ESSA

Research Laboratories

PROGRAMS *and* RESOURCES

U. S. DEPARTMENT OF COMMERCE
ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION

U.S. DEPARTMENT OF COMMERCE

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ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION

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RESEARCH LABORATORIES

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PROGRAMS and RESOURCES

This Document is prepared in the Office of Programs, ESSA Research Laboratories

Frank White Smith & William D. Kleis Editors

ESSA RESEARCH LABORATORIES

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ESSA RESEARCH LABORATORIES
(ERL)

Introduction

ESSA and ERL

ESSA, the Environmental Science Services Administration, was created by Presidential reorganization of the Department of Commerce in July of 1965, merging the Weather Bureau and the Coast and Geodetic Survey. The Central Radio Propagation Laboratory was added by Secretarial authority in October 1965 to make ESSA a national focus to describe, understand, and predict the state of the oceans, the state of the upper and lower atmosphere, and the size and shape of the earth.

From the staff and resources so assembled, ESSA Research Laboratories was organized to conduct basic research necessary in fulfilling the responsibilities of ESSA. Headquartered at Boulder, Colorado, ERL provides a comprehensive study of man's environment ranging from the solid earth and the oceans to the earth's atmosphere and near space. ERL research contributes to our knowledge and understanding of the physical environment, helps to provide more accurate and timely warnings of threatening elements in the environment, and leads to methods of modifying the environment for the public benefit.

Like many federal activities, ESSA Research Laboratories is presently experiencing tightened levels of budgetary and manpower resources. To maintain and even to improve our capacity for serving the nation through the conduct of high quality, relevant research and services in these circumstances is a challenge of increasing magnitude. It has become imperative that new or continuing research programs meet new tests of both excellence and relevance.

The principal goal of any research laboratory is to conduct a high quality program of research -- one with a high standard of excellence. High quality work is self-fulfilling and socially profitable; low quality work is often worse than none at all since misleading results can flow from such programs. Research programs can differ by orders of magnitude in their effectiveness depending on the technical ability in the program, its working environment, the quality of support services available to the group, and the encouragement provided by laboratory management. Excellence in research requires three essential ingredients: well-trained and effective scientists,

well-motivated supporting staff, and a research-oriented management which is effective in providing needed resources and providing long-term program guidance. ERL is attempting to develop and utilize all of these attributes.

ERL selects research undertakings in which there is good promise for high quality results which are relevant for study in the framework of ESSA's environmental sciences mission. Exercise of this quality-relevance philosophy acts to limit the number and duration of our separate undertakings so as to enable program resource allocations which will maintain a healthy, vital program.

The mission statement of ERL can be stated as follows:

> The ESSA Research Laboratories performs an integrated program of research and research services relating to the oceans and estuarine waters, the lower and upper atmosphere, the environmental factors in telecommunication, the space environment, and the solid earth to increase understanding of man's geophysical environment, and to provide the scientific basis for improved services.

ESSA Research Laboratories' Structure

ERL is managed through 12 principal research laboratories and supporting administrative and service units. The Office of the Director, ERL, is at Boulder, Colorado, as are six of the research units: Earth Sciences Laboratories, Atmospheric Physics and Chemistry Laboratory, Space Disturbances Laboratory, Aeronomy Laboratory, Wave Propagation Laboratory, and the Institute for Telecommunication Sciences.

The Pacific Oceanographic Laboratories are located in Seattle, Washington; Atlantic Oceanographic and Meteorological Laboratories and the Research Flight Facility in Miami, Florida; Air Resources Laboratories, Silver Spring, Maryland; Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey; and the National Severe Storms Laboratory at Norman, Oklahoma.

Summary functional statements of the major laboratories of ERL follow:

The *Earth Sciences Laboratories* conducts research in geomagnetism, seismology, geodesy and related earth sciences, seeking fundamental knowledge of earthquake processes, the internal structure and accurate figure of the earth and the distribution of its mass toward improved geo-environmental services.

The *Atlantic Oceanographic and Meteorological Laboratories* conducts oceanographic and meteorological research toward a fuller understanding of processes in the ocean, research on hurricanes and tropical meteorology to predict formation and movement of hurricanes, and studies of methods for changing atmospheric processes.

The *Pacific Oceanographic Laboratories* conducts oceanographic research toward fuller understanding of the ocean basins and margins, physical oceanographic processes, sea-air, and land-sea interactions to improve the marine scientific services and operations of ESSA.

The *Atmospheric Physics and Chemistry Laboratory* performs research on processes of cloud physics and precipitation and the chemical composition and nucleating substances in the lower atmosphere. This Laboratory provides ESSA's main focus for design and conduct of laboratory and field experiments toward developing methods of practical, beneficial weather modification.

The *Air Resources Laboratories* conducts research on diffusion, transport, and dissipation of atmospheric contaminants using laboratory and field experiments to develop methods for prediction of atmospheric pollution for control and abatement programs.

The *Geophysical Fluid Dynamics Laboratory* conducts investigations of the dynamics and physics of ocean and air mass geophysical fluid systems to develop a sound theoretical basis, by mathematical modeling and computer simulation of the behavior and properties of the atmosphere and the oceans for extending weather, marine and related forecast services.

The *National Severe Storms Laboratory* conducts studies to improve the understanding of tornado, squall line, and other severe local storm phenomena; to provide improved capabilities for their prediction; and to develop improved methods for their early detection and identification.

The *Space Disturbances Laboratory* conducts research on the nature of solar space disturbances and provides forecasts of their occurrence. Studies are made of the behavior of these disturbances, the mechanisms producing them, and their consequences to man's activities. An operational forecasting service continuously monitors those characteristics of the space environment necessary for the early detection and warning of important disturbances.

The *Aeronomy Laboratory* studies the nature and roles of the physical and chemical processes of the ionosphere and exosphere of the earth and other planets. The program includes theoretical, laboratory, rocket, satellite, and ground-based studies.

The *Wave Propagation Laboratory* acts as a focal point for wave propagation research directed toward the extension of telecommunication capabilities into higher frequencies, and to develop new applications for electromagnetic remote sensing of the geophysical environment.

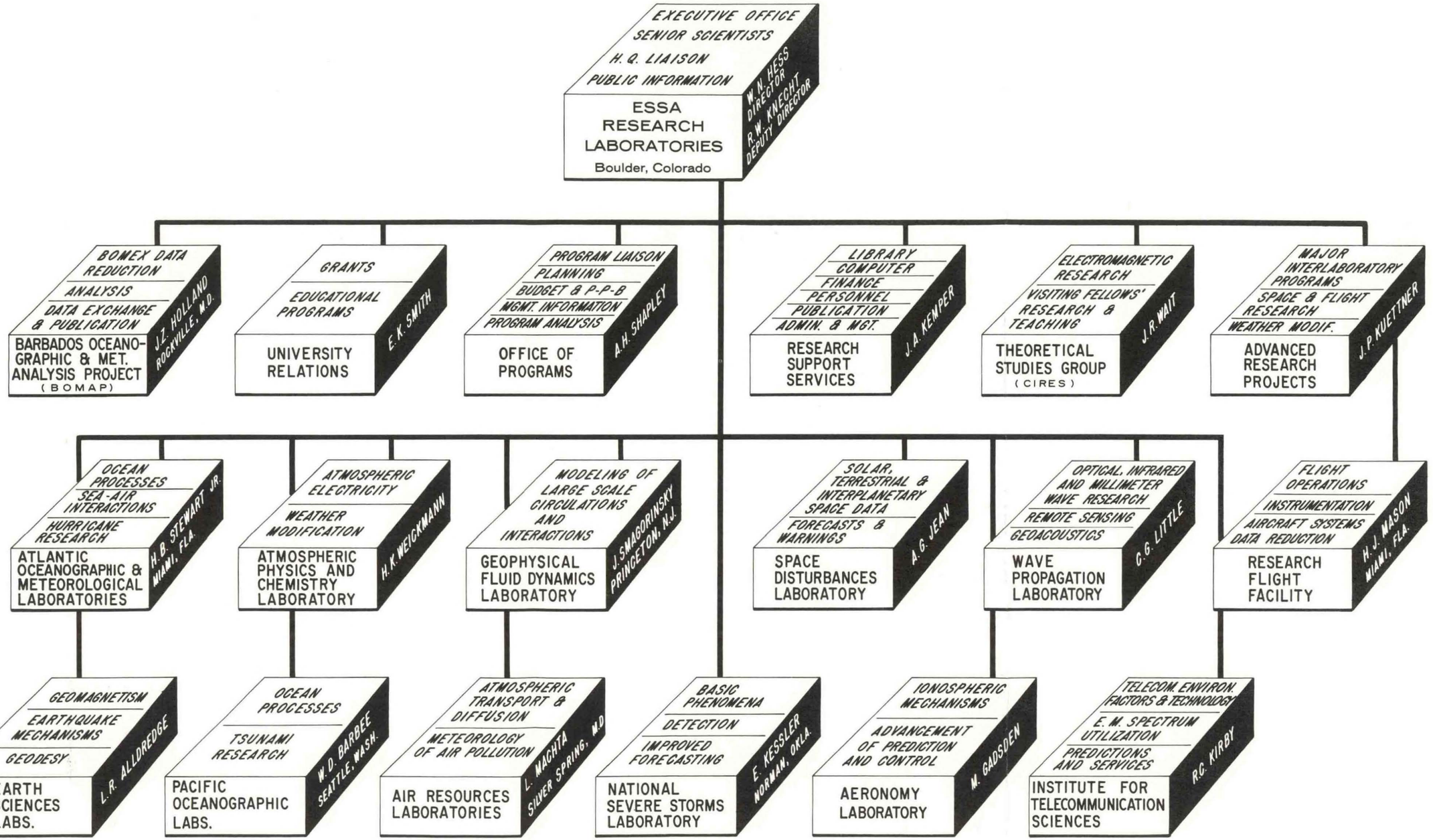
The *Institute for Telecommunication Sciences* serves as the central federal agency for the conduct of research and sponsored research services on the propagation of radio waves, on the electromagnetic properties of the earth and its atmosphere, on the nature of radio noise and interference, on information transmission and antennas, and on methods for the more effective use of the electromagnetic spectrum for telecommunication purposes.

The *Research Flight Facility* meets requirements of ESSA and assists other interests in atmospheric and other environmental measurements from aircraft, and for outfitting and operating aircraft specially instrumented for research.

ESSA Research Ships

ESSA research ships are utilized by the Research Laboratories to conduct the oceanographic and marine meteorological research programs at sea. The ships, OCEANOGRAPHER and DISCOVERER, based in Seattle, Washington, and Miami, Florida, respectively, are operated and maintained by the ESSA Coast and Geodetic Survey. These deep-ocean research ships are designed and staffed to provide an integrated multidiscipline data acquisition system and working platform in the ocean.

In addition to the research ships, other ships and vessels of the ESSA fleet often accommodate research projects to meet unique requirements outside OCEANOGRAPHER's or DISCOVERER's schedule and deep-ocean design capabilities.



ORGANIZATION OF ESSA RESEARCH LABORATORIES

(Biographical sketches appear with laboratory program summaries)

THE SCIENTIFIC AND TECHNICAL PUBLICATION EFFORT

As indicated in the foregoing, we take as our first obligation the conduct of high quality, relevant research and scientific services and second, a vigorous publications effort.

In the next several pages appears a summary of the publications output of the ERL during fiscal 1969; the full listing of these publications is given in the companion document "Scientific and Technical Publications of the ESSA Research Laboratories, FY 1969".

Our grouping of publications distinguishes outside journal and the various types of internal publications as follows:

External Publications - articles in scientific journals, books, etc., edited and printed in the open literature.

ESSA Journals - part of the permanent, formal scientific literature, serially published by ESSA, e.g., Radio Science, and Monthly Weather Review.

ESSA Monographs - major authoritative treatises covering ing a specialized topic of inquiry, as would texts.

ESSA Professional Papers - results of extensive individual research or compilation of experimental data.

ESSA Technical Reports - an ERL series discussing single research projects or a completed phase of research.

Laboratory Technical Memoranda - used to report work in progress, describe procedures or processes.

Others, including some of the Contractor and Grantee Reports - to the ERL by research contractors and grantees which may become subject of one of the above classes.

For additional information on ERL scientific publications, inquiries may be directed to:

Chief, Publication Services Division, R 57
ESSA Research Laboratories
Boulder, Colorado 80302

OUTPUT OF SCIENTIFIC AND TECHNICAL PUBLICATIONS

July 1, 1968 - June 30, 1969

	External Publications	ESSA Journals	ESSA Monographs	ESSA Professional Papers	ESSA-ERL Technical Reports	Technical Memoranda	Others, including Contractor and Grantee Reports	TOTAL
Office of the Director	20	6			2	2	12	42
Earth Sciences Laboratories	17	3					1	21
Atlantic Oceanographic and Meteorological Laboratories	14	6				9	15	44
Pacific Oceanographic Laboratories	7				2			9
Atmospheric Physics and Chemistry Laboratory	3				4		1	8
Air Resources Laboratories	16	2			1	8	15	42
Geophysical Fluid Dynamics Laboratory	3	7						10
National Severe Storms Laboratory	1					4	1	6
Space Disturbances Laboratory	20	3			9	4	8	44
Aeronomy Laboratory	34				1	2	5	42
Wave Propagation Laboratory	17				4	2	2	25
Institute for Telecommunication Sciences	25	3			12	44	3	87
Research Flight Facility	2							2
Total - ERL	179	30	0	0	35	75	63	382

Outstanding Scientific Papers

Of particular interest in the ERL's scientific and technical writing program is the annual selection of "outstanding papers" by ad hoc ERL jury. The criteria for selection embrace originality, scientific and/or applied importance, quality of writing, lasting power (longevity) of the work and relevance to the ESSA mission(s); and the papers selected are the basis for incentive awards to the authors.

The authors and their papers selected for award in 1969 were:

T. M. Georges, ITS *"Ionospheric Effects of Atmospheric Waves"*, ESSA Technical Report IER 57-ITSA 54 (Oct. 1967), Government Printing Office, Washington, D.C. An examination of evidence that neutral air disturbances cause ionospheric motions which affect radio communications, through generation of long atmospheric waves propagated to ionospheric heights. Atmospheric waves move ionization mainly through neutral-electron collisions under the influence of the earth's magnetic field but neutral-density variations may also move ionization by altering electron-loss times.

W. Harrison, et al., AOML *"Circulation of Shelf Waters Off the Chesapeake Bight"*, ESSA Professional Paper 3, (July 1967). For 17 consecutive months, drift bottles and seabed drifters were released and 15 monthly shipboard surveys were made to trace temperature and salinity variations off the Chesapeake Bight. Results were used to suggest that winds, runoff and shelf water thermal characteristics determine variations in the surface flow. A partial correlation model and predictor equations are developed by subjecting 20 some possible predictors to a computer screening process. It is concluded that the approach should be modified and applied to longer time series to develop better extrapolative performance.

Kendall R. Peterson, ARL *"Continuous Point Source Plume Behavior Out to 160 Miles"*, Journal of Applied Meteorology, Vol. 7, No. 2 (April 1968). Behavior of the plume emitted from the Brookhaven Laboratory has been examined by measuring radioactive Argon-41 with an airborne gamma-ray spectrometer out to 160 miles on a day with neutral stability. The plume is shown to be well organized, with nearly uniform distribution to 2000 ft, and concentration is shown decreasing by a factor of 7-10 over the distance of 150 nautical miles and travel time of 10-12 hours.

Byron B. Phillips, APCL *"Ionic Equilibrium and the Electrical Conductivity in Thunderclouds"*, Monthly Weather Review, Vol. 95, No. 12 (Dec. 1967). Under assumptions that a primary positive dipole distribution exists within the electrified cloud, results show that the cloud is nearly non-conducting by small ion conduction mechanism when electric fields are present.

Joanne Simpson, AOML , *Glenn W. Brier*, ARL, and *R. H. Simpson*, WB *"Stormfury Cumulus Seeding Experiment 1965: Statistical Analysis and Main Results,"* Journal of the Atmospheric Sciences, Vol. 24, No. 5 (Sept. 1967). A randomized cloud seeding experiment was carried out on 23 tropical oceanic cumulus clouds on nine days in 1965. Seeded clouds grew vertically 1.6 km, matching well a numerical model of cumulus dynamics, predicting top heights as a function of ambient sounding and horizontal tower dimension. Results demonstrate that (1) seeding has a clear effect on cumulus growth under specifiable conditions and (2) the model has considerable skill in predicting the amount of growth and in specifying the conditions.

Constance S. Warwick, SDL *"Sunspot Configurations and Proton Flares"*, Astrophysical Journal, Vol. 145, No. 1 (July 1966). Practically all solar flares that emit energetic protons occur in sunspot groups with the Potsdam δ-configuration, in which sunspot umbras of opposite magnetic polarity appear close together within the same penumbra. This property is related to the known tendency of flares to occur where the magnetic field has a steep gradient, and to special flare-sunspot configurations identified earlier by other workers. The δ-configuration is a relatively reliable and easily recognizable symptom of major flare activity and particularly of proton emission.

OFFICE OF THE DIRECTOR - ESSA RESEARCH LABORATORIES
Boulder, Colorado

Dr. Wilmot N. Hess
Mr. Robert W. Knecht

Components

Office of the Director
University Relations
Advanced Research Projects
Theoretical Studies Group (CIRES)
Office of Programs
Office of Research Support Services
Barbados Oceanographic and Meteorological Analysis Project (BOMAP)

The Office of the Director provides general direction of the research activities in support of the mission of ESSA. Within this Office, University Relations maintains liaison with universities, nonprofit research organizations and other agencies with related interests for the development of joint research and the granting and administration of research funds to universities and other institutions. Advanced Research Projects plans and implements projects requiring coordinated activities across laboratories of ERL, specifically in the areas of weather modification, flight and satellite utilization. The Research Flight Facility reports to Director, Advanced Research Projects.

The Office of Programs serves as focal point for policy and management advice to the Director on research and service programs, the development of resource allocations among laboratories, and review and evaluation of current programs and plans within policy, mission and resource constraints.

The Office of Research Support Services provides support in personnel management, administrative specialties, budget and financial support, computer facilities, scientific documentation, and management analysis.

The Theoretical Studies Group is comprised of the ESSA members of the Cooperative Institute for Research in Environmental Sciences, a joint activity with the University of Colorado. Dr. J. R. Wait is currently the Director of the Group.

Present activities include research on electromagnetic propagation in nonuniform media with particular emphasis on a quantitative appraisal of environmental effects in antenna radiation.

The approach is to exploit mathematical techniques from one discipline to solve problems in another.

In the forthcoming year, the transient or time domain formulations will be stressed, using pulse distortion of the system as a diagnostic tool; for example, the pulse response of the surface electromagnetic fields of a transient buried dipole may tell a great deal about the characteristics of the earth's crust.

A study of the ionospheric applications of the cross-field plasma instability has been carried out. This instability gives rise to small scale irregularities in plasma density. The mechanism is probably largely responsible for the ionospheric irregularities that have been studied experimentally for many years, and for the development of pronounced striations in artificial ion clouds released from rockets and satellites in the ionosphere.

The recent expansion of quantitative laboratory measurements of chemical reactions of likely importance in the lower ionosphere has stimulated a renewed study of mechanisms for the production and loss of free electrons in this region. It was found that the clustering of water vapor molecules to positive ions probably greatly enhances their effective recombination coefficient, thus greatly influencing the electron concentration at 70 to 85 km altitude, which, in turn, influences the propagation of radio waves in the VLF to HF portion of the spectrum.

In the forthcoming year a quantitative investigation will be made of the likely concentrations of water vapor in this altitude region and their seasonal variations. Also under active study is the problem of the production and loss of electrons, and positive and negative ions during polar cap events at high latitudes.

Due to limitations on funding, CIRES' formulation of a varied program of research has not been advanced as proposed. However, within available resources, both in ERL and in the University, the commitment to establishing a viable joint Institute is fully retained, and progress continues at an appropriate rate. Current emphasis is on the interests of the present Fellows, rather than on organizational and housing arrangements which will require large, new resource commitments.

The BOMAP group under Joshua Z. Holland, is currently conducting follow-on activities to the BOMEX field work. BOMAP was established in October 1969 to carry forward ESSA's mission as lead agency in the Barbados Oceanographic and Meteorological

Experiment (BOMEX). The three principal objectives of BOMAP are (1) to direct the reduction of the BOMEX ship, aircraft, radar and satellite data which were collected under the direction of ESSA; (2) to complete the BOMEX "Core" experiment to determine the transfer of water substance, sensible heat, kinetic energy, momentum and trace substances between the tropical ocean and atmosphere by a variety of methods and to evaluate the accuracy and efficiency of the available data acquisition systems and analytical techniques; and (3) to serve as a continuing clearing house for data exchange, scientific information and research plans among the roughly 100 distinguishable research projects comprising BOMEX.

It is expected that the data reduction and validation will require primary emphasis during the remainder of FY 1970, and should be largely completed during that time. Plans for the scientific analysis, pilot studies on samples of the data, and studies of system errors, calibrations and corrections will be proceeding simultaneously, at an increasing rate as validated data become available.

In addition to their administrative duties, various members of the Office of the Director conduct research in the following several subjects:

Production of Artificial Auroras	W. N. Hess
Mechanics of Cratering Impacts	W. N. Hess
Man-Environment Relationships	R. W. Knecht, F. W. Smith
Utilization of Space Data for Environmental Research	V. J. Zurick
Clear Air Turbulence and Leewave Study over Mountains	J. P. Kuettner
Earth Strains and Heat Flow	J. S. Rinehart
Stratosphere-Ionosphere Interactions	A. H. Shapley

Production of Artificial Auroras

A rocket-borne electron accelerator capable of putting out a pulsed beam of 0.5 amp of 10 Kev electrons was flown from Wallops Island in February 1969. The beam produced auroral rays when it entered the earth's atmosphere at about 100 km. These were photographed by high sensitivity TV cameras on the ground. Analysis of this experiment is continuing including studies of the plasma instabilities involved, beam propagation problems and cross-field diffusion. Plans are being developed for carrying out a second experiment in 1971 to shoot the beam several thousand km.

Mechanics of Cratering Impacts

By using two-dimensional computer programs developed by the AEC and including three equations of state, elastic, plastic, and fluid, the process of a meteorite impacting a ground surface and producing a crater can be studied. This should lead to a general picture of the pressure history of each particle in the throw-out and a description of the dynamics of the event. Such data can be compared with terrestrial explosion craters and lunar impact craters. The code is now operational and should start producing numerical experiments this year.

Man-Environment Relationships

ERL sponsors a multi-disciplinary working seminar, directed toward development of a theory of the essential relationships between man and the physical environment (see Social Sciences and the Environment, Garnsey, M.E. and Hibbs, J.R., Univ. of Colorado Press, 1967).

The seminar includes members from the University of Colorado, senior staff from ERL laboratories, the National Center for Atmospheric Research and other organizations.

Utilization of Space Data for Environmental Research

During FY 69 a satellite and weather information center was installed at ERL Headquarters to obtain operational data from ESSA, Nimbus, and ATS satellites in conjunction with conventional weather data for ERL scientists in support of on-going field programs and for long-term research. Satellite data are received via land line from Washington, D.C., and directly from satellites as they pass over Boulder. Mosaic data developed by computer at the National Environmental Satellite Center at Suitland, Maryland are relayed via WEFAX through the NASA ATS-1 satellite over the Pacific and received in Boulder. Various products and types of data are displayed to assist the researcher in specifying data requirements.

Clear Air Turbulence and Leewave Study over the Rocky Mountains

The ESSA Research Laboratories and the National Center for Atmospheric Research, in cooperation with other United States and Canadian research groups, are coordinating a field project in the Colorado Rockies to determine airflow, turbulence, and aviation hazards in mountain waves. In a prior investigation of mountain waves in 1968, severe turbulence was encountered at altitudes between 50,000 and 70,000 feet (the supersonic aircraft operating altitude). Particular objectives will be the genesis of clear air turbulence, its intensity and role in the dissipation of kinetic energy in the general circulation.

Earth Strains and Heat Flow

An attempt is being made to establish causative relationships between state of stress in the earth and heat flow. Rate of heat flow in geothermal areas is being correlated with earthquake activity and earth tides.

Plans for FY 70 include analyses of existing data and further field observation.

Stratosphere-Ionosphere Interactions

The well-known winter variability in conditions, at middle-high latitudes of the highest level of the stratosphere (about 30 km) and of the lower ionosphere has been shown to be correlated with the occurrence of minor or major "stratospheric warmings". The correlation is weakened by magnetic storm effects present in ionospheric variability and there is evidence that not all stratospheric circulation changes reach as low as 30 km.

The present studies include attempts at systematic identification of ionospheric winter anomaly periods in North America where the data base is less than optimum for this purpose. These studies with ionosonde data have as by-products, the development of correlations of radio wave absorption indices in the high D region, with solar x-ray flux and geomagnetic activity.

Dr. Wilmot N. Hess, Director of the ESSA Research Laboratories.

Dr. Hess joined the Environmental Science Services Administration (ESSA) in September 1969.

A native of Ohio, Dr. Hess attended Columbia University where he received his Bachelor of Science degree in electrical engineering in 1946. He did graduate study at Purdue University and Oberlin College, receiving his Master's degree in physics from the latter institution in 1949. In 1954 the University of California awarded him the Ph.D. in physics.

Before joining ESSA Research Laboratories, Dr. Hess planned and conducted research in earth and lunar sciences at the National Aeronautics and Space Administration (NASA) Manned Spacecraft Center in Houston, Texas. In this post, he was responsible for direction of the Lunar Receiving Laboratory in addition to providing the environmental data necessary to support mission and spacecraft design. Dr. Hess' group also conceived, developed, and integrated experimental meteorological programs and instrumentation for space, while providing space environment data and support during manned space flights.

From 1961 to 1967, Dr. Hess served as head of the Theoretical Division at NASA's Goddard Space Flight Center, Greenbelt, Maryland. Here he directed research in various disciplines of space science including particles and fields, aeronomy, ionospheric physics and geodesy. His groups also worked in quantum mechanics, studies of atomic collisions, celestial mechanics, the origin and development of radiation belts, theoretical astrophysics, and lunar science.

He is a Fellow of the American Geophysical Union and the American Physical Society and a member of Sigma Xi.

As Director, ESSA Research Laboratories, he provides general scientific direction to the activities of the laboratories and other activities described herein, as well as general administrative and policy guidance. As head of an ESSA Major Line Component, he serves the Administrator and the Department of Commerce in planning research needed for meeting the goals and public service objectives within the competency of the Research Laboratories.

In 1967 Dr. Hess was named one of the 10 Outstanding Young Men of Government by the United States Junior Chamber of Commerce. His publications cover a wide field, from using nuclear explosions for industrial applications, to measuring neutron flux in space.

Dr. Hess, his wife, Winifred Esther, and their three children reside at 4927 Idylwild Trail in Boulder, Colorado.

Robert W. Knecht, Deputy Director, ESSA Research Laboratories

Born in Ogdensburg, New York in 1928, Mr. Knecht saw active duty in the Navy during World War II in naval aviation. Mr. Knecht was graduated in 1949 from Union College, Schenectady, New York with a B.S. degree in physics.

He joined the National Bureau of Standards in 1949 where he worked with the Upper Atmosphere Research Section, studying lunar tidal effects in the ionosphere and the analysis of radar reflection from meteor trails. In the early 1950's Mr. Knecht was detailed to the NBS Ionosphere Sounding Station at Barrow, Alaska and to the NBS station at Anchorage, where he was physicist in charge of the North Pacific Radio Warning Service.

Shortly after his return to NBS-Boulder in 1954, Mr. Knecht was appointed Chief of the Sun-Earth Relationships Section. Then followed (in 1959-1960) a year of study at the Cavendish Laboratory, Cambridge, England on the F region of the ionosphere. Upon his return from England he was named Chief of the Ionosphere Research and Propagation Division, and in 1965 he was promoted to Director of the Space Disturbances Laboratory which position he held until appointed Deputy Director of ERL in 1968.

In recognition for his service to the government, Mr. Knecht received the Department of Commerce Gold Medal (group award) in 1965, for leading the NBS effort in the International Topside Sounder Satellite Group, which explored the hitherto inaccessible upper atmosphere and plasma physics. Other awards received include the Meritorious Supervisors Award, Denver Federal Executive Board Community Participation Award, and the Boulder Jaycee Good Government Award.

Active in community and civic affairs, Mr. Knecht is serving his eighth year on the Boulder City Council and his fourth year as Mayor of the City of Boulder. He is also presently serving his second term as Chairman of the Denver Regional Council of Governments.

Dr. Ernest K. Smith, Director of University Relations

Dr. Smith was born in Peking, China in 1922. He came to the United States in 1940 and entered Swarthmore College from which he received his B.A. in physics in 1944. He received the M.Sc. and Ph.D. in 1951 and 1956, in radio wave propagation from Cornell University. His academic appointments have been instructor in physics (1947) at New York University, Visiting Professor and Affiliate Professor in atmospheric science (1964-1969) at Colorado State University, Associate at Harvard College Observatory (1966), Visiting Fellow of CIRES (Cooperative Institute for Research in the Environmental Sciences) and lecturer in astrogeophysics (1968-1969), and Professor Adjoint, Department of Electrical Engineering (currently), all in the University of Colorado.

Dr. Smith was in the Radio Propagation Unit of the Signal Corps during World War II. He spent the ensuing four years with the Engineering Department of Mutual Broadcasting System, first as an assistant radio engineer, and later as Chief of the Plans and Allocations Division. He joined the Central Radio Propagation Laboratory (CRPL) of the National Bureau of Standards in 1951 and transferred with CRPL into ESSA in 1965. He was successively Chief of three divisions in CRPL/NBS, and since moving to ESSA, he was Director of the Aeronomy Laboratory until 1967 and Acting Director of the Institute for Telecommunication Sciences (1968) until assuming his current position in November of 1968.

Dr. Smith's research has been in ionosphere propagation and phenomenology (in particular, sporadic E) and radio meteorology. He has authored more than 30 professional papers and edited several books or special issues of journals. He is a Fellow of the IEEE and AAAS, a member of the U.S. Commission III of the International Scientific Radio Union (URSI), a member of Sigma Xi, and Vice-Chairman of the International Radio Consultative Committee (CCIR) and Study Group VI.

Dr. Joachim P. Kuettner, Director, Advanced Research Projects.

Born in Germany, Dr. Kuettner received a doctorate in law from the University of Breslau and a doctorate in physics from the University of Hamburg.

In 1948 Dr. Kuettner came to the Air Force Cambridge Research Center, where he was in charge of geophysical flight research using jet aircraft and high-altitude sailplanes. During this time he was also Scientific Director, Mt. Washington Observatory.

In 1958 he joined the Army Ballistic Missile Agency, later NASA's Marshall Space Flight Center, where he was Director of the Mercury-Redstone Project that resulted in the ballistic space flights of Alan Shepard and Virgil Grissom. Later he became Chief of Saturn-Apollo Systems Integration and Deputy Director of the Saturn-Apollo Office.

When ESSA was formed in 1965, Dr. Kuettner was named Chief Space Scientist of the National Environmental Satellite Center. In 1967 Dr. Kuettner joined ERL as Director of Advanced Research Projects, responsible for coordinating several major research programs and facilities: the weather modification program, utilization of space for environmental research, and the Research Flight Facility. In 1969 he was Director of the Barbados Oceanographic Meteorological Project (BOMEX), which explored the sea-air interaction over the tropical Atlantic. He holds several national and international sailplane altitude records during atmospheric research flights.

Dr. Kuettner is scientific chairman of the International Scientific Gliding Organization, OSTIV. He is a Fellow of the American Institute of Aeronautics and Astronautics and past Chairman of the AIAA Committee on Atmospheric Environment and recent Chairman of the AIAA Subcommittee on UFO's. He is a Research Associate of the Mt. Washington Observatory and a member of the Geophysical Union, the American Meteorological Society, the American Association for the Advancement of Science, and the German Aeronautical and Astronautical Society.

Dr. Kuettner has published numerous papers in the fields of meteorology, aeronautics and astronautics.

Dr. Kuettner, his wife, Monica, and their younger children live in Boulder, Colorado. One son is presently serving in the U.S. Marine Corps.

Alan H. Shapley, Director Office of Programs.

Mr. Shapley was born in Pasadena, California in 1919. He received an A.B. in astronomy from Harvard University in 1940 and pursued graduate work at both Harvard and the University of Wales in Great Britain.

From 1942 to 1946 he was a physicist at the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. He joined the staff of the NBS Central Radio Propagation Laboratory where he was in charge of programs on solar influence in the ionosphere and forecasting radio propagation disturbances. In particular, he developed the worldwide cooperative observing network needed for short-term propagation forecasting, established the forecast center at Anchorage for the North Pacific region, and developed the center at Washington for the North Atlantic region. He was an NBS member of the task forces preparatory to the formation of ESSA, and has headed the ERL Office of Programs since 1967.

In 1965, Mr. Shapley received the Department of Commerce Gold Medal (group award) for his work with the Ionospheric Topside Sounder Satellite Group. He has also received citations from the National Academy of Sciences for work in international scientific activities. Mr. Shapley was Vice-Chairman of the U.S. National Committee for the International Geophysical Year, 1957-1959, and a member of the international committee for the IGY enterprise, in which his main responsibilities were concerned with worldwide coordination of observations and data exchange. He continues as leader or member of numerous national and international committees in these areas. Mr. Shapley was active in planning the Antarctic and Arctic programs of the IGY and continues this interest as ERL Antarctic Coordinator and as a member of the National Academy's Committee on Polar Research.

He has continued in equivalent roles in subsequent programs of international cooperation in solar terrestrial sciences. He is a member of the Inter-Union Commission on Solar-Terrestrial Physics and has been Chairman, since 1962, of the International Ursigram and World Days Service. In addition to professional publications in recent years on the association of ionospheric and stratospheric disturbances, he is the compiler of several volumes of the Annals of the IGY and of the IQSY.

He is a Fellow of the American Geophysical Union and the American Association for the Advancement of Science, and a member of the American Astronomical Society and the Arctic Institute of North America. He is the Department of Commerce member of the U.S. National Committee for the International Scientific Radio Union, and member of several committees of the National Academy of Sciences in the areas of solar-terrestrial and space science. Mr. Shapley, his wife, Kay, and daughter live in Boulder, Colorado.

Jack A. Kemper, Director, Office of Research Support Services.

Born in Denver in 1927, Mr. Kemper was graduated from the University of Denver in 1950 with a B.S. degree in electrical engineering, and following graduation was selected for the Westinghouse graduate student training program and subsequently appointed electronic engineer in the Air Armament Division. He held that position until joining the National Bureau of Standards in 1953 as an electronic engineer working in very low frequency (VLF) radio propagation research and development.

In 1959 he became Assistant Chief of the LF/VLF Research Section of NBS and also was the Security Officer for the Central Radio Propagation Laboratory (CRPL). From 1959 to 1961 he was assistant director for technical planning and administration for the CRPL Radio Systems Division, and from 1961 to 1964 he served in the same capacity for the Ionosphere Propagation Division.

Mr. Kemper was assistant director for technical planning and administration of ERL's Space Disturbances Laboratory from its formation in 1965 until he moved to his present job in 1968. An important part of his work with the Space Disturbances Laboratory was the reorganization of the laboratory along lines of an "unstructured" concept that developed a "circular organization" with research program leaders reporting to the Director. The concept proved highly successful.

The Department of Commerce awarded Mr. Kemper the Meritorious Service Award (Silver Medal) in 1959. He received Sustained Superior Performance Awards in 1958 and 1962, and was commended by the U.S. Army in 1954 for important accomplishments.

Mr. Kemper is a registered Professional Engineer with the State of Colorado. He and his wife, Mary, live in Boulder, Colorado.

Dr. James R. Wait, Director, Theoretical-Studies Group (CIRES).

Dr. Wait was born in Ottawa, Canada in 1924. From 1942 to 1945 he was a radar technician in the Canadian Army. He received the B.S. Sc. and M.A. Sc. degrees in engineering physics in 1948 and 1949, and the Ph.D. degree in electromagnetic theory in 1951, all from the University of Toronto, Toronto, Canada.

From 1948 to 1951, he was associated with Newmont Exploration Ltd. in New York, N.Y., and Jerome, Arizona. From 1952 to 1955 he was a Section Leader at the Canadian Defence Research Telecommunications Establishment, Ottawa, where he was primarily concerned with electromagnetic problems. Since joining the National Bureau of Standards, Boulder, Colorado in 1955, he has concentrated on the theoretical aspects of radio propagation. In 1961 he was appointed Adjoint Professor of Electrical Engineering at the University of Colorado. During 1960 he was a Visiting Research Fellow at the Laboratory of Electromagnetic Theory in the Technical University of Denmark at Copenhagen. For the academic year 1966-67, he was a Visiting Professor at Harvard University, Cambridge, Massachusetts. From 1963-67 he was Senior Research Fellow and Consultant to the Director, Institute of Telecommunication Sciences and Aeronomy. Currently he is Senior Scientist in the Office of the Director of the ESSA Research Laboratories, Boulder, and Fellow of the Cooperative Institute for Research in Environmental Sciences.

Dr. Wait was awarded the Department of Commerce Gold Medal for highly distinguished authorship in the field of radio propagation in 1958, the Boulder Scientist Award sponsored by the Scientific Research Society of America in 1960, the NBS Samuel Wesley Stratton Award in 1962, and the Arthur S. Flemming Award, Washington, D.C., Chamber of Commerce, and the Harry Diamond Award from the IEEE, both in 1964. He is also a Fellow of the IEEE, AAAS, and the Institution of Electronic and Radio Engineers (India Division).

He was responsible for the establishment of the journal Radio Science which started in 1959 as Section D of the NBS Journal of Research. He has completed his third term as Editor and he is now a member of the editorial board. He is also in his third term as an associate editor of the Journal of Geophysical Research. In addition, he is U.S. Regional Editor of Electronics Letters.

Dr. Wait has published three books and numerous papers on subjects ranging from electromagnetics to geophysics. Among his outside activities he is a member-at-large on the U.S. National Committee of the International Scientific Radio Union. He is also very active in planning cooperative scientific programs in India and he has maintained a close contact with Indian radio physicists.

He and his wife and their children live in Boulder, Colorado.

Dr. Joshua Z. Holland, Director, Barbados Oceanographic and Meteorological Analysis Project.

Born in Chicago, Illinois in 1921, Dr. Holland received his B.S. in mathematics at the University of Chicago in 1941, and Ph.D. in atmospheric sciences at the University of Washington in 1968.

In 1942 Lt. Holland taught meteorology cadets at the University of Chicago and New York University, and participated in research on single-station forecasting, and later assisted in developing techniques and training programs in radar meteorology at Fort Monmouth. In 1945 he served as a forecaster and Officer-in-Charge at the 20th Air Force Weather Central, Guam, and also conducted a study of temperature and humidity gradients over the ocean in the vicinity of Saipan as part of an investigation of anomalous radar performance.

From 1948 to 1953 he was in charge of the Weather Bureau Office at Oak Ridge, Tennessee. There he directed a micrometeorological survey of the Oak Ridge area and developed equations for calculating dispersion and deposition of radioactivity, including a widely used formula for the height of rise of stack plumes.

At the Weather Bureau Central Office, he assisted in the development of plans for fire-weather and drought research and served as coordinator of civil defense activities. He initiated the training and assignment of regional civil defense meteorologists, initiated a program of routine fallout wind transmissions over weather teletype circuits, and served as staff meteorologist at the Federal Government's emergency relocation site. During this time he also conducted further technical studies on nuclear reactor hazards for the Atomic Energy Commission's Advisory Committee on Reactor Safeguards (ACRS).

In 1956 he received the Department of Commerce Silver Medal and was appointed Executive Secretary of the ACRS. He later joined the AEC Division of Biology and Medicine where he established the Fallout Studies Branch. For the next decade he directed the AEC's research and sampling programs on atmospheric transport and dispersion, deposition of aerosols at the land and ocean surface and radioactive contamination of soils, food and the human body. In 1963 he received the Superior Service Award from the AEC.

During 1964-65 he attended the University of Washington on an AEC scholarship and began his thesis research on the statistical structure of turbulent eddies. In 1969 Dr. Holland was loaned to ESSA to direct the Air-Sea Interaction Program of BOMEX. After completion of the field phase, he joined ESSA to supervise the analysis of BOMEX data.

Dr. Holland has been a member of interagency committees, panels of the National Academy of Sciences and professional societies. He and his wife, Anabel, live in Bethesda, Maryland with their three children.

EARTH SCIENCES LABORATORIES

Boulder, Colorado

Leroy R. Alldredge

In participating in ESSA's drive to understand and control man's physical environment, the Earth Sciences Laboratories conducts exploratory, advanced and applied research in geomagnetism, seismology, geodesy, and related earth sciences.

Program Areas

1.	Geomagnetism	Wallace H. Campbell
2.	Earthquake Research	Don Tocher
3.	Geodetic Research	Leroy R. Alldredge

Geomagnetism

This effort encompasses: (1) new measurement and analysis techniques for geomagnetism observations; (2) historical field changes from which we can imply the future of the earth's magnetism; (3) geological effects both spatial and dynamic; (4) temporal changes of the surface measurements due to perturbations far above the earth; and (5) mathematical modeling of the sources of the magnetic field.

The main objectives of paleomagnetism research within the Earth Sciences Laboratory include: obtaining information relating to the characteristics of the geomagnetic field during the transition state of a reversal in polarity; the development of new techniques for thermal demagnetization of rocks (generally volcanic) containing magnetic minerals; determining the feasibility and accuracy of paleo-intensity measurements; and application of observations and analyses to the past and present long-term trends of the earth's magnetic field.

Research in paleomagnetism affords the opportunity to apply previously unused techniques and approaches to paleo-intensity measurements which will, through the analysis of prehistoric data, contribute to the understanding of the earth's magnetic field origin, present condition, and anticipated change. These studies become relevant to our national interest because of the role of the geomagnetic field in such activities as navigation, mineral resource surveys, and radiowave communications.

The present state of paleomagnetism contains many uncertainties and assumptions. The most important relates to uncertainty underlying field reversals. Most geomagnetic research done to

date has emphasized declination and inclination measurements but has failed to attach the proper significance to intensity measurements. The advantages we can offer rest in the emphasis on intensity measurements before, during, and after a particular reversal, through the application of new techniques for controlling the atmosphere surrounding the rock inside a furnace. This will enable one to recreate the theoretical environment of the rock at the time of its formation. The past year has seen the near completion of the construction and testing of the measurement systems and facilities that are necessary for our effort in paleomagnetic research.

Continuing observations of variations in the absolute geomagnetic field increasingly demonstrate the immediate need for an accurate, sensitive, stable magnetometer. In geomagnetism as in most other areas of science, an increase in measurement accuracy brings with it the resolution of major questions regarding the physics of origin of natural phenomena. Because of ESSA's extensive involvement in a wide variety of geomagnetic observations about the world, we continue to pursue new and refined instrumentation for such work.

The relative ease of application and sensitivity of the Rubidium self-oscillating magnetometer being developed by ESL, in cooperation with the University of Colorado, continue to make this instrument a likely candidate if only its inherent drifts can be eliminated. Our single-line Rubidium magnetometer, which has operated successfully in initial development tests, gives promise of satisfying these goals. Construction is complete on a second system. Simultaneous operation of the two systems will establish their accuracy, sensitivity, and stability. Once initial short-term tests have been completed, we intend to operate these two systems at varying separations in order to define the extent of spatial uniformity of magnetic field variations. These data will serve to describe in part the nature of the source of the field's variations, the induction effects associated with the areas of study, and will permit more accurate investigations of geopiezomagnetic variations.

The objectives of our activity in micropulsations and field variations are to investigate the nature of rapid variations of the geomagnetic field in the frequency range of 0.001 Hz to 5.0 Hz and to determine the upper atmospheric source, transmission, and earth's effects upon detection of these signals. In clarifying the physical nature of these signals, it then becomes possible, using surface observations, to interpret certain physical features of the ionosphere and magnetosphere far above the earth. In recent years the changing conditions in this region, or "space weather" as it is sometimes called,

has become of increasing value to the understanding and use of this region by our nation's space program.

The micropulsation work concerns a detailed examination of the rather irregular form of amplitude variations with a generally "white" spectra in the frequency band of about 1.0 to 0.02 Hz. Using data from ten widely-spaced stations about the globe, the occurrence time, amplitude, and spectral changes are being evaluated. The objective of this evaluation is the determination of the magnetospheric excitation and ionospheric absorption effects on the received signals. An investigation is also being initiated of the magnetic field pulses expected from the ionized trails of certain meteors.

Five problems are being studied in the area of field variations. The first problem is completed, the last is in its initial stages: (1) The detailed interrelationship of auroral luminosity pulsations and concurrent magnetic field changes. Since the auroral fluctuations can be identified with bundling of the bombarding magnetospheric electrons, this study gives insight into the magnetic field effects of these processes. (2) Equatorial field variations and their relationship to high latitude phenomena. (3) Global arrival time of sudden onset pulsations. (4) Propagation times of hydromagnetic waves guided between hemispheres on earth field lines, and from high to low latitudes within ionospheric ducts. (5) Polar-cap pulsation types and sources.

The studies in geopiezomagnetics, or "geological magnetism", encompass problems related to the distribution and recent changes of the earth's crustal magnetic material. Applications of such studies would vary in the extreme range from sensing geological stresses preceding earthquakes, to the discovery of moon-surface lava caves for astronaut housing.

Geomagnetic spatial studies conducted on Hawaiian lava flows have shown distinct properties which could be related to the geological structure.

Using the fortuitous circumstances of a lowering of the water level behind Grand Coulee Dam in Washington, the magnetic effect of a known stress by a non-magnetic load on the geological structure is being investigated. This particular investigation may establish the boundaries on the magnitude of the piezomagnetic effects detectable in the field with the presently available instrumentation. After a reconnaissance trip in 1968, the investigation began with a second field expedition in 1969. During this expedition, an attempt was made to determine the feasibility of using the C&GS Newport Magnetic

Observatory as a base point for the Columbia River project. Preliminary analysis of simultaneous field measurements at Newport and a point 50 km away indicates that formidable mathematical treatment may be required in order to use Newport data to establish a base. Also during this second expedition, 36 fixed observation points were established up to 10 km from the lake. Magnetic observations were made at each of these points while the lake was at its highest level. During a third trip in 1969, the stations were reoccupied while the lake was at its lowest level. Plans are to again reoccupy the stations during the summer of 1970 when the lake is again full. Analysis of the field data, which appears to be of excellent quality, should provide a great deal of insight into the piezomagnetic effects. It is expected that the lake lowering-refilling cycle will be repeated in 1973 as new turbines and other equipment are installed at the Grand Coulee Dam. A repeat of this investigation at that time may prove the repeatability of the experiment. We hope that new, more sensitive and accurate field instruments will be available by that time.

ESSA conducts a wide range of observational, analytical, and compilation activities directed towards furnishing data and information to a broad range of users of geomagnetic information. Some of the most important outputs of these activities are: publication of U.S. Magnetic Charts; compilation of data for World Magnetic Charts; and insight into those processes in the earth's interior which create the main magnetic field and cause its secular changes and long-term reversals. Effective use of these activities can be demonstrated by applications in navigation, mapping and charting, geophysical research, and telecommunications.

ESL does research aimed at increasing the basic understanding of these items. During the past year success was achieved in adjusting dipole parameters for 21 dipoles to fit the 1955 Finch-Leaton field of the earth to a root-mean square of only 28 gammas. The dipole parameters were then adjusted to fit the secular change for the Finch-Leaton 1955 field to a root-mean square value of 2.125 gammas per year in the vertical component. This adjustment showed the typical westward drift of approximately .15 degrees per year. Work was started for a similar kind of fit to the field and secular change for the new International Geomagnetic Reference Field just recently determined by the International Association of Geomagnetism and Aeronomy.

Spherical Harmonic Analysis of epochs 1725, 1760 and 1800 were performed yielding information concerning secular change of the geomagnetic field during historic times. These results

will be included with other analyses of later epochs to improve our knowledge of fluid motions in the core of the earth and its relation to changes in the earth's magnetic field.

Earthquake Research

Seismologists, like most geophysicists, are concerned with various portions of the environment. All seismologists must start with the surface manifestations of seismic events. Some seismologists are concerned with the effects of seismic events on the works of man -- buildings, bridges, roads, dams, etc. Others are concerned with the works of man in a different way -- seismic detection of underground nuclear testing. On the more esoteric side, other seismologists are concerned with the causes of earthquakes. Still other seismologists join geophysicists in general in seeking to picture and understand the crust-mantle-core structure of the earth by using seismic events -- both natural and artificial -- as "probes" or sources of information on what lies below the visible portion of the earth's surface.

The search for understanding of the earthquake mechanism is international in scope. A national program is currently being considered, as evidenced by such documents as "Earthquake Prediction - A Proposal for a Ten Year Program of Research" prepared for the Office of Science and Technology in 1965 and the more recent (1968) "Proposal for a Ten-Year National Earthquake Hazard Program - A Partnership of Science and the Community" prepared for the OST and the Federal Council for Science and Technology.

Within the Research Laboratories, the bulk of the seismological effort is concentrated in the Earth Sciences Laboratories with most of the effort in ESL's Earthquake Mechanism Laboratory. ESL's seismology research contains the following elements: (1) the detection of movements and monitoring geophysical parameters along active faults; (2) special area studies; (3) investigation of the effects of earthquakes; (4) interpretive and analytical studies related to earthquake mechanism; and (5) studies of the propagation of seismic energy through the earth, and the relation of the propagation characteristics to global tectonics.

The objective of our efforts to monitor geophysical phenomena on fault zones is to continually or periodically measure with the greatest possible sensitivity all possible indicators which might foretell an earthquake. It represents an empirical approach in the absence of confirmed theories for the mechanism of earthquakes. A variety of techniques are being employed in

fault monitoring. The Earthquake Mechanism Laboratory has established an important geophysical monitoring facility at Stone Canyon near Hollister, California. Creep measuring stations have been established at approximately 30 points along the San Andreas Fault. In cooperation with Stanford University, magnetic recording sites are being occupied along the San Andreas Fault to seek piezomagnetic effects. Temporary and permanent seismic stations have been occupied for various periods of time along the complex of faults in California and Utah. In cooperation with the Colorado School of Mines, quartz-bar strain meters have been installed in California, Nevada, Utah, and Colorado.

EML greatly expanded its capability to monitor fault creep at several places along the San Andreas and other faults in California. Initial steps were to install 25 Invar-rod creep-meter units at 14 locations. Units at six locations use recording instruments and must be read with calipers at selected intervals of time. At the other locations, creep-meters are equipped with dial gauges which are also read at selected intervals. EML is making a concerted effort to equip all creep-meters with automatic visual recorders so that continuous records will be available at a greatly reduced operating cost. Installation began in 1963. Installation and operation of these gauges is a truly cooperative effort in California. The city governments of San Francisco, Los Angeles, Hollister, Fremont, and Hayward are participating by supplying sites, providing some equipment and installations, and by taking readings on the units not equipped with recorders. Another aspect of the long range fault creep monitoring program involves the periodic measurement of a series of survey lines. These resurveys detect movement in the immediate vicinity of the faults.

Piezomagnetic effects associated with the San Andreas Fault are also being studied. Stanford University, supported by an ESL grant, operates an array of optically pumped Rubidium vapor magnetometers to observe the possible magnetic effects from tectonic stresses associated with earthquakes and creep events. The investigation shows that some creep events are preceded by magnetic precursors. Limited laboratory experiments at Stanford and elsewhere have shown that the electrical resistivity of rocks is also stress dependent. The telluric current array, recently fully operational, is a valuable complement to the magnetic array.

Even though the installation of creep-meters is only partially complete, some worthwhile data have already been obtained. Analysis of these data has delineated the occurrence of fault

creep on the San Andreas, Hayward, and Calaveras Faults. Preliminary analysis of the measurements show that the time character of fault creep varies considerably from one site to another, even at sites within tens of kilometers of one another and on the same fault. The creep appears to be eventful at some places and continuous at others. Creep events measured at two sites on the San Andreas Fault suggest a rate of creep propagation along the fault on the order of 10 km/day.

An essential element in analysis and interpretation of seismic signals is knowledge of the geology and seismic background characteristics of both the areas of seismic activity (natural and man-made) and the areas where the detection instruments are located. For areas of particular interest to the ESL research program, current information from other agencies is frequently not available in sufficient detail. The unique portable seismic instruments developed by the Earthquake Mechanism Laboratory as part of its Data Acquisition and Analysis (DACAN) System provide the means by which the needed information can be obtained. The DACAN equipment and experience of the EML staff applicable to special area studies is also of interest to other government agencies such as ARPA and the AEC.

The University of California Seismographic Station at Berkeley and the Earthquake Mechanism Laboratory cooperated in an experiment to record seismic waves along a profile from the eastern slope of the Sierra Nevada to San Francisco Bay, by using as energy sources the BOXCAR and BENHAM events -- high yield nuclear explosions detonated under the Piute Mesa in Nevada. A line of stations was established along the azimuth from the source area to San Francisco Bay and beyond; beginning with Mammoth Ski Lodge on the east slope of the Sierra Nevada, through Yosemite Valley, across the Central Valley and west to Lamont-Doherty Geological Observatory's Ocean Bottom Station off Point Arena.

The data indicate a bi-layered crust under the eastern edge of the Central Valley having a total thickness of 30 to 31 km. Travel-time lag to Valley stations is as high as 1.4 sec, indicating an additional sedimentary layer of 4.5 to 5 km or a total crustal thickness of about 35 km under the central portion of the valley.

The early travel times to the Yosemite stations do not permit an appreciable root under the Sierra Nevada within 30 km east of Yosemite Valley unless the material of that root, if it exists, has a relatively high velocity. Crustal layers to the east of Mammoth appear to be somewhat thicker than 30 to 35 km, but less than the 50 km heretofore postulated for that region.

A large seismic array in Norway, currently partly installed by ARPA, is expected to greatly enhance the capability of seismologists to detect and identify small seismic events. During FY 1969, important preliminary tests and calibrations were performed on the new array by EML research groups. EML developed and built six systems to make the DACAN units compatible with Large Aperture Seismic Array (LASA) type sensors and tested them at the LASA-Montana facility. Four EML staff members and five DACAN portable seismic recording systems were sent to Norway. Outputs from the downhole and surface seismometers were recorded. Questions to be answered by this field experiment were: (1) Do we gain a noticeable amount of seismic information by recording at the bottom of the 60m wells at the Norway site?; and (2) At what distance from the sensors do microseisms become incoherent at the site? Specific field tests were made to determine: (1) amplifier (LASA and DACAN) frequency response and gain; (2) seismometer and amplifier frequency response and gain; and (3) amplifier data-line tape recorder system noise. Other field recordings of particular interest were earth-noise at 7-hour intervals, earthquakes heard on an audiomonitor, and cultural noise heard on an audiomonitor. Selected portions of the field data recorded in analog form have been converted to digital form. Some preliminary analysis was done in time to supplement the work while still in the field by using the Sandia Corporation computer facilities at Livermore. The field experiment is complete and data analysis is progressing. The final report of the analysis for ARPA is in preparation for submission.

Within ESSA, the Coast and Geodetic Survey has mounted a major effort to understand the effects of seismic events on man-made structures and terrain features. Earthquake risk maps, special reports on the effects of major earthquakes, aftershock studies, and strong motion studies of the response of structures to various earthquake-generated ground motions, are some of the results of this effort.

ESL supplemented this effort by activities of a reconnaissance nature in support of EML's fault monitoring and special areas studies. Work is being done only intermittently at the present time with some effort devoted to the effects of earthquakes on large engineered structures.

EML's efforts in this area were much more "public relations" in nature than scientific and engineering. In March and April 1969, a rumor surfaced in the San Francisco Bay area that a devastating earthquake was expected in April. The EML staff spent considerable time answering questions from the general public, newspapers, and other news media. Past exposure of the general public to EML's activities, through the local

papers and TV, made EML the point of contact for these inquiries. Needless to say, the prophesied earthquake did not happen but EML's efforts to allay the public's fears were worthwhile.

EML staff members served as consultants with or speakers to such local groups as: The Office of Emergency Planning Regional Preparedness Committee developing emergency plans to be put into effect in the event of a major earthquake in California; the Society of Real Estate Appraisers; the Coordinating Committee for East Bay Fault Slippage in Hayward; a meeting of representatives from engineering-geology firms in the San Francisco Bay area; and the Governmental Services Committee of the City of San Francisco concerned with a proposed parapet hazard abatement law.

These activities demonstrate the awareness and concern of local government, professional, and civic groups toward earthquake hazards and part of the role that government organizations must play.

We do not know with certainty the cause (or causes) of earthquakes. A great earthquake is associated with an irreversible deformation which can involve volumes of the earth on the order of hundreds of thousands of cubic kilometers, stress drops of less than 100 bars, and release of stored elastic strain energy of the order of 10^{25} ergs. The physical process involved is not yet understood. Seismologists are, therefore, forced to emphasize semi-empirical approaches including many different types of field observations over large areas. Any advances in knowledge concerning the earthquake mechanism would improve chances of prediction by elimination of non-pertinent observations and concentration in more limited areas.

EML's work in earthquake mechanisms is analytical and interpretive in nature. Inputs are data from fault monitoring, special seismicity studies, special field studies, and information from the Worldwide Network of Standardized Seismographs operated by ESSA's Coast and Geodetic Survey. Outputs are theories published in the scientific journals and feed-back to fault monitoring and special area studies.

In a cooperative project involving EML, the C&GS, and Colorado School of Mines, two quartz-bar strainmeters were entrenched north of Beatty, Nevada, to observe the BENHAM underground nuclear test of December 19, 1968. These instruments, oriented approximately radially to the source, were located at distances of 28 kilometers and 71 kilometers from ground zero. Good records were obtained during the test.

Step-like residual strains of 1.8×10^{-7} and 3.5×10^{-8}, respectively, were recorded. These results agree with those reported for earthquakes of M = 6.2. They also tend to substantiate the decay with distance law of $R^{-3/2}$ observed for earthquakes, as opposed to the theoretical R^{-3}.

A most significant observation was that, whereas earthquake steps do not decay within several days, if at all, the strain step from BENHAM apparently decayed to near zero within half an hour. This decay with time appears to be a reflection of the pressure history of the cavity.

Passing a low pass digital filter through the frequencies of the Denver earthquakes as a function of magnitude and using the computed result as an average, residuals have been obtained for the frequencies from the first 3-1/2 years and for the last 3-1/2 years. Even over the whole seven years, the correlation of frequency versus magnitude between the above two sets of residuals was close to significance at the 5% level. In other words, there was about one chance in twenty that as strong a positive correlation would have arisen by chance alone.

Another investigation is the result of examination of records of fault and joint spacing in crystalline rock in the Roberts Tunnel between Dillon and Grant, Colorado. Intervals between joints tend to be strongly grouped in the Precambrian crystalline rock of the type found at the bottom of the well at Derby.

The hypothesis presented in this investigation is that in double-couple earthquake mechanisms, slippage occurs on two faults intersecting at a considerable angle, one fault moving in right lateral fashion, the other left laterally. The adjustment between the two fault systems involves shearing rock as yet unsheared. The energies derived from the formula $W = \sigma A \cdot E \cdot S$, where W = ergs or dyne - cm, σ = shear stress, A = area or fault face affected by the shear, E the resulting strain and S the displacement along the fault, are comparable with values expected from the accepted energy-magnitude relationship.

One to ten percent of the energy computed by the above formula is radiated as elastic waves. The formula checks out dimensionally, giving thin sections of rock in shear for a well determined, magnitude 3.6, Imperial Valley earthquake of 1966. These thin sections of 1 to 3 meters are found in nature as mentioned above.

Breakage occurs from fracture to fracture in azimuth and dip appropriate to the stress orientation in the vicinity of the

fault. Total area of the fault faces in movement may be much larger than the newly formed fault due to the shear. If the regular old fracture spacing determines the length of new fracture formed, and this determines energy involved in the new shear, it is seen that earthquake magnitudes have reason to group into preferred sets over a matter of weeks or months, slowly changing as the fault environment is slowly modified.

Seismic waves propagating through the earth are a major tool in learning about the structure and composition of the earth's interior and the processes by which the surface of the earth was formed and is being changed. Conversely, understanding of the mechanism by which earthquakes are generated and the ability to precisely locate earthquakes also depend on the study of seismic energy propagation characteristics. To illustrate this dichotomy, seismology has been instrumental in developing theories on global tectonics -- theories relating to the formation of the earth's crust, faulting, and continental drift. At the same time, seismologists have developed the ability to locate many earthquakes from data received at seismic observatories over large teleseismic distances to an accuracy of approximately 18 km of the true geographic position and their focus (below the earth's surface) to an accuracy of 24 km. (More accurate locations are possible using data from portable instruments located close to the site of the seismic event.) Additional research in seismology will continue to improve our understanding of the earth's physical and dynamic processes and increase the accuracy with which seismic events can be identified and located.

Two studies pertinent to earthquake mechanism solutions are nearing completion. In one, solutions for deep and intermediate-depth earthquakes are being investigated on a worldwide basis in an attempt to study the distribution of stress within descending plates of lithosphere (as postulated in the new global tectonics). The results support the idea that plates of lithosphere sink into the asthenosphere as a result of body forces on excess mass within the plates and "hit bottom" beneath the asthenosphere. In the second study, focal mechanism solutions are being obtained in a regional study of western South America. These include the largest earthquakes that occurred during the 7-year interval 1962-1968. The data are in overall agreement with an E-ENE direction of underthrusting of the Pacific plate beneath the continent of South America.

Another investigation in which ESL is currently active is a study of the velocity structure of the Tonga-Fiji region. This includes a study of the detailed structure of the deep seismic zone of the Tonga island arc using a specialized version of the "master earthquake" method, and a detailed study of anomalies in seismic wave attenuation in the upper mantle of the New Hebrides-Tonga-Kermadec region.

In FY 1970, ESL will investigate the effect of source bias on hypocenter computations under a contract from AFOSR. The study will utilize well-located earthquakes and the variation with azimuth about seismic sources of p_P and PcP-P time difference to estimate errors in hypocenter computation.

A series of papers on P-wave Travel Times was published in the Bulletin of the Seismological Society of America. These papers represent the culmination of three years of cooperative work among 14 seismologists representing universities, governmental agencies, and private research organizations in the United States and Great Britain. The principal use of the results will be to improve our ability to locate earthquakes and underground nuclear explosions.

Geodetic Research

A 451-page book on "Mathematical Geodesy" which updates the mathematical theory of geometrical geodesy, based on the application of tensor calculus, has been published as ESSA Monograph No. 2.

Dr. Leroy R. Alldredge, Director, Earth Sciences Laboratory

Dr. Alldredge joined ERL in July 1966 after seven years as a research geophysicist in the Office of Research and Development, U.S. Coast and Geodetic Survey. He was a research analyst in the Johns Hopkins Operations Research Office from 1955 to 1959. From 1945 to 1955 he was a physicist for the U. S. Naval Ordnance Laboratory. He served as a radio engineer in the Department of Terrestrial Magnetism, Carnegie Institute of Washington from 1944 to 1945, as radio engineer with the Federal Communications Commission from 1941 to 1944, and as an instructor in physics at the University of Arizona from 1940 to 1941.

Born in Mesa, Arizona, in 1917, Dr. Alldredge holds B.S. and M.S. degrees in physics from the University of Arizona, an M.S. from Harvard in engineering physics, and a Ph.D. in physics from the University of Maryland.

Dr. Alldredge was honored with the Arthur S. Flemming Award from the Naval Ordnance Laboratory in 1949, a Presidential Citation in 1964, and the Gold Medal of the Department of Commerce in 1965.

He is past president of the Geomagnetism Section of the American Geophysical Union and is currently Secretary of the Central Bureau of the International Association of Geomagnetism and Aeronomy. He is a member of several other organizations and the author of numerous scientific papers.

Dr. Alldredge, his wife, Larita, and children live at 4475 Chippewa Drive in Boulder.

ATLANTIC OCEANOGRAPHIC AND METEOROLOGICAL LABORATORIES
Miami, Florida

Harris B. Stewart, Jr.

The objective of these laboratories is to increase knowledge and provide understanding of the interactions of ocean processes, hurricanes and other tropical phenomena, with particular reference to the Atlantic and Caribbean Sea, studying their influences and interactions as factors in the physical environment, and for extending the marine services and operations of ESSA. We use the ocean and atmosphere as our laboratory for experimentation and development of forecasting and prediction techniques and instrumentation. Liaison is maintained with other agencies and scientific organizations in the several disciplines embraced in the following program areas:

Structure and Motion of the Ocean	Donald V. Hansen
Ocean Basin Characteristics	George H. Keller
Sea-Air Interaction	Feodor Ostapoff
Modification of Clouds and Precipitation	Joanne Simpson
Hurricane Modification Experiments	R. Cecil Gentry
Theoretical Investigations and Models	Stanley L. Rosenthal
Diagnostic Studies of Tropical Systems	Harry F. Hawkins
Forecasting Hurricane Motion	Banner I. Miller

Program highlights of Fiscal 1969 and plans for Fiscal 1970 in AOML follow. The reader should understand that many of these program areas cross laboratory lines, receiving project contributions from several ERL researchers.

Structure and Motion of the Ocean

The objective of this program is to increase our understanding of the physical and dynamic properties of the ocean to facilitate prediction systems for various oceanographic phenomena as required to improve the marine services of ESSA.

During the past year a time series study has been completed of track lines following the core of the Gulf Stream. The illustration (fig. 1) shows the interpreted evolution of the Gulf Stream meanders, September 1965 to May 1966. The diagonal lines denote phase propagation; the solid lines are supported by other evidence and the dashed lines are postulated from the track lines only. An evaluation of the potential of orbiting spacecraft for mapping large scale oceanic phenomena was initiated last year with the objective of applying the observations to this and similar studies.

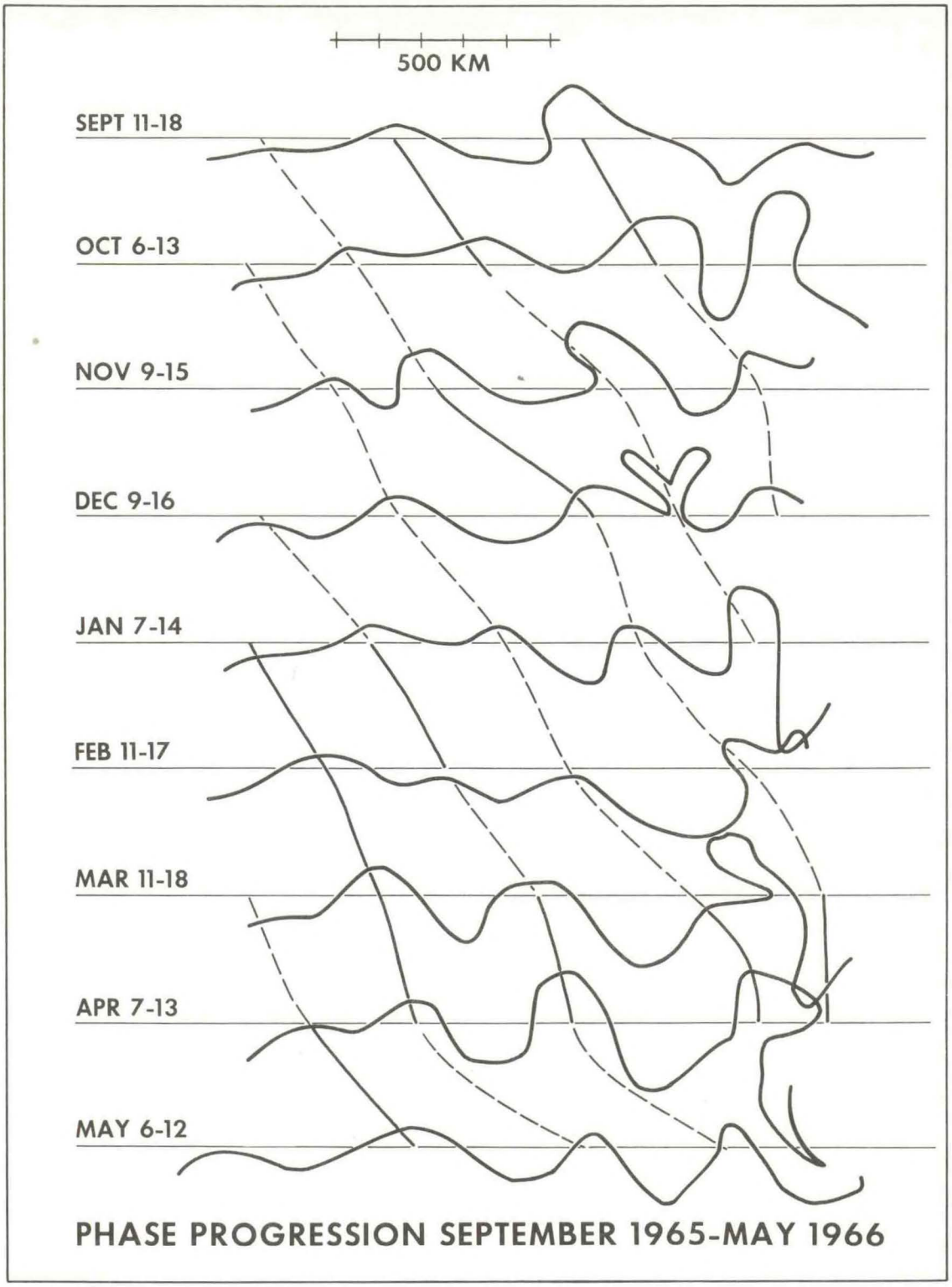

500 KM
SEPT 11-18
OCT 6-13
NOV 9-15
DEC 9-16
JAN 7-14
FEB 11-17
MAR 11-18
APR 7-13
MAY 6-12
PHASE PROGRESSION SEPTEMBER 1965-MAY 1966

Fig. 1.

Preliminary results from a study of drogue movement in the Florida Current have been incorporated in a paper accepted for publication. Other studies completed and accepted for publication include "Fluctuation of the Florida Current Inferred from Sea Level Records" and "Tidal Modulation of the Florida Current Surface Flow." In the field of tides, a paper on tides in the Gulf of Mexico and "A Suggested Procedure for the Analysis of Pelagic Tidal Measurements" is accepted for publication.

This Laboratory has been deeply involved in the planning and execution of the oceanography program for BOMEX since the inception of the project and will be concerned with analysis of BOMEX data pertinent to the general question of oceanographic variability.

A cooperative study with Sippican Corporation and Humble Oil is the use of bathythermograph observations to optimize oil tanker transit times between Gulf and northeast ports by identifying displacements of the core of the Gulf Stream. A longer range goal is a generalized technique that may be applied in other areas, particularly on routes to the Persian Gulf.

Two principal phenomena to be investigated in 1970 and following years are currents in the Gulf of Mexico and the Antilles Current. The Loop Current, connecting the Yucatan Channel and Florida Straits, has a remarkably variable position in the eastern half of the Gulf of Mexico; the objective of the study will be to document the variability in an effort to understand the mechanism for the change and thereby permit meaningful predictions of its behavior. The Antilles Current, flowing northwest north of the Bahamas, combines with the Florida Current to double the total transport of the Gulf Stream between the Florida Strait and Cape Hatteras. This major current has been only superficially explored: studies will be designed to document structure, mean flow across a lateral section, and the modulation of this flow.

A program in estuarine dynamics will also be initiated in 1970 to provide the scientific basis for enhanced ESSA services for estuaries. Particular emphasis will be on evaluation of advection-diffusion parameters required for rational design of waste disposal systems in estuaries, but improved tide and tidal current predictions are expected as an ancillary benefit.

The tide program will primarily use bottom tide gauges and near-bottom current meters to investigate a hypothesis that has been proposed for the nature of tides in the Gulf of Mexico. It is proposed to use the tide data now being obtained from six

gauges in the Lesser Antilles in a study of variability of flow from the Atlantic Ocean into the Caribbean.

Ocean Basin Characteristics

The principal objectives of this research are: determination of the morphology, structure, history and genesis of ocean basins; and the determination of the character and origin of the sediments which carpet the basins. These objectives are pursued mainly within the deeper areas of the ocean basins, utilizing the capabilities of our long-range, deep-ocean survey vessels.

The first objective of marine morphology is to measure and describe the multitude of forms which comprise the sea floor. Once described, the seascape cannot be properly interpreted unless the major factors which have influenced its evolution are fully appreciated. An understanding of these factors, including volcanism, tectonic deformation of the floor, and sedimentation, is essential to predict morphological changes and their potential hazards for practical utilization of the ocean basin floor.

Recent accomplishments within this area of study include a bathymetric map from the Upper Mantle Project area off the coast of California; a study of the morphology of the continental margin along Brazil and Uruguay; descriptions and interpretations of two submarine canyons (Cayar and Trou sans Fond) along the Atlantic margin of Africa; a continuous east-west profile across the South Pacific basin yielding new information pertinent to the evolution of this area was published; a detailed bathymetric map of the Straits of Florida and an accompanying text has been submitted for publication; a related series of submarine canyons off Ceylon has been interpreted and the results are in press; and an interpretation of a previously unknown deep-sea channel south of the Aleutians which has provoked new ideas on the pattern of sediment deposition in the Northeast Pacific. Work continues on the study of the morphology of the Chesapeake Bay (15 sheets at a scale of 1:50,000) as well as the depositional and erosional history of the lower Potomac River.

Future work in marine morphology will be concentrated in and adjacent to the Caribbean Basin as part of the international program "Cooperative Investigations of the Caribbean and Adjacent Regions" (CICAR). Interpretive morphology will constitute the initial phase of FY 1970 geophysical programs in the Lesser Antilles, along the Venezuelan shelf, off the Amazon River, and in Abaco Canyon northeast of the Bahamas Islands.

The objective of research in marine geophysics is the determination of the structure and evolution of ocean basins and the continent-ocean basin junction (continental rise, slope and shelf). Interpretations are based on seismic, magnetic, gravity, and heat flow data. The crust of the earth is conceived as composed of a series of rigid plates, including segments of sea floor, bounded by narrow zones of high seismicity where sea floor is either created or destroyed or where two plates are in motion with respect to one another. Thus, the sea floor is conceived as continually renewed, young in age, and mobile with respect to the underlying mantle. Part of our present and much of our future work will involve testing, modifying or rejecting these new hypotheses.

Much effort has been concentrated on the analysis and interpretation of magnetic anomaly patterns in the deep ocean basins. Work has been completed off the California coast and in the northeast Pacific from the Aleutians to the Juan de Fuca Ridge off the Washington-Oregon coast. Results from these areas have demonstrated the complexity of the patterns of generation of new sea floor and the masking effect of subsequent deformation of the basin.

Other studies have determined the shallow structure of the entire continental margin of Brazil and Uruguay as developed following the postulated separation of South America and Africa by creation of the South Atlantic ocean basin. Intensive efforts in the southeastern Caribbean, at the junction between the Lesser Antilles island arc and the South American continent, have placed severe constraints on any postulated lateral movement between the arc and the continent as predicted by the recent plate tectonics concept.

During the coming year, new efforts will be directed toward determining the crustal structure along the edges of the Caribbean basin, particularly along the coast of Venezuela. Segments of the margins of the Caribbean basin have been postulated as areas of lateral movement between the basin and the North American and South American continents. Other segments of margin may represent areas of destruction of ocean floor. As a test of the "rigid plate tectonics" hypothesis, a detailed study is being undertaken of the sea floor's magnetic, gravity and morphological characteristics in the vicinity of the Coiba Ridge, south of Panama. An intensive geophysical study of a crustal section (3° wide) across the Atlantic basin from Cape Hatteras to Cape Blanc, Mauretania will be initiated in FY 1970. This study will extend the Transcontinental Geophysical Survey of the U.S. across the Atlantic basin to provide a better understanding of the crust-mantle relationships beneath continents and oceans.

Research in geotectonics is concerned with the structure and evolution of global features of the earth; in particular, the origin and developmental history of the ocean basins and their relationship to continents. Research encompasses entire ocean basins or continents and emphasizes relationships on a global scale.

Principal efforts during the last year have centered on the "jigsaw fit" of the edges of the Australian and Antarctic continents. A computer-evaluated reconstruction of the postulated Australia-Antarctica protocontinent shows a high degree of probability that these two continents were once joined.

Research efforts in the immediate future will be concerned with the evolution of the entire Bahamian platform, which seems related to the opening of a gore in the continental crust during the early stages of development of the North Atlantic ocean basin. Similarly, the Gulf of Mexico may have formed through rotational opening of continental blocks during this same period. On the opposite side of the world, the Indian subcontinent was probably mobile during this time; its pre-drift position and subsequent path of motion are targets for research.

Sedimentological research is directed toward the interpretation of ocean basin materials as they relate to the source, diagenesis, composition, and transportation of sediments. Sedimentological and geochemical techniques are applied to samples collected in systematic studies designed to investigate the processes and geochemistry of the sea-floor deposits.

Research is focused on the mass physical properties of submarine sediments as an approach to investigating such problems as stability of sea floor deposits, the effects of loading and shock, the engineering properties (shear strength, density, porosity) of deep-sea sediments, and the process of lithification.

Recent studies have been completed on such subjects as the degree of variation in selected mass properties both geographically and for different types of submarine sediments. With the aid of a submersible, a detailed study of the local (400 sq. cm. area) variability of certain mass properties was completed for a deep-sea carbonate deposit. Field work was completed on the in-place measurements of shear strength and bulk density. Presently, an investigation is in progress on sedimentary characteristics of the Tobago-Trough, S.E. Caribbean, to define the dynamics and processes involved in the deposition of material in this basin.

Research ahead will be concerned with the depositional environment and deposits found in the Amazon and Abaco (NE of the Bahamas) submarine canyons. In addition, a detailed study will be undertaken on the processes and sedimentary characteristics associated with slump deposits off the island of Barbados.

Sea Air Interaction

The energy and moisture exchange between the ocean and atmosphere is basic to weather and climate world wide and to the major ocean currents. SAIL's effort has been directed toward the development of mathematical models of the exchange processes; major field investigations to provide data on the exchange processes; and modeling of storm surge flooding of coastal areas.

The Sea Air Interaction Laboratory coordinated United States participation in the Atlantic Tradewind Experiment (ATEX). This experiment included the German research ships PLANET and METEOR, the British ship HYDRA and the United States ship DISCOVERER. Major emphasis was on the investigation of the trade wind inversion as the ships drifted in a 400-mile triangular array southwest of the Cape Verde Islands during late January and February 1969. F. Ostapoff, Director of SAIL, served as Chief Scientist for the United States aboard the DISCOVERER and SAIL staff conducted the meteorological investigations. Several foreign and U.S. scientists participated aboard the DISCOVERER conducting investigations related to atmospheric electricity, radiation, chemical oceanography and marine biology.

Mathematical modeling of exchange processes continued with development of specific programs for utilization of BOMEX generated data.

BOMEX preparation and field operations required participation of the majority of SAIL's staff from March to August. The coordination and direction of the observational program on the ESSA ships was the responsibility of SAIL personnel aboard each ship. Dr. William McLeish of SAIL supervised the research flights of Scripps DC-3 aircraft in the BOMEX area with a dual channel radiometer. Results indicate the successful measurement of total heat flux from the ocean.

The storm surge group is working on models involving storm surge resonance phenomena with the passage of tropical storms traveling parallel to the coast. Using a geometric-optics technique for resonance modes, indications are that typical storms with a radius of maximum winds on the order of 30 to 50 miles may be too large to generate progressive edge waves

as forecasted by past theoretical work. Computer runs of models for storms with a maximum wind radius of 15 miles do show generation of progressive edge waves.

Further work will incorporate the coriolis parameter, storms crossing the coast at a 45° angle, a general coastal depth profile and a 5-point finite difference scheme to handle the angular coastal approach.

Reduction and analyses of ATEX and BOMEX data will require a major portion of SAIL's resources during the next year. In addition a cooperative study with the University of Miami (Dr. Eric Kraus) involving pressure-wind fields in the Miami-Bahamas area is at the instrument development and testing stage. Field work is planned during 1970.

Modification of Clouds and Precipitation

ESSA's Experimental Meteorology research is part of ESSA's Weather Modification activity and is concerned with the dynamics and physics of cumulus clouds in mesosystems, to develop a science and technology of useful modification of these clouds and cloud systems. The hoped-for benefits are threefold: (1) controlled precipitation modification under specifiable conditions, (2) improved paramaterization of convective processes in large-scale numerical forecasts, and (3) eventual mitigation of destruction by severe storms.

Using the joint tools of numerical modeling, laboratory modeling and full-scale field experiments with aircraft and radar measurements, a science and technology for modification of individual supercooled cumulus clouds has been developed, and execution and analysis of a supercooled cloud seeding experiment in south Florida is planned in the spring of 1970. The primary objective of the experiment is to determine how and under what conditions rainfall from supercooled subtropical cumulus clouds can be increased by silver iodide seeding. When the analysis of the 1970 experiment is completed (in 1971) it should be feasible to design and execute a successful rain augmentation program in the south Florida area and in other subtropical coastal regions with similar cumulus conditions.

A secondary goal in experimental meteorology is to assess the prospects of warm cloud seeding in these areas using salt or other hygroscopic condensation nuclei as the seeding agent. On this latter topic time will be devoted to numerical modeling, feasibility studies and the development of seeding and measurement technology. A preliminary field experiment may be attempted in the Miami area in the spring of 1971.

Other related objectives include the improvement and testing of more efficient and effective pyrotechnic cloud seeding chemicals, devices and dispensing mechanisms for use with aircraft, and further development and refinement of a new generation of airborne hydrometeor sampling and recording probes and instruments.

Preliminary results of the ESSA Florida Cumulus Seeding Experiment conducted in 1968 have been reported. Briefly, there were 19 "Go" clouds selected on a randomized basis. Fourteen of the "Go" clouds were seeded, while five were studied identically as controls. The vertical growth difference, following seeding between seeded and control clouds, was 11,400 ft, significant at the 1/2 percent level. Thirteen of the 14 seeded clouds grew explosively, while the remaining seeded cloud had virtually no seedability and died without growth.

The most important result is that seeded clouds produced on the average twice the rainfall of the unseeded control clouds. The difference amounted to about 100-150 acre-feet of water, which is about the average amount of water produced by a control cloud. The correlation between the predicted seedability and the water production of a given cloud was 0.67, with a significance at the 2 percent level. This means that the rainfall augmentation we can expect from a seeding experiment can be predicted in advance of the actual seeding operation.

Hurricane Modification Experiments

Hurricanes caused an average annual damage in the United States of $13 million between 1915 and 1924. For the period 1958 to 1968 this jumps to almost $300 million. Even after adjustment to take into account the inflated cost of construction in the more recent years, the average annual cost of hurricane damage has increased about 500 percent in less than 50 years. The current practice of constructing valuable buildings in hurricane areas indicates that damage costs will continue to increase. Hurricane Betsy (1965) by itself caused more than $1.4 billion in damage. If the United States continues supporting hurricane modification research at the present rate for the next 10 years, and if by that time we modify just one severe hurricane such as Betsy sufficiently to reduce damage by only 10 percent, the nation will obtain more than 1000 percent return on its investment. Similarly, if within 10 years we can reduce the damage caused by such a storm by only one percent, the nation will have a 100 percent return on its investment. The benefits in terms of prevention of human suffering are, of course, incalculable.

This research, Project STORMFURY, is conducted jointly with

the Navy and the Air Force. Experimental flights are made into hurricanes to investigate the feasibility of seeding supercooled clouds with freezing nuclei under the hypothesis that the release of the latent heat of fusion in certain sectors of the storm will produce changes in pressure gradients and/or areas of divergence that will either change the intensity of the hurricane or its direction of travel. As many as fifteen research aircraft are deployed to collect data before, during, and after the seeding experiment and to learn more about the processes within hurricanes. Plans include an experiment for seeding tropical cloud lines indirectly associated with tropical storms to evaluate the influence of seeding on the dynamics of tropical clouds, as well as studies of the feasibility of modifying a hurricane by reducing the rate of heat and energy transfer from the sea to the atmosphere inside the storm's circulation.

The STORMFURY field experiments are supplemented by laboratory research and by research flights to obtain data for determining feasibility of cloud modification in tropical cyclones. These data include measurements of liquid water, ice particles, and freezing nuclei found naturally in hurricane clouds.

Theoretical Investigations and Models

Nonlinear dynamical models are valuable tools for extending our knowledge of the dynamics and energetics of tropical cyclones, and they also have utility in the design of hurricane modification experiments. For these reasons, the National Hurricane Research Laboratory has actively pursued the design of such models for the past two years.

Experiments are currently being carried out with a 7-level, primitive equation model. The major weakness of this model is the assumption of circular symmetry which is made for computational economy. Nevertheless, numerous integrations have been carried out with extremely encouraging results. The life cycle from weak vortex to mature hurricane to weak vortex is simulated remarkably well by the model, and the structure of the model storm is remarkably realistic. The model is still undergoing refinement and even better results are expected in the next year. A few simulations of Project STORMFURY field experiments have yielded interesting but inconclusive results.

We have begun testing a model which eliminates the assumption of circular symmetry. To achieve a computationally feasible model, we will have to design one with substantially less vertical resolution and with a variable horizontal resolution.

Diagnostic Studies of Tropical Systems

A careful analysis is being made of data of Hurricane Hilda (1964) from stations forming an ellipse around the Gulf of Mexico and adjacent areas. Hurricane Hilda reached its maximum intensity near the middle of the Gulf.

The objective of the analysis is to determine whether an energy budget study, which includes days before Hilda was formed, will show any significant differences from the day when Hurricane Hilda was in the middle of the Gulf, i.e., is there any considerable export of energy away from the hurricane in the high levels at the radii considered?

Plans for FY 1970 include intensive data collection in situations of hurricane genesis for diagnostic studies to determine the conditions necessary and sufficient for hurricane formation.

We will also seek to get data to fully describe the 3-dimensional structure of another hurricane and study the mechanisms by which energy is transformed and transmitted throughout the hurricane. This study should provide information needed for evaluating the more sophisticated numerical models which are being developed.

A 7-level diagnostic model has been applied to three low latitude sequences: (1) a late season (October) vigorous low which extends through the troposphere, (2) an easterly wave which deepens into a closed vortex, and (3) a dying easterly wave. A rough summary of the findings, to date, follows:

1. Vertical motions (synoptic scale) are generally small and depend in large measure on the cyclonic vorticity. In the vigorous low they achieve cm/sec order of magnitude. In the easterly waves they are smaller, consistent with the weaker vortices.

2. The geostrophic vertical motions are very similar to the more sophisticated ones determined by the balanced model.

3. The vertical motions relate reasonably to the observed weather.

4. Synoptic scale convergence may reach 10^{-5} sec^{-1} in vigorous circulations but is normally of a lesser order of magnitude.

5. An evaluation of the magnitude of the terms in the vorticity equation reveals that in all three synoptic sequences the horizontal advection of vorticity was

the dominant term. The divergence weighted vorticity was next important and roughly half as large. The vertical advection and twisting terms were mostly quite small, about an order of magnitude less than the horizontal advective term.

6. The vorticity tendency computed from these terms correlated postively with the "observed" tendency computed from maps 24 hours apart.

7. There was some indication that errors in the computed tendency could be related to cumulus scale advection of vorticity at low levels to higher levels when consideration was taken of the upward vertical velocities in combination with the vertical gradient of vorticity.

Further study of low latitude African disturbances has indicated that these perturbations are most marked in the 500 to 700 km levels. One comes off of the African coast every three to five days during the months mid-June to mid-October. They are accompanied by identifiable (satellite photo) cloud systems which frequently appear best developed as they cross the African coast. Usually they weaken as they proceed westward across the tropical Atlantic; however, they can be detected in the upper air reports of the Lesser Antilles and frequently can be traced to and across Central America. On occasion these perturbations deepen into tropical storms and may intensify further and become hurricanes. The presence of cooler than normal waters off the African bulge and a stronger than normal long wave trough in the Atlantic tend to discourage this type of transition and to diminish the vigor of existing systems.

In October 1965, an upper tropospheric cold core cyclone moved westward over the Antilles and across the eastern Caribbean. At the same time an intensive reconnaissance expedition, known as Project ECCRO (Eastern Caribbean Cooperative Reconnaissance Operation), was engaged in gathering meteorological data in this area for research purposes by means of simultaneous multilevel aircraft flights and special radiosonde ascents. The flights extended over a six-day period. Vertical motions have been computed for the six days, and a kinetic energy budget for the region has been constructed. During the first three days the kinetic energy inside the volume increased. The computations indicate that the increase was caused by lateral advection of kinetic energy into the volume, plus a small internal conversion of potential to kinetic energy. The kinetic energy decreased during the last three days, as the circulation became indirect. Visual agreement between the vertical motions and the observed weather was good.

Forecasting Hurricane Motion and Formation

A multilevel primitive equation model for hurricane forecasting has been developed and programmed at NHRL. A fine grid (140 km grid length) is used, and adiabatic and viscous effects are incorporated. The model has been tested on nonhurricane data for a relatively small geographical area. In one case (Alma, 1962) the model successfully forecast the development of a hurricane vortex. The movement of the developing cyclone was also predicted reasonably well.

Continued tests of the primitive equation model on the Hurricane Alma (1962) and the Hurricane Betsy (1965) data are also planned. The omega equation derived as part of the prediction model will be used to analyze vertical motion patterns and energy transformations associated with several tropical weather systems, including easterly waves, tropical cyclones, and an upper tropospheric cold low. The omega equations include frictional and heating effects, and the time-dependent terms that are usually eliminated from the conventional omega equations by the assumption of balanced motion. Differences between the vertical motions obtained by the use of the several different computational procedures are being investigated.

Work on improving the statistical forecast techniques (NHC-67) is being continued.

Dr. Harris B. Stewart, Jr., Director, Atlantic Oceanographic and Meteorological Laboratories.

Born in Auburn, New York in 1922, Dr. Stewart entered Princeton in 1941. The following year he left college to serve four years in the Army Air Force as a flying instructor and as a pilot in the southwest Pacific. He returned to Princeton to receive an A.B. degree in geology in 1948.

Joining the U.S. Navy Hydrographic Office, he acted as a hydrographic surveyor in the Middle East, after which he accepted a position as instructor at the Hotchkiss School in Lakeville, Connecticut. In 1951 he undertook graduate studies at the Scripps Institution of Oceanography, La Jolla, California. There he received his M.S. in oceanography in 1952 and his Ph.D. in 1956. In 1956 and 1957 Dr. Stewart was Project Director of currents surveys off San Diego and in the fall of 1957 he became Chief Oceanographer, U.S. Coast and Geodetic Survey.

From 1957 through 1965 Dr. Stewart was engaged in enlarging the oceanographic activities of the Coast and Geodetic Survey. He was Deputy Assistant Director for Oceanography until his appointment in December 1965 as head of ESSA's Institute for Oceanography. Dr. Stewart continues as Director since it moved to Miami in 1967 and was reorganized as the Atlantic Oceanographic and Meteorological Laboratories.

Dr. Stewart has been Chief Scientist on several oceanographic expeditions and has published numerous professional papers in the fields of marine geology and physical oceanography. At various times he has served as the Chairman of the International Programs Panel and the Survey Panel of the Interagency Committee on Oceanography, as well as chairing the Advisory Board to the National Oceanographic Data Center and the U.S. Delegation to various intergovernmental meetings relating to marine science. Presently he is Chairman of the Florida Commission on Marine Sciences and Technology, President of the Zoological Society of Florida, and U.S. National Coordinator for the Cooperative Investigations of the Caribbean and Adjacent Regions (CICAR) sponsored by the Intergovernmental Oceanographic Commission. He is the author of two books, The Global Sea and Deep Challenge.

Dr. Stewart, his wife, Elise, and their daughter live in Coral Gables, Florida.

PACIFIC OCEANOGRAPHIC LABORATORIES

Seattle, Washington

CPT William D. Barbee (Acting)

The objective of these laboratories is to increase knowledge and provide fuller understanding of the ocean basins and borders, oceanic processes, sea-air and land-sea interactions and in support of the Tsunami Warning Service, the research is guided toward perfecting the warning services and improvement of our knowledge of the characteristics of tsunamis and methods for detection. POL initiates and fosters joint research efforts with other academic and governmental research organizations to supplement in-laboratory competence.

Program Areas:

Structure and Motions of the Ocean	William D. Barbee
Ocean Basin Characteristics	Robert Burns
Tsunami Research	Gaylord Miller

Highlights of fiscal 1969 and plans for fiscal 1970 are reviewed in the following:

Structure and Motions of the Ocean

This research increases knowledge and provides better understanding of the dynamics of the Pacific Ocean through experimentation and descriptive studies.

During FY 1969 POL initiated an experimental project in internal waves. This investigation is being conducted jointly with the University of Washington Department of Oceanography, and draws heavily on C&GS for ship time and operational competence.

The geophysical significance of internal wave phenomena and their importance to the ESSA mission are nearly inseparable. Internal waves are clearly a mechanism for energy transfer, in the ocean, and since there is a vertical component to this energy transfer, the waves provide one of the few possibilities for significant energy flux through the thermocline into or out of the mixed surface layer. Thus internal waves must be considered in energy budget calculations for air-sea interaction studies; as a possible energy source for deep sea mixing; in tidal energy dissipation studies; and in deep sea tide programs.

Recent theoretical advances in the hydrodynamics of internal waves have provided striking progress toward understanding internal waves and their role in ocean processes. Our experimental program is based on a theoretical model developed by Dr. Maurice Rattray, Jr., Chairman of the Department of Oceanography, University of Washington. This model postulates the generation of internal waves by the surface tide as it impinges on a continental shelf. In the latitude of our experiment -- 42°N -- standing waves of semidiurnal frequency are generated over the shelf, and free waves of the same frequency are propagated seaward. These internal tides are well suited to our experimental program in that they emanate from a well-defined source; they are a line of high energy at a known frequency in the spectrum; and details of their seaward propagation can be predicted.

An ocean experiment was conducted in FY 1969 to test the model in the region of seaward propagating waves. Two ships were used in the experiment, the OCEANOGRAPHER and the Coast Guard ship IVY. Measurements were taken over a period of eleven days. At the end of FY 1969 analysis of the experimental data was underway, being conducted by POL personnel with assistance from University of Washington's Department of Oceanography.

A second ocean experiment will be conducted during FY 1970, and will refine tests on the theoretical model and provide direction for future experiments. Measuring equipment more suitable to the experiment are now available. The experimental goal is to acquire high quality data for approximately 21 days.

Analysis of the data from the two field experiments will be completed during FY 1970, and the first experimental results will be reported.

In addition to direct support by POL, the Department of Oceanography, and the U.S. Coast Guard, this joint study of internal waves is supported indirectly by the Office of Naval Research, the National Science Foundation, the Applied Physics Laboratory of the University of Washington and the Institute of Geophysics and Planetary Physics, La Jolla Laboratory.

At the beginning of FY 1970 action was in process to employ an additional investigator in studies of internal waves. Plans are to add at least one more researcher with interest and experience in the investigation of internal waves -- hopefully also in FY 1970.

The effort toward investigating internal waves is projected beyond FY 1970, and indeed, beyond the five and ten year plans developed in POL. Over the next three to five years

the effort should be increased to support: 3-4 independent researchers; and 6-10 support personnel. A total capital outlay of about $200,000 for measuring equipment will be necessary during that period. This will allow for a major ocean experiment at least annually; for a vital interaction between theoretical and experimental progress; and rapid analysis and reporting of results.

Field measurements supporting the Polar Front - North Pacific Intermediate Water Study (a study of physical and chemical structure being conducted as a cooperative effort with Oregon State University) were extended westward to 155°E. Data for fall and winter conditions were obtained for comparison with spring conditions measured in FY 1968. Analysis of the unexpectedly complex structure of the Intermediate Water directed toward determining its origin, development and trajectory, continues. Oregon State investigations are concerned primarily with the chemical and biological processes active at the Front.

Two papers on the currents in the Tasman Sea were prepared: one reporting a hitherto unknown countercurrent of the East Australian Current; and one reporting the speed and direction of bottom currents in the Tasman, measured for the first time. The measurements were made utilizing an automated current meter, an acoustic signalling device and bottom photography.

A study of the properties of the central North Pacific deep water at three, four, and five km revealed a gradual warming, dilution of salinity, and reduction of dissolved oxygen in a general south to north direction. The report, based largely on the ESSA SEAMAP data, included a proposed trajectory for the water which indicates a circuitous path for the extreme northern region. Plans to extend the study in FY 1970 to include all the deep basins in the North Pacific as a joint study with Scripps Institution of Oceanography were cancelled due to conflicts in ship schedules.

Analysis of geostrophic data supplemented with parachute drogue measurements revealed a 37 percent reduction in the mass transport of the Alaska Stream from winter to late summer, whereas, year to year variation during the same season was small. The variability is attributed to the seasonal variations in atmospheric pressure patterns.

A study of temperatures and other properties of water confined to deep basins, trenches and deeps off the west coast of Central and North America revealed an anomalous situation in the Panama Basin suggesting either discernable heating of bottom water from geothermal sources or the presence of an uncharted topographic barrier. As the latter seems improbable,

the thermal gradient was used to develop a coarse flow pattern. A field study is scheduled in mid-FY 1970 to attempt to resolve which alternative is applicable, and to develop new information on the microthermal structure of bottom waters in this region of very high geothermal flux.

A more precise, new method for computing the mean vertical speed of sound through the ocean, applicable for echo sounding, and equations for utilizing the method in the central Pacific were published, and the method programmed for routine use at the USC&GS Pacific Marine Center.

Plans are being developed for a cooperative study of the subtropical surface currents of the central Pacific in mid-FY 1971. The investigation is to test for the existence of countercurrents, which had been predicted from theoretical consideration of the curl of the wind stress by the Japanese oceanographer, Dr. Kozo Yoshida. Following a discussion of the observational evidence for the current at the December 1968 meeting of the American Geophysical Union, interest in a joint study was expressed by representatives of the University of Tokyo, Scripps Institution of Oceanography and the Bureau of Commercial Fisheries, Hawaii. Radio-equipped current drogues are being considered to assist in establishing the continuity and persistence of suspected countercurrents.

As the Pacific Oceanographic Laboratories matures, it will undertake experimental studies in other areas of ocean dynamics. As in the studies in internal waves, the essentials are: strong ESSA mission orientation; geophysical significance; a theoretical base sufficient to identify tractable problems and specify suitable experiments; and adequate technical resources available either in-laboratory or through joint studies.

Several areas have been identified that fulfill these requirements: studies in estuarine dynamics to enhance ESSA service programs on flushing and pollution control; studies in air-sea interaction to further ESSA capabilities in environmental prediction; and studies in near- and along-shore processes to promote more effective and harmonious utilization of the nearshore environment.

Ocean Basin Characteristics

Objective: Formulation and testing the hypothesis on the origin of structures of the Pacific sea-floor, in order to understand the processes determining these structures and their relationship to associated continental margin structure.

In FY 1969 results were published on investigations of the magnetic characteristics associated with the Amlia and Adak Fracture Zones, the characteristics of the westward extension of the Murray Fracture Zone, the SEAMAP deap-sea channel, the morphology of an area north of the Hawaiian Ridge, and the general bathymetric setting and gravity anomaly of Cobb Seamount. Initial reports were presented on the gravity of the Aleutian Trench; field work was conducted in support of the continuing study of magnetic anomalies and topographic data in the central north Pacific; and the summary of the GLOBAL scientific program was completed.

In FY 1970, the main field investigation will examine the East Pacific Rise between 25-40°S, where crustal symmetry appears to be relatively undisturbed by interaction with a continental plate. A short field investigation of the Musician Seamounts will be conducted. Work on the central north Pacific magnetic anomalies and topography will continue with emphasis on the Mellish Rise, Chinook and Emperor Troughs, and the Musician Seamounts. Interpretation of the bathymetric character of the Aleutian Abyssal Plain will be continued. The detailed investigation of gravity anomalies from the SEAMAP area north of the Hawaiian Ridge will continue.

Tsunami Research

To increase understanding of generation, propagation, and onshore runup mechanisms of tsunamis to improve the operation of the tsunami warning system in the Pacific.

In the cooperative research program of ERL and the University of Hawaii, progress has been made on developing several types of deep-sea tsunami gauges. Six open-ocean free-drop wave measurement systems have been completed and shipped to Amchitka to be used in an experiment in the Aleutian Islands. The design is completed and components are being life-tested for a permanent tsunami measuring system which will be placed on the sea bottom under a North Pacific weather ship. Computer programs utilizing pattern recognition techniques have been applied to the problem of distinguishing source regions of earthquakes. Numerical solutions to hydrodynamic problems have been compared with measurements made at Hilo Bay and other locations. Theoretical work on the large scale water motions which may be calculated from electromagnetic measurements has been reported. Reports were prepared on elastic moduli of minerals at high pressures and temperatures. Travel time charts obtained by computer have been produced for the Tsunami Warning System.

During FY 1970 we will make a series of deep-sea wave measurements after the Aleutian experiment is completed. The first will be emplacement of a triangular array of three recorders separated by about 10 km; this will be an attempt to obtain the directional spectrum of tsunami frequency background wave noise. Another planned measurement is to record tides in the North Pacific. Numerical hydrodynamic computations will be made and compared with field measurements and model studies currently being conducted cooperatively with the University of Hawaii. Preparations for a cruise along the magnetic dip equator will be made; the magnetic and electric field measurements made on the cruise will provide a profile of the conductivity structure of the upper mantle.

Captain William D. Barbee, USESSA, Acting Director, Pacific Oceanographic Laboratories

Capt. Barbee was born in Spalding, Nebraska in 1928 and grew up in Lusk, Wyoming. He received a B.S. in civil engineering from the University of Wyoming in 1950 and an M.S. in oceanography from the University of Washington in 1964.

He was commissioned in the Coast and Geodetic Survey in 1950 and was assigned to various ships and to triangulation and geodetic leveling parties. He commanded the USC&GSS SOSBEE in 1957. He participated in the International Indian Ocean Expedition aboard the USC&GSS PIONEER in 1964.

He was named Chief of the Marine Data Division in 1964. He represented the Department of Commerce and the Coast and Geodetic Survey on various interagency or interdepartmental panels on marine navigation, oceanography, and water quality.

Upon formation of ESSA in 1965, he was named Program Planning Officer in the Institute for Oceanography. In 1967 he returned to the University of Washington for further graduate training and to conduct research in physical oceanography. He was named Acting Director of the Pacific Oceanographic Laboratories in September 1969.

ATMOSPHERIC PHYSICS AND CHEMISTRY LABORATORY

Boulder, Colorado

Helmut K. Weickmann

The objectives of this laboratory are to increase the understanding of atmospheric physical and chemical processes important to meteorology and to develop methods of beneficial weather modification through theoretical and applied research. A program of research toward these ends is implemented by the staff and by contract. The results of studies of cloud and precipitation physics, of the secular change of the chemical and particulate composition of the atmosphere and the inferences thereof on weather and climate, of atmospheric electricity, and of radiation and atmospheric heat transfer are used for defining improved concepts and field experimentation in small and large scale weather modification.

The components of this laboratory are as follows:

Great Lakes Snowstorm Modification	H. K. Weickmann
Mitigation of Severe Storm Effects	B. B. Phillips
Atmospheric Electric Interaction	H. Kasemir
Inadvertent Modification	E. Barrett
Thermal Modification	P. Kuhn
Warm Fog Dissipation	L. Ruhnke
Instrumentation and Data Handling	H. Grote

Great Lakes Snow Storm Modification

Research in this area is an attempt to develop a complete understanding of the physical mechanisms that produce early winter snowstorms which deposit copious amounts of snow in narrow bands to the leeward of Lake Erie and Lake Ontario. It is planned to attempt modification of these storms in order to: (1) intensify precipitation over the lake in order to release the water before the clouds reach the shoreline, (2) or overseed to attempt precipitation distribution over a much larger area.

The results of two field expeditions in 1968 and 1969 yielded a wealth of scientific information on seeding effects with mesoscale weather systems caused by the Great Lakes. Sometimes precipitation can be released or increased, sometimes it can be decreased or redistributed. The most important controlling factor for this different behavior is the temperature. Most cloud systems are less than 3000 m deep and if

the temperature at the top is in the approximate range of -12C to -20C, nature does not produce precipitation but seeding will; if the temperature at the top is less than -20C, nature produces precipitation efficiently and seeding will only modify the crystal types and properties which may cause a redistribution of precipitation. The effects of urbanization and of urban pollution on the local weather have also been studied and several significant effects have been observed.

In coming years this research will emphasize all aspects of human interference with weather both intentional and inadvertent in that particular region.

Mitigation of Severe Storm Effects (Hail)

This effort is directed toward a definition of the critical storm-properties in the hail process which must be known before a suppression experiment can be designed in detail. An intensive hail research program has been conducted in northeastern Colorado by the Atmospheric Physics and Chemistry Laboratory as a part of a cooperative hail project with the National Center for Atmospheric Research and Colorado State University. The purposes of the program were to measure the mesoscale features and life history of the storm, using an aircraft mesometeorological observation and analysis system and also to explore infrared remote probing methods for airborne hail streak analysis. A surface network, using a specially designed "poor man's" hail and raingage, yielded data on the discharge of hail and rain in a hailstorm.

APCL will again participate in a joint CSU-ESSA-NCAR hail investigation in northeastern Colorado. Investigations are to be made utilizing a C-45 mounted scanning radiometer to define and investigate surface hotspots and hailswaths and a mobile hail laboratory for observing the characteristics of hailstones collected in a surface hail-collection network.

Atmospheric Electric Interaction

The objectives are several fold: to investigate the feasibility of inhibiting the charge process which produces lightning; to develop an accurate short range lightning location system, and to continuously monitor the basic atmospheric electric parameters in order to describe the electrical state of the earth's atmospheric envelope.

Activities are centered around measurements of the distribution of the electrical field in and around thunderstorms, using improved electrical field mills; and in the development of computer analysis methods for the evaluation of these data.

Lightning suppression studies have been carried out since 1966 jointly with the U.S. Army. The concept is to eliminate lightning through discharging the thunderstorm electric field by corona current before the field reaches values that trigger lightning. The corona current will be created by metallized nylon chaff needles, 10 cm long, which initiate the corona in a field of 35,000 V/m. This threshold was confirmed by both laboratory and field experiments. To discharge a steady current of several amperes, approximately one million needles are required. This research has led to detailed measurements of the field distribution underneath thunderstorms, and from these measurements a numerical model of charge development and distribution in the storm has been constructed to provide information that is essential for effective chaff seeding.

Inadvertent Modification

Research in this area deals with inadvertent weather modification by pollution of the air with manmade and natural contamination. Direct and indirect weather modification involves changes in radiative transfer and cloud physics processes in the atmosphere, which may eventually modify global temperature distribution and precipitation.

Atmospheric constituents are monitored in order to determine their secular trends and to examine the role of these uncompensated changes in the chain of heat budget events and their influence on weather and climate.

During FY 70 a primary geophysical monitoring observatory site will be sought in the mountains west of the Boulder-Denver area for development in FY 70 or 71, the Mauna Loa Observatory monitoring programs will be updated and automated, and CO_2 and O_2 monitoring techniques will continue to be refined.

A portable Lidar (optical radar) installation will be used to obtain the vertical distribution of aerosols and their contribution to turbidity.

Thermal Modification

Surface and airborne radiation measurements will be conducted as a means of collecting vertical profile radiation and heat budget information. An immediate consequence of these measurements will be a definition of the secular trend in modification of climate by thermal radiation.

Also, aircraft and computer studies will be conducted of the atmospheric radiational influences of jet contrails and natural cirriform clouds. Horizontal profiles of stratospheric water

vapor will be collected from a NASA Convair 990 aircraft.

Warm Fog Dissipation

The objectives of this program are to investigate the technical feasibility of dissipating warm fog by electrostatic or other means and to determine design criteria for an operational fog dissipation system.

During FY 70 computer simulation of the physical process of fog dissipation by seeding with unipolar ions, to determine design parameters for a system to test the concept under field conditions, will be started. Also, development of a field unit and field testing at a suitable location is planned.

Instrumentation and Data Handling

This effort is directed toward the development and/or refinement of the specialized instrumentation and data handling techniques required for the implementation of weather modification projects carried on by APCL.

Plans for FY 70 include: wind tunnel calibration of an airborne raingage that continuously monitors the amount of rain encountered in flight; a theoretical evaluation to determine the accuracy of divergence and wind measurements collected with an airborne Doppler radar navigation system; and a design study for digitizing Mauna Loa data.

Dr. Helmut K. Weickmann, Director, Atmospheric Physics and Chemistry Laboratory.

Dr. Weickmann, who joined ESSA in 1965, is responsible for the meteorological research of the atmospheric physics and chemistry, as well as weather modification programs of ESSA.

Born in 1915 in Munich, Germany, Dr. Weickmann studied physics at the Universities of Leipzig and Frankfurt, earning a Ph.D. from the latter university in 1939. From 1949 until joining ESSA he served as Project Scientist and Chief of the Atmospheric Physics Branch, Army Electronics Command, Fort Monmouth, New Jersey.

Dr. Weickmann is a member and Fellow of the American Meteorological Society and the International Union of Geodesy and Geophysics. He was honored with the U.S. Army Signal Corps Research and Development Laboratories Achievement Award in 1961 and the U.S. Army Electronics Command Certificates of Achievement in 1962. Dr. Weickmann serves as President of the International Commission on Cloud Physics, International Association of Meteorology and Physics (IAMAP), IUGG. He is also a member of the Panel on Cloud Physics, American Meteorology Society.

He is the author of more than 50 technical publications. Some of his major works include: "The Ice Phase of the Atmosphere", "The Language of Hailstorms and Hailstones", "A Realistic Appraisal of Weather Control", and "Conceptual Models of Hail Suppression". He has participated in numerous international advisory panels and symposiums related to his scientific fields. His most recent publication is the ESSA Technical Report entitled "Progress in Hailstorm Research", ERL 129-APCL 7, dated May 1969.

Dr. Weickmann, his wife, Ruth, and their four children reside at 603 Wewoka Drive near Boulder.

AIR RESOURCES LABORATORIES

Silver Spring, Maryland

Lester Machta

The Air Resources Laboratories perform research and development on meteorological diffusion, transport, and deposition of atmospheric contaminants for a better understanding of the processes controlling atmospheric pollution, leading to prediction and abatement procedures. Special meteorological activities are performed for the Atomic Energy Commission, the Department of Health, Education and Welfare's National Air Pollution Control Administration and the Federal Aviation Administration. Research in meteorological statistical methods is conducted to benefit all meteorological programs.

The scientific activities of the ARL are carried out in the following scientific program areas:

Meteorology and Nuclear Energy	Lester Machta
Meteorology of Urban Air Pollution	Robert A. McCormick
Meteorology and Environmental Quality	Lester Machta
Statistical Meteorology and Special Studies	Lester Machta

Meteorology and Nuclear Energy

Meteorology for Nuclear Testing

Applied research is oriented toward improving the meteorological service which this laboratory provides to programs for testing nuclear weapons, rocket engines, and industrial nuclear explosives. Models of mesoscale meteorological circulations in the geographical areas used for nuclear tests are developed and used with adapted diffusion and deposition models to provide evaluations of radiological hazards.

Predictions of radioactive effluent transport and resulting exposure levels were prepared for all underground nuclear explosions and nuclear rocket engine tests. These trajectories and exposure estimates were used by the Test Manager's staff for event scheduling, area clearance and control, and monitoring in off-site areas.

Extensive post-event analyses of radiological and meteorological data have been made for nuclear rocket reactor effluents and detonations in the cratering series. These analyses provide ultimately the final documented available radiation exposures

for these events and accumulated exposure in off-site areas.

Studies are continuing in the areas of wind and precipitation prediction. Attention during this year has been on improving measurement techniques and equipment, and in evaluating available numerical/statistical prediction techniques involving computers. A contract was awarded for construction of six improved modern wind finding radars. These are portable and use a small computer to convert position data into wind information. Authorization of funds for PLOWSHARE research has resulted in a new attack on long range trajectory and diffusion problems using theories that have been proposed in recent years.

The next two fiscal years will see deployment of the new PACER wind-finding radars (now being manufactured) and retirement of most of the large and obsolete M-33 radars now used for this purpose, enabling the ARL-LV electronics staff to place more emphasis on improving the performance of other meteorological sensing equipment.

In anticipation of using the AEC computer facility for processing operational weather and radiation data in numerical models, the research programs will be developing and testing models of mesoscale atmospheric motion and diffusion. The long-range goal of a completely automated meteorological data system, producing numerical extrapolations of air trajectories and computing exposure levels, will thus be brought nearer reality during this period, even though the procurement of additional equipment has been deferred.

Interoceanic Canal Meteorology

Meteorological data including wind profiles, trajectories, and surface and radar precipitation measurements, are required to analyze potential fallout hazards as they affect the feasibility of nuclear excavation of a canal in Panama or Colombia. Meteorological observations were completed in FY 69. Criteria were developed for acceptable weather for nuclear detonations and the frequency of occurrence of acceptable conditions as determined. Sample detonation schedules were developed for the proposed canal excavations and the resulting fallout patterns were estimated.

Data analysis and final reports on the feasibility studies are scheduled to be completed during FY 70.

Meteorology for Radioactivity (Global Scale Processes)

The program aims at improving techniques for predicting the distribution, transport, and deposition of trace substances

in the atmosphere, with particular emphasis on nuclear debris and other radioactive tracers. Simultaneously it uses measurements of these tracers to investigate atmospheric processes and to study intermediate and large scale motions in the troposphere and stratosphere.

Information on large scale stratospheric processes derived from measurements of strontium-90, carbon-14, tungsten-185, rhodium-102, cadmium-109, and plutonium-238 has been used to derive a kinematic model of stratospheric motions. An empirical technique for estimating the global distribution of deposited radioactivity from atmospheric nuclear detonations as a function of location, yield, season, and type of burst has been developed.

An analysis of all stratospheric carbon-14 data obtained from 1955 through 1968 for use in continuing studies on stratospheric motions will be made during FY 70.

A study of the sources of radioiodine in pasteurized milk during the period 1963-68 has been completed.

An aircraft equipped with an on-board computer and large silver-iodide crystals capable of detecting the argon-41 plume from the Brookhaven reactor to distances as great as 300 miles has been used to study plume behavior in several different weather regimes. Analysis and interpretation of these data is continuing to give information not previously obtainable on plume behavior over these distances.

In addition to providing quality control and reviewing operational procedures in the Atomic Energy Commission's high-altitude balloon program, a new balloon-borne high-altitude carbon-14 sampler has been developed and tested and is now available for operational use. A thorough review and re-evaluation of all sampling systems presently in use in the AEC balloon program is planned for FY 70. A complete description, recompilation, and evaluation of all data obtained by the balloon program from 1960 through 1968 will also be undertaken. This will give the scientific community a single, evaluated source for all these data.

Meteorology for Nuclear Reactors

Research in this area is directed towards current and anticipated environmental problems associated with the release of airborne radioactive wastes in the use of nuclear reactors for power sources.

The ground deposition of micron-sized radioactive aerosols is an important factor in determining depletion of an airborne

effluent. Three field studies were conducted whereby the airborne concentration was measured on a 3200 x 3200 m grid for the simultaneous release of uranine dye and molecular radioiodine (particulate tracers) and methyliodide (nondepositing, inert, gaseous tracer). By use of concentration ratios of the depositing to nondepositing tracers an estimate is being obtained of the tracer depletion, presumably due to deposition loss.

A field experiment is being initiated to study the aerodynamic effect of a single rectangular or cylindrical building upon atmospheric diffusion rates. The tests will be conducted primarily under low wind speed, power diffusion (inversion) conditions. A cooperative effort is being arranged with a university group doing similar studies in a wind tunnel in order to establish the efficacy of the wind tunnel modeling of the experiment.

A technique has been developed for constructing atmospheric trajectories from a network of 22 wind-recording stations over a 60 x 90 mi grid. The technique is the standard one of interpolating the observed wind to the positions of particles at each of 165 grid points and using an interative scheme for advecting the particles. Computer results, so far, look realistic and field experiments are being planned in which constant density balloon flights will be tracked and compared with trajectories constructed from mesoscale wind fields.

As part of an effort to determine the effect of the urban planetary boundary layer upon atmospheric transport and diffusion, three studies are in progress based on data from tall towers in or near cities. The first deals with the profile of the standard deviation of the horizontal wind direction with height. Results so far show an observed maximum value at some height within the layer depending on the surface roughness. The second investigation deals with the vertical variation of the frequency of wind direction trace types, whether stable (slow diffusion) or not. Stable trace types are less common over cities than over rural areas at the same height. The third study in progress deals with wind profiles and estimates of turbulence statistics from an instrumented television tower (270 m) in Philadelphia where the flow is usually over quite irregular terrain. Very different turbulence and wind speed profiles are observed, depending upon whether the wind has passed the tower after traversing the Schuylkill River Valley or the rough terrain in other directions.

The 445-page volume Meteorology and Atomic Energy-1968 was issued in August 1968. This book has the traits of a guide, handbook, and textbook, as well as having the characteristics

of a research report in atmospheric transport and diffusion. It replaces a widely used volume issued in 1955. A number of universities are already using the next text in atmospheric diffusion courses. A third printing is now in progress.

Meteorology of Urban Air Pollution

This research is in support of the National Air Pollution Control Administration, Department of Health, Education and Welfare.

Initial attempts to quantify air pollution potential forecasts have employed a simple box model, based on mixing depth and wind speed values, to yield an average normalized concentration. The mixing depth concept is most applicable in regions of light winds (stagnation) and, fortunately, it is in such regions that forecasts of mixing depth and wind speed verify best.

A comprehensive investigation of the transport and dispersion of plumes from tall stacks (800 ft), was initiated at a coal-burning power station complex in western Pennsylvania. Plume rise, plume geometry, dispersion, and SO_2 concentration measurements have been obtained, using instrumented helicopters and a mobile lidar, both under contract. Peak ground level SO_2 concentrations as high as 1.4 parts per million, about 1 km from the stack source, have been measured; a 30-minute average concentration of 0.3 ppm has been measured at a distance of 10 km.

Field investigations of the urban heat island have been conducted in Cincinnati to describe the nocturnal urban temperature and wind structure under selected weather conditions. Studies have shown a pronounced modification of the vertical temperature structure over the urban area; this modified layer of air over the city, designated as an "urban boundary layer" was about 150 to 300 feet deep when a strong inversion existed upwind of the city. Within the urban boundary layer the lapse rate was superadiabatic in the central business district, and isothermal to weak inversion in the downwind suburban areas; a strong inversion was maintained above the modified urban boundary layer.

An analysis of low level tracer experimental data, obtained during the St. Louis Dispersion Study, indicates that the urban area enhances the initial horizontal and vertical dispersion of a plume, compared to plume dispersion over relatively flat non-urban terrain.

Tabulations by the National Weather Records Center of morning and afternoon mixing depths, and the vertically averaged wind speeds through each corresponding depth, have been prepared

for 41 Weather Bureau upper air stations. These data are being analyzed to prepare an air pollution potential climatology of the contiguous states.

As a prelude to the designation of Air Quality Control Regions, required by the Air Quality Act of 1967, a geographical delineation of eight atmospheric areas for the 48 contiguous states was accomplished. Each area represents a region of dilution climate homogeneity based on professional judgment and documented studies of certain relevant meteorological experience.

Measurements in Cincinnati of turbidity indicate that the total number of particles suspended in the atmosphere is less in winter with a higher proportion of large particles, than in summer. The wavelength variation of turbidity indicates absorption in the spectral region of 0.59μ, which may be due to ozone. Measurements of ultraviolet radiation show a marked reduction of UV received at the ground on days of heavy air pollution.

An initial model of a thermometric sounding system for indirect determination of vertical temperature profiles has been developed (under contract) and is now undergoing extensive field testing.

Work continues on improving forecasts of high air pollution potential through more precise specifications of the areas involved and development of quantitative measurements of pollution potential. The Large Power Plant Effluence Study has been extended to a second plant in the area and studies of precipitation scavenging and cooling tower effects have been initiated.

The long term geophysical aspects of air pollution are being studied to identify effects and to enable the design of specific programs in this area.

Urban effects on pollution are the subject of several projects including mathematical modeling and pilot observational studies of wind flow and stability over a medium-sized city (Columbus, Ohio).

A feasibility study of indirect methods for determining wind profiles has been carried out by the ESSA Wave Propagation Laboratory and two promising techniques, acoustic "radar" and "cross beam spectrometry" will be studied in detail.

Meteorology and Environmental Quality

Atmospheric Turbulence and Diffusion Research

The Laboratory at Oak Ridge serves as the focus for basic and applied research in turbulence, diffusion and the structure of the atmospheric boundary layer, and supports the AEC requirements for expertise in these fields as they relate to problems of nuclear reactors and other nuclear activities.

In FY 1969, a pulsed-laser meteorological probe was assembled for smoke plume geometry studies. The neodymium laser will be utilized to determine particle distributions in plumes from elevated and surface air pollution sources.

Meteorological support of the Nuclear Safety Information Center was continued, and meteorological assistance was provided in the formulation of guidelines to be used by shift supervisors in the event of a nuclear reactor accident.

A thorough study of published models of wind spirals and turbulence in the boundary layer of the atmosphere was conducted. Various methods of determining the thickness of the boundary layer were applied to the 1953 Great Plains data and critical comparisons were drawn.

Large helical roll-vortices in the boundary layer and the part played by these vortices in the formation of longitudinal sand dunes were studied. Laboratory flow simulations, mathematical models and observations in the atmosphere support the hypothesis that dominant forms of motion in the boundary layer are longitudinal roll vortices aligned approximately in the direction of the wind and having diameters comparable to the thickness of the boundary layer.

Smoke plume studies were conducted at Idaho Falls and at Oak Ridge, together with concurrent measurements of mean winds, temperatures, and wind fluctuations in order to establish basic turbulence parameters, chiefly the ddy energy dissipation rate.

A study of changes in the spatial distribution of solar radiation within a tulip-poplar forest was initiated. Measurements are being made during the winter-spring-summer transition to determine how the distribution of solar energy within a forest changes as the trees pass from bare to fully leafed conditions. Studies of characteristics of wind and turbulence in and above a loblolly pine plantation have been initiated. Necessary instrumentation and data logging equipment have been selected and procurement proceedings are under way.

Plume rise studies were extended by considering some of the details of the entrainment process and by utilizing recent

turbulence data from the planetary boundary layer to derive an expression for buoyant plume rise at large distances downwind in neutral conditions. The expression is confirmed by observations as far as they go, but observations are still lacking at distances over a mile downwind. The basic hardware of a fumigation modeling facility has been assembled, including a modeling tank, two auxiliary tanks, plumbing, and an automated filling system.

During FY 1970 experimentation with "Lidar" (Laser-Radar) equipment will continue. Results of these trials will be used to evaluate theoretical models of smoke plume behavior.

A small smoke plume will be photographed over the flats of the Clinch River and concurrent measurements of turbulence parameters will also be made. Computer modeling of the reaction of a tetroon to sinusoidally varying air motion will continue. The hydrodynamic stability of roll vortices will be studied mathematically. Simplified models of the urban boundary layer will be developed.

The fumigation modeling facility will initially be used to fill in some gaps in data on penetration of inversions by plumes and on plume rise through a linear temperature gradient. It then will be used to model the spreading of forced plumes after rising through a calm, stratified environment; these results will be used to develop a fumigation model for calm conditions.

Wind and turbulence instrumentation and a data logging system should be operable. Data acquisition in the loblolly pine plantation and analysis of these data should be underway. Aerodynamic characteristics of the plantation will have been determined.

Sonic Boom

The meteorological factors that affect the characteristics of the sonic boom created by supersonic aircraft are being explored. With Federal Aviation Administration support, a program to collect meteorological data at Pendleton, Oregon, for comparison with detailed sonic boom data has begun. Complete data sets from the Pendleton overpressure grid are not yet available, consequently analysis of these data has been restricted. Radiosonde data are now obtained daily at the site and a light airplane is used to obtain atmospheric temperatures and turbulence data whenever there are particular high performance supersonic aircraft flights in the area. The superboom phenomenon will be studied at Goldburg, Idaho, and various specially developed overpressure instruments will be placed in that area shortly. An advanced computer program

("ARAP") to simulate overpressures has been successfully adapted to the ESSA CDC-6600 and theoretical overpressures derived from it will be compared with observed overpressure both at Pendleton and Goldburg. An extensive analysis is being made of the overpressure traces obtained earlier at Edwards AFB, California.

Statistical Meteorology and Special Studies

Meteorological Statistics Studies

This project conducts basic research in the application of mathematical statistics to problems in the atmospheric sciences concerned with the understanding, prediction or ultimate control of the physical processes of the atmosphere. The staff also provides consulting services in applied mathematical statistics, computer programming, and data processing to ESSA personnel.

The primary research emphasis in FY 69 was directed toward the problems of improving long range forecasts of geophysical phenomena by developing more effective techniques of time series analysis. It is now recognized that most meteorological and many other geophysical time series are not stationary and that a more general approach is needed if statistical methods are to be more successful in predicting events months or years in advance. New procedures were developed which show considerable promise and have been applied to predicting atmospheric and solar indices for periods of a year and longer. These predictions appear accurate enough to be useful in long range planning.

Research was continued on the influence of the lunar-solar gravitational tide on various atmospheric phenomena. Evidence was found that variations in solar activity are related to the tides in the solar atmosphere produced by the motions of the planets and that a mathematical analysis of the planetary periods could produce valid predictor variables of sunspot activity.

In FY 70 research will continue on the tidal relationships to the atmosphere of the earth and the sun, and an effort will be made to obtain a greater physical understanding of the phenomena. The tidal framework will be used to derive variables to include in multivariate and regression analyses, with the objective of more accurate forecasts for periods of a year or longer.

Mesoscale Transport and Diffusion

Knowledge of mesoscale motions is fundamental for investigating the dynamics of the planetary boundary layer. Studies of

these motions in irregular terrain and the "heat island" effect of an urban area were examined. The dominant vertical periodicities at hourly intervals along the 42 tetroon flights past the 1500-ft BREN tower (Nevada Test Site) in May, 1968, have been determined from the vertical-velocity spectral peaks. In the mean the resulting period varies from 8 minutes, before sunup, to 24 minutes at noon, and closely corresponds to the Brunt-Vaisala period as determined from the lapse rate on the BREN tower. The significance of this periodicity in the planetary boundary layer probably has not been sufficiently recognized in the past.

The influence of a sudden 100 m change in terrain height on the three-dimensional low level air flow has been estimated from tetroon flights made several years ago at Bodega Bay, California. In the mean, a maximum in upward air motion (6 cm s^{-1}) occurs 250 m above the maximum in terrain slope and is associated with a 10^{o} backing of the wind and an increase in wind speed, suggesting a Venturi effect.

The influence of a moderate-sized urban area on the three-dimensional low level air flow at night is being studied by means of 80 tetroon trajectories obtained in the vicinity of Columbus, Ohio in March, 1969. When the surface wind is weak there is evidence for a strong (10-15 ms^{-1}) low level jet with wind direction changes exceeding 90^{o} in a few hours. When the surface wind is strong the trajectories tend to swerve around the center of town as if the downtown area acts as a partial barrier to the wind.

The bivane data obtained on the BREN tower during the tetroon flyby have now been reduced and the Eulerian-Lagrangian analysis will be completed in the next few months. During the next fiscal year an extensive analysis of the Columbus tetroon flights will be carried out. A similar tetroon experiment is being conducted in Los Angeles.

Dr. Lester Machta, Director, Air Resources Laboratories

Dr. Machta has served the U.S. Government since joining the Weather Bureau in 1948 after receiving his Sc.D. from the Massachusetts Institute of Technology. As Chief of the ARL he directs research on the meteorological aspects of pollution and on its global scale effects that have a direct and indirect effect on man and nature.

The Department of Commerce has recognized his scientific achievements by awarding him its Gold Medal in 1957.

In addition to his Sc.D. in meteorology from MIT, Dr. Machta received a B.A. in mathematics-physics from Brooklyn College and an M.S. in meteorology from New York University. Before joining the Weather Bureau he taught meteorology for the U.S. Air Force, mathematics at the University of Illinois, and was a research associate at the MIT Department of Meteorology.

Dr. Machta represented the United States in the United Nations Scientific Committee of the Effects of Atomic Radiation, and participated in the Geneva Test Ban Treaty. He acted as advisor to the test manager for several continental and Pacific nuclear tests and served as advisor on safety in the conduct of several national defense efforts. In addition, he has held membership in numerous other governmental and international committees. His scientific contributions exceed 35 published papers.

Dr. Machta, his wife and their two children live in Silver Spring, Maryland.

GEOPHYSICAL FLUID DYNAMICS LABORATORY

Princeton, New Jersey

Joseph Smagorinsky

Research is directed toward fundamental understanding of large-scale circulation systems of the atmosphere and oceans and their interaction. The objective is to develop a comprehensive theory of the dynamics of geophysical fluid systems and processes which are larger than microscale. The successful development of such a theory in the form of numerical models will lead to the systematic improvement of short range prediction; will establish the limits and the means for long range predictions; and will provide techniques for discovering and testing means for large scale weather and climate modification.

Large scale model experimentation and development are conducted in the following scientific program areas:

Atmospheric Circulation	S. Manabe and Y. Kurihara
Ocean Circulation	K. Bryan, M.D. Cox, H.J. Friedrich, W. R. Holland, and I. Orlanski
Experimental Prediction	K. Miyakoda, R. Clarke, J. Sadler, and P. Roundtree
Observational Studies	A. H. Oort and E. Rasmussen
Basic Geophysical Fluid Dynamics	G.P. Williams, F. B. Lipps, R.C.J. Somerville, and I. Orlanski
Computational Facility	H. Engelbrecht

Highlights for FY 1969 and plans for FY 1970:

Atmospheric Circulation

The long term objective of this work is to develop a comprehensive theory of the large scale global motions of the atmosphere. The numerical simulation of the seasonal variation of the thermal and dynamical structure of the troposphere-stratosphere system is being conducted using the global circulation model with the actual distribution of mountains and ocean-continents and the observed seasonal variations of sea-surface temperature.

The successful development of such a theory in the form of numerical models will permit simulation of the earth's climate by numerical time integration of the models. This atmospheric

model combined with an ocean model forms a joint ocean-atmosphere model which is necessary for a definitive dynamic climatology study.

A study of controlled experiments is being performed to determine the relationship between the climate and various factors such as: land-sea configuration, mountains, annual march of solar insolation, solar constant, concentration of various atmospheric absorbers such as carbon dioxide and cloudiness.

Simulation of the January-February global climate was particularly successful in accounting for the global rainfall distribution, the corresponding world deserts and the main river runoff basins. The key role of the large mountain chains was reaffirmed. These experiments also succeeded in predicting the location of the spawning grounds of tropical cyclones. A detailed analysis of the tropical part of these models has been conducted to determine the mechanism of maintaining the kinetic energy of disturbances in the actual tropics. Higher resolution models were used for some of these experiments.

Ocean Circulation

The development of numerical models has added a new tool for investigating basic problems in the dynamics of ocean currents and for developing a comprehensive theory of the large scale circulation of the World Ocean. The successful development of such a theory in the form of a numerical model will permit its combination with an atmospheric model for studying large scale dynamic climatology on a sound quantitative basis.

The generalized ocean circulation model will be applied systematically to all the world's oceans in turn, taking into account the actual shoreline and bottom topography of the world's major oceans.

Extensive hydrographic data must first be collected, analyzed, and studied diagnostically as a means of testing the model predictions. Calculations are also performed for a wide range of the governing parameters for simplified cases, with the emphasis on gaining a basic understanding of the physics of ocean circulation.

The generalized ocean circulation model for basins with irregular bottom topography and side boundaries was applied to the study of the circulation of the Indian Ocean and calculations gave an excellent prediction of the variations of the ocean currents with the changing monsoons. An analytic study of the Gulf Stream meanders has been successful in explaining many observed features of these phenomena.

Experimental Prediction

The research objectives are to: (a) determine the relative performance of various models of the atmosphere by testing and comparing computed results with real data; and (b) establish criteria and levels of predictability of the large scale atmospheric motions and accompanying weather phenomena such as temperature, precipitation, wind, etc.

Predictability experiments are being carried out on the IBM 360/91 computer with higher resolution global models than was possible with computers available to us in the past. Low resolution truncation errors will therefore not be present to obscure the results and a better assessment of the limit of predictability and of the sensitivity of the model to various modeling parameters will be possible.

Extended experimental prediction experiments have been performed globally, in the southern hemisphere, and in tropical regions. They suggest the theoretical limit of atmospheric predictability to be at least three weeks, and that several parameters thought essential for an initial description of the state of the atmosphere may in fact be redundant. They are the surface pressure, the vertical velocity, the water vapor, the boundary layer temperature, and the boundary layer wind. It is not yet entirely conclusive, but it is suspected that these quantities may be dynamically redundant and not essential to the definition of the initial conditions in extratropical latitudes. The experiments show that the predictions are the same after about two days, irrespective of the initial values of these quantities. The significance of large scale sea surface temperature anomalies on mid-latitude circulation has been established as well as the interhemispheric atmospheric coupling for forecast spans between one and two weeks.

Observational Studies

These studies are to determine and evaluate the important real atmospheric variables using all conveniently available observations. These studies are then compared with similar diagnostic studies of the model atmosphere developed at GFDL. They thus aid in the evaluation of the effectiveness of the models in simulating the real atmosphere.

Analysis of hemispheric radiosonde data from the 5-year period, May 1958 to April 1963, will continue and is expected to give a quantitative picture of the role of both the mean meridional circulation and the eddies in the general circulation. The total energy will be subdivided into its internal, latent,

potential, and kinetic components. Calculations of the vertically and zonally integrated convergence of each form of energy between selected latitude belts as a function of season will continue to be studied. Investigation of the atmospheric humidity on a global basis will continue.

Definitive studies have been completed of the atmospheric kinetic spectrum derived from 10 years of data and of the water balance over North America, the Gulf of Mexico, and the Caribbean Sea for a 5-year period.

Basic Geophysical Fluid Dynamics

A finite difference model of annulus circulation which yields solutions to the three-dimensional Navier-Stokes equations in polar coordinates for laminar fluid flow has been completed. The fluid motion is driven by rotation and a lateral temperature differential. The model was set up to describe and examine geophysical fluid modes in pure and isolated form, and at present is being used to analyze such basic annulus dynamical modes as vacillation. Because the model system is fully three-dimensional, i.e., the hydrostatic assumption is not made, it can be used to model other geophysical phenomena in which vertical motion is large. Such an application is being made to study the genesis and evolution of frontal systems as a supplement to analytical studies.

Two-dimensional numerical experiments have been run to simulate dry convection with and without a mean wind shear with height. A full three-dimensional model is now in operation and initial efforts are directed toward the simulation of laboratory experiments. A primary goal in this study is to gain an understanding of the breakdown of laminar convection into turbulent convection with increasing Rayleigh number. Later numerical experiments may be directed toward simulation of convection in the earth's boundary layer. In studies of thermal convection equilibrium with rotation, the objective is to study the fundamental processes in convection, including the roles of Ekman layers, variable fluid parameters, and finite-amplitude effects between rigid boundaries in uniform rotation.

The two-dimensional Boussinesq approximation is applied to the steady Navier-Stokes equations, and the numerical simulation is quantitatively compared with analytic theory and high-precision laboratory data. Frontal dynamics is being evaluated by studies of frontal genesis and instability through linear stability analysis. The energetics involved are being investigated by analytic and numerical techniques. The growth of surface water waves and the subsequent air-water interaction when a turbulent shearing flow in the air blows over a

body of water initially at rest is also being studied. The problem will be treated numerically with the goal of ultimately attacking the non-linear, finite-amplitude case.

Computational Facility

The services objective of the facility is to provide top-of-the-line digital computer facilities with an expert operating staff and a small group of systems analysts. The facilities and staff are utilized to provide the computing power necessary to perform long-time-integrations of numerical models simulating the earth's atmosphere and oceans.

GFDL will have use of one UNIVAC 1108 computer for about 7700 hours and an IBM 360/91 computer for nearly 1500 hours during 1970. The 360/91 permits running a class of problems which are impracticable on the 1108.

Dr. Joseph Smagorinsky, Director, Geophysical Fluid Dynamics Laboratory.

Born in New York City in 1924, Dr. Smagorinsky received his degrees from New York University - B.S. (1947), M.S. (1948), and Ph.D. in meteorology (1953).

He began his scientific career as research assistant and instructor in meteorology at New York University. In 1948 he joined the U.S. Weather Bureau as research meteorologist and has been affiliated with the Weather Bureau and ESSA ever since, except for a three-year period (1950-1953) when he was a meteorologist at the Institute for Advanced Study, Princeton University.

In 1954, he became Chief of the Computation Section, Joint Numerical Weather Prediction, U.S. Weather Bureau. From 1955 to 1963, he was Chief of the Weather Bureau's General Circulation Research Section. The following year he became Director of the newly established Geophysical Fluid Dynamics Laboratory, and in 1965 he served as Acting Director of ESSA's Institute for Atmospheric Sciences.

Dr. Smagorinsky received the Gold Medal of the Department of Commerce in 1967 and the Meisinger Award of the American Meteorological Society the same year. He is a Fellow of the American Meteorological Society, a member of the Royal Meteorological Society (for which he was a Symons Memorial Lecturer), and a member of the Philosophical Society of Washington. He has also participated in scientific efforts for such prominent organizations as the National Academy of Sciences, Presidential Scientific Advisory Committee, and the Interdepartmental Committee on Atmospheric Science. His scientific publications are numerous.

Dr. Smagorinsky, his wife and children live in Princeton, New Jersey.

NATIONAL SEVERE STORMS LABORATORY

Norman, Oklahoma

Edwin Kessler

The National Severe Storms Laboratory seeks better understanding of tornadoes, squall lines, thunderstorms, and other severe local storms, and develops improved methods for their early detection, identification, and prediction. Research data are obtained during the spring season, when there is a program of intensive observations on storms from a dense network of weather stations, an instrumented tower, serial releases of rawinsondes, conventional and Doppler weather radars, electric field monitors, and instrumented aircraft. Observations provide new information on the structure and dynamics of severe local storms and bases for improved weather forecasting and other services. Advanced techniques are developed for probing the atmosphere by radar and for processing,displaying, and transmitting radar data.

NSSL projects receive support from several government agencies, and many groups cooperate in the acquisition and analysis of data. A modest contract and grant program originating in NSSL encourages cooperation among various investigators and the study of severe storm topics at various universitities and elsewhere.

The investigations of severe storms are undertaken in the following scientific program areas:

Severe Storm Morphology and Dynamics	Stanley L. Barnes
Storm Hazards to Aircraft Safety	Jean T. Lee
Electricity of Severe Storms	Gilbert D. Kinzer
Doppler Radar Techniques	Edwin Kessler
Weather Radar Interpretation	Kenneth E. Wilk and Edwin Kessler
Thunderstorm Forecast Technique Development	Rex L. Inman
Data Acquisition and Processing	Kenneth E. Wilk

Severe Storm Morphology and Dynamics

The development of a comprehensive description and explanation of severe storm characteristics is emphasized, with the objective of improving our understanding and forecasting of storms.

Data from a special network of upper air and surface stations augmented by radar, aircraft, and instrumented tower observations, form the basis of project studies. Procedures have been

implemented for taking serial soundings to 23,000 feet altitude at 40-minute intervals at stations spaced only 15 nmi apart, and sounding reduction procedures have been greatly improved through the use of a new in-house computer facility.

Instrumentation and sampling techniques involving aircraft and balloons have been developed to obtain data on the flow of air in and around storms, and on the internal structure of storms and their energy budgets. Boundary-layer influences, characteristic magnitudes and scales of parameters associated with storm development, storm motion forecasting parameters, and tornado models are also investigated. Data are used to test and improve theoretical models of severe thunderstorms, and to aid the planning of future observations.

Analyses have progressed on several cases of interest, including one in which a sounding instrument was carried aloft in the core of a developing storm. Laboratory model studies of tornado-like vortices produce new information on the role of inflow momentum in the dynamics of vortex formation.

Storm Hazards to Aircraft Safety

The distribution of storm hazards to aviation, such as turbulence and hail are investigated and improved means for identifying such conditions and communicating information about them are developed.

Flights by Canadian Research Council T-33 aircraft, in conjunction with NSSL, have indicated how turbulence between clouds is related to distance from cloud and storm intensity. Analysis of RB-57F flights shows a positive correlation between ambient wind speed and turbulence above thunderstorms. Maximum cloud top heights photographed by the RB-57F correspond closely to cloud top heights computed by the use of the parcel method.

Data concerning turbulence, temperature, and other meteorological data are being collected by aircraft, with concurrent radar and tower data, to determine relationships between data obtained by various methods. The distributions of convective cloud heights and rates of change of temperature near and above thunderstorms are being evaluated. During FY 70, results of flights during FY 69 and earlier will be documented. Flights during the spring season of calendar year 1970 should be coordinated with operation of an X-band pulse Doppler radar at Chickasha, Oklahoma, 24 miles west of NSSL Headquarters.

Electricity of Severe Storms

The association of electricity with other features of severe storms being poorly understood, the objective of this project

is to measure areas of lightning activity and relate them to areas of precipitation, locations of air inflow and outflow, and the direction and speed of storm movement and development. The National Severe Storms Laboratory investigates correlations between areas of lightning and patterns of radar reflectivity in order to improve the identification of likely areas of lightning in and around severe thunderstorms by using radar displays. A secondary objective is to assess the extent that models of severe storm electricity conform with observed distributions of lightning. Lightning is located using standard radio direction finding techniques to obtain azimuth angles, and the ray model of multiple ionospheric reflections to obtain range.

The planned effort in FY 70 is to correlate observations now in hand and to indicate the results in a suitable publication or report. It is anticipated that the principal dimensional and temporal relationships between lightning and the precipitation patterns of severe storms will be established and discussed.

Doppler Radar Techniques

Our objective is to develop an improved Doppler radar data acquisition and processing capability at NSSL and to apply the data to identification of turbulence and analysis of air circulation in thunderstorms.

During FY 69 a graduate student from the University of Chicago participated with NSSL staff in acquisition of pulse-height fluctuation data. Subsequent analyses at NSSL and at the University of Chicago illuminated the problems and prospects inherent in this approach to the study of turbulence. An integrating and contour-mapping circuit was provided for use with our 30-ft antenna, and a tower with a radome is being erected to protect the antenna's steerability during strong winds. A design study for a full Doppler capability has been started and an FPS-18 system has been acquired. During FY 70, NSSL will concentrate on the acquisition and development of a fully coherent 10-cm Doppler radar capability. The X-band Doppler radar at Chickasha will be used during spring 1970, and the amplitude fluctuation studies concluded while the 10-cm Doppler capability is being developed. This project is being guided jointly by the staff of NSSL and the University of Oklahoma Department of Electrical Engineering. Computer simulation of two- and three-Doppler scanning of severe storms and different meteorological conditions is being examined under contract.

Weather Radar Interpretation

Objectives in this area are (1) to determine the relationships between weather radar data and associated meteorological phenomena including rainfall rate, hail, damaging wind gusts, and tornado occurrences, and (2) to determine effective means for interpreting and displaying the fields of radar data. Knowledge of the relative merits of radars designed primarily for airborne, air traffic control, and weather study, respectively, is essential for the efficient development and use of the systems of men and equipment which must assure the safety of flight during severe storm activity. Interpretation of radar observations should be based upon known correlations of hazardous weather events with radar measurements.

The development of a systematic method for recording the radar-measured intensitities has extended and expedited the analysis for hydrologic interpretation. Using such data, Wilson (contract) has defined the operational accuracy of the radar to be equivalent to a raingage density of at least one gage per 500 km^2, and found that calibration of the radar using a raingage can reduce the root-mean-square error in the areal measurement by 40 percent. Eagelson (contract) is developing a catchment model for analyzing the use of joint radar-raingage observations to improve the forecasting of peak flood flows. An experiment involving NSSL staff with the Weather Bureau Southern Region River Forecast Center involves real-time radar data acquisition, transmission, and computer processing. Problems in radar calibration, observational accuracy, and processing are being defined in the operational environment.

Detailed observations of severe weather events have been collected and correlated to weather radar data characteristics. The short-term motion, intensity, and predictability of the digital radar data fields are being analyzed in detail. During FY 70, studies will be made to link the short-term variations in echo intensity and motion to the occurrences of wind gusts and hail falls. Work will continue on determining the predictability of severe storm patterns observed by radar.

Thunderstorm Forecast Technique Development

This project started during FY 67 as a collaborative effort between the U.S. Weather Bureau and the ESSA Research Laboratories. Research involving staff of the National Severe Storm Forecasting Center, Kansas City, Missouri, and of NSSL in FY 68 was directed toward improving operational techniques for analysis of the current state of the atmosphere and more efficient use of observational data. Significant progress was made in objective and automated analysis and data proces-

sing techniques. Objective analyses that resulted from this joint research effort included the low level moisture field and calculations of the kinematic vertical velocity. Automated procedures for checking radiosonde data for hydrostatic consistency and coding errors were introduced and have resulted in a substantial increase in the number of daily soundings usable at NSSFC on a real-time basis for severe storm forecasting and warning services.

The barotropic-mesh model was programmed for the NSSFC CDC-3100 computer. This forecast model is run when requested by the duty forecaster. A modified version of the Bushby-Timpson 10-level fine-mesh primitive equation model has been programmed and tested on the IBM 360/40 computer at the University of Oklahoma. Data have been accumulated for use in the determination of initial conditions for the model and a preliminary analysis of the initial conditions utilizing objective analysis procedures similar to those employed at **NMC** has been accomplished.

Data Acquisition and Processing

An objective of the NSSL program is to acquire comprehensive and accurate data on the meteorological parameters associated with severe storms, and to process these data into a form for presentation and distribution that meets the data requirements for application in, and support of, defined research projects of NSSL research staff and the national meteorological community.

A digital recorder was installed for the wind and temperature system already in place on the WKY television tower. High-quality measurements of temperature and horizontal wind are now obtainable at one-second intervals at seven levels from the ground to 1458 feet above it. Data processing and summarizing routines are being prepared for local computers.

With a closer spacing and special arrangements of surface stations, the Laboratory will continue to make systematic measurements of pressure, temperature and wind fields associated with localized severe storm features such as tornadoes, shafts of hail, wind, and intense rainfall. We expect that the increased density of surface measurements in the vicinity of severe storms will aid in development of severe storm models.

Digital radar and tower data acquired systematically during the past three years are being summarized. This will include the statistical properties of severe storm patterns as depicted by the WSR-57 radar, and the boundary layer wind direction and shear distributions measured in the environment

of the Oklahoma City TV tower.

Expanded utilization of automated collection devices has resulted in increased data collection and improved processing procedures. An IBM 1620 computer is being utilized to improve data handling.

Dr. Edwin Kessler III, Director, National Severe Storms Laboratory

Dr. Kessler was born in New York City in 1928. He graduated from Columbia College, New York City, in 1950; he received S.M. and Sc.D. degrees in meteorology from Massachusetts Institute of Technology in 1952 and 1957, respectively.

He is a Fellow of the American Meteorological Society, past President of its Greater Boston Branch, past National Councilor of the American Meteorological Society, Chairman of the American Meteorological Society Committee on Radar Meteorology, Associate Editor of the Journal of Applied Meteorology, and has been certified by the AMS as a Consulting Meteorologist. He is also a member of several other scientific societies, and is Adjunct Professor of Meteorology at the University of Oklahoma.

Dr. Kessler is the author of numerous publications on radar meteorology and on relationships between atmospheric circulations and the distribution of water substance. In 1969 his studies of the latter problem were published as a Monograph of the American Meteorological Society.

Dr. Kessler lives with his wife and two children in Norman, Oklahoma, where he serves as a member of the Boards of Directors of the Oklahoma University Research Institute, the Red Cross, and the United Fund.

SPACE DISTURBANCES LABORATORY

Boulder, Colorado

A. Glenn Jean (Acting)

Activities of the Space Disturbances Laboratory (SDL) may be classified in three broad areas:

Solar-Terrestrial Research. An active program of research into geophysical phenomena and the physics of solar-terrestrial relationships for improved knowledge of man's space environment, which finds direct application in utilization for telecommunications and space activities.

Laboratory Mission Support. Complex logistic and technical operations in acquisition, computer processing and dissemination of large amounts of data, in support of both the scientific and service missions of this laboratory, are conducted. Other important support functions include instrumentation, statistical verification of forecasts and planning for acquisition of satellite data.

Services. The mission-oriented services of the Laboratory provide monitoring, warning and forecasting of solar flares and flare-producing disturbances through its Space Disturbance Forecast Center (SDFC). In addition, the Aeronomy and Space Data Center (World Data Center A, Upper Atmosphere Geophysics) collects, archives and disseminates comprehensive geophysical data through systematic, international publication of data received from observatories throughout the world.

Program Areas:

1.	Solar Physics	F. H. Leinbach, Jr.
2.	Interplanetary Medium	M. Dryer
3.	Magnetosphere	H. H. Sauer
4.	Ionosphere	K. Davies
5.	Data Acquisition and Processing	R. N. Grubb
6.	Numberical Analyses and Computer Techniques	R. J. Slutz
7.	Instrumentation Development Services	R. N. Grubb

8.	Long Baseline Interferometer	W. K. Klemperer
9.	Space Disturbance Forecast Center	R. B. Doeker
10.	Aeronomy and Space Data Center	J. V. Lincoln

Solar-Terrestrial Research

The major areas of uncertainty and therefore of particular scientific interest may be defined by tracing the etiology of geophysical disturbances. These areas and some of the more pertinent questions relating to them are stated briefly below.

The Sun. The role of the sun as prime source of both electromagnetic and particle radiation is reasonably well understood, but major questions remain on the details of the dynamics of active solar regions, flare production, and the consequent impulsive production of energetic radiations.

The Interplanetary Medium. Given the existence of a solar wind, as described both by theoretical studies and satellite observations, questions involving the storage and transmission properties of such a medium are crucial to our understanding of solar-terrestrial relationships.

The Geomagnetic Interaction Region. The paramount question in this area is the nature of the interaction of the solar wind with the earth's magnetic field and the mechanisms for consequent entry of solar particles into the magnetosphere.

The Magnetosphere. Of concern here is the topology of magnetospheric fields and their time and disturbance variations, as well as the dynamics and distribution of these particles within the magnetosphere. In particular, how do particles move through the magnetosphere to impact into the atmosphere?

Ionospheric Interaction. Finally, and of immediate interest to ionospheric physics, are the questions of the detailed ionization processes of electromagnetic and particle radiation from the sun and of particles precipitated from the magnetosphere.

The specific research projects of this Laboratory are currently addressing each of these areas of inquiry in concert with the efforts of the international community of space scientists. The understanding gained from such inquiry will allow more effective utilization of man's environment.

The Sun

Detailed study of individual solar flare-producing active regions is being made in an effort to understand the causal sequence of the development and decay of sunspot groups. New and better observations of active regions are available, allowing detailed analyses of spot features. Interesting details available on the high resolution films include pre-flare brightenings and filament disappearances which occur from minutes to an hour prior to a flare, the "red flash" of flares during their early history, and manifestations of magnetic field configurations in the H_α structure of the flare.

An exciting addition to our own observations is the development at Lockheed of a method for observing the structure of magnetic fields on the sun with a resolution approaching that of optical intensity observations. Preliminary test pictures show up regions of opposite magnetic polarity in an active region with fine resolution and detail. These observations may allow the eventual forecasting of flares through study of optical precursors and a knowledge of the evolving magnetic structures of a region.

Development of a spectrohelioscope is also underway to allow high spatial resolution and monochromatic observation of the solar disk, with a capability for easily changing the observing wavelength. Solar observation at several emission lines allows distinct features on the sun to be examined. The ability to change the observing wavelength by a fractional line-width permits the examination of material motions and magnetic structure on the solar disk through application of Doppler and Zeeman effects.

Further studies have been accomplished on the morphology of flares and flare occurrence. Analyses of flares occurring over the last century indicate that the distribution of proton-producing flares is significantly non-random, while other groups of flares seem random.

Interplanetary Medium

Estimates have been made of the energy distributed to the solar wind by flare-generated shock waves. The theoretical hydrodynamic "blast wave" treatment has been combined with spacecraft observations of shock-wave plasma parameters which have recently become available for the first time. The results appear to confirm the blast-like origin of some flares. A study also has been made of solar-wind drag on comets and the ionized material forming their tails. The plasma pressure force acts in a calculable way to slow a comet's approach to the sun, a

possible explanation of observed anomalies which require a nongravitational force in cometary orbits.

Radio astronomical observations of interplanetary scintillations of the Crab Nebula emissions have been analyzed. It appears that good estimates of the solar wind velocity near the sun can be obtained through this ground-based technique. Fluctuations in solar wind parameters are associated with subsequent geomagnetic activity and therefore provide useful information for the ionospheric forecasting activities of the Telecommunications Service Center as well as indicating other geophysical consequences.

Future observations will be forwarded to the Space Disturbance Forecast Center. Further study of the properties of the interplanetary medium will be enhanced by the occurrence of several solar proton events (PCA) during the past year. The time history of these events at the earth allows inference of the propagation of solar protons through the interplanetary medium. The data from these events are now under study.

The Geomagnetic Interaction

A hydrodynamic model has been used to study the dynamics of the interaction of a flare-generated blast wave with the standing magnetospheric shock (fig. 2). Since the magnetic shock features are not included, the treatment provides only a bound on expected behavior, but in conjunction with experiments conducted elsewhere, the results serve to provide insight into the actual processes occurring at the geomagnetic transition region.

An approximate solution has been obtained for the viscous drag predicted by a magnetohydrodynamic boundary-layer interaction between the solar wind and the earth's magnetosphere. Reasonable values of boundary stresses and drag were obtained in support of the requirement of several ad hoc magnetospheric models. However, definitive results require high resolution measurements of particle flux and magnetic field in the magnetospheric boundary region which are as yet unavailable.

The Magnetosphere

The energetic particle environment of the earth is studied by a variety of techniques, both ground-based and in space. In the latter category, the new ITOS Operational Satellite will carry a solar proton monitor intended to record fluxes of solar protons as they enter the earth's polar caps. The first launch is scheduled for the fall of 1969 and essentially

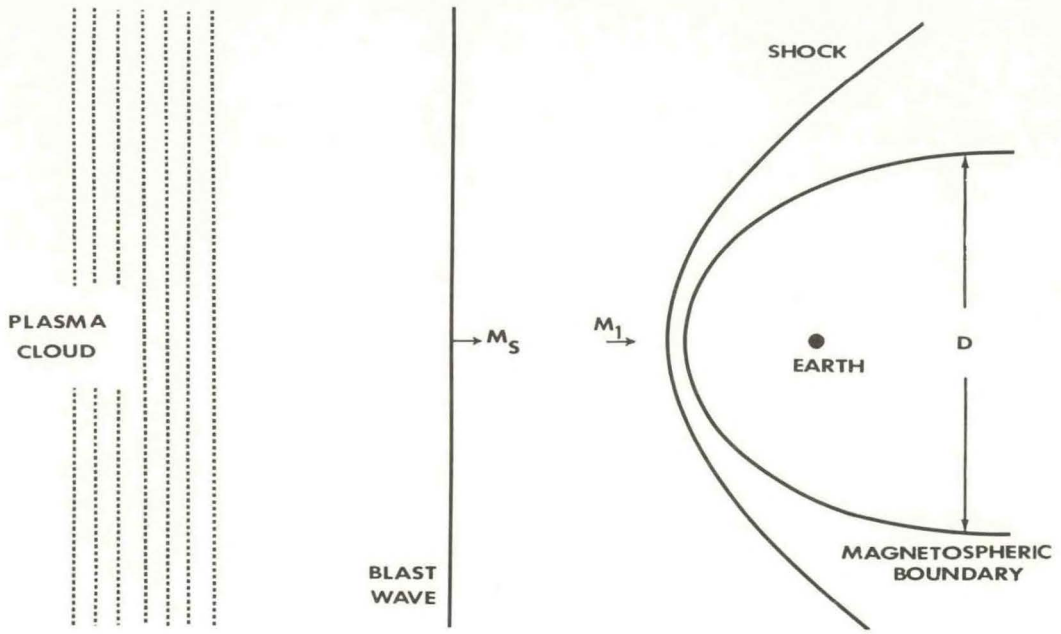


Fig. 2. Schematic diagram of blast wave shock front approaching the earth's magnetosphere. (M_S = Shock Mach Number M_1 = Solar Wind Mach Number)

continuous recordings of proton fluxes should begin shortly thereafter. Data from this equipment should provide an invaluable source for research into the interplanetary propagation of protons from the sun to the earth, and the effects of the geomagnetic field on incoming proton fluxes.

Fundamental to understanding particle dynamics is a knowledge of the topology of the magnetospheric electric and magnetic fields as well as their time and disturbance variations **(fig. 3)**. To this end, a model of the magnetospheric magnetic fields has been constructed, incorporating a realistic dipole orientation, and a tail current consistent with recent satellite observation. The asymmetries of such a model can be expected to produce diurnal and seasonal dependence in geophysical phenomena already suggested by experiment. Correlations of satellite particle measurements with ground-based observations are being carried out, and are useful in establishing field-line connectivity and particle dynamics, particularly in the critical tail region. Such inquiries are directed toward an understanding of the dynamic properties of the so-called "polar substorm" which forms the focus of much of the

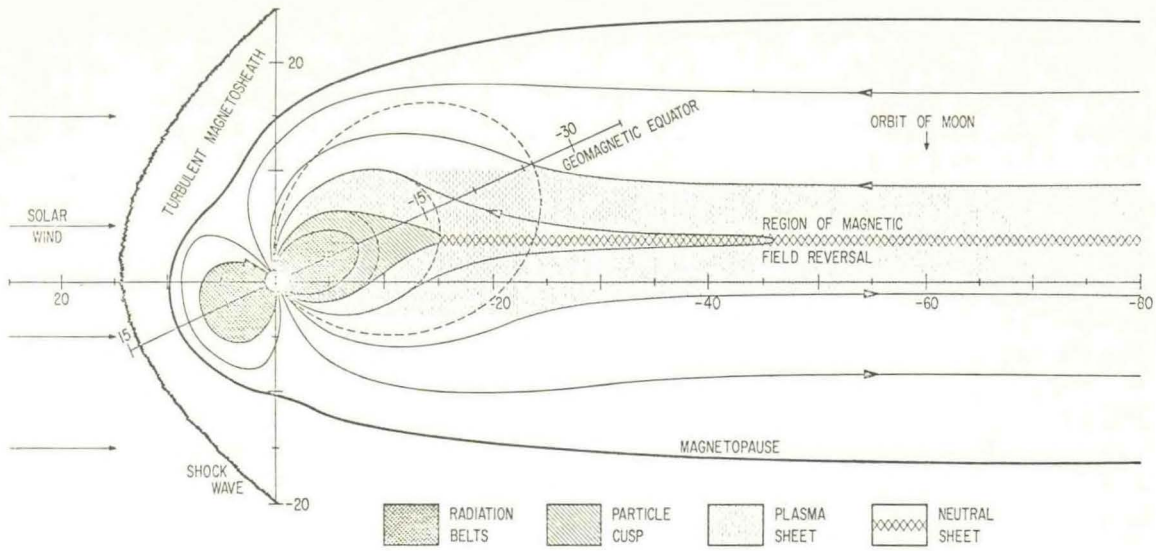


Fig. 3. Magnetosphere and Tail.

high latitude auroral activity, and undoubtedly forms the vital link needed to transform the solar-wind energy into the energy represented by auroral displays, magnetic storms and trapped particles.

Ground-based studies of energetic particles are being carried out by radio propagation techniques, through absorption of cosmic noise and forward-scatter characteristics of VHF signals. A network of riometers has been installed to study the geographical distribution of polar-cap absorption and of auroral precipitation and their variation during magnetic storms, as well as their conjugate properties. Studies of auroral radar and their conjugate properties have been launched, and continuing comparison between the ground-based observations and satellite measurements is leading to a better understanding of particle dynamics in the magnetosphere.

Ionospheric Interactions

Ionospheric response to prompt short-term electromagnetic radiation from solar flares has been intensively studied using high-frequency radio waves with a view to early detection of solar flares. Doppler techniques and analysis of sudden ionospheric disturbances (SID) and sudden frequency deviations (SFD) have been examined with respect to x-ray, extreme ultraviolet, and solar radio emission from solar flares.

Indirect determination of ionospheric response to ionizing radiation has been pursued through VHF forward-scatter observations, as well as with riometer observation of PCA, and has produced a more consistent value of the effective recombination coefficient of the ionosphere as well as reiterating the importance of atomic oxygen in maintaining the high electron densities in the lower ionosphere. In addition, direct rocket determinations of the diurnal variations of excited oxygen molecules have been made, as well as further determinations of proton flux and electron density during a PCA. These parameters will yield directly an effective recombination coefficient of the ionosphere during these periods.

Coupling between the neutral atmosphere and the ionosphere has been examined with HF Doppler studies indicating a remarkable agreement between the motion of ionospheric disturbances and the predictions of gravity wave theory. It also has been shown that infrasonic waves propagate to the F-region of the ionosphere from severe thunderstorms, the detailed propagation being dependent upon temperature and wind profiles, and the effect of the geomagnetic field on the motion of ionospheric electrons.

Study of ionospheric and exospheric electron content using OGO satellite radio beacon data has continued with a detailed study of the electron content changes occurring during a partial solar eclipse. Further experiments are planned aboard geostationary satellites, based on the experience with this program.

Laboratory Mission Support

The data acquisition and processing activities of the laboratory provide data support to its research activities and other agencies and are responsible for the acquisition, processing and integrity of data for service functions performed by the Laboratory. Because of the large volume and the variety of data processed, we make a continuing critical evaluation of the types of data acquired, their relevance to the ultimate usage, and the development of a systematic plan for their efficient and effective processing. Significant improvements made recently in SDL data acquisition and processing, as well as plans for further developments in this area, are outlined below.

Computer Network

The Anchorage, Alaska, data system provides riometer, magnetic field HF scatter, and VLF data which are processed with the SCC 660 computer, and transmitted via teletype to the Space

Disturbance Forecast Center. Unusual events are recognized automatically and transmitted to Boulder. The Anchorage data system can be interrogated at any time automatically by a dedicated teletype line for data of the past four days in any of several different formats.

The Table Mountain Field Site, near Boulder, is equipped with a variety of ionospheric, solar radio noise and magnetic sensors. Data from these sources are processed with an SDS 930 computer (acquired under Project HANDS) to provide automatic detection of SID, magnetic indexes and raw data to the Space Disturbance Forecast Center (SDFC) in real time, via telephone line. A small computer (SCC 650) is available in the SDFC as a switching device for use in forwarding data received from various sources to desired destinations.

A plan for further improvements in handling data required in the SDFC and in the Aeronomy and Space Data Center (ASDC) is represented in figure 4. As illustrated, this plan would interconnect four computers: the SCC 660 at Anchorage, Alaska; the SDS 930 at Table Mountain; the SCC 650 switching computer in the SDFC; and the ERL Computer Division SDS 940 time-share computer, via teletype data sets. This plan also utilizes the Computer Division CDC 3800 to process data recorded in the interconnected computer system.

Through computer programming by the SDL staff, the computer system will be able to store and pre-edit the incoming data, format TWX messages, recognize unusual geophysical events and display selected data. These functions will materially assist the SDFC and the ASDC and also will benefit the Telecommunications Service Center (TSC) of the Institute for Telecommunication Sciences.

Satellite Plans

Continuing improvements are being made in the acquisition and use of satellite data for operations and research. Included in the latter category is the calibration of ground-based experiments. Data are received regularly from SOLRAD, VELA and Pioneer satellites through the courtesy of the Navy, the Air Force and NASA. Further improvements are expected in the data flow.

Plans are underway to receive the VHF telemetry signal from the geostationary satellite, ATS-1. When completed, energetic proton data from ATS-1 will be provided in real time to the SDFC via the 930 computer at Table Mountain. Plans also are to obtain proton data from the ITOS series of satellites, the first of which will be launched late in 1969. Proposals have

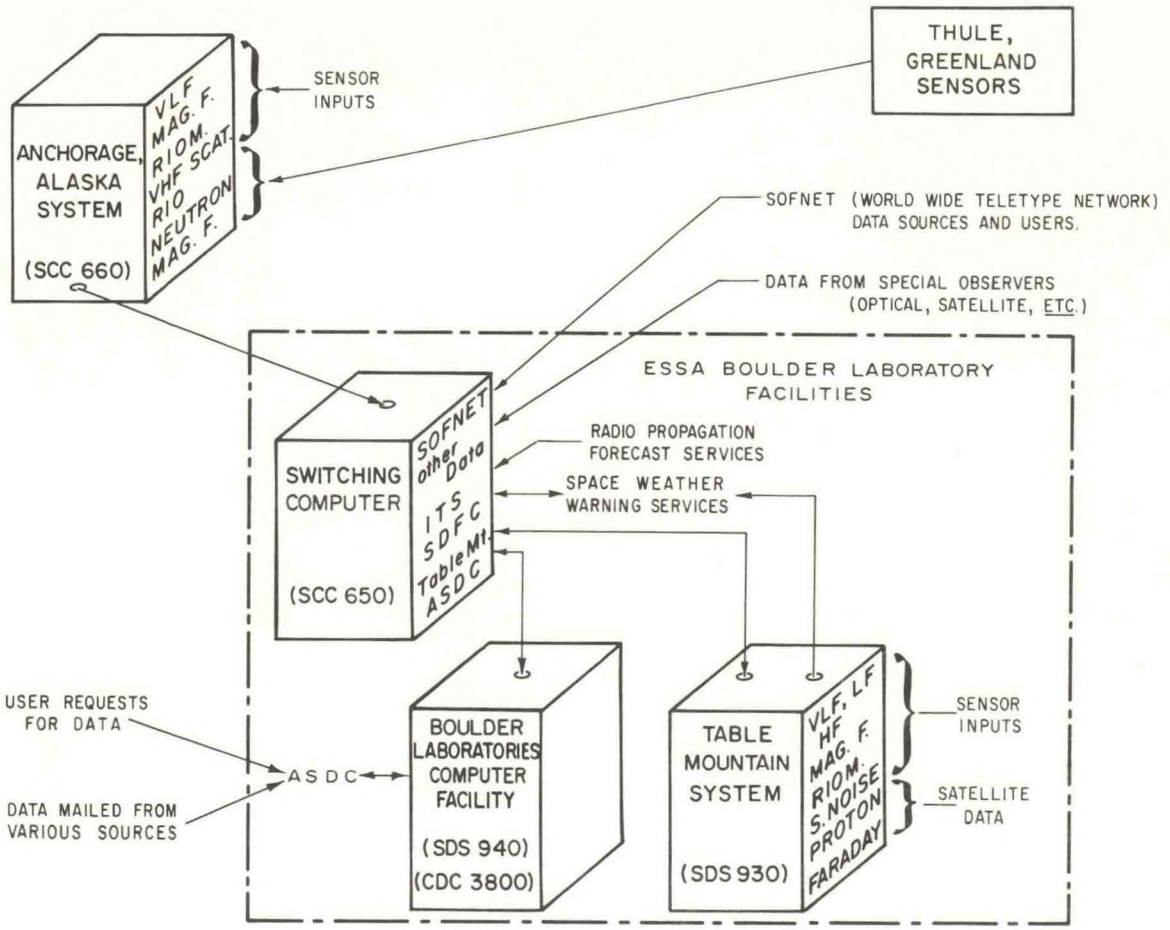


Fig. 4. Space Disturbances Laboratory data systems.

been submitted for solar x-ray and proton monitors on GOES (Geostationary Operational Environmental Satellite), scheduled for launch in 1971. The proposed GOES system would most nearly fulfill the SDL real-time data requirements.

Another major satellite activity is participation in the International Satellites for Ionospheric Studies (ISIS) Program, in support of scientific programs in other Laboratories of ERL. This includes the acquisition and processing of data from the ionospheric topside sounder satellites in the Alouette and ISIS series. An operational station at Gunbarrel Hill northeast of Boulder commands data readout and records data on magnetic tape. These data together with topside ionogram data acquired at other NASA stations are then processed to produce film ionogram records.

Digital Data Processing

A number of computer routines have been developed to process and display geophysical data. Figures 5 and 6 give two illustrative examples of generally applicable routines. In figure 5, the top trace represents the infrasonic signal as recorded in digital form at Boulder, Colorado, from a nuclear detonation. The lower left trace is a contour plot of the spectrum of this signal and the lower center and lower right-hand traces give two views of its equivalent three-dimensional surfaces. Figure 6 displays the spectrum of a high-frequency radio signal received after ionospheric reflection. In this plot a dynamic range of approximately 70 dB, with a frequency resolution of about 1 Hz is attained over a 120-Hz bandwidth. The data in figures 5 and 6 were plotted on microfilm, using the ERL computer. These, and other computer-analyses routines are available for general application.

Forecasting and Verification

Verification of a variety of forecasts of space disturbances indices was continued during Fiscal Year 1969. Further development of techniques has produced programs for regression analyses, using both linear and non-linear predictor combinations. These results are being incorporated in forecast procedures to improve the accuracy of the forecasts issued.

A special plotting program was developed to provide greater insight into the nature of analysis problems. These techniques have been applied to the problem of forecasting the disturbance index, Kp, of the earth's magnetic field. This is a continuation of work begun during Fiscal Year 1968. Preliminary analysis of the problem of forecasting both the 10 cm solar radio noise flux and the sunspot number was begun.

As a service to the ESSA Research Laboratories and NBS, a new service was initiated to provide consultative advice to members of ERL in the area of numerical techniques, especially computer methods of problem solving. This service has been utilized by many of the different laboratories in ERL and by NBS, ranging over a variety of topics, including compiler modification, matrix inversion techniques, numerous raw data conversion routines and the application of programming languages to information problems.

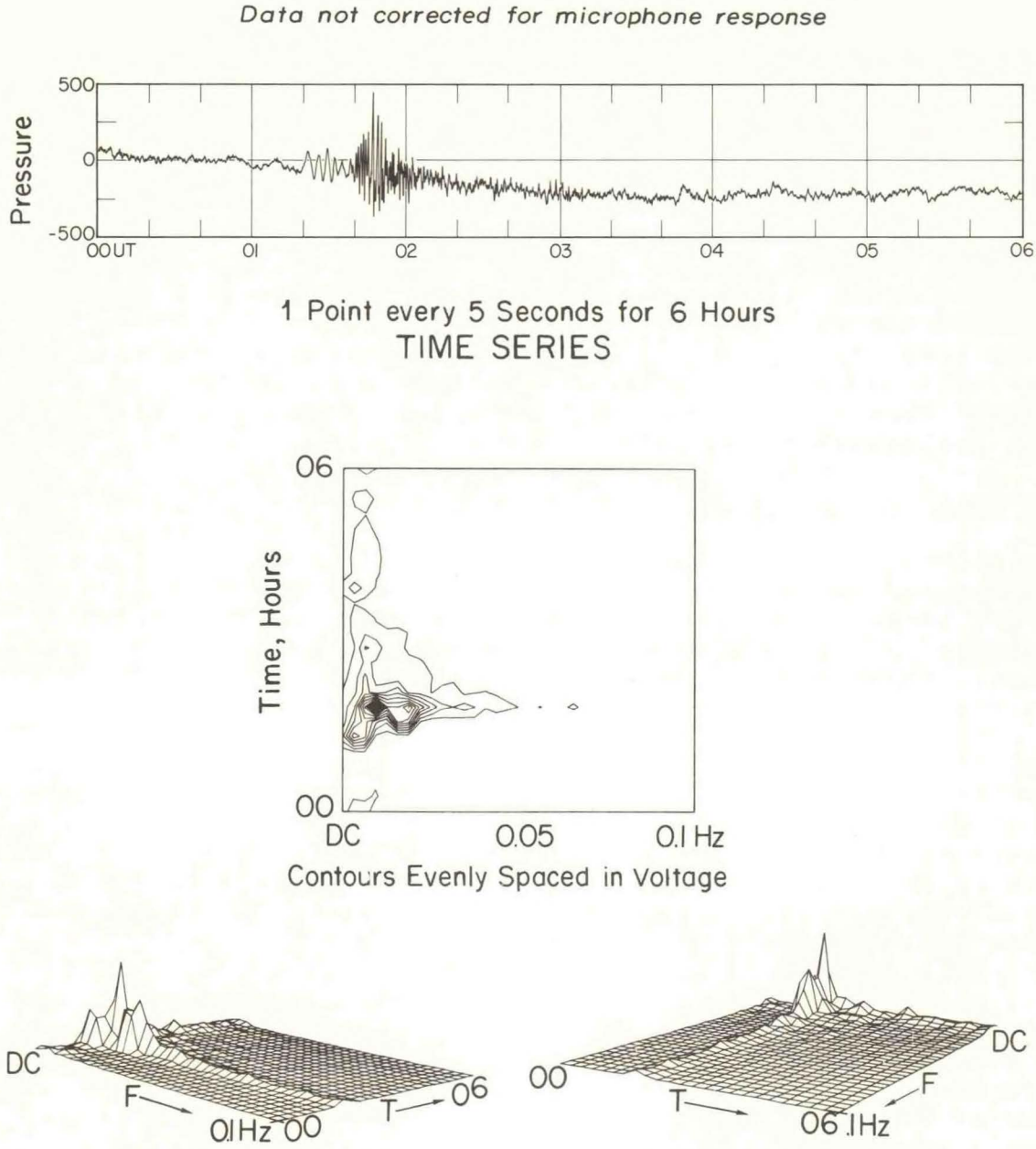


Fig. 5. Spectral analysis of an infrasonic event observed at Boulder, Colorado, August 25, 1968.

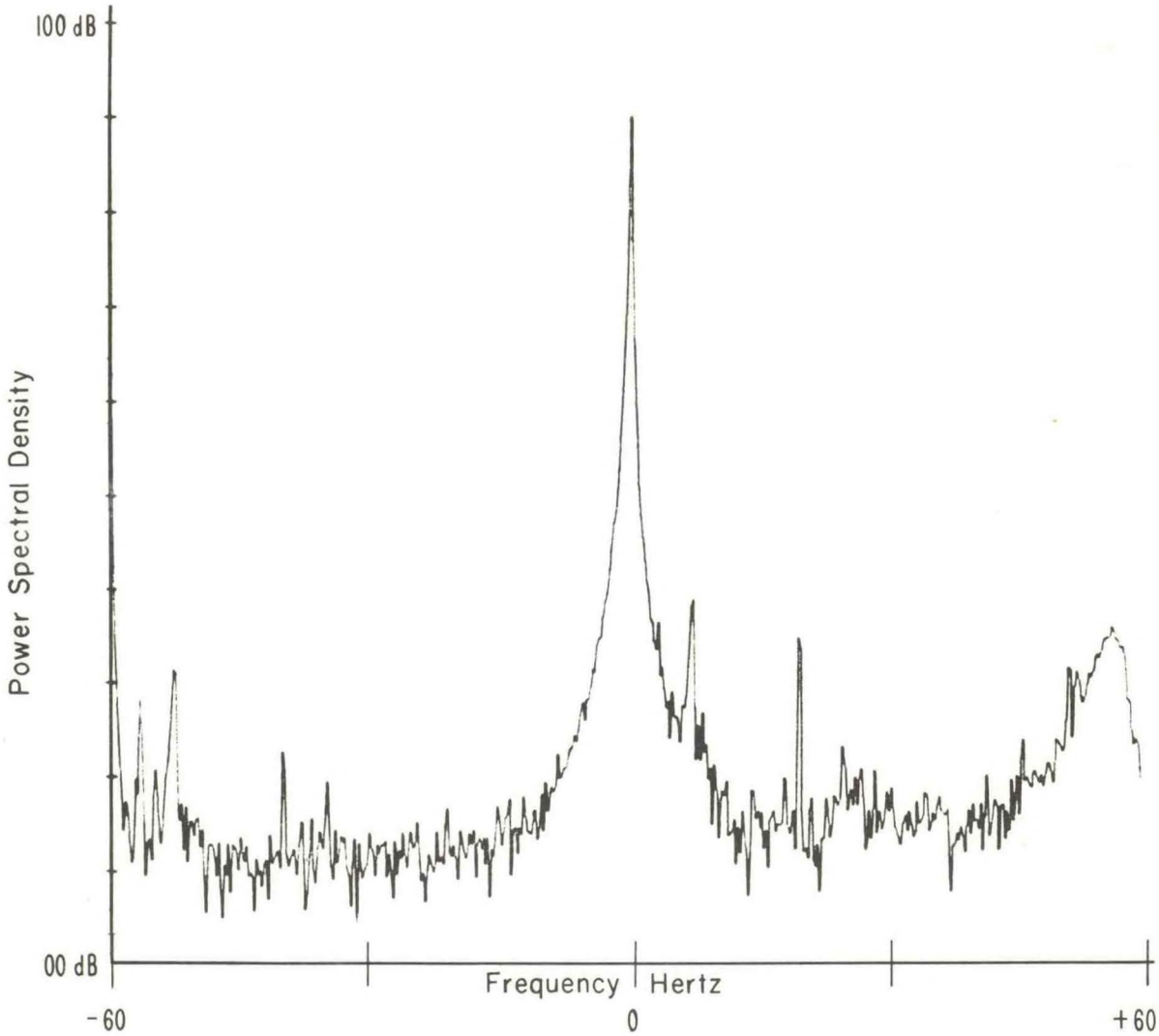


Fig. 6. Spectrum of 10.8 MHz signal received at Boulder, Colo., from Stanford, Calif., illustrating digital recording and processing techniques.

Instrumentation

The Instrumentation Group provides general support to the Laboratory in areas requiring the design and construction of special purpose instruments and also undertakes related work at the request of other ESSA groups and government agencies. The Group also has a special responsibility within ERL for the acquisition of data from satellite sensor systems and also for recommending and planning such sensor systems to serve the needs of the Space Disturbance Forecast Center. This latter work includes active planning for the ITOS Solar Proton Monitor which will fly in 1969 and for the energetic particle and solar x-ray sensor systems to be carried by the ESSA GOES series satellites to be flown in 1971 and beyond, and also liaison and technical planning for the geostationary radio beacon experiment to be carried on the ATS-F and -G satellites which are expected to be launched in 1972 and 1973.

Other special experience and competence worth noting within the Group are in areas of the design and construction of scientific payloads for small D- and E-region sounding rockets and in the design of interface equipment for connection of scientific experiments to on-line computer systems. Projects recently completed include:

New ARCAS rocket photometer and telemetry system for high latitude measurements by the Ionosphere Responses Group.

Greatly expanded and improved closed circuit television system for remote viewing and measurement of the solar H_α image from the Space Disturbance Forecast Center Observatory.

General purpose VHF Faraday rotation measurement system for geostationary satellite beacon measurements.

Conversion of the 3 centimeter solar radiometer used by the Space Disturbance Forecast Center to a Dicke measurement system.

Projects at present underway or planned in the near future include:

Completion of an on-line data acquisition system for experiments measuring energetic particles on board the ATS 1 satellite.

A data processing system to provide integrated digital data from the H_α solar image television system for computer storage and display.

Receiving system for making carrier and modulation phase Faraday rotation and carrier amplitude absorption measurements on transmissions from the planned ATS-F and -G beacon.

Six-channel rocket photometer for use by the Ionosphere Responses Group in further high latitude aeronomy studies.

Remote control and possible relocation of receiving command and data acquisition station for ISIS satellites.

Laboratory Services

The service activities of the Laboratory encompass two programs, national and international in scope. The Space Disturbance Forecast Center (SDFC) provides monitoring, warning and forecast service of solar flares, associated proton and x-ray events, and magnetic storms, which affect the nation's telecommunications, electrical power transmission, and space flight activities. The Aeronomy and Space Data Center (World Data Center A, Upper Atmosphere Geophysics) collects, archives, and disseminates upper atmosphere data relating to the ionosphere, airglow, aurora, cosmic rays, solar flares and geomagnetic fluctuations. Messages and data from these activities are transmitted to customers throughout the United States and the world.

Space Disturbance Forecast Center

The Forecast Center, as the national center for space environment forecasting service, provides forecasts of solar flares and related geophysical events to meet the common needs of the nation, as well as specialized civilian needs. The Forecast Center also meets an international commitment, through the International Ursigram and World Days Service (IUWDS), serving as the Western Hemisphere Regional Warning Center and the World Warning Agency (SOLTERWARN) for solar geophysical events.

Routine space disturbance forecasts for a three-day period are issued by the Center twice a day. Warnings are issued of the expected imminent occurrence, and early confirmation of: (1) a major solar flare; (2) energetic solar particles near the earth; (3) a major geomagnetic storm; or (4) a major solar radio burst. This real-time warning service may be used to

determine the launch time of rockets, defer "space walks," or to activate experiments for collecting scientific data.

An important recipient of the data and forecasts provided by the Center is the Telecommunication Service Center (TSC) of the Institute for Telecommunication Sciences; its ionospheric prediction activity is co-located with the Space Disturbance Forecast Center, to share facilities and to interchange information.

In its international role as SOLTERWARN, the Forecast Center receives and transmits messages from the other regional warning centers concerning existing and anticipated solar geophysical conditions. Daily GEOALERTS are prepared and given worldwide distribution via teletype including the WMO teletype circuits, and radio messages transmitted from WWV and WWVH, the HF standard time and frequency stations operated by the National Bureau of Standards.

The data which provide the bases for the forecasts and warnings are obtained from globally-located solar observatories, satellites, and ground-based sensors of geophysical phenomena. Displays of Boulder-based sensors are shown in figure 7.

Observatories

The Space Disturbances Laboratory operates observatories at the Canary Islands and at Boulder, Colorado. These observatories, manned by skilled solar observers, provide flare information and detailed descriptions of the sun's active regions. The Boulder solar optical observatory, shown in figure 8 is equipped with both H_α and white-light telescopes. A television system remotely monitors the solar activity and brings it into the Forecast Center.

Through contractual arrangements the Laboratory receives H_α optical observations from the University of Michigan; Carnarvon and Culgoora, Australia; The Royal Swedish Observatory at Anacapri, Italy; and Tel-Aviv, Israel, as well as solar radio data from Stanford University, the University of Colorado, and the University of Sydney, Australia. Data also are received from the U.S. Air Force, Air Weather Service observatories at Tehran, Iran; Athens, Greece; Ramey Air Force Base, Puerto Rico; Sagamore Hill, Massachusetts; Sacramento Peak, New Mexico; Aerospace Corporation, California; Maui, Hawaii; and Manila, Philippine Islands (fig. 9).

Data from these observatories flow into the Forecast Center via seven teletype circuits and one telecopier machine. A

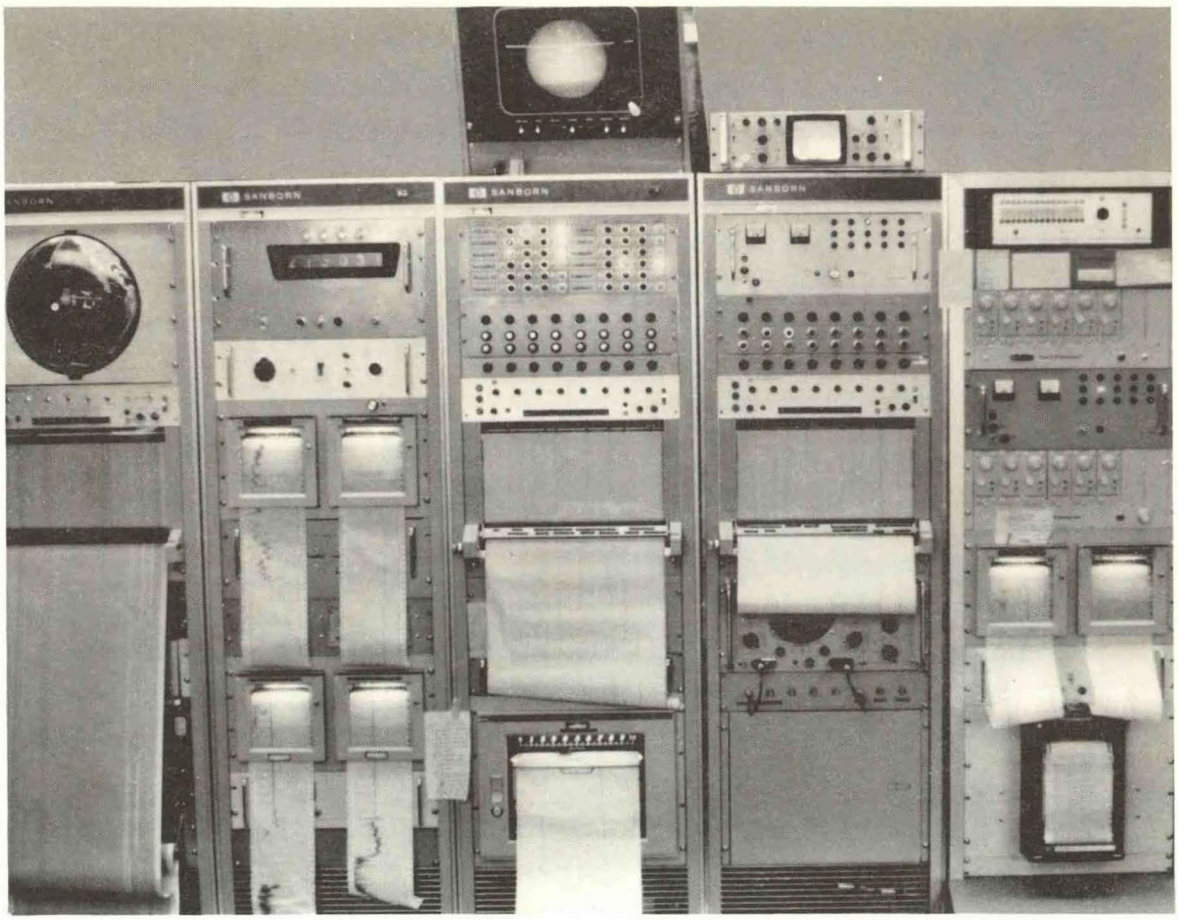


Fig. 7. Display of ionospheric and solar monitor sensors in the Space Disturbance Forecast Center, Boulder. (Note TV display at top center).

partial view of the communications center is shown in figure 10. At the present time, at least 10 messages a day are sent to over 100 addresses. It is anticipated that many parts of the communication facility will be automated with computer-prepared data messages and computer-route forecasts and warnings.

There has been gradual progress in the objectivity and a decrease in the subjectivity in the analysis and forecast process. The use of standard reporting formats, procedures and classifications, along with a more rigorous reporting system has assisted in the development of a more meaningful automated data processing system. As international programs such as the Proton Flare Project and the IUCSTP are implemented, it is anticipated

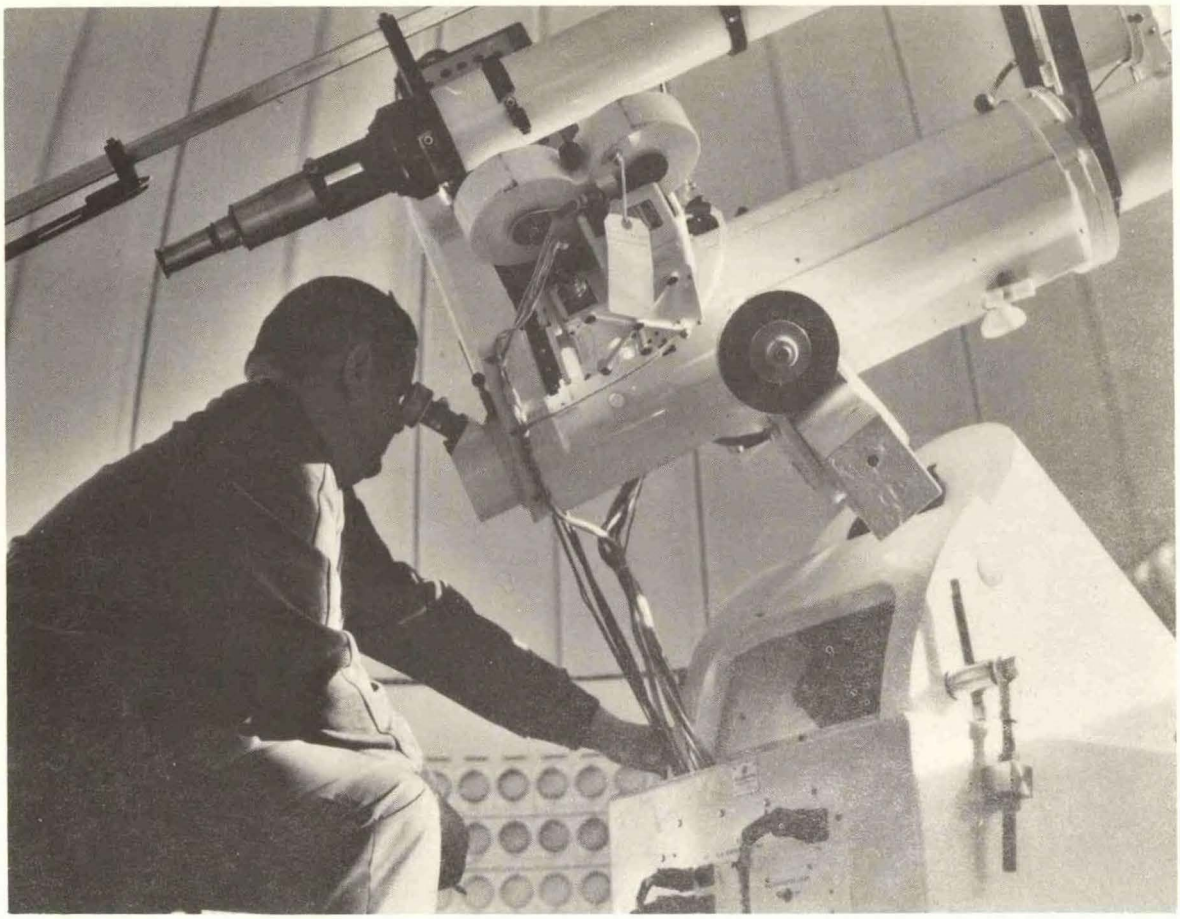


Fig. 8. View inside the Space Disturbances Laboratory's solar observatory, Boulder, showing Hα white-light telescope, TV monitor, and 35 mm camera.

that greater international cooperation will result in meeting the real-time needs of operational space programs as well as the corresponding needs of the research community itself.

In the past year a major development was the classification of solar flares, based upon their geophysical effects rather than their optical importance and size. The new classification system will be further refined and better documented in the flare listings. This effort, plus the addition of semiobjective reporting procedures for the optical solar observatories, will produce significant improvements in forecast service.

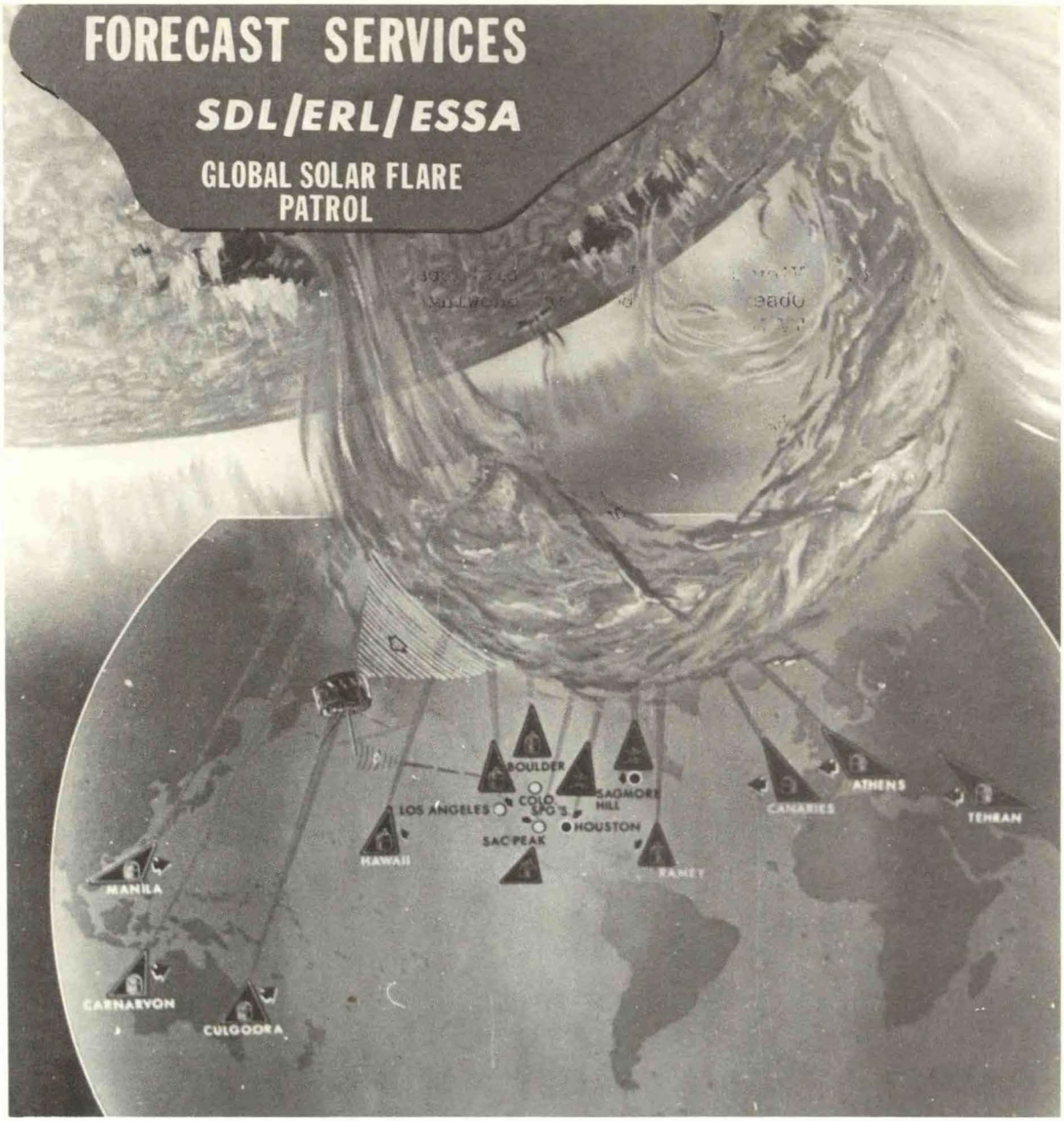


Fig. 9. Global Solar Flare Patrol (showing locations of observatories which contribute data to the Space Disturbances Forecast Center, Boulder, Colo.).

Fig. 10. View of the Communication Center of the Space Disturbance Forecast Center, Boulder, Colo., showing fron left to right: the SOFNET teletype, the Anchorage teletype, and military teletypes.

Work is underway to improve the capability for making quantitative solar flare forecasts: a case history study of solar active regions was started and techniques are being developed for the real-time monitoring of solar flare precursors.

SDL will assume a major role in providing the solar data and forecasts of solar activity to the NASA APOLLO Telescope Mount (ATM) program. A study is underway to determine and meet the requirements of the principal investigators of the ATM program for solar information.

Aeronomy and Space Data Center (World Data Center A, Upper Atmosphere Geophysics)

In meeting the requirements of the worldwide scientific community, the Aeronomy and Space Data Center develops improved methods for collecting, standardizing, archiving (see fig. 11) and retrieving, and publishes data from the solar-terrestrial physics disciplines. These include solar and interplanetary phenomena, ionospheric phenomena, flare-associated events,

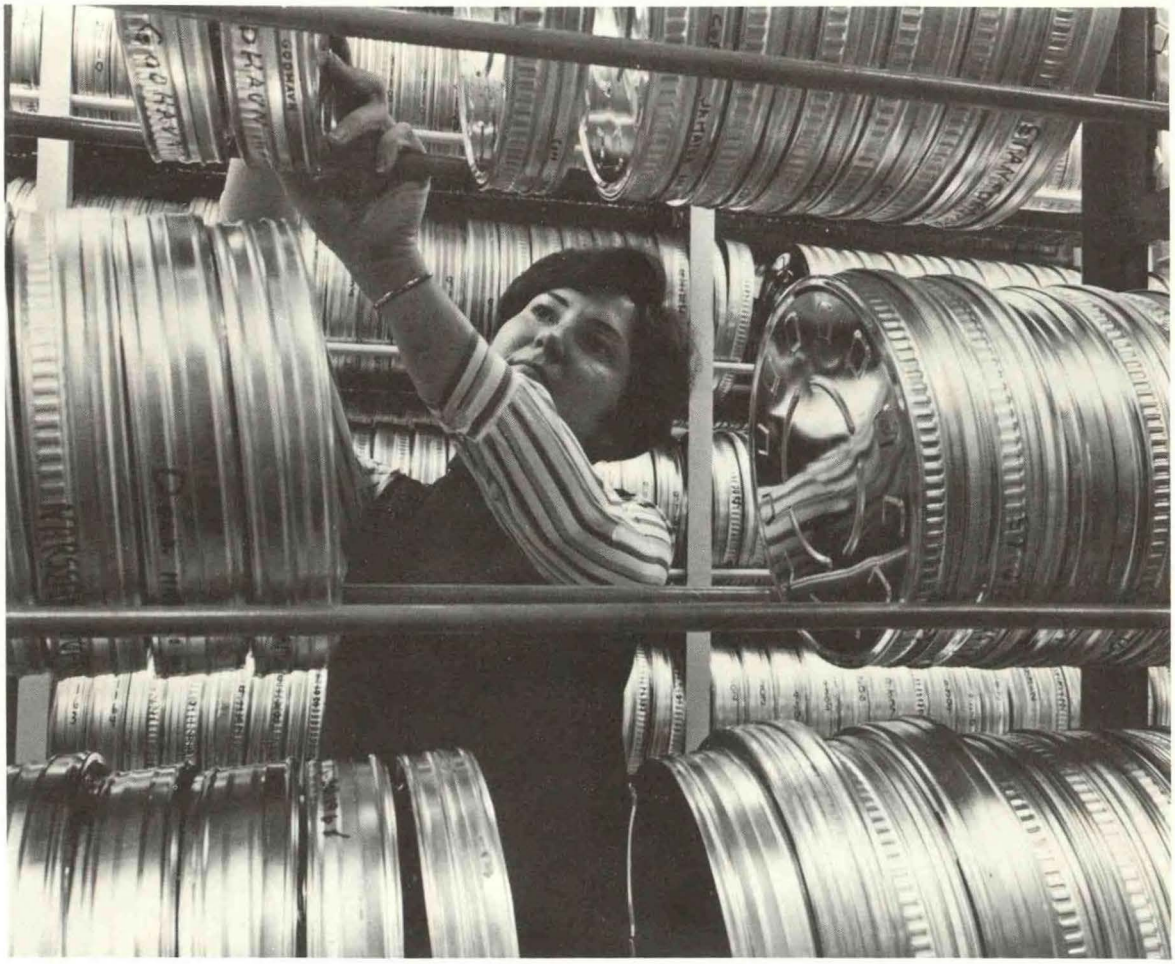


Fig. 11. Ionogram film room of the Aeronomy and Space (World) Data Center, Boulder, Colo.

aurora, cosmic rays and airglow. The Center continues to receive some 15,000 requests per year for data which are distributed in the form of paper copies, microfilm, punched cards, magnetic tapes, and publications to other Federal agencies, universities, commercial laboratories, foreign institutions and to individuals. Of the data supplied, 10 percent goes to research workers within ESSA, 75 percent to other U.S. scientists scattered in at least 24 states, and 15 percent to foreign scientists in about 23 different countries. In its role as World Data Center A, Upper Atmosphere Geophysics, data are exchanged regularly with World Data Center B in the Soviet Union, and World Data Centers C located throughout Europe and the Far East. This activitis under the international coordination of the Inter-Union Commission on Solar-Terrestrial Physics (IUCSTP). For IUCSTP, the Center has assisted in preparation of a revision of the Guide for International Exchange of Data in Solar-Terrestrial Physics in the updating of the list of participating stations. There have been research visitors to the World Data Center, staying for periods of several days to a few weeks. Such visitors find the opportunities of working with the total data collection of great benefit (see fig. 12) rather than requesting only a restricted amount of data as described in the World Data Center catalogue.

The international reputation of the monthly "Solar-Geophysical Data" reports, and of the new World Data Center A, Upper Atmosphere Geophysics Report Series, initiated in 1968, was recently enhanced by the commendation of the first IUCSTP general conference which urged other data centers to adopt similar methods of data synthesis and dissemination.

Automated systems for archiving, retrieval and publication of data continue to be expanded. The availability of the now computerized format data was clearly designated in the June 1969 edition of the Data Center catalogue. A computerized data information bank has been initiated for comprehensive knowledge concerning each station, including dates of operation, equipment used, sponsoring organizations, and the like.

For the International Ursigram and World Days service, a second revision of the IUWDS Synoptic Codes for Solar and Geophysical Data has been printed for coordination of international data interchange. In addition, the Center prepares the International Geophysical Calendars used for the overall coordination of solar and geophysical observations and data flow.

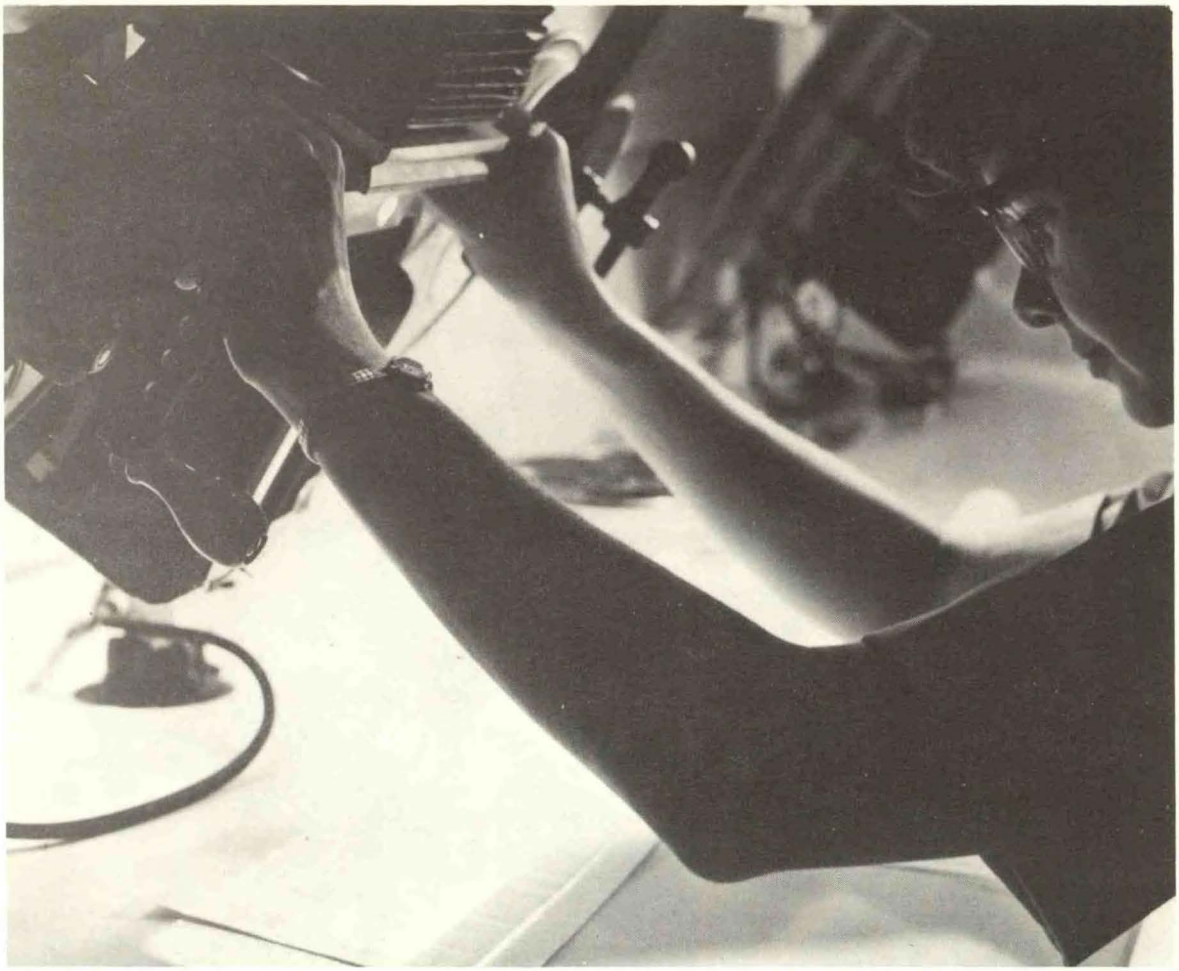


Fig. 12. Scaling ionograms in the Aeronomy and Space (World) Data Center, Boulder, Colo.

Acknowledgements

Valuable contributions which, because of their nature do not normally find expression in publication lists, are hereby acknowledged:

Data Processing, Numerical Analyses

Coordination of the SDL computer network, and Verification of forecasting	R. J. Slutz
Operation of the SDL data system at Anchorage, Alaska	A. Gray, and W. E. Ecklund
Programming of the Anchorage Computer, and the SDFC Switching Computer	J.R. Winkelman
Programming of the Table Mountain Computer	C. Hornback
Programming of SDL Requirements on the Time-share Computer	T. Gray
Developments in computer processing, and Data Display	D. Lewis, and L. Matheson

Instrumentation

SDFC Data Display System, Rocket and Satellite Instrumentation (GOES, ITOS and ATS)	R. N. Grubb, and Staff
Acquisition, Processing of Topside Sounder Data from ISIS	E. Schiffmacher, and Staff
Operation of SDL Data Facility at Table Mountain	E. Berger, and Staff

Data Services

Continuous Operation of the SDFC, Weekly Publication of Preliminary Report and Forecast of Solar-Geophysical Activity, etc.	R. Doeker, and Staff
Operation of the Aeronomy and Space Data Center, Bi-monthly, monthly and annual publications of solar geophysical data, etc.	J. V. Lincoln, and Staff

Much of the research, development and the services performed in the Space Disturbances Laboratory is of interest and benefit to other Government agencies. Accordingly, the Laboratory receives financial support from such agencies, which is a significant factor in the success of many of its programs. During the past year, the following have supported Laboratory programs:

Defense Atomic Support Agency (DASA): Polar Cap Absorption, Twilight Response, Ionosphere Responses.

National Science Foundation (NSF): Magnetosphere Particle Dynamics, Transient Ionosphere Phenomena, Hi-Latitude Data Service.

National Aeronautics and Space Administration (NASA): OGO Beacon Analysis, ATM Solar Data/Forecasts, Solar Activity, Solar Prediction, MSC-NASA Support, ISIS Participation.

Advanced Research Projects Agency (ARPA): Hi-Latitude Ionosphere Absorption, Hi-Frequency Doppler Studies, Synoptic Geophysical Measurements and High Altitude Nuclear Detection Studies.

United States Air Force (USAF): Nuclear Environment, Rocket Instrumentation, Stanford University Solar Radio Data.

The Aeronomy and Space Data Center, by virtue of its data service role, receives requests from numerous government agencies, universities, foreign institutions, and from private industry. The larger users of the Data Center services are: NASA, USAF (Air Force Cambridge Research Laboratories), AVCO Corporation, Martin-Marietta Corporation, the Japan Science Council, and the Danish Meteorological Institute.

A. Glenn Jean, Jr., Acting Director, Space Disturbances Laboratory.

Mr. Jean joined the staff of the Central Radio Propagation Laboratory of the National Bureau of Standards in June 1948.

With a B.S. degree in electrical engineering earned at Vanderbilt University in 1944, Mr. Jean spent two years in the Army before returning to Vanderbilt to teach in its Engineering Department.

At the National Bureau of Standards Mr. Jean first served as electronic engineer for a joint U.S.-Canadian study of the propagation of high-frequency radio waves in the arctic and auroral regions and was then assigned to research on the nature of radio-frequency energy released from nuclear explosions, and use of these signals in the remote detection of nuclear detonations. In 1958 he shared in a Sustained Superior Performance Award for his group's outstanding work, and in 1959 was awarded the Department of Commerce Silver Medal for Meritorious Service. From 1963 to 1968 he was Chief of the High Altitude Nuclear Detonation Studies (HANDS) program, which utilizes integrated geophysical-sensor data and an on-line digital computer for monitoring a large number of geophysical parameters.

Mr. Jean has published many papers in the fields of radio-wave propagation and correlated solar-geophysical phenomena, and has served both as consultant to the Radio Physics Panel of the International Geophysical Year in the low frequency propagation area and to the Western Delegation of the 1958 Geneva Conference on detection of nuclear explosions. He is a member of the Special Committee on Worldwide Atmospheric Electricity Problems, of the IEEE, RESA, and of Commissions III and VIII of the International Scientific Radio Union (URSI).

AERONOMY LABORATORY

Boulder, Colorado

Michael Gadsden (Acting)

This laboratory conducts research to increase and disseminate knowledge and understanding of the physical and chemical processes of the ionosphere and exosphere of the earth and other planets, and of the dynamics of their interactions with high altitude meteorology, with a view toward prediction and control for the benefit of telecommunications and other space age needs.

Program Areas:

1.	Aeronomy Studies	M. Gadsden
2.	Laboratory Plasma Physics	W. Calvert
3.	Atmospheric Collision Processes	Eldon E. Ferguson
4.	Rocket and Satellite Studies	E. C. Whipple
5.	Scatter Radar Studies	T. E. Van Zandt
6.	Optical Aeronomy	M. Gadsden
7.	Instrumentation	G. R. Sugar

Aeronomy Studies

In FY 69, technical advice and information was supplied to a number of government agencies, universities, and industry. Studies of a basic nature that span several program areas and encompass several broad fields were also conducted, in particular a study by Wynne Calvert concerning the interface between laboratory plasma studies and studies of the ionosphere as a plasma. Robert Cohen aided organization of a Symposium on Equatorial Aeronomy held in Ahmedabad, India, and the Spring 1969 meeting of the Aeronomy section of the American Geophysical Union.

Senior scientists are undertaking studies outside their usual fields so that their specialized knowledge will be broadened and applied in new ways. During FY 69, this work was concentrated at the Jicamarca Observatory where Thomas E. Van Zandt and Vern L. Peterson conducted studies relating optical observations of airglow at low latitudes to ionospheric observations made at the Jicamarca scatter radar facility. During

his stay at Jicamarca, Mr. Peterson lectured in aeronomy at the Latin American School of Space Research in Cordoba, Argentina.

An interesting effort involved Franklin E. Roach in training NASA astronauts in the visual detection of geophysical and astronomical phenomena.

In FY 70, Aeronomy Laboratory scientists will continue to provide consultation services to the national and international scientific community, and the training of NASA astronauts will continue.

Exploratory Plasma Physics

Theoretical and experimental basic research is conducted in plasma processes which occur in the earth's upper atmosphere and beyond. Such processes include plasma turbulence; wave propagation; and mass, charge, and energy transport. These studies are partially supported by DASA and the AEC.

Plasma turbulence, in particular, has a direct effect upon telecommunications, radar, and the disposition of both naturally and artificially produced (e.g., radioactive) ionization in the atmosphere. Plasma turbulence can enhance radio communications between points on earth by scatter propagation, while it can also seriously degrade surface communications to space vehicles. Accordingly, an all-inclusive theory of plasma turbulence is being developed by J. Weinstock to provide answers to questions concerning atmospheric manifestations of plasma turbulence. Physically, this theory accounts for the effect of turbulent electric fields on the perturbed trajectories of diffusing particles in a remarkably simple but realistic fashion. The spectrum of turbulence is then determined by these perturbed trajectories. An intimate relationship is demonstrated between enhanced diffusion and the structure of plasma turbulence.

The theory offers considerable promise for predicting the effects of ionospheric turbulence on the propagation of radio and radar waves. In a recent application, it has provided the first realistic explanation of the intensities of primary equatorial E-layer irregularities as observed at Jicamarca, Peru. In addition to the explanation of intensities, turbulence studies have been initiated to explain the spectral widths and anomalous shifts observed in radar returns from these irregularities, which spectral quantities will provide information about ionospheric drift motions and electric fields. Theoretical investigations are also being made of waves and weak turbulence that are generated by cross-field instabilities in both the E and F layers of the ionosphere.

An experimental study of plasma sheaths continues to provide needed information concerning the plasma sheath surrounding space vehicles, and the transmission of radio waves to and from space vehicles.

In association with the theoretical studies, plasma waves and turbulence are experimentally studied by K. Geissler. Laboratory devices simulate plasma wave and turbulence processes that are suspected or known to exist in the ionosphere with the advantage of laboratory control. The relation between diffusion coefficients and correlations of density fluctuations provides a unique and powerful method for measuring diffusion coefficients in a plasma. This method has been developed and proven in the Aeronomy Laboratory for a quiescent plasma in the absence of a magnetic field.

In FY 70, the theoretical turbulence studies will be extended to include the effects of varying magnetic fields in addition to the electric field effects. The development of the Weinstock theory of strong plasma turbulence will be continued to provide an understanding of enhanced diffusion, to extend the relation between density cross-correlation coefficients and plasma diffusion to turbulent plasmas, and to uncover improved methods of measuring and controlling enhanced diffusion under shielded controlled conditions. Within a shielded room, plasma turbulence and diffusion will be studied by cross-correlation of microscopic density fluctuations as reflected in the noise generated by the plasma, received by two highly sensitive Langmuir probes, with the noise correlation directly related to the diffusion coefficient in a plasma. This method of diffusion measurement will be applied to studies of transverse diffusion in the presence of a magnetic field.

Atmospheric Collision Processes

This experimental and theoretical basic research on atomic and molecular processes pertinent to the earth's atmosphere has continued the development and application of techniques for measuring ionospheric ion-neutral reactions. Laboratory measurements of the rates of reaction among ionized and neutral constituents have proved extremely valuable for the understanding of the behavior of ionization in the wake of re-entering space vehicles.

During FY 69, the reaction scheme which produces the major D region positive ions, $H_5O_2^+$ and H_3O^+ below 80 kilometers altitude was discovered and these reactions are now included in models of positive ion D-region chemistry. Water cluster ions are produced in sequence commencing with O_4^+ production. These and other studies conducted with this unique laboratory technique

have developed strong evidence that the observed water cluster ions in the high atmosphere cannot be entirely explained as rocket contamination, an important implication for understanding the chemistry of the ionospheric D region.

The studies of temperature-dependence of various ionospheric rate constants have been continued with a temperature-variable flowing afterglow facility, in which the temperature can be controlled within a range from 80 to 600 degrees Kelvin.

Studies of ionospheric positive and negative ion-neutral reactions will continue in FY 70. Work will be initiated to construct a laboratory facility in which a tunable dye laser will provide a major breakthrough in technique for measuring upper atmosphere chemical reactions in the laboratory. With this facility it will be possible to measure the rates and energy thresholds for photodetachment and photodissociation of constituents of the high atmosphere, making major progress in understanding the solar radiation effects on ionospheric chemistry.

Rocket and Satellite Studies

Rockets and satellites are used in research on the ionosphere and exosphere to extend our knowledge of their composition and dynamics, plasma phenomena and other processes, including the interactions between rocket or satellite and the ionospheric and exospheric plasma.

The problems that have been selected fall primarily into two classes: Disturbances to the normal ionosphere, which may be investigated by means of rocket and satellite experiments, such as magnetic storms, red arcs, and polar cap absorption events; and investigation of the fundamental physical processes occurring in the interaction between the high altitude ionospheric and exospheric plasma and a vehicle, such as the radio frequency resonances excited by a satellite transmitter in the surrounding plasma, the electrical charging of a satellite by the plasma, and the consequent structure (and effects on experiments) of the resultant plasma sheath surrounding a satellite.

During FY 69, a study of magnetic storms and auroral red arcs has correlated data from several satellite experiments, primarily ionospheric topside sounders, and ground based optical data. One of the major findings was a pronounced enhancement in electron temperature in the region of the visual red arc. In FY 70, the study of magnetic storms and other kinds of ionospheric disturbances will be continued to identify the important ionospheric processes.

A technique for obtaining very precise electron concentration and temperatures from ionospheric topside sounder data has been perercted and used to measure electron concentrations accurate to 0.1 percent, and temperatures accurate to 1 percent. In FY 1970, the data produced by this technique will be compared with electron concentrations, and the temperatures obtained with various other probe techniques, to establish the accuracy of the probe instrumentation.

A theory for probes on satellites that takes into account satellite electric charge effects on ion traps has been extended to allow for secondary electron emission from the spacecraft surfaces caused by energetic particles and photons. In FY 70, the theory for probes on rockets and satellites will be further extended to mass spectrometers in an effort to obtain an absolute calibration for this important technique.

Three rockets carrying experiments for the investigation of polar cap absorption (PCA) events were flown from Fort Churchill, Canada, measuring electron density profiles in the D region. In FY 70, Boosted Arcas rockets carrying other kinds of instrumentation will be launched at Fort Churchill during PCA events to gain further insight into the response of the ionospheric D region to PCA events.

An atomic oxygen detector, based on reaction with thin films, has been used successfully in the laboratory and has been incorporated into a rocket experiment that was flown at Fort Churchill. The results indicate that more study is needed on the effects of rocket outgassing on the detector. In FY 70, additional flights will be made with the atomic oxygen detector and investigations will be initiated to determine the possibility of using thin film techniques for detecting other minor constituents of the atmosphere.

A digital display system, complete with buffer and interface, has been completed to aid in the analysis of topside sounder data. With this real time display, unusual ionospheric events can be selected for further study.

Scatter Radar Studies

Incoherent scatter and other observation techniques have been used to monitor the condition of the equatorial ionosphere at the Jicamarca Radar Observatory near Lima, Peru.

The experiments were carried out in order to monitor the complex interaction between solar radiation, tidal motions, and the upper atmosphere. For this purpose, routine observation of the electron density, and the electron, ion, and neutral temperatures in the altitude range from 200 to 800 kilometers, is made.

The first direct measurements of vertical drifts of the ionospheric plasma were made at Jicamarca by a refinement of the incoherent scatter observing technique. Atmospheric tidal motions induce a horizontal (East-West) electric field because of interactions between the neutral and ionized constituents of the atmosphere near 100 kilometers altitude. These electric fields are propagated from the 100 kilometer level (the dynamo region) along geomagnetic field lines to higher altitudes over the equator. The electrical field at these higher altitudes will cause the ionosphere to move up during the daytime and down during the night. These motions, which profoundly affect the vertical distribution of ionization over the equator, also operate over a wider range of latitudes north and south of the equator through downward diffusion along the geomagnetic field lines. The vertical drift measurements are directly interpretable as electric field measurements. The ability to monitor these electric fields from the ground, as a function of height and time, is a significant development, since rocket sounding techniques are difficult, rarely carried out, and provide only instantaneous coverage, usually limited to the twilight period.

Jicamarca is the only observatory in the world with this capability. The electric fields deduced from these vertical motions of the ionosphere have been compared with those measured at the height of the dynamo region, and with the strength of airglow emissions, and all of these Jicamarca observations now appear to form a consistent picture. Jicamarca electron temperatures, when compared with temperatures deduced from simultaneous satellite probe measurements, are about a factor of 1.7 lower. This discrepancy is as yet unexplained. Similar results are now being reported from several other incoherent scatter observatories.

Another incoherent scatter technique is providing accurate observations of the direction of the magnetic field vector, in hopes that magnetic disturbances may be monitored in this way.

Radio astronomy studies at Jicamarca have measured the lunar albedo, showing that the apparent dielectric constant of the lunar surface material is 3.7 ± 0.7 at a wavelength of 6 meters.

In FY 70, research will be continued using the Jicamarca data already available. However, ERL's Jicamarca observations will be discontinued as of April, 1970, and Aeronomy Laboratory personnel have already left Peru.

Optical Aeronomy

Observations and interpretations of optical wavelength emissions from the upper atmosphere and interplanetary space include studies of polar cap auroras by means of scanning spectrophotometers at McMurdo Sound, Antarctica, and aboard a NASA aircraft in the northern hemisphere. At Fritz Peak Observatory, a photometer automatically monitors night sky radiance at 16 wavelengths between 3500 and 7600 Angstroms. Scientists in New Zealand, Hawaii; Richland, Washington; and San Juan, Argentina, are collaborating in the program of routine monitoring of airglow which yields data relating to global atmospheric dynamics. A facility for the calibration of filters and standard lights for airglow observations is in operation at Boulder, and has been utilized by scientists from NASA, Rice University, India, New Zealand, Lesotho, and Canada.

Studies of stable mid-latitude red auroral arcs continue, to determine their frequency and location, and the relation between the occurrence of red arcs and anomalies in the electron density profiles as seen in topside sounder data.

In cooperation with the Space Disturbance Laboratory, an auroral radar was recently constructed near Anchorage, Alaska. The radar operates at 49.64 MHz, and will be used to observe in two directions. The observations should determine if the relationship between the occurrence of radio aurora and the direction of the ionospheric line current, as earlier observed at Plum Island, Boston, is an observational or an ionospheric phenomenon. The radar will also be used to measure the rates of growth and decay of reflecting centers to compare with the predictions of linearized ion-acoustic wave theory. In cooperation with an auroral radar facility in New Zealand, conjugate point studies of the radar aurora will be conducted.

Under the sponsorship of NASA, ground airglow observations from Haleakala, Richland, and Argentina are being compared with satellite photometer measurements made concurrently on the POGO satellite when over the observatories. The comparison will assist in determining the earth's albedo effects on the satellite observations, and establish the extent to which the satellite data can be used for morphological studies of the night airglow.

Studies of atmospheric sodium are underway using a scanning spectrophotometer to make twilight observations at the Fritz Peak Observatory, and at Byrd, Pole, and McMurdo Sound, Antarctica. As a result of this study, considerable progress has been made towards developing a complete model to account for all of the observations. The model explains the pertinent

observations of meteor trail ablation, ion drift, atomic oxygen/ozone ratios, and possibly global horizontal transport. In cooperation with Dr. Fraser, a visiting Fellow at the National Center for Atmospheric Research in Boulder, the precise relationship between sodium height distribution and winds at 90 kilometers altitude is being studied by means of correlations between twilight airglow observations at Lauder, New Zealand, and winds measured near Christchurch, New Zealand, by a partial reflection technique.

In FY 70, cooperative studies of airglow morphology will continue, along with further observations and investigations of stable red arcs and the radar aurora.

Construction will begin on a meteor trail radar at Boulder to be used for measuring winds in the 80-100 kilometer altitude region. The wind observations will be compared with observations of optical emissions at these altitudes to ascertain the role of atmospheric dynamics and transport in the observed variations in airglow intensity.

To further the study of the relationship between dynamic motions of the atmosphere and the sodium airglow intensity, a Lidar operating at the sodium resonance frequency will be constructed to measure the vertical movements of the sodium layer near 90 kilometers. These observations will be correlated with those of sodium airglow intensity variations, and horizontal wind variations from the radar meteor trail equipment.

Instrumentation

Development work in digital instrumentation is carried on to provide research workers with state-of-the-art equipment that is not yet commercially available. Data logging and data reducing equipment is developed to satisfy the diverse requirements of the Aeronomy Laboratory and other ERL laboratories in respect to types, acquisition rates, measurement precision, display, and ultimate data use.

In FY 69, a number of inexpensive low-speed data logging systems were completed. They are made entirely with integrated circuits, and can transmit data over a teletype line to either a teletype or a computer, and can be built for about $1500. Consultation was provided to numerous ERL groups regarding definitions of, and solutions to digital instrumentation problems.

In FY 70, development of inexpensive data logging equipment will be continued, with particular emphasis on the application of these for direct entry of data to on-line computers such as the SDS 940 time-share computer.

Dr. Michael Gadsden, Acting Director, Aeronomy Laboratory

Dr. Gadsden was born in the United Kingdom in 1933. He received a B.Sc. in 1954, a D.I.C. (Diploma of Membership of Imperial College) in 1957, and the Ph.D. in 1957. All degrees were in physics and were obtained at the Imperial College of Science and Technology, London, England. His Ph.D. thesis was "The Application of Colorimetry to Some Astronomical and Meteorological Phenomena".

In May 1957 Dr. Gadsden accepted an appointment as Scientific Officer at the Department of Scientific and Industrial Research, Omakaw, New Zealand. In June 1961 he was promoted to Senior Scientific Officer. During this period he supervised and conducted optical studies of the Aurora and Airglow Section with responsibility for operation of the Fritz Peak Observatory as visiting scientist, and joined ESSA in 1965. In September 1968 he was promoted to Chief of the Optical Aeronomy Program. In July 1969 Dr. Gadsden was appointed Acting Director of the Aeronomy Laboratory.

He is an internationally recognized aeronomer. He has published some 40 research papers in his field reflecting unique laboratory and field experimentation, data analysis, and creative theoretical interpretation. He has made basic contributions, not only to airglow observations and theory, but also to radar auroral theory, meteor astronomy, lower ionospheric dynamics and meteorology, and atomic and molecular physics.

Dr. Gadsden is a member of several professional societies including the Royal Astronomical Society (Fellow), the British Astronomical Society (Toronto), the American Geophysical Union, and the Scientific Research Society of America.

He and his wife, Marvis, and their children live in Boulder, Colorado.

WAVE PROPAGATION LABORATORY

Boulder, Colorado

C. Gordon Little

This laboratory, formed in May 1967, devotes itself to studies of the telecommunication capabilities and limitations of optical, infrared, and millimeter frequencies, and to the development of new remote sensing techniques. Included are investigations of the propagation of sound waves in the atmosphere. The goals of the laboratory are to extend telecommunication capability to higher frequencies and to advance geophysical research through the development and application of new remote sensing techniques.

Program areas are as follows:

Optical Propagation	Robert S. Lawrence
Submillimeter Wave Propagation	Vernon E. Derr
Millimeter Wave Propagation	Martin T. Decker
Radio Meteorology	Bradford R. Bean
Meteorological Doppler Radar	Roger M. Lhermitte
Geoacoustics Research	Richard K. Cook
Acoustic Sounding	C. Gordon Little (acting)

In addition, advisory and consultative services in electromagnetic and acoustic wave propagation are provided to industry, government agencies, and scientific institutions. Wave propagation technology is furthered through the sponsorship of conferences, special studies, and participation in technical meetings.

Optical Propagation

Highlights

Demonstration of improved precision in the measurement of distances of several kilometers using a two-color, optical distance-measuring instrument.

Elucidation of the statistical properties of optical scintillations in the puzzling "saturation" regime where scintillation no longer increases with increasing strength of turbulence.

Recent Accomplishments and Future Plans

Theoretical and experimental studies of the interaction of electromagnetic waves at optical and near infrared frequencies with the lower atmosphere are needed for the optimum design of optical communications systems (including earth-to-space links), imaging systems, and a variety of special-purpose systems such as target illuminators. In addition, the interactions promise to provide useful means for remotely sensing such atmospheric properties as temperature, wind, and turbulence.

Observations of atmospheric amplitude scintillation, beam spread, and beam wander of a 0.63 μm laser source have been completed over a horizontal path of 5 to 145 km. More detailed measurements of the statistics of laser-beam fluctuations and the associated variations of atmospheric temperature are in progress on shorter paths, using both digital techniques and real-time displays of statistical parameters. Investigation is continuing on the puzzling "saturation effect" wherein the strength of scintillations fails to increase above a certain level with increasing strength of turbulence and path length. Knowledge and understanding of the saturation phenomenon is vital to the optimum design of optical systems (see fig. 13).

A two-color optical distance-measuring device is being developed and tested. This device has already demonstrated an accuracy of 3 parts in 10^7, better than any presently available device, and promises to have important applications in geodesy, in geophysical studies of the motions of the earth's crust, and in studies of earth deformations associated with earthquakes.

Immediate plans include extension of the scintillation measurements to other wavelengths, particularly those in the near infra-red. The distance-measuring device will undergo further tests and improvements, and work will begin on the construction of a three-wavelength device, incorporating a micro-wave signal and two optical beams. This proposed device will permit the user to correct for the effects of water vapor in the air, and should have greater range and be at least 10 times more accurate than the two-color instrument.

Submillimeter Wave Propagation

Highlights

Details of water vapor absorption spectrum from 0.9 micron to 1.35 cm have been computed.

Important additions to the theory of the hole-coupled Fabry-Perot resonator were calculated.

Successful crossed-beam correlation experiments with infrared radiometers.

Recent Accomplishments and Future Plans

Theoretical, laboratory, and field research is conducted on the use of millimeter, submillimeter and far infrared wavelength electromagnetic waves (roughly 10^{11} to 10^{14} Hz) for telecom-

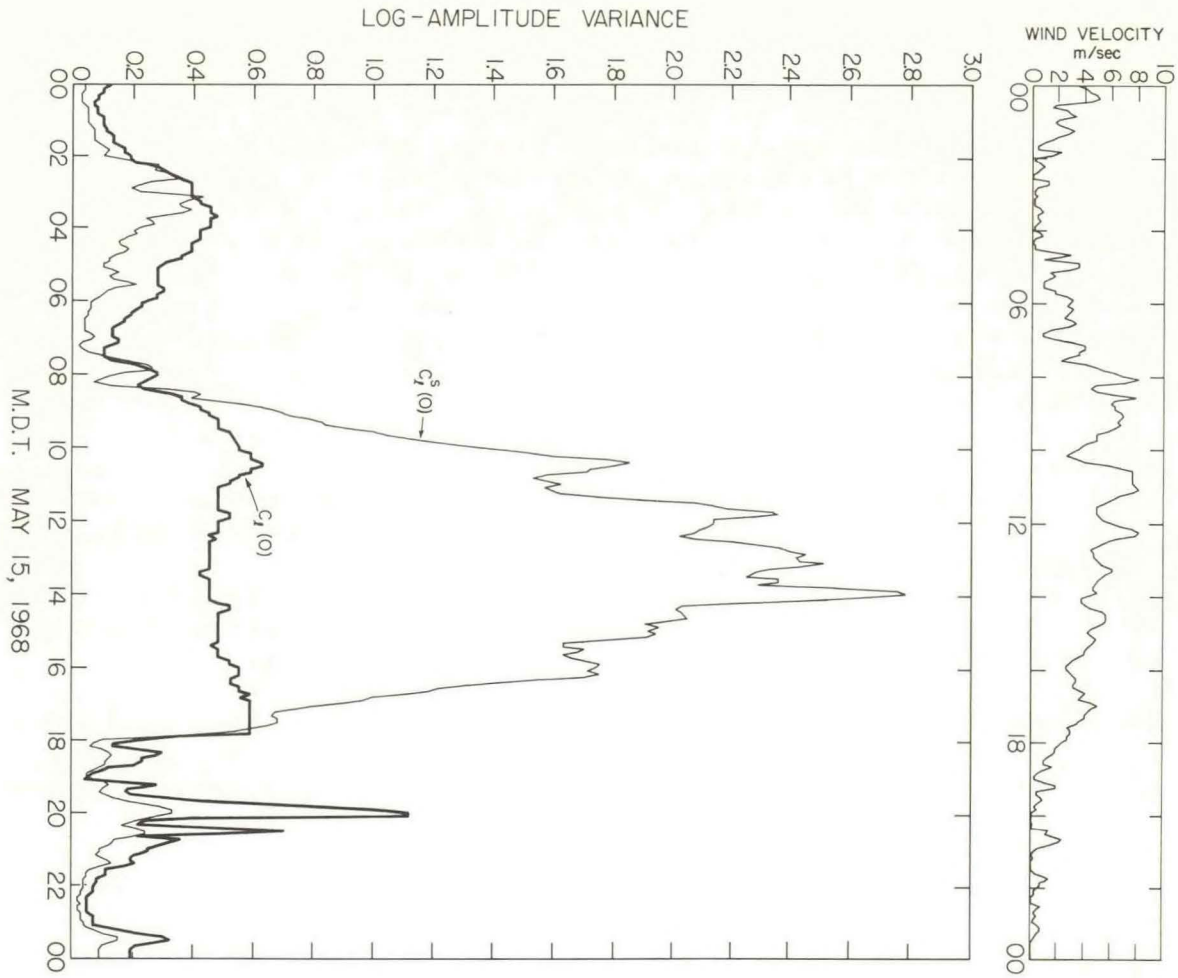


Fig 13. An illustration of data showing the "saturation" phenomenon in optical scintillations. The fine line on this 24-hr record is derived from measurements of turbulence made with high-speed, miniature thermometers. It shows the scintillation depth ("log-amplitude variance") to be expected on a 1-km optical path if scintillations increase directly with strength of turbulence. The heavy line shows the actual measurements of optical scintillation depth on the same path. The scintillations behave as expected when the turbulence is weak, but fail to increase during the turbulent midday. When the wind is calm, as at 8 p.m. on this day, strong optical effects may be caused by stratification of the atmosphere. The reasons for this saturation effect are not fully understood, but the phenomenon has important implications in the design of optical systems.

munications and for remote sensing of the geophysical environment. Special emphasis is placed on spectroscopic techniques applied to atmospheric gases and other constituents, especially pollutants.

This research program was established in FY 68. More precise knowledge of atmospheric attenuation characteristics of water vapor, CO_2, D_2O and N_2O bands have already been obtained. All details of the water vapor absorption spectrum from about 0.9 micron to the limit at 1.35 cm have been completed with the collaboration of Dr. William S. Benedict of the University of Maryland. Comparisons with careful measurements in a number of laboratories shows that the computations of the strength of individual absorption lines are accurate to within a few tenths of a percent. For describing attenuation over long paths, the effect of line shapes on the continuum of water vapor absorption has been adjusted to correspond with recent laboratory measurements. The same program yields information on the anomalous dispersion of atmospheric water vapor. Detailed infrared spectral information on atmospheric pollutants is now being compiled. Pulsed and CW HCN lasers have been designed, constructed, and put into operation to provide a source of submillimeter waves. Important additions have been made to the theory of the hole-coupled Fabry-Perot resonator. Signal-to-noise ratio limitations of the passive infrared cross-beam systems for measuring low level winds have been determined.

In FY 70, the effects of atmospheric pollutants on propagation, and the feasibility of remote sensing of pollutants by absorption and emission techniques will be analyzed. System studies of remote sensing by Rayleigh, Raman, and fluorescent scattering will be continued, and quantitative measurements of scattering cross sections of the most important atmospheric gases will be made.

Development of sources, detectors, frequency measurement components, and modulation techniques at submillimeter wavelengths will be continued. Differential lidar methods and active cross-beam mtehods will be developed.

Millimeter Wave Propagation

Highlights

Experimental observations of atmospheric attenuation and emission at 15, 31 and 53 GHz were performed in Hawaii to obtain data on telecommunications systems and to evaluate techniques for remote sensing of the vertical temperature profile of the atmosphere.

Measurements of atmospheric emission at 20.6 GHz were made to improve a technique for range corrections in missile tracking systems.

A series of papers was published on remote sensing of the vertical temperature profile through the atmosphere and estimation of the liquid water content in clouds using passive radiometric techniques.

These projects are jointly supported by ESSA, the U.S. Army Electronics Command, the U.S. Army Satellite Communications Agency, and the U.S. Air Force Electronic Systems Division.

Recent Accomplishments and Future Plans

This group performs theoretical and experimental research in the interaction of millimeter waves with the lower atmosphere, with special emphasis on delineating the usefulness of this part of the electromagnetic spectrum for telecommunication and remote sensing purposes.

The major remote sensing efforts in FY 69 were: continuation of research in techniques for inferring the vertical temperature structure of the atmosphere from radiation measurements in the 50-60 GHz region, theoretical and experimental studies in remote determination of the liquid water content of thunderstorm cells, and evaluation of a radiometric technique for decreasing ranging errors in missile tracking systems.

A series of theoretical papers on inversion of radiation measurements to obtain vertical temperature profiles was published. During FY 68 and FY 69, a series of radiometric and meteorological measurements was performed to obtain data for the testing of angular inversion techniques.

Data from other sources were also obtained for similar analysis. In FY 70, a multichannel radiometer operating in the 50-60 GHz band will be acquired and a multifrequency technique will be evaluated. In addition, the extent to which clouds may be a contaminant in the measurements will be examined. This work is jointly supported by ESSA and the U.S. Army Electronics Command.

Analysis of radiometric data obtained at 20.6 GHz in Hawaii shows a high degree of correlation between atmospheric emission and the line integral of refractive index over a 65 km mountaintop-to-sea-level path. Thus the technique of obtaining refraction corrections from radiometric measurements appears feasible. Additional data are being obtained in parallel with an operating missile tracking system at the Air Force

Eastern Test Range for further evaluation of the range correction technique. These studies are supported by the U.S. Air Force Electronic Systems Division.

Several research projects in this program area produce data and techniques that are applicable to both remote sensing and telecommunications. A study of the determination of liquid water content in thunderstorm cells using radiation measurements at 10.7 GHz shows promise for use of this technique as a tool in remotely sensing cloud properties. This program also directly benefits telecommunications because information on the absorption properties of liquid water in thunderstorm cells is relatively scarce. These properties must be well understood if millimeter waves are to be efficiently employed in telecommunnications (see fig. 14). Additional measurements were conducted during the 1969 thunderstorm season in Colorado using improved equipment operating at frequencies at 4.9 and 10.7 GHz. The use of two frequencies will hopefully extend the range of drop sizes in which the Rayleigh approximation can be reasonably applied in calculating absorption by liquid water droplets in clouds. These studies are supported by ESSA R&D funds.

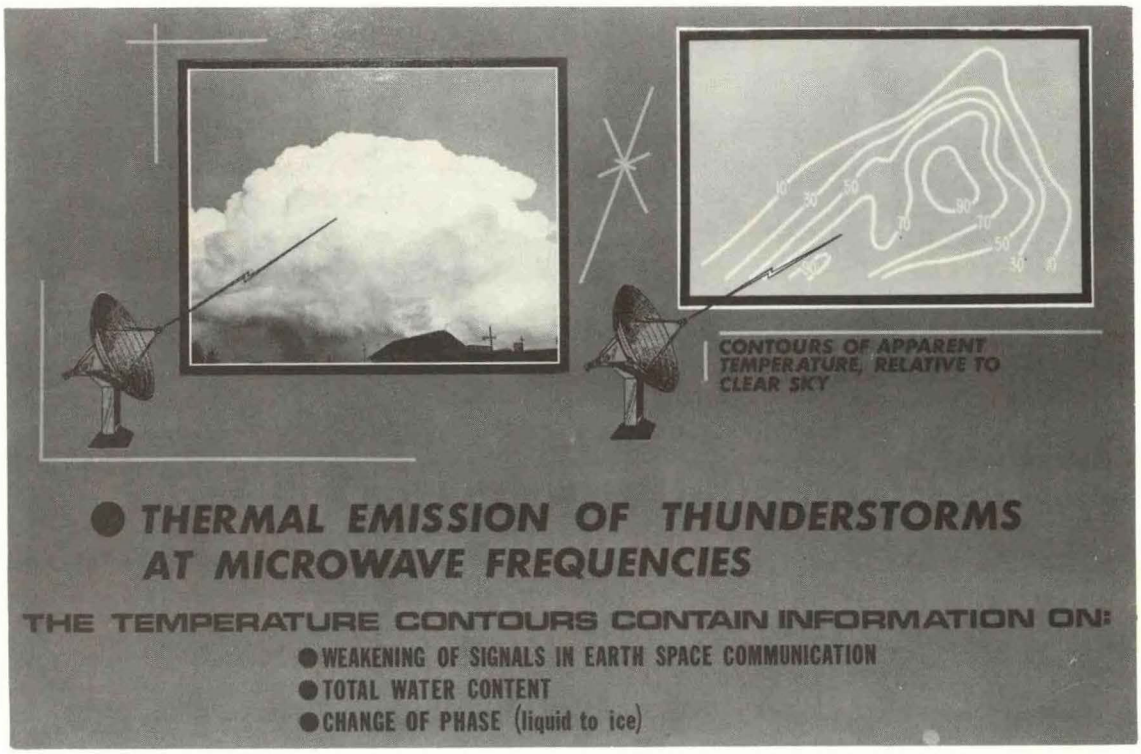


Fig. 14.

The results of atmospheric attenuation measurements at 15, 31 and 53 GHz in Colorado and Hawaii serve a number of objectives in both remote sensing and telecommunications. These data may lead to improved estimates of the line width constant of oxygen in the lower wings of the 60 GHz O_2 absorption spectrum and greater accuracy in absorption calculations. Improved methods of predicting atmospheric attenuation of electromagnetic energy and its effects upon telecommunication systems using millimeter waves are another goal of this program. In FY 70, study of millimeter wave attenuation in clouds will be emphasized and plans to extend observations to 94 GHz will be completed. This work is jointly supported by ESSA and the U.S. Army Satellite Communications Agency.

A continuing effort in FY 70 will be to propose experiments for measuring environmental characteristics from earth-orbiting satellites. In particular, studies to determine the spectral intervals that could be used to measure surface conditions and vertical profiles of temperature, humidity, precipitable water, and composition of clouds will be emphasized. Studies in this area are supported by the ESSA National Environmental Satellite Center.

Radio Meteorology

Highlights

Development of technique for measuring water evaporation rate with microwave refractometer and sonic anemometer.

Micro-scale fluctuations of temperature and refractive index in the atmosphere found to be reduced by strong turbulent winds.

Recent Accomplishments and Future Plans

This research program consists of studies on the interaction of microwave and lower radio frequencies with the lower atmosphere to facilitate radio telecommunications and to aid the development of new remote sensing techniques. Under study are atmospheric turbulence and structure and their relations to electromagnetic propagation and atmospheric dynamics. Meteorological consultation and services are provided to other research programs.

A direct technique for determining evaporation with a microwave refractometer and sonic anemometer was developed. This instrument was used to assist the U.S. Bureau of Reclamation in measuring the effectiveness of monomolecular layers in reducing evaporation from reservoirs. It was also used to determine evaporation over the BOMEX area in flights with the

DC-6 of the ERL Research Flight Facility. A parallel development was made of an optical/microwave instrument to measure atmospheric water vapor remotely over paths more than 10 km long.

Results of recent research studies show that fluctuations of dynamically passive parameters, such as the radio and optical refractive index, may effectively vanish during periods of strong wind-induced mechanical mixing.

During FY 70, a 500-ft tower will be used for a detailed investigation of the turbulent characteristics of temperature, radio refractive index, water vapor, and wind as a function of atmospheric stability. Comparisons will be made between the characteristics of optical and radio beams traversing the tower and the turbulent fluctuations.

The program of investigating interference fields by monitoring VHF and UHF broadcasts will be continued; fine-scale atmospheric structure and concurrent synoptic weather over the radio paths will be measured.

Meteorological Doppler Radar

Highlights

Observation of a thunderstorm cell with Doppler radar showed that persistent features of the wind field and their time evolution can be identified in the azimuth-range patterns of radial velocity, this in spite of wide Doppler spectra indicative of intense local turbulence or vorticity.

Recent Accomplishments and Future Plans

Studies of atmospheric phenomena are conducted by means of microwave pulsed Doppler radar techniques capable of sensing air motions through reflections from raindrops, hail, snowflakes, or chaff carried by the air. Particular emphasis is placed upon detailed study of severe convective storm dynamics by simultaneous use of 2 or 3 Doppler radars observing the same storm from different locations, the study of mesoscale particle motion field in widespread storms, and the study of atmospheric turbulence.

The design and fabrication of a first mobile X-band Doppler radar was completed in FY 68 and a second was made operational in August 1969. The first was operated in FY 68 and FY 69 during various meteorological conditions. The analysis of the data acquired from Doppler observations of a huge experimental fire has lead to the study of kinematic processes inside the

smoke column and the assessment of the radar detectability of the smoke cloud. The two radars were operated simultaneously during the 1969 summer thunderstorm season in Colorado, and are currently being operated in western New York State to study the motion in convective cells in the lee of Lake Erie.

Doppler data obtained from observing the particle motion inside a convective storm during the 1968 summer season in Colorado have clearly shown that, at certain stages of the development of the convective storm, the wind and the reflectivity patterns are persistent and well organized. The analysis also revealed that a slowly moving large cell in a shear environment is an obstacle to the low level air flow and therefore originates local instability, convergence, and vorticity of the flow in the "downwind" region of the cell. The flow instability in this region is also shown by the presence of very wide Doppler spectra, indicative of local intense vorticity (fig. 15). Statistical processing of the time evolution of the velocity and radar reflectivity patterns reveals that the wind field exhibits organization and persistence earlier than the reflectivity field which always shows more variability. At certain times of the storm development, however, both the reflectivity and the velocity fields show the same persistence.

During FY 68, a study of the variability of snowflake motion in space and time from Doppler data was made, leading to the assessment of some of the kinematical characteristics in the boundary layer. During FY 70, studies are being undertaken to determine the feasibility of tracking 1.6 cm chaff to obtain information on the structure of turbulence. Preliminary results indicate that the chaff needles are excellent tracers of the small scale air motion and that these needles can be easily tracked by the radars. Plans for 1970 include the use of the chaff to study standing waves in the lee of the front range of the Rockies.

In August 1969 the two radars were operated simultaneously to observe the radial velocity pattern in a thunderstorm cell, and the horizontal motion field at several levels within the cell was derived. The experiment showed that both radars can now be used simultaneously to map the two-dimensional wind field in convective storms. Since the dual radar method relies heavily on computer treatment of the data, a system capable of recording the Doppler radar signals in a digital format compatible with large computer requirements must be available in both the radar units. An electronic system capable of digitally recording the Doppler signals at 24 selected ranges every two seconds, has been designed and fabricated for both radars. A computer program for fast Fourier transform operation needed to provide the Doppler

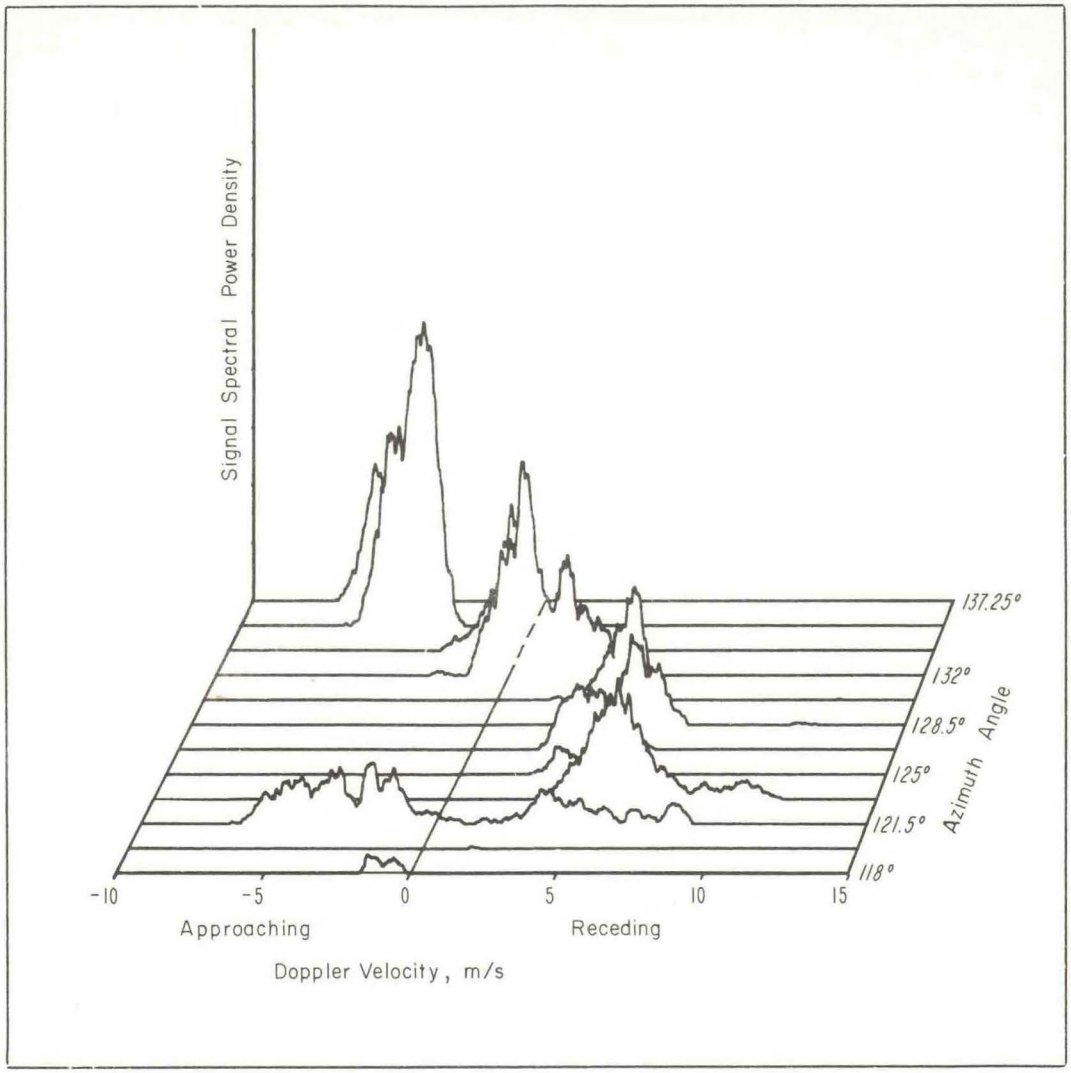


Fig. 15. Three-dimensional presentation of the Doppler spectra at a fixed radar range of 26 km as a function of the azimuth of the Doppler radar beam. The radar beam elevation angle was 3°, corresponding to an altitude of 1 km at this range.

The azimuth angle was stepped 11 times every 1.75° from 118° (front of the graph) to 137.25° (back of the graph). Note spectrum shape and the systematic variation with azimuth of the average velocity. Also note the presence of a very wide, bimodal, Doppler spectrum at 121.5° indicative of local, intense vorticity in the storm circulation.

spectra, and for analytical estimate of two-dimensional reflectivity and radial velocity fields in a form suitable for space coordinate transformation has been tested. The computer program also includes mapping the horizontal wind field at different altitudes and the computation of the convergence and vorticity of the wind field, as well as estimation of the vertical motion from the equation of continuity. A feasibility study has been made of the potential of a 3-radar system to provide the complete description of the three-dimensional wind field at any altitude in a convective storm.

Geoacoustics Research

Highlights

Infrasound waves from the explosion of a volcano in the Galapagos Islands in June 1968 were recorded at stations in North and South America.

Plans are formulated for study of microbaroms, thought to be generated by ocean waves, and investigation of mountain-associated waves.

Recent Accomplishments and Future Plans

Theoretical studies and experimental measurements are conducted on the generation and propagation of infrasonic waves (oscillation period: 1-1000 sec) through the atmosphere, and on the relation of such waves to other geophysical phenomena. Typical sources of the waves are aurora, volcanic explosions, Rayleigh waves (a type of seismic wave) from earthquakes, and long wavelength gravity waves on large bodies of water. Results of the research are used to deduce certain fundamental physical properties of the atmosphere, earth, and seas.

Data are collected by a network of 7 stations in North America, South America and the Middle East. In addition to the infrasonic equipment, the Washington, D.C. station includes a 4-element array of short period vertical seismometers, permitting direct comparison of Rayleigh waves with the infrasound they generate.

Observations of various geophysical sources were continued during the past year. For example, the explosion of the Caldera on Isla Fernandina in the Galapagos Islands (June, 1968) produced readily measurable infrasound at the North and South American infrasonic stations. The record waveforms are still being studied to evaluate the propagation of infrasound in the atmosphere.

Plans are being developed for automatic data processing with the help of a digital computer at the Washington, D.C. station.

Two puzzling and controversial infrasonic phenomena will be studied in detail during the coming year. One phenomenon is the worldwide presence of microbaroms, which are sound waves having oscillation periods of about 6 seconds, presently thought to be generated by waves on the oceans. Microbaroms will be studied using data from the stations at Washington, D.C., Boulder, Colorado, and Pullman, Washington. The other phenomenon is the sporadic radiation of "mountain-associated" infrasonic waves from a source which seems to be located near the Pacific coast of Canada. In addition to the above-named stations the College, Alaska, infrasonic station will be used to study the mountain-associated waves.

A new infrasonic station for the Argentine, probably near Cordoba, is planned for next year.

Research will be continued at higher acoustical frequencies (periods of 1 to .01 sec) on the interplay between sound waves and non-uniformities in the atmosphere.

Acoustic Sounding

Highlights

Analysis and a preliminary experiment indicate that it should be possible to develop acoustic echo sounding methods of measuring vertical profiles of wind, turbulence, temperature inhomogeneity, and humidity to heights of better than 1500 meters.

Recent Accomplishments and Future Plans

This new program area is being created to develop the use of acoustic waves for remote sensing of atmospheric parameters. Theoretical and field studies are conducted to identify the full potential of the acoustic echo-sounding technique.

An analysis has been completed and published on the potential of the acoustic echo-sounding technique for remote sensing of the boundary layer of the atmosphere. The analysis shows that it should be possible to develop the acoustic echo technique to measure remotely vertical profiles of wind, turbulence, temperature inhomogeneity and humidity, all as a function of time, to heights of at least 1500 meters.

A prototype acoustic "echo-sounder" has been developed and tested alongside equivalent Australian equipment in a complex experiment conducted next to the 500-ft meteorological tower

at Haswell, Colorado. Excellent recordings were obtained of acoustic echoes from atmospheric turbulence and temperature eddies associated with thermal plumes, radiation inversions, etc. The data from the different echo-sounders will be compared quantitatively with each other and with the meteorological data obtained simultaneously on the 500-ft tower. Considerable insight has already been obtained from the Haswell experiment; new experiments are being planned for 1970 to extend the nominal height range of the sounder from 500 to 5000 ft, and to identify to what extent noise pollution problems will limit its usefulness in an urban environment.

Dr. C. Gordon Little, Director, Wave Propagation Laboratory

Born in China in 1924, Dr. Little was graduated from the University of Manchester, England in 1948 in physics and received the Ph.D. in radioastronomy from that institution in 1952. He became a senior research worker in 1952 at the Jodrell Bank Radio Astronomy Station.

From 1954 to 1958 Dr. Little served as Deputy Director and professor of geophysics at the Geophysical Institute, University of Alaska.

Dr. Little came to Boulder in 1958 as a consultant to the NBS Central Radio Propagation Laboratory and was appointed Chief of the Radio Astronomy and Arctic Propagation Section in 1959. In 1960 he was appointed the first Director of the Upper Atmosphere and Space Physics Division and in 1962 he became Director of the Central Radio Propagation Laboratory which was brought into ESSA in October 1965.

In 1966 Dr. Little accepted appointment as Deputy Director of ESSA Research Laboratories while continuing to head ESSA's telecommunications and aeronomy activities. In 1967 he was named Director of the Wave Propagation Laboratory, an appointment that permits him to undertake new research activity.

Dr. Little has been awarded the Department of Commerce Gold Medal for distinguished contributions to the physics of radio propagation and other research programs in radio science.

He is a Fellow of the Royal Astronomical Society, a Fellow of the Institute of Electrical and Electronics Engineers, a member of the American Geophysical Union and the Research Society of America, and he is past Chairman of U.S. Commission 3, Ionospheric Radio Propagation, International Scientific Radio Union.

Dr. Little, his wife, Mary, and their children reside in Boulder.

INSTITUTE FOR TELECOMMUNICATION SCIENCES

Boulder, Colorado

Richard C. Kirby

The Institute for Telecommunication Sciences conducts research and provides services to determine the effects of the earth's variable surface and changing atmosphere upon telecommunications, to advance its technology, and to broaden our technical understanding of these environmental factors as required for improving national utilization of the electromagnetic spectrum for telecommunications.

The Institute for Telecommunication Sciences serves as a central federal agency for the acquisition, analysis and dissemination of information on the propagation of electromagnetic waves, on the electromagnetic properties of the earth and its dynamic atmospheric environment, and on the characteristics of electromagnetic noise and interference. It also carries out research on information transmission and antennas, and on means for more effective use of the electromagnetic spectrum for telecommunications.

The work of the Institute falls into the following broad program areas:

Electromagnetic Environmental Research

Ionospheric Radio Research	D. D. Crombie
Environmental Radio Physics	L. A. Berry
Tropospheric Radio Physics	M. C. Thompson

Propagation Prediction Development and Services

Ionospheric Propagation Predictions	A. F. Barghausen
Tropospheric Radio Systems Predictions	A. P. Barsis

Communication Technology and Systems Analysis

Communication Technology and Systems	T. deHaas
Spectrum Utilization and Satellite Systems	W. R. Hinchman

In addition, there is a significant amount of consulting services for federal agencies carried on by the Institute staff, as well as participation in various local, national and international technical groups.

In FY 69, Interim Meetings of the International Radio Consultative Committee (CCIR) Study Groups V and VI were held in Boulder with active participation by Institute members. Later in the year, several Institute members participated in meetings of Study Groups III and IV held in Geneva, Switzerland. In addition to CCIR, Institute personnel participate in planning groups of the World Meteorological Organization (WMO), the Panel on Telecommunications for the Integrated Global Ocean Station System (IGOSS), in the Institute for Electrical and Electronics Engineers Committee on Antennas, in the Inter-Department Radio Advisory Committee (IRAC), and the Joint Technical Advisory Committee of the IEEE Industry Association (JTAC). These activities are in addition to the assistance given other governmental agencies, industrial companies, universities, and foreign countries. Illustrative of programs receiving technical assistance from the Institute staff are the SENTINEL and SAMSO programs.

Electromagnetic Environmental Research

Ionospheric Radio Research

-- Lower ionosphere research and EM propagation at frequencies below 1.5 MHz.

-- Upper ionosphere research and EM propagation at frequencies above 1.5 MHz (includes ionospheric radar research).

-- Models and synoptic data for propagation and systems predictions.

-- Remote sea wave measurement and tornado detection.

The research objectives in ionospheric radio are to devise and verify methods of predicting several environmental effects: the normal propagation loss and phase delay of electromagnetic signals at frequencies less than about 1.5 MHz as a function of frequency, direction of propagation, latitude, time of day and season; the electrical constants of the ground, and determination of the appropriate ionosphere and ground parameters for use in such predictions; and the effects of natural ionospheric irregularities and other disturbances, such as those caused by solar flares, polar cap events, and nuclear explosions, on the propagation of signals of frequencies less than about 1.5 MHz.

Theoretical and experimental studies of radio signal propagation at frequencies from about 2 MHz to 50 MHz are conducted to describe the variable characteristics in time and space

of the ionosphere. Ionospheric data are obtained from cooperating ionosphere sounding stations in this country and abroad, and from stations operated by program personnel or through contracts. ERL and other agency groups are provided with experimental transmissions or engineering services tailored to their requirements.

The pulsed low-frequency sky wave experiment initiated in cooperation with DASA to determine D region ionospheric reflection coefficients as a function of frequency, and subsequently, D region electron density profiles, will be continued. The "partial reflection" method of determining D region electron density profiles is yielding useful data (fig. 16) which are being compared with solar X radiation information as it becomes available.

Results of HF propagation studies include validation of the three dimensional ray-tracing program as an accurate tool for simulation of ionospheric propagation, development of a technique for accurately estimating the range to a distant transmitter, and establishment of a relation between the quality of radio direction-of-arrival determinations and the characteristics of ionospheric radar records made simultaneously.

In this year, data on 40 atmospherics recorded simultaneously in the United States and Japan are being analyzed and exchanged with cooperating Japanese scientists. Experimental evaluation of phase errors in Loran-D radio navigation systems will be carried out for the Air Force.

Data on coherent backscatter of HF radio ground waves collected at Barbados during the BOMEX experiment are being analyzed to determine suitability for detecting sea surface conditions remotely. Ionospherically propagated signals, backscattered from the sea, have been separated from similar signals originating from the land. This opens up the possibility of determining sea state at distances of several thousand kilometers.

Observations of electromagnetic noise at frequencies below 1 MHz made in Oklahoma during the past tornado season are being examined, and plans for further observations, at frequencies up to 200 MHz, during the CY 1970 tornado season are being implemented.

VLF data taken on long paths are being examined for possible stellar X-ray effects which have been suggested by preliminary analysis.

Data on signal strength and noise obtained over operational LF paths will be collected and compared with current reduction methods to determine the validity of the prediction methods and ways in which improvements can be obtained.

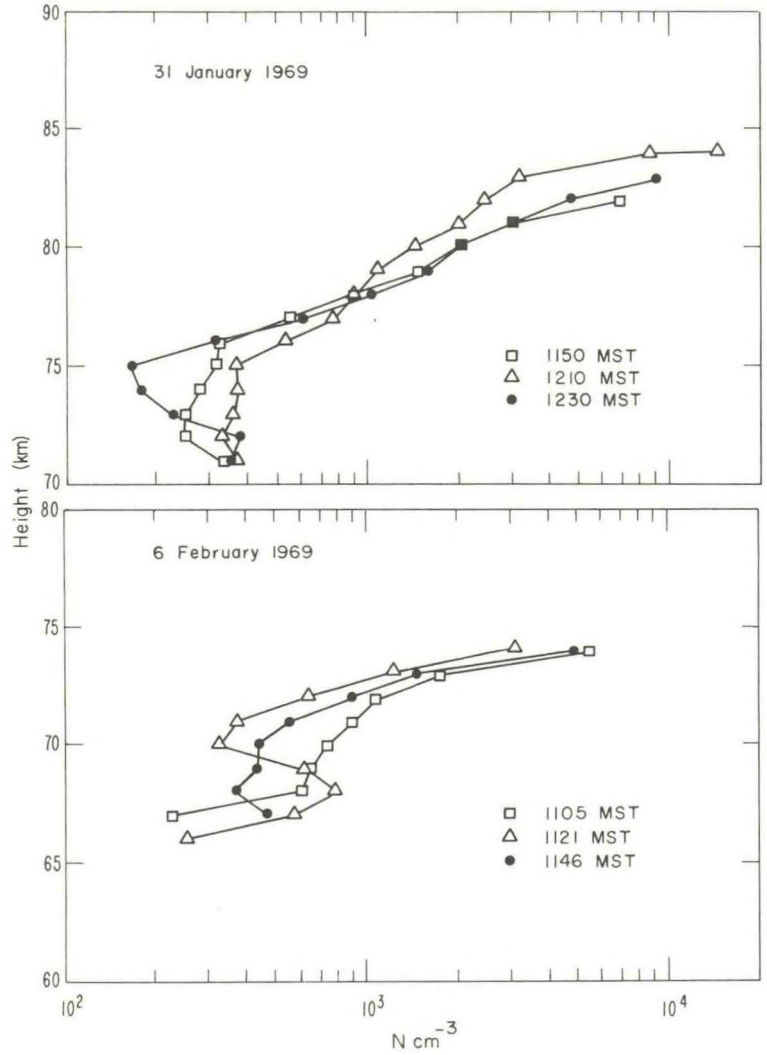


Fig. 16. Profiles of electron density in the D region of the ionosphere, obtained by the partial reflection method. The upper graph shows three profiles obtained at 20-min intervals on a "normal" day. Profiles in the lower graph were obtained at nearly the same time of day on a day of abnormally high absorption and abnormally high electron densities at the lower heights. On that day, absorption was so high that usable signals were not obtained above 75 km.

Environmental Radio Physics

-- Ionosphere research and EM propagation.

-- Radio atmospheric dynamics.

-- Models and synoptic data for propagation and systems predictions.

Research is conducted in Environmental Radio Physics to determine the spatial and temporal characteristics of the radio environment and their effects on the propagation of radio waves. This includes theoretical and experimental studies of the irregular and dynamic properties of the neutral atmosphere and the ionosphere, and the effects of these properties on the propagation of radio waves. Study is also done on the propagation, diffraction, and scattering of radio waves by rough and irregular terrain, and other surface features, as well as the radiation characteristics of antennas.

Recent studies have shown that the extent to which waves in the neutral atmosphere cause motions in the ionosphere depends on the direction of propagation of the atmospheric waves relative to the earth's magnetic field (especially at F region heights) and relative to the azimuth angle to the sun (especially at E region heights). In addition, radio methods of observing these ionospheric motions have inherent biases. Various experimental techniques are being evaluated to determine their effectiveness as high altitude atmospheric wave sensors. For example, measurements of total electron content using ground recording of satellite signals have been shown to be insensitive to many possible atmospheric waves, and that simple, direct interpretation of ionospheric radar data misrepresents the speed and direction of wave propagation.

Observations have been made which show that distinctive at-atmospheric oscillations with periods near 3 minutes at heights near 200 km are associated with severe weather activity shown on weather radar maps (see fig. 17). Kinesonde observations interpreted with sophisticated correloid analysis techniques have been used to measure convective motions and turbulence at E region heights. In the past year, such measurements have compared favorably with drifts measured with optical techniques.

Theoretical studies have been conducted on the effect of irregular terrain on HF antenna radiation patterns, and on Loran navigation ground wave signals. Handbooks on "Nuclear Effects on LF-VLF Communication Systems" have been produced for the Defense Atomic Support Agency.

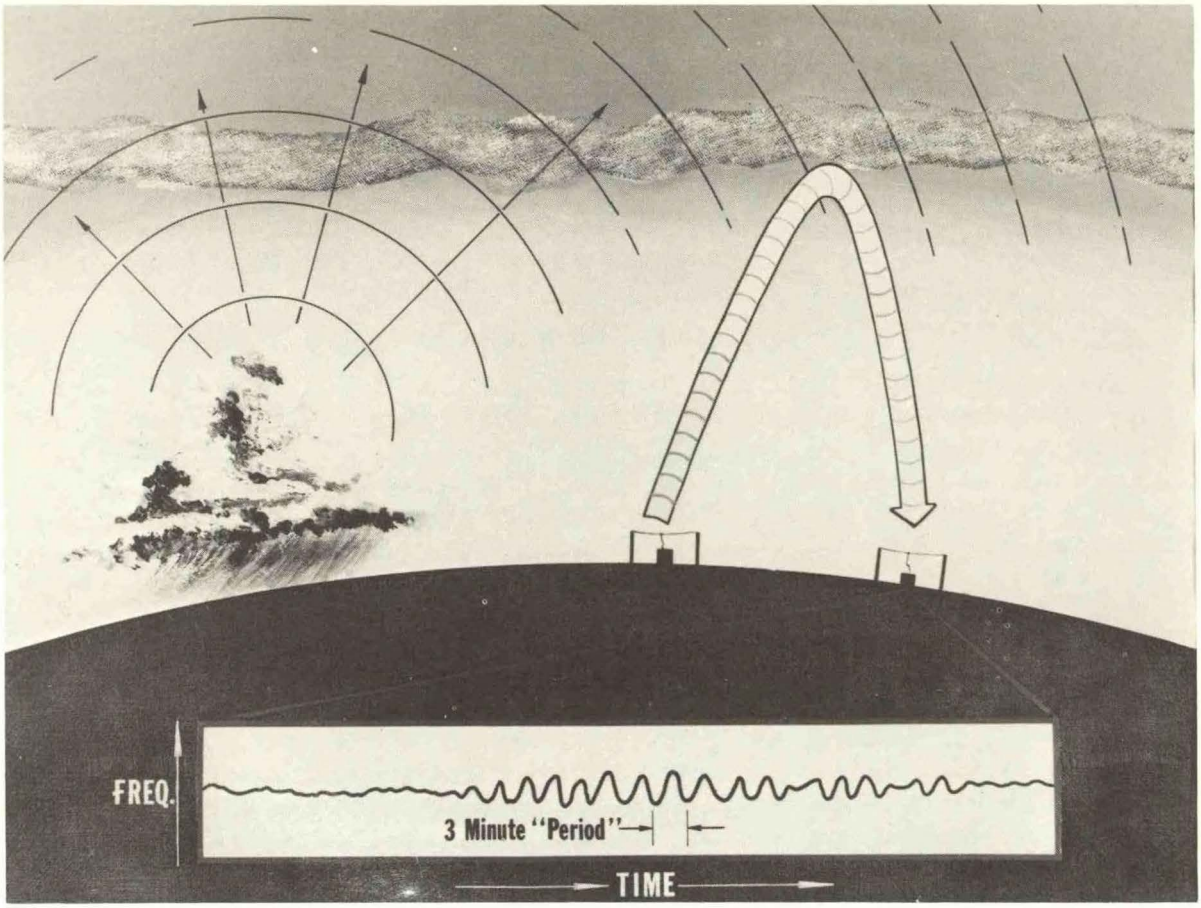


Fig. 17. Waves of about 3-min period have been detected in the ionosphere at distances up to several hundred km from severe weather activity in the troposphere. Vertical movements induced in the ionosphere cause "Doppler" shifts of a few cycles/sec in the frequencies of radio waves reflected from the ionosphere.

An atlas of ionospheric backscatter records is being compiled, and will be used in conjunction with the simulation program to determine dynamic characteristics of the ionosphere. Studies will be directed toward discovering the sources of various traveling ionospheric disturbances, and a book on ionospheric dynamics will be started. A digital instrument capable of sounding the full range of the dynamic variation of the ionosphere is being developed, and will be field-tested in the next year.

Theoretical results for the effects of irregular terrain on radio propagation will be compared with experimental measurements. Several fundamental problems in electromagnetic theory must be solved before much more progress can be made in the area of terrain effects. These problems are being considered.

Tropospheric Radio Physics

-- Line of sight and guided wave.

-- Beyond the horizon.

Tropospheric radio physics studies include research on the effects of the troposphere on the propagation of electromagnetic waves at frequencies above 300 MHz, with emphasis on the signal phase distortion imposed by the atmospheric medium, evaluation of the limits on the accuracy of rocket and satellite tracking systems imposed by atmospheric turbulence, and accuracy determination of electromagnetic distance and angle measuring systems used in geodesy and seismology through studies of the tropospheric refractive index structure. Techniques are developed for phase stabilization over tropospheric-scatter, line-of-sight, and satellite-relay paths.

Past work has been concentrated on the following:

Analysis and interpretation of data obtained in a series of 10 major propagation experiments designed to study several types of atmospheric errors in missile and satellite tracking systems. These experiments were sponsored jointly by the U.S. Air Force Electronic Systems Division, Avionics Laboratory, and Cambridge Research Laboratory.

Participation with the Millimeter Wave Propagation Group (WPL) in experimental determination of the usefulness of millimeter-wave sky temperature data to correct for refraction errors in radio tracking measurements. The experiments included side-by-side operation of several radiometers and concurrent range variation measurements over the slanted 65-km over-ocean path in Hawaii used in the 1967 experiments.

An investigation was made of the correlation between phase-of-arrival variations observed in the slanted-path, radio-tracking configuration and the corresponding spatial variations in the atmospheric refractive index observed with an airborne microwave refractometer. Theoretical research at the University of Michigan has predicted a useful correlation of these two variables, and the first measurements to test the theory were made in April 1968 over the same slanted 65-km path in Hawaii. This work was sponsored by the U.S. Air Force Avionics Laboratory.

In conjunction with the field tests above, experiments were conducted to determine the effects of radio frequency separation on the relative behavior of phase and amplitude fluctuations of signals propagated through the troposphere. This is

in response to increasing need for basic information to be used in designing high-rate digital type telecommunication systems. The results are being subjected to cross-spectrum and coherence analysis to provide a comprehensive comparison of phase and amplitude characteristics at two closely-spaced microwave frequencies.

The dispersive characteristics of the troposphere at millimeter and optical wavelengths is also being investigated. The objectives of the study are to determine the extent to which dispersion can be used to correct atmospheric errors in radio and optical distance measurements, and as a tool to probe the structure of the troposphere itself. In general, the experiments are designed to correlate measurements of tropospheric path length variations made at one wavelength simultaneously with measurements of differential path length variations at two or three wavelengths in the millimeter and/or optical regions of the electromagnetic spectrum.

In addition, a study is being made (under U.S. Air Force Cambridge Research Laboratory sponsorship) of the phase-front distortion observed at millimeter wavelengths. An orthogonal array of horn antennas is being used to observe the phase-front distortion and amplitude characteristics of a 35-GHz signal propagated over a 15-km path. The objective is to determine the extent to which the turbulent troposphere affects the efficiency of large-aperture and phased-array antennas.

Propagation Prediction Development and Services

Ionospheric Propagation Predictions

-- Ionospheric predictions, development and services.

-- Telecommunication HF disturbance warning and short-term frequency predictions.

Ionospheric predictions is the area concerned with the development of models for predicting the expected performance of telecommunication systems at radio frequencies used in ionospheric transmission applications. The models are based upon basic and applied research in the fields of ionospheric physics and electromagnetic propagation through a time-varying medium and over the surface of the earth. System performance predictions and ionospheric data are prepared and disseminated for military and civilian radio and scientific uses in satellite, missile, and space programs, and for other scientific and engineering applications.

A computer program employing suitable models to represent the monthly median ionospheric characteristics and wave propagation effects has been developed for predicting the long-term operational parameters of HF skywave telecommunication systems. This program is being adopted as the standard method for HF communication planning and operational agencies in all of the military services and other governmental agencies. HF system performance predictions are supplied to over 50 different private and foreign government organizations. On a regular monthly basis, ESSA/ITS provides a comprehensive analysis of the expected performance of various military communication systems in 29 different world areas. Calculations of the maximum usable frequency, optimum traffic frequency, and lowest useful frequency are made at hourly intervals throughout the day for 17 possible systems, using 12 different antennas on paths ranging in length from 160 km to 2400 km. Over 1200 copies are prepared and supplied to 480 users in all military and government organizations. In addition, a regular monthly publication is issued to 252 different users which contains predictions of the ITU HF aeronautical off-route frequency band which is expected to provide the most satisfactory two-way communication between 52 world-wide aeronautical communication stations and aircraft flying within a 4500-nmi radius of these stations.

Numerical methods for predicting both solar cycle and annual variations of ionospheric characteristics have been extended to a five-dimensional numerical map, depending continuously on two geographic coordinates (latitude and longitude), universal time, month, and solar index. Use of the annual variations makes it possible to predict the map of median values of a characteristic for any 30-day period during the year. Therefore, predictions can be made daily, or weekly, as well as monthly, to take account of the seasonal variation within a month, which can be relatively large near equinox periods. Application to predictions of the expected operational parameters of HF telecommunication systems indicate changes as high as 3 to 5 MHz in the maximum usable frequency between medians centered on the beginning and end of the month.

Three-dimensional numerical world maps of ionospheric plasma frequency (electron density) for November 1966 (see fig. 18) were developed for the Raytheon Corporation for use in analyzing radio propagation data obtained from the Air Force OV-4 twin-satellite experiment to study ducted propagation between the E and F layers.

Monthly summary values of ionospheric characteristics for the world net of ionospheric observing stations are published in the CRPL-F Series, Part A, "Ionospheric Data". This

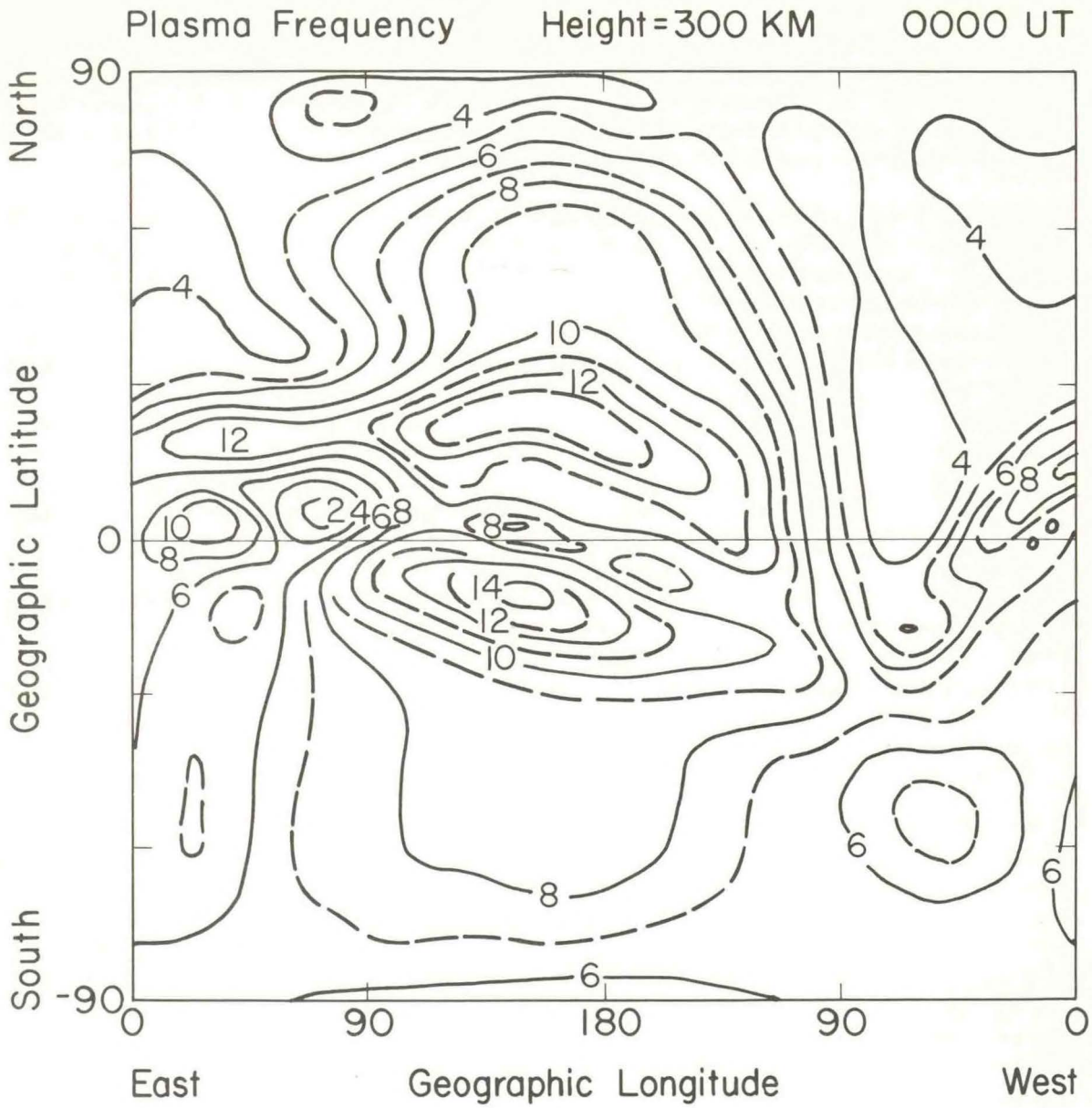


Fig. 18. Sample of 3-dimensional maps of ionospheric plasma frequency (electron density) for Nov. 1966, based on data from 36 vertical-incidence sounding stations around the world. The plasma frequency was obtained as a function of height and time of day for each station by inversion of the virtual height ionograms, and then represented as a continuous function of height, geographic coordinates, and time of day by numerical mapping methods. Such numerical maps can be used with computers for numerical ray tracing.

publication is issued monthly as part of an international data exchange program. Of the 278 copies prepared, 45 are distributed to government agencies; 54 to nongovernment research laboratories and institutions; 144 to foreign government agencies and research workers; and 35 to the World Data Center A, Upper Atmosphere Geophysics.

Another publication issued monthly, ESSA/ITS "Ionospheric Predictions", contains predicted world contour maps of the zero and 4000-km maximum usable frequencies for every even hour of universal time. These predicted maps are derived from the predicted numerical coefficients representing ionospheric characteristics and are issued three months in advance of the period to which they apply. The U.S. Government Printing Office prints approximately 3200 copies monthly. Over 1600 copies are supplied to the military; 700 are distributed to cooperating laboratories and government organizations; and over 800 copies are for subscriptions from foreign and domestic users.

In addition, the ESSA/ITS numerical coefficients representing the global variations of ionospheric characteristics were used to prepare CCIR Report 340, "Atlas of Ionospheric Characteristics". This atlas has been adopted as the standard reference to be used by the International Frequency Registration Board in determining international frequency allocations for ionospheric radio propagation.

A time-share computer system is now operational which provides warnings and forecasts of solar-geophysical disturbances and their effects on the performance of HF systems. Users access the computer at the ITS Telecommunication Services Center via remote dedicated or non-dedicated terminals for specific information relating to short-term changes in the operational parameters of HF circuits under their control. Objective methods utilizing computer analysis of near real-time solar-geophysical data calculates the beginning times, probabilities of occurrence, and intensities of short-wave fadeouts (SWF), polar cap absorption events (PCA), and geomagnetic storms and their expected effects on the operational parameters of HF systems. Solar-geophysical data are received in near real-time from the Space Disturbance Forecast Center of the ESSA Research Laboratories and entered immediately into the time-share computer. Remote access terminals are currently installed in offices of the Defense Communications Agency, White House Communications Agency (Andrews Air Force Base), Voice of America, U.S. Army Strategic Communications Command, Department of Commerce, Naval Communications Command, Air Force Communications Systems Command (Scott Air Force Base), Air Force Frequency Management Group

(AFOCCF), and Air Force Systems Command (Eastern Test Range, Patrick Air Force Base, and Western Test Range, Vandenburg Air Force Base).

Tropospheric Radio Systems Predictions

-- Mathematical models and computation methods for tropospheric propagation, diversity design and performance evaluation.

-- Experimental studies and data evaluation for propagation over irregular terrain and tropospheric point-to-point systems.

-- Propagation models, experimentation, and data evaluation for spectrum sharing and utilization studies.

The research conducted in tropospheric radio systems predictions is primarily in the application of theoretical methods and experimental data to the development of models and methods for computing radio wave propagation through the non-ionized atmosphere and over irregular and cluttered terrain. Results from this research are used to (1) estimate performance characteristics of telecommunication systems affected primarily by this environment and (2) to support studies for efficient utilization of the radio frequency spectrum.

A data pool of previously obtained propagation measurements in irregular terrain serves as the basis for statistical information on transmission loss distributions as a function of carrier frequency, antenna height, and terrain characteristics for a wide range of these parameters. This information was organized to provide a base for comparisons with propagation models and for direct application to telecommunication problems in similar environments. Analyses of air-ground propagation data are in progress for extension of the applicability of the propagation models to such applications.

Evaluations of the actual and potential performance of point-to-point microwave communication links were primarily concerned with identifying causes of fading, and with finding means to alleviate the effects of fading on the telecommunication objectives. Recommendations regarding choice of antenna height and size, and use of diversity were made to Defense Department agencies and to the Federal Aviation Administration for several specific links and systems. Severe fading on microwave links was associated in many cases with the occurrence of high-pressure ridges, which favor atmospheric stratification particularly at night. Thus standard

weather reports and forecasts may provide a means to alert microwave system users to the possibility of outages due to fading, at least in some cases.

Studies of microwave propagation were extended to the 14- to 15-GHz range where absorption by rainfall becomes a serious limitation to the transmission of information. With support from the FAA, data over a short link in a wet climate (Mississippi) were obtained, and analysis and evaluation is in progress (see fig. 19). It appears now that atmospheric stratification at low levels (less than 50 m above ground) can produce severe fading on the 14-GHz signals as well as on signals at lower frequencies. Further experimental studies are planned for a much longer path in Colorado, again with support from the FAA.

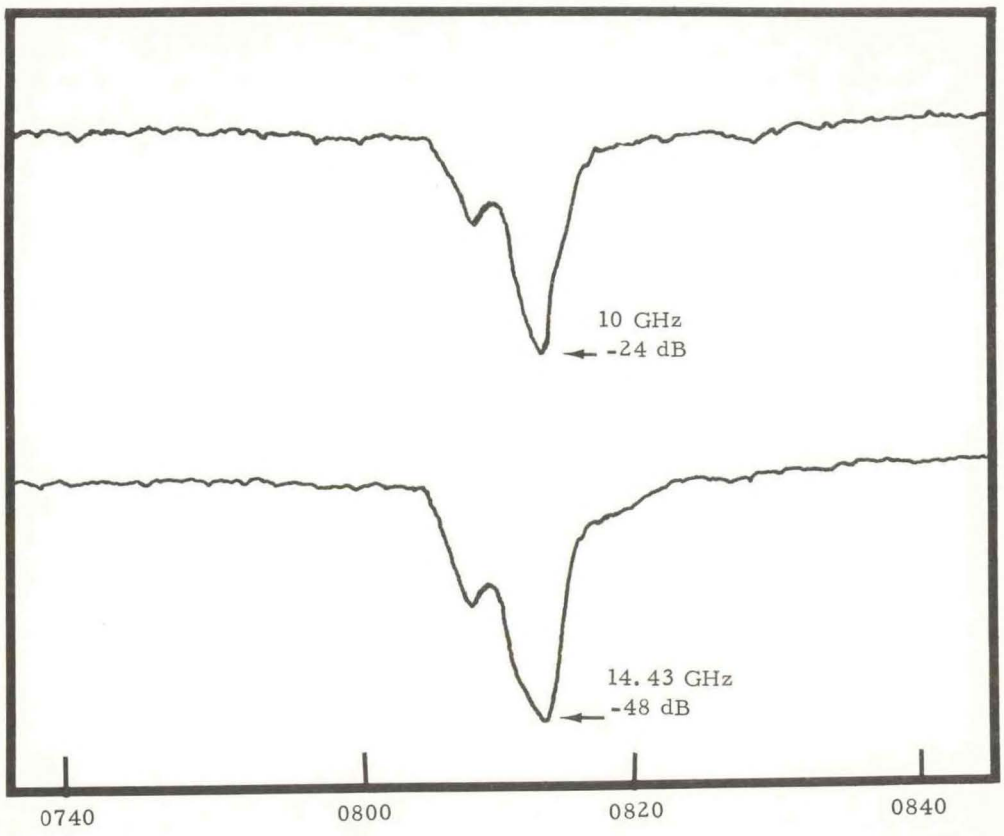


Fig. 19. Example of rain attenuation fading on X-band (10.0 GHz) and Ku-band (14.43 GHz) at Mississippi State University, where the 3-mile radio path had 20 tipping bucket gages spaced approximately 800 ft apart. Path average rainfall was 5.40 inches/hr at time of peak attenuation (13 Apr 1969).

Extensive technical assistance was provided to the U.S. Army Strategic Communications Command and other Defense agencies in design, test, and evaluations of point-to-point communication link performance in southeast Asia and in Europe. This work is continuing in FY 70 with emphasis on meteorological effects on the performance of beyond-the-horizon links operating at 1.8 GHz in the Mekong Delta region. At the request of the Defense Communications Agency, ITS performed a major role in the reformulation of design and testing standards for beyond-the-horizon point-to-point tropospheric communication systems.

Emphasis in FY 70 will be on consolidation and improvement of models for propagation through the lower atmosphere taking into account the effects of terrain irregularity and terrain clutter, and on the feasibility of utilizing meteorological data for short-term prediction of tropospheric transmission loss variability particularly for microwave communication links. The available data pool will be used to evaluate and compare various models, and to provide empirical parameters for propagation models when required.

Communication Technology and Systems Analysis

Communication Technology and Systems

-- Communications technology and systems evaluation research.

-- Laboratory simulation of radio channels.

-- System analysis, design, engineering services.

-- ESSA telecommunications development.

A major responsibility of the communication technology and systems research is to provide system support in terms of operational analyses and assistance in evaluation of systems performance and design to other agencies. In this category many large programs are in progress such as the Integrated Global Ocean Station System (IGOSS) and the low-frequency communications part of the Civil Defense Decision Information Distribution System. Another responsibility is to assist in analyses of areas and programs within the Institute for Telecommunication Sciences where the utility of the product can be enhanced.

During the current year the group has contributed heavily to the development of the systems aspects of the development stage of the IGOSS. Work is continuing on various systems

programs for other government agencies. An ionospheric radio path simulator was constructed and is used for modem testing.

For the coming year a major portion of the effort of the group will concentrate on development of computer models and systems design for IGOSS and on simulation of radio channels. Assistance will also be provided to the U.S. Air Force in low frequency communications and to the Civil Defense Agency for the Decision Information Distribution System.

A program in ionospheric simulation will be maintained to assist in the evaluation of performance of existing systems and to aid in providing improved inputs for the development of more accurate ionospheric system predictions. It is planned that this program will be extended to tropospheric simulation in the near future.

Spectrum Utilization and Satellite Systems

-- System analysis, design, engineering services.

-- Spectrum sharing research (technical).

-- EM noise and interference environment.

This program has the objective of characterizing the electromagnetic environment and interactions between radiating systems employing common frequency bands, and to develop criteria for effective spectrum utilization, both inter- and intra-system. The work emphasizes mathematical description, experimental measurement, and systems implications. Primary emphasis is in the range 30 MHz - 40 GHz.

A very significant interference experiment is currently being implemented to obtain valid data to aid in determining the criteria required for sharing the same frequency bands by communications satellite and terrestrial radio-relay systems as the numbers of both systems increase. To meet this objective, the experiment will: (1) measure transmission loss occurrence for realistic configurations of an earth station and several terrestrial radio relay stations, emphasizing off-great-circle configurations of antenna beams, and beam elevation angles typical of earth stations in a domestic system, and (2) develop the capability to extrapolate the results to other locations, times, and frequencies by determining the relative influences of the different mechanisms, such as precipitation scatter, their governing relationships and their correlations with available meteorological parameters.

A high priority task is that of summarizing the advantages and disadvantages of available mathematical models for systems, signals, noise, channels, antennas, coding and decoding, modulation and demodulation, and diversity schemes. For this fiscal year and the next, this includes a consolidation of recently completed work on a variety of diffraction problems, including attention to the modeling of terrain, and both computer methods and graphical methods for summarizing available data and theory.

A mobile radio noise laboratory is operated to obtain the direct measurement of several statistical averages of the r-f noise envelope and spectrum occupancy at a number of frequencies.

We are currently emphasizing work for the International Radio Consultative Committee (CCIR), and related work concerned with communication, navigation, and data collecting systems involving satellites.

Richard C. Kirby, Director, Institute for Telecommunication Sciences

Born in Galesburg, Illinois, Mr. Kirby received his B.S. in electrical engineering from the University of Minnesota and joined the Department of Commerce in 1948. His primary field of research has been ionospheric wave propagation and radio systems. He was formerly Chief of the Radio Systems Division of CRPL and Director of the Ionospheric Telecommunications Laboratory.

Mr. Kirby has been particularly active in the United States participation in the International Radio Consultative Committee, serving as Chairman of the U.S. Committee on Fixed Systems and as a U.S. delegate to several international meetings. Recently he has been appointed Chairman of a special working group of the Scientific Committee for Antarctic Research to study technical problems of communications in the Antarctic.

In addition, he has been active in solving military communications problems, working closely with the Air Force, Navy, and Army in a consulting capacity.

In 1965, Mr. Kirby was awarded a Department of Commerce fellowship in science and technology. In 1968 he received Commerce's Gold Medal for outstanding federal leadership in telecommunications. He had previously received the medal in 1956 for contributions as a senior member of a research group working on ionospheric propagation scatter.

Mr. Kirby is a Fellow the Institute of Electrical and Electronics Engineers (IEEE), is currently Chairman of the IEEE Communication Technology Group, and is past Chairman of the Board of Directors of the annual IEEE International Conference of Communications. In addition, he is a member of the International Scientific Radio Union, Commission III on Ionospheric Radio. He has also served as a member of the science advisory group of the Voice of America and other important government agencies.

RESEARCH FLIGHT FACILITY

Miami, Florida

Howard J. Mason, Jr.

The objectives are to meet the requirements of the ESSA Research Laboratories and of other government-supported research for environmental measurements from aircraft.

Operations	William S. Callahan
Instrument Development	Gerald Conrad
Systems Maintenance	T. E. Apstein

Air Fleet

Consists of two DC-6 A/B; one C-54 (DC-4); and one B-57A (see figs. 20, 21, 22).

Fig. 20. RFF DC-6A/B aircraft. Long range, pressurized four-engine (reciprocating type) land plane capable of flying at altitudes up to 25,000 ft, with a cruise speed of 220 knots (TAS), mission radius of 1100 nmi and equipped with standard and Doppler aids to navigation with highly flexible communications system.

Fig. 21. RFF B-57A aircraft. High altitude, twin jet research-reconnaissance aircraft, normally operated at altitudes between 30- and 45,000 feet at speed of approximately 430 knots (TAS), with a mission radius of 950 nmi. Standard and Doppler navigational/communications facilities are available on this aircraft.

Fig. 22. RFF C-54 (DC-4) aircraft. Long range, unpressurized, four-engine (reciprocating type) land plane capable of flying at altitudes up to 25,000 ft, with a cruise speed of 217 knots (IAS), mission radius of 1350 nmi. In addition to its uses for operational research missions, the aircraft serves as a test-bed for developmental instrumentation and logistical support. The aircraft is equipped with standard and Doppler aids to navigation and a highly flexible communications system.

PARAMETERS MEASURED AND/OR RECORDED BY THE RFF AIRCRAFT SYSTEMS

Parameter	Aircraft		
	DC-6 A/B	B-57A	C-54(DC-4)
Time	X	X	X
Total Elapsed Time	X	X	
Magnetic Heading	X	X	X
Magnetic Variation	X	X	X
Differential Pressure	X	X	X
Ambient Pressure	X	X	X
Pressure Altitude	X	X	X
Radar (Absolute) Altitude	X	X	X
Indicated Air Speed	X	X	X
True Air Speed	X	X	X
Total (Rosemount) Temperature	X	X	
Vortex Temperature	X	X	X
Thermocouple Vortex Temperature	X		X
Sea-Surface (IR) Temperature	X		X
Dropsonde Data	X		
Humidity (Vapor Density)	X		X
Humidity (Dew Point)	X		X
Liquid-Water Content	X		
Icing Rate	X	X	
Volume Median Drop Size	X		
Rain Drop Charge	X		
Latitude	X	X	X
Longitude	X	X	X
Ground Speed	X	X	X
Drift Angle	X	X	X
Wind Direction	X	X	X
Wind Speed	X	X	X
Distance Traveled Count	X	X	
Aircraft Pitch/Roll Angle	X	X	
Doppler System Status	X	X	X
Engine Power	X		
Event-Data Indicators	X	X	X
Flight Identification	X	X	X
Cloud Cameras (Forward)	X	X	
Cloud Cameras (Side)	X		
Cameras (Photo-Panel)	X	X	X
Cameras (Vertical Mapping)	X		
Radar Cameras	X	X	X
Cloud Construction	X		
Radiation Detection	X	X	X
Radar Systems (APS-20, 10 cm)	X		
Radar Systems (Wp-101, 5.6 cm)	X		
Radar Systems (RDR-1D, 3.2 cm)	X	X	
Radar Systems (APS-42, 3 cm)			X
Digital Recording System	X	X	X
Visicorder Recording System	X		X
Photo-Panel Recording System	X	X	X
Special Instrumentation	X	X	X
Turbulence Measuring System	X		
Inertial (stable) Platform	X		

FLIGHT HOURS BY PROJECT - FY 69

PROJECT	39C	40C	005	282	TOTALS
Hail (APCL)	-	42:00	-	-	42:00
Stormfury	-	25:35	10:35	23:40	59:50
NHRL (Research)	-	14:00	-	-	14:00
EMB (Flare)	-	-	4:10	-	4:10
BOMEX	285:45	251:10	-	239:15	776:10*
Calibration	5:35	1:05	2:45	6:05	15:30
Aircraft Test	9:55	3:45	3:35	-	17:15
Easterly Wave	-	37:55	-	-	37:55
Proficiency	-	:45	-	103:30	104:15
Cloudline (Stormfury)	11:20	11:45	6:00	12:35	41:40
Hurricane Gladys	35:10	3:30	3:35	7:50	50:05
Lake Effects (APCL)	79:45	-	-	-	79:45
TOTALS	427:30	391:30	30:40	392:55	1242:35

* BOMEX Hrs for FY 69

BOMEX Hrs thru July 3, 1969 = 824:20

Operations in FY 1969

Colorado Hail Suppression

The Colorado Hail Suppression Project, June 12 through July 19, employed one DC-6 A/B aircraft. Twenty-two separate missions were accomplished during this period. Special equipment used for measuring the electrical field strength in the vicinity of comulonimbus clouds was installed for the experiment.

Project Stormfury

On August 5, RFF DC-6 A/B N6540C and C-54 (DC-4) N91282 aircraft proceeded to Roosevelt Roads, Puerto Rico, in order to participate in the dry run exercise of Project Stormfury which was conducted on August 6 and 7. Upon completion of the exercise, DC-6 A/B N6540C continued on to the island of Barbados. A pre-BOMEX (Barbados Oceanographic and Meteorological Experiment) calibration mission was completed in the vicinity of Barbados on August 10. Enroute missions (Miami-Puerto Rico-Barbados-Miami) were used in order to obtain air (filter) samples, supporting research being conducted by the ESSA Air Resources Laboratory.

Hurricane Research

A cloud line experiment, utilizing the DC-6 A/B and C-54 (DC-4), aircraft was attempted on October 2 and 3 in support of the ESSA National Hurricane Research Laboratory. Atmospheric conditions precluded actual cloud seeding during the period.

Two DC-6 A/B aircraft investigated Hurricane Gladys on October 16 and 19. In addition, the RFF C-54 (DC-4) completed a mission designed to measure the sea surface temperature field in the vicinity of the hurricane's track. These flights and all hurricane missions support the requirements of the ESSA National Hurricane Research Laboratory and the ESSA/WB National Hurricane Center.

Great Lakes Snow Storm Project

RFF DC-6 A/B N6539C participated in the Lake Effect Snow Project from November 7 through December 14. Special equipment was installed on the aircraft for this project which included: AgI burners, dry ice dispensers, infra-red radiation equipment, and nuclei measuring instruments. Twenty-two flights were completed during this project. Patterns were conducted mostly in the vicinity of Dunkirk, New York, where heavy snow fall occurs due to the moisture uptake from Lake Erie. A comparison of silver-iodide (AgI) flares, AgI steady-state

flame-type generator, and dry ice seeding techniques were made during this project.

BOMEX

Extensive preparations for BOMEX (Barbados Oceanographic and Meteorological Experiment) began early in the year. On May 2 the two RFF DC-6 A/B and C-54 (DC-4) aircraft were deployed to the island of Barbados to support the field program of BOMEX. During the first three phases of BOMEX (May 2 to July 3), DC-6 A/B N6540C and C-54 (DC-4) N91282 were utilized in various types of line integral flights while DC-6 A/B N6539C, with its special turbulence measuring system, was collecting water vapor flux measurements in the boundary layer. The three aircraft completed a total of 824 hours for BOMEX by the end of the third phase.

Other Activities

The RFF aircraft also supported the ESSA Experimental Meteorology Laboratory (flare tests with B-57A aircraft); National Hurricane Research Laboratory and National Hurricane Center (easterly wave investigation); and calibration, comparison, test and proficiency mission objectives.

Instrument Development

An instrumentation system consisting of turbulence measuring equipment, a gust probe sensor, inertial platform and a microwave refractometer was developed for determing vapor flux. Attendant data processing procedures were also developed. Calibration flights at 60 feet altitude near instrumented towers indicated that high quality, high accuracy data were being obtained. This system was used extensively during BOMEX.

The RFF, which has a requirement to maintain workable programs for field-staging operations, is now faced with the additional problem of eventually being able to locate and use data processing systems all over the world. The facility will not be able to have a complete set of programs available for every different system located in areas remote from the main operating base (Miami), but the RFF is currently investigating possible solutions to this highly relevant problem.

Plans and Goals for FY 70-71

A study is being planned to define and describe an integrated airborne sensor and data acquisition system for meteorological research, reflecting the state of the art for such systems.

Suitability and availability of so-called "off-the-shelf" subsystems which could be utilized will be evaluated and additional engineering and development requirements will be identified.

Specifications in sufficient detail for procurement purposes will be incorporated in the recommendations for systems and subsystems being considered for development.

A program is planned to supply engineering specifications for installation of basic meteorological sensors and recording systems directed toward the acquisition of new aircraft and/or the updating of present RFF aircraft and systems.

The RFF will continue to study proposals for the acquisition of new and improved cloud physics instrumentation. The recently acquired turbulence measuring system will continue to be operated for boundary layer measurements of turbulent fluxes and other parameters of interest, and the system will be used during the Florida Tropical Cumulus Experiment, to be performed in the spring of 1970, to measure the sustained vertical velocity profiles found in the tropical cumulus environment.

Improvements in the accuracy and reliability of the RFF integrated meteorological data collection complex will be continued.

ERL's RESEARCH GRANTS TO UNIVERSITIES

To supplement the in-house research program, ERL underwrites selected environmental research by making working grants to highly qualified university researchers. In this way, certain important inquiries are conducted by nationally-known, leading scientists whose services are not otherwise available. Thus, ERL's needs for particular scientific talent are met, and quite often the creation of short-term, in-house programs is avoided.

On the following several pages appear the ERL grants which are active in the current fiscal year. Grants from prior fiscal years that extended into the current fiscal year are also included. Some of the major laboratories in the ERL also support external research through making grants of their own. These are included. Excluded from this list are grants which are being processed, but for which administrative arrangements have not been completed.

ESSA RESEARCH LABORATORIES
UNIVERSITY GRANTS

(As of 1 December 1969)

GRANT NUMBER	DESCRIPTION	AMOUNT	ERL MONITOR
E22-135-69(G)	Univ. of Calif. "Dynamics of Internal Waves & Turbulence in the Thermocline" (Corcos & Sherman)	$ 19,985	Benton
E22-2-70(G)	Univ. of Calif. "Earth Strain Studies" (Loveberg)	$ 49,013	Rinehart
	Univ. of Chicago "Dynamics of Low Latitude Circulations" (Kuo)	$ 17,500- (ERL) $ 27,700- (NESC)	Gentry and NESC
E22-14-70(G)	Colorado School of Mines "Earth Strain Studies-Denver, Colo.; Salt Lake City, Utah; Hollister, Calif." (Major)	$ 30,059	Alldredge
E22-27-70(G)	Colorado State Univ. "Studies of Tropical Cumulus Convection and Tropical Storms" (Gray)	$ 12,500	Gentry
E22-18-70(G)	Colorado State Univ. "Proposal on Hurricanes and Tropical Meteorology" (Riehl)	$ 31,000	Gentry
E22-141-68(G)	Florida State Univ."Cooperative Research Program on Hurricanes and Tropical Atlantic Meteorology" (LaSeur)	$ 18,497	Gentry
E22-58-69(G)	Florida State Univ."Severe Storm Research" (Jordan)	$ 9,720	Barnes
E22-15-70(G)	Florida State Univ."Specifications of Meso-Scale Weather from Large-Scale Dynamical Calculations" (Stuart and Krichnamurti)	$ 28,815	Kessler
E22-131-68(G)	Univ. of Hawaii "Tsunami Frequency Waves in the Deep Ocean" (Vitousek)	$ 50,489	Miller
E22-19-70(G)	Johns Hopkins "Theoretical & Experimental Studies of Rotating & Stratified Fluids" (Long)	$ 20,964	Smagorinsky
E22-36-70(G)	Johns Hopkins "Experimental Investigation Related to Clear Air Turbulence"(Long)	$ 10,739	Kuettner
E22-53-69(G)	Lamont Geol. Observatory Columbia Univ."Seismological Research Related to World-Wide Seismic Data" (Dorman)	$ 21,210	Alldredge
E22-3-70(G)	Lamont Geol. Observatory Columbia Univ. "Study of the Relationship between Earthquake & Crustal Displacements in Alaska & Calif. for Earthquake Prediction" (Oliver)	$ 25,442	Alldredge
E22-47-68(G)	Univ. of Miami "Theoretical Modeling of the Mature Hurricane" (Estoque)	$ 17,029	Gentry
E22-25-69(G)	New York Univ. "A Study of Severe Weather Phenomena" (Miller)	$ 6,438	Kessler
E122-67(G)	Univ. of Pittsburgh "Loading Response of Marine Sediments" (Richardson)	$ 5,033	Keller
E22-31-69(G)	Stanford Univ. "Magnetic & Electrical Array on the San Andreas Fault" (Kovach)	$ 12,000	Alldredge
E22-12-70(G)	Univ. of Toronto "Hail Storm Modeling"(List)	$ 4,375	Kessler
E22-60-69(G)	Univ. of Wisconsin "A Study of Radiation in a Tropical Atmosphere" (Suomi & Cox)	$ 30,000	Weickmann

PERSONNEL RESOURCES (As of 30 June 1969)

	Ceiling	On-Board	Avg. Grade	Avg. Salary
Full-time Permanent	1068	1069	10.4	$ 12,653
Other		244		
		1313		
Professional		659		
Non-Professional		654		

DISCIPLINES REPRESENTED IN THE PROFESSIONAL STAFF:

	Doctorate	Masters	Bachelor/ Equiv.	Total
Administrative	5	5	17	27
Astronomer	1			1
Cartographer			2	2
Chemist	3	1	2	6
Electronic Engineer	14	29	81	124
Engineer (General)		1	3	4
Geophysicist	6	5	16	27
Mathematician	7	24	39	70
Mathematical Statistician	2	2	2	6
Meteorologist	28	75	75	178
Oceanographer	12	9	13	34
Physical Scientist	3	1	3	7
Physicist	65	50	58	173
Totals	146	202	311	659

STAFF ON BOARD BY LABORATORY

	PROFESSIONAL					
	Doctorate	Masters	Bachelor/ Equiv.	TOTAL Prof.	Non-Prof.	Total
ESL	10	2	8	20	21	41
AOML	10	27	25	62	42	104
POL	4	1	9	14	4	18
APCL	4	7	12	23	13	36
ARL	10	43	34	87	105	192
GFDL	11	7	12	30	24	54
RFF	2		21	23	20	43
NSSL	8	5	10	23	16	39
SDL	8	23	27	58	55	113
AL	26	5	12	43	28	71
WPL	12	20	22	54	46	100
ITS	24	50	91	165	109	274
Ofc.Dir.	17	9	15	41	18	59
RSS		3	13	16	153	169
TOTALS	146	202	311	659	654	1313

GROSS LABORATORY FINANCING, FISCAL 1969

(in thousands, as of 1 January 1970)

		ESSA Appropriations	Other Agency Sponsorship	Total
ESL	R&D	$ 688	$ 254	$ 950
	S&E	8		
AOL/POL	R&D	$1,432	$ 61	$1,512
	S&E	19		
APCL		$1,056	$ 216	$1,272
ARL	R&D	$ 175		
	S&E	$ 7	$3,655	$3,837
GFDL		$2,872		$2,872
NHRL		$ 710	$ 3	$ 713
NSSL	R&D	$ 830	$ 125	$ 957
	S&E	$ 2		
SDL	R&D	$ 973	$1,299	$2,915
	S&E	$ 643		
AL	R&D	$1,473	$ 243	$1,727
	S&E	$ 11		
WPL	R&D	$ 891	$1,552	$2,524
	S&E	$ 81		
ITS	R&D	$1,694	$5,003	$7,316
	S&E	$ 619		
RFF		$1,167		$1,167
Grants		$ 669		$ 669
Off. Dir.	R&D	$ 335	$ 173	$ 513
	S&E	$ 5		
RSS	S&E	$ 628	$ 611	$1,239

General Support at ERL Level . . . . . ($1,368)

R&D	$14,965
S&E	2,023
Reimb	13,195
TOTAL	$30,183

Sources of Other Agency Reimbursables

Air Force	$2,243	DASA	$ 452
Navy	$ 299	NASA	$1,056
Army	$1,344	NSF	$ 472
ARPA	$1,055	AEC	$2,578
Misc DOD	$1,247	Other	$2,449

GROSS LABORATORY FINANCING, FISCAL 1970

(in thousands, as of 1 January, 1970.)
(other agency funding estimated as of 30 June 1970)

		ESSA Appropriations	Other Agency Sponsorship	Total
ESL	R&D	$ 813	$ 698	$1,517
	S&E	$ 6		
AOML		$2,228	$ 114	$2,342
POL		$ 426		$ 426
APCL		$ 852	$ 139	$ 991
ARL	R&D	$ 207	$3,399	$3,620
	S&E	$ 14		
GFDL		$1,879		$1,879
NSSL	R&D	$ 883	$ 158	$1,043
	S&E	$ 2		
SDL	R&D	$ 941	$1,347	$2,888
	S&E	$ 600		
AL	R&D	$1,399	$ 310	$1,749
	S&E	$ 40		
WPL	R&D	$ 929	$1,830	$2,832
	S&E	$ 73		
ITS	R&D	$1,690	$5,157	$7,625
	S&E	$ 778		
RFF		$1,185		$1,185
Grants		512		512
Off. Dir.	R&D	$ 527	$ 207	$ 777
	S&E	$ 43		
RSS	S&E	$ 590	$ 398	$ 988
BOMAP	R&D	$ 170		$ 450
	S&E	$ 280		

General Support at ERL Level . . . . . ($1,466)

R&D	$14,641
S&E	2,426
Reimb	13,757
TOTAL	$30,824

Sources of Other Agency Reimbursables

Air Force	$1,629	DASA	$ 415
Navy	$ 188	NASA	$1,688
Army	$ 874	NSF	$ 257
ARPA	$2,001	AEC	$2,925
Misc. DOD	$1,311	Other	$2,469

LABORATORY OFFICE ADDRESSES

LABORATORY OFFICES REMOTE FROM BOULDER:

Air Resources Laboratories Environmental Science Services Administration Silver Spring, Maryland 20910	FTS 301-495-2252
Atlantic Oceanographic & Meteorological Laboratories 901 South Miami Avenue Miami, Florida 33130	FTS 305-350-4104
Geophysical Fluid Dynamics Laboratory Princeton University P.O. Box 308 Princeton, New Jersey 08540	FTS 609-599-3304
National Severe Storms Laboratory 1616 Halley Avenue Norman, Oklahoma 73070	FTS 405-236-2311 (ask for) 405-329-0388
Pacific Oceanographic Laboratories 1801 Fairview Avenue East Seattle, Washington 98102	FTS 206-583-4546
Research Flight Facility P.O. Box 197, Internatl. Airport Br. Miami, Florida 33148	FTS 305-350-4130

LABORATORY OFFICES LOCATED IN BOULDER:

Aeronomy Laboratory	FTS 303-447-3218
Atmospheric Physics & Chemistry Lab.	FTS 303-447-6382
Earth Sciences Laboratories	FTS 303-447-6235
Institute for Telecomm. Sciences	FTS 303-447-3484
Space Disturbances Laboratory	FTS 303-447-3311
Wave Propagation Laboratory	FTS 303-447-6261

ERL MAIN SWITCHBOARD, BOULDER, COLORADO 303-447-1000

Mailing addresses for Boulder Laboratory Offices:

(name of Laboratory)
ESSA Research Laboratories
Boulder, Colorado 80302

GPO 856-648