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Carbon Dioxide and Climate: Summaries of Research in FY 1985

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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 Year 1985. It includes descriptions of all projects funded. 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 Year (FY) 1985, is organized into four main sections as follows:

SECTION	DESCRIPTION
Introduction	o Describes overall CO_2 issues
	o Ties CO_2 issues to the research approach, program goals, and objectives
	o Relates each specific research area to the overall goals of the program
	o Shows the level of the Federal effort
Research Areas and Project Descriptions	o Describes scientific questions in each research area
	o Provides descriptions of individual research projects
	o Shows the research approach or methodology used in each project
	o Lists the expected product for each project
	o Provides indexes of keywords, principal investigators, and research institutions for easy reference
Appendixes	o Provides more in-depth information on the total research approach
Indexes	o Provides locator information on subjects, principal investigators, and research institutions for the overall report

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.

INTRODUCTION

Worldwide monitoring indicates that the amount of carbon dioxide (CO_2) in the earth's atmosphere is gradually increasing. CO_2 has risen from 316 parts per million (ppm) in 1958, when continuous monitoring was initiated, to 344 ppm in 1984. 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_2 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_2. 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 resaerch program is the identification of possible policy options for governmental action in response to changes in the atmospheric CO_2 concentration. Achievement of this goal requires increased understanding of CO_2 interactions involving the atmosphere, the biosphere, the oceans, and the cryosphere. The functions assumed by the program to fulfill this goal are to

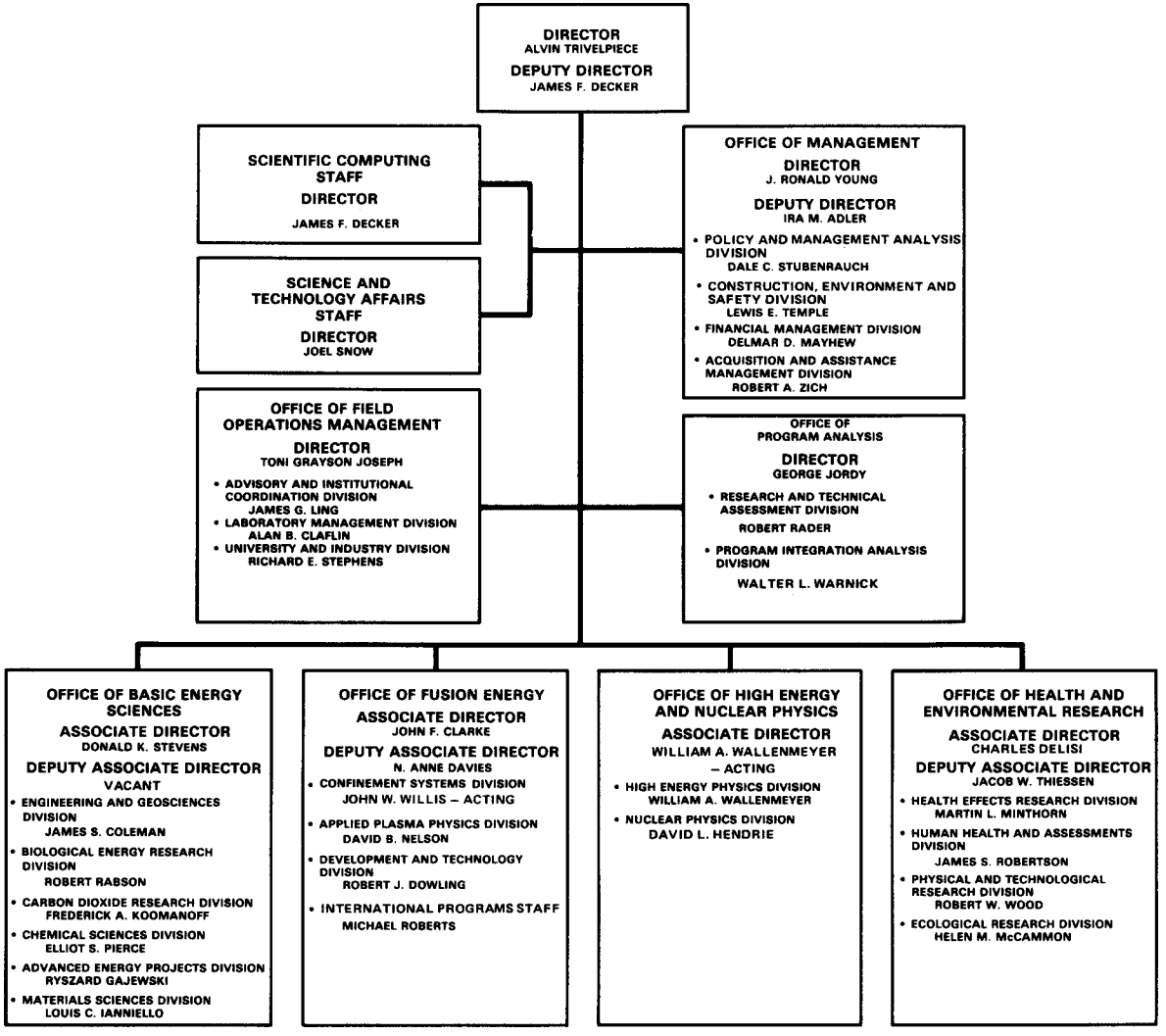
- Sponsor specific projects that would either increase the knowledge base or support refinement of the conceptual tools being used to help understand the phenomenon
- Communicate to the domestic and international research communities potential priority issues and the implications of research findings
- Perform a continuing technical review of the products of the varied research efforts worldwide to expand the growing knowledge base
- Coordinate Federal research related to CO_2

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_2 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.

FIGURE 1. OFFICE OF ENERGY RESEARCH



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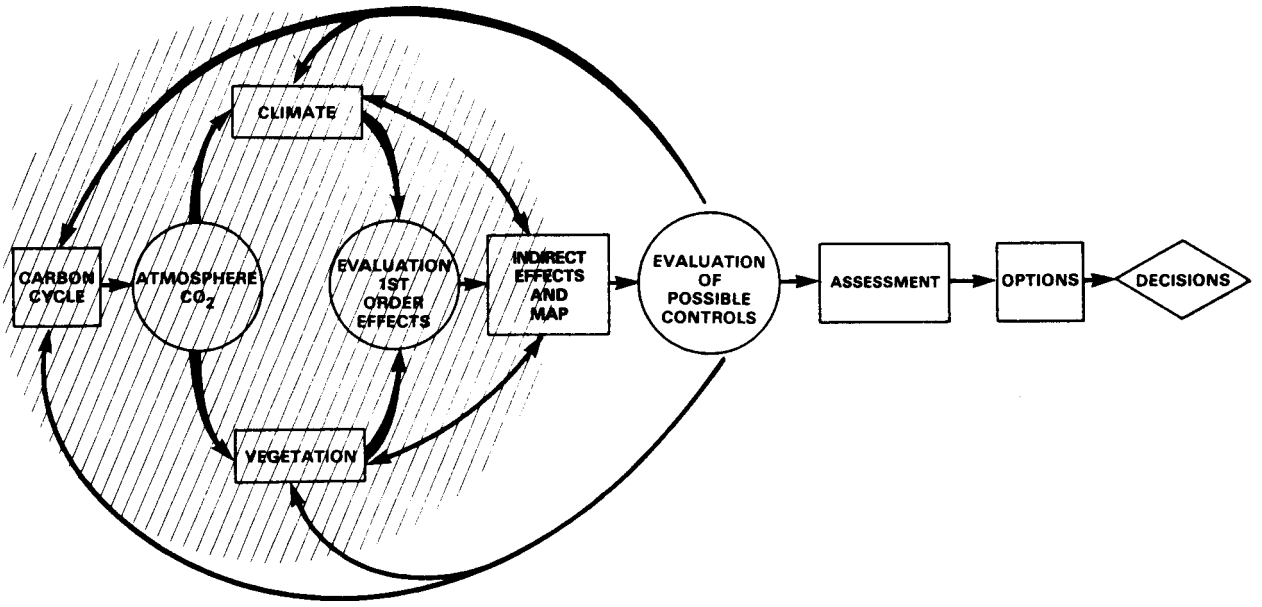
Understanding the global carbon cycle leads to determining what direct effects rising levels of CO_2 will have on climate and vegetation. Research in climate is directed at determining the extent to which rising levels of CO_2 will lead to global and regional climate changes. A major project is to establish 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_2 will focus on the role of CO_2 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 policy-making 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 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 first detection--plus two auxiliary reports, one on indirect

FIGURE 2. THE CO_2 PROGRAM



effects and a National Research Council, Polar Research Board report on sea level. The SOF to be issued in 1986, 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 1985, the budget reached $13,072,000. During the first years of the program, the research budget was concentrated in the carboncycle and climate areas, but as of FY 1985 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.

Table 1: Carbon Dioxide Budget History - Type Of Institution
(in 1,000 dollars)

Type of Institution	FY78-80	FY1981	FY1982	FY1983	FY1984	FY1985	TOTAL	Percent of Program Funding (all fiscal years)
University	5,736	5,357	4,613	2,949	4,092	5,697	28,444	43
Laboratory	2,941	3,177	4,894	4,206	6,059	5,368	26,645	40
Government	550	595	1,790	1,078	1,286	778	6,077	9
Industry	51	110	249	510	536	603	2,059	3
Other	1128	497	460	213	427	596	3321	5
Total	10,406	9,736	12,006	8,956	12,400	13,042	66,546	100
Budget Adjustment			-35	10	73	30	78	
Total Budget			11,971	8,966	12,473	13,072	66,624	

Organization of the Program Summary Descriptions are provided for all projects funded by DOE under annual contracts in FY 1985. 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 area: 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 This document has been indexed to aid the reader in locating research topics, participants, and research institutions in the text and the project descriptions. Comprehensive subject, principal investigator, and institution indexes are provided at the end of the text for this purpose. The comprehensive subject index includes keywords from the Introduction and chapter texts in addition to those from the project descriptions.

Table 2: Carbon Dioxide Budget History - Work Breakdown Structure (in 1,000 dollars)

Work Breakdown	FY78-80	FY1981	FY1982	FY1983	FY1984	FY1985	TOTAL	Percent of Program Funding (all fiscal years)
Carbon Cycle	6,240	5,515	5,160	3,389	3,565	3,435	27,304	41
CO_2-Climate	1,888	2,029	3,327	1,936	3,525	4,272	16,977	26
Vegetation Response	361	917	1,688	1,444	2,514	2,454	9,378	14
Indirect Effects and Map	374	45	374	525	1,441	970	3,729	6
Scientific Interface	40	65	926	1,082	1,253	1,482	4,848	7
Integration and Evaluation	630	679	531	580	102	429	2,951	4
Program Development and Management	873	486	0	0	0	0	1,359	
Total	10,406	9,736	12,006	8,956	12,400	13,042	66,546	100
Budget Adjustment			-35	10	73	30	78	
Total Budget			11,971	8,966	12,473	13,072	66,624	

CARBON CYCLE

There are four principal reservoirs, or regions of the earth, in which carbon behaves in a systematic manner. These are the oceans, the atmosphere, the terrestrial biosphere, 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_2 levels. This goal is contigent 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_2 concentration from past and future anthropogenic (i.e., human) activities. Primary areas of study are atmospheric observations of CO_2 concentrations and trends, fossil fuel emissions, oceans, and biosphere, depositories (sinks), transfers (fluxes) of CO_2, and modeling of the global carbon cycle.

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

- What future releases of CO_2 to the atmosphere from fossil fuel combustion can be expected under alternative levels of use? What is the history of such releases?
- What is the trend, annual cycle, and geographic variability of atmospheric CO_2? How has the concentration of CO_2 in the atmosphere changed over the past centuries and millennia? Was there a steady-state condition in the carbon cycle prior to anthropogenic perturbations?
- Is the terrestrial biosphere a net source or sink (or is it in equilibrium) for atmospheric CO_2? 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_2? Has the situation changed substantially in the past 100 years?
- What is the variability over time and over regions of ocean-atmosphere CO_2 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_2?
- How can one determine whether there are significant sources or sinks of atmospheric CO_2 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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Project Title:

DEVELOPMENT OF A 3-D MODEL OF THE NATURAL CARBON CYCLE IN THE OCEAN AND ITS PERTURBATION BY ANTHROPOGENIC CARBON DIOXIDE

Current Contract Period:
12/01/84-11/30/85

Funding: FY1985 149
FY1984 63
FY1983 0

Principal Investigator/s:

BACASTOW, ROBERT B.

Organization/s: SCRIPPS INSTITUTION OF OCEANOGRAPHY

Objective: The immediate objective is to develop a three-dimensional (3-D) transport model of the natural carbon cycle in the ocean, and to link it to an atmospheric transport model to improve our understanding of atmospheric CO_2. The ultimate objective of producing a 3-D oceanic carbon cycle model is to estimate the uptake of anthropogenic CO_2 by the world's oceans.

Product: The principal product will be a model of partial pressure of CO_2 in ocean surface waters and total CO_2 in surface and subsurface waters. Coupling the model to the Goddard Institute for Space Studies/Scripps Institution of Oceanography (GISS/SIO) atmospheric CO_2 model will improve our understanding of seasonal and geographic variations in atmospheric CO_2.

Approach: The 3-D transport model, adapted from an ocean circulation model developed at the Max-Plank-Institute for Meteorology, Hamburg, FRG, will be analyzed and modified as required. An improved vertical circulation field, in particular, will be added in collaboration with Klaus Hasselman and co-workers at the Max-Plank-Institute. In addition, several other specific projects and model applications will be conducted:

(1) The GISS/SIO model indicates that the seasonal cycle of atmospheric CO_2 is primarily due to uptake and respiration of land biota, but some part of it is due to seasonal changes in pCO_2 of the ocean surface water. Coupling the 3-D ocean transport model to the GISS/SIO model should improve our understanding of atmospheric CO_2 variations.

(2) The carbon cycle model will be used to test the effect of mixing between water masses and of pCO_2 variation on preformed dissolved organic carbon (DIC) values. The goal is to eventually calculate correction factors for the various water masses that make up the oceans.

(3) Recent measurements of CO_2 and ^{18}O in ice cores indicate that during the last glacial epoch there were repeated simultaneous peaks in CO_2 and world temperature. It is likely that these changes were caused by a change in ocean circulation. This effect will be studied by varying all the components of ocean velocity together for several varied relationships between the photosynthetic productions and nutrient concentration.

(4) A parameterization for ^{13}C will be incorporated into the carbon cycle model, and the accuracy of the result will be tested by comparing simulated ^{13}C distributions with actual data.

Project Title:

ANALYSIS OF SOUTHERN HEMISHPERE CO2 DATA IN RELATION TO VARIATIONS IN ATMOSPHERIC CIRCULATION AND SEA ICE CONDITIONS

Current Contract Period:
10/01/84-09/30/85

Funding: FY1985 24
FY1984 0
FY1983 0

Principal Investigator/s:

BARRY, ROGER G.

Organization/s: UNIVERSITY OF COLORADO

Objective: To understand more fully intra- and interannual fluctuations of atmospheric CO_2 concentrations in relation to three southern hemisphere ocean/atmosphere elements: (1) atmospheric circulation; (2) ocean surface temperatures; and (3) sea ice extent.

Product: This project focuses on understanding the relationships between atmospheric circulation conditions in the southern hemisphere and sea surface temperature (SST) patterns, sea ice extent, and corresponding feedbacks to the atmosphere from ocean and ice conditions. Results will be reported in written progress reports, presentations, master's thesis, and open literature publication.

Approach: This study will include the following tasks:

Task 1: At present there is a sixfold seasonal variation in spring maximum to fall minimum ice extent in the Southern Ocean, which exceeds the glacial/interglacial amplitude of ice extent. This task will attempt to find a statistical link between Antarctic CO_2 and sea ice as well as atmospheric and oceanic parameters.

Task 2: The ^{13}C data from the South Pole indicate negligible seasonality whereas CO_2 data show clear seasonality. Carbon isotope ratios of atmospheric CO_2 for southern hemisphere stations will be examined to determine the dependence of the annual CO_2 data upon land biotic effects.

Task 3: In low and mid-latitude areas, the wind stress and oceanic temperature data can be correlated to CO_2 data from each station. Maps of correlation coefficients will be produced for seasonal and annual data. In addition, El Nino Southern Oscillation (ENSO) indices will be related to CO_2 data to reveal the phase relation between the two.

Task 4: If area of high correlation between CO_2 data and SST or wind data are found, then air flow from these areas will be studied. Advection times and event frequencies can be calculated for both atmospheric and oceanic processes.

Task 5: A modified box model of the carbon cycle (in collaboration with Dr. Dale Gillette of NOAA/GMCC) will be used to study the recent decrease in CO_2 seasonal amplitude at the South Pole in contrast to the 1957-1979 increase; the three- to four-season lag of CO_2 variation at the South Pole with the ENSO index; the aforementioned lack of seasonality in ^{13}C measurements at the South Pole; and other questions posed by the statistical analyses.

Project Title:

OCEAN TRACER MODELING: DATA EVALUATION AND COMPARISON OF PRELIMINARY MODELS

Current Contract Period:
01/01/85-04/30/86

Funding: FY1985 115
FY1984 62
FY1983 60

Principal Investigator/s:

BROECKER, WALLACE S.

Organization/s: LAMONT-DOHERTY GEOLOGICAL OBSERVATORY

Objective: To analyze the results of geochemical surveys of the ocean (e.g., GEOSECS, NORPAX, and TTO data) for their application in the modeling of ocean circulation. Using the results of these analyses as constraints on models of ocean mixing and ocean nutrient cycles will aid in the planning of future data collection to improve our understanding of carbon cycling in the ocean.

Product: The principal product of this research will be to set limits or constraints on ocean circulation models. This will be accomplished in the following five areas: (1) the origin of subsurface waters and the modes and fate of flow; (2) ventilation of the deep sea; (3) surface water transport, downwelling and upwelling, and vertical mixing in the major oceans; (4) separation of natural and anthropogenic contributions of carbon from what we see in the ocean today; and (5) temporal changes in the rate of deep ocean ventilation.

Approach: Subsurface waters will be studied by carefully considering the distribution of all tracer properties in the Antarctic Ocean, particularly preformed phosphate content, $^{3}He/^{4}He$ ratio, $^{13}C/^{12}C$ ratio, and the bomb ^{14}C distribution in the upper waters. Preantropogenic distribution of $^{13}C/^{12}C$ ratios will be determined from about 250 seawater samples collected (1) during the 1981 Transient Tracers in the Ocean (TTO) expedition, (2) during the current seasonal surface water carbon cycle study being conducted by Taro Takahashi at LDGO under separate subcontract, and (3) by other chemical oceanography expeditions in which LDGO scientists participate.

A simple model of the ventilation of the deep sea will be constructed consistent with the deep water recycling scheme and calibrated using existing ^{14}C and ^{39}Ar data. The global distribution of bomb ^{14}C and of bomb ^{3}H water column inventories will be mapped and incorporated into ocean models to constrain the transport of surface waters between various regions of the oceans. Joint sigma CO_2, ^{13}C, ^{14}C, pCO_2, PO_4 models for the North Atlantic will be constructed showing how the three anthropogenic effects (i.e., excess CO_2, decreasing $^{13}C/^{12}C$, and bomb ^{14}C) can be tied together and be linked to the distribution of natural ^{14}C. The intent is to use this joint model to explain the relationship between delta ^{13}C and PO_4 of the world ocean. Temporal changes in the rate of deep ocean ventilation will be studied by measuring the differences in ^{14}C content in planktonic and benthic foraminifera from deep sea cores. Deep sea sediment bioturbation will be modeled to correct for changes in abundance of forams and dissolution effects through time.

Project Title:

THE ROLE OF TROPICAL FORESTS IN THE GLOBAL CARBON CYCLE

Current Contract Period:
11/24/84-11/23/85

Funding: FY1985 88
FY1984 88
FY1983 80

Principal Investigator/s:

BROWN, SANDRA & LUGO, ARIEL

Organization/s: UNIVERSITIES OF ILLINOIS AND PUERTO RICO

Objective: 1. To determine the expansion factors for converting commercial biomass estimates of tropical forests to carbon standing stocks by life zone and/or forest type.

2. To estimate the rate of decomposition of woody debris left on site during the conversion of tropical forests to agriculture.

Product: Development of expansion factors for converting commercial biomass to carbon standing stocks will result in new estimates and improved accuracy on the initial carbon storage in tropical forest vegetation. Results from the studies on the decomposition of woody debris will improve our understanding of the carbon fluxes resulting from conversion of tropical forests to agriculture. Both of these products are vital components of models of the terrestrial carbon cycle.

Approach: The determination of the expansion factors for converting forest volumes to carbon standing stocks will rely on a literature survey and mathematical analysis. Original data on forest volumes including tree diameters, heights, etc., and associated biomass regressions will be obtained. The appropriate expansion factors will be determined by comparing the commercial biomass estimates with total biomass estimates calculated from the regression equations. New estimates of the carbon densities of tropical forests and of the carbon pool based on the FAO/UNEP volume data will then be calculated.

Rates of decomposition of woody debris will be determined by studying changes in the density of decomposing wood collected from known-age logs of known species. The initial density of wood will be determined by collecting tree cores from nearby live trees of the same species and determining their green volume and dry weight. Samples will be collected from Costa Rica and Venezuela (representing four tropical forest life zones) and from Dominica where six years ago a hurricane created an abundance of woody debris covering several life zones.

Project Title:

THE ROLE OF ARAGONITE IN THE MARINE CARBON CYCLE

Current Contract Period:
12/15/84-12/14/85

Funding: FY1985 82
FY1984 0
FY1983 0

Principal Investigator/s:

BYRNE, ROBERT H.

Organization/s: UNIVERSITY OF SOUTH FLORIDA

Objective: To quantitatively characterize the solubilities and dissolution kinetics of naturally occurring aragonitic particulates in seawater.

Product: The principal product of this research, quantitative characterization of the solubilities and dissolution kinetics of marine aragonitic detritus, should significantly improve our capability to model and predict the role of the oceans in limiting the buildup of atmospheric CO_2 derived from combustion of fossil fuels.

Approach: Aragonitic particulates will be collected in the oceanic water column and in surficial sediments of the Indian and Northeast Pacific Oceans. Dissolution rate analyses will subsequently be conducted on these samples in natural seawater at temperatures $-2^{\circ}C$ and $25^{\circ}C$, and at pressures between 1 and approximately 500 atmospheres. The analyses will be performed at sea and in the laboratory, but will emphasize work at sea in order to examine aragonitic particulates within minutes to several hours of collection. Methods of examining aragonite dissolution will include both potentiometric and spectrophotometric procedures, each of which has been used successfully in the laboratory and at sea.

Field investigations will be conducted in the Southwest Indian Ocean in cooperation with Dr. A. Poisson of the Laboratoire de Physique et Chimie Marines in Paris, France, and Dr. C.-T. A. Chen of Oregon State University, in the Northeast Pacific Ocean (Hilo, Hawaii to Kodiak, Alaska) in conjunction with the CO_2 investigations of Dr. R. Feely of the National Oceanic and Atmospheric Administration (NOAA).

Project Title:

ON THE INCREASE OF TOTAL CARBON DIOXIDE IN THE WORLD OCEANS

Current Contract Period:
01/01/85-12/31/85

Funding: FY1985 101
FY1984 89
FY1983 0

Principal Investigator/s:

CHEN, CHEN-TUNG (ARTHUR)

Organization/s: OREGON STATE UNIVERSITY

Objective: The purpose of this project is to measure the concentration and fluxes of carbon in the Southern Ocean, and to further quantify oceanic penetration of anthropogenic or excess carbon dioxide by using direct measurements of carbonate data.

Product: Field research will provide 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_2 uptake. A synthesis of information on excess CO_2 calculations based on carbonate data will assess the utility of the technique in determining the penetration of anthropogenic CO_2 in the oceans.

Approach: The analysis of carbonate chemistry data represents a potentially important approach for quantifying the oceanic distribution of CO_2 derived from combustion of fossil fuel. 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 Southwest Indian Ocean from the ice edge northward across the polar and subtropical fronts.

The first cruise was accomplished on July and August 1984. Alkalinity, pH, total CO_2, and nitrates were measured; French collaborators measured alkalinity, total CO_2, PCO_2, oxygen, and tritium. The measurements will be repeated during two cruises in 1985, one in February/March and the other in December. All GEOSECS stations in the West Indian Ocean will be reoccupied and additional supporting data will be collected, including chlorophyll a (under this subcontract), particulates (by the University of South Florida), and ^{14}C (by the University of Miami).

Two more cruises are planned for 1986, one in February/March and the other in July/August. The combined data sets should reveal interannual seasonal variabilities in carbonate and nutrient dynamics. Comparison of the data with those from GEOSECS should provide critically needed information on secular changes in oceanic CO_2 penetration.

Project Title:

UNCERTAINTIES IN FUTURE CARBON DIOXIDE EMISSIONS

Current Contract Period:
10/01/84-09/30/85

Funding: FY1985 100
FY1984 150
FY1983 0

Principal Investigator/s:

EDMONDS, JAMES

Organization/s: OAK RIDGE ASSOCIATED UNIVERSITIES

Objective: To develop a better understanding of uncertainty in future carbon dioxide emissions and to make the results of that research available to the scientific community.

Product: Subtask A. A draft final report will be provided on the uncertainty analysis including model documentation. Subtask B. A DOE technical report. Subtask C. Personal computer software.

Approach: State-of-the-art statistical techniques, including Latin-hypercube sampling methods, will be used along with model input uncertainty distributions both developed during FY 1984 and Version A84 of the IEA/ORAU Long-Term Global Energy - CO_2 Model to assess implied uncertainty surrounding future CO_2 emissions and to begin initial explorations of the role of model structure in CO_2 emissions uncertainty.

The following subtasks will be carried out during the current contract period:

Subtask A. Documentation of the Uncertainty Analysis

This task requires the submission of a final contractor report on uncertainty in global CO_2 emissions for the period 1975-2075, including complete documentation on:

i) model improvements and the development of version A84;
ii) model input uncertainty;
iii) methodology;
iv) results.

Subtask B. Preparation of a DOE Technical Report

This task requires that the contractor report on uncertainty in CO_2 emissions be externally reviewed, revised and submitted for publication as a DOE technical report.

Subtask C. Development of personal computer software for the IEA/ORAU Long-Term Global Energy - CO_2 Model, Version A84.

Project Title:

STUDY OF CARBON DIOXIDE SOURCE/SINK DISTRIBUTIONS WITH A 3-D MODEL

Current Contract Period:
08/01/85-07/31/86

Funding: FY1985 150
FY1984 140
FY1983 67

Principal Investigator/s:

FUNG, INEZ Y.-S.

Organization/s: LAMONT DOHERTY GEOLOGICAL OBSERVATORY

Objective: To investigate the potential information about CO_2 sources and sinks contained in temporal (seasonal and interannual) and geographical variations of atmospheric CO_2, using a 3-D atmospheric tracer model.

Product: A three-dimensional model of atmospheric CO_2 circulation which treats spatial and temporal exchange of CO_2 between atmosphere and biosphere and ocean will be refined. The model will be used to analyze information on relationships among sources and sinks, and deviations from the long-term secular trend of CO_2.

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_2 for specified sources and sinks (biosphere, ocean, man). The modeling is based on first principles or on the best available input data, and the ability of the computed global distribution of CO_2 to account for observed seasonal and interannual variations in CO_2 abundance is examined. During the next year, the studies will focus on the CO_2 distributions in the southern hemisphere and on the latitudinal gradient of atmospheric CO_2. The studies will employ the fine resolution (4^o latitude x 5^o longitude) tracer model with improved treatment of inter-hemispheric transport as well as of the sources and sinks.

The biospheric exchange will be improved by using satellite data of photosynthetic activity as well by extending the derivation of empirical relationships between biospheric carbon exchange and environmental parameters to include the effects of litter amount and canopy development. The ocean source/sink will include the use of refined maps of oceanic pCO_2 and of the piston velocity.

Project Title:

MERGING THE TROPICAL BIOSPHERE MODEL AND CARBON INVENTORY ESTIMATES WITH LAND USE CHANGE ESTIMATES

Current Contract Period:
01/01/85-07/31/85

Funding: FY1985 33
FY1984 47
FY1983 41

Principal Investigator/s:

HALL, C. A. S.

Organization/s: CORNELL UNIVERSITY

Objective: To complete the assessment of net carbon exchange between vegetation and the atmosphere resulting from human activities for the entire tropics (76 countries). Data from a variety of sources (e.g., Food and Agriculture Organization (FAO) and other Department of Energy-funded researchers including J.F. Richards, S. Brown, A.E. Lugo, J.S. Olson, and W.M. Post) will be integrated with an existing tropical land use/carbon model developed by C.A.S. Hall and colleagues. The Life Zone analysis for Brazil will also be completed.

Product: The principal product will be an estimate of carbon exchange and associated uncertainties resulting from land-use changes in the tropics. The analyses will include a synthesis of the last six years' work on this subject; therefore, all computer programs and data sets for this project will be documented.

Approach: The existing computer model (GLOBC7) will be finalized, incorporating various estimates of land-use change (e.g., Richards and FAO) as well as biomass and soil carbon estimates. Emphasis in this year's research will be to summarize the past six years' work to arrive at a defensible best estimate of carbon release due to land-use change for the tropics. The model has been refined to the point that it is very unlikely that much more effort will be put into model development. All models and data sets used to satisfy the broad objective of this research will be presented in a comprehensively documented, accessible, and reusable format with clear and explicit instructions so that in the future there will be no questions as to how the results were derived and so that any qualified person can use the entire suite of programs.

A study of land-use change in Brazil will complete the Life Zone assessment. The analysis will use methods developed earlier for Costa Rica, Panama, Peru and Bolivia. Total area of each Life Zone in Brazil will be measured by a planimeter. Estimates of land-use change for each state will be calculated, using these rates in the model to calculate the release of carbon from vegetation and soil due to land-use change.

Project Title:

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

Current Contract Period:
10/01/84-09/30/85

Funding: FY1985 274
FY1984 175
FY1983 0

Principal Investigator/s:

HOUGHTON, RICHARD A.

Organization/s: MARINE BIOLOGICAL LABORATORY

Objective: To continue development of a model with high geographic resolution (GEOM), and to apply that model to calculate the annual net flux of carbon from South Asia to the atmosphere between 1800 and 1980.

Product: A geographically based model, $1/2^{o}$ x $1/2^{o}$ resolution, for use in calculating the net flux of carbon between terrestrial systems and the atmosphere resulting from changes in land use. The matrix of data for the model is based on maps of geology, soil, vegetation, and history of land use.

Approach: Initial (1800) vegetation and soil maps at $1/2^{o}$ x $1/2^{o}$ resolution will be established for biome and soil types and for carbon stocks. General responses of vegetation and soils to different changes in land use will be determined based on a review of literature, on comparisons of successive photographs of Indian forests available in Oxford, and on consultation with ecologists in India. Data on rates of historical land-use change in South Asia, assembled by John Richards at Duke University, will be incorporated into the $1/2^{o}$ x $1/2^{o}$ grid. Ultimately, the geographically based model (GEOM) will be applied to these data collectively to calculate the annual net flux of carbon in South Asia between 1800 and 1980. The GEOM model will be validated by comparing land use and vegetation with those derived independently by other investigators.

Project Title:

HIGH ACCURACY STANDARDS AND REFERENCE METHODOLOGY FOR CARBON DIOXIDE IN AIR

Current Contract Period:
05/01/85-12/31/85

Funding: FY1985 200
FY1984 180
FY1983 280

Principal Investigator/s:

HUGHES, ERNEST E.

Organization/s: NATIONAL BUREAU OF STANDARDS

Objective: To develop a reference set of CO_2-in-air standards to assist in assuring traceability to national standards of world-wide atmospheric CO_2 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_2 in air.

Product: The primary products of this program will be two-fold: (1) an initial set of CO_2-in-air Standard Reference Materials (SRMs) in the atmospheric concentrations range (nominally 320, 340 and 360 ppm), plus a subsequent set of wider range CO_2-in-air SRMs or Research Materials from about 200-1000 ppm; and (2) absolute reference analytical methodology for high-accuracy measurements of CO_2-in-air standards. The former, taken together with demonstration of consistency in CO_2-in-air standard measurements between NBS and Scripps, will provide a potential for future measurements of atmospheric CO_2 to be directly traceable to NBS standards, thereby assuring continuity in long-range stability and intercomparability of atmospheric CO_2 data. The latter will provide a wholly independent absolute method for ensuring high accuracy measurements of CO_2 in air. These two themes ar mutually-consistent and interactive.

Approach: The initial set of CO_2-in-air SRMs will be prepared by NBS using gravimetry as a basis for accuracy. This preliminary set of standards has been analyzed for a period of over one year with an uncertainty which does not exceed 0.1% relative (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 gravimetry and isotope dilution) will be correlated with the Scripps manometric methods.

Project Title:

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

Current Contract Period:
08/01/85-07/31/86

Funding: FY1985 84
FY1984 83
FY1983 65

Principal Investigator/s:

LONG, AUSTIN

Organization/s: UNIVERSITY OF ARIZONA

Objective: To develop an accurate atmospheric $^{13}C/^{12}C$ record, representing the contributions of CO_2 from fossil-fuel burning and changes in the biosphere, back to preindustrial times through $^{13}C/^{12}C$ measurements in tree rings.

Product: The main product of this project will be a curve representing the $^{13}C/^{12}C$ changes in atmospheric 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 CO_2 source or sink in the recent past.

Approach: Our understanding of the factors influencing $^{13}C/^{12}C$ trends will be expanded by analyzing additional sites to determine the regional extent of synchroneity of delta-^{13}C trends, by scrutinizing some site conditions whic' may, in theory, affect $^{13}C/^{12}C$ ratios, and by studying effects of temperature and CO_2 concentration on tree $^{13}C/^{12}C$ ratios. Specific tasks include: (1) expanding the number of pinyon pine delta-^{13}C chrononogies 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 $^{13}C/^{12}C$ 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 $^{13}C/^{12}C$ 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 CO_2.

Project Title:

OCEAN MODELS IN THE GLOBAL CARBON CYCLE

Current Contract Period:
02/01/85-01/31/86

Funding: FY1985 106
FY1984 0
FY1983 0

Principal Investigator/s:

MOORE III, B.

Organization/s: UNIVERSITY OF NEW HAMPSHIRE

Objective: The overall goal of this three-year project is to understand the role of oceans in the global carbon cycle. Specific objectives are: (1) to examine the sensitivity of the existing 84-box model of the Atlantic Ocean; (2) to develop a revised model of the Atlantic Ocean which accurately describes the uptake of CO_2, can be validated against data, and will be subjected to a similar set of sensitivity tests used in Objective #1; and (3) to develop and evaluate a model of the world's oceans based on the approach used for the revised model of the Atlantic Ocean.

Product: Development of more complex three-dimensional compartment models of the ocean carbon cycle will provide necessary information needed for refinement and improvement of models based on ocean circulation. The results of this research will also provide an appropriate compromise between the simple one-dimensional models and ocean general circulation models for studying the current rate of oceanic uptake of CO_2.

Approach: The existing 84-box model of the Atlantic Ocean will be examined for sensitivity to both the steady-state solution and the model's response as a function of tracer profiles, boundary values, and weights on different equations. Other numerous technical issues associated with model implementation/operation will be mastered before proceeding with Objectives #2 and #3. The Atlantic Ocean model will be revised to incorporate increased geographic detail to define critical boundary currents, to reduce ambiguities regarding horizontal and vertical flows, to more accurately describe surface phenomena, and to recognize seasonality in the surface boundary conditions. Achievement of Objective #3 will occur by developing individual models of the Pacific and Indian Oceans similar to the model of the Atlantic Ocean developed for Objective #2. During the early stages of development, these models will not be linked, but rather the Atlantic-Pacific interfaces will be treated as known boundary conditions. This is similar to the technique that has been used to date and will be used in Objective #2. These individual models will be evaluated in a manner similar to those used in Objectives #1 and #2. The models of the Atlantic, Pacific, and Indian Oceans will then be linked and the entire system, in which the advective and turbulent exchanges at the ocean interfaces are treated as unknowns, will be inverted simultaneously.

Project Title:

GLOBAL CARBON CYCLES AND CLIMATIC RISKS

Current Contract Period:
10/01/84-09/30/85

Funding: FY1985 385
FY1984 403
FY1983 240

Principal Investigator/s:

OLSON/PENG/EMANUEL/DEANGELIS

Organization/s: OAK RIDGE NATIONAL LABORATORY

Objective: To extend understanding of the global carbon cycle in order to explain the causes of observed changes in atmospheric CO_2 concentration and to provide a capability to project future changes in CO_2 levels as further fossil fuel use occurs.

Product: The project focuses on the development, testing, and application of mathematical models of the global carbon cycle. Products include papers in the scientific literature describing these models, underlying data, testing, verification, and applications to address carbon cycle issues.

Approach: Studies of the global carbon cycle rely heavily on modeling and related methods because of the long time and large-space scales involved. Mathematical models of the carbon cycle will be continually improved as additional data and understanding become available (e.g., new Siple ice-core CO_2 measurements which reveal historical concentrations of atmospheric CO_2). With each major refinement, the expected response of the cycle to fossil fuel use and other perturbations will be reassessed, and the capability to analyze secondary effects such as the feedback of climate change on the carbon cycle will be improved.

Because substantial releases of CO_2 are likely to have occurred from land-use changes as well as from fossil fuel combustion, ocean work focuses on evaluating spatially detailed models for potential increased rates of oceanic uptake. Current research emphasizes process modeling and data assembly/evaluation for use in more complex models which incorporate more realistic ocean circulation. Terrestrial modeling work concentrates on improving the reliability of estimates of the history of releases from vegetation and soil pools. A set of digital maps with 0.5^{o} resolution will be used to incorporate geographic detail into the analysis of land use. Factors other than land-use history may also affect the net biotic flux of CO_2 over the past 200 years. This requires an assessment of ecosystem sensitivity to variations in biotic, climatic, land-use, and other environmental variables which may affect both succession patterns and steady state conditions. A key submodel in the global carbon cycle is concerned with understanding the oscillations, seasonal fluctuations, and circulation of atmospheric CO_2. Work to develop seasonal carbon exchange models for each major biome or ecosystem complex continues.

Project Title:

INDIAN OCEAN RADIOCARBON

Current Contract Period:
08/01/85-07/31/86

Funding: FY1985 49
FY1984 51
FY1983 0

Principal Investigator/s:

OSTLUND, H. GOTE

Organization/s: UNIVERSITY OF MIAMI

Objective: To measure radiocarbon in seawater samples collected in the Indian Ocean to further quantify the removal of CO_2 from the atmosphere by the ocean.

Product: A data base of radiocarbon information from a N-S section in the Indian Ocean will be developed. 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_2 reservoirs cannot be made.

Approach: During the first year of this research, seawater samples were collected in the Indian Ocean on board the French research vessel, MARION DUFRESNE. The samples will be shipped back to Miami, Florida, and ^{14}C will be measured to $\pm 3.5^{o}/_{oo}$ on all samples available and of quality good enough to warrant this effort, to a maximum of 140 samples including blanks, etc. The ^{14}C data will be released early to the participating principal investigators for internal use as soon as the data are available. Final data will be reported for unrestricted use to be in the U.S. Department of Energy (DOE) data banks before 31 December 1985. Even if shipping delays, etc., should occur, data should be available no later than 1 June 1986. It is anticipated that total CO_2 data will be available through the joint efforts of Dr. C.-T. A. Chen in a separate proposal and by Dr. A. Poisson and that accompanying hydrographic data will be supplied by the operators of the French research vessel.

Project Title:

SOIL CARBON IN THE GLOBAL CARBON CYCLE

Current Contract Period:
10/01/84-09/30/85

Funding: FY1985 215
FY1984 200
FY1983 91

Principal Investigator/s:

POST/MANN/PASTOR

Organization/s: OAK RIDGE NATIONAL LABORATORY

Objective: To determine quantitatively the role of soil organic carbon in the the global carbon cycle.

Product: (1) Previous efforts to collect and statistically analyze data from soil profiles under natural and managed systems will be extended to include a broader range of North American soil types.

(2) Total carbon and ^{14}C content in pairs of archived and recently collected soils will be measured and modeled to account for carbon fluxes between organic fractions, soil horizons, and the atmosphere.

(3) A model which integrates the effects of climate and soil nutrient and water availabilities on ecosystem carbon dynamics (developed under previous DOE funding) will be improved and validated for two types of southeastern forests.

Approach:

(1) Data (largely from the USDA-Soil Conservation Service [SCS] National Soils Analytical Laboratory) on carbon, nitrogen, total cation concentrations and carbon-nitrogen ratios will be compared between cultivated and uncultivated profiles of similar soils. To estimate the change in total carbon due to cultivation, regression relationships of carbon loss as a function of initial carbon present or other parameters will be derived for each available suborder.

(2) Samples from each horizon of two pre- and post-bomb soil profiles will be separated into two density fractions (corresponding to recent and old organic matter) and the amount of ^{14}C in each fraction will be determined. A model will be constructed to estimate the transfers of organic matter consistent with the ^{14}C data obtained. The recent soils data will be analyzed using this model to determine if bomb produced ^{14}C can be used as a tracer for organic material in soils.

(3) Collaborative arrangements have been made to use data from numerous studies in the southeastern United States to improve and validate the existing forest productivity/soil carbon and nitrogen model. The model will be validated using data on biomass, productivity, and soil organic matter and nutrient levels. The model will be improved by incorporating data on growth rates, litter chemistry, and decay rates for southern species in relation to nitrogen and phosphorus availability. Results based on these revisions will determine what additional data are needed.

Project Title:

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

Current Contract Period:
06/01/85-05/31/86

Funding: FY1985 240
FY1984 202
FY1983 155

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 present-day nations) from 1700 to 1980 AD.

Product: The principal product will be 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_2 can be made.

Approach: The data will continue to 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 AD) will be summarized for the two major regions only (South Asia and Southeast Asia). More detailed information, including a composite picture of land use and vegetation for ten-year intervals, will be compiled for the period 1820 to 1980 AD 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.

Specific tasks during 1985-86 includes (1) completion of first stage data collection for Thailand, Indonesia, and the remaining districts in India, and (2) begin second stage archival research for areas already completed. Research will focus on colonial record holdings in London, England, Amsterdam, Holland, and the National Archives on India at New Delhi. Transportation and research expenses associated with the Indian studies will be paid by a grant from the Smithsonian Institution.

Conversions of land-use change into carbon densities will be done in collaboration with ecologists at the Oak Ridge National Laboratory (ORNL) and the Marine Biological Laboratory (MBL). These data will be used by modelers at MBL to estimate carbon flux from land-use change in South and Southeast Asia.

Project Title:

ESTIMATE OF CARBON DIOXIDE EMISSIONS FROM FOSSIL FUEL

Current Contract Period:
10/01/84-09/30/85

Funding: FY1985 150
FY1984 187
FY1983 0

Principal Investigator/s:

ROTTY, RALPH M.

Organization/s: OAK RIDGE ASSOCIATED UNIVERSITIES

Objective: Task 1. (1) To monitor and update data on CO_2 emissions from fossil fuels. (2) To provide data to the carbon cycle community about seasonal and spatial distribution of CO_2 emissions from fossil fuels. (3) To develop a time series of global fuel wood data.

Product: Estimates of annual rates of emission of CO_2 from fossil fuel production will be a primary product of this research, 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. Conversion factors of raw national data to consistent tons coal equivalent or from cubic meters of gas to terajoules are incorporated when evidence suggests this is appropriate. A time series of CO_2 emissions resulting from the use of wood as a fuel will be developed - similar to that prepared for fossil fuels.

Objective: Task 2. To review the prospects of several energy supply systems of the twenty-first century within the context of projected atmospheric CO_2 concentration and evaluate the impact such systems will have on atmospheric CO_2. Expanded electrification will be emphasized.

Product: The study will produce a technical evaluation of energy systems which can have a major impact on future energy supply affecting CO_2 emissions.

Approach: 1. Two major trends in global energy demand have been predominant since the first oil crisis: a lowering in the overall growth rate of energy use from about 5% per year to about 2.5% per year (4.5% per year to less than 2% per year for CO_2 emissions), and a marked shift toward electrification. The hypothesis is that the second of these trends is occurring in all parts of the world and that it is highly likely to continue will into the next century. This hypothesis will be tested using electric energy data tabulated in the UN Yearbook of World Energy Statistics.

2. The feasibility of individual supply technologies for meeting the future world's needs, especially in regard to electricity, will be examined. This assessment will review, summarize and critique strengths and weaknesses of the energy supply technologies selected. Emphasis will be placed on energy technologies useful in the production of large amounts of electricity.

Project Title:

MODELS OF NUTRIENT AND CARBON CYCLES IN THE OCEANS

Current Contract Period:
01/01/85-12/31/85

Funding: FY1985 155
FY1984 0
FY1983 0

Principal Investigator/s:

SARMIENTO, JORGE L.

Organization/s: PRINCETON UNIVERSITY

Objective: To develop a three-dimensional (3-D) grid-point model of the oceanic carbon cycle that will be used to predict a time dependent response of the oceans to the fossil fuel transient on a time scale from about 10 to 100 years.

Product: A model will be developed aimed at improving our understanding of the carbon cycle and our ability to make time dependent predictions of the ocean circulation and the carbon cycle.

Approach: The first step of this three-year study is to assemble the basic elements of existing ocean circulation, and nutrient and carbon cycle models for their use in developing a 3-D oceanic carbon cycle model. A series of model calibration and sensitivity studies will be performed to improve the performance of the 3-D model and to identify areas where further study is needed. A variety of tracers will be used, among them trace metals and sediment trap measurements because of the information they carry regarding particulate cycling.

The 3-D model will be used to predict a large variety of tracer distributions such as tritium, natural and bomb C-14, and the fossil fuel carbon dioxide signal. Because data sets thus generated will be known in full detail, they should provide an excellent way of testing the strengths and weaknesses of the one- and two-dimensional model being used to predict future levels of carbon dioxide at the present time. The ultimate goal will be to use the 3-D model to simulate a series of scenarios for future changes in atmospheric CO_2 due to fossil fuel burning. However, this will be done only after greater confidence has been developed in the models. It is planned that a series of experiments will be conducted with the 3-D model to identify and elucidate the dynamical mechanisms controlling the distribution of carbon dioxide between the atmosphere and ocean, and how this distribution can change in time.

Project Title:

ATMOSPHERIC CARBON DIOXIDE ABUNDANCE - AN ARCHIVAL STUDY OF SPECTROSCOPIC DATA

Current Contract Period:
10/01/84-09/30/85

Funding: FY1985 100
FY1984 260
FY1983 240

Principal Investigator/s:

STOKES, G. M.

Organization/s: PACIFIC NORTHWEST LABORATORY

Objective: To extend knowledge of the atmospheric CO_2 burden back as far as possible using archived solar spectra as the data base. To compare in situ measurements of the modern era with spectroscopic measurements of the modern era and to evaluate solar spectra as a source of information concerning other trace gases using CO_2 as a test case.

Product: A time series of atmospheric CO_2 will be 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_2 burden.

Approach: Spectroscopic data can produce CO_2 column densities of precision and accuracy of about 1%, and past records of atmospheric CO_2 will be derived from Smithsonian spectrobolograms. Measurements of the near-infrared solar spectrum containing CO_2 absorption bands have been accumulated since the mid-1890s for astronomical purposes. Analysis of these spectra will provide an extension of CO_2 abundance information into the early 20th century. Analysis of new spectroscopic data will be accomplished with the Fournier Transform Spectrometer (FTS) of the Kitt Peak National Observatory (KPNO). 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:
01/01/85-12/31/85

Funding: FY1985 32
FY1984 158
FY1983 159

Principal Investigator/s:

STUIVER, MINZE

Organization/s: UNIVERSITY OF WASHINGTON

Objective: The purpose of the proposed research is to determine the history of past changes of atmospheric CO_2 changes by studying $^{13}C/^{12}C$ isotope ratios in tree rings. The objective of this final year of research is to provide a detailed synthesis of the information in 30 long-term $^{13}C/^{12}C$ records obtained in previous years on this subject.

Product: Data collected on $^{13}C/^{12}C$ ratios in tree rings will be used to model historical estimates of atmospheric CO_2.

Approach: Trees can potentially record changes in atmospheric CO_2 isotope ratios because cell wall cellulose, which can be observed as annual growth rings, incorporates carbon from the atmosphere, and hence reflects the isotope ratio of atmospheric CO_2 for that year of growth. The $^{13}C/^{12}C$ signal has been measured in 30 trees. Seven of these trees were studied for inter-ring variability and juvenile effects. The remaining 23 trees, all with time spans exceeding 200 years, are from 19 Pacific coastal areas in North and South America, and from four sites in New Zealand.

Results obtained for 11 trees measured during the earlier phases of the project (under a direct DOE grant) have been presented in an open literature publication. Only six long-term records were used in this paper to calculate atmospheric CO_2 levels. With the actual laboratory measurements supported by ORNL now finished, and having an additional 17 long-term records available, a detailed synthesis of the much enlarged data base is planned. This synthesis involves the derivation of a composite $^{13}C/^{12}C$ time history (the oldest materials go back in time as far as 1800 B.C.) and an evaluation of correlations with ring area (ring thickness) and density. Model calculated atmospheric CO_2 levels will be derived from the $^{13}C/^{12}C$ composite record, and an evaluation of the uncertainties in the method will be given. This will complete the $^{13}C/^{12}C$ project.

Project Title:

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

Current Contract Period:
09/01/85-08/31/86

Funding: FY1985 194
FY1984 215
FY1983 0

Principal Investigator/s:

TAKAHASHI, TARO

Organization/s: LAMONT-DOHERTY GEOLOGICAL OBSERVATORY

Objective: To investigate through field observations the seasonal and regional variability of CO_2 chemistry in the major oceanic regimes, including the formation areas of deep waters in high latitudes, temperature gyres, and equatorial upwelling belts.

Product: The data base of CO_2 chemistry in the upper layers of major oceanic regions will be expanded. Such data will aid modelers in understanding the nature of the feedback mechanisms in the coupling of the CO_2-induced climatic change with the oceanic uptake/discharge of CO_2.

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 use of a gas chromatographic system specifically constructed for high precision analyses of CO_2.

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

(1) The net CO_2 flux across the air-sea interface will be measured in the central equatorial Pacific using the pCO_2 and Rn-222 methods. The results will be compared with those obtained during the earlier Hawaii-Tahiti studies in order to see interannual variability of this important oceanic CO_2 source.

(2) The pCO_2 and total CO_2 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 a) to determine the seasonal variability in the surface water CO_2 chemistry between 40° N to the Antarctica in the Pacific, and b) to determine the secular variation of surface water pCO_2 in the Pacific during the past 10 years by comparing the new data with those obtained along a similiar transect during GEOSECS in 1974.

(3) The seasonal variability, in particular between the winter and summer values, of the surface water pCO_2 in northern North Pacific Ocean will be investigated using commercial freight ships sailing between Japan and the NW United States as a sampling platform. This area is a known water mass formation area and is a strong CO_2 sink during the summertime. To date, very little is known about the CO_2 chemistry in this area during the winter season.

Project Title:

CARBON CYCLE PROGRAM MANAGEMENT

Current Contract Period:
10/01/84-09/30/85

Funding: FY1985 26
FY1984 176
FY1983 142

Principal Investigator/s:

TRABALKA, JOHN R.

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: Management assistance will be provided to the DOE Carbon Dioxide Research Division in their efforts to accurately predict future atmospheric concentrations of CO_2 that will result from releases of carbon dioxide anticipated from the combustion of fossil fuels. A state-of-the-art report on the status of knowledge about the global carbon cycle will be prepared and communicated to contractors and the research community in 1985.

Approach: 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 CO_2 Research Division's planning process. An additional task will be to prepare topical reports on the technical status of specified program elements. Assist in communicating the DOE CO_2 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 CO_2 Research Division's program with other national and international activities. To achieve the aforementioned objectives, Oak Ridge National Laboratory (ORNL) is coordinating with existing federally sponsored research, performing research, and subcontracting to university centers of excellence for research supporting global carbon cycle modeling, specifically including subsystem model development and terrestrial biospheric and oceanic data acquisition.

Project Title:

COMPARISON OF PRE- AND POST-BOMB RADIOCARBON IN SOILS AND SOIL FRACTIONS

Current Contract Period:
12/01/84-11/30/85

Funding: FY1985 126
FY1984 0
FY1983 0

Principal Investigator/s:

WHITE, J. & BROECKER, W.

Organization/s: LAMONT-DOHERTY GEOLOGICAL OBSERVATORY

Objective: To determine the rates of loss or accumulation of organic carbon in soils by comparing the distribution of ^{14}C in pre-bomb and post-bomb soils and soil fractions.

Product: The results of this research will provide constraints on modeling the accumulation and decay of soil carbon thereby increasing our understanding of the global carbon cycle, and hence, future concentrations of atmospheric CO_2.

Approach: Soils will be collected from cultivated and forested sites from which pre-bomb soils are available as archived or preserved samples. Due to the microscale differences in soil chemistry and characteristics, these soils will be collected as nearly as possible in the exact location as pre-bomb soils. In order to verify that there has been no loss or alteration of carbon in the pre-bomb soils, the percentages of the major fractions in the pre- and post-bomb soils will be compared, as well as the percentages of carbon in these fractions. In addition, the molecular weight distribution of organic carbon in pre- and post-bomb soils will be determined.

Bulk soil carbon will be separated into a number of fractions, each ideally with a uniform distribution of delta^{14}C values and a uniform degradation rate. By measuring the delta^{14}C in the pre- and post-bomb soil fractions, and using input flux functions developed by other investigators, the net output flux due to microbial degradation can be calculated, and then modeled as a decay function.

A critical yet difficult part of studying carbon turnover rates in soils in this way is devising and testing a satisfactory fractionation scheme for the soil. The goal is to find soil fractions in which the degradation rate is not a strong function of the age of the fractions, thereby facilitating the modeling of the turnover rates. Thus, initial efforts will focus on examining a variety of fractionation schemes, including separation by chemical procedures, size, and density. In addition, the evolution and delta^{14}C content of the CO_2 evolved during microbial degradation of these fractions will be monitored under controlled laboratory conditions. Because the amount of CO_2 produced from soil fractions will be small, the delta ^{14}C will be measured using the techniques of accelerator ^{14}C dating.

Project Title:

REMOTE SENSING OF DEFORESTATION IN THE AMAZON BASIN

Current Contract Period:
12/10/84-12/09/85

Funding: FY1985 257
FY1984 156
FY1983 0

Principal Investigator/s:

WOODWELL, GEORGE M.

Organization/s: MARINE BIOLOGICAL LABORATORY

Objective: To determine the rates of change in forest area and the net flux of carbon from the Amazon Basin over the past 20 years as a prelude to a systematic global survey. Specific objectives are (1) to continue the development of methods for efficiently using satellite imagery to measure deforestation and reforestation, (2) to test the methods, using them to determine rates of forest clearing in the Brazilian state of Mato Grosso over the last decade, (3) to develop a stratified LANDSAT sampling approach to be used with the change detection technique, (4) to compare the LANDSAT sampling approach with the LANDSAT-AVHRR calibration approach, and (5) to summarize the status of the methods.

Product: Results from this phase of the research will indicate if LANDSAT-AVHRR remote sensing can be used to accurately estimate rates of deforestation in the tropics.

Approach: A combination of the low resolution AVHRR (1.1 km) and the higher resolution LANDSAT (40 m and 80 m) satellite images will be used to detect land-use change. Areas of maximum deforestation (fronts of activity) will be determined on the low resolution imagery, and the higher resolution LANDSAT imagery will be sampled to determine rates of change in specific localities. The amount of land cleared is determined by comparing pairs of images from different years using a change detection algorithm and through photointerpretation techniques. Substantial changes over previous efforts have been made in processing LANDSAT data, improving the accuracy of the initial classification on the data and the results of the change detection techniques.

The AVHRR data will be used for an initial stratification of Mato Grosso. Three strata will be identified: areas currently being disturbed, areas cleared earlier, and areas of no deforestation. A 30% sample of LANDSAT data will be ordered for use with the change detection algorithm. For areas already cleared, a sample of 20% will be analyzed to examine change; reforestation is expected to be the most significant component for this analysis. For areas of no obvious change as seen in the AVHRR IMAGERY, a sample of 20% of the LANDSAT scenes will be analyzed to determine whether clearing has occurred and how much area has been cleared. These same LANDSAT data can be used to estimate the changed area within the three AVHRR strata through the use of calibration relationships, a technique used earlier to study deforestation in Rondonia.

CLIMATE AND FIRST DETECTION

The present concentration of atmospheric CO_2, acting in combination with other infrared-absorbing and emitting gases, plays an important role in maintaining the current climate. Without CO_2 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_2 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_2-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_2-induced climate changes are, in fact, occurring.

Research Objectives Research in climate and first detection is intended to reduce uncertainties concerning any CO_2-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_2-induced climate change and to establish when a CO_2 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_2, climate analogs, and analysis and estimates of CO_2-induced climate change.

Research Questions To determine the climate response to the projected increases in atmospheric CO_2, climate research will focus on answering the following questions:

- 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_2 concentration?
- 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_2?
- To what extent do the projected changes interact with and depend on other climatically related events and activities of man and nature?
- What portion of recent past or current climate changes evidenced in the climate record can be attributed to the influence of CO_2?

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Project Title:

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

Current Contract Period:
12/01/84-11/30/85

Funding: FY1985 35
FY1984 47
FY1983 46

Principal Investigator/s:

BARRY, ROGER G.

Organization/s: UNIVERSITY OF COLORADO

Objective: To determine if lake freeze-up/break-up data can be used as an additional as well as proxy indicator of seasonal climate change. Determine if freeze-up/break-up can be monitored from satellite data and then be used as a proxy temperature record.

Product: The project will provide a feasibility assessment for use of lake ice regimes to detect and monitor CO_2-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 freeze-up and break-up 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 a considerable potential for 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 and European statistics of lake freeze-up/break-up in relation to readily available climatic data. The lake data will be stratified according to variables related to the water body and its geographical location for an assessment for local variability. Satellite data will be obtained to test the feasibility of using these data to estimate regional temperature (fall/spring) in remote areas.

Project Title:

STUDIES OF CLIMATIC VARIABILITY DURING THE PERIOD OF INSTRUMENTAL RECORDS

Current Contract Period:
02/01/85-01/31/86

Funding: FY1985 150
FY1984 0
FY1983 0

Principal Investigator/s:

BRADLEY, KELLY, JONES & DIAZ

Organization/s: UNIVERSITY OF MASSACHUSETTS

Objective: To produce and document an expanded, northern hemisphere instrumented climate record. To analyze the record on a regional and seasonal basis for possible cause/effect relationships.

Product: A northern hemisphere climate data base of sufficient quality to assess regional climate on seasonal time scales.

Approach: The instrumented northern hemispheric data base will be expanded to include precipitation, circulation, marine data, and other variables of interest. The data set will be analyzed using standard statistical techniques (regionally and seasonally) to assess possible cause/effect events that must be accounted for in the climate model validation experiments. The possible CO_2 "fingerprint" is the end objective.

Project Title:

SENSITIVITY ANALYSIS OF THE IMPACT OF CARBON DIOXIDE ACCUMULATION ON CLIMATE

Current Contract Period:
10/01/84-09/30/85

Funding: FY1985 100
FY1984 260
FY1983 260

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 will allow 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 radiative convective model (RCM). Interpretation of the results continues for the RCM demonstration case and is assisting in understanding of model sensitivity.

Project Title:

RESEARCH PROJECT ON CO2-INDUCED CLIMATE CHANGE

Current Contract Period:
02/01/85-01/31/86

Funding: FY1985 308
FY1984 0
FY1983 0

Principal Investigator/s:

CESS, R. D. & HAMEED, S.

Organization/s: STATE UNIVERSITY OF NEW YORK AT STONY BROOK

Objective: To compare GCM's and 1-D and 2-D climate models documenting processes responsible for agreement and disagreement. To statistically analyze the USA and Chinese regional temperature data set for relationships between large scale and regional climate.

Product: An understanding of the GCM's abilities to represent large scale climate and the relationships between large scale climate and regional climate.

Approach: The approach is a model-to-model and model-to-data intercomparison that progresses from swamp-ocean (annual-average) through full-ocean (seasonal) models. Models other than GCM's will be included to help understand the differences and agreements.

The statistical data analysis will utilize two techniques - Fourier Transform and Maximum Entropy Method. The shortcomings of each technique tend to complement each other. Thus with the dual approach a more accurate assessment of the relationships between large scale climate and regional climate (as supported by the data) is likely.

The two tasks will be brought together to guide the estimation of regional climate change.

Project Title:

RESEARCH ON THE DYNAMICS OF THE CLIMATE

Current Contract Period:
06/01/85-05/31/86

Funding: FY1985 225
FY1984 250
FY1983 90

Principal Investigator/s:

GATES/SCHLESINGER/HAN

Organization/s: OREGON STATE UNIVERSITY

Objective: To apply the two-layer OSU GCM to study the climatic effects of increasing CO_2 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: Results from the OSU GCM will provide important additional information on the seasonal and regional response of climate to increasing CO_2 concentrations. The OSU 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 1985, 1986 and 1987 special analysis will be done on the ocean lag question, OGCM seasonal and interannual variations, and OGCM hindcast validation experiment.

Approach: The two-layer OSU GCM has been well tested and documented. This model and the multi-layer OGCM will be coupled in a series of diagnostic experiments and subsequent analyses to assess seasonal and interannual ocean/atmosphere connections and longer term (e.g., ocean lag) connections as well as a hindcast validation experiment.

Project Title:

MODEL INTERCOMPARISON

Current Contract Period:
02/01/85-01/31/86

Funding: FY1985 100
FY1984 100
FY1983 15

Principal Investigator/s:

GATES, W. L./POTTER, G.

Organization/s: OREGON STATE UNIVERSITY/LLNL

Objective: To develop and carry out 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_2 sensitivities of two-and three-dimensional models will be used to investigate the differences that can arise between models and the mechanisms that contribute to the differences.

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 one model to be used in interpretation of results from three-dimensional models by allowing use of lower dimension models to investigate how some of the mechanisms are responding.

Approach: The OSU GCM, the NCAR GCM, the AER 2-D model and the LLNL 2-D 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:

STUDY OF A CARBON DIOXIDE OBSERVATIONAL PLATFORM SYSTEM (CO-OPS)

Current Contract Period:
06/01/85-05/31/86

Funding: FY1985 200
FY1984 200
FY1983 0

Principal Investigator/s:

GUTTMAN, CHARLES H.

Organization/s: MARSHALL SPACE FLIGHT CENTER

Objective: Determine the feasibility and technical specifications for an ultra-light, microwave powered, measurement platform for CO_2 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_2 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 a microwave powered, ultra-light measurements platform. The device would operate between 60,000 and 110,000 feet 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 MSFC and its contractors to evaluate the feasibility of the platform concept.

Project Title:

GEOPHYSICAL MODELS OF THE FOSSIL FUEL CARBON DIOXIDE PROBLEM

Current Contract Period:
06/08/85-06/07/86

Funding: FY1985 160
FY1984 0
FY1983 0

Principal Investigator/s:

HOFFERT, MARTIN I.

Organization/s: NEW YORK UNIVERSITY

Objective: Develop a coupled 2-D ocean/atmosphere model.

Product: The 2-D coupled model will be used to address issues related to the role of the ocean in transient climate change.

Approach: The project is divided into four tasks. Tasks 1 and 2 develop the model for application to the transient climate experiment (Task 3). The NYU 2-D ocean model will be coupled with the LLNL 2-D atmospheric model. The work will use TTO and GEOSECS data to validate the ocean. Task 4 will separately address the role of turbulence in the transport of heat.

Project Title:

VARIATIONS IN ARCTIC CLOUD COVER IN SUMMER

Current Contract Period:
03/01/85-08/31/85

Funding: FY1985 25
FY1984 80
FY1983 64

Principal Investigator/s:

KUKLA, GEORGE

Organization/s: LAMONT-DOHERTY GEOLOGICAL OBSERVATORY

Objective: The objective of the project is to investigate the variation in cloud cover over the Arctic basin. Generated information will enable improved parameterization of clouds and of the resultant radiation transfer in climate models used to assess the CO_2 impact.

Product: Charts will be digitized and the data set extended to cover additional years of the 1974-82 interval. 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 to atmospheric circulation outside the Arctic will be analyzed.

Approach: Clouds of three different types are being charted in a scale of 1:15,000,000 in three day intervals. Shortwave and infrared DMSP satellite imagery and images of the NOAA polar orbiting satellites are used. Areal proportion of the different cloud types and of the cloud free surface is measured separately for 10 geographic segments. Attempts are also underway 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. They also have tested recognition of different stages of the snow and ice formation and dissipation.

Project Title:

RECENT CLIMATE CHANGE IN NORTH AMERICA AND CO2: SEARCH IN STRATIFIED DAILY DATA

Current Contract Period:
09/01/85-08/31/86

Funding:

FY1985	133
FY1984	0
FY1983	0

Principal Investigator/s:

KUKLA, GEORGE

Organization/s: LAMONT-DOHERTY GEOLOGICAL OBSERVATORY

Objective: (1) To define regional trends in mean, maximum and minimum surface air temperature over North America during the 20th century. (2) To analyze the possible CO_2-effects on the observed temporal and spatial anomaly patterns.

Product: The research will result in a regional data base for first detection and produce an assessment of probable regional CO_2-induced climate change. The information will provide a data set for model validation.

Approach: The research will be based on the fact that CO_2 affects primarily the longwave, but not the shortwave radiation exchange (shortwave is slightly affected, but not significantly). Weather conditions will be separated such that surface temperatures most directly affected by longwave radiation can by analyzed for a CO_2 impact. This involves sorting out cloud and humidity effects. The resultant data set will then be compared to climate model calculations for model validation.

Project Title:

CLOUD/RADIATION INTERACTIONS AND CLIMATE

Current Contract Period:
10/01/84-09/30/85

Funding: FY1985 225
FY1984 300
FY1983 0

Principal Investigator/s:

LUTHER, FREDERICK M.

Organization/s: LAWRENCE LIVERMORE NATIONAL LABORATORY

Objective: Comparison of longwave radiation transfer models; comparison of short and longwave radiation codes used in GCMs; comparison of both sets of models to satellite data and laboratory/atmospheric measurements to establish model and data uncertainty ranges.

Product: The comparison will establish the range of uncertainty between models and between models and the data. These results contribute to development and validation requirements for cloud/radiation interactions in climate models.

Approach: The proposed research builds upon an already existing longwave radiation model comparison study. This model comparison currently includes 20 scientists from 12 institutions in the United States, and several European scientists have recently agreed to participate in the study. The five major general circulation climate models 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 is being 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 radiative calculations. The comparison of GCM radiative 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 radiative 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:
10/01/84-09/30/85

Funding: FY1985 870
FY1984 865
FY1983 673

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_2.

Task 1. Objective: To understand the factors that contribute to the latitudinal and seasonal sensitivity of climate models to increasing CO_2 concentrations.

Product: 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/Potter, OSU/LLNL, "Model Intercomparison").

Task 3. Objective: State-of-the-art estimates of the climate effects of increasing CO_2 and the extent that such changes have started to occur and to provide technical oversight and coordination of the climate research area.

Product: (1) A focal point for CO_2/climate research undertaken by federal and international climate programs; (2) technical coordination of the DOE contract research; (3) Specific, sponsored studies on timely CO_2 climate issues; and (4) state-of-the-art reports in FY 1985 on climate modeling and first detection.

Approach: To stimulate the CO_2/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_2 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:

ATMOSPHERIC METHANE: RESEARCH PROGRAM FOR A STUDY IN CHINA

Current Contract Period:
02/01/85-01/31/86

Funding:

FY1985	264
FY1984	0
FY1983	0

Principal Investigator/s:

RASMUSSEN, R.A.

Organization/s: OREGON GRADUATE CENTER

Objective: Measure the magnitude of the methane source from rice paddy fields and bio-gas generators including seasonal cycles.

Product: Rice growing and bio-gas generators are thought to be large sources of atmospheric methane and contributors to the seasonal cycles in the time series documenting methane trends. This project will provide new information on the magnitude of these sources and their seasonal characteristics. This provides major new information for understanding the time series documenting the increase in atmospheric methane.

Approach: OGC will cooperate with the Chinese to measure methane releases to the atmosphere from rice paddy fields, non-agricultural soils, and bio-gas generators. Standard techniques developed by OGC will be used. The measurements will be made such that seasonal characteristics of the releases can be determined. This data will be used in analysis and modeling programs to understand the time series record of atmospheric methane.

Project Title:

THE ROLE OF CARBONACEOUS AEROSOL IN CLIMATE MODIFICATION

Current Contract Period:
10/01/84-09/30/85

Funding: FY1985 250
FY1984 200
FY1983 118

Principal Investigator/s:

ROSEN, HAL J.

Organization/s: LAWRENCE BERKELEY LABORATORY

Objective: Carbon-based aerosols resulting from fossil fuel use have been measured in the Arctic. The objective is to determine whether this is a regional phenomenon and whether the potential climatic effects will influence the first detection of a CO_2 signal in the Arctic.

Product: Rosen has demonstrated that carbonaceous aerosols from combustion processes are present during late winter and spring in at least two areas in the Arctic. Filter samples from airplane flights indicate that the aerosol is not just at ground level. Preliminary analyses show that present concentrations of the aerosol may cause local radiative effects comparable to doubling CO_2 during the spring. Filter samples have been collected primarily in the Alaskan Arctic. This sampling program will be extended to determine the spatial extent and temporal variations on the carbonaceous aerosol, extending from the Alaskan Arctic through the Canadian Arctic to the Norwegian Arctic. Vertical and horizontal distributions were obtained by an aircraft sampling expedition in March and April, 1983. 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 Bay) and two sites in the Norwegian Arctic (Spitzbergen and Bear Island) will be obtained from the Canadian Atmospheric Environment Service and the Norwegian Institute for Air Research. 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 was modified and installed in a NOAA WP-3D aircraft to determine the vertical and horizontal distributions of absorption coefficients in March-April 1983. Filter samples describe the scope of the problem. Analysis of the flight data continues.

Project Title:

A RESEARCH PROGRAM ON NATURAL AND ANTROPOGENIC CLIMATE CHANGE

Current Contract Period:
01/10/85-12/31/85

Funding: FY1985 100
FY1984 0
FY1983 0

Principal Investigator/s:

WANG, WEI-CHYUNG

Organization/s: ATMOSPHERIC AND ENVIRONMENTAL RESEARCH, INC.

Objective: To compare climate data and climate model results to improve the understanding of local/regional climate changes in relationship to large scale climate, in particular the desertification problem.

Product: Possible cause/effect physical mechanisms between local/regional climate changes and large scale climate.

Approach: The research program includes two elements:

1. 2-D model study of trace gases climatic effects; and

2. Participation in the USA/CHINA CO_2 research project. This task consists of two subtasks:

   2.1 climate data analysis, and

   2.2 project scientific coordination.

The first element will (1) incorporate a boundary layer parameterization into the 2-D radiative-dynamical model of Wang and study its impact of the calculated trace gases climatic effects, and (2) validate the 2-D radiative-dynamical models through comparisons with data and with other more comprehensive climate models so that our confidence in the model simulation of trace gases climatic effects can be increased.

The second element is intended (1) to analyze the climate data to improve our understanding of local/regional climate changes, in particular the desertification problem, and (2) to coordinate the various research programs within the USA/CHINA CO_2 project, which is critical in successfully achieving the research project scientific goals.

Project Title:

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

Current Contract Period:
09/01/85-08/31/86

Funding: FY1985 138
FY1984 129
FY1983 108

Principal Investigator/s:

WANG, WEI-CHYUNG

Organization/s: ATMOSPHERIC AND ENVIRONMENTAL RESEARCH, INC.

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

Product: Initial focus will be on improving the radiative treatment of overlapping IR 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_2.

The effect of humidity/cloud cover-radiation feedback and atmosphere-ocean interaction will be evaluated using the interactive one-dimensional tropical model. This work will clarify the proposed significant role that ocean-atmosphere interaction plays in affecting sensitivity to increased CO_2.

Future levels of COS, H_2S, CS_2, CH_4, SO_2 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 model and one-dimensional photochemical dynamic model 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:
05/01/85-04/30/86

Funding: FY1985 260
FY1984 245
FY1983 0

Principal Investigator/s:

WASHINGTON, WARREN M.

Organization/s: NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

Objective: To apply the NCAR coupled ocean/atmosphere GCM to study the climatic effects of increasing CO_2 concentrations, with emphasis on seasonal, regional and oceanic aspects of the change.

Product: Analysis of the results from the recently updated NCAR coupled model will provide estimates of the pattern of regional and seasonal changes in climate and of possible changes in ocean circulation and temperatures. Because this model is global, seasonal, and contains interactive prescriptions for ocean dynamics, clouds, and sea ice, the results will add significantly to the available set of 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_2 concentrations.

Approach: The recently updated NCAR coupled ocean/atmosphere general circulation model, developed and verified by NCAR with NSF support, will be used to simulate the regional and seasonal sensitivity of the climate to increasing CO_2 concentrations. Detailed diagnostics will be conducted comparing observations and the control experiment. These will be used to aid interpretation of 2 x CO_2 experiments. 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.

Project Title:

MODEL VALIDATION RESEARCH: COMPARISON OF SIMULATED AND OBSERVED CLIMATE PATTERNS FOR THE PAST 18,000 YEARS

Current Contract Period:
02/01/85-01/31/86

Funding: FY1985 459
FY1984 0
FY1983 0

Principal Investigator/s:

WEBB, THOMPSON III

Organization/s: BROWN UNIVERSITY

Objective: To attempt to validate the National Center for Atmospheric Research GCM against paleoclimate data.

Product: GCM's must be validated against past climate, current climate, and the detailed time series of the instrumented record for the last 150 years. The effort will begin an initial attempt to conduct a comparison between paleoclimate data and the National Center for Atmospheric Research GCM.

Approach: The proposed research will focus on 1) using general circulation models to simulate a series of climatic changes from the past, 2) assembling paleoclimatic data from large areas of the tropics and the northern hemisphere mid-to-high latitudes for the comparison of model-simulations and observations, 3) developing methods and procedures for improving the comparability of the observed and simulated data, and 4) comparing the model results with the paleoclimatic data. The third set of tasks are required because preliminary work has shown that both the simulated and observed data require transformation and averaging before telling comparisons are possible.

Project Title:

VALIDATION OF GENERAL CIRCULATION MODEL CONTROL RUNS

Current Contract Period:
10/15/84-11/30/85

Funding: FY1985 20
FY1984 0
FY1983 0

Principal Investigator/s:

WIGLEY, T.M.L.

Organization/s: UNIVERSITY OF EAST ANGLIA

Objective: Pilot project to compare observed climate data to GCM control experiments on a regional basis.

Product: An initial experimental design to validate GCM control experiments against observed climate data on a regional scale.

Approach: The University of East Anglia climate data base will be compared to Oregon State University GCM control experiments. On a regional basis a pilot study will examine a series of questions to determine how best to compare data and model output. Questions relate parameter to be compared, grid size, time related items (averages, other statistics, length of time average, etc.), and what constitutes a significant difference.

Project Title:

TRACE GAS INTERACTIONS IN THE GLOBAL ATMOSPHERE

Current Contract Period:
10/01/84-09/30/85

Funding: FY1985 250
FY1984 200
FY1983 0

Principal Investigator/s:

WUEBBLES, DONALD J.

Organization/s: LAWRENCE LIVERMORE NATIONAL LABORATORY

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

Product: The product will be an understanding of what measurements are required to develop and validate 1 and 2-D climate-trace gas models. This will also define the state-of-the-art of the theory that is available for model development.

Approach: The comparison of model calculations with observed trace species concentrations is an important aspect of validating the performance of numerical models of the atmosphere. Such comparisons constitute a necessary, although not sufficient, conditions for model validation, both for diagnostic and prognostic applications of atmospheric models. It is necessary to clearly evaluate the relationship between theory and measurements. LLNL will examine the capabilities and limitations of trace gas observations relative to the understanding of atmospheric photochemistry. Of new special interest is the uncertainty produced by the failure of current models to adequately consider the interaction between chemical and climatic processes.

The evaluation of potential future effects on climate and atmospheric chemistry requires the development of reasonable sets of scenarios for future spatial and temporal changes in trace gas abundances. The sources and sinks of relevant gases require further analysis to determine why their concentrations are currently changing, what pre-industrial concentrations may have been, and what aspects of their budgets are likely to be significant in the future. Such budget analyses would help establish where necessary measurements and further theoretical studies are needed.

The primary research tools to be used in the majority of the studies proposed in the previous sections are the LLNL 1-D and 2-D models of tropospheric and stratospheric chemical and physical processes.

VEGETATION RESPONSE

Irrespective of whether a CO_2-induced climate change occurs, it is clear that vegetation will be directly affected by a higher concentration of CO_2. Plants obtain carbon from the atmosphere's CO_2, and research has shown that photosynthesis is CO_2-limited at contemporary atmospheric levels of CO_2. Considerable evidence from controlled-environment experiments reveals that most crops experience increased growth and yield in CO_2 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_2. In addition, CO_2-accelerated vegetation growth will act to sequester additional amounts of anthropogenic CO_2 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_2. Specific objectives are (1) to determine yield of major crops in relation to CO_2 concentration and other key variables affecting crop productivity; (2) to determine fundamental effects of long-term elevated CO_2-level exposure on plant physiology and growth; and (3) to evaluate ecosystem responses to CO_2 in terms of productivity, altered composition of plant communities, and carbon change from CO_2 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_2 on plant physiology; and estimates of future ecosystem response, with particular emphasis on the effect of CO_2 growth enhancement on storage of carbon in the global biosphere.

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

- What are the effects of long-term exposure to elevated CO_2 concentrations on photosynthesis and growth of representative types of plants?
- To what extent will increased CO_2 affect water-use efficiency and change geographic distribution of crop production systems?
- 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?
- What field-scale approaches are applicable for evaluating potential effects on ecosystems of long-term continuous exposure to rising levels of CO_2?
- What modeling approaches are most appropriate for estimating future physiological, structural, and functional responses of crops and ecosystems?

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Project Title:

SIMULATION MODELING OF CROP RESPONSE TO CO2 ENRICHMENT

Current Contract Period:
08/01/85-07/31/86

Funding: FY1985 173
FY1984 0
FY1983 0

Principal Investigator/s:

ACOCK, BAKER, & RICKMAN

Organization/s: CROP SIMULATION RESEARCH UNIT & SOIL AND WATER CONSERVATION LAB.

Objective: There are three parts to the proposed research: Part I - Objectives for validation, testing and application of GLYCIM (1) To validate model performance for a wide range of environmental and crop conditions at ambient CO_2, and, where unused data exist at elevated CO_2, (2) To make yield predictions for large area with GLYCIM.
Part II - Objectives for development of growth simulation model for WINTER WHEAT (3) To develop preliminary rate equations for wheat growth at elevated CO_2, (4) To modify the AGRISTARS version of WINTER WHEAT for CO_2 simulations, including sensitivity and uncertainty analysis, (5) To validate WINTER WHEAT at ambient CO_2.
Part III - Objective of developing a "generic" model. (6) To define "generic" crop modeling approach based on mechanistic processes of GOSSYM, GLYCIM, WINTER WHEAT.

Product: The product is a validated plant growth simulation model that can treat CO_2-dependent physiological processes in the framework of the whole plant and the associated environmental factors affecting growth. The whole-plant growth models (e.g., GOSSYM, GLYCIM, WINTER WHEAT) will first provide large area simulations of crop response to CO_2 enrichment; then the models will be generalized for use with different crop species.

Approach: The validation of GLYCIM will compare soybean growth and yield simulations with field data from Mississippi, Florida, and South Carolina. Validation will be limited to the ambient CO_2 case; although several sets of data at elevated CO_2 from SPAR chamber experim may be suitable for validating the CO_2 enrichment case. Ways will be explored for exercising GLYCIM to make predictions of CO_2 effect on yield for large areas encompassing variable soil, weather, and farming conditions. Several approaches include: (1) predicting crop response for representative soil types and weather sequences of a crop region; (2) simplifying model structure and data requirements consistent with regional data, e.g., weather records, SCS soil data bases, crop reporting districts.

With WINTER WHEAT, equations of photosynthesis, transpiration and other CO_2-dependent processes will be derived from literature and unpublished data. Yield from various locations, weather and soil conditions, will test model performance at ambient CO_2. Requirements for validation at enriched levels of CO_2 will be specified.

A "generic" crop model will be derived from existing whole-plant models (GLYCIM, GOSSYM, WINTER WHEAT). The "generic" approach will incorporate essential CO_2 dependent processes that are common to all crop species.

Project Title:

ASSESSMENT OF CROP RESPONSE TO INCREASED ATMOSPHERIC CARBON DIOXIDE

Current Contract Period:
07/01/85-06/30/86

Funding: FY1985 1/8
FY1984 0
FY1983 0

Principal Investigator/s:

ALLEN & KIMBALL

Organization/s: PLANT SCIENCE RESEARCH LAB. & WATER CONSERVATION LAB.

Objective: The goal is to assemble and develop data and models to assess crop response to increased atmospheric CO_2. First focusing on soybean, the research objectives are: (a) to obtain data on interactive effects of increased CO_2 and temperature on soybean physiology and growth; (b) to determine effects of CO_2 enrichment on yield and water use of cotton for well-watered and water-stressed situations.

Product: Research data and analysis of the CO_2 X temperature interaction are the main products of the soybean research. For cotton, data will be produced on the effect of CO_2 on water use.

Approach: Two tasks of this research involve, (1) interactions of CO_2 and temperature on photosynthesis, growth, development and water use of soybeans, and (2) effects of increasing atmospheric CO_2 on yield and water use of crops. The integrated research calls for data acquisition, modeling and field experiments. Data on physiological processes are derived from environmental chamber experiments which maintain elevated CO_2. Generalized growth response data, in conjunction with key environmental variables, are used in empirical and simulation crop models to estimate increased yield in relation to elevated CO_2.

Project Title:

EFFECTS OF ELEVATED ATMOSPHERIC CO2 ON PLANT COMMUNITIES

Current Contract Period:
09/01/85-08/31/86

Funding: FY1985 142
FY1984 120
FY1983 0

Principal Investigator/s:

BAZZAZ, F.A.

Organization/s: HARVARD UNIVERSITY

Objective: To determine relative responses of native plant species to elevated CO_2, to evaluate effects of elevated CO_2 on plant competition and community structure, and to examine interactive effects of CO_2, light, nutrients, water and temperature.

Product: Data on growth and physiology responses will be provided for simple plant communities exposed to elevated levels of CO_2. Effects of CO_2 will be documented for relative contribution of different species to community biomass. Data on physiology will provide insight on causes of differential responses to CO_2. 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_2-controlled growth chambers, the designs will examine relative responses at 3 CO_2 levels, 2 light intensities, variable water, nutrient and temperature conditions. Data will be used in a plant competition model to simulate CO_2 effects on community growth and composition change.

Project Title:

PHYSIOLOGICAL AND BIOCHEMICAL EFFECTS OF HIGH ATMOSPHERE CARBON DIOXIDE ON SWEET POTATOES AND COWPEAS

Current Contract Period:
08/01/85-07/31/86

Funding: FY1985 113
FY1984 260
FY1983 168

Principal Investigator/s:

BISWAS, P.K.

Organization/s: TUSKEGEE INSTITUTE

Objective: Direct response to CO_2 will be investigated for two vegetable crops, sweet potatoes and cowpeas (black-eyed peas). As a root crop, the tubers provide a physiological sink for carbohydrate material produced at different levels of CO_2 enrichment. Specific objectives are:

1. To determine morphology, physiology growth and yield responses to elevated CO_2 for both sweet potatoes and cowpeas.

2. To study biochemical changes in sweet potatoes and cowpeas as affected by elevated levels of CO_2.

3. To determine the effects of an enriched CO_2 atmosphere on the rate of nitrogen fixation of cowpeas.

4. To provide data for a generalized crop growth model for predicting yield of both sweet potatoes and cowpeas as a function of atmospheric CO_2 enrichment.

Product: Growth and physiological responses of sweet potatoes and cowpeas as a function of variable CO_2 are the principal products of the research. These data, when used with a regional crop model, will provide estimates of productivity changes due to future changes of atmospheric CO_2.

Approach: 1) Growth and physiological responses of sweet potatoes to elevated CO_2. Rates, amount and distribution of phytomass will be determined for variable levels of CO_2 and growth and yield responses will be related to photosynthesis, stomatal conductance and water use. 2) Biochemical changes in sweet potatoes and cowpeas in an enriched CO_2 atmosphere. Quantitative estimation of carbohydrates will be determined for both sweet potatoes and cowpeas. 3) Growth and nitrogen fixation response of cowpeas. Rate of nitrogen fixation will be determined in relation to CO_2-induced growth responses. 4) Water use efficiency of sweet potatoes. Effect of CO_2 enrichment on water-use efficiency will be experimentally determined from season-long measurements of precipitation, soil moisture change and estimates of evapotranspiration. 5) Regional modeling of crop yield. 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 CO_2. The primary data set used with this modeling approach is yield response to the interactive effects of CO_2 enrichment and water stress.

Project Title:

INFLUENCE OF NITROGEN AND PHOSPHORUS NUTRITION ON CARBOHYDRATE PARTITIONS AND GROWTH RESPONSE OF SOYBEANS AT ELEVATED CO2

Current Contract Period:
09/01/85-08/31/86

Funding: FY1985 127
FY1984 0
FY1983 0

Principal Investigator/s:

CURE, J.

Organization/s: DUKE UNIVERSITY

Objective: Questions and corresponding objectives are: (1) How do different levels of nutrients affect CO_2 assimilation and photosynthate partitioning in relation to CO_2 enrichment? The research objectives are to (a) determine minimum solution and tissue concentration on N and P for optimal growth at different CO_2 levels, (b) describe effects of nutrient concentration on rate of dry matter accumulation in terms of leaf initiation and area expansion for different CO_2 levels, (c) determine patterns and rates of carbohydrate accumulation, leaf export (in light), mobilization (in dark) at different CO_2 levels.

(2) How does elevated CO_2 affect nutrient uptake at different levels of nutrient supply? The research objectives are to (a) determine nutrient uptake and distribution of N and P in different plant parts as N and P availability varies, (b) determine effects of CO_2 on nutrient uptake efficiency (e.g., N uptake/g root/time), (c) determine relative distribution in plant parts of carbohydrate, nutrients and dry matter.

Product: This research will produce experimental data on the effects of CO_2 enrichment on nutrient uptake and distribution for different levels of N and P supply. Experimental data will also be produced for the alternative situation of how N and P stress affects CO_2 assimilation and photosynthate distribution within the plant. The data are expected to improve the way nutrient dynamics can be modeled with mechanistic whole-plant growth models. Data and models (to be developed and tested in another project) will examine the questions of whether CO_2-enhancement of yield will require proportional increases of fertilization.

Approach: Four experiments are planned; an initial one to establish target nutrient levels for in-depth studies of vegetative growth, leaf development and yield formation. Three systematic studies will be done with a nonnodulating variety of soybeans so that nutrient data are not confounded by N-fixation. Soybean, a broadleaf C_3 species, was selected for the process-level study because considerable background information and experience is available from other research on CO_2 enrichment with this species. To aid transfer of the findings to other C_3 plants, selected tests will be carried out with other C_3 species as time and growth-chamber space permit. Two CO_2 levels will be used in the experiments because a pilot study found a linear growth response function between ambient and 700 ppm of CO_2 with intermediate treatments giving intermediate responses.

Project Title:

A FIELD STUDY OF THE EFFECTS OF ELEVATED AMBIENT CO2 ON ECOSYSTEM PROCESSES IN CHESAPEAKE BAY WETLANDS

Current Contract Period:
09/01/85-08/31/86

Funding: FY1985 170
FY1984 0
FY1983 0

Principal Investigator/s:

DRAKE, BERT G.

Organization/s: SMITHSONIAN INSTITUTION

Objective: The experimental effort will specifically address questions about effects of CO_2 enrichment on ecosystem-level photosynthesis, respiration, net productivity, and carbon storage; change of species composition in plant communities; partitioning of biomass between above-ground and below-ground components; changes of carbon: nitrogen ratios of tissue; decomposition rates; and change of water balance of tissues. Six hypotheses will be tested:

(1) Elevated CO_2 concentration increases net production wetlands communities which contain C_3 species.

(2) Elevated CO_2 increases net assimilation rate per unit of leaf area.

(3) Chronic exposure to elevated CO_2 will alter the species composition of estuarine wetlands in favor of C_3 species.

(4) Elevated CO_2 alters elemental composition of plant biomass.

(5) Elevated CO_2 increases the rate of litter decomposition.

(6) Increased CO_2 increases leaf water potential and turgor pressure and decreases osmotic potential.

Product: This research is a field study of a representative wetlands plant community, and thus will provide process (mechanistic) information at the ecosystem level of organization. Data will be produced on effects of CO_2 on species composition of plant communities, as well as effects on net ecosystem production. The most important aspect of this research is to determine if species composition changes. The research will also produce a data base for modeling the effects of CO_2 enrichment on ecosystem processes, specifically community photosynthesis, carbon accumulation, and change in species composition.

Approach: The long term continuous CO_2 enrichment will be carried out at the Smithsonian Environmental Research Center, a brackish (part saltwater) research site near Edgewater, Maryland. Three community-types will be investigated in the field where elevated CO_2-level will be controlled by small (0.8m dia. x 0.8m high), replicated (5 plots per treatment) open-top chambers. The field set-up and experimental design will produce data for testing the stated hypotheses and for investigating system-level responses to elevated CO_2 (660 ppm) relative to those at ambient (330 ppm). Process and mechanistic data will be produced from tne single enrichment; although response curves based on a range of CO_2 enrichments will not be determined.

Project Title:

PRELIMINARY STUDIES OF ELEVATED ATMOSPHERIC CO2 ON CONIFERS

Current Contract Period:
10/01/84-09/30/85

Funding: FY1985 130
FY1984 0
FY1983 0

Principal Investigator/s:

HELMS, JOHN

Organization/s: UNIVERSITY OF CALIFORNIA, BERKELEY

Objective: This research provides field data on the response of Colorado and Sierra eco-types of ponderosa pine seedlings to elevated CO_2. The goal is to obtain dose-response curves of growth under year-long exposure to elevated CO_2. Plant studies are collaborative with Lawrence Livermore National Laboratory to determine physiological and morphological expression of response to elevated CO_2 and to compare two genotypes of the same species. Explanations and mechanisms for pathological effects are sought.

Product: This research provides a data base for testing empirically-based models (CACTOS for timber production and SILVA for western conifer trees) under different CO_2 exposure levels, and provides a predictive technique for very long-lived plants that must compete and adapt in a variety of stresses.

Approach: Field experiments are being carried out at Livermore, California, by University of California, Berkeley. Open-top chambers for CO_2 exposure of seedlings and saplings are the same as used in the project "Assessment of the Effects of Atmospheric CO_2 on U.S. Field Crops" (Shinn). Growth and carbon allocation measurements will be made by UCB on seedlings and saplings exposed to elevated CO_2 levels. Nutrients, carbohydrates, roots and enzymes are studied to determine effects of CO_2. CACTOS model will be tested as a possible method for calculating effects.

Project Title:

PHOTOSYNTHESIS, WATER USE EFFICIENCY OF SORGHUM AND WINTER WHEAT AT ELEVATED LEVELS OF CO2

Current Contract Period:
06/01/85-05/31/86

Funding: FY1985 85
FY1984 100
FY1983 0

Principal Investigator/s:

KANEMASU, E., KIRKHAM, M.

Organization/s: KANSAS STATE UNIVERSITY

Objective: For field conditions of CO_2 exposure, the objectives are: (a) to determine the effect of elevated CO_2 on water use efficiency of sorghum and winter wheat for dry and well-watered conditions. Sorghum will be grown under only the well-watered conditions. Photosynthetic rate will be determined only for winter wheat.

(b) to determine the effect of CO_2 on transpiration, stomatal resistance, and canopy temperature for the same plants and water conditions.

(c) to evaluate, for the same plants and water treatments, leaf- and root-growth rates during the entire life cycles and yield and yield components at harvest.

Product: The research will provide data for: (a) A possible increase in water use efficiency of two dryland crop species, winter wheat (C_3) and sorghum (C_4), at augmented concentrations of CO_2.

(b) A systematic knowledge of stomatal responses and interaction with transpiration and canopy temperatures at elevated levels of CO_2.

(c) A determination if an earlier development of a larger leaf with higher-than-ambient levels of CO_2 means more fruiting and yield. The plant-water measurements will show if the increased rate of leaf expansion at elevated levels of CO_2 is related to an improved plant water status. Root/shoot dry matter ratio determined at harvest will indicate the effect of an elevated CO_2 environment on the partitioning of photosynthate.

(d) A test of an energy exchange model. The higher CO_2 levels may increase leaf growth and leaf area; therefore, even with a decrease in stomatal resistance, the transpirational flux may be greater from the elevated levels. The lower transpirational flux per unit leaf area may indicate a higher canopy temperature, and thus a greater sensible heat flux to the atmosphere.

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 where root growth and soil water loss can be carefully monitored throughout the growing season. It permits measurement of both above- and below-ground plant growth as a function of elevated CO_2 and soil-water stress.

Project Title:

EFFECTS OF ATMOSPHERIC CO2 ON INSECT HERBIVORES AND THEIR HOST PLANTS

Current Contract Period:
07/01/85-06/30/86

Funding: FY1985 43
FY1984 43
FY1983 0

Principal Investigator/s:

LINCOLN, DAVID E.

Organization/s: UNIVERSITY OF SOUTH CAROLINA

Objective: 1. To examine how CO_2 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.

2. To examine how CO_2-induced changes in secondary plant biochemicals (e.g. phenols, terpenes) will affect feeding and growth of the insects.

Product: Data will be produced on the effect of CO_2 on nutritive properties of two plants, soybeans and peppermint. Changes in secondary biochemicals (phenolics, terpenes) will be documented, and insect feeding rates will also be documented in relation to CO_2-altered nutritive and biochemical properties (if any). Data and analysis of host-insect relationships will be reported to DOE and to the open literature.

Approach: Experimental approaches will utilize CO_2 plant-growth facilities at the Duke University Phytotron for producing plant materials at elevated CO_2. While plants are exposed continuously to CO_2 insects will be allowed to feed on live plant material, and feeding rates will be determined on plants growing at different levels of CO_2. Effects of CO_2 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:

ELEVATED CARBON DIOXIDE EFFECTS ON WOODY PLANT SOIL SYSTEMS

Current Contract Period:
10/01/84-09/30/85

Funding: FY1985 185
FY1984 210
FY1983 150

Principal Investigator/s:

LUXMOORE, ROBERT J.

Organization/s: OAK RIDGE NATIONAL LABORATORY

There are two subprojects with this research: (1) To examine effects of CO_2 on nutrient uptake and growth of white oak and yellow poplar under nutrient-poor soil conditions (Luxmoore, Norby). (2) To use a forest succession model for predictions of forest response to CO_2 fertilization (West).

Objective: (1) To test the hypothesis that elevated atmospheric CO_2 levels will increase nutrient uptake and growth of woody plants in nutrient-poor soils and to examine plant root-symbiotic systems and rhizosphere responses to elevated CO_2 as physiological bases for these phenomena. (2) To parameterize a forest succession model in studies of the fertilization effect of CO_2 upon the composition and biomass dynamics of a mixed deciduous forest stand.

Product: (1) Data will be produced on effects of CO_2 enhanced growth on plant and microbial processes affecting nutrient availability to forest species. Improved knowledge of CO_2-nutrient relationships will be used in modeling tree responses to increasing atmospheric CO_2. (2) A stochastic stand growth model of forest succession, possible implications of a species-level differential effect of CO_2-induced growth changes within a natural forest system will be evaluated, with emphasis on compositional and biomass changes through time of forests with and without CO_2 enrichment.

Approach: (1) Atmospheric CO_2 treatments of 350, 500, 800 ppm will be applied to white oak and yellow poplar seedlings in pots under controlled environment conditions. Data to be collected include: (a) rhizosphere responses - bacterial colonies/g soil, pH; (b) symbiotic responses - nitrogen fixation, rate of mycorrhizal development, ^{32}P transfer to plant from soil; (c) root exudation - quantity and type of chemical exudation from roots; (d) plant growth, water use and nutrient content. Simulation modeling will be used to summarize experimental findings. (2) Available data regarding CO_2 effects on woody species will be gathered from all known and practical sources. The FORET model will then 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:
07/01/85-06/30/86

Funding: FY1985 280
FY1984 250
FY1983 35

Principal Investigator/s:

OECHEL, WALTER

Organization/s: SAN DIEGO STATE UNIVERSITY

Objective: (1) To determine effects of CO_2 on growth enhancement, species population dynamics and the community carbon balance of tussock tundra. (2) To determine effects of CO_2 on growth and carbon dynamics of selected tundra plants. (3) To develop and validate simple models of whole-system response to CO_2; to modify existing process simulation models (ARTUS, NECS) for predicting population, community and ecosystem response to elevated CO_2.

Product: Field experiments and models of vegetation response will produce information related to (a) carbon exchange in tussock tundra, (b) medium and short term effects of CO_2 (340, 500 and 680 ppm) on carbon storage by arctic ecosystems, (c) effect of elevated CO_2 on species growth, composition, changes in cover and other factors which affect carbon storage and (d) differential growth responses of natural species to elevated CO_2.

Approach: The research involves experimental and modeling approaches. An experimental field study provides data on the direct effects of CO_2 enrichment on net carbon gain, species composition, and ecosystem processes of tussock tundra at Toolik Lake, Alaska. The physiological measurements will be carried out in replicated field greenhouses maintained continuously for the entire growing season at three different levels of atmospheric carbon dioxide. The temperature and humidity controlled greenhouses are set up on the tussock tundra near Toolik Lake and operated at 340, 500 and 680 ppm CO_2. Experiments are carried out at ambient microclimatic conditions except for differences in level of CO_2. Data from these experiments will be used with simulation models to 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. Measurements from the field study will be used to validate the model and to extrapolate changes suggested by the experimental data.

Project Title:

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

Current Contract Period:
10/01/84-09/30/85

Funding: FY1985 470
FY1984 475
FY1983 208

Principal Investigator/s:

SHINN, JOSEPH

Organization/s: LAWRENCE LIVERMORE NATIONAL LABORATORY

Objective: This research provides field data on the response of a perennial crop (alfalfa) and an important western conifer tree (ponderosa pine) to elevated CO_2. The goal is to obtain CO_2 dose-response curves for photosynthesis, growth and water-use of these species in their normal culture, but under continuous exposure to elevated CO_2 for three years. Similar objectives apply to complementary field experiments on conifer species by University of California, Berkeley, which is collaborating on this project.

Product: The research provides a data base for testing empirically-based models (H-B-K for crops and SILVA for western conifer trees) under different CO_2 exposure levels, and provides a predictive technique for very long-lived plants that must compete and adapt in a variety of stresses.

Approach: Field experiments are carried out at Livermore, California in open-top chambers which provide CO_2 levels at +75, +150, +300 ppm and a control at ambient level. Dose-response curves are obtained for photosynthesis, transpiration, growth and yield. Leaf-level physiological measurements are made with special mini-cuvettes, and rates of soil water consumption are measured by the neutron-probe method. Model calculations will be applied to regional scale determination of long-term CO_2 effects.

Project Title:

INTEGRATION OF KNOWLEDGE ON THE RESPONSE OF VEGETATION TO RISING CARBON DIOXIDE

Current Contract Period:
08/01/84-03/31/86

Funding: FY1985 83
FY1984 219
FY1983 40

Principal Investigator/s:

STRAIN, B.R./REYNOLDS, J.

Organization/s: DUKE UNIVERSITY

Objective: There are two tasks: (1) To assemble and integrate collective scientific knowledge of the responses of vegetation to rising atmospheric CO_2, and to present the known and unknown information, along with attendant uncertainties as a state of the science report. (2) a. To survey existing ecosystem models for usefulness in assessing ecological effects of CO_2 enrichment, b. To define key CO_2-dependent processes that govern plant and/or ecosystem responses, and determine how best to represent such processes in a generic ecosystem model, c. To develop and test a generic model, including sensitivity/uncertainty of predictions in relation to model structure, data and assumptions.

Product: An integrated report of the state of science which will be compiled for the preparation of the SOA Report on the Response of Vegetation to Rising CO_2. The state of scientific understanding of crop productivity and responses of native species to CO_2 will be determined. In addition, the structure of a generic model containing CO_2-dependent process affecting native species and ecosystems will be developed.

Approach: Strain (PI) will organize the report, select technical experts to author chapters, provide scientific leadership, direction and technical review of manuscript contributions, and assure that information used in the report is traceable to authentic scientific sources. The PI will synthesize draft manuscripts into a coherent, integrated report that is consistent with three other SOA Reports being prepared simultaneously by DOE. The modeling activity (Reynolds) involves a review of candidate models for application to the CO_2 problem, including an evaluation of known strengths and weaknesses of existing models for predicting response to CO_2 enrichment, and sensitivity and uncertainty studies of model structure, data requirements and process aggregation in relation to model performance.

Project Title:

DETECTION OF FOREST RESPONSE TO INCREASED ATMOSPHERIC CARBON DIOXIDE

Current Contract Period:
10/01/85-09/30/86

Funding: FY1985 275
FY1984 128
FY1983 0

Principal Investigator/s:

WEST, DARRELL C.

Organization/s: OAK RIDGE NATIONAL LABORATORY

Objective: This is a phased study with two principal objectives. The phase I objective is to determine if the x-ray densitometry technique can provide a wood-mass data base for detecting tree response to increased atmospheric CO_2. This phase examines feasibility and "test-of-concept". The phase II objective is to develop a more comprehensive data base, and to quantify tree response in relation to increasing CO_2 over the past century. This data base will be used in model simulation of forest response to CO_2.

Product: Detailed tree-ring data provide an important historical record for analyzing the CO_2 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. If the tree-ring response can be successfully correlated with atmospheric CO_2 change, it will represent an important data set for estimating net forest productivity, and for estimating net carbon sequestering by forests.

Approach: Mass of wood in a ring segment will be determined by simultaneous measurement of ring width and wood density. Tree-ring growth and density patterns will then be correlated with observed changes of atmospheric CO_2 for the same time period. The CO_2 effect on growth increment will also be analyzed for young trees continuously exposed to CO_2 in related experiments. Mass of wood laid down in tree rings will be determined from x-ray densitometry and ring width measurements; data will be statistically analyzed for effects of climate, pollution, site nutrition factors and effects of CO_2 level on growth. Ring-width parameters of existing tree-ring chronologies from the Arizona Tree-Ring Laboratory have been analyzed, and the growth response function will be extracted from these records. Should phase I prove successful, 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 wood and last wood will be used as an indicator of variation. If a growth response is evident, tree-ring growth data will be expressed as CO_2 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_2.

INDIRECT EFFECTS AND MODIFICATION, ADAPTATION AND PREVENTION

Changes in climate and vegetation caused by a rising level of atmospheric CO_2 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 rainfall may significantly affect inland and oceanic fisheries and sea level.

Research Objectives The research on indirect effects of CO_2 is organized around the question: How will the direct effects of CO_2-induced changes in climate and vegetation affect human health and welfare? Current research involves identification, charcterization, 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:

- Will global warming caused by increasing levels of atmospheric CO_2 shift the regional distribution of diseases afflicting human populations?
- To what extent will the direct fertilization of plants by CO_2 be offset by possible adverse effects of decreased soil moisture?
- How will global and regional water quantity and quality be affected by changes in temperature and precipition? To what extent will these changes alter the consumptive demand for water in agriculture, residences, and industry?
- 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?
- Will CO_2-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:
10/01/84-09/30/85

Funding: FY1985 75
FY1984 135
FY1983 118

Principal Investigator/s:

BLASING, TERENCE J.

Organization/s: OAK RIDGE NATIONAL LABORATORY

Objective: To refine data/information requirements from the direct effects program elements for indirect applications and assess the match between requirements and the information provided.

Product: A continuing dialog on user needs and the extent to which these needs are met will be established between the direct effects research and the indirect effects research.

Approach: The PI will participate in the State-of-the-Art process from the user's point of view for climate data.

Project Title:

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

Current Contract Period:
10/01/84-09/30/85

Funding: FY1985 150
FY1984 125
FY1983 145

Principal Investigator/s:

CALLAWAY, JOHN M.

Organization/s: PACIFIC NORTHWEST LABORATORY

Objective: (1) Identify characterize and define existing or projected regional and global water resource management issues which may be affected by CO_2-induced climate changes. (2) Develop research priorities for acquiring additional information about the potential effects of a CO_2-induced climate change and the availability and allocation of freshwater supplies.

Product: (1) A report which will identify, characterize and define the potential effects of water resource issues which may result from CO_2-induced climate changes. (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: (1) A comprehensive list of world-wide water supply/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_2-induced changes to the timing of each water resource issue will be estimated. (2) Criteria will be developed to identify issues with the highest probability of being impacted by a CO_2-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. (3) Detailed analysis of several regions/sites will be done in a qualitative and quantitative manner to illustrate the potential impacts from CO_2-induced climate changes. (4) Issues which need research to lessen the critical uncertainties will be outlined and prioritized. Data/information requirements from direct effects program elements will be defined.

Project Title:

AGRICULTURE - EFFECTS OF CARBON DIOXIDE INDUCED CLIMATE CHANGE

Current Contract Period:
10/01/84-09/30/85

Funding: FY1985 59
FY1984 62
FY1983 54

Principal Investigator/s:

DECKER, WAYNE L.

Organization/s: UNIVERSITY OF MISSOURI

Objective: To define the effects of climate changes on agricultural animals, including the feed-back to the health of the animals of any climate-related effects on pests, pathogens, nutrients, etc.; to study in depth the probable effects on predicted CO_2-induced climate changes on one or two economically important species (e.g., cattle, sheep) as examples of effects.

To define the effects of climate changes on crops to include any climate-related effects on pests, pathogens, noxious plant competition, etc., which may affect such things as growth or yields; to study in depth the probable effects of predicted CO_2-induced climate changes on a few selected species (e.g., soybeans, corn, wheat) as examples of effects.

Product: A report describing climate-related effects on agriculture, the probable effects of predicted CO_2-induced climate changes on some specific agriculture entities. The report will include knowns, unknowns, and uncertainties and a plan for clarifying the uncertainties.

Approach: A list of world-wide agricultural issues related to climate will be generated. Using preliminary predictions regarding probable CO_2-induced climate changes and the world list, the agricultural issues most likely to be affected by CO_2-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) made, in order to predict and illustrate the probable effects of CO_2-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. Research will be outlined which will define the data and information needed, from both direct and indirect effects studies, in order 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 world-wide agriculture.

Project Title:

ROSS SEA HEAT FLUX EXPERIMENT

Current Contract Period:
01/01/85-12/31/85

Funding: FY1985 105
FY1984 137
FY1983 0

Principal Investigator/s:

PILLSBURY, DALE

Organization/s: OREGON STATE UNIVERSITY

Objective: To monitor the flux of heat to the region beneath the Ross Ice Shelf, to evaluate the relative roles of vertical and horizontal fluxes in the Ross Sea circulation, to define relationships between the Ross Sea thermohaline structure and its glacial ice and sea ice, and to establish the systems's basic spatial and temporal scales in order to model its sensitivity to naturally and anthropogenically-induced perturbations.

Product: 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_2-induced polar amplified climatic warming in particular.

Approach: This is a three-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. During the first year already completed, three moorings were deployed. Six moorings were planned for year two. The DOE supplement expanded the second year array to ten moorings and 23 current meters permitting greater spatial coverage to allow heat flux at the extreme edge of the shelf, a more westerly location and a potential site of deep convective circulation to be looked at.

Project Title:

SURGING AS A POTENTIAL RESPONSE OF ICE SHEETS TO CO2-INDUCED CHANGES IN THE POLAR ENVIRONMENT

Current Contract Period:
01/01/85-12/31/85

Funding:

FY1985	150
FY1984	140
FY1983	0

Principal Investigator/s:

RADOK, UWE

Organization/s: UNIVERSITY OF COLORADO

Objective: Quantitative assessment of chances for CO_2-triggered or spontaneous ice sheet surges leading to sea level rises of the order of meters in the next 100-200 years.

Product: The answer to the question, could one or more of the major ice drainage basins of Antarctica and Greenland surge in the next one to two hundred years under present climatic conditions or those projected for increased atmospheric CO_2.

Approach: Establish fine-scale (20 km grids) physical characteristics of key ice drainage basins of Antarctica, using zero-net-mass-balance models. Determine equilibrium basin profiles, using transient ice deformation models and assumed ice shelf strain rates. For different sliding parameterizations, establish surging ranges of key parameters and surge characteristics (period, speed, mass discharge, limiting ice sheet shapes). With recent climatic forcing, model drainage basin histories and extrapolate into CO_2 temperature (atmosphere and ocean) and precipitation scenarios.

Project Title:

EFFECTS OF INCREASED ATMOSPHERIC CARBON DIOXIDE ON FISHERIES

Current Contract Period:
10/01/84-09/30/85

Funding: FY1985 124
FY1984 90
FY1983 75

Principal Investigator/s:

SIBLEY, THOMAS H.

Organization/s: UNIVERSITY OF WASHINGTON

Objective: To define the probable scope of the effects of increased CO_2 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_2 on fisheries, using the Pacific Northeast fisheries area 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, world-wide, which affect fisheries production, e.g., ocean/atmospheric interactions such as changes in the magnitude, rates of change and seasonal and regional variability of such things as temperature, salinity, currents and upwelling. Using preliminary predictions regarding probable CO_2-induced climate and water chemistry changes, the fishery issues most likely to be affected by increasing atmospheric CO_2 will be identified. A selected set of species (e.g., salmon, halibut, shrimp) in a selected region (e.g., the northeast Pacific) will be used for an in-depth study to illustrate the probable CO_2-related effects on fisheries. The knowns, unknowns and uncertainties with regard to these effects will be defined. Research will be developed which will define the data and information needed, both from direct and indirect effects studies, in order 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:

TECHNOLOGY EFFECTS ON CO2 EMISSIONS

Current Contract Period:
10/01/84-09/30/85

Funding: FY1985 115
FY1984 155
FY1983 0

Principal Investigator/s:

STEINBERG, MEYER

Organization/s: BROOKHAVEN NATIONAL LABORATORY

Objective: The purpose of this study is to establish the impacts of improved technology efficiencies in reducing global CO_2 emissions.

Product: The results of the study will be a series of memoranda and reports summarizing the findings, and will consist of the following:

1. A listing of technologies outlining present, theoretical, and most probable improved efficiencies.

2. An estimate of the geographic areas of significance for application of improved technologies, and the time frames in which they may be employed.

3. An evaluation of their significance in reducing global CO_2 emissions.

4. An estimate of the costs involved in substituting for or improving the existing technology.

Approach: The study will focus on evaluating various technologies in the energy system in terms of present, potential and probable efficiencies. These technologies may be grouped into three classes:

- o Presently employed processes
- o Emerging technologies
- o Advanced, ("far-out") concepts

They will be analyzed to determine their present status with regard to efficiency, the theoretical maximum efficiency, and the most probable actual efficiency obtainable. This provides a set of boundary conditions for each technology. In this manner, a screening process evolves which can be used to choose those technologies which are significant in reducing CO_2 emissions.

Subsequent to the screening process, the significant technologies will be assessed in terms of their applicability to global regions of the world; i.e., U.S., Western Europe, the Soviet Bloc, China, and the Lesser Developed Countries (LDCs). This will permit global CO_2 impacts to be assessed appropriately. Significant technologies will also be evaluated in terms of cost differentials vis-a-vis existing systems.

Project Title:

ASSESSMENT OF THE INDIRECT EFFECTS OF INCREASED CARBON DIOXIDE

Current Contract Period:
10/01/84-09/30/85

Funding: FY1985 192
FY1984 198
FY1983 133

Principal Investigator/s:

WHITE, MARGARET

Organization/s: LAWRENCE BERKELEY LABORATORY

Task 1: Indirect Effects on Human Health

Objective: Based on current knowledge, identify, characterize and define the probable effects on humans from projected CO_2-induced climate change.

Product: (1) Definition of the probable effects on human health of climate modification as a result of increased atmospheric CO_2. (2) Definition of data and information 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_2 Climate Program. Using these projections the literature will be searched for possible effects on human health of the estimated changes in temperature, humidity and water quality. The possible effects will be summarized and the uncertainties defined.

Task 2: Program Management

Objective: (1) To provide oversight of program projects and ensure that these studies provide the best currently available response to the major issues. (2) To provide oversight of program projects and ensure that these studies provide the best currently available response to the major issues.

Product: (1) Coordination and supervision of research and reports. (2) Preparation of state-of-the-art reports.

Approach: Using the available literature and outputs of the DOE Carbon Cycle, Vegetation Effects and Climate Program Elements on the CO_2 issue, characterize, define and prioritize the issues affecting human health and welfare. Assess the knowns, unknowns and uncertainties. Plan and coordinate a program to address the most urgent uncertainties.

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_2 through the Carbon Dioxide Information Center.

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Project Title:

REVIEW OF CARBON DIOXIDE RESEARCH STAFFING AND ACADEMIC SUPPORT

Current Contract Period:
10/01/84-09/30/85

Funding: FY1985 69
FY1984 45
FY1983 0

Principal Investigator/s:

BLAIR, LARRY M.

Organization/s: OAK RIDGE ASSOCIATED UNIVERSITIES

Objective: To determine if the CO_2 program need support special educational opportunities to ensure that a core of researchers and managers exist for eventual policy decision.

Product: Phase I will provide the data on which to determine if such a program is required and determine (if appropriate) the resource requirements to design such a program. Phase II will document foreign nationals enrolled in CO_2 related areas at U.S. schools.

Approach: The assessment will take place in two phases. The first phase will culminate in a working paper report and workshop to review the findings of the first 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 the first phase. Phase I will require approximately eight months to complete including assessment work, preparation of the working paper report, workshop presentation and review, and definition of phase II work scope, direction, and level of effort. Foreign nationals enrolled in CO_2 related areas will also be documented as a crude indicator of international sources for joint programs.

Project Title:

CDIC (CARBON DIOXIDE INFORMATION CENTER)

Current Contract Period:
10/01/84-09/30/85

Funding: FY1985 1166
FY1984 729
FY1983 550

Principal Investigator/s:

FARRELL, MICHAEL P.

Organization/s: OAK RIDGE NATIONAL LABORATORY

Objective: The Carbon Dioxide Information Center's goal is to support the nation's carbon dioxide-climate research effort by providing a focal point for the compilation and distribution of CO_2-related information under systematic quality control.

Product: The product of this effort is a fully integrated information and analysis center program needed in support of a global assessment of the CO_2 issue.

Approach: (1) Identify users' needs, data sources, and computer technologies relevant to CO_2 research activities and cooperate with the user community in establishing CDIC priorities for obtaining, documenting and/or analyzing the quested information; (2) Serve as a liaison between other national and international data centers having data needed for CO_2 research efforts and establish networking capabilities with these data centers to promote and facilitate information exchanges with CDIC's user community; (3) Obtain, process, quality assure, document, package, disseminate, and evaluate numeric data, computer codes, bibliographic information, and other CO_2 related information in support of ongoing research activities and fulfill the need to provide a formal and documented source for data, computer models, and information used for evaluation purposes.

Project Title:

SUPPORT FOR ACTIVITIES OF THE POLAR RESEARCH BOARD, NAS

Current Contract Period:
10/30/84-10/31/85

Funding: FY1985 25
FY1984 25
FY1983 0

Principal Investigator/s:

HUSHEN, W. TIMOTHY

Organization/s: NATIONAL ACADEMY OF SCIENCES

Objective: (1) To advise on U.S. research activities and needs in the Arctic and 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. In this capacity the Board represents the U.S. scientific and technical community in SCAR activities and fosters 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; (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.

Product: The Board's ad hoc Committee on Antarctic Physical and Chemical Oceanography is preparing a draft report that will serve as a basis for a workshop in spring 1985. The workshop will provide an opportunity to discuss the material in detail and to develop recommendations.

The Board will continue to cooperate with the Ocean Science and Polity Board's Panel on Polar Ocean Climate Studies, which is reviewing the MIZEX (Marginal Ice Zone Experiment) and the Air-Sea-Ice International Research Program for the 1980s and the International Arctic Ocean Advisory Board.

Approach: Advice, guidelines, and recommendations on polar research 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 representation from marine and terrestrial biology, earth sciences, engineering, medicine, physical sciences, and social sciences. Members are drawn from academic institutions, industry, and national laboratories. In addition, the Board always has one member representing Canadian research activities. Federal agencies such as the Department of Energy, with programs in the Arctic or the Antarctic, have liaison representation on the Board and brief the Board periodically at its meetings on these activities.

Project Title:

VIDEO TELECONFERENCE PROJECT ON THE ATMOSPHERIC CARBON DIOXIDE PROBLEM: SCIENTIFIC ISSUES AND RESEARCH NEEDS

Current Contract Period:
03/01/85-02/28/86

Funding: FY1985 116
FY1984 0
FY1983 0

Principal Investigator/s:

JACKSON, C. IAN

Organization/s: SIGMA XI: THE SCIENTIFIC RESEARCH SOCIETY

Objective: To increase knowledge among scientists of the implications of the observed increases in atmospheric carbon dioxide in recent decades, and especially to stimulate young scientists to undertake research on carbon dioxide related problems.

Product: A ninety-minute video teleconference linking twenty or more sites at universities in the U.S.A., Mexico and Canada with a central studio where leading scientists in the field of CO_2 research will make presentations and respond to questions.

Approach: A video teleconference will take place from 8:00 p.m. to 10:30 p.m. Eastern time on a week night in September 1985. Participants will view the program on television monitors or large video screens and have the opportunity to relay their questions to the panelists via dedicated phone lines. All participants will have received background information about the topic prior to the teleconference. Following the teleconference, the transcript of the proceedings and an edited videotape will be available for broad distribution. The sixty-minute videotape summary of the teleconference will be prepared in time for showing at Sigma Xi's annual meeting in October 1985, so that delegates from the 500 chapters and clubs can appreciate its significance and plan to use it in their chapter/club programs.

Project Title:

SNOWWATCH 85: WORKSHOP ON CO2/SNOW INTERACTIONS

Current Contract Period:
08/01/85-03/31/86

Funding: FY1985 18
FY1984 0
FY1983 0

Principal Investigator/s:

KUKLA, GEORGE

Organization/s: LAMONT-DOHERTY GEOLOGICAL OBSERVATORY

Objective: To document the quality of the existing snow cover data bases and compare the data to model calculations.

Product: Assessment of the snow data base for detecting climate change and for verifying climate models.

Approach: The conference is organized around five topics including ground based measurements, remote sensing, snow impact on climate, modeling snow and climate feedbacks and international cooperation.

Project Title:

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

Current Contract Period:
01/04/85-09/06/86

Funding: FY1985 345
FY1984 326
FY1983 310

Principal Investigator/s:

MADDEN, MICHAEL S.

Organization/s: MAXIMA CORPORATION

Objective: 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.

Product: The Maxima Corporation will support the Carbon Dioxide Research Division Director in planning and conducting program review meetings, conferences and workshops. This will entail communicating with CO_2 research contractors, coordinating activities and producing draft and final reports. MAXIMA will also perform technical editing of technical reports, state-of-the-art reports and 1985 Statement of Findings Report. In addition, they will assist in statistical analysis and assembling and compiling technical data and other information for the preparation of reports or other documentation.

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 are submitted to DOE for review. All logistics and administrative arrangements are closely coordinated with DOE staff.

Project Title:

SUPPORT OF THE BOARD ON OCEAN SCIENCE AND POLICY

Current Contract Period:
03/01/85-02/28/86

Funding: FY1985 15
FY1984 0
FY1983 0

Principal Investigator/s:

MAYNARD, NANCY C.

Organization/s: NATIONAL ACADEMY OF SCIENCES

Objective: To provide a better understanding of the capability of oceanographers to provide energy related information.

Product: A long-range national plan with supporting documentation on critical issues and priorities for studies in the oceans as well as recommendations for the programmatic and institutional implementation of the plan.

Approach: The National Academy of Sciences through its Board on Ocean Science and Policy will advise the U.S. agencies and serve as the National Research Council focal point for the consideration of ocean issues and will identify, consider and conduct studies on appropriate science and policy issues as well as respond to specific requests from federal agencies and private foundations. The Board will carry out the following activities that are of special interest to DOE:

- National Strategies for Ocean Science and Policy for the Year 2000
- Ocean Climate Research Committee
- Global Ocean Flux Study
- The Polar Oceans Climate Studies Panel
- International Ocean Science Policy Group
- Study of Methods for Defining the Outer Boundaries of the U.S. Continental Shelf and Their Policy Implications
- Effects of Human Activity on the Coastal Oceans
- Liaison and Report Publication

Project Title:

PARTIAL SUPPORT OF THE JOINT ASSEMBLY IAMAP/IAPSO

Current Contract Period:
11/1/84-10/31/85

Funding: FY1985 5
FY1984 0
FY1983 0

Principal Investigator/s:

SPILHAUS, A.F.,JR.

Organization/s: AMERICAN GEOPHYSICAL UNION

Objective: To assess the scientific status of large-scale atmospheric and oceanic processes, and their interactions.

Product: A joint assembly of the International Association of Meteorology and Atmospheric Physics and the International Association for the Physical Sciences of the Oceans which should attract approximately 1200 research scientists.

Approach: The American Geophysical Union will organize a joint assembly of the International Association of Meteorlogy and Atmospheric Physics and the International Association for the Physical Sciences of the Oceans to be held at the Hilton Hawaiian Village, Honolulu, August 5-16, 1985. The meeting will cover such areas as: the Southern Oscillation and El Nino; CO_2 in the Ocean/Atmosphere System; New Techniques for Monitoring the Ocean/Atmosphere System; Modeling the Global Ocean/Atmosphere System; Heat Transports-Heat and Water Budgets; Monsoon Circulations in Ocean and Atmosphere.

Project Title:

A WORKSHOP ON SPATIAL AND TEMPORAL VARIABILITY OF BIOSPHERIC AND GEOSPHERIC PROCESSES

Current Contract Period:
08/01/85-03/31/86

Funding: FY1985 5
FY1984 0
FY1983 0

Principal Investigator/s:

UMAN, M.

Organization/s: NATIONAL ACADEMY OF SCIENCES

Objective: To identify and describe research needed to solve problems of spatial and temporal scale associated with quantifying and interpreting interactions of the biosphere and geosphere in relation to global change.

Product: A report will be produced outlining key questions and approaches for addressing biospheric and geospheric processes of global change.

Approach: The workshop will be conducted by the Environmental Studies Board of the NAS/NRC Commission on Physical Sciences, Mathematics and Resources. Working with the U.S. National Committee of SCOPE and its international sponsor, ICSU, the workshop will bring together an international group of scientists of different disciplines to identify and describe research needed to solve problems of spatial and temporal scales related to the geosphere, biosphere and global change.

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 Four 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 uncertainities surrounding the data and research results of four research areas (i.e., carbon cycle, climate, vegetation and first detection). Two auxiliary reports will also be issued, one on indirect effects and a National Research Council, Polar Research Board report on sea level. Then, in 1986, 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_2 rather than definitive recommendations pertaining to amelioration policies and strategies.

Project Title:

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

Current Contract Period:
07/10/85-06/30/86

Funding: FY1985 120
FY1984 0
FY1983 0

Principal Investigator/s:

MADDEN, MICHAEL S.

Organization/s: MAXIMA CORPORATION

Objective: 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 seminars for researchers and other experts and carrying out special projects.

Product: The Maxima Corporation will support the Carbon Dioxide Research Division Director in planning and conducting small conferences and workshops emanating from the State-of-the-Art/Statement of Findings process. MAXIMA will also perform technical final editing the Statement of Findings Report. In addition, they will assist in statistical analysis and assembling and compiling technical data and other information for the preparation of reports or other documentation.

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 are submitted to DOE for review. All logistics and administrative arrangements are closely coordinated with DOE staff.

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_2 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_2

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_2

H. Management
   1. Program
   2. Area

II. **CO_2 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_2-Induced Climate Change
   1. Data Analysis
   2. Experimental Observations
   3. Monitoring

D. Analysis and Estimated Climate Change
   1. Analysis
   2. Estimated CO_2-Induced Climate Change

E. Management
   1. Program
   2. Area

III. **VEGETATION EFFECTS**

A. Response of Crops to CO_2
   1. Direct CO_2 Effects
   2. Yield Response
   3. Interactions of Nutrients and Water Use
   4. Crop Yield Models

B. Fundamental Effects of CO_2 on Plants
   1. Physiology
   2. Growth
   3. Plant Growth Models

C. Response of Ecosystems to CO_2
   1. Direct CO_2 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 AND 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
   2. Conferences

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** TBD

SUBJECT INDEX

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