EPOCS

EQUATORIAL PACIFIC OCEAN CLIMATE STUDIES

A PROGRAM PLAN FOR INVESTIGATING THE OCEAN'S ROLE IN CLIMATE

JUNE 1977

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EXECUTIVE SUMMARY

This document contains the rationale and a recommended plan for a new NOAA research program to investigate the ocean's role in influencing interannual climate fluctuations. Initially, this program, entitled Equatorial Pacific Ocean Climate Studies (EPOCS), will focus on the large sea surface temperature anomalies in the equatorial Pacific Ocean. It is hypothesized that these anomalies significantly alter the geographic pattern of heat input to the tropical atmosphere, the related mid-latitude circulation, and the year-to-year climate fluctuations in the United States.

The long-term research goal of the EPOCS program is to obtain the requisite knowledge of the underlying physcial and thermodynamic processes in the equatorial Pacific so that we may anticipate, plan for, and eventually alleviate the adverse social and economic impacts of short-term climatic variations.

To achieve the objectives of EPOCS, the program will be carried out through three primary research components: (1) empirical studies, (2) a major field experiment, to be conducted in an area of the central equatorial Pacific bounded by 20°N, 20°S, 120°W, and 150°W, and (3) modeling and analysis activities.

Measurements and observations in the region of the field experiment will be made using vertical mooring arrays, drifting buoys, current profilers, NOAA vessels and ships-of-opportunity, satellites, and NOAA research aircraft.

Program planning by NOAA scientists is being closely coordinated with related national and international research projects in order to benefit from the complementary atmospheric and oceanographic data sets that will be available from these other activities. For this reason, the deployment of the EPOCS field experiment is scheduled simultaneously with the Global Weather Experiment (formerly FGGE) standard observation periods in early 1979.

Base resources are currently being utilized to the maximum extent possible in preparation for this climate research effort. However, these personnel and financial resources must be supplemented by ten persons and an estimated annual expenditure of $2,820,000 in order to achieve the objectives of the EPOCS program.

The EPOCS program is a sharply-focused research activity in which resources are concentrated on investigating the most influential recurring ocean thermal fluctuations and their interactions with the atmosphere. Because EPOCS is designed as a distinct, manageable, and tractable program, it can be expected to make important, and relatively immediate contributions toward meeting the goals of understanding and predicting interannual climate fluctuations.

INTRODUCTION

NOAA proposes to initiate a research program to investigate the ocean's role in year-to-year climate fluctuations. The central importance of the ocean is based on: (1) its enormous capacity to store and transport thermal energy and (2) the influence of its surface temperature in regulating the behavior of the atmosphere. Variability in ocean thermal patterns appears to be a major factor in producing year-to-year climate fluctuations. This program will concentrate on understanding and predicting interannual climate fluctuations due to their serious economic and social impacts.

In this program plan, research efforts have been applied to those areas most likely to yield the earliest practical results. The mutual influence of the ocean and atmosphere is largest in the equatorial region. Due to the magnitude and variability of the physical processes in this region, it affords the best scientific opportunity to identify and understand the principal cause and effect relationships.

Initially this program will focus on the large thermal anomalies in the equatorial Pacific Ocean. The type of sea surface temperature fluctuations which occur in this region are illustrated in Figure 1. Interannual fluctuations of $6^{o}F$ to $10^{o}F$ extending over thousands of kilometers are not uncommon. It is hypothesized that these anomalies significantly alter the geographical pattern of heat input to the tropical atmosphere, the related mid-latitude circulation, and year-to-year climate fluctuations in the United States. The reasons for their occurrences are not understood. The central purpose of this research program is to investigate the complicated equatorial ocean current system, including its driving forces and interactions with the large scale atmospheric circulation, and attempt to discover precursors that have predictive value for climate.

The selection of this research approach is based in large part on previous empirical and numerical simulation studies, such as those conducted by Rowntree, Julian, and Chervin, which show that ocean surface temperature anomalies in the equatorial regions have a pronounced effect on atmospheric circulation in the high and low latitudes. These and other studies provide strong evidence of long term "lags" between atmospheric and oceanic indices which can signal the advent of climatic fluctuations through the use of empirical and numerical models for climate prediction.

A striking example of the economic impact on the United States that these seemingly remote equatorial thermal anomalies can have is illustrated in Figure 2. The waters along the coast of

Figure 1. Sea Surface Temperature Anomalies in the Equatorial Pacific 1971-73

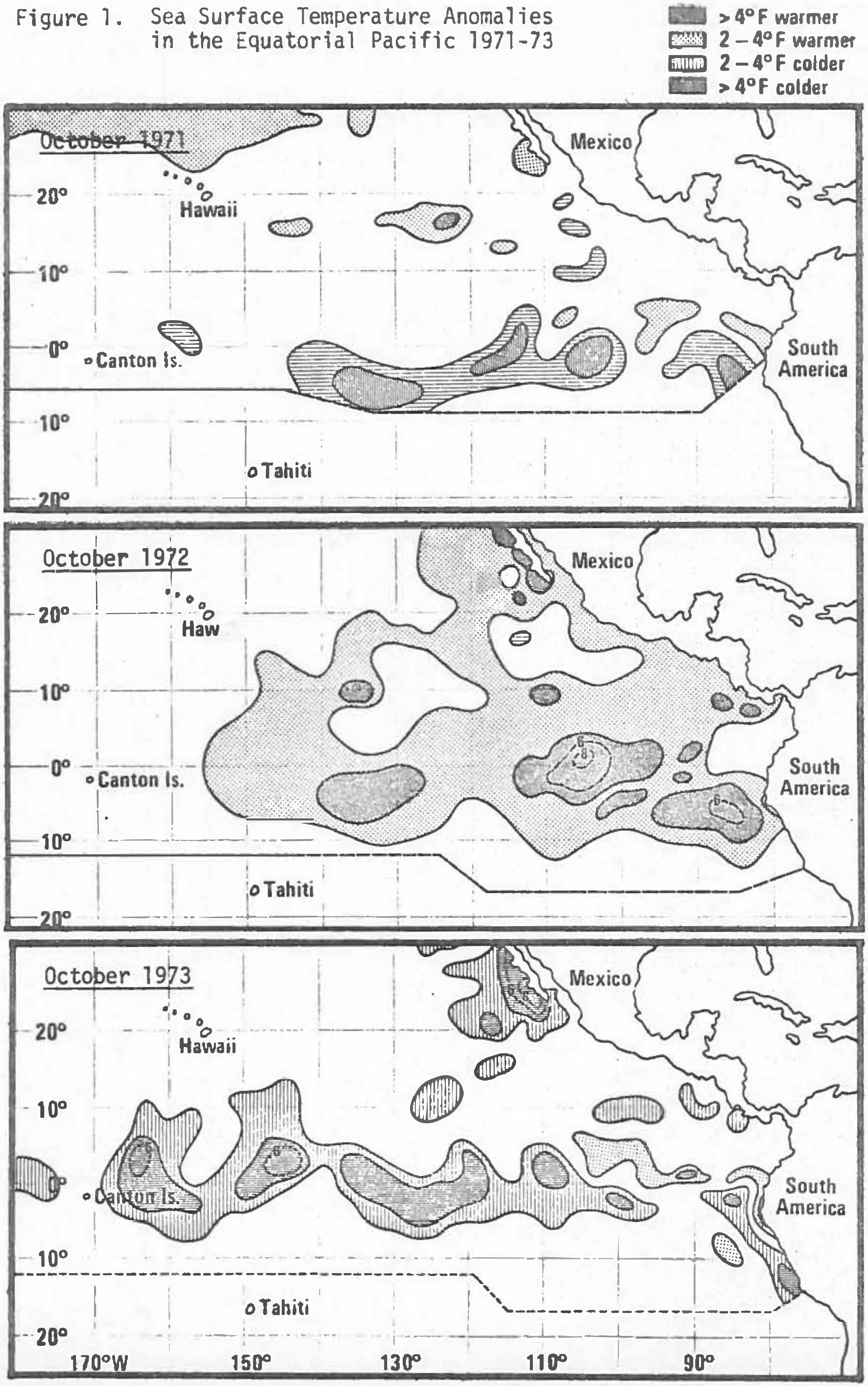
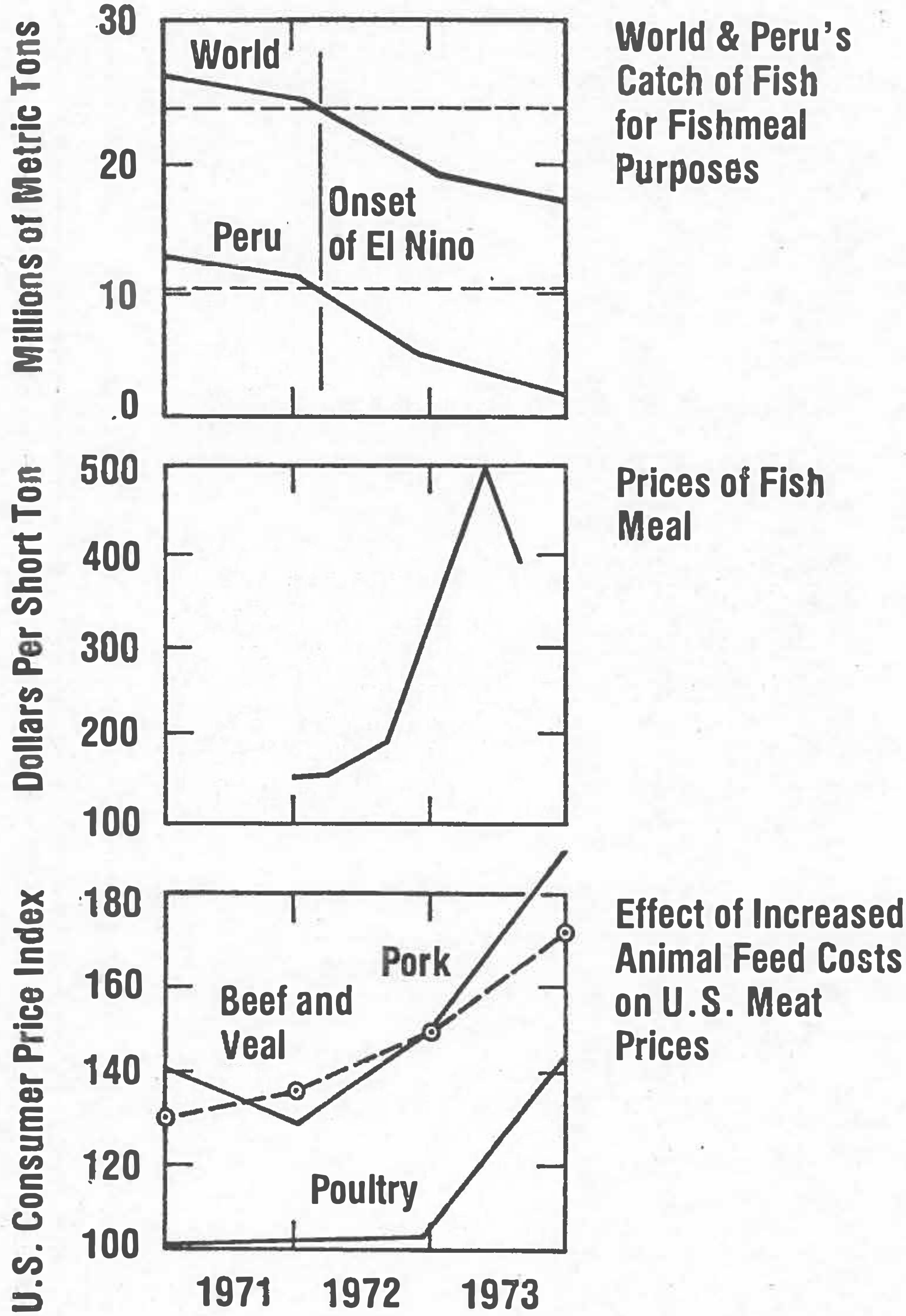


Figure 2. Impact of El Nino on U.S. Meat Prices



Peru are normally cold because they have been drawn up from depths by upwelling. Upwelling brings nutrients from the bottom to the surface where sunlight and oxygen can promote ecosystem growth. An end product of the marine food chain in these waters is the anchovy which is ground into fish meal and is used as animal food. In Europe, livestock thrives on its high protein value and here in the United States it is the mainstay of our poultry industry. Every few years, the Peruvians observe a phenomenon they call "El Nino" from the fact that it first appears, like the Christ Child, at Christmas. With the start of El Nino, the coastal waters warm up, causing the food chain to go dormant and the anchovies to starve and die. This drives the price of fish meal up and also sends parallel waves in the supply and price of substitute feed grains, such as soybeans. As shown in the figure, the jump in meat prices in 1973 can be related to the failure of the Peruvian anchovy harvest and in turn to thermal anomalies in the eastern Equatorial Pacific.

NOAA proposes to carry out this program, entitled Equatorial Pacific Ocean Climate Studies (EPOCS), through three major research activities: empirical studies; field experiments; and modeling and analysis studies.

Empirical studies will be conducted to identify significant meteorological and oceanic variations having interannual and decadal time scales, geographic coherency, apparent telecommunications, and other potentially predictive relationships. These studies depend on large volumes of data gathered over extended periods of time. The data base utilized in this activity will consist of over 50 million observations of sea surface temperature, wind, and air temperature collected by merchant ships over the past one hundred years.

In the first year of the EPOCS program, a major field experiment will be initiated in the equatorial Pacific to gain better data and knowledge of the substantial energy transfer processes operating in this region. The magnitudes and rates of these transfer processes are related to various phenomena such as the periodic fluctuation and meandering of the equatorial currents, the downward dissipation of momentum and thermal energy by means of vertical propagating waves, frictional losses due to current shear, and convective transport due to upwelling. Measurements and observations in the area 20^{o}N to 20^{o}S and 120^{o}W to 150^{o}W will be made using vertical mooring arrays, drifting buoys, current profilers, NOAA vessels and ships-of-opportunity, satellites, and aircraft from NOAA's Research Facilities Center.

Vertical arrays of instruments will be moored in the main ocean currents in the area of the experiment in order to measure the long term variations of temperature and currents as a function of depth. These moored buoys will also have the capability of recording surface meteorological data.

A series of free buoys with drogues will be set adrift in the EPOCS region to track the eastward flow of the equatorial countercurrent while also recording water temperature and meteorological variables along their route.

The NOAA ships that deploy the moored and drifting instruments will also be used to measure subsurface temperature and salinity with STD casts and vertical current shear with profiling current meters. Water samples for geochemical tracer studies will also be taken as a means of obtaining estimates of relatively slow, but significant, convective upwelling processes.

An ongoing ship-of-opportunity program will be utilized to obtain subsurface temperature sections at various points across the equator using expendable bathythermographs (XBT's). As the spatial and temporal frequencies of these XBT measurements depend, of necessity, on merchant ship routes and schedules, they will be augmented by XBT's launched at predetermined intervals (and otherwise inaccessible locations) by NOAA research aircraft. These aircraft are also equipped to measure the exchange of heat, moisture, and momentum between the atmosphere and the ocean.

Satellites, such as the Geostationary Operational Environmental Satellite (GOES), will be used to obtain large area surface wind, sea surface temperature, and rainfall estimates. The importance of obtaining dependable estimates of surface wind stress has long been recognized as requisite to the general understanding of the air-sea momentum transfer process, and in particular, to the proper interpretation of ocean current measurements, and sea level (dynamic topography) variations. Surface wind estimates derived from satellite cloud motion vectors in conjunction with ground truth data from routine marine observations will be used to compute surface wind stress fields, wind stress curl, and time series of these parameters.

Recent sea surface temperature measurements by satellite have raised the possibility that such measurements could be used to monitor the intensity of the oceanic currents. The satellite photographs clearly show long westward propagating waves along the temperature front between the westward south equatorial current and the warmer eastward equatorial countercurrent. The waves are believed to be due to an instability caused by the large shear between these currents. If this proposition is true, then the characteristic period and wavelength of the waves must be related to the intensity of the currents.

As most of the heat input to the atmosphere is heat of condensation from rainfall, variations in the distribution and intensity of tropical rainfall are important elements in understanding mid-latitude climatic responses. Recent technological advances have been made by NOAA in estimating rainfall from satellites. This method, which utilizes digitized geosynchronous satellite imagery, will be used to estimate tropical Pacific rainfall during the EPOCS field experiment.

In addition to the empirical studies and field experiment described above, modeling and analysis activities will be undertaken during the EPOCS program to assist in synthesizing and integrating the results obtained in the other aspects of the program. The specific purposes of the modeling and analysis activities are: (1) to incorporate the new data sets and parameterization techniques into existing ocean-atmosphere numerical models; (2) to improve understanding of the important physical processes and their interrelationships that operate in the equatorial region; and (3) to develop new boundary layer models particular to this regime.

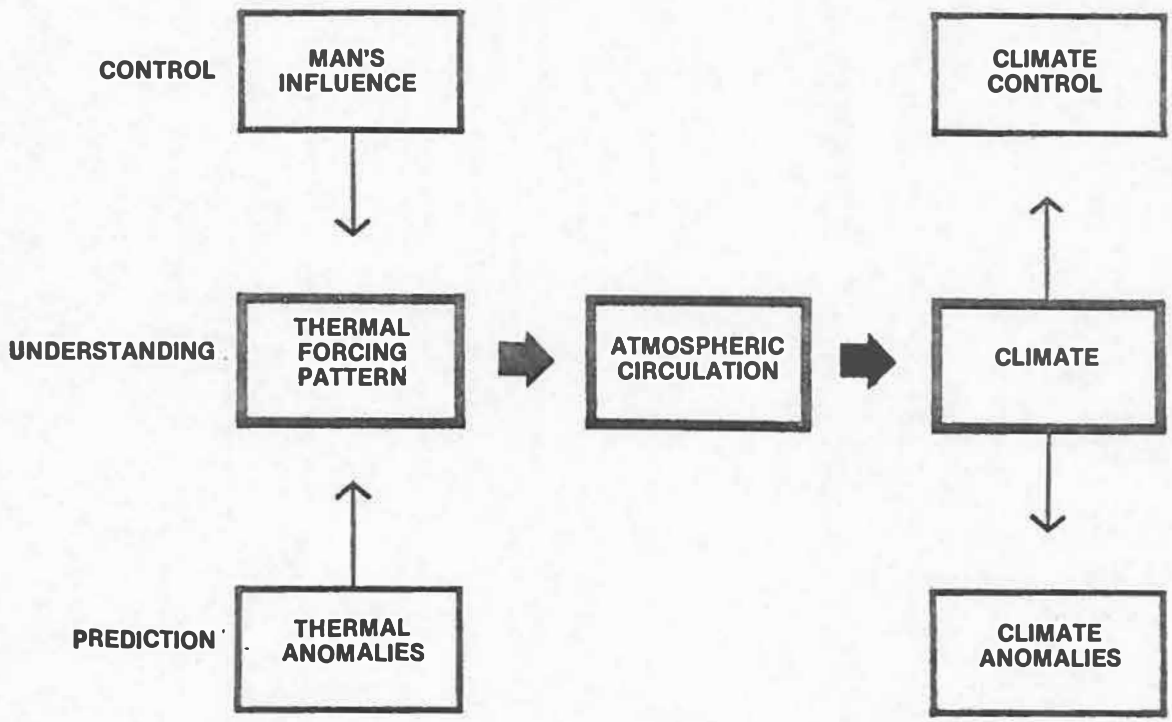
EPOCS is a multi-year, level-funded program. The funds used in the first year to purchase equipment, such as buoys and current profilers, and the logistic expenses of the field program will be required in subsequent years to meet the maintenance and operation costs of the equipment and to augment the program's empirical studies and modeling and analysis activities.

NOAA scientists are working presently with the Scientific Committee on Oceanographic Research (SCOR) in planning field experiments in adjacent areas of the Pacific, e.g., the Global Weather Experiment (previously FGGE) and the North Pacific Experiment (NORPAX). These projects will provide substantial benefits to the EPOCS experiment in the form of complementary atmospheric and oceanographic data sets. However, these benefits will be realized only if EPOCS can be conducted within the same time frame. To take maximum advantage of these related climate programs, the EPOCS measurement systems should be deployed simultaneously with the Global Weather Experiments standard observation periods in early 1979.

Our most fundamental needs--food and water--are climate dependent. The hardships imposed on millions of the world's population as a result of recurrent droughts, floods, and temperature extremes are a matter of record. The EPOCS program is a sharply-focused research activity in which resources are concentrated on investigating the most influential recurring ocean thermal fluctuations and their interaction with the atmosphere. Because EPOCS is designed as a distinct, manageable, tractable experiment, it can be expected to produce important, and relatively immediate, contributions toward meeting the goals of understanding and predicting interannual climate fluctuations.

As illustrated in Figure 3, only when the requisite knowledge of the underlying physical processes is obtained may we eventually anticipate, plan for, and therefore alleviate the adverse effects of climate variations.

Figure 3. Climate Understanding as a Prerequisite for Prediction and Eventual Control



SCIENTIFIC BACKGROUND

The climate of the earth depends on the energy input from the sun and subsequent redistribution of this energy by the circulation of the atmospheric and oceanic fluids. The interactions of these fluids with one another as well as with the earth's land masses and cryosphere are the dynamic processes which determine global and regional climate.

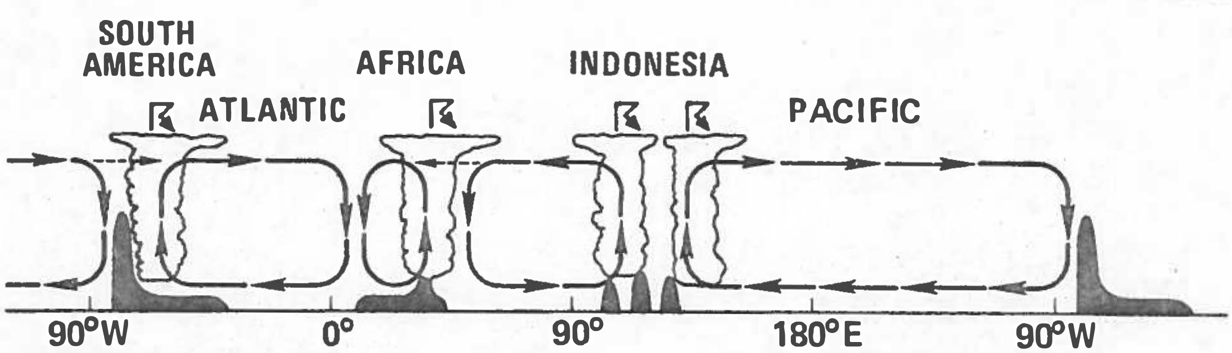
The atmosphere is more volatile than the ocean, possessing about 25 times more kinetic energy. However, the ocean plays the role of the strong, but more slowly acting, partner in the ocean-atmosphere interactive relationship. As shown in the following table, the ocean has many times the momentum, mass, and heat capacity of the atmosphere.

Table 1: Ratio of Ocean to Atmosphere Physical Attributes

Kinetic Energy	1 : 25
Momentum	4 : 1
Mass	400 : 1
Heat Capacity	1,600 : 1

Most of the heat input to the atmosphere comes as heat of condensation from rainfall. Variations in the distribution and intensity of tropical rainfall are believed to be a large "climatic signal" associated with year-to-year climate fluctuations over the globe. Figure 4 is an idealized sketch of zonal circulation, and the associated rainfall distribution, along the equator.

Figure 4: Zonal Circulation Along the Equator



It shows three intense heat input regions: the Amazon Basin, where the Andes wring out the moisture from the easterly trade winds; the African continent, where the pattern is also anchored to the land mass; and the Indonesian-Western Pacific region, which is the strongest of these three heavy rainfall regions. This latter region is not anchored by topography and is subject to being displaced by changing ocean surface temperatures. These changing patterns of ocean temperature and rainfall in the equatorial Pacific may be the most variable, influential feature of the general atmosphere circulation on the year-to-year time scale.

In the idealized circulation depicted in Figure 4, easterly trade winds over the equatorial Pacific cause upwelling at the equator. This upwelling maintains a cold water tongue over the eastern equatorial Pacific, which in turn causes cooling and subsidence of the atmosphere, thus reinforcing the trade winds--a positive feedback loop. When the trade winds falter, as they do every few years, this positive feedback loop also reinforces the faltering tendency.

To illustrate how dramatically this system changes, Figures 5 and 6 show the deviation from the long-term mean of sea surface temperature in successive Octobers from 1971 to 1976. As indicated by the legend to these figures, shaded areas represent temperatures at least 2°F warmer than normal and cross-hatched areas are 2°F or more colder than normal. Therefore, there is at least 4°F difference between the shaded and cross-hatched areas.

In October 1971 the subtropical atmospheric high pressure cells were stable, the easterly trade winds were strong and steady, and the ocean surface temperature was about 4°F colder than normal over about one-third of the earth's circumference. One year later, in October 1972, ocean temperatures were about 8°F warmer over 6,000 miles. This was the year of the collapse of the Peruvian anchovy harvest, the soybean embargo, the Soviet crop failure, and escalating grocery bills.

By October 1973, the system had recovered with a cold equatorial ocean down 8°F from the previous year. In Octobers 1974 and 1975 the equatorial Pacific Ocean was still cold.

In October 1976, however, a major warming pattern was evident. It began in May in the eastern Pacific, spread westward along the equator and reached a maximum size and intensity in November. It was still strong in the central Pacific during December and January. As can be seen in these figures, the thermal pattern in 1976 was substantially different from that of 1972, a demonstration that anomalous years are not all alike.

To illustrate the way in which warm ocean anomalies influence rainfall, Figure 7 (from Bjerknes) shows sea surface temperature, surface air temperature, and rainfall at Canton Island (near the equator at 170°W) from 1956 to 1967. As shown, when the sea surface temperature

Figure 5. Sea Surface Temperature Anomalies in the Equatorial Pacific 1971-73

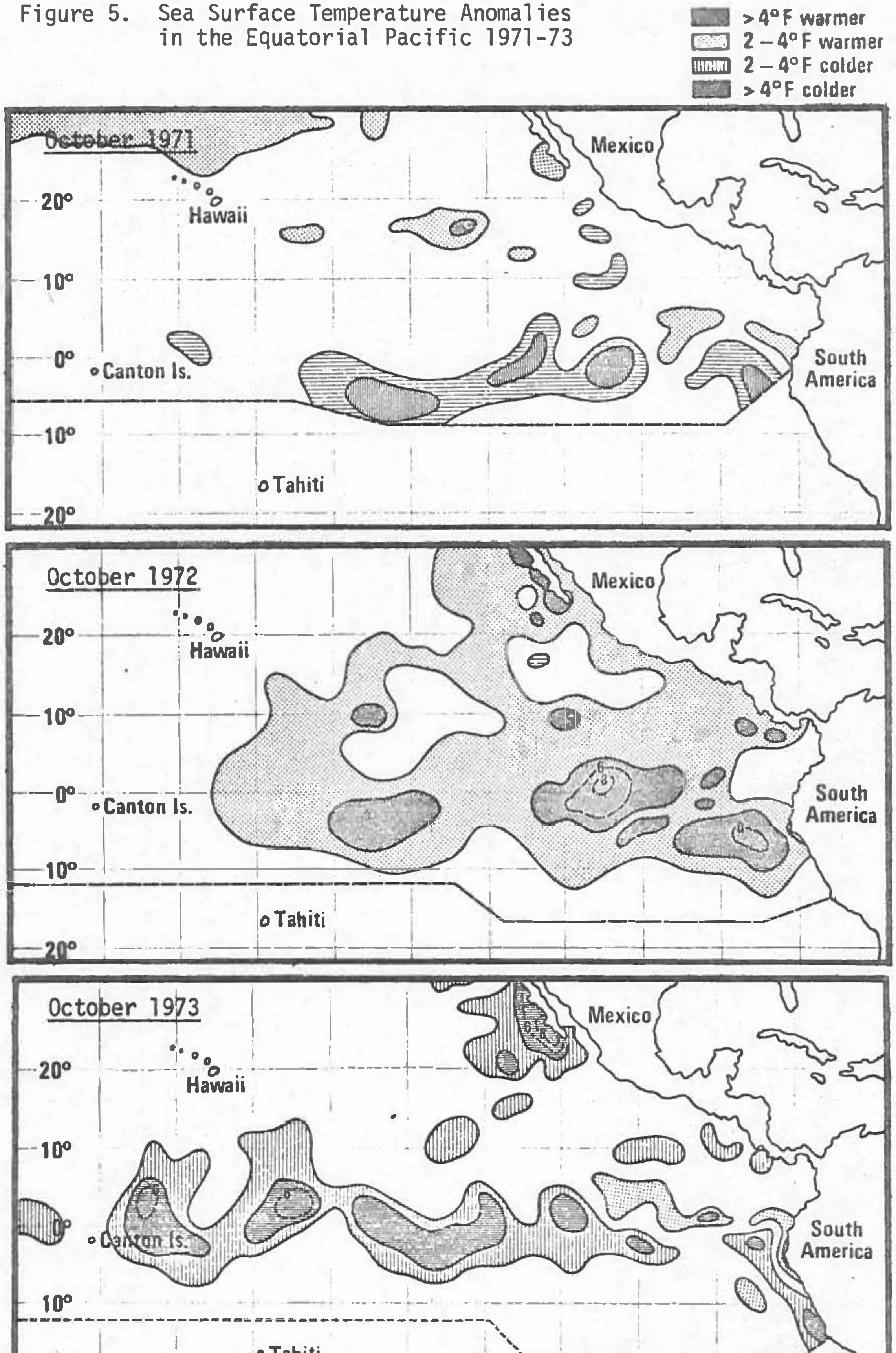


Figure 6. Sea Surface Temperature Anomalies in the Equatorial Pacific 1974-76

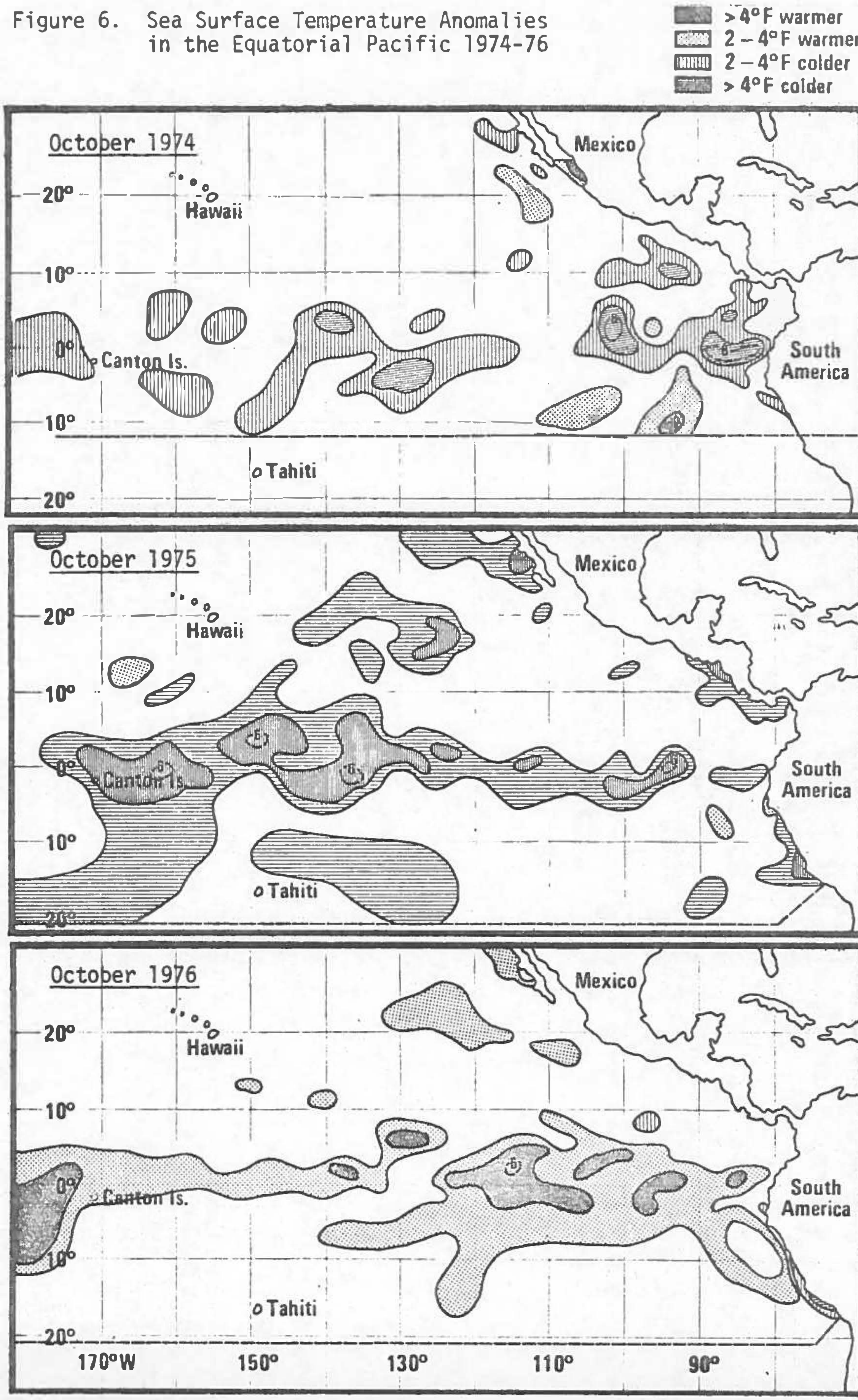
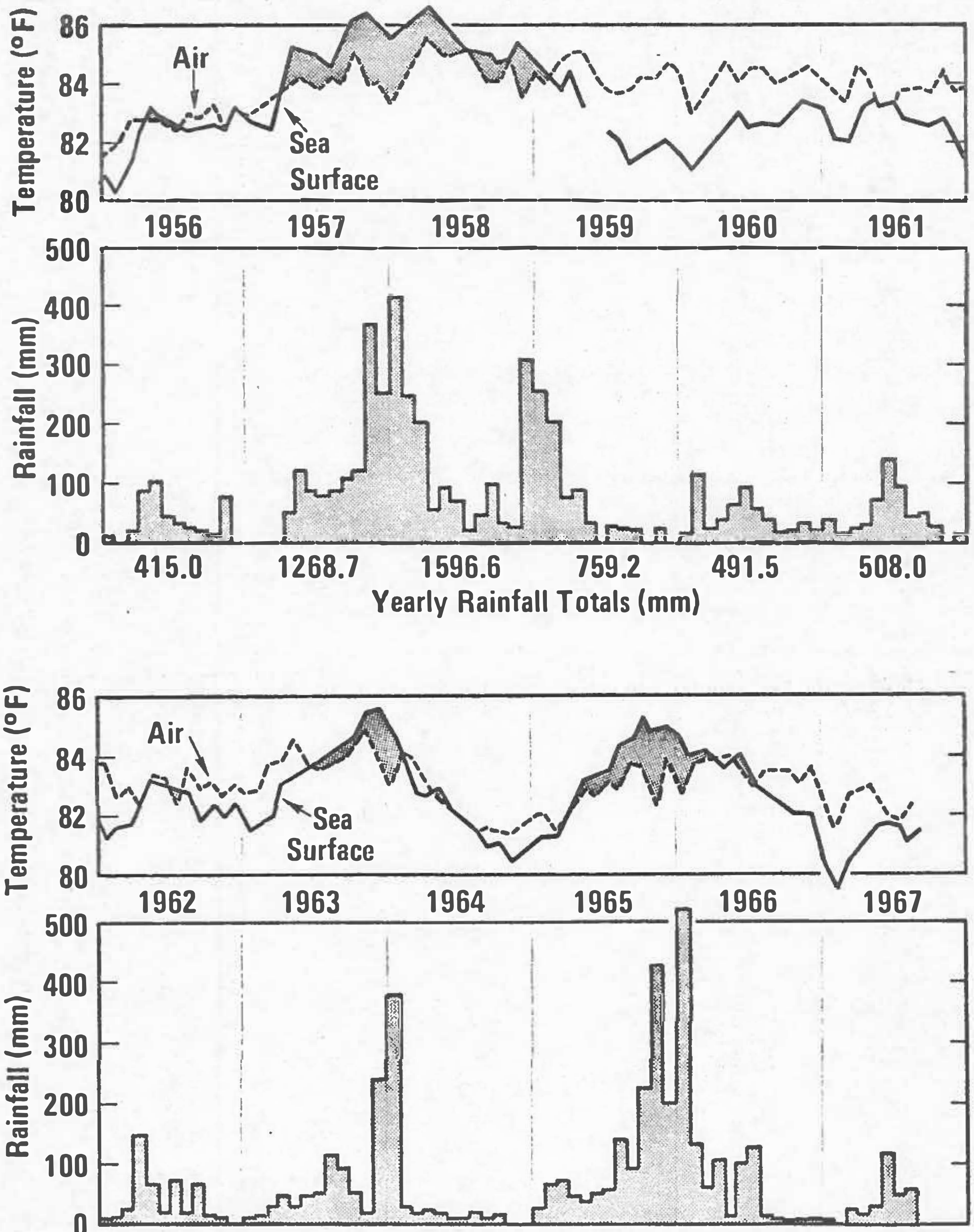


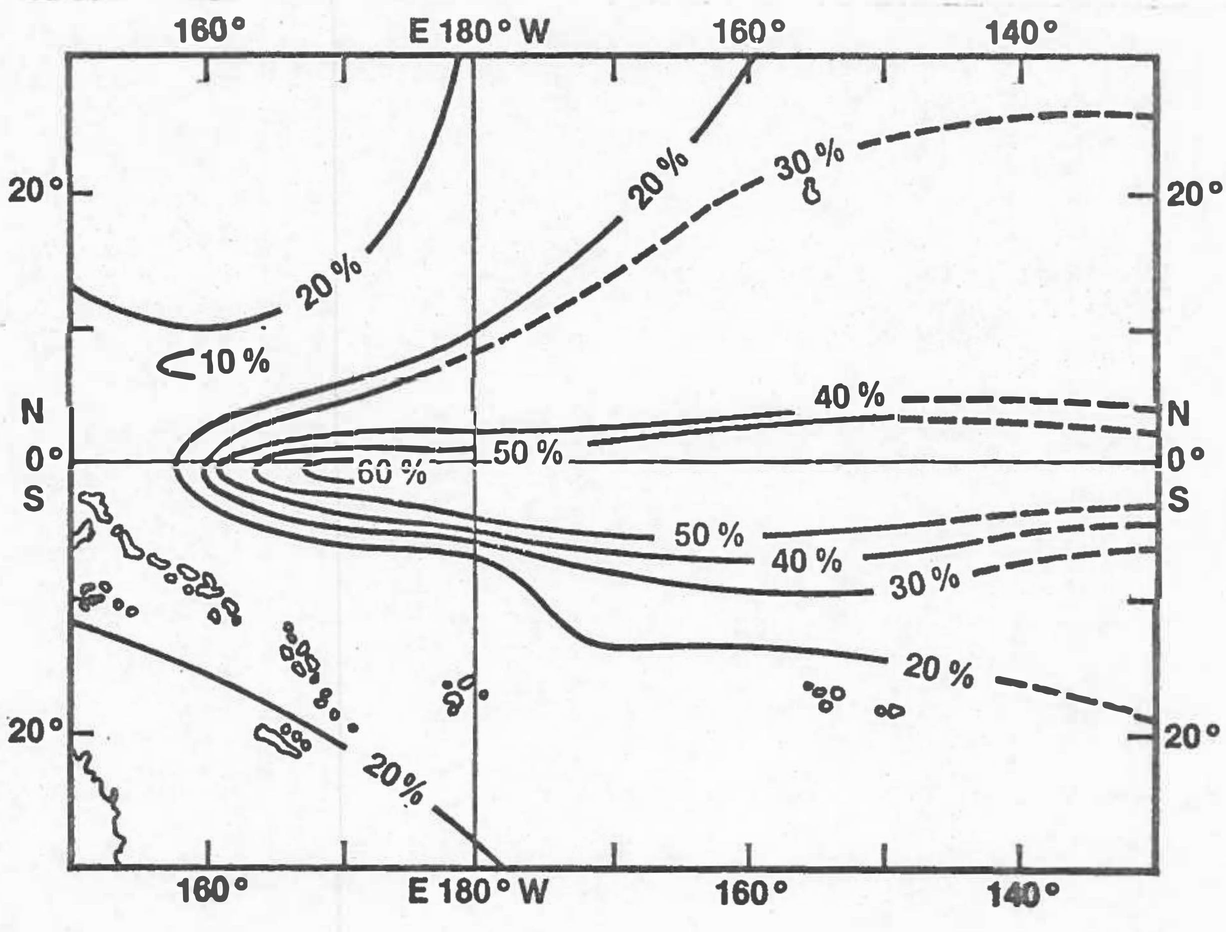
Figure 7. Rainfall Correlated with Air and Sea Surface Temperatures at Canton Island (1956-1967)



was warmer than the surface air temperature it destabilized the air column and brought a dramatic rise in rainfall. This happened in 1957, 1963, and 1965.

In summary, where the sea surface temperature is highly variable, rainfall and heat input to the tropical atmosphere is highly variable. Figure 8 compiled from rainfall observations over many years, shows high variability over the whole equatorial Pacific with the highest variability in the western part (where the rainfall amount is also higher).

Figure 8. Rainfall Variability (i.e. Standard Deviation/Mean) in the Pacific Ocean (1951-1960)



Bjerknes associated these ocean temperature anomalies with variations in the intensity and position of the subtropical high pressure centers, especially the southern hemisphere center west of South America that furnishes the easterly trade winds over most of the equatorial Pacific.

Wyrtki has mapped these wind stress fields for several years and believes that another important factor is internal ocean dynamics. Figure 9 illustrates the major oceanographic surface currents of the world, where the length of the arrows is proportional to the mean speed of the current. Shown in the equatorial Pacific are the strong, westward flowing, north and south equatorial currents, as well as the eastward flowing countercurrent just north of the equator.

Figure 9. Global Ocean Surface Currents

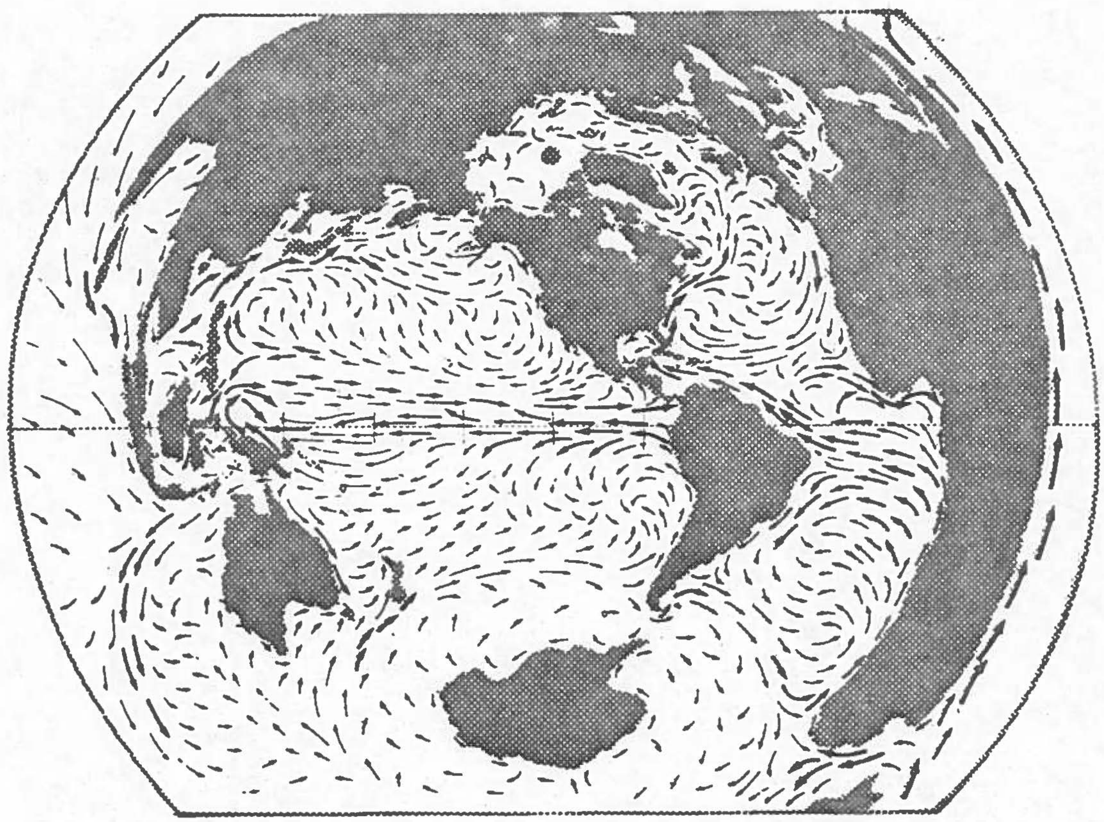
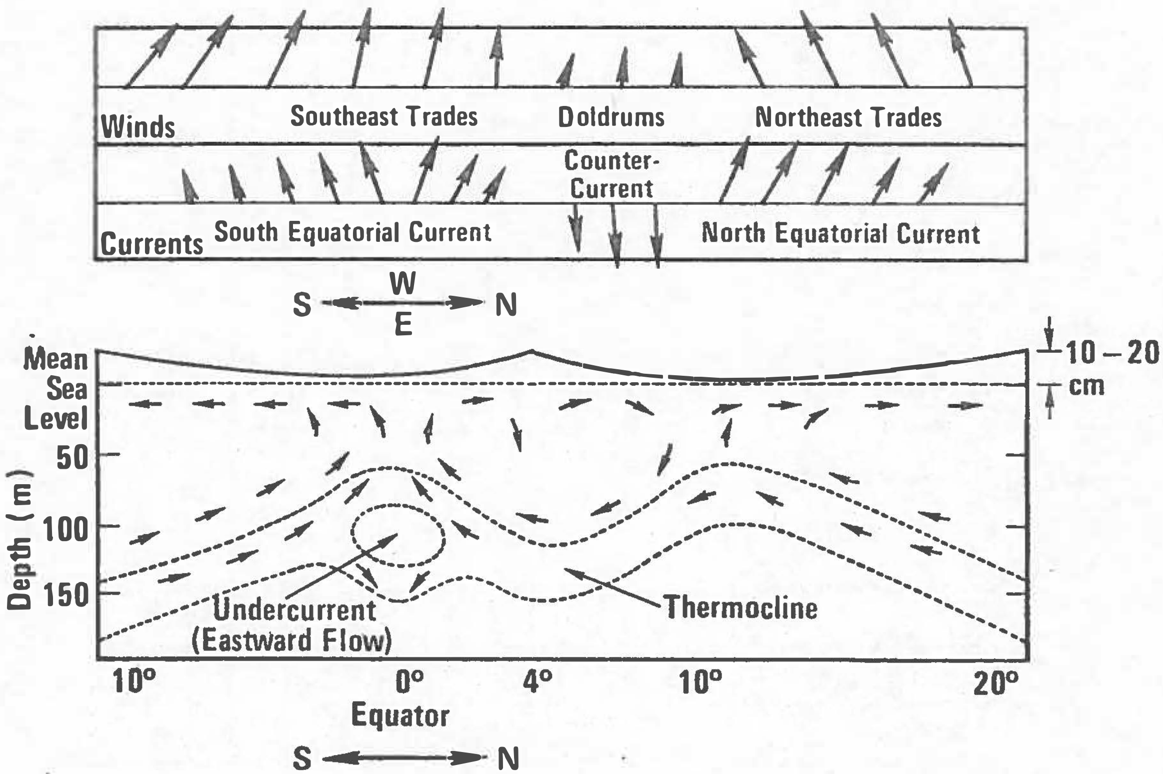


Figure 10 is an idealized cross-section of the equatorial Pacific from $10^{o}S$ to $20^{o}N$. The wind stress is shown as the top layer in this diagram. The westward flowing equatorial currents are shown as the next layer. Also illustrated are the tilt of the ocean surface, the equatorial countercurrent, the equatorial undercurrent beneath the equator, and the location of the thermocline.

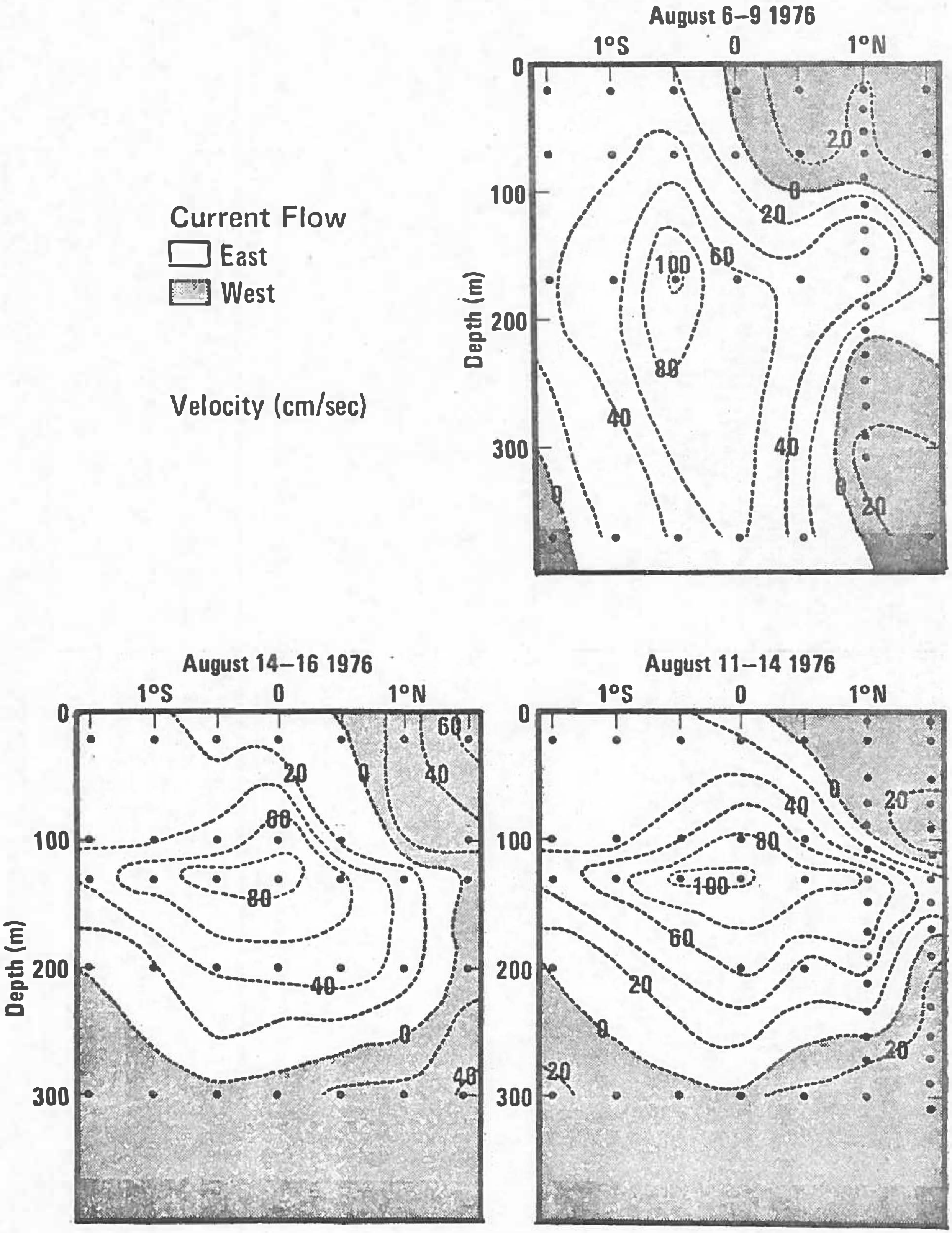
Figure 10. Pacific Equatorial Cross-Section



An example of the shape, strength, and variability of the equatorial undercurrent may be seen in Figure 11. The measurements from which these cross-sections were drawn were taken during a pilot experiment conducted in August 1976. In this experiment (which was piggy-backed on a Deep Ocean Mining Environmental Study cruise using NOAA's Oceanographer) two buoys were moored along 150°W--one at the equator and one at 8°N--for 36 days. Also four drifter buoys were deployed which revealed long waves in the boundary between currents.

Fluctuations in the eastward transport of the warm equatorial countercurrent and the cold equatorial undercurrent are believed to be responses to the accumulation in the western Pacific of warm water from several years of strong trade winds. It is suspected that as the wind stress falters this water comes surging back eastward, further weakening the trade winds by reducing the atmospheric subsidence over the equator.

Figure 11. Equatorial Undercurrent Along 150^{O}W During August 6-16, 1976



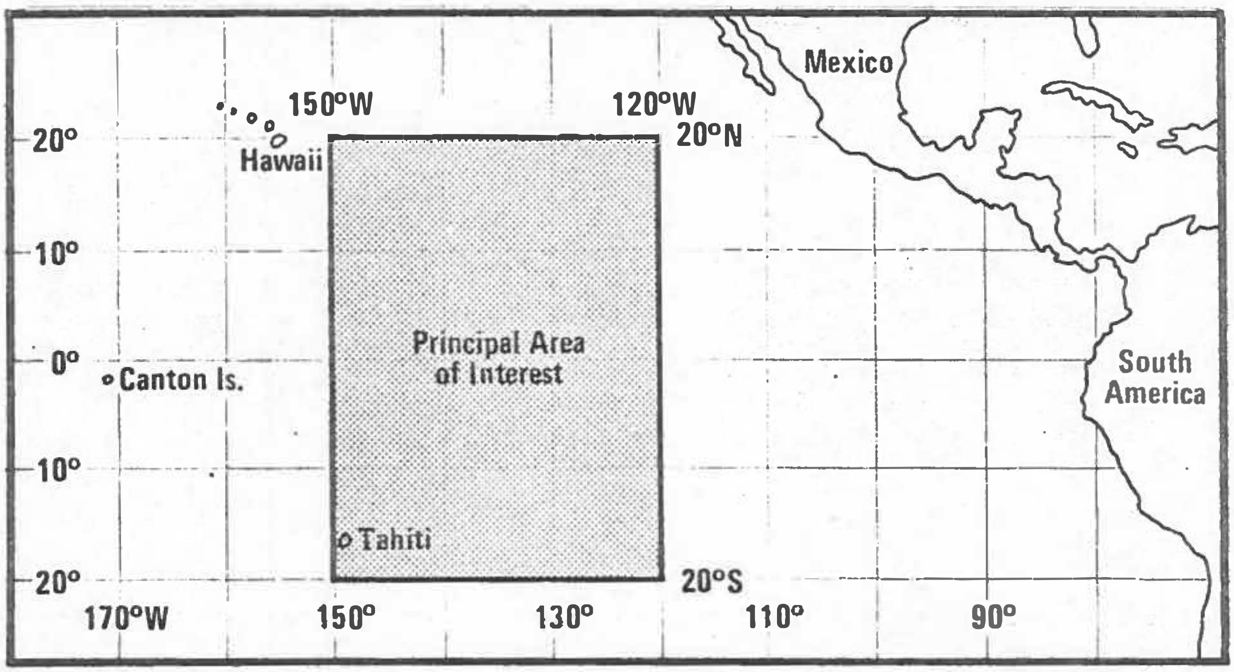
Current speeds are on the order of one to two knots (i.e. approximately 1500 kilometers per month), so a typical response time is about one-half year. Data from ocean pressure gauges in the central Pacific provide evidence in support of this theory.

PROGRAM PLAN

THE CENTRAL EQUATORIAL PACIFIC

NOAA proposes to focus the major part of its oceanographic climate research efforts on the central equatorial Pacific in an area bounded by 20°N, 20°S, 120°W, and 150°W as shown in Figure 12.

Figure 12. EPOCS Region of Study.



As discussed in the preceding section, this is a region in which there is a large variability of ocean thermal structure and dynamics. The decision to concentrate limited research resources on the central equatorial Pacific is based in part on the following considerations.

- Previous studies have shown a correlation between ocean dynamics in this area and severe climatic events. For example, numerical experiments performed by Rowntree (1970), Julian (1976), and others have shown that sea surface temperature anomalies in low latitudes have substantial effects on the atmospheric circulation in the mid-latitudes. A program designed to give a better understanding of the processes that affect these anomalies will clearly contribute to the development of coupled ocean-atmosphere models.

- The mixed layer near the ocean surface plays a crucial role in the transfer of heat and momentum at the air-sea interface. There are two reasons why this mixed layer is of special interest in low latitudes: (1) this is where the atmosphere gains its heat and water vapor from the ocean; and (2) the physics of the mixed layer is unique in low latitudes because advection, mixing, and upwelling are all influential processes.

- Equatorial upwelling is not only one of the most important processes impacting the sea surface temperature in the low latitudes, but due to its associated vertical transport of nutrients, it is of considerable interest to marine biologists and a sizeable portion of the world's fishing industry.

- The equatorial Pacific in the vicinity of 150°W is the principal spawning area for skipjack tuna which migrate to the eastern Pacific from one year to one and a half years later. It would be useful to understand the effect of equatorial ocean currents on the migration of this important commercial species.

- The atmospheric forcing in low latitudes, especially the forcing due to atmospheric waves that are coherent with oceanic waves, causes an oceanic response from which it may be possible to draw valuable inferences regarding dissipative processes. It is necessary to study waves over a wide range of frequency because the dissipative effect of the thermocline will vary with frequency. The frequencies of particular interest are two days (Orlanski, 1976), three to five days (Wunsch and Gill, 1976--these waves propagate along the Intertropical Convergence Zone), 14 days (Krishnamurti, 1976), 45 days (Julian and Madden, 1969) and 365 days (the seasonal cycle). The parameterization of these dissipative processes is arbitrary in all existing numerical models because virtually nothing is known concerning dissipation in the oceans. It has recently been pointed out (Philander, 1976) that oceanic disturbances that propagate downward from the ocean surface could: (a) be reflected by the sharp thermoclines in the tropics and thus could be trapped near the ocean surface; (b) be dissipated while propagating through the thermocline because the wavelengths become very small in regions of high stability; (c) be scattered into shorter waves that are readily dissipated by topographic features on the ocean floor, or (d) be imperfectly reflected from the ocean floor and thus be attenuated. Information about the energy spectrum of the ocean as a function of depth would be of immense value in future modelling activities.

- Satellite photographs of the eastern equatorial Pacific clearly show the front between the south equatorial current and the equatorial countercurrent, as well as the westward propagating waves along this front. This raises the possibility that with availability of additional field measurements for ground truth, a method may be developed to monitor the intensity of the equatorial currents using satellite imagery.

- A number of process-oriented studies, many directly relevant to understanding the ocean's role in climate, are in progress or are being planned. A research effort in the central equatorial Pacific would complement these other studies, such as the North Pacific Experiment (NORPAX).

For the above reasons, the central equatorial Pacific has been chosen as the initial area of concentration for exploring the ocean's role in climatic variations. The research strategy pursued in this program plan is to understand the interannual fluctuations in the intensity and spacial distribution of heat input to the atmosphere in the equatorial Pacific. This may be near the "heart of the problem," for no other interannual oceanic/atmospheric variability is known to be of comparable magnitude or of influence on the mid-latitudes. In this way, NOAA has the best chance of realizing early and significant progress from the investment of limited personnel and financial resources.

PROGRAM GOAL

The long-term research goal of the EPOCS program is:

- To obtain the requisite knowledge of the underlying physical and thermodynamic processes in the equatorial Pacific so that we may anticipate, plan for, and eventually alleviate the adverse social and economic impacts of short-term climatic variations.

PROGRAM OBJECTIVES

The objectives to be pursued in the initial phase of the EPOCS program are the following:

- To statistically identify empirical relationships among oceanic and atmospheric characteristics in the equatorial Pacific contained in records of historical observations.

- To describe the temporal and spatial structure of the complicated ocean current system, the temperature and salinity fields, and the surface winds over the equatorial Pacific.

- To accurately model the processes of upwelling, waves, and advection that determine the vertical flux of heat and momentum between the ocean and atmosphere in the equatorial Pacific.

- To determine the energy spectrum of the equatorial Pacific as a function of depth in order to parameterize dissipation mechanisms for incorporating in existing numerical climate models.

PROGRAM COMPONENTS

To achieve the objectives of EPOCS, the program will be carried out through three primary research components: (1) empirical studies, (2) a major field experiment, and (3) modeling and analysis activities.

Empirical Studies

Empirical studies will be conducted using long-term meteorological and oceanic measurements to identify significant variations having inter-annual and decadal time scales, geographical coherency, and other potential predictive relationships. The supporting data for these studies will be obtained primarily from the archives maintained by the Environmental Data Services' (EDS) National Climatic and National Oceanographic Data Centers.

The most important data base consists of a collection of over 50 million observations of sea surface temperature, wind, and air temperature taken by merchant ships over the world oceans during the past century. Recognizing the uniqueness and importance of this data set, a cooperative international effort, supported by the National Science Foundation (IDOE), has been underway for the past several years aimed at updating and consolidating this historical data for the 100-year period 1860-1960. The observations for the Pacific basin, the area of responsibility of the United States, is being archived by the National Climatic Center of EDS and is scheduled for completion prior to the start of EPOCS.

These data will be supplemented with selected data from other sources when appropriate for specific analyses. These additional data include: (1) island and ocean weather ship observations; (2) historical bathythermograph data; (3) surface wind data derived from operational and experimental satellite systems; and (4) historical collections of surface temperature and sea level pressure maps.

Field Experiment

A major field experiment will be conducted in the central Equatorial Pacific in the area bounded by 20°N, 20°S, 120°W and 150°W. Measurements and observations in this region will be made using vertical mooring arrays, drifting buoys, current profilers, NOAA vessels and ships-of-opportunity, aircraft from NOAA's Research Facility Center, and satellites to make large area surface wind, sea surface temperature and rainfall estimates.

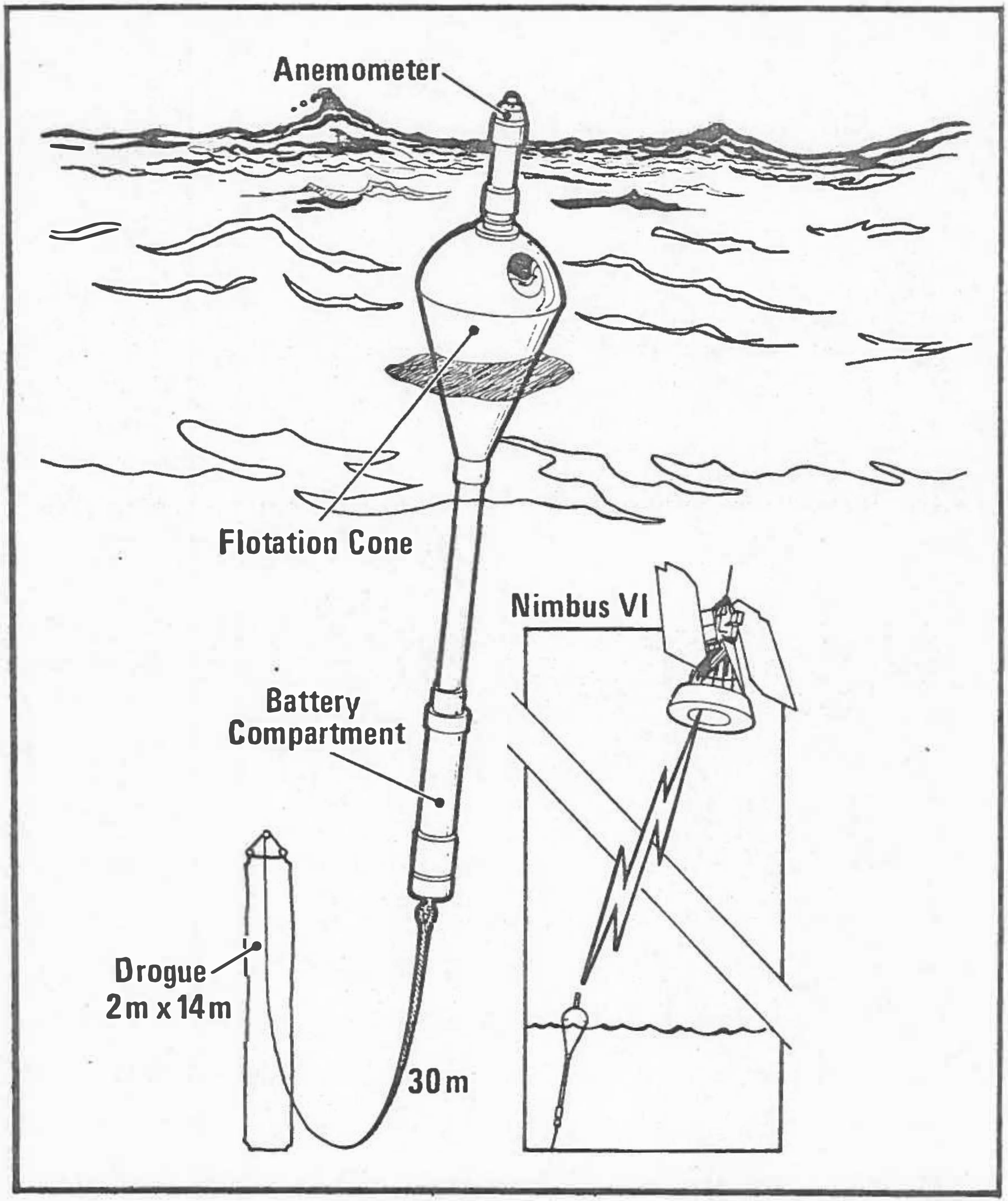
Detailed measurements of the equatorial currents and their frequency spectra with depth will be provided by instrumented moorings. Moored buoy arrays, within reasonable proximity of each other, will provide information about energy levels as a function of zonal wavenumbers. Both oceanographic and meteorologic variables will be recorded by the moorings so that the resulting data set will permit studies of upwelling due to local winds and Ekman divergence, surfacing and meandering of the equatorial undercurrent, and equatorially trapped waves.

Individual moored buoys will be deployed for periods of three to five months. As a buoy is retrieved to recover the data cassettes and to recalibrate and refurbish the instruments, it will be replaced by another new or refurbished system. In this way, attempts will be made to keep at least one moored buoy in place and operable throughout the field experiment so as to obtain a continuous record of observations.

It is planned that each moored buoy array will have a string of ten current meters suspended below it (at 20, 50, 100, 200, 300, 500, 1000, 1500, 2000, and 3000 meters) and, therefore, will provide measurements with high vertical resolution. These buoy arrays will also be able to measure wind, sea surface conductivity (salinity), air temperature and ocean temperature at 25 depths. Survival engineering and maintenance operations of current meter moorings are sufficiently expensive so that deployment of only a small number of them is economically feasible and, therefore, horizontal resolution will be limited.

Relatively inexpensive, expendable drifting buoys, as illustrated in Figure 13, offer great promise for economic sampling of spatial structures of near surface ocean currents. Little application has been made of this method historically because being able to position the buoys with high accuracy is an essential requirement. This capability presently exists in the NIMBUS-6 satellite and will also be available after 1978 in the TIROS-N satellite. NOAA's Office of Ocean Engineering has developed low cost buoys and buoy electronics for use with these systems. Deployment of drifting buoys, which are positioned daily and have lifetimes of several months, is planned for EPOCS as an efficient means of determining the spatial structure of the currents. Some of these buoys will be equipped with wind and temperature sensors to provide additional information on the structure of the upper ocean and lower atmosphere.

Figure 13. Schematic of Drifting Buoy to be Used During EPOCS Field Experiment



The selection of a definitive deployment strategy will be made following completion of pilot experiments to be carried out prior to the EPOCS field experiment. However, deployment of 20 to 30 drifting buoys at the start of the experiment and a subsequent deployment, four months later, of 10 to 20 buoys is envisioned as appropriate.

The NOAA research vessels that will deploy, service, and recover the moored buoys, as well as deploy the drifting buoys, will provide platforms from which to measure temperature and salinity with STD casts and vertical current shear with profiling current meters. Such high resolution vertical and horizontal measurements will provide data concerning the current, temperature, and salinity fields in the vicinity of the moored buoys. It is estimated that a total of five ship-months on two ships--one from Miami and one from Seattle--are needed to carry out the buoy logistics.

Commercial vessels provide a platform from which the ocean temperature can be measured inexpensively and regularly along certain routes. The National Marine Fisheries Service (NMFS) (and its predecessor, Bureau of Commercial Fisheries) have operated monitoring programs in this manner, in the northeast Pacific for the past ten years. It is planned to extend the area of coverage to the equatorial zone. The few trans-equatorial expendable bathythermograph (XBT) sections from ships-of-opportunity that have been made over the past several years show that this approach can be used to monitor the equatorial undercurrent and the geostrophic flow of the north equatorial current.

The specific plans of the NMFS for the EPOCS program are to install XBT recorders on the Farrell Line freighters Austral Moon, Austral Rainbow, and Austral Lightning. These ships will make two equatorial XBT sections, from Los Angeles to Samoa and from New Guinea to Puget Sound, approximately every two months. About 50 XBT drops will be made on each crossing. Additional coverage of surface temperature and salinity observations will be obtained from the Polynesian Lines ship Tayabas Bay on the Coos Bay, Oregon to Tahiti and Samoa to Los Angeles routes (40 days round trip). It is also planned to collaborate with French oceanographers by providing them with two XBT recording systems for installation on a Japanese and a French ship to take additional measurements in the equatorial Pacific.

Processing of all ship-of-opportunity data will be carried out by NMFS's Pacific Environmental Group in Monterey, California in cooperation with the Navy's Fleet Numerical Weather Central. Analysis of the data will be contracted to the Equatorial Pacific Group of the Global Weather Experiment (formerly FGGE).

NOAA's new, well-instrumented research aircraft (especially adapted Navy Orion P3-D's) will be used in the EPOCS program to investigate high frequency dynamic processes in the vast region of the field experiment. The long range (over 4,000 nautical miles) and versatility of these sophisticated aircraft offer a unique opportunity to study air-sea interactions on a temporal and spacial scale not previously available. For example, a flight from 20°N to 20°S can be made in ten hours compared to ten days or more for a research vessel. It is estimated that 200 flight hours per year will be utilized during the field experiment to obtain boundary layer fluxes, to launch AXBT's, and to collect other ocean and atmospheric data.

The most economical way to make large-scale oceanographic measurements is by satellite. During an experiment in 1975 and 1976, it was demonstrated that an equatorial current, in this case the westward flowing south equatorial current in the Pacific, could be delineated qualitatively by means of infrared imagery from the Geostationary Operational Environmental Satellite (GOES). Only standard GOES imagery was utilized in this experiment. An EPOCS activity to be undertaken by NOAA's National Environmental Satellite Service (NESS) is to optimize the GOES imagery for detecting sea surface temperature fronts and to quantify these temperatures using digital data. The digital data from a ten degree latitude band centered on the equator will be collected daily and stored on magnetic tape. The data will then be enhanced on photographic film, and time lapse sequences will be produced to allow visual detection and analysis of equatorial fronts. Attempts will also be made to obtain absolute temperature values using satellite calibration techniques in conjunction with ground truth data from other measurement systems deployed during the field experiment.

Understanding the response of the ocean to atmospheric forcing requires two types of detailed information--the frequency-zonal wavenumber spectrum of the atmospheric forcing and the time-history of the surface winds. It is reasonable to assume that the spectrum is in equilibrium so historical data can be used for this first requirement. The time-history of the tradewind strength and surface wind stress over large areas, however, will be obtained via satellite during the EPOCS field experiment. This technique involves using the GOES to monitor low-level cloud motions that, in turn, are used to infer the surface winds. This technique will continue to be developed further, and as field measurements are obtained from buoys and surface vessels during the field experiment, these measurements will be useful in refining the calibration procedure.

Because precipitation is directly proportional to the latent heat provided to the atmosphere, the capability to estimate rainfall over large areas of the equatorial Pacific is very important to the EPOCS program. Historically, precipitation over the ocean has been calculated as a residual in studies of the earth's energy budget. This situation has changed as a result of recent technological advances made by NOAA's National Hurricane and Experimental Meteorology Laboratory (NHEML). This laboratory has developed (motivated by weather modification experiments in southern Florida) a technique for estimating rainfall from digitized geosynchronous satellite imagery. During the EPOCS program, routine estimates of rainfall within an equatorial latitudinal band of 20°N to 20°S will be provided weekly with a resolution at least as fine as 5° by 5°. Prior to the field experiment, archived infrared digital satellite data for the years 1976-1978 will be used to refine the estimation method for the equatorial Pacific.

Modeling and Analysis

During EPOCS, there will be close collaboration between the above experimental activities and modeling and analysis studies. The field experiment is designed, in large part, to address specific modeling issues. Consequently, as experimental data on processes that need to be parameterized in numerical models become available, the models will be modified to incorporate this new information.

Several NOAA laboratories, such as the Atlantic Oceanographic and Meteorological Laboratory (AOML), the Geophysical Fluid Dynamics Laboratory (GFDL), and the Pacific Marine Environmental Laboratory (PMEL) are presently engaged in numerical modeling related to climate studies. In particular, boundary layer (or mixed layer) models have been developed to link the atmospheric and oceanic general circulation models. These models, which are predominately one-dimensional, may be classified as one of three types: integral models, moment closure models, and stochastic models.

Nevertheless, considering the large number of significant (and in some cases, unique) physical and thermodynamic processes operating in the equatorial regions, present boundary layer model formulations may not be applicable. For example, in the tropical regions, the mixed layer is well-defined and shallow, and the ocean is highly statified. Boundary layer formulations in this region must take into account the transformation of a mixed layer from the equatorial and near-equatorial regions, where the Coriolis force is nil or very small, to adjacent higher latitudes, where the force is effective. Moreover, the existence of the equatorial undercurrent imposes its own internal dynamics on the boundary layer development.

For these reasons, boundary layer models that incorporate such features as horizontal advection by currents, upwelling, and other processes particular to the equatorial region will be developed in the EPOCS program.

In addition, analytical studies at GFDL will be conducted on the stability and vertical structure of equatorial currents. One objective of these studies will be to determine whether the period and wavelength of unstable waves can be related to the intensity of the equatorial currents. Investigations of the vertical structure of oceanic motion will also aid in parameterizing vertical diffusion of heat and momentum in numerical simulation models.

COORDINATION WITH OTHER PROGRAMS

Climate fluctuations are a global phenomena, and ideally the variations of the whole global system should be studied in detail. Toward this goal, NOAA scientists are planning their research efforts cooperatively with scientists from other countries. For example, some participants in the EPOCS program are working members of the international Scientific Committee on Oceanographic Research (SCOR), which is planning and coordinating field experiments in adjacent areas of the Pacific, e.g. the Global Weather Experiment (formerly FGGE) and future Northern Pacific Experiment (NORPAX) activities.

The oceanographic portion of the Global Weather Experiment (GWE) in particular, is directly relevant to the EPOCS program, and the participation of NOAA scientists in SCOR planning, as well as, pilot experiments preliminary to the GWE field year, will provide many benefits to EPOCS and other NOAA climate programs. These advantages include:

- NOAA involvement in planning global climate research
- available critiques from a large international scientific community of NOAA's planned empirical studies, and field and modeling activities
- shared development of technology and techniques for ocean measurements and analyses that are applicable to ocean climate studies
- utilization of data and findings of all SCOR participating scientists to supplement NOAA's programs and assist in improving climate prediction

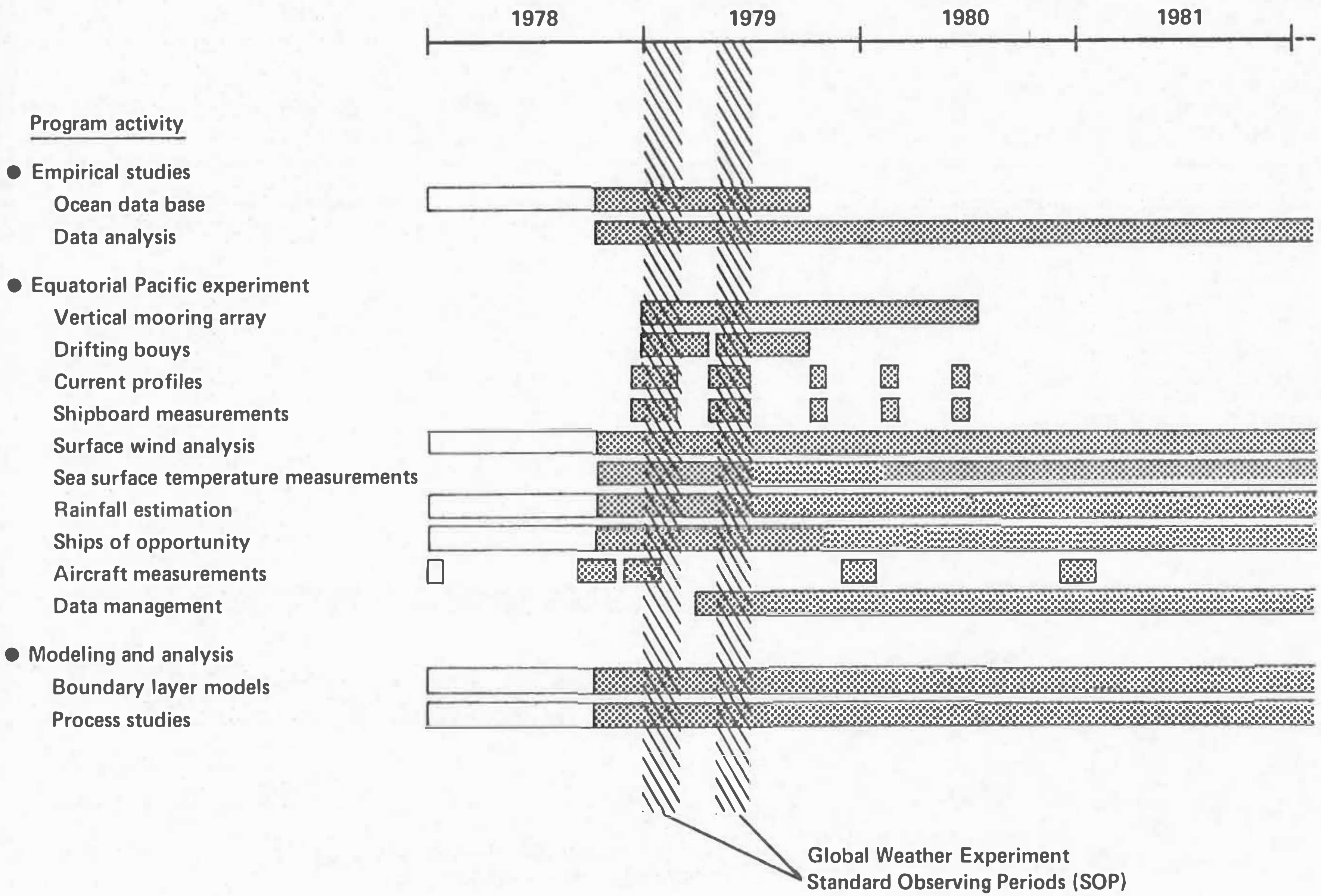
The GWE offers a unique opportunity to initiate an ocean climate study, such as EPOCS, due to the excellent meteorological data sets that will be collected during the experiment. The GWE objectives, however, relate to improving weather prediction on a time scale of two weeks, and, consequently, the planned data gathering periods will be concluded within one year. For the time scale important for climate fluctuations, describing the ocean dynamics over several seasonal cycles is a necessity. Therefore, for climate research, data will have to be collected over a several year period.

PROGRAM SCHEDULE

EPOCS is scheduled to start at the beginning of FY 1979 (i.e. October 1, 1978) coincident with the availability of new financial and personnel resources to carry out the program. Prior to the initiation of EPOCS, existing base resources will be applied, to the greatest possible extent, in preparation for the EPOCS program activities.

The urgency for initiating the program in FY 1979 derives in part from the schedule of the Global Weather Experiment, in which intensive observations will be taken during two "standard observing periods" in January-February, 1979, and May-June, 1979. The excellent meteorological data sets which will result from these GWE observing periods provide a unique opportunity to obtain contemporaneous and complementary atmospheric and oceanographic data sets in the equatorial Pacific. Therefore, scheduling EPOCS such that the field measurement systems are deployed by early 1979 will be of substantial benefit to the program. Figure 14 contains a schedule of each of the major EPOCS program activities through 1981.

Figure 14. EPOCS Schedule by Major Program Activity Through 1981



RESOURCE REQUIREMENTS

A detailed breakdown of the FY 1979 additional resource requirements for EPOCS is presented below in Table 2. Of the total new funds of $2,820,000 needed to supplement existing base resources to carry out the program in the initial year, approximately 10% will be spent on empirical studies, about 15% will be allocated to modeling and analysis activities, and 75% will be required for the field experiment and data management functions.

As shown in the table, 14 major program activities will be undertaken by seven separate NOAA organizational elements, as well as by cooperative institutes at three universities (i.e. University of Colorado, University of Miami, and University of Washington).

Table 2: EPOCS FY 1979 Resource Requirements

Program activity	Responsible organization	FY 1979 budget
• Empirical studies ($250K)		
Ocean data base	EDS	$150K
Data analysis	EDS	100
• Equatorial Pacific experiment ($2,120K)		
Vertical mooring array	PMEL	3/800
Drifting buoys	AOML	2/300
Current profiles	AOML	1/200
Shipboard measurements	AOML	100
Surface wind analysis	NESS	1/100
Sea surface temperature measurements	NESS	1/75
Rainfall estimation	NHEML	1/100
Ships of opportunity	NMFS	1/85
Aircraft measurements	RFC	300
Data management	EDS	60
• Modeling and analysis ($450K)		
Boundary layer models	AOML	150
Process studies	University cooperative Institutes	300
Total FY 1979 requirement		10/$2,820K

In addition to the NOAA personnel that will be reassigned to EPOCS from existing base program activities, ten new positions are needed to successfully carry out the program. Specifically, an oceanographer, meteorologist and an electronics engineer are needed to help design, fabricate, and deploy the vertical mooring arrays for measuring vertical and horizontal fluxes of heat and momentum. Two oceanographers and a computer programmer will conduct the current measurement program utilizing drifting buoys and subsurface profilers. A meteorologist will assist in refining the new technique for estimating oceanic rainfall from digitized geosynchronous satellite imagery. A meteorologist will investigate the relationship between low-level cloud vectors and surface wind, and a computer programmer will develop and operate the computer software for manipulating and analyzing sea surface temperature data obtained from the GOES satellite. A computer programmer is also needed to handle the data processing activities associated with the expendable bathythermograph (XBT) measurements obtained from the ships-of-opportunity.

EPOCS is planned as a multi-year, level-funded program. Table 3 contains a projection of the EPOCS budget for the first five years.

Table 3: EPOCS Five-Year Budget

	FY 79	FY 80	FY 81	FY 82	FY 83
• Empirical studies	$250K	320	350	350	300
• Field experiments and data management	2,120	1,900	1,820	1,770	1,770
• Modeling and analysis	450	600	650	700	750
Total	$2,820K	2,820	2,820	2,820	2,820

A portion of the funds used in FY 1979 to purchase equipment, such as buoys and current profilers, and the logistic expenses of the field program will be required in subsequent years to meet the maintenance and operation costs of the equipment. Also, it is anticipated that as the program develops over time, less funds will be applied to data collection and more will be allocated to modeling and analytical activities.