PERTURBATIONS DUE TO FOSSIL  
FUEL UTILIZATION

**Current Contract Period:**

09/01/84-08/31/85

**Funding:** FY1984      129  
              FY1983      108  
              FY1982      93

**Principal Investigator/s:**

WANG, WEI-CHYUNG

**Organization/s:** ATMOSPHERIC AND ENVIRONMENTAL RESEARCH, INC.

**Objective:** To develop an improved capability for predicting the climatic effects of fossil fuel emissions by improving the treatment of overlapping infrared absorption bands, atmosphere-ocean interaction, and cumulus convective processes in a one-dimensional radiative-convective model.

**Products:** Improvement of the radiative treatment of overlapping infrared absorption bands by using a narrow-band radiation model. The approach has been shown to reduce substantially the cooling in the upper stratosphere for a doubling of CO<sub>2</sub>.

The effect of humidity and cloud cover radiation feedback and atmosphere-ocean interaction will be evaluated by using the interactive one-dimensional tropical model. This will clarify the proposed significant role that the ocean-atmosphere interaction plays in affecting sensitivity to increased levels of CO<sub>2</sub>.

Future levels of CO<sub>2</sub>, H<sub>2</sub>S, CS<sub>2</sub>, CH<sub>4</sub>, SO<sub>2</sub> and chlorocarbons will be projected and the radiative and climatic effects of these increases will be assessed. Parameterizations of radiative and cloud processes will be developed and evaluated for inclusion in higher-dimensional models so that feedback processes can be treated more accurately.

**Approach:** The existing one-dimensional radiative-convective and photochemical dynamic models will be used in these sensitivity and assessment studies. A one-dimensional tropical atmosphere-ocean interactive model will be completed and applied to studies of the possible importance of the ocean on model sensitivity.

**Project Title:**

ENHANCED RESEARCH PROGRAM ON THE LONG-RANGE  
CLIMATIC EFFECTS OF INCREASING ATMOSPHERIC  
CARBON DIOXIDE

**Current Contract Period:**  
05/01/84-04/30/85

**Funding:** FY1984        245  
              FY1983        0  
              FY1982        400

**Principal Investigator/s:**  
WASHINGTON, WARREN M.

**Organization/s:** NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

**Objective:** To apply the NCAR coupled ocean/atmosphere general circulation model (GCM) to study the climatic effects of increasing CO<sub>2</sub> concentrations, with emphasis on seasonal, regional, and oceanic aspects of the change. The model includes a hierarchy of ocean parameterizations ranging from a swamp model to a fully dynamic ocean model. Sea ice parameterizations are included in all versions, and the atmosphere is also well-treated, including interactive cloud cover.

**Product:** Estimates of the pattern of regional and seasonal changes in climate and of possible changes in ocean circulation and temperatures. Initial estimates in FY 1982 indicated expected changes due to a doubling and quadrupling of CO<sub>2</sub> concentrations. Because this model is global and seasonal and contains interactive prescriptions for ocean dynamics, clouds, and sea ice, the results will add significantly to available results of such cases, thereby allowing a preliminary estimate of uncertainties. Later studies will refine these results for use in first-detection analyses by providing initial estimates of climatic effects for the case of slowly increasing CO<sub>2</sub> concentrations.

**Approach:** The recently updated NCAR coupled ocean/atmosphere GCM, developed and verified by NCAR with National Science Foundation support, will be used to simulate the regional and seasonal sensitivity of the climate to increasing CO<sub>2</sub> concentrations. Detailed diagnostics will be conducted which will compare observations and the control experiment. These will be used to aid interpretation of doubling-CO<sub>2</sub> experiments.

**Project Title:**

GLOBAL TEMPERATURE PATTERNS 6000  
YEARS AGO

**Current Contract Period:**

05/01/82-01/31/84

**Funding:** FY1982 493  
(Funded for 32 months)

**Principal Investigator/s:**

WEBB, THOMPSON III

**Organization/s:** BROWN UNIVERSITY

**Objective:** To assemble contoured Northern Hemisphere climate maps for the Hypsithermal period 5000 to 7000 years ago as a means of supporting verification of model projections of a CO<sub>2</sub>-warmed climate. Because this period appears to have been warmest in the last hundred thousand years, temperature and moisture anomaly maps will be compared with model predictions for the CO<sub>2</sub>-induced warm climate.

**Product:** Maps and magnetic tapes of analyzed data on climate conditions during the Hypsithermal period, and difference maps between the Hypsithermal period and the present. During the last hundred thousand years the earth has experienced few periods warmer than the present and none believed warmer than that expected if CO<sub>2</sub> concentration doubles. The Hypsithermal period is the one extended period when sufficient proxy data may be available to reconstruct what such warm climates may actually be like.

**Approach:** Established calibration techniques will be used to transform lake-level, geological, pollen, and marine-plankton data into quantitative estimates of temperature and moisture balances and qualitative estimates of the atmospheric circulation. Mapping these estimates will allow construction of contours and depiction of climate patterns from 5000 to 7000 years ago. Work will focus on mapping and calibration of the available geological data from North America, Europe, northern Africa, and the North Atlantic and North Pacific Oceans. This contract will also serve as an umbrella contract for subcontracts to U.S. and European scientists who can provide the needed data.

**Project Title:**

ON THE GEOGRAPHICAL PATTERNS OF CLIMATIC CHANGE

**Current Contract Period:**

09/01/84-11/30/85

**Funding:** FY1984      135  
          FY1983      86  
          FY1982      78

**Principal Investigator/s:**

WIGLEY, T.M.L.

**Organization/s:** UNIVERSITY OF EAST ANGLIA

**Objective:** To assemble and analyze climatic data of the past 150 years as a basis for detecting CO<sub>2</sub>-induced climatic change and in support of model verification.

**Product:** A high-quality data base describing the climatic conditions of the last 150 years to serve as a baseline for detecting changes in climate brought on by changing CO<sub>2</sub> concentrations.

**Approach:** The natural climate fluctuates and responds to such factors as volcanic eruptions and solar variations in addition to CO<sub>2</sub> concentrations. The data base available in 1982 will be improved and extended. Uncertainties in the data base will be determined and quantified. The new data base will be used to determine the spatial characteristics of natural variability ("noise") on various time scales. Warm and cold year temperature, precipitation, and circulation anomalies will be documented. The data will be analyzed to determine the potential influence of factors other than CO<sub>2</sub> on past climate variations. These analyses are primarily oriented toward the search for early evidence of CO<sub>2</sub>-induced climatic change that would lead to confirmation, rejection, or modification of model projections.

The data base will be assembled by using the extensive resources available to the Climatic Research Unit at UEA. Data from the University of Massachusetts at Bradley will be used as input for pre-1900 data. Data analyses will focus on the use of specialized statistical techniques with interpretation recognizing the interrelationships of regional climatic changes, particularly in the Northern Hemisphere.

**Project Title:**TRACE GAS INTERACTIONS IN THE GLOBAL  
ATMOSPHERE**Current Contract Period:**

02/01/84-09/30/84

**Funding:** FY1984      200  
              FY1983      0  
              FY1982      0**Principal Investigator/s:**

WUEBBLES, DONALD J.

**Organization/s:** LAWRENCE LIVERMORE NATIONAL LABORATORY

**Objective:** To establish clear relationships between theoretical models and the measurement of atmospheric constituents being made in the troposphere and stratosphere.

**Product:** An understanding of what measurements are required to develop and validate one and two dimensional climate-trace gas models, respectively. This will also define the state-of-the-art theory available for model development.

**Approach:** The comparison of model calculations with observed trace species concentrations constitutes a necessary, although not sufficient, condition for model validation, both for diagnostic and prognostic applications of atmospheric models. Model sensitivity studies will be a key aspect in defining the overall uncertainties of potential trace gas influences on the atmosphere. Of special interest will be the uncertainty produced by the failure of current models to adequately consider the interaction between chemical and climatic processes.

The primary research tools to be used in the majority of the studies proposed in the previous sections will be the LLNL 1- and 2-D models of tropospheric and stratospheric chemical and physical processes. The 1-D model will remain the basic diagnostic and prognostic tool because of its computational efficiency. It will be particularly well suited to study the potential impact of newly suggested chemical and physical processes, to answer questions concerning chemical balances, to study chemical uncertainties and model sensitivity, and to provide guidance for more complex model studies. The 2-D model is currently under development, with the first stage (i.e., the parameterized transport version) to be completed in FY 1984. The use of the 2-D model is crucial for analyzing and understanding latitudinal and seasonal variations in trace species distributions. We hope to extend the 2-D model research to consider the coupled effects of climatic and chemical processes.

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## VEGETATION RESPONSE

Irrespective of whether a CO<sub>2</sub>-induced climate change occurs, it is clear that vegetation will be directly affected by a higher concentration of CO<sub>2</sub>. Plants obtain carbon from the atmosphere's CO<sub>2</sub>, and research has shown that photosynthesis is CO<sub>2</sub>-limited at contemporary atmospheric levels of CO<sub>2</sub>. Considerable evidence from controlled-environment experiments reveals that most crops experience increased growth and yield in CO<sub>2</sub> concentrations of up to 1000 parts per million or possibly higher, and that plant species vary significantly in their response rates. Thus productivity of crop systems as well as structure and function of natural ecosystems are likely to change with more CO<sub>2</sub>. In addition, CO<sub>2</sub>-accelerated vegetation growth will act to sequester additional amounts of anthropogenic CO<sub>2</sub> and may mitigate the trend to higher global concentration.

**Research Objectives** The purpose of vegetation research is to determine the response of plants to an increased concentration of atmospheric CO<sub>2</sub>. Specific objectives are (1) to determine yield of major crops in relation to CO<sub>2</sub> concentration and other key variables affecting crop productivity; (2) to determine fundamental effects of long-term elevated CO<sub>2</sub>-level exposure on plant physiology and growth; and (3) to evaluate ecosystem responses to CO<sub>2</sub> in terms of productivity, altered composition of plant communities, and carbon change from CO<sub>2</sub> enhancement of growth. Areas of study are crop response of soybeans, corn, wheat, cotton, alfalfa, rice, potatoes, trees, and other commercial plants; fundamental effects of CO<sub>2</sub> on plant physiology; and estimates of future ecosystem response, with particular emphasis on the effect of CO<sub>2</sub> growth enhancement on storage of carbon in the global biosphere.

**Research Questions** To fulfill these objectives, the following types of questions must be answered:

- o What are the effects of long-term exposure to elevated CO<sub>2</sub> concentrations on photosynthesis and growth of representative types of plants?
- o To what extent will increased CO<sub>2</sub> affect water-use efficiency and change geographic distribution of crop production systems?
- o Will plant-pest interactions be affected by changes in growth and composition of biochemical products? Will altered plant biochemistry create different pest and disease management problems?
- o What field-scale approaches are applicable for evaluating potential effects on ecosystems of long-term continuous exposure to rising levels of CO<sub>2</sub>?
- o What modeling approaches are most appropriate for estimating future physiological, structural, and functional responses of crops and ecosystems?

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**Project Title:**

EFFECTS OF ELEVATED ATMOSPHERIC CO<sub>2</sub> ON PLANT COMMUNITIES

**Current Contract Period:**

09/01/84-08/31/85

**Funding:** FY1984      120  
              FY1983      80  
              FY1982      81

**Principal Investigator/s:**

BAZZAZ, F.A.

**Organization/s:** HARVARD UNIVERSITY (UNIVERSITY OF ILLINOIS, FY1982-83)

**Objectives:** (1) To determine relative responses of native plant species to elevated CO<sub>2</sub>; (2) to evaluate effects of elevated CO<sub>2</sub> on plant competition and community structure; and (3) to examine interactive effects of CO<sub>2</sub>, light, nutrients, water, and temperature.

**Products:** Data on growth and physiology responses for simple plant communities exposed to elevated levels of CO<sub>2</sub>. Effects of CO<sub>2</sub> are to be documented for the relative contribution of different species to community biomass. Data on physiology will provide insight on the causes of differential responses to CO<sub>2</sub>. Responses of individuals and mixtures will be parameterized, and data will be used in models describing plant competition in relation to key controlling environmental variables.

**Approach:** Experiments will be carried out with mixtures of species from native grasslands and with fast-growing woody species. With CO<sub>2</sub>-controlled growth chambers, the designs will examine relative responses at three CO<sub>2</sub> levels; two light intensities; and variable water, nutrient, and temperature conditions. Data will be used in a plant competition model to simulate CO<sub>2</sub> effects on community growth and composition change.

**Project Title:**

PHYSIOLOGICAL AND BIOCHEMICAL EFFECTS OF HIGH  
ATMOSPHERE CO<sub>2</sub> LEVELS ON SWEET POTATOES  
AND COWPEAS

**Current Contract Period:**

08/01/83-07/31/84

**Funding:** FY1984      260  
              FY1983      198  
              FY1982      0

**Principal Investigator/s:**

BISWAS, P.K.

**Organization/s:** TUSKEGEE INSTITUTE

**Objectives:** To investigate the direct response of sweet potatoes and cowpeas (black-eyed peas) to CO<sub>2</sub>. Scientific objectives will be: (1) to determine morphology, physiological growth, and yield responses to elevated levels of CO<sub>2</sub> for both sweet potatoes and cowpeas; (2) to study biochemical changes in sweet potatoes and cowpeas as affected by elevated levels of CO<sub>2</sub>; (3) to determine the effects of an enriched CO<sub>2</sub> atmosphere on the rate of nitrogen fixation of cowpeas; (4) to determine the effects of an enriched CO<sub>2</sub> atmosphere on the morphology, physiological growth, and yield of sweet potatoes and cowpeas in competition with several weed species; and (5) to provide data for a generalized crop growth model for predicting yield as a function of atmospheric CO<sub>2</sub> enrichment.

**Product:** Growth and physiological responses of sweet potatoes and cowpeas as a function of variable levels of CO<sub>2</sub>. These data, when used with a regional crop model, will provide estimates of productivity changes due to future changes of atmospheric CO<sub>2</sub>.

**Approach:** The following functions will be performed:

- o Rates, amount, and distribution of phytomass of sweet potatoes will be determined for variable levels of CO<sub>2</sub>, and growth and yield responses will be related to photosynthesis, stomatal conductance, and water use.
- o Quantities and qualities of carbohydrates will be determined for both sweet potatoes and cowpeas in enriched CO<sub>2</sub> atmospheres. Comparisons between leaves and seed carbohydrates for cowpeas and between leaves and tubers of sweet potatoes will be made to determine the sink effects on the rate of photosynthesis and CO<sub>2</sub> fixation.
- o Rate of nitrogen fixation will be determined in relation to CO<sub>2</sub>-induced growth responses. Carbohydrate allocation for fixation and harvestable yield of cowpeas will be examined, and the results will be compared with allocation patterns of sweet potatoes.
- o Relative responses of crop plants and weed species will be examined; e.g., mixtures of sweet potatoes, cowpeas, redroot pigweed, and spiny amarantha will be tested at variable levels of CO<sub>2</sub>.
- o Growth response data for sweet potatoes and cowpeas will be applied to a generalized crop yield model for predicting field-scale productivity changes of these species as a function of variable levels of CO<sub>2</sub>.

**Project Title:**

ASSESSMENT OF CROP RESPONSE TO INCREASED  
ATMOSPHERIC CARBON DIOXIDE

**Current Contract Period:**

07/01/84-06/30/85

**Funding:** FY1984      475  
              FY1983      480  
              FY1982      745

**Principal Investigator/s:**

CARTER, MARY E.

**Organization/s:** U.S. DEPARTMENT OF AGRICULTURE, AGRICULTURAL RESEARCH  
SERVICE

**Objectives:** (1) To obtain data on morphological, physiological, water-use, growth, and yield responses to elevated CO<sub>2</sub>; (2) to develop models of crop yield and physiological responses to CO<sub>2</sub>; and (3) to conduct field validation tests of the models focusing on soybeans and cotton. Research at the USDA laboratories involves the acquisition of laboratory and field data and development of models for predicting crop response to elevated levels of CO<sub>2</sub>.

**Products:** (1) Data on physiological responses (RuBP carboxylase activity, photosynthesis, stomatal control, water use, carbon and nitrogen metabolism) to elevated CO<sub>2</sub> levels and other environmental factors; (2) data on growth and productivity of field crops; and (3) simulation and empirical models of plant and crop growth.

**Approach:** The integrated research calls for data acquisition, modeling, and field experiments. Data on physiological processes will be derived from environmental chamber experiments which maintain elevated levels of CO<sub>2</sub>. Generalized growth response data, in conjunction with key environmental variables, will be used in empirical crop models to estimate increased yield in relation to elevated levels of CO<sub>2</sub>.

**Project Title:**

RESPONSE OF A HARDWOOD FOREST TO CARBON  
DIOXIDE

**Current Contract Period:**

07/01/84-06/30/85

**Funding:** FY1984      127  
              FY1983      0  
              FY1982      240

**Principal Investigator/s:**

GATES, DAVID M.

**Organization/s:** UNIVERSITY OF MICHIGAN

**Objectives:** (1) To quantify the carbon dynamics of northern hardwood forests, with primary emphasis on CO<sub>2</sub> removal and storage by successional regrowth forests; (2) to develop data, methodologies, and models on leaf and forest canopy photosynthesis and whole tree growth and carbon storage in relation to controlling environmental variables of light, temperature, water, CO<sub>2</sub>, and nutrition; and (3) to validate whole-tree models against successional forest regrowth data and in relation to tree-ring records of growth.

**Products:** (1) CO<sub>2</sub> exchange curves and other physiological data for representative hardwood species under field conditions, which in combination with other environmental information (temperature, light, water, nutrients) will provide the basis for estimating response of hardwood trees to elevated CO<sub>2</sub>; (2) an empirically based model of photosynthesis and CO<sub>2</sub> exchange for several species (sugar maple, big-tooth aspen, red oak), which, when combined with related biomass and carbon data, will permit carbon dynamics for hardwood trees to be evaluated, and carbon storage to be estimated for elevated CO<sub>2</sub> levels; and (3) validation of the model against independent forest growth data obtained from the same geographical area but different sites.

**Approach:** Empirical and modeling approaches will focus on the response of forest species to elevated CO<sub>2</sub>. Data on CO<sub>2</sub> exchange and growth response will be collected for several hardwood species, including sugar maple, big-tooth aspen, red oak, and red maple. Leaf CO<sub>2</sub> exchange will be measured in situ with small cuvettes in which CO<sub>2</sub>, water vapor, and other leaf resistance properties can be precisely determined at the leaf level. Physical factors (temperature, light, humidity) will be measured simultaneously, and response curves will be developed for the actual environment and in relation to nutrient and water stress treatments. Data will be normalized to leaf area, which will permit extrapolation to the entire tree canopy by using whole-tree dimensional data. Tree growth will be modeled from these data plus other measurements of biomass, physiological, and ecological influences.

**Project Title:**

PHOTOSYNTHESIS, WATER USE EFFICIENCY, AND LEAF AREA INDEX OF BARLEY AND SORGHUM AT ELEVATED LEVELS OF CO<sub>2</sub>

**Current Contract Period:**

06/01/84-05/31/85

**Funding:** FY1984        100  
              FY1983        0  
              FY1982        0

**Principal Investigator/s:**

KANEMASU, E.T., KIRKHAM, M.B.

**Organization/s:** KANSAS STATE UNIVERSITY

**Objectives:** For field conditions of CO<sub>2</sub> exposure, the objectives are to (1) determine the effect of elevated levels of CO<sub>2</sub> on the photosynthetic rates of barley and sorghum under dry and well-watered conditions; (2) determine the effect of CO<sub>2</sub> on transpiration and water-use efficiency for the same plants and water conditions; and (3) evaluate leaf and root growth rates under elevated CO<sub>2</sub> and dry and well-watered conditions.

**Products:** (1) Data on the photosynthetic responses of two dry land crop species, barley (C<sub>3</sub>) and sorghum (C<sub>4</sub>); (2) data for a possible increase in water-use efficiency at augmented concentrations of CO<sub>2</sub>; (3) data to show whether an earlier development of a larger leaf with higher-than-ambient levels of CO<sub>2</sub> means more fruiting and yield; and (4) the root:shoot dry matter ratio indicating the effect of elevated CO<sub>2</sub> environment on the partitioning of photosynthate.

**Approach:** Experiments will be carried out at the Evapotranspiration Laboratory's Research Site near Manhattan, Kansas. Plants will be grown in a rhizotron, which is a facility in which root processes and soil water content can be carefully observed throughout the growing season. It permits measurement of both above- and below-ground plant growth as a function of elevated CO<sub>2</sub> and soil-water stress.

**Project Title:**EFFECTS OF ATMOSPHERIC CO<sub>2</sub> ON INSECT  
HERBIVORES AND THEIR HOST PLANTS**Current Contract Period:**

07/01/84-06/30/85

**Funding:** FY1984        43  
          FY1983        0  
          FY1982        0**Principal Investigator/s:**

LINCOLN, DAVID E.

**Organization/s:** UNIVERSITY OF SOUTH CAROLINA

**Objectives:** (1) To examine how CO<sub>2</sub> (through increased photosynthesis) alters leaf protein, water content, and leaf thickness and, in turn, how modified plant parameters affect feeding rates of the soybean leaf looper and the southern army worm; and (2) to examine how CO<sub>2</sub>-induced changes in secondary plant biochemicals (e.g., phenols, terpenes) will affect feeding and growth of the insects.

**Product:** Data on the effect of CO<sub>2</sub> on nutritive properties of two plants, soybeans and peppermint. Changes in secondary biochemicals will be documented, as well as insect feeding rates, in relation to CO<sub>2</sub>-altered nutritive and biochemical properties (if any). Data and analysis of host-insect relationships will be reported to DOE and in the literature.

**Approach:** Experimental approaches will utilize CO<sub>2</sub> plant-growth facilities for producing plant materials at elevated levels of CO<sub>2</sub>. While plants are exposed continuously to CO<sub>2</sub>, insects will be allowed to feed on live plant material, and feeding rates will be determined on plants growing at different levels of CO<sub>2</sub>. Effects of CO<sub>2</sub> on plant nutrition and biochemical properties will be determined simultaneously, and feeding rates will be correlated with the changed (if any) plant properties. These experiments will be done for two host-insect relationships: soybean and soybean looper and peppermint and army worm.

**Project Title:**

BICARBONATE UTILIZATION OF PHOTOSYNTHETIC ORGANISMS

**Current Contract Period:**

05/01/84-04/30/85

**Funding:** FY1984        7  
              FY1983        0  
              FY1982        0

**Principal Investigator/s:**

LUCAS, WILLIAM J.

**Organization/s:** UNIVERSITY OF CALIFORNIA, DAVIS

**Objective:** To support a conference on bicarbonate utilization by photosynthesizing plants, with special emphasis on cellular biochemical responses to  $\text{HCO}_3^-$ ;  $\text{CO}_2$  fixation, with special reference to the influence of photorespiration; genetic and immunological aspects of  $\text{HCO}_3^-$  assimilation; and ecological aspects of inorganic carbon accumulation in photosynthesizing cells.

**Product:** Conference proceedings to be published by the American Society of Plant Physiology and a report summarizing meeting proceedings and research recommendation.

**Approach:** An international conference of experts will be used to review status of research.

**Project Title:**

ELEVATED CARBON DIOXIDE EFFECTS ON  
TERRESTRIAL ECOSYSTEMS

**Current Contract Period:**

10/01/83-09/30/84

**Funding:** FY1984        210  
              FY1983        150  
              FY1982        100

**Principal Investigator/s:**

LUXMOORE, ROBERT J.

**Organization/s:** OAK RIDGE NATIONAL LABORATORY

There are two tasks: (1) to examine effects of CO<sub>2</sub> on nutrient uptake and retention and growth of forest ecosystems; and (2) to use a forest succession model for predictions of forest response to CO<sub>2</sub> fertilization.

**Objectives:** (1) To test the hypothesis that elevated atmospheric CO<sub>2</sub> levels increase nutrient retention and plant growth of soil-plant systems and to examine symbiotic relationships (mycorrhizae, N-fixation) and soil microbial responses to elevated CO<sub>2</sub> as a physiological basis for these phenomena; and (2) to parameterize a forest succession model to predict the fertilization effects of CO<sub>2</sub> on the composition and biomass dynamics of a mixed deciduous forest stand.

**Products:** (1) Data on the effects of CO<sub>2</sub>-enhanced growth on plant and microbial processes affecting nutrient availability to forest species, with improved knowledge of CO<sub>2</sub>-nutrient relationships necessary for model woody plant response to increasing atmospheric CO<sub>2</sub>; and (2) data on the possible implications of a species-level differential effect of CO<sub>2</sub>-induced growth changes within a natural forest system using the FORET model of forest succession, with computer-generated graphic output showing compositional and biomass changes through time of forests with and without CO<sub>2</sub> enrichment.

**Approach:** (1) Atmospheric CO<sub>2</sub> treatments of 340 (ambient), 500, and 800 ppm will be applied to white oak, yellow poplar, and short leaf pine seedlings in pots or microcosms grown under controlled environmental or field chamber conditions to test the hypothesis and to investigate mechanisms; and (2) available data regarding CO<sub>2</sub> effects on woody species will be gathered from all known and practical sources. A stochastic stand growth model will be used to simulate a forest through time by incorporating the species-specific growth changes with other silvicultural characteristics and competition effects.

**Project Title:**RESPONSE OF ARCTIC ECOSYSTEMS TO ELEVATED  
CARBON DIOXIDE REGIMES**Current Contract Period:**

07/01/84-06/30/85

**Funding:** FY1984 250  
FY1983 35  
FY1982 200**Principal Investigator/s:**

OECHEL, WALTER

**Organization/s:** SAN DIEGO STATE UNIVERSITY

**Objectives:** (1) To determine effects of CO<sub>2</sub> on growth enhancement, species population dynamics, and the community carbon balance of the tussock tundra; (2) to determine effects of CO<sub>2</sub> on growth and carbon dynamics of selected tundra plants; and (3) to develop and validate simple models of whole-system response to CO<sub>2</sub> and to modify existing process simulation models (ARTUS, NECS) for predicting population, community, and ecosystem response to elevated levels of CO<sub>2</sub>.

**Product:** Information on (1) carbon exchange in tussock tundra; (2) medium- and short-term effects of CO<sub>2</sub> (340, 500, and 680 ppm) on carbon storage by arctic ecosystems; (3) the effect of elevated CO<sub>2</sub> on species growth, composition, changes in cover, and other factors which affect carbon storage; and (4) differential growth responses of natural species to elevated CO<sub>2</sub>. Experimental results and model calculations obtained from field experiments and models of vegetation response will be provided in reports to DOE and in open literature publications.

**Approach:** The research involves experimental and modeling approaches. An experimental field study will investigate the direct effects of CO<sub>2</sub> enhancement on net carbon gain, species composition, and ecosystem processes of tussock tundra at Toolik Lake, Alaska. The physiological measurements of this CO<sub>2</sub> enhancement study will be carried out largely in replicated greenhouses at contemporary and two atmospheric CO<sub>2</sub> levels projected for the near future. Small temperature- and humidity-controlled greenhouses will be installed on the tussock tundra near Toolik Lake, Alaska, and operated throughout the growing season at 340, 500, and 680 ppm CO<sub>2</sub> in air. Experiments will be carried out under ambient microclimatic conditions, except for differences in the level of CO<sub>2</sub>. Simulation modeling approaches will examine and predict carbon storage, changes in community structure and dynamics, and potential modifications of the distributional area of the tundra type over a longer term than that of the experimental study. The intensive measurements of the field study will be used to validate the model.

**Project Title:**

A STUDY OF THE ABUNDANCE OF CARBON DIOXIDE IN THE ATMOSPHERE

**Current Contract Period:**

01/01/83-06/30/83

**Funding:** FY1984           0  
              FY1983           13  
              FY1982           0

**Principal Investigator/s:**

REVELLE, ROGER R.

**Organization/s:** SCRIPPS INSTITUTION OF OCEANOGRAPHY

**Objective:** (1) To examine regional and seasonal data from atmospheric CO<sub>2</sub> measurement stations in relation to the annual photosynthesis and respiration cycle of terrestrial ecosystems; (2) to analyze the possible effect of CO<sub>2</sub> enrichment on water stress of plants and compute the possible increases in productivity from alleviation of water stress; and (3) to examine potential increases of ecosystem and crop productivity from global changes of availability of nitrogen and phosphorus from human sources.

**Product:** An evaluation of the role of the biosphere in the global carbon system, addressing ranges of future carbon storage under interacting effects of climate change and increasing CO<sub>2</sub>.

**Approach:** One major approach of the CO<sub>2</sub> issue concerns effects of rising atmospheric CO<sub>2</sub> on the biosphere. Recent data on seasonal variation of atmospheric CO<sub>2</sub> indicate an increasing amplitude of 0.6-0.7% per year which may be related in part to changes of the annual photosynthesis-respiration cycle of terrestrial plants. The biotic significance of these observations and the potential for increased photosynthesis of natural and crop ecosystems in relation to rising CO<sub>2</sub> are unclear, and data from the Mauna Loa Observatory and other sources will be evaluated to determine their utility for addressing global biotic response to CO<sub>2</sub>.

**Project Title:**

ASSESSMENT OF THE EFFECTS OF ATMOSPHERIC  
CARBON DIOXIDE ENRICHMENT ON U.S. FIELD CROPS

**Current Contract Period:**

10/01/83-09/30/84

**Funding:** FY1984        100  
              FY1983        240  
              FY1982        0

**Principal Investigator/s:**

ROGERS, HUGO H.

**Organization/s:** USDA, ARS, PLANT EFFECTS LABORATORY

**Objective:** The research provides field data on the response of soybeans and corn to elevated CO<sub>2</sub>. Objectives of field experiments at the Plant Effects Laboratory (N. Carolina) are to determine CO<sub>2</sub> dose-response curves for soybeans as a function of water stress. Similar objectives apply to field experiments on corn at the Lawrence Livermore National Laboratory (California).

**Products:** A data base for the development and testing of an empirically based model for computation of CO<sub>2</sub> effects on soybean and corn crop yields for different conditions of water stress and validation data for testing GLYCIM (a soybean simulation model) simulations of soybean growth and yield as a function of increasing atmospheric CO<sub>2</sub>.

**Approach:** Experiments will be carried out in open-top chambers which control CO<sub>2</sub> levels at ambient, +75, +150, +300, and +600 ppm. Dose-response curves will be obtained for well-irrigated and water stress conditions. Growth and yield data will be obtained. Physiological measurements will include photosynthesis, stomatal conductance, and leaf water potential. Rates of soil water utilization will be determined for different CO<sub>2</sub> treatments and water stress conditions. Dose-response and yield data will be used in model calculations of crop growth, computational techniques will be applied to regional scale assessment of the CO<sub>2</sub> effect on crop yield.

**Project Title:**

ASSESSMENT OF THE EFFECTS OF ATMOSPHERIC  
CARBON DIOXIDE ON U.S. FIELD CROPS

**Current Contract Period:**

10/01/83-09/30/84

**Funding:** FY1984        475  
              FY1983        208  
              FY1982        272

**Principal Investigator/s:**

SHINN, JOSEPH

**Organization/s:** LAWRENCE LIVERMORE NATIONAL LABORATORY

**Objective:** To provide field data on the response of soybeans and corn to elevated CO<sub>2</sub> levels, based on field experiments to determine CO<sub>2</sub> dose-response curves as a function of water stress for soybeans at the Plant Effect Laboratory (North Carolina) and for corn at the Lawrence Livermore National Laboratory (California).

**Products:** A data base for the development and testing of an empirically based model for computation of CO<sub>2</sub> effects on soybean and corn crop yields for different conditions of water stress and validation data for testing GLYCIM (a soybean simulation model) simulations of soybean growth and yield as a function of increasing atmospheric CO<sub>2</sub>.

**Approach:** Experiments will be carried out in open-top chambers which control CO<sub>2</sub> levels at ambient, +75, +150, +300, and +600 ppm. Dose-response curves will be obtained for well-irrigated and water stress conditions. Growth and yield data will be obtained. Physiological measurements will include photosynthesis, stomatal conductance, and leaf water potential. Rates of soil water utilization will be determined for different CO<sub>2</sub> treatments and water stress conditions. Dose-response and yield data will be used in model calculations of crop growth, computational techniques will be applied to regional scale assessment of the CO<sub>2</sub> effect on crop yield.

**Project Title:**

INTEGRATION OF KNOWLEDGE ON THE RESPONSE OF  
VEGETATION TO RISING LEVELS OF CO<sub>2</sub>

**Current Contract Period:**

08/01/83-07/31/84

**Funding:** FY1984        219  
              FY1983        40  
              FY1982        0

**Principal Investigator/s:**

STRAIN, BOYD R.

**Organization/s:** DUKE UNIVERSITY

**Objectives:** To assemble and integrate collective scientific knowledge on the responses of vegetation to rising levels of atmospheric CO<sub>2</sub> and to present the known and unknown information, along with attendant uncertainties, as a state-of-the-science (SOA) report.

**Product:** An integrated report on the state of science to be used for the preparation of the SOA Report on the Response of Vegetation to Rising CO<sub>2</sub>. The state of scientific understanding of crop productivity and responses of native species to CO<sub>2</sub> will be determined.

**Approach:** The principal investigator (PI) will organize the report; select technical experts to write chapters; provide scientific leadership, direction, and technical review of manuscript contributions; and ensure that information used in the report is traceable to authentic scientific sources. The PI will synthesize draft manuscripts into a coherent, integrated report that will be consistent with three other SOA reports being prepared simultaneously by the Department of Energy.

**Project Title:**

DETECTION OF FOREST RESPONSE TO INCREASED  
ATMOSPHERIC CARBON DIOXIDE

**Current Contract Period:**

07/01/84-09/30/84

**Funding:** FY1984      128  
              FY1983      0  
              FY1982      0

**Principal Investigator/s:**

WEST, DARRELL C.

**Organization/s:** OAK RIDGE NATIONAL LABORATORY

**Objective:** Phase I. To determine whether the X-ray densitometry technique can provide a wood-mass data base for detecting tree response to increased atmospheric CO<sub>2</sub>. This phase will examine feasibility and test-of-concept. Phase II. To develop a more comprehensive data base and to quantify tree response in relation to increasing CO<sub>2</sub> over the past century. This data base will be used in model simulation of forest response to CO<sub>2</sub>.

**Product:** Detailed tree-ring data to provide a historical record for analyzing the CO<sub>2</sub> fertilization effect. Quantitative growth response information will serve as an indicator of forest productivity and will provide an important parameter for global carbon cycle models. This information is needed for estimating the net amount of carbon sequestered by global vegetation, and is crucial information for balancing the global carbon budget.

**Approach:** Tree-ring growth and density patterns will then be correlated with observed changes of atmospheric CO<sub>2</sub> for the same time period. The CO<sub>2</sub> effect on growth increment will also be analyzed for young trees continuously exposed to CO<sub>2</sub> in related experiments. Data will be statistically analyzed for effects of climate, pollution, site nutrition factors, and effects of CO<sub>2</sub> level on growth. Ring-width parameters of existing tree-ring chronologies from the Arizona Tree-Ring Laboratory have been thoroughly analyzed for climate effects, and these records will be examined for the growth response function.

Tree-ring chronologies will be developed for deciduous species of eastern North America where climate, pollution, and nutrient factors contribute negligible year-to-year or secular variation. Detailed data on the mass of early and late wood will be used as an indicator of variation. If a growth response is evident, tree-ring growth data will be expressed as CO<sub>2</sub> response functions and used in stand models of forest growth. Simulations with differential growth response functions will suggest possible changes in forest growth and composition as a function of rising atmospheric CO<sub>2</sub>.

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## INDIRECT EFFECTS AND MODIFICATION, ADAPTATION AND PREVENTION

Changes in climate and vegetation caused by a rising level of atmospheric CO<sub>2</sub> may affect human health and welfare in many ways. Climate has long been tied to the incidence of various diseases worldwide, and significant changes in climate may shift the regional incidence of disease. Agricultural productivity may be altered by changes in temperature and/or precipitation. Similarly, changes in water temperatures and the characteristics of rain-fall may significantly affect inland and oceanic fisheries and sea level.

**Research Objectives** The research on indirect effects of CO<sub>2</sub> is organized around the question: How will the direct effects of CO<sub>2</sub>-induced changes in climate and vegetation affect human health and welfare? Current research involves identification, characterization, and definition of the potential impacts. Specific objectives are to define the data and research required for such an evaluation and to develop possible options for modification, adaptation, and prevention (MAP). Primary areas of study are climate and hydrology/agriculture, climate and cryosphere (ice-covered areas), climate and health analysis, and climate and natural ecology interactions, including fisheries.

**Research Questions** To fulfill these objectives, the following types of questions must be answered:

- o Will global warming caused by increasing levels of atmospheric CO<sub>2</sub> shift the regional distribution of diseases afflicting human populations?

- o To what extent will the direct fertilization of plants by CO<sub>2</sub> be offset by possible adverse effects of decreased soil moisture?
- o How will global and regional water quantity and quality be affected by changes in temperature and precipitation? To what extent will these changes alter the consumptive demand for water in agriculture, residences, and industry?
- o How will changes in precipitation and runoff alter the balance of organic matter, salinity, and other mineral materials in rivers, estuaries, and oceans? What would be the impact of these changes, as well as changes in winds and currents, on fisheries?
- o Will CO<sub>2</sub>-induced climate warming cause melting of polar ice sheets and glaciers? Will this melting lead to a rise in sea level with resultant flooding along the world's shorelines?

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**Project Title:**

BIOCLIMATOLOGY OF ENERGY IMPACTS

**Current Contract Period:**

10/01/83-09/30/84

**Funding:** FY1984      135  
              FY1983      118  
              FY1982      118

**Principal Investigator/s:**

BLASING, TERENCE J.

**Organization/s:** OAK RIDGE NATIONAL LABORATORY

**Objectives:** To identify, characterize, and define 20th-century climate features as a possible analogue to projected CO<sub>2</sub>-induced warming. This information will be used to estimate forest growth and composition changes and shifts in agricultural production patterns as they relate to warming trends. This will characterize and define data and information requirements from the direct effects program elements.

**Products:** Projected shifts in regional and seasonal distribution of precipitation and growing degree days and projected regional shifts in agricultural practices (geographic displacements of characterized agricultural regions, such as the corn belt) and forest communities (distribution of commercially important species and community above-ground biomass) resulting from the projected climatic warming (near- and long-term).

**Approach:** Established statistical analyses will be applied to data on climatic parameters of particular importance to crops and forests, especially annual distribution of precipitation and length of growing season. The extent to which relatively small anomalies in the recorded data can be linked with greater anomalies projected for CO<sub>2</sub> doubling will be determined in order to estimate the temporal sequence of climatic changes between present conditions and the CO<sub>2</sub>-enhanced equilibrium climate. This will characterize and define data and information requirements from the direct effects program elements.

**Project Title:**

THE IMPACT OF CARBON DIOXIDE-INDUCED CLIMATE CHANGE ON THE WORLDWIDE AVAILABILITY AND ALLOCATION OF FRESH WATER SUPPLIES

**Current Contract Period:**

10/01/83-09/30/84

**Funding:** FY1984 125  
FY1983 145  
FY1982 56

**Principal Investigator/s:**

CURRIE, J. WILLIAM

**Organization/s:** PACIFIC NORTHWEST LABORATORY

**Objectives:** (1) To identify, characterize, and define existing or projected regional and global water resource management issues which may be affected by CO<sub>2</sub>-induced climate changes; and (2) to develop research priorities for acquiring additional information about the potential effects of a CO<sub>2</sub>-induced climate change and the availability and allocation of freshwater supplies.

**Products:** (1) A report which will identify, characterize, and define the potential effects of water resource issues which may result from CO<sub>2</sub>-induced climate changes; and (2) an outline, with priorities, of research which may reduce the uncertainties in the water resources issues and data required from the climate program element for the analysis phase of the indirect effects program.

**Approach:** The following functions will be performed:

- o A comprehensive list of worldwide water supply and demand issues will be prepared. The time frame in which these issues will become critical will be estimated. The issues will be related to changes in temperature and precipitation. The relationship of the timing of CO<sub>2</sub>-induced changes to the timing of each water resource issue will be estimated.
- o Criteria will be developed to identify issues with the highest probability of being impacted by a CO<sub>2</sub>-induced climate change. The criteria will be used to relate the generic impacts associated with each type of climate change to the type of impacts that could actually occur within specific climate zones. Criteria will be developed and used to select specific regions for detailed analysis.
- o Detailed analysis of several regions and sites will be done in a qualitative and quantitative manner to illustrate the potential impacts from CO<sub>2</sub>-induced climate changes.
- o Issues which need research to lessen the critical uncertainties will be outlined and prioritized. Data and information requirements from direct effects program elements will be defined.

**Project Title:**

AGRICULTURE - EFFECTS OF CO<sub>2</sub>-INDUCED  
CLIMATE CHANGE

**Current Contract Period:**

10/01/83-09/30/84

**Funding:** FY1984      62  
              FY1983      54  
              FY1982      0

**Principal Investigator/s:**

DECKER, WAYNE L.

**Organization/s:** UNIVERSITY OF MISSOURI

**Objectives:** (1) To identify, characterize, and define the effects of climate changes on agricultural animals, including the feedback to the health of the animals of any climate-related effects on pests, pathogens, nutrients, etc. and to study in depth the probable effects of predicted CO<sub>2</sub>-induced climate changes on one or two economically important species (e.g., cattle, sheep) as examples of effects; (2) to identify, characterize, and define the effects of climate changes on crops and forests, including any climate-related effects on pests, pathogens, noxious plant competition, etc., which may affect such things as growth or yields and to study in depth the probable effects of predicted CO<sub>2</sub>-induced climate changes on a few selected species (e.g., soybeans, corn, wheat, maples, white oaks) as examples of effects; and (3) to evolve a research plan to clarify the uncertainties regarding the probable effects of CO<sub>2</sub>-induced climate changes on agriculture.

**Product:** A report describing climate-related effects on agriculture, and the probable effects of predicted CO<sub>2</sub>-induced climate changes on some specific agriculture entities. The report will include knowns, unknowns, and uncertainties, as well as a plan for clarifying the uncertainties. The plan will include data and research needed from the CO<sub>2</sub> Research Program direct effects elements and from the agricultural research community.

**Approach:** A list of worldwide agricultural issues related to climate will be generated. By using preliminary predictions regarding probable CO<sub>2</sub>-induced climate changes and the world list, the agricultural issues most likely to be affected by CO<sub>2</sub>-induced climate changes will be identified. A limited set of plant and animal species and geographic regions will be selected, and an in-depth study of historical data (parametric where appropriate) will be made to predict and illustrate the probable effects of CO<sub>2</sub>-induced climate changes on agriculture. The extent to which any beneficial effects may offset detrimental effects will be estimated. The knowns, unknowns, and uncertainties will be defined. A research program will be outlined from both direct and indirect effects studies which will define the data and information needed to reduce the critical uncertainties about effects. Priorities for research will be defined based on the current perception of the probable importance of the effects to worldwide agriculture.

**Project Title:**

ASSESSMENT OF THE RELATIONSHIP BETWEEN LAND  
ICE AND SEA LEVEL

**Current Contract Period:**

05/14/84-04/31/85

**Funding:** FY1984        99  
              FY1983        0  
              FY1982        0

**Principal Investigator/s:**

HUSHEN, W. TIMOTHY

**Organization/s:** NATIONAL ACADEMY OF SCIENCES

**Objective:** To assess the relationship between land ice and sea level, especially as it relates to possible CO<sub>2</sub>-induced climate change.

**Product:** A definitive report which will represent the collective viewpoint of the national and international research community on the relationship between the volume of land ice and sea level. The report will assess current information, identify gaps and uncertainties, and identify research needs in order of priority to lead to a reduction in uncertainties.

**Approach:** The National Research Council will establish under its Polar Research Board's Committee on Glaciology a study committee of approximately seven to eight individuals which will conduct a study on the relationship of terrestrial ice and sea level change. The Committee expects to hold approximately two meetings and a workshop to which national and international experts will be invited to participate.

The study will build on past efforts of other groups, including the emerging Committee on Glaciology report "The Environment of West Antarctica: Potential CO<sub>2</sub>-Induced Changes." The study will also examine the basic problem of how much water has been exchanged between land ice and ocean through time in the last century, as well as what is happening now, and given existing CO<sub>2</sub> climate modeling predictions, and how much exchange can be expected in the future.

**Project Title:**

ROSS SEA HEAT FLUX EXPERIMENT

**Current Contract Period:**

05/21/84-12/31/84

**Funding:** FY1984      137  
              FY1983      0  
              FY1982      0

**Principal Investigator/s:**

PILLSBURY, DALE

**Organization/s:** OREGON STATE UNIVERSITY

**Objectives:** (1) To monitor the flux of heat to the region beneath the Ross Ice Shelf; (2) to evaluate the relative roles of vertical and horizontal fluxes in the Ross Sea circulation; (3) to define relationships between the Ross Sea thermohaline structure and its glacial ice and sea ice; and (4) to establish the system's basic spatial and temporal scales in order to model its sensitivity to naturally and anthropogenically induced perturbations

**Products:** A better understanding of the heat and mass fluxes and potential feedback loops of the Ross Ice Shelf and the potential sensitivity of the ocean circulation to climatic changes in general and to CO<sub>2</sub>-induced polar-amplified climatic warming in particular.

**Approach:** This is a 3-year multi-institutional program to monitor the flux of heat to the region beneath the Ross Ice Shelf using moored arrays of current meters equipped with temperature sensors. Three moorings have been deployed. Six moorings were planned for the second year, although a DOE supplement will expand the second year array to 10 moorings and 23 current meters, permitting greater spatial coverage of heat flux at the extreme edge of the shelf, a more westerly location, and observation of a potential site of deep convective circulation.

**Project Title:**

SURGING AS A POTENTIAL RESPONSE OF ICE SHEETS  
TO CO<sub>2</sub>-INDUCED CHANGES IN THE POLAR  
ENVIRONMENT

**Current Contract Period:**

01/01/84-12/31/84

**Funding:** FY1984      140  
              FY1983      0  
              FY1982      0

**Principal Investigator/s:**

RADOK, UWE

**Organization/s:** UNIVERSITY OF COLORADO

**Objective:** To perform a quantitative assessment of the chances for CO<sub>2</sub>-triggered or spontaneous ice sheet surges leading to sea level rises of the order of meters in the next 100 to 200 years.

**Product:** A determination of whether one or more of the major ice drainage basins of Antarctica and Greenland could surge in the next 100 to 200 years under present climatic conditions or those projected for increased levels of atmospheric CO<sub>2</sub>.

**Approach:** Fine-scale (10- to 20-km grids) physical characteristics of key ice drainage basins of West Antarctica will be established by using zero-net-mass-balance models. Equilibrium basin profiles will be determined by using transient ice deformation models and assumed ice shelf strain rates. For different sliding parameterizations, surging ranges of key parameters and surge characteristics (period, speed, mass discharge, limiting ice sheet shapes) will be established. With recent climate forcing, model drainage basin histories will be studied and extrapolated into CO<sub>2</sub> temperature (atmosphere and ocean) and precipitation scenarios.

**Project Title:**

EFFECTS OF INCREASED ATMOSPHERIC CARBON  
DIOXIDE ON FISHERIES

**Current Contract Period:**

10/01/83-09/30/84

**Funding:** FY1984        90  
              FY1983        75  
              FY1982        0

**Principal Investigator/s:**

SIBLEY, THOMAS H.

**Organization/s:** UNIVERSITY OF WASHINGTON

**Objectives:** To identify, characterize and define the probable scope of the effects of increased CO<sub>2</sub> on commercially important fisheries and document the data requirements necessary to clarify uncertainties with regard to the effects.

**Product:** A report defining the probable effects of increased atmospheric CO<sub>2</sub> on fisheries, using the Pacific Northeast fisheries area and Alaska pollock, Pacific herring, yellowfin sole, and pink shrimp as examples. The report will include knowns, unknowns, and uncertainties and data/research needed to reduce any critical uncertainties.

**Approach:** Determine the climate and water chemistry variables, worldwide, which affect fisheries production, e.g., ocean/atmospheric interactions such as changes in the magnitude, rates of change, and seasonal and regional variability of temperature, salinity, currents, upwelling, and other factors. Using preliminary predictions regarding probable CO<sub>2</sub>-induced climate and water chemistry changes, the fishery issues most likely to be affected by increasing atmospheric CO<sub>2</sub> will be identified. A selected set of species (e.g., Alaska pollock, Pacific herring, yellowfin sole, pink shrimp) in a selected region (e.g., the northeast Pacific) will be used for an in-depth study to illustrate the probable CO<sub>2</sub>-related effects on fisheries. The knowns, unknowns and uncertainties with regard to these effects will be defined. A research plan will be developed which will define the data and information needed from direct and indirect effects studies to reduce the critical uncertainties. Priorities for research will be defined, based on the current perception of the probable importance of the effects.

**Project Title:**

ATMOSPHERIC CARBON DIOXIDE CONTROL

**Current Contract Period:**

10/01/83-09/30/84

**Funding:** FY1984      155  
              FY1983      85  
              FY1982      0

**Principal Investigator/s:**

STEINBERG, MEYER

(FY1983 funding was assigned to the Integration and Evaluation component of the Research Program.)

**Organization/s:** BROOKHAVEN NATIONAL LABORATORY

**Objective:** To investigate the science and technology for mitigating or controlling the effects of CO<sub>2</sub> in the atmosphere resulting from the use of fossil fuel and other sources.

**Product:** Physical, chemical, and biological studies of CO<sub>2</sub> relating to processes dealing with the reduction of the effects of CO<sub>2</sub> and description of the information bases, energy requirements, environmental aspects, and potential.

**Approach:** A descriptive list of all aspects of the chemistry, physics, and biology of the CO<sub>2</sub> molecule as it relates to the processes and systems for mitigating or controlling the effects of CO<sub>2</sub> in the atmosphere will be created. A descriptive list will be developed for conceivable processes and systems for CO<sub>2</sub>, originating from various sources, and for the removal, recovery, disposal, and utilization of CO<sub>2</sub>. A logic and set of criteria for evaluating the need for further development of the science and technology of the CO<sub>2</sub> molecule and the processes and systems for controlling CO<sub>2</sub> in the atmosphere and mitigating its effects on the environment will be included.

**Project Title:**

ASSESSMENT OF THE INDIRECT EFFECTS OF  
INCREASED CARBON DIOXIDE

**Current Contract Period:**

10/01/83-09/30/84

**Funding:** FY1984      198  
              FY1983      133  
              FY1982      150

**Principal Investigator/s:**

WHITE, MARGARET

**Organization/s:** LAWRENCE BERKELEY LABORATORY

This project involves two tasks: Task 1, Indirect Effects on Human Health; and Task 2, Program Management.

**Task 1. Objectives:** (1) Identify, characterize, and define the probable effects on humans from CO<sub>2</sub>-induced climate change; and (2) prepare a research plan to reduce the uncertainties for projecting the CO<sub>2</sub>-induced climate effects on human health.

**Products:** (1) Definition of the probable effects on human health of climate modification as a result of increased atmospheric CO<sub>2</sub> levels; and (2) definition of data required from direct effects program elements for the analysis phase of the indirect effects program element.

**Approach:** Estimates of probable climate modifications will be obtained from the CO<sub>2</sub> Climate Program. With these projections, the literature will be searched for possible effects of these modifications on human health.

**Task 2. Objectives:** (1) To prepare state-of-the-art assessments of the effects of increasing CO<sub>2</sub> levels and consequent climate change on human health and welfare; and (2) to provide oversight of program projects and to ensure that these studies provide the best currently available response to the major issues.

**Products:** (1) Plan for defining the indirect effects of increasing CO<sub>2</sub> levels on humans, agriculture, water resources, and fisheries; and (2) coordination, supervision, and preparation of state-of-the-art reports.

**Approach:** Using the available literature and outputs of the CO<sub>2</sub> Research Plan, the issues affecting human health and welfare will be defined and prioritized. The knowns, unknowns, and uncertainties will be assessed.

**Project Title:**

MODIFICATION, ADAPTATION, AND PREVENTION (MAP)  
RESEARCH PROGRAM

**Current Contract Period:**  
10/01/83-09/30/84

**Funding:** FY1984      300  
              FY1983      125  
              FY1982      0

**Principal Investigator/s:**  
WILZBACH, KENNETH E.

(FY1983 funding was assigned to the Integration and Evaluation component of the Research Program. The principal investigator for this project was A. R. Valentino.)

**Organization/s:** ARGONNE NATIONAL LABORATORY

**Objective:** To conduct basic research to identify alternative means for modifying CO<sub>2</sub> releases to the atmosphere and for adapting to climatic, vegetative, and other changes that may result from increased atmospheric CO<sub>2</sub> levels.

**Product:** Comprehensive reports, suitable for support of policy making decisions, summarizing feasible alternative CO<sub>2</sub> modification means and projections of historical data to adaptation alternatives applicable in the future. Research will be undertaken on the basic energy sciences of CO<sub>2</sub> modification and on historical evidence of adaptation to major changes in climate, technology, resource availability, etc.

**Approach:** History includes many instances of adaptation to major changes in climate, technology, resources, etc. This can guide our thinking concerning practical adaptation schemes for the future should this be necessary. Research will be undertaken to identify and characterize these historical data and to project the data to future applications. Consideration will be given to various facets of adaptation, including agricultural strategies, animal behavior, and changes in urban living.

Basic research will be undertaken on innovative chemical and engineering means for modifying or preventing release of CO<sub>2</sub> to the atmosphere from combustion processes. Of principal importance are the means that are applicable to large centralized fossil energy power plants. Existing technology will be reviewed and assessed, but it is clear that new concepts will be needed if practical methods are to be deployed.

The initial steps in this effort will include information gathering and meetings with related Carbon Dioxide Program areas. A literature study will be performed. A preliminary state-of-the-science study will be performed to support the DOE CO<sub>2</sub> Program FY 1985 Statement of Findings. Short-term pilot research will be used to provide additional information.

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## SCIENTIFIC INTERFACE

Knowledge is of little use if the persons needing it are not aware of it or cannot obtain it. In a program such as the CDR Program, which must explore scientific issues that are often both comprehensive and complex, the need for effective communication among scientists, policymakers, and the interested public is vital. Research among various groups must also be coordinated to avoid redundant efforts, and must be managed efficiently to permit the maximum amount of benefit from scarce resources and funds.

**Objectives** The scientific interface component of the CDR Program provides (1) mechanisms through which scientific information can be readily accessed; and (2) effective coordination and management of a diversity of research efforts. Coordination and management requirements must take place across national boundaries and across industrial, professional and academic research institutions. Specific objectives include preparing numerous scientific

and informational reports, sponsoring scientific conferences, and providing scientists access to current scientific material and data on CO<sub>2</sub> through the Carbon Dioxide Information Center.

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**Project Title:**

REVIEW OF CARBON DIOXIDE RESEARCH STAFFING  
AND ACADEMIC SUPPORT

**Current Contract Period:**

05/01/84-09/30/84

**Funding:** FY1984      45  
              FY1983      0  
              FY1982      0

**Principal Investigator/s:**

BLAIR, LARRY M.

**Organization/s:** OAK RIDGE ASSOCIATED UNIVERSITIES

**Objective:** To determine whether the CO<sub>2</sub> Research Program needs to support special educational opportunities to ensure that a core of researchers and managers exist for eventual policy decision.

**Products:** To provide data with which to determine whether such a program is required and to determine (if appropriate) the resource requirements for designing such a program.

**Approach:** The assessment will take place in two phases. The first phase will culminate in a report and workshop to review the findings of that phase. The direction, scope of work, and level of effort for the second phase will be determined by the end of phase I and will be based on the findings and alternatives developed during that phase. Phase I will require approximately 8 months to complete, including assessment; preparation of the report; workshop presentation and review; and definition of phase II work scope, direction, and level of effort.

**Project Title:**

CARBON DIOXIDE ASSESSMENT, EMISSIONS,  
INFORMATION AND SERVICES

**Current Contract Period:**

10/01/82-09/30/83

**Funding:** FY1984        0  
              FY1983        101  
              FY1982        369

**Principal Investigator/s:**

COOPER, CHESTER L.

**Organization/s:** OAK RIDGE ASSOCIATED UNIVERSITIES

**Objective:** (1) To provide technical, logistical, and administrative support for conferences and meetings; and (2) to prepare special technical reports and papers for the Carbon Dioxide Research Division.

**Product:** Logistical and administrative support for conferences and meetings, including detailed planning and coordination with DOE staff, IEA staff, the participants, and others. It may include providing rapporteurs for meetings; preparing the proceedings for publication; and preparing appropriate, special technical reports, papers, and essays on a variety of topics, as requested by DOE.

**Approach:** Work is conducted in close collaboration with members of the DOE staff. Reports, papers, and essays are submitted to DOE for review, and logistical and administrative arrangements for conferences and meetings are coordinated with DOE staff.

**Project Title:**

CARBON DIOXIDE INFORMATION CENTER (CDIC)

**Current Contract Period:**

10/01/83-09/30/84

**Funding:** FY1984      729  
              FY1983      600  
              FY1982      470

**Principal Investigator/s:**

FARRELL, MICHAEL P.

(\$50K of FY1983 funding was assigned to a task classified under Work Breakdown Structure VI.)

**Organization/s:** OAK RIDGE NATIONAL LABORATORY

**Objective:** To support the nation's carbon dioxide research effort by providing a focal point for the compilation and distribution of CO<sub>2</sub>-related information under systematic quality control.

**Product:** A fully integrated information and analysis center program in support of a global assessment of CO<sub>2</sub>.

**Approach:** The following functions will be performed: (1) users' needs, data sources, and computer technologies relevant to CO<sub>2</sub> research activities will be identified, and CDIC will cooperate with the user community in establishing CDIC priorities for obtaining, documenting, and/or analyzing the requested information; (2) CDIC will serve as a liaison between other national and international data centers that have data necessary for CO<sub>2</sub> research efforts and will establish networking capabilities with these data centers to promote and facilitate information exchanges with the CDIC user community; and (3) CDIC will obtain, process, quality ensure, document, package, disseminate, and evaluate numerical data, computer codes, bibliographic information, and other CO<sub>2</sub>-related information in support of ongoing research activities and will provide a formal and documented source for data, computer models, and information used for evaluation purposes.

**Project Title:**

PARTIAL SUPPORT FOR THE NATIONAL ACADEMY OF SCIENCES' BOARD ON ATMOSPHERIC SCIENCES AND CLIMATE

**Current Contract Period:**

04/01/83-08/31/84

**Funding:** FY1984        65  
              FY1983        0  
              FY1982        20

**Principal Investigator/s:**

HECHT, ALAN

**Organization/s:** NATIONAL CLIMATE PROGRAM OFFICE

**Objective:** To provide scientific leadership and guidance to the government on important national and international issues in the atmospheric sciences and climate, including the National Climate Program and U.S. participation in the World Climate Program.

**Product:** Regularly scheduled board, committee and panel meetings which will review current national and international issues and provide advice and assistance to the government as needed.

**Approach:** The following functions will be performed: (1) the board on Atmospheric Sciences and Climate will review current national and international issues in the atmospheric sciences and climate and will remain prepared to offer timely advice and assistance as needed; (2) the Climate Research Committee will maintain cognizance of and liaison with the domestic and international climate research programs; (3) the Panel on Climate-Related Data will complete its study and report during this period; (4) the Panel on Mesoscale Research will meet twice during this period; and (5) the Board intends to explore the potential for a study of weather and climate information services for agriculture.

**Project Title:**

AN ASSESSMENT OF PHYSICAL AND CHEMICAL  
OCEANOGRAPHIC RESEARCH IN THE SOUTHERN OCEAN

**Current Contract Period:**

07/01/84-06/30/85

**Funding:** FY1984        10  
              FY1983        0  
              FY1982        0

**Principal Investigator/s:**

HUSHEN, W. TIMOTHY

**Organization/s:** NATIONAL ACADEMY OF SCIENCES

**Objective:** To identify the principal research questions in southern ocean physical and chemical oceanographic research, recommend priorities to guide the direction of future research in this field, and to indicate the facilities and support required for a meaningful research program.

**Product:** An authoritative report on the needs and priorities of Antarctic geosciences research.

**Approach:** The Polar Research Board jointly with the Board on Ocean Science and Policy will establish an ad hoc Committee on Southern Ocean Physical/Chemical Oceanography Research to undertake the study. The committee will meet approximately two times. In addition, a 3-day workshop will be held to bring into the report the comments and views of a selection of experts in southern ocean science.

**Project Title:**

SUPPORT FOR ACTIVITIES OF THE POLAR RESEARCH BOARD, NAS

**Current Contract Period:**

11/01/83-10/31/84

**Funding:** FY1984        25  
              FY1983        0  
              FY1982        45

**Principal Investigator/s:**

HUSHEN, W. TIMOTHY

**Organization/s:** NATIONAL ACADEMY OF SCIENCES

**Objectives:** (1) To provide advise on U.S. research activities and needs in the Arctic and the Antarctic; (2) to serve on behalf of the National Academy on Sciences as the U.S. National Committee for the Scientific Committee on Antarctic Research (SCAR) of the International Council of Scientific Unions representing the U.S. scientific and technical community in SCAR activities and fostering U.S. participation in the planning and coordination of international cooperative research programs recommended by SCAR; (3) to maintain awareness of the activities of other national and international organizations concerned with research in the Arctic and Antarctic; and (4) to organize and conduct a series of studies in the various disciplines of polar research as a basis for recommendations on priorities and on a strategy for polar research over the coming decades.

**Products:** (1) A workshop held by the Committee on Glaciology in conjunction with the December 1983 AGU meeting, which will follow up on specific recommendations of its report, Snow and Ice Research: An Assessment. Specifically, the committee will assess the possible change in sea level due to the melting of nonpolar snow and ice; (2) continue work on a strategy report dealing with the polar regions and climatic change; and (3) a workshop in Spring 1984 held by the ad hoc Committee on Physical and Chemical Oceanography of the Southern Ocean.

**Approach:** Advice, guidelines, and recommendations on polar research will result from interaction during the semiannual meetings of the board and the meetings of its subgroups and from special studies organized by the board to respond to particular problems or to develop long-range plans and priorities.

The board is a multidisciplinary body with a regional orientation. On the board and its various subgroups will be representatives from the fields of marine and terrestrial biology, the earth sciences, engineering research, medicine, the physical sciences, and the social sciences. Membership will be drawn from academic institutions, industry, and national laboratories. Federal agencies such as the Department of Energy, with programs in the Arctic or the Antarctic, will have liaison representation on the board and will brief the board periodically at its meetings on these activities.

**Project Title:**

TECHNICAL AND ADMINISTRATIVE SUPPORT SERVICES  
TO THE DOE CARBON DIOXIDE RESEARCH DIVISION

**Current Contract Period:**

09/01/84-08/31/85

**Funding:** FY1984      326  
              FY1983      310  
              FY1982      0

**Principal Investigator/s:**

MADDEN, MICHAEL S.

**Organization/s:** THE MAXIMA CORPORATION

**Objectives:** To support the Carbon Dioxide Research Program in its mission of disseminating interim and final results from its research project, conducting expert reviews of these findings, holding conferences and seminars for researchers and other experts and carrying out special projects.

**Products:** Support the Carbon Dioxide Research Division Director in planning and conducting 9 to 12 program review meetings, conferences, and workshops. This will entail communicating with CO<sub>2</sub> research contractors, coordinating activities, and producing draft and final reports. Technical editing of research plans, technical reports, state-of-the-art reports, and the 1985 Statement of Findings will also be performed. In addition, assistance in statistical analysis and assembling and compiling technical data and other information for the preparation of reports or other documentation will be provided.

**Approach:** The activities undertaken by Maxima in support of the Carbon Dioxide Research Program will be initiated through task order. Each task will be conducted in close collaboration with members of the DOE staff. Reports, papers, and documentation will be submitted to DOE for review. All logistics and administrative arrangements will be closely coordinated with DOE staff.

**Project Title:**

CARBON DIOXIDE OVERVIEW BY THE NATIONAL  
ACADEMY OF SCIENCES

**Current Contract Period:**

12/30/82-09/30/83

**Funding:** FY1984        7  
              FY1983        50  
              FY1982        0

**Principal Investigator/s:**

PERRY, JOHN S.

**Organization/s:** NATIONAL ACADEMY OF SCIENCES

**Objectives:** To conduct an independent assessment of potential effects of CO<sub>2</sub> and prepare a critique of the national CO<sub>2</sub> research program, including the research areas of carbon cycle, climate modeling, and indirect environmental effects of CO<sub>2</sub>.

**Approach:** The NAS will conduct this independent assessment for the Office of Science and Technology Policy with assistance from the Department of Energy and the National Science Foundation. The overview of the national CO<sub>2</sub> research program will encompass a review of the CO<sub>2</sub> effects research and assessment program to identify any deficiencies and gaps in the program and is expected to yield timely and constructive recommendations to improve the program's scientific integrity, productivity, and utility.

**Project Title:**

PARTIAL SUPPORT OF THE COMMITTEE ON THE  
INTERNATIONAL GEOSPHERE-BIOSPHERE PROGRAM

**Current Contract Period:**

09/01/84-08/31/85

**Funding:** FY1984        20  
              FY1983        0  
              FY1982        0

**Principal Investigator/s:**

PERRY, JOHN S.

**Organization/s:** NATIONAL ACADEMY OF SCIENCES

**Objectives:** To weigh the merits and explore the coherence and necessity of an International Geosphere-Biosphere Program (IGBP) and to prepare and disseminate the results of the study in a written report.

**Product:** A report on the merits, coherence, and necessity of an IGBP.

**Approach:** A committee of the NAS on the IGBP will be formed, and will be composed of about 20 people, with balanced representation from researchers studying the lithosphere, the oceans and the atmosphere, the biosphere, and the solar-terrestrial area. The full committee will establish panels to examine particular areas (e.g., the biosphere). Among the major questions that need additional analysis will be whether links between areas of study are strong enough to justify an IGBP and whether the formation of a new program will damage important ongoing and proposed programs.

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## INTEGRATION AND EVALUATION

The various strands of research must be gathered together and consolidated into a coherent and reinforcing set of findings and response options. Given that numerous potential modification, adaptation, and prevention strategies will be identified, cost/benefit analysis will serve as a means for recommending among them.

**Objectives** Five State-of-the-Art (SOA) Reports on carbon dioxide research will be prepared for distribution in 1985. These will be definitive, scientific statements about what is and is not known. They will identify the uncertainties surrounding the data and research results of each of

the four research areas (i.e., carbon cycle, climate, vegetation response, and indirect effects and modification, adaptation and prevention) and the issue of first detection. Then, in mid-1985, a Statement of Findings (SOF) will be released that will synthesize the SOA reports and other studies and present an integrated systems view of the entire research program needed to reduce uncertainties. The SOF is expected to provide a comprehensive state-of-knowledge discussion of the potential long-term implications of increasing levels of CO<sub>2</sub> rather than definitive recommendations pertaining to amelioration policies and strategies.

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**Project Title:**

CARBON DIOXIDE LOGIC DIAGRAM SYSTEM

**Current Contract Period:**

11/01/82-09/30/83

**Funding:** FY1984        81  
              FY1983        44  
              FY1982        0

**Principal Investigator/s:**

BLACKWOOD, B.

**Organization/s:** CALCULON CORPORATION

**Objectives:** To develop and implement a computer-based Carbon Dioxide Logic Diagram System to assist the Carbon Dioxide Research Division in making decisions.

**Products:** A developed and implemented Carbon Dioxide Logic Diagram System with training and documentation, including the following: (1) provide the Carbon Dioxide Research Division with graphic capabilities; (2) develop and maintain data base integrity among field office users and headquarters; (3) develop the capability to integrate data by subsystems and elements; (4) provide the ability to maintain trend data; (5) develop a method to produce user-defined reports from keyword input; (6) develop system test plan and prepare for system turnover; (7) complete system documentation and provide training; and (8) develop additional enhancements as required.

**Approach:** The effort to complete the implementation of the Carbon Dioxide Logic Diagram Systems will include the review of appropriate material and documents relative to the Carbon Dioxide Information Center and available graphic software. Interviews will be conducted with staff members of the Carbon Dioxide Research Division. In addition to developing system software, the project will document the implemented system and provide staff training.

**Project Title:**

TECHNICAL SUPPORT TO THE CARBON DIOXIDE  
RESEARCH DIVISION

**Current Contract Period:**

09/01/83-11/30/85

**Funding:** FY1984        21  
              FY1983        163  
              FY1982        0

**Principal Investigator/s:**

BURNS, DAVID M.

**Organization/s:** AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

**Objective:** To provide the assistance of recognized expert scientific personnel to ensure that the CO<sub>2</sub> state-of-the-art reports are complete, that uncertainty is fully addressed, and that the most complete quantitative knowledge base has been utilized.

**Products:** Task 1. Review and critique of the outline and work breakdown for the state-of-the-art reports for carbon cycle, climate modeling, vegetative effects, and indirect effects. Task 2. Anonymous peer review of the four state-of-the-art reports. Task 3. Review and critique the Executive Summary of the Statement of Findings.

**Approach:** The AAAS Climate Committee will serve as an independent quality control group of the scientific knowledge base compiled and used in the five CO<sub>2</sub> state-of-the-art reports and the statement of findings executive summary. These reports are designed to be comprehensive statements of what is known, unknown, and uncertain in regard to the carbon cycle, climate-CO<sub>2</sub> effects, first detection, and vegetation response to higher levels of atmospheric CO<sub>2</sub>. The AAAS Climate Committee will appoint at least four subcommittees, with internationally recognized experts assisting them. The work will be performed by the AAAS Climate Committee, Roger Revelle, Chairman. Members include George Brown, Jr., David Gates, Michael Glantz, Robert Kates, Nathan Keyfitz, Lester Lave, Estella Leopold, J. Murray Mitchell, Harry Perry, Dean Peterson, David Pimentel, and Robert M. White.

**Project Title:**

CARBON DIOXIDE ASSESSMENT, EMISSIONS,  
INFORMATION AND SERVICES

**Current Contract Period:**

10/01/82-09/30/83

**Funding:** FY1984        0  
              FY1983        65  
              FY1982        0

**Principal Investigator/s:**

COOPER, CHESTER L.

**Organization/s:** OAK RIDGE ASSOCIATED UNIVERSITIES

**Objective:** To explore the bases for consensus-building on issues involving the use of incomplete and/or potentially conflicting scientific advice. Uncertainty often underlies and promotes disagreements among scientists; this in turn hinders the construction of effective political consensus on questions with scientific content.

**Product:** An outline for a comprehensive, well-constructed evaluation framework that guarantees the consideration of all uncertainties and identifies priority areas for further work. Work on understanding the consensus-building role of explicit uncertainty analysis is still in its formative stages. To build consensus on the overall assessment, scientists must apparently be convinced that their uncertainties are being treated on an equal footing with those of their colleagues and sister disciplines. We presently lack such a framework.

**Approach:** Reasoned consensus in science usually requires recognition that a research finding has survived a fair and rigorous process of critical peer review. To promote better consensus on uncertainty assessments thus requires improvements of both the conduct of these assessments and the processes by which they are reviewed. This research seeks to identify and describe such improvements through a retrospective review of attempts to analyze uncertainty and build consensus in past systems studies, especially those dealing with energy/environment interactions.

**Project Title:**

TECHNICAL SUPPORT TO THE CARBON DIOXIDE  
RESEARCH DIVISION

**Current Contract Period:**

08/10/83-06/29/84

**Funding:** FY1984           0  
              FY1983           48  
              FY1982          156

**Principal Investigator/s:**

GUTIERRIEZ, JUAN J.

**Organization/s:** INTERAMERICA RESEARCH ASSOCIATES, INC.

**Objective:** (1) To develop a technology tree for climate and first detection; and (2) to draft a definition of climate for the CO<sub>2</sub> issue.

**Product:** A technology tree for climate, establishing the historical rates at which basic mathematics, physics, and geophysics have come together to form climate modeling. The tree will be used as a management tool to estimate where we are and where we might go in the sciences to aid climate modeling. A working definition of climate will be established.

**Approach:** A literature review will be conducted to establish the database. Program experts will be consulted to ensure quality control of the product.

**Project Title:**

STUDY OF THE UTILIZATION OF SPACE  
FOR CARBON DIOXIDE RESEARCH

**Current Contract Period:**  
07/01/82-06/30/83

**Funding:** FY1984        0  
              FY1983        0  
              FY1982        300

**Principal Investigator/s:**  
GUTTMAN, CHARLES H.

**Organization/s:** MARSHALL SPACE FLIGHT CENTER

**Objective:** To specify existing and potential requirements for data collection from space and any potential use of space technology for CO<sub>2</sub> mitigation.

**Product:** Documentation of the need for utilization of space for CO<sub>2</sub> research and its relationship to the CO<sub>2</sub> program, the data required, the status of the technology to meet the requirement, and action or research necessary to obtain the data and make it available to the user community.

**Approach:** Project objectives will be met by consulting with experts in the three major areas where data collection from space may offer significant advantages. These are in the monitoring of worldwide cloud cover, of the biosphere, and of the West Antarctic ice shelf and sheet. The cloud cover data provide an example of the importance of this monitoring. Climate modelers can show that clouds could enhance, negate, or play a neutral role in CO<sub>2</sub>-induced climate change. The problem is that one cannot define an average cloud for a model. Modelers require satellite irradiance data to solve this problem, as it tells what clouds are doing on the average.

**Project Title:**

STUDY OF AN ULTRA-LIGHT PLATFORM FOR CARBON  
DIOXIDE RESEARCH

**Current Contract Period:**

10/01/83-09/30/84

**Funding:** FY1984        200  
              FY1983        0  
              FY1982        0

**Principal Investigator/s:**

GUTTMAN, CHARLES H.

**Organization/s:** MARSHALL SPACE FLIGHT CENTER

**Objective:** To determine the feasibility and technical specifications for an ultra-light, microwave-powered measurements platform for CO<sub>2</sub>-related remote sensing data needs.

**Product:** The concept and feasibility of an ultra-light, microwave-powered measurements platform will be developed and evaluated against CO<sub>2</sub>-related remote sensing data requirements.

**Approach:** The remote sensing data requirements, as modified from the space data requirements, will be examined against the capabilities of an ultra-light, microwave-powered measurements platform. The device would operate between 60 and 110 kilometers, taking stratospheric data (temperature, pressure, humidity, aerosol loading, and air samples) as well as remote sensing data (profiles of temperature, pressure and atmospheric species). The first step will be the development by DOE and MSFC of a straw man technical measurement specification. This specification will be used by a contractor (to be selected competitively by MSFC) to evaluate the feasibility of designing the platform.

## Keyword Index for Integration and Evaluation

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**APPENDIX A**  
**ADDRESSES OF PRINCIPAL INVESTIGATORS**

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**APPENDIX B**  
**CARBON DIOXIDE AND CLIMATE WORK BREAKDOWN STRUCTURE**

- I. CARBON CYCLE
  - A. Atmospheric Observations
    - 1. Contemporary Atmospheric Observations
    - 2. Past Atmospheric Observations
    - 3. Standards
    - 4. Atmospheric Circulation Models
  - B. Fossil Emissions
    - 1. Record of Fossil Fuel Emissions
    - 2. Projections
    - 3. Uncertainty Analysis
  - C. Oceans
    - 1. CO<sub>2</sub> Absorption/Exchange
    - 2. Carbon Removed to Deep Ocean
    - 3. Biotic Effects
    - 4. Ocean Carbon Models
  - D. Biosphere
    - 1. Contemporary Carbon Change of Vegetation
    - 2. Historical Record of Terrestrial Carbon
    - 3. Biosphere Carbon Models
  - E. Other Sources, Sinks, and Fluxes for Atmospheric CO<sub>2</sub>
  - F. Modeling of the Global Carbon Cycle
    - 1. Global Carbon Cycle Models
    - 2. Coupled Atmosphere/Ocean, Atmosphere/Biosphere Models
    - 3. Sensitivity/Uncertainty Analysis
  - G. Estimates of Future Atmospheric CO<sub>2</sub>
  - H. Management
    - 1. Program
    - 2. Area
- II. CO<sub>2</sub> AND CLIMATE
  - A. Modeling Climate
    - 1. One-dimensional Climate Models
    - 2. Two-dimensional Climate Models
    - 3. Three-dimensional Climate Models
    - 4. Sensitivity/Uncertainty Analysis
  - B. Supporting Data and Analysis
    - 1. Climate Record
    - 2. Geophysical Data
  - C. First Detection of CO<sub>2</sub>-Induced Climate Change
    - 1. Data Analysis
    - 2. Experimental Observations
    - 3. Monitoring
  - D. Analysis and Estimated Climate Change
    - 1. Analysis
    - 2. Estimated CO<sub>2</sub>-Induced Climate Change
  - E. Management
    - 1. Program
    - 2. Area

**Appendix B:**

**Carbon Dioxide and Climate  
Work Breakdown Structure (continued)**

- III. VEGETATION EFFECTS
  - A. Response of Crops to CO<sub>2</sub>
    - 1. Direct CO<sub>2</sub> Effect
    - 2. Yield Response
    - 3. Interactions of Nutrients and Water Use
    - 4. Crop Yield Models
  - B. Fundamental Effects of CO<sub>2</sub> on Plants
    - 1. Physiology
    - 2. Growth
    - 3. Plant Growth Models
  - C. Response of Ecosystems to CO<sub>2</sub>
    - 1. Direct CO<sub>2</sub> Effect--Native Species
    - 2. Population/Community Effects
    - 3. Ecosystem Production and Carbon Storage
    - 4. Ecosystem Models
  - D. Estimates of Future Crop/Ecosystem Response
  - E. Management
    - 1. Area
    - 2. Program
- IV. INDIRECT EFFECTS & MODIFICATION, ADAPTATION, AND PREVENTION
  - A. Climate Change and Water Resources/Agriculture
    - 1. Definition
    - 2. Analysis
  - B. Climate Change and Sea Level
    - 1. Measurement and Analysis
    - 2. Modeling
  - C. Climate Change and Health Analysis
  - D. Climate Change and Natural Ecology Interactions, Including Fisheries and Forestry
  - E. Management
    - 1. Program
    - 2. Area
- V. SCIENTIFIC INTERFACE
  - A. Carbon Dioxide Information Center
  - B. Coordination and Cooperation
    - 1. International
    - 2. Industrial/Professional
  - C. Management
    - 1. Reports
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- VI. INTEGRATION AND EVALUATION
  - A. State-of-the-Art Reports
  - B. Statement of Findings
  - C. Risk and Cost/Benefit Analysis
- VII. POLICY OPTIONS
  - To be determined (TBD)
- VIII. DECISION
  - TBD
- IX. IMPLEMENTATION
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