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BOARD ON ATMOSPHERIC SCIENCES AND CLIMATE

COMMISSION ON PHYSICAL SCIENCES, MATHEMATICS, AND RESOURCES

CONTENTS

PREFACE

The global system of earth, ocean, ice, and atmosphere that determines our climate is vast, complex, and infinitely challenging to science. In recent years, we have become increasingly interested in the fluctuations of climate on time scales of months, seasons, or several years. It has become clear that these involve not only the global atmosphere, but also the ocean--indeed the entire climate system. This report outlines a program of observations and research to advance our understanding of the most powerful family of atmospheric and oceanic variations on these time scales--those associated with the El Nino phenomenon and the Southern Oscillation (jointly referred to in this document as ENSO).

Study of phenomena such as these, spanning a major fraction of the globe and several years' duration, is clearly a formidable challenge, as well as an exciting opportunity. Thus, it is not surprising that the scientific planning for such an enterprise passes through a lengthy and complex gestation period. As the World Climate Research Program (WCRP) took shape in the late 1970s, prediction of seasonal and interannual climate fluctuations emerged as one of its major objectives. In June 1981, the Climate Research Committee (CRC)--which serves as the U.S. national scientific supporting body for the WCRP--reviewed a growing body of research pointing to connections between tropical ocean events and subsequent climate anomalies in midlatitudes. In July 1981 at Boulder, Colorado, the CRC organized an informal discussion group in conjunction with a meeting of scientists associated with the EPOCS (Equatorial Pacific Ocean Climate Studies) program. Based on this discussion, conceptual papers were drafted by T. Barnett and J. M. Wallace, both CRC members, with most welcome assistance from P. Julian of the National Center for Atmospheric Research (NCAR). Additional informal discussions among groups of meteorologists and oceanographers were held in September 1981 at NCAR and at the Scripps Institution of Oceanography in La Jolla, California.

In February 1982, the CRC reviewed the results of these discussions--results that had begun to assume the form of embryonic plans for a major multiyear field observational program in the Pacific. By this time, many interested scientists and research groups in both the academic community and in government had become entrained in this process of exploratory planning. Indeed, planners in the National Oceanic and Atmospheric Administration (NOAA), the National Science Foundation, and other agencies were already discussing the organizational and logistical challenges of such a program, which would form a logical extension of a number of highly successful Pacific-oriented U.S. research programs. Thus, a significant national constituency was growing. In order to elicit the contributions of this larger community to the evolving plan, the CRC organized a Study Conference at the Geophysical Fluid Dynamics Laboratory in Princeton, New Jersey, in October 1982, at which the draft plans were intensively discussed and extensively revised. Subsequently, a follow-up workshop was convened in Miami, Florida, in May 1983 to discuss implementation possibilities.

The CRC also realized that a fully developed ENSO program would require the support and participation of other nations and would, moreover, be an important component of the international WCRP. Indeed, the Joint Scientific Committee for the WCRP rapidly seized on ENSO as a major building block for an even more comprehensive program to study the interannual variability of the Tropical Ocean and Global Atmosphere (TOGA). The Committee on Climatic Changes and the Ocean (CCCO), sponsored by the Intergovernmental Oceanographic Commission and the Scientific Committee on Oceanic Research as the oceanic counterpart to the Joint Scientific Committee, defined subprograms of TOGA in the Atlantic, Indian, and Pacific Oceans, the last of these meshing with U.S. ENSO aspirations. These programs were also discussed favorably at the well-attended Joint Organizing Committee/Scientific Committee on Oceanic Research Conference on Large-Scale Ocean Experiments in Tokyo in the spring of 1982. At this writing, an international TOGA steering committee has been formed, and a TOGA study conference is expected to be organized in the relatively near future.

The scientific plan presented in this report should be considered in the context of the national and international developments outlined above. Despite the exceptionally broad participation in its development over the last two years, it should be viewed as but a snapshot of a complex and rapidly changing scene. Moreover, the empirical data base on which the plan is based continues to grow, as witnessed by the 1982-1983 Pacific warming episode.

The plan attempts to present the scientific rationale and objectives of an ENSO-directed program and to sketch the broad outline of observational and research programs that could address these objectives. This global-scale and almost inescapably international research program is based on a number of existing or planned elements that have already been developed for other compatible motivations. However, other elements--notably long-lead-time systems such as satellites--urgently require definition and initiation. It is implicitly assumed that the federal agencies, coordinating their work through an interagency program office, will support the requisite field activities, observing platforms, and research proposals. We envisage also that the scientific community will continue to guide the program's further development and implementation as it has fostered its conception and infancy. It is conceivable that the CRC can continue to play a constructive role.

The present document does not attempt to deal with the practical problems of manpower, resources, or costs--problems that are currently being explored by concerned federal agencies. Thus, this report is only a beginning; but we believe that it is a sound beginning.

On behalf of the Climate Research Committee and its parent body, the Board on Atmospheric Sciences and Climate, I want to express my appreciation to the many individuals who participated in the development of this plan and to the institutions that lent their facilities and support. I am particularly appreciative of the contributions of T. Barnett, J. M. Wallace, and P. Julian. The work was sponsored by the National Oceanic and Atmospheric Administration, the National Science Foundation, the National Aeronautics and Space Administration, the National Climate Program Office, and other agencies participating in the National Climate Program. Staff support at the National Research Council was most effectively provided by T. H. R. O'Neill and J. S. Perry with administrative support by D. Bouadjemi.

Joseph Smagorinsky, Chairman
Climate Research Committee

A SCIENTIFIC PROSPECTUS

The vagaries of global climate seem at first glance random, almost chaotic. However, there is a strong signal that stands out above the otherwise noisy background of short-term climate change. This signal is loosely called the Southern Oscillation (SO). Traditionally, it has been regarded as primarily comprising a large-scale seesaw of atmospheric mass between the Pacific and Indian Oceans in the tropics and subtropics. The oscillation is irregular, but its preferred period lies in the range of two to seven years. Studies over several decades have shown that the SO actually involves a "family" of oceanic and atmospheric climatic fluctuations around the globe involving many regions of both northern and southern hemispheres and operating on both seasonal and interannual time scales. It is associated with interannual variations of the monsoon over India, shifts in the Intertropical Convergence Zone (ITCZ) and South Pacific Convergence Zone (SPCZ) over much of the equatorial Pacific Ocean, interannual variations of the monsoon over India, and "teleconnections" that link atmosphere and ocean conditions in the tropical Pacific to conditions in other parts of the tropics and to weather over North America and elsewhere. Related changes also occur in various other regions of the world's oceans. The most dramatic of these appears in the equatorial Pacific Ocean and is commonly termed El Nino (EN), an anomalously large warming of the coastal waters off South America, a phenomenon often damaging to the important local fishery industry. A brief description of the most recent such event, which ran its course during the development of this report, is presented in Appendix A.

The SO and related phenomena comprise the largest signal in short-term global climate variability. Because of the involvement of the ocean, the characteristic time scale of the phenomenon is long enough so that various elements of its early evolution may be useful in predicting subsequent changes in global climate. In the last few years, statistical relationships between various elements of the SO and North American climatic anomalies have been used as a basis for rudimentary seasonal climate prediction models (Barnett, 1981). The physical concepts behind these models are associated with the shifts in planetary wave systems noted above, which result in changes in the jet stream positions and hence changes in storm tracks, surface air temperature, precipitation, and other climatic variables.

The first predictive models (Barnett, 1981) have been purely statistical and have capitalized on the long time scale associated with SO phenomena, e.g., models to predict surface air temperature over North America several seasons in advance. Recent gains in explaining the dynamics of SO phenomena give hope that it may soon be possible to integrate physics into the forecast process to develop more reliable and skillful short-term climate prediction models.

The program described in this report is designed to investigate this promising possibility. Its goals are to describe and to seek an understanding of the mechanisms that control the SO, and to express this understanding in a hierarchy of models aimed ultimately at improving the prediction of short-term, regional climate changes over North America and other important agricultural regions.

1.1 THE SOUTHERN OSCILLATION FAMILY

Around the turn of the century scientists began documenting fragments of the SO phenomenon. However, it was left to Sir Gilbert Walker (Walker, 1923) to describe it as a "swaying of pressure on a big scale backwards and forwards between the Pacific and Indian Oceans. . . ." Differences in station pressures reflect this movement in mass and have been used to compute an "SO Index." Associated with this swaying of mass between the hemispheres are remarkable changes in wind, temperature, and rainfall in the monsoon regions, the central and western equatorial Pacific, and indeed throughout the tropics. While not simply periodic, the phenomenon is certainly a recurrent one, with the interval between events ranging from two to seven years. Huge changes in the equatorial[1] thermocline of the Pacific Ocean accompany these atmospheric events.

The global extent of the SO phenomenon can be illustrated by enumerating some further members of the SO family.

- El Nino is generally referred to as an anomalous warming of ocean water temperature off South America usually accompanied by heavy rainfall in the coastal regions of Peru and Chile. The resulting effect on the local fishery industry of Peru is often devastating. The warm sea surface temperatures extend in the east-west direction along the equator over a quarter of the earth's circumference. During such an event, the earth's thermal equator, which normally lies at about 7°N, moves southward toward the geographic equator. The ITCZ is closely coupled to the thermal equator and also moves southward and intensifies. Major changes of a similar nature occur in the SPCZ in the southern hemisphere. At the same time, the region of concentration of equatorial precipitation moves eastward from Indonesia to the dateline.
- Associated with the changes from "warm" to "cold" sea surface temperature anomalies and the rearrangement of the ITCZ, SPCZ, and other convective areas are major changes in the atmospheric tropical circulation. First investigated in the context of the EN and SO phenomena (Bjerknes, 1966), these changes include principally the zonal component of low- and high-tropospheric winds. The resulting circulation cell oriented in a vertical zonally-oriented plane was termed by Bjerknes the Walker circulation cell. A schematic version of the extremes in the position of the Walker cell is included in Figure 1. It has long

[1] In this document, the term "equatorial" is used to refer to a narrow oceanic zone (approximately 5°N to 5°S) centered on the equator where the unique dynamics imposed by small values of the Coriolis parameter dominate. The term "tropical" refers to the larger conventional definition of the tropics, taken for convenience to be 30°S to 30°N.

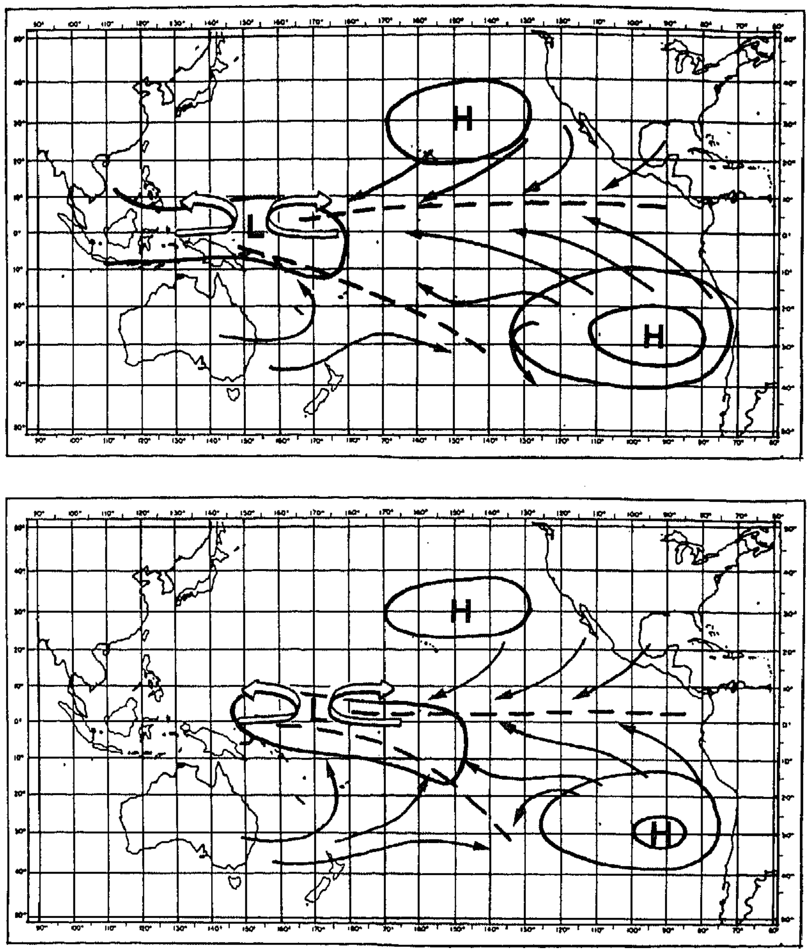

FIGURE 1. Schematic depiction of the two phases of the Southern Oscillation corresponding to the "cold-phase" or normal conditions (top) and the "warm phase" or El Nino conditions (bottom). Sea level pressure is shown by the solid contours and the surface wind flow by the solid arrows. The location of the Intertropical Convergence Zone (ITCZ) and South Pacific Convergence Zone (SPCZ) are indicated by the heavy dashed lines. The full arrows indicate the rising portion of the Walker Circulation.

been known that variations in the monsoon system over India cause great changes in the rainfall over that subcontinent, as well as the Indonesian maritime continent. As described in Sir Gilbert Walker's definition of the Southern Oscillation, the variations in pressure and rainfall in these regions appear to be closely related to the SO cycle. For example, there is a tendency for the EN events to precede relatively dry Indian monsoon seasons but to follow a weak winter monsoon.

- The connection in the atmosphere between the SO, EN, and the Walker Circulation in the tropics and associated changes in the high latitudes has recently been demonstrated both empirically and theoretically (Horel and Wallace, 1981; Hoskins and Karoly, 1981). This clearly suggests that perturbations in the pattern of atmospheric heating over the equatorial Pacific affect the planetary wave structure over much of the North Pacific Ocean, North America, and probably other parts of the globe. An example of the latter type of result is schematically shown in Figure 2. A number of studies have constructed forecast models that attempt to predict surface temperatures over North America using the empirical correlations between the SO and EN and subsequent seasonal temperature anomalies (Barnett, 1981; van Loon and Madden, 1981). Figure 3 portrays the pattern of potential predictability owing to the correlation field. This pattern closely matches the observed pattern of sea surface temperature anomalies during January and February 1983.

Because of its close relation with the atmosphere, the ocean appears to be a key element in stabilizing and/or driving the SO phenomenon. The ocean stores, rearranges, and gives up heat to fuel the atmospheric circulation system while the latter provides momentum to the ocean to help drive the ocean current systems and influences the fluxes of radiation and sensible/latent heat from the ocean surface. The physics and dynamics of this coupled system clearly provide a rich set of scientific problems.

Recent investigations show that the oceans and atmosphere communicate most effectively in the tropics, where the thermodynamic time scale of ocean response is comparable with the corresponding atmospheric time scales and the dynamic response of the oceanic mixed layer to the wind is stronger. At higher latitudes this ocean

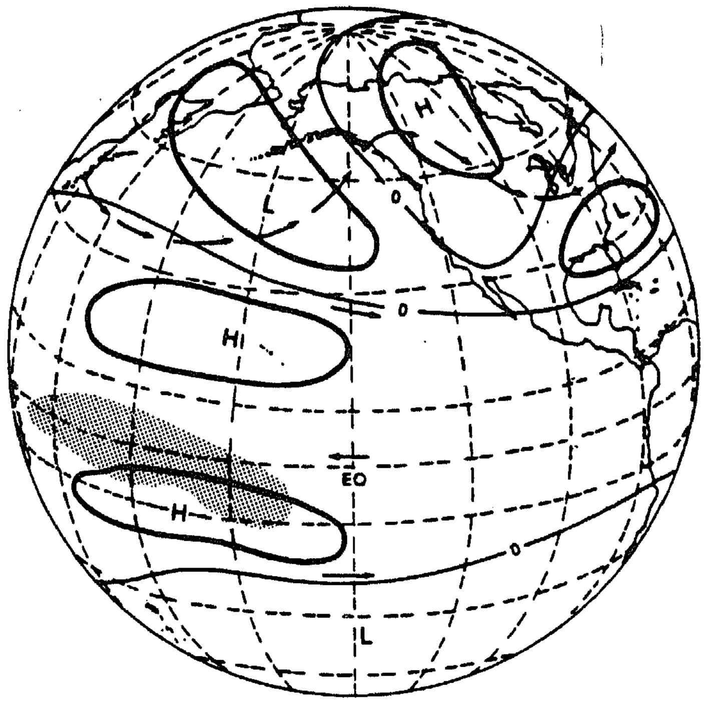

FIGURE 2. Schematic illustration of hypothesized global pattern of middle and upper tropospheric geopotential height anomalies during a northern hemisphere winter during an episode of warm sea surface temperatures in the equatorial Pacific. The heavy arrows reflect the strengthening of the subtropical jets in both hemispheres and stronger easterlies near the equator. The lighter arrows depict an actual streamline as distorted by the anomaly pattern, with pronounced troughing over the central North Pacific and ridging over western Canada. Shading indicates enhanced cloud and rain (from Horel and Wallace, 1981).

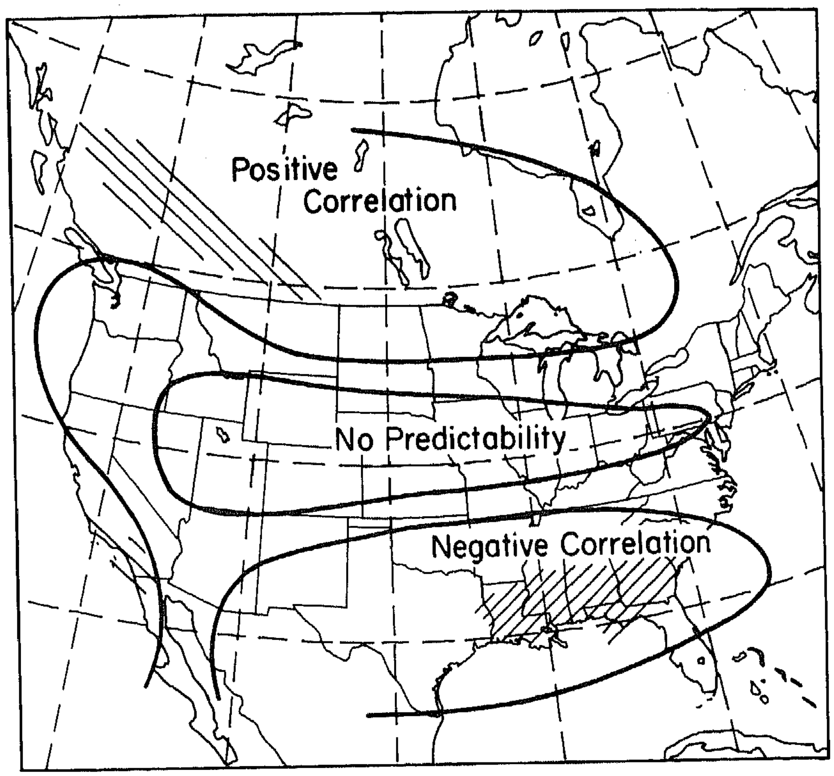

FIGURE 3. The general relationship between an objectively defined Southern Oscillation, El Nino index, and seasonal temperature anomalies over continental North America the following winter season. Positive and negative correlations of significant magnitude exist for the regions indicated and are particularly strong in the hatched areas. The region of no correlation and no predictability is also shown (after studies by Barnett, 1981; van Loon and Madden, 1981).

response is much more sluggish, effecting some degree of decoupling between the two media. Thus, it appears that a key to understanding the global fluctuations of climate associated with the SO lies in studying the interaction between the oceans and the atmosphere in the tropics. Present knowledge clearly indicates that this coupling is strongest in the equatorial Pacific Ocean. This is partially due to the huge size of the Pacific (whose time scales span several annual cycles) and also to the fact that the western Pacific experiences atmospheric forcing from both the monsoon and the trade wind systems, both key elements in the Southern Oscillation.

1.2 PROGRAM JUSTIFICATION

There are a number of compelling reasons for initiating a SO program now. They fall into three general classes, outlined below: scientific, practical, and organizational.

1.2.1 Scientific

- The cumulative studies of the SO phenomenon have in the last several years been pulled together into the first fragments of a theory for short-term global climatic variation. In view of the importance of climate variations to society and the global economy, it seems that we should pursue, without delay, these encouraging beginnings.
- The number of scientific investigators turning their attention to the study of short-term climate problems is already substantial and rapidly increasing both in the United States and abroad. The recent scientific results noted above give a sense of excitement and urgency to the field. Also, the recently organized World Climate Research Program (WCRP) offers excellent opportunity for an efficiently coordinated attack on the SO problem. The subject area is clearly one ripe with scientific opportunity.
- The SO can be investigated as an atmospheric and as an oceanographic problem separately. These simpler disciplinary problems appear tractable as observational and modeling studies, and they are likely to yield important, useful results in their own right, while simultaneously contributing to an understanding of the workings of the coupled atmospheric-oceanic system.

1.2.2 Practical

- o There is little doubt that the world badly needs improved seasonal and interannual climate predictions. Society today makes heavy demands on vital resources such as water, food, and energy, and we must therefore effectively manage these resources to ensure our continuing welfare. Foreknowledge of major climatic variations (e.g., drought, severe winters) would be of great value in this effort. For example, in the winter of 1976-1977 heating oil supplies in the United States were virtually annihilated by severe and extended cold weather. Major features of that winter temperature pattern were predicted, but not in time nor with sufficient confidence to allow the necessary management decisions to be made. Recent research suggests that it may be possible to predict with useful skill such extremely cold winters several seasons in advance in certain regions of the United States (see Figure 3).
- o Study of the SO phenomena also holds some promise of improving our ability to predict weather at medium ranges, i.e., seven to ten days. For example, there is evidence that cold air outbreaks over eastern Asia tend to be followed, within several days, by an enhancement of convective activity over parts of the tropical Pacific.

1.2.3 Organizational

- o Current research efforts are attacking some subelements of the SO problem. However, the programs do not have a framework for coordination and overall management commensurate with the global nature of the problem they are addressing. Thus, it is not surprising to find that many important practical areas of scientific endeavor are not being addressed. The present plan is intended to help focus both current and future research on the SO problem to an efficient, satisfactory conclusion. It will also serve as a mechanism for engendering a vigorous international program required to address the global problem.
- o Required observations are to a considerable extent either in hand or within our grasp. Ongoing observing programs such as the surface-based components of the World Weather Watch and the already-planned satellite

programs of India, Japan, and the United States will provide essential information. The observational and research programs of the past decade have left a rich legacy of capabilities. For example, the Global Weather Experiment demonstrated that buoys can provide valuable observations over large expanses of ocean at low cost. Thus, a SO program will not require de novo development of an expensive observing system.

1.3 SCIENTIFIC ISSUES

In order to make progress toward understanding the physics of the SO and using this knowledge to improve short-range climate predictability, it will be necessary to address an array of scientific issues, which can be grouped into three rather general categories:

- Issues that concern the atmospheric response to a prescribed sea surface temperature anomaly, irrespective of how the anomaly came about. Modeling studies indicate that the atmosphere adjusts to the presence of such an anomaly on a time scale of a week or two, in a manner dependent in part on the general character of the extratropical circulation.
- Issues that concern the response of the tropical ocean basin to a prescribed, time-dependent surface wind stress and air-sea energy exchange on time scales ranging from months to seasons.
- Issues that can be addressed only in the context of the coupled ocean-atmosphere system.

For each of these categories, we will briefly review existing knowledge, the work currently in progress, and the scientific problems that need to be addressed in future studies. Specific scientific objectives and research strategies for achieving them are discussed in later sections.

1.3.1 <u>Atmospheric Response to a Prescribed Sea-Surface Temperature Anomaly</u>

The fact that precipitation anomalies in the central equatorial Pacific persist for periods of a year or longer and are strongly correlated with sea-surface temperature anomalies on that time scale suggests that

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THE PROGRAM PLAN

The El Nino/Southern Oscillation (ENSO) scientific program has three major components.

(1) An observational effort to:
   (a) monitor atmosphere-ocean interactions associated with the ENSO phenomenon over a period of a decade;
   (b) provide a more detailed description of a fairly representative El Nino (EN) episode spanning a 15-18 month period; and
   (c) provide detailed information concerning the processes that control the sea-surface temperature and the fluxes at the atmosphere/ocean surface.

(2) The upgrading and analysis of historical data sets that provide a partial description of the ENSO phenomenon during the past 30 years and more limited but nonetheless valuable information concerning its behavior over the past century.

(3) A modeling effort devoted to testing hypotheses concerning atmosphere-ocean interactions relevant to the ENSO phenomenon and to developing a predictive capability.

The observational effort is described from oceanographic and meteorological perspectives in the next two sections, followed by sections describing the work related to historical data sets and the modeling effort. Chapter 3 deals with management considerations: data management, relationship to existing programs, and coordination with international programs.

2.1 OBSERVATIONS: AN OCEANOGRAPHIC PERSPECTIVE

This section describes in somewhat greater detail the observations required in order to address the oceanographic questions relevant to the ENSO phenomenon. It is divided into three subsections.

2.1.1 lists the observations required for monitoring atmosphere-ocean interactions in the tropical Pacific, with emphasis on those fields that are essential for documenting oceanographic aspects of the ENSO phenomenon. The monitoring effort encompasses fluctuations on time scales ranging from weeks to years and includes as one of its objectives a more detailed determination of the climatological mean annual cycle. Major emphasis is on phenomena with large space scales, and therefore the monitoring network is thin but broad enough to encompass the entire Pacific basin. The monitoring activity is planned to extend through the full ten-year duration of the ENSO program.

2.1.2 describes a more intensive observational effort designed to be carried out in connection with one single EN event. It will commence several months before sea-surface temperature rises along the South American coast are expected to begin, and it will continue for 15-18 months. Since the special observations will be initiated with short lead time, in response to an early warning of an impending event, this component of the ENSO program is referred to as the EN Rapid Response Project.

Neither the monitoring effort nor the EN Rapid Response Project directly addresses the major gaps in existing knowledge of how the large sea-surface temperature anomalies and the associated anomalies in air-sea energy exchanges are created over a period of just a few months and sustained for a year or longer. For this purpose a set of three regional, process-oriented experiments, described in 2.1.3, will be carried out. In order to minimize competition for ships and other resources, these experiments will be carried out sequentially during the ten-year ENSO program, with little or no overlap between them. Each experiment will be designed so as to take maximum possible advantage of the background monitoring network described in 2.1.1.

There is considerable overlap between the observational requirements for the oceanographic part of the ENSO program described in this section and those for the meteorological part described in section 2.2.

2.1.1 Pacific Basin Monitoring

The objective of the Pacific Basin monitoring effort during the next decade is to describe the large scale aspects of the ENSO phenomenon in the tropical Pacific Ocean. The program must be designed to document all major large-scale changes in ocean circulation, heat storage, heat exchange, and wind forcing during the ten-year period. The monitoring program encompasses the following elements:

- The wind field, which is the driving force for the ocean circulation, will be estimated on the basis of observations from ships and islands, together with low level cloud motion vectors. A satellite-borne scatterometer would provide complete areal coverage.
- The thermal structure, which determines the heat content and the baroclinic component of the geostrophic flow, will be documented on the basis of XBT sections from ships of opportunity and research ships, and data from drifting buoys with thermistor chains.
- Sea surface topography, which is needed for documenting sea-level changes and for inferring the barotropic component of the ocean circulation, will be monitored using the existing network of sea level stations, augmented by a few additional stations in regions of special importance. An altimetric satellite would provide uniform coverage over important data-sparse regions.
- Sea surface temperature, which serves as an indicator of oceanic heat storage and is required as a lower boundary condition for atmospheric models, will be mapped on the basis of data from ships of opportunity and satellites. The collection of ship weather reports needs to be improved, and the quality of satellite-derived sea surface temperatures needs to be carefully determined.

It will be necessary to monitor winds, surface temperatures, and thermal structure in dynamically important regions not covered by shipping routes. For this purpose fixed buoys are needed in the core region of the southeast trade winds in the vicinity of 20°S, 85°W and 10°S, 105°W (see Figure 5). Since the equatorial

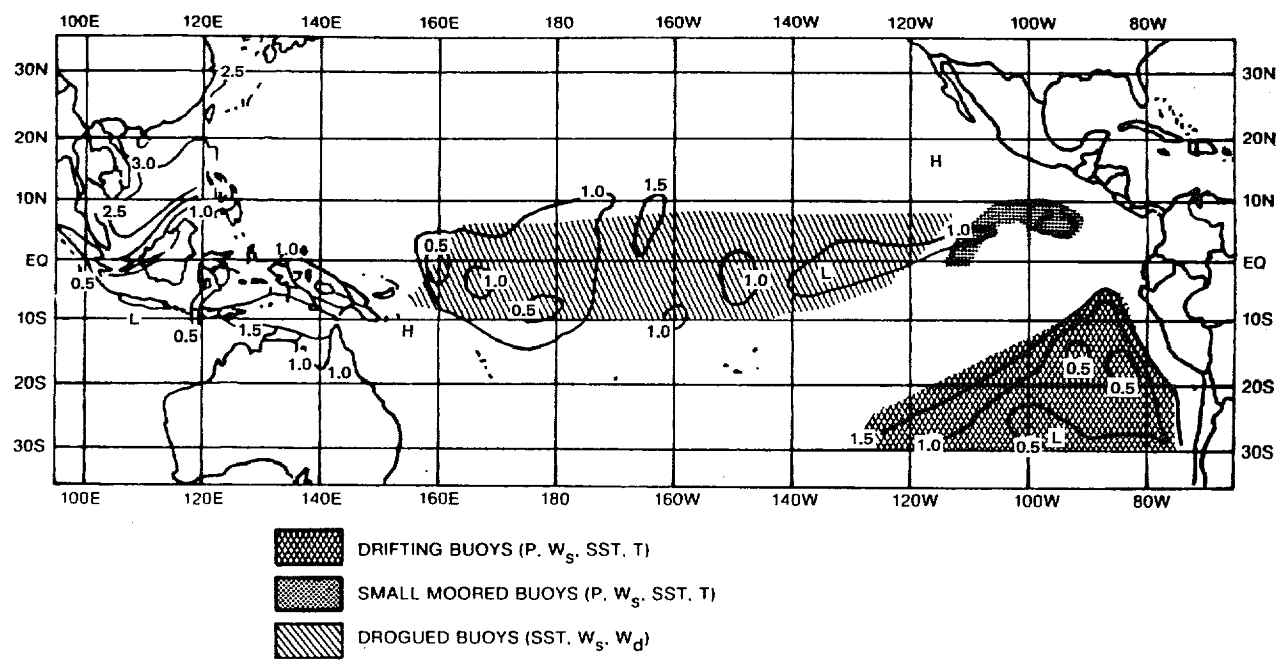

FIGURE 5. Composite map showing the density distribution of ship-of-opportunity meteorological reports (logarithmic scale) and the location of proposed buoy deployment to augment the ship reports.

undercurrent cannot be monitored by indirect methods, moorings at appropriate longitudes need to be maintained during the entire experiment to monitor this important component of the ocean circulation.

2.1.2 The El Nino Rapid Response Project

The continuing basin-wide observations listed in the previous subsection will yield data that can be used to identify the potential for the occurrence of a strong swing in the indices of the Southern Oscillation (SO) and the initiation of an EN event. A scientific team will be established to monitor and predict oceanic conditions associated with the occurrence of EN, thereby providing a basis for signaling a tentative start-up of the Rapid Response Project. The prediction methods will include both statistical and dynamical models with experimental predictions being made and verified at regular intervals. The full implementation of the project will await verification that the event has begun.

The El Nino Rapid Response Project will be instituted in two phases.

Phase I: A detailed operational plan will be developed. A preliminary plan is already in hand, but it will need to be revised based on (a) the strong, somewhat unusual 1982 EN event and (b) forthcoming information concerning the array of instruments that will actually be deployed in the Pacific-wide monitoring effort described above.

Phase II: The rapid response project will be instituted based on the forecast of an incipient El Nino event. The elements of this action can be conceptualized based on preliminary planning conducted to date. The essential observing systems that could be employed are illustrated schematically in Figure 6. They include: Current meter moorings deployed to fill in the long term current monitoring array; hydrographic cruises in key areas; aircraft flights to augment mapping the thermal structure with AXBTs. These aircraft will also be available for meteorological missions. Satellite-tracked drifting buoys would augment the current measuring arrays and the mapping of the upper ocean thermal structure.

4

COORDINATION WITH OTHER PROGRAMS

4.1 NATIONAL PROGRAMS

ENSO is visualized as a U.S. component of the recently defined international program for study of the interannual variability of the Tropical Ocean and the Global Atmosphere (TOGA), a component of the World Climate Research Program (WCRP). ENSO, as defined in this report, is focused on oceanic processes in the tropical Pacific and on atmospheric processes globally. TOGA is yet to be planned in detail. It will, however, have components that go beyond those of this ENSO plan, involving tropical ocean studies in the Atlantic and Indian Oceans. As ENSO evolves, it must be closely tied to the other components of TOGA.

ENSO can profit from cooperation with other experiments in the WCRP. Many of these programs [e.g., the World Ocean Circulation Experiment (WOCE), Cage, International Satellite Cloud Climatology Project (ISCCP)] will have need for common facilities that can be of benefit as well to ENSO and TOGA. Examples are for satellites, ocean and atmosphere monitoring systems, modeling facilities, and observational technique development. Plans for the other WCRP experiments are still being developed, so that it is premature to spell out the details of cooperation with them.

The Monsoon Climate Program (MCP) is directed at an understanding of the nature of long-period fluctuations of monsoons, the mechanisms that determine the interannual variability of monsoons, the predictability of the variations, and the relation of the long-period fluctuations to planetary-scale circulations. The close relation between Indian and Pacific Ocean phenomena within the SO argues for close cooperation between ENSO and the MCP as related parts of the WCRP.

Two regional programs in the Pacific are worth special attention in developing cooperative plans for ENSO. These are the western Pacific (WESTPAC) program in the western Pacific and the Estudio Regionale del Fenomino El Nino (ERFEN) program in the eastern Pacific.

WESTPAC is an international scientific program involving the countries on the western rim of the Pacific (and the United States). One of the programs being sponsored by WESTPAC is the improvement of the data coverage on heat content currents and sea level in a large area of the western Pacific. This involves the encouragement of member countries to contribute observing platforms and sensors. A number of countries have already established networks and more are planned. The Japanese Hydrographic Office has been designated as the repository for the data. This data base is of great potential value to the ENSO studies of the ocean. Exchange of data between ENSO and WESTPAC will be of great benefit.

Four countries on the west coast of South America began in 1974 to cooperate in the international program, ERFEN. Under the auspices of the Commission Permanente del Pacifico Sur (CPPS), the Intergovernmental Oceanographic Commission (IOC), and the World Meteorological Office (WMO), this program provides a mechanism for coordination of marine research activities, upgrading of operations in support of meteorological services, sharing of data, and identifying training and technical needs. The long-range objectives of ERFEN reflect exactly the regional manifestation of ENSO. Close cooperation with scientific agencies in Peru and Ecuador have already been initiated within the EPOCS program, and will be increased for mutual benefit.

4.2 INTERNATIONAL PROGRAMS

The phenomena to which ENSO is addressed are inherently global. The SO has world-wide oceanic and atmospheric manifestations. Tropical sea-surface temperature anomalies correlate with variations in the intensity of Indian monsoon rainfall, with droughts in India and China, and with cold winters in North America. The study of such global phenomena must be done internationally.

The United States needs the participation of other countries in the study of the SO. This participation should occur at many levels and for many components of the research work. The program elements on which ENSO is based are already international.

Just as the benefits of programs in prediction of the ENSO phenomena will accrue to individuals of all nations, so do the logistics and economics of systematic large-scale monitoring of the ocean and the atmosphere mandate that it must be undertaken as an international enterprise. Several nations have already initiated or participate in activities that contribute strongly to the ENSO program. Among these may be noted the activities of the WWW and the Integrated Global Ocean Station System (IGOSS), which provide regular sampling of the global atmosphere and some oceanographic data. Oceanographic monitoring activities are generally less well institutionalized. The principal oceanographic monitoring activities are done by means of the international sea-level network, and programs primarily of the United States and France for regular collection of data from ships of opportunity, using merchant vessels of many countries.

Modeling and theoretical studies carried out in other countries have played an important role in providing a scientific basis for ENSO. Continued international cooperation will be needed in modeling for optimum progress. As an example of the type of activity that should be strongly supported by ENSO, there are the cooperative SST sensitivity experiments being carried out with atmospheric general circulation models. This activity is sponsored by the Working Group for Numerical Experimentation of the WCRP. The SST sensitivity experiments are intended to pinpoint those areas in the ocean where SST anomalies have the greatest effect on the large-scale atmospheric flow. At present six nations are participating in this international undertaking, committing a formidable array of modeling experience and computer resources to this cooperative activity.

Several special sampling and research programs that will be of particular value to ENSO have already been initiated by other countries. An outstanding data set along 137°E in the western Pacific exists as a result of a monitoring program initiated by Japan in 1967. In the southwestern Pacific, similar monitoring was carried out by France between 1965 and 1973 along 170°E and will be reactivated in 1984. On the eastern side of the basin, Peru, in view of the great value of the coastal fisheries and the economic impact of varying environmental conditions, of which the major manifestation is EN, has endeavored to sustain a research program on the EN. Likewise, Equador is planning quarterly cruises in the region between South America and the Galapagos Islands in support of research on EN.

Basic measurements, such as sea-level and temperature data, will continue to be of great value in the ENSO research program, and can be collected by many nations, including developing countries. For example, much of the quantitative historical information on the ENSO phenomena derives from many years of collecting data at coastal stations by Peruvian scientists. Implementation of these observations will usually require some technical assistance and training, and can be used to help realize scientific aspirations in these countries. As these aspirations develop, it will become possible to have the programs evolve from simple surface sampling to more general oceanographic observations using regional vessels of opportunity. For example, sea-level data from the Indonesian archipelago would be of great value to ENSO in relating Indian Ocean and western Pacific phenomena. Because oceanographic programs are less well institutionalized than meteorological programs in most of these countries, mechanisms must be developed to facilitate their commitment to the international effort.

U. S. participation in the WCRP should be coordinated through the Joint Scientific Committee (JSC) for the WCRP and the Committee on Climatic Changes and the Ocean (CCCO). The JSC/CCCO are developing the international plans for studies of the interannual variability of the TOGA. ENSO, as a principal U.S. contribution to TOGA, will likely influence its planning.