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OAK RIDGE NATIONAL LABORATORY

MARTIN MARIETTA

Catalog of Data Bases and Reports

Environmental Sciences Division
Publication No. 3676

MANAGED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

ORNL/CDIAC--34/R1

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CARBON DIOXIDE INFORMATION ANALYSIS CENTER

CATALOG OF DATA BASES AND REPORTS

Environmental Sciences Division
Publication No. 3676

February 1991

Prepared by the
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MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
Carbon Dioxide Research Program
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INTRODUCTION

This booklet, *Catalog of Data Bases and Reports*, provides information about the many reports and other materials made available by the U.S. Department of Energy's Carbon Dioxide Research Program (CDRP). It is divided into six sections plus an author and a title index:

Section A - Research Plans and Budget Summaries
Section B - Technical Reports
Section C - Workshops, Proceedings, and Reports
Section D - Other Reports
Section E - USDA Reports on Response of Vegetation to Carbon Dioxide
Section F - Numeric Data Packages and Computer Model Packages

The reports in Section A provide information about the scope, activities, and direction of the CDRP. Sections B, C, and D contain information about research, workshops, symposia, and reviews that have been sponsored by CDRP. Section E describes reports about research in the joint program of the U.S. Department of Agriculture and CDRP.

The computer model packages (CMPs) and numeric data packages (NDPs) (described in Section F) have been compiled by CDRP's Carbon Dioxide Information Analysis Center (CDIAC). CMPs and NDPs include documents and magnetic tapes or floppy diskettes. The documentation provides complete descriptions of the data set, describes limitations and restrictions of the data, suggests data applications, provides tabular listings and graphical displays of the data, and includes reprints of pertinent literature. The magnetic tapes or floppy diskettes provide machine-readable data files, FORTRAN and SAS retrieval codes to read and print the data files, and descriptives file that explain the contents and format of each data file.

Catalog of Data Bases and Reports is updated as new reports and materials become available. These documents are distributed free of charge by CDIAC while supplies last. Documents in Sections A, B, C, D, and F (document only, no magnetic media) can also be purchased from the National Technical Information Service. Prices are determined by the number of pages in the publication.

Other materials and services are available including a semiannual publication, *CDIAC Communications*, which provides information about current CO_2 research, CDIAC services, and new CO_2-related publications and upcoming meetings. *CDIAC Communications* is distributed to about six thousand individuals. All persons interested in the CO_2-issue may ask to receive copies.

To fulfill information requests, CDIAC will provide documents listed in this booklet and use its other information sources. As one alternative source, CDIAC can provide the means for exchanging information among CDIAC and other information and data centers.

To request any of the materials listed in this booklet call or write:

Carbon Dioxide Information Analysis Center
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(615) 574-0390 or FTS 624-0390
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OMNET: CDIAC

SECTION A

RESEARCH PLANS AND BUDGET SUMMARIES

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RESEARCH PLANS AND BUDGET SUMMARIES

DOE/ER-0178 **THE CARBON DIOXIDE RESEARCH PLAN: A SUMMARY**
(November 1983)

Carbon Dioxide Research Division, U.S. Department of Energy

The purpose of this plan is to provide all present and potential participants in evaluating the carbon dioxide issue with a clear picture of the current scope and activities of the Department of Energy's Carbon Dioxide Research Program and the direction it is likely to take in the near future. The plan summarizes the goals, objectives, and approaches used in research on the carbon cycle, climate and first detection, vegetation responses, and indirect effects.

DOE/ER-0186 **CO_2 CLIMATE RESEARCH PLAN**
(December 1983)

M. R. Riches

This research plan, which is part of the U.S. Department of Energy's Carbon Dioxide Research Program, addresses the questions related to the global and regional rate of CO_2-induced climate change. The objective of the plan is to define the key questions in such a way that research is directed at experiments where answers are needed, rather than at experiments where answers can be easily obtained.

DOE/ER-0187 **VEGETATION RESPONSE TO CARBON DIOXIDE RESEARCH PLAN**
(January 1984)

R. C. Dahlman

This report summarizes the U.S. Department of Energy Carbon Dioxide Research Program's research plan on vegetation response to carbon dioxide. The plan includes a short history of the effects of CO_2 on vegetation followed by a description of the structure of the vegetation response system. The main part of the plan describes the research tasks within the system, and the final section summarizes the program priorities and scheduling.

DOE/ER-0188 **CARBON CYCLE RESEARCH PLAN**
(January 1984)

R. C. Dahlman

This report summarizes the carbon cycle research plan of the Carbon Dioxide Research Program of the U.S. Department of Energy. It includes a short history of atmospheric CO_2 levels and what is known about global carbon cycle exchanges. The main part of the plan describes the research tasks and the relationship and priorities of the components.

DOE/ER-0202 **CARBON DIOXIDE AND CLIMATE: SUMMARIES OF RESEARCH IN FY 1983 and FY 1984**
(September 1984)

Carbon Dioxide Research Division, U.S. Department of Energy

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

DOE/ER-0202/1 **CARBON DIOXIDE AND CLIMATE: SUMMARIES OF RESEARCH IN FY 1985**
(September 1985)

Carbon Dioxide Research Division, U.S. Department of Energy

This Program Summary documents the activities and products of the Carbon Dioxide Research Program in Fiscal Year 1985. It includes descriptions of all projects funded and a brief summary of the CDR Program's goals, objectives, and organization.

DOE/ER-0299 **CARBON DIOXIDE AND CLIMATE: SUMMARIES OF RESEARCH IN FY 1986**
(October 1986)

Carbon Dioxide Research Division, U.S. Department of Energy

This Program Summary documents the activities and products of the Carbon Dioxide Research Program in Fiscal Year 1986. It includes descriptions of all projects funded and a brief summary of the CDR Program's goals, objectives, and organization.

DOE/ER-0347 **CARBON DIOXIDE AND CLIMATE: SUMMARIES OF RESEARCH IN FY 1987**
(October 1987)

Carbon Dioxide Research Division, U.S. Department of Energy

This Program Summary documents the activities and products of the Carbon Dioxide Research Program in Fiscal Year 1987. It includes descriptions of all projects funded and a brief summary of the CDR Program's goals, objectives, and organization.

DOE/ER-0385 **CARBON DIOXIDE AND CLIMATE: SUMMARIES OF RESEARCH IN FY 1988**
(October 1988)

Carbon Dioxide Research Division, U.S. Department of Energy

This Program Summary documents the activities and products of the Carbon Dioxide Research Program in Fiscal Year 1988. It includes descriptions of all projects funded and a brief summary of the CDR Program's goals, objectives, and organization.

DOE/ER-0425 CARBON DIOXIDE AND CLIMATE: SUMMARIES OF RESEARCH IN FY 1989 (October 1989)

Carbon Dioxide Research Program, U.S. Department of Energy

This Program Summary documents the activities and products of the Carbon Dioxide Research Program in Fiscal Year 1989. It includes descriptions of all projects funded and a brief summary of the CDR Program's goals, objectives, and organization.

DOE/ER-0470T CARBON DIOXIDE AND CLIMATE: SUMMARIES OF RESEARCH IN FY 1990 (October 1990)

Carbon Dioxide Research Program, U.S. Department of Energy

This Program Summary documents the activities and products of the Carbon Dioxide Research Program in Fiscal Year 1990. It includes descriptions of all projects funded and a brief summary of the CDR Program's goals, objectives, and organization.

Four State-of-the-Art (SOA) volumes document what is known, unknown, and uncertain about CO_2 data, analyses, and modeling capabilities. They also outline potential avenues of research for reducing critical uncertainties. The four volumes are:

DOE/ER-0235 DETECTING THE CLIMATIC EFFECTS OF INCREASING CARBON DIOXIDE (December 1985)

M. C. MacCracken and F. M. Luther (eds.)
Lawrence Livermore National Laboratory

The objective of this volume is to document what is known about detecting the CO_2-induced changes in climate and to describe the uncertainties and unknowns associated with this monitoring and analysis effort.

DOE/ER-0237 PROJECTING THE CLIMATIC EFFECTS OF INCREASING CARBON DIOXIDE
(December 1985)

M. C. MacCracken and F. M. Luther (eds.)
Lawrence Livermore National Laboratory

This volume summarizes what is known about projections of the climatic effects of the increasing CO_2 concentration and describes the uncertainties and unknowns associated with such projections.

DOE/ER-0238 DIRECT EFFECTS OF INCREASING CARBON DIOXIDE ON VEGETATION
(December 1985)

B. R. Strain and J. D. Cure (eds.)
Duke University

This volume summarizes the current knowledge of the direct effects of increasing atmospheric CO_2 on vegetation and the subsequent effects on ecosystems.

DOE/ER-0239 ATMOSPHERIC CARBON DIOXIDE AND THE GLOBAL CARBON CYCLE
(December 1985)

J. R. Trabalka (ed.)
Oak Ridge National Laboratory

This volume focuses on the global cycle of carbon, the dynamic balance among global atmospheric CO_2 sources and sinks, which determines the rate of increase in the atmospheric CO_2 concentration.

In addition to the four SOAs are two companion volumes:

DOE/ER-0236 CHARACTERIZATION OF INFORMATION REQUIREMENTS FOR STUDIES OF CO_2 EFFECTS: WATER RESOURCES, AGRICULTURE, FISHERIES, FORESTS AND HUMAN HEALTH
(December 1985)

Margaret R. White
Lawrence Berkeley Laboratory

This companion volume to the SOAs establishes a baseline of knowns and unknowns and delineates the data and improvements in methodology required to estimate the impacts on humankind from increased atmospheric CO_2.

DOE/EV/60235-1 GLACIERS, ICE SHEETS, AND SEA LEVEL: EFFECT OF A CO_2-INDUCED CLIMATIC CHANGE
(September 1985)

Polar Research Board
National Research Council

This report summarizes the consensus of the Workshop on the Interactions between Land Ice and the Oceans (in Seattle, Washington, September 13-15, 1984), mentions areas of uncertainty, and makes recommendations for research.

DOE/ER-0316 MASTER INDEX FOR THE CARBON DIOXIDE RESEARCH STATE-OF-THE-ART REPORT SERIES
(March 1987)

M. P. Farrell (ed.)

This volume is a comprehensive citation and subject index for CDRD's four State-of-the-Art reports and the two companion volumes. This comprehensive subject index has been formatted in a matrix arrangement to graphically show the distribution of subject treatment in the six reports. A glossary of terms, tables, conversion factors and other aids are also included in this volume.

DOE/ER-0406 GLOBAL DISTRIBUTION OF TOTAL CLOUD COVER AND CLOUD TYPE AMOUNTS OVER THE OCEAN
December 1988

Carbon Dioxide Research Division, U.S. Department of Energy and
National Center for Atmospheric Research

These two oversized volumes (11 x 17 in.) are the third and fourth in a series of atlases that have resulted from a study of the global cloud distribution from ground-based observations. The first two atlases (NCAR/TN-201+STR and NCAR/TN-241+STR) described the frequency of occurrence of each cloud type and the co-occurrence of different types. They did not include any information on cloud amounts. The volumes cited here describe the average total cloud cover; the amounts of each cloud type; the clouds' geographic, diurnal, seasonal, and interannual variations; and the average base heights of the low clouds. One volume does all this for the land areas of the Earth, and the other for the ocean areas. The great preponderance of each of these two volumes is made up of maps displaying the data gathered with a resolution of 5° x 5°. About 30 pp. of each volume is taken up with a narrative description, discussion, and analysis of the data and of the means used to gather the data. Graphs of data are also presented on microfiche cards. The data plotted on the maps and other data contained in these atlases are available on magnetic tape from CDIAC as Numeric Data Package NDP-026.

DOE/ER-0411 ATMOSPHERIC CARBON DIOXIDE AND THE GREENHOUSE EFFECT
(May 1989)

Carbon Dioxide Research Program, U.S. Department of Energy

A popular guide to the greenhouse effect and its relation to atmospheric carbon dioxide concentrations. Discussions include comparison of the problems with the problems of acid rain and ozone loss, and the quantification of increases in atmospheric CO_2 effects on climate, vegetation, and sea level. Potential responses to these effects are discussed, and further information on all these topics identified.

DOE/ER-0441 ATMOSPHERIC RADIATION MEASUREMENT PROGRAM PLAN
February 1990

Atmospheric and Climate Research Division, Office of Health and Environmental Research, U.S. Department of Energy

Scientists from the DOE National Laboratory community contributed to the preparation of the ARM Program Plan with input from members of the academic community, the private sector, and from scientists from other Committee on Earth Sciences (CES) agencies. The Plan was subjected to an extensive peer review and the many helpful comments we have received have been incorporated into this document. We believe that ARM will serve the CES objectives in Global Change research and support the DOE mission of formulating a National Energy Strategy that takes into account the potential for global climate change.

DOE/ER-0442 ATMOSPHERIC RADIATION MEASUREMENT PROGRAM PLAN, EXECUTIVE SUMMARY
February 1990

Atmospheric and Climate Research Division, Office of Health and Environmental Research, U.S. Department of Energy

Scientists from the DOE National Laboratory community contributed to the preparation of the ARM Program Plan with input from members of the academic community, the private sector, and from scientists from other Committee on Earth Sciences (CES) agencies. The Plan was subjected to an extensive peer review and the many helpful comments we have received have been incorporated into this document. We believe that ARM will serve the CES objectives in Global Change research and support the DOE mission of formulating a National Energy Strategy that takes into account the potential for global climate change.

DOE/ER-0479T BUILDING AN ADVANCED CLIMATE MODEL
PROGRAM PLAN FOR THE CHAMMP CLIMATE MODELING PROGRAM
(December 1990)

Atmospheric and Climate Research Division, Office of Health and Environmental Research, U.S. Department of Energy

The program has two aspects that are inescapably coupled and must be conducted in an increasingly comprehensive series of coordinated projects. First, advanced climate models must be developed that dramatically increase the computational throughput of climate model simulations by combining state-of-the-science supercomputing systems with advances in numerical methods and model physics. These new generation models

must be used to address three critical problems: more accurate prediction of regional climatic changes that may occur over decadal to centennial periods, determination of the limits to climate predictability imposed by the inherent variability of climate as a dynamic system, and development of realistic schedules for achieving improved predictions of climatic change.

SECTION B

TECHNICAL REPORTS

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TECHNICAL REPORTS

TR001 ON POSSIBLE CHANGES IN GLOBAL SEA LEVEL AND THEIR POTENTIAL CAUSES (DOE/NBB-0022, November 1982, 49 p.)

T. P. Barnett
Scripps Institution of Oceanography

The purpose of this paper is to review the behavior of global sea level over the last century. This analysis of global sea level avoids the space and time bias of previous works. Between 1903-1969, a coherent pattern of increasing relative sea level (RSL) was found to exist on average at all stations analyzed. Subject to numerous assumptions, RSL increase associated with this pattern was 15 cm/century. A similar analysis of the period 1930-1975 again showed RSL increasing everywhere except in the western half of the North Pacific Ocean in which a decrease was found. This decrease in RSL is substantiated further by hydrographic data. Thus, in recent years, the concept of a global sea level rise is not supported. The temporal behavior of the near global signals from both time periods was approximated well by a simple linear trend. There was no evidence of a more rapid rise in RSL in recent years.

In this analysis, potential causes of the above RSL change were investigated. Changes in the position of the earth's axis of rotation support the idea that the RSL change was caused by approximately equal melting of Greenland/Antarctica ice. Changes in the length of day only marginally support this idea. However, other attractive geophysical explanations for variations in both these astronomical parameters exist. Observed change in sea surface temperature (SST), if representative of reasonable changes in vertical thermal structure, could give the observed RSL change. However, the SST data are likely biased instrumentally toward an increasing trend. Also, thermal expansion of the oceans would not significantly affect the rotational parameters although changes in these parameters could be the result of non-RSL related processes. Changes in ocean circulation and subsidence along all the coastal margins seem unlikely causes of the observed change in RSL. In summary, it is not possible at this time to explain reliably the apparent increase in RSL.

TR002 EFFECTS OF APPROXIMATE RADIATION TREATMENTS USED IN THE CLIMATE MODELS ON THE CLEAR SKY THERMAL RADIATION FLUX AND ITS PERTURBATION DUE TO CO_2 INCREASE (DOE/ER/60023-1, January 1983, 41 p.)

W.-C. Wang
Atmospheric and Environmental Research, Inc.

This report presents an assessment of the effects of approximate radiation treatments, which are commonly adopted in climate models, on the calculated thermal radiation flux, and of the effect of the approximations on the flux's perturbation due to CO_2 increase.

In this assessment, the uncertainties in the calculated clear sky thermal flux associated with the approximations (Curtis-Godson and correlated-k methods) for inhomogeneous atmosphere, the use of exponential kernel (diffusivity factor) approximation, the treatment of model layer temperature (constant and linear Planck function), and the representation (narrow and wide band) for the correlation of spectral features between the overlapping gases and the Planck function are examined.

The results indicate that for an inhomogeneous atmosphere the correlated-k method calculates nearly identical flux and flux perturbation as those computed using the Curtis-Godson method. The results also suggest that the use of a diffusivity factor (1.66) to represent the zenith angle integration is appropriate for CO_2 thermal radiation calculations.

However, the narrow band representation which accounts for the correlation of spectral features tends to calculate a smaller atmospheric opacity than the wide band representation which neglects such a correlation. As a result, the latter computes a much larger downward flux at surface as well as its increase due to CO_2 increase. It is also found that the calculated thermal flux is very sensitive to the treatment of model layer temperature.

TR003 CARBON DIOXIDE EMISSIONS FROM FOSSIL FUELS: A PROCEDURE FOR ESTIMATION AND RESULTS FOR 1950-1981
(DOE/NBB-0036, June 1983, 75 p.)

G. Marland and R. M. Rotty
Oak Ridge Associated Universities
Institute for Energy Analysis

The purpose of this report is to provide detailed documentation for a procedure to estimate CO_2 emissions from fossil fuels and to make independent and updated estimates of the rate at which fossil fuel combustion has released carbon dioxide into the atmosphere.

With new data and revised methods, an attempt is made to reduce the uncertainties. For each type of fuel, the annual global CO_2 emissions are the product of three terms: the amount of fuel produced, the fraction of the fuel that becomes oxidized, and a factor for the carbon content of the fuel.

An important outcome of this independent examination of the full computation of CO_2 emissions from fossil fuels is that no fundamental oversights in the earlier methods of Keeling and of Rotty were discovered. An additional result of this examination is estimates of the uncertainties in the final numbers. The largest absolute uncertainty enters the computation with the United Nations data set for fuel production but even here global fuel production is dominated by a small number of countries, most of which are believed to maintain and publish good statistical records. Although the estimated uncertainty in the CO_2 emissions is about 10 percent, the trend of increasing emissions from fossil fuels is firmly established.

TR004 CARBON IN LIVE VEGETATION OF MAJOR WORLD ECOSYSTEMS
(DOE/NBB-0037, June 1983, 152 p.)

J. S. Olson, J. A. Watts, and L. J. Allison
Oak Ridge National Laboratory

The objectives of this research were to make a computer generated world map of vegetation and carbon density for natural and modified ecosystem complexes and to illustrate some human influences on the global carbon cycle. A data base was compiled to make a seven color ecology map (1:30,000,000 near the equator) of 44 land ecosystem mosaics or subdivisions in seven broad groups: Forest and Woodland; Interrupted Woods; Mainly Cropped, Residential, Commercial, and Park; Grass and Shrub Complexes; Tundra and Desert; Major Wetlands; and Other Coastal, Aquatic, and Miscellaneous.

The map provides a basis for making improved estimates of vegetation areas and carbon quantities, natural biological exchanges of CO_2, and net historic shifts of carbon between the biosphere and the atmosphere. It is derived from the patterns of preagricultural vegetation or potential vegetation types and their relation to carbon content and from modern aerial surveys and intensive biomass data from research sites. Ecosystem complexes are defined and located (with a 0.5° x 0.5° grid) to reflect the major climatic, topographic, and land-use patterns.

Estimates of biomass in trees and total carbon in live plants per unit are tabulated. The results help define the role of the terrestrial biosphere in the global carbon cycle. Results also imply major historic reductions of global carbon for broad regions and most vegetation types. Lowered estimates of carbon caused by forest harvest or clearing for crops in the last century imply lowered estimates of input of nonfossil CO_2 to the atmosphere. The map of Major World Ecosystem Complexes indicates where some of the recent and future changes of organic carbon are most likely: in tree formations and wetlands where wood or peat reserves are still high in some of the interrupted woods where recent land-use transition rates have been high. Refinement and use of the map and its associated data bases continue in research, for example, on flux estimates for fire, forest clearing, and other carbon exchanges in models of the global carbon cycle.

TR005 **DEFORESTATION MEASURED BY LANDSAT: STEPS TOWARD A METHOD (DOE/EV/10468-1, June 1983, 62 p.)**

G. M. Woodwell, J. E. Hobbie, R. A. Houghton, J. M. Melillo, B. J. Peterson, G. R. Shaver, and T. A. Stone
The Ecosystems Center, Marine Biological Laboratory

B. Moore
Complex Systems Research Center, University of New Hampshire

A. B. Park
The Space Systems Division, General Electric Company

The increase in atmospheric CO_2 over the past century is due in part to deforestation. The LANDSAT system appears to have the potential for providing objective, synoptic and repetitive information on rates of clearing of forests globally. The purpose of this work was development of a method for using the LANDSAT system to determine net change in the area of forests, and therefore in the amount of carbon held in terrestrial systems, globally. Three approaches to the use of LANDSAT data for this purpose seemed possible. First, if a sufficiently detailed classification of a vegetation can be made from a single LANDSAT image, an estimate of net flux is possible through use of the model. This is the single image approach. Second, LANDSAT imagery might be used to construct two classification inventories of the amount of carbon in the vegetation at different dates. Finally, the technique of change detection using satellite imagery might be applied by subtracting the digital information in a later image from a former image to produce a third data set that records only the changes. It is, of course, these changes that are the objective.

The change detection method holds the greatest promise because it reduces the problems of misclassification evident in the single and double inventory methods. The method was simplified further by establishing the criteria of change as two gross changes, that from forest to non-forest, and that from non-forest to forest. The problems of classification of imagery have thereby been reduced to little more than detection.

A system of sampling was suggested for a global survey. Sampling would be stratified to favor areas where changes are abundant. Thirty-nine countries or states within countries account for 90% of published estimates of deforestation in the tropics and subtropics. To cover these countries once by LANDSAT requires about 1,200 scenes. Further stratification within countries can be based on zones or fronts of intense deforestation. LANDSAT imagery required to cover these zones is about 500 scenes. Since current estimates of deforestation in the tropics may vary by 600%, a reduction of the uncertainty to +/- 10% may be a greater improvement than is appropriate. If an uncertainty of +/- 25% were acceptable, the required sample for the important tropical countries and for the fronts of deforestation would be 360 and 75 scenes, respectively. The cost of a five year program designed to reduce the uncertainty to +/- 25% was estimated as 4 to 7 million dollars for data and imagery analysis.

TR006 RESPONSE OF THE NORTH AMERICAN CORN BELT TO CLIMATE WARMING (DOE/NBB-0040, August 1983, 27 p.)

T. J. Blasing and A. M. Solomon
Oak Ridge National Laboratory

This report explains the projections of the influence of a climatic change on the location of the North American corn belt. The climate of this corn belt was characterized to estimate the effects of climatic change on that agricultural region. Heat and moisture characteristics of the current corn belt were identified and mapped based on a simulated climate for a doubling of atmospheric CO_2 concentrations. The result was a map of the projected corn belt corresponding to the simulated climatic change. Such projections were made with and without an allowance for earlier planting dates that could occur under a CO_2-induced climatic warming. Because the direct effects of CO_2 increases on plants, improvements in farm technology, and plant breeding are not considered, the resulting projections represent an extreme or "worst" case.

The results indicate that even for such a "worst" case, climatic conditions favoring corn production would not extend very far into Canada. Climatic "buffering" effects of the Great Lakes would apparently retard northeastward shifts in corn-belt location.

Changes in timing of annual climatological events are important to crop responses, but little is currently known about these phenomena. Timing is thus a major source of uncertainty in specifying agricultural responses to climatic change.

TR007 AN ANALYSIS OF CONCEPTS FOR CONTROLLING ATMOSPHERIC CARBON DIOXIDE (DOE/CH/00016-1, December 1983, 66 p.)

M. Steinberg
Brookhaven National Laboratory

This report reviews and analyzes possible mitigating technologies and processes for the control of the CO_2 effect. This analysis addresses the mitigation of the CO_2 effect mainly by controlling the CO_2 content in the atmosphere. As such, the steps involve either restriction of emission, or the removal, recovery, disposal, and reuse of CO_2.

TR008 CARBONATE CHEMISTRY OF THE WEDDELL SEA
(DOE/EV/10611-4, March 1984, 118 p.)

C.-T. A. Chen
College of Oceanography, Oregon State University

Concurrent pH, calcium, and total alkalinity data were obtained in the eastern Weddell Sea during the winter of 1981. These data represent the initial concentrations of calcium, alkalinity, and total CO_2 in the most important source region of world ocean bottom waters at the time they were formed. For the first time, an evaluation of the variation of calcium and carbon cycles in the deep oceans referenced to the source water were made. The data were analyzed together with data from the literature, and the results indicated that: (1) the October pH values south of the Polar Front are indistinguishable from the November values, but the seasonal effect is large north of the front; (2) a large change in pH occurs at the ice edge; (3) partial pressure of CO_2 in the Weddell Sea surface water is only slightly lower than the atmospheric value; (4) alkalinity does not show cross-ice-edge or seasonal variations, but the values seem to increase at a slower rate with decreasing temperature south of the Polar Front; (5) sea ice is relatively high in calcium and alkalinity concentrations; (6) mixing dominates the distribution of chemical properties; (7) pH is useful in identifying the sources of waters in the Weddell Sea, whereas calcium and alkalinity are not; (8) the surface water is deficient in CO_2 from human activities because the pack ice blocks the air-sea exchange of gases; and (9) little excess CO_2 can be found in the Antarctic Bottom Water. The situation may change, however, if the Weddell Sea ice coverage is reduced because of CO_2-induced global warming.

[The data set is available on tape (NDP-028) from the Carbon Dioxide Information Analysis Center at Oak Ridge National Laboratory.]

TR009 RESPONSE OF UNMANAGED FORESTS TO CO_2-INDUCED CLIMATE CHANGE: AVAILABLE INFORMATION, INITIAL TESTS, AND DATA REQUIREMENTS
(DOE/NBB-0053, April 1984, 93 p.)

A. M. Solomon, M. L. Tharp, D. C. West, G. E. Taylor, J. W. Webb, and J. L. Trimble
Oak Ridge National Laboratory

In this report, the scientific literature is reviewed to determine how tree recruitment, growth, and mortality are related to climate directly and indirectly through climate's modulation of plant competition, succession, and migration. The resulting potential responses of forest communities to climate changes expected under increased atmospheric CO_2 concentrations are described. Empirical data sets, containing measurements of climate variables and tree densities in the eastern United States, are evaluated for their potential use in statistical projections of forest responses to climate change. Also evaluated for projection purposes is a forest-stand simulation model based on many of the processes that determine forest dynamics. The ability of the model to reproduce extant forests at 21 sites in eastern North America was first verified. Then, a model experiment simulated responses of forests at those 21 locations to a scenario in which climate responds to doubling and quadrupling of CO_2. The implications of the forest simulations are discussed in terms of internal forest dynamics and requirements for specified information from climate projections, as well as for additional model developments that could address remaining ecological uncertainties.

TR010 COMPUTER IMPLEMENTATION OF A GLOBALLY AVERAGED MODEL OF THE WORLD CARBON CYCLE
(DOE/NBB-0062, July 1984, 79 p.)

W. R. Emanuel, G. G. Killough, W. M. Post, and H. H. Shugart
Oak Ridge National Laboratory

M. P. Stevenson
Science Applications, Inc.

A model of the global carbon cycle and its computer implementation are described in this report. Three major components of the cycle - the atmosphere, oceans, and terrestrial ecosystems - are represented. The dynamics of total carbon (i.e., mass of ^{12}C + ^{13}C and ^{14}C), and the two less abundant isotopes, ^{13}C and ^{14}C, are treated. The model equations are derived from a compartment diagram of the cycle by expressing mass balance for each compartment as a first-order differential equation. The atmosphere is represented by a single compartment and the oceans by 19 globally-averaged layers with depth. Carbon in terrestrial ecosystems is divided among five compartments. The model simulates phenomena on time scales from several years to several centuries. Carbon dioxide released to the atmosphere by fossil fuel combustion and ^{14}C produced naturally in the atmosphere or by nuclear weapons tests are incorporated as exogenous inputs. Forest clearing results in a direct transfer of carbon to the atmosphere to "trees" and "ground vegetation" are altered as a result of land-use change.

The model is implemented in FORTRAN. Readily available routines are used for standard numerical procedures. The model does not access exogenous data sets; parameter values and control variables are set in data initialization statements. Tabulated results are provided as printed output.

TR011 HISTORICAL CARBON DIOXIDE: ABUNDANCES DERIVED FROM THE SMITHSONIAN SPECTROBOLOGRAMS
(DOE/NBB-0063, August 1984, 114 p.)

G. M. Stokes, J. C. Barnard, and E. W. Pearson
Pacific Northwest Laboratory

This report describes results of the analysis of the Smithsonian Solar Constant Program spectroscopic data to determine atmospheric CO_2 concentrations before 1958. A representative sample of Smithsonian Spectrobolograms were analyzed for 1935, 1941, and 1948. The resulting carbon dioxide concentrations for those years were 297.7 +/- 5.6, 298.4 +/- 6.3, and 308.3 +/- 4.6 ppm, respectively. These results also yield an annual increase of 0.59 +/- .27 ppm for the average trend for the period of 1935 through 1948.

The method of analysis used to obtain these results is described in detail. It appears to be much less sensitive to the sources of error that have plagued earlier analyses of the same data. The results also offer obvious guidance on steps that may be taken to improve the analysis of the data.

TR012 SEASONAL CLIMATE SCENARIOS FOR EUROPE AND NORTH AMERICA IN A HIGH-CO_2 WARMER WORLD
(DOE/EV/10098-5, August 1984, 70 p.)

J. P. Palutikof, T. M. L. Wigley, and J. M. Lough
University of East Anglia, Norwich, UK

This report presents work done to determine possible patterns of climate change in Europe and North America associated with a global CO_2-induced warming. The scenarios presented are based on warm and cold periods from the twentieth-century instrumental record. Four sets of scenarios were prepared, each using different criteria for the selection of data used in the construction process. One of these sets is based on twenty-year time-scale data from the period of warming that occurred during the early twentieth century. Since this warming may be partly attributed to increasing CO_2, and since the warming effect of CO_2 is a medium to long time scale phenomenon, this particular scenario is preferred over the others.

The regional patterns of three surface parameters are discussed for the different scenarios: sea level pressure, temperature, and precipitation. Contrasts that arise between the scenarios because of differences in the construction method are critically examined. Where the construction process allows, maps are also presented of the change in temperature and rainfall variability.

Although contrasts do occur between the patterns of the four scenarios for Europe, there are also some notable similarities. Winters are expected to become colder (and more variable) over large parts of the continent. This cold zone is associated with an increase in blocking frequency. Rainfall should decrease overall in spring and summer, whereas autumn and winter should be wetter in a warm world. The changes for both temperature and rainfall can be related to the scenario pressure patterns.

The North American scenarios for temperature and pressure exhibit much less inter-seasonal contrast than is the case for Europe. Temperatures are shown to be generally higher throughout the year in a warm world. Of the three scenarios for which temperature maps are presented, only that based on long time scale changes during the early twentieth century warming shows any extensive development of cooler conditions over continental areas. Temperature variability should be lower. North America shares with Europe indications that winters will be wetter, but autumns are expected to be mainly drier.

TR013 AN ANALYSIS OF POSSIBLE FUTURE ATMOSPHERIC RETENTION OF FOSSIL FUEL CO_2
(DOE/OR/21400-1, September 1984, 109 p.)

J. A. Edmonds and J. Reilly
Institute for Energy Analysis

J. R. Trabalka and D. E. Reichle
Oak Ridge National Laboratory

This report discusses the probable rates and potential range of future CO_2 emissions and estimates a range of future atmospheric CO_2 concentrations through the year 2075. Historic fossil fuel usage to the present, increasing at a rate of 4.5% per year until 1973 and at a slower rate of 1.9% after 1973, was combined with three scenarios of projected emissions growth

ranging from about 0.2 to 2.8% per year to provide annual CO_2 emissions data for two different carbon cycle models. The emissions scenarios were constructed using an energy-economic model and by varying key parameters within the bounds of currently expected future values. The extreme values for CO_2 emissions in the year 2075 of about 500 to 1500 ppm, with a median of about 700 ppm. The time at which atmospheric CO_2 would potentially double from the preindustrial level ranges from year 2025 to >2075. The practical programmatic value of this forecast exercise is that it forces quantitative definition of the assumptions and the uncertainties, which are the basis for understanding the natural biogeochemical cycle of carbon and both historic and future human influences on the dynamics of the global cycle. Assumptions about the possible range of future atmospheric CO_2 levels provide a basis on which to evaluate the implications of these changes on climate and the biosphere.

TR014 **THE CHANGING PATTERN OF FOSSIL FUEL CO_2 EMISSIONS**
(DOE/OR/21400-2, September 1984, 24 p.)

R. M. Rotty, G. Marland, and N. Treat
Institute for Energy Analysis

This report analyzes the fossil fuel CO_2 emissions from developing nations of the world compared with emissions from developed nations during the past three decades. The world was divided into six fuel-consuming regions (North America; Western Europe; U.S.S.R. and eastern Europe; Japan, Australia, and Oceania; Asian countries with centrally planned economies; and developing countries) and CO_2 emissions were calculated from U.N. data on fuel consumption.

Emissions from developing nations have been increasing at a higher rate than those from the developed world. Developing nations do not show the reduction in growth rate of CO_2 emissions that occurred for North America, western Europe, and Japan after 1973. Discontinuities evident for the People's Republic of China appear to coincide with times of major change in governmental policies.

For the next few decades, increases in atmospheric CO_2 concentrations will be largely determined by fuel policies in the developed nations of the world. However, before the middle of the next century, fuel policies of the rapidly growing nations will become extremely important, if not dominant, in the world CO_2 picture.

TR015 **A PROPOSED REFERENCE SET OF SCENARIOS FOR RADIATIVELY ACTIVE ATMOSPHERIC CONSTITUENTS**
(DOE/NBB-0066, October 1984, 51 p.)

D. J. Wuebbles, M. C. MacCracken, and F. M. Luther
Lawrence Livermore National Laboratory

The development of reference scenarios for coordinated scientific investigations of the effects of man-made trace species emissions necessary both for model intercomparisons and governmental decision-making is needed. The species that should be considered include; CO_2, chlorocarbons,

stratospheric ozone, tropospheric ozone, methane, nitrogen oxides, nitrous oxide, tropospheric aerosols, carbonaceous and other light-absorbing aerosols, stratospheric aerosols, carbon monoxide, hydrocarbons, and water vapor.

This report proposes a set of scenarios for past and future concentrations of radiatively active atmospheric constituents. The following concentrations may be reached in the next century: CO_2, 340 to 680 ppmv; CH_4, 1.7 to 3.4 ppmv; N_2O, 302 ppbv to 375.5 ppbv; CFC-11, 0 to 744.8 pptv; and CFC-12, 0 to 1789.5 pptv. The report stresses the major uncertainties underlying our understanding of the budgets of the species and the uncertainties in projecting future changes in societal and economic actions. The scenarios are intended to promote discussion leading to generally accepted sets of scenarios that can serve not as a forecast, but as a reference for all research groups using the continental and global-scale chemical interactions and climatic effects of these concentrations.

TR016 **A SYSTEMS STUDY FOR THE REMOVAL, RECOVERY AND DISPOSAL OF CARBON DIOXIDE FROM FOSSIL FUEL POWER PLANTS IN THE U.S.**
(DOE/CH/00016-2, December 1984, 76 p.)

M. Steinberg, H. C. Cheng, and F. Horn
Brookhaven National Laboratory

The U.S. contributes about 30% of the world's total man-made CO_2 emissions; utilities are responsible for about 30% of the U.S. total. This report summarizes research on the removal, recovery, and disposal of CO_2 from U.S. utilities as one option for preventing the "global greenhouse effect."

The removal and recovery system evaluated in this report is based on an absorption/stripping system using an improved stack gas scrubbing solvent. The recovered CO_2 is then liquefied for transmission to the ultimate disposal site. The CO_2 control process is integrated with the power plant operation in that low-pressure steam from the power-generating turbines is used to regenerate the solvent. For 90% removal of CO_2, the efficiency of the power plant is reduced from the conventional 38% to a value of 35%. Three methods of disposal are discussed: (1) injection into the 500-m-deep ocean below the thermocline, about 100 miles off the U.S. coastal waters; (2) storage in depleted oil and gas wells; and (3) storage in excavated salt caverns.

The report recommends evaluating this type of control system in other nations that are major CO_2 contributors. It is estimatedthat the worldwide application of a CO_2 control system could reduce the annual incremental CO_2 concentration by as much as 32%.

TR017 **A CLIMATIC DATA BANK FOR NORTHERN HEMISPHERE LAND AREAS, 1851-1980 (DOE/EV/10739-2, January 1985, 335 p.)**

R. S. Bradley
University of Massachusetts

P. M. Kelly, P. D. Jones, and C. M. Goodess
University of East Anglia, Norwich, UK

H. F. Diaz
NOAA/ERL

A necessary prerequisite for studies of climatic fluctuations and the causes of climatic variability is a comprehensive set of long-term climatic data for as wide an area as possible. This report documents a new compilation of long-term temperature and precipitation station data for the Northern Hemisphere. The authors surveyed libraries, archives, and data centers to obtain climate data to supplement and improve existing data banks. While the authors report long-term data on mean monthly temperatures and monthly precipitation totals, the primary focus is on the former.

More than 700 temperature and 120 precipitation records extending back into the 19th Century have been incorporated into the data bank. Problems that contribute to potential inconsistencies in the records are discussed (particularly changes in methods of computing mean daily temperature). The temperature data have been used in producing a gridded set of departures from a reference period (1946-1960). The authors discuss problems associated with changes in spatial data coverage with reference to the computation of the "hemispheric" average temperature through time.

[The data set is available on tape (NDP-012) from the Carbon Dioxide Information Analysis Center at Oak Ridge National Laboratory.]

TR018 **A GLOBAL PALEOCLIMATIC DATA BASE FOR 6000 YEAR B.P. (DOE/EV/10097-6, February 1985, 155 p.)**

T. Webb, III
Brown University

The testing of climate-model simulations for past climates requires subcontinental to global maps of paleoclimatic data. Such maps reveal the magnitude and pattern of climatic variables at enough model grid-points that useful comparisons are possible. This report documents a global data base of pollen, lake-level, and marine plankton data for 6000 year B.P. (the mid-Holocene period); a total of 797 stations are included. This data base provides a core of paleoclimatic information for 6000 year B.P. to which other sources such as ice cores, paleodunes, paleosols, and fluvial geomorphology data can be added.

Pollen data record the broad-scale vegetational patterns that are related to climate. Lake-level data record the relative water depth in lakes and thus provide records of past changes in moisture. Marine plankton data contain information about the geographic distribution of plankton, which (like vegetation) reflect climatic patterns.

Pollen data are available from eastern North America, Alaska, Europe, the Soviet Union, South America, and New Zealand. Lake-level data exist for Australia, Africa, southwestern Asia, western North America, eastern North America, and South America. Marine plankton data are mainly available from the North Atlantic and northwestern Indian Oceans, but isolated samples exist for the Pacific and Southern Oceans.

Estimated temperature values are presented for eastern North America, Europe, and the ocean samples. Precipitation is estimated for central North America and isolated sites in India and Africa. The data are displayed on maps, and the site locations and other descriptive information are tabulated.

[The data set is available on tape (NDP-011) from the Carbon Dioxide Information Analysis Center at Oak Ridge National Laboratory.]

TR019 CARBON DYNAMICS OF NORTHERN HARDWOOD FORESTS: GAS EXCHANGE CHARACTERISTICS
(DOE/EV/10091-1, February 1985, 70 p.)

T. W. Jurik, G. M. Briggs, and D. M. Gates
University of Michigan

There is considerable interest in the response of plants to increased mole fractions of CO_2 in the atmosphere. The objective of the research reported in this document is to quantify the carbon dynamics of northern hardwood forests and to predict the response of these forests to changing environmental conditions in the future, particularly to increases in CO_2 levels. This report presents studies of physiological responses in relation to environment, based on field studies at five sites at the University of Michigan Biological Station near Pellston, Michigan.
Leaf CO_2 exchange and conductance for water vapor were measured in situ using a mobile laboratory. Measurements of leaf conductance for water vapor were also made with a portable porometer. Leaf water potential was measured in the field with a Scholander-type pressure bomb. Photosynthesis; leaf CO_2 exchange rate (CER); leaf conductance; transpiration; water use efficiency (WUE); leaf water potential; gas exchange of leaves, stems, and twigs; and soil respiration were studied.

The optimal temperature for CER was 23 to 25C for leaves growing in the sun and 20 to 24C for those growing in the shade. In saturating CO_2 and saturating light, the temperature optimum for CER shifted upward to 33 to 38C, and maximum CER was more than doubled. Red oak, red maple, and big-tooth aspen have increased WUE in high CO_2.

There is now considerable information on variation in CER and photosynthetic capacity of a single leaf with environmental conditions. Variation among leaves in a given microenvironment and among different microenvironments is known for several physiological characteristics. Variation as a function of habitat (e.g., site fertility) is less understood.

TR020 RECONSTRUCTION OF PAST ATMOSPHERIC CO_2 CONTENTS FROM THE CHEMISTRY OF THE CONTEMPORARY OCEAN: AN EVALUATION
(DOE/OR-857, March 1985, 79 p.)

W. S. Broecker, and T. Takahashi
Lamont-Doherty Geological Observatory

T.-H. Peng
Oak Ridge National Laboratory

This report summarizes attempts to reconstruct the CO_2 using contemporary ocean data. Although a beautiful idea, this approach becomes a geochemical nightmare because the uncertainties in the reconstructions will always be larger than the uncertainties ultimately available from other approaches (e.g., ice cores and carbon 13 records). Thus, the value of the ocean data lies in understanding oceanic processes rather than in reconstructing past atmospheric CO_2 contents. When the history of atmospheric CO_2 has been reconstructed from ice core CO_2 and carbon 13 records, then the ocean distribution of CO_2 can be used to constrain some of the current uncertainties in models of the uptake of fossil fuel CO_2 by the ocean.

TR021 A TWO DIMENSIONAL CO_2-OCEAN MODEL INCLUDING THE BIOLOGICAL PROCESSES
(DOE/NBB-0070, May 1985, 33 p.)

C. F. Baes, Jr. and G. G. Killough
Oak Ridge National Laboratory

The purpose of the research reported in this document was to develop a 2-dimensional ocean model that includes biologically controlled processes (photosynthesis and calcium carbonate precipitation) to (1) determine if these processes can be represented with sufficient simplicity to permit rapid computation of the steady-state distribution of carbon in a many-box model, and (2) to conduct various time-integrations from the steady-state initial condition to examine how the response to increasing atmospheric CO_2 depends on the forcing of the model. The authors' approach differs from previous approaches in that (1) they model half a world ocean as a single water volume extending from the equator toward one pole and (2) they describe the flow of water between boxes in the idealized ocean in terms of a small number of parameters with the dimension of diffusivities.

Atmospheric carbon content depends on photosynthesis and the concentration of nutrients, a finding consistent with earlier estimates from one-dimensional models. The effects of circulation rate and warming are secondary. The rate of uptake by the model ocean at any given time in the past is found to vary linearly with the excess carbon in the ocean and in the atmosphere; this suggests that the current rate of carbon uptake by the real oceans may be strongly affected by the forcing that occurred over the previous century or so, and that a model cannot be tested against the current response of the oceans unless the excess carbon taken up in past years can be determined. While the airborne fraction (AF) of excess carbon (airborne + oceanic) in the years just after 1980 depends on previous history, integrating to the year 2100 shows that AF becomes more dependent on total excess carbon and its rate of growth. For the rapid-release scenario, AF reaches values greater than 0.8 by the year 2100.

TR022 **A GRID POINT SURFACE AIR TEMPERATURE DATA SET FOR THE NORTHERN HEMISPHERE**
(DOE/EV-10098-2, July 1985, 251 p.)

P. D. Jones, S. C. B. Raper, B. Santer, B. S. G. Cherry, C. Goodess, P. M. Kelly, and T. M. L. Wigley
University of East Anglia, Norwich, UK

R. S. Bradley
University of Massachusetts

H. F. Diaz
NOAA/ERL

This report consists of a compilation of 2,666 station records of monthly surface-air temperatures for the Northern Hemisphere. To use these data to form a gridded data set for the Northern Hemisphere the homogeneity of each of these records, where provided, was assessed. The results of this assessment are presented in the report and stations are classed as immediately usable, corrected, or uncorrectable. Full details of how this was achieved for each station are presented in tabular form. Of the 2,666 station records, 1,584 were used to produce the gridded temperature data set. Temperature anomalies were calculated for monthly means for the reference period 1951-70 using the homogenized data. Anomalies at each point of a 5° latitude by 10° longitude grid were interpolated from the station data for each month for the period 1851 to 1984.

[The data set is available on tape (NDP-020) from the Carbon Dioxide Information Analysis Center at Oak Ridge National Laboratory.]

TR023 **THE EFFECT OF ELEVATED ATMOSPHERIC CO_2 ON PLANT COMMUNITIES**
(DOE/EV/04329-5, July 1985, 39 p.)

F. A. Bazzaz, K. Garbutt, and W. E. Williams
Harvard University

This report summarizes exploratory research on the effects of elevated carbon dioxide concentrations on the growth of a variety of ecologically important plants. Although the plant responses were subtle and complex, the following broad conclusions could be drawn from the study:

1. Different species showed different degrees of growth enhancement, suggesting that competition relationships may have changed.

2. Flowering and fruiting did not always change to the same degree, or even in the same direction, as total plant weight. Thus, experiments not carried through to fruit maturity can lead to incorrect conclusions.

3. Because of fruiting and flowering changes, some effects from exposure to increased carbon dioxide concentrations were not completed for several generations. Thus, evolutionary changes in the characteristics of the individual species may be expected.

4. Elevated carbon dioxide can have a slight protective effect against other pollutants.

TR024 METHODS OF UNCERTAINTY ANALYSIS FOR A GLOBAL CARBON DIOXIDE MODEL
(DOE/OR/21400-4, July 1985, 41 p.)

R. H. Gardner and J. R. Trabalka
Oak Ridge National Laboratory

This report describes the results of applying Monte Carlo methods of uncertainty analysis to Oak Ridge National Laboratory's World Carbon Cycle Model to examine the time-dependent variability of predicted values of atmospheric carbon dioxide and relate them to uncertainties associated with model parameters. The report presents the details of the statistical methods used to reveal significant relationships between model parameters and predictions. When emission rates of carbon from fossil fuel combustion were considered a part of the CO_2 release scenario (e.g., fixed for all model simulations) then, (1) predicted atmospheric concentrations of carbon dioxide showed relatively low levels of variability through time, (2) parameter importance levels were time dependent, and (3) model parameters associated with absorption of carbon in the ocean and release rates of carbon from forest clearing accounted for over 90% of the uncertainty of predicted atmospheric CO_2 in the year 2075. The implementation and refinement of these techniques for the carbon cycle model now make it possible to examine, in a manner consistent with available data, the uncertainties associated with other scenarios of carbon emission rates and to compare the results in a quantitative manner with those of other models.

TR025 THE STABILITY OF LOW-LATITUDE SEA SURFACE TEMPERATURES: AN EVALUATION OF THE CLIMAP RECONSTRUCTION WITH EMPHASIS ON THE POSITIVE SST ANOMALIES
(DOE/ER/60167-1, October 1985, 57 p.)

W. L. Prell
Brown University

This report examines the stability of low-altitude sea surface temperatures over the past 18,000 years and evaluates the evidence for positive sea surface temperature anomalies (i.e., warmer than present) in the CLIMAP 1981 reconstruction of the oceans during the last glacial maximum about 18,000 years ago. A global array of planktonic foraminiferal population data were compiled and then applied both to CLIMAP temperature equations and to the modern analog technique of temperature estimation. The modern analog technique of estimating temperature is substantially different from the CLIMAP method and gives equal or high correlation with observed data and lower standard estimates of error than comparable CLIMAP equations. The comparison indicates that the estimates of relatively stable low-latitude temperatures and, in some cases, warmer sea surface temperatures are inherent in the planktonic foraminiferal populations and are not a function of CLIMAP's 1981 method of temperature estimation.

TR026 CARBONATE CHEMISTRY OF THE BERING SEA
(DOE/EV/10611-5, September 1985, 79 p.)

C.-T. A. Chen, C.-L. Wei, and M. R. Rodman
Oregon State University

The dynamics of atmospheric-ocean exchanges of carbon dioxide, and of carbon dioxide fluxes with the oceans, are important, but largely unquantified factors in understanding the global carbon cycle. This report has the following goals with respect to defining the carbonate chemistry of the Bering Sea: (1) to obtain the first winter oxygen and carbonate data in the Bering Sea; (2) to evaluate seasonal, cross-frontal, and cross-ice-edge variations of oxygen and carbonate chemistry; (3) to estimate the effect of pack ice on air-sea exchange of gases; (4) to estimate the penetration depth of the excess, anthropogenic CO_2 in the Bering Sea; and (5) to compare the results with data reported in the literature and to estimate the importance of the Bering Sea in removing the excess CO_2 from the atmosphere.

The analyses in this report are based on data collected aboard the U.S. Coast Guard icebreaker *Polar Sea* in the late winter of 1983 (part of the outer Continental Shelf Environmental Assessment Program) and on summer data available in the literature. Wintertime oxygen, pH, alkalinity, and calcium data across the marginal ice zone of the central and southeastern Bering Sea shelf are analyzed and compared with summer data.

The Bering Sea pack ice impedes but does not stop the air-sea exchange of gases. Mixing dominates the distribution of chemical properties on the shelf. Excess CO_2 has probably saturated the Bering Sea shelf water but does not penetrate more than 1000 m in the Aleutian Basin. No excess CO_2 was detected in the bottom waters. Overall, the Bering Sea contains 0.19 +/- 0.05 x $10E^{15}$ g excess carbon.

TR027 A GRID-POINT SURFACE AIR TEMPERATURE DATA SET FOR THE SOUTHERN HEMISPHERE
(DOE/EV/10098-6, February 1986, 73 p.)

P. D. Jones, S. C. B. Raper, C. M. Goodess, B. S. G. Cherry, and
T. M. L. Wigley
University of East Anglia

A truly representative time series of average temperatures for Earth can only be achieved by incorporation of data from both the land and marine areas of both hemispheres (most studies to date have been representative of conditions over only the Northern Hemisphere land masses). In this study, a compilation of 610 station records of monthly surface air temperature has been assembled for the Southern Hemisphere, north of 62.5°S. The basic source of data was the digitized form of the World Weather Records; additional data were incorporated for Indonesia, Australia, some Pacific islands (particularly Tahiti), New Zealand, Peru, and Antarctica.

To use these data to reconstruct the first grid-point temperature data set for the Southern Hemisphere, the homogeneity of each of the station records has been assessed. Each station has been classed into one of three groups: immediately usable, corrected, or uncorrectable. The results are presented in tabular form.

Of the 610 station records, 293 were used to produce a gridded data set on a 5° latitude by 10° longitude grid between 5°S and 60°S, inclusive. Grid-point anomalies for 1851-1984, with respect to the reference period 1951-1970, were interpolated from station data using a simple inverse-distance weighting algorithm. To produce a best-possible data set, Antarctic data were included after they became available in 1957.

The time series of the Southern Hemisphere area average shows little overall trend during the nineteenth century. After 1900, the series shows a warming trend to the mid 1940s. Between about 1945 and 1970, no trend can be seen. Since 1970 a strong warming trend has set in. The three warmest years of the entire record are 1980, 1981, and 1983. The overall warming trend since 1900 is about 0.5°C, of which roughly 0.3°C occurred between 1900 and 1945 and 0.2°C since 1970. The history of the land-based Southern Hemisphere temperature series is, therefore, not dissimilar to that for the Northern Hemisphere. However, the early twentieth-century warming up to 1940 is smaller in magnitude, and the cooling evident in the Northern Hemisphere between 1940 and 1965 appears only as a hiatus in the longer-term warming trend.

[The data set is available on tape (NDP-020) from the Carbon Dioxide Information Analysis Center at Oak Ridge National Laboratory.]

TR028 DEFINITION AND CHARACTERIZATION OF DATA NEEDS TO DESCRIBE THE POTENTIAL EFFECTS OF INCREASED ATMOSPHERIC CO_2 ON MARINE FISHERIES FROM THE NORTHEAST PACIFIC OCEAN (DOE/NBB/0075, December 1985, 139 p.)

R. M. Strickland, D. J. Grosse, A. I. Stubin, G. K. Ostrander, and T. H. Sibley
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Increased concentrations of atmospheric CO_2 will have direct effects on climate and on dissolved CO_2 in the oceans and indirect effects on abiotic (physical and chemical) properties of the oceans. Effects of increased concentrations of dissolved CO_2 are expected to be minimal, except for the possible effects of increased availability of trace metals. The abiotic effects that are most important for marine fisheries are changes in temperature, ice cover, turbulence, and current patterns in the upper layer of the ocean. Equally important fishery impacts may be transmitted via biotic effects on prey and predators of immature fish. The most promising avenue for both general and specific climate-related fishery research at this time is the effects of the abiotic environment on the planktonic food supplies of larval and juvenile fish, especially as mediated by primary production. Global warming will shift the present latitudinal domains of most fish species poleward, but the magnitudes of this shift and of possible associated changes in fishery yield are unknown. Uncertainty is related to lack of knowledge of the ways that temperature and other factors regulate fish populations, as well as to uncertainties in the rate and magnitude of changes in the environment. Uncertainty also arises because of differing species characteristics and local factors such as rivers, bathymetry, and ice that makes it difficult to generalize among fisheries.

Four northeast Pacific region case-study species were studied to determine individual fishery responses to climate change (Alaska pollock, *Theragra chalcogramma*; Pacific herring, *Clupea harengus pallasi*; pink shrimp, *Pandalus borealis*; and yellowfin sole, *Limanda aspera*). Because unique properties of individual fisheries are as important as the general properties of all fisheries

for determining climatic effects, the ability to project the effects of climate change on fisheries without performing detailed case studies is limited. Likewise, it is difficult to extrapolate from the results of the present case studies to other fisheries. These results are particularly inapplicable to other major categories of fisheries, including open-ocean, upwelling, and tropical and subtropical shelf fisheries. Such fisheries should be the focus of additional case studies. Possible temperature effects on the incidence of disease and parasitism in fish also should be investigated.

Ultimately, greater understanding of the effects of climate on fisheries will depend on improvements in coordinated large-scale data gathering in the field. In the interim, useful supporting studies can be performed on the small-scale laboratory responses of fish larvae and plankton to abiotic changes (especially CO_2, temperature, and turbulence) and on developing quantitative relationships using these results and other existing field and laboratory data. In particular, there is sufficient theoretical and empirical knowledge to justify beginning the development of a global marine primary-production model, which would have the corollary benefit of complementing global carbon cycle models.

TR029 PRELIMINARY DATA REPORT FOR THE INDIVAT NUMBER 1 AND INDIGO 1/INDIVAT 3 CRUISES IN THE INDIAN OCEAN (DOE/NBB/0074, January 1986, 106 p.)

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The main objective of this research was to quantify the oceanic penetration of excess CO_2 by using carbonate data directly. The specific objectives were (1) to obtain the first winter carbonate data in the South Indian Ocean, which is near the major point of origin for the bottom waters in the world oceans; (2) to evaluate seasonal and cross-frontal (Subtropical and Antarctic Front) variations of carbonate chemistry; (3) to estimate the depth of penetration of the excess man-derived CO_2 in the Indian Ocean from both carbonate and transient tracer data; and (4) to compare the results with reported literature data.

This report summarizes the experimental data and a limited preliminary analysis from the first two of a series of cruises scheduled for the Indian Ocean for the period 1984 to 1987. When the tracer data become available, a full report will be published.

Preliminary results of this study are:

1. The surface pH and normalized nitrate, alkalinity, and total CO_2 values correlated linearly with temperature.

2. Small deviations from the linearity are related to the Subtropical Front and the equatorial upwelling.

3. Large nitrate variations occurred in surface waters collected at the same station but in different seasons; however, there was less variation between normalized nitrate concentrations in waters with the same temperature.

4. There appeared to be a seasonal difference in alkalinity and total CO_2.

5. The decrease in alkalinity and total CO_2 between the Antarctic Waters and the Indian Central Waters from north of the Subtropical Front may be caused by the decrease in nitrate and the increase in temperature.

6. The remnant North Atlantic Deep Water, which has a weak salinity signal, can be identified by pH and total CO_2 data, but nutrient, oxygen, and calcium data also help in tracing this water.

7. The alkalinity and total CO_2 data for subsurface waters agree well with GEOSECS data for GS 427 and 428 but not for GS 429.

These results permit for the first time an evaluation of the variations in the carbon and nitrogen cycles in the Antarctic Intermediate Water in the Indian Ocean with reference to the source water in winter.

TR030 EFFECTS OF ENERGY TECHNOLOGY ON GLOBAL CO_2 EMISSIONS (DOE/NBB/0076, April 1986, 92 p.)

H. C. Cheng, M. Steinberg, and M. Beller
Brookhaven National Laboratory

This study was done to investigate the effects on global energy consumption and CO_2 emissions of end-use and electricity-generation technologies, with emphasis on efficiency improvement. The following are the conclusions of the study.

1. The large margins of efficiencies between present and future improved energy technologies, and the wide variations in efficiency levels among countries, indicate considerable room for major long-term reductions in energy consumption through technological improvements.

2. Savings achievable by more efficient end-use and electricity-generation technologies, if effectively implemented, are estimated as about 145 exajoules (10^{18} joules) of liquids fuels, 118 exajoules of gas fuels, and 236 exajoules of solid fuels, with an overall fossil-fuel savings of 500 exajoules, which is about 58% of the fossil-fuel demand without technology improvements for year 2050.

3. The distribution of these fossil-fuel savings by end-users is 175 exajoules (39%) for residential and commercial users, 227 exajoules (46%) for industrial users, and 76 exajoules (15%) for transportation users. Breakdown by fuel type for each type of user shows that technologies could produce savings in solid fuels for industrial users and in liquid fuels for transportation users.

4. The regional breakdown of the overall fossil-fuel savings of 500 exajoules, is 97 exajoules (19.5%) from the U.S., 101 exajoules (20%) from Canada and Western Europe, 56 exajoules (11%) from OECD Pacific, and the remaining 245 exajoules (49%) from the Soviet Union, China, and all the other developing countries. Except for the USA, the general global structure of fuel savings is 50% from solid fuels, 26% from liquids, and 24% from gases. Because the USA has a larger demand for liquid fuels, especially by transportation users, than all the other regions, it has a higher potential for liquid fuel savings through technology improvement.

5. The associated overall reduction of carbon emission in year 2050 is 10 petagrams (10^{15} g), i.e., carbon emissions could be reduced from 17 petagrams without efficiency improvements to 7 petagrams with the efficiency improvements discussed in this study--a 59% reduction. The largest share of the reduction is from solids, 5.6 petagrams carbon, with liquids contributing 2.8 and gases 1.6 Pg C.

6. The distribution of the overall reduction of CO_2 emissions by end-users is 3.8 Pg C (38%) for residential and commercial users, 4.7 (47%) for industrial users, and 1.5 (15%) for transportation users.

7. The regional breakdown of the overall reduction of 10 petagrams of carbon emissions is 1.9 Pg C (19%) from the U.S., 2.0 (20%) from Canada and Western Europe, 1.1 (11%) from the OECD Pacific, and the remaining 5.0 Pg C (50%) from the Soviet Union, China, and all the other developing countries. Hence, the developing regions have the same potential for reducing CO_2 emissions as do the developing regions in year 2050 through technology efficiency improvements.

8. The largest share of energy savings by residential and commercial users is from space conditioning technologies, about 75% of the fossil-fuel savings and 35% of the electricity savings, with water-heating technologies accounting for most of the remaining fossil-fuel savings (20%) and about 15% of the electricity savings. For industrial users, about 80% of the fossil-fuel savings are from improvements of efficiencies in process heat, and about 80% of the savings in electricity are from improvements in electric drives. Automobiles and trucks account for about 80% of the liquid-fuel savings by transportation users. Overall CO_2 emission in year 2050 could be reduced by 46% compared with that without technology improvement, through improvements of these technologies; this is about 80% of the reduction due to general technology improvements.

9. Use of the savings in electricity generated from non-fossil energy (i.e., nuclear, solar, and hydro) due to technology improvement to replace demand for electricity generated from fossil fuels produces additional savings of 13 exajoules of liquids, 14 exajoules of gases, and 56 exajoules of solids. Combining the improvements in end-use and electricity-generation technologies with such replacement raises the total fossil-fuel savings in year 2050 to 580 exajoules, which is 68% of the fuel demand without the technology improvements. The associated reduction of CO_2 emission is 11.8 petagrams of carbon. This means that CO_2 emissions in year 2050 could be reduced by 68%, compared with 59% without such replacement.

10. The actual savings of fossil fuels should be larger than the estimates given if account is taken of the energy needed for producing and transporting the saved energy, and the actual reduction of CO_2 emission should be correspondingly larger.

11. The total capital costs for technology implementation for year 2050 are about 6.0 and 24.0 trillion 1980 USA dollars, resulting in total returns on investment based purely on fuel savings of about 8% and 10% for the USA and the world, respectively. The industrial sector has more potential than the other users for reducing CO_2 emissions (50% of the overall reduction) with low capital requirements for technology implementation (6% of overall capital requirements) and high return on investment (40%).

TR031 THE IMPACT OF CLIMATE CHANGE FROM INCREASED ATMOSPHERIC CARBON DIOXIDE ON AMERICAN AGRICULTURE
(DOE/NBB/0077, May 1986, 100 p.)

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This report summarizes the current knowledge of potential effects of CO_2-induced climate change on agriculture in the United States. Emphasis is placed on the fourteen-state midwestern region (Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, Oklahoma, South Dakota, Texas, and Wisconsin) and on four crops (corn, soybeans, wheat, and sorghum) and animal production. The report begins with a review of American agriculture by describing developments in the twentieth century, natural and institutional resources that support the farm enterprise, and the magnitude of production of crops and livestock. The report then discusses the effects of climate change on crop production (with a summary of the direct effects of CO_2 on plants); topics include changes in growing-degree days, cropping patterns, genetic selection, farm management alternatives, and pest management. Next the report covers the effects of climate change on animal production in relation to the following topics: effects of temperature, rainfall, humidity, and day length; animal management; genetics; and effects of climate on forages such as grasses and legumes. In the summary chapter, knowns, unknowns, and required research are presented for each of eight issues or concerns (for example, water availability, genetic development).

TR032 A COMPARISON OF TROPICAL FOREST SURVEYS
(DOE/NBB/0078, June 1986, 66 p.)

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Over the years several assessments of tropical forest areas have been made. This report examines the two most recent studies of tropical forest areas and rates of forest loss: Norman Myers' Conversion of Tropical Moist Forests (1980), and the FAO/UNEP Tropical Forest Resources Assessment Project (1981a,b,c) to identify and clarify discrepancies between them. These reports were chosen for comparison because the apparent discrepancy between their respective estimates of deforestation rates has been the basis of a continuing controversy. Myers' report, prepared under the auspices of the National Academy of Sciences, was concerned principally with the conversion of virgin forests to other land use and the resulting extinction of tropical species. His report concluded that tropical moist forests are being converted from a primary state to various human-impacted categories at a rate of 200,000 km^2 per year, but only about one-half of this amount is permanently deforested. The remainder is cleared, cultivated for a few years, and allowed to recover in a process called shifting cultivation. Although shifting cultivation allows a forest to recover, the regrowth may exhibit reduced biological diversity and biomass. The FAO/UNEP (1981a,b,c) report emphasized the availability of forest resources to meet the future fuelwood, housing, and economic needs of UN member states. The report concluded that conversion of forest to nonforest land is occurring at a rate of 73,000 km^2 per year.

Different definitions apparently have caused a misinterpretation of the results of the two reports. The present paper attempts to identify more precisely the differences between the two studies to integrate the large tropical forest data base from these two sources into a cohesive whole. Specifically, those countries covered in both surveys where the largest differences occur are identified. Then, further research can be directed where it will be most useful. The present study does not assess all discrepancies between the reports of Myers and FAO but only those for countries where both investigators have given specific numbers.

TR033 HIGH ACCURACY STANDARDS AND REFERENCE METHODOLOGY FOR CARBON DIOXIDE IN AIR
(DOE/PR-06010-31, June 1986, 101 p.)

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This report summarizes the activities and accomplishments of a three-year NBS program for the development of standards and reference methodology for carbon dioxide in air that was designed to:

- Develop defined Standard Reference Materials (SRMs) for CO_2 in air at atmospheric concentrations having a total uncertainty (95% confidence level) not exceeding 0.1 percent relative;

- Assess the equivalency of absolute gravimetry employed by the National Bureau of Standards (NBS) and absolute manometry employed by the Scripps Institution of Oceanography (SIO) for the development of accurate standards for CO_2 in air at atmospheric concentrations; and

- Develop a state-of-the-art isotope dilution mass spectrometer (ID-MS) system and associated methodology to serve as an NBS-based reference method for absolute independent confirmation of CO_2 concentrations in CO_2 in air standards.

The first of these objectives has been realized in the issuance of seven CO_2 in air SRMs in the 300-400 parts-per-million (ppm) range of interest. Each SRM cylinder in these seven SRMs contains a CO_2 in air concentration that is individually certified to be stable for a period of at least two years within a total uncertainty of 0.2 ppm with 95% confidence. The first three of these were issued in 1983, covering nominal concentrations of 330, 340, and 350 ppm. Four additional SRM's were issued in 1985, covering nominal concentrations of 340 and 380 ppm. Two of these four SRMs were certified in size 150 cubic foot cylinders to address the higher volume needs of investigators, while the remaining two were certified in standard SRM size cylinders (30 cubic foot). All four of the latest SRMs also were certified for nitrous oxide levels in the part-per-billion (ppb) range and have information (non-certified) values for methane (1.7-1.8), and for halocarbons F-11 and F-12 in the part-per-trillion (ppt) range. Five additional CO_2 in air SRMs are planned for certification in 1986 at nominal concentrations of 200, 300 (two SRMs), 360, and 1000 ppm.

The second of these objectives was to assess the equivalency between absolute gravimetry (NBS) and absolute manometry (SIO), in order to ensure a scientific basis for the transfer of responsibility for CO_2 in air standards from SIO to NBS. The differences that were observed

between CO_2 concentrations assigned by gravimetry by NBS and those measured by SIO using the constant volume manometer (CVM) for multiple intercomparisons were within the limits of experimental error of the two systems. Hence, standards from one system (NBS) can be used interchangeably with standards from the other system (SIO). This achieves one of the primary goals of the program: namely, that NBS standards may be used for calibrating measurements of atmospheric CO_2 without compromising the existing data record, and, further, that the institutionalization at NBS of the availability of standards will ensure the long-term continuity and integrity of this data record for the indefinite future. These intercomparisons represent the completion of a convergence plan prepared at the outset of this program by principal scientists of SIO (C.D. Keeling) and NBS (E.E. Hughes).

The third objective has involved the design, construction, testing, and evaluation of a computer-controlled ID-MS system to serve as an independent reference method for the analysis of CO_2 in air SRMs. In practice, this method would be used to independently verify the accuracy of randomly-selected, gravimetrically-certified CO_2 in air calibrations covering a range of CO_2 concentrations within 300-400 ppm and extensions above and below this range. A separate report detailing the characteristics of this system and its performance will be issued. NBS plans to use this system and its associated methodology as a confirmatory reference method for CO_2 in air SRMs.

Current research extensions to this program include the development of an NBS master calibration curve incorporating numerous primary gravimetric standards covering the 300-400 ppm range and an assessment of the absolute minimum error associated with the preparation of such standards and the development of SRMs. Specifically, this continuing research is directed at (1) the development of a global calibration curve interrelating all NBS primary gravimetric standards within a predictable uncertainty, and (2) a detailed evaluation of the feasibility of further reducing the total uncertainty at 95% confidence for certified SRM concentrations, below its current level of 0.2 ppm (0.6% relative). A separate report describing the results of this extended research will be issued.

TR034 CARBONATE CHEMISTRY OF THE NORTH PACIFIC OCEAN (DOE/NBB-0079, October 1986, 176 p.)

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The objective of this research was to quantify the oceanic penetration of excess CO_2 by using carbonate data directly, and to understand better the oceanic carbon cycle. Data collected along two longitudinal cruises serve as the main data sources, and supplementary data sets in the literature are selected for delineating the distribution of physical and chemical properties in a wide area of the North Pacific Ocean.

Oxygen, pH, alkalinity, total CO_2, and nutrients are interrelated parameters. Along two longitudinal sections these parameters show a core structure underlying the salinity minimum layer. From these oxidation-related parameters, the researchers concluded that the subsurface water of the eastern North Pacific Ocean is older than that of the western North Pacific Ocean.

Alkalinity data can be used as a water mass tracer. Different water masses reveal their own mixing trends which can be identified when examining the correlation of normalized alkalinity with temperature. The vertical distribution of the normalized alkalinity shows a maximum core at a depth of about 2500 m in the North Pacific Ocean. Calcium carbonate dissolution and circulation in the deep and bottom layers contribute to the formation of the normalized $CaCO_3$ dissolution rate of 0.060 and 0.053 umol/kg/yr, respectively, referenced to the Weddell Sea Deep Water for waters deeper than 2000 m.

This analysis of carbonate data shows that about 25% of the increase in total inorganic CO_2 in deep water, in its journey from the surface of the Southern Ocean to the depth of the North Pacific, results from inorganic $CaCO_3$ dissolution. No significant difference in the inorganic carbon/organic carbon ratio exists between the two longitudinal sections. However, the eastern section has a higher total TCO_2 input than that of the western section.

The degree of saturation of calcite and aragonite was calculated from all available data sets. Four selected cross-sections, three longitudinal and one latitudinal, and two three-dimensional graphs show that a large volume of the North Pacific is undersaturated with $CaCO_3$. The saturation horizon generally shows a shoaling from west to east and from south to north in the North Pacific Ocean. It was found that the lysocline falls at a depth much deeper (about 2500 m deeper) than the saturation horizon of calcite and several hundred meters shallower than the calcium carbonate compensation depth. Results appear to support the kinetic point of view on the $CaCO_3$ dissolution mechanisms.

Calculations on the excess CO_2 show that its penetration depth is strongly related to circulation. The shallowest penetration depth is less than 300 m found in the eastern equatorial region where upwelling prevails and the deepest penetration depth is deeper than 2000 m off Japan where an interaction of Oyashio and Kuroshio currents is found. These results agree with conclusions drawn based on Freons, tritium, and carbon-14 data. Overall the North Pacific contains 14,7 +/- 4 x 10^{15} g excess carbon.

[The data set is available on tape (NDP-029) from the Carbon Dioxide Information Analysis Center at Oak Ridge National Laboratory.]

TR035 AN ANNOTATED INVENTORY OF CLIMATIC INDICES AND DATA SETS (DOE/NBB-0080, November 1986, 195 p.)

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This publication describes 34 prominent climatic indices and provides an annotated listing and bibliography of additional indices to help meet the information needs of researchers who are evaluating the effects of increased atmospheric CO_2 levels. The goal was to discuss a wide range of indices that would be useful to scientists working directly in diverse areas of CO_2-climate research and those individuals interested in climate research results for other applied studies. This publication is a source to consider first to determine what information is available and how knowledge of climatic indices may help investigators meet their research goals.

To ensure that a broad spectrum of indices was considered, indices from the following ten subject areas are included:

1) Global/Hemispheres, 2) Marine Data Sets, 3) Long-Term Regional and Local Temperature and Precipitation Data Sets, 4) Atmospheric Constituents Data Sets, 5) Upper Air Data Sets, 6) Southern Oscillation/El Niño Data Sets, 7) Solar Data Sets, 8) Proxy Data Sets, 9) Lake Levels and River Flows Data Sets, and 10) Snowcover and Sea Ice Extent Data Sets.

Each description provides a brief but detailed summary of the index's relevance, importance, and derivation. Seventeen descriptor fields were used to describe each index, including primary references, relevant background information, calculation of the index, temporal resolution, spatial coverage, unit of measurement, period of record, reliability, relationship to other indices, application, and citation information.

TR036 **UNCERTAINTY IN FUTURE GLOBAL ENERGY USE AND FOSSIL FUEL CO_2-EMISSIONS 1975 to 2075 (DOE/NBB/0081, December 1986, 95 p.)**

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This report summarizes the results of work with the IEA/ORAU Long-Term Global Energy-CO_2 model to analyze model predictions of future global carbon emissions from fossil fuel use and the uncertainty surrounding such forecasts.

The methods used were the latest techniques of uncertainty analysis along with review and revision of the IEA/ORAU model structure, and review and description of uncertainty surrounding model assumptions and parameters to explore uncertainty in fossil fuel CO_2 emissions over the period 1975-2075. Possible interrelationships among assumptions and parameters, and their effects on overall forecast uncertainty are explored.

The major findings include:

1. The median rate of CO_2 emissions grow at an average annual rate of 1.0 percent per year. This rate is substantially lower than the post World War II experience and lower than that found by earlier studies.

2. Overall uncertainty in the emission rate was found to be considerable. A range of 3.0 percent per year growth in emissions and a decline of 1.4 percent per year are needed to bracket 90 percent of the 400 randomly generated scenarios.

3. Low and declining CO_2 emissions rates appear more likely than past research has indicated. Roughly one quarter of the scenarios show global emissions falling from current levels.

4. The three most important determinants of variation in CO_2 emissions were labor productivity, rate of improvement in end-use energy efficiency, and the income elasticity of demand for energy in the developing world.

5. Based on the analysis of potential correlation among assumptions, model structure plays a key role in the determination of median estimates of fossil fuel CO_2 for energy emissions.

6. Conspicuously absent from the list of key variables were the rate of interfuel substitution and the fossil fuel resource base by fuel type.

TR037 **MONTHLY MEAN PRESSURE RECONSTRUCTIONS FOR EUROPE (BACK TO 1780) AND NORTH AMERICA (TO 1858)**
(DOE/ER/60397-H1, February 1987, 99 p.)

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Monthly grid-point pressure data are reconstructed from station records of air temperature, precipitation and pressure for Europe, back to 1780, and North America, back to 1858. The reconstructions are based on a principal components regression technique which relates surface pressure patterns to those of the temperature, precipitation and station pressure data. The relationships are derived over a calibration period and the results are tested with independent data from another period. To illustrate the results, examples are given of pressure anomalies over Europe during 1816 (the "year without a summer"), anomalies over both Europe and North America for January and November 1862 (months with particularly strong anomalies), and anomalies over North America during 1884 (the year after Krakatau).

The reconstructions are compared with other monthly mean pressure maps produced by Lamb and Johnson (1966) for Europe for 1780 to 1872 and for North America for 1858 to 1898, and by Kington (1980) for Europe for 1781 to 1785. Both of these map series show systematic biases relative to the present reconstructions. The reconstructed data are available on a magnetic tape.

[The data set is available on tape (NDP-025) from the Carbon Dioxide Information Analysis Center at Oak Ridge National Laboratory.]

TR038 **A DATA BANK OF ANTARCTIC SURFACE TEMPERATURE AND PRESSURE DATA**
(DOE/ER/60397-H2, June 1987, 52 p.)

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D. W. S. Limbert
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A data bank of monthly-mean surface air temperature and sea-level or station-level pressures is presented for 29 stations over the Antarctic region south of 60°S. Considerable attempts have been made to locate missing data in nationally published sources and in World Weather Records. By cross-checking neighboring station data, suspect values have been either verified or corrected.

At four sites in the Antarctic Peninsula region, composite records were produced by amalgamating records from a number of short and longer length records at or near the key sites. The four sites were Bellingshausen, Faraday, Esperenza, and Rothera.

The mean Antarctic temperature series produced by Raper et al. (1984) is updated using the same method of calculation.

TR039 THE PROSPECT OF SOLVING THE CO_2 PROBLEM THROUGH GLOBAL REFORESTATION
(DOE/NBB-0082, February 1988, 66 p.)

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and
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We are confronted with the possibility that it may become necessary to try to limit the increase in atmospheric CO_2 in order to avert adverse changes in the global climate. One short-term approach would be to stimulate the growth of forests to take up in woody matter enough carbon to balance the discharge of CO_2 from fossil fuel burning. This study evaluated the extent to which the area and/or net growth rate (mean annual increment) of global forests would need to be enhanced in order to remove an additional 5×10^9 tons of carbon per year from the atmosphere.

Although it is physically possible to plant large areas of new plantation and/or to stimulate tree growth via advanced silviculture techniques, conflicts in land use and resource allocation are quickly encountered in efforts of sufficient magnitude. The scale of the effort required is approximately equal to doubling the new annual yield of all of the world's closed forests or planting new fast growing forests over an area equivalent to the total of global forest clearing to date. The cost of such a scheme is immense but it needs to be compared with the costs of other approaches to dealing with atmospheric CO_2 or of coping with the attendant changes in climate. It is clear that although it is impractical to think in terms of solving the CO_2 problem through forestry alone, forestry could play a significant role.

TR040 A PRIMER ON GREENHOUSE GASES
(DOE/NBB-0083, March 1988, 100 p.)

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The purpose of this document is to provide a reference summarizing current understanding of basic information for important greenhouse gases. Each of the gases included is recognized to be important to the future state of global atmospheric chemistry and climate. Included as greenhouse gases are those of direct radiative importance to climate, those that act as radiative precursors, and those of importance as intermediate constituents because of their chemical activities. Knowns, unknowns, and uncertainties for each gas are described. This document focuses on information relevant to understanding the role of energy and atmospheric chemical and radiative processes in the determination of atmospheric concentrations of greenhouse gases.

The document takes the form of a large table. Two summary tables highlight the contents. One outlines the basic information given in the main document table, and the other gives an indication of the relative potential importance of the gases to chemistry and climatic effects on the global atmosphere.

In the course of the development of this document several conclusions became clear. The most important of these conclusions are:

1. There are major uncertainties regarding the source budgets for key gases including CH_4, CO, N_2O, and NO_x. These uncertainties greatly exceed those for the sources of CO_2 emissions.

2. Of particular concern is the relatively primitive evaluation of the relationship between energy activities and emissions of these gases, despite the fact that these gases are estimated to have energy sources amounting to between 32 and 75% of all man-made sources.

3. The relationship between energy and emissions sources for the gases evaluated in this study is stronger than had been anticipated before the study began.

4. Chemical processes in the atmosphere represent an important link between energy and other emissions sources and the composition of the atmosphere. Understanding atmospheric composition is essential to detecting and quantifying the role of energy and CO_2 in climate change.

5. More definitive studies of the interactions between chemical and climatic processes are necessary to facilitate an early detection of a CO_2/climate-change signal. This is intended to be a living document to be updated as additional information in important greenhouse gases becomes available. The reader is invited to contribute to the updating process. This version of the report did not consider several currently minor but potentially important greenhouse gases. Namely, non-methane hydrocarbons and additional chlorocarbons, particularly CFC-113, CCl_4, and CH_3CCl_3, deserve consideration.

TR041 REGIONAL INTERCOMPARISONS OF GENERAL CIRCULATION MODEL PREDICTIONS AND HISTORICAL CLIMATE DATA (DOE/NBB-0084, April 1988, 291 p.)

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This study is a detailed intercomparison of the results produced by four different General Circulation Models (GCMs) that have been used to project the climatic consequences of a doubling of the atmospheric CO_2 concentration. The results for the models developed by groups at the National Center for Atmospheric Research (NCAR/CCM, Washington and Meehl, 1984), the Geophysical Fluid Dynamics Laboratory of NOAA (GFDL, Manabe and Wetherald, 1987), and the Goddard Institute for Space Studies of NASA (GISS, Hansen, et al., 1984) have been described by Schlesinger and Mitchell (1985) in the DOE state-of-the-art (SOA) report, "Projecting the Climatic Effects of Increasing Carbon Dioxide." The fourth model examined here is the Oregon State University GCM (OSU, Schlesinger, 1986), results for which did not become available until after publication of the SOA.

We have chosen to examine only two model variables here: (1) surface air temperature, and (2) precipitation. We consider these variables for both seasonally and annually averaged periods, for both the current climatic conditions and the predicted equilibrium changes after a doubling of the CO_2 concentration. For the current climate (1 x CO_2), the model results for these two variables were compared with each other and with several data sets representing observed climate conditions over recent 15 to 30 year periods; the domain covered is global, although the adequacy of data over many regions is very limited. The grid resolution of the different models varies from 4° latitude by 5° longitude to 8° latitude by 10° longitude; the data are typically available with similar resolution. Thus, each data point (on the model or observation grid) represents a region of about 400 km by 400 km or larger, or roughly the size of Colorado, even though regions of this size may have very diverse local climates.

In Schlesinger and Mitchell (1985), the analyses emphasized the global scale nature of the models. Here, the major focus is the intercomparison of models and data over a range of scales: global, hemispheric, zonal, continental, and regional (typically representing 5 to 20 model gridpoints). The fundamental question addressed is: "How well do the predictions from different GCMs agree with each other and with historical climatology over different areal extents, from the global scale down to the range of only several gridpoints?"

The major conclusion of this study is that, although the models often agree well when comparing seasonal or annual averages over large areas, substantial disagreements become apparent as the spatial extent is reduced, particularly when detailed regional distributions are examined. Tabulations are provided to document these differences quantitatively. At scales below continental, the correlations observed between different model predictions are often very poor, particularly for land gridpoints during Northern Hemisphere (NH) summer, with differences of as much as 5°C between models and observations and between one model and another over relatively large areas.

A more limited analysis, using the results from only two GCMs, examines the seasonal variability of surface air temperature for the control climates. These results suggest that both models exhibit serious differences with historical climatology in at least one of the two meteorological seasons which are analyzed [December-January-February (DJF) or June-July-August (JJA)]. The implications of this work for investigation of climatic impacts on a regional scale are profound. For these two very important variables, at least, the poor agreement between model simulations of the current climate on the regional scale calls into question the ability of these models to project the amplitude of future climatic change on anything approaching the scale of only a few (<10) gridpoints, which is essential if useful resource assessment studies are to be conducted. Much work remains to be done by the modelling community to better resolve the sources of disagreements among models and between models and observations so that model improvements can be made which will improve the climatic projections produced by these models. A stronger cooperative effort among the different modelling groups, including such recent initiatives as calculating results with a common set of boundary conditions, will be necessary so that we are sure that we are getting model agreement for the right reasons, a prerequisite for improving confidence in model projections.

TR042 SURFACE ENERGY BALANCE OF THREE GENERAL CIRCULATION MODELS: CURRENT CLIMATE AND RESPONSE TO INCREASING ATMOSPHERIC CO_2 (DOE/ER-60422-H1, MAY 1988, 119 p.)

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We examine the surface energy balance simulated by state-of-the-art general circulation models at GFDL, GISS and NCAR for climates with current levels of atmospheric CO_2 concentration (control climate) and with twice the current levels. The work is part of an effort sponsored by the U.S. Department of Energy to assess climate simulations produced by these models. The surface energy balance enables us to diagnose differences between models in surface temperature climatology and sensitivity to doubling CO_2 in terms of the processes that control surface temperature. Our analysis compares the simulated balances by averaging the fields of interest over a hierarchy of spatial domains ranging from the entire globe down to regions a few hundred kilometers across.

Principal Findings

1. For the global average control climate, individual surface fluxes of sensible heat (SH), latent heat (LH), shortwave radiation (SW) and upward (LW↑) and downward (LW↓) longwave radiation agree between the models to within 25 Wm^{-2} (Figure E-1). In all three models the surface energy balance is dominated by longwave radiation (the "greenhouse" effect). Other surface fluxes are smaller, but the models also agree on their relative magnitudes. The 25 Wm^{-2} difference is only a small fraction of the magnitudes of the largest fluxes, LW↓ and LW↑. However, the difference is a large fraction of the net longwave radiation at the surface (~60 Wm^{-2}), and it is as large as any of the global-average seasonal changes in these fluxes. From this perspective, differences between surface fluxes in these state-of-the-art models are substantial even for the global average.

2. Global average changes in surface fluxes when CO_2 doubles agree between models to within 3 Wm^{-2} (Figure E-2); intermodel discrepancies are only small fractions of the flux changes from CO_2 doubling. However, the apparent agreement between models in Figure E-2 should be viewed with caution because flux changes associated with doubled CO_2 are about the same size as the differences between models in their control climates: 25 Wm^{-2}. Furthermore, averaging over the globe obscures much larger differences occurring on smaller scales (cf. points 4 and 6 below).

3. Spatial variation of net longwave radiation at the surface is small compared to the spatial variability of near-surface air temperature and moisture, both of which exert significant control on the new surface longwave flux. The relatively small variability of LW_{net} appears to be a consequence of compensation among variations of temperature, atmospheric moisture and clouds.

4. Intermodel differences in doubled-CO_2 surface flux changes of up to 100 Wm^{-2} occur near the limits of polar ice caps. Differences in ice modeling approach contribute strongly to the flux differences. Differences in control climate sea ice limits also help produce the strong differences in flux changes.

5. Differences between models for surface fluxes in regions a few hundred km across are often closely linked to differences in zonal mean climatology.

6. Intermodel surface flux discrepancies in the regional averages are as large as 50 Wm^{-2}, which is twice the difference found for the global average. Furthermore, models often disagree over the sign of regional flux changes when CO_2 doubles (Figure E-3). Such differences appear to be closely associated with differences in model hydrology.

7. Fields that are subject to orographic control show relatively small intermodel discrepancy, i.e., differences between models for the same region tend to be smaller than interregional differences. A most notable example is precipitation, examined here because of its indirect relation to the surface energy balance through the hydrological cycle.

Recommendations

1. Effort should be given to developing a better understanding of the hydrological cycle and how to simulate it. Progress in this area appears to be especially important for improving regional climate modeling (point 6 above). Relatively large flux discrepancies on the global scale (points 1 and 2) may also be reduced by such progress because the hydrological cycle, through water vapor and cloud cover, strongly influences the longwave radiation transmitted from the atmosphere to the surface. Examples of the work needed are Manabe and Wetherald (1987) and Meehl and Washington (1987) who have analyzed soil moisture sensitivity in NCAR and GFDL model simulations of current and doubled CO_2 simulations.

2. Better agreement in zonal mean climatology between models is needed, since much of the intermodel difference in regional climatology is attributable to zonal mean differences between models.

3. Effects of increased resolution on regional simulation should be studied. Our results suggest that improvements in orographically dependent fields are possible simply by increasing resolution. Grid nesting needs to be explored as a means of improving regional modeling over land areas where orographic control may be important for regional climatology.

TR043 THE USE OF STATISTICAL CLIMATE-CROP MODELS FOR SIMULATING YIELD TO PROJECT THE IMPACTS OF CO_2 INDUCED CLIMATE CHANGE (DOE/ER/60444-H1, July 1988, 42 p.)

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Climate change has been projected to result from increased levels of greenhouse gasses. Obviously, significant changes in climate will influence agricultural production. Analysis techniques are needed to determine the consequences of climate change on agriculture production and food supply.

This report discusses (1) the historical perspective for the development of statistical models, (2) statistical models for assessing the impacts of CO_2-induced climate change, (3) production transformations resulting from climate change and CO_2 fertilization, (4) integration of direct effects of CO_2 fertilization with the indirect effects caused by climate change, and (5) the value of statistical modeling for estimating crop production for large areas having increased CO_2 concentrations.

The report recommends development in three areas important in modeling crop production: (1) a technique that results in a more reasonable adjustment than a fixed percentage increase by CO_2 fertilization and incorporates interactions between climate anomalies and CO_2 concentrations, (2) refinement of the relationship between yield and transpiration to provide a more rational approach to the estimation of production for large areas, and (3) comparison of estimations obtained from a process model and a statistical model for a large area (crop reporting district or state) and simulation of the variabilities of these two techniques using historical climatic records.

TR044 DOCUMENTATION OF IAP TWO-LEVEL ATMOSPHERIC GENERAL CIRCULATION MODEL

(TR044, DOE/ER/60314-HI, February 1989, 383 p.)

Zeng Qing-Cun
Zhang Xue-Hong
Liang Xin-Zhong
Yuan Chong-Guang
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Since 1980, a group directed by Qing-Cun Zeng at the Institute of Atmospheric Physics (IAP) of the Chinese Academy of Science has been developing grid-point general circulation models (GCMs) for climate simulations. Unique characteristics make the dynamic framework of the models different from other GCMs.

1. Departures of temperature, geopotential, and surface pressure from their "standards" are introduced to cancel the large truncation errors in the mountain regions.

2. New coordinates and variables are introduced, leading the energy equation to a very compact form and the grid to a more flexible arrangement.

3. The computation scheme conserves the "available" energy conservation exactly (if the dissipation is omitted), and is free from computational modes.

4. No false source exists because the formulation and calculation of boundary terms or boundary conditions at the atmosphere-ocean and atmosphere-land interfaces are physically consistent.

Taking these characteristics into consideration, the authors have designed several schemes using spherical grids. One of the schemes, on C-grid system, was first designed and reported by Zeng and then extended to the atmosphere-ocean-coupled model. Most recently the authors also designed a B-grid scheme. Both schemes conserve the "available" energy of dissipative and adiabatic atmosphere under the "standard stratification approximation" or provide a bounded norm of the predicted variables in L_2 space if the implicit and split methods are applied, without using the standard stratification approximation. The B-grid scheme is used to compute wind vector directly at gridpoints, without using interpolations of wind components, and can easily be used in conjunction with implicit or semi-implicit methods. However, the C-grid scheme is economical in computation and suitable to stepwise topography. It is this scheme that has been thoroughly and systematically tested and applied to climate simulations. Based upon the C-grid scheme, a two-level global atmospheric GCM (AGCM) and a four-level world ocean GCM (OGCM) have been completed with 4° x 5° horizontal resolution and have been applied to climate simulations. The report documents the control version of the IAP two-level AGCM.

The physical parameterization schemes such as longwave radiation, cloud prediction, convective processes, boundary layer treatment and the ground surface hydrology developed by OSU are adopted with appropriate modifications in the current version of IAP two-level AGCM. However, in IAP AGCM, some nonlinear horizontal diffusion is included and the solar radiation is calculated using the delta-Eddington model, which accommodates the inclusion of atmospheric smoke and dust in addition to atmospheric Rayleigh scattering and absorptions of ozone and water vapor. The IAP AGCM emphasizes the prediction of water vapor transport because the condensation process is extremely important not only in causing precipitation, which is a main variable characterizing the regional climate, but also in controlling the internal energy source in atmospheric motions. The scheme presented can avoid drastic variations in water vapor distribution.

A full presentation of the model's dynamic framework; the calculations of the physics (source and sink terms) and treatment of boundary conditions; the FORTRAN program, including a directory of purpose, algorithm, and IO information for each subprogram; the FORTRAN symbols in the named common blocks, together with a brief description or definition, the mathematical equivalent, the units, and location in the code listing; a physics dictionary summarizing the treatment of numerous variables and giving their location in the code and references; and a guide to model use and operation, including a complete collection of IO information in a model integration are included.

TR045 **A PRELIMINARY ANALYSIS OF U.S. CO_2 EMISSIONS REDUCTION POTENTIAL FROM ENERGY CONSERVATION AND THE SUBSTITUTION OF NATURAL GAS FOR COAL IN THE PERIOD TO 2010**
(TR045, DOE/NBB-0085, February 1989, 56 p.)

J. A. Edmonds and W. B. Ashton
Pacific Northwest Laboratory

H. C. Cheng and M. Steinberg
Brookhaven National Laboratory

This report sheds light on the issue of U.S. CO_2 emissions reduction potential from the present to the year 2010 from energy conservation and the substitution of natural gas for coal. A preliminary assessment of the technical feasibility and consequences of reducing U.S. CO_2 emissions from 1985 levels by 10, 25, or 50% by either the year 1995 or 2010. Conservation potential studies were also examined to see what energy and conservation efficiency improvements are feasible at current and anticipated energy technologies and prices.

TR046 **GLOBAL LAKE-LEVEL VARIATIONS FROM 18,000 TO 0 YEARS AGO: A PALAEOCLIMATIC ANALYSIS**
(TR046, DOE/ER/60304-H1, SEPTEMBER 1989, 213 p.)

F. A. Street-Perrott, D. S. Marchand, N. Roberts, and S. P. Harrison
Oxford University

Historical data on fluctuations in lakes' water levels can provide important information about past climates and can be used to validate the palaeoclimatic simulations of atmospheric general-circulation models. The Oxford Lake-Level Data Bank contains information about variations in the water levels of about 360 lake basins during the past 30,000 years. The data

were compiled as part of the Climates of the Holocene Mapping Project. This report presents the lake status (high, intermediate, or low) of many of these lakes at 0, 3, 6, 9, 12, 15, and 18 thousands of years before the present. These data are presented on regional and global maps. The data are compared with numerical simulations made for the same time slices with the National Center for Atmospheric Research (NCAR) Community Climate Model. Agreement between the data and the model is generally excellent, although significant discrepancies occur. These discrepancies may reflect the effects of changes in boundary conditions that were not included in the simulations (such as increased glacial-age aerosol loadings of the atmosphere) and they may also reflect the inability of the model to portray some of the complexities of the climate system, such as oceanic and orographic effects.

TR047 AN EVALUATION OF THE RELATIONSHIP BETWEEN THE PRODUCTION AND USE OF ENERGY AND ATMOSPHERIC METHANE EMISSIONS (DOE/NBB-0088P, April 1990, 234 p.)

D. W. Barns and J. A. Edmonds
Pacific Northwest Laboratory

Methane is the most abundant hydrocarbon in the atmosphere. It has an assumed lifetime of about 10 years, and its atmospheric concentration is increasing about 1% per year. It is also one of the most potent of the greenhouse gases, with more than 30 times the warming potential of carbon dioxide on a per molecule basis.

Much of the atmosphere's methane comes from natural sources like wetlands. But a significant portion comes from human activities; probably 20 to 30% of the overall total comes from the production, distribution, and use of energy. Unlike carbon dioxide, only a small fraction of the methane in the atmosphere is produced by combustion. Rather, it comes from coal mining, natural gas production and distribution, automotive exhausts, biomass burning, and landfill decay. Moreover, the quantitative relationships are much more ambiguous with methane than they are with carbon dioxide.

Those relationships were estimated and emission coefficients were determined to extend the Edmonds-Reilly Long-Term Energy-CO_2 Model to include the effects of methane emissions. This report discusses the sources of information on emissions, the difficulties in assessing coefficients, and the final values chosen for the expanded model.

Methane emissions from coal mining are essentially a function of coal rank and depth; a weighted average of 250 cubic feet per short ton of production was used. Natural gas is mostly methane, and a 2% loss to the atmosphere was assessed. Venting and flaring data are available for most countries, but much of that data is of questionable accuracy, so the fraction vented was assessed at one-fifth. The range of methane emissions from automobiles and trucks is very wide; the global total emission was estimated to be 1 to 2 teragrams per year (Tg/y). Traditional biomass (fuel wood and bagasse) burning was estimated to introduce 10 to 15 Tg/y into the air. Finally, landfill emissions were estimated to contribute 30 to 70 Tg/y to the atmosphere.

These estimated methane emissions total about 110 Tg/y. In comparison with similar studies, this value is in the low end of the range. Use of these values in the model, therefore, provides an element of conservatism.

TR048 EFFECTS OF AIR TEMPERATURE ON ATMOSPHERIC CO_2-PLANT GROWTH RELATIONSHIPS
(DOE/ER-0450T, April 1990, 61 p.)

S. G. Allen, S. B. Idso, and B. A. Kimball
U.S. Water Conservation Laboratory

J. T. Baker and L. H. Allen, Jr.
USDA-ARS and the University of Florida

J. R. Mauney and J. W. Radin
Western Cotton Research Laboratory

M. G. Anderson
Arizona State University

In general, doubling the concentration of atmospheric CO_2 increases the productivity of C3 plants by about one-third. Because temperature may influence this effect, the literature on this topic was searched and is summarized in this report.

The enhancement in plant growth and photosynthesis of C3 species brought about by greater CO_2 concentration increases with air temperature. Increased temperature and a doubling of CO_2 concentration produced a maximum increase in growth of 300% and in net photosynthesis of 170% in C3 plants. The interaction between temperature and CO_2 concentration differs considerably among species. This interspecies variation may explain much of the wide range in plant responses to CO_2 concentration reported in the literature. Crop species' responses to increased CO_2 concentration and temperature should therefore be studied individually. In addition, CO_2 concentration appears to interact with other climatic variables, such as solar radiation, in its effect on plant productivity.

Growth and productivity effects are nowhere near as pronounced with C4 species as they are with C3 species because of the more efficient photosynthetic mechanism of C4 plants. Stomatal conductance of C4 species did, however, respond to combined increases in CO_2 concentration and temperature; the decrease in stomatal conductance produced by enriched CO_2 was enhanced by increasing temperature. As a result, a significant increase in water-use efficiency of C4 crops can be expected in a high-CO_2 environment.

TR049 SIMULATING CLIMATE WITH TWO DIFFERENT NUMERICAL SCHEMES
(DOE/34-0459T, JUNE 1990, 57 p.)

W. J. Gutowski and M. J. Iacono
Atmospheric and Environmental Research, Inc.

Liang Xin-Zhong
State University of New York, Stony Brook

Wei-Chyung Wang
State University of New York, Albany

To determine the dependence of climate simulation on model numerics, two simulations of a perpetual July were run on the Oregon State University two-layer atmospheric-physics model,

one that used gridpoint techniques for the numeric treatment of atmospheric dynamics and one that used spectral techniques.

The gridpoint model produced a stronger circulation. The differences in atmospheric transport predicted by the two models have a significant influence on the atmospheric portion of the hydrologic cycle. The gridpoint model produces more frequent precipitation, especially in the tropics, and higher amounts of atmospheric moisture. Consequently, it indicates greater cloud cover, producing differences in other fluxes, such as solar and terrestrial radiation. Substantial regional differences in the models' simulations were found, but differences in zonal averages typically dominate differences appearing in spatial distributions of climatological fields.

Removing certain feedbacks in the climate system underscored the differences produced by the choice of numeric technique. For example, diabatic heating tends to amplify differences resulting from the choice. Varying horizontal resolution also alters the model climatology. To a certain degree, these differences are tempered when a model is tuned to account for and reflect current climate. However, the choice of numeric technique should be made carefully because it may still influence a model's sensitivity to forcing changes.

TR050 MODELING pCO_2 IN THE UPPER OCEAN: A REVIEW OF RELEVANT PHYSICAL, CHEMICAL, AND BIOLOGICAL PROCESSES (DOE/RL-01830T-H5, December 1990, 63 p.)

Carbon Dioxide Research Program, U.S. Department of Energy

The pCO_2 of the surface ocean is controlled by a combination of physical, chemical, and biological processes. Modeling surface ocean pCO_2 is analogous to modeling sea surface temperature (SST), in that sea surface pCO_2 is affected by fluxes across the air-sea interface and by exchange with deeper water. However, pCO_2 is also affected by chemical and biological processes which have no analog in SST. Seawater pCO_2 is buffered by pH equilibrium reactions between the species CO_2, HCO_3^-, and $CO_3^=$. This effect provides an effective reservoir for CO_2 in seawater that is 10 times larger than it would be for an unbuffered gas. The equilibrium between dissolved and atmospheric CO_2 is sensitive to temperature, tending to higher pCO_2 in warmer water.

Biological export of carbon as sinking particles maintains a gradient of pCO_2, with lower values near the surface (this process is called the "biological pump"). In most of the ocean, biological activity removes all of the available nutrients from the surface water; that is, the rate of carbon export in these locations is limited by the rate of nutrient supply to the euphotic zone. However, in much of the high-latitude oceans, primary production does not deplete the euphotic zone of nutrients, a fact to which the atmospheric pCO_2 is extraordinarily sensitive. Understanding the limits to phytoplankton growth in the high latitudes, and how these limits might change under different climatic regimes, is essential to prediction of future ocean uptake of fossil fuel CO_2.

Because many of the processes controlling sea surface pCO_2 are driven by mixing in the upper ocean, fluctuations in the depth of the mixed layer are of primary importance to modeling sea surface pCO_2. The depth of the mixed layer can be predicted using a numerical model of the upper ocean. Fluxes of heat, momentum, and dissolved gases provide the boundary conditions for such a model. A major limitation on the precision of calculated heat fluxes is the effect of clouds on the atmospheric radiative heat fluxes.

Three families of mixed layer models have been developed, and although the physical mechanisms by which mixing occurs differ among the model groups, all are successful at predicting the observed ocean mixed layer depth. The "integrated turbulent kinetic energy" (TKE) models construct a budget for surface ocean TKE, using the wind stress as source and dissipation as sink for TKE. Excess kinetic energy is converted to potential energy by mixing denser water up into the surface mixed layer. The "shear instability" models maintain profiles of current velocity resulting from the wind stress; when the current shear becomes too large relative to density stratification, the model mixes (entrains) deep water into the surface layer. "Turbulence closure" models are the most general and the most complicated of the three types, and are based on laboratory studies of fluid turbulence. This paper explores behavioral distinctions between the three types of models, and summarizes previously published comparisons of the generality, accuracy, and computational requirements of the three models. The application of mixed layer models to treatment of sea ice is also reviewed.

Simulation of the upper ocean on a global scale is limited by finite computation resources and by imperfect meteorological forcing data. The air-sea heat fluxes can either be calculated as described above or imposed using an "SST restoring" strategy which pushes the model SST toward observations within some relaxation time constant. Simulation of free convection driven by surface cooling, particularly deep convection in high-latitude winter, is essential to modeling formation of deep water and is therefore an integral part of virtually all circulation models. Convection driven by the wind (forced convection) requires higher spatial resolution and more detailed meteorological forcing data. One strategy for reducing overhead associated with the mixed layer is to "embed" the mixed layer into a surface box of variable thickness, within a deeper surface box. All three mixed layer model types have been incorporated into global-scale simulations.

SECTION C

WORKSHOPS, PROCEEDINGS, AND REPORTS

SECTION C

WORKSHOPS, PROCEEDINGS, AND REPORTS

005 CARBON DIOXIDE RESEARCH PROGRESS REPORT
(DOE/EV-0071, April 1980)

R. C. Dahlman, T. Gross, L. Machta, W. Elliot, and M. MacCracken

This is a report of progress made by Department of Energy contractors on the carbon dioxide issue during fiscal year 1979. The report is largely limited to questions on the global carbon cycle and the effect of increased carbon dioxide on the global climate system.

008 A COMPREHENSIVE PLAN FOR CARBON DIOXIDE EFFECTS RESEARCH AND ASSESSMENT-PART I: THE GLOBAL CARBON CYCLE AND CLIMATIC EFFECTS OF INCREASING CARBON DIOXIDE
(DOE/EV-0094, August 1980)

Carbon Dioxide and Climate Division, U.S. Department of Energy

This plan outlines, in order of priorities, the first part of an urgently required research effort on carbon dioxide effects. The Department of Energy is guided by this plan in developing its research program and offers it to the governmental and scientific communities as a focus about which the required major national and international effort can be developed.

009 WORKSHOP ON ENVIRONMENTAL AND SOCIETAL CONSEQUENCES OF A POSSIBLE CO_2-INDUCED CLIMATE CHANGE
(CONF-7904143, October 1980)

Office of Health and Environmental Research
U.S. Department of Energy

This is a report of a workshop held on April 2-6, 1979, at Annapolis, Maryland. This was one of the major events in the development of the Department of Energy's research program on the carbon dioxide issue. The workshop was on the development of the program on the environmental and societal consequences resulting from a climate change and increase in atmospheric concentrations of carbon dioxide.

011 PROCEEDINGS OF THE CARBON DIOXIDE AND CLIMATE RESEARCH PROGRAM CONFERENCE
(CONF-8004110, December 1980)

L. E. Schmitt (ed.)

This is a report of a conference held in Washington, D.C., on April 24-25, 1980, to review research progress through fiscal year 1979 of the DOE's Carbon Dioxide and Assessment Program, and to review a draft update of the Comprehensive Plan, Part I: The Global Carbon Cycle and Climatic Effects of Increasing Carbon Dioxide (subsequently issued as document 008).

012 PROCEEDINGS OF THE INTERNATIONAL MEETING ON STABLE ISOTOPES IN TREE-RING RESEARCH
(CONF-790518, December 1980)

G. Jacoby (ed.)

This is a report of the proceedings of a meeting held on May 22-25, 1979, at Mohonk Mountain House in New Paltz, New York. The meeting was convened to accelerate the flow of information between scientists in the relatively new and rapidly developing field of measurements of stable isotopes in tree rings. The report contains most of the papers presented at the meeting.

014 SOME ASPECTS OF THE ROLE OF THE SHALLOW OCEAN IN GLOBAL CARBON DIOXIDE UPTAKE
(CONF-8003115, January 1981)

R. M. Garrels and F. T. Mackenzie (eds.)

These are the proceedings of a workshop, which was supported jointly by the U.S. Department of Energy and the Gas Research Institute of Chicago, held on March 20-22, in Atlanta, Georgia. The purpose was to assess the role of the oceanic mixed layer, especially the shallow waters of shelves, seas, and estuaries as a sink or source for atmospheric carbon dioxide.

016 FLUX OF ORGANIC CARBON BY RIVERS TO THE OCEANS
(CONF-8009140, April 1981)

Committee on Flux of Organic Carbon to the Oceans
Division of Biological Sciences National Research Council

The state of knowledge about the role of rivers in the transport, storage, and oxidation of carbon is the subject of this report. It summarizes a workshop of the Committee on Flux of Organic Carbon to the Ocean, Division of Biological Sciences, National Research Council held at Woods Hole, Massachusetts on September 21-25, 1980.

017 WORKSHOP ON OCEANIC CO_2 STANDARDIZATION
(CONF-7911173, February 1982)

H. G. Ostlund and D. Dyrssen (eds.)

This report contains detailed information on the measurements of carbon dioxide and alkalinity made during the GEOSECS (Geochemical Ocean Section) program.

021 PROCEEDINGS: CARBON DIOXIDE RESEARCH CONFERENCE: CARBON DIOXIDE, SCIENCE AND CONSENSUS
(CONF-820970, February 1983)

Institute for Energy Analysis
Oak Ridge Associated Universities

This is a record of the technical papers presented at a conference held at Coolfont, West Virginia on September 19-23, 1982. These papers reviewed the uncertainty on future atmospheric CO_2 levels, global and regional climate changes (as measured by temperature, precipitation, cloudiness, etc.), effects of elevated CO_2 levels on crops and ecosystems, and the potential impact on the West Antarctic.

023 PROCEEDINGS FROM THE SECOND SCIENCE TEAM MEETING OF THE UNITED STATES OF AMERICA DEPARTMENT OF ENERGY AND THE PEOPLE'S REPUBLIC OF CHINA ACADEMIA SINICA JOINT RESEARCH PROGRAM ON CO_2-INDUCED CLIMATE CHANGE
(CONF-8708252, June 1988)

W.-C. Wang and M. R. Riches (eds.)

The Carbon Dioxide Research Division of the U.S. Department of Energy (DOE), brought together 30 Chinese and American scientists at Harper's Ferry, West Virginia, for the second science team meeting of the United States of America Department of Energy (US/DOE) and the People's Republic of China Academia Sinica (PRC/CAS) Joint Research Program on CO_2-Induced Climate Change. The purpose of the conference was to review recent progress and to set new goals for cooperative research and the exchange of data regarding carbon dioxide research. Six papers are presented as Proceedings of the August 1987 PRC/CAS and USA/DOE Joint Carbon Dioxide Research Conference investigating the influence of carbon dioxide upon world climate and are examples of research progress during the last two years. Each of the four task areas set forth are represented: Climate Modeling, Data Preparation, Data Analysis, and Methane Studies.

"A Description of IAP Two-Level Atmospheric General Circulation Model" is documentation of the first numerical climate simulation model developed by the Institute of Atmospheric Physics (IAP) in Beijing. This paper is presented by X. Zhang and X. Liang of CAS/IAP, now visiting scholars at the Laboratory for Planetary Atmosphere Research, State University of New York at Stony Brook.

The category of Task II, Data Preparation, is represented by two papers from the National Oceanic and Atmospheric Administration's National Climatic Data Center at Asheville, North Carolina. These papers, "Historical Sunshine Data in the United States" (P. J. Young, F. T. Quinlan, and T. R. Karl) and "United States Historical Climatology Network (HCN) Serial Temperature and Precipitation Data" (F. T. Quinlan, T. R. Karl, and C. N. Williams, Jr.), demonstrate the work being done on the United States Historical Climatology Network data (the time series of temperature, precipitation, and sunshine) in the United States. These two papers have been published previously; accordingly, we present them here in that format.

"Climate Patterns in China and U.S.," by W.-C. Wang, B. Ronberg, and D. Portman of Atmospheric and Environmental Research, Inc., speaks of climate variability on a regional scale being much larger than that based on averages of global-wide data and therefore being

more difficult to predict. The China Precipitation Proxy Index covers a period of 510 years. This permits comparison of contemporary climate patterns (i.e., the last 100 years) with the period of the Little Ice Age, when the mean temperature over China was 2° colder than present. "The Shift of the Climate Zone and Boundaries of Animals and Plants in China During Historical Times," by Gaofa Gong, P. Zhang, and J. Zhang, is fascinating documentation of the effects of climate change upon the wild elephant whose habitat has shifted from as far north as Beijing in historical times to its current habitat, a small, sequestered section in the southwest corner of the country.

The final paper of this series, "CH_4 Flux from Biogas Generators and Rice Paddies as Measured in Sichuan, China," is the joint work of the Institute of Atmospheric Physics of Beijing and the Institute of Atmospheric Physics at the Oregon Graduate Center at Beaverton, Oregon (M. X. Wang [CAS/IAP], H. A. K. Khalil, and R. A. Rasmussen) and demonstrates the pragmatic exchange of both data and technical assistance between the two countries.

024 WORKSHOP ON SEA LEVEL RISE AND COASTAL PROCESSES (DOE/NBB-0086, March 1989)

A. J. Mehta and R. M. Cushman (eds.)

The possibility in the coming decades of a higher rate of relative sea-level rise globally is now thought to be sufficiently great to warrant serious consideration for its potential implications to human populations. However, the complexities of shoreline response to sea-level rise are contingent on a wide range of interrelationships between physical and ecological factors. The question of how shorelines and shore environments will change with sea-level rise must ultimately focus on our capability to predict such changes, which in turn requires an understanding of the processes involved and availability of data.

As a first step, the University of Florida (UF) undertook a study during the summer of 1987, which resulted in a report, "Some Considerations on Coastal Processes Relevant to Sea Level Rise," by Ashish Mehta, Robert Dean, William Dally, and Clay Montague. In this report, the effects of potential sea-level rise on the shoreline and shore environment were briefly examined by considering the interactions between sea-level rise and coastal processes.

Considerations amply demonstrated the complexities of the interaction between sea-level change and loose-boundary shoreline, their site-specificity, and the inadequacy of inundation models. It was concluded that, with some minor exceptions, the basic knowledge of coastal processes--including hydrodynamics, sedimentary processes, and their interaction, and the available data base are inadequate fore predictive modeling. Apart from difficulties in modeling boundary layer turbulence and associated mixing processes, sediment transport formulations require knowledge of a host of free coefficients that tend to be highly site-specific and, therefore, difficult to evaluate in the complex coastal environment. Besides further improvements in theory, and the need for better definition of wave forcing through adequate long-term monitoring of the coastal wave field via field measurement is emphasized.

To critique the conclusions of the UF report and to reach a broader agreement on research needs to vastly improve the capability to predict shoreline response, the "Workshop on Sea Level Rise and Coastal Processes" was held at Palm Coast, Florida, on March 9-11, 1988. The report on the workshop includes a version of the UF report (modified by its authors after the

workshop) and an appendix. The appendix contains comments by workshop participants, excluding the authors of the UF report. In addition, the appendix includes the comments of John de Ronde, who was invited to the workshop to present his view of the Dutch experience, which provide insight into what higher relative sea level might mean worldwide.

Participants comments largely reinforce the conclusions of the UF report through additional illustrative examples, clarifications, and qualifications, in some cases.

CONF-8608144 **PROCEEDINGS OF THE INTERNATIONAL SYMPOSIUM ON ECOLOGICAL ASPECTS OF TREE RING ANALYSIS**
(April 1987)

G. C. Jacoby, Jr. and J. W. Hornbeck (eds.)

The objective of this proceedings of the meeting is to aid communications within the field of tree-ring analysis, stimulate others to see the potential for even more applications, and serve as a resource for those entering the field.

CONF-890525 **PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON GLOBAL AND REGIONAL ENVIRONMENTAL ATMOSPHERIC CHEMISTRY**
(May 1989)

L. Newman, W. Wang, and C. S. Kiang (eds.)

Today, the economy of the People's Republic of China stands at an important turning point because of the open-door policy adopted by that country in 1978. The changes in infrastructure and in attitude toward socialistic modernization that resulted from that shift in policy are having far-reaching consequences on the industrial and agricultural output and the local, regional, and global atmospheric environment. During the past four decades in China, annual grain production (about half of it rice) has increased by a factor of 3, annual production of coal by a factor of 30, and annual production of crude oil by a factor of about 900. These changes have an inescapable influence on the atmosphere, both regional and global. Moreover, the great deserts in western China produce dusts that blow over the Pacific Ocean and may alter the chemistry and radiative processes in the troposphere. This conference, attended by more than 250 scientists and presenting more than 170 papers, was held because China has become such an important source region to the global atmosphere.

Topics covered at this conference include atmospheric chemistry; the greenhouse effect; sea-level rise; atmospheric dynamics and transport; modelling techniques; the biogeochemical cycles of carbon, sulfur, nitrogen, halogens, and trace elements; the effects of sulfur and nitrogen on climate; the ecological effects of airborne chemicals; acid precipitation and deposition processes, detection, and effects; methane sources; polar ozone depletion; atmospheric aerosols; particulate air pollutants; and sandstorms.

CONF-9006134 **GLOBAL CLIMATE FEEDBACKS: PROCEEDINGS OF THE BROOKHAVEN NATIONAL LABORATORY WORKSHOP (JUNE 1990)**

B. Manowitz (ed.)

The present General Circulation Models (GCMs) do not model important feedbacks, including those from clouds, oceans, and land processes. The purpose of this workshop was to identify such potential feedbacks, to evaluate the uncertainties in the feedback processes (and, if possible, to parameterize the feedback processes so that they can be treated in a GCM), and to recommend research programs that will reduce the uncertainties in important feedback processes.

The following papers were presented:

"Observational Determination of the Greenhouse Effect," A. Raval and V. Ramanathan

"Interpretation of Cloud-Climate Feedback as Produced by 14 Atmospheric General Circulation Models," R. D. Cess

"Cloud Parameterization," D. A. Randall

"Comments on Atmospheric Feedbacks," A. Heymsfield

"Atmospheric Feedbacks: Comments," S. E. Schwartz

"Ocean Thermal Transients: A Program of Data Analysis, Modeling, and Monitoring of the Atlantic Ocean Thermohaline Circulation," K. Bryan

"Paleo Deep Water Variability: Magnitude and Rapidity," E. A. Boyle

"Role of the Ocean Carbon Cycle in Determining Atmospheric pCO_2," J. L. Sarmiento

"Comments on the Problem of Ocean Circulation," C. Wunsch

"Elements of Oceanic CO_2 Feedback in Response to Climate Change," T. Takahashi

"Terrestrial Ecosystems and Climatic Change," W. R. Emanuel and D. S. Schimel

"The Response of Ecosystems to Global Change: Research Agenda," F. A. Bazzaz

"Sea Ice Response to Global Climate Change," W. D. Hibler III

"Commentary on Sea Ice Feedbacks," R. E. Moritz

SECTION D

OTHER REPORTS

SECTION D

OTHER REPORTS

DOE/NBB-0039

INTERNATIONAL CARBON DIOXIDE-RELATED ACTIVITIES: THE INTERNATIONAL ORGANIZATIONS INVOLVED AND U.S. BILATERAL ARRANGEMENTS
(July 1983)

R. Dougher
Oak Ridge Associated Universities

This paper describes the international organizations and the type of CO_2-related activities they conduct and outlines the CO_2 research work conducted through bilateral arrangements.

DOE/NBB-0068

REVIEW OF CARBON DIOXIDE RESEARCH STAFFING AND ACADEMIC SUPPORT
(April 1985)

S. B. Clark, L. Howard, W. Stevenson, and J. Trice
Oak Ridge Associated Universities

The report summarizes the research staffing and academic support of the U.S. Department of Energy's Carbon Dioxide Research Division (CDRD) for 1983 and 1984. About 60% of CDRD's staff were university-affiliated and about 20% were students; however, carbon dioxide research will probably not affect the general labor market for scientists and engineers because it uses only a small part of the total labor pool. The report also discusses options for academic support by CDRD. These include: (1) modifying procurement procedures for research contracts to increase academic involvement; (2) sponsoring summer institutes on issues of interest to CDRD; and (3) supporting traveling lecture programs to inform technical and nontechnical audiences of CDRD's interests.

BERN

CO_2 SYMPOSIUM

Published by the American Geophysical Union

This report presents papers given at the symposium held September 14-18, 1981, at the University of Bern, Switzerland. The participants were scientists directly responsible for making atmospheric carbon dioxide measurements or were involved in interpreting these measurements. A large body of new atmospheric CO_2 data, supplemented by isotopic and oceanic measurements, were presented at the conference.

DOE/ER/60085-H1 GLOBAL DISTRIBUTION OF TOTAL CLOUD COVER AND CLOUD TYPE AMOUNTS OVER LAND
(October 1986)

S. G. Warren
University of Washington

C. J. Hahn and J. London
University of Colorado

R. M. Chervin and R. L. Jenne
National Center for Atmospheric Research

Clouds exert large influences on the earth's climate by virtue of their radiative properties both in the solar and thermal-infrared spectral regions and because of their role in the hydrological cycle. These effects depend on cloud thickness, height, and water content, and therefore, it is useful to distinguish clouds by type. Currently, the surface identification of clouds by type is more accurate than identification from satellites.

This is the third in a series of atlases resulting from a study of global cloud climatology from ground-based observations. This atlas describes, for the land areas of the earth, the average total cloud cover; the amounts of each cloud type and geographical, diurnal, seasonal, and interannual variations in these quantities; and the average base heights of the low clouds. This atlas presents a method for determining the average fractional coverage of each cloud type, taking into account the overlap of different cloud types present simultaneously in a single observation. The method is designed to derive the true average amounts rather than the amounts seen from below or above. The method separately obtains the average frequency of occurrence and the average amount-when-present and multiplies these to derive the average amount of each cloud type. These quantities are mapped for six cloud types, and the average total cloud cover is also mapped for each of four seasons at 5° x 5° latitude-longitude resolution (poleward of 50° latitude, the size of the box is increases in longitude to maintain approximately equal area in each box). Biurnal and interannual variations of cloud type quantities are mapped at the same spatial resolution. The numbers plotted in this atlas as well as more detailed information not included in this atlas, such as average frequencies and amounts for individual year/seasons and individual reporting hours, are available on magnetic tape from the Data Support Section at the National Center for Atmospheric Research and from CDIAC.

The first two atlases in this series described the frequency of occurrence of each cloud type and the simultaneous occurrence of different types but included no information about cloud amounts. A fourth atlas, in preparation, provides data on cloud amounts for the ocean areas of the earth.

DOE/ER/60197-H1 ANTARCTIC SURGES--A CLEAR AND PRESENT DANGER?
(July 1987)

U. Radok
CIRES, University of Colorado

D. Jenssen and B. McInnes
University of Melbourne

Antarctic ice streams typically move hundreds of meters in a year. The investigation here outlined for nonspecialists was carried out with the support of the U.S. Department of Energy at the University of Colorado at Boulder and at the University of Melbourne, Australia, in order to determine whether polar ice streams, like some mountain glaciers, can accelerate their motion from time to time by one or two orders of magnitude in the span of a few years, with appreciable effects on global sea level.

The necessary factual background can be derived from the fact that the mass gains and losses of the Antarctic ice sheet as a whole closely balance one another. The working hypothesis that they do so exactly was used to construct three-dimensional steady-state fields of ice velocity and temperature in broad agreement with the as yet very scant observational record for the ice sheet. Next, a numerical model (due to Budd and McInnes 1974 and Budd 1975), which links the sliding motion of the ice to the energy dissipated by the friction between the ice and the underlying rock, was used to simulate the time-dependent behavior of eight ice streams representing the full range of Antarctic conditions.

In contrast to the realistic alternation between fast advances and stagnating retreats which the model had produced for some mountain glaciers known to surge, the modeled ice streams instead went from steady to irregular continuous fast sliding when the prescribed ice deformability was reduced and/or the implied lubrication by frictional heating was increased. Substantial rapid advances did not develop, except as transient phases in two experiments.

The inability of the model in general to create surges in ice streams could be due solely to its over-simplified treatment of the complex hydraulic processes taking place below the ice. More adequate treatments of these processes are being developed and, when expanded into new self-propelled models, could show ice stream surges to be feasible. However, it may be significant that along surging glaciers the accumulation decreases and becomes strongly negative ("ablation") in the lower reaches. By contrast, the accumulation on Antarctic ice streams increases all the way from their regions of formation to the regions of discharge into the ocean. It is then possible that ice stream surges are prevented by the strong downstream increase in mass flow and also by the flexible restraint exerted by terminal ice shelves.

DOE/PE-0094P

GLOBAL CLIMATE TRENDS AND GREENHOUSE GAS DATA: FEDERAL ACTIVITIES IN DATA COLLECTION, ARCHIVING, AND DISSEMINATION
A REPORT TO THE CONGRESS OF THE UNITED STATES
(June 1990)

Office of Environmental Analysis
U.S. Department of Energy

This report examines the current holdings of data related to greenhouse-gas emissions and climate trends that have been collected by federal agencies; the procedures for collecting, archiving, and disseminating those data; and the coordination of those information activities. It examines what procedures are necessary for improving the availability of the data and information needed to deal with greenhouse-gas and climate-change issues. It also considers what information is needed for the scientific understanding, estimation, and projection of emissions; for the modeling of climate-system processes; for the detection and characterization of trends; and for the support of assessment and policy studies. To explain the kinds of data needed and the special requirements for processing these kinds of data, the methods for estimating greenhouse-gas emissions and for detecting climate trends are summarized.

Particular gaps in data coverage and targets of opportunity for improved data (i.e., data collected but never encoded for computer use and prepared for distribution) are identified. Additional types of data that especially need collection for special purposes have also been pointed out.

The numerous and often extensive appendixes include lists and descriptions of data sources, descriptions of data needed for specific subject areas, the theory and philosophy of data management, and a bibliography.

NCAR/TN-201
+ STR

ATLAS OF SIMULTANEOUS OCCURRENCE OF DIFFERENT CLOUD TYPES OVER THE OCEAN
(November 1982)
(Reprinted 1990)

C. J. Hahn
Cooperative Institute for Research in Environmental Sciences

S. G. Warren
University of Washington

J. London
University of Colorado

R. M. Chervin and R. Jenne
National Center for Atmospheric Research

The importance of clouds for the earth's radiation budget is receiving a great deal of attention in current atmospheric research. This includes both studies of the mechanisms of cloud formation and theoretical and experimental work on radiative

properties of clouds. Recognition of the importance of clouds for global and regional climate has led to the plan for the International Satellite Cloud Climatology Project (ISCCP). Preparation for the five-year project is now under way, in that the methods for obtaining cloud information from satellite radiation observations are being developed. This atlas of co-occurrence of different cloud types over the ocean is expected to aid in the development of these methods by providing ground-based data for comparison with satellite observations. It should also assist the development of cloud-generation schemes in climate models.

Cloud observations from ships are used to investigate the co-occurrence of different cloud types and the geographical and seasonal variation of these co-occurrences. Ground-based observations are used because they provide a more definitive identification of clouds by type than do satellite observations. The clouds are grouped into six types (cirrus-type clouds, altostratus + altocumulus, nimbostratus, cumulus, stratus + stratocumulus, and cumulonimbus). The results are expressed as contingency probabilities; that is, given that one cloud type is present, the probability that another particular type is also present is computed. Since higher clouds are detectable only when the lower clouds are not overcast, a procedure is developed to remove the resulting bias is computing the co-occurrence probabilities. Thus both upward-directed (e.g., cumulus implies cirrus) and downward-directed (e.g., cirrus implies cumulus) contingency probabilities should be reasonably accurate. Maps of these quantities, as well as of the overall frequency of occurrence of each cloud type, of fog, and of clear sky, are presented at 15° latitude x 30° longitude resolution. These contingency probabilities should be useful for testing cloud-generation algorithms in general circulation models and for interpretation of cloud observations from satellites.

NCAR/TN-241 + STR

ATLAS OF SIMULTANEOUS OCCURRENCE OF DIFFERENT CLOUD TYPES OVER LAND

(August 1984)
(Reprinted 1990)

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Cooperative Institute for Research in Environmental Sciences

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University of Washington

J. London
University of Colorado

R. M. Chervin and R. Jenne
National Center for Atmospheric Research

This is the second of a series of atlases to be published as part of an extensive study of the global cloud climatology from ground-based observations. This first atlas, published as NCAR/TN-201 + STR, described the observed simultaneous occurrence of different cloud types over the oceans. The present atlas covers a similar analysis of cloud observations over the land. The classification and grouping of cloud types, and the general methodology of determining different cloud type co-occurrences was

discussed in the first atlas, and the reader is referred to that atlas for details of the procedures used. Additional discussion is contained in the present atlas to describe those cases where a different procedure was followed either as an improvement, or to fit the different circumstances under which land-based cloud observations are made.

The current cloud climatology study is part of the International Satellite Cloud Climatology Program (ISCCP) and will provide a complementary data set for evaluating and validating results from the First ISCCP Regional Experiment (FIRE) and subsequent field experiments.

ORNL/CDIAC-21 **GRADUATE STUDENT THESES SUPPORTED BY CARBON DIOXIDE RESEARCH DIVISION OFFICE OF BASIC ENERGY SCIENCES, U.S. DEPARTMENT OF ENERGY (September 1987)**

R. E. Millemann
Oak Ridge National Laboratory

The U.S. Department of Energy's Carbon Dioxide Research Division (CDRD) has a strong commitment to support graduate education. Over the years, CDRD has funded graduate thesis research, the results of which have not been summarized. The purpose of this report is to summarize information on thesis research supported by CDRD and to make it available to carbon dioxide researchers and other interested persons. The file will be updated annually. Copies of theses can be obtained upon request from CDIAC.

The information used to prepare this report was obtained through a questionnaire sent to CDRD contractors in early 1987. The cutoff date for assembling this information was August 1987, so the actual number of theses completed during 1987 may be greater than that indicated on the summary page and in the figures.

To date, 25 Ph.D. and 23 Master's theses, including 4 internship reports for the M.En. degree from Miami University (Ohio), have been written based on research supported wholly or in part by CDRD funds. Of these, 16 are in the carbon cycle area and 11 relate to climate, 17 to vegetation response, 3 to sea level, and 4 to CDIAC; a few theses are relevant to more than one program area. The number of universities involved in awarding degrees based on thesis research is 20, including one foreign university, the University of Melbourne. Of the contractors for the period 1981 through 1987, 82 responded to the questionnaire, and of these, 26 supported thesis research. Most of the contractors also served as the major professors for the students.

After the summary and figure pages, four lists appear in this report: an Author List containing the complete thesis citation, name(s) of the major professor(s), major department, contractor, and contract number; a Contractor List having the affiliation of and the thesis research supported by each contractor; a Program Area List in which the theses are grouped by subject area; and a University List in which the theses are grouped by the degree-granting institutions.

ORNL/CDIAC-23 **PRELIMINARY DEVELOPMENT OF A SEASHORE-EFFECTS ANALYSIS SYSTEM (February 1989)**

D. B. Miller and R. M. Cushman
Oak Ridge National Laboratory

A melting of polar ice sheets and mountain glaciers and a thermal expansion of ocean water could lead to a rise in sea level as a result of increasing atmospheric CO_2 concentrations and subsequent global temperature increases.

The coastal erosion and inundation caused by this event could create agricultural, economic, demographic, and ecological problems along coastal zones.

A preliminary Sea Shore Effects Analysis System (SEAS) data base was developed to answer questions on the effects of global sea level rise. Resources potentially affected by a rise in sea level were identified, resulting in the acquisition of eight data sets. Ten other sources of data were located but are currently unavailable. The data are stored in SAS data sets.

This information can be analyzed using the Geographic Information System (GIS) of the Environmental Sciences Division at Oak Ridge National Laboratory and the newly developed Digital Line Graph elevational terrain data of the U. S. Geological Survey. All SEAS data have latitude/longitude locational variables, and, when merged with the terrain data on the GIS, they can be used for a detailed (e.g., 1-m increment) analysis of the effects of sea level rise.

Development of the SEAS data base can be continued with an emphasis on locating and obtaining additional data and using the GIS for analysis.

ORNL/CDIAC-24/VI **BIBLIOGRAPHY ON TROPICAL RAIN FORESTS AND THE GLOBAL CARBON CYCLE. VOL. 1. AN INTRODUCTION TO THE LITERATURE (May 1988)**

C. A. S. Hall
State University of New York and University of Montana

S. Brown
University of Illinois

F. M. O'Hara Jr.
Consultant, Oak Ridge National Laboratory

P. B. Bogdonoff, D. Barshaw, E. Kaufman, and S. Underhill
Cornell University

This bibliography is Part I of a two-part volume; the second part will be an ecological and land-use bibliography on South Asia by J. F. Richards.

World literature on tropical rain forests, tropical deforestation, land-use change in the tropics, tropical forest conversion, and swidden agriculture as related to the global carbon cycle is covered in this bibliography. Historic papers and books are included, but comprehensive coverage was only sought for 1980 through 1987. This compendium of nearly 2000 entries forms the point of departure for a series of bibliographies on this topic. Other works in this series will be on the global carbon cycle and rain forests in specific geographic areas, whereas this volume includes references to literature about the global carbon cycle and rain forests anywhere in the world. The bibliography is ordered alphabetically by author and is indexed by subject and author.

This bibliography is the third in a series of up-to-date, specialized, and evaluated bibliographies that have been produced by the cooperative efforts of the U.S. Department of Energy's Carbon Dioxide Information Analysis Center (CDIAC) and carbon dioxide researchers.

ORNL/CDIAC-24/V2

BIBLIOGRAPHY ON TROPICAL RAIN FORESTS AND THE GLOBAL CARBON CYCLE. VOL. 2. SOUTH ASIA (February 1989) (CDIAC-24 V2)

E. P. Flint and J. F. Richards
Duke University

Considerable debate has centered on the role of biotic carbon release and uptake in the global carbon cycle. Carbon release caused by deforestation may contribute significantly to increased global atmospheric CO_2. The first bibliography in this series addressed worldwide tropical rain forests and the carbon cycle, emphasizing the most recent literature. The focus of this bibliography is South Asia, primarily India, Pakistan, and Bangladesh and including some references to Nepal, Bhutan, Sri Lanka, Burma, and other nations.

This bibliography covers a range of ecological, botanical, forestry, agricultural, geological, and geographical sources for the period from 1889 to the present. References include land-use change as it affects all South Asia vegetation types, from tropical rain forests to high mountain systems to deserts. This broad scope was chosen because forests are believed to have covered most of South Asia within the past few millennia and because massive human impact is believed to be responsible for the prevalence of grassland, semidesert, and thorn forests in the regional landscape today.

Major emphases include biomass and productivity of all natural and agricultural South Asian vegetation types, forest area and volume, deforestation and environmental degradation, official land-use statistics, descriptive and quantitative studies of vegetation and animals, forest history, and local and regional case studies of land-use.

This bibliography is the fourth in a series of up-to-date, specialized, and evaluated bibliographies that have been produced by the cooperative effort of the U.S. Department of Energy's Carbon Dioxide Information Analysis Center (CDIAC) and CO_2 researchers.

ORNL/CDIAC-28 ENVIRONMENTAL CONSEQUENCES OF CO_2-CLIMATE INTERACTIONS: THE NEED FOR INTEGRATED RESOURCE ANALYSIS (January 1989)

R. M. Cushman, J. C. Waterhouse, and M. P. Farrell
Oak Ridge National Laboratory

The increasing concentration of atmospheric carbon dioxide is expected to alter the global climate and thereby affect agriculture, forestry, fisheries, and water resources. Resources such as these interact on a regional scale, and realistic projections of the effects on these resources must take into account the important interactions and feedbacks linking them. In addition, carbon dioxide directly affects the water use and growth of vegetation; therefore, the interactive effects of carbon dioxide and climate must also be considered. These interactions and feedbacks pose a significant challenge to any attempt to model the response of resources to changing carbon dioxide and climate. In particular, model linkage and the integration of processes that operate on different spatial and temporal scales are problems that must be addressed.

ORNL/CDIAC-38 DOCUMENTATION AND ANALYSIS OF A GLOBAL CO_2 MODEL DEVELOPED BY PENG ET AL. (July 1990)

H. I. Jager, T.-H. Peng, A. W. King, and M. J. Sale
Oak Ridge National Laboratory

In 1983, Peng et al. developed a modification of the Oeschger et al. 1975 ocean model. Both the original and the modification are one-dimensional representations of the ocean, including (1) CO_2 exchange between a well mixed atmosphere and a well mixed ocean surface layer and (2) diffusive mixing into the waters lying below the mixed layer. Peng et al. also added a representation of deep-water cycling from intermediate depths to the surface polar outcrop to the ocean bottom and then back to the surface. In addition, they incorporated oceanic primary productivity into the model and benchmarked the model against the penetration of bomb-produced tritium measured by the Geochemical Ocean Sections Study (GEOSECS) program.

This report documents that modified model and describes how the model was standardized to allow comparison with other models. Before being subjected to sensitivity analysis, the standardized version of the model was supplemented with a calibration routine to define reasonable combinations of initial conditions. This routine improved the model's ability to hold an initial equilibrium state. The subsequent sensitivity analysis showed that the model was sensitive to different parameters at different points in its run time. For short runs, the initial conditions selected were of greatest importance; the significance of the initial conditions declined in longer simulations. With the pCO_2 excluded from the sensitivity analysis, ocean surface area was always second in importance. Next, the CO_2 exchange rate was most important in short runs, but the alkalinity of the oceans was in all but the shortest runs.

ORNL/CDIAC-39 GLOSSARY: CARBON DIOXIDE AND CLIMATE (August 1990)

R. M. Cushman
Oak Ridge National Laboratory

The impact of increased concentrations of carbon dioxide (CO_2) and other trace gases in the atmosphere is of concern in both scientific and nontechnical fields. This glossary contains definitions of selected CO_2-related terms and has been compiled to help fill the gaps in information related to climate-change terminology.

Terms in the glossary are defined with an emphasis on their relationship to CO_2 and climate. Many of the definitions are then followed by a more comprehensive discussion of the terms and their use. References to the literature from which the definitions were taken are listed at the end of the glossary.

This is the third edition of *Glossary: Carbon Dioxide and Climate*. This new edition contains more than a hundred new terms, redefinitions of many of the original terms, and an expansion of a section of tables.

In addition to terminology associated with the CO_2-climate issue, a variety of other types of nomenclature is required to fully understand crucial relations between emissions, atmospheric conditions, and changing climate. The *Glossary* also contains seven tables of International System of Units Prefixes, common conversion factors, useful quantities found in CO_2 research, geological time scales, and abbreviations and acronyms commonly used in atmospheric research.

SECTION E

USDA REPORTS ON RESPONSE OF VEGETATION TO CARBON DIOXIDE

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USDA REPORTS ON RESPONSE OF VEGETATION TO CARBON DIOXIDE

DA001 FIELD STUDIES OF PLANT RESPONSES TO ELEVATED CARBON DIOXIDE LEVELS, 1980

H. H. Rogers, G. E. Bingham, J. D. Cure, W. W. Heck, A. S. Heagle, D. W. Israel, J. M. Smith, K. A. Surano, and J. F. Thomas

During the summer of 1980 techniques were developed for the generation of large-scale test atmospheres in the field. These methods are applicable to the study of CO_2 dose-response relationships of agronomic and forest species. The system performed satisfactorily and its feasibility for the study of responses of field vegetation to CO_2 was demonstrated.

DA003 EFFECTS OF INCREASED CARBON DIOXIDE ON PHOTOSYNTHESIS AND AGRICULTURAL PRODUCTIVITY OF SOYBEANS, 1981

L. H. Allen, Jr., K. J. Boote, J. W. Jones, J. W. Mishoe, P. H. Jones, C. V. Vu, R. Valle, and W. J. Campbell

Part A of this report describes responses of soybean crops that were grown from seeding to final harvest in outdoor, controlled environment chambers, Soil-Plant-Atmosphere- Research (SPAR) units, that were used to conduct experiments at CO_2 concentrations from 330 vpm to 800 vpm. This report also contains information on plant growth, staging, and components of dry matter at final harvest, as well as preliminary information on leaf RuBP carboxylase. Part B of this report includes laboratory analyses of nonstructural carbohydrates and nitrogen of leaves during diurnal samplings, and of plant components of the final harvest (leaves, stems, petioles, seed).

DA022 FIELD STUDIES OF SWEET POTATOES AND COWPEAS IN RESPONSE TO ELEVATED CARBON DIOXIDE, 1985

P. K. Biswas, J. R. Allen, N. C. Bhattacharya, J. Y. Lu, R. D. Pace, H. H. Rogers, K. B. Coleman, J. F. Eatman, P. P. Ghosh, N. Mbikayi, J. N. McCrimmon, and A. Menefee

This report summarizes the results of a study on the physiological and biochemical effects of enriched CO_2 on sweet potatoes and cowpeas. The following are the results of the study.

Sweet potatoes grown in the open top chambers, at ambient CO_2 concentrations had fewer leaves, less total runner length, and lower fresh and dry weights of shoots, leaves, and tubers as compared with sweet potatoes grown in the open field without chambers. While shoot growth in sweet potatoes increased with increasing CO_2, few of the effects were large enough to be significant, but the percentages of nitrogen and protein nitrogen in sweet potato leaves decreased significantly at higher CO_2 concentrations. The total fresh weight of tubers increased significantly at the higher levels of CO_2, primarily due to an increase in the number of tubers. There were no differences in the density of stomates or in stomatal conductances in sweet potato leaves. Protein, total carotenoids, and insoluble dietary fiber of tubers all decreased with increasing CO_2, while dry matter content increased with increasing CO_2.

In phytotron studies with pot-grown sweet potatoes, plants grown at 675 or 1000 ppm CO_2 showed increases in the length of the main stem, total branch length, the number of branches, and leaf area as compared with those grown in 350 ppm CO_2. At each harvest interval the production of total dry matter increased in response to increasing CO_2. Specific leaf weight also increased with increased CO_2 concentrations. At the final harvest, the dry weights of roots and tubers increased 1.8 and 2.6 times in plants grown at 675 and 1000 ppm CO_2, respectively, compared with those grown at 350 ppm CO_2. The number and size of tubers increased at high CO_2 concentrations. Carbon dioxide enrichment resulted in early tuber maturation in sweet potatoes.

Cowpeas were studied in two experiments in open top chambers. In the row crops study, the fresh and dry weights of cowpea plants grown in chambers at ambient CO_2 were slightly lower than in plants grown in the open field, but the differences were statistically insignificant. Within chambers, the fresh and dry weights of plants were significantly greater at 506 and 655 ppm CO_2 as compared to plants grown at ambient CO_2 (354 ppm). The number of leaves, leaf area, plant height, number of nodules and pods, and the fresh weight of seeds were significantly greater at enriched CO_2 levels. Protein nitrogen of seeds increased significantly with increased CO_2 concentrations. The number of stomata did not differ among the different chambers. Stomatal conductances were significantly greater in plants grown at 506 ppm CO_2 than in plants grown in chambers at ambient CO_2.

In the cowpea pot study, plants grown at elevated CO_2 had greater dry weights of seeds and vegetative parts and produced more leaves than plants grown in a chamber at ambient CO_2, but there were not differences in plant height or rate of growth. Differences in the number of nodules and the rate of nitrogen fixation were not significant, but nitrogen fixation rates in plants grown at elevated CO_2 were approximately 45% higher, on a per plant basis, than in plants grown in ambient chambers. In phytotron studies with pot-grown cowpeas, the length of the main stem and branches, the number of leaves and leaf area were greater at 675 and 1000 ppm CO_2 than at 350 ppm CO_2. Flowers appeared 10-12 days earlier in an enriched CO_2 atmosphere. Carbon dioxide enrichment hastened pod and seed formation in cowpeas and also caused greater partitioning of biomass into pods than into roots, stems, or leaves. Total seed weight and number of seeds per pod were significantly greater at elevated CO_2, but CO_2 enrichment did not affect the harvest index of cowpeas.

SECTION F

COMPUTER MODEL PACKAGES AND NUMERIC DATA PACKAGES

SECTION F

COMPUTER MODEL PACKAGES (CMPs) AND NUMERIC DATA PACKAGES (NDPs)

CMP-002 THE IEA/ORAU LONG-TERM GLOBAL ENERGY-CO_2 MODEL

J. A. Edmonds and J. M. Reilly (contributors)

This mathematical model, written in FORTRAN IV and adapted for use on an IBM® 370/3033, makes projections concerning global energy and CO_2 emissions at 25-year intervals from 1975 through 2100 based on economic, demographic, and energy interactions. The model separates the world into nine regions, each having four components: demand, supply, energy balance, and CO_2 emissions. Energy demand is a function of the population, economic activity, technological change, energy prices, and energy taxes and tariffs existing in each region. Supply is dependent upon resource constraints, behavioral assumptions, and energy prices in a region. Energy balance reconciles the global energy supply and demand for fuels. Emissions are determined by applying appropriate carbon coefficients at the points in the energy flow where carbon is released. The model offers three energy/emission scenarios through 2100 and illustrates the complex relationships between global CO_2 emissions, rising populations, and energy parameters. The model is in nine files, three containing the source code and subroutines and one input-data and one output file each for low, mid, and high cases. These files range in size from 45.6 to 422 kB and are available on 9-track magnetic tape only.

CMP-002/PC THE IEA/ORAU LONG-TERM GLOBAL ENERGY-CO_2 MODEL: PERSONAL COMPUTER VERSION A84PC

The IBM® PC version of the Edmonds-Reilly model reflects considerable refinements and improvements over the mainframe version (see CDIAC CMP-002). It has the capability to calculate both CO_2 and CH_4 emission estimates by source and region. The basic methodology and features of the PC version are the same as those for the mainframe version. Population, labor productivity, end-use energy efficiency, income effects, price effects, resource base, technological change in energy production, environmental costs of energy production, market-penetration rate of energy-supply technology, solar and biomass energy costs, synfuel costs, and the number of forecast periods may be interactively inspected and altered producing a variety of global and regional CO_2 and CH_4 emission scenarios for 1975 through 2100. The executable versions of the model and the source code are contained in 74 files ranging in size from 10 bytes to 292 kB.

NDP-001/R1 ATMOSPHERIC CO_2 CONCENTRATIONS--MAUNA LOA OBSERVATORY, HAWAII, 1958-1986

C. D. Keeling (contributor)

Since 1958, air samples have been continuously collected at Mauna Loa Observatory and analyzed by infrared spectroscopy for CO_2 concentrations. Data are averaged to give monthly and annual atmospheric CO_2 concentrations.

These data represent the longest continuous record of atmospheric CO_2 concentrations in the world. This precise data record covers a single site (Mauna Loa Observatory, Hawaii). It is a reliable indicator of the regional trend in the concentration of atmospheric CO_2 in the middle layers of the troposphere and is critical to CO_2-related research. The data are in one file taking 2.5 kB.

NDP-002 TREE RING CHRONOLOGY INDEXES AND RECONSTRUCTIONS OF PRECIPITATION IN CENTRAL IOWA, USA

T. J. Blasing and D. N. Duvick (contributors)

Tree core samples (4 mm in diameter) were extracted from the trunks of white oak (*Quercus alba*) at three sites in central Iowa (Duvick Back Woods, Ledges State Park, and Pammel). At least 60 trees were sampled at each site, and at least two cores were taken from each tree. The growth rings of each core were dated by calendar year and measured; the measurements were then transformed into dimensionless ring-width indices and correlated with annual precipitation. Data were collected for the years 1680 through 1979. Each tree ring was characterized by the site, year, tree-ring-width index, number of core samples, decade year, and the annual reconstructed precipitation estimate. These data have more than 50% of their variance in common with the known annual statewide average precipitation for Iowa and serve as useful indicators of the precipitation and drought history of the region for the past 300 years. The data are in two files: tree-ring-chronology data (8 kB) and the annual reconstructed precipitation data for central Iowa (2 kB).

NDP-003/R1 GLOBAL SURFACE AIR TEMPERATURE VARIATIONS: 1851-1984.

P. D. Jones, S. C. B. Raper, T. M. L. Wigley, R. S. Bradley, P. M. Kelly, and H. F. Diaz (contributors)

Monthly and annual surface-air temperature anomalies relative to the 1951–1970 mean surface-air temperature were calculated for the periods of 1851–1984 for the Northern Hemisphere, 1858–1984 for the Southern Hemisphere exclusive of Antarctica, and 1958–1984 for the Southern Hemisphere inclusive of Antarctica. These estimates are derived from land-based meteorological station data and fixed-position weather-ship data interpolated onto a 5° latitude by 10° longitude grid. The data are in three files, one for the Northern Hemisphere temperature anomalies (10 kB) and two for the Southern Hemisphere temperature anomalies (9 kB, 2 kB).

NDP-004/R1 TRANSIENT TRACERS IN THE OCEANS (TTO)--HYDROGRAPHIC DATA AND CARBON DIOXIDE SYSTEMS WITH REVISED CARBON CHEMISTRY DATA

P. G. Brewer, T. Takahashi, and R. T. Williams (contributors)

The 1981 TTO North Atlantic experiment cruise consisted of seven legs and visited 250 hydrographic stations across the North Atlantic Ocean in 200 days. About 9000 water samples were taken for analysis of salinity, oxygen, and nutrients. More than 3000 samples were collected for tritium analysis, and more than 1000 samples for radiocarbon analysis. Samples were characterized hydrographically (e.g., sample depth, ocean depth, and water temperature) and chemically (e.g., alkalinity, salinity, silicate concentrations,

and nitrate concentrations). They may be used for ocean-mixing studies, for testing models of ocean CO_2 uptake, and for determining the exchange of carbon dioxide between the atmosphere and the ocean. The data are in two files [original TTO data (0.67 MB) and revised TTO data (0.86 MB)].

NDP-005 **ATMOSPHERIC CO_2 CONCENTRATIONS - THE NOAA/GMCC FLASK SAMPLING NETWORK**

T. J. Conway and P. Tans (contributors)

Flask air samples are collected approximately once per week at 29 stations scattered around the globe. The earliest samples were taken in 1968, but the period of record varies from station to station. The samples are analyzed for atmospheric CO_2 concentration on a nondispersive infrared gas analyzer apparatus at the NOAA/GMCC laboratory in Boulder, Colorado. The measurements are directly traceable to the World Meteorological Organization primary CO_2 standards. Each sample is characterized by station, year, sampling date and time, flask identification number, CO_2 concentration, date and time of analysis, and quality indicators. The data are in 30 files [one file that contains data through 1981 (946 kB), and one file for each site with data from 1981 through 1986 (ranging from 3.6 to 55.8 kB)].

NDP-006 **PRODUCTION OF CO_2 FROM FOSSIL FUEL BURNING BY FUEL TYPE, 1860-1982**

R. M. Rotty and G. Marland (contributors)

Global carbon dioxide emissions for 1950 through 1982 were estimated by Marland and Rotty (1984) from fuel production data from the U.N. *Energy Statistics Yearbook* (1983, 1984). Data before 1950 came from Keeling (1973). Fuel-production data were used in these calculations because they appeared to be more reliable on a global basis than fuel-consumption data. The data given are the year and annual global CO_2 emissions (annual global total; cumulative global total since 1860; and annual global emissions from solid fuels, liquid fuels, natural gas, gas flaring, and cement manufacturing). These data provide the only pre-1950 estimates of the amount of carbon emitted to the atmosphere from fossil-fuel burning. The CO_2 emission record since 1950 has been updated and revised several times with the most recent estimates being published by Marland et al. (1989). The data are in one file taking 7.5 kB.

NDP-007 **ATMOSPHERIC CO_2 CONCENTRATIONS--THE CSIRO (AUSTRALIA) MONITORING PROGRAM FROM AIRCRAFT FOR 1972-1981**

D. J. Beardsmore and G. I. Pearman (contributors)

From 1972 through 1981, air samples were collected in glass flasks from aircraft at a variety of latitudes and altitudes over Australia, New Zealand, and Antarctica. The samples were analyzed for CO_2 concentrations with nondispersive infrared gas analysis. The resulting data contain the sampling dates, type of aircraft, flight number, flask identification number, sampling time, geographic sector, distance in kilometers from the listed distance measuring equipment (DME) station, station number of the radio

navigation distance measuring equipment, altitude of the aircraft above mean sea level, sample analysis date, flask pressure, tertiary standards used for the analysis, analyzer used, and CO_2 concentration. These data represent the first published record of CO_2 concentrations in the Southern Hemisphere expressed in the WMO 1981 CO_2 Calibration Scale and provide a precise record of atmospheric CO_2 concentrations in the troposphere and lower stratosphere over Australia and New Zealand. The data are in one file taking 263 kB.

NDP-008/R1 **ANNUAL AND SEASONAL GLOBAL TEMPERATURE ANOMALIES IN THE TROPOSPHERE AND LOW STRATOSPHERE, 1958 - SUMMER 1986**

J. K. Angell and J. Korshover (contributors)

For 1958 through 1986, the annual and seasonal temperature anomalies relative to a 1958–1977 mean (expressed in degrees Celsius) were calculated for the surface, troposphere (850–300 mb), tropopause (300–100 mb), and low stratosphere (100–50 mb and 100–30 mb) layers on regional, hemispheric, and global bases. Most of the values are column-mean temperatures obtained from the differences in height between constant-pressure surfaces at individual radiosonde stations. The pressure-height data before 1980 were obtained from published values in Monthly Climatic Data for the World. These temperature anomalies may be used to analyze long-term temperature trends for a layer of the atmosphere (i.e., surface, troposphere, tropopause, and low stratosphere), a region (i.e., polar, temperate, subtropical, and equatorial), a hemisphere, or the globe. The data are in one file taking 64.5 kB.

NDP-009 **GROWTH AND CHEMICAL RESPONSES TO CO_2 ENRICHMENT--VIRGINIA PINE (*Pinus Virginiana Mill.*)**

R. J. Luxmoore, R. J. Norby, E. G. O'Neill, D. G. Weller, J. M. Ells, and H. H. Rogers (contributors)

From June 28 to October 29 in 1982, Virginia pine seedlings were exposed to elevated CO_2 levels in open-top growth chambers at one of four concentrations (75, 150, 300, and 600 ppm above ambient).

Plant dry weight; height; stem diameter; and chemical contents of leaf, stem, and root tissues were measured before and after exposure. Soil variables were also characterized. These data illustrate the short-term physical and chemical response of Virginia pine seedlings to elevated levels of CO_2. The data are in seven files: initial dry weights before exposure (844 kB), dry weights after exposure (4 kB), major nutrient concentrations after final harvest (12 kB), minor nutrient concentrations after final harvest (17 kB), soil nutrient concentrations after final harvest (4 kB), soil leachate elements after final harvest (5 kB), and soil leachate solutes after final harvest (4 kB).

NDP-010 ATMOSPHERIC CO_2 CONCENTRATIONS--THE CSIRO MONITORING PROGRAM: SURFACE DATA FOR CAPE GRIM, TASMANIA

D. J. Beardsmore, G. I. Pearman and R. C. O'Brien (contributors)

From 1976 through 1983, air samples collected from a high-volume general intake 10 m above the roof of the laboratory at Cape Grim, Tasmania, were dried and analyzed for CO_2 concentrations with a nondispersive infrared gas analyzer. This baseline CO_2 record from Cape Grim indicates the CO_2 concentrations in large, maritime air masses devoid of vegetative influences in this region of the Southern Hemisphere. The data available on each sample are sampling date; daily, monthly, and annual CO_2 concentrations; standard deviation associated with each concentration; number of hours of data used to calculate the CO_2 values; and the analyzer used. The data are in three files: daily (17 kB), monthly (3 kB), and annual (310 bytes).

NDP-011 GLOBAL PALEOCLIMATIC DATA FOR 6000 YR B.P.

T. Webb, III (contributor)

To determine regional and global climatic variations during the past 6000 years, pollen, lake level, and marine plankton data from 797 stations were compiled to form a global data set. Radiocarbon dating and dated tephras were used to determine the ages of the specimens. The data available for the pollen data are site number, site name, latitude, longitude, elevation, and percentages of various taxa. For lake-level data, the data are site number, site name, latitude, longitude, and lake-level status. And for marine plankton, the data are site number, site name, latitude, longitude, water depth, date, dating control code, depth of sample, interpolated age of sample, estimated winter and summer sea-surface temperatures, and percentages of various taxa. The data are in 55 files: 5 files for each of 9 geographic regions and 10 supplemental files. The files for each region include (1) a FORMAT file describing the format and contents of the data for that region, (2) an INDEX file containing descriptive information about each site and its data, (3) a DATA file containing the data and available climatic estimates, (4) a PUBINDEX file indexing the bibliographic references associated with each site, and (5) a REFERENCE file containing the bibliographic references. The files range in size from 2 to 66 kB.

NDP-012 CLIMATIC DATA FOR NORTHERN HEMISPHERE LAND AREAS, 1851-1980

R. S. Bradley, P. M. Kelly, P. D. Jones, C. M. Goodess, and H. F. Diaz (contributors)

For the period 1851 through 1985, approximately 700 temperature records and 1200 precipitation records for Northern Hemisphere stations were added to the World Weather Records data base with the supplemental data obtained by surveying major libraries, archives, and meteorological data centers and by contacting scientists and meteorological agencies directly. The quality of these supplemental data were assessed when possible by using station-history information. For each addition, the WMO station identification number, station name, country, latitude, longitude, station elevation, beginning year of record, ending year of record, monthly temperature, and monthly precipitation were entered. The data are in two files, one for monthly temperature

(6.40 MB) and one for monthly precipitation data (8.06 MB). Because of the size of this data set, it is available only on 9-track magnetic tape.

NDP-013 VOLCANIC LOADING: THE DUST VEIL INDEX

H. H. Lamb (contributor)

Lamb's Dust Veil Index (DVI) is a numerical index that quantifies the impact of a particular volcanic eruption's release of dust and aerosols over the years following the event, especially the impact on the Earth's energy balance. DVIs have been calculated for eruptions occurring from 1500 through 1983. The methods used to calculate the DVI have been intercalibrated to give a DVI of 1000 for the eruption of Krakatoa in 1883. The DVI for any volcanic eruption is based on a review of the observational, empirical, and theoretical studies of the possible impact on climate of volcanic dust veils. The DVI allows one to compare volcanic eruptions by a single numerical index. The data base includes the name of the erupting volcano, year of eruption, volcano latitude and longitude, maximum extent of the dust veil, veil duration, DVI for the entire globe, DVI for the Northern Hemisphere, and DVI for the Southern Hemisphere. The data are in one file (22.6 kB).

NDP-014 SOLAR RECORDS: THE WOLF SUNSPOT INDEX AND UMBRAL/ PENUMBRAL RATIO

D. V. Hoyt (contributor)

These data from observations of sunspot activity cover the period 1875 through 1981; reconstructions are possible back to 1832. Available sunspot models and the theory of mixing length indicate that the observed changes in the umbral/penumbral (U/P) ratio may be equivalent to changes in the solar constant. The U/P ratio is calculated from measurements of solar activity and has been shown to be in good agreement with the Northern Hemisphere temperature record. The data consist of year, number of sunspot groups, Wolf sunspot number, umbra area, whole area, penumbral area, and umbral/penumbral ratio. The data are in one file (3.3 kB).

NDP-015 SURFACE AIR TEMPERATURE ANOMALIES FOR THE NORTHERN HEMISPHERE: THE RUSSIAN DATASET

A. Robock, I. I. Borzenkova, G. V. Gruza, and K. Ya. Vinnikov (contributors)

These Northern Hemisphere surface-temperature anomalies cover the period from 1891 through 1980 and were derived from maps compiled at the Main Geophysical Observatory (Leningrad) and maps appearing in the Synoptic Bulletin of the State Hydrometeorological Committee. The data include the year, month, and monthly surface-air-temperature anomaly (relative to a reference period mean in degrees Celsius). They may be compared with other Northern Hemisphere surface-air-temperature-anomaly data sets and used for studies attempting to detect carbon-induced climate change. The data are in seven files (three of monthly surface air temperature anomalies, three of monthly average temperature norms, and one of grid points' altitudes above sea level) that range from 5 kB to 1.46 MB and are available on 9-track magnetic tape only.

NDP-016 CLIMATIC DATA FOR SELECTED U.S. AND CANADIAN STATIONS, 1941-1980

T. R. Karl and F. T. Quinlan (contributors)

For 1941 through 1980, monthly temperature and precipitation data were recorded for 130 nonurban stations in the U.S. and Canada. These stations were selected because they provide reasonably uniform spatial coverage of that area; consist of nonurban stations; have few missing daily and monthly data; have experienced few station relocations; and have undergone little change in observation times. These data were obtained from the archives of the National Climatic Data Center and the Canadian Climate Centre. Included in the data are the station identification number, station name, state abbreviation, province code, country code, station latitude and longitude, station population (1940, 1960, and 1980), name of observer, observing schedule code, time of observation bias codes, year, monthly precipitation, mean temperatures, mean daily maximum temperatures, mean daily minimum temperatures, and difference between the monthly mean daily maximum and minimum temperatures. The data are in eight files [five data files (530 kB each), one station history file (56 kB), one station inventory file (11.7 kB), and one file that lists the Canadian observers (7.9 kB)] and are available on 9-track magnetic tape only.

NDP-017 MAJOR WORLD ECOSYSTEM COMPLEXES RANKED BY CARBON IN LIVE VEGETATION: A DATABASE

J. S. Olson, J. A. Watts, and L. J. Allison (contributors)

In 1980, this data base and the corresponding map were completed after more than 20 years of field investigations, consultations, and analyses of published literature. They characterize the use and vegetative cover of the Earth's land surface with a 0.5° x 0.5° grid. The data include latitude, longitude, and vegetation code. This world-ecosystem-complex data set and the accompanying map provide a current reference base for interpreting the role of vegetation in the global cycling of CO_2 and other gases and a basis for improved estimates of vegetation and soil carbon, of natural exchanges of CO_2, and of net historic shifts of carbon between the biosphere and the atmosphere. The data are in one file of 109 kB.

NDP-018 WORLDWIDE ORGANIC SOIL CARBON AND NITROGEN DATA

P. J. Zinke, A. G. Stangenberger, W. M. Post, W. R. Emanuel, and J. S. Olson (contributors)

This data base was begun with the collection and analysis of soil samples from California. Additional data came from soil surveys of Italy, Greece, Iran, Thailand, Vietnam, various tropical Amazonian areas, and U.S. forests and from the soil-survey literature. The analyzed samples were collected at uniform soil-depth increments and included bulk-density determinations. The data on each sample are soil profile number; soil profile carbon content; soil profile nitrogen content; sampling site latitude and longitude; site elevation; profile literature reference source; and soil profile codes for Holdridge life zone, Olson ecosystem type, and parent material. These data may be used to estimate the size of the soil organic carbon and nitrogen pools at equilibrium with natural soil-forming factors. The data are in one file of 323 kB.

NDP-019/R1 UNITED STATES HISTORICAL CLIMATOLOGY NETWORK (HCN) SERIAL TEMPERATURE AND PRECIPITATION DATA

F. T. Quinlan, T. R. Karl, and C. N. Williams, Jr. (contributors)

Extending through 1987, this data base contains monthly total precipitation and temperature data from 1219 stations in the contiguous U.S. To be included in the Historical Climatology Network (HCN), a station had to be currently active (1987), have at least 80 years of monthly temperature and precipitation data, and have experienced few station changes. These data were derived from a variety of sources including the National Climatic Data Center archives, state climatologists, and published literature. The data base contains several hundred variables, including state number; station number; monthly temperatures (minimum, maximum, and mean); total monthly precipitation; and time of observation. This is probably the best monthly temperature and precipitation data set available for the contiguous U.S. because station moves, instrument changes, urbanization effects, and time-of-observation differences have been considered and, where necessary, the data have been corrected. The data are in 13 files [one station inventory file, one station history file, six temperature files, one precipitation file, one time-of-observation correction file, and two quality-assessment files]. The file sizes range from 5 kB to approximately 50 MB and are available on 9-track magnetic tape only.

NDP-020 A GLOBAL GRID POINT SURFACE AIR TEMPERATURE DATA SET: 1851-1984

P. D. Jones, S. C. B. Raper, B. S. G. Cherry, C. M. Goodess, T. M. L. Wigley, B. Santer, P. M. Kelly, R. S. Bradley, and H. F. Diaz (contributors)

For 1851 through 1984, this data base presents monthly surface-air temperature anomalies for both hemispheres, relative to a 1951 through 1970 reference period, on a 5° latitude by 10° longitude global grid. The basis of the data set is derived from the World Weather Records published by the Smithsonian Institution and the U.S. Weather Bureau. Additional data were added from meteorological archives. The records include the year, month, latitude, longitude, surface air temperature anomaly, number of stations used to calculate each gridded anomaly, and the mean value of the inverse of the great circle distance between the station and the grid point. The data are in two files (Northern and Southern hemispheres) of 19.63 MB each on 9-track magnetic tape only.

NDP-021/R1 HISTORICAL SUNSHINE AND CLOUD DATA IN THE UNITED STATES

P. M. Steurer and T. R. Karl (contributors)

This data base presents monthly sunshine data from 240 U.S. stations (including Puerto Rico and nine Pacific Islands) and monthly cloud amount data from 197 U.S. stations. The longest periods of record are 1891 through 1987 for the sunshine data and 1871 through 1987 for the cloud data. The sunshine data were derived from measurements taken by a variety of sunshine-recording instruments. The cloud data were derived from land-based estimates of fractional cloud amount, which were made with observation practices that have varied during the period of record. Station number, station name, latitude, and longitude are given for all stations in each network. The sunshine data

include monthly and annual total hours of recorded sunshine, monthly and annual maximum possible hours of sunshine, monthly and annual percentages of possible sunshine (hours recorded/hours possible), and dates of use for specific types of sunshine recorders at each station. The cloud data contain monthly and annual cloud amount (in percent of sky cover). The sunshine data are in four files: one station inventory (34.1 kB), one monthly and annual hours of measured sunshine (1.6 MB), one monthly and annual maximum possible hours of sunshine (21.5 kB), and one monthly and annual percentage of possible sunshine (2.1 MB). The cloud data are in two files: one station inventory (20.4 kB) and one monthly and annual cloud amount (2.4 MB). All files are available on 9-track magnetic tape only.

NDP-022/R1 **GLOBAL AND HEMISPHERIC ANNUAL TEMPERATURE VARIATIONS BETWEEN 1861 AND 1988**

P. D. Jones, T. M. L. Wigley, and P. B. Wright (contributors)

This data set contains estimates of global and hemispheric annual temperature variations, relative to a 1950 through 1979 reference period, for 1861 through 1988. The estimates are based on corrected land and ocean data. Land data were derived from meteorological data and fixed-position weather-ship data that were corrected for nonclimatic errors, such as station shifts and/or instrument changes. The marine data used were those in the Comprehensive Ocean-Atmosphere Data Set (COADS) compilation, which with updates covers to 1986. Updates to 1988 were made with hemispheric sea-surface temperature estimates produced by the U.K. Meteorological Office. Each record includes year and six annual temperature variations: one estimate each for the globe, the Northern Hemisphere, and the Southern Hemisphere and another estimate each that reflects an adjustment to account for the influence of El Niño/Southern Oscillation events. The data are in one file of 13 kB.

NDP-023 **ANNUAL AND SEASONAL GLOBAL VARIATION IN TOTAL OZONE AND LAYER-MEAN OZONE, 1958-1986**

J. K. Angell, J. Korshover, and W. G. Planet (contributors)

For 1958 through 1986, this data base presents total ozone variations and layer mean ozone variations expressed as percent deviations from the 1958 to 1977 mean. The total ozone variations were derived from mean monthly ozone values published in *Ozone Data for the World* by the Atmospheric Environment Service in cooperation with the World Meteorological Organization. The layer mean ozone variations are derived from ozonesonde and Umkehr observations. The data records include year, seasonal and annual total ozone variations, and seasonal and annual layer mean ozone variations. The total ozone data are for four regions (Soviet Union, Europe, North America, and Asia); five climatic zones (north and south polar, north and south temperate, and tropical); both hemispheres; and the world. Layer mean ozone data are for four climatic zones (north and south temperate and north and south polar) and for the stratosphere, troposphere, and tropopause layers. The data are in two files [seasonal and year-average total ozone (13.4 kB) and layer mean ozone variations (24.2 kB)].

NDP-025 MONTHLY MEAN PRESSURE RECONSTRUCTIONS FOR EUROPE (1780-1980) AND NORTH AMERICA (1858-1980)

P. D. Jones, T. M. L. Wigley, and K. R. Briffa (contributors)

Real and reconstructed measurements of monthly mean pressure data have been constructed for Europe for 1780 through 1980 and North America for 1858 through 1980. The reconstructions use early pressure, temperature, and precipitation data from a variety of sources including *World Weather Records*, meteorological and national archives, circulation maps, and daily chart series. Each record contains the year, monthly mean pressure, quality code, and annual mean pressure. These reconstructed gridded monthly pressures provide a reliable historical record of mean sea-level pressures for Europe and North America. The data are in two files: pressure reconstructions for Europe (1.47 MB) and for North America (0.72 MB).

NDP-026 CLIMATOLOGICAL DATA FOR CLOUDS OVER THE GLOBE FROM SURFACE OBSERVATIONS

C. J. Hahn et al. (contributors)

With some data from as early as 1930, global long-term monthly and/or seasonal total cloud cover, cloud type amounts and frequencies of occurence, low cloud base heights, harmonic analyses of annual and diurnal cycles, interannual variations and trends, and cloud type co-occurrences have been compiled and presented in two atlases (Warren et al. 1988, 1990). These data were derived from land and ship synoptic weather reports from the "SPOT" archive of the Fleet Numerical Oceanography Center (FNOC) and from Release 1 of the Comprehensive Ocean-Atmosphere Data Set (COADS) for the years 1930–1979. The data are in 12 files (one containing latitude, longitude, land-fraction, and number of land stations for grid boxes; four containing total cloud, cloud types, harmonic analyses, and interannual variations and trends for land; four containing total cloud, cloud types, harmonic analyses, and interannual variations and trends for oceans; one containing first cloud analyses for the first year of the GARP Global Experiment (FGGE); one containing cloud-type co-occurrences for land and oceans; and one containing a FORTRAN program to read and produce maps). These files range in size from 12.5 kB to 5.67 MB and are available on 9-track magnetic tape only.

NDP-027 GEOSECS ATLANTIC, PACIFIC, INDIAN, AND MEDITERRANEAN RADIOCARBON DATA

H. G. Ostlund and M. Stuiver (contributors)

Radiocarbon data for the Atlantic, Pacific, and Indian oceans were obtained between 1972 and 1977 as part of the Geochemical Ocean Section Study (GEOSECS) cruises during which more than 2200 water samples were collected. Some Mediterranean Sea data were also collected. Samples for ^{14}C were collected at 124 stations, and

approximately 18 samples were collected at each station from intervals throughout the water column. The data included in the data base are ship position (latitude and longitude), sample number, depth, potential temperature, salinity, and delta ^{14}C. The GEOSECS data sets allow a better understanding of large-scale oceanic transport and mixing and the establishment of the gross rate of deep-ocean circulation. The data are in three files (radiocarbon data for the Atlantic, Pacific, and Indian Oceans) ranging in size from 39.9 to 50.4 kB.

NDP-028 CARBONATE CHEMISTRY OF THE WEDDELL SEA

C.-T. A. Chen (contributor)

In the late austral winter of 1981, carbonate data were obtained from the Weddell Sea as part of the U.S.–U.S.S.R. Weddell Polynya Expedition (WEPOLEX-81). Both surface samples and vertical-station samples were taken. The data include ship position (latitude and longitude), date, station number, sample depth, salinity, water temperature, pH, normalized surface total alkalinity, and calcium. These data represent the first comprehensive carbonate data obtained in the Weddell Sea during late winter. Because of the importance of the Weddell Sea as a source of deep water for the world's oceans, these data have improved the understanding of the oceanic circulation of excess CO_2 in the carbon cycle. The data are in two files [one for data from surface stations (15.5 kB) and one for data from vertical stations (5.9 kB)].

NDP-029 CARBONATE CHEMISTRY OF THE NORTH PACIFIC OCEAN

C.-T. A. Chen et al. (contributors)

Carbonate chemistry data from 41 stations in the North Pacific Ocean were obtained during two NOAA CO_2 Dynamics Cruises (June–July 1981 and May–June 1982) and two legs of the NORPAX Hawaii–Tahiti Shuttle Experiment (April 1979 and March–April 1980). The data for each sample include ship position (latitude and longitude), date, station number, sample depth, salinity, water temperature, pH, normalized total alkalinity, and normalized calcium. The data from each of the three cruises are in separate files ranging in size from 7.1 kB to 10.1 kB.

NDP-030 ESTIMATES OF CO_2 EMISSIONS FROM FOSSIL FUEL BURNING AND CEMENT MANUFACTURING BASED ON THE UNITED NATIONS ENERGY STATISTICS AND THE U.S. BUREAU OF MINES CEMENT MANUFACTURING DATA

G. Marland, T. A. Boden, R. C. Griffin, S. F. Huang, P. Kanciruk, and T. R. Nelson (contributors)

For 1950 through 1986, global and national annual estimates of CO_2 emissions from fossil-fuel burning and cement production were calculated from energy statistics compiled by the U.N. Statistical Office and cement-manufacturing data compiled by the U.S. Bureau of Mines. The resulting data base contains the annual global CO_2 emissions and national CO_2 emission estimates for more than 200 countries. Among

many variables, these data include total emissions; emissions from gas, liquid, and solid fuels; and emissions from cement production. The data are in six files (three for the U.N. statistics; one for the Bureau of Mines data; one for global CO_2 emission estimates; and one for the national CO_2 emission estimates) ranging in size from 427 bytes to 4.85 MB and are available on 9-track magnetic tape only.

NDP-031 AVERAGE TOTAL SNOWFALL DATA FOR SELECTED U.S. STATIONS

National Climatic Data Center

From 1868 through 1986, the average monthly snowfalls for 286 U.S. stations were extracted from the *Local Climatological Data Annual Summary*. Only stations operating in 1986 and having a minimum of 3 years data and at least 1 month on record with snowfall greater than a trace (>0.05 in.) were included in the record. The data contain the station name, number of years of data used to estimate the average monthly snowfall, average monthly snowfall, and annual snowfall. The monthly average snowfall data for 286 U.S. stations are in one 46.4-kB file.

NDP-032 ANTARCTIC SURFACE TEMPERATURE AND PRESSURE DATA

P. D. Jones and D. W. S. Limbert (contributors)

Monthly mean surface temperature and pressure data for 30 Antarctic stations (the earliest beginning in 1903 and all extending through 1988) were assembled primarily from *World Weather Records* and *Monthly Climatic Data for the World*. The data were assessed for quality and long-term homogeneity. The data presented are station name, station latitude and longitude, station elevation, first and final year of data record, year, mean monthly sea-level or station-level pressure, and mean monthly surface temperature. The data are in four files (two temperature and two pressure data files) ranging in size from 25 to 43 kB.

NDP-034 ATMOSPHERIC CO_2 CONCENTRATIONS - THE CANADIAN BACKGROUND AIR POLLUTION MONITORING NETWORK

N. B. A. Trivett (contributor)

Flask air samples collected at roughly weekly intervals at three Canadian sites [Alert, Northwest Territories (July 1975 through October 1987); Sable Island, Nova Scotia (June 1975 through October 1987); and Cape St. James, British Columbia (May 1979 through October 1987)] were analyzed for CO_2 concentration with the measurements directly traceable to the WMO primary CO_2 standards. Each record includes the date, atmospheric CO_2 concentration, and flask classification code. They provide an accurate record of CO_2 concentration levels in Canada during the past decade. Because these data are directly traceable to WMO standards, this record may be compared with records from other Background Air Pollution Monitoring Network (BAPMoN) stations. The data are in three files (one for each of the monitoring stations) ranging in size from 3.2 to 12.8 kB.

NDP-036 **INDIAN OCEAN RADIOCARBON: DATA FROM THE INDIGO 1, 2, AND 3 CRUISES**

H. Göte Östlund and C. Grall (contributors)

This data set presents ^{14}C activities from water samples taken at various locations and depths in the Indian and Southern oceans through the Indien Gaz Ocean (INDIGO) project. These data were collected as part of the INDIGO 1, INDIGO 2, and INDIGO 3 cruises, which took place during the years 1985, 1986, and 1987, respectively. These data have been used to estimate the penetration of anthropogenic CO_2 in the Indian and Southern oceans. The records include the station, date, ocean bottom depth, latitude and longitude, sampling depth, potential temperature, salinity, density, total CO_2, ^{13}C, and ^{14}C activity. The data are in one file of 25 kB.

NDP-038 **ATMOSPHERIC METHANE CONCENTRATIONS—THE NOAA/CMDL GLOBAL COOPERATIVE FLASK SAMPLING NETWORK, 1983—1988**

L. P. Steel and P. M. Lang (contributors)

This data set presents monthly averages and sampling statistics for atmospheric methane concentrations from measurements made by the global cooperative flask sampling network of the National Oceanic and Atmospheric Administration/Climate Monitoring and Diagnostics Laboratory (NOAA/CMDL) from 1983 through 1988. The data are derived from a network of 30 stations (26 of which were still active at the end of 1988), which collected flask air samples approximately once per week for measurement of both methane and CO_2. The samples were analyzed for atmospheric methane concentration on a gas chromatograph (fitted with a flame ionization detector) at the NOAA/CMDL laboratory in Boulder, Colorado. The data consist of station identification code; year; and mean monthly methane concentration, standard deviation, and number of samples contributing to the mean for each month. The data are in one file of 66.5 kB.

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368. E. R. Williams, Office of Environmental Analysis/EH-22, 1000 Independence Avenue S.W., U.S. Department of Energy, Washington, DC 20036

369. R. C. Wood, Acting Director, Ecological Research Division, ER-70, U.S. Department of Energy, Washington, DC 20545

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