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CONTENTS

BOMEX BIBLIOGRAPHY

This bibliography represents an attempt to bring together all publications dealing with the Barbados Oceanographic and Meteorological Experiment (BOMEX) that have appeared to date. Informal reports have been omitted. New items will be added to this bibliography over the next year and a half, and at the end of the Barbados Oceanographic and Meteorological Analysis Project (BOMAP) a formal complete annotated bibliography of all published research that has emerged as a result of BOMEX will be published. Toward this goal, it is requested that BOMEX investigators notify us of any publications not included here, as well as of forthcoming ones as they become available.

History - Plans - General Description

Barbados Oceanographic and Meteorological Analysis Project, *BOMEX Field Observations and Basic Data Inventory*, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Rockville, Md., March 1971, 428 pp.

This book documents the Barbados Oceanographic and Meteorological Experiment (BOMEX) in terms of history, background, objectives, programs, individual projects, observation platforms used during the field operations, and the basic data obtained. The numerous individual projects are described in detail within the framework of the five major BOMEX programs: the sea-air interaction, tropical convection, oceanographic, radiation, and satellite programs. The role played by the various acquisition platforms - ships, aircraft, buoys, satellites, and land stations on the island of Barbados - are discussed, and details are given on instrumentation and parameters measured. Included are over 80 illustrations of equipment and flight tracks. Inventory sheets, constituting a significant part of the volume, give a day-to-day picture of times and types of observations made. The 100 BOMEX experiments and the principal investigators responsible for these experiments are listed in the appendix.

The BOMEX Project Office, An Interagency Scientific Planning Group, *BOMEX Bulletin* No. 1, 6010 Executive Boulevard, Rockville, Md., 1968, 15 pp.

This first issue of the *BOMEX Bulletin* is devoted to a statement of the broad objectives of the Barbados Oceanographic and Meteorological Experiment, a list of the participating agencies and available resources, and a brief preliminary climatological description of the experimental area.

The BOMEX Project Office, An Interagency Scientific Planning Group, *BOMEX Bulletin* No. 2, 6010 Executive Boulevard, Rockville, Md., 1968, 11 pp.

Aspects of BOMEX concerned with synoptic-type observational resources are discussed. A tentative configuration of fixed-ship stations, oceanographic buoys, and roving ships is shown, and plans for studies of momentum transfer and vapor flux are described. Shipboard scientific equipment is listed, and details are given on the Scanwell Wind Finding at Sea System. Objectives and commitments on the part of the various participating agencies are reviewed.

The BOMEX Project Office, An Interagency Scientific Planning Group, *BOMEX Bulletin* No. 3, 6010 Executive Boulevard, Rockville, Md., January 1969, 45 pp.

Information is provided concerning plans and schedules for the implementation of BOMEX. Particular attention is given to the ship schedules and to observations to be taken from the ships and from buoys. The overall management framework within which BOMEX will be conducted is briefly described, and an overall BOMEX schedule is included. Appendices contain detailed information on a variety of subjects that are of importance in the preparation for the field operations.

The BOMEX Project Office, An Interagency Scientific Planning Group, *BOMEX Bulletin* No. 4, 6010 Executive Boulevard, Rockville, Md., May 1969, 105 pp.

This Bulletin describes the overall experimental design and management of the Barbados Oceanographic and Meteorological Experiment (BOMEX) and the major program areas: the sea-air interaction, oceanographic, tropical convection, radiation, and satellite programs. Planned ship and buoy arrays, aircraft participation, the signal conditioning and recording device (SCARD), and the data acquisition flow for the fixed ships are discussed. Aircraft flight patterns are illustrated, and logistics outlined. Brief descriptions of 87 individual experiments are given, and the principal investigators and their affiliations are listed.

The BOMAP Office, *BOMEX Bulletin* No. 5, Environmental Science Services Administration, U.S. Department of Commerce, Rockville, Md., November 1969, 26 pp.

This first post-BOMEX bulletin reviews briefly the field operations and preliminary findings. Thirteen experiments are added to the 87 listed in *BOMEX Bulletin* No. 4. The establishment of BOMAP (Barbados Oceanographic and Meteorological Analysis Project), an office within NOAA, is announced, and the three BOMAP objectives outlined: data handling and exchange, analysis and reduction of data collected, and the BOMEX "Core Experiment," which is concerned with the evaluation of the energy budget of the atmospheric volume overlying the BOMEX array and the heat budget of the upper ocean beneath the array, and with estimating the energy fluxes through the sea-air boundary.

The BOMAP Office, *BOMEX Bulletin* No. 6, Environmental Science Services Administration, U.S. Department of Commerce, Rockville, Md., March 1970, 63 pp.

An outline is given of BOMAP plans for the BOMEX "Core Experiment" analysis, BOMEX data processing, and statistical analyses. A detailed description, with flow diagrams, of the data processing plan is given, with specific reference to ship, aircraft, radar, radiation, precipitation, cloud, and general weather data reduction. A section on BOMEX participants information exchange is included, which indicates current status of the 100 projects listed in *Bulletins* 4 and 5, expected dates of data availability, and reports and papers derived from BOMEX data. The appointment of the BOMAP Advisory Panel under the direction of the National Academy of Sciences/ National Research Council is announced. The Panel members are listed and suggestions by the Panel cited.

The BOMAP Office,*BOMEX Bulletin* No. 7, Environmental Science Services Administration, U.S. Department of Commerce, Rockville, Md., July 1970, 34 pp.

Abstracts are given of BOMEX-related papers presented at the Second Annual International Geoscience Electronics Symposium, Washington, D.C., April 14-17, 1970, the American Geophysical Union Fifty-First Annual Meeting, Washington, D.C., April 20-24, 1970, and the Symposium on Tropical Meteorology, Honolulu, Hawaii, June 2-11, 1970. The status of processing and reduction of nine categories of BOMEX data is discussed in detail. Also included are samples of BOMEX high-level cloud photography and of radar data.

The BOMAP Office, *BOMEX Bulletin* No. 8, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Rockville, Md., October 1970, 70 pp.

Progress and status of the 100 individual BOMEX projects are reported by the individual investigators. Samples and formats of rawinsonde, dropsonde, radiometersonde, salinity-temperature-depth (STD), Boundary Layer Instrument Package (BLIP), and ship boom and surface reduced data are presented. A status report is also given of continuing BOMEX data reduction.

The BOMAP Office, *BOMEX Bulletin* No. 9, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Rockville, Md., January 1971, 120 pp.

Announcement is made of the establishment of the BOMEX Temporary Archive in NOAA on February 1, 1971. Over 80 pages of tables list the various BOMEX data that are available, and ordering instructions and costs are given. This *Bulletin* also contains an unannotated bibliography of 126 BOMEX-related papers and reports, as well as a modified and abbreviated version of an article by M. Garstang, N.E. LaSeur, K.L. Warsh, R. Hadlock, and J.R. Petersen, "Atmospheric-Oceanic Observations in the Tropics," that appeared in *American Scientist*, September/October 1970. For an abstract of the article, see entry under Garstang et al.

The BOMAP Office, *BOMEX Bulletin* No. 10, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Rockville, Md., June 1971, 84 pp.

Brief reports are given by various BOMEX investigators on the status and progress of their individual projects. The following papers are included: "The Structure and Dynamics of the African Dust Layer Over the Equatorial Atlantic Ocean During BOMEX," by Joseph M. Prospero and Toby N. Carlson; "Measurements of Absorbed Shortwave Energy in a Tropical Atmosphere," by Kirby J. Hanson, Stephen K. Cox, Verner E. Suomi, and Thomas H. Vonder Haar; "Interim Report on Results From the BOMEX Core Experiment," by Joshua Z. Holland; "BOMEX Atmospheric Mass and Energy Budgets - Preliminary Results," by Eugene M. Rasmusson, "Three-Dimensional Model of Precipitation Echoes for X-Band Radar Data Collected During BOMEX," by Michael D. Hudlow; "A Technique for Assessing Probable Distribution of Tropical Precipitation Echo Lengths for X-Band Radar From Nimbus 3 HRIR Data," by Wolfgang D. Scherer and Michael D. Hudlow; and "Analysis of Radiosonde Humidity Errors Based on BOMEX Data," by H.L. Crutcher, L.D. Sanders, and J.T. Sullivan. (For abstracts of these papers, see entries under the respective authors.) The final section of the *Bulletin* contains tabulations of data that have been added to the BOMEX Temporary Archive.

Carter, Luther J., "Project BOMEX: Biggest Weather Study Yet," *Science*, Vol. 163, March 1969, pp. 1435-1436.

This brief article gives an overview of the Barbados Oceanographic and Meteorological Experiment (BOMEX). Participating agencies and the observation platforms to be used are listed. The goal of BOMEX as stated by Dr. Joachim P. Kuettner, Director of BOMEX, is "to gain new understanding of the interaction of the air and tropical oceans, a primary process in determining atmospheric circulation and world weather systems." The role of the Environmental Science Services Administration (ESSA) as lead agency for BOMEX is discussed.

Cook, Ann K., "The Barbados Story," *ESSA World*, Vol. 4, No. 4, October 1969, pp. 18-21.

This is a brief account of the Barbados Oceanographic and Meteorological Experiment (BOMEX), a national program. For three months, a parcel of tropical sea and air was transformed into a scientific laboratory, as 1,500 persons, fleets of ships and aircraft, several satellites, a dozen buoys, and a large variety of instruments on land gathered data in the operational phase. The project took detailed measurements of the energy exchange between sea and air in a 90,000 mi^2 area over the Atlantic, east of Barbados. In July, the emphasis was on wide-ranging airborne investigation of tropical cloud systems. The volume of data to be analyzed and correlated is prodigious. Early findings suggest that the Intertropical Convergence Zone is probably the governing force in the tropical atmosphere and is closely linked with the development of tropical disturbances.

Davidson, Ben, "The Barbados Oceanographic and Meteorological Experiment," *Bulletin of the American Meteorological Society*, Vol. 49. No. 9, September 1968, pp. 928-934.

This overview of the Barbados Oceanographic and Meteorological Experiment, to be conducted in May, June, and July 1969 east of Barbados, deals with the background, scientific objectives, observational techniques, and field operations schedule of BOMEX. Participating agencies and observation facilities are listed, and tentative deployment of these facilities is illustrated.

Environmental Science Services Administration, U.S. Department of Commerce, "BOMEX Study of Air-Sea Interaction to Begin in May," *ESSA World*, Vol. 4, No. 2, April 1969, p. 44.

This paper briefly describes the Barbados Oceanographic and Meteorological Experiment, designed to study sea-air interaction under the leadership of ESSA. It lists various agencies and institutions (with their 10 ships, several satellites, 24 aircraft, a dozen buoys, and the FLIP) that will in May, June, and July 1969 gather data from a parcel of atmosphere and ocean covering 90,000 mi^2 of the Atlantic east of Barbados, and stretching vertically from an altitude of 100,000 ft to the sea floor at a depth of 18,000 ft. Some of the numerous separate projects and project officials are mentioned.

Environmental Science Services Administration, U.S. Department of Commerce, "Where the Air Meets the Sea," *ESSA World*, Vol. 4, No. 3, July 1969, pp. 5-8.

This illustrated description of the BOMEX field operations contains a brief discussion of the overall design of the experiment, the objectives, observation platforms, and the scientific programs.

Greeley, R.S., G.R. Kelly, W.H. Keenan, R.C. Landis, R.B. Shäller, and J.T. Willis, "The 100 Experiments in BOMEX," *Report*, M70-6, The Mitre Corporation, Washington, D.C., January 1970, 31 pp.

An overview is given of the Barbados Oceanographic and Meteorological Experiment in terms of objectives, observation systems, data collected, the various BOMEX programs and individual experiments, and first results.

Holland, Joshua Z., and Scott L. Williams, "On Planning for Large-Scale Observational Programs," *Bulletin of the American Meteorological Society*, Vol. 52, No. 9, September 1971, pp. 850-856.

Based on experience gained from BOMEX, a number of recommendations are made for carrying out future large-scale observational programs. Necessary or desirable steps in planning and executing such programs are the following: automated data processing; keeping the same key personnel throughout the experiment; well-organized documentation at all stages; sufficient lead time;

and field tests well in advance of the experiment to permit necessary modifications in equipment and procedures. Of particular importance are adequate procedures for measuring and eliminating systematic errors by carefully controlled comparison readings between different sensor systems, use of redundant sensors, and careful documentation of all calibration and comparison readings. Other aspects discussed are equipment maintenance, real-time monitoring and analysis of data, personnel orientation and training, written standard operating procedures, manual and automated recording, and search and rescue plans.

Kuettner, Joachim P., and Joshua Holland, "The BOMEX Project," *Bulletin of the American Meteorological Society*, Vol. 50, No. 6, June 1969, pp. 394-402.

This article, written a few days before the beginning of the field operations, summarizes the scientific and operational plans for the Barbados Oceanographic and Meteorological Experiment (BOMEX). The basic concept of BOMEX has been described earlier by its former director, Ben Davidson. 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 S. 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.

Maury Center for Ocean Science, "U.S. Navy Participation in the Barbados Oceanographic and Meteorological Experiment," Department of the Navy, Washington, D.C., January 1969, 26 pp.

Following a general description of the planned Barbados Oceanographic and Meteorological Experiment, including a historical review, this document deals with the anticipated Navy participation in terms of programs, platforms, logistics, and participating Navy organizations.

Military Sealift Command, "USNS *Gilliss* Chosen as Flagship in Barbados Long-Range Weather Experiment," *Sealift*, Vol. 19, No. 6, June 1969, pp. 4-6.

This article describes, illustrates, and lists the equipment and facilities of the *Gilliss*, which will serve as the roving flagship of the sizable fleet of research vessels participating in BOMEX (Barbados Oceanographic and Meteorological Experiment), including FLIP (Floating Laboratory Instrument Platform), which is also described. During BOMEX, the primary mission of the *Gilliss* will be ocean stations and buoy surveillance. The names of the participating ships of the Coast and Geodetic Survey, the U.S. Coast Guard, and the Bureau of Commercial Fisheries are given. The task of FLIP will be to measure velocity of the winds that drive the ocean currents. The experimental area east of the island of Barbados and the deployment of the ships, aircraft,

satellites, and buoys are shown. The information to be obtained by BOMEX is essential in construction of more seaworthy ships and development of naval capabilities.

The MITRE Corporation, "Final Report of MITRE Activities for the BOMEX Project Office," Washington, D.C., August 1969, 18 pp.

This report gives an overview of the various tasks The MITRE Corporation performed for the BOMEX Project Office between April 1968 and March 1969, when the contract was terminated. These tasks included participation in design review and testing, categorization of individual BOMEX experiments, and data management planning. An appendix lists the various formal and information publications pertaining to BOMEX issued by The MITRE Corporation.

Research Flight Facility, *Operations Plan 1-69, Barbados Oceanographic and Meteorological Experiment (BOMEX)*, Environmental Science Services Administration, U.S. Department of Commerce, Miami, Fla., April 1969, 118 pp.

In support of BOMEX, the ESSA Research Flight Facility will provide two DC-6's, one C-54, and one B-57 aircraft plus air crew and support personnel for a 90-day period beginning May 2, 1969. This plan is in support of BOMEX and defines the operational concept for the initial RFF deployment to Barbados; operations in the experimental area east of Barbados for operational phases 1, 2, and 3; operations for phase 4, including staging from South America or West Africa; redeployment during break periods; and final redeployment after completion of the experiment.

Sea-Air Interaction Laboratory, "Plan for a Major Field Experiment in Support of the Federal Air-Sea Interaction Research Program," *Technical Report*, Institute for Oceanography, Environmental Science Services Administration, U.S. Department of Commerce, Washington, D.C., March 1967, 22 pp.

The Federal Air-Sea Interaction Research Program is described in terms of historical background and the events that led up to establishing such a program, consisting of four phases: Research and Development; Pilot Study; Tropical Ocean Area Study; and Global Ocean-Atmosphere Interaction Experiment. Guidelines are laid down for the Barbados Oceanographic and Meteorological Experiment (Phase II), and problem areas and possible solutions are discussed.

Sea-Air Interaction Laboratory, "Barbados Oceanographic and Meteorological Experiment: The ESSA Contribution to Phase II of the Federal Air-Sea Interaction Research Program," *Technical Report*, Institute for Oceanography, Environmental Science Services Administration, U.S. Department of Commerce, Washington, D.C., March 1967, 22 pp.

The comprehensive field investigation now being planned, to be carried out in 1969 near Barbados, is intended to fulfill the basic requirements stated for Phase II of the Federal Air-Sea Interaction Research Program. This report explains the choice of the experimental area, and describes the various programs, as well as the planned observational network and schedule.

Turbulent Fluxes

Bean, B.R., R. Gilmer, R.L. Grossman, R. McGavin, and C. Travis, "An Analysis of Airborne Measurements of Vertical Water Vapor Flux During BOMEX," To be published in *Journal of the Atmospheric Sciences*, July 1972.

The initial analysis of the water vapor flux measurements taken on board a NOAA DC-6 aircraft during the Barbados Oceanographic and Meteorological Experiment (BOMEX) is presented. The flux of water vapor seems to be constant in the lower subcloud layer. Day-to-day variations as well as variations within a day are apparent in the evaporation data. Spatial variations of evaporation also seem to be present. The average value of water vapor flux for the experimental period is $\sim$ 0.5 cm day^{-1}. Spectra of the instantaneous flux reveal significant alongwind-crosswind differences. Height variation of the wavelength of maximum spectral density for crosswind runs is confirmed. The instantaneous flux is intermittent in nature. Consideration of the cross spectra and time series signatures allows some speculation upon models that may be responsible for a major portion of the water vapor transport in the lower subcloud layer during BOMEX.

Bunker, Andrew F., "BOMEX Meteorological Data. Part I: Turbulent Fluxes Observed From the WHOI Aircraft. Part II: Solar Radiation Averages," *Technical Report*, Reference No. 70-34, Woods Hole Oceanographic Institution, Woods Hole, Mass., August 1970, 29 pp.

The turbulence and turbulent flux observations made from the WHOI C-54 aircraft between June 26 and July 28, 1969, during BOMEX have been processed. Root-mean-square values of the vertical and horizontal components of the turbulent velocity, the temperature and humidity fluctuations, and the turbulent fluxes of sensible heat, latent heat, momentum, and kinetic energy are tabulated, together with supplementary position and weather information. Ninety-seven individual 1-min runs made at altitudes from 15 m to 1,400 m have been processed. The method of obtaining the observations and computing the turbulence parameters is discussed. Averages of the values for several height ranges have been formed for both undisturbed and disturbed conditions of the trade winds. The average values of the sensible heat fluxes in the lowest 500 m are -0.14 mcal $cm^{-2}sec^{-1}$ in undisturbed conditions and -0.08 mcal cm^{-2} sec^{-1} in disturbed conditions. This decrease in the average downward flux of sensible heat is produced by the presence of numerous upward fluxes in disturbed areas. The average latent heat fluxes are 1.97 mcal $cm^{-2}sec^{-1}$ for undisburbed conditions and 0.26 mcal $cm^{-2}sec^{-1}$ for disturbed conditions. The lower average latent heat flux for disturbed conditions is the result of numerous large negative fluxes in the 200-m to 500-m layer outweighing increased positive latent heat fluxes in the lowest 200 m. The average shearing stresses in the lowest 400 m are 0.5 dynes cm^{-2} for undisturbed conditions and 0.8 dynes cm^{-2} for disturbed conditions.

Cain, Jimmy Darrell, "A Comparison of Momentum Fluxes Determined From Time and Space Structure Functions," *M.S. Thesis*, College of Geosciences, Texas A&M University, College Station, Tex., August 1971, 87 pp.

Estimates were made of the rate of turbulent energy dissipation and of the shearing stress at a height of 10 m in the marine atmosphere from measurements taken aboard FLIP during BOMEX, May 17-28, 1969. Two types of structure functions were used in determining energy dissipation rate and shearing stress: the mean square of the difference in wind speed between two points aligned normal to the mean wind, D_3, and the mean square of the difference observed between two times at a fixed point in space, D_2. Comparisons were made between the two methods to improve knowledge of the relationships uniting them. Results indicated a relationship of the form $D_2 = \gamma D_3$, where $\gamma \simeq 0.8$ under existing conditions. Further investigation of this relationship is needed in order to properly interpret results obtained from the space-based structure function, which is less affected by platform motion at sea than is the time-based structure function. Related drag coefficients revealed, somewhat unexpectedly, a Neumann-type decrease with mean wind speed over a range of 5 to 11 m/sec. Diurnal variations in resulting values of wind stress were also examined and, based on a very limited sample, a semi-diurnal variation was indicated. This variation showed an apparent correlation with observed diurnal variations in other meteorological parameters. In addition, computations were made of the universal constant in Kolmogorov's third similarity hypothesis and values obtained were found to agree qualitatively with results of earlier investigators.

DeSouza, R.L., C.I. Aspliden, M. Garstang, and N.E. LaSeur, "A Low-Level Jet in the Tropics," *Monthly Weather Review*, Vol. 99, No. 7, July 1971, pp. 559-563.

A temporary mesoscale network of pilot balloon stations established on the island of Barbados during July 1969 revealed the existence of a low-level jet at 700 m above mean sea level, with a maximum wind near 40 m/sec and a duration of at least 2 hours. The phenomenon appears to be associated with the Venturi effect produced in the low levels by a traveling gravity wave at the inversion. It is suggested that jets of this kind probably exist over other tropical islands.

Donelan, Mark Anthony, "An Airborne Investigation of the Structure of the Atmospheric Boundary Layer Over the Tropical Ocean," *Ph.D. Thesis*, Institute of Oceanography, The University of British Columbia, Vancouver, B.C., October 1970, 147 pp.

Instrumented light aircraft were used in this investigation of the vertical turbulent transfers of momentum, heat, and moisture in the boundary layer of the atmosphere. The data were collected in May 1969 during BOMEX at several altitudes between 18 m and 500 m in the Atlantic trade-wind zone east of the island of Barbados. Since the tropical ocean is the primary source of heat input to the atmospheric heat engine, good estimates, in this region, of the transfer of heat and moisture and their vertical variations are essential to any numerical atmospheric prediction scheme. The fluctuations of the velocity components, temperature, and humidity, and the transfers of momentum, heat, and moisture were investigated, primarily by means of their spectra and cospectra. It was found that 90 percent of the heat input to the atmosphere was in the form of latent heat; the sensible heat flux was positive (upward) at the small scales generated near the surface and negative at the large scales due to subsiding air; the latent heat flux was positive at all scales and similar in spectral distribution to the momentum flux; the flow appeared to be anisotropic even at scales 100 times smaller than the distance from the boundary; the drag coefficient, from direct measurements of the momentum flux (or stress) was $(1.45 \pm 0.08) \times 10^{-3}$; and shear-generated turbulence was not entirely dissipated locally.

Franceschini, Guy A., and Jimmy D. Cain, "The Structure Function Approach to the Measurement of Wind Stress From a Moving Platform," *Colloque International sur l'Exploitation des Océans, Theme V, Systemes de measure a la mer pour l'analyse et la prevision de l'environement, Tome II*, Bordeaux, March 1971, Secretariat du Colloque, c/o CNEXO - B.P. 107, Paris-XVI^{e}, France, 12 pp.

A sample of the results obtained from observations made on the research platform FLIP during BOMEX in May 1969 are presented to demonstrate the validity of the structure function approach in computing wind stress. Computed values of wind stress parameters and energy dissipation rates for 5-min runs collected aboard FLIP are given, and comparisons are made between the structure function approach and other methods commonly used in computing wind stress.

Garstang, Michael (Principal Investigator), "Synoptic Scale Energy Fluxes Between Tropical Oceans and Atmosphere," *Final Report*, Contract No. E-129-69(N), Department of Oceanography, Florida State University, Tallahassee, Fla., December 1969. Contents: Garstang, M., and J.R. Petersen, "FSU Observational Program in Cooperation With BOMEX," 38 pp.; Garstang, M., M. Murday, and W. Sequin, "Turbulent Structure of the Sub-Cloud Layer," 10 pp.; Warsh, K.L., K.L. Echternacht, and M. Garstang, "An Observation of an Inertial Flow at Low Latitude," 3 pp.

The first of these three reports describes the Florida State University (FSU) observational program during BOMEX. It includes a discussion of the various observation systems used, and tabulations of the data collected with these systems. The second paper shows sample results obtained with the FSU Subcloud Instrument Telemetry System (SITS), which provided readings of temperature, humidity, horizontal wind speed, and vertical wind speed from a modulator suspended below a tethered balloon. The third short report deals with a study made in 1968.

Gibson, Carl H., and Paul J. Masiello, "Observations of the Variability of Dissipation Rates of Turbulent Velocity and Temperature Fields, *Lecture Notes in Physics*, Vol. 12, Statistical Models and Turbulence, Proceedings of Conference, University of California, San Diego, July 15-21, Springer-Verlag, New York, pp. 427-453.

Based on BOMEX and other data, velocity and temperature derivatives are squared and averaged for comparison with lognormality theories of Kolmogoroff, Obukhoff, Yaglom, and Gurvich for the variability of local dissipation rates. Averaged squared derivatives were found to depart from lognormaility for small values, especially velocity at lower Reynolds numbers, contrary to the proposal by Gurvich and Yaglom. The universal constant μ of Kolmogoroff's third hypothesis was estimated to be 0.47 ± 0.03 from the variation of $\sigma^2_{\ln u_r \cdot 2}$ with $\ln(L_o/r)$, and 0.49 ± 0.2 from the variance of the ratio (u_r^2/u_{2r}^2) for various scales r. The departure from lognormality for small values may be due to the fact that squared derivatives are not always proportional to the local dissipation rates.

Gibson, Carl H., Gilbert R. Stegen, and Steve McConnell, "Measurements of the Universal Constant in Kolmogoroff's Third Hypothesis for High Reynolds Number Turbulence," *The Physics of Fluids*, Vol. 13, No. 10, October 1970, pp. 2448-2451.

The viscous dissipation ε_r averaged over regions of size r is assumed log normal with variance $\sigma_{\log \varepsilon_r}{}^2 = A + \mu \log (L/r)$ in Kolmogoroff's third hypothesis, where A depends on the large-scale motions, L is the energy scale of the turbulence $\gg$ r, and μ is a universal constant. The constant μ was measured from the slope of squared velocity derivative spectra by means of an expression given by Yaglom. The $(du_1/dx_1)^2$ spectra were measured with a hot-wire anemometer over the open ocean at about 2, 4, 7, and 12 m from the Scripps Floating Laboratory Instrument Platform (FLIP) during BOMEX. The constant μ was also inferred from measurements of velocity derivative kurtosis K at various L/r values from the defining expression and the fact that $\sigma_{\log \varepsilon_r}{}^2 = \log K$ for log normal ε_r, where $r \ll (\nu^3/\varepsilon)^{1/4}$. An average value of 0.51 ± 0.02 was obtained from the spectral slopes over a 6:1 range of Reynolds number. A value of 0.44 ± 0.25 was indicated by the other method. Previous measurements range from 0.33 to 0.64.

Gibson, Carl H., Gilbert R. Stegen, and Robert Bruce Williams, "Statistics of the Fine Structure of the Turbulent Velocity and Temperature Fields Measured at High Reynolds Number," *Journal of Fluid Mechanics*, Vol. 41, Part 1, March 1970, pp. 153-167.

Based on measurements made from Scripps Floating Laboratory Instrument Platform (FLIP) over the Pacific Ocean off Mexico in 1968 and in May 1969 during BOMEX, derivatives of velocity and temperature were found to be quite variable. Probability distribution functions of squared derivatives were consistent with lognormality predictions by Kolmogoroff, Obukhoff, and Yaglom. Kurtosis values for velocity derivatives ranged from 13 to 26 and from 26 to 43 for temperature derivatives. Universal inertial subrange constants were evaluated from dissipation spectra and were found to be 40 to 300 percent larger than most values reported previously. Evidence for local anistropy of the temperature field is provided by non-zero values of the measured derivative skewness.

Miyake, Mikio, Mark Donelan, and Yasushi Mitsuta, "Airborne Measurement of Turbulent Fluxes," *Journal of Geophysical Research*, Vol. 75, No. 24, August 1970, pp. 4506-4518.

A description is given of an airborne turbulent flux measurement system consisting of fast response sensors to measure two components of the relative wind velocity, temperature, humidity, and aircraft motion. Its performance and attendant data reduction schemes are illustrated with some data obtained during the Barbados Oceanographic and Meteorological Experiment (BOMEX) in May 1969. The nature of typical BOMEX data is discussed, based on spectra and cospectra obtained through this airborne sensor system.

McBean, Gordon Almon, "The Turbulent Transfer Mechanisms in the Atmospheric Surface Layer," *Ph.D. Thesis*, The University of British Columbia, Vancouver, B.C., 1970, 119 pp.

The objective of this study was to investigate the turbulent transfer mechanisms near the surface. Direct measurements of the turbulent fluxes of momentum, heat, and moisture were made in the atmospheric surface layer - principally, 2 m above a grass surface at Ladner, Canada, and for comparison 8 m above the Atlantic Ocean near Barbados, during BOMEX. The spectral correlation coefficients were considered to be a measure of the transfer efficiency as a function of scale size. For momtntum transfer the efficiency decreased at all scales as instability increased. It was postulated that this was due to greater amounts of momentum being transferred in bursts of short duration, making the spectral correlation coefficient, averaged over sufficient time, smaller. The Ladner results for heat transfer showed that its transfer efficiency increased at all scales when instability increased. The ratios of the transfer efficiency of heat to that of momentum were greater than 1 for most scales, even for near-neutral stratifications, and increased to between 2 and 3 for more unstable conditions. The efficiency of moisture transfer, when moisture is a passive scalar, was usually smaller than that for heat transfer and was found to depend on the correlation between moisture fluctuations and those of temperature, which is the active scalar. The results from Barbados pointed out two main differences between the subtropics and midlatitudes: the temperature spectrum is much narrower in bandwidth and the humidity fluctuations make an equally important contribution to buoyancy. These features are reflected in the transfer mechanisms.

Pandolfo, Joseph P., and Philip S. Brown, Jr., "Simulation Experiments With a Numerical Sea-Air Inter Planetary Boundary Layer Model and Its Extension to Three Space Dimensions," Vol. 1, 132 pp.; Sekorski, Joseph A., "Program Descriptions," Vol. 2, 107 pp., *Final Report*, Contract E-22-43-69(N), TRC-7449-386a and TRC-7449-386b, The Travelers Research Corporation, Hartford, Conn., February 1970.

A model representing a complex local theory for the atmosphere-ocean planetary boundary layer is described. The principal processes parameterized are the boundary layer turbulence in stratified (humidity and salinity dependent) conditions, mixing due to wind-generated waves on the interface, cloud-dependent radiative heating, and horizontal advection due to externally specified horizontal variations of the dependent variables. Simulation experiments run during the planning phases of BOMEX show (1) a wind-speed-dependent effective drag coefficient that is consistent with the available data, (2) climatologically realistic mean values and seasonal trends of simulated interface temperature and surface layer humidity and wind speed, and (3) realistic diurnal variations of sea-surface temperature and salinity. The model also simulates satisfactorily the simultaneous presence of a characteristic diurnal period of variation in the wind and a characteristic inertial period of variation in the current. Hand-processed data for BOMEX Period III were used as input to the numerical air-sea boundary layer model described earlier by the author. Five-day average vertical aerological and hydrographic profiles for three ships, and 5-day average surface conditions for the five fixed ships in the array were prepared. The input data revealed that surface conditions were characterized by warmer temperature, stronger wind, and lower humidity than indicated in atlases; that oceanic conditions at a few hundred meters were remarkably well represented by mean charts; and that atmospheric conditions at the 850-mb level were cooler and drier than would be expected from an earlier 5-year aerological data sample. The model generally simulated these observed departures. The model output indicates an evaporation rate of about 6 mm/day. The extention of the model to three space dimensions is also described. The three-dimensional model uses a highly diffusive finite difference scheme, i.e., the upwind scheme. No explicit horizontal diffusion is included in the formulation. The stability criterion is derived and the diffusive properties of the upwind advective scheme are analyzed for a two-dimensional flow. It is shown that all the second order error can be expressed as diffusion in an orthogonal pair of horizontal coordinates. Perturbation analysis of disturbances in a linear analogue of the numerical model shows that two stationary wavelengths that appear in the numerical solutions are physically plausible, and that meridionally bounded ageostrophic perturbations can exhibit growth or decay. The study was extended to consider such disturbances in more general barotropic and baroclinic linear models.

Pandolfo, Joseph P., "Numerical Experiments with Alternative Boundary Layer Formulations Using BOMEX Data," *Boundary Layer Meteorology*, Vol. 1, No. 3, January 1971, pp. 277-289.

The basic numerical air-sea boundary-layer model described earlier by the author was varied to produce a set of models with differing atmospheric boundary-layer formulas, four of which are discussed here. Model I is the basic model itself, with stability, and sea-state-dependent eddy viscosity, conductivity, and diffusivity that may, in certain ranges of *Ri*, be unequal. This model is applied on a relatively fine grid. Model II, applied on the same grid, uses formulas that yield equal eddy conductivity, diffusivity, and viscosity. The calculated eddy coefficients depend only on the height and wind shear. Model III uses the same exchange coefficient formulas as Model II, but the surface-layer eddy flux is calculated by assuming logarithmic profiles of the transported variables to be present in this layer. Model IV is the same as Model III in these respects, but is applied on a relatively coarse vertical grid. This model, therefore, includes boundary-layer formulas very similar to those conventionally used in large-scale atmospheric models. The four models were integrated numerically with identical inputs of initial, boundary, and auxiliary data prepared from observations made over the eastern half of the BOMEX area during June 21-25, 1969. Models I and IV, in general, are in better agreement with each other than either is with Model II. This is true for the model-generated upper and lower boundary fluxes of mean momentum and latent heat, and for the internal boundary-layer production of mean kinetic energy by the cross-isobaric flow component. Model I agrees about as well with Model IV as does Model III. The solutions for Models I, III, and IV are also, in general more consistent with observed data, i.e., 5-day average temperature profiles in the layer from the surface to 1,000 m, and 5-day averages of sea surface temperature and of surface-layer atmospheric humidity. Solutions for Model I are in better overall agreement with the observed data, and with the average observed surface-layer wind. The results show that, under the limitations implicit in these preliminary experiments, accurate simulations of observed data are possible with boundary-layer formulas of the type used in Model IV, and that the modest refinements represented by Model I results in even more accurate simulation. Piecemeal imposition of such refinements could, however, lead to models, such as Model II, that have significantly different energetic properties and less simulative accuracy. The results support the speculation that the shallowness of the simulated trades noted in some large-scale models is due to deficiencies in the boundary-layer eddy stress formulations used.

Pandolfo, Joseph P., "Preliminary Analysis of BOMEX Data Using a Numerical Boundary Layer Model," Paper No. 4, *Recent Collected Papers in the Numerical Simulation of the Oceanic and Atmospheric Boundary Layer*, The Center for the Environment and Man, Inc., Hartford, Conn., 1971.

Data for the third general observation period of BOMEX had been gathered and processed by hand for input to the numerical air-sea boundary layer model described earlier by the author. Five-day average vertical profiles were prepared for each of three ships from which aerological and hydrographic soundings were made, and 5-day average surface conditions for the five fixed ships in the array. Preparation of input data for the model revealed that surface conditions for this period were characterized by warmer temperature, stronger wind, and lower humidity than indicated in atlases; that oceanic conditions at a few hundred meters are remarkably well represented by mean charts; and that atmospheric conditions at the 850-mb level are cooler and drier than would be expected from a previously available 5-year aerological data sample. The model generally simulates the observed departures from climatological surface conditions, as it previously simulated climatological surface conditions when used with climatological input data. Interpretation of the model output indicates that an evaporation rate of about 6 mm/day could well be characteristic of the observation period. Evolution of observed humidity profiles in the upper boundary layer is not well simulated by the model. A model that includes parameterization of the cumulus convection is probably required for satisfactory simulation of some of the observed features of this layer.

Paquin, James Edward, "A Comparison of Eddy Correlation and Dissipation Techniques for Computing the Fluxes of Momentum, Heat and Moisture in the Marine Boundary Layer," *Ph.D. Thesis*, Oregon State University, Corvallis, Oreg., 1972, 71 pp.

The results of measurements of the fluxes of momentum, moisture, and sensible heat in the marine boundary layer are described. Two techniques for obtaining the fluxes are discussed. The fluxes of these quantities are most directly obtained by the eddy correlation method, that is, by measuring the fluctuating vertical and downstream velocity (w and u), temperature (T), and humidity (q) and computing the covariances $\overline{wu}$, $\overline{wT}$, and $\overline{wq}$. The fluxes are also computed by obtaining a measure of the energy dissipation rate from second-order structure functions and relating the dissipation to the production of energy. To use the dissipation method, values of universal inertial-convective subrange constants (Kolmogoroff constants) are required. Kolmogoroff constants are computed from second- and third-order structure functions. Most of the data were collected on FLIP during BOMEX (Barbados Oceanographic and Meteorological Experiment) and during a pre-BOMEX trial cruise near San Diego. A small amount of additional data was collected from a site at South Beach, Oreg. The value of the Kolmogoroff constant for velocity is consistent with other recent observations. The temperature and humidity constants are found to be equal within the measurement error and have values of about 0.8. The two methods for computing the fluxes agree on the average for momentum and moisture flux. The two methods do not agree for sensible heat flux during BOMEX although there is fair agreement for the San Diego data.

Paquin, J.E., and S. Pond, "The Determination of the Kolmogoroff Constants for Velocity, Temperature and Humidity Fluctuations From Second- and Third-Order Structure Functions," *Journal of Fluid Mechanics*, Vol. 50, Part 2, 1971, pp. 257-269.

From measurements in the atmospheric boundary layer, second- and third-order structure functions were calculated to determine the Kolmogoroff constants for velocity, temperature and humidity fluctuations. The Floating Laboratory Instrument Platform (FLIP) was the platform for the measurements, which were made during BOMEX in May 1969 and on a pre-BOMEX cruise off

San Diego in February 1969. Universal inertial-convective subrange constants were computed from these structure functions. The constant for velocity is consistent with other recent observations. The temperature and humidity constants are found to be equal within the measurement error and have values of about 0.8.

Paulson, Clayton A., Eric Leavitt, and Robert G. Fleagle, "Tabulation of Mean Profiles of Wind Speed, Temperature and Specific Humidity for BOMEX, May 2 to 13, 1969," *Scientific Report,* National Science Foundation Grant GA-4091, Department of Atmospheric Sciences, University of Washington, Seattle, Wash., December 1970, 31 pp.

Profiles of mean wind speed, temperature, and specific humidity observed from the Floating Laboratory Instrument Platform (FLIP) and corrected for sampling error are tabulated for the period May 2 to 13, 1969. Vertical fluxes of momentum, sensible heat, and latent heat are computed using formulas developed earlier by Paulson. Due to structural interference by the measuring platform, the fluxes of water vapor and sensible heat appear to be underestimated by about 20 percent, while the drag coefficients and stress are underestimated by about 40 percent.

Phelps, George Thomas, "The Fluxes of Latent and Sensible Heat in the Marine Boundary Layer," *Ph.D. Thesis,* Oregon State University, Corvallis, Oreg., June 1971, 117 pp.

Measurements of the fluctuations of humidity, temperature, and velocity were made in the marine boundary layer. The humidity fluctuations were measured with a Lyman-alpha humidiometer. Temperature fluctuations were measured with a dry thermocouple and a platinum resistance thermometer. Velocity fluctuations were measured with a three-component sonic anemometer. These measurements were made from the Floating Laboratory Instrument Platform (FLIP) operated by the Scripps Institution of Oceanography near San Diego in February 1969 and during the Barbados Oceanographic and Meteorological Experiment (BOMEX) in May 1969. The data were processed by digital techniques, and the the various spectra, cospectra, and quadspectra between the velocities, humidity, and temperature were obtained. Integrals of the cospectra were produced that allowed estimates of the fluxes of latent and sensible heat to be made. The normalized spectra of humidity fluctuations in San Diego and BOMEX have similar shapes. The normalized cospectra between vertical velocity and humidity near San Diego and during BOMEX also have similar shapes. Universal forms for the normalized humidity spectrum and the normalized cospectrum between vertical velocity and humidity may exist. The normalized spectra of the temperature fluctuations near San Diego and during BOMEX have different shapes. These differences may be related to stronger radiation effects during BOMEX than near San Diego. The normalized cospectra between vertical velocity and temperature in San Diego and during BOMEX also have different shapes. It is probable that a universal form does not exist for the normalized temperature spectrum or for the normalized cospectrum between vertical velocity and temperature. Directly measured values of the latent and sensible heat fluxes were used to test the validity of the bulk aerodynamic method of predicting the latent and sensible heat fluxes from the mean wind speed and mean air-sea humidity or temperature differences. The limited results from San Diego indicate that the sensible heat flux can probably be predicted from the mean wind speed and the mean air-sea temperature difference in temperate regions. The bulk aerodynamic method was not useful for predicting the sensible heat flux during BOMEX. The observed values for the sensible heat flux were much larger than would be predicted. The latent heat flux could be predicted from the mean wind speed and the mean air-sea absolute humidity difference with a probable error of less than 20 percent. The validity of the formula developed by Bowen for predicting the Bowen ratio (sensible heat flux/latent heat flux) was tested with directly measured values of the Bowen ratio. It was found that near San Diego the Bowen ratio could be predicted with a probable error of 15 percent. The Bowen ratio predicted for BOMEX was too low by a factor of two or more. The ability to predict the Bowen ratio from the ratio of the temperature fluctuations to the humidity fluctuations in the 0.05- to 0.1-Hz range was investigated. The method predicted the Bowen ratio with a probable error of 15 percent for San Diego and 20 percent for BOMEX.

Phelps, G.T., and S. Pond, "Spectra of the Temperature and Humidity Fluctuations and of the Fluxes of Moisture and Sensible Heat in the Marine Boundary Layer," *Journal of the Atmospheric Sciences*, Vol. 28, No. 6, September 1971, pp. 918-928.

Temperature and humidity fluctuation data were collected on FLIP during BOMEX in May 1969 and during a pre-BOMEX trial cruise near San Diego in February 1969. The program was a cooperative one with a number of groups on board. In a companion paper prepared in collaboration with personnel from the University of British Columbia, the equipment and data analysis are described in more detail and the results of measurements of the fluxes of momentum, moisture, and sensible heat are given. The emphasis of this paper is on the similarities and differences between temperature and humidity and on their cospectra and correlations with the velocity fluctuations. During the San Diego experiment it was found that humidity and temperature fluctuations were very similar. During BOMEX the humidity fluctuations were similar to those obtained during the San Diego experiment and to measurements over land, but the low-frequency ends of the temperature spectra are much lower for BOMEX than for San Diego and, consequently, so are the low-frequency ends of the temperature-vertical velocity cospectra. On the basis of our results and comparison with other results, we conclude that the humidity spectra and humidity-vertical velocity cospectra have "universal forms" when normalized according to the Monin-Obukhov similarity theory. The temperature spectra cannot be interpreted in terms of similarity theory because this theory does not include the effects of radiative transfer. These radiative transfer effects depend in part on the moisture content of the air; when it is high, the temperature field, particularly gradients and large-scale fluctuations, is strongly affected. Having identified such effects for BOMEX, similar but much smaller effects can be seen in the San Diego results. Thus, temperature and humidity are not similar scalars, and measurements of one are not necessarily indicative of the behavior of the other.

Pond, S., G.T. Phelps, J.E. Paquin, G. McBean, and R.W. Stewart, "Measurements of the Turbulent Fluxes of Momentum, Moisture and Sensible Heat Over the Ocean," *Journal of the Atmospheric Sciences*, Vol. 28, No. 6, September 1971, pp. 901-917.

This paper describes results of measurements of the fluxes of momentum, moisture, and sensible heat by both the eddy correlation and "dissipation" techniques. The data were collected on FLIP during BOMEX and during a pre-BOMEX trial cruise near San Diego in February 1969. The results are based mainly on data collected by personnel from Oregon State University and the University of British Columbia. We are grateful to the University of Washington personnel who have made their data and results available to us to check some of our results and allowed us to use their temperature fluctuation data from the San Diego cruise when our equipment failed to provide such data. The methods of determining the fluxes, and the instrumentation and methods of data analysis are discussed. The effects of FLIP's interference on the flow are described and the method of removing the interference from the results is given. The spectra of the three components of velocity fluctuations and the cospectra between the vertical velocity fluctuations, w, and the downstream velocity, u, temperature, T, and humidity, q, fluctuations are presented. The fluxes determined by the eddy correlation method are compared with fluxes estimated from the rates of dissipation of kinetic energy and scalar fluctuations. These fluxes are then used to evaluate the constants in the bulk aerodynamic formulas for estimating the fluxes. The normalized velocity component spectra and the normalized uw cospectra appear to have universal forms and are similar to earlier results. The normalized wT cospectra do not appear to have a universal form. The normalized wq cospectra do appear to have a universal form and are very similar to the normalized uw cospectra. As has been found before, the dissipation and eddy correlation methods agree quite well on the average for the momentum flux. The two methods do not give the same results for the sensible heat flux during BOMEX although there is fair agreement for the small number of San Diego results. The two methods do give good agreement for the moisture flux. Comparison of the eddy correlation flux for momentum with the mean wind speed squared leads to a drag coefficient of 1.5×10^{-3}. The sensible heat flux, however, does not show a good relationship with the mean wind speed times the mean sea-air temperature difference during BOMEX. For the San Diego results the relationship is fair, and similar to other measurements. The moisture flux shows a strong correlation with the wind speed times the mean sea-air humidity difference. The nondimensional aerodynamic evaporation coefficient (corresponding to the drag coefficient for momentum) was found to be 1.2×10^{-3} with an uncertainty of about 20 percent. This result based on direct measurements of the flux agrees rather well with some earlier indirect estimates based on evaporation pan data.

Portman, Donald J., and Kenneth L. Davidson, "An Investigation of the Structure of Turbulence and of the Turbulent Fluxes of Momentum and Heat Over Water Waves," *Report and Proposal to Office of Naval Research, Part I: Annual Report for the Period of 15 August 1968 to 15 August 1969*, The University of Michigan, Ann Arbor, Mich., August 1969, 34 pp.

Two experiments are discussed: measurements of wave heights, velocity components, and temperature fluctuations from a research tower in Lake Michigan in 1968; and turbulence measurements from the Floating Laboratory Instrument Platform (FLIP) during BOMEX in May 1969. Sensors used for these experiments are described, and summaries of the measurements are presented in tabular form.

Portman, Donald J., Kenneth L. Davidson, and Michael A. Walter, "Turbulence Measurements Made From FLIP in BOMEX," *Third Annual Report, An Investigation of the Structure of Turbulence and of the Turbulent Fluxes of Momentum and Heat Over Water Waves*, Contract N00014-67-A-0181-005, Department of Meteorology and Oceanography, University of Michigan, Ann Arbor, Mich., August 1970, 40 pp.

Simultaneous measurements of wind velocity components with hot-film anemometers, of air temperature fluctuations, and of wave heights were made about 200 mi east-northeast of Barbados during BOMEX. A total of 54 hours of measurements were made during the last 2 weeks in May 1969. Of these, 23 yielded simultaneous recordings of wind velocity components and temperature fluctuations at two heights. Measurement heights were 2, 3, 6, and 8 m above mean water level. Three different computer facilities were used in processing the data to obtain probability distribution functions, joint probability distribution functions, spectrum functions, and cross-spectrum functions for velocity components, temperature fluctuations, and wave heights. Examples of the calculation results are given and briefly described. They show specific effects of waves on the velocity components.

Superior, William J. (Principal Investigator), "BOMEX Flux and Profile Measurements From FLIP," *Final Report*, Contract N62306-69-C-0186, C.W. Thornthwaite Associates, Elmer, N.J., 1969, 34 pp.

The Floating Laboratory Instrument Platform (FLIP) of Scripps Institution of Oceanography is described, and its operational behavior and instrumentation are discussed. Details on data recording and reduction procedures are given. Appendices contain tabulations of wind profiles, wind direction, and state of the sea; graphical display of wind profiles; tabulations of air temperature profiles, wet bulb temperatures, dT/dz and Ri; and graphical display of air temperature profiles. The data presented were obtained during BOMEX in May 1969.

Woodruff, R.K., "The Development of a System for Processing Digital Turbulence Data Observed During BOMEX and Test Data Results," *Pacific Northwest Laboratory Annual Report for 1970 to the USAEC, Division of Biology and Medicine, Vol. II, Physical Sciences, Part I, Atmospheric Sciences*, BNWL-1551, Vol. II, Part I, UC-53, Battelle Pacific Northwest Laboratories, Richland, Wash., June 1971, pp. 134-138.

Participation in the Barbados Oceanographic and Meteorological Experiment required the development of a digital data processing capability for the turbulence data collected. Hardware modifications have been accomplished and software has been developed to permit reading data on field tapes directly into a computer. Additional programs have been written to restore the continuity of the data series, scale and edit the data, and determine gross statistics. Test results from data collected from Barbados are comparable with oceanic data collected elsewhere by other investigators.

Atmospheric Budgets

Horner, Theodore W., "A Statistical Data Plan for BOMEX," *NOAA Technical Memorandum*, ERL BOMAP-2, The BOMAP Office, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Rockville, Md., December 1970, 109 pp.

The object of this contract report was to provide a methodology for estimating the values of terms of the atmospheric energy budget equations for the BOMEX volume based on data derived from fixed-ship rawinsonde ascents and aircraft line integral flights. The optimum merging of two such sets of data, which differ significantly in accuracy and temporal and spatial resolution is investigated, and a computational scheme, designed to make use of the unique information content of each data set, is proposed.

Rasmusson, Eugene M., "Mass, Momentum, and Energy Budget Equations for BOMAP Computations," *NOAA Technical Memorandum*, ERL BOMAP-3, The BOMAP Office, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Rockville, Md., January 1971, 32 pp.

Atmospheric budget equations for mass, momentum, and energy are derived for an x, y, p* coordinate system, where p* is the pressure differential relative to sea level. These basic equations are then modified for use in computing the budgets of mass, momentum, and energy for the atmospheric part of the BOMEX volume, as related to the Barbados Oceanographic and Meteorological Experiment (BOMEX) May-July 1969.

Rasmusson, Eugene M., "BOMEX Atmospheric Mass and Energy Budgets," *BOMEX Bulletin* No. 10, The BOMAP Office, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, June 1971, pp. 44-50.

The BOMEX Core Experiment is focused on an evaluation of the mass and energy budgets of a 500-km x 500-km square centered at 15°00'N, 56°30'W. Consequently, a major portion of the observational program was directed toward the evaluation of the horizontal fluxes of mass, including water vapor, and heat through the lateral boundaries of this box. Data from a variety of observational systems used in the experiment have been examined to determine the spatial and temporal resolution required for budget computations in this particular atmospheric environment. Covariances between the horizontal wind components and temperature and specific humidity, respectively, arising from variations of scale less than 500 km are seldom of importance in the budget computations. A detailed analysis of a selected 5-day period, including budget computations, are presented. Biases exist in the raw data, but preliminary results indicate that once these are removed, meaningful averages can be computed for many of the budget terms for periods of 24 hours or less.

Reeves, Robert W., "Preliminary Velocity Divergence Computations for BOMEX Volume Based on Aircraft Winds," *NOAA Technical Memorandum*, ERL BOMAP-5, The BOMAP Office, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Rockville, Md., April 1971, 21 pp.

These preliminary calculations of the horizontal velocity divergence within the BOMEX volume are based on a limited sample of wind measurements from line integral aircraft night flights around the perimeter of the BOMEX volume at a level of 1,000 ft and stepped soundings at seven different heights at the midpoint of each side of the volume. Results indicate that with careful systematic calibration wind data may be useful in determining divergences.

Oceanography

Assaf, G., R. Gerard, and A.L. Gordon, "Some Mechanisms of Oceanic Mixing Revealed in Aerial Photographs," *Journal of Geophysical Research*, Vol. 76, No. 27, September 1971, pp. 6550-6572.

Estimates of circulation rates within the mixed layer of the ocean have been made based on aerial photographs of a variety of dye injections and floating cards in the surface and near-surface levels under different wind, sea-state, and thermal profile conditions. The 12 experiments, one of which was conducted during BOMEX, reveal three different mechanisms of oceanic mixing: thermohaline mixing, Ekman flow, and Langmuir circulation. Thermohaline mixing was found under calm sea conditions. Ekman flow was observed under moderate conditions, but its effectiveness in vertical transport was found to be marginal. The most common and effective mechanism of vertical transport in the mixing layer is Langmuir circulation, and under moderate to strong winds this process dominates the other mechanisms.

Bunker, Andrew F., and Margaret A. Chaffee, "BOMEX Meteorological Data. Part I: Quantitative Cloud Measurements. Part II: Sea Surface Temperatures. Part III: Final Report," *Technical Report*, Reference No. 70-49, Woods Hole Oceanographic Institution, Woods Hole, Mass., September 1970, 64 pp.

See entry under "Clouds."

Landis, R.C., "Preliminary Graphic Results of Oceanographic Radio Message Data During BOMEX," *Report*, M70-7, The Mitre Corporation, Washington, D.C., February 1970, 37 pp.

Part of the BOMEX design included the use of a sensor to measure profiles of salinity and temperature to a depth of 1,000 m. The design also required that the ships taking these observations send the data by radio message to the BOMEX Field Headquarters on Barbados four times a day. This report presents some of the large-scale analysis of the salinity-temperature-depth data. Most of the analysis was completed during the field phases of BOMEX.

Landis, Robert C., "Early BOMEX Results of Sea Surface Salinity and Amazon River Water," *Journal of Physical Oceanography*, Vol. 1, No. 4, October 1971, pp. 278-281.

The Amazon River outflow during the spring rainy season is detected in the Atlantic Ocean far from its source. Radio message data from ocean stations taken during BOMEX in 1969 indicate the vast extent of the water mass. The fresh water on the surface permits a warm stable layer to exist below the surface.

McAlister, E.D., William McLeish, and Ernst A. Corduan, "Airborne Measurements of the Total Heat Flux From the Sea During BOMEX," *Journal of Geophysical Research*, Vol. 76, No. 18, June 1971, pp. 4172-4180.

Airborne measurements of the total heat flux from the sea were successfully made during the Barbados Oceanographic and Meteorological Experiment in May 1969. The values found at night ranged from 0.05 to 0.45 cal cm^{-2} min^{-1} and are 1/2-hour averages over continuous strips of ocean 1.6 km long and 75 m wide. These are the first airborne measurements of this oceanic factor and the method used is new.

Monahan, Edward C., "Oceanic Whitecaps," *Journal of Physical Oceanography*, Vol. 1, No. 2, April 1971, pp. 139-144.

The variation of oceanic whitecap coverage with wind speed was determined from the analysis of groups of five or more photographs taken, along with measurements of wind speed and air water temperatures, during each of 71 observation periods at locations on the Atlantic Ocean and adjacent salt water bodies. The fraction of the sea surface covered by whitecaps is always < 0.1 percent for wind speeds $V < 4$ m sec^{-1}. For winds from 4 to 10 m sec^{-1}, the maximum percentage of the sea surface covered by whitecaps is given by $W = 0.00135\ V^{3.4}$. Forty of the observations were made to windward of Barbados during the Barbados Oceanographic and Meteorological Experiment (BOMEX) under conditions of ample fetch and often long duration. The BOMEX results indicate significant whitecapping at lower wind speed, and greater whitecap coverage at all wind speeds, than the results obtained from the observations taken at more northerly locations in the Atlantic Ocean in bays, straits, and gulfs.

Vukovich, Fred M., "Physical Oceanography Feasibility Study Utilizing Satellite Data: Part II," *Final Report*, Contract No. E-236-69(N), Research Triangle Institute, Research Triangle Park, N.C., October 1970, 72 pp.

A technique that reduces the effect of noise in the Nimbus HRIR data, and that yields sea-surface temperatures free of cloud interference was developed. The spatial resolution of the data after the technique was applied was about 20 n mi. The results obtained through application of the data processing technique were compared with ground truth data gathered by the Cape Fear Technical Institute's research vessel *Advance II* in the BOMEX grid during Period III, and by the Duke University Marine Laboratory's *Eastward*, off the North Carolina coast. Comparison between the processed HRIR data and the ground truth data revealed a high degree of correlation in some cases. The best agreement was attained in the Gulf Stream studies off the North Carolina coast. High-frequency and low-amplitude temperature features that were detected in the ground truth analysis were also detectable in the HRIR analyses. Good agreement was obtained also in the BOMEX studies. Alternating cold and warm tongues, which characterized the eastern portion of the BOMEX grid during Period III, were discernible in the HRIR data. The basic discrepancy that arose in the BOMEX analysis was a matter of data-positioning errors. In the Gulf Stream analyses, the North Carolina coast was used to position the HRIR data. The outline of the coast was detectable in the HRIR analysis. In the BOMEX grid no such land marks were available, with the exception of the island of Barbados, which was not detected in any of the analyses. Shifting the HRIR analyses yielded better agreement with the ground truth data. Since no evidence could be found to support the contention that the displacements were real, it was concluded that they were a result of data-positioning errors. A 1.0°C magnitude discrepancy existed between the processed HRIR and the ground truth data. The HRIR temperatures were, on the whole, lower than the ground truth temperatures. The discrepancy arose after the HRIR data had been corrected for attenuation by water vapor and carbon dioxide absorption. It is possible that some residual cloud effects remained in the processed data, but the results of a limited study suggested most of these effects were removed. The discrepancy was attributed to extinction of the radiant energy, which was not accounted for in the calculations.

Vukovich, Fred M., "Detailed Sea-Surface Temperature Analysis Utilizing Nimbus HRIR Data," *Monthly Weather Review*, Vol. 99, No. 11, November 1971, pp. 812-817.

A technique that reduces the effect of noise in the Nimbus High Resolution Infrared Radiometer (HRIR) data and that yields sea-surface temperatures free of cloud interference has been developed. It allows a spatial resolution of about 20 n mi, and the resulting HRIR temperature pattern compares well with ground truth data obtained over the entire BOMEX grid in 1969 and off the North Carolina coast in 1966. A 1.0°C discrepancy was found between the modified HRIR and the ground truth data, the HRIR temperatures being lower. The HRIR data were corrected for attenuation by water vapor and carbon dioxide absorption.

Aircraft Observations

Cole, H., L. Griffee, D. Hill, J. Ledgerwood, and W.E. Marlatt, "Support Data for NASA Convair 990 Meteorological Flight V, July 2 - July 29, 1969," *Technical Report*, 2 Vols., Department of Atmospheric Science, Colorado State University, Fort Collins, Colo., December 1969, 172 pp.

This two-volume report documents 14 flights by the NASA Convair 990. The objectives of these flights were to investigate energy transfer from the air-sea interface between the 4,000- to 5,000-ft level and the 60,000-ft level; conduct coordinated passages with Nimbus III, including vertical temperature profile measurements, etc.; determine characteristics of cloud cover, ground terrain, and sea surface, such as the liquid water content of the clouds; demonstrate the feasibility of various approaches in determining cloud physics, such as cloud height, type, composition, etc.; support BOMEX; and test new instrumentation and collect data for the individual scientific experiments. The first volume includes a brief coverage of the flights, summary of experiments, summary of photographic coverage, and time record of the aircraft environment. Book 2 contains maps of the flight tracks.

Friedman, Howard A., Gerald Conrad, and James D. McFadden, "ESSA Research Flight Facility Aircraft Participation in the Barbados Oceanographic and Meteorological Experiment," *Bulletin of the American Meteorological Society,* Vol. 51, No. 9, September 1970, pp. 822-834.

Specially instrumented aircraft of the Environmental Science Services Administration (ESSA) Research Flight Facility (RFF) have supported environmental research efforts for more than a decade. In 1969, the RFF participated in the Barbados Oceanographic and Meteorological Experiment (BOMEX) providing, in addition to approximately 1,000 flight hours during the field operating periods of the program (May through July), flights designed to develop operational patterns, and to test, calibrate, and compare sensor-derived data. The three participating RFF research aircraft flew 146 missions, for a total of approximately 1,138 hours of flying time, and collected about 3 million digitally recorded meteorological observations, numerous sea-surface temperature and water vapor flux measurements, 2 million cloud and radar photographs, and other special data. A brief description of the scientific objectives of the program, aircraft and instrumentation systems used, sample tracks, data collected, and subsequent procedures are presented.

Friedman, Howard A., John D. Michie, and James D. McFadden, "The NOAA Research Flight Facility's Airborne Data Collection Program in Support of the Barbados Oceanographic and Meteorological Experiment," *NOAA Technical Report,* ERL 198-RFF 4, Environmental Research Laboratories, U.S. Department of Commerce, Boulder, Colo., October 1970, 178 pp.

In 1969, the Research Flight Facility (RFF) joined with other groups from the Environmental Science Services Administration (ESSA) and the scientific community at large to participate in the Barbados Oceanographic and Meteorological Experiment (BOMEX), the first major field effort of the Global Atmospheric Research Program (GARP). The three RFF aircraft supporting the overall program of BOMEX flew 146 missions for approximately 1,138 hours. During these flights, almost 3 million digitally recorded meteorological observations, numerous sea surface temperature and water vapor flux measurements, over 2 million cloud and radar photographs, and other special data were obtained for subsequent analysis and research application. Part I of this report briefly describes the scientific objectives of the program, the RFF aircraft capabilities, and the instrumentation systems that supported BOMEX. Part II is an inventory of the BOMEX field experiment data collected by the RFF from May through July 1969.

Marlatt, William E., and G. Cobb, "Support Data for Aero-Commander 500B Meteorological Flights in Conjunction with BOMEX, June 1 - June 20, 1969," *Report,* Department of Atmospheric Science, Colorado State University, Fort Collins, Colo., January 1970, 67 pp.

This is a time record of the position, attitude, and environment of Colorado State University's Aero-Commander 500B during 29 BOMEX flights. The following instruments were carried: wet- and dry-bulb temperature unit outside the aircraft; a particle sampling system; a Barnes PRT-5 infrared radiometer for measuring earth surface temperature; a microwave refractometer for measuring the effect of water vapor on the refractive index of the atmosphere; and Yellott sol-ameters and an Eppley pyranometer for measuring incoming, outgoing, and reflected solar energy.

Whitehead, Victor S., "Guide to the Use of Data Collected by the NASA NP3A Aircraft in the BOMEX Between June 2 and June 10, 1969," *NASA Technical Memorandum*, NASA TM X-58049, Manned Spacecraft Center, Houston, Tex., September 1970, 39 pp.

The NASA NP3A aircraft participated in the Barbados Oceanographic and Meteorological Experiment between June 2 and 10, 1969. This report provides potential users of the data with the information required to select and use the data in a knowledgeable and effective manner. The systems aboard the aircraft and the format of their archived output are described. The ground tracks of the aircraft are depicted, and the logs manually taken aboard the aircraft are provided.

Clouds

Barbados Oceanographic and Meteorological Analysis Project, *BOMEX High-Level Cloud Photography Atlas*, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Rockville, Md., 1971, 123 pp.

B-57 jet aircraft of the 58th Weather Reconnaissance Squadron, 9th Weather Wing, Air Weather Service, U.S. Air Force, flew high-level cloud Photography missions during the Barbados Oceanographic and Meteorological Experiment (BOMEX) in May, June, and July 1969. Cloud pictures taken from 50,000 ft on 12 flights and from 60,000 ft on two flights are presented in composite format around the south, east, and north sides of the BOMEX square. This atlas is a picture inventory of midday cloud conditions on June 21, 22, 23, 24, 25, 26, 28, 29, 30, and July 2, 1969. It is intended to facilitate correlation studies of cloud conditions as viewed from 50,000 and 60,000 ft with low-level cloud photography, satellite cloud pictures, radar precipitation measurements, and other BOMEX weather observations.

Bunker, Andrew F., and Margaret A. Chaffee, "BOMEX Meteorological Data. Part I: Quantitative Cloud Measurements. Part II: Sea Surface Temperatures. Part III: Final Report," *Technical Report*, Reference No. 70-49, Woods Hole Oceanographic Institution, Woods Hole, Mass., September 1970, 64 pp.

Cloud photographs and sea-surface temperature observations were made from the WHOI C-54Q aircraft on 11 flights during the Barbados Oceanographic and Meteorological Experiment (BOMEX). The cloud images on the time-lapse film have been measured for heights and analyzed for cloud amounts and types. Cross sections of the clouds have been constructed and are presented with photographs from Nimbus III and ESSA 9 satellites. Charts showing the aircraft tracks, solar radiation received, winds, and showers are presented to aid in the interpretation of the data. No study of the significance of the cloud formations has been made. Sea-surface temperatures were measured by a PRT-5 infrared radiometer from the aircraft. The values obtained have been corrected and averaged by 1° squares. A chart of the 1° square averages is presented. The final report describes the BOMEX flights, data reduction, and distribution of the data.

Environmental Science Services Administration, U.S. Department of Commerce, "Weather Satellites Play Key Role in BOMEX Project," *ESSA News*, Vol. 5, No. 25, June 1969, p. 3.

A variety of satellites are providing saturation coverage over the area where the Barbados Oceanographic and Meteorological Experiment scientists are seeking to fill fundamental gaps in knowledge of the mechanisms of sea-air interaction. Satellite photos of cloud motion will be used to get wind information and to compare it with that received from ship measurements. Reflected sunlight captured by satellite pictures will provide information on changes in the sea state and possibly on surface winds. Satellite photos will be used to help in planning aircraft operations.

Kuettner, Joachim P., "Cloud Bands in the Earth's Atmosphere: Observations and Theory," *Tellus*, Vol. XXIII, No. 4-5, 1971, pp. 404-426.

It is now well known that parallel cloud bands are widespread in the earth's atmosphere. Observations from manned and unmanned spacecraft and from high-altitude aircraft in connection with soundings from ships and ground stations have shed light on their origin. These and a special investigation of tropical cloudstreets during BOMEX suggest the following typical characteristics of convective cloudstreets: length - 20 to 500 km; spacing - 2 to 8 km; layer height - 0.8 to 2 km; width-to-height ratio - 2 to 4; wind structure - little change of direction with height; vertical gradient of wind shear (profile curvature) - 10^{-7} to 10^{-6} cm^{-1} sec^{-1}; alignment - along the mean wind of the convective layer. On the theoretical side, linear wind shear is known to favor convective "streeting." The theory presented in this paper is used for investigating the effect of the observed profile curvature, neglecting linear shear effects. It shows that the curvature itself enforces alignment of convective cells with the flow direction. Inertial forces arising from the vorticity field counteract buoyancy forces. Their ratio as expressed in a modified Froude number determines the value of the critical Rayleigh number responsible for the onset of convection. In a flowing medium this number is raised, often by several orders of magnitude, over that of a resting medium for all convective modes, except the longitudinal mode. Some three-dimensional computer presentations illustrate these results. A quantitative application of the simplified theory to actual atmospheric conditions is attempted. It indicates that in strong flows heated from below longitudinal rolls may double their amplitude in a matter of 10 min while transverse rolls decay at a similar rate, with symmetric cells having nearly neutral stability. The relations of this concept to other hypotheses and to the Goertler/Taylor rolls are discussed. Finally it is speculated that the formation of wind streaks on water surfaces may be related to a similar mechanism.

Myers, Vance A., "High-Level Cloud Photography Inventory, BOMEX Period IV, July 11-28, 1969," *ESSA Technical Memorandum*, ERLTM-BOMAP 1, The BOMAP Office, Environmental Science Services Administration, U.S. Department of Commerce, Rockville, Md., September 1970, 66 pp.

This memorandum documents the high-level cloud photography missions flown by U.S. Air Force RB-57F aircraft during BOMEX Period IV, July 11-28, 1969. Tables and flight tracks give the time and location of each of the 1,245 photographs taken. A brief description is given of the procedure used in reconstructing the flight tracks and position the photographs, and the availability of archived data.

Myers, Vance A., "High-Level Cloud Photography Inventory, BOMEX Period II, May 24-June 10, 1969," *NOAA Technical Memorandum*, ERL BOMAP-4, The BOMAP Office, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Rockville, Md., March 1971, 86 pp.

This memorandum documents the high-level photography missions flown by U.S. Air Force RB-57F aircraft during the Barbados Oceanographic and Meteorological Experiment (BOMEX) Period II, May 24-June 10, 1969. Tables and flight tracks give the time and location of each of the 1,500 photographs taken.

Myers, Vance A., *BOMEX Atlas of Satellite Cloud Photographs*, Barbados Oceanographic and Meteorological Analysis Project, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Rockville, Md., July 1971, 262 pp.

A selection of satellite photographs of the BOMEX area is presented as a part of the permanent archive of data obtained during the Barbados Oceanographic and Meteorological Experiment and as a research tool for scientists engaged in analysis of BOMEX data. For each day of the three BOMEX Observation Periods, a full earth disc photograph transmitted by the ATS-III satellite in the middle of the day was selected; these photographs are in each case accompanied by an enlargement of the BOMEX area. Blow-ups of ATS-III pictures transmitted in the morning or before local sunset are also included, when available. For May 24 through May 31, ESSA 9 photographs are substituted. Selection criteria and gridding procedures are described.

Myers, Vance A., "High-Level Cloud Photography Inventory, BOMEX Period I, May 3-15, 1969," *NOAA Technical Memorandum,* ERL BOMAP-7, Center for Experiment Design and Data Analysis, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Rockville, Md., December 1971, 55 pp.

This memorandum documents the high-level cloud photography missions flown by U.S. Air Force RB-57F aircraft during the Barbados Oceanographic and Meteorological Experiment (BOMEX) Period I, May 3-15, 1969. Tables and flight tracks give the time and location of each of the 893 photographs taken.

Myers, Vance A., and Martin Predoehl, "BOMEX Flight Tracks Reconstructed From Near-Simultaneous High-Level Cloud Photography by Two Aircraft," *NOAA Technical Memorandum,* ERL BOMAP-8, Center for Experiment Design and Data Analysis, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Rockville, Md., December 1971, 13 pp.

Near-simultaneous high-level photography of clouds by two aircraft during the Barbados Oceanographic and Meteorological Experiment (BOMEX) gives some clues to the precision of navigation on this type of mission. Photographs were taken from 50,000 and 60,000 ft, respectively, on two days during BOMEX Period III. On one of the days, the assigned flight track separation of 35 n mi is roughly verified, but on the other day the actual separation was found to be less. Examples of the dual photography are shown.

Krishna Rao, P., "Estimating Cloud Amount and Height From Satellite Infrared Radiation Data," *ESSA Technical Report,* NESC 54, National Environmental Satellite Center, U.S. Department of Commerce, Washington, D.C., July 1970, 11 pp.

A simple statistical technique uses the difference between the actual surface temperature and the radiation temperature measured by the satellite as the prime input to yield a cloud height and amount classification for areas as small as 1° latitude on a side. An example of the cloud information obtained from Nimbus III high resolution infrared (HRIR) data over the BOMEX area is shown. The method is designed for a completely automated production of cloud analyses or climatological studies on a global scale.

Broecker, W.S., and T.-H. Peng, "The Vertical Distribution of Radon in the BOMEX Area," *Earth and Planetary Science Letters*, Vol. 11, No. 2, May 1971,pp. 99-108.

Measurements of the vertical distribution of ^{222}Rn in the BOMEX area yield a number of important pieces of oceanographic information. They yield a gas exchange piston velocity of 777 m/yr (equivalent to a stagnant boundary layer thickness of 60 μ). They allow a limit of greater than 160 cm^2/sec to be placed on the coefficient of vertical eddy diffusion in the 0- to 20-m depth zone and of less than 4 cm^2/sec in the 30- to 40-m depth zone. They also provide a vertical profile of the ^{226}Ra concentration in sea water.

Carlson, T.N., and J.M. Prospero, "The Large-Scale Movement of Saharan Air Outbreaks Over the Equatorial North Atlantic," To be published in the *Journal of Applied Meteorology*, April 1972.

The intense and prolonged heating of air passing over the Sahara during the summer and early fall forms a deep mixed layer, which reaches its maximum height of about 500 mb in July. Heated air from the Sahara slides over the maritime northeasterlies and curves over the Caribbean in successive pulses or plumes primarily in a layer between 600 and 800 mb. Measurements made during BOMEX show that the Saharan air layer is characterized by high concentrations of radon-222 and of dust whose mineral composition confirms a desert origin, and by a potential temperature of about 40°C essentially constant with height, a mixing ratio that averages between 2 and 4 gm kg^{-1}, and visible haze; the layer is capped by an inversion. The lower portion of the isentropic Saharan air layer may be 5 to 6°C warmer than surrounding air masses; aircraft penetrations of the Saharan air front near the base of the layer ($\sim$ 800 mb) show that the temperature and mixing ratio may change by several degrees centigrade and several grams per kilogram, respectively, over a distance of a few kilometers. Above 650 mb, the dusty air may be slightly cooler than the normal tropical environment. A strong wind maximum is observed frequently in the Saharan air layer, usually between 600 and 700 mb; these winds form large-scale anticyclonic eddies behind the leading edge of the Saharan air, i.e., the dust front, which typically has a westward speed of 15 kt. These wind maxima may be associated with the so-called "surges in the trades" that are often observed in the tropical Atlantic. Successive pulses of Saharan air appear to be associated closely with the movement of large-amplitude African disturbances from the sub-Sahara to the Caribbean. Saharan air leaves the continent of Africa with a potential temperature of 43 to 44°C and thereafter cools at a rate of about 0.7°C per day as the result of net radiation losses. At the same time, the upper surface of the isentropic layer subsides at a mean rate of about 1 to 2 mm/sec for a total descent of 50 to 100 mb by the time the air reaches the Caribbean some 5 to 7 days later. A model is presented that depicts the movement of Saharan air from Africa to the Caribbean and its interaction with African disturbances. It is clear that the warmth of the Saharan air has a strong suppressive influence on the cumulus convection and, therefore, the advancing dust pulse often is marked by rapid clearing behind the disturbances.

Decker, Clifford E., James R. Smith, and Gordon C. Ortman, "An Evaluation of Techniques for the Measurement of Low Concentrations of Trace Gases in the Atmosphere," *Final Report*, Contract No. CPA 22-69-109, Research Triangle Institute, Research Triangle Park, N.C., February 1970, 89 pp.

During June and July 1969, the Research Triangle Institute conducted a research cruise aboard the SS *Advance II* from Wilmington, N.C., to the vicinity of the equator and return. Ozone, total oxidant, carbon monoxide, and methane concentrations were measured, and comparative evaluation of the chemiluminescent and coulometric techniques for measuring ozone and oxidant at low atmospheric concentrations was made. The results suggest that both the chemiluminescent and coulometric measurement techniques will provide useful data at the low concentrations found in a relatively unpolluted marine environment. The chemiluminescent meter is more reliable than the coulometric meter under the conditions encountered. Although a precise quantitative estimate of the accuracy of the two techniques cannot be made on the basis of the data obtained, the evidence indicates that the chemiluminescent technique is significantly more accurate. As indicated by the calibration data, and a comparison of the ambient measurements at low concentrations, errors of at least 100 percent might be expected with the coulometric meter. The interference problem is greater with the coulometric meter. The following mean concentrations were observed: ozone - 0.5 pphm, oxidant - 0.9 pphm, CO - 0.18 ppm, and CH_4 - 1.36 ppm.

Dinger, J.E., H.B. Howell, and T.A. Wojciechowski, "On the Source and Composition of Cloud Nuclei in a Subsident Air Mass Over the North Atlantic," *Journal of the Atmospheric Sciences*, Vol. 27, No. 5, August 1970, pp. 791-797.

Measurements of the concentration of cloud nuclei, which are activated at a supersaturation of 0.75 percent, were made aboard an aircraft at various altitudes in a subsident air mass over the North Atlantic Ocean and on the east coast of Barbados, West Indies, in May and June 1969. The measurements were made on air samples at normal temperatures as well as on air samples heated to various temperatures up to 600°C. In this way the volatility of the cloud nuclei was compared with the volatility as measured in a similar manner in the laboratory on nuclei artificially generated and of known composition. The measurements at Barbados showed that 50 percent of the cloud nuclei were nonvolatile at the temperatures used and thus were similar to artificially generated nuclei composed of sea salt; the remaining nuclei were destroyed by temperatures $\gtrsim$ 320°C. The aircraft measurements showed the fraction of volatile cloud nuclei to increase with altitude, with all nuclei being volatile above the inversion layer. These measurements indicate that in a subsident marine atmosphere only a fraction of the cloud nuclei at the sea surface are composed of sea salt, this fraction decreasing with altitude so that the sea salt nuclei are confined to the lower few kilometers. Based on the work of other investigators it is suggested that the volatile cloud nuclei are sulfates or sulfuric acid particles that result from the oxidation in the atmosphere of SO_2 or H_2S.

Elderkin, C.E., "Meteorological Analysis," *Pacific Northwest Laboratory Monthly Activities Report for November 1969, Division of Biology and Medicine Programs,* BNWL-1281-UC-48, Battelle Northwest, Richland, Wash., December 1969, pp. 14-15.

The mean concentration distribution of ^{95}Zr between 1,000 and 60,000 ft for the entire third BOMEX measurement period was compared with that for the first period, showing that the level of concentration had increased appreciably. Since higher concentrations of ^{95}Zr are expected in the midlatitudes, air mass movement from these latitudes could explain the increase in concentration over the array during the third period. To test this hypothesis, back trajectories were initiated on the 200-mb surface with the assumption that material measured at 40,000 ft was moving with the 200-mb wind field. The back trajectories for the first period generally indicated that the air movement was from lower latitudes, less than 30°N, with one trajectory traced backward to the vicinity of the equator. A check on ratios of radionuclides for the latter case indicated that the air had a source in the southern hemisphere. The concentrations at 40,000 ft during the third period corresponded very well with concentrations normally found at the latitudes resulting from the 3 to 5 days' back trajectories. The peak concentrations of ^{95}Zr on June 22, 25, and 30 were related to air moving from the 30 to 40°N latitude range. The minima during the period were all traced back to below 30°N. (Entire text.)

Prospero, Joseph M., and Toby N. Carlson, "Radon-222 and African Dust in the North Atlantic Trade Winds," *BOMEX Bulletin* No. 10, The BOMAP Office, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, June 1971, pp. 2-10.

The concentration in the atmosphere of radon-222, a useful tracer of air motions, was measured during BOMEX from two NOAA DC-6 aircraft. A case study between July 11 and 14, 1969, demonstrated a close correlation between radon-222 activity and dust outbreaks over the Sahara. A disturbance that passed the Cape Verde Islands was clearly identified in satellite photographs as carrying dust westward from such an outbreak. Soundings from one of the BOMEX ships revealed a layer of anomalously high temperatures, which are characteristic of air originating over the Sahara, and observations by the two aircraft penetrating the disturbance showed a sharp increase in radon activity accompanied by dense haze.

Prospero, J.M., and T.N. Carlson, "Saharan Dust in the Atmosphere of the Northern Equatorial Atlantic Ocean: A Major Constituent of the Marine Aerosol," To be published in *Journal of Geophysical Research*, July 1972.

The vertical and areal distribution of African dust over the western tropical Atlantic was studied in detail during May, June, and July 1969 as a part of the Barbados Oceanographic and Meteorological Experiment (BOMEX). Maximum dust concentrations were found to occur in a layer (the "Saharan air" layer) between 6 and 12,000 ft. The average concentration of insoluable mineral aerosol within this layer was approximately 50 $\mu gm\ m^{-3}$ of air, a dust load comparable to that of a moderately polluted urban environment; the dust load in low level air was markedly less, about 10 $\mu gm\ m^{-3}$. The temperature within the Saharan air layer may be as much as 5 to 6°C warmer than the air immediately below. This strong inversion severely inhibits convective mixing. The suppressive effect is reflected in the vertical distribution of sea salt (i.e., the soluble sodium component of the aerosol samples), which shows a sharp cutoff above the base of the Saharan air layer; as a result, the air within the layer is essentially salt-free. In contrast, the salt concentration in low-level air is typical of what one would expect for a marine atmosphere; however, even here, the average dust load exceeded that of salt. These studies suggest that the aerosol over the entire northern equatorial Atlantic Ocean should be regarded as being predominantly continental in nature. On the basis of our measurements of the temporal, vertical, and areal distribution of Saharan dust and of mean wind velocities, we estimate that in excess of 50 megatons of dust is transported through the longitude of Barbados between 10°N and 25°N by winds below 14,000 ft. If, for purposes of illustration, we assume that an equivalent quantity of material was deposited into the Atlantic in this 15° latitude belt between Africa and Barbados, we obtain a sedimentation rate of 0.5 $gm\ cm^{-2}$ per thousand years, a rate consistent with the measured carbonate-free sedimentation rate in the North Atlantic. Consequently, it is conceivable that wind-borne African dust may be a major contributor to oceanic sediments.

Schink, D.R., J.J. Sigalove, R.L. Charnell, and N.L. Guinasso, Jr., "Use of Rn/Ra Ratios To Determine Air/Sea Gas Exchange and Vertical Mixing in the Ocean," *Final Technical Report*, Contract No. N00014-69-C-0254, PALTR-223, Teledyne Isotopes, Palo Alto, Calif., February 1970, 43 pp.

A program to measure Rn^{222}/Ra^{226} ratios in the ocean surface layer as part of BOMEX has demonstrated that blanks are acceptably low - but significant; that radon collection is essentially complete; and that the gas can be transferred and counted at sea. Nine radon blanks and 10 radon samples were run. One profile of radon ratios gave results much as expected. The results are consistent with a boundary film thickness of 10 to 15 μ. Below the uppermost water layer the vertical eddy diffusivity is approximately 5 cm^2/sec. Absolute values of radon concentration were lower then previously observed. The differences may be due to our larger sample volumes with correspondingly less contamination effect and better blank control. With air-sampler equipment furnished by Battelle, five air samples were analyzed for radon daughter products. Marine air in this region has 6 dpm/m , much less radon than "average" continental air, but slightly more than expected in the average marine environment.

Wolgemuth, K., and W.S. Broecker, "Barium in Sea Water," *Earth and Planetary Sciences Letters*, Vol. 8, No. 5, June 1970, pp. 372-378.

Vertical profiles of barium content were determined in the Atlantic, during BOMEX, and in the Pacific Ocean by the isotope dilution method. The Atlantic shows a range from 8 to 14 and the Pacific from 8 to 31 μgm/l (surface to deep water). Although similar in magnitude to previous results, these differ significantly in detail. They confirm the hypothesis that barium is incorporated into the remains of organisms in the surface ocean and released to the deep sea as the organic debris sinks toward the bottom. The greater surface to deep concentration increase observed in the Pacific is consistent with that found for other biologically active elements (i.e., Si, C, N, P. etc.). The similarity of Ba and Ra profiles supports the expected chemical coherence between these elements.

Young, J.A., and W.B. Silker, "Project BOMEX Studies of Atmospheric and Oceanic Mixing and Air-Sea Interchange Using Radioactive Tracers," *Pacific Northwest Laboratory Annual Report for 1970 to the USAEC, Division of Biology and Medicine, Vol. II, Physical Sciences, Part I, Atmospheric Sciences*, BNWL-1551, Vol. II, Part I, UC-53, Battelle Pacific Northwest Laboratories, Richland, Wash., June 1971, pp. 130-134.

During the Barbados Oceanographic and Meteorological Experiment, air-sea exchange rates were determined from measurements of the activities of cosmogenic ^{7}Be and other radionuclides produced from fallout. The inventories of the radionuclides in the sea varied by a factor of 2.5 during the measurement period. A large portion of this variation appears to originate with the entry of large amounts of fresh water into the sampling area. Air filter samples collected on the island of Barbados indicate that the air concentration varies seasonally by almost an order of magnitude. Assuming that the ^{7}Be transfer rate across the sea surface is proportional to the air concentration alone gives the result that the seawater inventories also vary seasonally but with a time lag of 2 or 3 months. The vertical profiles of radionuclide activity did not vary significantly between 0.3 and 9.1 km in altitude. Whatever variations occur seem to depend on the mechanisms of precipitation scavenging of the air and intrusions of southern hemispheric air. Large time increases of activity at the same location were traced back to air masses originating in higher latitudes, in general agreement with known results.

Fernandez-Partagas, Jose J., and Mariano A. Estoque, "A Preliminary Report on Meteorological Conditions During BOMEX, Fourth Phase (July 11-28, 1969)," *Report*, Grant No. NSF GA 10201, Rosenstiel School of Marine and Atmospheric Sciences, Division of Atmospheric Science, University of Miami, Coral Gables, Fla., February 1970, 95 pp.

Meteorological conditions that prevailed over the BOMEX-Lesser Antilles network during the BOMEX Fourth Phase (July 11-28, 1969) are analyzed. The characteristics of both the mean circulation and the individual disturbances are investigated. The method of investigation is based on an analysis of the conventional meteorological variables and their perturbations from suitably defined averages. The mean position of the Intertropical Convergence Zone was found to be near normal. Pressure oscillations of both synoptic and larger scales were observed. Six significant disturbances occurred. Five out of the six showed characteristics of cyclonic circulations at the high or middle troposphere. At levels below, these circulations are reflected as wave-type perturbations. The sixth disturbance was a well-developed tropical depression. This study leads to the conclusion that interactions among upper level conditions, the Intertropical Convergence Zone, and the trades are significant.

Janota, Paul, "An Empirical Study of the Planetary Boundary Layer in the Vicinity of the Intertropical Convergence Zone," *Ph.D. Thesis*, Massachusetts Institute of Technology, Cambridge, Mass., September 1971, 279 pp.

Marshall Islands data for May 1956 are used to evaluate the balance of forces in the equatorial tropics. flow is balanced north of the Intertropical Convergence Zone (ITCZ), while south to the equator various inertial and Reynolds stress terms are important. Friction is important in the first 2 km at all latitudes. Composite profiles of wind, humidity, and temperature in the boundary layer near the ITCZ are derived from the Line Islands Experiment and BOMEX Period IV as well as the Marshalls data. On the average, an Ekman layer north of the ITCZ accounts for the equatorward flux. The layer is 2 to 3 km deep, but 50 percent of the transport is below 750 m. The poleward flux south of the ITCZ is much deeper and winds back with height above a shallow veering layer below the clouds. The boundary layer on the equator is on the order of 2 km deep and winds either turn very little or back with height. Daily case studies from BOMEX based on aircraft and satellite-derived winds reveal excellent correlation between ITCZ cloud bands and mesoscale patterns of cyclonic vorticity and convergence in the boundary layer. These data support the hypothesis that CISK (conditional instability of the second kind) maintains the ITCZ. Characteristics of tropical waves and an easterly jet at 700 mb are also shown in the case study. The jet forms in the temperature gradient established by intrusions of African air and may be unstable in the manner of an internal jet.

Blau, H.H., Jr., M.L. Cohen, L.B. Lapson, P. von Thüna, R.T. Ryan, and D. Watson, "A Prototype Cloud Physics Laser Nephelometer," *Applied Optics*, Vol. 9, No. 8, August 1970, pp. 1798-1903.

The design and performance characteristics of a prototype cloud physics laser nephelometer are described. The instrument measures radiation scattered from individual cloud droplets, determining droplet concentrations from scattered light-pulse count rates and size distributions from pulse amplitude. Flights by the NASA Convair 990 during BOMEX in July 1969 served as a test for the nephelometer and yielded some interesting results, demonstrating the instrument's potential for obtaining much of the microstructure necessary for cloud physics and modification studies.

Drummond, A.J., and J.R. Hickey (Principal Investigators), "Total and Spectral Short-Wave Radiation Program on the NASA CV-990 Research Aircraft: BOMEX, July 1969," *Final Report*, Contract NAS5-21083, The Eppley Laboratory, Inc., Newport, R.I., September 1970, 74 pp.

A series of four Eppley precision spectral pyranometers was installed, in 1968, on the NASA CV-990 research aircraft, for experimental participation in the NASA Goddard Meteorological Flights and in the NASA Ames Solar Transit Flights conducted that year. During July 1969 the same instrumentation was made available for BOMEX as one of the 12 experiments in which this aircraft was used. Magnetic tape readout supplemented the standard DVM paper printout, to facilitate data handling and dissemination. Copies of the three volumes of complete computer sheet solar radiation serial values have been made available to NASA Goddard Space Flight Center. The first sections of this report describe the pyranometers and their calibration (including in-flight checks of similar pyranometers deployed in other BOMEX aircraft), the associated readout instrumentation, and the aircraft installation procedures. Succeeding sections deal with radiation data evaluation and presentation (in the computer sheet form). Data analysis is essentially of a restricted nature since a detailed study is beyond the contractual requirements. However, the topics covered include atmospheric scattering of short-wave radiation in the presence of absorption, total and spectral albedo of natural surfaces and atmospheric systems, and vertical radiative profile measurements; results are compared with those obtained by other investigators. A special feature of this experiment was the isolation of downward (global) and upward shortwave radiation into well-defined wavelength intervals, as well as the separation of the ultraviolet-visible region from the near-infrared one, where Rayleigh and aerosol scattering and water vapor absorption, respectively, predominate.

Hanson, Kirby J., Stephen Cox, Verner E. Suomi, and Thomas H. Vonder Haar, "Radiation Experiment in the Vicinity of Barbados," *Final Report*, NSF Grant GA 12603, Space Science and Engineering Center, The University of Wisconsin, Madison, Wis., April 1970, 100 pp.

The objective of the Wisconsin Radiation Program in BOMEX was to obtain direct measurements of the absorption of solar radiation in the atmosphere. These measurements were obtained by aircraft flying in two different modes, both of which are illustrated. A real-time satellite data receiving system that was established at BOMEX Field Headquarters to support the radiation program is described. Appendix A summarizes the scientific objectives and data requirements for the BOMEX radiation studies, and a catalog of ATS-III satellite analog (magnetic tape) pictures obtained during BOMEX is contained in Appendix B.

Hanson, Kirby J., Stephen K. Cox, Verner E. Suomi, and Thomas H. Vonder Haar, "Measurements of Absorbed Shortwave Energy in a Tropical Atmosphere," *BOMEX Bulletin* No. 10, The BOMAP Office, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, June 1971, pp. 12-19.

In May, June, and July 1969, observations of heating rates due to shortwave (.3 μm to 3 μm) radiation absorption in the tropical atmosphere were collected as part of the Barbados Oceanographic and Meteorological Experiment (BOMEX). Data were collected in 3-min horizontal passes by upward and downward pyranometers mounted on a National Center for Atmospheric Research (NCAR) Queen Air aircraft. The pyranometers were sampled every second, and sample averages were formed from the data. Initial analysis of these measurements of shortwave irradience in a cloudless atmosphere showed larger absorption by the atmosphere than can be explained by the gaseous constituents alone. The observed heating rate was 50 percent greater than the calculated one for the lowest 4,000 ft of the atmosphere, and it is believed that in the presence of a low cloud deck the absorption would be even greater in this layer. On the basis of these preliminary results, it is suggested that the role of solar radiation absorbed directly by the atmosphere in the tropics has been seriously underestimated.

Kuhn, Peter M., "Airborne Observations of Contrail Effects on the Thermal Radiation Budget," *Journal of the Atmospheric Sciences*, Vol. 27, No. 6, September 1970, pp. 937-942.

Direct infrared and solar radiometric observations were made between 35,000 and 40,000 ft over California in June 1968 and at the same altitudes in the Barbados region in 1969 in order to analyze the effects on the environment of any alterations in the radiation budget in regions of heavy jet traffic. The observations, made from the NASA Convair 990 jet laboratory, were coupled with Mie scattering and absorption theory calculations. It was found that a 500-m thick contrail sheet increases the infrared emission below the sheet by 21 percent, but decreases the solar power below the sheet by 15 percent. The infrared increase cannot make up for the solar depletion, resulting in a net available incoming power depletion at the base of the sheet of 12 percent. Such a change results in a 7 percent reduction in the net total available thermal power at the earth's surface, which, in turn, results in a 5.3°C decrease in the surface temperature, if contrail persistence is assumed. The actual temperature decrease is ~ 0.15°C with 5 percent contrail persistence.

Kuhn, P.M., and L.P. Stearns, "Radiative Transfer Observations and Calculations During BOMEX," *NOAA Technical Report*, ERL 203-APCL 19, Environmental Research Laboratories, U.S. Department of Commerce, Boulder, Colo., April 1971, 171 pp.

During the Barbados Oceanographic and Meteorological Experiment in 1969, over 220 balloon-borne radiometersonde ascents were made from the NOAA research vessels *Discoverer* and *Rainier*, the U.S. Coast Guard cutter *Rockaway*, and the Seawell Airport on Barbados. The radiative power derived from these ascents provided a massive comparison between observed values and calculations based on temperature and moisture profiles of the radiosonde. A summary and brief analysis of the observations and of the calculations by the radiative transfer equation, as well as comments on the radiative cooling, are given.

Kuhn, P.M., and L.P. Stearns, "Radiosonde Humidity Retrieval by Simultaneous Radiation Measurements," *Journal of Applied Meteorology*, Vol. 11, No. 1, February 1972, pp. 130-135.

A radiometric method for the retrieval of moisture data at altitudes above the radiosonde hygristor cutoff region or in situations where a malfunction of the hygristor occurs is described. The method was applied to BOMEX radiation soundings. Regardless of the exact moisture profile, the method is designed to radiometrically infer the average decrease of moisture through the entire atmospheric column through a solution of the radiative transfer equation. This enables recovery of the total mass of atmospheric water vapor. In at least 25 percent of all BOMEX radiometersonde ascents, humidity retrieval did produce a more realistic moisture profile and total mass of precipitable water vapor. In these cases, the radiosonde hygristor humidity deficiencies averaged from -45 percent at 800 mb to -30 percent at 600 mb. For such pressure levels, the optical mass of water vapor retrieved for the soundings discussed averaged 1.68 gm cm^{-2}. This represents 56 percent of the hygristor-measured optical mass. Above 400 mb the optical mass recovered averaged 0.7 gm cm^{-2} for all BOMEX radiometer soundings. It is suggested that a simple radiometer could be used to improve moisture measurements for soundings requiring the best possible water vapor data.

Collis, R.T.H., "Lidar," *Applied Optics*, Vol. 9, No. 8, August 1970, pp. 1782-1788.

Lidar uses laser energy in radar fashion to observe atmospheric backscattering as a function of range. The concomitant attenuation of energy along the intervening path complicates the evaluation of the observations, but even on a qualitative basis the delineation of clouds or of structure in the apparently clear air is of considerable value in operational meteorology and atmospheric research. Under certain conditions the atmosphere's optical parameters may be evaluated and related to meteorologically significant characteristics. Advanced techniques based on resonant absorption and Raman shift backscattering are briefly noted. The current attainment and future prospects of lidar are reviewed, with reference made to the method of application and capability of lidar as illustrated by some results of BOMEX observations.

Davis, Paul A., "Airborne Ruby-Lidar and Radiometric Measurements of Currus and Haze During BOMEX," *Final Report*, Contract E-263-68, Stanford Research Institute, Menlo Park, Calif., April 1970, 97 pp.

A ruby lidar (laser radar) system was installed aboard the NASA CV-990 aircraft for investigations in July 1969 during the Barbados Oceanographic and Meteorological Experiment (BOMEX). The airborne lidar, its information potential, and methods for analyzing the data records are described and illustrated. Cirrus cloud and haze layers were detected and ranged by the lidar from both upward and downward views from the aircraft. Thicknesses of cirrus varied from thin wisps to about 10,000 ft; the highest cirrus extended to almost 50,000 ft. About a third of the cirrus returns were analyzed in terms of the volume backscattering coefficient, the optical thickness, and the transmittance at the ruby wavelength. The maximum backscatter and extinction coefficients, observed only on a single occasion, were 0.05 $km^{-1}sr^{-1}$ and 0.08 km^{-1}, respectively. Quantitative analysis of lidar returns in terms of optical coefficients required the establishment of reference profiles of the backscattering at the ruby wavelength from cloud-free air above the boundary layer. Average profiles of the backscattering from cloud-free air suggested that molecular backscattering (180° scattering angle only) was dominant above 26,000 ft in the BOMEX area, but particulate contributions to the backscattering were significant at lower altitudes. Boundary layer particulates dominated the backscattering below 7,000 ft; considerable variability was observed in the region between about 8,000 and 13,000 ft. Comparison of the lidar observations of cirrus with infrared transmittances deduced from concurrent radiance measurements in the 10.2-to-11.6-μ region showed that the infrared transmittance was directly related to the geometrical thickness of the cloud. Except for the geometrically thickest clouds, the relationship was linear. The optical thickness (at the ruby wavelength) of the cloud was less well correlated than the geometrical thickness to the infrared transmittance. Therefore, the simple lidar measurement of geometrical cloud thickness appears to be one of the best direct indicators of the IR transmittance of the cirrus clouds observed in this study.

Davis, Paul A., "Applications of an Airborne Ruby Lidar During a BOMEX Program of Cirrus Observations," *Journal of Applied Meteorology*, Vol. 10, No. 6, December 1971, pp. 1314-1323.

A ruby lidar was mounted in an aircraft to obtain measurements of cirrus and haze layers concurrently with an airborne infrared radiometer during Project BOMEX in July 1969. The capability of the lidar for detecting cirrus or haze layers and for describing directly their range and thickness provided uniquely the information essential to a meaningful analysis of radiometric data. In addition to the geometric descriptions, analyses of lidar returns were performed to determine optical parameters. The procedure for conducting these analyses required that an average profile of the clear-air backscattering coefficient in the troposphere above the boundary layer be established. Samples of lidar data and derived optical parameters are shown; one illustration includes data from a dense dust layer below an altitude of 12,000 ft. Comparison of analyses of lidar and radiometric data from cirrus clouds indicated that the infrared transmittance (10.2 to 11.6 μ) was directly related to the geometric thickness of the cloud. This important statistical result suggests a basis for simplified modeling of the influence of cirrus on infrared transfer.

Hudlow, Michael D., "Weather Radar Investigations on the BOMEX," *Research and Development Technical Report*, ECOM-3329, U.S. Army Electronics Command, Fort Monmouth, N.J., September 1970, 106 pp.

The Atmospheric Sciences Laboratory (ASL), Fort Monmouth, N.J., participated in the Barbados Oceanographic and Meteorological Experiment (BOMEX) from May through July 1969. A radar team, using an AN/MPS-34 weather radar from ASL, provided 24-hour radar surveillance of all echo areas within the vicinity of the BOMEX array. The primary objective was to obtain measurements of storm characteristics, including reflectivity distributions, for the duration of BOMEX. Radar scope photography was used. Time-lapse photographs with "gain-stepping" were taken with an automatic 35-mm camera. In addition, a minimum of one Polaroid photo every 3 hours was taken for real-time documentation. Elevation sequences were taken twice daily. A description of the experiment, including all pertinent information and calibrations necessary for interpretation of the films, is presented. Some preliminary analyses of the radar pictures, primarily the Polaroid photos, were made. Storm characteristics, such as size, height, and intensity, are illustrated. The temporal and spatial variations in echo statistics are considered. Recommendations concerning further processing and analyses of the radar film and other data pertinent in deriving precipitation inputs for a line integral experiment are offered.

Hudlow, Michael D., "Radar Echo Climatology East of Barbados Derived from Data Collected During BOMEX," *Preprints of Papers Presented at the 14th Radar Meteorology Conference, Tucson, Ariz., November 17-20, 1970,* American Meteorological Society, Boston, Mass., pp. 432-437.

Statistics on tropical echo dimensions (horizontal and vertical), areal coverages, temporal variations, and interspacing are presented. The data were collected during the months of May, June, and July 1969 in support of the Barbados Oceanographic and Meteorological Experiment (BOMEX). Two X-band radars were used. One was situated on the east coast of Barbados and the other aboard ESSA's USC&GS ship *Discoverer,* which was located approximately 400 mi due east of Barbados. The statistics are stratified into two classes; one class is associated with a relatively undisturbed tropical atmosphere and the other with "synoptic" scale disturbances. Dependence of temporal and spatial echo scales on the Intertropical Convergence Zone is considered.

Hudlow, Michael D., "Three-Dimensional Model of Precipitation Echoes for X-Band Radar Data Collected During BOMEX," *BOMEX Bulletin* No. 10, The BOMAP Office, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, June 1971, pp. 51-63.

"Gainstep" and antenna tilt-sequence data were collected in support of the Barbados Oceanographic and Meteorological Experiment. From a sample of 62 echoes, a three-dimensional statistical model for precipitation was derived. The sample was selected to include a spectrum of echo sizes from 4 to 160 mi in length. Lengths are obtained from PPI presentations recorded at a 0° tilt angle. The sample consists of echoes that occurred during disturbed and undisturbed weather. Day and nighttime events were considered for June and July 1969. Echo length is demonstrated to be a pertinent estimator of echo intensity and other dimensional characteristics, e.g., echo height and area. An exponential model relating returned power ($\overline{P}_r$) to the square root of echo area ($\sqrt{A_e}$) persisting at gain threshold (t) is formulated. The functional relationship between $\overline{P}_r$ and A_e is found to be consistent with models derived for the Montreal and Oklahoma regions. A drop-size model is adopted and via the radar equation $\overline{P}_r$ is transformed to give rainfall rate and liquid water content as a function of echo size. An equation is derived which relates total precipitation/unit time to echo size. A similar equation is included for liquid water content. A graph giving the percent of total echo precipitation within echo subareas is presented. The precipitation model is tested on seven independent echoes and for three continuous time periods.

Johnson, Warren B., and Edward E. Uthe, "Lidar Observations of the Lower Troposphere During BOMEX," *Interim Report,* Contract AT(04-3)-115, Stanford Research Institute, Menlo Park, Calif., December 1969, 49 pp.

This Interim Report is succeeded by a Final Report. See entry under Uthe, Edward E., and Warren B. Johnson, "Lidar Observations of the Lower Tropospheric Aerosol Structure During BOMEX."

Scherer, Wolfgang D., and Michael D. Hudlow, "A Technique for Assessing Probable Distributions of Tropical Precipitation Echo Lengths for X-Band Radar From Nimbus 3 HRIR Data," *BOMEX Bulletin* No. 10, The BOMAP Office, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Rockville, Md., June 1971, pp. 63-68.

Radar and satellite data from the Barbados Oceanographic and Meteorological Experiment (BOMEX) are compared for areas of overlap. Transfer functions, which transform IR temperature maps into probable distributions of echo lengths, are developed. Fourteen cases for May and June 1969 are used for the development of these transfer functions, and two cases serve to independently test the statistical relationships. The data are divided into three classes, reflecting disturbed, undisturbed, and intermediate weather conditions, based on characteristics of the areal distribution at various pressure contours. Transfer functions are obtained from cumulative frequency distributions of the ratio of radar echo to satellite image area. Ratios are computed for 20,000 mi^2 areas. Frequency distributions are also used for dividing the radar data into three classes. A constant average ratio of radar echo area to satellite cloud area of 0.25 is obtained by choosing appropriate pressure levels. Since satellite characteristics are used in selecting the optimum class, probable estimates of radar echo lengths are assessed solely from satellite data. From echo size and a three-dimensional statistical model relating size to the vertical distribution and intensity of the echo, liquid water and precipitation within the echo can be estimated.

Uthe, Edward E., and Warren B. Johnson, "Lidar Observations of the Lower Tropospheric Aerosol Structure During BOMEX," *Final Report*, Contract AT(04-3)-115, Stanford Research Institute, Menlo Park, Calif., January 1971, 126 pp.

A lidar (laser radar) was flown on a U.S. Air Force WC-130B aircraft over the BOMEX area during Period III, June 20 to June 3, 1969. The instrument used a neodymium laser with a wavelength of 1.06 μm and had a firing rate of approximately one pulse per 3.5 sec. During the eight flight missions, 5,192 lidar signatures were collected, most of them over the eastern part of the BOMEX area at an altitude of 10,000 ft and an aircraft speed of 100 m/sec, with a lidar pointing angle of 60° below the horizon. Under these conditions, the backscattered signal was generally above the receiver noise level over the complete path to the surface, allowing construction of vertical cross sections of optical density. A computer technique is described that adjusts and corrects the data for range effect, instrumention nonlinearities, and pulse-to-pulse variations in transmitted energy, and then objectively performs a contour analysis of the resulting data matrix. Vertical cross sections of normalized lidar signal return obtained in this way are presented along with the associated average vertical profiles. These lidar results are interpreted qualitatively in terms of changes in aerosol density and/or particle size in the lowest 3,000 m of the atmosphere. They are compared with vertical profiles of temperature, dew point, and the radionuclides ^{7}Be and ^{95}Zr, which were obtained from supplementary data sources. The data analyzed clearly reveal the existence and location of well-defined scattering layers associated with the subcloud layer, the trade-wind inversion, and the Sahara dust stream.

Almazan, James A., "The BOMEX Boundary Layer Instrument Package," *Preprints, Second Symposium on Meteorological Observations and Instrumentation,* San Diego, Calif., March 27-30, 1972, American Meteorological Society, Boston, Mass., pp. 138-144.

During the Barbados Oceanographic and Meteorological Experiment (BOMEX) in the summer of 1969, an attempt was made to measure meteorological profiles in the boundary layer by means of a new Boundary Layer Instrument Package (BLIP). The package, released from surface vessels, was attached to a tethered balloon and kept at a constant level for several hours. Generally, the data obtained during BOMEX consisted of wind direction and speed, dry- and wet-bulb temperatures, and pressure. Problems encountered during the field operations and during data reduction are discussed; the type of meteorological data obtained with the BLIP and the application of these data to the overall BOMEX objectives are described; and suggestions for future work on types of instrumentation for boundary layer measurements are made, with emphasis on the lessons learned from BOMEX.

Brousaides, Frederick J., "Dew-Point Data From a Balloon-Borne Optical Hygrometer and Range Refractive Index," *Preprints of Papers Presented at the American Meteorological Society's Fourth National Conference on Aerospace Meteorology,* Las Vegas, Nev., May 4-7, 1970, American Meteorological Society, Boston, Mass., pp. 162-169.

Meteorologists at the Eastern Test Range are especially sensitive to the need for better refractive index data because of the critical tracking functions carried out at that site. This paper reports on the development of an optical dew-point hygrometer and describes its pertinence to range application. The ML-476 carbon humidity element, and selected flight intercomparisons with the optical dew-point hygrometer, are also discussed. A limited series of experiments made in conjunction with BOMEX afforded an opportunity to examine the performance of the dewpointer for the first time under semitropical conditions; the test results are given.

Crutcher, H.L., L.D. Sanders, and J.T. Sullivan, "Analysis of Radiosonde Humidity Errors Based on BOMEX Data," *BOMEX Bulletin* No. 10, The BOMAP Office, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Rockville, Md., June 1971, pp. 68-76.

The carbon hygristor in the radiosonde currently used in the United States yields incorrect humidities because its temperature differs from that of the air sampled by it, which in turn may differ from that of the ambient air. The errors depend on thermal lag, heating caused by solar radiation, surface exposure effects, and ventilation rate. BOMEX radiosonde, dropsonde, aircraft, and surface humidity observations are used to assess the problem and derive data modification procedures. Comparison of nighttime dropsonde and radiosonde data is very useful in attacking the thermal lag problem of the hygristor, since the two types of sonde traverse the vertical temperature gradient in opposite directions. Preliminary results are given based on rawinsonde data from the ship *Oceanographer* during June 20-30, 1969. Specific humidities (gm/kg) given here are first estimates of median values and illustrate the problem. Only the error due to thermal lag of the hygristor is discussed in detail. For the 2,000-ft layer above the ship, nighttime median values are 17.0, 16.2, and 15.2 for dropsonde, aircraft and radiosonde, respectively. Lag correction effectively removes the discrepancies, leaving a probable median value of 16.2. Daytime radiosonde median values are 13.8, 12.0 and 12.5 for local times 0700, 1200, and 1600, respectively. The remaining discrepancy presumably is attributable to solar radiation and ventilation effects.

Hilsenrath, E., and R.L. Coley, "Performance of an Aluminum Oxide Hygrometer on the NASA CV 990 Aircraft Meteorological Observatory," *Report*, X-651-71-37, Goddard Space Flight Center, Greenbelt, Md., January 1971, 14 pp.

An aluminum oxide hygrometer has been flown on the NASA Convair 990 aircraft on several meteorological expeditions, including BOMEX and the June 1970 flights over the Arctic Ocean, the continental United States, and the Gulf of Mexico. Water vapor data are available for most of these flights. A standard aluminum oxide probe was mounted in a specially designed air sampler. A control unit was designed such that the hygrometer system would be compatible with the flight environmental computer flown during the 1970 expedition. Comparisons were made with other aircraft measurements yielding water vapor data and with humidity data from radiosondes, when available. These comparisons substantiate the validity of the suggested corrections to radiosonde data obtained during BOMEX. These flights have also demonstrated the negligible temperature dependence of the hygrometer data and the rapid time response of the configuration flown in a jet aircraft, which yield useful water vapor data in the range from +15°C to -60°C.

McAlister, E.D., and W. McLeish, "A Radiometric System for Airborne Measurement of the Total Heat Flow From the Sea," *Applied Optics*, Vol. 9, No. 12, December 1970, pp. 2697-2705.

An airborne system for measurement of the total heat flow from the sea has been developed and was used successfully during BOMEX in May 1969. Details of the system are described, and its operation is illustrated by one day's results at Barbados, W.I. Continuous recalibration of detector sensitivity was a major improvement, which permits measurement of sea-surface temperature to 0.01°C.

Mollo-Christensen, Erik, "Wind Tunnel Test of the Superstructure of the R/V FLIP for Assessment of Wind Field Distortion," *Report*, 68-2, Fluid Dynamics Laboratory, Massachusetts Institute of Technology, Cambridge, Mass., December 1968, 31 pp.

In view of the intent during BOMEX, scheduled for May, June, and July 1969, to make observations of the atmospheric boundary layer above the sea surface, it was decided at a meeting of prospective users of the Floating Laboratory Instrument Platform (FLIP) that wind tunnel tests of the wind interference produced by FLIP would be a valuable guide to boom design and instrument placement. Therefore, a 1/30 scale model of the FLIP was built at Scripps and tested in the MIT Wright Brothers Wind Tunnel. The results showed that the obstruction presented to the wind field by FLIP is more like a sphere than a cylinder, that the wind velocity deviation decreases with distance inversely by a power between two and three. The surface shear is modified significantly by interference. The optimum instrument location is at the tips of the side booms with the keel of FLIP facing downwind. Profiles of wind disturbance are given for a number of vertical lines near FLIP.

Teweles, Sidney, "A Spurious Diurnal Variation in Radiosonde Humidity Records," *Bulletin of the American Meteorological Society*, Vol. 51, No. 9, September 1970, pp. 836-840.

In dealing with differences in upper-air relative humidity over short distances and during small time intervals, investigators have noted a tendency for low values to be reported by U.S. radiosondes, particularly those sent aloft in daytime. This paper summarizes the proceedings of a colloquium of experts who described the nature of the spurious diurnal variation and recommended the manner in which the radiosonde should be modified and in which archived data might be corrected. Reference is made to BOMEX, during which aircraft carrying the optical dewpointer apparatus passed close to ascending radiosondes. When compares, the daytime humidities reported by the dewpointer were found to be higher than those reported by the radiosondes.

Warsh, K.L., M. Garstang, and P.L. Grose, "A Sea-Air Interaction Deep-Ocean Buoy," *Journal of Marine Research*, Vol. 28, No. 1, January 1970, pp. 99-112.

A stable spar buoy, Triton, has been developed as a platform for sea-air boundary-layer measurements in the deep ocean. The buoy has operated for 60 days on station in the tropical Atlantic and for 7 days in the Gulf of Mexico. In 2-m seas, the horizontal, vertical, and angular displacements are less than 36 cm, 10 cm, and 1°, respectively. Over the 60-day period, the stable character of the buoy resulted in negligible wear on the anchor system, despite two tropical storms having winds of more than 20 m/sec. Triton is equipped to record digital time series of air-sea temperature, current speed, current direction, humidity, wind speed, wind direction, rainfall, and wave heights. Triton was also operated for 90 days during BOMEX.

Watts, J.M., "Instrumentation for Observing HF Sea Scatter," *ESSA Technical Memorandum*, ERLTM-ITS 223, Institute for Telecommunication Sciences, ESSA Research Laboratories, U.S. Department of Commerce, Boulder, Colo., March 1970, 18 pp.

Instrumentation for recording digitally the relative phase and amplitude of MF and HF radio signals backscattered from ocean waves is described. This instrumentation was installed in a trailer on the windward coast of Barbados during BOMEX, and observations were made during June and July 1969. Eight stepped frequencies, two spaced receiving antennas, and four different ranges are used. The coherent system allows spectra and correlations to be calculated by a general-purpose computer.

Wisner, Warren M., "Ship's Influence on Surface and Rawinsonde Temperatures During BOMEX," *NOAA Technical Memorandum*, ERL BOMAP-6, The BOMAP Office, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Rockville, Md., June 1971, 44 pp.

The Barbados Oceanographic and Meteorological Experiment (BOMEX), conducted in the summer of 1969, provided an opportunity for examining the representativeness of data on sea-air interaction processes obtained from a variety of sensors. This paper presents a comparative analysis of observations made from conventional facilities located amidships on five fixed ships with data obtained from instruments mounted on a boom extending forward from the bow of each ship. Results based on temperature recordings indicate that the boom measurements probably are more reliable when the relative wind blows off the sea past the boom and then over the ship. When the wind off the sea blows over the ship and then over the boom, however, ship's influence is such that the boom and shipboard instrumentation provide equally reliable measurements.

Surveys of Results

American Geophysical Union, "Early Results of BOMEX Air-Sea Study Announced," *EOS, Transactions*, Vol. 52, No. 3, March 1971, pp. 109-111.

This brief review includes the following examples of early BOMEX findings: the invasion of African dust and the presence of cirrus clouds were found to have an important effect on the atmospheric radiative energy budget; in the oceans the structure of the upper or boundary layer was more complex than existing charts indicate; the movement of heat upward from the air-sea interface into the atmosphere was found to be accomplished by very small wind eddies, while moisture was transported by much larger eddies. The fact that, in many cases, the same parameters were measured by several methods has made it possible, through cross-checking and correction, to upgrade the quality of all data gathered during the experiment.

Environmental Science Services Administration, U.S. Department of Commerce, "BOMEX Finds New Temperature-Humidity Relationship," *ESSA News*, Vol. 5, No. 23, June 1969, p. 3.

Initial BOMEX measurements made by the instrument cluster mounted on FLIP show that in small atmospheric "fronts" (3 to 4 mi long), sudden temperature and humidity increases are often followed by a rapid temperature drop, while the humidity goes back slowly, over a period of about 10 min. It appears from the new data that in the most rapid fluctuations, temperature and humidity do go up and down together to a great extent, but in the low frequency fluctuations or longer period trends, they do not parallel each other closely. Reported also is another BOMEX study in which Navy hurricane hunters and a NASA Nimbus satellite rendezvous around midnight over a point in the Atlantic 390 mi east of Barbados to take photos simultaneously of the earth's cloud cover.

Fleagle, Robert G., "Summary of Symposium on 'Early Results From BOMEX'," *Bulletin of the American Meteorological Society*, Vol. 51, No. 4, April 1970, pp. 319-320.

The chief objective of the symposium on "Early Results From BOMEX" was to bring together the various BOMEX principal investigators for an exchange of ideas in the early stages of data analysis. The following generalizations can be drawn from the raw data: both the oceanic and atmospheric data show greater inhomogeneity in time and space than is often inferred for the BOMEX area; surface temperatures varied significantly over distances less than the width of the array; near-surface currents were highly variable; radionuclide concentrations showed market coherent changes at widely separated stations; and large changes in cloud structure occur as systems move within the easterly trade winds. There was general agreement that caution should be observed in assuming similarity and in applying the Kolmogoroff theory to atmospheric turbulence.

Garstang, Michael, N.E. LaSeur, K.L. Warsh, R. Hadlock, and J.R. Petersen, "Atmospheric Oceanic Observations in the Tropics," *American Scientist*, Vol. 58, No. 5, September/October 1970, pp. 482-495.

It is demonstrated how direct observation of interacting scales of motion in the tropical ocean-atmosphere system can provide the basis for viewing the atmosphere as a heat-driven system. The scientific background, problem approach, experiment design, measuring systems, and results of observations made in 1968 near Barbados and in 1969 as part of the Barbados Oceanographic and Meteorological Experiment (BOMEX) are described. The multiscale observational program was aimed at obtaining simultaneous measurements in the atmospheric boundary layer, in the region of dry convection between the boundary layer and cloud bases, and in and above the cloud layer itself. By this means a quantitative description of scales of motion in each layer could be obtained, leading to insight into their interaction and role in atmospheric energy transfer. The observations and preliminary findings are treated under the following general headings: field experiments and their design; boundary layers of ocean and atmosphere; the boundary layer and subcloud layer; the cloud layer and middle and upper troposphere; and the outlook for the future, with special reference to current GARP plans.

Hammond, Allen L., "Global Meteorology (I): Experiments in the Tropics," *Science*, Vol. 174, No. 4006, October 1971, pp. 278-279.

This is a brief discussion of BOMEX findings as a base for forthcoming Global Atmospheric Research Program (GARP) field experiments, notably the GARP Atlantic Tropical Experiment (GATE) planned for 1974. The article contains some information provided by Joshua Holland of NOAA concerning some BOMEX results related to evaporation from the sea surface, water vapor transport, solar radiation, and convective processes in clouds. Some details on GATE are given.

Holland, Joshua Z., "Preliminary Report on the BOMEX Sea-Air Interaction Program," *Bulletin of the American Meteorological Society*, Vol. 51, No. 9, September 1970, pp. 809-820.

The principal objective of the Barbados Oceanographic and Meteorological Experiment (BOMEX) was to measure the rate of exchange of the "properties" heat, water substance, and momentum between the tropical ocean and atmosphere over a 500-km square. The Sea-Air Interaction Program (Core Experiment) of BOMEX determined the ship and aircraft array configuration and observation schedule from May 1 to July 2, 1969. Intensive, and in many cases redundant, observations by several methods were made to determine vertical eddy flux of the property in the surface layer of the atmosphere; horizontal flux divergence of the property in the lower 600 mb of the atmosphere, integrated over the array area; vertical transport of the properties through the top surface of this volume by the mean vertical velocity; local rate of change of the volume integral of the property; and internal sources and sinks (radiation, precipitation, stress). Ranges of spatial resolution from 10 m to 500 km and temporal resolution from milliseconds to days are provided by the various sensor systems. Data reduction and analysis are underway. Preliminary results indicate that the goal of obtaining values of the significant energy transfer rates and conversions, with accuracy and resolution about an order of magnitude better than any previously available, will be attained. If so, a test of available parameterization formulas will be possible even under the relatively constant and uniform conditions over the tropical oceans.

Holland, Joshua Z., "Interim Report on Results From the BOMEX Core Experiment," *BOMEX Bulletin* No. 10, The BOMAP Office, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, June 1971, pp. 31-43.

The Sea-Air Interaction Program, or "Core Experiment" of BOMEX, has given information on the relative roles of different parts of the eddy spectrum on vertical and horizontal transport of water vapor. Aircraft measurements of vertical eddy flux in the lowest 150 m show a pronounced peak at wavelengths of a few hundred meters in the crosswind direction, and somewhat longer in the direction of the wind. In the horizontal directions, subsynoptic scale eddy transport plays a relatively minor role. Considerations of measurement accuracy suggest that the "line integral" method of measuring an area average horizontal flux divergence, based on Gauss' theorem, may be inferior to direct integration across the area in question by means of aircraft traverses. The observed horizontal divergence was, not surprisingly, found to be larger in the clear neighborhood of an extensive convective system (about $5 \times 10^{-6} sec^{-1}$) than in a large area of undisturbed trade weather (about $1 \times 10^{-6} sec^{-1}$). The area average evaporation rates estimated from the atmospheric volume budgets (about 6 mm/day) agreed rather well with the average of a number of measurements by the airborne microscale vertical eddy flux instruments.

Holland, Joshua Z., "The BOMEX Sea-Air Interaction Program: Background and Results to Date," *NOAA Technical Memorandum*, ERL BOMAP-9, Center for Experiment Design and Data Analysis, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Rockville, Md., April 1972, 26 pp.

The Barbados Oceanographic and Meteorological Experiment (BOMEX) Sea-Air Interaction Program has been the outgrowth of two lines of planning, begun in the early 1960's, in which the American Meteorological Society, the National Academy of Sciences, and Federal agencies have played important parts. One line was directed towards a national effort on the scientific problems of sea-air interaction. The other was directed towards an international effort to extend the range of meteorological forecasts. The Sea-Air Interaction Program, or "Core Experiment," of BOMEX ruled the layout of the ship array, scheduling of observations and deployment of aircraft during the first three BOMEX observation periods: May 3-15, May 24-June 10, and June 19-July 2, 1969. It was designed to provide data on the sea-air flux of energy by three methods: (1) measurement of atmospheric budget terms over a 500-km square; (2) direct measurement of surface-layer vertical eddy fluxes at various times and places within the square; and (3) measurement of the major terms of the heat budget of the upper ocean at each of the ship stations. The momentum flux was also to be evaluated by the first two methods. After a long period of data reduction, some estimates of the evaporation rate, stress, sensible heat flux,and kinetic energy flux have now been obtained by each of the methods. Preliminary estimates of the evaporation rate are typically about 5 mm/day during early May, based on data from several investigators on the Navy's Floating Laboratory Instrument Platform (FLIP), and from turbulence measurements made on NOAA's Research Flight Facility (RFF) DC-6 aircraft. By late June, while FLIP was no longer in the BOMEX array, evaporation rates of at least 6 mm/day are indicated by the RFF aircraft data and preliminary volume budget analyses. Previous estimates were 4 to 5 mm/day based on Budyko's and Jacobs' climatological analyses for this season. Stresses measured by various methods range from a few tenths to more than 1 $dyne/cm^2$.

Smith, J.R., "Summary Report: S.S. *Advance II* Participation in BOMEX," *Report*, Engineering and Environmental Sciences Division, Research Triangle Institute, Research Triangle Park, N.C., July 1969, 18 pp.

The S.S. *Advance II*, with a variety of experiments aboard, participated in the third observation period of BOMEX. Departing Wilmington, N.C., on June 8, the course of the *Advance II* carried her through the BOMEX grid, across the equator in the region of the Amazon River, northwestward along the coast of South America to Trinidad, across the Caribbean Sea, and through Mona Passage, returning to Wilmington on July 21. In addition to its assignment as a roving vessel in the BOMEX grid, the ship collected data for special experiments along the entire cruise track. Twelve separate agencies were directly involved in the *Advance II* program. Although detailed analyses of the data have not begun, it is estimated that at least 85 percent of the program originally planned was accomplished. This report represents a "quick-look" at the data collected.

Data Inventories

Barbados Oceanographic and Meteorological Analysis Project, *BOMEX Field Observations and Basic Data Inventory*, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Rockville, Md., March 1971, 428 pp.

See entry under "History - Plans - General Description."

The BOMAP Office, *BOMEX Bulletin* No. 9, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Rockville, Md., January 1971, 120 pp.

See entry under "History - Plans - General Description."

de la Moriniere, Terry C., "BOMEX Temporary Archive: Description of Available Data," *NOAA Technical Report*, EDS-10, Environmental Data Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Washington, D.C., March 1972, 312 pp.

This report describes in detail the data available from the BOMEX Temporary Archive, a depository at NOAA for data collected during the Barbados Oceanographic and Meteorological Experiment (BOMEX) during May, June, and July 1969. Procedures used in processing these data are described, tabulated inventories of the archived data are presented, and ordering instructions and costs are given.

NUMERICAL MODEL STUDIES OF AIR-SEA INTERACTIONS BASED ON BOMEX DATA

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Center for the Environment and Man, Inc.

INTRODUCTION

Under a grant from the National Science Foundation, studies of air-sea interactions based on BOMEX data have been conducted. Detailed information on the models has been published (Pandolfo, 1968, 1969) and will not be repeated here. What we wish to present is a synopsis of the work accomplished over a 1-year period. This work consisted of experiments of limited scope, focused on selected aspects of the one- and three-dimensional models. These experiments are essential steps in the long-term evolution of a set of complex and valuable research tools. The major advances are:

(a) The completion of a series of three-dimensional model simulations that generate atmospheric vertical velocity fields that are consistent with the first estimates of large-scale vertical velocity over the BOMEX area during the 1969 field observations.

(b) The simulation with a one-dimensional model of realistic time changes of near-surface conditions during the period June 22 to 24, 1969, the input consisting of the observed time-varying 850-mb wind. This simulation is the third in a series; the first set realistically simulated climatological near-surface conditions with climatological input data (Pandolfo, 1968), and a second set realistically simulated 5-day average near-surface conditions with 5-day average input data for the period June 21 to 25, 1969 (Pandolfo, 1969).

(c) The completion of an experiment in which simulations with alternative formulations for parameterized eddy flux in the boundary layer were compared with each other and with observed conditions (Pandolfo, 1971).

MODIFICATION AND CHECKOUT OF COMPUTER PROGRAMS

We have made model changes that have allowed the following:

- Incorporation of time-varying upper boundary conditions.
- Calculation of precipitation effects on the flux budgets of heat and salinity.

- Adoption of new formulas describing oceanic density-salinity-temperature relationships.

- Improved computational procedures for the calculation of the effects of the transparency of the upper oceanic layers on the heat absorption.

- Input of gradients at every level of the model for a better definition of the boundary layer.

The effects of these modifications are discussed below in connection with the model experiments.

Other studies concurrently carried out at CEM have yielded results that have either already been adopted as modifications to the computer programs or will be adopted in the near future. These include:

(a) Incorporating more flexibility in defining horizontal grid arrays in three-dimensional boundary layer simulation experiments in the ocean and atmosphere.

(b) Including formulas for calculating effects of suspended particulates on atmospheric radiative fluxes and thermal budgets.

(c) Improving numerical techniques for the integration of conservation equations containing advective terms.

ACQUISITION AND USE OF BOMEX DATA FOR INPUT

The basic body of data used throughout the year consisted of the seven volumes of BOMEX preliminary data prepared by the Barbados Oceanographic and Meteorological Analysis Project (BOMAP) in December 1969 (BOMAP Office, 1969). Selected data for the period June 21 to 25, 1969, have been used for all simulation experiments. The sensitivity of the one-dimensional simulations to the program changes outlined above was tested with data from the three ship stations in the eastern half of the BOMEX area (the *Rockaway*, *Discoverer*, and *Oceanographer*), since these were the only data available before December 1969. However, the three-dimensional model simulations were carried out with input data from all five ship stations. In March 1971 we received from the BOMAP Office time averages of high-resolution rawinsonde data (18 soundings per day) for each of the five ship stations for the period June 21 to 26, 1969. These data have not yet been used in any simulation experiments.

MODEL EXPERIMENTS

The Three-Dimensional Model

The three-dimensional model can simulate, in addition to the features simulated by the one-dimensional model, intraregional spatial variations of the meteorological fields, as well as fields of vertical velocity. The most recent simulation was begun with initial horizontal fields derived from a plane-fit to the observed temperature, humidity, and salinity over the region, and horizontally uniform wind and current. After one simulation day, the fields of interface stress, heat flux, and vapor flux evolved to those shown in figures 1 to 4. The intraregional variation of stress at this time shows a range of values of approximately 25 percent of the minimum value in the field; that of sensible heat flux into the atmosphere, a range of about 20 percent; that of sensible heat into the ocean, a range of about 300 percent; and that of evaporation, a range of about 50 percent. All the fluxes generally increase from southwest to northeast, except for the sensible heat flux into the atmosphere, which increases from southeast to northwest. As will be noted later, turbulent flux measurements have not yet been reported, analyzed, and synthesized to the extent necessary for verifying these features of the model simulation. We hope that such a comparison can be made in the near future.

Implicit in the initial conditions for this simulation is that the vertical velocity is zero everywhere in the field at beginning time. An inflow lateral boundary condition is imposed at each vertical grid level for all time, i.e., the outside (normal) velocity gradients remain zero. The vertical velocity field that develops at the end of the first simulation day and at the upper boundary of the modeled region, i.e., at the 1,500-m level, is shown in figure 5. The field is characterized by subsiding vertical velocities of the order of 1 mm/sec, which is consistent with estimates obtained by Robert W. Reeves (private communication) at the BOMAP Office from an analysis of observed wind fields during the period June 21 to 25, 1969.

A time series of the model-generated vertical velocities at the upper boundary for one of the central points in the horizontal grid array is shown in figure 6. This figure indicates that the subsiding vertical velocities, after an initial adjustment period of about one day, range between 0.5 and 2.5 mm/sec during the remainder of the simulation period, which will be described in more detail below.

The One-Dimensional Model

The one-dimensional model was modified to enable the geostrophic wind and currents used as input to become time dependent. This option allows additional detail derived from observed time variations to be incorporated in simulation experiments.

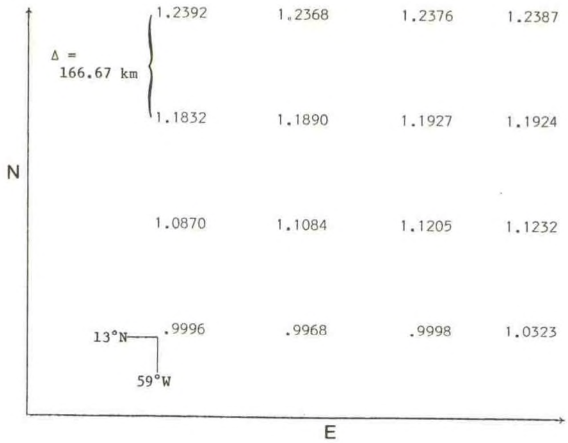

Figure 1. *Surface field of wind stress (dynes/cm^2) as calculated by the three-dimensional model after 24 hours of simulation. All succeeding three-dimensional model results were computed on the same grid array.*

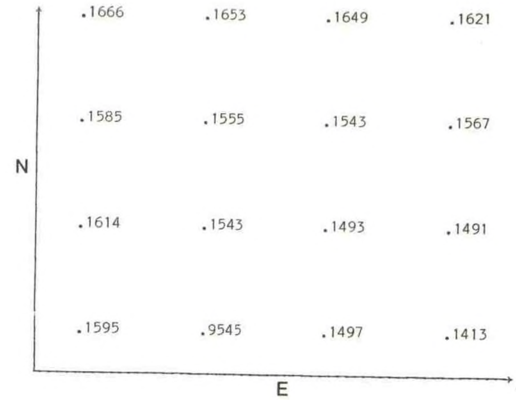

Figure 2. *Field of sensible heat flux (mly/sec) into the atmosphere from the interface as calculated by the three-dimensional model after 24 hours of simulation. Positive values indicate fluxes away from the interface (into the atmosphere).*

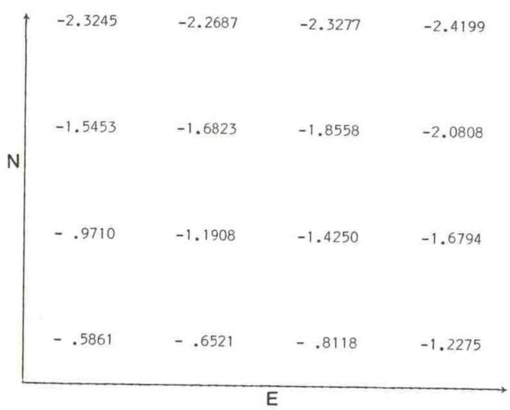

Figure 3. *Field of sensible heat flux (mly/sec) into the ocean from the interface as calculated by the three-dimensional model after 24 hours of simulation. Negative values indicate fluxes toward the interface (out of the ocean).*

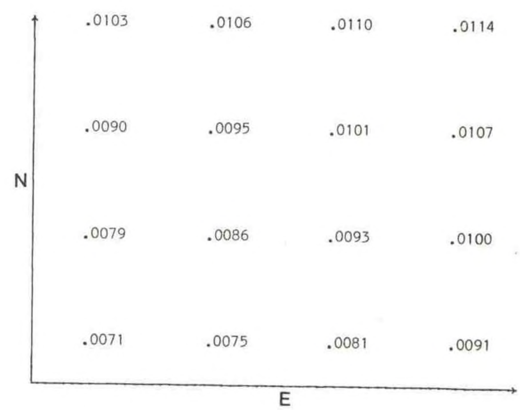

Figure 4. *Evaporation from the interface (mg/sec cm^2) as calculated by the three-dimensional model after 24 hours of simulation.*

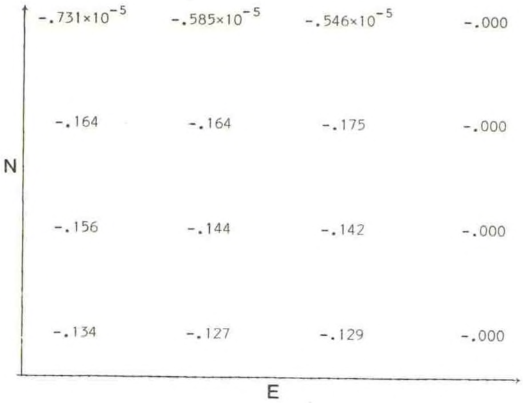

Figure 5. The field of vertical velocity (cm/sec) at 1,500 m as calculated by the three-dimensional model after 24 hours of simulation. Negative values indicate subsidence.

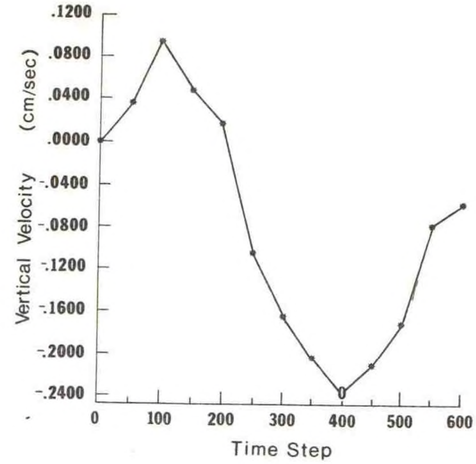

Figure 6. Time series of the vertical velocity at 1,500 m at a station in the central portion of the grid array. Negative values indicate subsidence. The character "0" indicates an extreme value used in determining scale of the graph.

BOMEX data were used in two experiments to illustrate the sensitivity of the one-dimensional model to the upper boundary wind conditions. For the first experiment, a time-constant wind was obtained from a 5-day average of the 850-mb wind observations at 1200 GMT from the *Rockaway*, *Discoverer*, and *Oceanographer*. These observations revealed an average wind speed of 13.3 m/sec and direction of 114.5°. The second experiment was run with a time-varying wind at the upper boundary. For this experiment, the winds consisted of the average of the wind observed from all three ships at 1200 GMT each day, i.e., five space-averaged observations from June 21 to 26. Values of the wind at times other than those used as input were obtained by linear interpolation.

All other input conditions were derived from 5-day averages of the observations, except for the initial velocity profiles. Since no observations were available, these profiles were obtained from previous simulations with climatological data (Pandolfo, 1968). Because there is strong evidence in analyses carried out at the BOMAP Office that the humidity measurements from the BOMEX rawinsondes significantly underestimate the actual humidity, the initial humidity values at all grid levels above the 6-m level are probably unrealistically low. The value at the 6-m level was derived from shipboard instrumentation and is presumably more realistic. Therefore, there is good reason to expect an initial period of adjustment in the simulation runs from these somewhat unrealistic initial humidity and wind profiles.

Three parameters were chosen to illustrate the differences that could be generated under the influence of these two upper wind boundary conditions. Figures 7 and 8 show the sea surface temperature and the 6-m humidity and wind, respectively. The time variations in these near-surface parameters observed during the simulation period are indicated by "3" and were computed by taking a three-ship average of the appropriate parameter at the times shown in these figures. Only averages for all three ships were used; two-ship averages had a distinct bias.

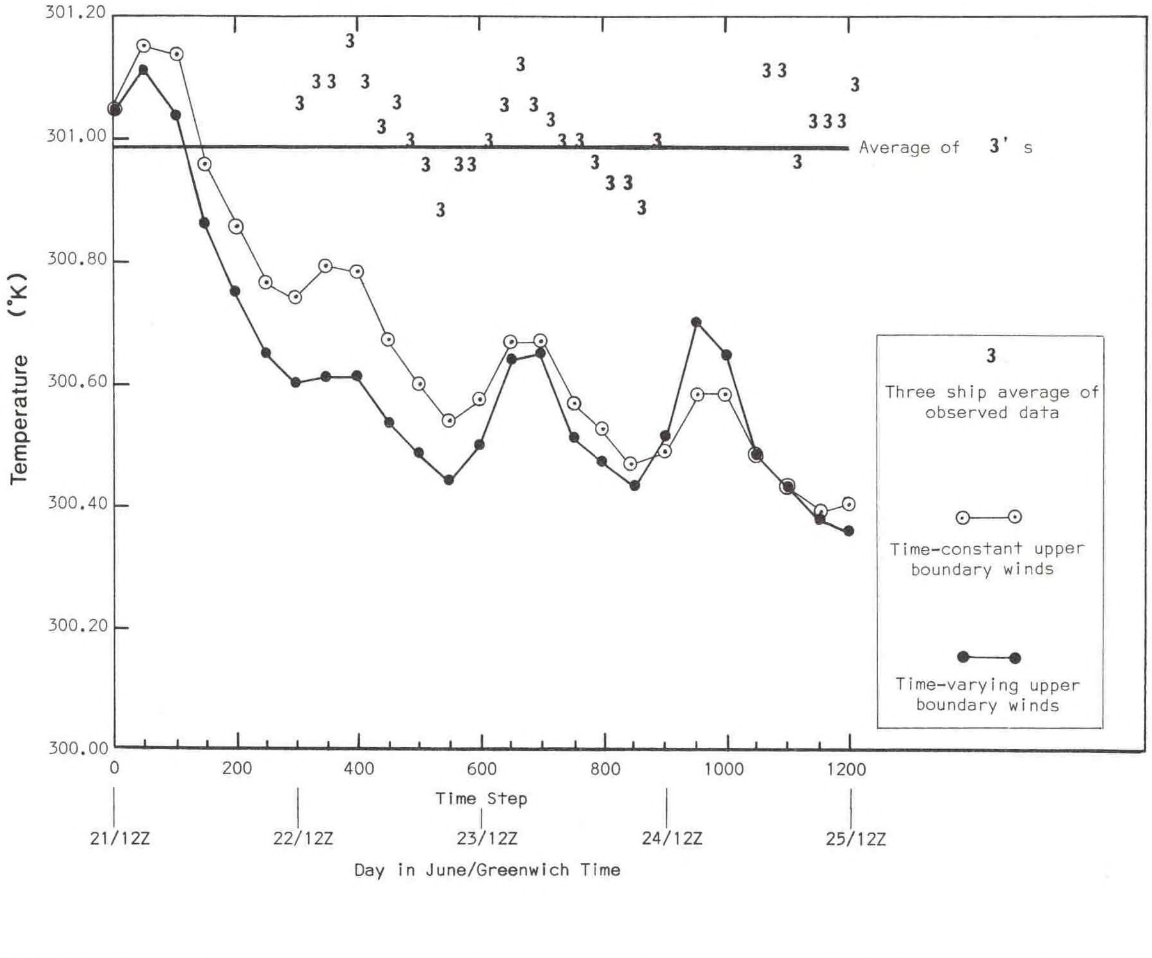

Figure 7. Sea-surface temperatures obtained from two 4-day simulations. The time-constant upper boundary wind was based on a time and space average of the 1200 GMT, 850-mb winds observed from three ships (Rockaway, Discoverer, and Oceanographer). The time-varying wind was a space average of these 1200 GMT observations. Observed values based on a three-ship space average are indicated by "3."

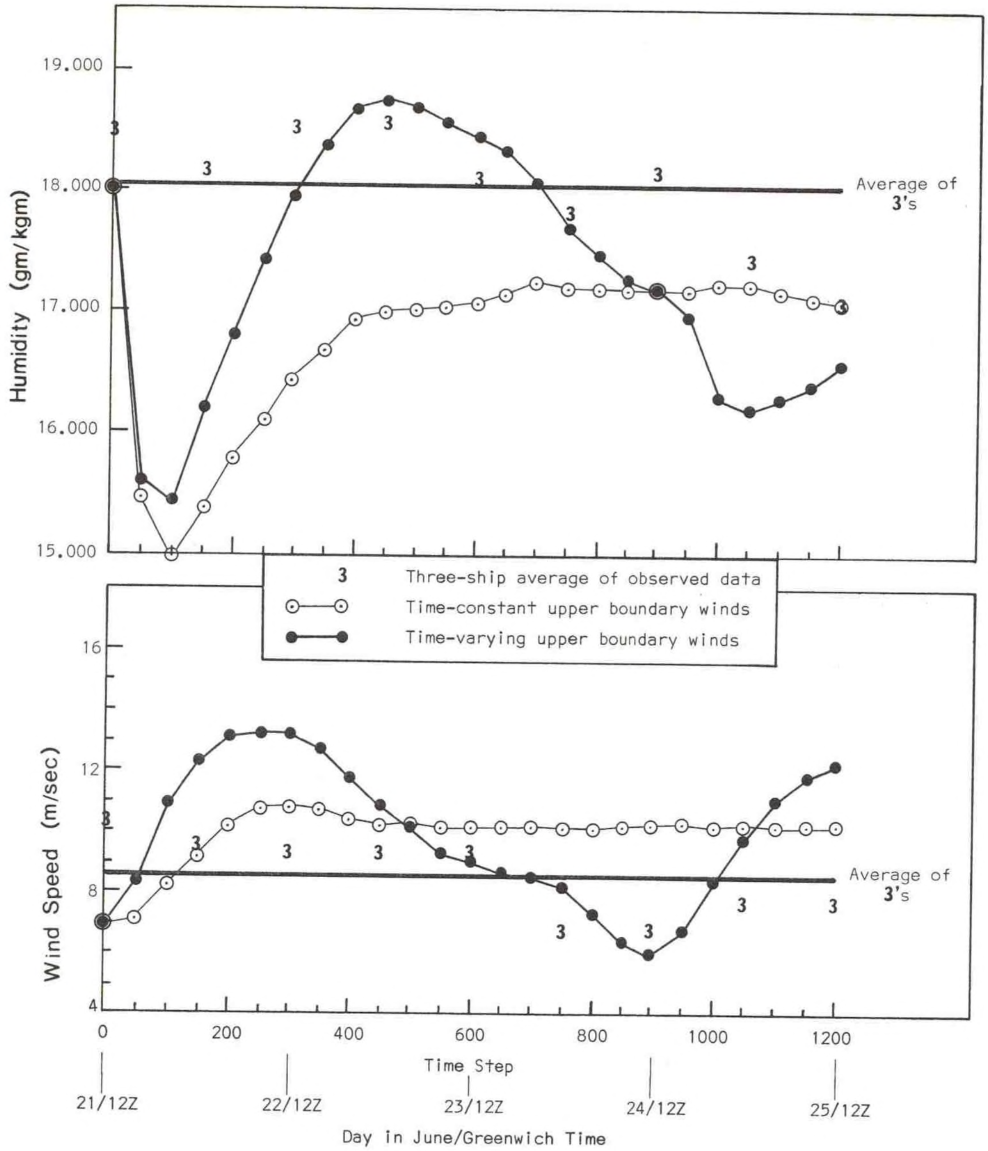

Figure 8. Top: humidities at 6 m obtained from the simulations described in fig. 7. Bottom: winds at 6 m obtained from the simulations described in fig. 7.

After the first simulation day, the variations in the 6-m humidity and wind appear to be simulated most realistically with a time-varying upper boundary wind. This same conclusion is not as easily drawn with regard to the sea-surface temperature. For atmospheric parameters, better definition of the atmosphere by incorporation of more observations appears to result in a better simulation.

Two simulations were carried out to illustrate the effects of precipitation on the salinity and temperature of the upper layers of the ocean. The BOMEX data used as input for these 2-day runs were identical in all aspects except one: the second run simulated rain falling at a rate of 1 cm/day; in the first run there was no rain.

The sea-surface salinity for the two runs is plotted in figure 9. The downward trend in salinity in time is primarily caused by advective processes. The salt budget reveals that, on the average, the reduction in salinity due to rain is only about 2.6 percent of the reduction due to advection.

The reduction in sea-surface temperature between the two runs was .02°K. The reason lies in that the temperature of the rain striking the sea surface was assumed equal to the average wet-bulb temperature in the lower 25 m of the atmosphere, which in tropical regions, such as the Barbados area, is often very nearly the case.

The influence of precipitation on the upper layers of the ocean is best reflected in the density variations with time, which are plotted in figure 10 for the surface and 20 m. The density curves for 20 m are not shown until time step 350 because there were no differences between the two simulation runs until that time. The density at this depth undergoes relatively large reduction during the entire simulation period whether or not there is precipitation. This change is largely due to advective processes (mostly in salinity), which continually reduce the static stability of the upper layers ($\leq$ 20 m), and by time step 450 the "mixed layer" is unstable. The instability is largest when there is no rain, reaching a maximum value at time step 550 and decreasing to near-neutral stability by time step 600. With rain, this instability is not as large, and at a depth of 25 m there is no difference between the two cases. If the advective processes were removed, the effects of precipitation would not be seen at 20 m for a longer period of simulation than 28 hours (time step 350).

Results of other rain simulations with moderate-to-heavy precipitation ($\geq$ 1 in./12 hrs) have revealed similar characteristics, the most notable feature being that in all the simulations the mixed layer depth is maintained at 25 m to 30 m. The effects of rain simply intensify the thermocline, as shown in figure 11, where contours of salinity differences between two simulations, one with rain, are plotted against depth and time. Advective processes have been eliminated in the plotted results. The contours are in parts per million, and the negative sign refers to a reduction in salinity. The rainfall rate is 1 cm/day and continues for the entire 8-day simulation. The positive differences below the thermocline are the result of decrease in mixing through the thermocline that occurs because of the intensification of the thermocline when there is rain.

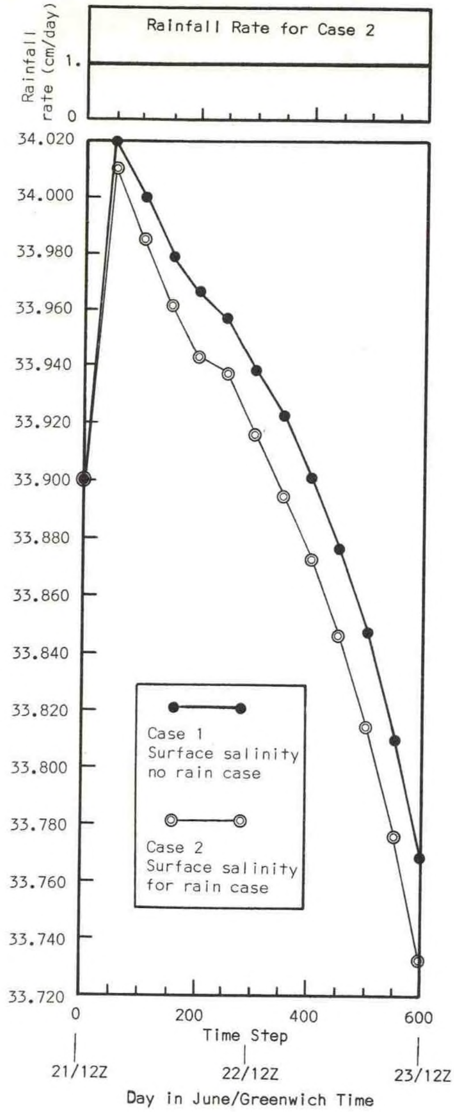

Figure 9. Sea-surface salinities resulting from two 2-day simulations. These simulations differed only in that in Case 1 there was no rain, while in Case 2 rain was falling at a continuous rate of 1 cm/day for 2 days.

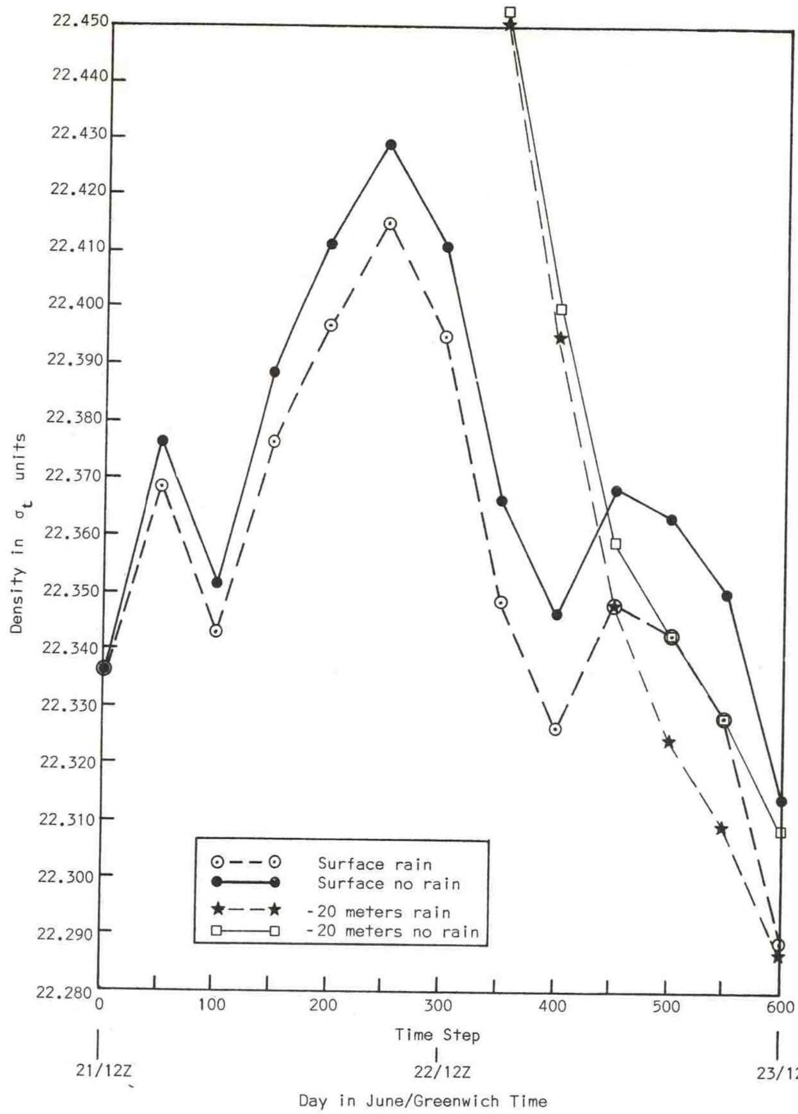

Figure 10. Water densities at the surface and 20 m obtained from the two simulations described in fig. 9.

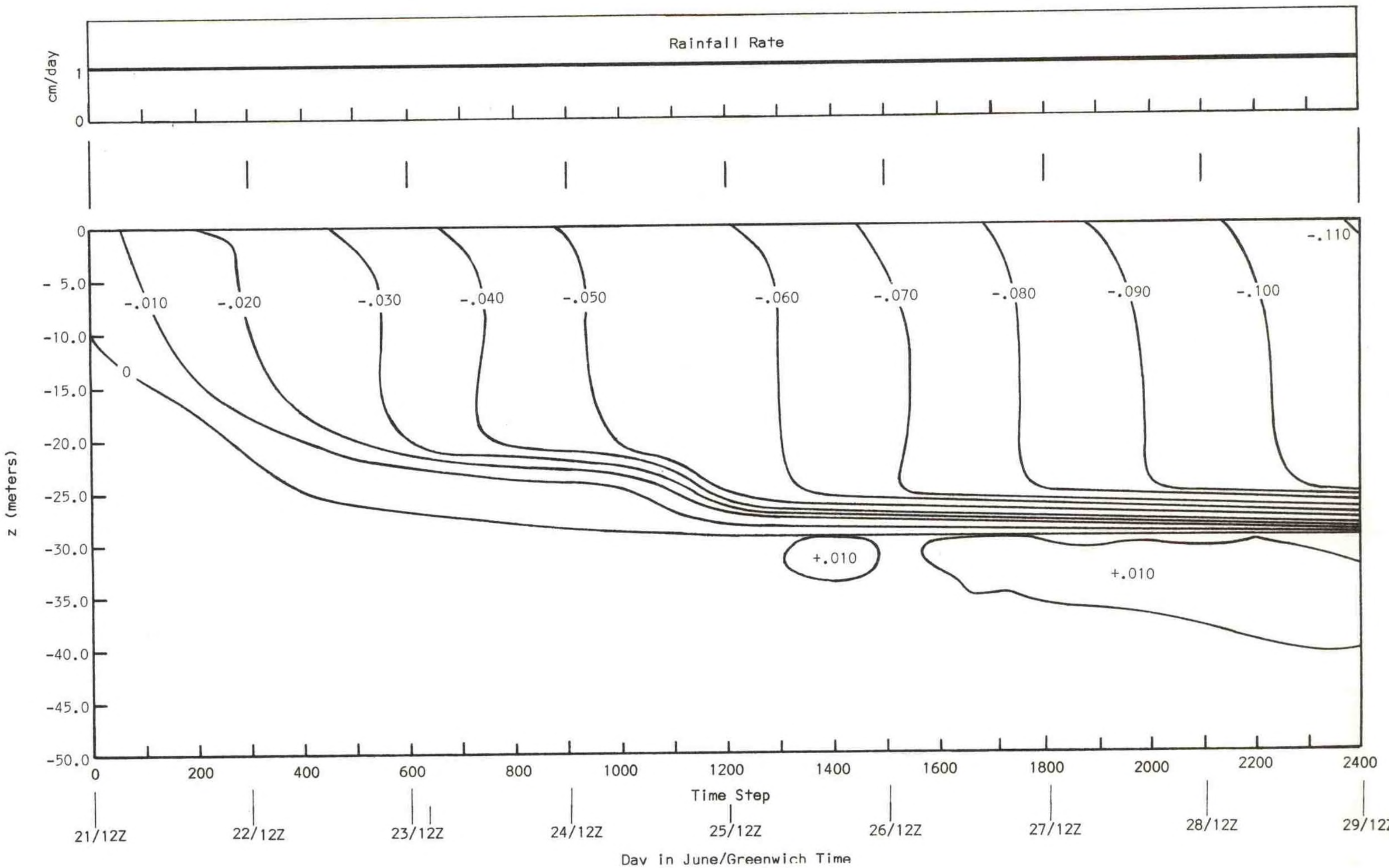

Figure 11. *Contours of salinity differences, in parts per million, plotted against depth and time, based on two 8-day simulations, one with a rainfall rate of 1 cm/day (top of figure), the other without rain. The results of simulation without rain were subtracted from those with rain, eliminating advective effects.*

A new formula describing oceanic density-salinity-temperature relationships has been established and has been adopted in the one-dimensional model to facilitate the calculation of more accurate density gradients. The density gradients in the ocean are used in computing the exchange coefficients and the vertical gradient of geostrophic current, e.g., the vertical density gradient is computed through the formula

$$\frac{\partial \rho}{\partial z} = 10^{-3} \frac{\partial \sigma_t}{\partial z} = 10^{-3} \left(\frac{\partial \sigma_t}{\partial T} \frac{\partial T}{\partial z} + \frac{\partial \sigma_t}{\partial s} \frac{\partial s}{\partial z} \right),$$

where the values of $\partial \sigma_t / \partial T$ (s,T) and $\partial \sigma_t / \partial s$ (s,T) were obtained by second-degree interpolation from a table originally calculated by Hesselberg and Sverdrup (1914, 1915). This indirect means of computing vertical density gradients was necessary because, until recently, no adequate empirical formula expressing the relationship between density, temperature, and salinity was known.

Based on a large number of samples, Cox et al. (1970) obtained an empirically derived relationship from which σ_t can be calculated as a function of temperature and salinity, and values of $\partial \sigma_t / \partial T$ and $\partial \sigma_t / \partial s$ can be obtained from their differentiated polynomial expression. In the near future, the model program will be changed so that the computations of $\partial \rho / \partial z$ can be carried out directly from the new formula.

The vertical density gradients computed by these two methods differ. This difference is apparent in the computation of the currents and Richardson numbers, as well as in the exchange coefficients and the temperature and salinity profiles. The differences in the temperature and salinity profiles are illustrated in figures 12 and 13 and were attained over a 600 time-step period based on identical input data.

As is evident from figure 7, the simulated sea-surface temperature is too low, one influencing factor being the absorption of solar radiation in the water.* The extinction coefficients govern the amount of radiation absorbed in a layer and consequently the amount of solar heating that will take place in that layer. The extinction coefficients used for the simulation illustrated in figure 7 were, for the most part, based on measurements obtained in oceanic water of average clarity. These measurements indicated that approximately 98 percent of the incident radiation is absorbed in the upper 20 m of the ocean.

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*The most recent model simulations have revealed that the simulated low sea-surface temperature in figure 7 is closely related to the excessive wind speed in the first 600 time steps (fig. 8). The wind speed at the near-interface levels in the model is predominantly influenced by the upper boundary winds.

A second set of extinction coefficients, based on measurements obtained in turbid coastal waters, was used in the model. In this case, absorption of incident solar radiation is very large, with approximately 98 percent being absorbed in the upper 5 m. The sensitivity of the model to the choice of extinction coefficients can be seen in figure 14, which offers a comparison between two identical simulations. For the curve that shows a lower sea-surface temperature, extinction coefficients for water of average clarity were used. Observed trends are indicated by "3."

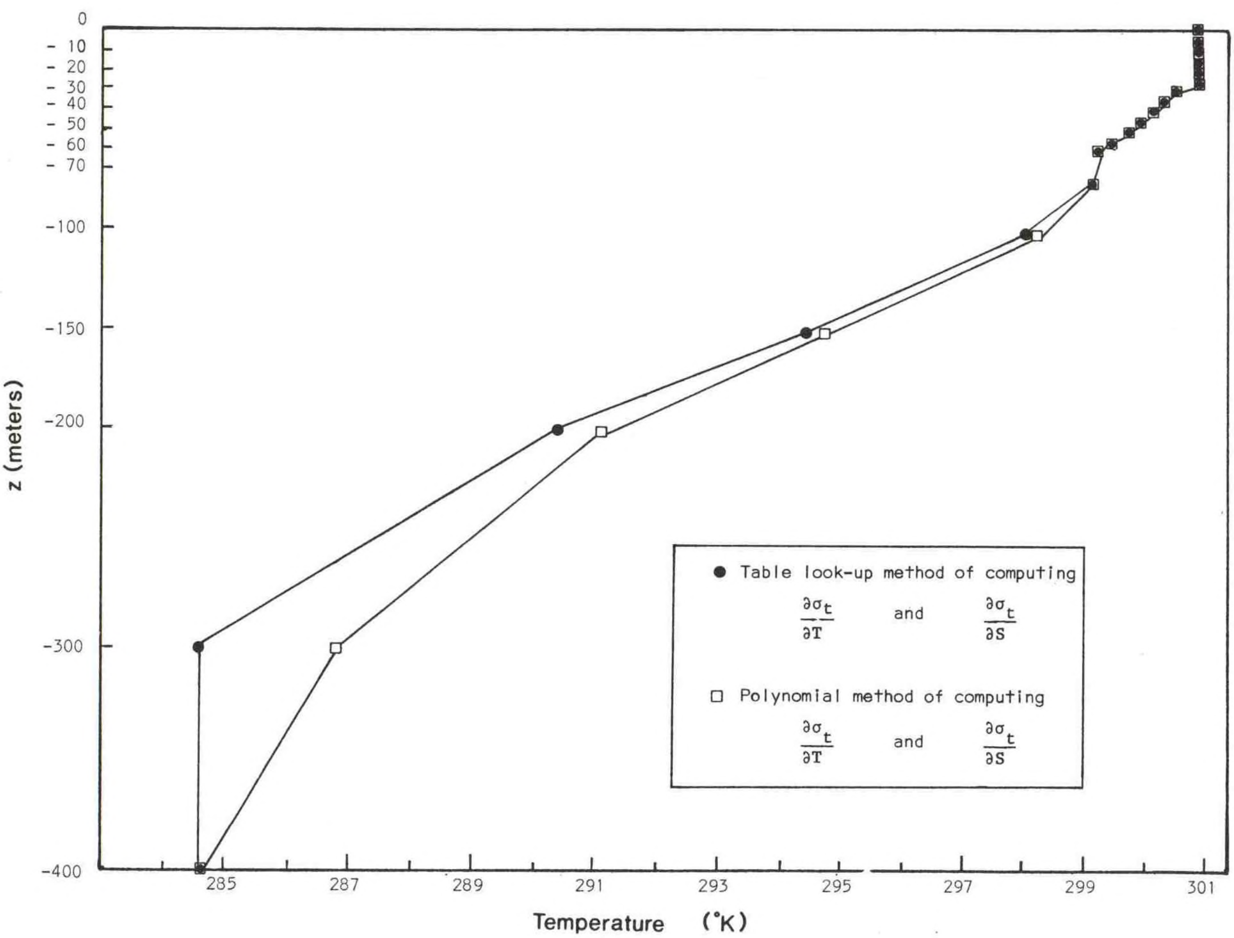

Figure 12. Ocean temperature profiles obtained after 2 days of simulation by two different methods of computing the vertical density gradients.

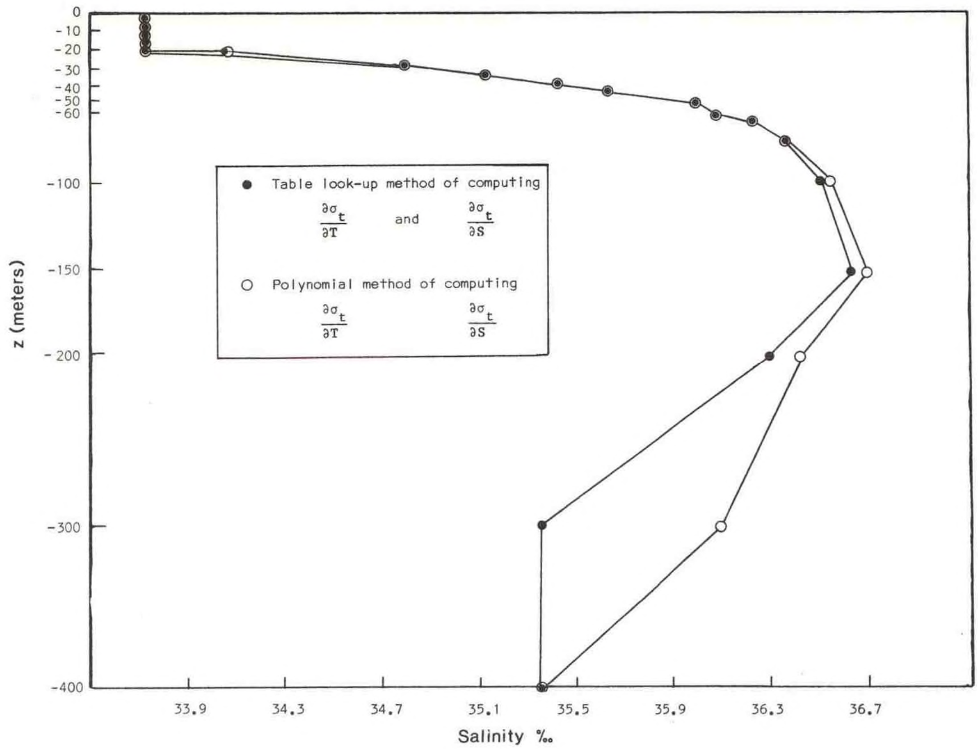

Figure 13. Salinity profiles obtained after 2 days of simulation by two different methods of computing the vertical density gradients.

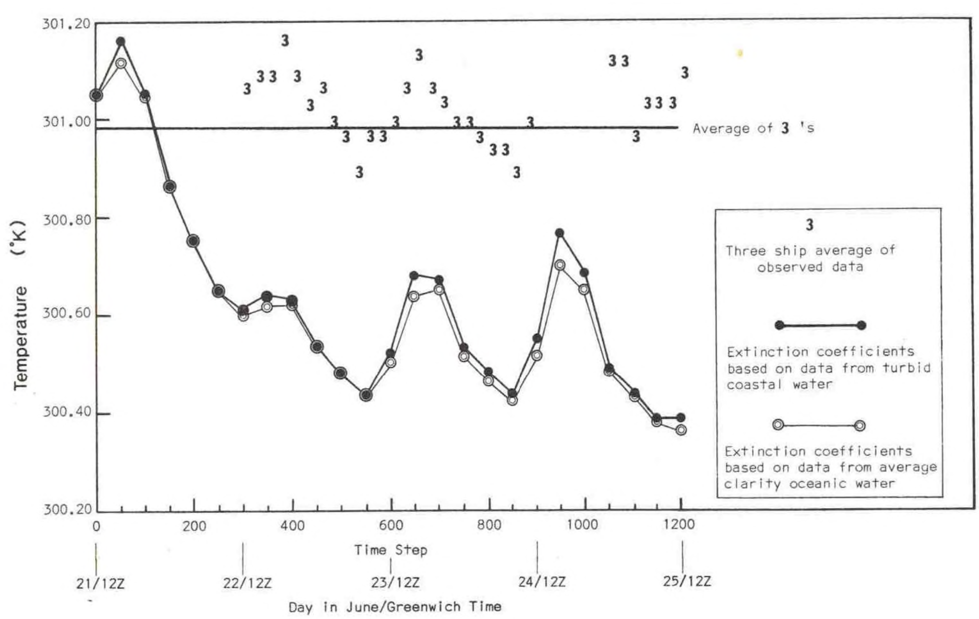

Figure 14. Sea-surface temperatures as influenced by different water transparancies. Solar radiation absorption in these two simulations is based on empirical data for oceanic water of average clarity and turbid coastal water.

Two sets of ocean temperature and salinity gradients were obtained. The first was based on 5-day average profiles from three ships (the *Rockaway*, *Oceanographer*, and *Discoverer*) for depths of 0, 20, and 200 m. The second set of gradients was obtained from 5-day average profiles from five ships (the three cited above, plus the *Mt. Mitchell* and the *Rainier*). By means of a least squares fit of data obtained from these profiles, temperature and salinity gradients were calculated for depths of 0, 10, 20, 30, 50, 75, 100, 200, 300, and 400 m.

Figure 15 shows two salinity profiles that were generated after 4 days of simulation with gradients of 3 and 10 levels in the vertical. The initial salinity profile for both runs is based on a 5-day average for the *Rockaway*, *Oceanographer*, and *Discoverer*. This figure implies that more realistic simulations can be obtained by averaging gradients over a large area rather than attempting to simulate subareas of the larger area. Also, use of a greater number of depths results in better simulations. If we assume near-steady-state conditions prevail in the ocean, maintaining the initial profile (the 5-day, three-ship average) throughout the simulation period would indicate that the gradients had been correctly established and the currents were being predicted properly. The results for the 10-level simulation in figure 15 are close to this.

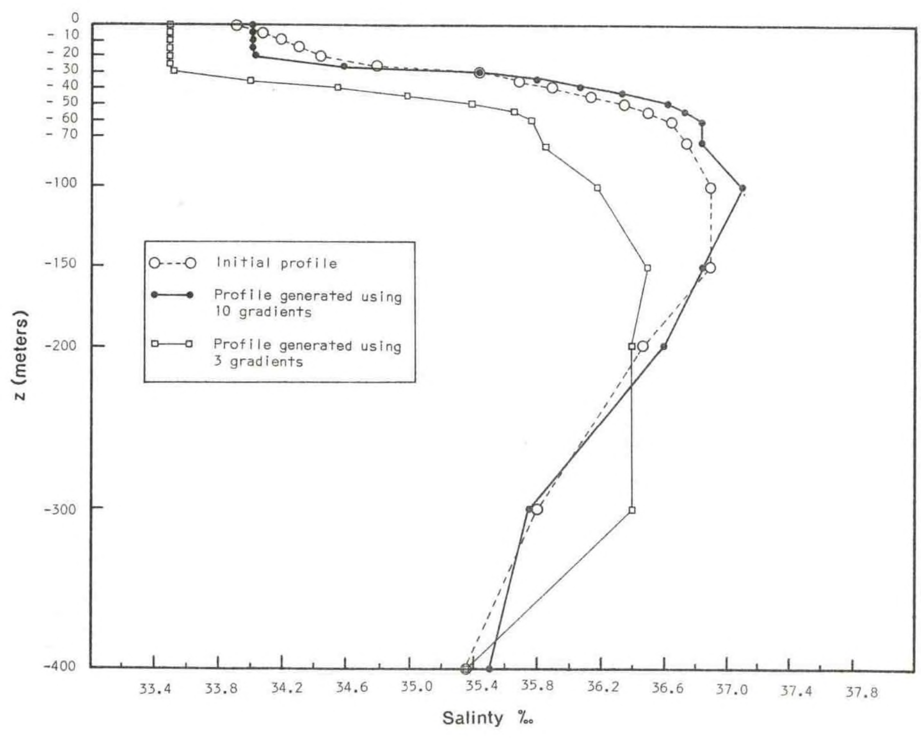

Figure 15. Two salinity profiles generated after 4 days of simulation with different salinity gradients, and the initial profile. The initial profile is a three-ship, 5-day average.

COMPARISON OF SIMULATED AND OBSERVED BOUNDARY LAYER FLUX DATA

A few aircraft measurements of turbulent fluxes have been reported by Miyake and Donelan (1970), and Bunker (1970). The former give data obtained from one sample 1/2-hour run made on May 29, 1969, at the 18-m level. Bunker gives the results of 97 individual 1-min runs at altitudes from 15 to 1,400 m on 10 days between June 26 and July 28, 1969.

The above dates do not coincide with the 5-day period for which the simulations were carried out. Also, there is reason to expect some systematic underestimates in the aircraft flux measurements. Bunker shows that the measurements of eddy flux by aircraft may be 40 percent lower than other measurements. Further, his runs were evidently restricted to the western half of the BOMEX area, while most of the simulation experiments used to obtain the results presented in this section were conducted with input data from the entire region. At this time, therefore, we can make only the grossest estimate of the consistency between simulated and observed fluxes.

The vertical profiles of the fluxes simulated by the one-dimensional model are compared in figure 16 with averaged profiles of measured fluxes as reported by Bunker. Bunker's values for stress and vapor flux are, in general, lower than model-simulated values characteristic of the entire BOMEX area. It should also be noted that the three-dimensional model simulation yielded fields of vertical flux at the interface that show regional variations (see figs. 1, 2, and 4). The momentum and vapor fluxes, as calculated by the model, are lower in the western half than in the eastern half of the area. If the model is predicting gross features correctly, Bunker's measurements, being in the west, would be lower than those predicted for the overall region. This regional difference may explain the disparity between Bunker's results and the model results in figure 16. Bunker's profiles for "disturbed" and "undisturbed" conditions (by his definition) were averaged with equal weight to obtain the "measured" profiles in these figures.

More definitive comparisons may be expected when (a) more simulations are conducted for other periods, (b) more independent measurements of turbulent flux become available, and (c) data-handling procedures are developed that permit determination of more accurate spatial and temporal averages.

PARAMETERIZATION OF BOUNDARY LAYER FLUXES

During the past year, four alternative formulations for the vertical eddy transfer mechanism were tested with BOMEX data. The experiments provided results of importance in the design of large-scale numerical circulation models and in the study of the boundary layer. Specifically, they showed that only minor refinement of the currently used parameterization of boundary layer mixing is necessary to achieve quite realistic simulations; thus no new parameterization concepts need to be developed. They also showed that piecemeal imposition of such refinements could produce intermediate models with significantly different energetic properties and less simulative accuracy. These experiments are described in a recently published paper (Pandolfo, 1971).

A formulation for the inclusion of the condensation, evaporation, and precipitation process in the atmospheric water budget model is being developed. This includes a parameterization of the moist convective process that yields fractional (convective) cloud cover, horizontally averaged liquid water content, and horizontally averaged latent heating (cooling) from horizontally averaged vertical profiles of temperature, wind, moisture content, and eddy diffusivity. These profiles are generated in the current models. Included also is a parameterization of the precipitation process based on that developed by Kessler (1969). First tests with a set of typical profiles of the governing parameters generated by the one-dimensional model have yielded reasonable quantities for the hydrologic budget components.

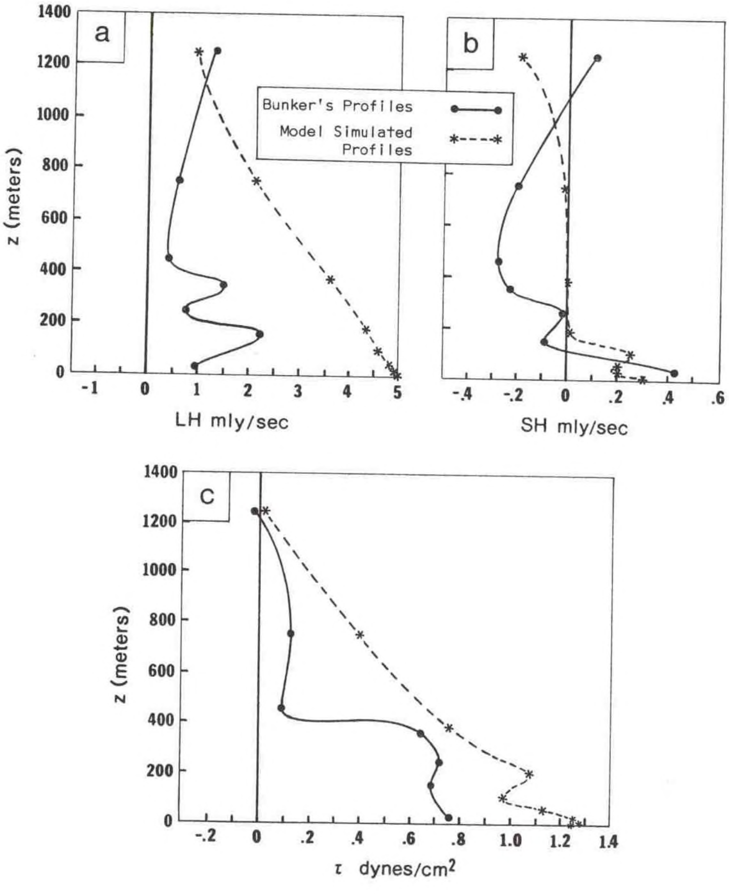

Figure 16. Comparisons of model-simulated vertical profiles of latent heat flux (a), sensible heat flux (b), and stress (c) with aircraft measurements of eddy fluxes reported by Bunker (1970).

SUMMARY

The results presented here constitute small but important achievements toward our goal to develop a complex numerical model that accurately simulates the sea-air boundary layer under a variety of realistic conditions.

The three-dimensional model can simulate intraregional spatial variations of the meteorological fields. The results of a simulation of the BOMEX area revealed intraregional variation of stress with a range of values of approximately 25 percent of the minimum value in the field; sensible heat flux into the atmosphere and ocean with a range of about 20 percent and 300 percent, respectively; and a range of evaporation of about 50 percent. The three-dimensional model also generated atmospheric vertical velocity fields that are consistent with the first estimates of large-scale vertical velocity over the BOMEX area.

Simulations with the one-dimensional model conducted with the observed time-varying 850-mb wind used as input provided realistic time changes of near-surface conditions. Simulation of hypothetical precipitation effects on the flux budgets of heat and salinity showed that the interface temperature remains essentially unchanged by precipitation, but that the salinity is reduced throughout the depth of the mixed layer. The incorporation of a more recent formula describing oceanic density-salinity-temperature relationships into the model results in unexpectedly large differences from ocean temperature and salinity profiles obtained by an earlier method. These differences are attributed to greater accuracy of the new formula in calculating the vertical density profiles in the ocean layer. Investigations of the sea-surface temperature's sensitivity to changes in the absorption of solar radiation in the upper layers of the ocean proved that a rather drastic change in the values assigned to characterize the absorption of solar energy in the sea produced little overall change in the temperature of the interface. The one-dimensional model was also used for better prediction of the salinity profile obtained through more comprehensive definition, in both the horizontal and vertical direction, of the salinity gradients.

An attempt to compare data simulated by the one-dimensional model with observed boundary layer flux data was made. Because the observations were made during periods and at locations that do not exactly correspond to the simulated results, only the grossest estimates can be made as to the consistency of simulated and observed fluxes. The observed values for stress and vapor flux are, in general, lower than model-simulated values averaged over the entire region. However, there appears to be some bias in the comparison as the model showed intraregional variations of vertical fluxes at the surface, with lowest values of momentum and vapor fluxes in the portion of the BOMEX region over which the observed values were collected.

Four alternative formulations for the vertical eddy transfer mechanism were tested with data obtained from BOMEX. The test revealed that only minor refinement of the currently used parameterization in large-scale models of boundary layer mixing is necessary to achieve quite realistic simulations and that no new parameterization concepts are required.

ACKNOWLEDGMENTS

The computing facilities of NOAA's Geophysical Fluid Dynamics Laboratory were used for this research. We wish here to acknowledge the interest and cooperation given by the members of that laboratory, by the BOMAP Office (now CEDDA), the National Meteorological Center, NOAA, and by our colleagues at the Center for the Environment and Man, Inc.

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ANNOUNCEMENTS

BLIP Data Now Available

Preliminary data obtained with the Boundary Layer Instrument Package (BLIP) have been added to the BOMEX Temporary Archive. Essentially a multichannel radiosonde, BLIP was flown from a tethered balloon from the afterdecks of four of the ships in the BOMEX array during Observation Periods II, III, and IV. The package was raised to a predetermined height and then lowered several hours later. Profiles and time series of the following meteorological parameters were obtained from the various sensors:

Wind speed and direction - measured by a WINDAV anemometer developed by the University of Wisconsin for BOMEX. The three-cup anemometer produces a signal that is a function of the position of one of the arms with respect to the earth's magnetic pole. This signal plus another one determines the orientation, or wind direction. The frequency determines the wind speed.

Dry- and wet-bulb temperatures - measured by bead thermistors. A distilled water-wick system was part of the wet-bulb sensor.

Pressure - measured by a modified aneroid barometer.

Relative humidity - measured by a hygristor.

The instruments were mounted on an A-frame, which was tied to the tether line and kept pointed into the wind by means of drogue chute. Dry cell batteries were used for power and transmission of the FM signals from BLIP to the ship, and analog recordings of these signals were made aboard ship. Subsequent digitization and reduction was done at NASA's Mississippi Test Facility. Examples of this reduction process are given in *BOMEX Bulletin* No. 8; the BLIP instrumentation system and its performance are described by James A. Almazan in "The BOMEX Boundary Layer Instrument Package," *Preprints of the Second Symposium on Meteorological Observations and Instrumentation*, San Diego, Calif., March 27-30, 1972, American Meteorological Society, Boston, Mass., pp. 138-144.

The archived data are available in two forms: as 1 sample-per-second (1-sps) tabulated values of wind speed, wind direction, and dry- and wet-bulb temperatures, and as graphic displays on a continuous time frame. The measured relative humidity values are part of the data, but in cases where the pressure sensor was used, relative humidity values were computed from the dry- and wet-bulb temperatures.

The BLIP data, which are the product of a preliminary "A_0" review, are also being processed on magnetic tape for the BOMEX Temporary Archive. After further review and editing, the data will be placed in a permanent archive to be established for all BOMEX data.

Tables 1 through 4 list the BLIP data available. Requests should be addressed to Mr. Arthur Cooperman, Chief, Data Information Group, Environmental Data Service, NOAA, Silver Spring, Md. 20910. In response to each request, documentation will also be provided, which includes a listing of the times and values of pressure contacts, a record of the ship's log, indications of missing data, and other information pertinent in the use of the data. Questions concerning the data should be directed to Dr. James A. Almazan, CEDDA, Rx8, NOAA, Rockville, Md. 20852 (tel: 301-496-8871).

Table 1.--BLIP data inventory - Oceanographer

Reel No.	Archived form of data	Date 1969	Julian day	BOMEX Observation Period	Run No.	Start time (GMT)	Stop time (GMT)
LB440	Tabulated data on 35-mm microfilm	May 25	145	II	1	2010	2327
"	"	May 26	146	"	2	1938	2353
"	"	May 28	148	"	3	1640	2326
"	"	May 30	150	"	4	0002	1039
LB441	"	"	"	"	5	1118	1245
"	"	"	"	"	6	1257	2119
"	"	May 31	151	"	7	0013	0900
LB442	"	"	"	"	8	0959	1411
"	"	"	"	"	9	1518	2045
"	"	"	"	"	10	2124	0426
"	"	June 1	152	"	11	0518	1024
"	"	"	"	"	12	1118	1750
"	"	"	"	"	13	1821	2107
"	"	June 2	153	"	14	0030	0253
LB443	"	June 3	154	"	15	2122	0100
"	"	June 4	155	"	16	1037	1941
"	"	"	"	"	17	2002	2350

Table 1.--BLIP data inventory - Oceanographer (continued)

Reel No.	Archived form of data	Date 1969	Julian day	BOMEX Observation Period	Run No.	Start time (GMT)	Stop time (GMT)
LB443	Tabulated data on 35-mm microfilm	June 6	157	II	18	0206	0223
"	"	"	"	"	19	1144	2013
"	"	"	"	"	20	2139	0854
LB444	"	June 7	158	"	21	0934	2020
"	"	"	"	"	22	2121	0758
"	"	June 9	160	"	23	0833	1917
LB445	"	"	"	"	24	2139	0721
"	"	June 10	161	"	25	0741	1720
"	"	"	"	"	26	2125	0700
LB446	"	June 21	172	III	1	0012	0016
"	"	"	"	"	2	1631	2037
"	"	June 22	173	"	3	0012	1157
"	"	"	"	"	4	1538	1930
LB447	"	"	"	"	5	2126	0112
"	"	June 23	174	"	6	0238	1316
"	"	"	"	"	7	1337	2105
LB448	"	"	"	"	8	2142	0847
"	"	June 24	175	"	9	1227	2110
"	"	"	"	"	10	2133	1305

Table 1.--BLIP data inventory - <u>Oceanographer</u> (continued)

Reel No.	Archived form of data	Date 1969	Julian day	BOMEX Observation Period	Run No.	Start time (GMT)	Stop time (GMT)
LB449	Tabulated data on 35-mm microfilm	June 25	176	III	11	1517	2114
"	"	"	"	"	12	2137	0753
LB450	"	June 26	177	"	13	0808	1222
"	"	"	"	"	14	1241	2122
"	"	June 27	178	"	15	2354	0507
"	"	June 28	179	"	16	0509	1248
LB451	"	"	"	"	17	1338	2114
"	"	"	"	"	18	2144	0658
"	"	June 29	180	"	19	1003	2103
"	"	"	"	"	20	2132	0358
LB452	"	July 12	193	IV	1	1237	1443
"	"	"	"	"	2	1555	2107
"	"	"	"	"	3	2136	0956
"	"	July 13	194	"	4	1022	1206
"	"	"	"	"	5	1733	2107
LB453	"	"	"	"	6	2123	0646
"	"	July 14	195	"	7	1703	1937
"	"	"	"	"	8	2258	2329
"	"	"	"	"	9	2331	0956

Table 1.--BLIP data inventory - Oceanographer (continued)

Reel No.	Archived form of data	Date 1969	Julian day	BOMEX Observation Period	Run No.	Start time (GMT)	Stop time (GMT)
LB453	Tabulated data on 35-mm microfilm	July 15	196	IV	10	1025	1234
LB454	"	"	"	"	11	1315	2300
"	"	July 16	197	"	12	2344	0203
"	"	July 17	198	"	13	0251	0957
"	"	"	"	"	14	1037	1330
"	"	"	"	"	15	1340	2108
LB455	"	"	"	"	16	2133	0953
"	"	July 18	199	"	17	1010	1325
"	"	"	"	"	18	1519	1743
"	"	"	"	"	19	2136	0851
"	"	July 19	200	"	20	1923	1330
LB456	"	"	"	"	21	1355	1905
"	"	"	"	"	22	2124	0907
"	"	July 20	201	"	23	0927	1053
"	"	"	"	"	24	1129	1406
"	"	"	"	"	25	1518	1905
LB457	"	"	"	"	26	1935	2208
"	"	"	"	"	27	2240	0957

Table 1.--BLIP data inventory - Oceanographer (continued)

Reel No.	Archived form of data	Date 1969	Julian day	BOMEX Observation Period	Run No.	Start time (GMT)	Stop time (GMT)
LB457	Tabulated data on 35-mm microfilm	July 21	202	IV	28	1014	1330
"	"	"	"	"	29	1658	1733
"	"	"	"	"	30	2137	0940
LB458	"	July 22	203	"	31	1002	1656
"	"	"	"	"	32	1917	2058
"	"	"	"	"	33	2138	0220
"	"	July 23	204	"	34	0404	0834
"	"	"	"	"	35	0902	0935
"	"	"	"	"	36	0957	2128
"	"	"	"	"	37	2132	0250

NOTE: Graphic displays of the above data are also available on 35-mm microfilm on three reels. Reel No. PB474 covers BOMEX Observation Period II; reel No. PB475, Period III; and reel No. PB476, Period IV.

Table 2.--BLIP data inventory - Mt. Mitchell

Reel No.	Archived form of data	Date 1969	Julian day	BOMEX Observation Period	Run No.	Start time (GMT)	Stop time (GMT)
LB459	Tabulated data on 35-mm microfilm	May 26	146	II	1	0330	0602
"	"	May 27	147	"	2	0718	1327
"	"	"	"	"	3	1704	2224
LB460	"	May 31	151	"	4	1805	2306
"	"	June 1	152	"	5	1327	2106
"	"	June 2	153	"	6	0044	0415
"	"	"	"	"	7	0728	1210
"	"	"	"	"	8	1429	1835
LB461	"	June 3	154	"	9	0015	0423
"	"	"	"	"	10	0810	1210
"	"	June 4	155	"	11	0000	0412
"	"	"	"	"	12	1830	2300
"	"	June 7	158	"	13	0135	0430
"	"	"	"	"	14	0735	1225
"	"	"	"	"	15	1310	2010
LB462	"	"	"	"	16	0015	0415

Table 2.--BLIP data inventory - Mt. Mitchell (continued)

Reel No.	Archived form of data	Date 1969	Julian day	BOMEX Observation Period	Run No.	Start time (GMT)	Stop time (GMT)
LB462	Tabulated data on 35-mm microfilm	June 8	159	II	17	0725	1050
"	"	"	"	"	18	1225	1535
"	"	"	"	"	19	2130	2345
"	"	June 9	160	"	20	0725	1220
"	"	"	"	"	21	1305	2015
"	"	June 10	161	"	22	2345	0405
LB463	"	June 23	174	III	1	0128	0424
"	"	"	"	"	2	0818	1103
"	"	"	"	"	3	1314	2055
"	"	June 24	175	"	4	0008	0421
"	"	"	"	"	5	0730	1216
"	"	"	"	"	6	1527	2000
"	"	June 25	176	"	7	0034	0413
LB464	"	"	"	"	8	0741	1214
"	"	"	"	"	9	1417	2017
"	"	June 26	177	"	10	0017	0426
"	"	"	"	"	11	0736	1218
LB465	"	"	"	"	12	1253	1912
"	"	June 27	178	"	13	0115	0421

Table 2.--BLIP data inventory - Mt. Mitchell (continued)

Reel No.	Archived form of data	Date 1969	Julian day	BOMEX Observation Period	Run No.	Start time (GMT)	Stop time (GMT)
LB465	Tabulated data on 35-mm microfilm	June 27	178	III	14	0738	1242
"	"	June 29	180	"	15	0232	0434
"	"	"	"	"	16	0744	1212
"	"	June 30	181	"	17	0006	0433
"	"	"	"	"	18	0753	1313
"	"	"	"	"	19	1600	1718
LB466	"	"	"	"	20	1946	2313
"	"	"	"	"	21	0017	0442
"	"	July 1	182	"	22	0743	1238
"	"	"	"	"	23	1315	2011
"	"	July 2	183	"	24	0036	0419
"	"	"	"	"	25	0737	1232
LB467	"	July 12	193	IV	1	1837	2040
"	"	July 13	194	"	2	0017	0421
"	"	"	"	"	3	0740	0829
"	"	"	"	"	4	1240	1945
"	"	July 14	195	"	5	0013	0409
"	"	"	"	"	6	0752	1218
LB468	"	"	"	"	7	1306	2003

Table 2.--BLIP data inventory - Mt. Mitchell (continued)

Reel No.	Archived form of data	Date 1969	Julian day	BOMEX Observation Period	Run No.	Start time (GMT)	Stop time (GMT)
LB468	Tabulated data on 35-mm microfilm	July 15	196	IV	8	0007	0302
"	"	July 17	198	"	9	1459	1959
"	"	July 18	199	"	10	0136	0442
"	"	"	"	"	11	0828	1219
"	"	July 19	200	"	12	-	-
"	"	"	"	"	13	-	-
"	"	"	"	"	14	1855	2246
LB469	"	July 20	201	"	15	0459	0541
"	"	July 21	202	"	16	0156	0433
"	"	"	"	"	17	0733	1246
"	"	"	"	"	18	1303	2002
"	"	July 22	203	"	19	0027	0426
"	"	"	"	"	20	0727	1233
LB470	"	"	"	"	21	1510	1957
"	"	July 23	204	"	22	0032	0417
"	"	"	"	"	23	2005	2305
"	"	July 24	205	"	24	0735	0854

Table 2.--BLIP data inventory - Mt. Mitchell (continued)

Reel No.	Archived form of data	Date 1969	Julian day	BOMEX Observation Period	Run No.	Start time (GMT)	Stop time (GMT)
LB470	Tabulated data on 35-mm microfilm	July 26	207	IV	25	1821	2059
"	"	July 27	208	"	26	0007	0417
"	"	"	"	"	27	0817	1246
"	"	"	"	"	28	1357	1513
"	"	July 28	209	"	29	0020	0440

NOTE: Graphic displays of the above data are also available on 35-mm microfilm on three reels. Reel No. PB477 covers BOMEX Observation Period II; reel No. PB478, Period III; and reel No. PB479, Period IV.

Table 3.--BLIP data inventory - Discoverer

Reel No.	Archived form of data	Date 1969	Julian day	BOMEX Observation Period	Run No.	Start time (GMT)	Stop time (GMT)
LB471	Tabulated data on 35-mm microfilm	June 24	175	III	1	0023	0640
"	"	"	"	"	2	-	-
"	"	June 28	179	"	3	0028	0600
"	"	"	"	"	4	0635	1035
"	"	"	"	"	5	1650	2055
LB472	"	June 29	180	"	6	0017	0445
"	"	"	"	"	7	0726	1300
"	"	"	"	"	8	1705	1939
"	"	June 30	181	"	9	0645	1253
"	"	"	"	"	10	1600	2012

NOTE: Graphic displays of the above data are also available on 35-mm microfilm on reel No. PB480, which covers BOMEX Observation Period III.

Table 4.--BLIP data inventory - Rainier

Reel No.	Archived form of data	Date 1969	Julian day	BOMEX Observation Period	Run No.	Start time (GMT)	Stop time (GMT)
LB473	Tabulated data on 35-mm microfilm	May 31	151	II	1	0003	0412
"	"	"	"	"	2	0737	1247
"	"	June 22	173	III	1	1407	1952
"	"	June 23	174	"	2	0029	0047
"	"	"	"	"	3	0115	0224
"	"	"	"	"	4	1624	2011
"	"	"	"	"	5	1711	1741

NOTE: Graphic displays of the above data are also available on 35-mm microfilm on reel No. PB481, which covers BOMEX Observation Periods II and III.

Invitation to Students

As stated in *BOMEX Bulletin* No. 10, research based on BOMEX data is progressing in government and university laboratories, but these programs will exploit only part of the research potential available. To take advantage of this scientific resource, NOAA recently announced that it is prepared to assist graduate students in atmospheric science and oceanography to visit the Center for Experiment Design and Data Analysis in order to examine data, confer with the CEDDA staff, and identify data sets to be requested for their research. To this end, NOAA offers to provide round-trip travel from anywhere in the contiguous United States, and per diem at the rate of $20 per day for up to five days for graduate students whose applications are approved. Inquires should be directed to Mr. Valti W. Powell, Operations Manager, CEDDA.

Since funds for this assistance program are limited, qualified applicants will be assisted on a first-come first-served basis. Applicants should have a general familiarity with BOMEX (see BOMEX bibliography in this *Bulletin*), should identify a reasonably specific research topic or area of interest in their letter of inquiry, and should include endorsement by a faculty member who is familiar with their qualifications and plans.