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DEPARTMENT OF INTERIOR-DEPARTMENT OF TRANSPORTATION

BOMEX BULLETIN NO. 5

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Prepared by

THE BOMAP OFFICE, ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
6010 EXECUTIVE BLVD. • ROCKVILLE, MD. 20852 • TELEPHONE 301-496-8637

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1. INTRODUCTION

The fifth in the series of BOMEX Bulletins outlines the transition from BOMEX to the new BOMAP (Barbados Oceanographic and Meteorological Analysis Project). The BOMEX Project Office has been disestablished and a new office, BOMAP, has been established within the ESSA Research Laboratories. This office will coordinate data handling and data exchange and will conduct the analysis of the primary sea-air interaction ("Core" Experiment).

This bulletin will review the field phases of BOMEX, which has been successfully concluded. The objectives and structure of BOMAP, and the plans for scientific analysis of the BOMEX data will be outlined. The management of the BOMEX data will be reviewed with specific information of how, when, and where to get data. The coordination of data processing and results with BOMEX investigators and the scientific community will be discussed.

2. REVIEW OF BOMEX FIELD OPERATIONS

A. General Operations

Barbados Oceanographic and Meteorological Experiment (BOMEX) was a national program, the first of a series of large-scale research projects planned by nations of the world under the Global Atmospheric Research Program (GARP).

The scientific objectives of BOMEX were described in BOMEX Bulletin Number 4. Briefly, the goal was to study the sea-air interaction, which drives the atmosphere's circulation and global weather systems. The sea-air interface has been described as the scene of a complex and continuous exchange of energy, water, gases, and particulates.

Most of the heat received from the sun is stored in the tropical oceans between latitudes 30°South and 30°North. In contrast, the earth loses heat by radiation almost uniformly at all latitudes, so heat has to be transported from equatorial regions to higher latitudes. Strangely enough, this transport is not done by the ocean, but primarily by the atmosphere. This process, of which relatively little is known, seems to occur in three stages. First, the energy in the ocean is transferred to the atmosphere in a turbulent boundary layer about 6,000 feet thick. Most of this energy moves from ocean to air as latent heat in the form of water vapor. Next, the energy finds its way from the boundary layer to the upper layers of the troposphere. Finally, it is transported to higher latitudes by fast-moving air currents, sometimes in the nature of jet streams.

BOMEX's objective was to explore the first two steps in the transport process. Data were collected to examine in detail the exchange of energy between the ocean and atmosphere and the vertical and horizontal transport of these energies within each fluid. ESSA -- as the lead agency for BOMEX -- coordinated and directed the experiment through the BOMEX Project Office and the control center on Barbados.

Seven Federal departments and independent agencies; universities, and six industrial research laboratories in the United States, Canada, and Barbados participated in BOMEX with the cooperation of the Government of Barbados. The U.S. Government participants were:

Department of Commerce
(Environmental Science Services Administration);

Department of Defense
(Air Force, Army, Navy, and National Guard);

Department of the Interior
(Bureau of Commercial Fisheries);

Department of Transportation
(Coast Guard);

Atomic Energy Commission;

National Aeronautics and Space Administration; and the

National Science Foundation.

In all, an armada of 12 ships, 28 planes, and 1500 scientists and technicians converged on Barbados at the beginning of May 1969, to conduct this most difficult and complex scientific research program.

The initial BOMEX array (May and June) was a square bounded by four Coast & Geodetic Survey ships -- the OCEANOGRAPHER, DISCOVERER, MT. MITCHELL, and RAINIER - with the Coast Guard Cutter ROCKAWAY stationed at the center. The five ships were provided with special instrumentation and supplies during March and April. This included signal conditioning and recording devices, sensor equipment, meteorological booms, boundary layer instrument packages, and free-fall mooring systems. The signal conditioning and recording devices (SCARD) recorded the basic data taken by the shipboard and oceanographic instruments.

Some difficulties were experienced with the free-fall mooring systems which were designed to permit the ships to anchor at their stations in 18,000 feet of water. The RAINIER mooring system failed on May 1, the MT. MITCHELL on May 3, the ROCKAWAY on May 25, and the DISCOVERER and OCEANOGRAPHER on June 21, 1969, but the ships were able to operate satisfactorily in a station-keeping mode.

Wind finding at-sea systems (Scanwell) were installed on the OCEANOGRAPHER, RAINIER, and MT. MITCHELL. These provided the capability for taking winds aloft observations and upper-air soundings from a moving ship. A special purpose meteorological radar (Selenia) was installed on the DISCOVERER for upper-air wind observations, and documentation of precipitation areas and rates.

A 30-foot boom was fixed to the bow of each of the five ships to measure near-surface environmental conditions. On the boom, an array of meteorological instruments sensed dry bulb, wet bulb, and sea surface temperatures, relative humidity, wind speed and direction, and net, incident, and reflected radiation.

Tethered, blimp-like balloons -- 26 feet long and 10 feet in diameter -- flown from four of the five station vessels, carried instruments that measured temperature, humidity, and wind at one or more levels within the lowest 2,000 feet of the atmosphere close to the sea surface. These systems were called BLIP (Boundary Layer Instrument Package). The fifth vessel, the ROCKAWAY, flew a similar system called Subcloud Instrumentation Telemetry System (SITS), developed by Florida State University.

In addition to the vessels at the corners and the center of the array, other ships participated in the project at various times. They were the Coast Guard Cutters LAUREL and COURAGEOUS, the U.S Navy Ship GILLISS, the Cape Fear Technical Institute's ADVANCE II, and the Bureau of Commercial Fisheries Research Ship UNDAUNTED.

A floating laboratory instrument platform (FLIP) was an unpowered 355-foot platform resembling part of a ship at the end of a 300-foot tube. When the tube was filled with water, the entire assembly was upended to furnish a stable platform. A network of instrumented booms extended outward, upward, and downward from the small portion above water.

Twelve buoys in the BOMEX array measured ocean currents and temperatures at different depths, sea-surface temperatures, and meteorological conditions close to the surface.

Information at levels up to 60,000 feet was gathered by a fleet of aircraft that included the four planes from ESSA's Research Flight Facility, weather reconnaissance and research aircraft from the Air Weather Service and the U.S. Navy, and other planes from the National Center for Atmospheric Research, the National Aeronautics and Space Administration, Woods Hole Oceanographic Institution, Colorado State University, and the University of California.

The first three BOMEX data-gethering periods: May 3-15, May 24-June 10, and June 19-July 2 were concerned with the interactions between ocean and atmosphere.

Two independent methods were used in the design of the experiment. One, the point method, measured the upward and downward flow of energy in both sea and air at specific points on the sea surface. The second, or volume method, treated the BOMEX area as a cube. Instrumented aircraft flying around the large cube of air and ships at the corners with both free and tethered balloons measured the inward and outward flow of air with its content of heat and moisture. Salinity, temperature, and depth were measured by instruments "STD's" lowered into the ocean at the ship stations.

In concentrated observation periods of approximately 4 days each, conditions in the BOMEX area were measured by the instrumented balloons, by instruments dropped from aircraft, by the ships at the corners of the array, and by day and night "line integral" flights around the cube's outer perimeter. During these intensive data-gathering periods, serial rawinsonde observations were made 15 times a day, dropsonde observations were taken at eight points within the array both day and night, and shipboard observations were scheduled to coincide with the rawinsonde observations.

These measurements will be used to calculate the net gains or losses in heat, moisture, and wind energy in the volume of air overlying the BOMEX square, and the amount of heat and moisture that the atmosphere over the area receives from the sea. The five ships in the BOMEX array also measured water vapor transport independently.

After logging at BOMEX Field Headquarters, the data tapes, associated data sheets, on-board recorded strip charts, and films were flown to NASA's Mississippi Test Facility for data processing and reduction.

The fourth period (July 11-28) was devoted to the exploration of convective systems. It is in these systems that most of the energy in the atmospheric boundary layer is transported to higher levels and distributed throughout the troposphere. During this period, a group of 11 aircraft was dispatched to take observations in areas of extensive convective activity. The choice of the areas was determined from cloud photographs from ESSA Satellites and the NASA ATS-III synchronous satellite.

To increase the chances of intercepting tropical disturbances, the ship array was changed on July 11 to the configuration shown in figure 1. In this way, the latitudinal spread was extended to incorporate the Intertropical Convergence Zone.

The structure of the normal ITC (Intertropical Convergence Zone) is of great importance to the general circulation. The operations during Phase IV are considered to be the best exploration of the ITC ever conducted. The structure and the way the structure and nature of disturbances related to it were investigated. Some 46 independent research projects were conducted during this tropical convection study.

B. Data and Preliminary Findings

The volume of data to be analyzed is prodigious. Instrumented aircraft of the participating agencies flew more than a million miles on 509 research missions, continuously recording observations of a variety of weather elements for more than 4,000 hours. Some 500 dropsondes were released from the participating aircraft during BOMEX operations.

The five ships in the BOMEX array carried out 1316 soundings of ocean temperature and salinity. These ships and an island station operated by the Air Force's Air Weather Service launched and tracked 2400 upper-air sounding balloons to gather information on temperature, humidity, air pressure, wind speed and direction, and radiation to altitudes as high as 100,000 feet.

A total of some 500 separate SCARD tapes were collected, covering 7680 hours of meteorological and oceanographic data.

A preliminary data summary of teletype messages from the five BOMEX array ships shows the following:

7110 hours of Boom operation;

1400 STD observations;

710 hours of boundary layer observations;

1060 hours of Atmospheric sampling -- AEC;

4405 hours of ship navigation.

Preliminary examination of the BOMEX data indicates that some concepts concerning the physical processes at work near the sea-air interface may have to be revised. Examples are:

1) Oceanographers found strong eastward-moving currents in the Atlantic off Barbados, where ocean atlases show predominately westward-flow.

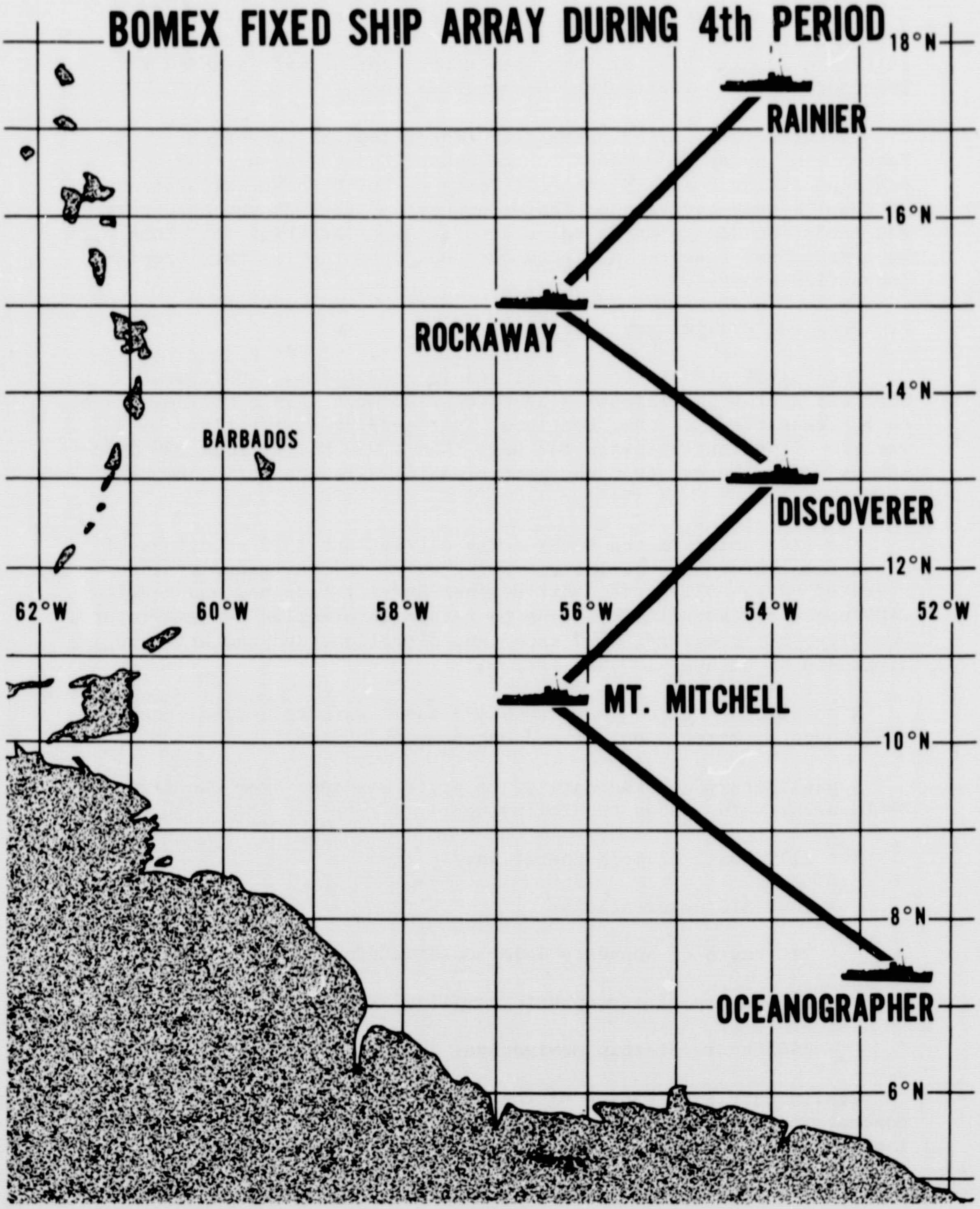
BOMEX FIXED SHIP ARRAY DURING 4th PERIOD
18°N
RAINIER
16°N
ROCKAWAY
14°N
BARBADOS
DISCOVERER
12°N
62°W
60°W
58°W
56°W
54°W
52°W
MT. MITCHELL
10°N
8°N
OCEANOGRAPHER
6°N

FIG. 1

2) Ocean measurements disclosed a large water mass, probably from the Amazon River, that remains unmixed with ocean water as far as 1,000 miles from the mouth of the river.

3) FLIP data indicated the presence of small atmospheric 'fronts', with sudden temperature and humidity increases or decreases, the humidity displacements continuing for several minutes, while the temperature returns quickly to its previous value. The existence of patches of moist and dry air a mile or so in diameter with little change in temperature was known to occur in the cloud-bearing layer, but the existence immediately adjacent to the sea surface and the sharpness of the boundaries were surprising.

4) Measurements of radiation taken at several levels revealed that perhaps twice as much incoming solar radiation is absorbed in the tropical atmosphere as had been believed (though still only a small fraction). Thus, the amount of solar radiation available to heat the oceans is slightly less than previously estimated.

5) Preliminary analysis of the fourth period data indicates that the ITC is easily deformed by weather disturbances farther north. This deformation apparently creates cloud circulations which are characteristic of tropical storms. The arrival of an inverted "V" cloud system created a bulge in the ITC and consistently brought disturbances to the BOMEX area.

C. <u>Additional Research Projects</u>

Nearly 100 independent research projects are included in BOMEX. These can be divided into five major areas: oceanographic, radiation, and satellite studies in addition to the sea-air interaction program and the exploration of tropical convective systems. Eighty-seven of these were listed in BOMEX Bulletin No. 4.

Thirteen additional research projects which were not listed previously in BOMEX Bulletin No. 4 are as follows:

88) EXPERIMENT TITLE: Experimental Microwave Radiometer Data in BOMEX.
PRINCIPAL INVESTIGATOR: Mr. F.T. Barath
AFFILIATION: JPL
FUNDING SUPPORT: NASA
EXPERIMENT DESCRIPTION: A 9.3GHz NADIR looking microwave radiometer measuring sea surface brightness temperature at a wavelength of 3.1 cm will be used for development of Earth Resources Satellite sensors.
PRINCIPAL PLATFORMS & SENSORS: CV-990: 9.3GHz, NADIR looking microwave radiometer.
SUPPLEMENTAL PLATFORMS & SENSORS: All data from CV-990.

89) EXPERIMENT TITLE: Aircraft LIDAR Measurements
PRINCIPAL INVESTIGATOR: Dr. Paul Davis
AFFILIATION: Stanford Research Institute
FUNDING SUPPORT: NASA
EXPERIMENT DESCRIPTION: Ruby Lidar measurements will be made to determine height and thickness of cirrus clouds and haze layers.
PRINCIPAL PLATFORMS & SENSORS: CV-990: LIDAR
SUPPLEMENTAL PLATFORMS & SENSORS: None

90) EXPERIMENT TITLE: Operational Use of Satellite Data in Scientific Mission Planning.
PRINCIPAL INVESTIGATOR: Captain G.J. Dittberner
AFFILIATION: U.S. Air Force
FUNDING SUPPORT: NSF, NCAR
EXPERIMENT DESCRIPTION: To test a method of expediting the data flow of real-time satellite data peculiar to field operations and daily planning of scientific aircraft missions.
PRINCIPAL PLATFORMS & SENSORS: ATS-III satellite, Hughes ATS ground station, APT ground station.
SUPPLEMENTAL PLATFORMS & SENSORS: Physical facilities available on Barbados.

91) EXPERIMENT TITLE: Area Precipitation Estimate
PRINCIPAL INVESTIGATOR: Captain G.J. Dittberner
AFFILIATION: U.S. Air Force
FUNDING SUPPORT: ESSA
EXPERIMENT DESCRIPTION: To establish a best estimate of the amount and distribution of precipitation over the BOMEX area as a function of time and of the errors of measurement and sampling.
PRINCIPAL PLATFORMS & SENSORS: Satellites: visual and IR photographs: Aircraft: weather radar, cloud photography.
SUPPLEMENTAL PLATFORMS & SENSORS: Island: radar, rain gage
Ship: rawinsonde

92) EXPERIMENT TITLE: Diffusion Studies in the Ocean Langmuir and Ekman Layers.
PRINCIPAL INVESTIGATORS: Mr. Sam Gerard and Dr. Arnold Gordon
AFFILIATION: Lamont-Doherty Geological Observatory
FUNDING SUPPORT: NAVOCEANO
EXPERIMENT DESCRIPTION: To obtain diffusion constants in the ocean Ekman Layer using dyes and other physical parameters.
PRINCIPAL PLATFORMS & SENSORS: U.S. Navy Ship GILLISS: STD, dye emitter, fluorometer, and command sampler. Aircraft: photography of dye.
SUPPLEMENTAL PLATFORMS & SENSORS: All ship STD's.

93) EXPERIMENT TITLE: Weather Radar Investigations on the BOMEX.
PRINCIPAL INVESTIGATOR: Dr. Michael D. Hudlow
AFFILIATION: U.S. Army
FUNDING SUPPORT: ESSA, U.S. Army Atmospheric Science Laboratory.
EXPERIMENT DESCRIPTION: To obtain measurements of storm characteristics, including reflectivity distributions, for the duration of BOMEX. Radar scope photography will be employed. Time-lapse photographs with gain-stepping, will be taken with an automatic 35mm camera. In addition, a minimum of one polaroid photo every 3 hours will be collected for real-time documentation. Elevation sequencies will be taken twice daily. From the radar photographs and other available data, temporal and areal estimates of precipitation can be made. Also, many statistical properties of storms can be deduced. Preliminary analyses of the radar pictures, primarily polaroid photos, will be made. Recommendations concerning further processing and analyses of the radar film, and other data pertinent in deriving precipitation inputs for the line integral experiment will be offered.
PRINCIPAL PLATFORMS & SENSORS: MPS-34 weather radar.
SUPPLEMENTAL PLATFORMS & SENSORS: Island and ship rain gages.

94) EXPERIMENT TITLE: Automatic Processing of Rawinsondes at BOMEX Field Headquarters.
PRINCIPAL INVESTIGATOR: Mr. George Langer
AFFILIATION: NCAR
FUNDING SUPPORT: NCAR
EXPERIMENT DESCRIPTION: Digital magnetic tape recordings will be made of all rawinsonde flights made at BOMEX Field Headquarters by the Sixth Mobile Weather Squadron, of the U.S. Air Force, using a GMD-1. The tape will be processed for developing automated rawinsonde techniques.
PRINCIPAL PLATFORMS & SENSORS: Barbados: rawinsondes.
SUPPLEMENTAL PLATFORMS & SENSORS: None.

95) EXPERIMENT TITLE: Day-to-day Variation of Divergence in Trade-Wind Region.
PRINCIPAL INVESTIGATOR: Mr. Robert W. Reeves
AFFILIATION: NHRL
FUNDING SUPPORT: ESSA
EXPERIMENT DESCRIPTION: To determine the day-to-day variation of divergence over the BOMEX array using line integral techniques.
PRINCIPAL PLATFORMS & SENSORS: All BOMEX aircraft: Doppler radar.
SUPPLEMENTAL PLATFORMS & SENSORS: None
FIELD PHASE: 1) Dates: May 2 to July 3, 1969
2) Part of group: ESSA "Core"
3) Miscellaneous

96) EXPERIMENT TITLE: Current Measurement Comparisons Between Free Floating RAFT's and GEK.
PRINCIPAL INVESTIGATOR: Mr. R. Ribe
AFFILIATION: NAVOCEANO
FUNDING SUPPORT: NAVOCEANO
EXPERIMENT DESCRIPTION: GEK measurements will be made simultaneous with current drogue tracking for intercomparison.
PRINCIPAL PLATFORMS & SENSORS: Coast Guard Cutter COURAGEOUS: GEK.
SUPPLEMENTAL PLATFORMS & SENSORS: Current drogue data and Navy current meter arrays.

97) EXPERIMENT TITLE: BOMEX Atmospheric Electricity Experiment
PRINCIPAL INVESTIGATOR: Dr. Stig Rossby
AFFILIATION: NCAR
FUNDING SUPPORT: NCAR
EXPERIMENT DESCRIPTION: To measure the rate of occurrence of VHF (165 MHz) sferics, the vertical component of the atmospheric electric field, the surface atmospheric space charge density, and precipitation charge from the island of Barbados.
PRINCIPAL PLATFORMS & SENSORS: Barbados: VHF receivers.
SUPPLEMENTAL PLATFORMS & SENSORS: Barbados: rawinsondes, precipitation and radar photos.

98) EXPERIMENT TITLE: Sea Surface and Cloud Photography from the CV-990.
PRINCIPAL INVESTIGATORS: Mr. John Semyan and Mr. William Vetter.
AFFILIATION: NASA/GSFC
FUNDING SUPPORT: NASA
EXPERIMENT DESCRIPTION: Sea surface and cloud pictures will be taken during all of the CV-990 missions in support of satellite sensor development and techniques.
PRINCIPAL PLATFORMS & SENSORS: CV-990: 70mm and 35mm data motion picture cameras; closed circuit TV.
SUPPLEMENTAL PLATFORMS & SENSORS: None.

99) EXPERIMENT TITLE: Geological and Geophysic Studies of the Ocean Bottom Layers near Barbados.
PRINCIPAL INVESTIGATOR: Dr. Watkins
AFFILIATION: University of North Carolina
FUNDING SUPPORT: ONR
EXPERIMENT DESCRIPTION: To conduct geophysical sampling in the surrounding ocean of Barbados to determine the geological derivation of the Island.
PRINCIPAL PLATFORMS & SENSORS: Cape Fear Technical Institute's ADVANCE II: 5kw Sparker, PDR.
SUPPLEMENTAL PLATFORMS & SENSORS: None.

100) EXPERIMENT TITLE: Studies of Ozone and Radiation in the Upp
Atmosphere during BOMEX.
PRINCIPAL INVESTIGATOR: Dr. Weinman
AFFILIATION: University of Wisconsin
FUNDING SUPPORT: NASA
EXPERIMENT DESCRIPTION: To measure profiles of ozone concentration and radiation flux in the upper tropical atmosphere.
PRINCIPAL PLATFORMS & SENSORS: Cape Fear Technical Institute's ADVANCE II: Ozone sondes and radiometer sondes.
SUPPLEMENTAL PLATFORMS & SENSORS: None.

Three research projects have been cancelled:

EXPERIMENT #21: Vertical Variations of Water Temperature and Sound Velocity.
PRINCIPAL INVESTIGATORS: Dr. F.H. Fisher and Dr. T.D. Foster.

EXPERIMENT #22: Vertical Variations of Current Profiles.
PRINCIPAL INVESTIGATORS: Dr. F.H. Fisher and Dr. T.D. Foster.

EXPERIMENT #55: Planetary Boundary Layer Turbulence Experiment (using the BUFFALO platform).
PRINCIPAL INVESTIGATORS: Dr. D.K. Lilly and Dr. J. Telford.

In many of these research projects, data are now in the process of being analyzed. Other experimenters are awaiting BOMEX data. It is anticipated that many valuable scientific papers will result from the coordinated BOMEX efforts.

3. BOMAP

A. Objectives

An office, the Barbados Oceanographic and Meteorological Analysis Project, has been established within the ESSA Research Laboratories.

BOMAP coordinates the reduction and scientific evaluation of observations made during the BOMEX field season, May 3 through July 28, 1969, and the production of results in meaningful form; for example, scientific and technical publications, so as to be of use to the environmental science community in both immediate service operational application, and in the planning for further field research projects: especially those related to the Global Atmospheric Research Program (GARP).

ESSA maintains its role as lead agency for the work (as was accomplished in the BOMEX Project) by establishing requirements and by coordinating, planning, and directing certain scientific data analyses and evaluations, including the application and use of resources pooled by the several cooperating agencies. In particular, reduction and analysis of data collected under the direction of the BOMEX Project Office in support of the Sea-Air Interaction Program will be directed by BOMAP. BOMAP will direct the reduction, but not the analysis, of data collected under direction of the BOMEX Project Office in the fourth phase of BOMEX in support of the Tropical Exploration Program. BOMAP will assist in coordinating but will not actively direct the reduction and analysis of data collected under the direction of other BOMEX participants. A more detailed outline of the BOMAP task areas is shown in figure 2.

B. Organization

Scientists, technical specialists and experts are detailed from ESSA's various components to work on phases of the project within a varying time frame established by the Director to accomplish milestones leading to the total objective of BOMAP.

Headquarters staff will consist of the Director, Deputy Director, technical, administrative and clerical assistants. The Project is organized as follows, according to location:

1) BOMAP Rockville Scientific Staff: developing data reduction and scientific computation requirements and synthesizing, evaluating, and interpreting the results of such computations.

2) BOMAP-MTF Field Office at NASA's Mississippi Test Facility, Bay St. Louis, Mississippi, with technical support at National Weather Records Center, Asheville, N.C., concerned with data reduction, scientific computation and archiving.

FIG.2 BARBADOS OCEANOGRAPHIC METEOROLOGICAL ANALYSIS PROJECT

TASK AREA STATEMENT
SEPT. 26, 1969

BARBADOS OCEANOGRAPHIC and METEOROLOGICAL ANALYSIS PROJECT (BOMAP)

Objectives:

1. To reduce all data collected in BOMEX under BOMEX PROJECT OFFICE direction and make it available to all investigators.

2. To complete analysis of the BOMEX "Core" Experiment (comparison of estimates of sea-air exchange of energy by the "line integral", "budget" and "aerodynamic" methods with direct measurements by eddy-covariance methods), for which ESSA, through BOMEX PROJECT OFFICE, provided the Principal Investigators, and for which the ship and aircraft arrays and operating schedules during the first three operational periods of BOMEX were designed.

3. To provide a central contact point and information exchange for all BOMEX investigators during the data reduction and immediate analysis period, and to provide a channel for unified publication of BOMEX experimental methods and results.

BOMEX DATA SYSTEM

MAJOR TASK AREAS:

1. To reduce all observations taken under BOMEX PROJECT OFFICE scientific direction, consisting of data taken from:
   (a) Ships holding station in the array;
   (b) Aircraft flights in support of the Core Experiment and the BOMEX Tropical Exploration Program;
   (c) Island stations operating under BOMEX PROJECT OFFICE direction.

2. To perform scientific computations required for the Core Experiment Analysis.

3. To provide a set of background analyses and charts of general meteorological and oceanographic conditions over the region and period within which BOMEX was conducted.

4. To archive all BOMEX data for the benefit of the general scientific community so as to insure proper:
   (a) Storage with minimal degradation of information content;
   (b) Prompt retrieval;
   (c) Dissemination.

BOMEX CORE EXPERIMENT ANALYSIS

MAJOR TASK AREAS:

1. Evaluation of the energy budget of the atmospheric volume overlying the BOMEX array.

   1a. Specification of computations required for atmospheric budgets of heat, mechanical energy, total mass, water vapor and momentum over the BOMEX array, and interpretation of the results;

   1b. Design of the statistical computations to produce minimum-error results and evaluations of the magnitudes of all errors of observation, sampling and computation, and their dependence on the temporal and spatial density of sampling;

   1c. Collation, evaluation and integration of direct observations of boundary layer fluxes of these properties;

   1d. Analysis of cloud observations and photographs, radiation flux measurements, rain gauge, salinity, radar and satellite data to obtain estimates of precipitation and radiative energy transfer and source terms.

2. Evaluation of the heat budget of the upper ocean underlying the BOMEX array.

3. Perform tests of the ability of currently available parameterization formulas to estimate the energy fluxes through the sea-air boundary.

BOMEX INVESTIGATORS INFORMATION EXCHANGE

MAJOR TASK AREAS:

1. Maintenance of a directory of all participants and projects in both the field phase and the data reduction and analysis phase of BOMEX.

2. Collecting and collating information from all BOMEX participants regarding their progress in BOMEX data reduction and analysis.

3. Preparation and issuance of a bulletin summarizing the progress, problems, and results of analysis of BOMEX data, approximately quarterly.

4. Otherwise expediting the exchange of scientific results among BOMEX participants.

5. Develop and produce a permanent publication series to serve as a medium for detailed accounts of BOMEX experimental and analytical techniques and data.

Approved: Joshua Z. Holland
Joshua Z. Holland
Project Director

Date: Sept 26 1969

3) BOMAP Miami Liaison Office, with support from National Hurricane Research Laboratory, Research Flight Facility, Atlantic Oceanographic Laboratory, and Sea-Air Interaction Laboratory, conducting tropical meteorological analysis, aircraft data-reduction and analysis, and oceanographic data analysis.

4) Special projects in cloud and precipitation analysis, vertical flux and precise ship tracking conducted at selected locations in the field and at headquarters.

The project is under the scientific and technical policy guidance of ESSA's Research Laboratories. The BOMAP Office is located physically adjacent to the Office of the Assistant Administrator for Environmental Systems for coordinating the contributions to BOMAP by ESSA components, other than ERL, and to facilitate interagency coordination and integration in the World Weather Program.

Figure 3 shows in very schematic form the major functional relationships between BOMAP and other organizational units.

The present BOMAP scientific staff consists of the following:

Joshua Z. Holland, Director
Arnold H. Glaser, Deputy Director

Rockville Scientific Staff

Calvin E. Anderson
Jose' Colon (part-time)
DeVer Colson
Terry C. de la Moriniere
Vance A. Myers
Eugene Rasmusson
Robert W. Reeves
James K. Sparkman
Scott L. Williams

Mississippi Test Facility Field Office

Raymond L. Joiner
Frank Quinlan
Mel Craddock
W. Wisner
M. Buchwald
J. Shelton

Miami Liaison Office

James McFadden

BOMAP ORGANIZATIONAL–WORKING RELATIONSHIPS FOR DATA REDUCTION AND PROCESSING

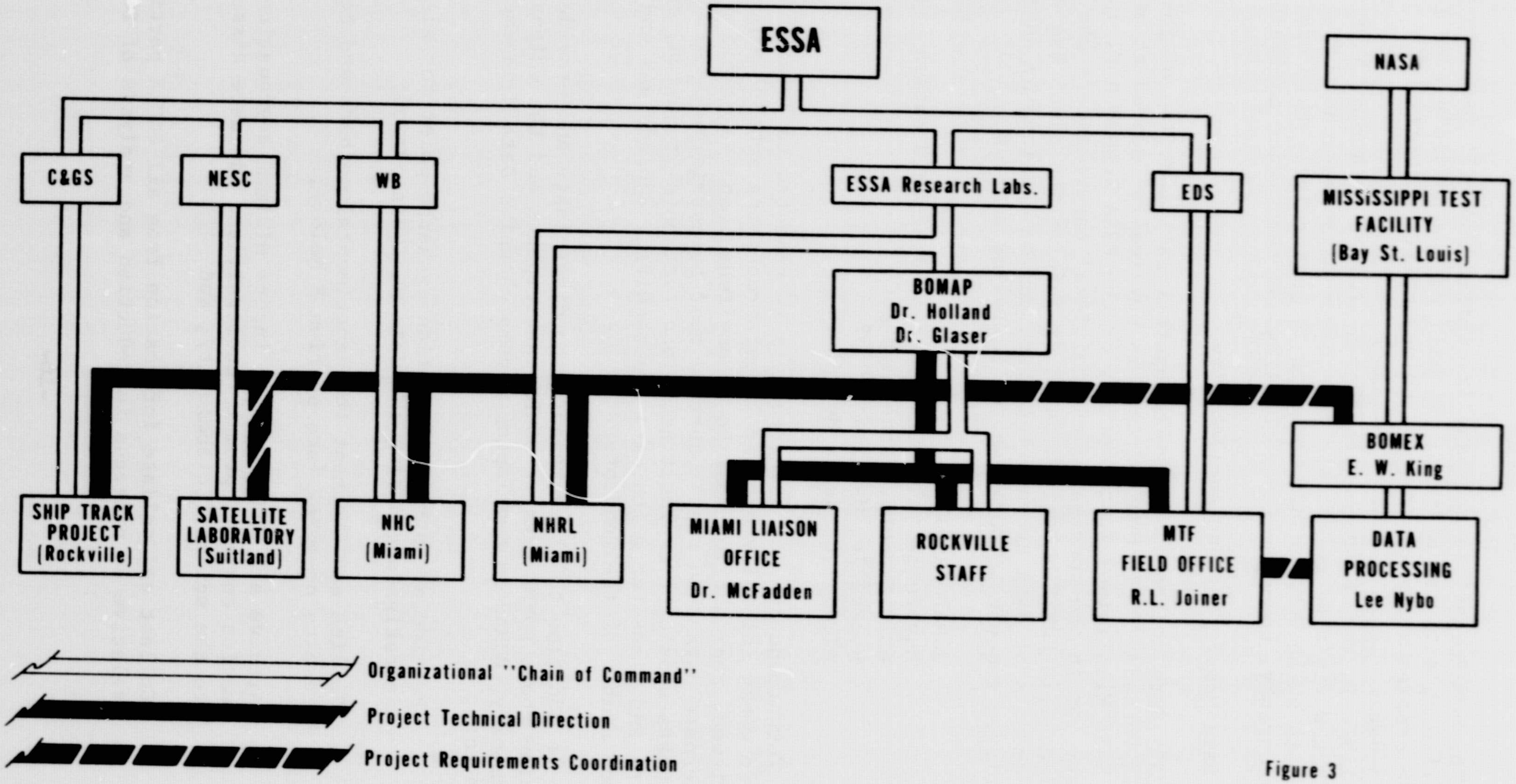

Figure 3

The BOMAP staff is necessarily limited and will focus on the specific objectives outlined. It will not be possible even in these problem areas to exhaust the scientific potential of the BOMEX data. It is planned that space and facilities can be made available in the BOMAP quarters for a limited number of participants and visiting scientists from other organizations. Specific areas in which BOMAP staff coverage is particularly thin are oceanography, boundary layer modeling and turbulence analysis.

C. Data Management and Availability

All data collected under the operational direction of the BOMEX Barbados Field Headquarters is physically located at either the NASA Mississippi Test Facility or the ESSA Research Flight Facility, or in the possession of individual experimenters who participated in BOMEX. Desired data, or information about the types and amounts of data at each location, can be obtained by submitting a written request to BOMAP at the following address:

BOMAP (Rx9)
Environmental Science Services Administration
6010 Executive Boulevard WSC5
Rockville, Maryland 20852
ATTN: T.C. de la Moriniere

Turnaround time on such requests is expected to be about two to three weeks initially because latest processing schedules must be reviewed, reproduction must be accomplished, and negotiation for alternate data than that requested must be considered. All data requests should be explicit as to observation(s) required, exact dates and times for which data are required, and address and telephone number of the requester.

In addition to these measures to disseminate and provide information about BOMEX data to BOMEX participants and the scientific community, BOMAP is developing a comprehensive Data Management System to:

Provide a central information exchange point for all BOMEX investigators during the data analysis period;

Publish and document the experimental methods and scientific results of BOMEX (see section F below);

Archive all BOMEX data to insure minimum degradation of information content, prompt retrieval, and adequate dissemination to the scientific community; and

Collect and collate information from all BOMEX participants relative to progress in reduction and analysis of BOMEX data.

Much of the preliminary design of such a data management system has been done (refer to Annex H of the BOMEX Operation Plan, January 1969). The framework established by the plan, which was adequate to support field operations, is being revised to reflect recent changes in the scope of the BOMAP data analysis objectives.

The BOMEX Data Catalog, which consists of one edition and two supplements, is being prepared for printing and distribution. The edition will contain a detailed inventory of observed data and an explanation of the mechanics for requesting and disseminating data that become available. This first edition is scheduled for distribution in early February 1970.

The first supplement will include an inventory of processed data products, supporting documentation, describing data processing, and the location of archived results which exist 1 year after the conclusion of the BOMEX Observation Phases. As implied above, this supplement amplifies the data inventory to reflect the availability of processed and validated data products, and support documentation 1 year after the BOMEX field data acquisition phase. This supplement is scheduled for distribution in September 1970. As validated data become available prior to that date, the cooperating investigators and the scientific community will be advised through the BOMEX Bulletin Series.

The second and final supplement will be a definitive and complete inventory of all observed data, processed data products, support documentation (processing techniques, instrument description, instrument operation histories, etc.), and archive locations at the conclusion of the planned BOMAP analysis activity.

Because of the nature and magnitude of the BOMEX data reduction problem, it is expected that a significant fraction of the reduced data will not be available for dissemination before early 1970. It is hoped that the data collected under BOMEX Field Headquarters direction will then become available in reduced form over a 6-month period.

In view of the large number of requests at BOMAP for basic meteorological and oceanographic data obtained during BOMEX, several volumes of unvalidated teletype data entitled "BOMEX Preliminary Data" are being published for limited distribution on request. It is hoped that these volumes will satisfy the immediate needs for planning and outlining future research studies. These volumes include:

Volume I: Ship-Station Surface Observations.

Volume II: Ship-Station Radiosonde Observations (Parts 1 & 2).

Volume III: Salinity - Temperature - Depth Observations (Parts 1 & 2).

Volume IV: Sea-Surface Temperature Observations.

Data in these volumes must be used with caution because of the following limitations:

1) The data must be considered unedited and unvalidated:

2) The data are assembled in chronological order only; no attempt was made to group the data according to ships;

3) Some data may be missing because of communication problems encountered in scheduled teletype messages (see BOMEX Operations Manual and BOMEX Bulletin No. 3 for schedules); and

4) Some data may be illegible because the data volumes are constructed from photographs of data on teletype paper.

D. Ship-Surface Data Reduction

The data referred to here are those recorded automatically on magnetic tape by the SCARD (Signal Conditioning and Recording Device) system. The SCARD system was designed and built by the General Electric Company as contractor to NASA's Mississippi Test Facility. Digitizing is being done primarily by NASA's Computer Operations Office at Slidell, La. Data reduction and much of the scientific computation will be done by the Mississippi Test Facility. The data recorded on SCARD include:

Time (from time-code generator)

Radiosonde temperature and humidity;

Rawinsonde slant-range and azimuth on the three ships with Scanwell wind-finding systems;

STD (oceanographic sounding) salinity, temperature, and depth;

Boom dry-bulb temperature, wet-bulb temperature, sea-surface temperature, wind direction, wind speed, incident solar radiation, reflected solar radiation, and net long-wave radiation;

Ship gyrocompass heading; and

Surface barometric pressure.

The data were recorded by SCARD as frequency modulated analog signals and are being converted to digital form prior to further processing. One ship, the DISCOVERER, recorded rawinsonde position information on punched paper tape, which was copied onto magnetic tape for data reduction. The ROCKAWAY recorded rawinsonde position information manually. ROCKAWAY rawinsonde position information and manually recorded supporting information from all ships are made available to the data-reduction program by means of punched cards or magnetic tape.

The use of computers in data-reduction is no longer a mystery, and its routine aspects will be omitted here. The factors peculiar to the BOMEX data reduction are:

Converting analogue data to digitized data;

Special measures taken to increase accuracy of the radiosonde data.

Direct reduction from raw data rather than from manually-selected data;

Problems introduced by automatic recording· and

Problems of accuracy resulting from the nature of analyses to be made from the data.

Digitizing is mentioned here merely to note that considerable effort is necessary to ensure that the digital numbers accurately describe the analog signals recorded from the sensors.

Several measures were taken to increase the accuracy of radiosonde data. The special calibrations made by the manufacturer were most important. Thermistors were calibrated individually and required to conform to a common calibration curve within 0.1°C maximum error. The carbon hygristors were lot calibrated and required to conform to a common calibration curve within 2 percent relative humidity maximum error. In addition, the resistance of each thermistor was measured at 30°C, eliminating one baseline computation. Finally, a special precision resistor, called the mid-reference resistor, was used in the normal high-reference position to allow the internal resistance of each sonde to be calculated. To complement the hygristor calibration, baseline readings were taken with precision thermometers graduated and calibrated to 0.1°C. The use of these special measures together with magnetic-tape recording and readout is expected to give system accuracy of about 0.25°C and 3 percent relative humidity.

Automated reduction of raw data, rather than manually-selected data, introduced the problems of data identification, noise rejection, significant point selection, determination of start and stop times, and selection of proper constants for transfer equations. Some of these problems are solved in the following ways:

1) The data identification problem was solved for the radiosonde as a by-product of the need to increase the density of humidity readings for BOMEX. Temperature and humidity sensors were placed on separate sondes, received by separate receivers, and thus the temperature and humidity data could be fed to the computer in separate channels.

2) Each STD sensor had its own frequency channel and presented no identification problems.

3) Boom and other surface data were commutated onto one channel and to date no problems have arisen from identifying data by commutation sequence.

4) A data identification problem does arise when radiometers are flown on the sondes. These data are being picked off the strip charts manually and are treated as noise by the automated program. There appear to be no insurmountable obstacles to strictly automated processing of these data but the manpower and time for programming and program checkout have not been available.

5) The most important factor in noise rejection is the use of a high sampling rate. This allows gross noise to be rejected immediately without contaminating adjacent samples. Noise close to expected sensor-output frequency or voltage can be handled by several methods, depending on circumstances or signal characteristics. The most obvious choice is to average or smooth several successive values together. Another choice requires new data to be within prescribed limits of previous data from the same sensor. Or, individual values within small groups can be required to be within prescribed limits of the group mean. In tests conducted to date, more elaborate schemes do not appear to be necessary or justified.

a) The basic digitizing rate for BOMEX data is ten samples per second. Values outside allowable ranges are discarded at this point and the remaining values combined by averaging into two-per-second samples, the averaging method depending on the type of data being treated. The two-sample-per-second data are fed to the data reduction program for further noise-elimination treatment and for reduction to meteorological units from the frequency or voltage values received from the digitizing process.

b) After noise elimination, the basic data for the data-reduction process are 5-second averages for all rawinsonde data and for STD depth, 1-second averages for STD temperature and salinity, and averages over the parameter sampling time (3/4-second) for boom and surface readings. The basic rate for BLIP (Boundary Layer Instrumented Package) is still to be determined.

c) Some further smoothing of 5-second averages of radiosonde temperatures, and possibly humidity, will be necessary. A study is being made to determine the best smoother to use in relation to resolution desired and noise to be eliminated.

6) A dual approach is planned in regards to selecting significant points from soundings and of averaging periods for archiving of boom/surface data.

a) First, reduced data from all sensors will be saved at the basic rates given in subparagraph 5b above, and these will be available to BOMEX experimenters on request.

b) To meet permanent archiving requirements, 30-minute averages will be saved for boom and surface data. Significant point data will be saved for rawinsonde temperature and humidity· significance criteria will be 0.25°C or 3 percent relative humidity departure from a straight line instead of the usual 1°C and 5 percent relative humidity. Rawinsonde winds will be archived as determined from 60-second average positions at 30-second intervals (i.e. two overlapping series of 60-second winds).

c) The final archiving sample rates for STD soundings and BLIP data have not been determined.

7) The problem of start and stop times is probably the most troublesome of all. No completely satisfactory method has been found for determining from recorded data exactly when a sounding started and stopped or when boom/surface sensors were operating properly. Several operating procedures and SCARD-recorded indicators were planned and more-or-less used, but all were victims of human failings, misguided ingenuity, and communication problems. The problem is further complicated by the apparent requirement for two start times for rawinsonde soundings: one for release time for wind determination, and one for actual start-of-rise time for other sounding computations. (The two times are not normally the same for shipboard releases.) The solution adopted is for start and stop times and sensor-inoperative times to be determined manually, using all available information, and to be fed into the program by means of punched cards or magnetic tape.

8) Many times during BOMEX it was found necessary to change sensors or to adjust output ranges of sensors. This requires that the data-reduction program select either the proper constant or the full transfer equation, depending on sensor serial number or on date and time of observation. (This short statement ignores the several man-months of work required to determine and cross-check transfer constants from calibration data and manufacturers' information.)

Data-reduction problems caused by automated recording are limited to those caused by rotary potentiometers. These devices were used to sense ship's heading from the gyrocompass and slant range and azimuth from the Scanwell rawinsonde equipment.

1) A loading correction is necessary for slant range and ship's heading. This is due to the current drain necessary to feed SCARD and calls for a maximum correction of about 0.035 volts. This is on the fringe of the noise level but is systematic.

2) Rotary potentiometers, of necessity, have a dead space between the terminals. This appears to have ranged from two to three degrees from one potentiometer to another. It is also suspected of changing from one revolution to the next on a given potentiometer, probably due to contact chatter or to accumulation of dirt or corrosion. The net effect will be a small uncertainty in ship's heading near true north and a small jump in slant range at 2000-meter intervals. Except for noting its presence, this problem will be ignored unless it is found to be significant.

3) The two problems mentioned above were avoided for Scanwell azimuth by providing a fine-azimuth potentiometer geared up 18:1 from the 360°-azimuth potentiometer. This reduces errors in the fine-azimuth to an acceptable size but it introduces another. This error arises from the practical impossibility of keeping the two potentiometers zeroed in precise synchronism. The problem was solved by using the fine-azimuth as reference in aligning the equipment and by requiring the data reduction program to allow for a small variable bias (or nonlinearity) in the 360° potentiometer.

4) Another problem with the rotary potentiometer, particularly for slant range, is the tendency of the signal to oscillate from maximum to minimum value several times before definitely changing. The simplest way to handle this is to treat such short-time oscillations as noise and to interpolate across the break after a change has definitely been made.

Problems of accuracy arise both from the better-than-normal accuracy available from some BOMEX sensors and from taking into account small errors that are normally overlooked.

1) The 0.1°C accuracy of radiosonde thermistors means that it becomes practical to correct for the 4- to 6-second lag coefficient of the standard Weather Bureau thermistor used for BOMEX. This gives a systematic correction of 0.1 to 0.2°C, making mean temperatures for layers slightly cooler and improving resolution somewhat for significant point location.

2) Using 5-second data as basic input for radiosonde computations makes it apparent that the baroswitch setting is generally disturbed during launch. Neglect of this error leads to computation of impossible balloon movements during the first minute or two of flight. A correction will be computed based on the difference between actual launch pressure and a launch pressure extrapolated from the first two pressure contacts after launch.

3) Scanwell rawinsonde slant-range values recorded on SCARD may begin with an initial reading of anything up to 2000 meters. The initial reading must be subtracted from subsequent readings to obtain the correct slant range. However, the signal is typically very erratic for the first few 5-second periods (probably because of interference from ships superstructure), requiring that the initial value be obtained by extrapolating backward after the signal has stabilized.

4) It has also been found that near the end of a rawinsonde flight, the direct shipboard output of slant range from the Scanwell recorder may differ by several hundred meters from that determined from data recorded on SCARD. This is due to the difference in time bases. The Scanwell recorder gets its time from 60 hz (cycles/second) ships power. SCARD obtained time from a time-code generator. There is no doubt that the time-code generator is a more accurate time keeper than the ship's frequency regulator, but the effect of the difference is to be evaluated.

5) Considerable doubt has arisen as to the proper source, or combination of sources, to use for surface temperature and humidity. The several sources available have only general agreement. Individual temperature readings from different sources typically differ by about a degree, but have been noted to be up to three degrees different. Pending further study, the problem has been resolved by obtaining radiosonde surface values by extrapolation downward from the 15- and 30-second readings.

6) Finally, there is the problem of accurate determination of ship's position. Even the Omega navigation system allows errors of up to 2 miles in the BOMEX area. The Coast and Geodetic Survey has agreed to restudy all navigation records and provide corrected position and velocity information. Corrections will then be applied to all computed winds.

E. Aircraft Data Reduction

One of the principal objectives of the sea-air interaction program was the collection of data to evaluate the budgets of mass, water vapor, momentum, and energy for the BOMEX volume. Several aircraft were flown in support of this objective. The U.S. Air Force WC-13C made dropsondes at several points along the diagonals of the array. The U.S. Navy WC-121 and the Research Flight acility (RFF) DC-6's and DC-4 gathered data on the perimeter of the array as well as on stepwise ascent soundings.

The diverse nature of the data-gathering systems requires different processing procedures. The data from the three RFF aircraft were gathered automatically on magnetic tape at the rate of one observation per second.

All of the Navy and Air Force data were hand tabulated. These data must be transferred to forms suitable for card punching, and then transferred to magnetic tape. Two to three months are required for this operation which will be done at the BOMAP Office in Rockville. This will be followed by evaluation of the errors in the wind-measuring sensors, and intercomparisons with other aircraft data and with shipboard data.

A quick partial reduction of the fourth period data will be done by Mr. Luis Cantilo of the University of Miami. A more complete processing of the RFF data will be done by RFF and NHRL using a modification of procedures normally executed in processing hurricane research flights. A set of basic, calibrated data is expected to become available in 4 to 6 months, and all BOMAX RFF flights are expected to be completed in 6 to 9 months.

F. Information Exchange and Publication

BOMEX investigators, including the BOMAP scientific staff, will require information from other BOMEX participants -- particularly the results of investigations that will aid in the interpretation of their own data. The BOMAP Office will attempt to maintain a directory of all research projects using BOMEX data and will serve as a clearing house for BOMEX data and scientific results. It is urgently requested that copies of all reports resulting from BOMEX, whether preliminary or final, be sent to the BOMAP Office. The availability of all BOMEX information will aid the BOMAP Staff in making appropriate referrals, in responding to inquiries, and in expediting communications among investigators.

BOMAP will utilize the following media for publication of scientific information:

1) BOMEX Bulletin series -- continued on a quarterly basis -- for rapid dissemination of information on status and progress of BOMEX data reduction and analysis, and for administrative information.

2) ESSA Technical Memoranda -- for prompt documentation and limited distribution of preliminary technical results.

3) ESSA Technical Reports -- for prompt publication of technical results expected to have a useful lifetime up to a few years, primarily as a means to further the development of final results and to permit BOMEX findings and techniques to be fully considered in the development of plans for future experiments.

4) Scientific journals -- for results of sufficient finality and importance to justify the delays in preparation, review and editing encountered in this type of publication.

5) A permanent BOMEX scientific publication series -- for more complete and detailed accounts of experimental and analytical methods, calibrations, and data tabulations than would normally be appropriate for journal publication.

The cooperation of all BOMEX investigators is needed to provide a definitive permanent record of BOMEX and to make the findings of BOMEX readily available to the entire scientific community.

It is expected that BOMEX investigators affiliated with other organizations and agencies will use their own normal channels for reporting results of the type mentioned in items (2), (3), and (4). Plans and procedures for item 5 will be developed with the benefit of suggestions from the BOMEX community and will be announced in future BOMEX Bulletins.

Recent arcicles describing BOMEX activities include:

1. **"The BOMEX Project," Joachim P. Kuettner and Joshua Holland, Bulletin of the American Meteorological Society, Vol. 50, No. 6, June 1969.**

2. **"Where the Air Meets the Sea," ESSA World, U.S. Department of Commerce, Environmental Science Services Administration, July 1969.**

3. **"The Barbados Story," Ann Cook, ESSA World, U.S. Department of Commerce, Environmental Science Services Administration, October 1969.**

4. LIST OF BOMEX MEETINGS

The first meeting on preliminary BOMEX results was held in Seattle, Washington, on November 20 and 21, 1969. Additional preliminary BOMEX results will be presented in a session on Meso-Scale and Larger Land and Sea Effects, at the Symposium on Planetary Boundary Layers, March 18-21, 1970, at NCAR, Boulder,Colorado. This meeting is under the auspices of IAMAP-IUGG* and is being organized by Dr. George Hidy.

It is expected that two sessions (Tuesday, April 21) will be devoted to BOMEX at the spring meeting of the American Geophysical Union and American Meteorological Society, to be held April 20-24, 1970, in Washington, D.C. Dr. Joachim P. Kuettner, of ESSA Research Laboratories, Boulder, Colorado, is organizing these sessions.

Additional information about these meetings can be found in the Bulletin of the American Meteorological Society, Vol.50, No.10, Oct. 1969.

* International Association of Meteorology and Atmospheric Physics -- International Union of Geodesy and Geophysics.