the BOMEX Project

Joachim P. Kuettner

Director BOMEX Project

Environmental Science Services Administration

and Joshua Holland

Chief Scientist BOMEX Sea-Air Interaction Program

Atomic Energy Commission

Abstract

This article, written a few days before the beginning of the field operations, summarizes the scientific and operational plans for BOMEX, the "Barbados Oceanographic Meteorological Experiment." The basic concept of BOMEX has been described earlier by its former director, Ben Davidson (1968). His untimely death created a temporary crisis in the scientific direction of the project; however, his experiment design and his underlying thoughts have proved sound and no major changes in the layout or scientific objectives have been necessary. In the opinion of the project staff, Ben Davidson remains the man behind BOMEX. Continuity has been preserved throughout the BOMEX preparations by the Project Manager, William Barney, and his multi-agency staff.

At this time, ships, airplanes and scientists are converging on Barbados. Therefore, the plans described here are by necessity final. Only facts of life can change them.

1. Scientific objectives

The very large and complex undertaking has been governed by its primary objective, the sea-air interaction experiment, which follows closely the recommendations of the Joint Panel on Sea-Air Interaction of the National Academy of Sciences (1962). However, the scientific community, taking advantage of the large number of floating and airborne platforms and of the large-volume data processing facilities being made available by the government, has joined BOMEX on such a scale that the project objectives had to be broadened.

The overall program, comprising now more than 80 independent research projects, has been divided into a number of major subprograms:

- 1) Sea-air interaction program
- 2) Oceanographic program
- 3) Radiation program
- 4) Satellite program
- 5) Tropical exploration program

An additional group of experiments has more specialized scientific and engineering objectives.

Although entities in themselves, all subprograms contribute to the solution of the basic scientific problems

underlying the design of BOMEX. In the simplest possible terms, this problem may be described as follows:

The energy received by the planet Earth in the form of short-wave solar radiation is stored primarily in the upper layers of the tropical oceans. In contrast, the Earth loses energy rather uniformly at all latitudes by infrared radiation. The resulting net gain of energy in tropical latitudes and its net loss in polar latitudes maintains an energy flux from low to high latitudes which, remarkably enough, is carried primarily by atmospheric rather than oceanic circulations. This energy flux may be visualized in three steps:

In the first step energy from the upper ocean layers transfers in various forms from the sea surface to an atmospheric boundary layer of 5,000 to 6,000 ft depth, the "tradewind layer." In the second step the energy stored in the boundary layer finds its way into deeper layers of the troposphere by convective action. The third step brings about the cross-latitudinal transport.

It is the first two steps which are the subject of the BOMEX Project. Step one is notoriously difficult to measure. Although responsible for atmospheric circulations on the largest scale, the energy transfer from the sea surface is governed by processes on the smallest scale, namely by turbulent action. We know that the primary component of the turbulent energy flux is the latent heat of evaporation, but the exchange of sensible heat, radiative and kinetic energy occurs at the same time and not always in the same direction. Many factors such as wind, sea state, air-sea temperature and humidity differences complicate this process. In the BOMEX Project, the problem of sea-air interaction will be attacked by all technological and scientific methods at our disposal, and the first two months of the project will be devoted primarily to this program.

Step two, the distribution of energy through deeper layers of the tropical atmosphere, is even more obscure and will be explored in the third month (July, 1969). There is increasing evidence from satellite observations that this process occurs in a spurt-like fashion in short-lived convective systems on the meso and synoptic scale. Taking advantage of the large fleet of highly instrumented aircraft available to BOMEX, we hope to get some preliminary insight into the nature of these dis-

turbances and to gain some operational experience on the conduct of future highly flexible long-range flight operations based on real-time satellite information. Final answers on the mechanism of step two and especially of step three will have to wait for the follow-on projects of the Global Atmospheric Research Program (GARP).

The scientific significance of BOMEX for GARP lies in the fact that an extension of the numerical forecast period to one or two weeks needs to take the atmospheric energy sources and sinks into account to prevent the decay of atmospheric motions by friction. At present, this problem does not arise because the lack of a global observing network prohibits such extended forecasts. Once the World Weather Watch corrects this deficiency, the results of BOMEX will supply needed quantitative information on the energy sources and sinks over the tropical oceans. In addition BOMEX may teach us how to approach future GARP field projects of similar or larger complexity.

2. Operational setup

Field operations have been divided into four *operating periods*:

Phase I	May 3–May 15	Resupply	May 16–May 23
Phase II	May 24–June 10	Resupply	June 11–June 18
Phase III	June 19–July 2	Resupply	July 3–July 10
Phase IV	July 11–July 28

FIG. 1. BOMEX fixed ship arrays.

During the first three periods, priority will be given to the sea-air interaction program, during the 4th period—to the tropical exploration program. The other subprograms will continue through all four phases; however, participation of individual scientists, ships and aircraft will vary during the different phases.

Fig. 1 shows the *geographical area* selected for intense observations. It is a square of 500×500 km with a land-free ocean extending for 3000 km to the east. It is hoped that with the prevailing East Northeast winds, the influence of land is minimized and that the area is sufficiently representative of conditions over other tropical oceans. The size of the square corresponds to the elementary finite-difference interval for synoptic observations. The island of Barbados has been chosen as operations base because of its excellent facilities (one of the best harbors in the Caribbean and an airport with a 9000-ft runway), and its progressive and cooperative government. Previous research conducted in Barbados by some of the BOMEX participants has enhanced the scientific climate so important for a research effort of this type (Garstang and LaSeur, 1968). Especially during May and June, rather steady atmospheric conditions are expected to prevail. During the month of July, the array will be flipped to a more southerly orientation with a higher latitudinal spread to improve the chances for the exploration of tropical convection systems (see Fig. 1).

Fig. 2 shows the *ship array* with the four oceanographic ships of ESSA at the corners of the square and the Coast Guard's *Rockaway* in the center, all moored to the bottom of the ocean. These ships (Fig. 3) are instrumented to take 15 rawinsondes a day, each, to release tethered balloons with BLIP packages (boundary layer instrument package), to measure numerous surface parameters from boom and shipboard, to probe temperature, salinity and depth of the ocean and to record all quantities on magnetic tape by the SCARD units (Signal Conditioning and Recording Device) developed and installed

FIG. 2. BOMEX instrument platforms.

FIG. 3. *Discoverer* with shipboard instrumentation, rawinsonde and tethered balloon for boundary layer investigation.

for BOMEX by NASA's Mississippi Test Facility. Scanwell and Selenia will serve as wind-finding systems at sea, the Selenia radar providing also excellent precipitation surveillance over part of the BOMEX area.

Near the center will be the 115-ft *Triton* buoy of Florida State University and the Navy *FLIP* (Floating Instrument Platform) of Scripps Oceanographic Institution, a 350-ft long vessel which "flips" in the vertical position (see cover photo) to provide a surprisingly stable platform in mid-ocean. It will carry some of the finest sea-air interaction experiments of BOMEX. Other roving ships and buoy arrays participating in BOMEX with a great variety of experiments are seen in Fig. 2. Table 1 gives a list of all major ships.

In July 1969, the two northern ships, *Rainier* and *Oceanographer*, will move south to their new positions near 8N, while the other fixed ship positions remain unchanged.

TABLE 1. Oceanographic ships participating in BOMEX.

ESSA Coast and Geodetic Survey	<i>Oceanographer</i> <i>Discoverer</i> <i>Rainier</i> <i>Mt. Mitchell</i>
U. S. Coast Guard	<i>Rockaway</i> <i>Laurel</i> <i>Courageous</i>
U. S. Navy	<i>Gilliss</i> <i>Flip</i>
Bureau of Commercial Fisheries	<i>Undaunted</i>
Cape Fear Technical Institute	<i>Advance II</i>

TABLE 2. BOMEX aircraft participation.

Aircraft	1 May-15 May	24 May-10 June	19 June-2 July	11 July-28 July	Remarks
DC-6 ESSA 39	X	X	X	X	Water vapor, turb., vert. flux
DC-6 ESSA 40	X	X	X	X	Water vapor, horizontal flux
DC-4 ESSA	X	X	X	X	Water vapor, horizontal flux
B-57 ESSA				X	Tropical disturb., wind field
WC-121 Navy	X	X	X	X	General support, wind field
EC-121 ASWEPS		(X)	(X)		Oceanographic experiments
EC-121 NRL		23-29 May (X)	17-21 June		Oceanographic experiments
C-130 AWS	X	X	X	X	Sampling, dropsonde
B-57F AWS	X	X	X	X	Sampling, cloud photos
B-47 AWS	X	X	X	X	Sampling, radar
CV990 NASA				X	Multiple radiation experiments & Nimbus III ground truth data
P3A NASA		(X) 2-10 June			Multiple exp., satellite ground truth
C-54 WHOI			(X) 23 June- 28 July	X	Turb. vert. flux
AERO. CDR. Colo. St. U.			(X) 23 June- 28 July	X	Subcloud layer, ocean surface
<i>Buffalo</i> NCAR			X	X	Turb. vert. flux
<i>Queen Air</i> NCAR	X	X	X	X	Multiple support
DC-3	X	(X)			Vert. temp. ground truth ocean surface
Univ. of Calif.	1-30 May				

X = Full time.
(X) = Part time.

Table 2 lists some of the 25 aircraft participating in various phases of BOMEX and their major functions. As can be seen, many Air Force, Navy, NCAR, and ESSA planes will be available through all four periods. Their specific roles will be described in connection with the discussion of the major scientific programs. With their help the atmosphere over the BOMEX array will be probed from 50 ft to over 60,000 ft altitude, the latter level being covered by the Air Force's RB-57F. Most aircraft will fly from airbases in Barbados or Puerto Rico. During the last period, however, advanced bases in South America or Africa may be used.

3. Scientific program and participation

As pointed out in Section 1, the scientific objectives of BOMEX have continuously broadened due to the unprecedented participation of the atmospheric and oceanographic scientific community. Table 3 A–C lists those government agencies, universities, and industrial laboratories which conduct research projects within the major program areas of BOMEX. The number of projects in each area are also listed.

The five program areas will now be briefly described.

1. Sea-air interaction program

Experiments in this program form the core of the BOMEX Project. Its principal aim during the first three operating phases is the determination of the energy flux between ocean and atmosphere, specifically the vertical flux of latent and sensible heat, momentum and radiative energy, and their divergence in the two media. Using all instrumental and scientific methods presently known, it is hoped that not only valid quantitative answers will be obtained regarding the different flux components, but that the most efficient and reliable method for their measurement will be found. Finally, an attempt will be made to estimate and parameterize the area integral of the total flux and its components from conventional observations made at the fixed corners of the array.

The energy budget will be evaluated for an atmospheric volume extending vertically from sea level to a surface whose pressure is exactly 500 mb below sea level pressure and bounded horizontally by the square determined by the four outer fixed ship positions. Within the ocean, the budgets will be evaluated for the volume extending downward to a depth of 500 m. There are then three independently observable quantities which must be equal. These are the net upward flux of energy measured at the sea-air interface and integrated over the BOMEX area, the net loss from the oceanic volume, and the net gain by the atmospheric volume after all other gains and losses have been taken into account. These other gains and losses include internal source and sink terms, local rates of change ("storage"), and transfer through the other boundaries. A schematic 3-dimensional depiction of the atmospheric and oceanic volumes and the observational methods is

TABLE 3A. BOMEX scientific participation.

Government organization	Sea-air interaction	Tropical convection	Oceanography	Radiation	Satellite	Other
AEC						
Argonne	1					
BOMEX project office	8		2			
Bureau of commercial fisheries			2			
ESSA						
ERL	2	1	1	1	1	
NESC						1
WB						1
NAPCA						
NASA					6	
GSFC						1
Langley			1			1
MSC						
MTF	1					
Navy						
NAVOCEANO	4		2			
NRL			1			
NUWR & ES			2			2
USAF						
AFCRL						1
U. S. Coast Guard			1			1
U. S. Geological Survey				1	1	1

TABLE 3B. BOMEX scientific participation.

University organization	Sea-air interaction	Tropical convection	Oceanography	Radiation	Satellite	Other
Univ. of British Col.	2					1
Univ. of Chicago						1
Colo. St. Univ.	1	1			1	
Fairfield Univ.					1	
Florida St. Univ.	2			1		
Lamont Obs.			1			
McGill Univ.				1		1
MIT		1				1
Miami Univ.		1				
Univ. of Michigan	1					
NCAR	1	1		1		
Univ. of Nevada						
Desert Res. Inst.	1					
Oregon St. Univ.	1					
Research Tri.						
Institute			1			
Scripps	3		2			1
Stanford Res. Institute						1
Texas A & M	1			1		
Univ. of Washington	1		1	1		
Univ. of Wisconsin				1	1	
Woods Hole	1		1	1		
Yale Univ.			2			
Univ. of California	1			1		

TABLE 3C. BOMEX scientific participation.

Industry organization	Sea-air interaction	Tropical convection	Oceanography	Radiation	Satellite	Other
Battelle N. W.	1					
Eppley Lab.				1		
Isotopes, Inc.			1		1	
A. D. Little, Inc.				1	1	
Thornthwaite Associates	1					
Travelers			1			

shown in Fig. 4. The experience gained in the Indian Ocean Expedition (Fleagle *et al.*, 1967) has been most useful in the detailed design of this experiment.

The most ambitious part of the BOMEX sea-air interaction program is that aimed at documenting all the

FIG. 4. Volume integral measurements over BOMEX array for determination of energy budget.

terms in the atmospheric water vapor budget. These terms are:

- 1) The upward flux in the first few tens of meters above the interface, determined by direct eddy-covariance methods on the FLIP and on the ESSA, Woods Hole and NCAR aircraft (some of which carry stabilized platforms) and by vertical profile ("aerodynamic") methods using several different sensor systems on FLIP, TRITON, and the basic ship array. Coefficients of eddy transfer will be estimated from those calculated for momentum from a large variety of stress measurements on several platforms, including eddy-covariance methods, dissipation and structure function (Kolmogoroff similarity) methods, the geostrophic departure method and others.

- 2) The horizontal flux divergence, measured by integrating the product of the specific humidity and the normal (outward) component of the wind along the vertical boundaries of the BOMEX array. This integration will be carried out during seven selected periods of intensive observations. It will utilize the ship rawinsondes which will be launched 15 times per day, line integral aircraft flights twice a day, and continuous BLIP balloon time series at selected altitudes in the lowest kilometer during part of the observation period.

- 3) The vertical flux through the top surface. This term is expected to be relatively small on the average except in the case of widespread convection penetrating above the 6-km level which will be observed and estimated by a variety of methods.

- 4) The rate of change of total moisture content of the BOMEX volume, determined from rawinsonde data supplemented by twice-daily sampling of the BOMEX volume by 8 dropsondes dropped from 20,000 ft by the U. S. Air Force's C-130.

- 5) Precipitation will be estimated by means of satellite observations in the visible spectrum (Nimbus, ESSA

and ATS) and in the infrared (Nimbus) several times a day, continuous radar coverage of part of the BOMEX area by X-band radars on Barbados and on the *Discoverer*, complete airborne radar photography coverage by Air Force B-47 once daily, nearly complete airborne radar coverage by Navy WC-121 each night, rain gage measurements on the five fixed ships, FLIP and TRITON, and special salinity profiles in the upper 15 m of the ocean at each ship during and following precipitation.

Each concentrated observation period will last four days. Serial rawinsondes and dropsondes will be taken all four days. Night line integral flights will be flown on three nights and day line integral flights employing two aircraft at a time will be flown on the two middle days of each period. BLIP observations will be continuous for selected two- to four-hour periods, coordinated with line integral flights. ESSA refractometer-gust probe flights will also be made during these periods.

The Chief Scientist for the Sea-Air Interaction Program is being assisted in developing the analysis plan by Robert Landis for the upper ocean heat budget, Dr. Joseph Pandolfo for the evaluation and synthesis of vertical flux measurements, Dr. James Rasmussen for the horizontal flux and volume integral computations, Capt. Gerald Dittberner for the precipitation analysis, and Prof. Richard Reed for the analysis of synoptic and subsynoptic fields of meteorological variables.

Primary scientific participants of this program are: Univ. of British Columbia (Dr. Miyake, Dr. Stewart), Univ. of California (Dr. Gibson, Dr. Stegen), Univ. of Michigan (Dr. Portman), Univ. of Nevada (Dr. Telford), Univ. of Washington (Dr. Fleagle), Texas A&M (Dr. Franceschini), Colorado St. Univ. (Dr. Gray, Dr. Marlatt), Florida St. Univ. (Dr. Garstang, Dr. Hsueh), Oregon St. Univ. (Dr. Pond), Lamont Geol. Obs. (Dr. Broecker), NCAR (Dr. Lilly, Dr. Lenschow, Dr. Rossby), Scripps Ocean. Inst. (Dr. Gibson, Dr. McAlister, Dr. Nierenberg), Woods Hole Ocean. Inst. (Dr. Bunker), BOMEX Project Office (Dr. Holland, Landis, Williams), AEC Argonne Nat. Labs. (Dr. Frenzen), ESSA Res. Labs. (Dr. Bean, Dr. Lettau, Dr. Ostapoff), Naval Ocean. Off. (DeLeonibus, Hanssen, Dr. James, Dr. Mazeika), Battelle Mem. Inst. (Dr. Wogman), Travelers Res. (Dr. Pandolfo), Thorntwaite Asso. (Superior).

Many additional projects and participants are supporting this program indirectly.

2. BOMEX oceanographic program

Five distinct groups of oceanographic experiments are planned.

The first group is concerned with the physics of the near-surface layers of the water, specifically with measurements of vertical shear, particle velocities in waves and turbulent motions.

The second group deals with the thermal structure of the ocean. Vertical temperature profiles and thermal

pattern of the sea surface will be measured directly and by infrared remote sensors from ships and aircraft.

Study of the generation and dynamics of surface and internal waves of the ocean comprises the third group of experiments. The mechanism of wind generated waves on the sea surface, of baroclinic waves and internal tides will be measured from ships, aircraft and coastal stations using airborne and ground based radar scatterometers STD, tide gages and holographic techniques.

The fourth group is concerned with a study of ocean currents and their time and space variability. A line of moored buoy stations will sense velocity and temperature fields. The current-meter data will be analyzed to estimate vertically integrated water transport in the area. Drifting drogued buoys will be radar tracked to determine trajectories and dispersions by eddy currents.

The last group concerned with the development of mathematical models of the ocean-atmosphere system will use the data gathered in oceanographic-prediction techniques.

Primary participants in the BOMEX Oceanographic Program are: Naval Research Laboratories (Dr. Stilwell), Naval Oceanographic Office (DeLeonibus, Hanssen, Dr. James, Dr. Mazeika, Banchemo), Naval Underwater Research and Engineering Station (Dr. Shonting, Cook, Massey), ESSA Laboratories (Dr. Crombie and Dr. Hansen), BOMEX Project Office (Landis), U. S. Coast Guard (Garcia), Scripps Institution of Oceanography (Dr. McAlister, Dr. Fisher), Woods Hole Oceanographic Institution (Dr. Saunders), Massachusetts Institute of Technology (Leetmaa), Yale University (Dr. Foster), and Isotopes Inc., Palo Alto Labs (Dr. Schink).

The BOMEX Oceanographic Program is coordinated by Mr. W. Maloney, Naval Oceanographic Office.

3. BOMEX radiation program

This program is designed to determine the radiation budget over a defined tropical ocean area from the surface to the top of the atmosphere, an analysis closely linked to the total energy budget of the sea-air interaction program. Solar and infrared radiation directed upward and downward will be measured from ships, land stations, aircraft and balloons in the atmosphere. In addition, one ship will measure the absorption of solar radiation in the oceans as a function of depth.

Four distinct radiation experiments are planned over the BOMEX area. The first experiment involves measurement of the sea-air interface budget from solar and infrared surface radiometers on shipboard at the four corners and the center of the array.

The second experiment, also from shipboard, involves vertical soundings by balloon-borne infrared radiometer-sondes. To complete the second experiment, aircraft will measure the divergence of solar radiation as a function of height within the troposphere, both by vertical soundings and by group flights in a vertical stack from 1000 to 40,000 ft. Flights over extended tropical cloud systems will be compared to simultaneously taken satel-

lite pictures and will serve to "calibrate" these pictures with respect to their radiative information.

The third experiment addresses itself to the total radiation budget at the top of the BOMEX array. Measurements of the solar constant and the upward reflected solar radiation from high flying aircraft, up and down welling infrared measurements by balloons flying to 100,000 ft and satellite observations in the visible and infrared spectral band conclude the high altitude analysis.

Finally, an estimate of the variation of vertical radiant fluxes along the lateral boundaries of the array will have to rely upon the "line-integral flights" around the array by some of the radiometer equipped aircraft.

Primary scientific participants of the radiation experiment are Florida State University (Dr. Garstang and Dr. Gille), University of Wisconsin (Dr. Cox and Dr. Hansen), Texas A&M (Dr. Franceschini), Woods Hole Oceanographic Institution (Dr. Bunker and Dr. Saunders), McGill University (Dr. Garnier), Eppley Laboratories (Dr. Drummond), and ESSA (Dr. Kuhn).

The radiation program will be coordinated by Dr. Kuhn (surface and balloon program) and by Dr. Cox (flight program).

4. BOMEX satellite program

The BOMEX Satellite Program will serve multiple purposes:

- 1) It will provide rather continuous satellite coverage of the BOMEX area for operational purposes. This information will be available on near real-time at the Barbados Control Center and will be vital during the 4th phase of BOMEX, the tropical exploration program, and for the conduct of the radiation flights.

- 2) It will provide scientific background information to be used in the analysis of many projects participating in BOMEX. It will be of special value to the sea-air interaction program in the determination of cloud cover and precipitation over the BOMEX array. Infrared measurements will help to determine sea surface temperature, patterns and cloud heights.

- 3) In the field of satellite meteorology advanced techniques for deriving winds and other parameters from satellite pictures will be compared with numerous direct measurements available from other platforms.

- 4) It will support the development of satellite instrumentation by comparing remote sensing data from satellites and aircraft with direct measurements from ships and aircraft ("ground truth program"). The high rate of radio and drop soundings over the BOMEX area (76 per day) will provide excellent ground truth to the infrared spectrometer soundings from NIMBUS-3 during passes overhead.

- 5) It will provide certain communication experiments with aircraft and ships via synchronous satellite for flight and ship operations and for experimental interrogation of ship sensors.

Among the platforms used in this program are NASA's Convair-990 and P-3A, which carry numerous remote sensors over a wide spectral range, and the ESSA satellites 2, 3, 6, 7, 9, the Nimbus-3 and the ATS-3 synchronous satellite. The latter will be moved eastwards during June so as to be at the optimum position with respect to the BOMEX area during July 1969, in support of the tropical exploration phase. During this month a complete Hughes ground station for ATS-3 will be operational on Barbados to provide continuous high resolution views of the Northern Hemisphere on real-time.

Direct reception at Barbados from ESSA, APT and NIMBUS satellites as well as WEFAX transmission via ATS-3, will provide excellent coverage during day and night (Table 4). ESSA's National Environmental Satellite Center will send a special mosaic of about 1000 × 1000 mi centered over Barbados every evening via WEFAX to BOMEX Control. Archival data will be made available to all interested parties participating in BOMEX. The University of Wisconsin will be responsible for the satellite ground operations in Barbados.

Participants and primary users of the BOMEX Satellite Program are: NASA, Goddard Space Flight Center (Mrs. Brennan, Dr. Conway, Dr. Hovis, Dr. Nordberg); NASA, Manned Spacecraft Center (Mr. Evans, Dr. Whitehead); NASA, Langley Research Center (Dr. Lawrence, Jr.); ESSA (Mr. Frank, Dr. Holland, Dr. Kuettner, Dr. McClain, Dr. Lettau, Dr. Wark); U. S. Coast Guard (Cdr. Johnson); University of Chicago (Dr. Fujita); Colorado State University (Dr. Marlatt, Dr. Riehl); Fairfield University (Dr. Callahan); MIT (Dr. Charney); University of Miami (Dr. Estoque); University of Wisconsin (Dr. Cox, Dr. Hansen, Dr. Von der Haar, Dr. Suomi); Research Triangle Institute (Dr. Vukovich); A. D. Little, Inc. (Dr. Blau).

5. Exploration of tropical convection systems

The last operating period of the BOMEX Project during the month of July 1969 will be devoted to an ex-

ploration of large convective systems over the tropical Atlantic. It is in these systems that most of the energy contained in the atmospheric boundary layer is transported to higher levels and distributed throughout the troposphere. Much of the latent heat of water vapor received from the ocean surface is transformed in these weather producing cloud systems to sensible heat.

For reasons not well understood at this time, convection over the tropical oceans takes place in large cloud clusters which are easily seen on satellite pictures and which form and die in a surprisingly short time (order of one day) in the general neighborhood of the Inter-Tropical Convergence Zone (ITC). They may reach diameters of 300 to 500 mi, that is of the same order of magnitude as the whole BOMEX ship array.

Another type of tropical disturbance, the so-called "Inverted V," in a synoptic disturbance of about 1,000 miles wave length with a characteristically shaped cloud pattern responsible for its name. Traveling westward from the African continent it sometimes "blows up" into a very large cloud cluster over the tropical Atlantic, and occasionally develops into a hurricane.

These and other types of tropical systems will be the subject of later projects of GARP. In the last month of the BOMEX Project, a highly instrumented fleet of aircraft (Table 5) will be used to get some preliminary scientific information and to learn how to operate in the most flexible way on the basis of real-time satellite inputs. These will be available during daylight hours from the ATS-3 synchronous satellite stationed over the BOMEX operations area.

In case a sufficient number of convective disturbances does not pass through the "flipped" BOMEX array (see Fig. 1), preparations have been made to operate on short notice from advanced bases in South America and Africa, such that a group of at least 6 long range aircraft will be able to reach any point over the tropical Atlantic between Africa and Barbados with an operational flexibility of two hours over the target area. Fig. 5 shows the range capability from different bases.

TABLE 4. Satellite information available at Barbados.

0600 Local time (May & June)	ATS 3	WEFAX
0745 to 0815 Local time	ATS 3	VHF communication with aircraft and experimental interrogation of ship sensors
0800 Local time (May & June)	ATS 3	WEFAX
0900 Local time	ESSA 8	APT
1030 Local time	ESSA 6	APT (tilted)
1200 Local time	NIMBUS	DRID (2 mile resolution)
*1200 Local time (May & June)	ATS 3	WEFAX
1700 Local time	ESSA 2	APT
*1700 Local time (May & June)	ATS 3	WEFAX
1800 Local time	ESSA 2	APT
1945 to 2015 Local time	ATS 3	VHF communication with aircraft and experimental interrogation of ship sensors
2100 Local time	ESSA 7 or 9	AVCS/WEFAX Mosaic 15°×15° Data time approximately 1500 local
2400 Local time Day light—continuous (July)	NIMBUS ATS 3	DRIR (4–5 mile resolution) Hughes Ground Station

* On a non-interference basis with APT.

TABLE 5. Available aircraft for tropical exploration phase.

Agency	Over BOMEX array	Over Atlantic
ESSA	DC-4 2 DC-6 B-57	DC-4 2 DC-6
Air Force	WC-130 WB-47 WC-135 (?) RB-57F	WC-130 WC-135 (?)
Navy	WC-121	WC-121
NCAR	<i>Buffalo</i> <i>Queen Air</i>	
NASA	990	990

Typical flight pattern for the cloud clusters (zig-zag track) and the synoptic disturbances (long distance triangular tracks) are shown in Fig. 6. In addition the height dependence of the horizontal divergence around large convective clouds will be measured. A vertical range from 500 to 60,000 ft will be covered by the available aircraft. Provisions are being made to satisfy requirements of the radiation program on the same flights. Flights will be planned at the BOMEX Control Center in Barbados, but an airborne mission control director will provide additional flexibility during the flight mission.

Long range communications between aircraft and home base will be via satellite at predetermined times.

FIG. 5. Exploration of tropical convection systems over the tropical Atlantic. Range of aircraft fleet from advanced bases in South America and Africa including two hours flight time over target area.

FIG. 6. Flight tracks of aircraft fleet for the exploration of tropical convection systems over "flipped" BOMEX ship array.

Primary scientific participants are: Colorado State University (Dr. Riehl), Massachusetts Institute of Technology (Dr. Charney), University of Miami (Dr. Estoque), ESSA (Mr. Hawkins, Mr. Frank, Dr. Kuettner).

Dr. Charney will be the scientific director of this program phase.

4. Data handling and publications

In view of the enormous amount of data to be gathered during the BOMEX operations, arrangements have been made for a large-volume data processing capability and for speedy exchange of validated data among the project scientists.

NASA's Mississippi Test Facility (MTF), a part of the Marshall Space Flight Center, serving primarily the Apollo Project, has the responsibility for processing the so-called "core data," i.e., most of the fixed ship and aircraft data for the Sea-Air Interaction Program. The ship data are signal conditioned, multiplexed and recorded by the SCARD system developed, installed and operated by MTF. After each experiment period, the records are flown to MTF where they are digitized, converted to engineering units and formatted. During the first operating period, a special data "SNATCH" by Air Force C-130's provides a "quick look" capability. Data collected by ESSA's Research Flight Facility are flown daily to a local computer facility on Trinidad, where they are validated before being sent to MTF. A considerable programming effort is underway at MTF to provide final data in the form specified by the project scientists. Spectral analysis of covariance data is included.

Guidelines for an early exchange of data among the participating scientists have been developed by the BOMEX project office according to recommendations made by the principal investigators and the BOMEX Advisory Panel of the National Academy of Sciences. Based on a "gentlemen's agreement" among the participating scientists, the prerogative of each researcher to make the scientific analysis of his own observations is protected, while assuring that validated data are made available to other participants, in what may be called a "controlled data exchange," within a reasonable time (estimated to be about February 1970).

Government data are of course accessible to the whole scientific community. All BOMEX data will be archived by the National Weather Record Center and the National Oceanographic Data Center.

A series of BOMEX reports will be published starting in 1970 to ensure that the results of the BOMEX Project are available in a consolidated form. Every participant is encouraged to contribute to this series, but he should also feel free to publish his results in a scientific journal of his choice. The series will allow the contributor to publish his material in more detail and with a minimum delay. A symposium covering some preliminary results of BOMEX is considered for late spring of 1970.

5. Project management

The BOMEX Project staff, located at ESSA's Office of World Weather Systems in Rockville, Md., is composed of members from many government agencies, universities and private companies, reflecting the interagency and co-operative nature of the whole project.

Government agencies participating in the organization and operation of the project in a major way are: U. S. Air Force, U. S. Navy, U. S. Army, National Guard, U. S. Coast Guard, NASA, ESSA, AEC, NCAR, National Science Foundation, National Academy of Science, and the National Oceanographic Data Center.

Although smaller than some of the space projects, the complexity of BOMEX is unprecedented, certainly in the atmospheric and oceanographic sciences. So far the cooperation among the 1500 participants, many of them occupying the numerous floating and flying platforms, is most encouraging.

The very difficult management of the operational planning, logistics, communications, procurement, etc., is in the hands of William S. Barney, Project Manager of BOMEX since its inception. He also heads up the BOMEX Field Office on Barbados with Cdr. Taggart as Operations Director.

Although Dr. Arnold Glaser, the Scientific Coordinator of the BOMEX Project, has joined the staff only in 1969, he has been able to form a focal point for the many different scientific programs, the principal investigators and their data requirements.

Depending on its success, BOMEX will set a pattern for the conduct of future complex projects in the environmental sciences, including GARP. It is our good intention to publish in this journal a report on the field operations and their results shortly after project termination.

References

- Davidson, B., 1968: The Barbados Oceanographic and Meteorological Experiment. *Bull. Amer. Meteor. Soc.*, **49**, 928-934.
- Fleagle, R. G., F. I. Badgley and Y. Hsueh, 1967: Calculation of turbulent FLUXES by integral methods. *J. Atmos. Sci.*, **24**, 356-373.
- Garstang, M., and N. E. La Seur, 1968: The 1968 Barbados Experiment. *Bull. Amer. Meteor. Soc.*, **49**, 627-635.
- National Academy of Sciences-National Research Council, 1962: Interaction between the Atmosphere and the Oceans. (Report of the Joint Panel on Air-Sea Interaction). Publication 983. Excerpts in *Bull. Amer. Meteor. Soc.*, **44**, 4-27.

news and notes

Data buoy conference

The Coast Guard's development of National Data Buoy Systems was the subject of a meeting of top marine scientists at the Coast Guard Academy, New London, Conn., on 12-14 May 1969. This was the first scientific advisory meeting for one of the nation's priority marine science programs and was also one of the first meetings of this kind where such an extensive gathering of experts in the meteorological and oceanographic fields had a chance to exchange ideas under the same roof.

At the request of the President's Marine Science Council, the Coast Guard is developing data buoys capable of collecting oceanographic and meteorological information from the oceans to serve the growing national need for more and better marine environmental information. The meeting was intended to coordinate the active interest and involvement of the scientific community in the development program for National Data Buoy Systems.

Among the participants in the meeting were: Dr. Peter S. Badgley, Gulf Universities Research Corp.; Dr. Kirk Bryan,

ESSA; Prof. Wayne Burt, Oregon State University; Dr. William J. Campbell, USGS; Dr. Wilbert M. Chapman, Ralston Purina Co.; Prof. Jule Charney, MIT; Prof. Robert Fleagle, University of Washington; Joseph Fletcher, Rand Corp.; Dr. Glenn Flittner, Bureau of Commercial Fisheries (BCF); Dr. Nicholas Fofonoff, Woods Hole Oceanographic Institution (WHOI); Dr. Richard Hallgren, ESSA; Dr. John Isaacs, Scripps Institution of Oceanography; Dr. Bostwick H. Ketchum, NSF; Prof. John A. Knauss, University of Rhode Island; Dr. Longuet-Higgins, Oregon State University; John E. Masterson, NCAR; Dr. Bruce McAllister, BCF; Prof. Erik Mollo-Christensen, MIT; Prof. Willard Pierson, New York University; Dr. Donald Pritchard, Johns Hopkins University; Prof. Maurice Rattray, Jr., University of Washington; Prof. Richard Reed, NAS; Prof. William Richardson, Nova University; John Schule, Naval Research Laboratory; Dr. Joseph Smagorinsky, ESSA; Prof. Henry M. Stommel, MIT; Prof. Verner E. Suomi, University of Wisconsin; Bertrand J. Thompson, Naval Oceanographic Office; Dr. John P. Tully, Canadian Committee on Oceanography; Dr. Ferris Webster, WHOI; Capt. Paul M. Wolff, Fleet Numerical Weather Facility; Dr. Warren Wooster, Scripps Institution of Oceanography.

Also in attendance were Dr. Charles Bates, scientific advisor to the Commandant of the Coast Guard; Capt. James A. Hodgman, manager of the National Data Buoy Project; three Coast Guard admirals, and others.

(More news and notes on page 500)

This compilation consists of 13 Special Bibliographies comprising over 3600 abstracts of literature pertinent to various aspects of Physical Oceanography, selected from 170 special bibliographies originally published in the monthly issues of *Meteorological Abstracts and Bibliography* and *Meteorological and Geostrophysical Abstracts* during the period 1950-1964.

CONTENTS

(1) Climatology on Marine Meteorology of the Pacific (2) General Oceanographic Meteorology (3) Wind Waves and Swell (4) Storm Surges (5) Waves, Currents and Swell (6) Physico-Chemical Oceanography (8) Oceanography (9) Energy Exchange Ocean-Atmosphere (10) Waves and Currents (11) Oceanographic Instruments (12) Oceanographic Instruments (pt 2) (13) Subsurface Ocean Currents.

The National Oceanographic Data Center, which assisted with financial support, attaches great importance to such systematic retrospective surveys of oceanographic literature as rich sources of scientific information and data useful in contemporary oceanographic research and operations.

Each bibliography contains a systematic outline of subject matter, and if pertinent, an outline of the geographic places involved in the documents listed. Some older material and items in foreign languages are also included. The tremendous increase in oceanographic research during and after the IGY has led to a far greater amount of literature and published data since 1957 than in previous years, and this increase is reflected in the present compilation.

PRICE \$12.00 clothbound

807 pages

Now Available

COLLECTED BIBLIOGRAPHIES ON PHYSICAL OCEANOGRAPHY (1953-1964)

Photo courtesy of WHOI.

Send orders to:

AMERICAN METEOROLOGICAL SOCIETY 45 BEACON STREET, BOSTON, MASS. 02108

Bulletin American Meteorological Society

403