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Prepared by
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An Interagency Scientific
Planning Group

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The BOMEX Project Office was established by the Interagency Committee for International Meteorological Programs to serve as the focus for planning and coordinating the Barbados Oceanographic and Meteorological Experiment.

The purpose of this bulletin is to inform you of the current status and developments in the scientific and operational planning of BOMEX. It is intended primarily to continue a useful exchange between a scientific planning group and the community of scientists and students in the universities, in government and in private laboratories.

1. INTRODUCTION

We would like to thank all who have responded to the initial issue of the BOMEX Bulletin. The programs, suggestions, criticisms and warnings are gratefully acknowledged.

It is not yet possible to give an overall view of the entire experiment. This is because a number of agencies are in the process of assessing their contributions to the program. In addition, the full extent of university participation cannot be determined until final funding arrangements have been made. The university programs should, of course, play a most important scientific role in BOMEX. To date the National Science Foundation has received BOMEX related proposals from eight universities while ESSA has received proposals from three universities. A meeting of ONR contractors in the field of heat budget and turbulence measurements was held in Washington in February. Considerable interest was expressed in BOMEX and it is anticipated that some of the attendees will be active participants in the experiment.

At the moment, the clearest aspect of the program concerns the synoptic type observational resources. Accordingly, we begin to discuss in Section 2 the largest scale studies associated with BOMEX.

In terms of narrow disciplines one may distinguish several groups of potential participants whose major observational interests cluster around radiation, turbulence measurement from mixed and/or fixed platforms, subcloud convective scale measurement, mesoscale measurement in both atmosphere and ocean, precipitation measurement, and, of course, synoptic type measurements. As soon as the full list of participants is available, we propose to hold meetings with each group in order to develop coherent programs and schedules within and between groups, and, if possible, to develop compatible data recording systems.

We list in Section 3 the scientific resources which will be available on the research vessels, as well as a description of the Windfinding At Sea System which will be on board three of the ships.

The last issue of the Bulletin was devoted to an initial statement of broad scientific objectives which was reasonably explicit for the sea-air interaction phase of the experiment and to a listing of resources committed to the experiment by various Federal agencies. Several of these agencies have supporting scientific programs, while many have scientific objectives which may be met as a result of the overall experiment. These are discussed in Section 4. In particular we call attention to the active participation of the Mississippi Test Facility of NASA's Marshall Space Flight Center in the sensor calibration, data reduction and data processing phases of BOMEX. This encouraging development places an experienced facility of proven competence at the disposal of the BOMEX participants.

Finally, climatological data of subsurface distribution of oceanic elements are given in Section 5.

2. SYNOPTIC ARRAY

a) MOMENTUM TRANSFER

For reference we display in Figure 1 a tentative configuration of resources, including fixed ship stations, oceanographic buoys, and roving ships capable of making oceanographic observations. We show nine oceanographic buoys and several roving ships although at the moment only five buoys and no roving ships are committed to the experiment. The 500 km spacing of the basic square reflects the maximum average synoptic network we may expect to have in GARP global experiments in the near future.

Within the context of sea-air interactions, the largest scale stress we can attempt to measure is determined by the quasi-synoptic array. This stress is on the geostrophic wind scale. Consequently, geostrophic departure techniques of measurement are suggested. Within the array, additional stress measurements will, of course, be made on smaller time and space scales ranging from fixed point determinations of the rate of energy dissipation (and thereby inferred stresses) to direct measurement of Reynolds flux from fixed and moving platforms. Most of the subsynoptic scale stress measurements will be made by university and other research groups.

In this issue we begin to discuss the largest scale stress measurement technique. There are a substantial number of references in the literature questioning the existence of any kind of Ekman layer over the subtropical oceans, but the evidence, on the whole, is not persuasive either way. It does not matter. The individual forces in the more or

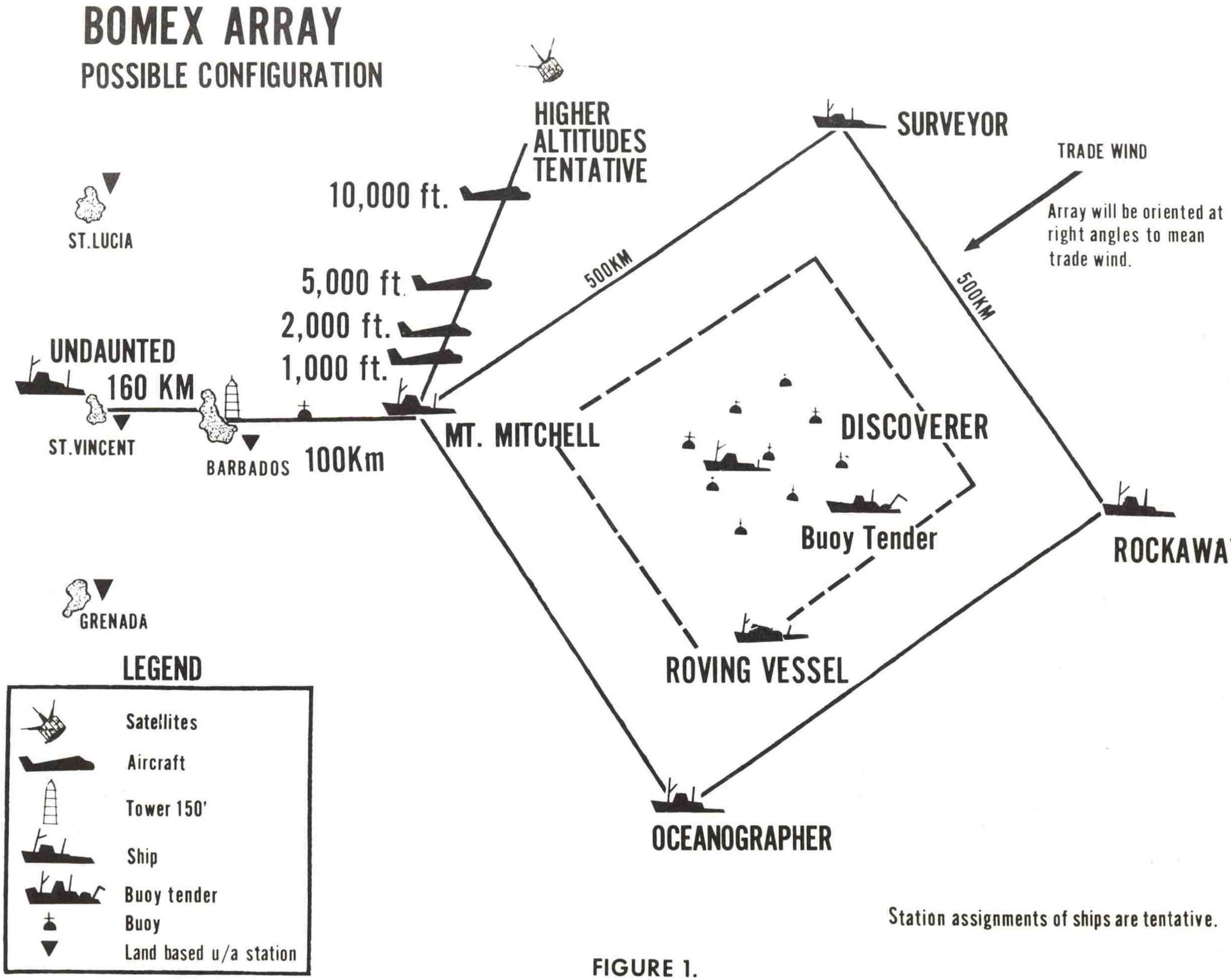

BOMEX ARRAY
POSSIBLE CONFIGURATION
HIGHER
ALTITUDES
TENTATIVE
10,000 ft.
5,000 ft.
2,000 ft.
1,000 ft.
UNDAUNTED
160 KM
ST. LUCIA
ST. VINCENT
BARBADOS
100Km
GRENADA
MT. MITCHELL
SURVEYOR
500KM
500KM
TRADE WIND
Array will be oriented at right angles to mean trade wind.
DISCOVERER
Buoy Tender
ROCKAWAY
ROVING VESSEL
OCEANOGRAPHER
LEGEND
Satellites
Aircraft
Tower 150'
Ship
Buoy tender
Buoy
Land based u/a station
Station assignments of ships are tentative.

FIGURE 1.

less complete equations of motion must be examined in detail. These equations are the essential connection between the small scale constant-flux layer scholar and his larger scale counterpart. The connection may and probably does involve mesoscale ensembles of individual convective elements as well as all other possible subsynoptic scale disturbances. In short, the problem is complicated but, on the other hand, the observational power available to BOMEX is unprecedented.

We list below the observational devices available for the large stress determinations.

Element	Device	Platform
$\bar{u}(z)$, $\bar{v}(z)$	Radiowind Radar wind	Ships (3) Ships (2)
$\bar{u}(z_1,z_2,t)$, $\bar{v}(z_1,z_2,t)$	Meteorological buoy	(3)
$\bar{u}(z)$, $\bar{v}(z)$	Doppler radar	Aircraft (300m)
$\bar{V}(z,t)=[u^2+v^2]^{\frac{1}{2}}$	Tethered balloon	Ships (5)
$u(z,t)$, $v(z,t)$	Tethered balloon (?)	Ships (5)
$\bar{p}(x,y,o)$	Aneroid barometer Mercurial barometer	Ships (5) Ships (5)
$T_v(x,y,z)$	Radiosonde Thermistor-hygrometer	Ships (5) Aircraft
$T_v(x,y,z,t)$	Tethered balloon	Ships (5)

where the symbols have their usual significance and T_v is virtual temperature.

One can view all the elements of this observational matrix as comprising a single system for the measurement of large scale stress. An error analysis of the entire system with respect to this specific objective is an instructive exercise which yields some information as to the precision of measurement required and the number of individual observations which must be averaged to yield acceptable values of stress. Such an analysis will be presented in a subsequent Bulletin.

Although this kind of error analysis defines some kind of yardstick as to the feasibility of the synoptic approach to stress measurement, it is probable that other factors are more confounding. For example, sampling a turbulent time series at infrequent and relatively short time intervals introduces serious error in the mean even if the sensors are capable of exact measurement. The response time, and scale and mode of averaging, of the available instrument systems differ substantially from each other. The problem then is to arrange the heights and duration of observation, the rate of rise of balloons, and the sampling time for aircraft runs at fixed heights so that we tend both to minimize the sampling errors and to provide ourselves with a rational data base with which to correct for residual sampling errors.

All of the above assumes that an appropriate averaging time exists and that on this scale of averaging, the winds are responding to the pressure gradients on a space scale determined by the fixed ship array. On a long term, almost climatological, scale this is probably the case. In a short term sense, the winds may be responding more to transitory mesoscale pressure patterms than to the synoptic scale pressure pattern. If this is the case we want to be able to recognize and evaluate the relative importance of mesoscale systems for each observational sequence.

b) VAPOR FLUX

The budget method of evaluating the sources and sinks of vapor in the atmospheric system is to measure 1) the time change of (ρq) in the observational volume, and 2) the differences in the flux of vapor $(\rho q V_n)$ across the lateral boundaries of the system. Here ρ is the density, q the specific humdity and V_n the component of velocity normal to a lateral boundary.

The observational matrix for this system is much the same as for momentum except that elements q (already present implicity in virtual temperature) and P (the vapor sink) must be added. The additional systems at our disposal are dropsondes, rain gauges, and radar observation of rainfall. Since the system cannot be observed to infinity at the top, the vapor flux at the effective top must also be observed. Translated into operational terms the latter requirement involves at least a census of cloud tops above the mean height of the moist layer.

The accuracy of the inferred values of evaporation from this system depend essentially on the ability to measure divergence. Every effort will be made to remove systematic error, but no matter what physical picture one assumes it appears that a relative humidity capability of the order of 1% is necessary to make reasonable short time scale estimates of evaporation, even when precipitation is completely absent. It is clear that the present rawinsonde system is unable to meet this requirement. It is equally clear that on a climatological time scale, and on somewhat larger space scales, use of the present rawinsonde system yields reasonable values of evaporation. A large number of observations are therefore required in order to reduce statistically the inherent sensor and sampling errors to reasonable limits. The release rate of rawinsondes is at our disposal and it is hoped that the rawinsonde budget techniques will yield bulk values of evaporation minus precipitation on at least a weekly time scale and, hopefully, on a one or two day time scale.

We are not yet certain but there is reason to believe that the infrared hygrometers available on the RFF aircraft (and some other available aircraft) have the required humidity capability. It appears therefore, that shorter time scale estimates of evaporation from the budget technique may be available from programmed aircraft flights. We will discuss the proposed flight paths in our next issue.

3. STATION VESSEL EQUIPMENT AND INSTRUMENTATION

a) SCIENTIFIC RESOURCES

A matrix of some specific facilities on those vessels presently committed to the experiment follows. Further details may be obtained from NODC publication, "Oceanographic Vessels of the World".

SCIENTIFIC EQUIPMENT	OCEANOGRAPHER	DISCOVERER	SURVEYOR	MOUNT MITCHELL	ROCKAWAY
*Multisensor, S.T.D	X	X			X
Bathythermographs	X	X	X	X	X
Current observations	X	X	X	X	X
Magnetometer	X	X	X	X	
Gravity meter	X	X	X	X	
Geological echo profiler	X	X	X	X	
Heat probes	X	X	X	X	
Plankton nets	X	X	X	X	X
Nansen bottles	X	X	X	X	X
GEK	X	X	X	X	
Continuous sea surface temperature					X
Bottom sampling	X	X	X	X	X
Chemical analysis instrument	X	X	X		X
Marine photographic equipment	X	X	X		
Meteorological equipment:					
Surface observations	X	X	X	X	X
Radiosonde	X	X	X	X	X
Windinfinding at Sea	X		X	X	
Met Radar (X Band)		X			X
Tethered balloon	X	X	X	X	X

*The Bissett-Burman Marine Multisensor (STD) will be a basic instrument on each main data station. Standard parameter accuracies are:

Salinity	$\pm$ 0.02 ppt
Temperature	$\pm$ 0.05^{o}C
Depth	$\pm$ 0.5%

The electrical power available on all ESSA vessels is shown below. It is generally regulated to 2% in voltage and frequency. In addition, each vessel is equipped with a limited amount of frequency controlled power, stable to 2 parts/10^7/day.

450V	60 cycle	3 phase
220V	60 cycle	3 phase
117V	60 cycle	single phase

The U.S. Coast Guard Cutter ROCKAWAY can supply 440/117V AC power, also with a limited amount of frequency controlled current.

b) WINDFINDING AT SEA SYSTEM

The Windfinding At Sea System to be installed on three ships represents the culmination of several years' development effort on the part of the Weather Bureau's Equipment Development Laboratory and the Scanwell Laboratories, Inc. The equipment is intended to provide, at reasonable cost, a capability for obtaining complete winds aloft and upper air soundings from aboard a moving ship. By eliminating the need for measuring elevation angles, the antenna stabilization problem for accurate observations has been made tractable. While the Weather Bureau's objective was to produce an instrument suited to their merchant ship program, the BOMEX timing is such that the operational prototypes could be made available for the project.

Equipment Description

Receiving Antenna: Gyro stabilized, phased dipole array, 1680 mHz; directional in azimuth. Connected to ship's gyrocompass for North orientation regardless of ship's heading and yaw.

Transmitting Antenna: Mounted on receiving antenna, 403 mHz, directional in azimuth.

Antenna Control: Manual or automatic tracking, electronic lobe scanning.

Receiver: Similar to Weather Bureau radiotheodolite.

Ranging Transmitter/Comparator: AN/GMD-2 "saddlebags".

Recorders (rack-mounted in meteorological lab below decks):

Meteorological Data - Standard Weather Bureau marine radiosonde recorder (similar to AN/FMQ-5).

Windfinding Data - Digital recording of time from release, azimuth angle, and slant range.

Analogue Angle Recorder - Plots continuous trace of azimuth angle versus time (permits smoothing of angle data when considered necessary).

Flight Equipment: Standard Weather Bureau "transpondersonde" (403 mHz receiver, 1680 mHz transmitter, modulator with calibrated baroswitch, temperature and humidity sensors).

Data Generated

Radiosonde Observation: Audio frequencies representing temperature and humidity, and calibrated baroswitch contacts, are reduced in the usual manner to give vertical profiles of temperature versus pressure, humidity versus pressure, and height versus pressure.

Wind Observation: Input data are azimuth angle versus time, slant range versus time, and height versus time (derived from radiosonde observation). Horizontal distance out (HDO) calculated from height and slant range at selected time. HDO and azimuth plotted in usual manner to derive winds.

Accuracies (rms)

Slant range: ± 10 meters

Azimuth: ± 0.2 degree

4. RECAPITULATION OF AGENCY PLANS, COMMITMENTS AND OBJECTIVES TO DATE

Agency participation in the form of objectives and commitments has been encouraging. When these change, and as the objectives and commitments of other participants become clear, they will be contained in later issues of the bulletin.

a) ATOMIC ENERGY COMMISSION

AEC will measure the budgets, fluxes, and deposition rates of natural and weapons-produced radionuclides over the sea, and compare these to the water, momentum and heat budget measured by the BOMEX observation network. The steady-state deposition rate will be estimated by inventorying short-lived radionuclides in the ocean (using AEC laboratory equipment on the BOMEX ships) and equating their decay rate to the deposition rate. Then this deposition rate will be used with the measured nuclide profiles in the air to help in understanding the mechansims of vertical exchange or flux of the nuclides. By sampling the radionuclide profiles and the air moisture profile from the same BOMEX aircraft, the respective budgets can be compared.

Because precipitation may substantially increase the vertical exchange of the nuclides, the AEC will also measure, for the first time, the scavenging efficiency of rain for the natural oceanic aerosol to which the radionuclides are attached. This will be feasible because the concentration of the radionuclides will be measured in the air being entrained into the rain clouds. Measurement of the precipitation, precipitation rates, drop sizes, electrical charges, and its chemical and radiochemical content will be undertaken by the AEC to help relate the field observations to laboratory experiments on scavenging. The AEC precipitation measurements will be correlated to the echoes on the BOMEX radar, which will assist in using the BOMEX radar coverage to evaluate the total precipitation in the test area. The total precipitation determination is needed for the water budget studies of BOMEX as well as in the evaluation of the total scavenging.

The AEC will provide a micrometeorological input to the program by measuring temperature and wind profiles at low levels, and possibly through the use of an aircraft equipped with a sonic anemometer.

b) DEPARTMENT OF COMMERCE

Commerce's Environmental Science Services Administration has committed the Coast and Geodetic Survey vessels DISCOVERER, MT. MITCHELL, OCEANOGRAPHER and SURVEYOR, and other personnel and materiel support. Contracts have been awarded for a stabilized shipboard meteorological radar (Selenia) and three Windfinding At Sea Systems (Scanwell).

The Sea-Air Interaction Laboratory of ESSA's Research Laboratories is actively engaged in the procurement and planning for the operation of the buoy network, Boundary Layer Instrument Packages and other parameter measuring devices, with the full support of the Coast and Geodetic Survey marine engineering staff. Research Laboratories have also committed two of their Research Flight Facility's fully instrumented DC-6's and one DC-4.

The Environmental Data Service of ESSA is providing support in data reduction, machine programming, formatting, and compilation and archiving. EDS's J. F. Bosen has been appointed Data Manager for BOMEX.

ESSA's Weather Bureau is providing engineering and other technical advice as well as commitments of personnel and materiel.

The ESSA National Environmental Satellite Center will provide a complete range of satellite observations and indirect sensing measurements. They seek as their objectives extensive ground truth testing based on surface observations of sea and air temperature, humidity, wind and sea state to compare with satellite pictures and infrared radiation data. They also desire vertical profile measurements for atmospheric attenuation studies and cloud observations from all-sky cameras and aerial photography to compare with satellite picture and radiation data.

c) DEPARTMENT OF DEFENSE

The DoD has authorized the Air Force, Army and Navy to negotiate directly with the BOMEX Project Office concerning their objectives and commitments.

Air Force has submitted several scientific objectives ranging from convective cloud growth under an artifical cirrostratus deck over the island to ionospheric experiments, and includes new equipment testing utilizing the BOMEX observational array. In the field of dynamics the plan to use BOMEX data for model development and simulation studies. Other objectives are the use of lightning locators to investigate the possibility of identifying lightning produced showers and thunderstorms and to determine whether warm clouds produce lightning; a radar study of gust-producing showers and thunderstorms to determine characteristics which will hopefully be useful as a short range forecasting tool; and, to calculate water fluxes to determine how to parameterize evaporation. Equipment scheduled for testing and use are the Air Force Cambridge Research Laboratories expendable dew point hygrometer, and low level sounding system. The Air Weather Service dropsondes modified for sea-surface temperature observation will also be tested. These objectives are being integrated into the overall experiment and will be discussed further in subsequent issues of the Bulletin.

The Air Force has conditionally committed low, medium and high altitude reconnaissance aircraft for vertical and horizontal observations across the spectrum; particulate and gaseous sampling, and colored panoramic photography of the experiment area; five mobile rawinsonde teams for shipboard and island stations with equipment; and expendable support for atmospheric soundings.

They have also designated Dr. J. L. Ryerson, Scientific Advisor for Science and Technology as an Assistant Scientific Director and have under study other contributions.

Army objectives are primarily the relation of the air-sea interaction to the design and operation of hurricane protection, beach erosion control and harbor projects. Another objective is in atmospheric radiation and aerosol size measurements over the tropical ocean as they pertain to tropical precipitation measurements. The Army has pledged cooperation within available resources upon request.

Navy intends to participate in BOMEX to the fullest extent possible and are planning participation in terms of scientific objectives, experimental procedures and resources. Firm objectives and commitments will be listed in the Bulletin when received.

d) DEPARTMENT OF THE INTERIOR

The DOI through its Bureau of Commercial Fisheries Tropical Biological Laboratory (TABL) plans to cooperate by scheduling the research vessel UNDAUNTED to operate west of St. Lucia, St. Vincent and the Grenadines during BOMEX. They plan to occupy a grid of stations to define fields of temperatue, salinity, and other parameters to depths of 500 meters. The vessel has been offered also as a meteorological platform if sensors and technicians can be provided. This offer is under study and acceptance depends on the requirements and objectives of other participating agencies.

e) NATIONAL AERONAUTICS SPACE ADMINISTRATION

The Mississippi Test Facility of NASA's George C. Marshall Space Flight Center is planning extensive support in the areas of test and calibration, data system planning and data reduction and processing. Because of their internationally recognized expertise in these areas their participation is a welcome and needed addition to BOMEX. As of this date several of their data calibration and processing experts are developing the calibration, and data reduction and processing programs for BOMEX. They have started an inventory of all sensors and platforms which will be diagramed and disseminated to all participants by 15 June 1968. Agencies are being contacted to schedule platform and sensor calibration. Although NASA will not launch a satellite specifically for BOMEX, they expect that several research satellites may still be furnishing useful data of great value. These are Nimbus B, Tiros M, ATS III and ATS D. In addition to the satellite objectives of the project, they have an interest in sensing oceanographic parameters via satellite.

f) NATIONAL SCIENCE FOUNDATION

The NSF will cooperate in BOMEX and plan to support selected proposals from the University scientists for well-planned field experiments that can be conducted within the framework of the BOMEX program as well as to support the efforts of the National Center for Atmospheric Research in the experiment.

g) DEPARTMENT OF TRANSPORTATION

Transportation's U.S. Coast Guard has committed the Cutter ROCKAWAY, a fully instrumented vessel, programmed the buoy tender CACTUS to support the buoy array and will provide communications support. Lieutenant Michael R. Johnson, USCG, has been designated as the Communications Officer for BOMEX. The USCG has also accepted the responsibility for Search and Rescue (SAR) support for the operation. It will be provided by the San Juan sector coordinator utilizing the ROCKAWAY and the other BOMEX vessels. Figure 2 is a photograph of ROCKAWAY, courtesy of U.S. Coast Guard.

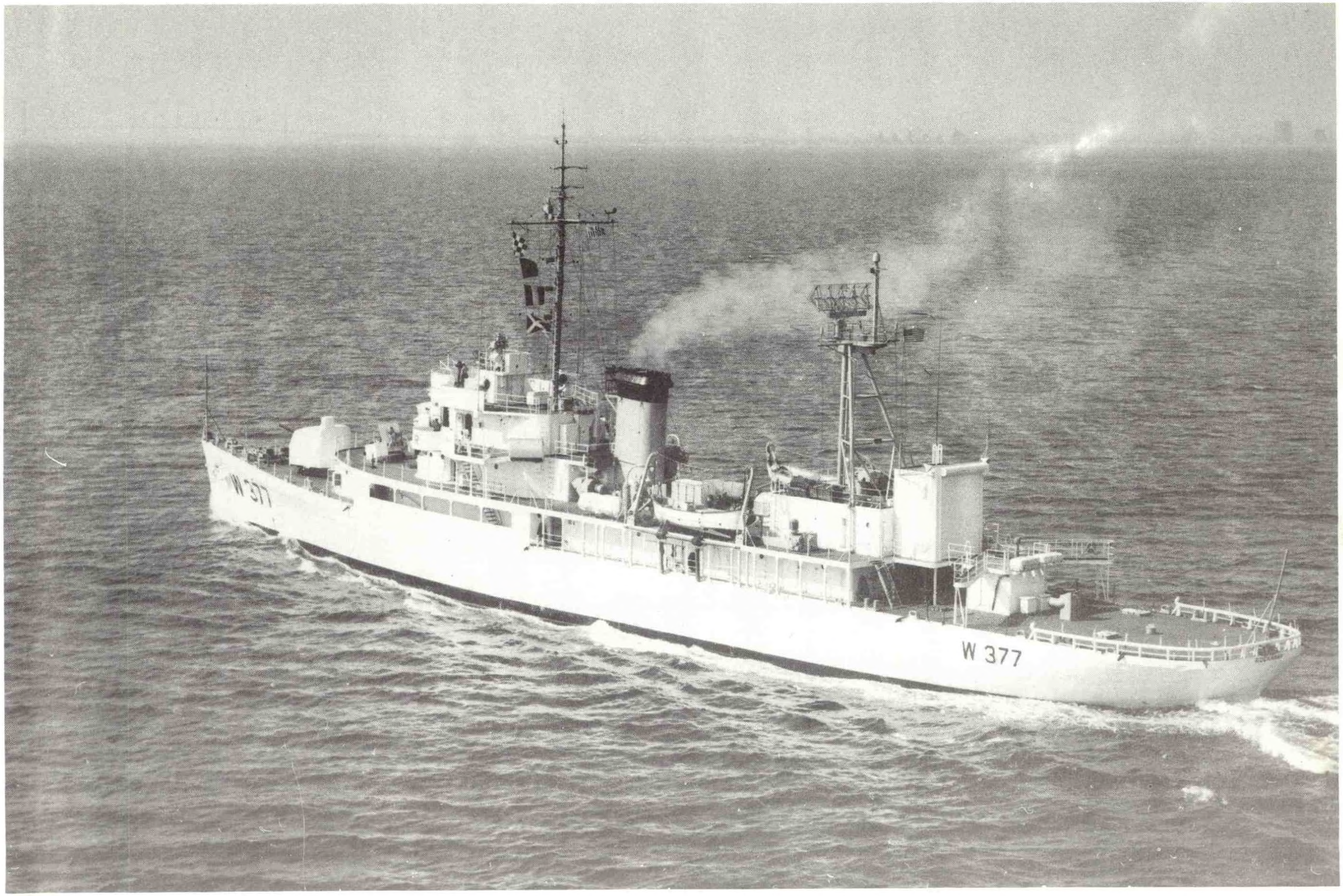


FIGURE 2. USCGC ROCKAWAY

h) NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

NCAR will participate in BOMEX in three ways: First, research projects conducted by members of the NCAR scientific staff as add-on experiments within the BOMEX framework; second, Facilities Laboratory support of individual research projects planned and conducted by university groups within BOMEX; and third, participation in the central planning activities of the project office. Dr. Firor has named Dr. Stig A. Rossby as the NCAR focal point for this activity and he has been active in the planning activities of the Project Office. NCAR indicates that it may be appropriate later as the program develops to attach additional NCAR engineering specialists.

NCAR plans to conduct at least two research projects within BOMEX. One is a continuation of their 1968 participation with Florida State University (FSU) in Barbados. The other is an effort to employ an aircraft system for measuring atmospheric fluxes. NCAR expects that the Cloud Physics and Atmospheric Dynamics (CPAD) aircraft will be available by 1969 for atmospheric dynamics observations and Drs. Lilly and Lenschow hope to be able to measure low-level fluxes of momentum, temperature and water vapor.

i) NATIONAL OCEANOGRAPHIC DATA CENTER

NODC will provide support in oceanographic data processing and has designated Mr. Irving Perlroth as their agency contact to BOMEX. NODC plans to provide personnel to aid in data handling design, scientific programming and formatting.

5. SUBSURFACE OCEANIC DATA

Consulting Atlantic Ocean Atlas (Fuglister, WHOI, 1969), it is apparent that at these latitudes the thermocline is most intense and shallow at the eastern portion of the Atlantic Ocean and becomes less pronounced and deeper on the western side of the Atlantic. For example, the cruise of CRAWFORD from Guadeloupe to French West Africa in November 1957 shows that at 16°N the 25°C isotherm slopes from about 40 meters at 25°W to about 100 meters at 60°W. Similarly, the 20°C isotherm slopes from 50 meters at 25°W to about 180 meters at 60°W. Figure 3 is a section of the record from this cruise between 50° and 60°W.

Some examples of BT slides within the BOMEX area are shown in Figure 4. All slides reveal a subsurface temperature increase of 1°C between 50 meters and 60 meters, the mixed layer depth being about 50 meters. From 50 to 70 meters down, the temperature decreases continuously to about 700 meters, and then at a lesser rate to 3000 meters.

Figures 5 and 6 summarize the data from oceanographic stations at locations and times indicated.

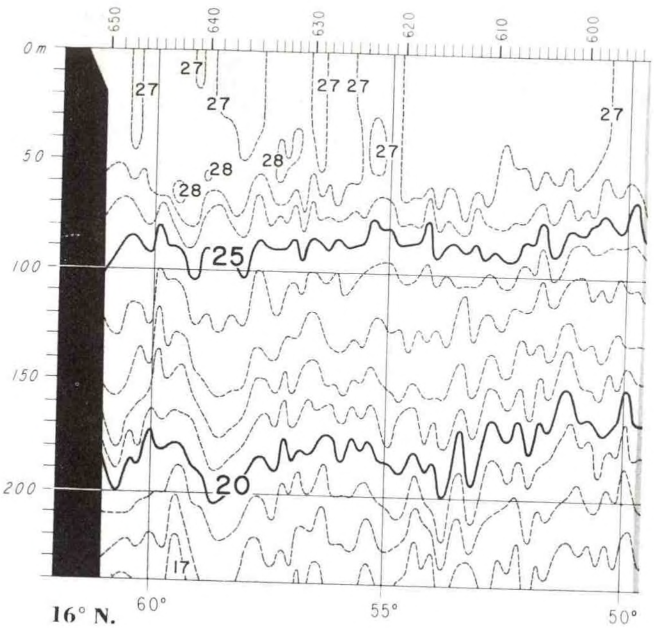


Figure 3.
(Source: Atlantic Ocean Atlas, Fuglister (1960), WHOI)

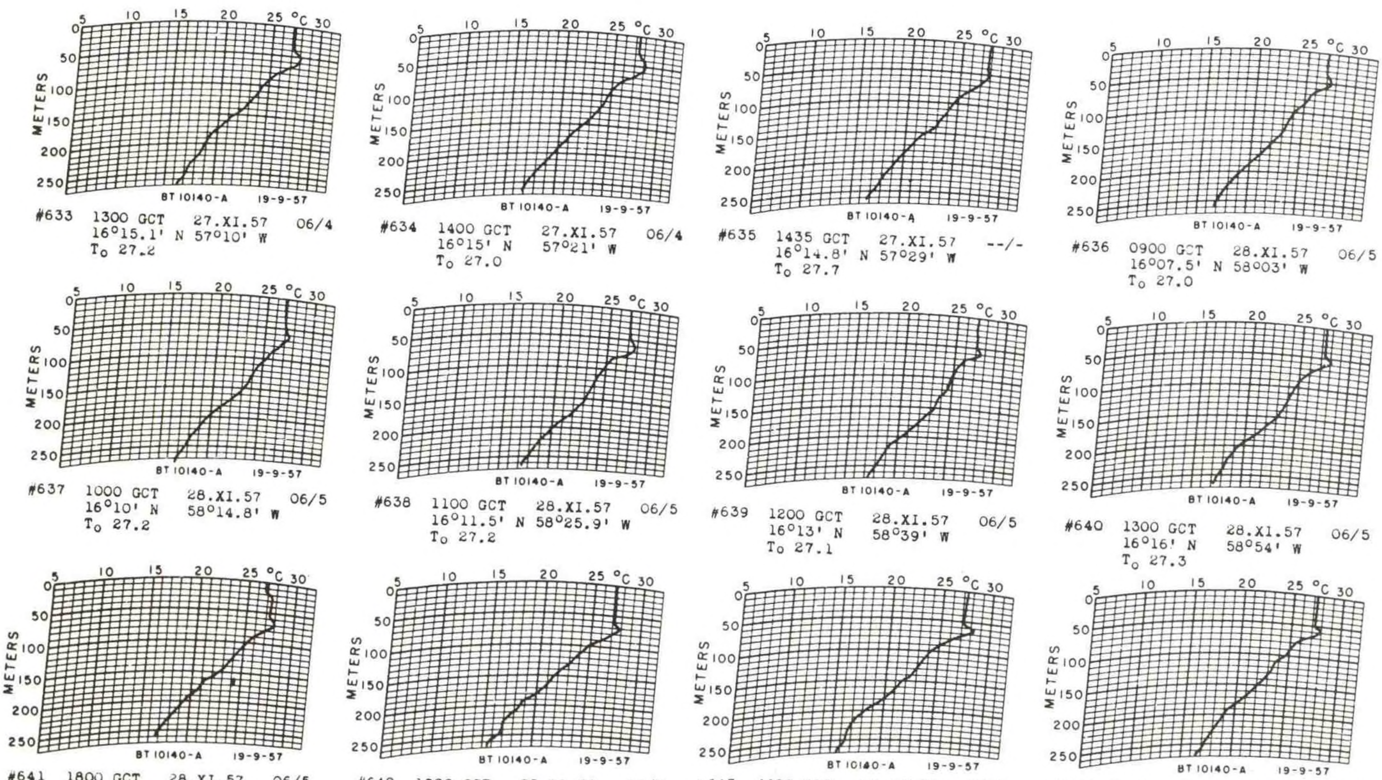
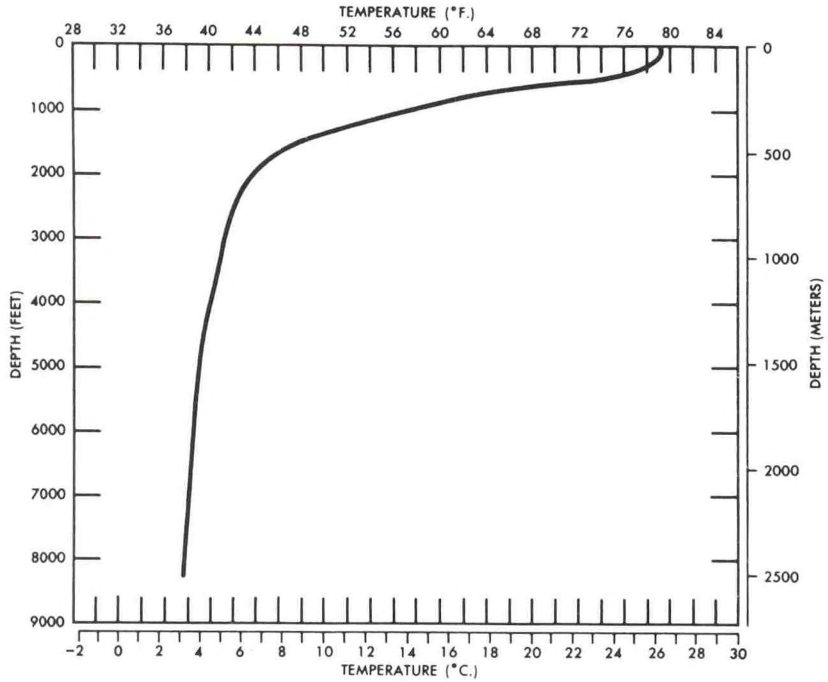
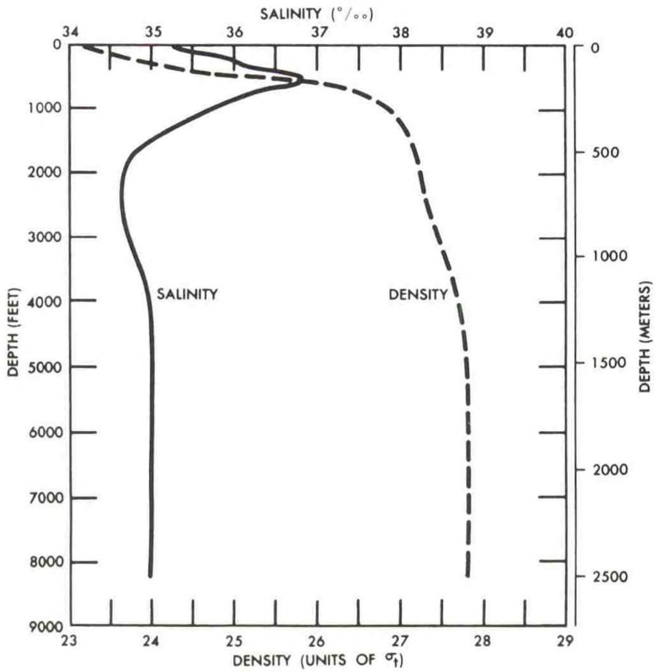


Figure 4.
(Source: Atlantic Ocean Atlas, Fuglister (1960), WHOI)





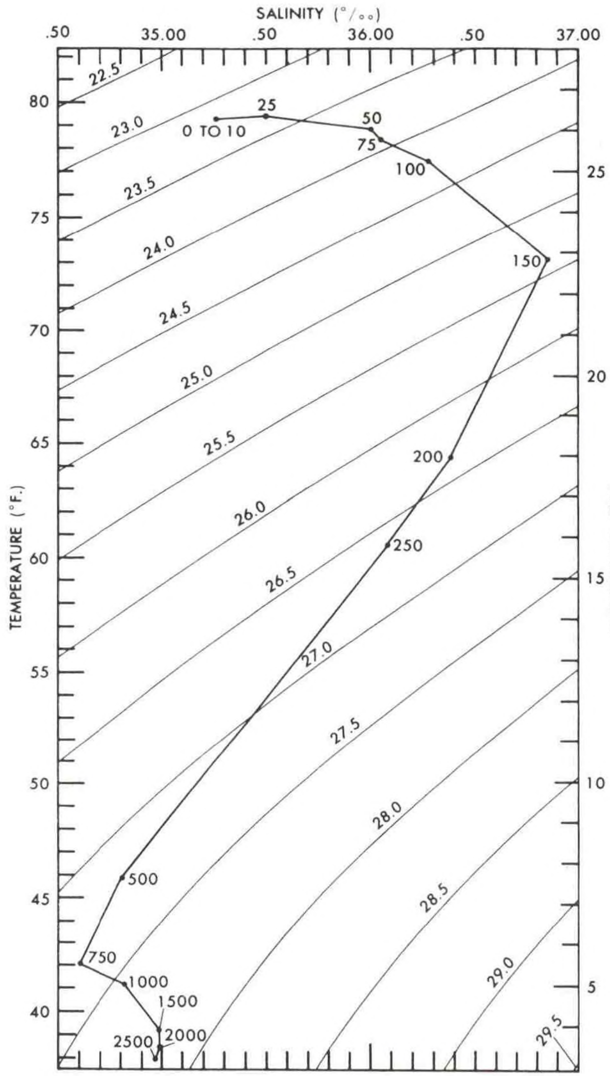


Figure 5

HMS CHALLENGER
3 May 1934, 14°00'N, 59°30'W

(Source: Oceanographic Atlas of the North Atlantic Ocean, Section II, USNOO (1967)

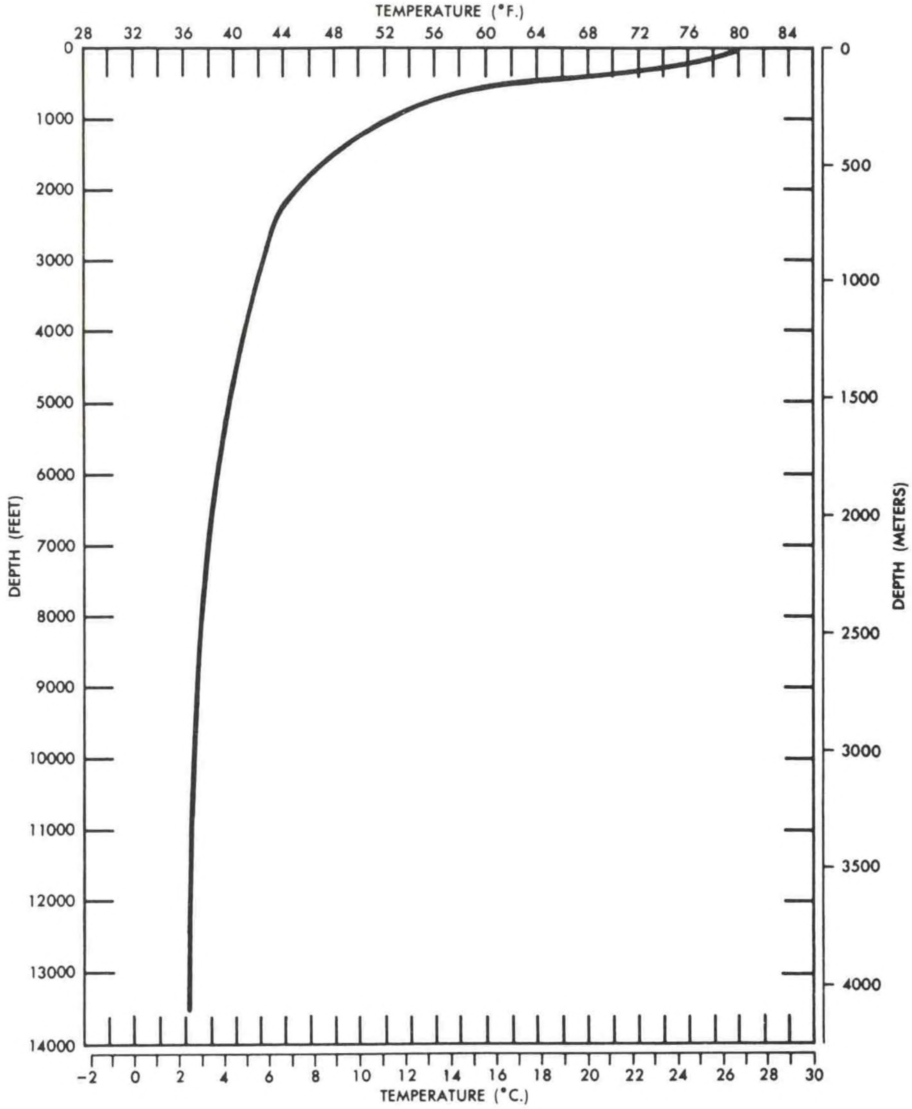


Figure 6. U.S.S. SAN PABLO, 16°00'N, 58°00'W

(Source: Oceanographic Atlas of the North Atlantic Ocean, Section II, USNOO (1967)

In September and October 1967, the Navy conducted oceanographic work east and south of Barbados. Current data from an oceanographic buoy is also available. The data is presently being analyzed by Dr. Paul Mazeika of the Navy Oceanographic Office. Summarized results will be published in one of the future issues of the Bulletin.