The World Climate Program: Collaboration and Communication on a Global Scale

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ABSTRACT: This article discusses the rationale and history of the World Climate Program (WCP) as a prime example of gains in scientific knowledge achievable only through collaboration and communication on a worldwide basis. The WCP is managed jointly by the World Meteorological Organization and the United Nations Environmental Program, both of which are specialized agencies of the United Nations, and by the International Council of Scientific Unions. This unique arrangement has both given strength and presented problems in getting governments and scientists from all over the world to work together in the pursuit of program goals. Vital to this work are the tools made available by contemporary communications technology, particularly supercomputers and satellites. Nevertheless, the availability and usefulness of those tools does not supplant the more basic groundwork that has to be laid and maintained in order to conduct global research. The necessary groundwork requires intra- and intergovernmental collaboration, and also continued progress in the underlying science base. The WCP is composed of the World Climate Data Program, the World Climate Applications Program, the World Climate Impact Program, and the World Climate Research Program.

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THE World Climate Program (WCP) represents many elements of a science program that is composed primarily of the physical sciences but is composed also of elements from the social and biological sciences. Progress is being made in the WCP because of cooperation between nearly a dozen U.S. government agencies and several agencies of the United Nations. These represent the governmental input to the program. The nongovernmental input comes via the National Academy of Sciences, within the United States, and the International Council of Scientific Unions (ICSU), representing other academies of science around the world. The WCP already can point to some successes; however, its ultimate success will be determined only if the science base needed to answer many of the issues that confront human beings and their environment is used carefully by decision makers so that legal circumstances and administrative decisions are in concert with scientific results.

BACKGROUND AND HISTORY OF THE WCP

The WCP is a natural outgrowth of the Global Atmospheric Research Program (GARP), whose original planning began in the late 1950s.[1] GARP was designed to study the physical processes in the troposphere[2] and in the stratosphere[3] that are essential for an understanding of (1) the transient behavior of the atmosphere as manifested in large-scale fluctuations that control changes of the weather[4]; understanding this behavior could lead to increasing the accuracy of forecasting over periods from one to several weeks; and (2) the factors that determine the statistical properties of the general circulation of the atmosphere; understanding these factors would lead to better understanding of the physical basis of climate.[5] The GARP field programs that were designed to provide the data required for the design of theoretical models and the testing of their validity now have been completed; however, analyses are proceeding still and will continue for some years.[6]

1. Jule G. Charney, *The Feasibility of Global Observation and Analysis Experiment*, A Report of the Panel on International Meteorological Cooperation to the Committee on Atmospheric Sciences, National Academy of Sciences-National Research Council, 1965. This report is reprinted in *Bulletin of the American Meteorological Society*, 47(3):200-220 (Mar. 1966).

2. The troposphere is the lower portion of the Earth's atmosphere extending from the surface to 10 to 20 kilometers. The troposphere is characterized by decreasing temperature with height, appreciable vertical wind motion, appreciable water vapor content, and weather.

3. The stratosphere is the layer of the atmosphere above the troposphere extending to 20 to 25 kilometers. The stratosphere is characterized by stability and persistence of circulation patterns. Ozone concentrations are highest in this layer.

4. Weather consists of short-term—minutes to weeks—variations of the atmosphere, popularly thought of in terms of temperature, humidity, precipitation, cloudiness, visibility, and wind.

5. World Meteorological Organization and International Council of Scientific Unions, Report of the Study Conference on the Global Atmospheric Research Program, jointly sponsored with the International Union of Geodesy and Geophysics, Geneva, 1967. Climate comprises the long-term—ranging from months to eons—manifestations of weather. The climate of a specified area is represented by the statistical collective of its weather conditions during a specified interval of time.

6. Jay S. Fein, Pamela L. Stephens, and Kristyne S. Loughran, "The Global Atmospheric Research Program: 1979-1982," *Reviews of Geophysics and Space Physics*, 21(8):1076-96 (June 1983).

The rise of public concern

The second objective of the original GARP concept concerning climate did not receive much attention immediately. In later years, during the early 1970s, however, climate became an important public issue. The early 1970s witnessed a number of climatic events that had disastrous consequences. The Sahel region of Africa suffered a five-year drought that brought famine and death on a large scale. In 1972 the Soviet Union had a significant drought and had to buy grain from the United States. That same year there was an El Niño, a warm current off the coast of Peru, that destroyed the anchoveta fishery. The year 1974 brought a severe monsoon to India that reduced food production. Cold weather reduced Brazil's coffee crop in 1975. Cold weather in Europe in 1976 caused widespread economic dislocation. An unusually cold winter in the United States the same year caused many industrial and school closings. Thus the attention of the public was drawn to the extremes of climatic variability.

U.S. government reactions

Was there any reaction to these disasters? There was indeed. Several agencies of the U.S. government established programs to study the dynamics of climate. The Climate Dynamics Program established in 1974 by the National Science Foundation is one result of that reaction. The U.S. Congress passed the National Climate Program Act of 1978, which set up an interagency office to coordinate the U.S. government's activities and to begin new ones where needed.[7] This office was established within the National Oceanic and Atmospheric Administration, and it was responsible for reporting to the Congress via the administrator of the National Oceanic and Atmospheric Administration, the secretary of commerce, and the president. The National Climate Program Office was responsible for writing the initial five-year plan laying out programs that were needed and keeping them within the framework of ongoing budgets of various agencies that were involved. There have been eight reports sent to Congress since 1979 describing the ongoing program and citing any needs, administrative or budgetary, that might be felt.[8]

International reaction

Meanwhile, activities were taking place internationally, under the auspices of the World Meteorological Organization (WMO). The Joint Organizing Committee for GARP, a committee composed of 12 scientists selected jointly by WMO and ICSU to give guidance to GARP, realized as early as 1973 that the second objective of GARP deserved some attention. This concept was not readily acted on by most of the scientific community because a great deal of effort was being expended in those days on the implementation of the major GARP experiment, the Global Weather Experiment, held in 1978 and 1979. Nevertheless, the Joint Organizing Committee proceeded to call the Study Conference on Climate, which was held in Stockholm, Sweden, in July of 1974. This study conference set the stage for all later activities under the

7. Public Law No. 95-376, 95th Cong., 2d sess. (17 Sept. 1978), 92 Stat. 601-5.

8. *Annual Report National Climate Program* (Rockville, MD: U.S., Department of Commerce, National Oceanic and Atmospheric Administration, National Climate Program Office, 1979-86).

ICSU-WMO banner.[9] The conference was supported also by the United Nations Environmental Program.

The Joint Organizing Committee continued to discuss climate at its meetings and in fact identified early on two important components of a climate program that deserved attention. Those components were ocean dynamics—that is, the interaction between the atmosphere and the oceans' surface—and the effect of clouds on long-wave and short-wave radiation. Both of these topics were discussed extensively, and plans were laid to identify how these components could be studied so that the results would be useful to modeling the general circulation of the atmosphere successfully. From the very beginning the WMO was envisioned as the scientific leader for the climate program. This was so primarily because WMO had a broad cross-section of member countries, it had the key to governmental action as evidenced by GARP, and, through its connection with ICSU, it also had a way to call on the academicians of the world.

By 1977 the Executive Committee of the WMO decided to request the Secretary-General of the WMO to make specific proposals regarding the establishment of the WCP within the WMO. In addition the Executive Committee decided to convene a high-level scientific and technical World Climate Conference in early 1979 to be attended by physical and social scientists as well as experts from climate-sensitive branches of national economies, including agriculture, energy, water resources, fisheries, and health. The main purposes of the conference were to review knowledge of climatic change and variability, due to both natural and anthropogenic causes, and to assess possible future climatic changes and variability and their implications for human activities. There were more than 350 attendees at the conference. The assembled group heard papers from users of climate information, researchers, politicians, and gatherers of climate data. It was a diversified group, many of whom had had interests in climate studies for years and others who were just beginning to understand that climate played an important role in the life and welfare of human beings.[10]

The World Climate Conference outlined, in general, the problems of climate studies and did something even more important. It discussed some of the interfaces between climate and human activities. These areas could be referred to as impact studies, depending upon whether there was an impact on policy considerations or, at least, on applications of climate information to selected problems. The major interfaces were with regard to climate's relation to food, water, energy, and urban planning. Although many important issues were discussed at the conference, it was May 1979, when the WMO's Eighth Congress met, before the WCP really came into being.

Components of the WCP

Eventually, the WCP was structured to have four components: the World Climate Data Program (WCDP), the World Climate Applications Program (WCAP), the World Climate Impact Program (WCIP), and the World Cli-

9. *The Physical Basis of Climate and Climate Modelling,* Report of the International Study Conference in Stockholm GARP Publications Series no. 16 (Geneva: World Meteorological Organization, 1975).

10. *Proceedings of the World Climate Conference,* WMO—No. 537 (Geneva: World Meteorological Organization, 1979).

mate Research Program (WCRP). One of the unique facets of the WCP is that the responsibility for managing its several components was not all vested in the WMO. The first two areas became the responsibility of the WMO because the WMO is the international agency responsible for observing, collecting, and disseminating meteorological data. Those data serve as the basis for weather forecasting, but they also serve as the basis for climate studies. In addition, the WMO was given the responsibility to direct, oversee, and coordinate the entire WCP.

Responsibility for the WCIP was given to the United Nations Environmental Program. The WCRP responsibility was assigned to WMO in cooperation with ICSU.

An international governmental-nongovernmental alliance

The alliance between WMO, an intergovernmental group, and ICSU, a nongovernmental group, had worked successfully during GARP, so it was thought that such an alliance could work again for climate studies even though it was recognized that studies of climate would be much more difficult and complicated than GARP had been. Such an alliance brings together the funding, planning, and other attributes of governments and the intellectual power of the world's academic community. Thus scientists anywhere in the world, whether in government or not, had a mechanism that would allow them to work together.

The actual working mechanism that allows WMO and ICSU to work together is the Joint Scientific Committee (JSC), composed of about 12 well-recognized scientists who were selected from throughout the world as individual scientists and not as representatives of their governments. The JSC is the equivalent of the Joint Organizing Committee for GARP. Its responsibility is to lay out in general terms plans for the WCRP. The JSC meets about every nine months to discuss how present programs are proceeding and what future ones should be planned. If a new program is selected, then the JSC gives general guidelines on how that program is to be implemented. The reports of JSC meetings are disseminated widely so the community of interested parties can be aware of the JSC's deliberations and plans.

Oceanographic participation

Because oceanography is such an important part of the WCRP, the oceanographic community established a Coordinating Committee on the Climate of the Oceans to plan the oceanographic aspects of the WCRP. The committee is similar to the JSC in that it is composed of scientists from the Scientific Committee for Oceanographic Research of ICSU and the International Oceanographic Commission of the United Nations Educational, Scientific, and Cultural Organization. Thus it has the ability to blend governmental views from the International Oceanographic Commission and academicians' views from the Scientific Committee for Oceanographic Research. It works closely with the JSC due to close staff liaison and sometimes overlapping membership on the two committees.

THE WORLD CLIMATE DATA PROGRAM

The WCDP is truly the foundation of the WCP. All of the aspects of the WCP

are dependent on the availability of relevant climate data. In order to manage, plan, and carry out programs within the WCP, it is necessary to have long time-series of the necessary data with sufficient spatial coverage. Thus the purpose of the WCDP is to ensure reliable climate data from the atmosphere, oceans, cryosphere, and land surfaces including the biosphere. These data have to be easily accessible and exchangeable in an acceptable format.

The long-term objectives of the WCDP are to

—improve national systems for climate data management and the availability of referral information on station networks, data sets, and publications;
—coordinate existing data exchange systems and consolidate requirements for observations and data exchange;
—assist nations in building data banks to serve their needs; and
—develop a monitoring, diagnostic, and dissemination system to highlight climatic events that may effect activities of human beings.

The following is a description of projects that are part of the WCDP.[11]

Projects within the WCDP

Improvement of climate data management systems and user services. Data are being rescued by microfilming original manuscripts before they deteriorate. Technical guidelines are being prepared on observing networks, data quality control, data processing and management, organization of data banks, and user services. Reference climatological stations will be established, and data sets, inventories, and catalogs of existing data will be compiled. Computerized procedures will be initiated at centers. Education and training workshops plus seminars will be held to aid in molding the data requirements to national needs. Coordination between countries and regions will be promoted.

Transfer of technology in climate data management and user services. The climate computer (CLICOM) project has as its goal the transfer of technology in climate data management and user services through the provision of comprehensive specifications for microcomputer systems. The CLICOM is a package concept that includes computer hardware, user-friendly software, and training. Within ten years it is hoped that all meteorological services throughout the world that desire such equipment will have a CLICOM system. An important component involves the application of climatic data to problems in agriculture and water resources management.

Consolidation of climate data requirements and improvement of data exchange. Climate applications and monitoring require time series and the operational exchange of monthly and daily data that have sufficient spatial density. A composite observing system using satellite remote sensing and a surface-based network is planned. It will be necessary to increase the exchange of data from one to ten stations per 250,000 square kilometers, and, as requirements change, more data and parameters may need to be observed and exchanged. A reference climatological station network will be

11. The description of WCDP projects and of projects of the other WCP component programs later in this article are based on World Meteorological Organization, "The World Climate Program 1988-1997," *Second WMO Long-Term Plan*, pt. 2, vol. 2 (Geneva: World Meteorological Organization, 1987).

established, and the exchange of daily precipitation data will be improved using the Global Telecommunications System.

Implementation of the climate data referral system. There is a need for concise information on climate data. Specifically, information is needed on the availability of data sets, data summaries, and station networks. Initial catalogs have been published, as have input and output formats and access codes for computerized retrieval and storage of information. Information on data centers and their holdings are included as well as cross-references to WMO, ICSU, International Oceanographic Commission, and United Nations Environmental Program centers.

Development of global and regional climate system data sets. Global data sets must be available in order to pursue climate diagnostic studies and climate prediction research. For the WCP, a variety of data sets will be required comprising regular observations of surface and upper-air meteorological variables—including remote-sensed parameters—as well as marine, oceanographic, cryospheric, land-surface and subsurface, vegetation, soil, topography, and other variables. Use of image processing, enhancement, and overlay techniques will aid studies.

Development of a climate system monitoring capability. The capability to monitor climate systems is needed to provide nations with information on large-scale climate system fluctuations and to facilitate the interpretation of anomalous climatic events. These aims are accomplished through monthly bulletins, special advisories, and annual summaries. Data and processed information for the climate system monitoring come from many sources in several countries such as the Climate Analysis Center of the National Oceanic and Atmospheric Administration within the United States, the University of East Anglia, in the United Kingdom, the Bureau of Meteorology in Australia, and the Hydrometeorological Service of the USSR.

THE WORLD CLIMATE APPLICATIONS PROGRAM

The real payoff to nations is the WCAP, for it is from this program that the uses for climate information will be identified and applied to the many problems that exist around the world. The WCAP has four subprograms: WCAP-Food, WCAP-Water, WCAP-Energy, and WCAP-Other Applications. Many of the activities within the WCAP are conducted with U.N. agencies such as the Food and Agricultural Organization and the United Nations Educational, Scientific, and Cultural Organization, and with other components of the WMO.

Projects within the WCAP

Definition of user information requirements for specific climate applications. It is anticipated that by 1995, 95 percent of the nations of the world will have defined their requirements for major climate applications.

Description of climate effects on food production. Past, present, and future purpose-oriented forecasts will be used to determine the influence of climate on the productivity of specific crops, forests, pastures, and animals.

Determination of climate implications for water resources management. A better understanding of the impact of climate, climate variability, and climate change on water resources will be developed.

Determination of climate implications for energy. What information is useful, how it will be collected, and how it will be presented will be determined.

Implementation of climate applications in other human activities. The effects of climate on buildings and human settlements will be documented in a report called Urban and Building Climatology. The specification of user requirements, creation of data formats, making of special observations, production of guidelines, and development of computer data bases will be undertaken.

Assistance in employing existing practical methodology. National climate application programs will be developed, and information on economic benefits of climate applications will be exchanged.

Combating effects of drought. Studies of observational network density, preparation of drought probability maps and guidelines on the use of climate data to combat the effects of drought, and studies on the assessment of semiarid zones for the support of human activities will be undertaken.

Development of a Climate Applications Referral System (CARS). The upgrading and completion of CARS-Food, the completion of CARS-Solar and Wind Energy, and the beginning of CARS-Water, Urban and Building Climatology, and Climate and Human Health will be accomplished.

Promotion of the development of new climate application methods. The use of satellite information will be promoted. New ways to present data and information and new methods to use statistical and real-time data for the formulation of application-oriented forecasts will be developed.

THE WORLD CLIMATE IMPACT PROGRAM

The purpose of the WCIP is to bring climate information into the consideration of policy alternatives and to warn of economic, political, and social impacts that climate change and variations might bring forth. This program is very sensitive because expectations are high, yet what can be delivered credibly is much less. Thus there is frustration with the scientific community because important questions cannot be answered. There also is frustration on the part of the scientific community itself because of the impatience of users and the knowledge by scientists that the answers desired will take years before they are available, if ever.

Projects within the WCIP

Assessment of the role of CO_2 and other radiatively active gases in climate variations and their impact. The assessment of effects on the atmosphere of changing greenhouse gas[12] concentrations in the atmosphere and the effects of the resulting climate change on human beings and their environment will be undertaken about every five years, with particular emphasis on the socioeconomic aspects.

Dissemination of information on the greenhouse gas/climate change issue. Through guidelines, brochures, and audiovisual materials, nations and individuals will be sensitized to the issue of greenhouse gas and climate change.

Regional assessment of impacts of

12. Greenhouse gas is a gas that traps solar energy in the atmosphere, thus contributing to the warming of the Earth. Examples of such gas are carbon dioxide, methane, nitrous oxide, and chlorofluorocarbons.

climate change. Six regional assessments will be carried out, three in developed regions and three in developing regions, to aid in national decision making.

Assessment of the impact of sea-level change. Analysis of the impact of sea-level change on environmental sectors and on human socioeconomic sectors will be undertaken, consistent with greenhouse-gas-induced warming of coastal, estuarine, and river delta regions.

Advisory group on greenhouse gases. The determination of the need for guidelines for a global framework convention for the protection of the tropospheric climate will be pursued.

Dissemination of knowledge and methods of climate impact assessment. Handbooks on climate impact assessment will be developed, and demonstration projects will be carried out.

Study of impacts of drought in developing countries. Support will be given to the African Centre of Meteorological Applications for Development. Support will also be devoted to research on the socioeconomic impact of droughts and to the development of strategies for the prevention, mitigation, and avoidance of adverse impacts of drought.

Monitoring of the impacts of the El Niño Southern Oscillation events and other teleconnections. Information will be exchanged on the impacts of climatic events on climatically sensitive sectors such as agriculture, fisheries, and water resources.

International network of climate impact studies. National and regional climate impact studies will be identified and national climate programs invited to exchange information. An inventory of climate impact studies will be made. A bibliography and a directory of scientists and institutions will be published.

Establishment of national impact studies programs. The development of national climate programs that have as a component climate impact studies will be encouraged. Once developed, they will become a part of the climate impact studies network.

Support to national climate impact studies. Special climate impact studies will be undertaken when gaps in knowledge are identified or when sufficient resources are not available in a region where such studies are needed.

THE WORLD CLIMATE RESEARCH PROGRAM

The research component of the WCP has as its goal the improvement of our knowledge of climate, climate variations, and the mechanisms that might bring about climate change so one can determine the extent to which climate can be predicted and the extent of human influence on climate. Such a program consists of studies of the global atmosphere, oceans, sea and land ice, and the land surface. The development of models to simulate the climate system so that the sensitivity of climate to natural and man-made influences can be determined is an important aspect of this work.

Projects within the WCRP

Global climate analysis and model development. Progressive improvement of the formulation of all significant physical processes in the climate system will be undertaken through numerical experiments and comparison with global climatological data or detailed observations during intensive field studies of

specific processes. Global estimates of derived quantities such as surface fluxes of momentum, energy, and water will be produced through three- and four-dimensional analyses of the primary meteorological fields.

Research on climate processes. A refining of the formulation, in terms of climate model parameters, of the physical processes that are significant in determining the mean state of climate and its variations is needed. Cloud-radiation feedback, atmospheric boundary layer exchanges, and hydrological processes over the land surface are priority areas for all aspects of climate research and for long-range weather prediction on time scales of one to two months. A fully interactive treatment of sea-ice processes in the polar oceans and studies of polar ice sheets and glaciers also are needed.

Study of the tropical ocean and global atmosphere (TOGA). Prediction of the evolution of the coupled system comprising the tropical oceans and the overlying atmosphere is important to the study of the mechanisms that determine the interseasonal and interannual variability of global large-scale monsoon flow.

World ocean circulation experiment (WOCE). Understanding the world ocean circulation and its relation to climate is necessary. Emphasis will be on the large-scale average heat and fresh water fluxes and their annual and interannual variations, the variations of the space-averaged ocean circulation on a time scale of months to years and the statistics of smaller-scale motions, and the volume and location of water masses with a ventilation time scale of 10 to 100 years.

Study of climate forcings. Determining the sensitivity of climate and climate variations to possible causal factors such as changes in solar radiation, composition or particulate matter loading of the atmosphere, land vegetation, and other earth environmental or external factors will be undertaken.

Study of global change. How the earth's land, sea, and atmosphere interact through the combination of physical, chemical, and biological processes and how ecosystems function to absorb, buffer, or generate changes on the global scale are important aspects of global change. An extension of the quantitative modeling methods used in earlier studies will be used to incorporate global or large-scale ecosystems using suitable parametric representations. Ecosystems will be characterized by expressing fluxes of the energy and chemicals that they absorb or yield, in quantitative terms, based on global surveys of large ecosystems using fast data acquisition techniques such as satellite remote sensing.

CONCLUSION

The WCP has addressed some important communications problems in very unique ways. It has brought in the U.S. scientific community through the National Academy of Sciences and has allowed the various federal agencies to work together through several interagency committees. Internationally, it has built upon an earlier relationship between WMO and ICSU, extended it to the climate research area, and continues to bring together the world's academicians and government scientists to make it work.

The WCP is grounded upon sound scientific principles and a successful set of global-scale experiments that were carried out under the aegis of GARP. The WCP is a logical extension of this

work. It incorporates much more oceanography into the research because the time scale of the predictions is months to years, and on those time scales, the oceans play a major role in storing, transporting, and distributing the energy received from the sun at the Earth's surface.

The JSC, jointly sponsored and supported by ICSU and WMO, is the mechanism that lays out the scientific program for the WCRP. Members of the JSC are selected on the basis of their scientific credentials and not on political considerations. Nevertheless, there is a balance maintained on the JSC between the superpowers and other countries that can contribute to the scientific efforts of the WCRP.

Credible data drive the WCP. Accurate and timely observations, made at the proper places, disseminated through the WMO, and archived in an acceptable format are now available. This achievement is due to the long history of exchanging meteorological data among countries of the world. All countries can make observations. Thus there is a real way for all countries to participate in a program like the WCP even though a given country might not be able to bring sophisticated instrumentation to an experiment or provide a modeling facility.

The availability of personal computers, software, and a data base composed of the country's own observational records provides the infrastructure for making excellent use of the climate data to help irrigation, design dams, and address other water resource management problems. The CLICOM will be in use in about 100 countries by the early 1990s. This project, which began as a U.S. idea, is now being funded by the United Kingdom, France, Finland, and the United States.

Policymakers and scientists working together can accomplish a great deal, as scientific issues have a way of becoming policy issues demanding solutions. The greenhouse effect, stratospheric ozone depletion, and climate change are specific examples. Policymakers and scientists alike must recognize that there always will be some scientific uncertainty involved in such issues. They must not let this uncertainty impede the decision-making process. Through the WCIP, it is anticipated that decision makers and policymakers will be able to work with scientists for the common good. That will be a very difficult task, however.

The WCP will continue for decades. Field experiments such as that concerning the tropical ocean and global atmosphere (TOGA) are long-term efforts that are scheduled to last for at least ten years. Analyses and interpretation will take another ten years, so some investigators conceivably could spend their entire research life on the project. A completion date for the WCP has not been set. The program is, in a sense, open-ended; moreover, it is stil evolving and projects are being designed and formulated even today.

The WCP is one of the building blocks for the future ICSU program known as the International Geosphere-Biosphere Program: A Study of Global Change. From the WCP will come a cadre of interdisciplinary scientists who have global horizons, an understanding of problems well beyond their own discipline, and experience in communicating internationally, independent of politics. The future is bright for the success of the WCP and the International Geosphere-Biosphere Program, but it will take many years before the harvest is gathered.