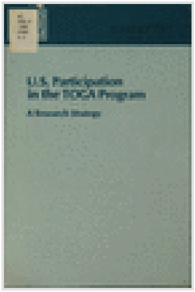

U.S. Participation in the TOGA Program: A Research Strategy (1986)

Pages
33

Size
5 x 9

ISBN
0309321425

Advisory Panel for the Tropical Ocean/Global Atmosphere (TOGA) Program; Climate Research Committee; Board on Atmospheric Sciences and Climate; Commission on Physical Sciences, Mathematics, and Resources; National Research Council

U.S. PARTICIPATION IN THE TOGA PROGRAM:

A RESEARCH STRATEGY

Advisory Panel for the Tropical Ocean/Global Atmosphere (TOGA) Program
Climate Research Committee
Board on Atmospheric Sciences and Climate
Commission on Physical Sciences, Mathematics, and Resources
National Research Council

NATIONAL ACADEMY PRESS
Washington, D.C. 1986

NOTICE The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

The National Research Council was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the federal government. The Council operates in accordance with general policies determined by the Academy under the authority of its congressional charter of 1863, which establishes the Academy as a private, nonprofit, self-governing membership corporation. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both Academies and the Institute of Medicine. The National Academy of Engineering and the Institute of Medicine were established in 1964 and 1970, respectively, under the charter of the National Academy of Sciences.

This material is based on work supported jointly by the National Science Foundation, the National Oceanic and Atmospheric Administration, the National Aeronautics and Space Administration, the Department of Agriculture, the Department of Defense, the Department of Energy, the Department of the Interior, the Department of Transportation, the Environmental Protection Agency, and the National Climate Program Office under Contract Number NA79RAC000104.

Available from the
Board on Atmospheric Sciences and Climate
2101 Constitution Avenue
Washington, D.C. 20418

ADVISORY PANEL FOR THE TROPICAL OCEAN/GLOBAL ATMOSPHERE (TOGA) PROGRAM

John M. Wallace, University of Washington, Chairman
Tim P. Barnett, Scripps Institution of Oceanography
Otis B. Brown, University of Miami
Mark A. Cane, Lamont-Doherty Geological Observatory, Columbia University
Ants Leetmaa, Climate Analysis Center, National Oceanic and Atmospheric Administration
George Philander, Geophysical Fluid Dynamics Laboratory, National Oceanic and Atmospheric Administration
Jagadish Shukla, University of Maryland
Kevin E. Trenberth, National Center for Atmospheric Research
Peter J. Webster, Pennsylvania State University
John A. Young, University of Wisconsin, Madison

Previous Members Who Contributed to This Report

Eli J. Katz, Lamont-Doherty Geological Observatory, Columbia University
Eugene M. Rasmusson, Climate Analysis Center, National Oceanic and Atmospheric Administration
Ferris Webster, University of Delaware

CLIMATE RESEARCH COMMITTEE

Joseph Smagorinsky, Princeton University, *Chairman*
Moustafa T. Chahine, California Institute of Technology
Robert E. Dickinson, National Center for Atmospheric Research
Arnold L. Gordon, Lamont-Doherty Geological Observatory, Columbia University
Isaac M. Held, Geophysical Fluid Dynamics Laboratory, National Oceanic and Atmospheric Administration
Norman Phillips, National Meteorological Center, National Oceanic and Atmospheric Administration
Veerabhadran Ramanathan, National Center for Atmospheric Research
Edward S. Sarachik, National Oceanic and Atmospheric Administration
Friedrich Schott, University of Miami
Alan S. Thorndike, University of Puget Sound
John M. Wallace, University of Washington
Ferris Webster, University of Delaware

Ex-Officio Members

D. James Baker, Joint Oceanographic Institutions, Incorporated
Thomas H. Vonder Haar, Colorado State University

COMMISSION ON PHYSICAL SCIENCES, MATHEMATICS, AND RESOURCES

CONTENTS

1. Introduction 1

2. Scientific Background 4

3. Structure of the Program 8

4. Data Management 19

5. Program Management 22

1

INTRODUCTION

The past 20 years have seen some major advances in understanding the time-dependent behavior of the coupled atmosphere-ocean climate system. Knowledge of the climate system has advanced to the stage where scientists are beginning to be able to simulate many aspects of its behavior with numerical models. This document describes a new international program devoted to extending this knowledge and modeling capability and applying them to the problem of monthly and seasonal climate prediction. The program is known by the acronym TOGA, which stands for the (Interannual Variability of the) Tropical Ocean and the Global Atmosphere. Planning for the TOGA program has been under way since 1981; research on atmosphere-ocean interaction has already undergone a major expansion, stimulated in part by the remarkable 1982-1983 El Niño event. The international TOGA program officially commenced January 1, 1985, and will continue for a period of 10 years.

The scientific objectives of the TOGA program are as follows:

1. To determine to what extent the time-dependent behavior of the tropical oceans and related planetary-scale circulation patterns are predictable on time scales ranging from weeks to a few years and to understand the mechanisms that give rise to this predictability.
2. To explore the potential of coupled atmosphere-ocean system models for predicting climatic variability on these time scales and, within the context of that predictive capability, to develop an observing and data management system to support operational climate prediction.

The international research strategy for the TOGA program incorporates elements that also may be viewed as integral parts of the closely related Monsoon Climate Program, whose objectives relate more specifically to the problem of understanding and predicting the interannual variability of monsoons.

The purpose of this document is to provide a scientific rationale that can be used as a basis for defining the U.S. role in the international TOGA program and as a foundation for detailed planning and preparation of research proposals by U.S. scientists.

The research strategy outlined in this document incorporates many major elements of the El Niño/Southern Oscillation (ENSO) scientific program plan (National Research Council, 1983*) and, consistent with international planning, encompasses studies of large-scale atmosphere-ocean interactions in all three tropical oceans. It represents a further development and refinement of ideas contained in Elements of the Research Strategy for the United States Climate Program (National Research Council, 1978†). In preparing this document, the NRC's Advisory Panel for the TOGA Program has drawn heavily on input from the broader scientific community as presented in workshops and planning documents for various elements of TOGA.

Although this strategy document addresses all major aspects of the TOGA program, it emphasizes those activities that require the highest level of coordination at the national level, i.e., observing and modeling of the tropical oceans and the global atmosphere and related data management tasks. It is recognized that more focused process studies will also play a vital role in TOGA, but the panel takes the view that the major initiatives for such projects should come from groups of principal investigators, working in concert with the major funding agencies involved in the program. It is not possible in this one, rather brief document to provide detailed guidance concerning specific budget and program decisions

---

*National Research Council (1983). El Niño and the Southern Oscillation: A Scientific Plan. National Academy Press, Washington, D.C., 72 pp.

†National Research Council (1978). Elements of the Research Strategy for the United States Climate Program. National Academy of Sciences, Washington, D.C., 46 pp.

throughout the extended duration of the TOGA program. It is anticipated that the NRC's Advisory Panel for the TOGA Program will be addressing more specific, short-term planning issues as the needs of the program dictate.

2

SCIENTIFIC BACKGROUND

The El Niño phenomenon is an episodic anomaly in the thermal structure and circulation of the upper layers of the equatorial Pacific Ocean that disrupts the marine ecosystem along the west coast of the Americas and throughout much of the tropical Pacific. It is now well established that the El Niño phenomenon is closely linked to the Southern Oscillation, a coherent, planetary-scale pattern of atmospheric pressure fluctuations centered over the tropical Pacific and the Asian monsoon region. The Southern Oscillation contributes to the year-to-year variability of monsoon rainfall over much of the tropics and wintertime circulation patterns over parts of North America and Asia. El Niño-like events have recently been identified in the equatorial Atlantic. Significant correlations have also been found between sea surface temperature (SST) anomalies in the tropical Atlantic and rainfall anomalies over parts of South America and Africa. The recognition of atmosphere-ocean interaction occurring on a planetary scale has attracted considerable interest on the part of researchers, and it has raised the hope that some of the variability in the global atmosphere and in the tropical oceans on monthly and seasonal time scales may be more predictable than was previously believed.

Coincidentally, while planning was under way for a coordinated international research program focusing on interactions between the tropical oceans and the global atmosphere, scientists witnessed during 1982-1983 what may prove to be the largest El Niño event of this century. This one-year episode was marked by disastrous floods in Peru and Ecuador, droughts in Indonesia, Australia, and many other areas of the tropics, and major shifts in jetstreams and stormtracks over much of the world, including parts of the United States. High sea levels flooded estuaries on the coast of Ecuador, while coral reefs in the western Pacific were exposed to the atmosphere at low tide for several months. The anomalous ocean circulation failed to maintain the normally high concentrations of nutrients in the upper layers of the equatorial Pacific, resulting in massive mortality of fish and seabirds.

Major atmospheric and oceanic interannual variations associated with the El Niño/Southern Oscillation tend to be phase-locked to the annual cycle, which is dominated by the vast atmospheric monsoon circulation over eastern Asia and the Indian Ocean. Circulation in the monsoon region also exhibits interannual variability, which is of considerable interest and importance in its own right and appears to be linked to the El Niño/Southern Oscillation.

The general character of the two-way interactions between atmosphere and ocean that are the central focus of the TOGA program is indicated schematically by the arrows labeled A, B, C, and D, in Figure 1. The large-scale atmospheric circulation and the distribution of rainfall in the tropics are highly sensitive to the

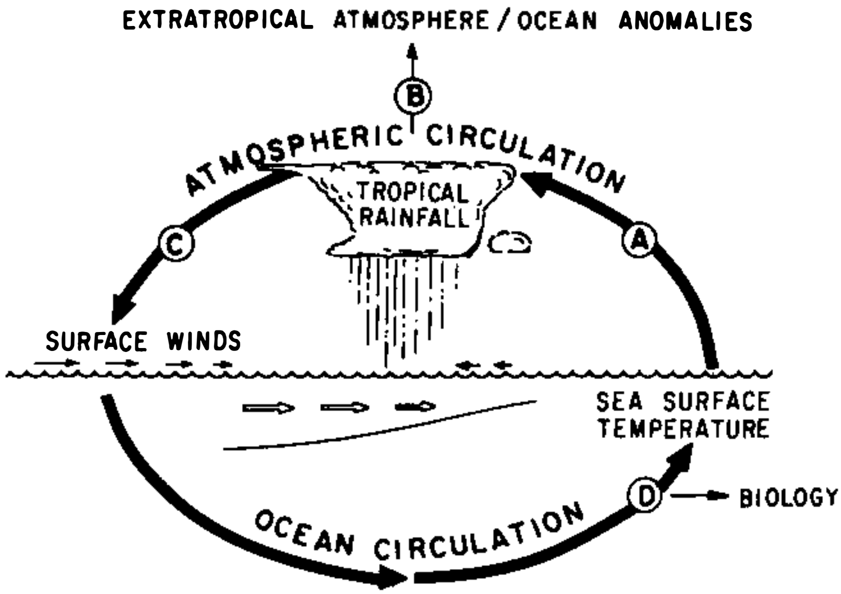

FIGURE 1 Schematic illustration of the atmosphere-ocean interactions that determine the time-dependent behavior of the coupled climate system. See text for explanation.

distribution of sea surface temperature (A). The pattern of tropical rainfall, in turn, influences the position and intensity of jetstreams and stormtracks in extratropical latitudes (B) and the surface wind field over the tropical oceans (C). These surface winds, in turn, drive the current systems in the upper layers of the equatorial oceans through the stress at the air-sea interface. The winds and currents determine the distribution of upwelling (D), which is of vital importance to marine biology and fisheries and plays a major role in determining the distribution of sea surface temperature, which feeds back on the atmospheric circulation.

The realization that interactions between winds, currents, sea surface temperatures, and tropical rainfall play an important role in interannual climate variability has brought atmospheric and ocean scientists together in search of an understanding of this coupled climate system. In a similar manner, recent demonstrations of the strong linkages between the monsoon circulations over the tropical continents and the circulation and precipitation patterns over the tropical oceans have given scientists a greater appreciation of the global character of the atmosphere's role in the coupled climate system.

Scientific understanding of these processes has progressed rapidly since 1980. Meteorologists have learned to recognize the patterns of atmospheric circulation anomalies that arise in response to a prescribed sea surface temperature anomaly in the tropics. Oceanographers have gained an understanding of the general character of the oceanic response to a prescribed change in surface winds over the tropical oceans. These one-way responses in both media have been qualitatively simulated with numerical models based on fundamental physical principles, and scientists are beginning to use coupled atmosphere-ocean models to investigate the two-way interaction described in Figure 1. Statistical analysis of past data has shown that the coupled atmosphere-ocean climate system exhibits a modest degree of predictability on time scales ranging from weeks to seasons and that this predictability extends into the monsoon regions and, to a lesser extent, into extratropical latitudes.

However, much remains to be learned concerning the time-dependent behavior of the tropical ocean/global atmosphere system.

• The subsurface signature of El Niño events and the time-dependent fluxes of momentum and energy at the air-sea interface are known only qualitatively, and existing observations are inadequate to define them with the accuracy needed for initializing and verifying models.

- Major uncertainties still exist concerning the tropical and southern hemisphere atmospheric circulations and their interannual variability.
- The processes that determine the sea surface temperature distribution and the surface wind field over the tropics are not yet well understood.
- The fundamental behavior and predictability of the coupled climate system are just beginning to be investigated.

3

STRUCTURE OF THE PROGRAM

The 10-year program of research envisioned for TOGA relies on state-of-the-art satellite sensors, oceanographic and meteorological instrumentation, and computer technology to observe and simulate the coupled atmosphere-ocean system with a view toward prediction. Four major program elements and their relation to the TOGA scientific objectives are summarized in Figure 2 and discussed in this section. A 10-year commitment by funding agencies is needed to provide a continuous level of effort to develop improved simulation and prediction models and a cost-effective operational observing system to support them. The level of effort devoted to process studies and the remaining program elements will vary with time in accordance with the needs of the TOGA program. As in the Global Atmospheric Research Program during the 1970s, the modeling activity is a unifying theme that will play a major role in defining program needs in other areas.

3.1 Modeling

Modeling efforts for the TOGA program should be guided by the long-range goal of operational prediction and the more immediate aim of establishing the limits of predictability of the coupled atmosphere-ocean system. Models relevant to the objectives of TOGA can be categorized as follows:

- Oceanographic models in which fluxes at the air-sea interface are prescribed, and the response of the upper layers of the tropical ocean is simulated or predicted, with emphasis on the evolution of the sea surface temperature field.

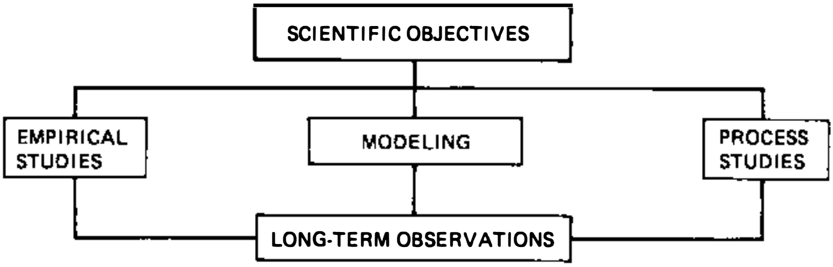

FIGURE 2 Major program elements of TOGA.

- Atmospheric models in which the tropical sea surface temperature field is prescribed, and the resulting global rainfall and circulation anomalies are simulated (or predicted, depending on the context of the experiment).
- Coupled atmosphere-ocean models which are integrated forward in time from a prescribed set of initial conditions. These models generate their own fluxes at the air-sea interface through which anomalies in one medium influence those in the other.

A hierarchy of models with a wide range of complexity will be needed in order to achieve the scientific objectives of the TOGA program. The more comprehensive models will require extensive use of advanced supercomputers and/or array processors. Simpler models will be used to build a sound theoretical foundation for interpreting the results of the more complex ones.

Models will play a crucial role in the analysis of virtually all observations taken during the TOGA program. Over the past decade, the implementation of four-dimensional data assimilation techniques has dramatically improved the accuracy and dynamical consistency of meteorological analyses. A major objective of the TOGA program is to work toward the development of an analogous capability for assimilating observations into tropical ocean models in near real time. The oceanographic data assimilation problem is somewhat different from its meteorological counterpart because of the sparsity of subsurface observations and the forced character of the tropical ocean circulation. In view of the high cost of obtaining subsurface observations, effective management of the TOGA program demands that these efforts be vigorously pursued.

Observing system simulation experiments conducted with atmospheric general circulation models during the 1970s were helpful in designing aspects of the global observing system that currently supports numerical weather prediction. Analogous experiments should be carried out later in this decade with ocean models to help determine the shape of the ocean monitoring system for the 1990s and beyond.

A number of existing atmospheric and ocean models are suitable for pursuing the scientific objectives of the TOGA program. Problems of climate drift (systematic errors in the simulation of the climatological mean state and the annual cycle) need attention. In the atmospheric models, there is need for improved parameterization of the boundary layer processes that influence the surface wind field over the tropical oceans and the sea-air fluxes of momentum, latent heat, and sensible heat. The oceanographic models need a more realistic representation of thermodynamical processes in the mixed layer and thermocline. However, even in their present state the models perform well enough to justify a vigorous program of numerical experimentation designed to elucidate the dynamical processes that determine the characteristics of the atmospheric response to a prescribed sea surface temperature anomaly and, conversely, the oceanic response to a prescribed time-dependent distribution of surface wind stress. These studies may yield a limited amount of predictive capability in their own right, and they will have a bearing on estimates of predictability of the coupled system and the design of coupled models.

Because it is not constrained at the air-sea interface, the coupled climate system and its time-dependent behavior are inherently more difficult to simulate than the atmospheric or oceanographic components alone. Thus it is not surprising that coupled models are still in a primitive stage of development. Simplified models capable of simulating some of the statistical properties of El Niño events and their relation to the annual cycle exist, but no coupled model has yet produced either an accurate simulation of such features as the intertropical convergence zone, the related system of ocean currents, the climatological mean annual cycle, or the interannual variability of the coupled system. In order to exploit the full measure of predictability believed to be inherent in the climate system, high priority needs to be given to advancing the development of realistic coupled models.

3.2 Empirical Studies

Descriptive and statistical studies are essential for estimating the predictability of the coupled climate system, and they contribute toward an understanding of the processes that control this predictable behavior. Empirically based research in TOGA includes studies of simultaneous and time-lag relationships within the coupled climate system, statistical properties of certain climatic time series, relationships between interannual climate variability and the annual cycle, and various diagnostics of past and current climate variability, including low-frequency intraseasonal fluctuations with periods on the order of 30 to 60 days, which appear to play a role in modulating the precipitation over the Asian and Indonesian monsoon regions.

The U.S. TOGA program will continue to support the development of historical data sets considered vital for empirical studies of interannual climate variability involving the tropical oceans and the global atmosphere. Of highest priority among these projects are efforts to recover and process wind and sea surface temperature data from ships operating in the tropical oceans outside the main shipping lanes from 1950 onward. In the design of future historical data sets it is important to be aware of the wide-ranging implications of intraseasonal fluctuations on the problem of climate prediction and perhaps even on the initiation and termination of El Niño events. It is important that data be archived in such a form that fluctuations with periods as short as a month can be adequately resolved.

3.3 Process Studies

Intensive, short-term, regional measurements, focused on specific processes identified as critically important for an understanding of large-scale atmosphere-ocean interaction, fall within the scope of the TOGA program. Results of these investigations will contribute to the more general objectives of the TOGA program and, more specifically, to the development and validation of numerical models.

These studies should be specifically targeted to TOGA-related questions. Process studies justified by the U.S. TOGA program must contribute to the TOGA objectives (i.e., prediction and model development).

It is expected that proposals for process studies will be submitted by groups of principal investigators as the scientific questions that need to be addressed become more clearly defined. These proposals should undergo the usual scientific peer review. In contrast, the monitoring activities described in the following section may require more direct solicitation by the TOGA office to ensure a balanced program.

Examples of oceanographic process studies relevant to TOGA include TROPIC HEAT, a detailed analysis of the heat budget of the equatorial mixed layer in the central Pacific; FOCAL/SEQUAL, a cooperative U.S./French effort to understand the annual cycle in the circulation thermal structure of the equatorial Atlantic; and the Arabian Sea Cooling Experiment, which is aimed at understanding the role of horizontal circulation as it affects the heat content variability in the upper mixed layer.

Results from these experiments have been useful in clarifying how sea surface temperature anomalies develop in response to processes in the upper ocean. Synthesis of these results might indicate the need for further process studies designed to address remaining uncertainties concerning the oceanic thermal structure and its response to the time-varying pattern of wind stress and heat flux along the equator.

Examples of possible candidates for atmospheric process studies include detailed analysis of the equatorial planetary boundary layer structure in various wind regimes, or relationships between tropical convection, sea surface temperature, and low-level wind patterns. Process studies might also prove to be the most effective means of calibrating estimates of sea-air fluxes derived by remote sensing from satellites.

A wide variety of important, intrinsically interesting meteorology, physical oceanography, and remote sensing questions will naturally fall outside the scope of the TOGA program.

3.4 Long-term Observations

Throughout the 10-year duration of the TOGA program, a concerted effort will be made to define the time-dependent structure of the tropical oceans and the global atmosphere and the interactions at the atmosphere-ocean interface. The resulting data set will be used as a basis for the following:

- Initialization, updating, and verification of model predictions.
- Descriptive and diagnostic studies of the physical mechanisms that determine the predictability and behavior of the coupled system.
- Decision making regarding the deployment of special observing systems designed to observe critical phases in the life cycle of El Niño events.

3.4.1 The Atmosphere-Ocean Interface

Data sets for wind stress and sea surface temperature and surface energy fluxes over the tropical oceans are needed not only for model verification but also as boundary conditions at the atmosphere-ocean interface for atmospheric and ocean models. Accurate surface wind analyses are a prerequisite for obtaining reliable estimates of wind stress, and they are important in their own right for the verification of atmospheric models.

Wind stress is the primary forcing for currents in the tropical oceans. An accurate description of this field is needed for the modeling and data assimilation activity described in Section 3.1, which provides the basis for interpreting other oceanographic data sets. Additional direct surface wind measurements from buoys and island stations are needed in order to fill gaps in this field, and further development work is needed in order to improve the accuracy and space and time resolution of operational surface wind analyses over the tropical oceans. These analyses are currently based on a blend of surface meteorological observations and low-level cloud motion vectors. The advent of satellite scatterometer measurements around 1990 represents a critical milestone in the TOGA program. A NASA scatterometer (NSCAT) is scheduled for launch on the U.S. Navy Remote Ocean Sensing System (NROSS), and scatterometer measurements will be made at the same time by the European Space Agency's Earth Resources Satellite (ERS1). A major research and development effort will be needed in order to effectively utilize this important new data set for improving estimates of surface wind and wind stress over data-sparse regions.

An accurate description of the sea surface temperature (SST) field, especially over the tropical oceans, is required for initializing atmospheric models and for computing heat and moisture fluxes at air-sea interface. Operational, global SST analyses are produced at the NOAA Climate Analysis Center (CAC) from a blend of satellite, shipboard, and moored and drifting buoy measurements. This product, which has a 0.7K rms accuracy in the equatorial belt, already satisfies many of the TOGA requirements, and research and development is currently under way to refine it further. Greater accuracy is required for defining the SST pattern in the region of warm water over the tropical western Pacific where the atmosphere is highly sensitive, even to small changes. Persistent cloudiness over this region tends to limit the accuracy of SST retrievals from satellites. Higher temporal and spatial resolutions are needed over the eastern Pacific and Atlantic where the SST field displays sharp fronts and mesoscale waves.

Latent and sensible heat fluxes and radiative fluxes at the air-sea interface are important for understanding the mean state of the coupled climate system and for diagnosis of coupled models. Temporal variations in these fluxes may be an important factor in explaining the variability of sea surface temperature and heat content of the mixed layer. The density of marine surface observations is not sufficient to provide adequate sampling of these fields. New and improved techniques for deriving spatially continuous fields of these fluxes based on satellite measurements are currently being developed, with support from the TOGA program.

3.4.2 The Atmosphere

Most of the atmospheric observations needed for the TOGA program will be acquired through the World Weather Watch/Global Telecommunications System (WWW/GTS) that supports operational weather analysis, forecasting, and numerical weather prediction. In the international TOGA program and in the World Climate Research Program the highest priority for atmospheric observations is assigned to maintaining continuous operation of certain key elements in the WWW/GTS and to eliminating some of the more serious deficiencies in the way the system operates. Specifically:

- The United States should ensure that two polar-orbiting satellites and global tropical coverage by geostationary satellites are maintained at all times. There has been at least one proposal to degrade the satellite coverage to one polar orbiter. Such an action would not only degrade the imagery and radiance data but also would have a significant impact on the recovery of data from remote platforms such as southern ocean buoys. More importantly, it would entail the unacceptable risk of having no polar-orbiting platform in the event of unexpected failure.
- The United States should vigorously support international efforts to upgrade the collection and real-time transmission of data from ships of opportunity operating in the tropics and from tropical and southern hemisphere surface and upper air stations.
- The United States should support intensified international efforts to collect delayed surface marine observations, particularly over the equatorial Pacific and the southeast Pacific, where the data currently being retrieved are insufficient to define the surface wind, SST, and sea-level pressure.

From the perspective of long-term atmospheric observations, the most critically needed improvements in the current operational data sets are in the specification of the following:

- The tropical circulation, including the divergent component of the wind, which tends to be largest in the tropics and not easily deduced from the mass field. Comparison of various operational analyses based on currently available tropical data reveals rather large differences, which are a reflection of uncertainties, particularly in the divergent component of the wind. The United States should explore the possibility of cooperative arrangements to provide new upper air stations at a few critical locations along the equator, and to increase the frequency of observations from existing stations in this region. The density and accuracy of cloud motion vectors from all operational centers need to be improved to some agreed-upon standard and maintained at that level.
- Precipitation between 30°N and 30°S. The United States should assume responsibility for providing estimates of precipitation based on radiance data provided by SMS/GOES satellite operators in the United States, Europe, Japan, and India in a standardized

format. Improved ground truth is needed in conjunction with improved algorithms for deriving rainfall from satellite radiance fields. A potential for improving algorithms based on infrared and visible imagery still exists, and high-resolution microwave imagery proposed for future low-inclination orbit satellites offers the prospect of much-improved tropical rainfall estimates.

- Circulation over the data-sparse southern oceans, where the uncertainties in operational analyses are unacceptably large. The South Pacific requires special emphasis because of its role in the Southern Oscillation. During the Global Weather Experiment, it was demonstrated that surface observations from a network of drifting buoys together with satellite radiance fields constitute an effective observing strategy for this region.

3.4.3 The Oceans

One of the primary objectives of the TOGA program is to work toward the development and implementation of an observing system that will define the time-dependent thermal structure and currents in the tropical upper oceans with an accuracy adequate for numerical simulation and prediction of the coupled climate system.

The Pacific receives highest priority for long-term oceanographic observations in the U.S. program plan because the eastern edge of the pool of warm surface waters extending from the eastern Indian Ocean into the western Pacific is the focus of the large El Niño/Southern Oscillation signal, which produces significant climatic anomalies over the globe including the U.S. mainland. However, programs of long-term observations should also be developed for the other oceans to the extent that resources are available. The Indian Ocean is of interest because of its role in the Asian/Australian monsoon, and the Atlantic provides a different environment in which to observe phenomena analogous to those responsible for the seasonal and interannual variability in the Pacific. All three oceans are of interest from the viewpoint of regional climate prediction.

The existing ocean observing system needs to be evaluated in order to identify deficiencies and redundancies, making use of observing system simulation experiments with numerical models as described in Section 3.1. While this work is in progress, the existing system should be maintained, and modest enhancements should be implemented in regions where substantial gaps are known to exist. From the perspective of long-term oceanographic observations, the critical fields are as follows:

- Thermal structure and heat content of the upper ocean. At present, the main means of achieving even partial coverage over the Pacific is through the XBT Ship of Opportunity Program. As other techniques such as moored and drifting thermister chains become reliable, a well planned program using all of these techniques needs to be implemented.
- Sea level. The present network for observing sea level needs to be evaluated for deficiencies and redundancies, and the utility and interpretation of tropical sea-level data need to be more fully explored before the advent of satellite altimeters, which will play a crucial role in providing for the continuity of the field in regions distant from coastlines and islands. Further development efforts will be needed to improve the methodology for processing altimetry fields and blending them with other sea-level data sets.
- Horizontal currents. Along the equator, currents must be measured directly with moored instrumentation. Because of large differences in the vertical structure of ocean currents and in the atmospheric forcing in the eastern, central, and western Pacific, sites in each of these regions need to be maintained during the early stages of TOGA. Off the equator, sea-level and XBT measurements proposed in the more detailed TOGA planning documents will be used to infer the vertical shear of geostrophic currents. Direct estimates using drifting buoys, acoustic Doppler profilers, and so on, will be used to estimate currents and their time variability.

3.4.4 Observing Priorities

At various stages in the program planning it will be necessary to make funding decisions based on assessments of the priority of the various long-term observational requirements described in the previous subsections and summarized in Table 1. Such assessments involve many considerations, including scientific importance of the measurement, cost, technical feasibility, and the extent to which the requirement can already be met or will be met without additional TOGA support. The establishment of priorities for the TOGA program will be an ongoing

TABLE 1 Summary of Long-term Observational Requirements for the TOGA Program

Atmosphere	Tropical circulation/ divergent wind component	Tropical precipitation	Sea-level pressure, Southern Oceans
Interface	Wind stress*	SST*	Evaporation, radiation sensible heat flux*
Ocean	Thermal structure*	Sea level*	Horizontal currents*

*Over tropical oceans: highest priority assigned to Pacific.

process involving broad input from the scientific community.

In terms of scientific importance, all of the long-term observational requirements listed in Table 1 are of sufficiently high priority to warrant a significant level of effort. Wind stress and sea surface temperature are the highest priority items on the list, since they are both central to the modeling effort and to the diagnosis of the current state of the climate system. Subsurface thermal structure is the most crucial field for the initialization and verification of ocean models. Tropical circulation and precipitation are the most crucial elements in the definition of the global atmosphere.

4

DATA MANAGEMENT

In order to promote effective use of TOGA program resources, early attention and high priority need to be given to the design of an effective data management plan to ensure that the observations described in Section 3.4 are

- monitored for accuracy and completeness on a regular basis,
- collected and made accessible to users as soon as possible,
- quality controlled and documented so that users can appraise their utility,
- archived permanently, in readily accessible formats, and
- synthesized in an orderly sequence of operations, culminating in the assimilation into comprehensive atmospheric and/or ocean general circulation models.

The type of system that is envisioned is described schematically in Figure 3. Along the outer rim are listed the various types of data sets that need to be collected, archived, and made available to the research community. Most of the data sets involve direct observations, but cloud motion vectors and atmospheric analyses are products of operational numerical weather prediction centers. There are no major scientific issues that need to be resolved before implementing the outer ring of the data management plan. Hence, it is not too early to define the U.S. role in these components of the international data management plan. In order for operational centers or research groups to qualify for funding from the U.S. TOGA program for major data management projects, they need to demonstrate through the

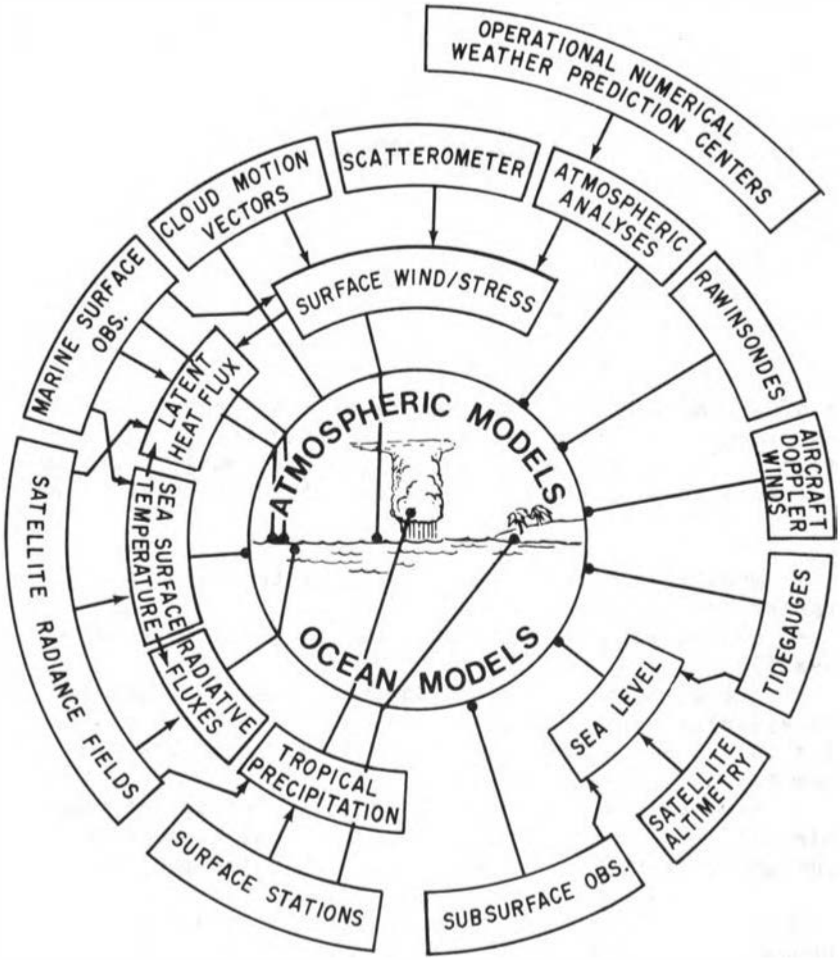

FIGURE 3 Data management system for TOGA.

appropriate peer review process that they have the scientific and managerial capability to carry out the tasks assigned to them in a cost-effective and timely manner.

The data products listed in the inner ring of Figure 3 involve continuous fields derived from a synthesis of two or more of the basic data sets described above. The methodology for generating these derived products is still evolving. Hence, it would be premature to designate data centers for them at this early stage of the TOGA program.

Research aimed at developing improved algorithms for recovering these fields needs to be encouraged, and the basic data sets from which they are derived need to be archived for future use.

Represented in the center of the diagram are the atmospheric and ocean models that will assimilate the derived fields of sea surface temperature, surface wind, air-sea fluxes, and so on, together with many basic data sets, in order to produce a complete, quantitative, dynamically consistent description of the climate system. Time integrations of these same models will, in turn, generate forecast fields to be verified by comparison with the data sets listed in the rings of the diagram. Atmospheric data assimilation is carried out in a real time operational mode based on data collected by the WWW/GTS as indicated in the upper right corner of the diagram. No operational center has yet made a commitment to repeat this process in a delayed-time mode incorporating atmospheric observations not collected on the WWW/GTS, as was done as part of the Global Weather Experiment. However, it is extremely important that the atmospheric data sets listed in the outer ring of the diagram be collected and archived so that reanalysis can be carried out at a later date. The success of future climate prediction efforts may yet require the reanalysis of atmospheric fields, making use of improved models and assimilation schemes and more complete data sets.

As noted above, the development of a data assimilation capability for ocean models, analogous to that which exists in support of operational numerical weather prediction, is one of the most pressing needs of the TOGA program. Necessary steps in this process in the area of data management include the following:

- Increasing the volume of oceanographic data carried on the GTS to the maximum extent practically feasible.
- Improving procedures for collecting, formatting, and distributing oceanographic data sets not carried on the GTS.
- Identifying data archiving and analysis groups that will assume responsibility for those tasks outlined in Figure 3 that involve oceanographic data.
- Making the necessary preparations to effectively handle the voluminous satellite data sets that will characterize the later part of the TOGA program.

5

PROGRAM MANAGEMENT

The management structure for the U.S. TOGA program and its relation to the international TOGA program is described schematically in Figure 4. The U.S. TOGA Project Office is the focal point for organizing and coordinating the national research effort, while the NRC's Advisory Panel for the TOGA Program provides oversight as explained below. The responsibilities of the U.S. TOGA Project Office include the following:

- Coordinating planning for U.S. participation in the international TOGA program in relation to (1) development, acquisition, and deployment of specialized systems for observing the climate system; (2) data management; and (3) basic and applied research programs, such as the modeling effort.
- Preparing an annual budget for TOGA research responsive to established scientific priorities for submission to agency managers, and carrying out long-range budgetary planning for the program.
- Facilitating the implementation of special observing systems.

Most of the activity supported through the U.S. TOGA Project Office involves long-term projects that fall within the scope of monitoring and data management. Support for modeling is shared by the project office and several federal agencies. Agencies other than the project office bear the major responsibility for supporting process studies and empirical studies.

The NRC's Advisory Panel for the TOGA Program oversees the project office in its performance of the tasks outlined above and keeps its parent body, the Climate Research Committee, advised on matters related to TOGA.

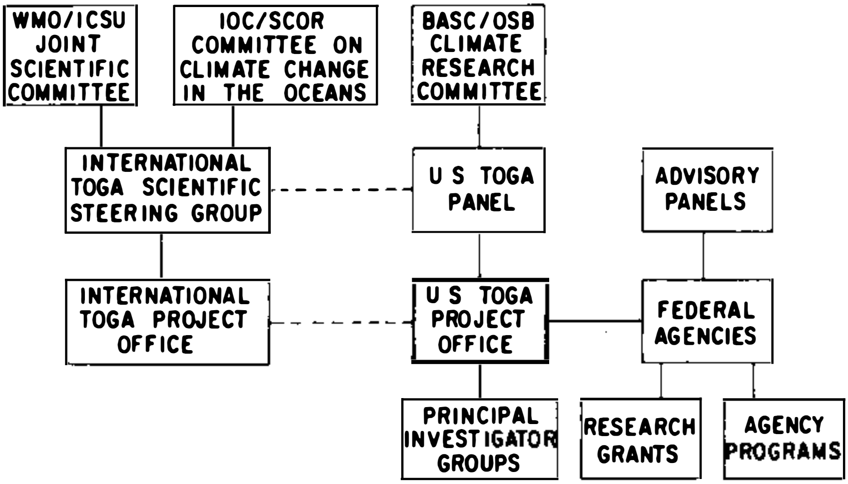

FIGURE 4 Organizational diagram showing international and U.S. panels, project offices, agencies, and programs involved in TOGA. International bodies are to the left of the dashed lines, national bodies to the right. Relationships to the international World Climate Research Program Office have been omitted for the sake of simplicity.

It also reviews and approves plans for U.S. participation in the international TOGA program, and it may make recommendations to the federal agencies regarding the implementation of plans for TOGA. It may be called on by its parent body to review TOGA research programs in the various federal agencies.

Participation in TOGA by federal agencies assumes a number of different forms. In some agencies, such as NOAA, some of the funding earmarked for TOGA supports research projects within their own laboratories. Decisions as to which of these projects are to be designated for TOGA support are made by agency administrators in consultation with the TOGA Project Office and, in some cases, with the assistance of special advisory panels that report directly to the agency.

The implementation of the TOGA program will require a high level of cooperation between federal agencies. NOAA, NSF, and NASA will bear the major responsibility for funding observations and research. TOGA will also benefit from research and development related to remote sensing of the oceans, sponsored by the Navy.

Groups of principal investigators on research grants will carry out much of the detailed scientific planning for many of the major components of the TOGA program. As the needs of the program dictate, the TOGA Project Office will invite such groups to prepare coordinated sets of research proposals designed to address specific TOGA objectives in the areas of long-term observations, data management, and modeling. Such groups may also play an important role in planning and carrying out process studies supported by federal agencies.

Close coordination between the U.S. and international TOGA programs is maintained through the formal link between the two project offices via the U.S. representative to the World Climate Research Program and through informal liaison between the international TOGA Scientific Steering Group and the NRC advisory panel, which have some overlap in membership. U.S. mission agencies and the TOGA Project Office bear the responsibility for international commitments to carry out monitoring or data management tasks related to the TOGA program and other elements of the World Climate Research Program.